Lower Duwamish Waterway Group

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

Sections 1 through 13

Draft Final Feasibility Study

Lower Duwamish Waterway
Seattle, Washington

FOR SUBMITTAL TO:

The U.S. Environmental Protection Agency
Region 10
Seattle, WA

The Washington State Department of Ecology
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Bellevue, WA

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Prepared by: AECOM

710 Second Avenue, Suite 1000 • Seattle, Washington • 98104

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List of Acronyms

AET	Apparent Effects Threshold
AOC	Administrative Order on Consent
AOPC	area of potential concern
API	Asian and Pacific Islander
ARAR	applicable or relevant and appropriate requirement
BAZ	biologically active zone
BCA	bias corrected accelerated
BCM	Bed Composition Model
BEHP	bis(2-ethylhexyl)phthalate
Bg	natural background
bgs	below ground surface
BHC	benzene hexachloride
BMP	best management practices
BOD	biological oxygen demand
C	combined technology
CAD	contained aquatic disposal
CAP	Cleanup Action Plan
CDF	contained disposal facility
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cfs	cubic feet per second
CLU-IN	EPA Hazardous Waste Clean-up Information
cm	centimeter
COC	chemical of concern
COPC	chemical of potential concern
cPAH	carcinogenic polycyclic aromatic hydrocarbon
CSL	cleanup screening level
CSM	conceptual site model
CSO	combined sewer overflow
CSTAG	Contaminated Sediment Technical Advisory Group
CT	central tendency

CTM	Candidate Technologies Memorandum
CWA	Clean Water Act
cy	cubic yards
D_{50}	median grain size
DAIS	Dredged Analysis Information System
DCA	disproportionate cost analysis
DDT	dichlorodiphenyl-trichloroethane
DEA	David Evans and Associates
DMMP	Dredged Material Management Program
DMMU	Dredged Material Management Unit
DNS	Determination of Non-Significance
DOH	Department of Health
DPD	City of Seattle Deparment of Planning and Development
DRCC	Duwamish River Cleanup Coalition
dw	dry weight
EAA	early action area
EE/CA	Engineering Evaluation/Cost Analysis
EB/DRP	Elliott Bay / Duwamish Restoration Program
Ecology	Washington State Department of Ecology
ENR	enhanced natural recovery
EOF	emergency overflow
EPA	U.S. Environmental Protection Agency
EPC	exposure point concentration
ERA	ecological risk assessment
ESA	Endangered Species Act
f_{oc}	fraction of organic carbon
ft	feet
FEMA	Federal Emergency Management Act
FRTR	Federal Remediation Technologies Roundtable
FS	Feasibility Study
g/cm^3	gram per cubic centimeter
GAC	granular activated carbon
GIS	geographic information system
HHRA	human health risk assessment

HI	Hazard index
HPAH	high-molecular-weight polycyclic aromatic hydrocarbon
HQ	hazard quotient
HTTD	high-temperature thermal desorption
IC	institutional control
IDW	inverse distance weighting
JARPA	Joint Aquatic Resource Permit Application
KCDOT	King County Department of Transportation
Koc	organic carbon coefficient
lb/ft^3	pound per cubic foot
LDW	Lower Duwamish Waterway
LDWG	Lower Duwamish Waterway Group
LOAEL	lowest-observed-adverse-effect level
LOEC	lowest-observed-effect concentration
LTTD	low-temperature thermal desorption
µg/kg	microgram per kilogram
µg/kg dw	microgram per kilogram dry weight
µm	micrometer
mm	millimeter
MCUL	minimum cleanup level
mg/kg	milligram per kilogram
mg/kg dw	milligram per kilogram dry weight
mg/kg OC	milligram per kilogram organic carbon
MHHW	mean higher high water
ML	maximum level
MLLW	mean lower low water
MNR	monitored natural recovery
MT	metric ton
MTCA	Model Toxics Control Act
MUP	master use permit
n/a	not applicable
NCP	National Contingency Plan
NEPA	National Environmental Policy Act
ng/kg	nanogram per kilogram

NOAA	National Oceanic and Atmospheric Administration
NOAEL	no-observed-adverse-effect level
NOEC	no-observed-effect concentration
NPDES	National Pollutant Discharge Elimination System
NRC	National Research Council
O&M	operations and maintenance
oc	organic carbon (carbon normalized)
OM&M	operations, maintenance, and monitoring
OSV	ocean survey vessel
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCP	pentachlorophenol
PEF	potency equivalency factor
pg/g dw	picograms per gram dry weight
PM_{10}	particulate matter less than 10 microns in diameter
ppt	parts per thousand
PQL	practical quantitation limit
PRG	preliminary remediation goal
PSAMP	Puget Sound Ambient Monitoring Program
PSEP	Puget Sound Estuary Program
PSNS	Puget Sound Naval Shipyard Complex
PSR	Pacific Sound Resources
QA/QC	quality assurance/quality control
QAPP	quality assurance project plan
R	removal emphasis
RAL	remedial action level
RAO	remedial action objective
RBC	risk-based concentration
RBTC	risk-based threshold concentration
RCRA	Resource Conservation and Recovery Act
RCM	reactive core mat
RCW	Revised Code of Washington
RD/RA	Remedial Design/Remedial Action
RI	Remedial Investigation

RI/FS	Remedial Investigation/Feasibility Study
RL	reporting limit
RM	river mile
RME	reasonable maximum exposure
RNA	restricted navigation areas
RP/PEIS	Restoration Plan and Programmatic Environmental Impact Statement
ROD	Record of Decision
R-T	removal with physical treatment
SARA	Superfund Amendments and Reauthorization Act
SCA	Source Control Area
SCAP	Source Control Action Plan
SCWG	Source Control Work Group
SD	storm drain
SDOT	Seattle Department of Transportation
SEPA	State Environmental Policy Act
SI	site investigation
SIM	selected ion monitoring
SITE	Superfund Innovative Technology Evaluation
SL	screening level
SMS	Sediment Management Standards
SPI	Sediment Profile Imaging
SPU	Seattle Public Utilities
SQS	sediment quality standards
STAR	Sediment Transport Analysis Report
STM	Sediment Transport Model
SVOC	semivolatile organic compound
SWAC	spatially-weighted average concentration
TBD	to be determined
TBT	tributyltin
TCDD	Tetrachlorodibenzo-p-dioxin
TCDD	2,3,7,8-tetrachlorodibenzodioxin
TEF	toxic equivalency factor
TEQ	toxic equivalent

TI	technical impracticability
TIN	triangulated irregular network
TOC	total organic carbon
TRV	toxicity reference value
TSCA	Toxic Substances Control Act
TSS	total suspended solid
U&A	Usual and Accustomed
UCL95	95% upper confidence limit
UECA	Uniform Environmental Covenants Act
UL	upper limit
USACE	U.S. Army Corps of Engineers
USC	United States Code
USGS	U.S. Geological Survey
VOC	volatile organic compound
VM	verification monitoring
WAC	Washington Administrative Code
WDFW	Washington State Department of Fish and Wildlife
WDNR	Washington State Department of Natural Resources
WQC	water quality criteria
WQS	water quality standards
WSDOT	Washington State Department of Transportation
ww	wet weight

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 FS evaluates the LDW as a whole (i.e., on a LDW-wide basis). Other previously released studies, including engineering evaluation/cost analyses, remedial designs, permitting, and construction/post-construction monitoring have been conducted for early 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 the entire five miles of the LDW (River Mile [RM] 0 to 5), extending from just south of Harbor Island to upstream of the Upper Turning Basin (Figure 1-1).

The RI/FS work required by the AOC is being conducted under the federal Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Washington State Model Toxics Control Act (MTCA). Any response actions identified in the FS must comply with both CERCLA and MTCA. The specific documents that define the conduct of the overall FS process include the following:

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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.

- 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 2007).

This FS is consistent with the following statutes and regulations:

- CERCLA, as amended by the Superfund Amendments and Reauthorization Act (SARA) (note that references made to CERCLA in this report should be interpreted as "CERCLA, as amended by SARA")
- National Oil and Hazardous Substances Pollution Contingency Plan (40 Code of Federal Regulations [CFR] Part 300), referred to in this document as the National Contingency Plan (NCP)
- MTCA, Title 173, Washington Administrative Code (WAC), Chapter 173-340
- Washington Sediment Management Standards (SMS), WAC, Chapter 173-204 (Ecology 1995)

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 2002)
- Contaminated Sediment Remediation Guidance for Hazardous Waste Sites (EPA 2005)
- 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 chemicals of concern within the LDW. This FS is based on the results of the RI (Windward 2008), which included the baseline human health and ecological risk assessments (Windward 2007a, 2007b).

The RI assembled data to identify the nature and extent of chemicals of concern 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 to 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 2005). 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 risk-driver chemicals, 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, 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 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, MTCA, and SMS requirements
- Evaluating how each alternative would achieve the RAOs for the identified risk drivers as well as how each alternative would address the other contaminants of concern.

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 SMS regulations by reference; therefore, the SMS regulations are also applied in this FS.

Table 1-1 compares the major criteria 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 for both state and federal regulations. In addition to these shared threshold requirements, MTCA requires a specific demonstration that the proposed remedy provides for compliance monitoring. While compliance monitoring is also required for remedial actions under CERCLA, it is required only 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. The implementing regulations for MTCA require that the nature of the compliance monitoring be discussed specifically.

Second, CERCLA and MTCA also share the same 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; that 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 also 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 may choose to combine these into one decision document for the LDW.

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 2005).
- 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, chemical 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

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. The SMS use the specific term **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 10 after completion of the active cleanup action" (WAC 173-204-

570(3)). 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 decision document (CERCLA ROD or MTCA CAP).

Chemicals of potential concern (COPCs)/Chemicals 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, chemical concentrations in sediment, water, and aquatic biota were compared to conservative risk-based screening levels or effects standards. Those chemicals present in any samples from the LDW at concentrations above the screening levels were identified as "chemicals 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. The terms "contaminant of concern" and "chemical of concern" are synonymous under CERCLA (EPA 1988, 2001, 2002b). This FS uses the term COC.

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 chemicals.

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 2005) 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.

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 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 chemicals that present the principal risks. PRGs are based on consideration of the following factors:

- Chemical-specific ARARs, to be considered criteria, and SMS criteria
- Risk-based threshold concentrations (RBTCs) developed in the risk assessments
- Background concentrations if protective RBTCs are below anthropogenic 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 decision documents (CERCLA ROD or MTCA CAP).

Remedial action objectives (RAOs) describe what the proposed remedial action is expected to accomplish (EPA 1999). 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.

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.

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

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.

Remedial action levels (RALs) are chemical-specific sediment concentrations that might trigger the need for active remediation (e.g., dredging, capping or 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 are 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, a range of RALs will be developed for risk drivers considering the magnitude of risk reduction achieved, the rate of natural recovery, and different types of remedial actions, such as dredging or enhanced natural recovery.

1.3.2 Sediment Concentrations

Sediment concentrations are expressed and evaluated in the FS in two ways: as individual point concentrations or as spatially-weighted average concentrations (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 chemical 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 are

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 calculated upper bound limit on a mean value calculated from environmental data. Whereas the goal of environmental sampling is generally to estimate the mean value, the true mean value is never known, and it is expected that there will be some error in estimating that value from environmental samples. There are both upper and lower 95% confidence limits, the former are higher than the estimated mean value and the latter are lower than the estimated mean value; they are calculated such that the true mean value has a 95% probability of lying within the interval between the upper and lower confidence limits. A UCL95 can be calculated either for arithmetic averages or for spatially-weighted averages; both are typically used in risk assessments to provide a reasonable upper bound limit on exposure concentrations.

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.

EAAs are areas identified for management actions (prior to the decision document) 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 (or portions of them) have been carried forward and 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

The EAAs include two early actions that were completed by King County and The Boeing Company. Sediment cleanups were conducted in the vicinity of 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. 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. Three other EAAs are in the planning stages under cleanup agreements 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 CERCLA effort for the site. As actions that have either been completed or are planned, and are expected to be completed before issuance of a decision document for the LDW, the EAAs are part of Alternative 1, No Further Action. Remedial alternatives for the EAAs were evaluated in design reports, engineering evaluation/cost analysis 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; AECOM et al., 2010; Project Performance Corporation 2003).

Areas of potential concern (AOPC) represent the area of surface sediment that present unacceptable risks and will likely require some consideration (e.g., remediation 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). 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, model predictions, and chemical trends observed in sediment samples. The potential for natural recovery is presumed to be limited in some areas, while natural recovery processes are presumed to be active in other areas and their potential contribution to remediation of those areas of the LDW will be considered.

1.3.4 Terms Related to Time Frames

The remedial alternatives use 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 RAOs. For clarity, the terms and 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 final decision documents, during which the following occurs: completion of the EAAs (i.e., Alternative 1), priority source control, negotiation of orders, initial remedial alternative design/planning, baseline monitoring, and verification monitoring.

Implementation period. The time that transpires between issuance of the final decision documents and the end of construction.

Natural recovery estimation period. The time that transpires between the start of construction and the achievement of RAOs, either individually or comprehensively.

MTCA restoration time frame. The time that transpires between the end of construction and the achievement of the RAOs, either individually or comprehensively. This is discussed in the context of the MTCA evaluation in Section 11.

Time to achieve RAOs. The time between issuance of the final decision documents and the achievement of the RAOs.

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 baseline dataset, which includes additional chemistry data not included in the RI baseline dataset and additional physical data needed for engineering considerations, are summarized in this section.
- Section 3 (Summary of Site Risks) presents the results of the baseline human health and ecological risk assessments (Windward 2007b and 2007a) and the RBTCs for risk-driver chemicals.
- 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) evaluated the 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, MTCA, and SMS Cleanup Requirements

Criteria	Federal Regulation	State Regulations	
	CERCLA Requirements	MTCA Requirements	SMS Requirements
CERCLA Threshold Criteria and MTCA Minimum Requirements	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)).	The SMS requires cleanup actions to "achieve a degree of cleanup that is protective of human health and the environment." (WAC 173-204-580(2)(b) and consider overall protectiveness of human health and the environment. (WAC 173-204-560(4)(f)(iii)(A)).
	Compliance with ARARs		
	40 CFR 400.430(e)(9)(iii)(B) • Compliance with chemical-specific ARARs • Compliance with action-specific ARARs • Compliance with location-specific ARARs • Compliance with other criteria, advisories, and guidance	MTCA's third threshold requirement is compliance with state and federal laws (WAC 173-340-360(2)(a)(ii)-(iii)).	The SMS requires cleanup actions to achieve "compliance with applicable state, federal and local laws," (WAC 173-204-580(2)(c)).
	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).	The SMS requires cleanup actions to provide "adequate monitoring to ensure the effectiveness of the cleanup action." (WAC 173-204-580(2)(g)).
CERCLA Balancing Criteria and MTCA Other 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)).	The final evaluation of cleanup alternatives under the SMS requires consideration of "Long-term effectiveness, including degree of certainty that the alternative will be successful, long-term reliability, magnitude of residual, biological and human health risk, and effectiveness of controls for ongoing discharges and/or controls required to manage treatment residues or remaining wastes cleanup and/or disposal site risks." (WAC 173-204-560(4)(f)(iii)(D)).

Table 1-1 Comparison of CERCLA, MTCA, and SMS Cleanup Requirements

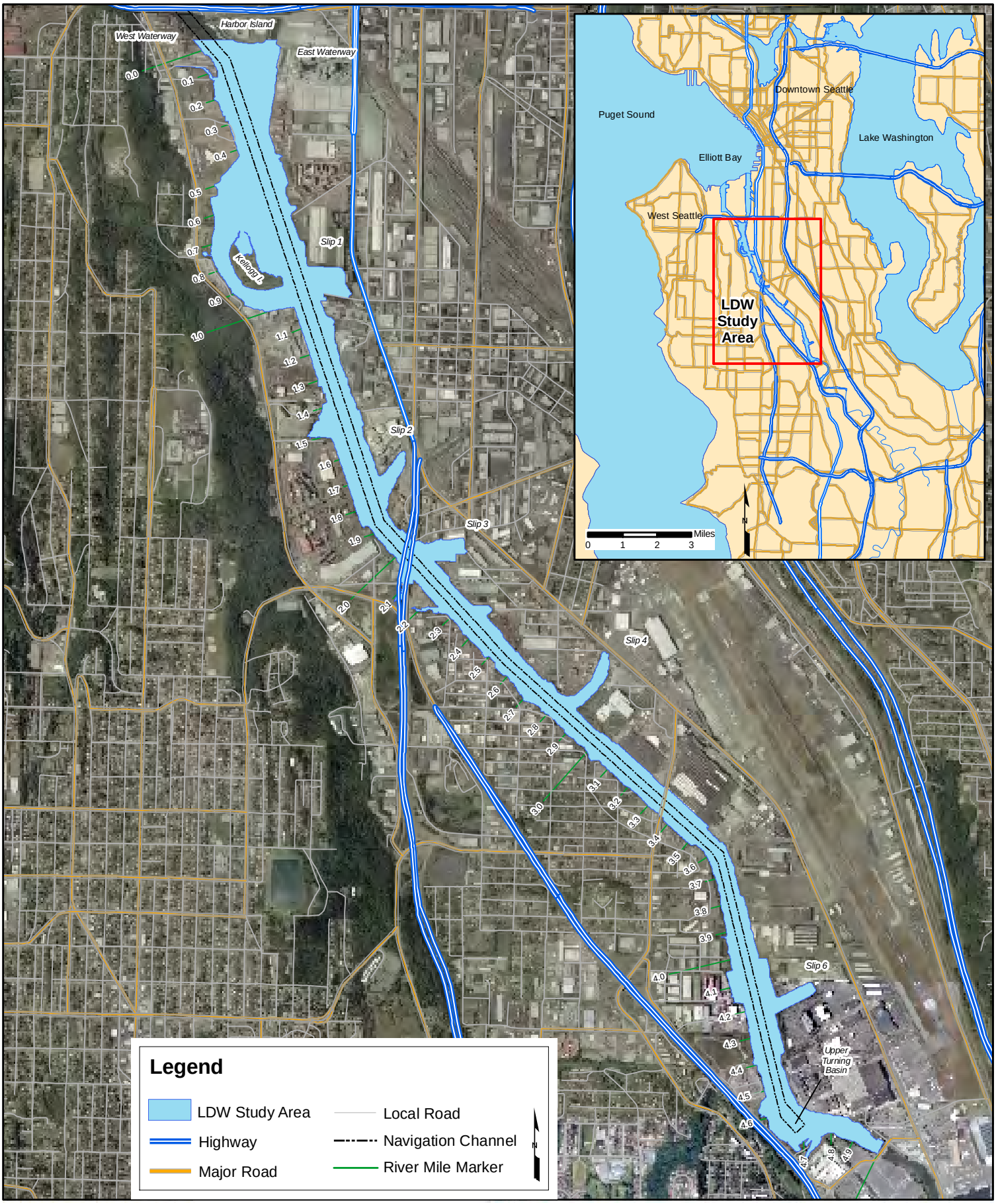
Criteria	Federal Regulation	State Regulations	
	CERCLA Requirements	MTCA Requirements	SMS Requirements
CERCLA Balancing Criteria and MTCA Other Requirements (continued)	Reduction in toxicity, mobility, or volume through treatment		
	40 CFR 300.430(e)(9)(D) • Treatment process used and materials treated • 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 • The degree to which treatment reduces the risks from principal threats	The corresponding criterion under MTCA is the evaluation of the permanence of an alternative conducted as part of 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.	None.
	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)).	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)). These factors relate to the CERCLA criterion of "Time until RAOs are achieved." WAC 173-204-560(4)(f)(iii)(C) requires that the cleanup study evaluate protection of human health and the environment during construction. WAC 173-204-560(4)(k) requires assessment of environmental impacts sufficient for SEPA review. Also, WAC 173-204-570(4) provides that selection of a cleanup standard shall consider the net environmental effects, and WAC 173-204-580(4)(a) specifies that Ecology shall consider residual effects, recovery rates, and any adverse effects of cleanup construction or disposal activities in selecting a remedy. These factors correspond to the CERCLA "environmental impacts and protection of workers" subcriteria.

Table 1-1 Comparison of CERCLA, MTCA, and SMS Cleanup Requirements

Criteria	Federal Regulation	State Regulations	
	CERCLA Requirements	MTCA Requirements	SMS Requirements
CERCLA Balancing Criteria and MTCA Other Requirements (continued)	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)).	The final evaluation of cleanup alternatives under the SMS requires consideration of implementability: [t]he ability to be implemented including the potential for landowner cooperation, consideration of technical feasibility, availability of needed offsite facilities, services and materials, administrative and regulatory requirements, scheduling, monitoring requirements, access for construction, operations and monitoring, and integration with existing facility operations and other current or potential cleanup actions. (WAC 173-560(4)(g)).
	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.	The final evaluation of cleanup alternatives under the SMS requires consideration of [c]ost, including consideration of present and future direct and indirect capital, operation, and maintenance costs and other foreseeable costs. (WAC 173-204-560(4)(h)).
CERCLA Modifying Criteria	Community acceptance		
	40 CFR 300.430(e)(9)(I) • Completed after the public comment period but may be discussed in the proposed plan issued for public comment.	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)).	The SMS requires Ecology to provide opportunity for public review and comment on all cleanup action study plans, reports, and decisions reviewed and approved by the department, for cleanup actions conducted under this chapter (WAC 173-204-580(5)).
	State and tribal acceptance		
	40 CFR 300.430(e)(9)(H) • Completed after the public comment period but may be discussed in the proposed plan issued for public comment.	Same as for Community Acceptance	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.

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



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

Lower Duwamish Waterway
Draft Final Feasibility Study
60150279-14.4

Lower Duwamish Waterway FS Study Area

DATE: 10/15/10 | DWRN:MVI/Sea | Revision: 0

FIGURE 1-1

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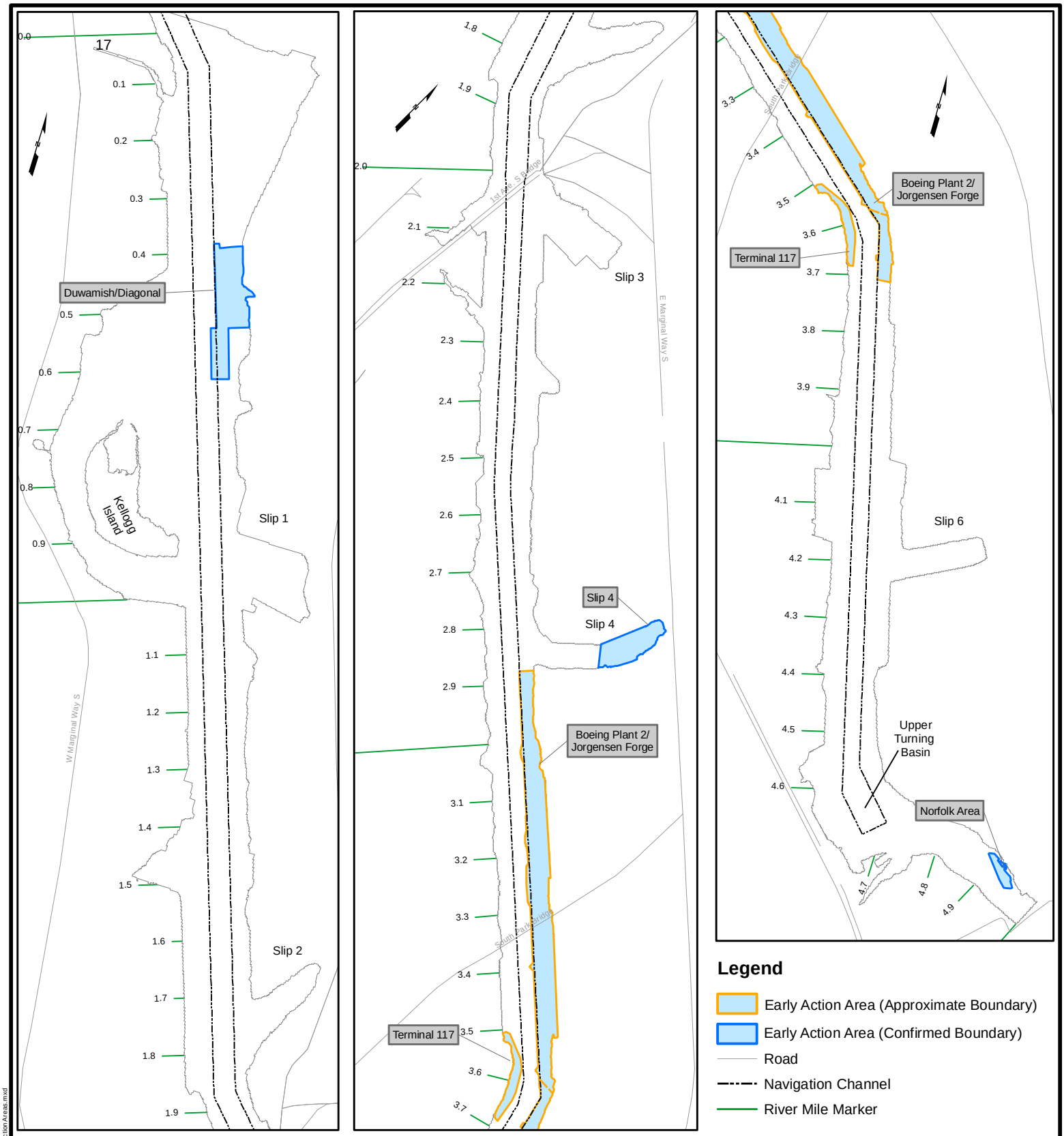

Notes:
1. The EAAs consist of 29 acres.
2. The Duwamish/Diagonal and Norfolk EAAs have been the subject of cleanup actions, and thus the boundaries shown on this map are confirmed. The Duwamish/Diagonal EAA boundary shown on this map has been revised from the version used in the RI (Windward 2010) by removing the thin-layer placement area from the EAA footprint. The Slip 4 EAA boundary shown on this map has been confirmed following design sampling, but no cleanup action has been conducted as yet. The Terminal 117 and Boeing Plant 2/Jorgensen Forge boundaries are approximate and have not been finalized by EPA/Ecology. The boundaries shown on this map for Slip 4, Terminal 117, and Boeing Plant 2/Jorgensen Forge have also been adjusted from those in the RI to match the study area (top of riverbank) boundary used in the FS.
3. 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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Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

Lower Duwamish Waterway
Draft Final Feasibility Study
60150279-14.4

Early Action Areas

DATE: 10/15/10 | DWRN:MVI/sea | Revision: 0

FIGURE 1-2

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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 19 km (12 mi), 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. The Lower Duwamish Waterway (LDW) 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 (Figure 1-1).

The LDW study area includes a 4.65-mile federally authorized navigation channel that has been straightened and channelized, and is maintained at depths between -30 ft mean lower low water (MLLW) and -15 ft MLLW. The 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 4.8.

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 modification activities.

In 1906, the White River was naturally diverted from the Green River to the Puyallup River as the result of a flood event.[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, resulting 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 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

[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).

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 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 creation of 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 its interior (Canning et al. 1979, as cited in Windward 2010).

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 3.6 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, King County Commercial Waterway District No. 1 created and maintained navigation depths 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 U.S. Army Corps of Engineers (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, becoming owner of the portion of the LDW extending 250 ft on either side of a center line through the LDW. Therefore, most of the LDW is now owned by the Port of Seattle.

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., 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 last lahar, which flowed from Mount Rainier approximately 1,100 years ago, extended the Duwamish Valley seaward by approximately 30 miles to its current extent (Collins and Sheikh 2005). The event is 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 1 to 6 m (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), younger alluvial deposits are of relatively constant thickness and depth, generally within 1.5 to 3 m (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 2-2 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) (Stoner 1967). 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 as cited in Windward 2010). 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 (Windward 2010). 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 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 include (Figure 2-3; Windward 2010):

- Port of Seattle/Coastal America at T-105 where a side channel slough was created at a former industrial property at RM 0.1 W
- T-107/Herring's House Park, at RM 0.3 to RM 0.5 W 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 0.6 E
- General Services Administration marsh restoration area at RM 0.8 E

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

- Derelict barge removal at RM 2.0 W
- Gateway North/8th Avenue South street end restoration area at RM 2.7 E
- South Portland street end park/Gateway South at RM 2.8 W
- Hamm Creek restoration area at RM 4.3 W, 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 4.6 W
- Upper Turning Basin at RM 4.7 W, where four restoration projects, including several derelict vessel removals, a Coastal America project, and expansion of intertidal marsh creation for project-specific mitigation have led to a total of 5 acres of intertidal habitat restoration
- South 112th Street mitigation site at RM 5.7 E
- King County's Cecil B. Moses Park at RM 5.7 W.

2.1.4.1 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 (Windward 2010).

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.

2.1.4.2 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 (as cited in Windward 2010).

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 (as cited in Windward 2010).

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 (as cited in Windward 2010). 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 between October and 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).

2.1.5 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 (Windward 2010). The upland areas along the upstream portions of the LDW and along the Green/Duwamish River were used for farming.

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 (Windward 2010).

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) 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.

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 300 m (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.

Three 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 3 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 2-3). In addition, two public parks (Terminal 107/Herring's House and Duwamish Waterway Park) exist along the LDW shoreline (Figure 2-3). 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 Baseline Dataset

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 preparation of 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 chemical contamination 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 newer data (Table 2-2). The sample count for each of the human health risk-driver chemicals (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 Administrative Order on Consent (AOC), (i.e., Duwamish/Diagonal and Boeing Developmental Center south storm drain), the pre-remedy data are used to characterize baseline conditions.[3] 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. Their locations are shown in Figure 2-4:

- Data collected around the perimeter of and upstream of the Boeing Plant 2/Jorgensen Forge EAA.
- Surface sediment post-remedy monitoring data collected around the perimeter of the Duwamish/Diagonal EAA (2005 to 2009).
- Surface and subsurface sediment data collected only around the perimeter of the Slip 4 EAA for the design report.
- Surface sediment data collected around the perimeter of the Terminal 117 EAA and analyzed only for total polychlorinated biphenyls (PCBs) and dioxins/furans.
- Data collected by individual parties at the 8801 E. Marginal (RM 3.8 E) and Industrial Container Services (RM 2.2 E) sites. These sites were proposed as candidate EAAs in the Candidate EAA Memo (Windward 2003b); however, these two sites have not been carried forward as EAAs at this time.
- Data collected by the Port of Seattle in the intertidal area of Terminal 115 (RM 1.5 W).
- Data collected by Ecology 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.

[3] 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).

- Data from a sediment profile imaging (SPI) study conducted by Ecology 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 Environmental Protection Agency (EPA) site investigation (SI) surface sediment stations 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 in that each trumped location is reviewed on a chemical-by-chemical basis. Only the chemical data for which newer data are available are replaced. Therefore, a location may remain in the dataset with a truncated chemical list, if the newer location was not analyzed for the same suite of chemicals as the older location. This occurs with dioxin/furan data and with PCB congeners (with the latter not evaluated in the FS because total PCBs are being evaluated).
- Dioxin/furan data collected by LDWG in 2009 and 2010. This sampling and analysis effort was conducted to increase the dioxin/furan dataset, which had contained 47 samples in the RI baseline dataset. A second objective of the 2009/2010 LDWG sampling event was to further characterize the assumed beach play areas identified in the HHRA.

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:** 355 samples collected in 2008 and 2009 along the western boundary of the Boeing Plant 2/Jorgensen Forge EAA and under the overwater historical Plant 2 building
- **PACCAR:** 25 samples collected in 2008 at RM 3.9 east (8801 East Marginal Way)
- **City of Seattle:** 38 samples collected in 2006 and 2008 in the Slip 4 EAA
- **Port of Seattle:** 11 samples collected in 2008 at Terminal 115 for dredged material characterization to support berth modifications
- **USACE:** 32 samples from 1990, 1991, and 1996 dredged material characterization to support dredging of the navigation channel; and 44 samples collected in 2008 and 2009 to support 2010 dredging

- **Delta Marine:** 4 samples collected from RM 4.2 west 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 a chemical-by-chemical basis), the surface sediment sample count for each chemical is not 174 greater than that for each chemical in the RI baseline dataset. Table 2-3 provides the sample counts for each of the human health risk-driver chemicals.

2.3 Conceptual Site Model

The conceptual site model (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 chemicals, specifically the risk-driver chemicals, in sediment. Sediment with the highest concentrations of risk drivers is not spread 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 from 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. The STM was calibrated over a 21-year period (1960 to 1980) using upstream river flow data to set initial bed conditions. Boundary conditions (i.e., upstream inflow) were then calculated over a 30-year period (1960 to 1989) to model the movement of suspended and bed load sediment into the LDW from upstream and through the LDW. 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 2-5a through 2-5c):

- 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 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 centimeters (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.
- Reach 3 is upstream of RM 4.0. 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 the LDW, 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; Figure 2-6) 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 2-7). 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 from 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.[4]
  - 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 2-8). 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 passing ship-induced bed scour, using parameters from two active,

[4] 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.

representative tugboats in the LDW, the *J.T. Quigg* and the *Sea Valiant*[5] (Windward and QEA 2008):

- 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 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.
- 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 2-5a through 2-5c). This series was developed originally for the STM report (QEA 2008).

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 on-going mixing process for surficial bed sediment. Transiting ships are not a major source of sediment transport

[5] 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.

or erosion in the LDW, except where slightly greater erosion depths (net erosion) are possible near the banks of the LDW.

Ship-Induced Bed Scour from Maneuvering Vessels

Ship-induced bed scour from vessel maneuvers near berthing areas was evaluated on a spatial basis by examining sun-illumination-manipulated bathymetry maps. 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 2-7). 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.

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). 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-yr 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 site-by-site basis. However, the areas identified by this analysis are consistent with mapped berthing areas, overwater structures (discussed in Section 2.6.3), and vessel traffic patterns discussed in Section 2.6.6, providing additional evidence that they are frequently subject to vessel scour. 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 solid (TSS) and bed loads (Figure 2-8).

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 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 profile of cores, but generally the empirical evidence supports the findings from the STM (QEA 2008).

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

An understanding of the distribution of chemicals in the LDW, or the chemical CSM, follows the development of the physical CSM (Section 2.3.1).

2.3.2.1 Chemical Concentrations

The baseline HHRA (Windward 2007b) identified four human health risk drivers: PCBs, arsenic, carcinogenic polycyclic aromatic hydrocarbons (cPAHs), and dioxins/furans. These risk-driver chemicals are evaluated in this FS at three spatial scales appropriate to human exposure: site-wide (netfishing), in potential tribal clamming areas, and in assumed beach play areas. Further, 42 of the 47 chemicals (including total PCBs and arsenic), for which Washington State Sediment Management Standards (SMS) criteria are available, are risk drivers for benthic invertebrates because detected concentrations of these chemicals in surface sediments exceeded SMS criteria at one or more sediment stations (these data are hereinafter referred to as SMS chemistry data). SMS chemicals are evaluated on a point basis, as relevant to benthic invertebrate exposure. Total PCBs are also a risk-driver chemical for river otters and are evaluated on a site-wide basis for this receptor. Section 3 provides a summary of the ERA, HHRA, risk-driver chemicals, and appropriate exposure scales.

Tables 2-3 and 2-4 summarize minimum and maximum detections, average concentrations, and detection frequencies of human health risk drivers and other chemicals of concern (COCs), respectively, in the LDW FS dataset. Chemicals with SMS exceedances (Table 2-4) 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 LDW-wide baseline SWAC for total PCBs is 346 micrograms per kilogram dry weight (µg/kg dw) [6], the LDW-wide baseline SWAC for cPAHs is 388 µg toxic equivalent (TEQ)/kg dw, and the LDW-wide baseline SWAC for arsenic is 15.6

[6] Two outliers in Trotsky inlet (RM2.2) 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. A "current" conditions LDW-wide SWAC using 2009 data collected from the Boeing Developmental Center cap and from the Duwamish/Diagonal EAA cap and ENR area is 306 µg/kg dw, when the two Trotsky inlet outliers are excluded.

milligrams per kilogram dry weight (mg/kg dw) based on inverse distance weighting (IDW) interpolation, discussed below.

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 TEQ per kilograms dry weight (ng TEQ/kg dw). A total of 123 samples with dioxin/furan data are in the FS baseline surface sediment dataset. Following finalization of the RI baseline dataset in 2006, additional dioxin/furan surface sediment samples were collected during 6 events, which are described in Table 2-1 and in the memorandum *2009/2010 Surface Sediment Sampling Results for Dioxins and Furans* (Windward 2010a).

For the SMS chemistry data, a total of 643 locations (41% of all FS baseline surface sediment locations from RM 0.0 to 7.1) had detected concentrations of at least one chemical 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 chemical analyzed in those samples. Many of the locations with exceedances of SMS criteria are in EAAs. Outside of the EAAs, 287 sampling locations had surface sediment chemistry data that exceeded the SQS, based on chemistry alone.[7]

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 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,[8] 44 of which passed for all endpoints tested. Of these 44 locations passing the toxicity tests, 41 were either SQS or cleanup screening level (CSL) exceedances based only on chemistry. Toxicity testing overrides chemistry results, when a location is evaluated relative to the SMS. Therefore, these 41 locations were identified as being below the SQS for mapping purposes.

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[7] One SMS chemical, 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 baseline datasets. However, this chemical exceeded the SQS/CSL (which are both 29 µg/kg dw) in the Ecology SPI event. This chemical was detected above the SQS/CSL in 25 of 30 SPI event samples. However, 20 of these samples have toxicity data passing the SQS criteria, so they are not considered SQS exceedances, following the data rules.

[8] 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, the toxicity test results for this location (LDW-SS22) were used in the FS baseline dataset.

Figures 2-9a through 2-9e display the exceedances of the SQS for any SMS chemical in each core. In subsurface sediments, the following observations were made regarding PCBs and other COCs:

- Fifty-two percent (779 of 1,506) of the subsurface sediment samples analyzed for PCBs either had detected total PCB concentrations below the SQS or PCBs were undetected.
- Ninety-five percent (507 of 534) of the subsurface sediment samples analyzed for arsenic either had detected arsenic concentrations below the SQS or arsenic was undetected.
- Seventy-five percent (458 of 539) of the subsurface sediment samples analyzed for bis(2-ethylhexyl) phthalate (BEHP) either had BEHP concentrations below the SQS or BEHP was undetected.
- Fifty-one percent (821 of 1,617) of the subsurface sediment samples analyzed for all SMS chemicals had no detected concentrations of SMS chemicals above the SQS.

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. These comparisons provide evidence of sedimentation, scour, temporal trends, and potential recovery, which are discussed in Section 5.

2.3.2.2 Interpolative Mapping of Risk-Driver Chemicals

Spatially interpolated data are used in this FS for several evaluations, including the estimation of contaminated sediment volumes, natural recovery modeling, and the delineation of the area of potential concern (AOPC; 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 is especially important for chemistry data applied to site-wide exposure scenarios and used as model inputs.

Human Health Risk-Driver Chemicals

The FS baseline dataset includes the following numbers of surface sediment samples between RMs 0 and 5.0: total PCB data for 1,395 stations; arsenic data for 918 stations; and cPAH data for 893 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 2-10 through 2-12.

There are 123 surface sediment samples for the fourth human health risk driver, dioxins/furans. 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 spatial interpolation method by which a polygon is drawn around every data point. The boundaries of each polygon are drawn at the mid-point locations between the data point of interest and each surrounding data point. All surface sediment within each polygon is then assigned the chemical concentration of the empirical data point contained within it; thus, a spatial extent is assigned to sample data at a given location. The dioxin/furan Thiessen polygons are shown on Figure 2-13.

Interpolated data for total PCBs, arsenic, cPAHs, and dioxins/furans are used in the bed composition model (BCM; discussed in Section 5) to evaluate the distribution of 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 over 1,390 data points with SMS chemical data. However, some of these stations were analyzed only for PCBs. Approximately 900 stations were analyzed for all SMS chemicals (or the majority of the SMS chemicals), and thus this smaller dataset was used to delineate the spatial extent of SMS results.

A polygon with more than one data point contained within it (e.g., where a polygon was defined by a station with SMS chemistry data but there was another station with only PCB data within that polygon) was assigned the exceedance level of the station having the highest level (pass, SQS, or CSL). The maximum exceedance status for individual SMS chemicals 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 polycyclic aromatic hydrocarbons (PAHs), and no exceedances for any other SMS chemicals, is designated as exceeding the CSL.

For mapping the AOPCs (see Section 6) and remedial alternative footprints (Section 8), it is too labor intensive to interpolate chemical data for all SMS chemicals using IDW. Each interpolation involves multiple steps of adjusting interpolation parameters and then calculating error metrics for each set of parameters. Because the SMS chemistry data include concentrations of multiple chemicals, data are mapped as points with spatial extents assigned by Thiessen polygons. In each polygon, an SMS status is

assigned relating to whether any chemical detected in any of the surface sediment samples in that polygon exceeds either of two criteria specific to that chemical: the SQS or the CSL.

When evaluating whether the Thiessen polygons represent the spatial extent of SMS exceedances, toxicity results override chemistry results in each polygon. If a polygon has toxicity data in it, the exceedance status of that toxicity test is assigned to that polygon. This toxicity exceedance level (also defined as pass, SQS exceedance, or CSL exceedance) trumps the exceedance level based on chemical concentrations. For example, a polygon with a toxicity pass in it, but a chemical SQS exceedance, was assigned a pass because the toxicity data override the chemistry data. All other polygons are not assigned a toxicity data status; the maximum chemistry SMS exceedance status for any location in the polygon is used to code the entire polygon.

Figures 2-10 through 2-13 show the distributions of total PCBs, arsenic, cPAHs, and dioxins/furans in surface sediment, respectively. The distribution of BEHP, a chemical with a number of stations exceeding the SMS criteria, is shown in Figure 2-14. The distributions of SMS chemistry and toxicity data in the surface sediment are shown in Figures 2-15a and 2-15b.

2.3.2.3 Chemical Distribution Patterns

Based on the surface sediment data, the LDW can be characterized as having localized areas of relatively high chemical concentrations ("hot spots") separated by relatively large areas with lower chemical concentrations.

The highest surface sediment concentrations of the human health risk-driver chemicals typically occur within the EAAs and other hot spots as noted below:

- Pre-remedy 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 third 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.
- Of the ten samples with the highest total PCB concentrations, six (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.

- In the Slip 4 EAA, 13 total PCB samples exceeded 1,300 µg/kg dw and 5 cPAH samples exceeded 1,500 µg TEQ/kg dw.
- A sample downstream of the Norfolk Area at RM 4.85 had the third highest total PCB concentration (223,000 µg/kg dw).
- Two of the highest concentrations of total PCBs (2,900,000 and 230,000 µg/kg dw) were collected in 2007 at RM 2.2 East (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 (412 ng TEQ/kg dw) was also collected in the Trotsky inlet.
- The highest arsenic concentration (1,100 mg/kg dw) was collected at RM 3.9 East (8801 East Marginal Way, PACCAR site). This area also had elevated cPAH concentrations (>1,500 µg TEQ/kg dw).
- Samples with the three highest dioxin/furan concentrations (463, 565, and 2,100 ng TEQ/kg dw) were collected from Glacier Bay (RM 1.5 West) . Dioxin/furan concentrations were also high in the navigation channel at RM 1.1 (120 ng TEQ/kg dw). This area (and the downstream area by Duwamish Shipyard) also contained elevated arsenic concentrations (>93 mg/kg dw).

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

- The Ash Grove Cement Area (RM 0.1 E) 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.

These areas are discussed in more detail in Section 2.8 in the context of state or federal orders to investigate upland sources of COCs to the sediments. Some areas exhibited high chemical 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 chemical concentrations near the surface could be the result of localized disturbances or recent, on-going 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 chemicals and the likely pathways by which these chemicals are transported into and within the LDW. Potential sources (and whether they are historical or ongoing) and pathways for the four human health risk drivers are discussed below.

2.3.3.1 Potential Historical Chemical Sources and Pathways

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 chemicals, such as PCBs, is due in part to banned production and use in the U.S.; however, significant sources of historical origin are still 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. Therefore, historical sources likely contributed to much of the sediment contamination in the LDW, but inputs from historical use continue.

Also, direct sanitary sewer discharges have been reduced as King County eliminated raw sewage outfalls and redirected wastewater to the West Point Wastewater Treatment Plant. Many industrial discharges have been rerouted from the LDW to the West Point Wastewater Treatment Plant as well. King County also developed industrial waste pretreatment and CSO reduction programs in accordance with the Clean Water Act. Since 1969, those programs have reduced chemical discharges to the sewer and reduced CSO discharges to the LDW. Although the pretreatment program is responsible for reducing the number of daily direct industrial discharges to the LDW, CSO release events still occur, such that combined sanitary water and stormwater is discharged to the LDW when flows exceed system capacity.

Potential historical chemical sources for total PCBs, arsenic, cPAHs, and dioxins/furans are summarized below:

- 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 continue to reach the LDW from nonpoint sources (e.g., soils historically impacted when PCBs were used) and from point sources (e.g., the former Rainier Brewery building, now known as Rainier Commons, still has paint on its exterior walls with total PCB concentrations up to 10,000 mg/kg dw).

- Arsenic was historically (and 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.
- PAHs are generated from the burning of organic matter, fossil fuels, and charcoal (pyrogenic) and are present in refined petroleum products (petrogenic). Therefore, PAHs continue to enter the LDW from nonpoint sources (atmospheric deposition and runoff from impervious surfaces in the watershed) related to 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. 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 (and can be transported to the LDW in runoff).
- 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 currently) released from the burning of waste and from paper mills, and historically as byproducts of pentachlorophenol (a wood-treating chemical) and pesticide production.

2.3.3.2 Potential On-going Chemical Sources and Pathways

Current chemical releases are believed to be associated with general urbanization, such as stormwater runoff and atmospheric deposition, and with upland contamination remaining from historical operations. Chemicals released to media such as air, soil, groundwater, and surface water or to impervious surfaces may migrate to the LDW through various potential pathways, including:

- Direct discharge into the LDW (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
- Bank erosion
- Scour of contaminated subsurface sediments
- Atmospheric deposition.

These sources are discussed in more detail below. Typically, on-going pathways to the LDW are a result of historical use of chemicals (such as PCBs), which can remain as legacy contamination in old equipment and building materials and in historically impacted media in the watershed, and as a result of general urbanization (for chemicals such as PAHs [fossil fuels], phthalates [plastics], zinc [tire wear], and copper [brake pads]).

Historically, controls on wastewater discharges and use of best management practices (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. Appendix F presents historical risk-driver chemical trends in Puget Sound, and Appendix J evaluates recontamination potential to the LDW by direct discharge pathways (CSOs and storm drains), which convey on-going sources of contaminants to the LDW.

Direct Discharges via Outfalls

Discharges to the LDW may occur from public or private storm drain systems, CSOs, and emergency overflows (EOFs). The LDW drainage basin is served by a combination of separated storm drains and sanitary sewers and combined sewer systems.

Storm drains convey stormwater runoff collected from streets, parking lots, roof drains, and residential, commercial, and industrial properties to the waterway. A wide range of chemicals may become dissolved or suspended in runoff as rainwater flows over impervious surfaces. 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 can 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 are covered by National Pollutant Discharge Elimination System (NPDES) industrial stormwater permits, but the majority of businesses in the LDW are not required to obtain such permits.

Stormwater is discharged to the LDW from approximately 200 public and private storm drains, CSOs, ditches, and streams. Contaminants discharged from these sources could affect LDW sediments. There are 277 industrial and construction stormwater NPDES permits for outfalls that discharge to the Green/Duwamish River drainage, within and upstream of the LDW (Ecology 2010).

Most of the waterfront properties within the LDW are served by privately-owned drainage systems that discharge stormwater directly to the LDW. The other upland areas 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. A wastewater treatment plant located

at RM 0.9 E, near the Duwamish/Diagonal EAA, operated until 1969. The Renton Wastewater Treatment Plant discharged treated effluent to the Green River upstream of the LDW until 1986.

The City of Seattle's storm drain system services approximately 61% of the LDW drainage basin. Other public sewer systems service about 24% of the drainage basin, and the remaining 15% of the basin is serviced by small, private waterfront storm drain systems (Seattle Public Utilities 2008). 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. These data are important for understanding on-going sources of watershed-related chemicals to the LDW. CSO #116 has not overflowed since 1999. Over the 6-year period of record (1999 – 2005), the total annual discharge volume at CSO #111 has ranged from 0.6 to 74 million gallons per year. 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).

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 total average 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; there has not been an emergency overflow there 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 2010).

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 of stormwater, treatment of stormwater, and education of businesses and residents on reducing delivery of pollutants into the storm drain system are all measures designed to reduce the pollutants entering the LDW from nonpoint sources. However, regional

development and population growth may tend to increase nonpoint source loads of PAHs (Ecology 2005).

Surface Water Runoff (Sheet Flow)

Surface runoff is a potential pathway for transport of COCs to the LDW. In areas lacking collection systems, spills or leaks on properties adjacent to the LDW could be carried directly over impervious surfaces (surface runoff) or through creeks and ditches to the LDW. .

Spills to the LDW

Near-water and overwater infrastructure and activities have the potential to release COCs to adjacent sediments. Overwater activities are currently conducted near physical structures (e.g., piers, wharves, dolphins) built along the shoreline (discussed in Section 2.6.3). Near-water spills at the properties adjacent to the LDW may reach the waterway. Contaminants in soil resulting from spills and releases on adjacent upland properties may also be transported to groundwater and subsequently to the LDW (see next subsection).

Groundwater Discharges and Migration

Groundwater discharge is a potential pathway for transport of COCs to the LDW. Contaminated groundwater has been documented at several properties adjacent to the LDW where groundwater flows toward the LDW. Multiple seep and porewater sampling events have also been conducted in the LDW. A 2004 seep study (Windward 2004) 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 source control efforts.

The determination of whether a chemical 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 localized sites will be the subject of site-specific remedial investigations. For example, at the Boeing Isaacson/ Thompson properties (RM 3.8), where there are high concentrations of arsenic 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 site.

As part of the RI (Windward 2010), an assessment was conducted to evaluate the potential for groundwater contamination to reach the LDW and contaminate sediment Groundwater information through 2002 was summarized for 12 upland sites[9]

[9] The 12 sites 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

identified by EPA and Ecology as preliminary sites of interest for the RI. Groundwater data collected from these sites were compared to chemical concentrations in receiving sediments. The following results were noted:

- At 11 of the 12 sites, no evidence was found for metals accumulation in sediment to concentrations greater than SMS criteria or Dredged Material Management Program (DMMP) guidelines in potential groundwater discharge zones.
- PCBs were not identified as a COC in groundwater based on groundwater data and known high retardation factors for PCB transport in groundwater. The same condition is expected for dioxins/furans; however, there are no dioxin/furan groundwater data.
- No sites were identified where cPAHs were detected in groundwater and elevated in adjacent sediment.
- Transport of volatile organic compounds (VOCs) to the LDW by groundwater from Great Western International (RM 2.3 to 2.4 E) is potentially a complete pathway based on detections of chlorinated ethenes in porewater and seeps. This site 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).

Bank Erosion

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.

Shoreline structures and conditions are discussed in more detail in Section 2.6.4. However, this pathway was not evaluated in the FS from a chemical perspective, because of the limited amount of data available for the banks. 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 chemical and physical

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).

conditions of the banks will be important on a case-by-case basis at the remedial design level, but not within the scope of the FS.

Subsurface Sediment Erosion

Subsurface sediments can be a secondary source of contamination to the surface sediments via scour. The STM (QEA 2008) delineates areas where sedimentation is expected to bury historically impacted sediment. However, in scour areas or areas disturbed by mechanical actions, contaminated subsurface sediments can become exposed. Section 2.3.1.1 discusses both high-flow- and ship-induced scour.

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 generated from point or non-point sources. Point sources include industrial smokestacks and activities such as painting, sandblasting, loading/unloading of raw materials, and other activities. Non-point 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. Air pollutants may be transported over long distances by wind, and can be deposited on land and water surfaces by precipitation or particle deposition. Section 9 of the RI (Windward 2010) reported (based on Puget Sound Clean Air Agency records) that over 200. businesses in the Duwamish Valley 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. On-going sources include off-gassing from historically impacted media (e.g., soils) and global atmospheric transport of PCBs from parts of the world where they are still used.

Atmospheric releases of arsenic have been significantly minimized by the closure of smelters. Releases of arsenic and other metals to the LDW have been minimized by housekeeping practices and controls on wastewater discharge at facilities that practice activities such as ship maintenance. However, migration from nonpoint sources (secondary or historically impacted media) to the LDW continues through upstream inflow of arsenic-containing suspended sediments and surface water, watershed runoff from the LDW drainage basin, and atmospheric deposition. Although controls have been placed on industrial atmospheric and wastewater discharges of chemicals such as dioxins/furans and PAHs, PAHs continue to be generated and released from general urban sources (e.g., vehicles) and enter the LDW from atmospheric deposition and watershed runoff. Continuing efforts to increase infiltration of stormwater, treatment of stormwater, and education of businesses and residents on reducing delivery of pollutants into the storm drain system are all measures designed to reduce

the amount of PAHs entering the LDW from nonpoint sources. However, regional development and population growth may tend to increase nonpoint source loads of PAHs (Ecology 2005). Dioxins/furans continue to be unintentionally generated from incineration of organic materials in the presence of chlorine.

2.4 Source Control Strategy

Ecology is the lead entity for implementing source controls in the LDW and works in cooperation with local jurisdictions and EPA to create and implement source control strategies and prioritize 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. The members of the SCWG are public agencies responsible for source control in the LDW, including Ecology, the City of Seattle, the City of Tukwila, King County, the Port of Seattle, and EPA. The purpose of the SCWG is to share information, discuss strategies, develop action plans, jointly implement source control measures, and share progress reports on source control activities in the LDW area.

Source control investigations assess the potential sources and pathways of chemicals in a specific area. In January 2004, Ecology issued the final Lower Duwamish Waterway Source Control Strategy with the purpose being to control sources of chemicals to LDW sediments in coordination with sediment remediation. The strategy focuses on meeting sediment cleanup goals, the prevention of post-remedy recontamination to levels that exceed the SMS criteria, or other LDW sediment cleanup goals that will be established in the LDW decision document. Ecology's source control investigation findings as well as plans for implementing source control activities are documented in a series of detailed, site-specific data gaps reports and source control action plans (SCAPs). The areas selected for source control activities were designated according to the following definitions:

- Tier One – Source control work associated with EAAs
- 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
- 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.

In 2003, Ecology designated seven Tier One source control areas (SCAs) for source control/sediment investigation. In 2007, eight other areas were designated as Tier Two Areas. In February 2008, Ecology expanded the boundaries of many of the 15 previously identified areas and added 8 additional SCAs. In 2010, Ecology added one more SCA; 24 SCAs now span the entire east and west shorelines of the LDW (Figure 2-16). The updated boundaries established for the 24 SCAs were developed to ensure that source control would be conducted for the nearshore bench areas of the LDW. These areas were delineated based on storm drainage subbasins and upland property boundaries. Ecology is in the process of developing SCAPs for each of these areas. Tier Three and Tier Four areas are included within these 24 areas, but have not been specifically designated at this time.

Initial efforts by the SCWG focused on the EAAs (5 of the 24 SCAs). Subsequent efforts are focused on the other SCAs. Ecology has in place several Model Toxics Control Act (MTCA) agreed orders to evaluate upland properties in the LDW watershed (shown on Figure 2-16 and described in Section 2.8). The EPA also has in place several Comprehensive Environmental Response, Compensation and Recovery Act (CERCLA) and Resource Conservation and Recovery Act (RCRA) agreed orders. These efforts to evaluate potential sources to the LDW and implement corrective actions will be ongoing.

In addition to the 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 sewers) within areas of the LDW drainage basin.[10] Total PCBs were detected in 84% of 953 storm drain sediment samples collected by Seattle Public Utilities, King County, and The Boeing Company. Through this source tracing exercise, PCBs have also been found in various building materials (e.g., paint, caulk, and other sealants). Unlike other chemicals, 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.

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.

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

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 sites 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 were 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 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 the Tribal Usual and Accustomed (U&A) 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 chemical 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 was located within fairly well-defined areas. The locations of the highest arsenic and total PCB concentrations were generally not in the same areas, indicating that sources likely differ for these two chemicals. Areas with the highest cPAH concentrations were located in many of the same areas identified for arsenic and total PCBs, but were also more dispersed. There are several areas with 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. 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 expected 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. Site-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, 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 those areas.

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 the selection of remedial technologies and the development of 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 specific gravity, 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 2-17 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+clay) 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 silt+clay content than other sediment. The average silt+clay content in the navigation channel was 62%; the 10th and 90th percentile silt+clay contents were 29 and 82%, respectively. Silt+clay 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 silt+clay contents have been calculated using point-based averages. Figure 2-18 displays an interpolation of the surface sediment fines content (sum of clay and silt percentages).

Three of the five slips along the LDW had high silt+clay contents relative to the overall LDW average. Slips 1, 3, and 6 had average silt+clay contents of 79, 71, and 87%, respectively. The silt+clay contents of Slips 2 and 4 were lower, with average values of 41% and 57%, respectively. The area above RM 5.0 had a much lower average silt+clay 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 2-19). 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 areas 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 micrometers (µm) (or 0.006 millimeter [mm]) to 520 µm (0.52 mm).[11] 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 specific gravity 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.
- 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 2-5 lists

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

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 2-6 and Figure 2-17 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.

Also, most of the historical subsurface sediment data in the RI baseline dataset were derived from sampling conducted to characterize sediments being evaluated for open-water disposal following dredging. Furthermore, 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 the evaluation of 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. Chemical 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 2-20):

- -30 ft MLLW and 200 ft wide from Harbor Island (RM 0.0) to the 1st Avenue South Bridge (RM 2.0), also known as the Harbor Island and Georgetown Reaches
- -20 ft MLLW and 150 ft wide from the 1st 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,[12] 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 2-7 summarizes recent maintenance dredging events in the LDW navigation channel between 1986 and 2010. Figure 2-21 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 2010).

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

[12] Figure 2-18 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.

operated by the Port of Seattle, lists berthing areas in the LDW. Table 2-8 and Figure 2-22 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 2-9 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 2-10.

- 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.[13] 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 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).
- Three 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, and Duwamish/Diagonal EAA). Sediments were dredged and capped in these areas. They are described in more detail in Section 2.7.

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

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

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 Structures

The majority of upland areas adjacent to the LDW have been industrialized for many decades. Overwater structures, primarily in the form of wharves, piers, and docks, 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 2-22 and 2-23).

The current overwater structures have been catalogued using the 2002 Port Series No. 36 publication (USACE 2002), the Duwamish Waterway Shoreline Inventory (Terralogic 2004), high-resolution ortho-rectified aerial photographs, oblique aerial photographs available at public internet sites (MSN live search), and field observations. Table 2-8 summarizes available details of these overwater structures.[14]

The distribution and types of overwater 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 and vessel interference.
- Marine structures such as piles, sheetpile walls, and foundations may be undermined by sediment removal.
- Remedial alternatives may have to be engineered to allow navigation depths to be maintained.

[14] 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.

- Vessel maneuvering can cause scour.
- Piles, moored vessels, floating docks, and other structures may need to be removed to implement the remediation.

Other in-water physical structures (e.g., bridges, utility crossings, dolphins, and piles) are also important to consider in this FS because they represent locations where:

- Remediation and data collection may be difficult because of restricted access.
- Bridge foundations, submerged pipelines and cables, and piles may be damaged or undermined by sediment remediation or removal.
- 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).
- Single piles or pile groups may have to be removed or cut off to achieve remediation goals.

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 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.

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.

Within Reach 3 (RM 4.0 to RM 4.8), there are only three major overwater structures: 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, 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.

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 2-23.

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, there are approximately 53,400 ft (10.1 miles) of armored shoreline, 5,480 ft (1.0 miles) of vertical bulkhead, 14,000 ft (0.3 miles) of dock face, and 19,300 ft (3.7 miles) of exposed shoreline. Dock face also overlaps the shoreline over 24,200 ft (4.6 miles). Figure 2-23 displays these features and notes the total dock face frontage (25,600 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 +12 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.

2.6.6 Vessel Traffic Patterns

A variety of 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 South Park Bridge[15]) and the Spokane Street Bridge are discussed in this section. These are opened periodically to allow the passage of vessels that exceed clearance heights.

[15] The South Park Bridge has been closed and is being removed, with no near-term plans to build a new bridge, at the time this FS was prepared.

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 (WSDOT). The South Park Bridge (at RM 3.3) is 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; WDOT 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 2-11). 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 (Windward 2010).

Logs for the Spokane Street Bridge from 2003 to 2005, portions of which are summarized in Table 2-11, record 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 20% 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 South Park Bridge (also referred to as the 14th Avenue Bridge) is 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 South Park Bridge shows that 35% to 40% of the vessels entering the LDW continue upstream at least as far as RM 3.3 (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 Bathymetry Coverage

Bathymetry 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 (Windward 2008)
- 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 2003).

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 carried forward and are referred to as the EAAs in this FS. The parties responsible for the five EAAs have conducted an intensive study of each EAA, and cleanups have occurred at two of the five EAAs: the Duwamish/Diagonal EAA and the Norfolk EAA. Currently, plans are underway for cleanup at the three remaining EAAs (Terminal 117, Slip 4, and Boeing Plant 2/Jorgensen Forge). The purpose of this section is to provide an update on the five EAAs.

2.7.1 Duwamish/Diagonal

In 2003 and 2004, the Duwamish/Diagonal EAA at RM 0.4 E was dredged (68,000 cy). In 2004, the dredged area (6.9 acres) was capped. These actions were conducted by King County as part of the Elliott Bay Duwamish Restoration Program (EB/DRP), as a MTCA interim action. 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 time trends, see Section 7). The occurrence of dredging residuals in this area was consistent with observations made regarding the contractor's initial operations. The contractor did not consistently use required BMPs to minimize the spread of dredging residuals. As a result, King County examined six options to reduce elevated PCB concentrations caused by the dredging residuals. After consultation with Ecology and EPA, King County selected the thin-layer placement option, also known as Enhanced Natural Recovery (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. This action was intended to immediately reduce receptor exposure to elevated PCBs and to accelerate the natural recovery time frame in this area. Over time, the natural process of bioturbation is expected to mix this clean sand into the underlying sediment containing PCBs. Monitoring continues to be performed 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.[16] The need for further cleanup for this 4-acre area is considered part of the development of the remedial alternatives.

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

A MTCA interim action at the Norfolk EAA was conducted by King County in 1999 as part of EB/DRP in the vicinity of the Norfolk CSO/SD. However, this action predates the LDW AOC. During this action, sediment was dredged as deep as 9 ft in one portion of the site in an attempt to remove all contamination. 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, such that this backfill material is at depths of 9 ft or more. This action was deemed suitable by Ecology.

In 2001, total PCB concentrations on the Norfolk CSO/SD cap 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.

The area immediately offshore of the Boeing Developmental Center at RM 4.9 E was excavated and capped in 2003 to address the recontamination of the Norfolk CSO/SD cap. During this event, Boeing removed 60 cy of sediment from a 0.04-acre area inshore of the Norfolk CSO/SD sediment cap, 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. 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 chemical concentrations on these caps are discussed in later sections of the FS.

2.7.3 Slip 4

An engineering evaluation/cost analysis (EE/CA) for a non-time-critical removal action at the Slip 4 EAA, prepared on behalf of the City of Seattle and King County (Integral 2006), was approved by EPA in February 2006. The EE/CA includes actions to address PCB contamination in Slip 4, as well as other contaminants that exceed SMS criteria, including BEHP, phenol, and indeno(1,2,3-cd)pyrene.

[16] Five years (2005 – 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.

EPA issued the Action Memorandum for Slip 4 in 2006 (EPA 2006), which selected a combined remedy of capping, bank excavation, and dredging. The 100% final design for the remedy was completed in 2007 (Integral 2007) and approved by EPA. Design elements include:

- Dredging/excavating approximately 10,000 cy of sediments and bank material
- Overexcavation of bank areas to expand intertidal and riparian habitat
- Pier demolition
- Piling and debris removal
- Capping of the entire 3.6-acre area with clean sand, gravel, and rock
- Cleanout and modification of the Georgetown Steam Plant flume and outfall
- Implementation of institutional controls and long-term monitoring.

As part of implementing the selected remedy, the City of Seattle has 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. Construction of the remainder of the Slip 4 cleanup has been delayed pending completion of other source control actions within the Slip 4 drainage basin.

No remedial activities have been conducted in the in-water portion of this EAA to date. Four surface sediment samples were collected in 2006 as part of the 2007 100% design submittal, and 13 subsurface samples were collected in 2008 (in addition to those in the RI baseline dataset).

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 both RCRA and MTCA. Surface sediment exceedances of the SMS criteria in this EAA included total PCBs, PAHs, phthalates, cadmium, chromium, copper, lead, mercury, phenol, silver, and zinc. In addition, the various investigations at upland properties in this EAA have identified chemicals 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. Stormwater lines were removed and/or cleaned, and catch basins connected to the storm drain conveyance system are routinely sampled and cleaned as needed. Soils and groundwater in some areas with

elevated chemical concentrations have been removed, remedied, or contained. There have also been some hot-spot removals of contaminated sediments in the intertidal area offshore of Boeing Plant 2. Finally, Boeing has conducted an evaluation of alternatives for a sediment removal project along the property (AMEC Geomatrix and Floyd Snider, Inc. 2008).

Other than the hot-spot removals of sediment, no other cleanup has been conducted to date in the in-water portion of this EAA. Eleven surface sediment and 355 subsurface sediment samples were collected from 2007 to 2009 (in addition to those in the RI baseline dataset).

The 22-acre Jorgensen Forge upland property 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 site. Underground storage tank removals and some upland soil investigations have occurred on site (Ecology 2007). In addition, in 2008, the Earle M. Jorgensen Company (a former owner of Jorgensen Forge) and EPA entered into an AOC to prepare an EE/CA for a non-time-critical removal action for sediments and associated shoreline bank soils. Some sampling of in-water sediments has occurred and a draft EE/CA (Anchor QEA 2009) has been submitted to EPA.

2.7.5 Terminal 117

The Terminal 117 (T-117) upland area at RM 3.5 West was historically used for the manufacture and storage of asphalt products. The Duwamish Manufacturing Company began manufacturing asphalt roofing materials at T-117 around 1937 and continued until 1978 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, after which it became known as the Malarkey Asphalt Company, which continued manufacturing asphalt roofing materials until 1993. During the oil embargo in the 1970s, used oils, some of which may have contained PCBs, were used as fuel for the asphalt manufacturing process (AECOM et al. 2010).

Soils on the upland portion of T-117 with elevated concentrations of PCBs were removed during two time-critical removal actions (1999 and 2006). The second removal was based on findings presented in a draft 2005 upland EE/CA. In addition, PCB-contaminated areas in the rights-of-way have been paved, and a temporary stormwater collection system was installed that conveys most runoff from the roadways adjacent to T-117 to the combined sewer system.

Except for the marina, industrial activities in the adjacent upland area have ceased, and a revised upland and in-water EE/CA was finalized on June 3, 2010, with a public hearing on June 17, 2010. The EE/CA included a presentation of environmental quality for: adjacent in-water sediments; upland soil and groundwater; adjacent city streets and residential yard soil; and the Recontamination Assessment Areas of Basin

Oil and the South Park Marina. Data gap findings and site groundwater occurrence and quality are presented in separate project documents. The final EE/CA (AECOM et al. 2010) presented two non-time-critical removal action alternatives, combining upland soil excavation, sediment dredging and capping, and site restoration (backfilling and compaction).

The EPA Action Memorandum for T-117 is expected to be finalized in late 2010 (along with the EPA National Remedy Review Board finding and the Responsiveness Summary). An amendment to the existing Administrative Settlement Agreement and Order on Consent to modify the Statement of Work to include design is expected by the end of 2010.

No remedial activities have been conducted to date in the in-water portion of this EAA. The in-water EAA boundary, used in this FS, was finalized in 2009 based on the results presented in the *Dioxin Investigation and PCB Sediment Removal Boundary Delineation Data Report* (Windward and Integral 2009). Seventeen surface sediment samples were collected in 2008 and analyzed for PCBs and dioxins/furans as part of this study.

2.8 Areas with Agreed Orders

Ecology has prioritized source control efforts first with upland areas related to the in-water EAAs. The sediment benches of the entire LDW have subsequently been divided into 24 SCAs; Figure 2-16). The next priority will be upland parcels and drainage areas associated with these 24 SCAs. Data gap reports are being prepared by Ecology for each SCA to summarize available information that may have implications for source control. SCAPs either have been prepared or are being prepared for each SCA. Each SCAP identifies potential releases of hazardous substances and actions needed to control the sources and evaluates whether on-going sources could recontaminate sediments after cleanup. In addition, the SCAPs describe source control actions that are planned or currently underway and sampling and monitoring activities that will be conducted to identify additional sources.

Within this framework, agreed orders have been negotiated, or are being negotiated, with upland property owners. The following upland properties (organized by in-water area) either have agreed orders in place or under negotiation. This list also includes properties under voluntary agreements or in the site investigation phase[17]:

- Boeing Plant 2/Jorgensen Forge EAA
  - Boeing Plant 2 (EPA RCRA)

[17] Each subbullet represents a separate order or action. Unless indicated otherwise by text in parentheses, the area is under a MTCA Agreed Order.

  - Jorgensen Forge Corporation/Earle M. Jorgensen Company (EPA-managed RCRA site)
- Terminal 117 EAA
  - Terminal 117 (CERCLA removal action)
  - South Park Marina (Former A&B Barrel; site investigation)
  - Basin Oil (site investigation)
- Duwamish/Diagonal EAA
  - Port of Seattle Terminal 108 (Ecology voluntary cleanup program)
- Slip 4 EAA
  - Slip 4 sediments (CERCLA removal order)
  - North Boeing Field/Georgetown Steam Plant
  - Crowley Marine Services
- RM 3.7 to 3.9 East
  - PACCAR/8801 Site
  - Boeing Isaacson/Thompson
- Trotsky Inlet, RM 2.2 West
  - Industrial Container Services/Trotsky Property/Former Northwest Cooperage
  - Douglas Management Company/Alaska Marine Lines (North of Northwest Cooperage)
- Glacier Bay: RM 1.3 to 1.6 West
  - Duwamish Shipyard
  - Glacier Northwest/Reichhold Chemical
  - Terminal 115 North (MRI)
- Slip 3 to Seattle Boiler Works:
  - Fox Avenue Building (Great Western Chemical)
- RM 1.2 to 1.7 East
  - Art Brass Plating

  - Blaser Die Casting (enforcement order)
  - Capital Industries
  - Philip Services Georgetown
- Slip 6
  - Rhône-Poulenc/Monsanto (EPA-managed RCRA site)
  - 8801 East Marginal Way Site
- Slip 2 to Slip 3 East
  - Duwamish Marine Center
- Other Agreed Orders
  - General Electric–Dawson Street Plant
  - South Park Landfill
  - Boeing Former Electronics Manufacturing Facility (EPA-managed RCRA site)

The in-water areas adjacent to or receiving drainage from these properties are coincident with elevated concentrations of the risk-driver chemicals in the LDW surface sediments, and these sediment areas are prioritized in this FS.

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 0.5 E 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 2001, *Duwamish/Diagonal Cleanup Study Report*; HistoryLink.org; USACE 1947 to 1981, Historical Conditions Surveys; Windward 2010a, *Lower Duwamish Waterway Remedial Investigation*.

Notes:

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

Table 2-2 FS Baseline Data Included Since RI Baseline Dataset

Sampling Event	Sample Date(s)	Number of Samples	Party; Notes
Surface Sediment			
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 chemicals. This event also included a collection of 6 beach sediment composite samples, but they are not part of the FS baseline dataset. 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
International Container Services (Trotsky)	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; data used in development of BCM input parameters (Section 5)
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 sample count		*174 in Study Area (does not include toxicity data or chemistry locations upstream of RM 5.0)*	
Subsurface Sediment			
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

Table 2-2 FS Baseline Data Included Since RI Baseline Dataset

Sampling Event	Sample Date(s)	Number of Samples	Party; Notes
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 Figure 2-4 for sample locations.

BCM = bed composition model; cPAH = carcinogenic polycyclic aromatic hydrocarbons; DMMO= Dredged Material Management Office; EAA=Early Action Area; ENR = enhanced natural recovery; PCB = polychlorinated biphenyls; RM = river mile; SMS = Sediment Management Standards; SPI = sediment profile imaging; USACE = United States Army Corps of Engineers.

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

Data Type/Chemical	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)	1.9	1,133[b]	2,900,000 230,000[b]	346[b]	1,395	1,314
Arsenic (mg/kg dw)	1.2	17	1,100	15.6	918	859
cPAHs (µg TEQ/kg dw)[c]	2.2	460	11,000	388	893	853
Dioxins/Furans (ng TEQ / kg dw)[d]	0.3	42	2,100	25.6	123	123
Subsurface Sediment						
Total PCBs (µg/kg dw)	0.05	1,950	890,000	n/a	1,506	1134
Arsenic (mg/kg dw)	1.2	28	2,000	n/a	534	456
cPAHs (µg TEQ/kg dw)[c]	1.2	371	7,000	n/a	546	453
Dioxins/Furans (ng TEQ / kg dw)[d]	0.15	16	194	n/a	59	59

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

Notes:

1. 95% upper confidence limits on the mean ranging from 544 to 702 µg/kg dw) for the interpolated RI baseline dataset total PCB data were calculated by Kern (2010) using various methods.

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. The highest remaining concentration (223,000 µg/kg dw) is located in the Norfolk area. If the two outliers were not removed, the SWAC would be 1,313 µg/kg dw. The SWAC for current conditions (i.e., using 2009 data on the Duwamish/Diagonal cap and ENR area and on the Boeing Developmental Center south storm drain area) is 306 µg/kg dw, with the two Trotsky inlet outliers excluded.

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

d Dioxin/furan TEQ calculated using World Health Organization (2005) mammalian toxic equivalent factors.

cPAH = carcinogenic polycyclic aromatic hydrocarbons; dw = dry weight; kg = kilograms; mg = milligrams; µg = micrograms; n/a = not applicable; ng = nanogram; PCB = polychlorinated biphenyls; TEQ = toxic equivalent

Table 2-4 Statistical Summaries for SMS Chemicals and Other Chemicals of Concern for Human and Ecological Health

Chemical	Summary Statistics for Surface Sediments			Total Number of Surface Sediment Samples in FS Baseline Dataset						Benthic Invertebrate Risk Driver[d]
	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]	
Metals and TBT (mg/kg dw)										
Arsenic	1.2	1,100	17	918	859	94%	5	9	14	yes
Cadmium	0.03	120	1.03	895	632	71%	2	12	14	yes
Chromium	4.80	1,680	41.49	907	907	100%	1	10	11	yes
Copper	5.0	12,000	106	909	909	100%	0	13	13	yes
Lead	2.0	23,000	139	909	909	100%	2	23	25	yes
Mercury	0.015	247	0.53	928	813	88%	20	30	50	yes
Nickel	5.0	910	28	837	837	100%	n/a	n/a	n/a	no
Silver	0.018	270	1.03	876	538	61%	0	10	10	yes
Vanadium	15	150	58	590	590	100%	n/a	n/a	n/a	no
Zinc	16	9,700	194	906	906	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	884	169	19%	1	4	5	yes
Acenaphthene	1.0	5,200	65	893	352	39%	16	4	20	yes
Anthracene	0.58	10,000	134	893	648	73%	2	0	2	yes
Benzo(a)anthracene	4.3	8,400	322	893	822	92%	10	6	16	yes
Benzo(a)pyrene	6.5	7,900	308	888	820	92%	7	5	12	yes
Benzo(g,h,i)perylene	2.4	3,800	164	893	764	86%	10	12	22	yes
Total benzofluoranthenes	6.6	17,000	731	887	830	94%	6	6	12	yes
Chrysene	5.0	7,700	473	893	847	95%	29	3	32	yes
Dibenzo(a,h)anthrecene	1.6	1,500	62	893	498	56%	18	6	24	yes
Dibenzofuran	1.0	4,200	54	890	276	31%	7	3	10	yes
Fluoranthene	11	24,000	887	893	870	97%	35	12	47	yes
Fluorene	0.68	6,800	78	893	431	48%	11	3	14	yes
Indeno(1,2,3-cd)pyrene	5.2	4,300	180	893	802	90%	16	13	29	yes
Naphthalene	3.0	5,300	49	884	183	21%	0	2	2	yes

Table 2-4 Statistical Summaries for SMS Chemicals and Other Chemicals of Concern for Human and Ecological Health

Chemical	Summary Statistics for Surface Sediments			Total Number of Surface Sediment Samples in FS Baseline Dataset						Benthic Invertebrate Risk Driver[d]
	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]	
Phenanthrene	4.1	28,000	429	893	833	93%	27	3	30	yes
Pyrene	8.3	16,000	723	893	861	96%	2	6	8	yes
Total HPAH	20	85,000	3,809	893	875	98%	25	6	31	yes
Total LPAH	4.7	44,000	696	893	836	94%	4	3	7	yes
Phthalates (µg/kg dw)										
Bis(2-ethylhexyl) phthalate	5.4	17,000	589	887	704	79%	46	58	104	yes
Butyl benzyl phthalate	2.0	7,100	87	879	479	54%	80	10	90	yes
Dimethyl phthalate	2.0	440	25	879	186	21%	0	2	2	yes
Chlorobenzenes (µg/kg dw)										
1,2,4-Trichlorobenzene	1.6	940	19	872	6	1%	0	2	2	yes
1,2-Dichlorobenzene	1.3	670	19	872	19	2%	0	4	4	yes
1,4-Dichlorobenzene	1.5	1,600	23	872	50	6%	0	4	4	yes
Hexachlorobenzene	0.4	95	17	875	46	5%	4	2	6	yes
Other SVOCs and COCs (µg/kg dw, unless otherwise noted)										
2,4-Dimethylphenol	6.1	290	44	870	29	3%	0	25	25	yes
4-Methylphenol	4.8	4,600	43	887	116	13%	0	4	4	yes
Benzoic acid	54	4,500	238	877	112	13%	0	9	9	yes
Benzyl alcohol	8.2	670	49	868	31	4%	9	7	16	yes
Carbazole	3.2	4,200	82	776	425	55%	n/a	n/a	n/a	no
n-Nitrosodiphenylamine	6.5	230	27	872	24	3%	0	2	2	yes
Pentachlorophenol	7.0	14,000	122	841	31	4%	1	1	2	yes
Phenol	10	2,800	91	887	283	32%	19	6	25	yes
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

Table 2-4 Statistical Summaries for SMS Chemicals and Other Chemicals of Concern for Human and Ecological Health

Chemical	Summary Statistics for Surface Sediments			Total Number of Surface Sediment Samples in FS Baseline Dataset						Benthic Invertebrate Risk Driver[d]
	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]	
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]	1.9	223,000	1,133	1394	1312	94%	336	179	515	yes

Source: Feasibility Study baseline surface sediment database queries.

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 Chemicals 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 chemicals (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.

2LAET = second lowest apparent effects threshold; CSL= cleanup screening level; HPAH = high molecular weight polycyclic aromatic hydrocarbon; LAET= lowest apparent effects threshold; LPAH = low molecular weight polycyclic aromatic hydrocarbon; n/a= not applicable; nc= not calculated; SQS= sediment quality standard; SVOC= semivolatile organic compound; TEQ = toxic equivalent; VOC= volatile organic compound.

Table 2-5 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 0.0 E	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

Table 2-5 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
0.4-0.5	1966-1971	Diagonal Yard	SPU	Kellogg Island	Boring logs, test pit logs, sludge pond probes	5	could not determine from materials
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 Bay	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 Bay	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 2-5 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
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 2.2	Boring logs	4	Foundation exploration
4.7	1988	Geotechnical Design Report, North Oxbow Bridge, Boeing Development 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 2-6 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 and 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.

Table 2-7 LDW Navigation Channel Maintenance Dredging (1986 to 2010)

River Mile	Dredge Date		Volume Dredged (cy)	Paydepth / Overdepth (ft MLLW)	Survey Dates		Side Slope
	Start	End			Pre-Dredge	Post-Dredge	
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 2009), and 2010 Payment Summary (USACE 2010).

Notes:

1. See Figure 2-21 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 2-8 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
Birmingham Steel 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)
Birmingham Steel 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	Proposed modifications to Berth 1: replace the center timber pier (Pier B) with a 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)[c]	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 No 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
Jore Marine Services 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
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
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

Table 2-8 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]
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
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 has a 92-ft horizontal clearance, and 21-ft vertical clearance (34 ft at center) when closed (NOAA 2008). Bridge has been closed to traffic and is being removed with no near-term plans for replacement.				
	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; National Oceanic and Atmospheric Administration (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:

See Figure 2-22 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.

c Details of Terminal 115 North Wharf provided by Doug Hotchkiss, Port of Seattle, July 23, 2008 personal communication.

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

Table 2-9 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]	
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
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	—	—	-25 to -15	Maintain depth of basin behind dolphins	—		x	—
Glacier NW	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 (approx)	W	Planned	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
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

Table 2-9 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]	
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 -15 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, -15 / -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

Sources:

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.

Notes:

See Figure 2-21 for locations of dredging events.

— = unknown / not documented; cy= cubic yards; DMMO= Dredged Material Management Office; DMMU= dredged material management unit; DNS= Determination of Non-Significance; MLLW= mean lower low water; SEPA= State Environmental Policy Act.

Table 2-10 Dredging Events for Contaminated Sediment Removal

Project/Site Name	River Mile	River Side	Dredging Year	Volume Dredged (cy)	Notes
Contaminated Sediment Removal from LDW					
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	1975	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 2-21 for locations of dredging events.

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

Table 2-11 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
South Park Bridge															
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.

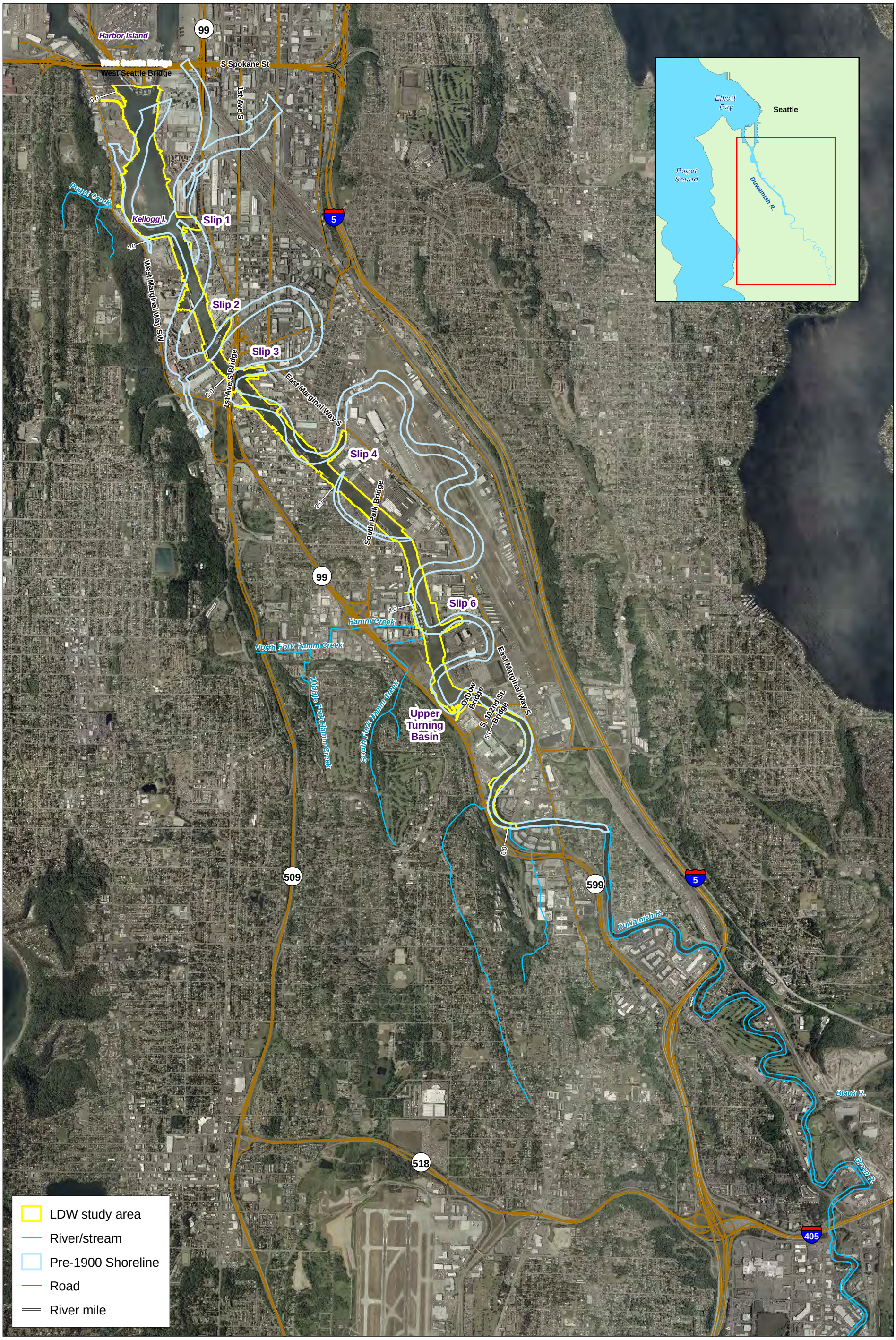
Washington State Department of Transportation. First Avenue Bridge Opening Logs, 2005-2006. Provided by Bridge/Structures Maintenance & Operations Manager. December 18, 2006.

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.

— = data not available at time it was requested.



Prepared by CEH 10/19/08; MAP #3091; W:\Projects\00-08-06_Duwamish_RI\data\gis\Phase2 RI\Intro - Env Setting

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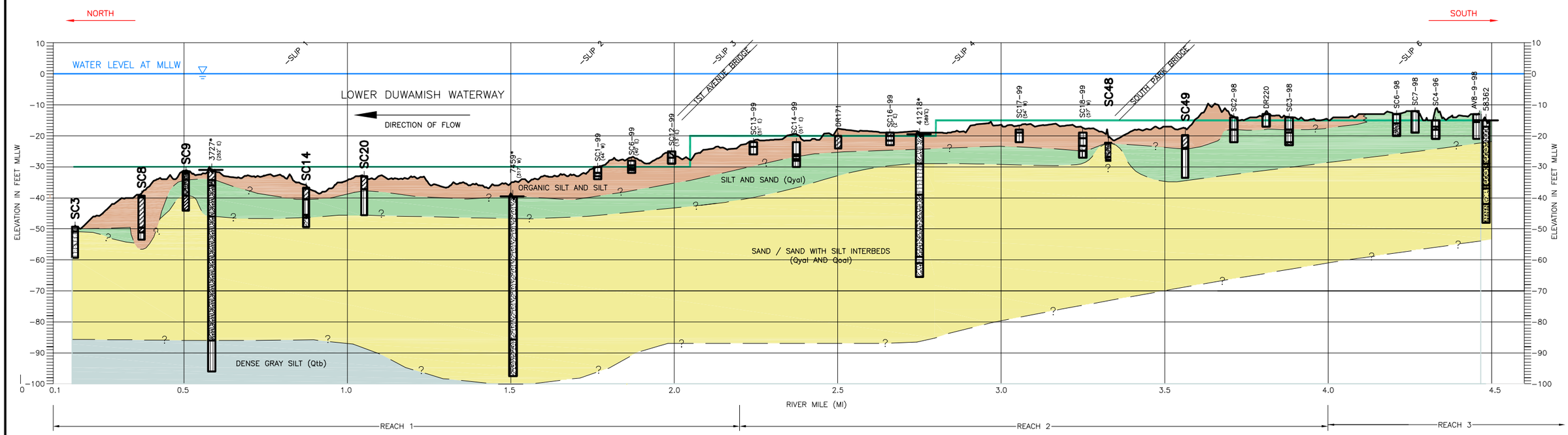
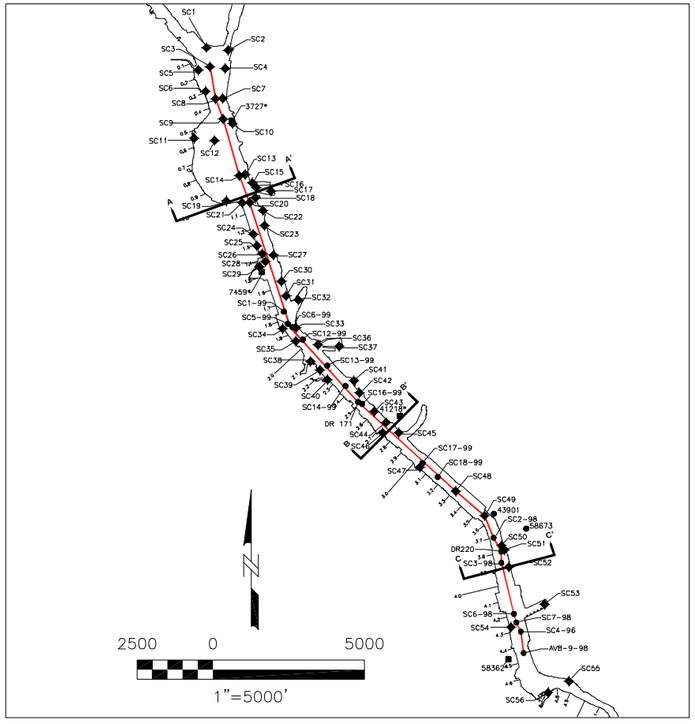
N

0 0.5 1 Miles

0 0.5 1 Kilometers

Figure 2-1. LDW and historical meanders





800 0 1600
HORIZONTAL SCALE IN FEET
VERTICAL EXAGGERATION = 50:1

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 bathymetry survey, ft MLLW)

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

STRATIGRAPHY**

- RECENT
- UPPER ALLUVIUM/TRANSITION
- LOWER ALLUVIUM
- DENSE POST-GLACIAL AND GLACIAL UNIT

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

LITHOLOGY

- Clay/Silt
- Organic silt
- Silt
- Sand with silt
- Sand with silt interbeds
- Sand
- Gravel, sandy gravel

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 Core 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).

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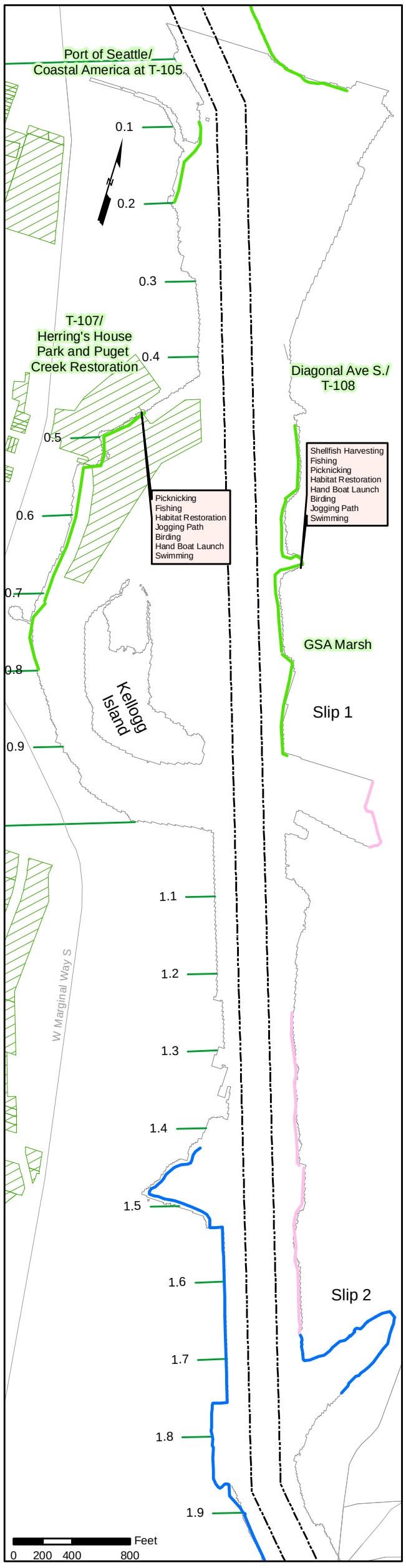
DRAFT FINAL FEASIBILITY STUDY
60150279-14.5

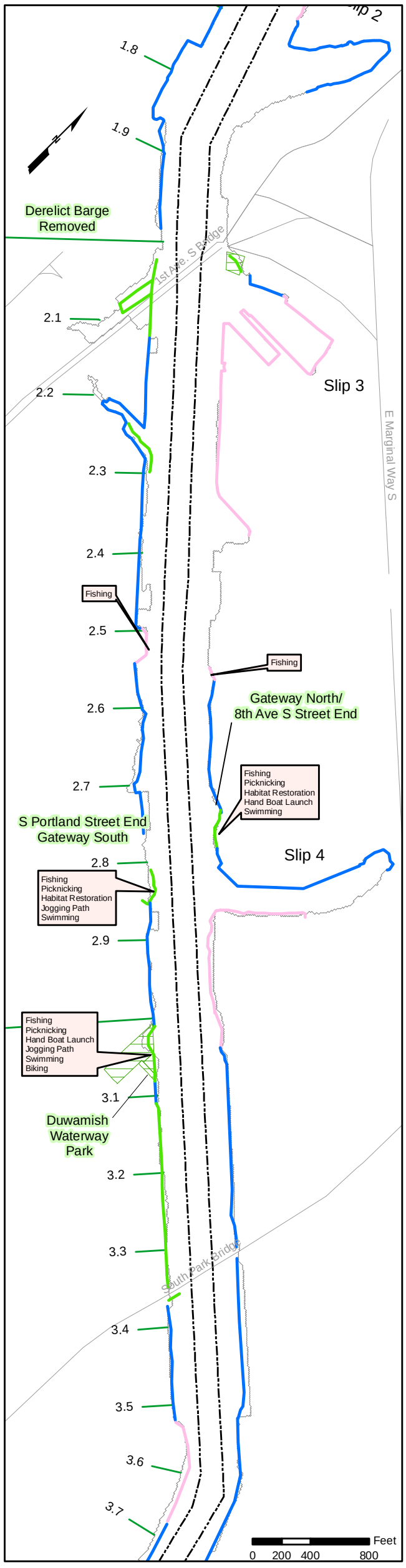
DATE: 04/02/10 | DRWN: E.M./SEA

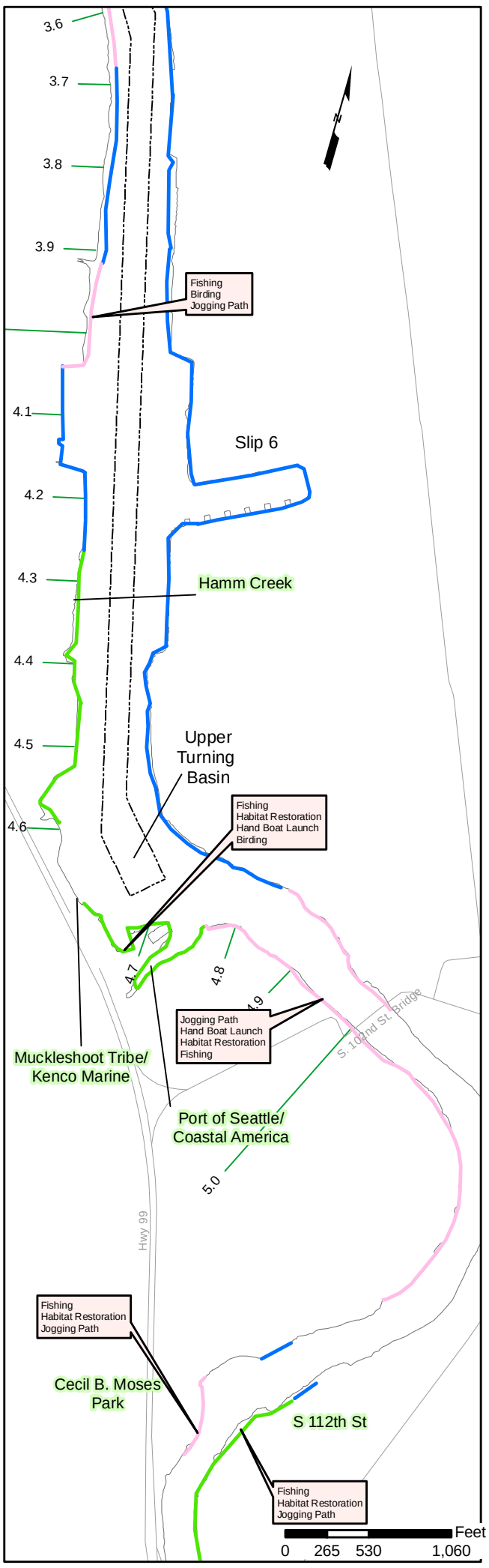
NAVIGATION CHANNEL LONGITUDINAL CROSS SECTION

FIGURE 2-2

File: M:\Lower Duwamish\X-SECTS 6-17-08\8220-LONG(c).dwg Layout: FIG User: MarshallE Plotted: Jul 08, 2010 - 8:00am Xref's:







Legend

Picnicking
Fishing
Shellfish Harvesting
Swimming
Jogging Path
Birding
Biking
Hand Boat Launch
Habitat Restoration

Shoreline Activity

Cecil B. Moses Park — Habitat Restoration Area

Notes:
1. Shoreline use and activities from Windward (2005) Human Use Survey. Activities based on questionaires 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.

Park
Road
Navigation Channel
River Mile Marker

Shoreline Use
Easy Public Access
Difficult Public Access
Restricted Access

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60150279-14.5

Habitat Restoration Areas, Parks, and Shoreline Access

DATE: 09/14/10 | DWRN: MVI/sea | Revision: 0

FIGURE 2-3

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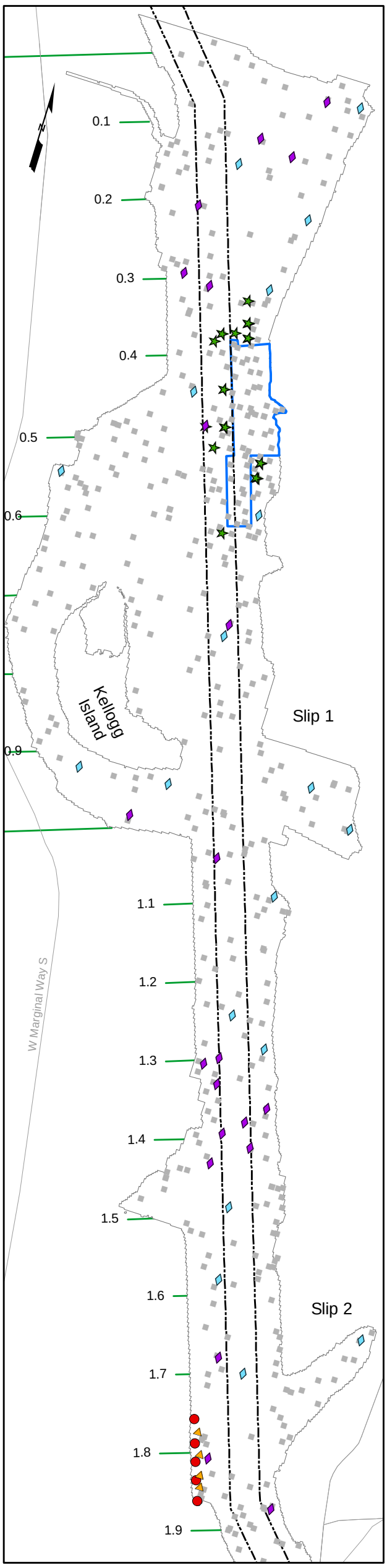

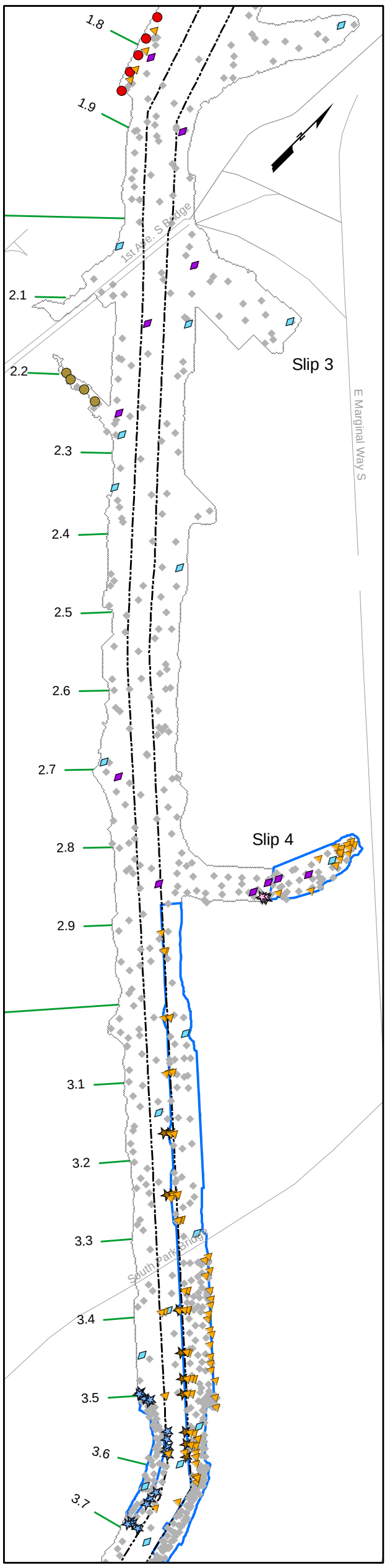

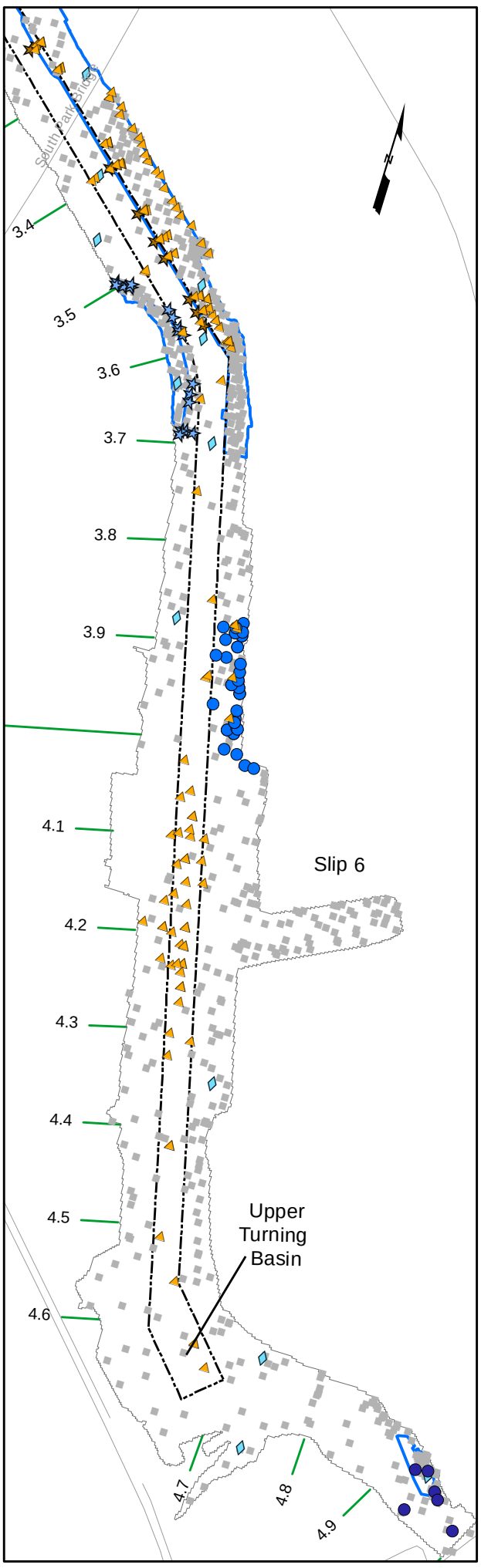

Notes:
1. FS baseline dataset dated April 28, 2010 was generated as the RI baseline dataset plus the events shown on this map.

Early Action Area
Navigation Channel
River Mile Marker
Road

Legend

Surface Sediment Event Added to FS Baseline Dataset

Site-wide Sampling

- 2006 Ecology Sediment Profile Imaging
- 2009 and 2010 LDWG Dioxins/Furans Site-wide

EAA Sampling

- 2005-2009 Duwamish/Diagonal EAA Perimeter
- 2007 Boeing Plant 2 EAA Western Boundary
- 2006 Slip 4 EAA Design
- 2008 Terminal 117 EAA Boundary

Other Area Sampling

- 2006 and 2008 8801 E Marginal (formerly Kenworth PACCAR)
- 2007 Industrial Container Services
- 2008 Ecology Upstream Surface Sediment
- 2009 Terminal 115 Intertidal

- RI Baseline Surface Sediment Location
- Core Added to FS Dataset

Feet
0 200 400 800

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

DATE: 07/08/10 | DWRN: mvi/SEA | Revision: 0

FIGURE 2-4

L:\Lower Duwamish FS\FS_GIS_01April2010\Section 2\MXDs\Fig2-xFSSamplesAdded.mxd

Figure 2-5a. LDW Conceptual Site Model for Reach 1

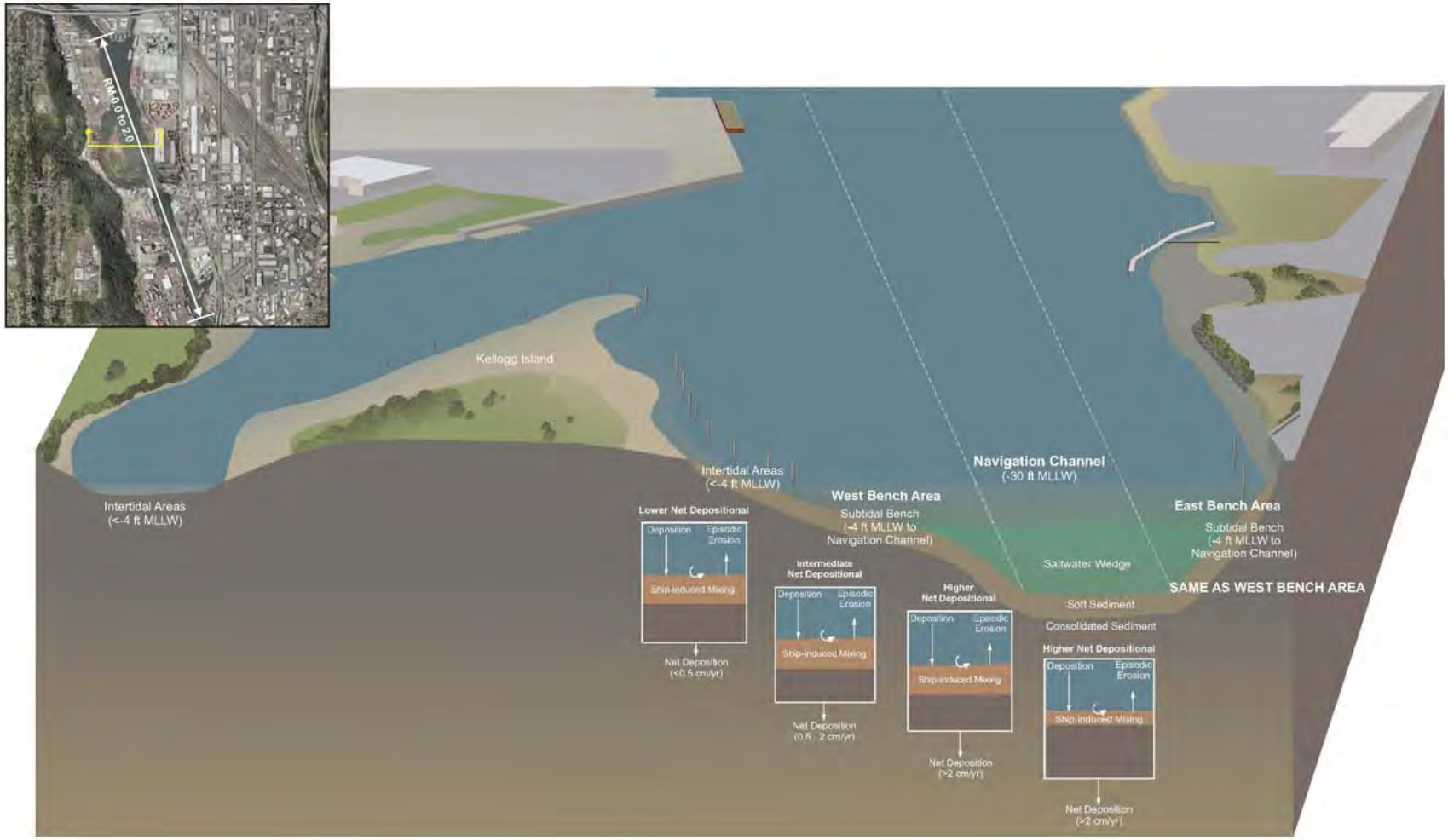
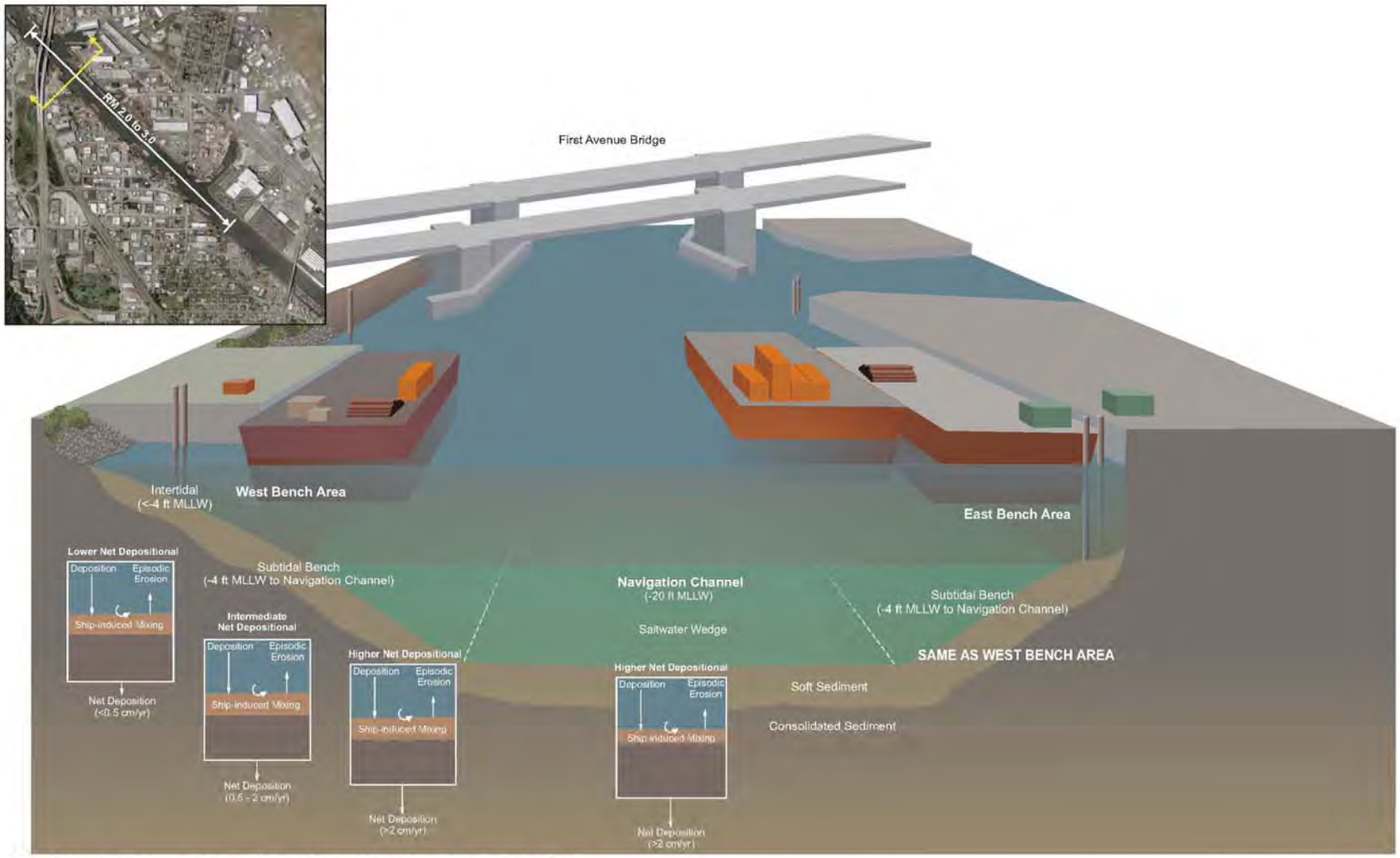
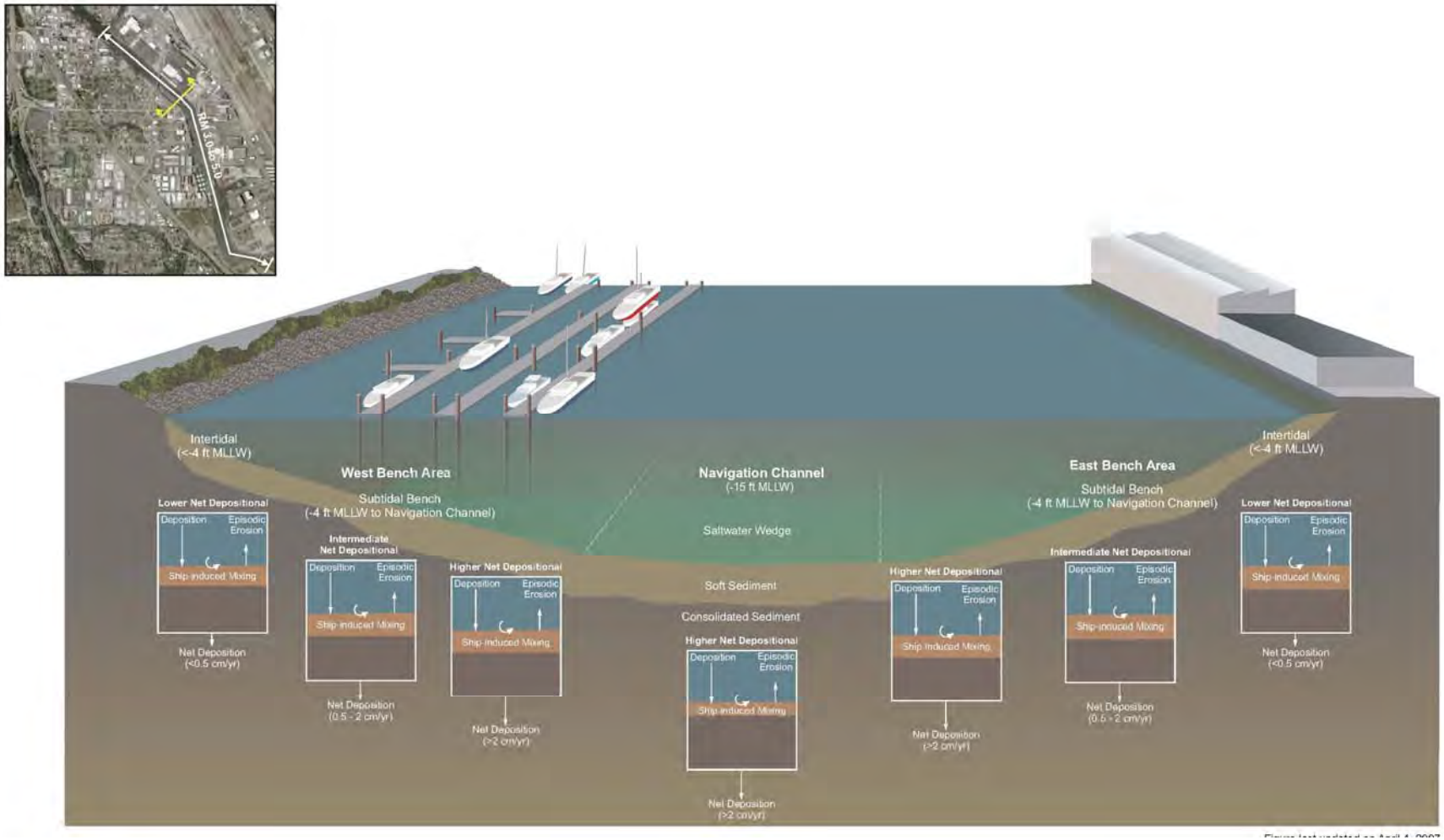


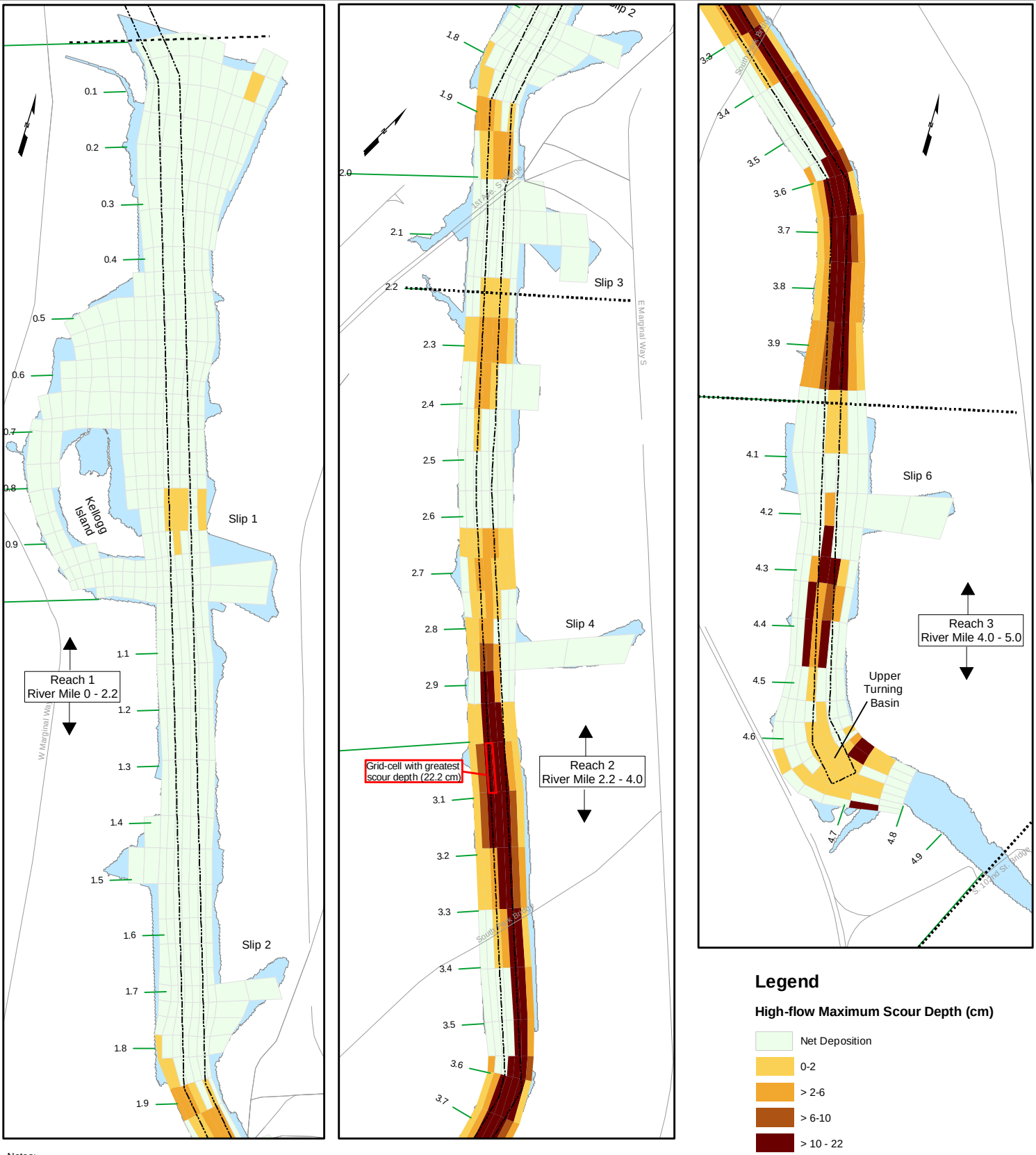
Figure 2-5b. LDW Conceptual Site Model for Reach 2



Notes: 1. Approximate net depositional rates from Sediment Transport Analysis Report, Windward and QEA 2006.

Figure 2-5c. LDW Conceptual Site Model for Reach 3





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.

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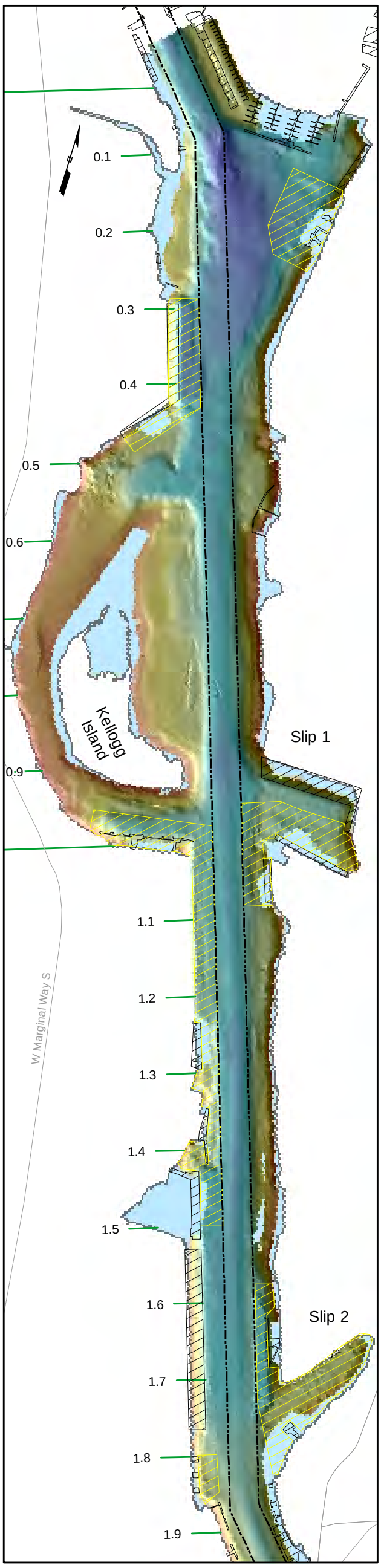
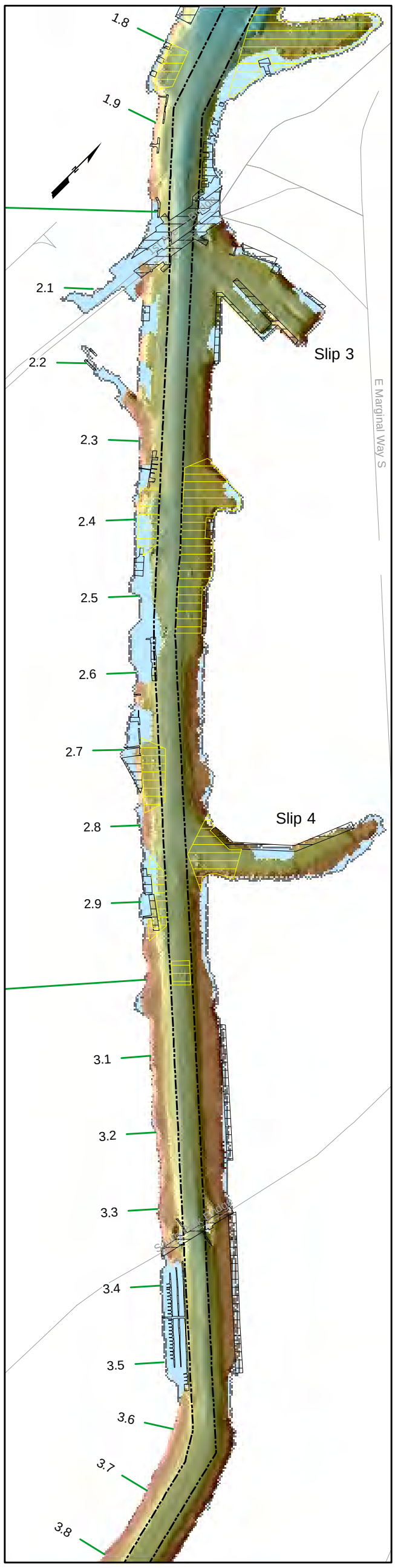
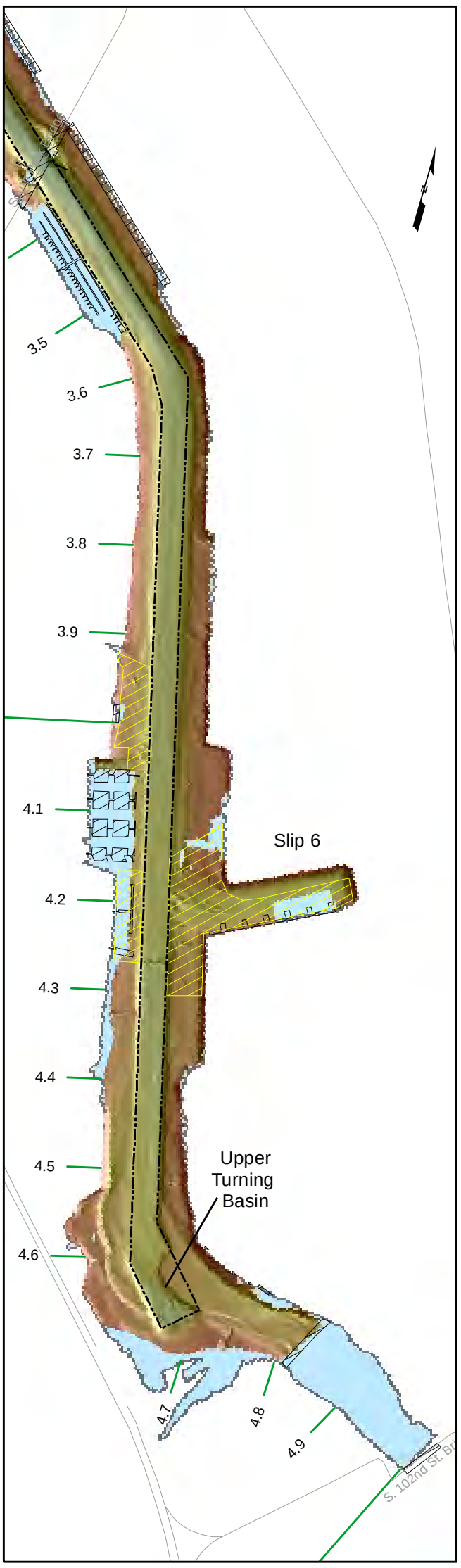
DATE: 07/08/10	DWRN:MVI/sea	Revision: 0	FIGURE 2-6

L:\Lower Duwamish FS\FS_GIS_01April2010\Section 2\MXDs\Figure2_xMaxScour.mxd







Legend

- Evidence of Propeller Wash Scour
- Overwater Structure
- No 2003 Bathymetry 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.

Feet
0 200 400 800

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Potential Propeller Wash Scour

DATE: 08/03/10 | DWRN:MVI/sea | Revision: 0

FIGURE 2-7

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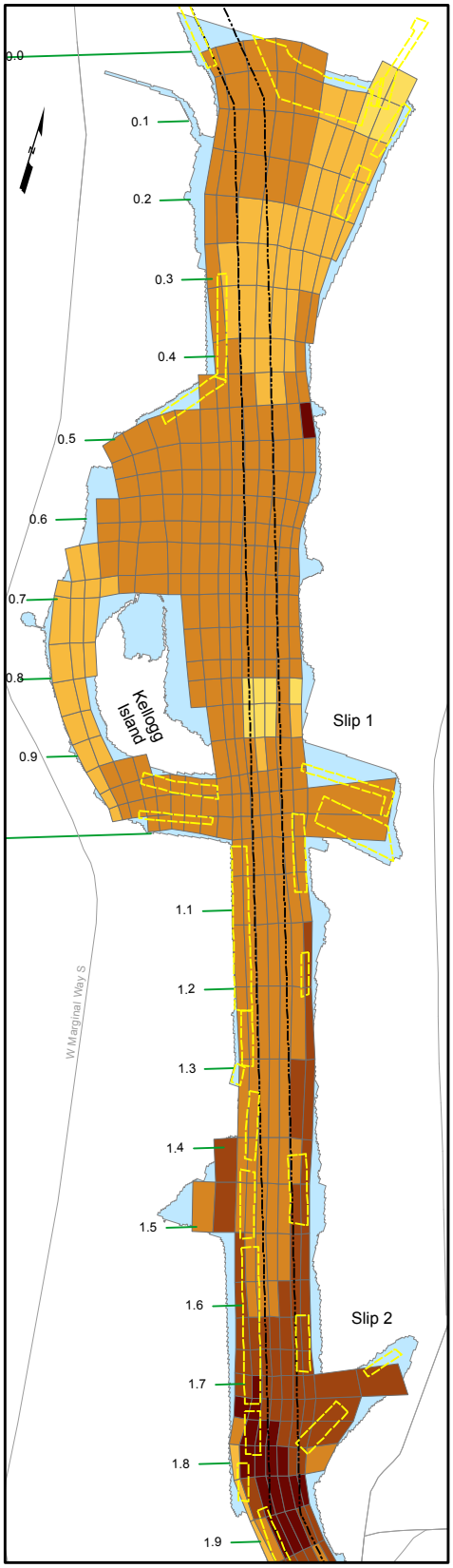

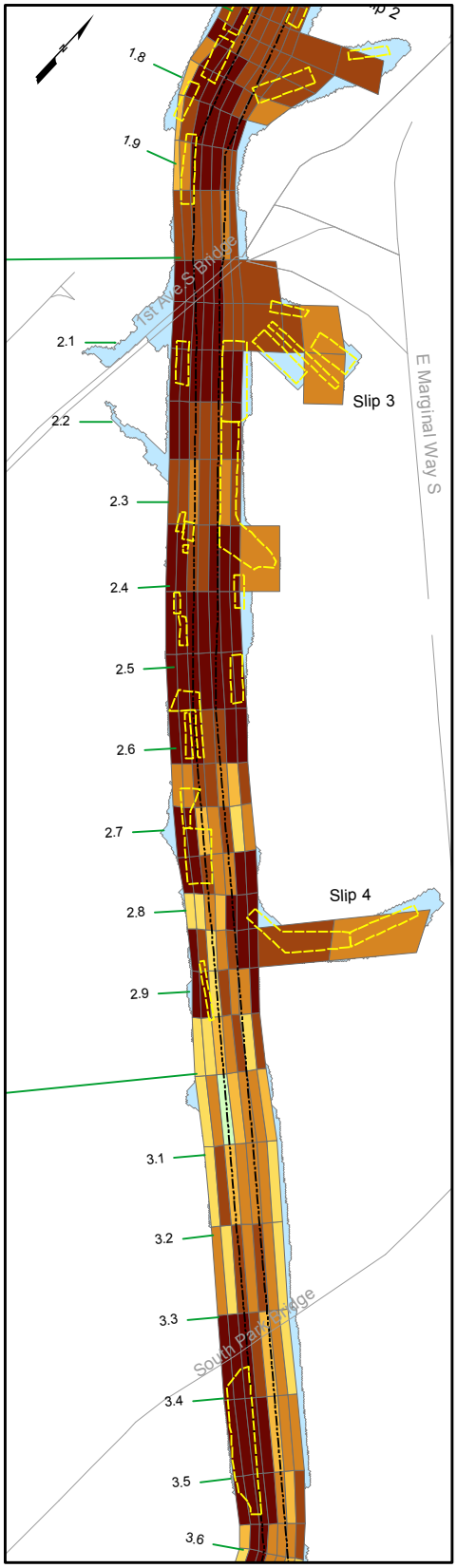

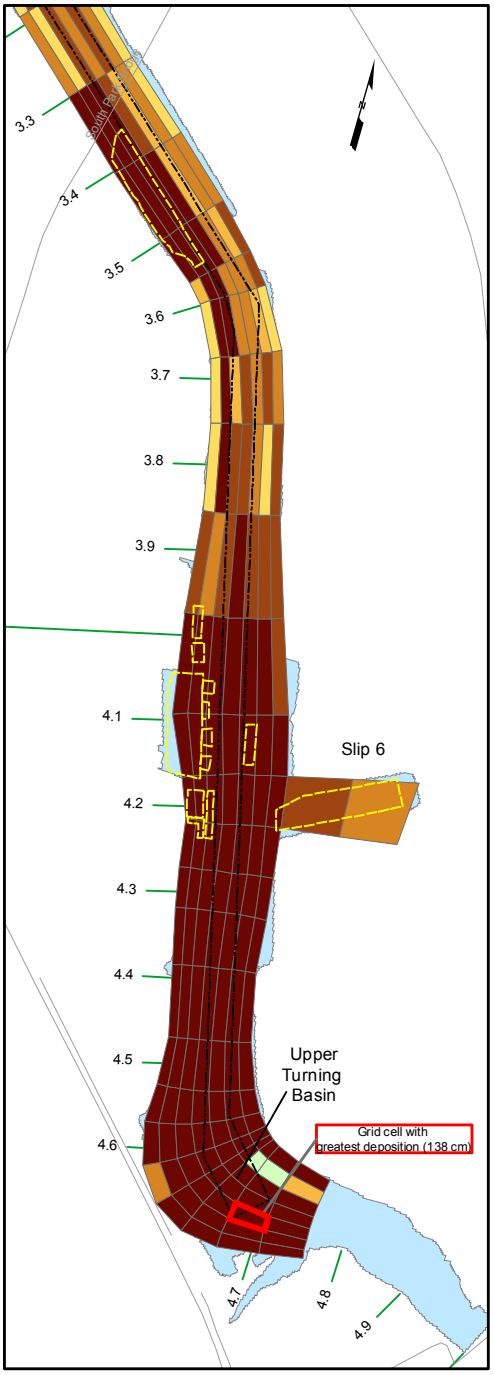

Notes:
1. 30-year STM GIS shapefile (QEA Feb. 2009).

Legend

Estimated Annual Net Sedimentation Rate (cm/yr)

- Net Erosion
- ≤ 0.5
- > 0.5 - 1.0
- > 1 - 2
- > 2 - 3
- > 3 - 145
- Outside of Model Domain

- Berthing Area
- Road
- Navigation Channel
- River Mile Marker

Feet
0 200 400 800

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Lower Duwamish Waterway Draft Final Feasibility Study 60150279-14.5			Estimated Annual Net Sedimentation Rates
DATE: 08/03/10	DWRN:MVI/sea	Revision: 0	FIGURE 2-8

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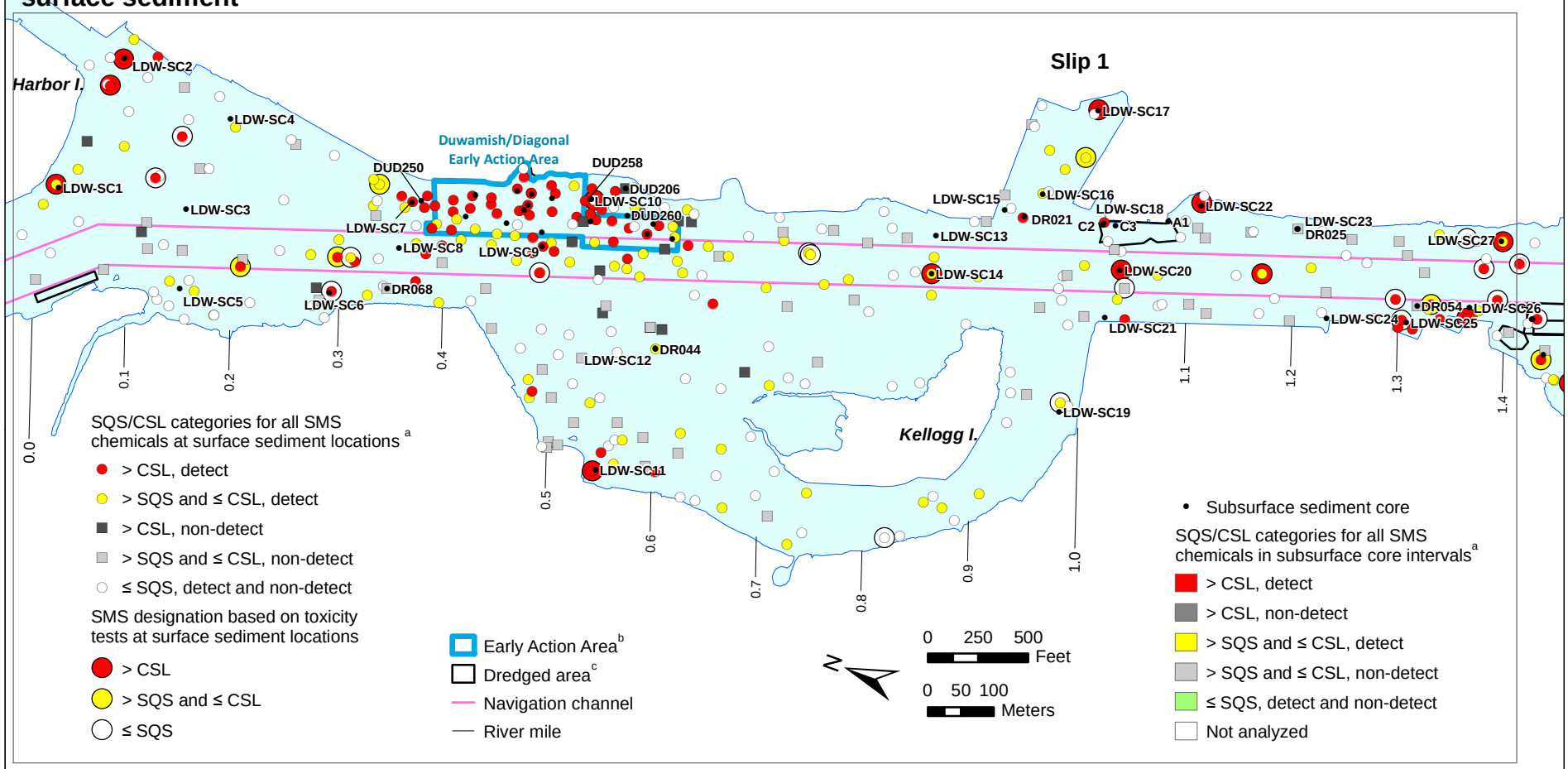
Subsurface sediment core locations and exceedances of SQS and CSL (chemical criteria and toxicity combined) in surface sediment



[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.

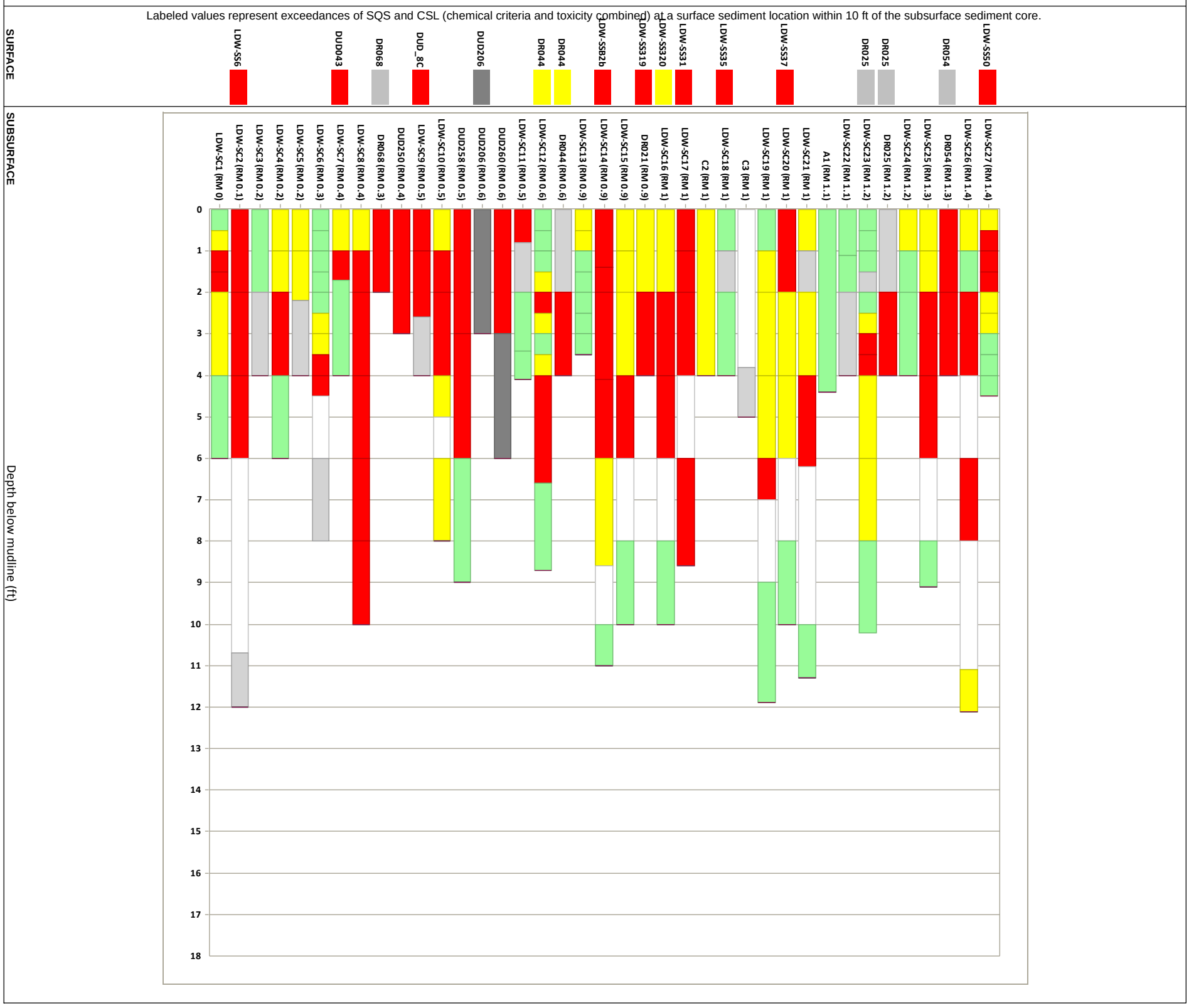
[b] Several of the EAA boundaries are approximate and have not been finalized by EPA/Ecology.

[c] Subsurface 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 area.

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.

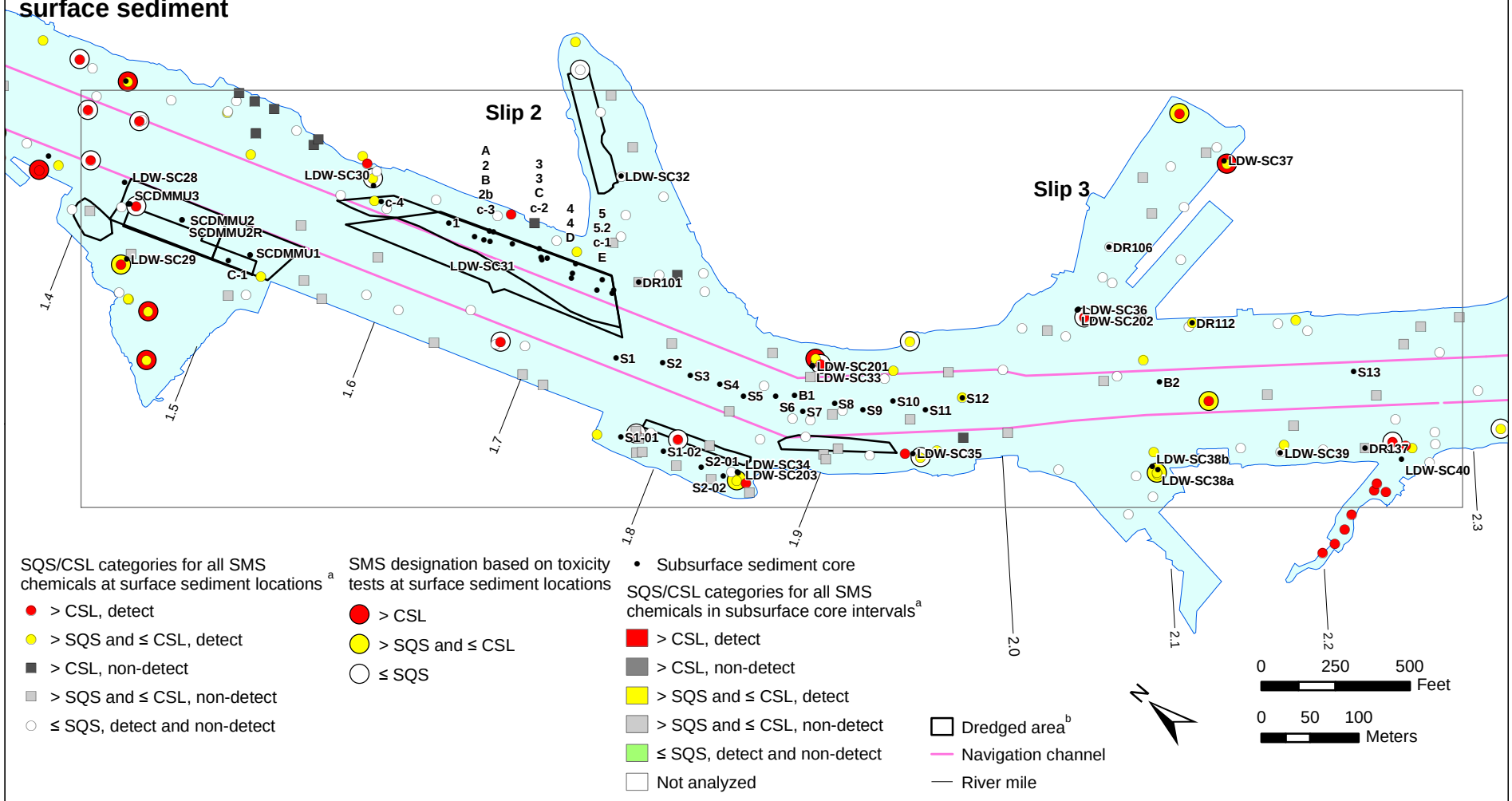


Wind Ward environmental LLC

Figure 2-9a. Comparisons of concentrations of all SMS chemicals to SMS criteria (SQS or CSL) in subsurface sediment cores, RM 0.0 to RM 1.4

Prepared by CEH, 10/11/10; MAP 2984; W:\Projects\00-08-06_Duwamish_RI\data\GIS\FS Support\RI updates for FS

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



SQS/CSL categories for all SMS chemicals 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

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

- > CSL, detect
- > CSL, non-detect
- > SQS and ≤ CSL, detect
- > SQS and ≤ CSL, non-detect
- ≤ SQS, detect and non-detect
- Not analyzed

- Dredged area[b]
- Navigation channel
- River mile

[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.

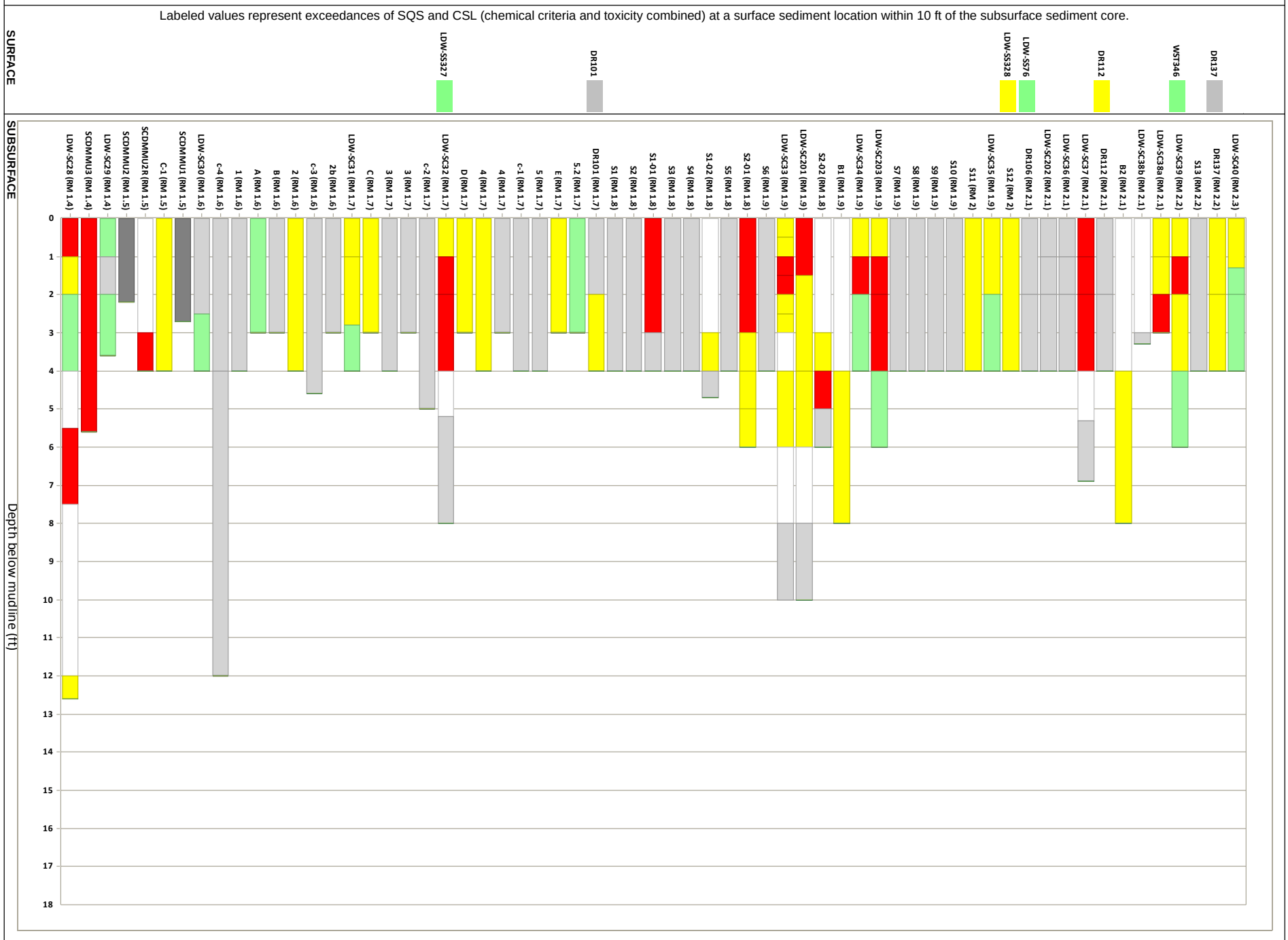


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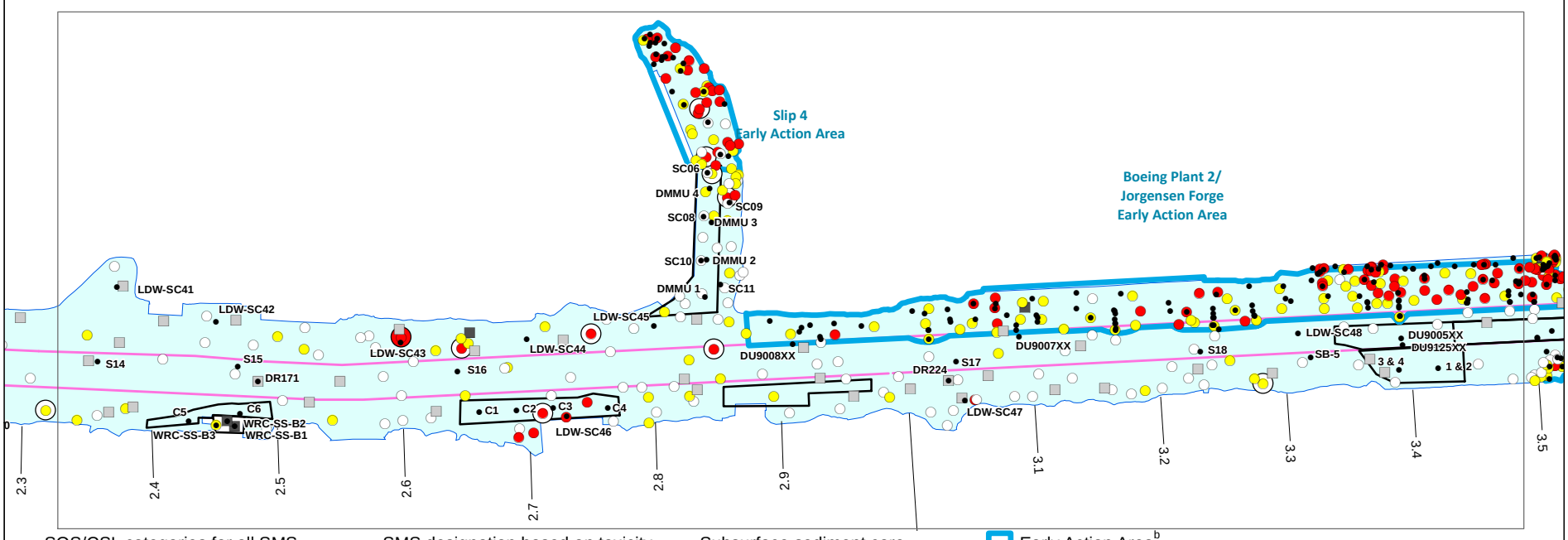
Figure 2-9b. Comparisons of concentrations of all SMS chemicals to SMS criteria (SQS or CSL) in subsurface sediment cores, RM 1.4 to RM 2.3

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



SQS/CSL categories for all SMS chemicals 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

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

- > CSL, detect
- > CSL, non-detect
- > SQS and ≤ CSL, detect
- > SQS and ≤ CSL, non-detect
- ≤ SQS, detect and non-detect
- Not analyzed

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

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] Several of the EAA boundaries are approximate and have not been finalized by EPA/Ecology; a description of each EAA boundary is presented in Section 9.2.2.

[c] 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.

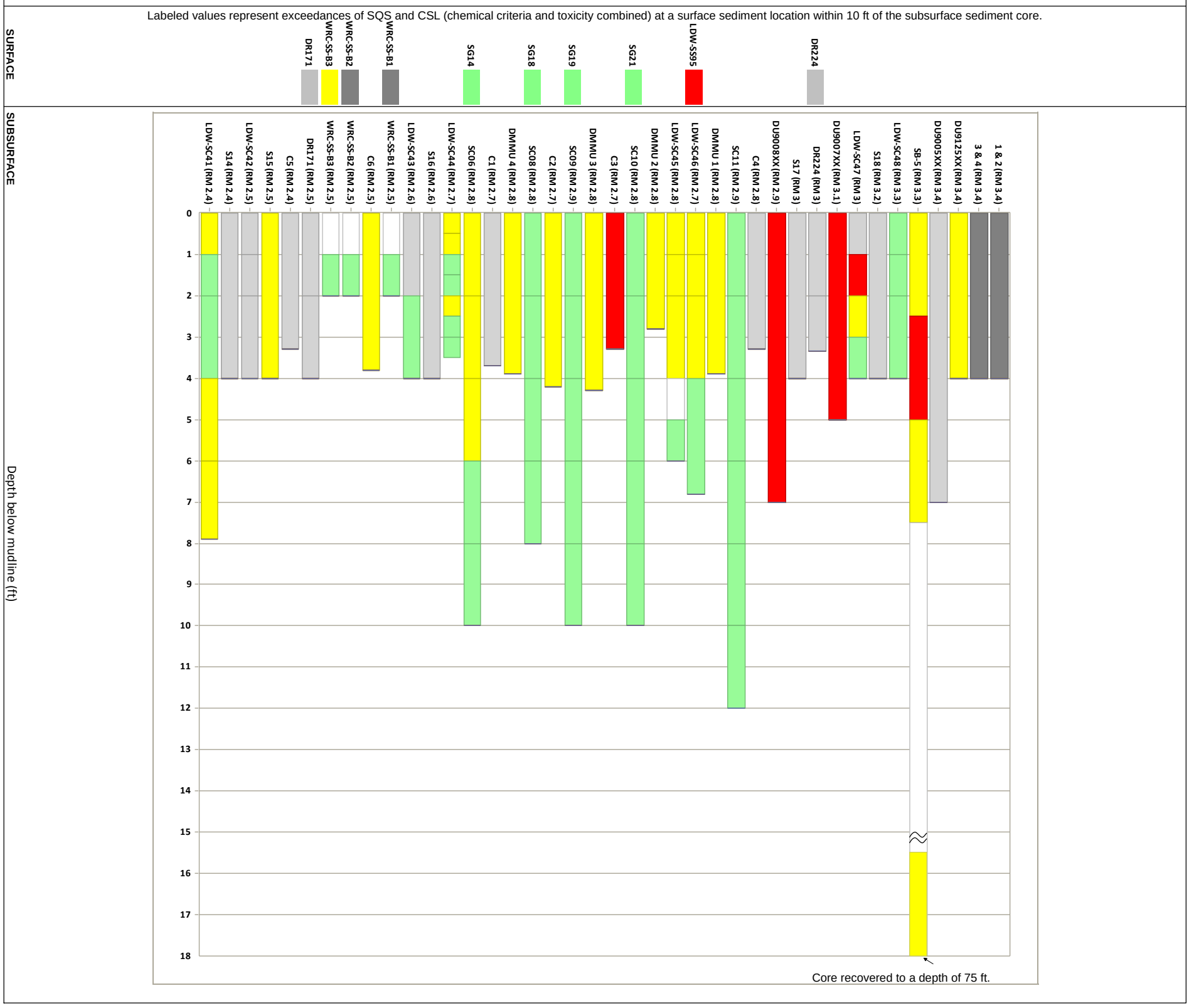


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Figure 2-9c. Comparisons of concentrations of all SMS chemicals to SMS criteria (SQS or CSL) in subsurface sediment cores, RM 2.3 to RM 3.5

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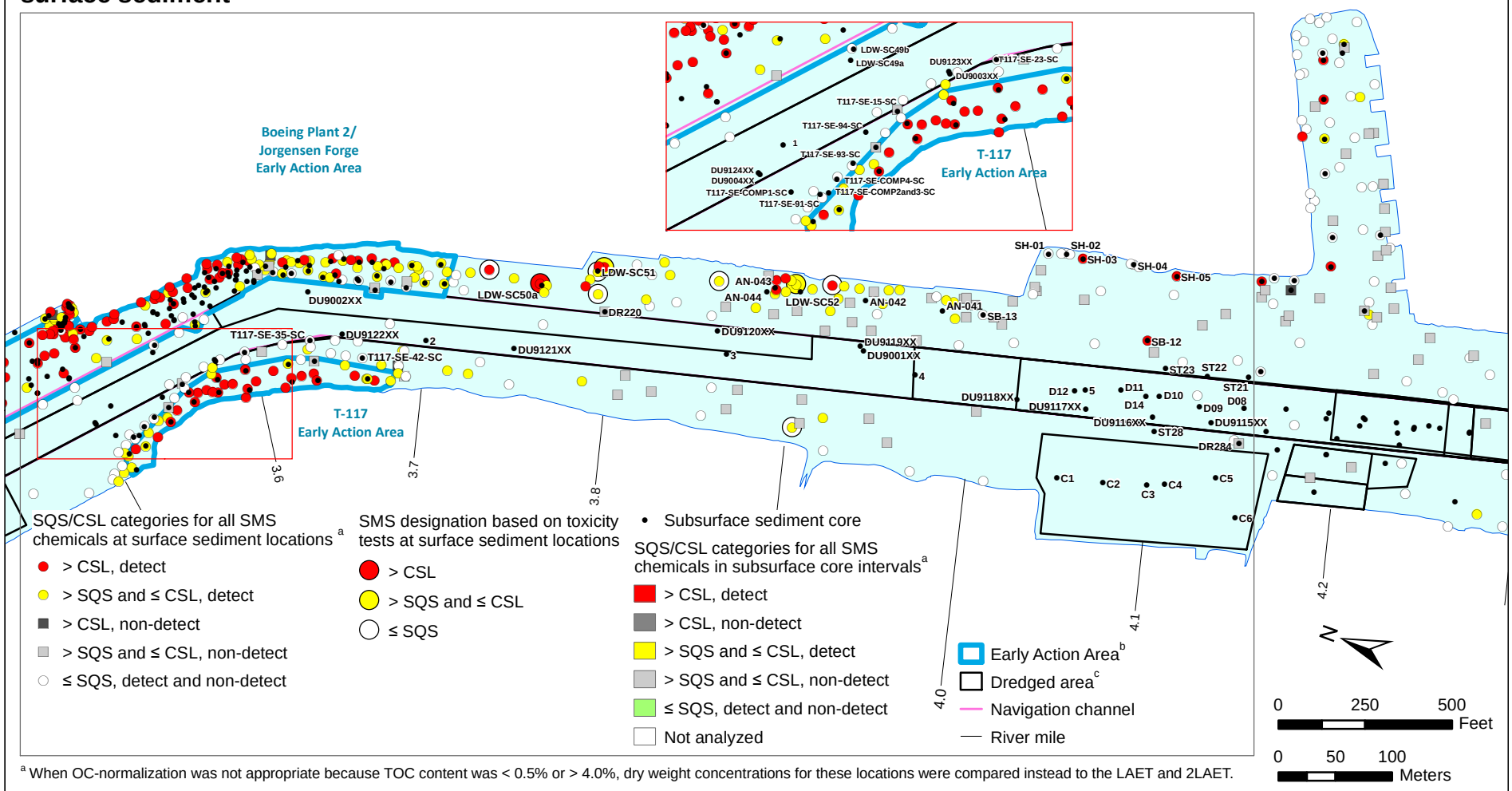
Subsurface sediment core locations and exceedances of SQS and CSL (chemical criteria and toxicity combined) in surface sediment



[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] Several of the EAA boundaries are approximate and have not been finalized by EPA/Ecology; a description of each EAA boundary is presented in Section 9.2.2.

[c] 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

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.

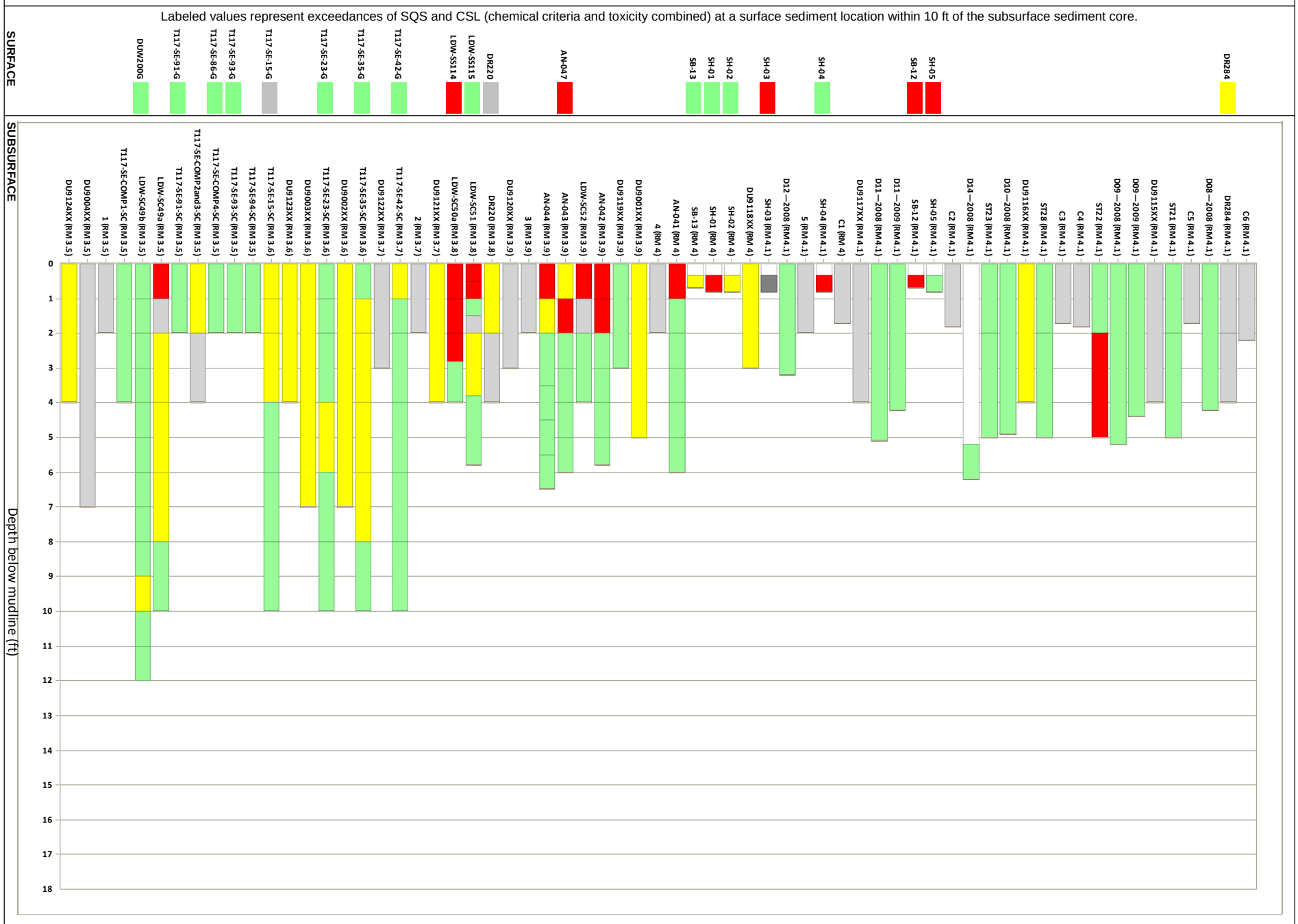


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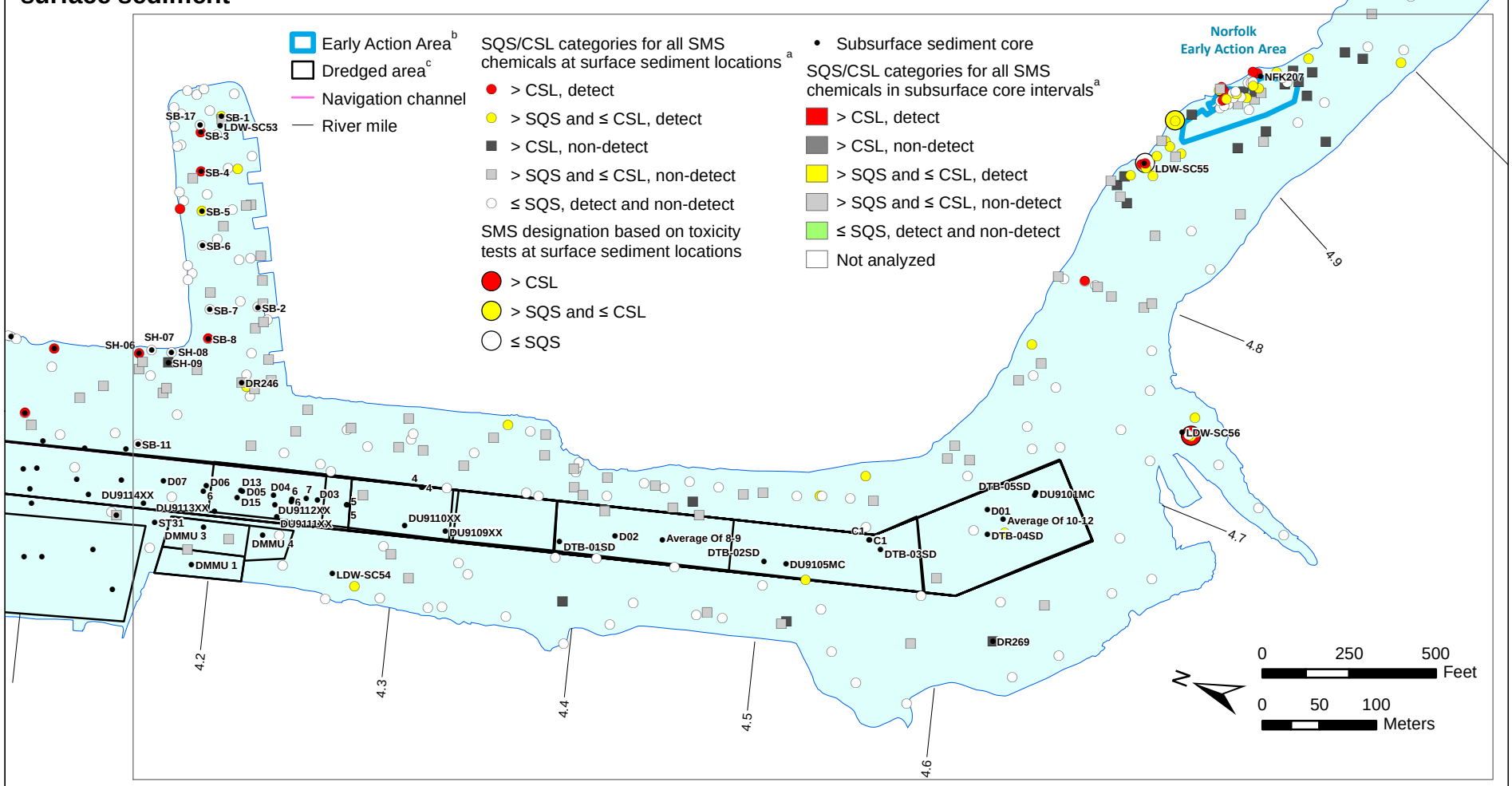
Figure 2-9d. Comparisons of concentrations of all SMS chemicals to SMS criteria (SQS or CSL) in subsurface sediment cores, RM 3.5 to RM 4.3

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] Several of the EAA boundaries are approximate and have not been finalized by EPA/Ecology; a description of each EAA boundary is presented in Section 9.2.2.

[c] 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.

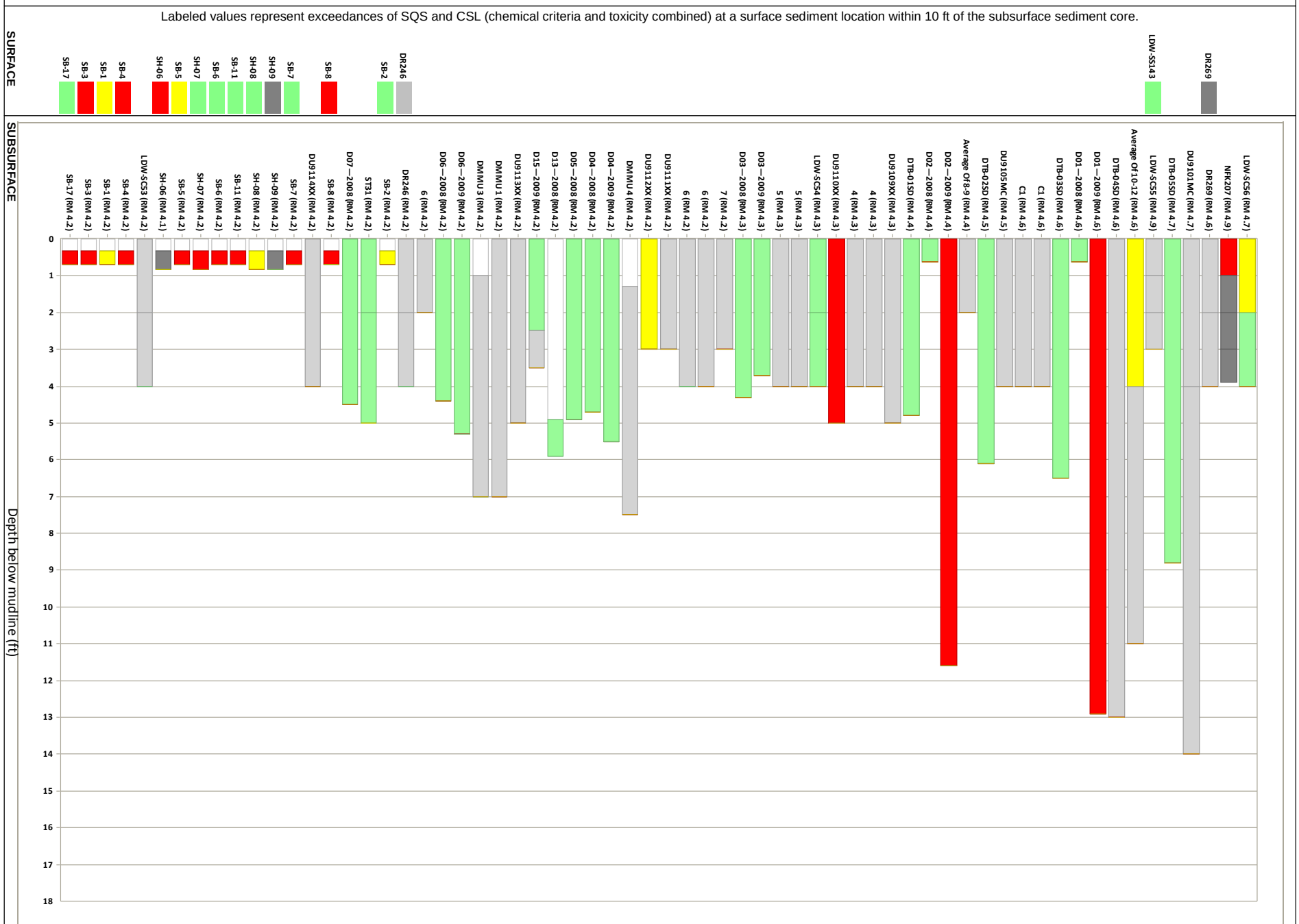


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Figure 2-9e. Comparisons of concentrations of all SMS chemicals to SMS criteria (SQS or CSL) in subsurface sediment cores, RM 4.3 to RM 5.0

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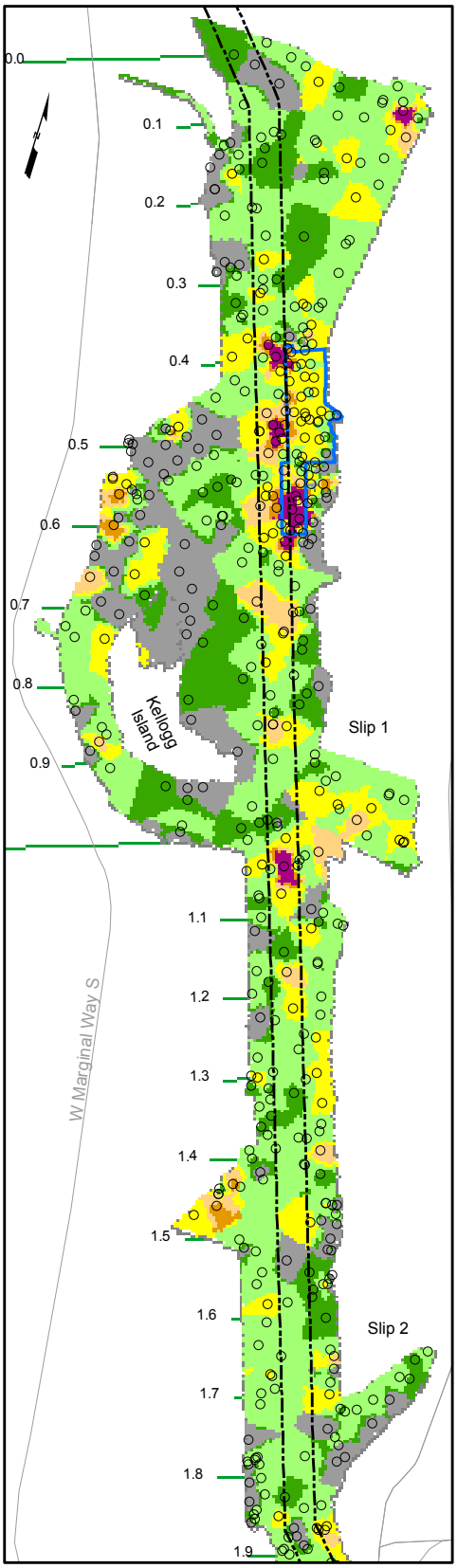

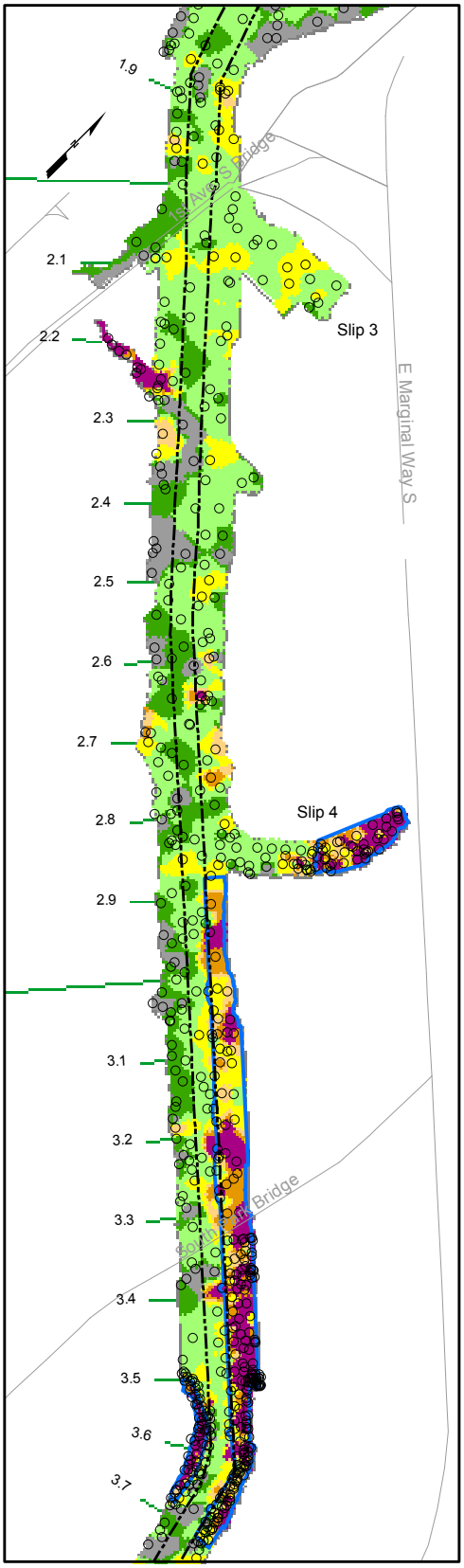

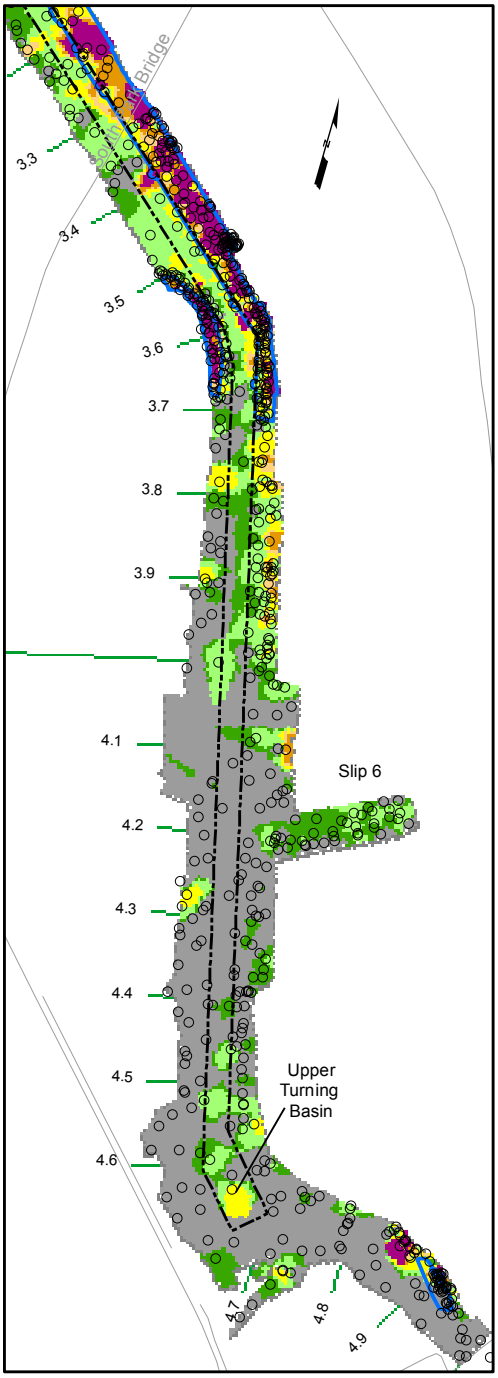

Legend

Interpolated Total PCB Concentration (µg/kg dw)

- ≤ 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) in the Trotsky inlet (RM 2.2) were excluded from use in the interpolation.

Feet
0 200 400 800

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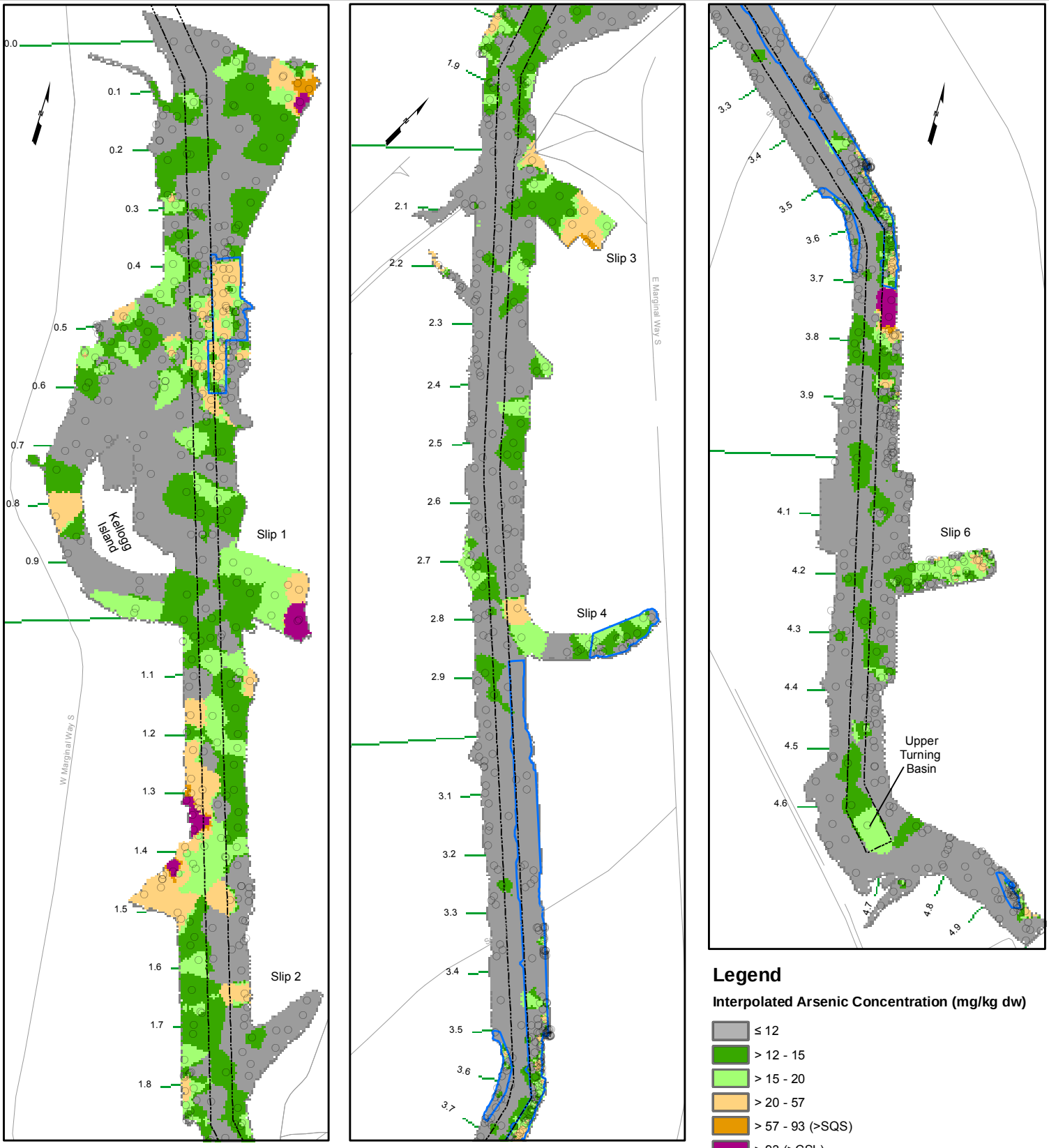
Interpolated Total PCB Distribution in Surface Sediment

DATE: 09/14/10 | DWRN:MVI/sea | Revision: 0

FIGURE 2-10

L:\Lower Duwamish FS\FS_GIS_01April2010\Section 2\MXD s\Figure2-xPCBInterp.mxd



Legend

Interpolated Arsenic Concentration (mg/kg dw)

- ≤ 12
- > 12 - 15
- > 15 - 20
- > 20 - 57
- > 57 - 93 (>SQS)
- > 93 (>CSL)

- Arsenic 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. Arsenic data from FS baseline dataset dated April 28, 2010.
3. Sampling dates of the data range from 1991 to 2010.

0 200 400 800 Feet

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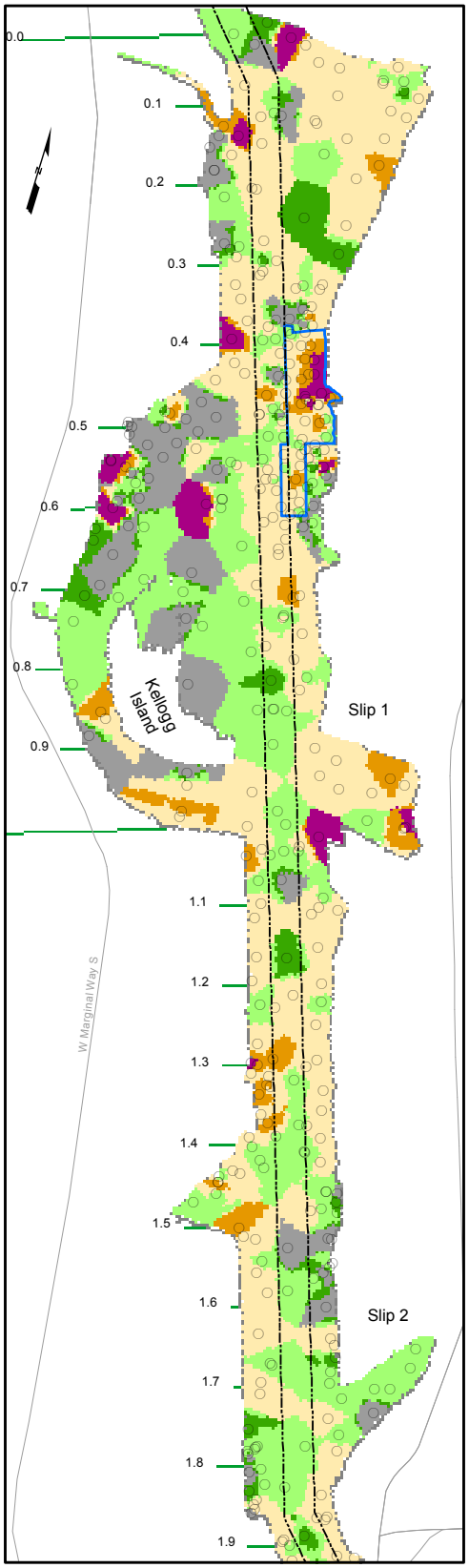
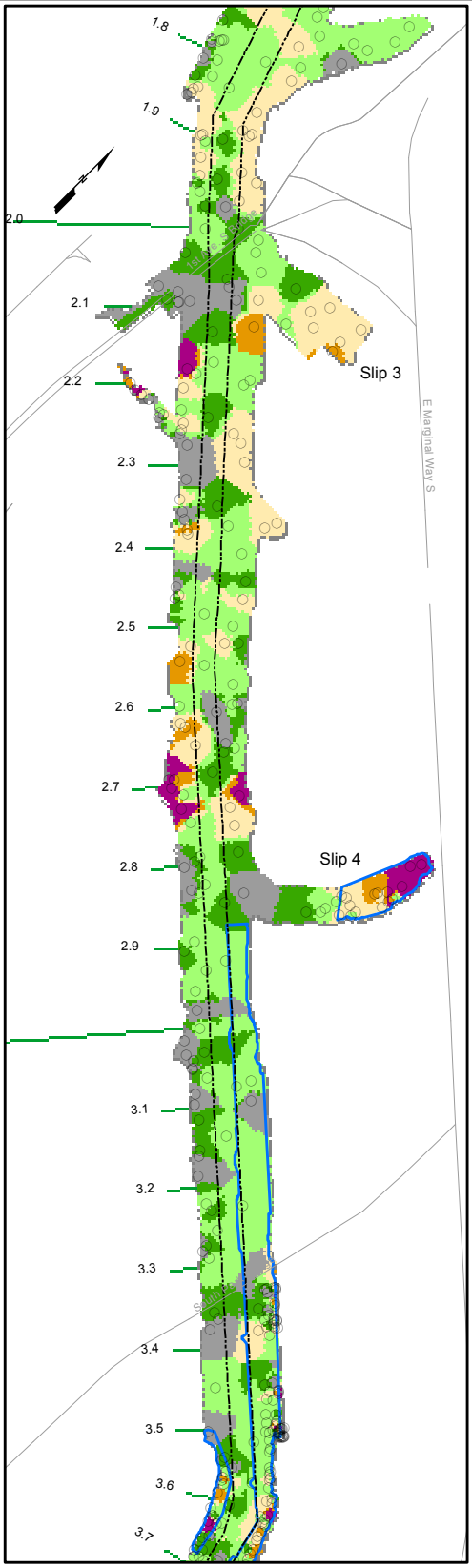
Interpolated Arsenic Distribution in Surface Sediment

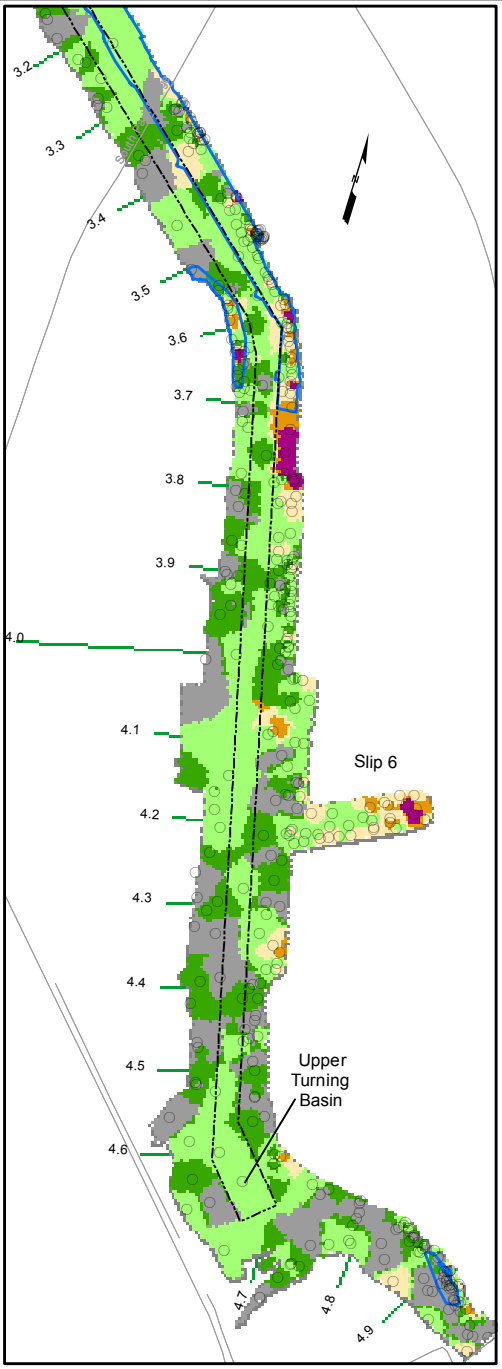
DATE: 07/08/10 | DWRN: MVI/sea | Revision: 0

FIGURE 2-11

L:\Lower Duwamish FS\FS_GIS_01April2010\Section 2\MXDs\Figure2-xAS Interp L.mxd







Legend

Interpolated cPAH Concentration (µg TEQ/kg dw)

- ≤ 90
- > 90 - 150
- > 150 - 380
- > 380 - 900
- > 900 - 1,500
- > 1,500
- cPAH Sample Location
- Road
- Navigation Channel
- River Mile Marker
- Early Action Area

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.

Feet
0 200 400 800

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Interpolated cPAH Distribution in Surface Sediment

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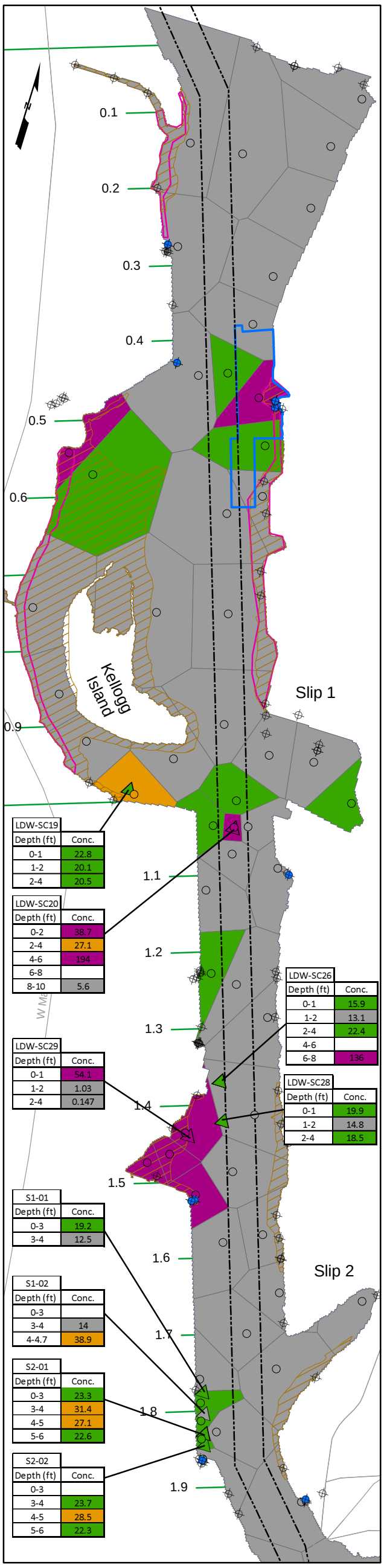
FIGURE 2-12

L:\Lower Duwamish FS\FS_GIS_01April2010\Section 2\MXDs\Figure2-xcPAHInterpL.mxd



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

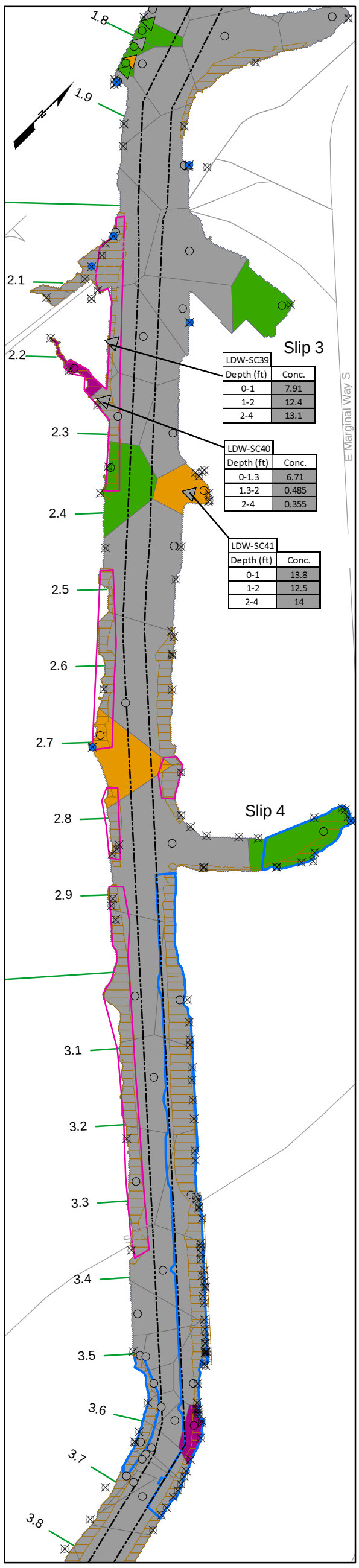
LDW-SC28	
Depth (ft)	Conc.
0-1	19.9
1-2	14.8
2-4	18.5

S1-01	
Depth (ft)	Conc.
0-3	19.2
3-4	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

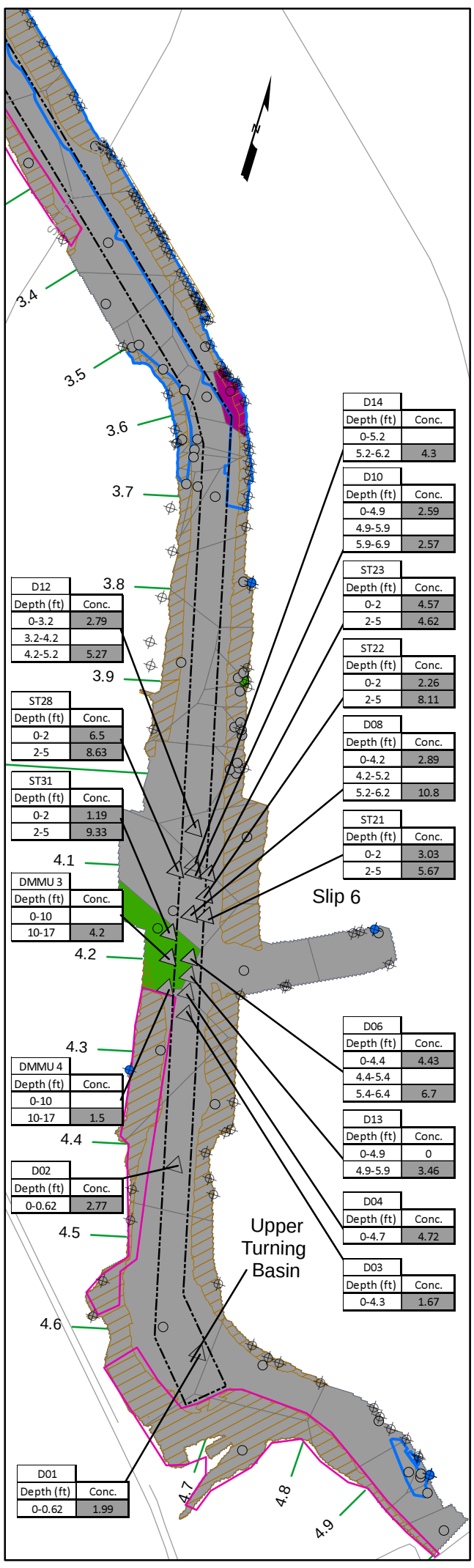
S2-02	
Depth (ft)	Conc.
0-3	
3-4	23.7
4-5	28.5
5-6	22.3



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



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

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

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

D02	
Depth (ft)	Conc.
0-0.62	2.77

D04	
Depth (ft)	Conc.
0-4.7	4.72

D03	
Depth (ft)	Conc.
0-4.3	1.67

D01	
Depth (ft)	Conc.
0-0.62	1.99

Legend

Dioxin/Furan Sediment Sample

Concentration (ng TEQ/kg dw)

- ≤ 15
- > 15 - 25
- > 25 - 37
- > 37

Station Type

- Core Location
- Surface Sediment Sample
- Outfall Location
- Discharge Location Modeled in STM
- Potential Clamming Area
- Assumed 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.

Core ID

S2-02	
Depth (ft)	Conc.
0-3	
3-4	23.7

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

0 200 400 800 Feet

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Distribution of Dioxins/Furans in Surface and Subsurface Sediment

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FIGURE 2-13

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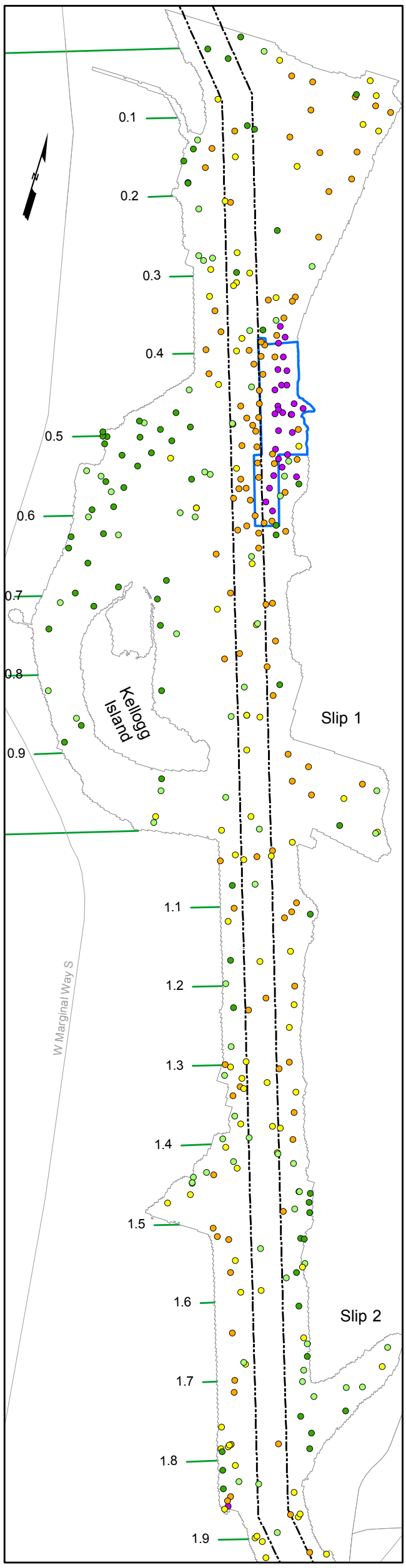

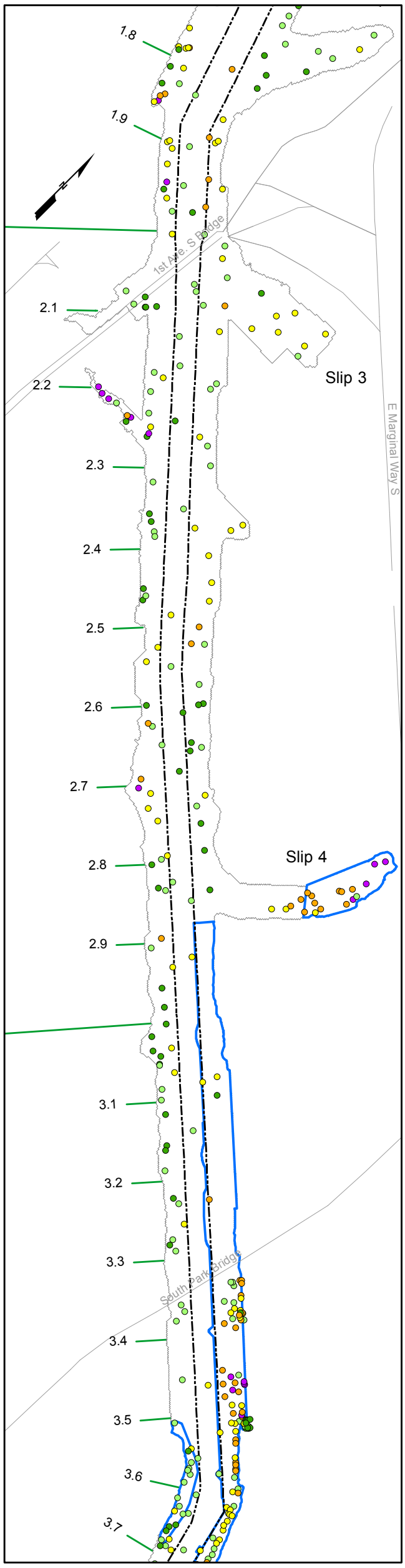

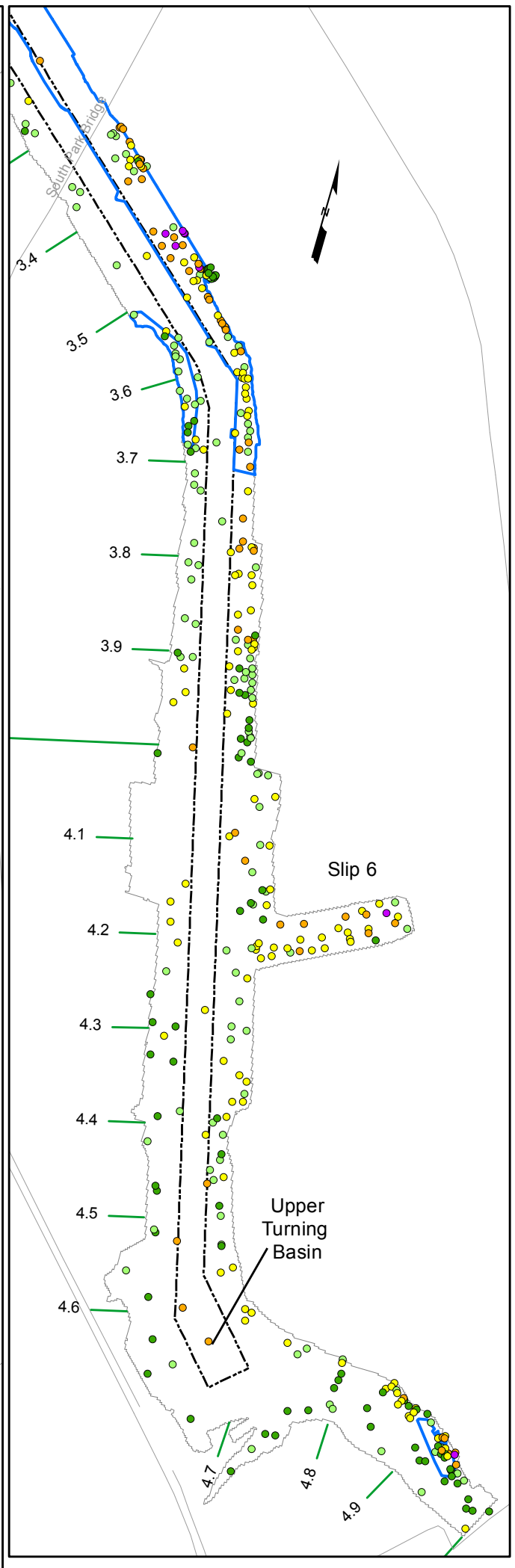

Notes:
1. BEHP = bis(2-ethylhexyl)phthalate.
2. BEHP concentrations binned by percentiles.
3. Sample dates for the data range from 1991 to 2009.
4. BEHP data from FS baseline dataset dated April 28, 2010.

Legend

BEHP Concentration (µg/kg dw)

- ≤ 84
- > 84 and ≤ 210 (25th percentile)
- > 210 and ≤ 460 (50th percentile)
- > 460 and ≤ 2,080 (75th percentile)
- > 2,080 (95th percentile)

- Road
- Navigation Channel
- River Mile Marker
- Early Action Area

Feet
0 200 400 800

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Distribution of BEHP in Surface Sediment

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FIGURE 2-14

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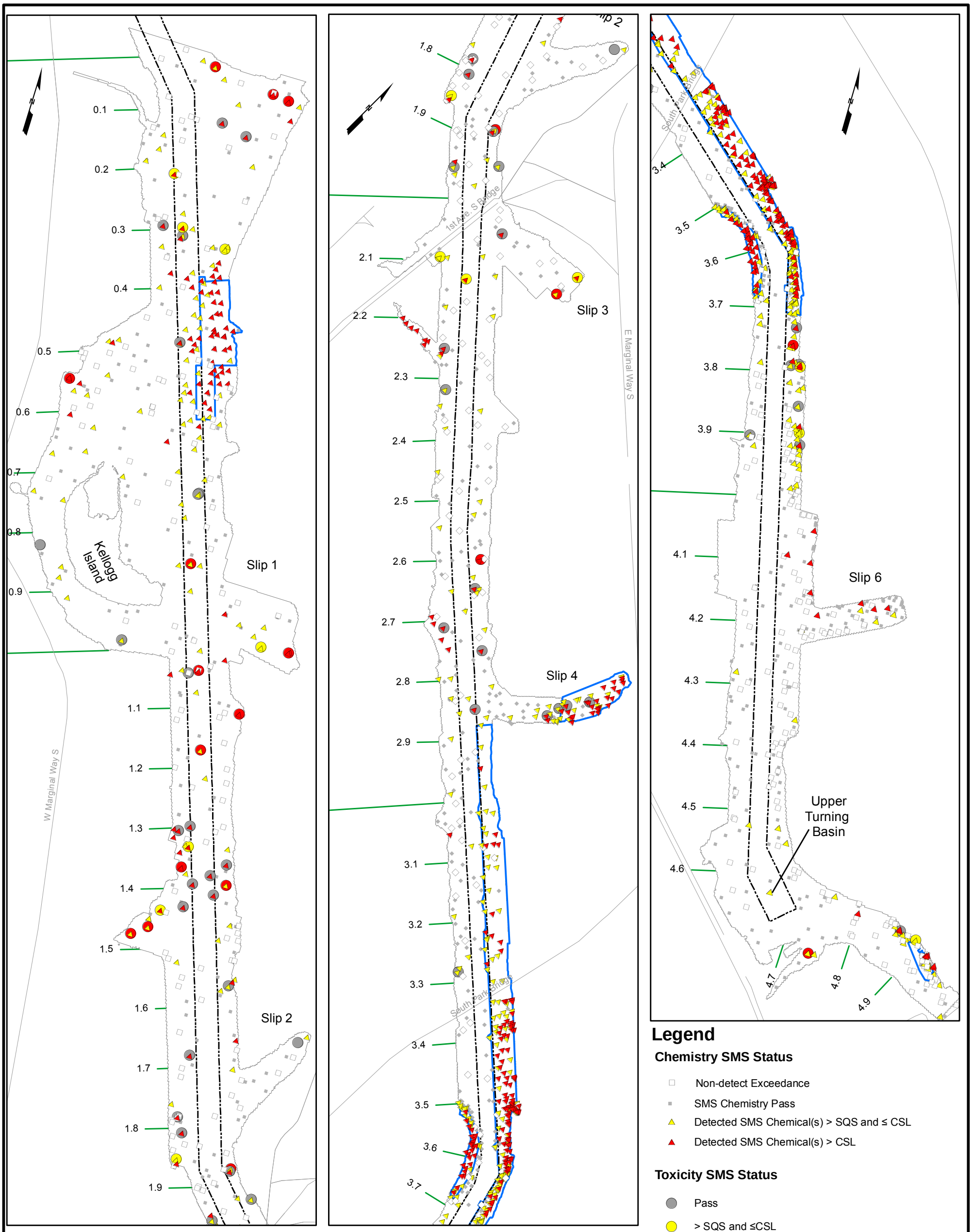

Notes:
1. Chemistry exceedances address all detected SMS chemical(s), including total PCBs and arsenic.
2. The sampling dates of the surface sediment data range from 1991 to 2010.
3. Chemistry exceedance data from FS baseline dataset dated April 28, 2010.

Legend

Chemistry SMS Status

- Non-detect Exceedance
- SMS Chemistry Pass
- Detected SMS Chemical(s) > SQS and ≤ CSL
- Detected SMS Chemical(s) > CSL

Toxicity SMS Status

- Pass
- > SQS and ≤CSL
- >CSL

- Road
- Navigation Channel
- River Mile Marker
- Early Action Area

Feet
0 200 400 800

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Distribution of SMS Toxicity and Chemistry Status in Surface Sediment

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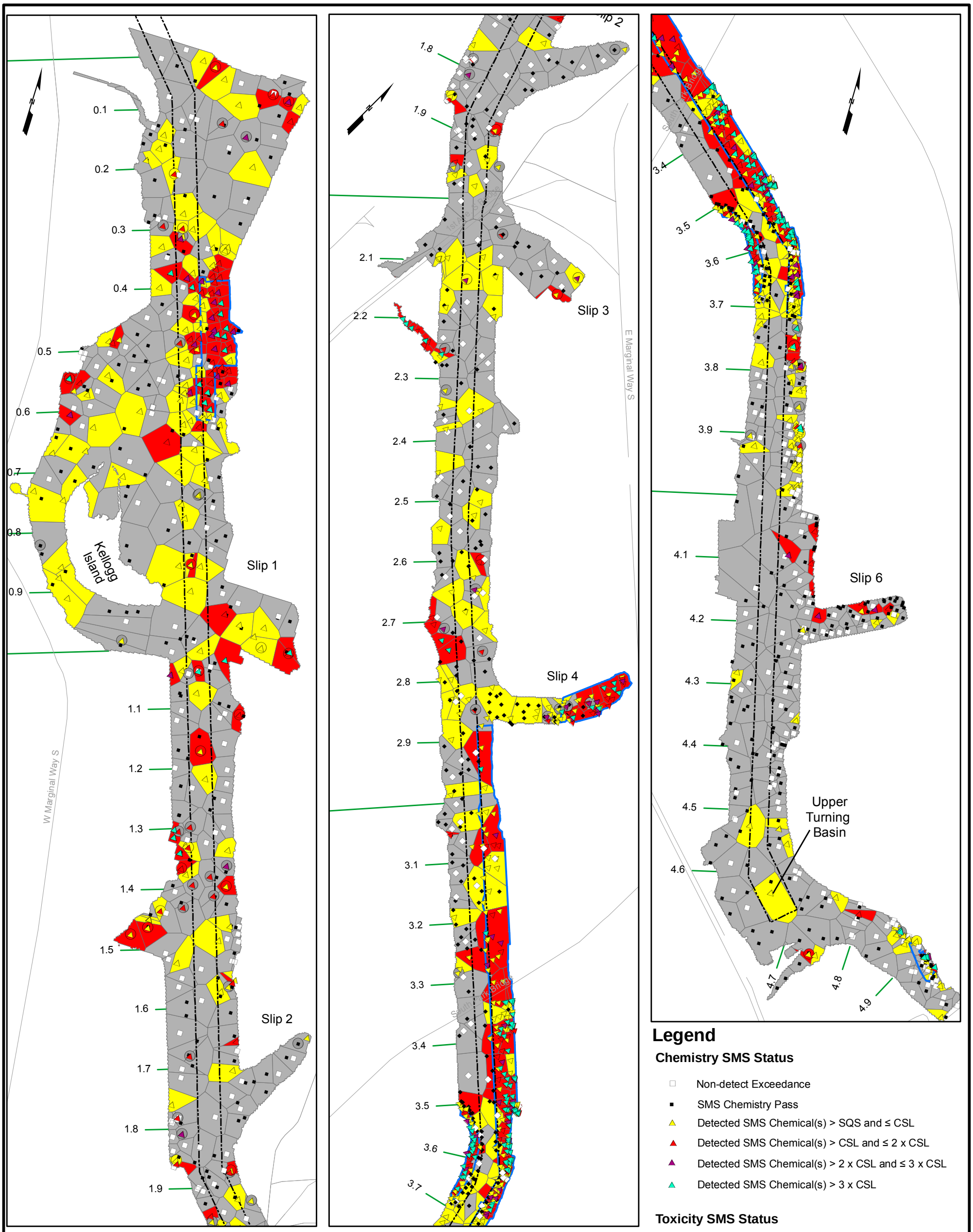
FIGURE 2-15a

L:\Lower Duwamish FS\FS_GIS_01April2010\Section 2\MXDs\Figure2-13ToxExceed.mxd



Notes:
1. Chemistry exceedances address all detected SMS chemical(s), including total PCBs and arsenic.
2. The sampling dates of the surface sediment data range from 1991 to 2010.
3. Chemistry 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 chemical 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

Feet
0 200 400 800

Legend

Chemistry SMS Status

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

Toxicity SMS Status

- Pass
- > SQS and ≤CSL
- >CSL

Thiessen Polygon SMS Status

- Pass
- > SQS and ≤CSL
- > CSL

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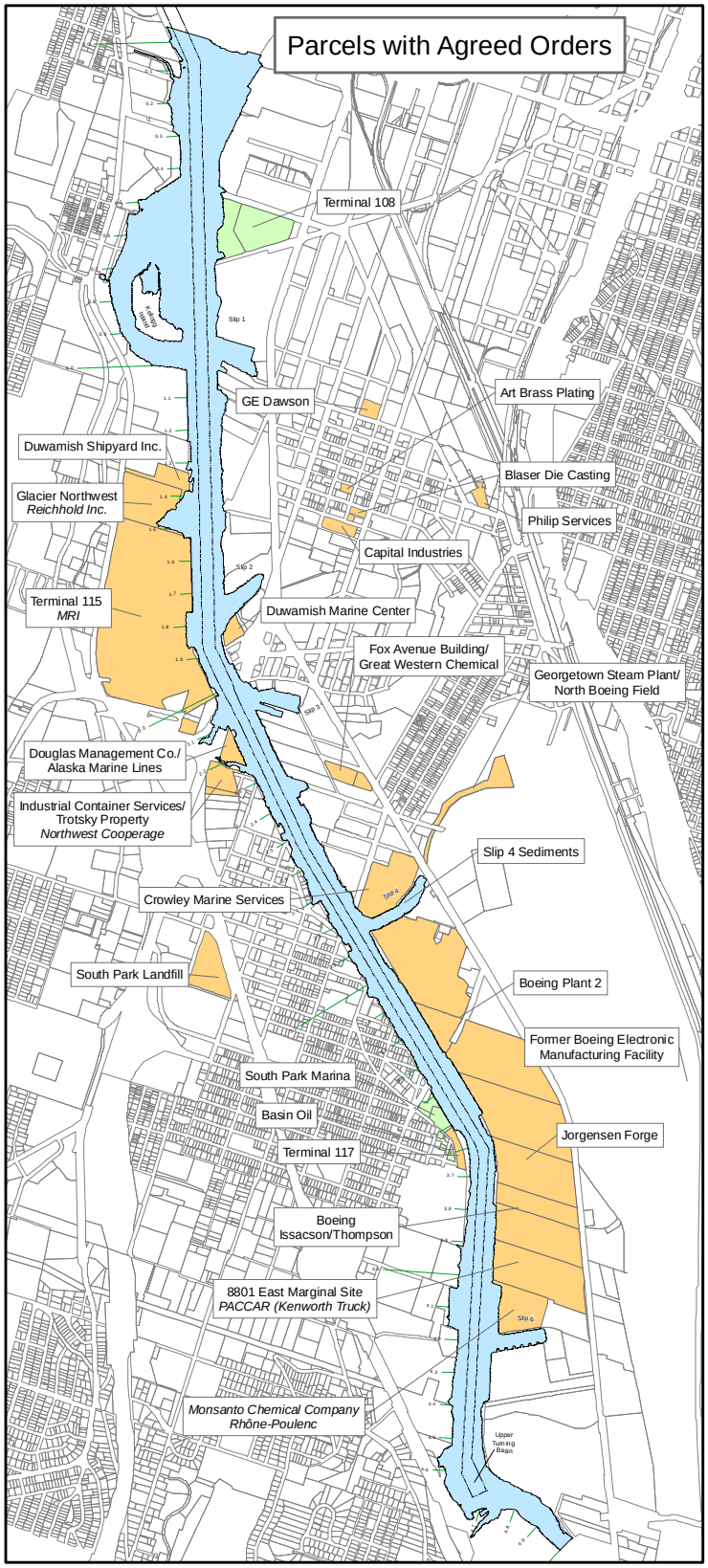
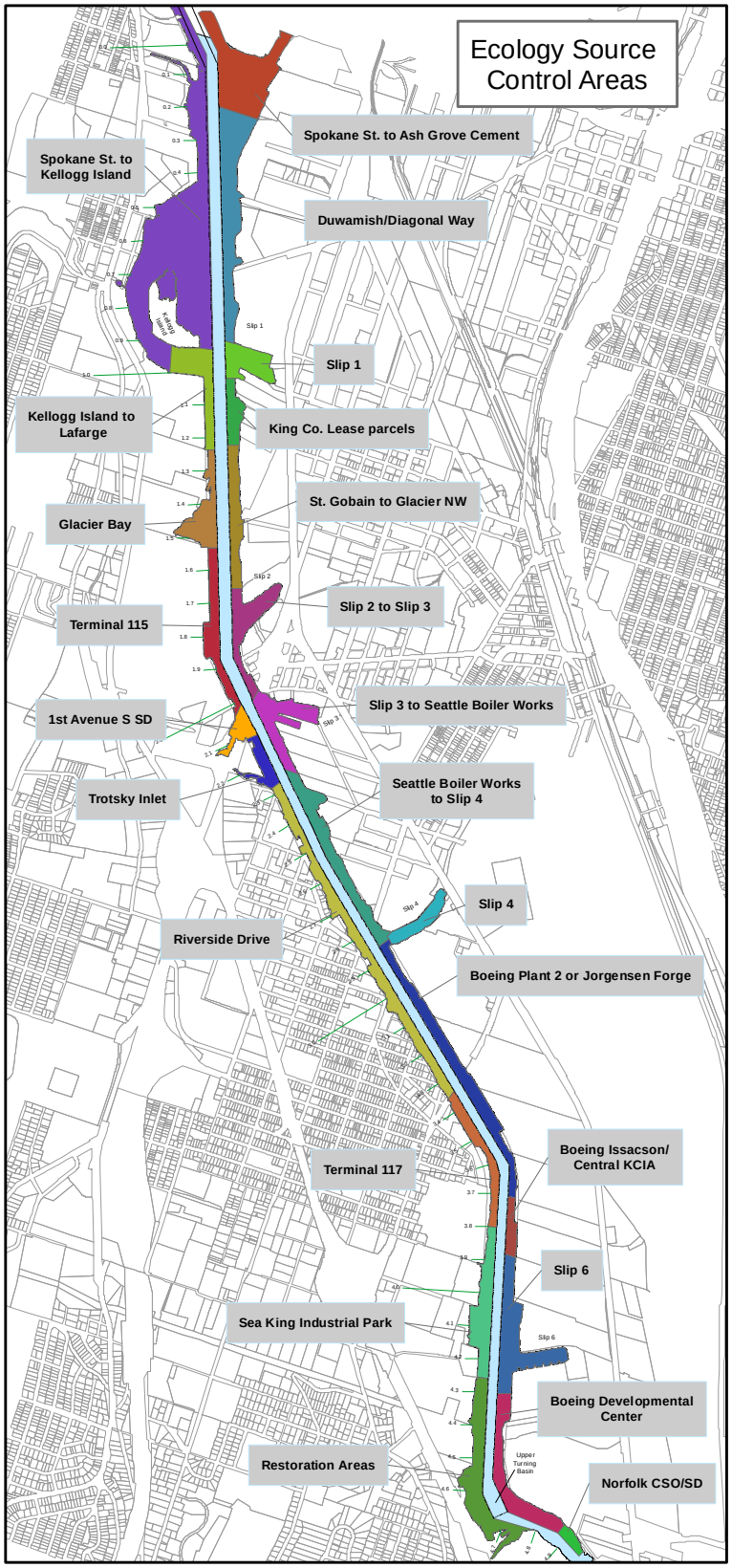
Interpolation of SMS Status in Surface Sediment

DATE: 10/04/10 | DWRN:MVI/sea | Revision: 0

FIGURE 2-15b

L:\Lower Duwamish FS\FS_GIS_01April2010\Section 2\MXDs\Figure2-13ToxExceed.mxd





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; MTCA= Model Toxics Control Act; RCRA= Resource Conservation and Recovery Act; SD= storm drain.

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

Legend

- 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

0 850 1,700 3,400 Feet

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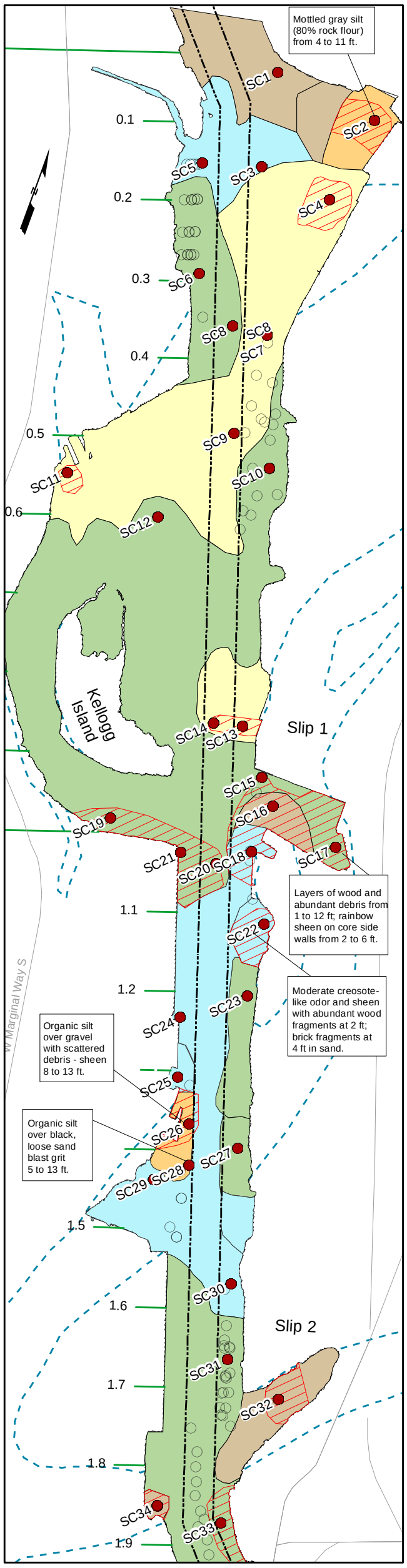
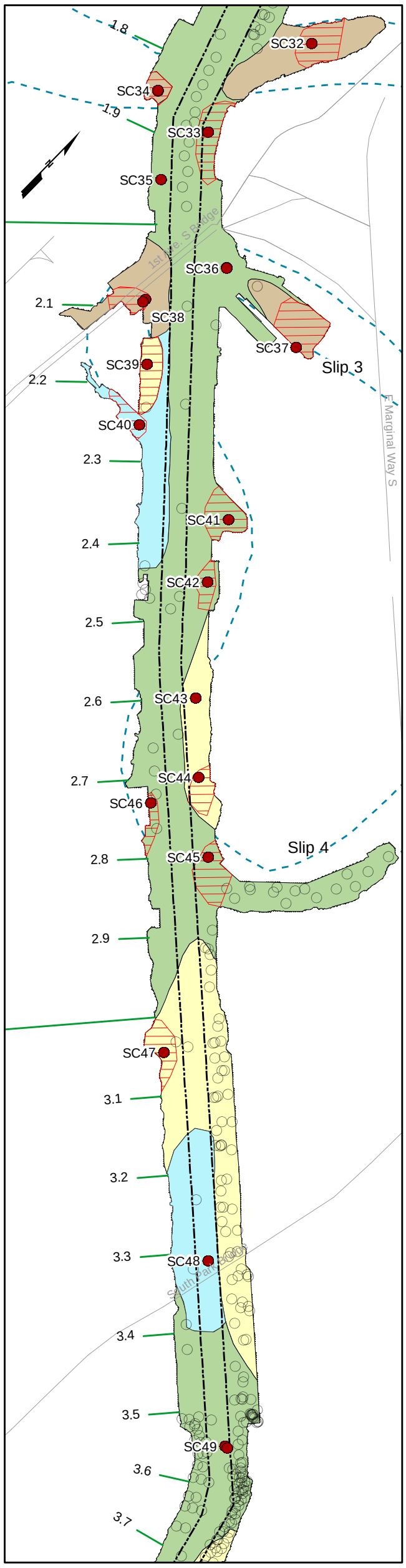
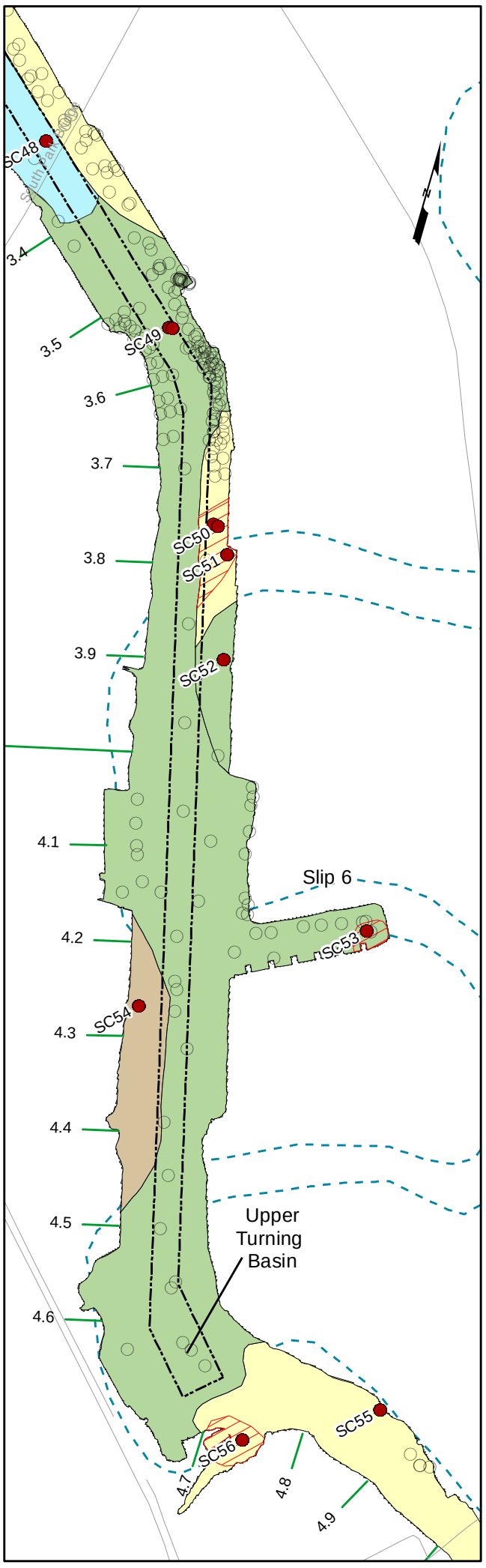
Lower Duwamish Waterway Draft Final Feasibility Study 60150279-14.5			Agreed Orders and Ecology Source Control Areas
DATE: 10/15/10	DWRN: MVI/sea	Revision: 0	FIGURE 2-16

L:\Lower Duwamish FS\FS_GIS_01April2010\Section 2\MXDs\Figure2-x-SourceContFocusAreas.mxd







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 grainsize 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 2-6 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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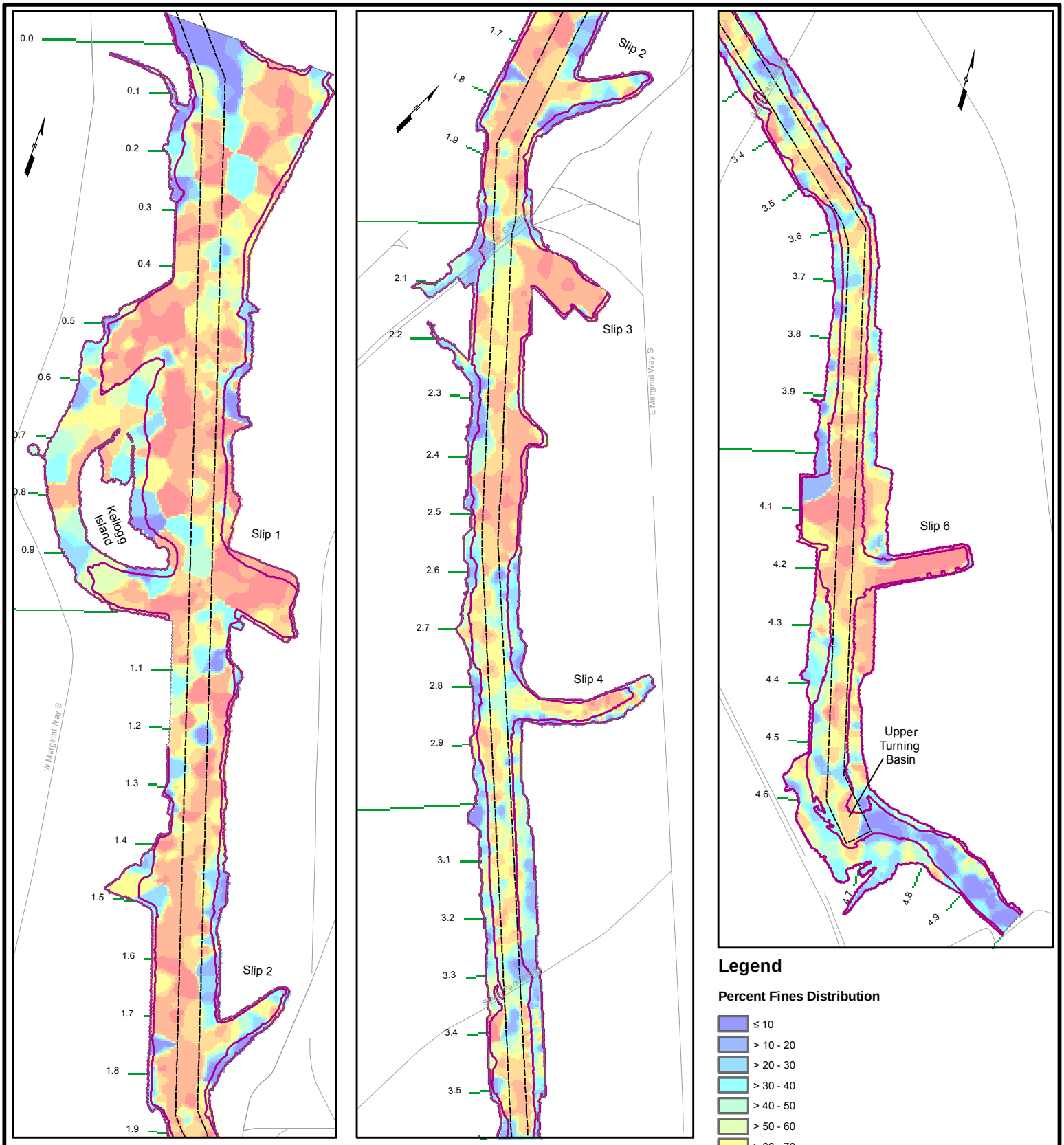
FIGURE 2-17

L:\Lower Duwamish FS\FS_GIS_01April2010\Section 2\MXDs\Fig2-xAnthroSubSurf.mxd



Notes:
1. Percent fines data from FS baseline dataset dated April 16, 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.

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Distribution of Fine-Grained Surface Sediments

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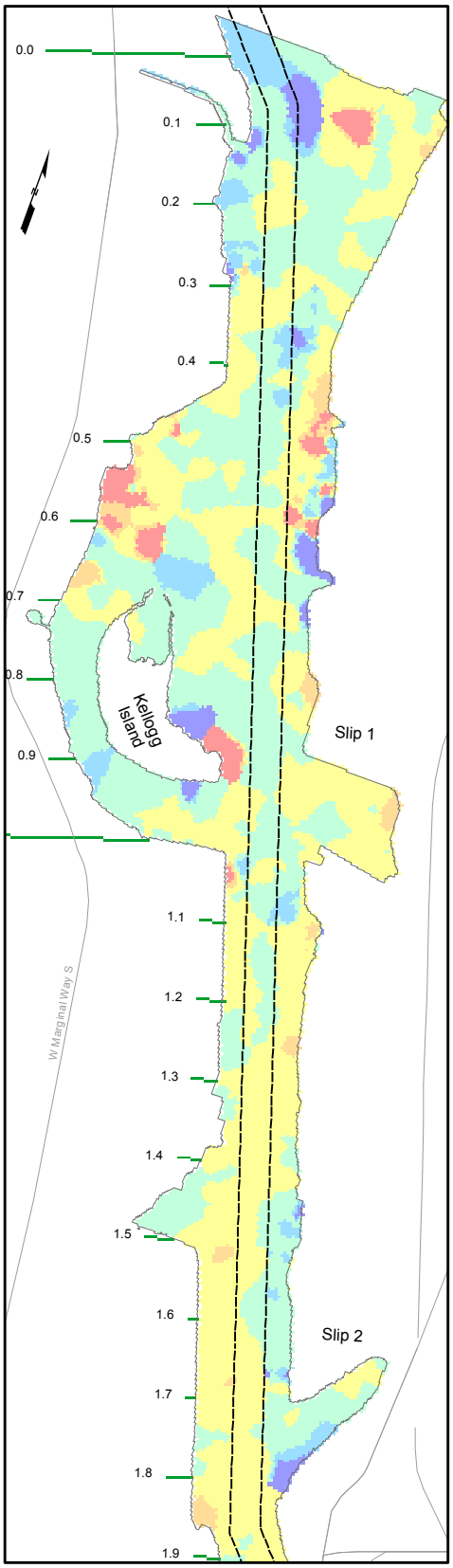
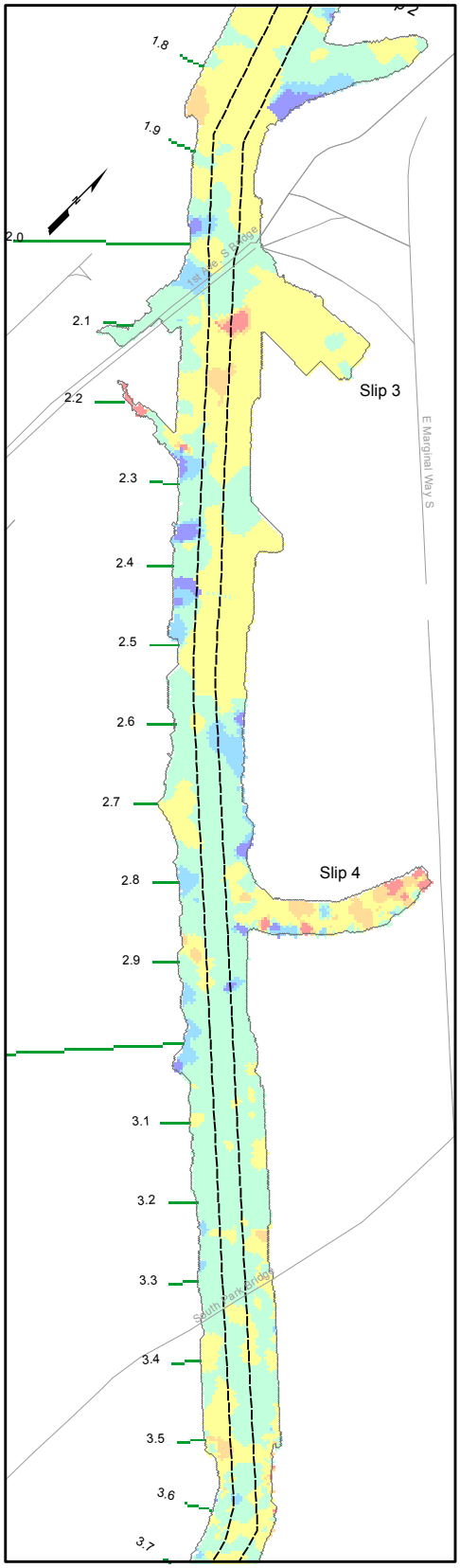
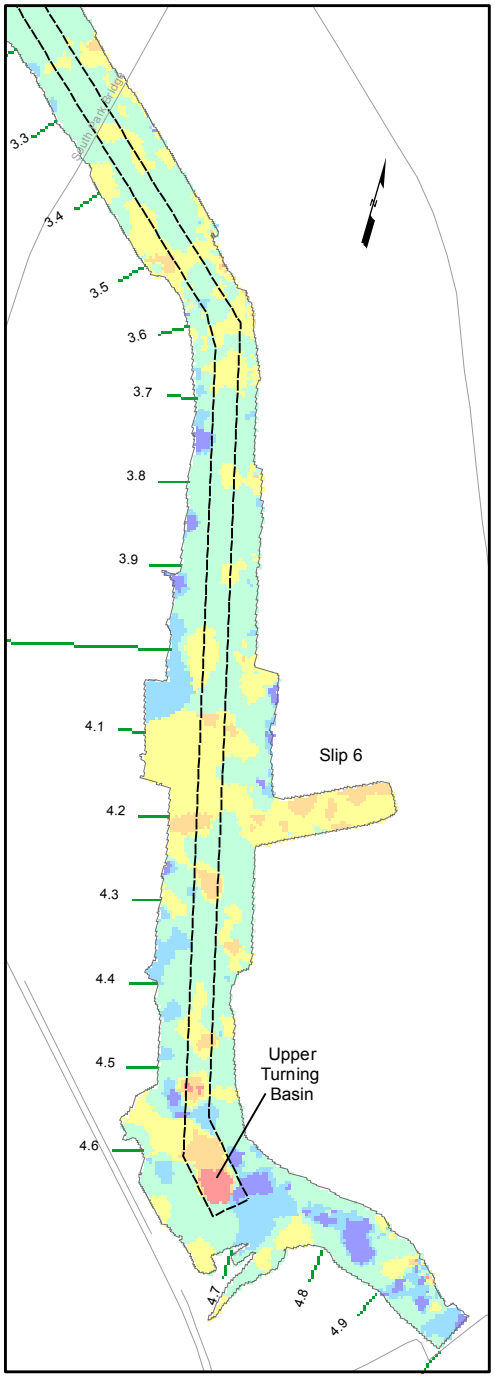
FIGURE 2-18

L:\Lower Duwamish FS\FS_GIS_01April2010\Section 2\MXDs\Figure2-17PercentFinesL.mxd







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.

Feet
0 200 400 800

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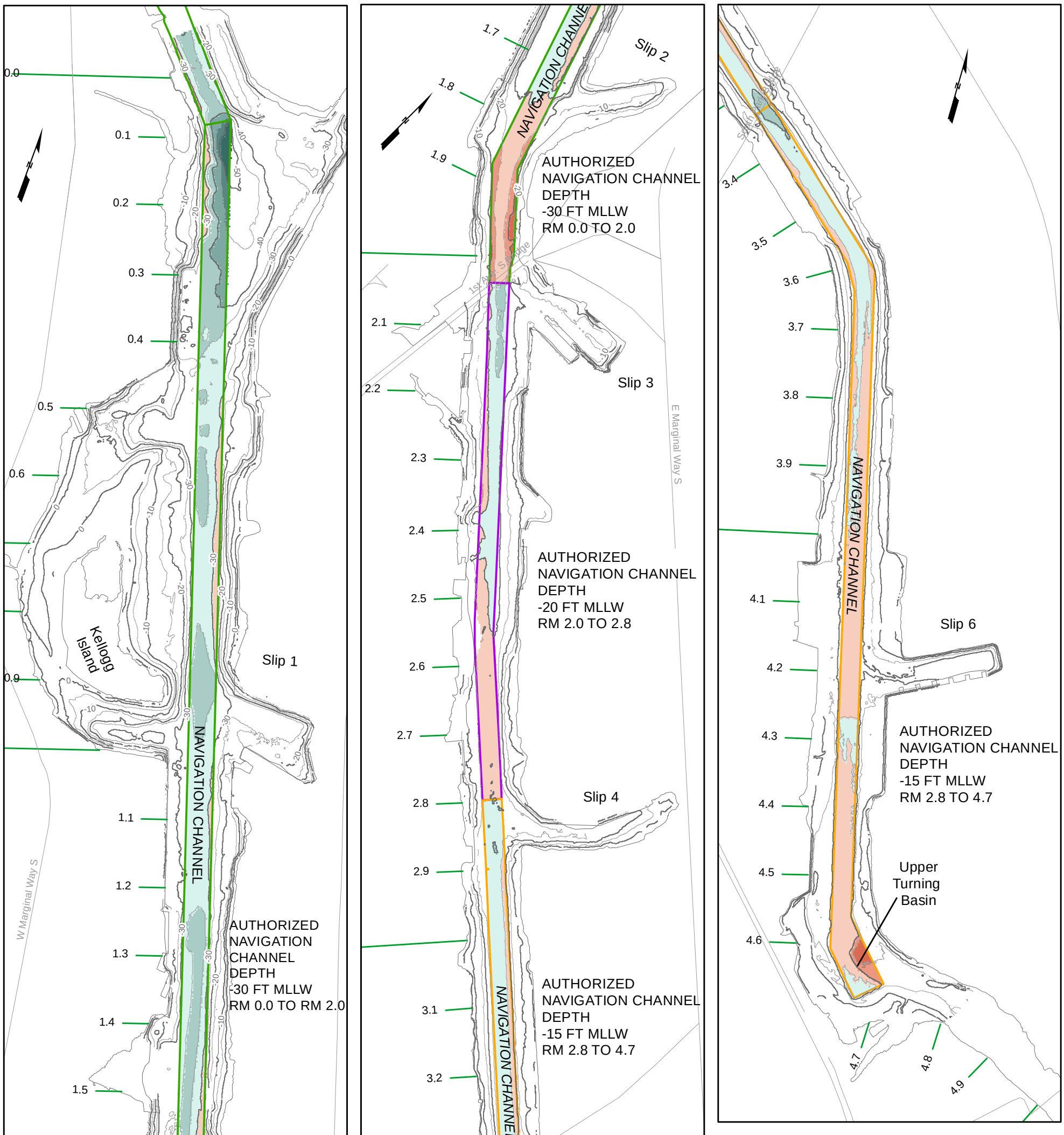
Lower Duwamish Waterway Draft Final Feasibility Study 60150279-14.5			Distribution of Total Organic Carbon in Surface Sediments
DATE: 05/24/10	DWRN: MVI/sea	Revision: 0	FIGURE 2-19

L:\Lower Duwamish FS\FS_GIS_01April2010\Section 2\MXDs\Figure2-xTOC.mxd



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.

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2003 Bathymetric Conditions Relative to Authorized Navigation Channel Depths

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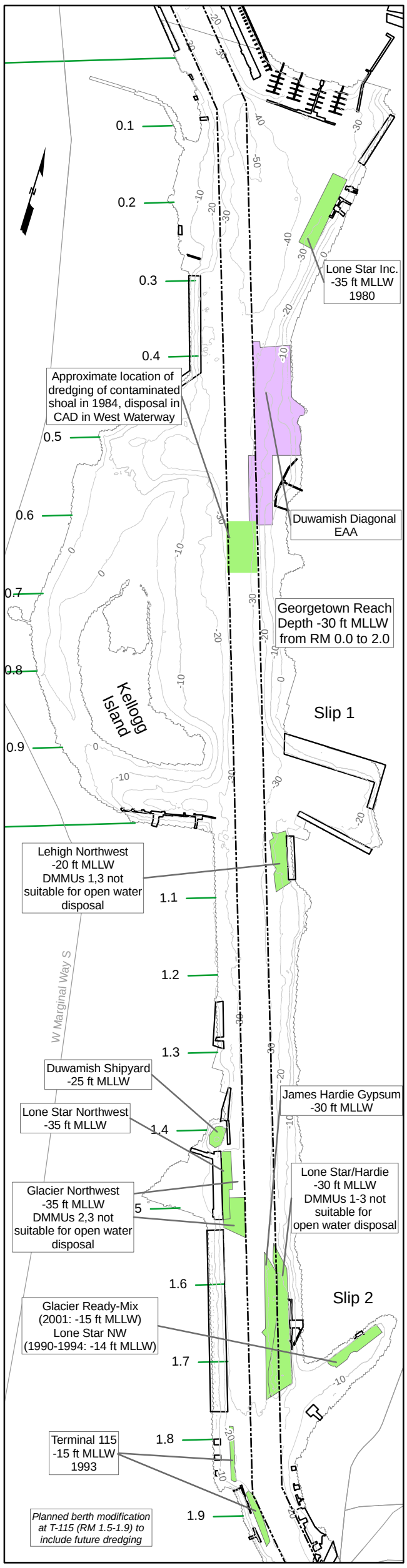
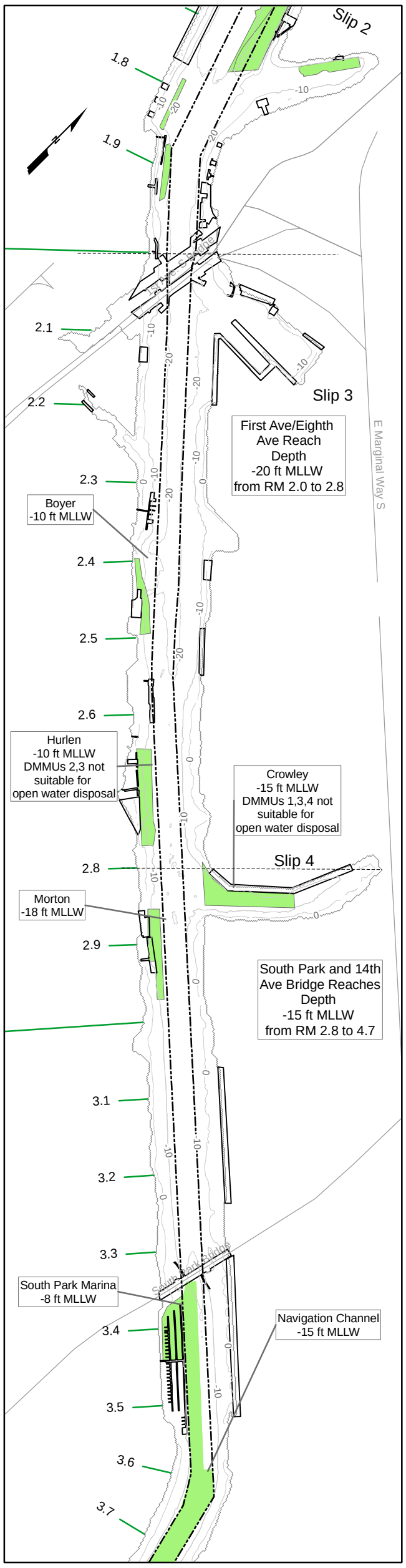
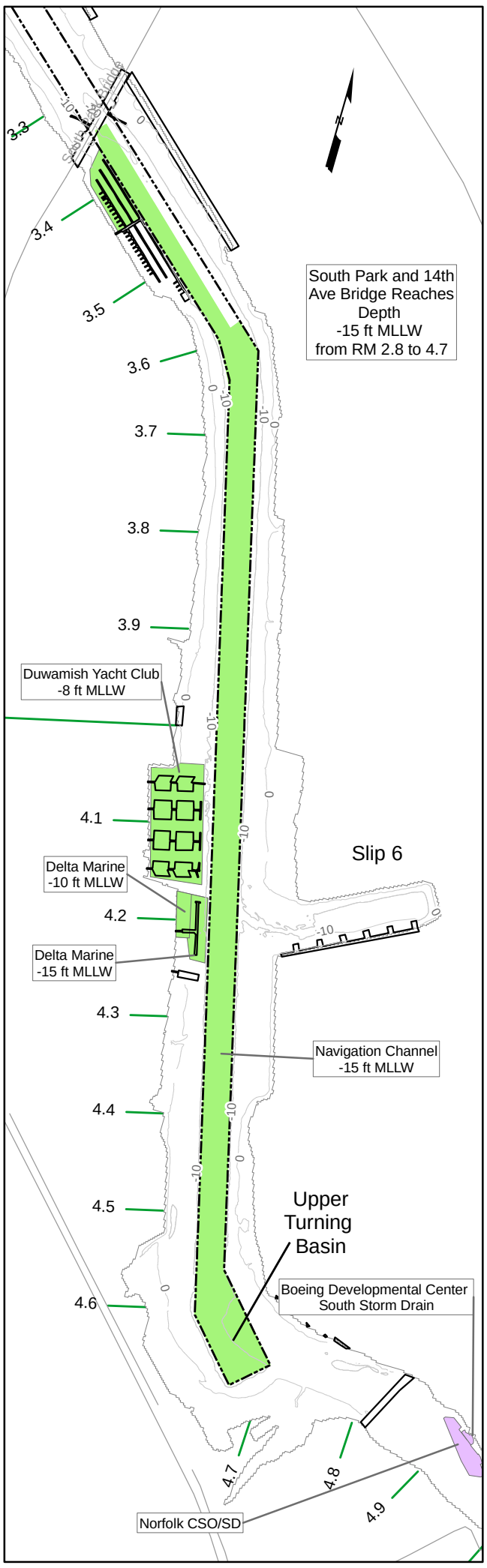
FIGURE 2-20

L:\Lower Duwamish FS\FS_GIS_01April2010\Section 2\MXDs\Figure2-xCurrentBathyConditions.mxd







Legend

Dredge Prism

- Dredge
- Dredge and Cap
- Overwater Structure
- 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

Notes:
1. See Tables 2-7, 2-8, and 2-9 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.

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

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Extent and Depth of Authorized Dredging Events (1980 to 2010)

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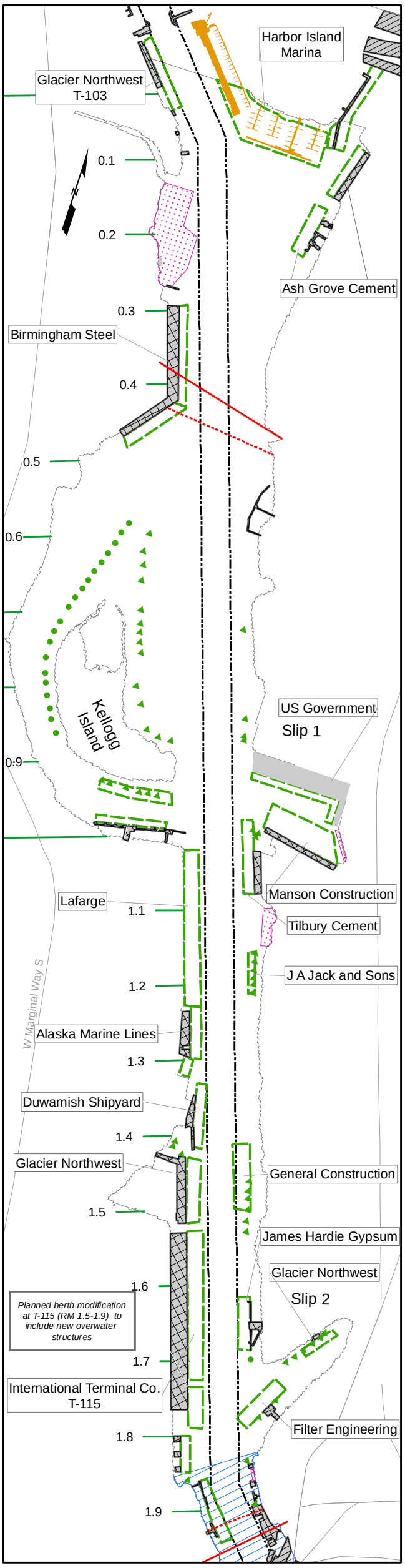
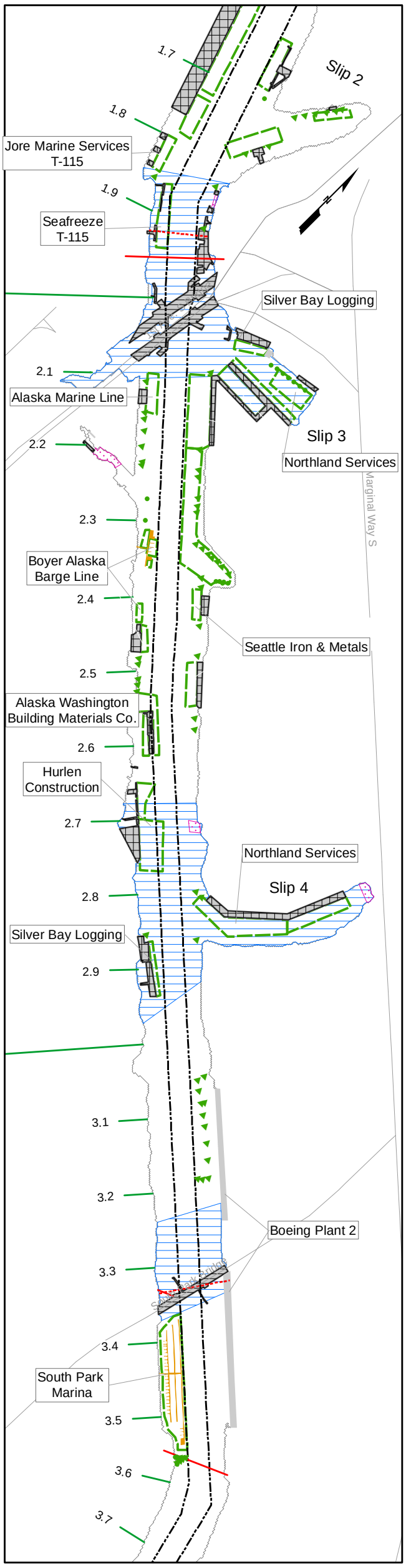
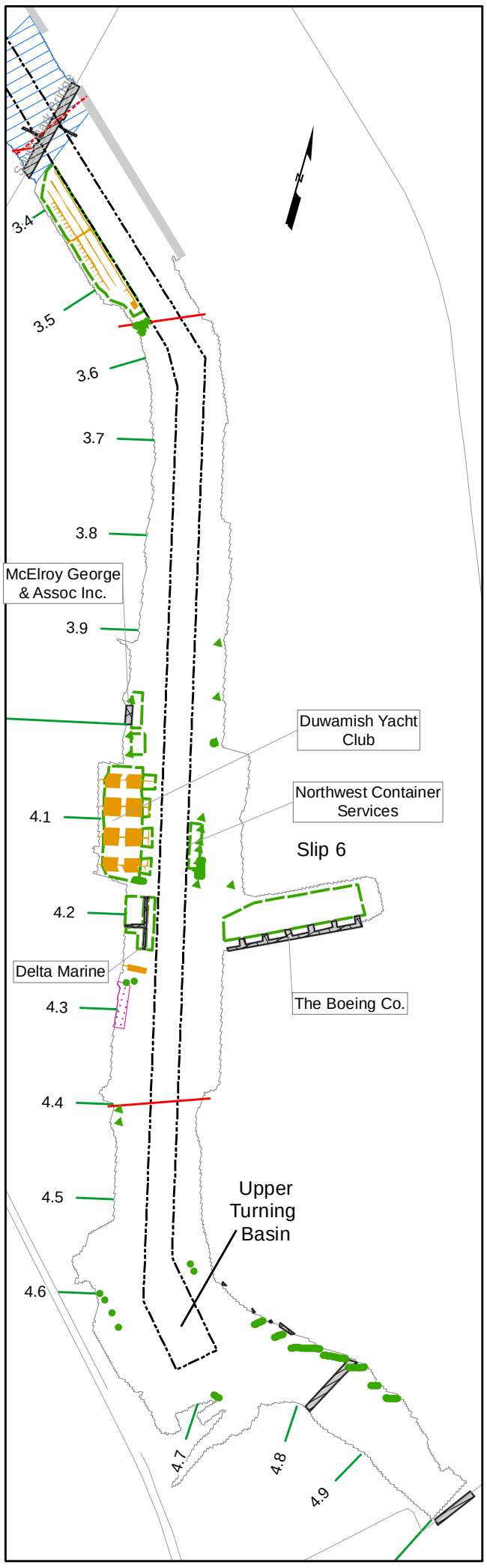
FIGURE 2-21

L:\Lower Duwamish FS\FS_GIS_01April2010\Section 2\MXDs\Figure2_xHistoricDredge.mxd







Legend

- Pile
- Dolphin
- Pile Group
- Cable Area
- Berthing Area

Overwater Structure

- Bridge
- Building
- Marina
- Pier or Dock

- Overwater Cable
- Underwater Cable or Pipe Structure
- Navigation Channel
- River Mile Marker
- Road

Berthing area or marina ownership

International Terminal Co. T-115

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 Tables 2-9 and 2-10 for additional physical structures and berthing area information.

0 200 400 800 Feet

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In-water and Overwater Structures and Berthing Areas

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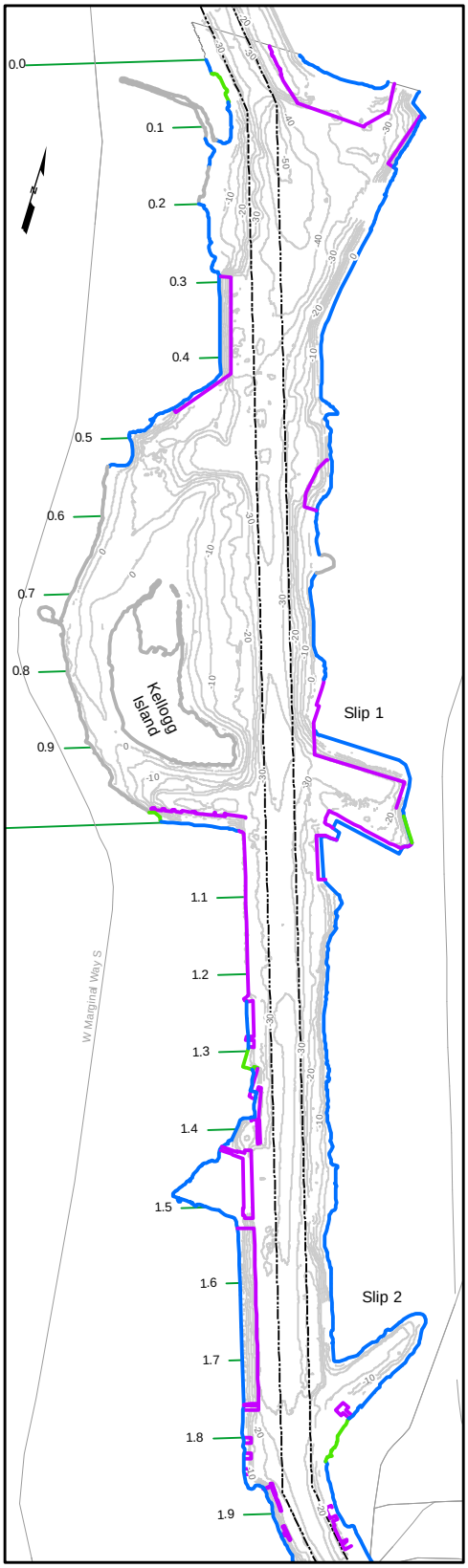
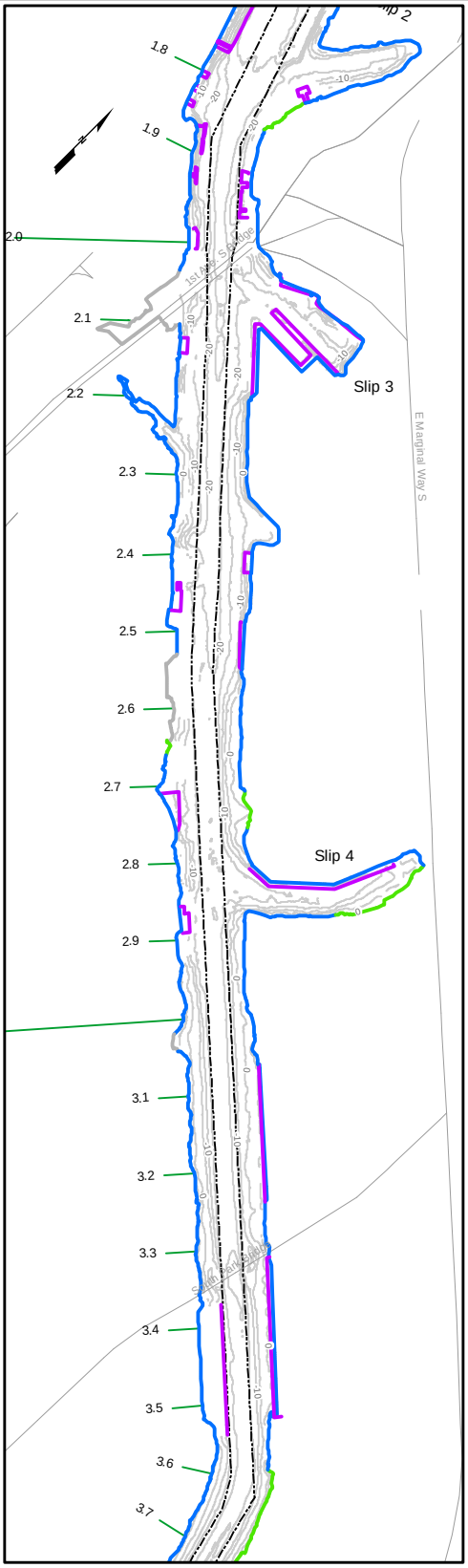
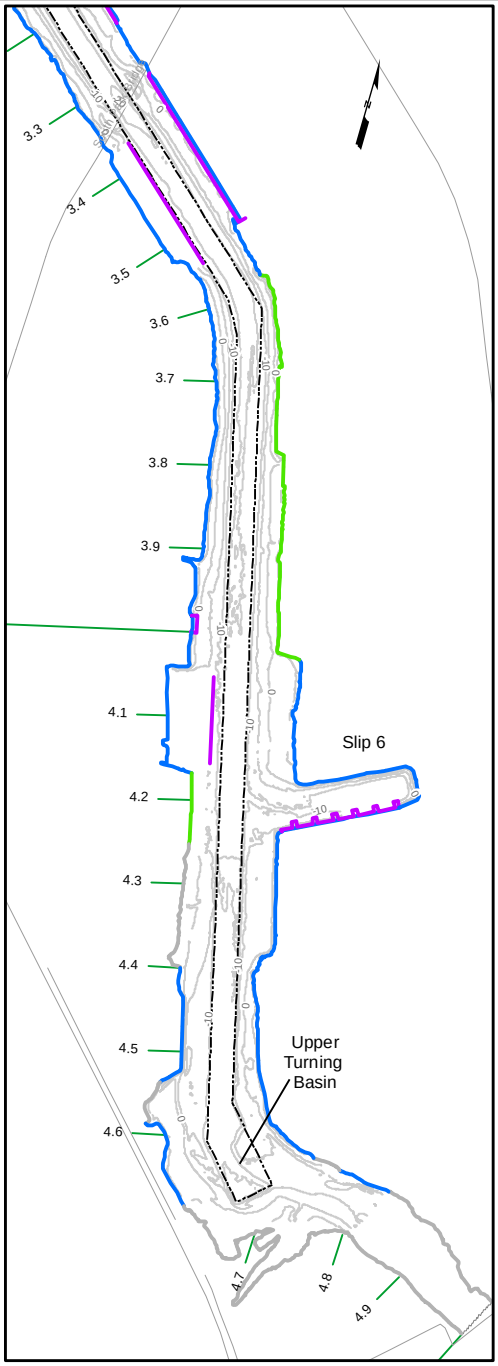
FIGURE 2-22

L:\Lower Duwamish FS\FS_GIS_01April2010\Section 2\MXDs\Fig2-xBerthingOstruct.mxd







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
- Road
- Navigation Channel
- River Mile Marker
- Bathymetric Contour (ft MLLW)

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 Draft Final Feasibility Study 60150279-14.5			Shoreline Conditions
DATE: 10/15/10	DWRN: MVI/sea	Revision: 0	FIGURE 2-23

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3 Summary of Site Risks

The baseline human health and ecological risk assessments were completed for the Lower Duwamish Waterway (LDW) in 2007 (Windward 2007a, 2007b). This chapter 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 chemicals 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 chemicals in the LDW through consumption of resident seafood from the LDW or through direct contact with sediment or water.

Risk-based threshold concentrations (RBTCs) are discussed in Section 3.3, which 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 Remedial Investigation (RI) 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 4.0. Finally, this chapter concludes with a summary of the key findings from the risk assessments (Section 3.4).

3.1 Baseline Ecological Risk Assessment

The baseline ERA (Windward 2007a) estimated risks for ecological receptors that may be exposed to chemicals in sediment, water, and through consumption of prey in the LDW.

Ten receptors of concern[1] 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 chemicals of potential concern (COPCs) for the ERA (Windward 2007a). In this process, chemical concentrations in

[1] Key considerations for selecting receptors of concern were the potential for direct or indirect exposure to sediment-associated chemicals, human and ecological significance, site use, sensitivity to COPCs at the site, susceptibility to biomagnification of COPCs, and data availability.

sediment, water, and aquatic biota were compared to risk-based screening levels. Those chemicals 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:

- Risk estimates for the benthic community were estimated by comparing chemical 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. Risk 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 site-specific study of imposex in gastropods.
- Risks for crabs and fish were estimated by comparing 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 chemical 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 chemicals derived from the ingestion of sediment, water, and prey 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

Chemical concentrations in surface sediments were compared to the sediment quality standards (SQS) and the cleanup screening level (CSL) numeric chemical values of the SMS. For the chemicals 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 chemical was selected as a chemical 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 chemicals were identified as COCs for the benthic invertebrate community. The three chemicals with the most frequent exceedances were total polychlorinated biphenyls (PCBs), bis(2-ethylhexyl)phthalate (BEHP), and butyl benzyl phthalate. For all other chemicals, exceedances occurred in 5% or less of the sediment samples.

For benthic invertebrates living in intertidal and subtidal sediments, sediment chemical concentrations and site-specific sediment toxicity test results indicated that harmful effects are not likely over approximately 75% of the LDW area.[2] There is a higher likelihood for adverse effects in approximately 7% of the LDW area, where chemical concentrations or biological effects were found to be in excess of the CSL criteria of the SMS. The remaining 18% of the LDW area had chemical concentrations or biological effects falling between the SQS and CSL criteria, indicating that risks to benthic invertebrate communities are less certain in these areas than in areas with chemical concentrations greater than one or more CSL values.

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 mile (RM) 2.4 at concentrations greater than the no-observed-effect concentration (NOEC) for the marine invertebrates but 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 based on a site-specific study of imposex in 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.

[2] Area estimates were based on the RI dataset and Thiessen polygons.

COCs for crabs, fish, and wildlife species were defined as chemicals with LOAEL-based HQs greater than or equal to 1, which indicate a potential for adverse effects. One chemical (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 chemicals (total PCBs, cadmium, chromium, copper, lead, mercury, and vanadium) were identified as COCs for at least one fish or wildlife species (Table 3-1).

No quantitative risk estimates were calculated for dioxins/furans 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 1998) and the Washington State Department of Ecology (Ecology) (WAC 173-340-703). 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 early action areas (EAAs).

In the baseline ERA (Windward 2007a), a total of 41 chemicals were selected as risk drivers for the benthic invertebrate community because concentrations of these chemicals exceeded the SQS at one or more locations.[3] 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. 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.

3.2 Baseline Human Health Risk Assessment

The baseline HHRA (Windward 2007b) estimated risks to people from exposure to chemicals in LDW seafood, sediments, and water (the exposure pathways). 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

[3] In the ERA (Windward 2007a), 44 chemicals were selected as COCs for benthic invertebrates. Of these, 41 chemicals were selected as risk drivers for benthic invertebrates because they had concentrations greater than the SQS in at least one sample. The other three chemicals (nickel, DDTs, and chlordane) were identified as COCs based on chemical concentrations greater than TRVs or toxicologically based DMMP guidelines; these three chemicals were not selected as risk drivers because of uncertainties in effects data and because samples with concentrations greater than the TRVs or guidelines were all (except for one) located within early action areas (Windward 2007a).

play. 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.

In the FS, the point of compliance for direct-contact risks in the assumed beach play and potential clamming areas is the upper 45 cm of the sediment. 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.[4]

A risk-based screening was first performed using EPA guidance to identify the COPCs to be evaluated. Based on an exceedance of the screening criteria (i.e., the risk-based concentration) of either detected concentrations or analytical reporting limits (RLs) (for samples with non-detected concentrations), the following COPCs were identified 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 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. 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 regional Asian and Pacific Islanders (API).

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:

[4] The most abundant clam species of harvestable size in the LDW is the Eastern soft-shell clam (*Mya arenaria*), and they may be found at depths up to 45 cm; thus, 45 cm was selected as the exposure depth for people clamming in the LDW.

- Tulalip tribal consumption rates from for adults and children EPA's tribal framework document (EPA 2007)
- Seafood consumption rates by API adults, modified by EPA based on the results of a survey of API consumers (EPA 1999) 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 seen 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 2007); 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 a variety of 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.

Chemical 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. Chemicals 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. Twenty chemicals were identified as COCs for the seafood consumption exposure pathway (Table 3-2).

The cumulative risk for all carcinogenic chemicals 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

[5] The highest RME cumulative excess cancer risk estimate reported here (4×10^{-3}) differs from that reported in Appendix B (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 (2009). 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 cumulative risk estimate includes risks from total PCBs but excludes risks from PCBs from a TEQ perspective to avoid double counting.

aromatic hydrocarbons (cPAHs) (Table 3-3a).[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 3-3b).

To provide additional information regarding the total excess cancer risks for the RME seafood consumption scenarios, Table 3-4 presents a summary of the excess cancer risks by chemical and includes the percentages of the total risks attributable to different chemicals 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 3-4 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). Inclusion of these data in the aforementioned risk calculations is still not possible because there are no dioxin/furan tissue data from the LDW for the other seafood categories. However, to put these new dioxin/furan concentration data in context, excess cancer risks were calculated assuming the same dioxin/furan concentrations would be present across all seafood categories. Recognizing that this is a highly questionable assumption, it is worth noting that 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 chemicals combined) under all three RME seafood consumption scenarios and therefore would not have substantially changed the overall risks (Table 3-4).

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. The exposure scenarios assumed for these activities were intended to represent exposures for a health-protective estimation of risks. 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 assumed beach play areas are shown on Figure 3-1.

[6] Seafood samples from the LDW were not analyzed for dioxins and furans, so risks from these chemicals are not included in seafood consumption risk estimates, but were assumed to be unacceptable.

Chemicals with 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 chemicals were identified as COCs for direct sediment contact exposure (Table 3-2). 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.

As presented in the RI (Windward 2010), total excess cancer risk estimates for 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 and ranged from 5 in 1,000,000 (5×10^{-6}) to 5 in 100,000 (5×10^{-5}) for the eight individual assumed beach play areas (Table 3-5a); none of the direct sediment contact exposure scenarios evaluated had non-cancer HQs greater than 1. Dioxins/furans were a significant contributor to total carcinogenic risk for netfishing and tribal clamming in the HHRA (2×10^{-5} [vs. a total of 3×10^{-5}] and 1×10^{-4} [equal to the total 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),[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 was finalized (Windward 2007b), additional sediment samples have also been collected in many of the assumed 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 assumed 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 eight individual assumed beach play areas (Table 3-5b 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 3-5b) compared with the estimated total excess cancer risks based on the HHRA dataset (Table 3-5a) (Windward 2007b). The other assumed 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

[7] Dioxins/furans were analyzed in sediments, and therefore, risk estimates are available.

[8] There were 43 samples available to characterize dioxin/furan TEQ netfishing exposure in the HHRA dataset, compared to 189 samples in the FS dataset. There were 11 samples available to characterize dioxin/furan TEQ tribal clamming exposure in the HHRA dataset, compared to 37 samples in the FS dataset.

high PCB concentrations in two post-RI samples that were collected from the head of the inlet at RM 2.2.

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 a subset of each of these areas (referred to as Area 4 modified and Area 5 modified). These modified areas were assessed to facilitate remedial decision-making (i.e., clarify which portions of the assumed 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 (1×10^{-5}), which excluded the inlet, was much lower than that for the entire area (6×10^{-4}) (Table 3-5b), consistent with the higher concentrations of arsenic, dioxins/furans, cPAHs, and especially total PCBs within the inlet. The estimated total excess cancer risk for Area 5 modified (4×10^{-6}), which excluded the northerly segment of Area 5 (which had higher concentrations of cPAHs and dioxins/furans), was also much lower than that for the entire area (3×10^{-5}) (Table 3-5b, Figure 3-1).

In addition to the increased excess cancer risk estimates for some assumed beach play areas (as presented in Table 3-5b), the highest total 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, largely as a result of a single sample with a very high total PCB concentration (2,900,000 microgram per kilogram dry weight [µg/kg dw]) from the head of the inlet at RM 2.2. If that single high total PCB concentration were omitted, the non-cancer HQ for total PCBs for Area 4 would be 15. The non-cancer HQ for total PCBs for Area 4 modified is 0.3. This analysis suggests that area of most concern is the inlet at Area 4 (which has been prioritized for remedial action in Alternative 2; see Section 8). None of the other assumed beach play areas had non-cancer HQs greater than 1 for any chemical.

3.2.3 Cumulative Risks for Multiple Exposure Scenarios

Risks for multiple exposure scenarios can be summed to represent possible exposure of the same individuals to LDW chemicals during different activities. Summed risks are presented in Table 3-6 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 low-end clamming, clam consumption, 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 three of the four above scenario groups 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 cumulative 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.

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). Briefly, the risk drivers were selected based on the magnitude of their risk estimates and the relative percentage of their contributions to 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 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 chemicals in sediment that are associated with specific risk estimates and exposure pathways. Cleanup of sediment to concentrations at or below a specific RBTC is expected to be protective for the particular risk-driver chemical, based on the exposure assumptions of the baseline risk assessments (Windward 2007a, 2007b). RBTCs were presented in Section 8 of the RI (Windward 2010),

[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.

and were used in this FS along with other site information to establish PRGs (as presented in Section 4.0).

As a reminder, risk drivers for ecological receptors include the SMS chemicals 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.

RBTCs for the ecological risk drivers include the following:

- SQS and the CSL sediment criteria from the SMS for the protection of benthic invertebrates.
- 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 3-7).

RBTCs for the human health risk drivers were calculated at three different excess cancer risk levels to humans from seafood consumption and direct contact with sediment (i.e., beach play, netfishing, and tribal clamming). The equations used to calculate the RBTCs are based on the risk equations used in the baseline HHRA (Windward 2007b). RBTCs for the seafood consumption and direct sediment contact human health exposure scenarios are described below:

- Sediment RBTCs for total PCBs for the three RME seafood consumption scenarios were calculated for the 1 in 10,000 (1×10^{-4}) excess cancer risk level (Table 3-7). These sediment RBTCs (based on tribal adult and child and API RME scenarios) were estimated using a food web model (see Appendix D in the RI). Sediment RBTCs for the RME seafood consumption scenarios could not be calculated at the cancer risk levels of 1 in 1,000,000 (1×10^{-6}) and 1 in 100,000 (1×10^{-5}) or at non-cancer HQ equal to 1 (Table 3-7); the contribution of total PCBs from water alone, even at concentrations similar to those in upstream water (i.e., 0.3 ng/L), was high enough to result in a risks above those levels for these consumption scenarios. Sediment RBTCs could not be calculated for dioxins/furans, arsenic, or cPAHs because either tissue data were not available (dioxins/furans) or the relationships between sediment and tissue concentrations for these chemicals were not sufficiently understood (arsenic and cPAHs).
- Sediment RBTCs for RME direct contact scenarios were calculated for all four risk drivers (i.e., PCBs, arsenic, cPAHs, and dioxins/furans) at all three risk levels (Table 3-8).

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 chemicals were identified as risk drivers for benthic invertebrates because concentrations of these chemicals in surface sediment exceed the SQS criteria at one or more locations (Table 3-9).
- For benthic invertebrates living in intertidal and subtidal sediment, sediment chemical concentrations and site-specific sediment toxicity test results indicated that harmful effects are not likely in approximately 75% of the LDW area. There is a higher likelihood for adverse effects in approximately 7% of the LDW area, where chemical concentrations or biological effects were found to be in excess of the CSL criteria The remaining 18% of the LDW area had chemical 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 chemical 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.
- Sediment RBTCs for the benthic invertebrate community were established at the SQS and CSL criteria.
- In consultation with EPA and Ecology, PCBs were identified as a risk driver for river otters (Table 3-9). The sediment RBTC for PCBs was calculated using the food web model based on seafood consumption by river otters. No other risk drivers were identified for crabs, fish, or wildlife.
- The highest risks to people were associated with the consumption of seafood, including resident fish, crabs, and clams (Tables 3-3a and 3-3b). Lower risks were associated with activities that involve direct contact with sediment, such as clamming, beach play, and netfishing (Tables 3-5a and 3-5b).
- Total PCBs, arsenic, cPAHs, and dioxins/furans were identified as risk drivers for human health (Table 3-9).
- For seafood consumption, sediment RBTCs could not be calculated for dioxins/furans, arsenic, or cPAHs because tissue data were not available (for dioxins/furans) or because the relationships between sediment and tissue concentrations for these chemicals were not sufficiently understood (arsenic and cPAHs).
- For total PCBs, sediment RBTCs could be calculated only for the 1 in 10,000 (1×10^{-4}) excess cancer risk level for the three RME scenarios (Table 3-7). RBTCs

for the 10^{-5} and 10^{-6} risk levels and non-cancer RBTCs for total PCBs for the RME seafood consumption scenarios could not be calculated because the contribution of total PCBs from water alone was high enough to result in risks above those levels.

- Sediment RBTCs for RME direct sediment contact scenarios were calculated for all four risk drivers and all three risk levels (Table 3-8).

The risk screening process used to identify COPCs, COCs, and risk drivers for human health and ecological receptors is summarized in Table 3-9. The COCs not selected as risk drivers were evaluated to assess the potential for risk reduction following remedial actions; this evaluation is discussed in Section 9.

Table 3-1 Summary of COCs for Crab, Fish, and Wildlife Species

COC[a]	Receptor of Concern	NOAEL-based HQ	LOAEL-based HQ
Total PCBs	crabs	10.0	1.0
	English sole	4.9 – 25.0	0.98 – 5.0
	Pacific staghorn sculpin	1.5 – 19.0	0.30 – 3.8
	river otter	5.8	2.9
	spotted sandpiper	1.9 – 15	0.18 – 1.5
Cadmium	juvenile chinook salmon	5.0	1.0
	English sole	6.1	1.2
	Pacific staghorn sculpin	3.0 – 5.2	0.60 – 1.0
Chromium	spotted sandpiper	1.3 – 8.8	0.26 – 1.8
Copper	spotted sandpiper	0.62 – 1.5	0.45 – 1.1
Lead	spotted sandpiper	0.58 – 19.0	0.17 – 5.5
Mercury	spotted sandpiper	1.1 – 5.3	0.21 – 1.0
Vanadium	English sole	5.9	1.2
	Pacific staghorn sculpin	3.2 – 5.9	0.65 – 1.2
	spotted sandpiper	2.0 – 2.7	1.0 – 1.4

Notes:

HQs for fish are highest when more than one approach was used.

Bold identifies NOAEL-based HQs greater than 1.0 or LOAEL-based HQs greater than or equal to 1.0.

a A chemical was identified as a COC if the LOAEL-based HQ was greater than or equal to 1.0.

b Spotted sandpiper PCB HQs listed are based on comparisons to the PCB TEQ NOAEL and LOAEL. Spotted sandpiper HQs based on comparisons to total PCB LOAEL and NOAEL were not greater than or equal to 1.0.

COC = chemical of concern; HQ = hazard quotient; LOAEL = lowest-observed-adverse-effect level; NOAEL = no-observed-adverse-effect level; PCB = polychlorinated biphenyl; TEQ = toxic equivalent

Table 3-2 Summary of COCs for Human Health

COC[a]	Exposure Route	
	Seafood Consumption	Direct Contact
Total PCBs[b]	X	X
Arsenic	X	X
cPAH TEQ	X	X
Dioxin/furan TEQ	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	

a Chemicals 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 chemicals 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 = chemical 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 3-3a Summary of Estimated Excess Cancer Risks for the Seafood Consumption Scenarios

COC	Adult Tribal RME (Tulalip Data)[a]	Adult Tribal CT (Tulalip Data)[a]	Child Tribal RME (Tulalip Data)[a]	Child Tribal CT (Tulalip Data)[a]	Adult Tribal (Suquamish Data)	Adult API RME	Adult API CT	Adult One Meal per Month			
								Benthic Fish	Clam	Crab	Pelagic Fish
Arsenic (inorganic)[b]	2×10^{-3}	7×10^{-5}	3×10^{-4}	3×10^{-5}	2×10^{-2} [c]	7×10^{-4}	1×10^{-5}	4×10^{-7}	1×10^{-4}	3×10^{-6}	6×10^{-6}
BEHP	6×10^{-6}	2×10^{-7}	1×10^{-6}	7×10^{-8}	4×10^{-5}	2×10^{-6}	3×10^{-8}	8×10^{-7}	8×10^{-8}	8×10^{-8} [d]	1×10^{-6}
cPAH TEQ[e]	8×10^{-5}	4×10^{-6}	8×10^{-5}	9×10^{-6}	8×10^{-4}	3×10^{-5}	8×10^{-7}	2×10^{-7}	7×10^{-6}	2×10^{-7}	3×10^{-7}
Dioxin/furan TEQ[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}	5×10^{-5}	2×10^{-4}	2×10^{-5}	7×10^{-3}	4×10^{-4}	7×10^{-6}	8×10^{-5}	2×10^{-5}	2×10^{-5}	2×10^{-4}
Total PCBs	2×10^{-3}	6×10^{-5}	3×10^{-4}	3×10^{-5}	1×10^{-2} [c]	5×10^{-4}	8×10^{-6}	1×10^{-4}	5×10^{-5}	2×10^{-5}	2×10^{-4}
Pentachlorophenol[b]	9×10^{-5} [g]	2×10^{-6} [g]	2×10^{-5} [g]	7×10^{-7} [g]	5×10^{-4} [g]	2×10^{-5}	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}	1×10^{-4}	7×10^{-4}	7×10^{-5}	3×10^{-2}	1×10^{-3}	2×10^{-5}	1×10^{-4}	2×10^{-4}	3×10^{-5}	2×10^{-4}
Subtotal (excluding total PCBs)	3×10^{-3}	1×10^{-4}	6×10^{-4}	6×10^{-5}	3×10^{-2}	1×10^{-3}	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]	1×10^{-6} [g]	8×10^{-6} [g]	6×10^{-7} [g]	2×10^{-4}	1×10^{-5}	2×10^{-7}	3×10^{-6} [d]	8×10^{-7} [d]	3×10^{-6} [d]	3×10^{-6}
alpha-BHC	2×10^{-5} [g]	5×10^{-7} [g]	3×10^{-6} [g]	2×10^{-7} [g]	6×10^{-5}	3×10^{-6}	6×10^{-8}	1×10^{-6}	1×10^{-7}	1×10^{-6} [d]	1×10^{-6}
beta-BHC	6×10^{-6} [g]	2×10^{-7} [g]	1×10^{-6} [g]	1×10^{-7} [g]	3×10^{-5}	1×10^{-6}	3×10^{-8}	3×10^{-7}	1×10^{-7}	3×10^{-7} [d]	6×10^{-7}
Carbazole	4×10^{-5}	9×10^{-7}	8×10^{-6}	4×10^{-7}	2×10^{-4}	1×10^{-5}	8×10^{-8}	1×10^{-6} [d]	9×10^{-8} [d]	1×10^{-6} [d]	1×10^{-5}
Total chlordane	6×10^{-6}	2×10^{-7}	1×10^{-6}	8×10^{-8}	3×10^{-5}	2×10^{-6}	3×10^{-8}	3×10^{-7}	7×10^{-8}	7×10^{-8}	1×10^{-6}
Total DDTs	2×10^{-5}	1×10^{-6}	4×10^{-6}	4×10^{-7}	1×10^{-4}	6×10^{-6}	1×10^{-7}	1×10^{-6}	2×10^{-7}	4×10^{-7}	4×10^{-6}
Dieldrin	1×10^{-4}	3×10^{-6}	3×10^{-5}	1×10^{-6}	1×10^{-3}	5×10^{-5}	4×10^{-7}	3×10^{-6} [d]	9×10^{-6}	3×10^{-6}	3×10^{-6} [d]
gamma-BHC	5×10^{-6}	1×10^{-7}	1×10^{-6}	5×10^{-8}	3×10^{-5}	1×10^{-6}	1×10^{-8}	2×10^{-7} [d]	1×10^{-7}	2×10^{-7}	1×10^{-7}
Heptachlor	1×10^{-5} [g]	4×10^{-7} [g]	3×10^{-6} [g]	2×10^{-7} [g]	6×10^{-5}	3×10^{-6}	4×10^{-8}	7×10^{-7} [d]	1×10^{-7} [d]	7×10^{-7} [d]	2×10^{-6}
Heptachlor epoxide	3×10^{-5}	1×10^{-6}	6×10^{-6}	5×10^{-7}	2×10^{-4}	9×10^{-6}	1×10^{-7}	1×10^{-6} [d]	6×10^{-7}	9×10^{-7}	4×10^{-6}

Table 3-3a Summary of Estimated Excess Cancer Risks for the Seafood Consumption Scenarios

COC	Adult Tribal RME (Tulalip Data)[a]	Adult Tribal CT (Tulalip Data)[a]	Child Tribal RME (Tulalip Data)[a]	Child Tribal CT (Tulalip Data)[a]	Adult Tribal (Suquamish Data)	Adult API RME	Adult API CT	Adult One Meal per Month			
								Benthic Fish	Clam	Crab	Pelagic Fish
Hexachlorobenzene	1×10^{-5}	2×10^{-7}	2×10^{-6}	1×10^{-7}	4×10^{-5}	2×10^{-6}	3×10^{-8}	6×10^{-7}	6×10^{-8}	6×10^{-7}	9×10^{-7}
Subtotal	3×10^{-4}	9×10^{-6}	7×10^{-5}	4×10^{-6}	2×10^{-3}	1×10^{-4}	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}	1×10^{-4}	8×10^{-4}	7×10^{-5}	3×10^{-2}	1×10^{-3}	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}	1×10^{-4}	7×10^{-4}	6×10^{-5}	3×10^{-2}	1×10^{-3}	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 (2009)). 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 chemical. 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 cPAH concentrations were based on benzo(a)pyrene equivalents. Data used in the risk characterization were only from 2004 because of high reporting limits in historical data. All cPAH TEQ data were analyzed in the uncertainty analysis (Appendix B, Section B.6) (Windward 2007b). Because of the potential for the increased susceptibility of children to carcinogens with mutagenic activity, as described in EPA guidance (2005), the risk estimate for children for cPAH TEQ was based on dose adjustments across the 0-to-6-year-old age range of children. See the HHRA, Section B.5.1 (Windward 2007b), for more information.

f Tissue data for dioxins and furans were not collected. Thus, the calculated total risk, which does not include risks from dioxins and furans, is underestimated to an unknown degree.

g Greater than 50% of the risk associated with this chemical is derived from seafood categories with no detected values.

API = Asian and Pacific Islander; BEHP = bis(2-ethylhexyl) phthalate; BHC = benzene hexachloride; COC = chemical of concern; cPAH = carcinogenic polycyclic aromatic hydrocarbon; CT = central tendency; DDT = dichlorodiphenyltrichloroethane; EPA = U.S. Environmental Protection Agency; HHRA = human health risk assessment; n/a = not available; PCB = polychlorinated biphenyl; RI = remedial investigation; RME = reasonable maximum exposure; TEQ = toxic equivalent

Table 3-3b Summary of Estimated Non-cancer Hazards for the Seafood Consumption Scenarios

COC	Adult Tulalip RME (Tulalip Data)[a]	Adult Tribal CT (Tulalip Data)[a]	Child Tribal RME (Tulalip Data)[a]	Child Tribal CT (Tulalip Data)[a]	Adult Tribal (Suquamish Data)	Adult API RME	Adult API CT	Adult One Meal per Month			
								Benthic Fish	Clam	Crab	Pelagic Fish
Hazard Quotients by Chemical[b]											
Arsenic (inorganic)[c]	4	0.4	8	0.7	38	3	0.2	0.002	0.7	0.01	0.03
Chromium[d]	0.2	0.02	0.4	0.04	2	0.1	0.01	0.002	0.03	0.006	0.007
Mercury[e]	0.5	0.07	1	0.1	2	0.3	0.02	0.06	0.02	0.07	0.04
Total PCBs	40	4	87	8	274	29	2	6	3	1	10
TBT (as ion)	2	0.2	3	0.4	15	1	0.1	0.002	0.3	0.02	0.06
Vanadium	0.9	0.1	2	0.3	9	0.8	0.07	0.01	0.2	0.01	0.06
Hazard Indices by Effect (Endpoint)[b]											
HI for cardiovascular endpoint[f]	5	0.5	10	1	47	4	0.3	0.01	0.9	0.02	0.09
HI for developmental endpoint[g]	41	4	88	8	276	29	2	6	3	1	10
HI for hematologic endpoint[h]	0.2	0.03	0.5	0.05	2	0.2	0.01	0.006	0.03	0.01	0.009
HI for immunological endpoint[i]	42	4	90	8	289	30	2	6	3	1	10
HI for kidney endpoint[j]	0.4	0.05	0.9	0.1	2	0.3	0.02	0.03	0.03	0.04	0.04
HI for liver endpoint[k]	1	0.1	32	0.3	7	0.8	0.05	0.1	0.1	0.09	0.3
HI for neurological endpoint[l]	41	4	88	8	276	29	2	6	3	1	10
HI for dermal endpoint[m]	4	0.4	8	0.7	38	3	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 (2009). 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 COCs by endpoint. However, only COCs with an HQ greater than or equal to 1 for at least one scenario are listed in this table.

c No mussel data were available for this chemical. 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 chemicals 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 chemicals 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 chemicals 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 = chemical of concern; CT = central tendency; DDT = dichlorodiphenyltrichloroethane; HI = hazard index; HQ = hazard quotient; PCB = polychlorinated biphenyl; RI = remedial investigation; RME = reasonable maximum exposure; TBT = tributyltin

Table 3-4 Summary of Estimated Excess Cancer Risks for the RME Seafood Consumption Scenarios

Chemical	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
cPAH TEQ	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 chemicals (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 total excess cancer risk[c]	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
Dioxin/furan TEQ[d]	6×10^{-5}	Not included in HHRA risk estimates; this risk is based on the assumption that all seafood categories in the diet had the dioxin/furan concentrations in English sole fillets collected in 2007 near Kellogg Island	1×10^{-5}	Not included in HHRA risk estimates; this risk is based on the assumption that all seafood categories in the diet had the dioxin/furan concentrations in English sole fillets collected in 2007 near Kellogg Island	2×10^{-5}	Not included in HHRA risk estimates; this risk is based on the assumption that all seafood categories in the diet had the dioxin/furan concentrations in English sole fillets collected in 2007 near Kellogg Island

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 (2009). 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 chemicals contributed less than 1.5%.

c Seafood consumption category-chemical combinations contributing greater than 5% of the total risk are listed separately. All other combinations are included in the "other" category.

d Data for dioxin/furan TEQ were available for only skin-off English sole fillets from a May 2007 PSAMP sampling effort (Gries 2008).

API = Asian and Pacific Islander; BEHP = bis(2-ethylhexyl) phthalate; BHC = benzene hexachloride; cPAH = carcinogenic polycyclic aromatic hydrocarbon; 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; TEQ = toxic equivalent; WB = whole body

Table 3-5a Summary of Estimated Excess Cancer Risks for the Direct Sediment Contact Scenarios from the RI

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}
cPAH TEQ[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}
Dioxin/furan TEQ	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) / Other COCs										
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 cPAH concentrations were based on benzo(a)pyrene equivalents. Because of the potential for the increased susceptibility of children to carcinogens with mutagenic activity, as described in EPA guidance (2005), the risk estimate for the beach play RME for cPAH TEQ 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 TEQ risk associated with netfishing was 3×10^{-6}.

c When risks were recalculated using the FS dataset, the dioxin/furan TEQ 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 = chemical of concern; EPA = U.S. Environmental Protection Agency; HHRA = human health risk assessment; n/a = not available; PCB = polychlorinated biphenyl; RI = remedial investigation; RME = reasonable maximum exposure; TEQ = toxic equivalent

Table 3-5b 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]	Area 5	Area 5 Modified[c]	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}	3×10^{-6}	3×10^{-6}	3×10^{-5}	3×10^{-6}	3×10^{-6}	1×10^{-6}
cPAH TEQ[d]	4×10^{-6}	8×10^{-5}	1×10^{-5}	1×10^{-5}	9×10^{-6}	3×10^{-5}	1×10^{-6}	8×10^{-5}	1×10^{-6}	3×10^{-6}	7×10^{-7}
Dioxin/furan TEQ	1×10^{-7}	3×10^{-6}	1×10^{-7}	1×10^{-5}	6×10^{-7}	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}	1×10^{-7}	1×10^{-7}	5×10^{-7}	5×10^{-8}	6×10^{-8}	1×10^{-7}
Total excess cancer risk of the above chemicals [e]	9×10^{-6}	9×10^{-5}	1×10^{-5}	6×10^{-4}	1×10^{-5}	3×10^{-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 excluding the inlet at RM 2.2.

c Beach 5 excluding the northerly section.

d cPAH TEQ concentrations were based on benzo(a)pyrene equivalents. Because of the potential for the increased susceptibility of children to carcinogens with mutagenic activity, as described in EPA guidance (2005), the risk estimate for beach play RME for cPAH TEQ 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 chemicals presented in this table. In the HHRA (Windward 2007b), risks from other COCs made up 1% or less of the total excess cancer risk for any given assumed beach play area, and thus if the risks for these other COCs were added, it is unlikely that the total risk estimates presented here would change.

COC = chemical 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; TBD = to be determined; TEQ = toxic equivalent

Table 3-6 Cumulative Estimated Excess Cancer Risks Estimates 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}
Total	4×10^{-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	**5×10^{-5}**
Child Tribal RME seafood consumption based on Tulalip data[d]	8×10^{-4}
Total	9×10^{-4}
Adult Low-End Clamming Scenarios	
Clamming – 7 days per year	1×10^{-6}
Swimming[c]	$<1 \times 10^{-6}$
Clam consumption – 1 meal per month	2×10^{-4}
Total	2×10^{-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}
Total	4×10^{-3}

Notes:

a All non-swimming risk estimates are presented in the HHRA (Windward 2007b); 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 1999). 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 1999). 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 1999) 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 (2009). 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 3-7 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				
Adult Tribal RME (Tulalip data)	<1[a]	<1[a]	5	<1
Child Tribal RME (Tulalip data)	<1[a]	<1[a]	178	<1
Adult API RME	<1[a]	<1[a]	100	<1
Ecological				
River otter	n/a	n/a	n/a	128 – 159[b]

Notes:

a For RBTCs presented as <1 µg/kg dw, a sediment RBTC could not be calculated because even if the total PCB concentration in sediment was set equal to 0 µg/kg dw, food web model-estimated total PCB concentrations in tissue were greater than the RBTC for the applicable risk level. These estimates result from a combination of the contribution from water, even at concentrations similar to those in upstream water (i.e., 0.3 ng/L) and key risk assumptions (e.g., seafood consumption rate).

b Represents best-fit estimates for two different fish consumption scenarios as presented in the ERA (Windward 2007a).

API = Asian and Pacific Islander; dw = dry weight; ERA – ecological risk assessment; HQ = hazard quotient; n/a = not applicable; PCB = polychlorinated biphenyl; RBTC = risk-based threshold concentration; RME = reasonable maximum exposure

Table 3-8 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
Dioxin/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

Notes:

a cPAH concentrations were based on benzo(a)pyrene equivalents.

b Dioxin/furan concentrations are represented as 2,3,7,8-TCDD mammalian TEQ equivalents.

cPAH = carcinogenic polycyclic aromatic hydrocarbon; dw = dry weight; PCB = polychlorinated biphenyl; RBTC = risk-based threshold concentration; RME = reasonable maximum exposure; TCDD = tetrachlorodibenzo-p-dioxin; TEQ = toxic equivalent

Table 3-9 Summary of Risk Screening and Identification of COCs and Risk Drivers

MTCA Terminology	CERCLA Terminology	Chemicals			
		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 chemicals with maximum exposure concentrations greater than TRVs.* *Human Health: COPCs are chemicals 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 chemicals	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 chemicals – 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 chemicals with LOAEL-based HQs greater than or equal to 1.0.* *Human Health: COCs are chemicals 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 chemicals – 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:

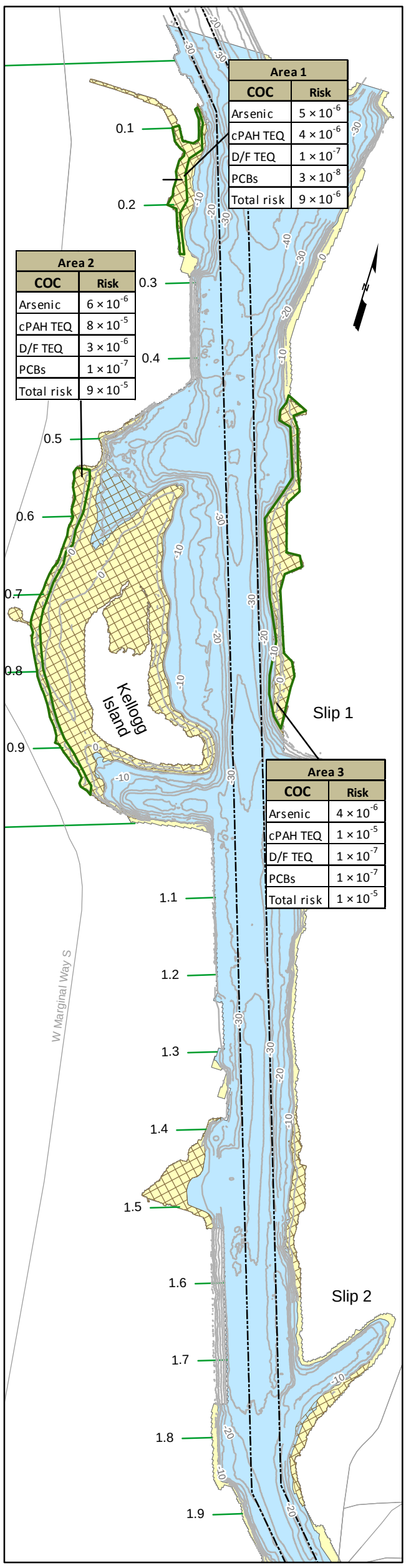
a Organochlorine pesticides were qualified as tentatively identified compounds at estimated concentrations (JN-qualified), indicating uncertainty regarding both their presence and concentration.

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-driver chemicals 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.

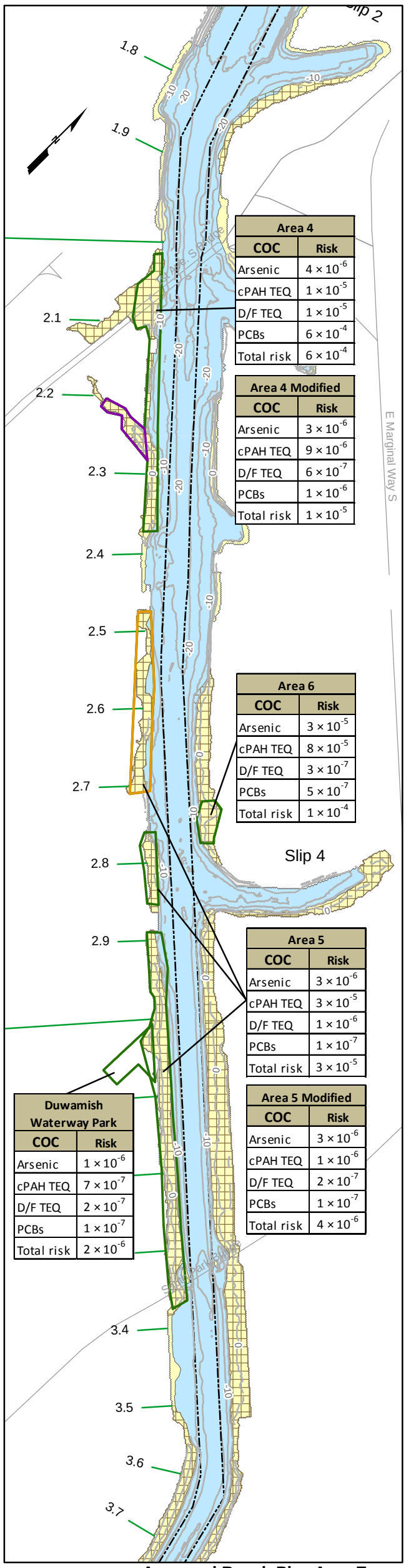
BEHP = bis(2-ethylhexyl) phthalate; BHC = benzene hexachloride; CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act; COC = chemical of concern; COPC = chemical of potential concern; cPAH = carcinogenic polycyclic aromatic hydrocarbon; DDT = dichlorodiphenyltrichloroethane; 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 TEQ	4×10^{-6}
D/F TEQ	1×10^{-7}
PCBs	3×10^{-8}
Total risk	9×10^{-6}

Area 2	
COC	Risk
Arsenic	6×10^{-6}
cPAH TEQ	8×10^{-5}
D/F TEQ	3×10^{-6}
PCBs	1×10^{-7}
Total risk	9×10^{-5}

Area 3	
COC	Risk
Arsenic	4×10^{-6}
cPAH TEQ	1×10^{-5}
D/F TEQ	1×10^{-7}
PCBs	1×10^{-7}
Total risk	1×10^{-5}



Area 4	
COC	Risk
Arsenic	4×10^{-6}
cPAH TEQ	1×10^{-5}
D/F TEQ	1×10^{-5}
PCBs	6×10^{-4}
Total risk	6×10^{-4}

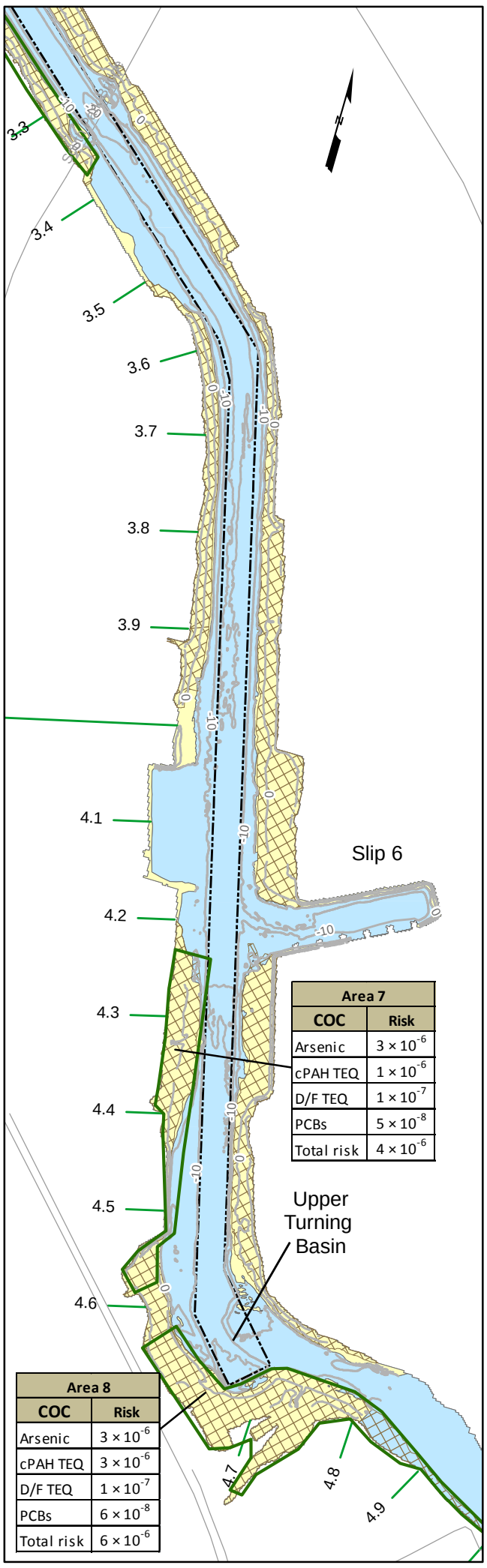
Area 4 Modified	
COC	Risk
Arsenic	3×10^{-6}
cPAH TEQ	9×10^{-6}
D/F TEQ	6×10^{-7}
PCBs	1×10^{-6}
Total risk	1×10^{-5}

Area 6	
COC	Risk
Arsenic	3×10^{-5}
cPAH TEQ	8×10^{-5}
D/F TEQ	3×10^{-7}
PCBs	5×10^{-7}
Total risk	1×10^{-4}

Area 5	
COC	Risk
Arsenic	3×10^{-6}
cPAH TEQ	3×10^{-5}
D/F TEQ	1×10^{-6}
PCBs	1×10^{-7}
Total risk	3×10^{-5}

Duwamish Waterway Park	
COC	Risk
Arsenic	1×10^{-6}
cPAH TEQ	7×10^{-7}
D/F TEQ	2×10^{-7}
PCBs	1×10^{-7}
Total risk	2×10^{-6}

Area 5 Modified	
COC	Risk
Arsenic	3×10^{-6}
cPAH TEQ	1×10^{-6}
D/F TEQ	2×10^{-7}
PCBs	1×10^{-7}
Total risk	4×10^{-6}



Area 7	
COC	Risk
Arsenic	3×10^{-6}
cPAH TEQ	1×10^{-6}
D/F TEQ	1×10^{-7}
PCBs	5×10^{-8}
Total risk	4×10^{-6}

Area 8	
COC	Risk
Arsenic	3×10^{-6}
cPAH TEQ	3×10^{-6}
D/F TEQ	1×10^{-7}
PCBs	6×10^{-8}
Total risk	6×10^{-6}

Legend

- Assumed Beach Play Area
- Area Excluded from Area 4 Modified
- Area Excluded from Area 5 Modified
- Potential Tribal Clamming Area

Intertidal and Subtidal Areas

- Intertidal Area (< -4 ft MLLW)
- Subtidal Area (> -4 ft MLLW)

- Bathymetric Contours (ft MLLW)
- Road
- Navigation Channel
- River Mile Marker

Notes:
1. Excess cancer risks were estimated using the FS dataset. Assumed 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.

Assumed Beach Play Area Excess Cancer Risks Based on FS Dataset

Area 3	
COC	Risk
Arsenic	4×10^{-6}
cPAH TEQ	1×10^{-5}
D/F TEQ	1×10^{-7}
PCBs	1×10^{-7}
Total risk	1×10^{-5}

COC = chemical of concern
Risk = excess cancer risk estimate
D/F TEQ = Dioxin/furan toxic equivalent
cPAH TEQ = carcinogenic polycyclic aromatic hydrocarbon toxic equivalent
PCBs = polychlorinated biphenyls

0 200 400 800 Feet

Wind Ward environmental LLC
AECOM
Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

Lower Duwamish Waterway
Draft Final Feasibility Study
05482015-710

Assumed Beach Play Areas and Potential Tribal Clamming Areas

DATE: 10/15/10 | DWRN:MVI/CEH | Revision: 5 | **FIGURE 3-1**

W:\Projects\00-08-06_Duwamish_RI\data\GIS\FS Support\HHRA updates for FS\figure3-1beachclammingareas.mxd

4 Remedial Action Objectives and Preliminary Remediation Goals

This section of the feasibility study (FS) identifies narrative remedial action objectives (RAOs) and numerical preliminary remediation goals (PRGs) for cleanup of the Lower Duwamish Waterway (LDW). RAOs for the LDW describe what a proposed cleanup remedy is expected to accomplish to protect human health and the environment (EPA 1999). PRGs are the chemical endpoint concentrations or risk levels associated with each RAO that are believed to be sufficient to protect human health and the environment based on available site information (EPA 1997b).

The step of identifying narrative RAOs provides a transition between the findings of the human health and ecological risk assessments and development of remedial alternatives in the FS. The RAOs pertain to the specific exposure pathways and receptors evaluated in the risk assessment and for which unacceptable risks were identified.

RAOs are developed herein for cleanup of contaminated sediment in the LDW Superfund site. Surface water within the site is also a medium of concern. However, no active remedial measures are anticipated for the water column. Improvements in surface water quality are expected following sediment cleanup and implementation of upland source control measures. Further, water quality monitoring will be part of long-term monitoring for the site.

PRGs are intended to protect human health and the environment and to comply with chemical-specific applicable or relevant and appropriate requirements (ARARs) (EPA 1991). For the LDW, PRGs are numerical concentrations or ranges of concentrations in sediment that protect a particular receptor from exposure to a chemical by a specific pathway. The PRGs are expressed as sediment concentrations for the identified risk drivers. PRGs are not developed in this FS for surface water. Instead, surface water quality will be discussed relative to water quality ARARs. The RAOs, ARARs, and PRGs presented here may be modified and will be finalized by the U.S. Environmental Protection Agency (EPA) and the Washington State Department of Ecology (Ecology) in the final decision document.

4.1 Development of Remedial Action Objectives

The RAOs are narrative statements of the medium-specific or area-specific goals for protecting human health and the environment. RAOs describe in general terms what the sediment cleanup will accomplish for the LDW. RAOs help focus the development and evaluation of remedial alternatives and form the basis for establishing PRGs.

EPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (EPA 1988) specifies that RAOs are to be developed based on the results of the

human health risk assessment (HHRA) and ecological risk assessment (ERA). Other EPA guidance (EPA 1991a, 1999) states that RAOs should specify:

- The exposure pathways, the receptors, and the chemicals of concern (COCs)
- An acceptable chemical concentration or range of concentrations for each exposure pathway.

Section 2 summarized the remedial investigation (RI), including the chemical and physical conceptual site model. Section 3 summarized the results of the risk assessments, which identified receptors, exposure pathways, risk drivers, and, where calculable, risk-based threshold concentrations (RBTCs). The RAOs presented here were crafted based on the RI and findings from the baseline ERA and HHRA (Windward 2010, 2007a, 2007b).

4.1.1 Remedial Action Objectives for the Lower Duwamish Waterway

The results of the baseline HHRA and ERA indicate that remedial action is warranted to reduce unacceptable human health and ecological risks posed by COCs in LDW sediments. Unacceptable risks were estimated for certain human health exposure scenarios (through seafood consumption and direct contact exposure pathways), and for certain ecological risks (for benthic organisms and for other ecological receptors).

For human health, EPA defines a generally acceptable risk range for excess cancer risks as between one in ten thousand (1×10^{-4}) and one in one million (1×10^{-6}) (i.e., the "target risk range") and for non-cancer risks a hazard index (HI) of 1 or less is considered acceptable (EPA 1991a). Excess cancer risks greater than 10^{-4} or HIs greater than 1 generally warrant a response action (EPA 1997b).

For purposes of establishing cleanup levels and remedial action levels (RALs), Model Toxics Control Act (MTCA) specifies that individual chemical excess cancer risks should be 1×10^{-6} or less, and cumulative excess cancer risks (all carcinogens combined) should not exceed one in one hundred thousand (1×10^{-5}). Cleanup levels should be adjusted downward to take into account exposure to multiple hazardous substances if the total excess cancer risk exceeds 1×10^{-5}. MTCA also specifies that risks resulting from exposure to multiple hazardous substances may be apportioned among hazardous substances in any combination as long as: 1) the cumulative excess cancer risk (all carcinogens combined) does not exceed 1×10^{-5}; and 2) the health threats resulting from exposure to two or more non-carcinogenic hazardous substances with similar types of toxic response does not exceed an HI of 1 (WAC 173-340-708).

Based on guidance provided by EPA under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and other requirements provided in the Washington State Model Toxics Control Act/Sediment Management Standards (MTCA/SMS), four RAOs have been identified for the cleanup of LDW sediments. These RAOs are identified below, and a discussion of each RAO follows.

RAO 1: Reduce human health risks associated with the consumption of resident LDW fish and shellfish by reducing sediment and surface water concentrations of COCs to protective levels.

Lifetime excess cancer risks from human consumption of resident LDW seafood are estimated to be greater than 1×10^{-4} under reasonable maximum exposure (RME) seafood consumption scenarios. In addition, the estimated non-cancer risks exceed an HI of one (Tables 3-3a and b; Windward 2010). These estimated risks warrant response actions to reduce exposure.

Total polychlorinated biphenyls (PCBs), arsenic, and carcinogenic polycyclic aromatic hydrocarbons (cPAHs) are the primary risk drivers that contribute to the estimated risks based on consumption of resident seafood. As discussed in Section 3, although risks associated with consumption of dioxins/furans in resident seafood were not quantitatively assessed in the baseline HHRA, those risks were assumed to be unacceptable; thus, dioxins/furans are also considered risk drivers with respect to the resident seafood consumption scenario.

Achieving RAO 1 requires that site-wide average concentrations of COCs in sediment be reduced, which in turn, is expected to reduce tissue COC concentrations in fish and shellfish exposed to these sediments. Exposure of fish and shellfish to COCs in sediment occurs within the biologically active zone. As reported in the RI (Windward 2010), this zone is estimated to be the upper 10 cm of sediment. Deeper, undisturbed sediments contribute negligibly to the risks addressed by this RAO. However, deeper sediments that contain chemicals at concentrations above action levels and that are potentially subject to disturbance (e.g., erosion, propeller scour) may warrant response actions to satisfy this RAO.

With regard to seafood consumption, bioaccumulative COCs enter the food web from both sediment and water. For example, the food web model used to predict tissue PCB concentrations (refer to Appendix D of the RI; Windward 2010) assumes that the exposure of fish and shellfish to PCBs occurs through their exposure to both sediments and surface water.

Substantial reductions in the concentrations of such chemicals in sediment achieved through remediation should also reduce the concentrations of those chemicals in surface water, thereby contributing to reducing their concentrations in fish and shellfish tissue and ultimately reducing human health risks, as stated in RAO 1. The relationships between sediment, surface water, and tissue concentrations are complex, and will be assessed through long-term monitoring of the remedial actions.

RAO 2: Reduce human health risks associated with exposure to COCs through direct contact with sediments and incidental sediment ingestion by reducing sediment concentrations of COCs to protective levels.

Lifetime excess cancer risks from human direct contact and incidental sediment ingestion RME scenarios (netfishing, tribal clamming, and beach play) are estimated to

be within EPA's 10^{-4} to 10^{-6} target risk range (Tables 3-5a and b) for the individual risk drivers. Some individual chemical excess cancer risks exceed 1×10^{-6}, and cumulative risks from all risk drivers exceed 1×10^{-5}, both of which are MTCA thresholds. Therefore, the risks associated with these exposure pathways warrant response actions to reduce exposure. No HIs were greater than 1 for any of the direct contact or incidental ingestion sediment RME scenarios, with the exception of one individual beach (Beach 4).[1] Total PCBs, arsenic, cPAHs, and dioxins/furans are the primary risk drivers that contribute to the estimated excess cancer risks, and total PCBs are also a risk driver for noncancer risks based on direct contact scenarios.

Achieving RAO 2 requires that site-wide average concentrations of COCs at depths within the sediment where people have the potential to be exposed to these chemicals be reduced in the corresponding spatial areas. For netfishing activities, exposure is over the entire LDW and to surface sediments (0 to 10 cm). Direct contact risks in the beach play and tribal clamming areas are assumed to result from exposure to the upper 45 cm depth interval, which accounts for potential exposures to children and clammers, who may dig holes deeper than 10 cm. Deeper sediments in other areas do not contribute appreciably to these risks unless they could be exposed by future disturbances (e.g., erosion, propeller scour). Achieving and maintaining this RAO may include response actions addressing deeper sediments containing the risk-driver chemicals above action levels if they are potentially subject to exposure as a result of disturbance of the overlying sediments over time.

RAO 3: Reduce risks to benthic invertebrates by reducing sediment concentrations of COCs to comply with the Washington State SMS.

The SMS provide both chemical and biological effects-based criteria. The numerical SMS chemical criteria are available for 47 chemicals or groups of chemicals (i.e., sediment quality standards [SQS] and cleanup screening levels [CSL]). These numerical chemical criteria are based on apparent effects thresholds (AETs) developed for four different benthic endpoints by the Puget Sound Estuary Program (PSEP) (Barrick et al. 1988). An AET is the highest "no effect" chemical-specific sediment concentration above which a significant adverse biological effect always occurred among the several hundred samples used in its derivation. In general, the lowest of the four AETs for each chemical was identified as the SQS; the second lowest AET was identified as the CSL. According to the SMS (WAC 173-204), locations with all chemical concentrations less than or equal to the SQS are defined as having no acute or chronic adverse effects on biological resources, locations with any chemical concentrations between the SQS and the CSL are defined as having minor adverse effects, and locations with any chemical concentration greater than the CSL are defined as having more pronounced adverse effects (refer to Section 5 of the RI, Windward 2010).

[1] HIs are calculated as the sum of hazard quotient (HQs) with similar non-cancer toxic endpoints.

The baseline ERA (Windward 2007a) reported that 41 chemicals were detected in surface sediment at one or more locations within the LDW at concentrations exceeding their respective SQS. Thus, the ERA determined that these 41 chemicals pose a risk to the benthic invertebrate community and are designated as risk drivers for this pathway.

Benthic organisms reside primarily in the biologically active zone (uppermost 10 cm) of intertidal and subtidal sediments of the LDW (Section 2 of the RI, Windward 2010). Deeper sediments in areas subject to disturbance (e.g., erosion, propeller scour) that contain chemicals at concentrations above the SQS may warrant response actions to satisfy RAO 3.

RAO 4: Reduce risks to crabs, fish, birds, and mammals from exposure to COCs by reducing concentrations of COCs in sediment and surface water to protective levels.

The ERA (Windward 2007a) determined that exposure to seven chemicals identified as COCs exceeded toxicity benchmarks for fish, birds, or mammals. In consultation with EPA and Ecology, total PCBs were designated as the risk driver associated with seafood consumption based on estimated risks to river otters. Thus, achievement of RAO 4 is based on addressing PCB risk to river otters (see Section 3.1.3 for discussion of other ecological COCs).

River otters are indirectly exposed to PCBs in sediment primarily through the consumption of prey. Therefore, achieving this RAO requires that site-wide average concentrations of PCBs in sediment be reduced, with the expectation that sediment cleanup will reduce PCB concentrations in fish and shellfish, and that concentrations of the remaining six COCs identified for this exposure pathway will also be reduced to acceptable levels for other receptors.

The potential for exposure of prey to COCs occurs primarily within the biologically active zone (upper 10 cm of sediment). Deeper sediments, if left undisturbed, contribute negligibly to the risks addressed by this RAO. Deeper sediments in areas subject to disturbance (e.g., erosion, propeller scour) that contain chemicals at concentrations above action levels may warrant response actions to satisfy RAO 4.

Reductions in the chemical concentrations in sediment achieved through remediation should also reduce the concentrations of those chemicals in surface water, thereby contributing to a reduction of their concentrations in the tissue of fish and shellfish (including prey species). The relationships between sediment, surface water, and tissue concentrations are complex, and will be assessed through long-term monitoring following completion of the remedial actions.

4.1.2 Role of Source Control

Control of on-going sources of contamination to the LDW is an implicit requirement for achieving RAOs for the site. Active sediment remediation in the absence of adequate source control could lead to sediment recontamination and continuing impairment of

surface water quality. An adequate level of source control is an assumed element of remedial design and implementation planning for the remedial alternatives to preclude unacceptable levels of recontamination during or following the remediation of contaminated sediment areas.

The primary known or potential continuing sources or affected media within the LDW include:

- Direct discharge of stormwater and combined sewer overflows
- Erosion of contaminated bank and shoreline soil
- Legacy waste, debris, and treated wood piles present in the sediment and banks
- Surface water runoff that contacts contaminated soil
- General marine and industrial uses of the waterway
- Direct discharge of wastewater from industrial/commercial facilities
- Atmospheric deposition from uncontrolled or partially controlled air emissions (e.g., from motor vehicles, the burning of wood and fossil fuels, and volatilization of chemicals)[2]
- Illicit discharges and spills
- Upstream contributions
- Groundwater discharges.

Understanding how each of these potential sources and pathways may impact an individual sediment remediation project area is a complex undertaking and beyond the scope of this FS. It is anticipated that the remedial design effort for each cleanup project or component of the overall site remedy will consider whether additional localized source control actions beyond those conducted up to that point are needed before the in-water work can be implemented. This will require a recontamination/source control assessment study that varies in scope and magnitude depending on the specific project area. This element of the remedial alternatives is discussed at greater length in the context of active remediation and monitoring (see Section 8).

Currently, source identification and control efforts in the LDW watershed are supported by a cooperative inter-agency program with the goal of identifying sources of chemicals to the LDW and promoting their control. Ecology, as the lead source control agency, formed the LDW Source Control Work Group (SCWG) in 2002. The SCWG is composed primarily of public agencies responsible for source control,

[2] PCBs are detected in the environment far from areas where they were originally used as a result of global mass transport.

including Ecology, the City of Seattle, the City of Tukwila, King County, the Port of Seattle, and EPA. Individually, these agencies are able to use their regulatory authority to promote source control in the LDW via source tracing sampling, stormwater, and combined sewer overflow (CSO) programs, permits, hazardous waste management and pollution prevention programs, inspection and maintenance programs, water quality compliance and spill response programs, and environmental and pathway assessments.

In 2004, Ecology issued the final *Lower Duwamish Waterway Source Control Strategy* (Ecology 2004). This strategy is consistent with sediment source control protocols described in EPA guidance (2002b) and the SMS (Ecology 1995). The strategy describes the process and timing for implementing source control and the roles of various regulatory agencies responsible for conducting source control (e.g., SCWG) and enforcement. The strategy also provides for tracking and documentation of source control progress in the LDW.

The focus of Ecology's source control strategy for the LDW is to identify and manage sources of chemicals to waterway sediments in coordination with sediment cleanups and to prevent post-remediation recontamination to levels exceeding cleanup goals established in the final cleanup decision document (Ecology 2004a). Specific goals for the source control program are:

- Minimize the potential for chemicals in sediments to exceed the SMS criteria (as stated in WAC 173-204) and the LDW sediment cleanup levels (to be established in the final cleanup decision document).
- Achieve adequate source control that will allow sediment cleanups to begin.
- Increase opportunities for natural recovery of sediments.
- Support long-term suitability and success of current and future habitat restoration opportunities.

Source control started in 2003 and is an on-going, iterative process that continually produces new information. During remedial design, the work accomplished by Ecology and other public entities will serve as a foundation for any additional source control investigations and actions necessary before implementing various components of the sediment cleanup.

4.2 Applicable or Relevant and Appropriate Requirements (ARARs)

CERCLA Section 121 requires remedial actions to achieve ARARs, which are defined as any legally applicable or relevant and appropriate standard, requirement, criterion, or limitation that has been promulgated under federal or state environmental laws. Similarly, MTCA requires that all cleanup actions comply with applicable state and federal laws (WAC 173-340-360(2)). MTCA defines applicable state and federal laws to include "legally applicable requirements" and "relevant and appropriate

requirements." Given the similarities in language between CERCLA and MTCA on this specific remedy compliance requirement, the FS uses the term ARARs to identify requirements that will enable compliance with both statutes. This subsection identifies ARARs for cleanup of the LDW. Section 9 of this document evaluates whether the remedial alternatives developed for cleanup of the LDW comply with these ARARs.

According to the National Contingency Plan (40 CFR 300.5), applicable requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance found at a CERCLA site. A requirement may not be applicable, but nevertheless could be relevant and appropriate. Relevant and appropriate requirements address problems or situations sufficiently similar to those encountered at CERCLA and MTCA sites that their use is well-suited to the particular site.

Washington State has promulgated environmental regulations to implement several major federal programs; in cases where the state requirement is more stringent than the federal requirement, the state requirement is the ARAR. Because this FS is being conducted under a joint CERCLA and MTCA order, applicable or relevant and appropriate provisions of MTCA and the SMS are considered to be ARARs for CERCLA, as well as governing requirements under MTCA.

Table 4-1 lists and summarizes ARARs for the LDW site. Some ARARs prescribe numerical standards applicable to sediment, surface water, fish tissue, and groundwater. Other ARARs place requirements or limitations on actions that may be undertaken as part of a cleanup remedy. Table 4-2 lists other legal requirements that are not considered to be ARARs by EPA. These requirements will not bear on selection of an appropriate remedy, but will nevertheless need to be considered during design and implementation.[3] For example, the Occupational Safety and Health Act is not listed as an ARAR because it must be adhered to under all circumstances, regardless of whether the activity is related to a CERCLA or MTCA action. Like CERCLA and MTCA, these are statutory requirements that must be met.

Some ARARs contain numerical values or methods for developing such values. These ARARs are used to establish the acceptable amount or concentration of a chemical that may remain in or be discharged to the environment and are important in the context of effectiveness and performance expectations for the remedial alternatives. The rest of this subsection focuses on these ARARs.

[3] Appendix C of the *Feasibility Study Work Plan* (RETEC 2007) contains an analysis of requirements that were identified in the Phase 1 RI (Windward 2003a) as potential ARARs and were determined to be neither applicable nor relevant and appropriate for the LDW.

There are no promulgated federal ARARs providing numerical standards for chemicals in sediment. However, Washington State has promulgated numerical standards in the SMS and these regulations are cross-referenced in MTCA. Under CERCLA, the SMS criteria are considered ARARs and are promulgated standards for the LDW under MTCA.

Surface water (i.e., the water column) is also a medium of concern in the LDW. Therefore, federal water quality criteria (WQC) developed to protect ecological receptors and human consumers of fish and shellfish are relevant and appropriate requirements or minimum levels or standards for remedial action pursuant to CERCLA Section 121 (d)(2)(A)(ii) and RCW 70.105D.030(2)(e). Under CERCLA and MTCA, state water quality standards (WQS) approved by EPA are generally applicable requirements under the Clean Water Act (CWA). National recommended federal WQC established pursuant to Section 304(a)(1) of the CWA are compiled and presented on the EPA website at http://www.epa.gov/waterscience/criteria/wqctable/. Although these criteria are advisory only for CWA purposes, the last sentence of CERCLA Section 121(d)(2)(A)(ii) makes them minimum cleanup levels or standards for the site. Consequently, the more stringent of the federal WQC and the state WQS approved by EPA for CWA purposes are the cleanup levels or standards for the site. Washington State WQS for the protection of aquatic life are found at WAC 173-201A-240. The numerical criteria for aquatic life meet the federal requirements of Section 303(c)(2)(B) of the CWA, are at least as stringent as the federal WQC, and have been approved by EPA as applicable CWA criteria in accordance with 40 CFR 131.21.[4] The numerical water quality criteria for human health are listed in EPA's regulations at 40 CFR 131.36(d)(14) and cross-referenced in Washington's regulations at WAC 173-201A-240(5). Specific considerations for compliance with federal and state aquatic life WQC and human health WQC are discussed in Section 4.2.2 of the RI (Windward 2010).

4.3 Process for Development of Preliminary Remediation Goals

PRGs are the chemical endpoint concentrations associated with each RAO that are believed to be sufficient to protect human health and the environment based on available site information (EPA 1997b). The PRGs are used in the FS to guide the geographic definition of areas of potential concern (AOPCs) and the evaluation of proposed sediment remedial alternatives. PRGs, as defined in the FS, are not the final CERCLA/MTCA cleanup levels and standards. EPA and Ecology will ultimately define the CERCLA/MTCA cleanup levels and standards in the final cleanup decision document.

[4] Except for the Washington State copper criteria, which were amended by Washington in 2007 (72 Fed. Reg. 37,109, 37,115 [July 9, 2007]) and approved by EPA (40 CFR 131.36). Federal WQC are also presented in the tables in Section 4.2.2 of the RI (Windward 2010), if their values are lower than the State WQC.

PRGs are developed in this subsection for each risk-driver chemical, and are expressed as sediment concentrations that are intended to achieve the corresponding RAO. PRGs are based on consideration of the following factors:

- ARARs and SMS criteria
- RBTCs based on the human health and ecological risk assessments
- Background concentrations if protective RBTCs are below background concentrations
- Analytical practical quantitation limits (PQLs) if protective RBTCs are below concentrations that can be quantified by chemical analysis.

This section presents the numerical criteria in these categories to enable a comprehensive analysis and identification of PRGs. The pertinent information is then compiled and numerical PRGs are identified for each risk driver and each RAO.

4.3.1 Role of ARARs

The SMS (WAC 173-204) are the only CERCLA ARAR that influences the selection of sediment PRGs in the LDW.[5] The SMS contain numerical sediment criteria pertinent to selecting PRGs that protect the benthic invertebrate community (and hence the SMS criteria apply to RAO 3).

The SMS chemical and biological criteria are applied on a point basis to the biologically active zone of the sediments (i.e., upper 10 cm). Under the SMS, sediment cleanup standards are established on a site-specific basis within an allowable range of contamination. The SQS and minimum cleanup level (MCUL) define this range. For the purposes of developing PRGs and analyzing alternatives, the lower end of this range (i.e., the SQS) is used in this FS.[6] However, the final cleanup level will be set by EPA and Ecology in consideration of the net environmental effects, cost, and engineering feasibility of different cleanup alternatives (WAC 173-204-570). The SMS also require that chemical concentrations (and toxicity) be below the cleanup standards within a reasonable time frame.

As described in Section 4.2, surface water quality criteria are ARARs for the site. This is because the LDW site includes the water column, and the water column is affected by the sediment. However, other factors that also affect water quality and the water column cannot be directly remediated. Thus, while surface water is included as a medium of concern to be addressed by RAOs 1 and 4, surface water quality ARARs are not appropriate for use as numerical PRGs.

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[5] The SMS are ARARs under CERCLA and promulgated numerical standards under MTCA.

[6] Co-located sediment toxicity test results that "pass," (i.e., indicate no toxicity) override exceedances of the SMS numerical chemical criteria for determining compliance with RAO 3.

Significant water quality improvements are anticipated as a result of sediment remediation and source control. Water quality monitoring will be part of the selected sediment cleanup remedy to enable an understanding of the efficacy of sediment remediation and source control efforts, and to make final assessments of compliance with ARARs. The remedial alternatives developed and evaluated in this FS may not comply with all surface water quality standards, in which case waiver of the surface water quality ARARs would be required.

4.3.2 Role of RBTCs

The RI developed site-specific sediment RBTCs (summarized in Section 3.3 of this document) for each of the risk-driver chemicals. RBTCs for human health were established based on risks associated with the direct sediment contact RME scenarios, and seafood consumption RME scenarios. RBTCs for ecological receptors were established based on prey consumption for river otters. For the benthic invertebrate community, RBTCs were set equal to the SQS and CSL.

Total PCBs, cPAHs, arsenic, and dioxins/furans are the risk drivers for the human seafood consumption pathway. Sediment RBTCs for total PCBs were calculated for the 1×10^{-4} target excess cancer risk level and are applied as site-wide average concentrations.[7] As discussed in Section 3.3, sediment RBTCs based on seafood consumption pathway were not calculated for arsenic, cPAHs, or dioxins/furans

Total PCBs, cPAHs, arsenic, and dioxins/furans are also the human health risk drivers for the direct sediment contact pathway. Sediment RBTCs for these chemicals were presented in Table 3-7 for each of the three direct sediment contact RME scenarios (i.e., netfishing, tribal clamming, and beach play). These sediment RBTCs are average concentrations applied to the spatial area over which exposure is expected.

Finally, a total PCB sediment RBTC was calculated to protect wildlife. Specifically, the RBTC protects river otters based on the consumption of prey species and is applied as a site-wide average concentration.

4.3.3 Role of Background Concentrations

Both CERCLA and MTCA consider background chemical concentrations when formulating PRGs and cleanup levels. Both acts recognize that setting numerical cleanup goals at levels below background is impractical. MTCA (WAC 173-340-200) defines natural background as the concentrations of hazardous substances that are consistently present in an environment that have not been influenced by localized human activities. Thus, under MTCA, a natural background concentration can be defined for man-made compounds even though they may not occur naturally (e.g., PCBs deposited by atmospheric deposition into an alpine lake). According to CERCLA

[7] Sediment RBTCs for total PCBs could not be calculated for lower risk levels because of contributions from water, even at concentrations similar to those in upstream water (i.e., 0.3 ng/L) (Table 3-7).

guidance, natural background refers to substances that are naturally present in the environment in forms that have not been influenced by human activity (e.g., naturally occurring metals).

MTCA cleanup levels cannot be set at concentrations below natural background (WAC 173-340-705(6)). Similarly, CERCLA guidance states that natural background concentrations establish a limit below which a lower cleanup level cannot be achieved (EPA 2005).

Both regulatory programs also recognize that natural and man-made chemical concentrations can occur at a site in excess of natural background concentrations, not as a result of local site-related releases but caused by human activities in areas remote from the site and natural processes that transport the chemicals to the site (e.g., atmospheric uptake, transport, and deposition). CERCLA defines "anthropogenic background" as natural and human-made substances present in the environment as a result of human activities, but not related to a specific release from the CERCLA site undergoing investigation and cleanup (EPA 2002a). MTCA defines the term "area background" to represent media-specific concentrations that are consistently present in the environment in the vicinity of a site that are attributable to human activities unrelated to specific releases from the site. Application of these two background concepts to cleanup actions differs between the two programs. CERCLA generally does not require cleanup to concentrations below anthropogenic background concentrations. MTCA defines natural background as the cleanup standard required for final remedies when natural background concentrations are higher than the calculated risk-based cleanup levels. Thus, under MTCA, a remedy that cannot achieve natural background concentrations under these conditions is not considered final.

EPA and Ecology have determined that MTCA requirements apply equally to CERCLA requirements under the Administrative Order on Consent and that MTCA requirements are CERCLA ARARs. Therefore, PRGs are to be set at natural background concentrations for those chemicals with risk-based concentrations below natural background concentrations. EPA and Ecology recognize that natural background concentrations are unlikely to be achieved at the site and that long-term sediment concentrations will be governed primarily by sediment input from the Green River and other inputs to the site following source control actions (see Section 5). Long-term monitoring will reveal what the technically practicable lower limits are for site concentrations. When these lower limits are reached, as demonstrated by monitoring data, a technical impracticability (TI) waiver of the MTCA ARAR could be used under CERCLA to provide closure. The TI waiver addresses the gap between the technically practicable limit and natural background concentrations. Under MTCA, institutional controls that address remaining human health risks may allow a decision for a final cleanup.

4.3.4 Natural Background in Sediment

This section presents estimates of natural background concentrations for total PCBs, arsenic, cPAHs, and dioxins/furans in sediment.[8] To characterize natural background, marine sediment data were compiled from areas within Puget Sound that have not been influenced by localized human activities. These data represent non-urban, non-localized concentrations that exist as a result of natural processes and/or the large-scale distribution of chemicals from anthropogenic sources.

The Dredged Material Management Program (DMMP) (comprised of the U.S. Army Corps of Engineers [USACE], EPA, Ecology, and the Washington State Department of Natural Resources [DNR]) collected sediment data throughout Puget Sound in the summer of 2008 and documented the results in a study called *Final Report: Puget Sound Sediment PCB and Dioxin 2008 Survey, OSV BOLD SURVEY REPORT* (EPA OSV *Bold* Survey; EPA 2008). EPA has determined that data from the EPA OSV *Bold* Survey will be used in this FS for natural background concentrations. Data were collected from 70 sampling locations throughout Puget Sound, as well as from the area around the San Juan Islands and the Strait of Juan de Fuca. Locations for each target sampling station are displayed in Figure 4-1. A subset of these sample locations (N = 20) were located within four reference areas (Carr Inlet, Samish Bay, Holmes Harbor, and Dabob Bay) established by Ecology. In each of these reference areas, five target sediment sampling locations were located based on a stratified random sampling design. The remaining 50 sample locations were spread throughout Puget Sound and the straits of Georgia and Juan de Fuca and were intended to represent areas outside the influence of urban bays and known point sources. At five stations, a duplicate sample (or field split) was collected for quality assurance (QA) purposes. Samples were analyzed for the full suite of DMMP chemicals, including semi-volatile organic compounds, PAHs, PCB Aroclors and PCB congeners, organochlorine pesticides, and trace metals, as well as for sediment conventionals (e.g., total organic carbon [TOC], grain size, percent solids). Summary statistics were then calculated for the EPA OSV *Bold* Survey data for each of the four human health risk drivers using the statistical software ProUCL version 4.00.04.

4.3.4.1 Natural Background for Arsenic in Sediment

Arsenic was detected in all of the samples from the EPA OSV *Bold* Survey (Table 4-3). Concentrations ranged from 1.1 to 21 mg/kg dw, with a mean concentration of 6.5 mg/kg dw, a 90th percentile of 11 mg/kg dw[9], and a 95% upper confidence limit on the mean (UCL95) of 7.3 mg/kg dw. Using UCL95 statistic, the background concentration for arsenic would be 7 mg/kg dw.

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[8] EPA and Ecology will set natural background concentrations and remediation goals in the final cleanup decision document.

[9] Using MTCAStat software, the 90th percentile for arsenic is 11.9 mg/kg dw (assuming 70 samples, averaged duplicates, and log-normal distribution).

4.3.4.2 Natural Background for Total PCBs in Sediment

Total PCBs as Aroclors were below reporting limits in the majority of sediment samples from the EPA OSV *Bold* Survey (Table 4-3). The PCB congener method, with its lower reporting limits, produced a detection frequency of 100%, based on quantifying at least one PCB congener in each sample. Total PCBs in each sample were calculated by summing the concentrations of all detected PCB congeners, consistent with the protocol in the SMS for reporting total PCBs by summing the concentrations of all detected PCB Aroclors. Using the congener results, total PCB concentrations ranged from 0.01 to 10.6 µg/kg dw, with a mean of 1.2 µg/kg dw, a 90th percentile of 2.7 µg/kg dw, and a UCL95 of 1.5 µg/kg dw. Using the UCL95 statistic, the background concentration for total PCBs would be 2 µg/kg dw.

4.3.4.3 Natural Background for cPAHs in Sediment

The detection frequency for cPAHs in the EPA OSV *Bold* Survey was 87%, based on quantifying at least one cPAH compound in each sample (Table 4-3). Total cPAHs in each sample were calculated by summing the concentrations of all detected cPAH compounds multiplied by their respective potency equivalency factors (PEFs), along with half the reporting limits of any undetected cPAH compounds multiplied by their respective PEFs. Concentrations ranged from 1.3 to 57.7 µg TEQ/kg dw, with a mean concentration of 7.1 µg TEQ/kg dw, a 90th percentile of 14.7 µg TEQ/kg dw, and a UCL95 of 8.9 µg TEQ/kg dw. Using the UCL95 statistic, the background concentration for cPAHs would be 9 µg TEQ/kg dw.

4.3.4.4 Natural Background for Dioxins/Furans in Sediment

The detection frequency for dioxins/furans in the EPA OSV *Bold* Survey was 100% based on quantifying at least one congener in each sample. The total TEQ of dioxins/furans (relative to that of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin) in each sample was calculated by summing the concentrations of certain detected polychlorinated dibenzo-*p*-dioxin or furan congeners multiplied by their respective toxic equivalency factors (TEFs), along with half the reporting limits of undetected polychlorinated dibenzo-*p*-dioxin or furan congeners multiplied by their respective TEFs. Concentrations ranged from 0.2 to 11.6 ng TEQ/kg dw, with a mean of 1.4 ng TEQ/kg dw (Table 4-3), a 90th percentile of 2.2 ng TEQ/kg dw, and a UCL95 of 1.6 ng TEQ/kg dw. Using the UCL95 statistic, the background concentration for dioxins/furans would be 2 ng TEQ/kg dw. These data are summarized in Table 4-3.

4.3.5 Role of Practical Quantitation Limits

Both CERCLA and MTCA allow consideration of PQLs when formulating PRGs to address circumstances in which a concentration determined to be protective cannot be reliably detected using state-of-the-art analytical instruments and methods. For example, if an RBTC is below the concentration at which a chemical can be reliably quantified, then the PRG for that chemical may default to the analytical PQL.

MTCA defines the PQL 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).

In simpler terms, the PQL is the minimum concentration of a chemical that can be reported with a high degree of certainty.

Tables 4-4 and 4-5 list the risk-driver chemical-specific PQLs developed for the RI sediment sampling programs and documented in the associated quality assurance project plans for the risk drivers. These PQLs represent the lowest values that can be reliably quantified when the sample matrix (in this case, sediment) is free of interfering compounds that can reduce sensitivity and raise reporting limits. Also, these tables present the range of actual sample PQLs reported by the laboratories for the data in the RI database. These results reflect the range of what the laboratories were able to achieve given the composition of and matrix complexity associated with LDW sediment samples.

Analytical quantitation limits are generally not expected to exceed RBTCs, SMS criteria concentrations, or natural background concentrations for samples of low matrix complexity. However, empirical evidence from the RI suggests that, on a case-by-case basis, matrix interferences have the potential to preclude quantification to concentrations below the PRGs (and ultimately the cleanup levels and standards) established for cleanup of LDW sediment.

4.4 Preliminary Remediation Goals

PRGs for sediment are derived from a comparison of ARARs, RBTCs, background concentrations, and PQLs. For each RAO and risk driver, the PRG is the highest value from among the applicable background concentrations or lowest RBTC.[10] PQLs were also considered and were not found to influence selection of the PRGs (i.e., all PRGs are above PQLs).The RAOs and PRGs are used in Section 6 of the FS to identify AOPCs and were considered in the selection of RALs. Section 9 compares estimated concentrations of risk drivers to PRGs as one measure of the effectiveness of the remedial alternatives.

Tables 4-4 and 4-5 summarize the analysis and selection of sediment PRGs for the risk-driver chemicals. Table 4-4 focuses on the four primary human health risk drivers and the ecological risk driver, and is subdivided to address the various spatial applications of the PRGs for each RAO. Table 4-5 contains the PRG analysis for the remaining SMS risk-driver chemicals (i.e., the risk drivers for RAO 3). PRGs were not developed for the

[10] SQS and CSL values for the 41 SMS risk-driver chemicals are the RBTCs for protection of benthic organisms. Sediment RBTCs were calculated (see Section 3) for protection of ecological receptors (river otter) and humans.

other COCs identified in the RI. The potential for risk reduction for the other COCs following remedial actions is evaluated in Section 9.

The PRGs identified in Table 4-4 are derived from RBTCs, natural background, or SQS values. The PRGs in Table 4-4 are applied on either a point basis or an average basis over a given exposure area depending on the chemical, exposure pathway, and receptor of concern. PRGs for RAOs 1, 2, and 4 are applied on a site-wide average basis that requires a sediment spatially-weighted average concentration (SWAC) over the applicable exposure area be below the PRG.

For RAO 1, the numerical PRG for total PCBs is natural background because the sediment RBTCs[11] are below natural background for the RME seafood consumption scenarios. RBTCs were not derived for dioxin/furans (see Section 3.2.4), but would most likely have been below natural background levels for the RME seafood consumption scenarios. Therefore, natural background is the PRG for dioxin/furans for RAO 1. Arsenic and cPAH PRGs are undefined for the human health seafood consumption pathway (RAO 1). With regard to seafood consumption, excess cancer risks for these two risk drivers were largely attributable to the consumption of clams. There is no credible relationship, based on the site data, relating cPAH or arsenic concentrations in sediment to concentrations in clam tissue (Section 8 of the RI, Windward 2010). However, the development and evaluation of remedial alternatives in the latter sections of the FS discuss the need for future investigations of the sediment/clam tissue relationships for arsenic and cPAHs. Further, it is anticipated that the range of remedial alternatives developed around the suite of PRGs defined in Tables 4-4 and 4-5 will lead to reductions in sediment concentrations of arsenic and cPAHs (see discussion of RALs in Section 6). PRGs based on natural background are unlikely to be achieved or even closely approximated, in some cases, by any of the remedial alternatives developed in this FS. Sediment concentrations approaching site-specific anthropogenic levels are the best that can realistically and practicably be achieved in the LDW given the urban setting of the site and inputs from upstream of the site. However, EPA has determined that natural background concentrations must be used in this FS for setting background-based PRGs to ensure compliance with MTCA. Section 5 presents datasets for upstream and lateral chemical inputs to the LDW. These datasets, coupled with modeling, provide a foundation for evaluating anthropogenic-influenced and therefore technically achievable outcomes of the remedial alternatives.

For RAO 2, PRGs are based on the sediment RBTCs (10^{-6} or natural background, whichever is higher) developed for three exposure scenarios: netfishing, tribal

[11] Sediment RBTCs were calculated only for the 1×10^{-4} risk threshold. The contribution of PCBs in water alone (even at concentrations similar to those in upstream water) was high enough to result in seafood consumption risks for Adult and Child Tribal RME and Asian and Pacific Islander RME scenarios exceeding the 1×10^{-6} and 1×10^{-5} thresholds even in the absence of any contribution from sediment (Table 3-7).

clamming, and beach play. PRGs are applied a spatially-weighted average basis over a given exposure area (e.g., site-wide for netfishing).

For RAO 3, the SMS chemical criteria apply on a point basis (Table 4-5). However, where co-located toxicity test data are available, a sediment toxicity "pass" overrides a sediment concentration that exceeds the chemical criteria for RAO 3. Under the SMS, sediment cleanup standards are established on a site-specific basis within an allowable range of contamination. The SQS and MCUL define this range. For the purposes of deriving PRGs and analyzing alternatives, the lower of the two chemical-specific SMS criteria (i.e., SQS) have been selected as the concentration-based PRG for that chemical. However, the final cleanup standard will be set in consideration of the CERCLA and MTCA evaluation criteria and the analogous SMS considerations of net environmental effects, cost, and engineering feasibility of different cleanup alternatives (WAC 173-204-570(4)).

For RAO 4, the PRG for seafood consumption by ecological receptors is set to the sediment RBTC for river otter (hazard quotient less than 1).

Table 4-1 ARARs for the Lower Duwamish Waterway

Topic	Standard or Requirement	Regulatory Citation		Comment
		Federal	State	
Sediment Quality	Sediment quality standards; cleanup screening levels		Sediment Management Standards (WAC 173-204)	The SMS is a statutory requirement under MTCA and an ARAR under CERCLA. Numerical standards for the protection of benthic marine invertebrates.
Fish Tissue Quality	Concentrations of chemicals in fish tissues	Food and Drug Administration Maximum Concentrations of Contaminants in Fish Tissue (49 CFR 10372-10442)		The Washington State Department of Health assesses the need for fish consumption advisories.
Surface Water Quality	Surface Water Quality Standards	Ambient Water Quality Criteria established under Section 304(a) of the Clean Water Act (33 USC 1251 et seq.)	Surface Water Quality Standards (RCW 90-48; WAC 173-201A)	State surface water quality standards apply where the State has adopted, and EPA has approved, Water Quality Standards. Federal recommended Water Quality Criteria established under Section 304(a) of the Clean Water Act that are more stringent than State criteria and that are relevant and appropriate also apply. Both chronic and acute standards and marine and freshwater are used as appropriate.
Land Disposal of Waste	Disposal of materials containing PCBs	Toxic Substances Control Act (15 USC 2605; 40 CFR Part 761)		
	Hazardous waste	Resource Conservation and Recovery Act Land Disposal Restrictions (42 USC 7401-7642; 40 CFR 268)	Dangerous Waste Regulations Land Disposal Restrictions (RCW 70.105; WAC 173-303, 140-141)	
Waste Treatment Storage and Disposal		Resource Conservation and Recovery Act (42 USC 7401-7642;40 CFR 264 and 265)	Dangerous Waste Regulations (RCW 70.105; WAC 173-303)	

Table 4-1 ARARs for the Lower Duwamish Waterway

Topic	Standard or Requirement	Regulatory Citation		Comment
		Federal	State	
Noise	Maximum noise levels		Noise Control Act of 1974 (RCW 80.107; WAC 173-60)	
Groundwater		Safe Drinking Water Act MCLs and non-zero MCLGs (40 CFR 141)	RCW 43.20A.165 and WAC 173-290-310	For on-site potable water, if any.
Dredge/Fill and Other In-water Construction Work	Discharge of dredged/fill material into navigable waters or wetlands	Clean Water Act (33 USC 401 et seq.; 33 USC 141; 33 USC 1251-1316; 40 CFR 230, 231, 404; 33 CFR 320-330) Rivers and Harbors Act (33 USC 401 et seq.	Hydraulic Code Rules (RCW 75.20; WAC 220-110)	For in-water dredging, filling or other construction.
	Open-water disposal of dredged sediments	Marine Protection, Research and Sanctuaries Act (33 USC 1401-1445) 40 CFR 227	DMMP (RCW 79.90; WAC 332-30-166)	
Solid Waste Disposal	Requirements for solid waste handling management and disposal	Solid Waste Disposal Act (42 USC 215103259-6901-6991; 40 CFR 257-258)	Solid Waste Handling Standards (RCW 70.95; WAC 173-350)	
Discharge to Surface Water	Point source standards for new discharges to surface water	National Pollutant Discharge Elimination System (40 CFR 122, 125)	Discharge Permit Program (RCW 90.48; WAC 173-216, 222)	
Shoreline	Construction and development		Shoreline Management Act (RCW 90.58; WAC 173-16); King County and City of Seattle Shoreline Master Plans (KCC Title 25; SMC 23.60); City of Tukwila Shoreline Master Program (TMC 18.44)	For construction within 200 feet of the shoreline.

Table 4-1 ARARs for the Lower Duwamish Waterway

Topic	Standard or Requirement	Regulatory Citation		Comment
		Federal	State	
Floodplain Protection	Avoid adverse impacts, minimize potential harm,	Executive Order 11988, Protection of floodplains (40 CFR 6, Appendix A); FEMA National Flood Insurance Program Regulations (44 CFR 60.3Ld)(3)).		For in-water construction activities, including any dredge or fill operations. Includes local ordinances: KCC Title 9 and SMC 25.09.
Critical (or Sensitive) Area ARAR			Growth Management Act (RCW 36.70a); King County Critical Area Ordinance (KCC Title 21A.24); City of Seattle (SMC 25.09); City of Tukwila Sensitive Area Ordinance (TMC 18.45)	
Habitat for Fish, Plants, or Birds ARAR	Evaluate and mitigate habitat impacts	Clean Water Act (Section 404 (b)(1)); U.S. Fish and Wildlife Mitigation Policy (44 CFR 7644); U.S. Fish and Wildlife Coordination Act (16 USC 661 et seq.); Migratory Bird Treaty Act (16 USC 703-712)		
Pretreatment Standards	National Pretreatment Standards		40 CFR Part 403; Metro District Wastewater Discharge Ordinance (KCC) To be considered (as is local requirement)	
Environmental Impact Review	State Environmental Policy Act		State Environmental Policy Act RCW 43.21C; WAC 197-11-790)	Applicable to MTCA cleanups. Because the LDW is under a joint EPA/Ecology Order, Ecology has determined that CERCLA requirements are the functional equivalent of NEPA, and SEPA

Notes:

ARAR = applicable or relevant and appropriate requirement; CERCLA = Comprehensive, Environmental Response, Compensation, and Liability Act; CFR = Code of Federal Regulations; DMMP = Dredged Material Management Program; EPA = U.S. Environmental Protection Agency; FEMA = Federal Emergency Management Act; KCC = King County Code; MCL = maximum contaminant level; MCLG = maximum contaminant level goal; MTCA = Model Toxics Control Act; NEPA = National Environmental Policy Act; PCB = polychlorinated biphenyl; RCW = Revised Code of Washington; SEPA = State Environmental Policy Act; SMC = Seattle Municipal Code; SMS = Sediment Management Standards; TMC = Tukwila Municipal Code; USC = United States Code; WAC = Washington Administrative Code

Table 4-2 Other Legal Requirements for the Lower Duwamish Waterway

Topic	Standard or Requirement	Regulatory Citation		Comment
		Federal	State	
Native American Graves and Sacred Sites		Native American Graves Protection and Repatriation Act (25 USC. 3001 et seq.; 43 CFR Pt. 10) and American Indian Religious Freedom Act (42 USC 1996 et seq.)		
Critical Habitat for Endangered Species	Conserve endangered or threatened species, consult with species listing agencies	Endangered Species Act of 1973 (16 USC 1531 et seq.; 50 CFR 200, 402); Magnuson-Stevens Fishery Conservation and Management Act (16 USC 1801-1884)	Endangered, threatened, and sensitive wildlife species classification (WAC 232-12-297)	Consult, and obtain Biological Opinions.
Historic Sites or Structures	Requirement to avoid, minimize, or mitigate impacts to historic sites or structures	National Historic Preservation Act (16 USC 470f; 36 CFR Parts 60, 63, and 800)		Considered if implementation of the selected remedy involves removal of historic sites or structures.
Occupational Health and Safety	Requirements to provide for worker health and safety	Occupational Safety and Health Act (29 USC; 29 CFR)	Washington Industrial Safety and Health Act (RCW 49.17; WAC 296)	

Notes:

CFR = Code of Federal Regulations; RCW = Revised Code of Washington; USC = United States Code; WAC = Washington Administrative Code

Table 4-3 Summary of Arsenic, Total PCBs, cPAHs and Dioxin/Furan Dataset for Natural Background

Analyte	Detection Frequency	Concentration						UCL Type
		Minimum	Maximum	Mean	Median	90th Percentile	95% UCL	
Arsenic (mg/kg dw)	70/70	1.1	21	6.5	5.9	11.0[a]	7.3	95% Approximate Gamma UCL
Total PCBs as Aroclors (µg/kg dw)	6/70	2.1	31	11	4.4	8.0	6.5	95% KM (Percentile Bootstrap) UCL
Total PCBs as Congeners (µg/kg dw)	70/70	0.01	10.6	1.2	0.6	2.7	1.5	95% Approximate Gamma UCL
cPAHs (µg TEQ/kg dw)	61/70	1.3	57.7	7.1	4.5	14.7	8.9	95% KM (BCA) UCL
Dioxin/Furans (ng TEQ/kg dw)	70/70	0.2	11.6	1.4	1.0	2.2	1.6	95% H-UCL

Notes:

1. Dataset collected throughout Puget Sound by EPA in 2008 and referred to as the EPA OSV *Bold* Survey.
2. Summary statistics and UCL were calculated using ProUCL 4.00.04 statistical software.
3. Total PCBs were calculated by summing the concentrations of detected PCB Aroclors or detected PCB congeners. In cases where no PCB Aroclors were detected, the highest reporting limit for an individual PCB Arcolor was used as the value of total PCBs. Total cPAHs were calculated by summing the concentrations of all detected cPAH compounds multiplied by their respective potency equivalency factors (PEFs), along with half the reporting limits of any undetected cPAH compounds multiplied by their respective PEFs.
4. The total toxic equivalent (TEQ) of dioxins/furans (relative to that of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin) was calculated by summing the concentrations of detected polychlorinated dibenzo-*p*-dioxin or furan congeners multiplied by their respective toxic equivalency factors (TEFs), along with half the reporting limits of undetected polychlorinated dibenzo-*p*-dioxin or furan congeners multiplied by their respective TEFs.

a Using MTCAStat software, the 90th percentile for arsenic is 11.9 mg/kg dw (assuming 70 samples, averaged duplicates, and log-normal distribution).

BCA = bias-corrected accelerated; cPAH = carcinogenic polycyclic aromatic hydrocarbon; dw = dry weight; H-UCL = UCL based on Land's H-statistic; kg = kilogram; KM = Kaplan Meier method for calculating a UCL; µg = micrograms; mg = milligram; ng = nanogram; PCB = polychlorinated biphenyl; PEF = potency equivalency factor; TEF = toxic equivalent factor; TEQ = toxic equivalent; UCL = upper confidence limit on the mean

Table 4-4 Preliminary Remediation Goals for Total PCBs, Arsenic, cPAH TEQ, and Dioxin/ Furan TEQ in Lower Duwamish Waterway Sediment

Analyte	Practical Quantitation Limits			Natural Background[b]	Risk-Based Threshold Concentrations					Preliminary Remediation Goals			
	EPA Method	RI QAPP RLs[a]	Range of RLs from undetected values		Spatial Scale of Exposure[c]	RAO 1: Human Seafood Consumption	RAO 2: Human Direct Contact	RAO 3: Benthic Organisms	RAO 4: Ecological (River Otter)	Value	Basis	Statistical Metric for Application	Spatial Scale of PRG Application
Total PCBs (µg/kg dw)	8082	4[d]	0.56 – 50[d]	2, 3	Site-wide	nc (19 - 320)[e]	1,300	n/a	(128 - 159)[f]	2 (RAO 1)/1,300 (RAO 2)	bg/RBTC	SWAC	Site-wide
					Tribal Clamming	n/a	500	n/a	n/a	500	RBTC	SWAC	Clamming Areas
					Beach Play	n/a	1,700	n/a	n/a	1,700	RBTC	SWAC	Individual Beaches
					Point	n/a	n/a	12/65[g]	n/a	12 (mg/kg oc)	RBTC (SMS)	Point Concentration or Toxicity Test Pass	Point
Arsenic (mg/kg dw)	6010B	5	3.1 – 31	7, 11[h]	Site-wide	n/c[i]	3.7	n/a	n/a	7[i] (RAO 2)	bg	SWAC	Site-wide
					Tribal Clamming	n/a	1.3	n/a	n/a	7	bg	SWAC	Clamming Areas
					Beach Play	n/a	2.8	n/a	n/a	7	bg	SWAC	Individual Beaches
					Point	n/a	n/a	57/93[g]	n/a	57	RBTC (SMS)	Point Concentration or Toxicity Test Pass	Point
cPAH (µg TEQ/kg dw)	8270D	6.3 – 20[j]	9.0 – 130[j]	9, 15	Site-wide	n/c[i]	380	n/a	n/a	380[i] (RAO 2)	RBTC	SWAC	Site-wide
					Tribal Clamming	n/a	150	n/a	n/a	150	RBTC	SWAC	Clamming Areas
					Beach Play	n/a	90	n/a	n/a	90	RBTC	SWAC	Individual Beaches
					Point	n/a	n/a	n/a[k]	n/a	n/a	n/a	n/a	n/a
Dioxins/Furans (ng TEQ/kg dw)	1613B	1 – 10[l]	0.12 – 7.7[l]	2, 2	Site-wide	nc (bg)	37	n/a	n/a	2 (RAO 1) 37 (RAO 2)	bg/RBTC	SWAC	Site-wide
					Tribal Clamming	n/a	13	n/a	n/a	13	RBTC	SWAC	Clamming Areas
					Beach Play	n/a	28	n/a	n/a	28	RBTC	SWAC	Individual Beaches
					Point	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Notes:

a Reporting limits from Table A-1, Round 3 Surface Sediment QAPP Addendum (Windward 2006) in dry weight units on untransformed data.

b Two values are shown for natural background for each risk driver (x, x): the first is the UCL95 value and the second is the 90th percentile, both calculated from the EPA OSV *Bold* Survey dataset using ProUCL.

c The spatial scale of site-wide exposure is RAO-specific: (seafood consumption for RAO 1 and RAO 4; netfishing for RAO 2)

d PCB RLs reported in Table A-1, Round 3 Surface Sediment QAPP Addendum (Windward 2006) are for individual Aroclors. Range of RLs for undetected values were queried from the RI database and represent RLs for undetected total PCBs, not undetected values of individual Aroclors. Individual undetected Aroclors were not reported because they are not included in the calculation of total PCBs when other Aroclors are detected in the sample.

e RBTC <1 µg/kg dw at risk levels of 10^{-5} and 10^{-6}, and RBTC range of 19 to 320 µg/kg dw for the three RME seafood consumption scenarios at the 10^{-4} risk level.

f Values represent best-fit estimates for two different dietary scenarios as reported in the RI (Windward 2010).

g Total PCB concentration units are mg/kg oc and the two values are SQS/CSL. Arsenic concentration units are mg/kg dw and the two values are SQS/CSL.

h Using MTCAStat software, the 90th percentile for arsenic is 11.9 mg/kg dw (assuming 70 samples, averaged duplicates, and log-normal distribution).

i Arsenic and cPAH PRGs are undefined for the human health seafood consumption pathway (RAO 1). Seafood consumption excess cancer risks for these two risk drivers were largely attributable to the consumption of clams There is no credible relationship, based on site data, relating cPAH or arsenic concentrations in sediment to concentrations in clam tissue (Section 8 of the RI, Windward 2010). Section 8 of the FS discusses the need for future investigations of the sediment/tissue relationships for arsenic and cPAHs.

j All individual PAH compounds used in the cPAH calculation have an RL of 20 except for dibenzo[a,h]anthracene, which has an RL of 6.3. RLs reported for undetected values are based on calculated cPAHs and can be found in Table A-1, of Round 3 Surface Sediment QAPP Addendum (Windward 2006).

k Low- and high-molecular weight PAHs are addressed by the SMS. Criteria are set for both groupings and for individual PAH compounds.

l Dioxin/furan TEQ RLs are based on those for the individual congeners used in the TEQ calculation. RLs for undetected values are in Table A-1, Round 3 Surface Sediment QAPP Addendum (Windward 2006).

bg = natural background; cPAH = carcinogenic polycyclic aromatic hydrocarbon; CSL = cleanup screening level; dw = dry weight; EPA = U.S. Environmental Protection Agency; LDW = Lower Duwamish Waterway; µg/kg = micrograms per kilogram; mg/kg = milligrams per kilogram; n/a = not applicable; nc = no value calculated; nc (bg) = not calculated, RBTC value expected to be below background; ng/kg = nanograms per kilogram; oc = organic carbon; PCB = polychlorinated biphenyl; PRG = preliminary remediation goal; QAPP = quality assurance project plan; RAO = remedial action objective; RBTC = risk-based threshold concentration; RL = reporting limit; SMS = Sediment Management Standards; SQS = sediment quality standard; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent

Table 4-5 Preliminary Remediation Goals for Benthic Risk-Driver Chemicals (RAO 3) in Lower Duwamish Waterway Sediment

Analyte	Practical Quantitation Limits			Risk-Based Threshold Concentrations RAO 3: Sediment Management Standards			Preliminary Remediation Goals[c]			
	EPA Method	RI QAPP RLs[a]	Range of RLs from Undetected Values[b]	Spatial Scale of Exposure	Sediment Quality Standard (SQS)	Cleanup Screening Level (CSL)	Value	Basis	Statistical Metric	Spatial Scale of PRG Application
SMS metals	(mg/kg dw)			(mg/kg dw)			(mg/kg dw)			
Cadmium	6010B	0.2	0.4 - 2.5	Point	5.1	6.7	5.1	SQS	Point Concentration or Toxicity Test Pass	Point
Chromium	6010B	0.5	0.25 - 1		260	270	260	SQS		
Copper	6010B	0.2	0.5 - 1		390	390	390	SQS		
Lead	6010B	2	1.25 - 8		450	530	450	SQS		
Mercury	7471A	0.05	0.02-0.1		0.41	0.59	0.41	SQS		
Silver	6010B	0.3	0.046-5		6.1	6.1	6.1	SQS		
Zinc	6010B	2	0.5 - 2		410	960	410	SQS		
Dry Weight Basis SMS Organic Compounds	(µg/kg dw)			(µg/kg dw)			(µg/kg dw)			
4-methylphenol	8270D	6.7	8.6-2,000	Point	670	670	670	SQS	Point Concentration or Toxicity Test Pass	Point
2,4-dimethylphenol	8270D	6.7	6.0-2,000		29	29	29	SQS		
Benzoic acid	8270-SIM	20	13-3,000		650	650	650	SQS		
Benzyl alcohol	8270-SIM	2	9.2-690		57	73	57	SQS		
Pentachlorophenol	8270-SIM	10	7.6-4,900		360	690	360	SQS		
Phenol	8270D	20	7.3-790		420	1,200	420	SQS		
oc-normalized SMS Organics Compounds[d]	(µg/kg dw)			(mg/kg oc)			(mg/kg oc)			
Acenaphthene	8270D	20	1.8-2,000	Point	16	57	16	SQS	Point Concentration or Toxicity Test Pass	Point
Anthracene	8270D	20	13-2,000		220	1,200	220	SQS		
Benzo(a)pyrene	8270D	20	6.4-350		99	210	99	SQS		
Benz(a)anthracene	8270D	20	6.4-200		110	270	110	SQS		
Total benzofluoranthenes	8270D	20	n/a		230	450	230	SQS		
Benzo(g,h,i)perylene	8270D	20	13-2,000		31	78	31	SQS		
Chrysene	8270D	20	18-170		110	460	110	SQS		
Dibenz(a,h)anthracene	8270D	6.3	1.0-2,000		12	33	12	SQS		
Indeno(1,2,3-cd)pyrene	8270D	20	6.4-1,600		34	88	34	SQS		
Fluoranthene	8270D	20	19-340		160	1,200	160	SQS		
Fluorene	8270D	20	1.8-2,000		23	79	23	SQS		
Naphthalene	8270D	20	1.0-2,000		99	170	99	SQS		
Phenanthrene	8270D	20	18-200		100	480	100	SQS		
Pyrene	8270D	20	18-170		1,000	1,400	1,000	SQS		
HPAH	8270D	n/a	n/a		960	5,300	960	SQS		
LPAH	8270D	n/a	n/a		370	780	370	SQS		
Bis(2-ethylhexyl)phthalate	8270D	20	15-1,500		47	78	47	SQS		
Butyl benzyl phthalate	8270-SIM	2	1.8-2,000		5	64	5	SQS		
Dimethyl phthalate	8270D	20	1.8-2,000		53	53	53	SQS		
1,2-dichlorobenzene	8270-SIM	2	0.4-2,000		2.3	2.3	2.3	SQS		
1,4-dichlorobenzene	8270-SIM	2	0.2-2,000		3.1	9	3.1	SQS		
1,2,4-trichlorobenzene	8270-SIM	2	0.4-2,000		0.81	1.8	0.81	SQS		
2-methylnaphthalene	8270D	20	1.0-2,000		38	64	38	SQS		
Dibenzofuran	8270D	20	1.7-2,000		15	58	15	SQS		
Hexachlorobenzene	8081A	1.0	0.11-2,000		0.38	2.3	0.38	SQS		
n-Nitrosodiphenylamine	8270-SIM	10	1.8-2,000		11	11	11	SQS		

Notes:
1. Although both arsenic and total PCBs are SMS chemicals and risk drivers for RAO 3, they are not included in this table because they are also human health risk drivers and PRGs for all applicable RAOs appear in Table 4-4.
2. All QAPP-based RLs are below the SQS except for n-nitrosodiphenylamine.
3. Background concentrations were not calculated for the chemicals listed in this table because benthic RBTCs are not below natural background.

a Reporting limits from Table A-1, Round 3 Surface Sediment QAPP Addendum (Windward 2006) in dry weight units. Low level reporting limits for contaminants analyzed by EPA method 8279-SIM from Analytical Resources, Incorporated (www.arilabs.com).
b Range of RLs reported in Remedial Investigation dataset in instances where constituent(s) were not detected. All RLs shown in dry weight units.
c Under the SMS, sediment cleanup standards are established on a site-specific basis within an allowable range of contamination. The SQS and CSL define this range. However, the final cleanup level will be set in consideration of the net environmental effects, cost, and engineering feasibility of different cleanup alternatives (WAC 173-204-570(4)).
d The tabulated SMS values are oc-normalized and are screened against the RLs using the underlying apparent effects threshold concentrations, which are dry weight-based.

CSL = cleanup screening level; dw = dry weight; EPA = U.S. Environmental Protection Agency; HPAH = high-molecular-weight polycyclic aromatic hydrocarbon; LDW = Lower Duwamish Waterway; LPAH = low-molecular-weight polycyclic aromatic hydrocarbon; µg/kg = micrograms per kilogram; mg/kg = milligrams per kilogram; n/a = not applicable; oc = organic carbon; PQL = practical quantitation limit; PRG = preliminary remediation goal; QAPP = quality assurance project plan; RAO = remedial action objective; RL = reporting limit; SIM = selected ion monitoring; SMS = Sediment Management Standards; SQS = sediment quality standards

Notes:
1. Sediment samples collected in 2008 by EPA aboard the Ocean Survey Vessel (OSV) *BOLD*.

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Lower Duwamish Waterway
Feasibility Study
60150279-14.7

2008 Puget Sound *OSV BOLD* Survey Locations

DATE: 10/15/10 | DWRN:mvi/SEA | Revision: 0

FIGURE 4-1

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5 Evaluation of Sediment Movement and Recovery Potential

This section presents a summary of the sediment transport and related contaminant transport modeling, as well as empirical data, and develops an understanding of potential natural recovery based on the models and data. The overall modeling approaches are presented in this section. The sediment transport modeling (STM) is presented in the STM Report (QEA 2008). The sediment-related contaminant transport modeling is presented in Appendix C, Part 1. The data evaluations supporting the natural recovery analysis are presented in Appendix F.

One of the U.S. Environmental Protection Agency (EPA) guiding principles for managing sediments is to develop a conceptual site model (CSM) that considers sediment stability and evaluates the assumptions and uncertainties associated with site data and models (EPA 2005). Models are tools commonly used at sediment sites to develop a better understanding of sediment stability used to inform the CSM. The use of a model is not limited to the remedial investigation/feasibility study (RI/FS) or remedial design phase. A well-developed and calibrated model can be used to adaptively manage a site and refine site predictions to the actual response of a system after various remedial actions and source control measures have either been completed or are under way. Sediment experts and site managers all recognize the unique challenges and difficulties in understanding the natural forces and man-made events that affect sediment movement, stability, and recovery potential, and that some uncertainty will always be present. Consistent with EPA's guiding principles, the goals of the Lower Duwamish Waterway (LDW) site-wide modeling efforts for this FS are:

- Illustrate how contaminant concentrations vary spatially in the LDW via sediment movement, scour, and deposition processes and empirical trends.
- Predict contaminant fate and recovery potential for risk-driver chemicals over periods of time (e.g., 10 years) via the primary mechanisms of burial and source control.
- Compare model results to empirical measurements to verify the information is comparable. Both the modeling results and empirical data have some measure of uncertainty; therefore, multiple lines of evidence are evaluated collectively to examine and reduce these uncertainties and to refine the CSM (EPA 2005).

First, the STM results are used to look at general trends in an analysis of net sedimentation rates and to review agreement with the CSM with respect to the depositional environment. This is accomplished by comparing the estimated net sedimentation trends to empirical data. Empirical data include subsurface cores used to

determine historical trends in net sedimentation rates, surface sediment locations that have been resampled over time, and evidence of propeller scour. The STM is used to evaluate sediment movement as it relates to potential remedial areas and alternatives. This step includes an evaluation of net sedimentation rates, sediment transport into early action areas (EAAs), and other specific model runs to better understand sediment dynamics in the system.

Second, a bed composition model (BCM), which takes output directly from the physical STM and applies chemical concentrations to modeled sediment particles, was developed to predict future chemical concentrations in surface sediments, and therefore recovery potential. The BCM (and associated empirical evidence) is used in the FS to provide a predictive tool for evaluating whether the surface layer/biologically active zone will experience decreasing contaminant concentrations through natural recovery processes. The STM, BCM, and empirical evidence are used to evaluate whether the sediment bed is stable (i.e., not subject to significant scour, erosion, and transport) and whether the sedimentation rate is sufficient for burial of contaminated sediments to occur. If these conditions are met in a given location, then monitored natural recovery (MNR) or enhanced natural recovery (ENR) may be applicable response actions for evaluation in one or more remedial alternatives. Conversely, if natural processes are not effectively reducing chemical concentrations in surface sediments, then active remedial measures may be considered appropriate.

Third, smaller scale areas are analyzed to evaluate local recovery potential and assess whether empirical data and predictive models agree. MNR is a potential remedy that relies on on-going, naturally-occurring processes (such as sediment deposition, mixing, and burial) to reduce the chemical concentrations in surface sediment, making them unavailable for biological uptake or exposure. Several lines of evidence (e.g., isotope cores, sediment transport analysis, chemical trends analysis, evaluation of erosion potential) are combined to assess whether contaminated subsurface sediments are stable, if they are effectively isolated, and whether surface sediment chemical concentrations are expected to decrease over time. The STM and BCM do not incorporate disturbances to bed sediments from propeller wash; therefore, bathymetric imaging data were used to identify these areas. These lines of evidence are used in the FS both when configuring remedial alternatives and when evaluating the long-term effectiveness of remedial alternatives.

This section focuses on details related to the three modeling goals:

- Providing an overview of the physical CSM and the STM relative to recovery.
- Discussing briefly the multiple lines of empirical evidence (i.e., sediment core trends, surface sediment sample trends at resampled stations, and

physical features) that validate the STM and identify trends not accounted for by the predictive model.

- Developing a predictive recovery model (i.e., the BCM), and inputs to the BCM.
- Evaluating the scour potential of vessels operating in the LDW.
- Performing additional STM scenario runs to help answer FS-specific questions related to sediment movement and MNR and ENR recovery potential.
- Defining uncertainties of the STM model, including a brief overview of how it impacts uncertainties in fate/transport processes for risk-driver chemicals.

Potential application of MNR and ENR and general response actions are described in Section 7 – Identification and Screening of Remedial Technologies. Additional STM runs are described in Appendix C. Empirical trends for individual areas of potential concern (AOPCs) are presented in Section 6.

5.1 Sediment Transport Modeling

Modeling of particle movement in and out of the LDW and sediment transport within the LDW was undertaken during the RI to better understand the CSM and support various FS elements.[1] The site-wide STM, which simulates the sediment resuspension and sedimentation processes active to varying degrees within the LDW, has shown that the LDW is net depositional on a site-wide scale and is divided into Reaches 1, 2, and 3 based on hydrodynamic characteristics and geomorphology (see Section 2 for more details regarding the CSM). Model development and calibration are detailed in the *Final Sediment Transport Analysis Report* (STAR; Windward and QEA 2008) and the *Final Sediment Transport Modeling Report* (QEA 2008). This section reviews the resulting general trends in an LDW-wide analysis (Section 5.1.1) and evaluates the model's ability, when combined with the BCM, to predict chemical trends. This is accomplished by comparing the predicted trends to empirical data (Section 5.4).

5.1.1 Composition and Sources of Sediment Loads

The STM estimated the movement of sediment from three sources over time into and through the LDW:

- Sediment from the upstream Green/Duwamish River system

[1] The STM tracks particle movement, but it does not model chemical transport processes or mechanical transport processes such as the effect of vessel traffic or waves on net sedimentation rates. The effect of vessel traffic was analyzed separately for moving and maneuvering tugs. The analysis of moving tugs is presented in the *Final Sediment Transport Analysis Report* (STAR; Windward and QEA 2008) and the effect of maneuvering tugs is summarized in Section 5.3.1 and in Appendix C, Part 7.

- Sediment from lateral sources (i.e., storm drains, streams, and combined sewer overflows [CSOs]) that discharge to the LDW
- Surface sediment existing in the LDW bed at the onset of the model period.

The STM modeled both the transport of total suspended solids (TSS) and bed load. The transport of TSS is the movement of suspended particles in the water column. Bed load transport is the movement of sand and gravel in a thin layer (about 1 millimeter [mm] to 1 centimeter [cm] in thickness) located along the surface of the sediment bed.

The Green/Duwamish River represents the predominant source of sediment to the LDW. Figures 5-1a and 5-1b show that surface sediment (0-10 cm) in most of the model grid cells in the LDW will be comprised of over 50% upstream solids at the end of the 10-year model simulation and over 75% upstream solids at the end of the 30-year simulation. The STM quantified sediment loading from this upstream source using a flow-rating curve for the Green/Duwamish River based on discharge data gathered from 1960 to 1980 and from 1996 to 1998. The grain size characteristics of the in-flow material were also evaluated to determine the contribution from suspended material in contrast to bed load. Of the total upstream solids load, approximately 24% is bed load and 76% is suspended load in both the 10-year and 30-year simulation periods. All of the bed load entering the LDW from upstream is deposited within the Upper Turning Basin and the upstream portions of the navigation channel, which are periodically dredged by the U.S. Army Corps of Engineers (USACE). Approximately 50% of the total solids load entering the LDW from upstream is deposited in the LDW with approximately 80% of this deposition occurring in the vicinity of the Upper Turning Basin in Reach 3.

Sediment loads from lateral sources were derived from analyses conducted by the City of Seattle and King County (Nairn 2007; Seattle Public Utilities 2008). Storm drains, CSOs, and streams discharge into the LDW at over 175 locations. These were initially aggregated in the STM report into 21 discrete discharges at 16 locations to simplify modeling. In the STM, the total annual sediment load from the lateral sources was estimated to be 1,257 metric tons per year (MT/year); of this, 76% was attributed to storm drains, 3% to CSOs, and 21% to streams.

The distribution and magnitude of sediment loads from lateral sources were updated after the STM report (QEA 2008) was completed. These updated sediment loads are presented in Appendix C, Part 4, Scenario 2. The updated loads provide a more accurate distribution of the loads reflecting better distribution of inputs and more actual outfall locations. Figure 5-2 illustrates the spatial distribution of the percentages of sediment from lateral sources at the end of the 10-year model simulation, using the updated lateral loads distribution. Updated lateral loads were used in all subsequent modeling in this FS. The grid cells with the greatest predicted lateral sediment contribution (i.e., the sediment bed after 10 years includes >10% lateral contribution) are

limited to the following areas in the LDW: at the heads of Slips 4 and 6, Hamm Creek at river mile (RM) 4.3W, RM 1.8W, near Glacier at RM 1.5W, RM 1.2E, RM 0.3W, and in the Duwamish/Diagonal EAA at RM 0.5.

A third component of sediment load is the movement of surface sediment from one model grid cell to another. Bed sediment can be resuspended during a high-flow event, after which it either resettles nearby or is transported downstream. The STM tracks the movement of these particles throughout the LDW, from grid cell to grid cell. The ability of the STM to track the movement of particles within the LDW was used to evaluate the transport of sediment between Reaches 1, 2, and 3, as summarized in Figure 5-3 and Appendix C, Part 4, Scenario 4.

The highest percentage of original bed sediments remaining in the surface layer after 10 years occurs in the grid cells east of Kellogg Island at RM 0.9 and at the Terminal 117 EAA (RM 3.0 to RM 3.5). The areas that have the highest percentage of original bed sediment remaining at the end of the 30-year simulation are not the result of a short term scour event, but are consistently present throughout the simulation. A higher percentage of original bed sediment indicates that much of the surface layer is not being replaced by upstream or lateral sediment (i.e., the bed surface sediments are not receiving much deposition and could be interpreted as having a more constant composition over time).

5.1.2 Solids Balance In and Out of the LDW

Figure 5-3 shows the mass of sediment moving through and within the three reaches of the LDW over 10-year and 30-year modeling periods. Over the 10-year period, more than 99% of the incoming sediment load (1,850,850 MT) originates from the Green/Duwamish River; less than 1% (12,580 MT) enters the LDW from lateral sources. Over a 30-year period, the magnitude of the sediment mass movement increases, but the percent contribution from upstream and lateral sources is essentially the same as for the 10-year period. About 50% of the incoming solids deposit within the LDW and are not exported farther downstream into the East and West Waterways and Elliott Bay.

The estimated average annual upstream incoming sediment load to the LDW over the 10-year model period is approximately 185,000 MT/year, although it is noted that year-to-year variation in sediment load occurs because of variability in river flow, with total sediment load increasing during years with relatively high flows. Over a 30-year period, the incoming sediment load averages about 207,000 MT per year and 6.2 million MT over 30 years.

Bed load (heavier, larger, grain size particles that skip and travel along the sediment bed) comprises 24% of the total sediment load, on average, at the upstream boundary of the STM domain, with the remaining 76% entering the LDW as sediment suspended in the water column (QEA 2008). According to the STM, most of the bed load deposits above RM 4.0; while the suspended sediment primarily deposits farther downstream or

is transported through the system. The proportion of bed load to total load is inversely dependent on flow rate, decreasing from 30% to about 17% to 18% as the flow rate increases (24% on average). The estimated average annual bed load transported during the 30-year model period was 50,000 MT/year, with a range of 10,000 MT/year (1978) to 132,000 MT/year (1975) for low-flow and high-flow years, respectively (QEA 2008). This solids mass balance supports the CSM conclusion that the LDW is net depositional over long time periods and that lateral sources are important, but localized to the receiving sediments in the vicinity of these sources.

5.1.3 Scour Potential from High-flow Events and Vessel Traffic

Figure 5-4 shows potential scour areas derived from two processes: high-flow events and scour from vessel traffic. The STM high-flow simulation results and observed potential scour from vessel traffic were compared to both the estimated net sedimentation rates from the STM and the empirically derived estimates based on subsurface sediment cores. Net sedimentation rates are modeled to be more than 1 cm/yr in most of the vessel scour areas, which means that potential exposure of subsurface contamination will likely be reduced by the deposition of new sediment over time even in these areas. However, areas of erosion from both high flows and vessel scour are considered during delineation of AOPCs (see Section 6).

Very few areas in the LDW that show significant high-flow erosion potential (10 cm scour depth or more) also have subsurface contamination. These areas are identified in Appendix C (Part 4, Scenario 5) and are evaluated in Section 6 for the delineation of the AOPCs. Alternatively, most areas with significant subsurface contamination (greater than sediment quality standards [SQS]) do not show erosion potential beyond a few centimeters depth during high-flow events. An analysis of how erosion and deposition impact surface concentrations over time is discussed in Section 5.2.

The 100-year high-flow event produces a maximum erosion depth of less than 1 foot (less than 30 cm) in limited areas (see Figure 2-6). Most of these areas do not show chemical concentrations at this depth that are greater than the SQS and that are not already expressed as exceedances at the surface. Subsurface chemical concentrations in areas with scour greater than 10 cm are analyzed in Appendix C (Part 4, Scenario 5) and discussed in Section 5.3.2.5.

5.2 Bed Composition Model (BCM)

In a companion effort to the STM, output from the physical STM was coupled with the concentrations of risk-driver chemicals in sediments to enable prediction of future surface sediment chemistry under various remedial action scenarios. This analysis is termed the BCM. This section of the FS describes the BCM, its applications, and its limitations.

Output from the STM is directly applied to the BCM. A basic and conservative assumption is that all contaminants are strongly bound to sediment particles. The BCM is conservative with respect to sediment concentrations because it only accounts for chemical movement associated with particles (i.e., transport, resuspension, burial) and assumes no loss of chemical mass via other physical, chemical, or biological degradation processes (e.g., desorption, diffusion, volatilization, biotransformation, dechlorination, etc.). Other degradation processes explored at other sites are documented at the end of this section to provide some context for understanding these processes.

The BCM is used later in the FS as one line of evidence to evaluate recovery potential of LDW sediments (Section 6), identify and screen remedial technologies (Section 7), and develop and evaluate remedial alternatives (Sections 8 and 9). The sensitivity of the BCM is also investigated by looking at how changes in input parameters affect the output (Section 9).

5.2.1 The BCM Calculation

The BCM is a spreadsheet-based tool that calculates an expected chemical concentration at individual model grid-cell locations[2] in the surface sediment layer (0 to 10 cm) by using a simple mass balance formula (RETEC 2007a, Appendix C):

$$C_{(time)} = C_{bed}*f_{bed\ (time)} + C_{lateral}*f_{lateral\ (time)} + C_{upstream}*f_{upstream\ (time)} \qquad \text{Equation 5-1}$$

Where:

- f_{bed}, $f_{lateral}$, and $f_{upstream}$ are, respectively, the fractions of surface sediment sourced from existing bed sediment, from lateral source sediment, and from upstream Green/Duwamish River sediment in each grid cell at a specific point in time. These surface sediment fractions change over time and are direct outputs of the surface sediment layer of the STM. The sum of these fractions in each grid cell is 1.
- C_{bed}, $C_{lateral}$, $C_{upstream}$ are the concentrations of a chemical of concern (COC) associated with each sediment source. These concentrations are derived from existing bed chemistry, lateral source samples (i.e., stormwater and CSO discharges), and upstream (Green/Duwamish River) lines of evidence.

An example of how the BCM computation uses the STM output is shown in Figure 5-5. Additional mechanics of the BCM are provided in Appendix C.

[2] STM grid cells are taken directly from the STM setup, as described in the STM report (QEA 2008), and overlain with inverse distance weighting 10-ft by 10-ft chemistry grid cells in the BCM. Consequently, the BCM calculates results for 100-ft^2 areas.

As noted in Equation 5-1, the sediment composition fractions (f) vary with time because the STM output varies with time[3] and on-going sediment transport changes the bed composition of each fraction. The concentration terms for the lateral source and upstream sediments ($C_{lateral}$ and $C_{upstream}$) are assumed to be constant over time for modeling purposes representing current best estimates of the long-term average inputs over time.[4] The derivation of these values is discussed in greater detail in Section 5.2.3. The BCM assigns the same chemical concentration (input value) to the lateral source and upstream sediments regardless of the variability observed over time or spatially (such as among different outfalls for the lateral sources). The bed concentration (C_{bed}) is the best estimate of the chemical concentration in the surface sediment bed at a given location at the start of the model period, defined by the FS surface sediment dataset. The BCM is implemented in a geographic information system (GIS) framework and MS Excel platform (described in Appendix B of RETEC 2007b).

The BCM (Equation 5-1) can be used to estimate chemical concentrations in surface sediment at each grid cell location in the LDW as a function of time under various remedial alternatives. Where active remediation is assumed within an alternative, the grid cells contained within the actively remediated footprint receive a post-remedy bed sediment replacement value for C_{bed}. The new value is an estimate of the COC concentration that exists in the surface sediment at the completion of the remediation (see Section 5.2.3.4).

5.2.2 BCM Assumptions

The predictive accuracy of the BCM hinges on two important findings from the STM:

- Over time, the surface sediment that erodes, moves, and redeposits within the LDW originates primarily from the Green/Duwamish River, as shown in Figure 5-3.
- The magnitude of high-flow bed scour is sufficiently minor such that subsurface sediments that exceed the SQS are generally not exposed or eroded and redistributed within the LDW.

Consequently, redistribution of existing sediments that exceed the SQS is not a significant process, and future bed sediment chemistry can be reasonably estimated as a

[3] STM output in 5-year increments is used in the BCM runs. The STM runs continuously for the entire 30-year simulation period at time steps on the order of minutes. The FS presents results in 5- or 10-year increments following the start of remedy construction. For remedial scenarios that take longer than 30 years to implement, the simulation starts over at the beginning of the 30-year hydrograph used for the STM.

[4] However, high and low "sensitivity" concentrations will also be used as input values to bracket the range of uncertainty in the input values and demonstrate the effects from anticipated reductions in contaminant concentrations over time.

mass balance between present bed sediment and incoming sediment loads from the Green/Duwamish River and lateral sources.

These key findings are supported in three ways: by the CSM (Section 2.3), by a comparison of empirical trends to model estimates of net sedimentation and recovery rates (Section 5.4), and by additional STM special scenario runs (Section 5.3.2) used to help refine the CSM for the FS.

In addition, the BCM assumes that:

- All COCs are conservative and permanently bound to sediment particles; degradation or phase transfer processes such as solubilization are not assumed to reduce COC concentrations over time. This assumption is generally consistent with the known properties of the COCs, and is inherently conservative because some degree of degradation or phase transfer likely occurs.
- COC concentrations from drainage basins that have not been sampled are expected to be similar to or lower than those at drainage basins sampled for source control evaluation. This is consistent with the sampling strategy of the Source Control Work Group, which has focused first on areas with the most significant sediment contamination and associated outfalls identified as being the most likely sources of contaminated sediments to the LDW. The COC concentrations derived from the empirical data are then applied to all outfalls in the model.
- The biologically active zone for most of the LDW is 10 cm or less, and therefore the top 10 cm model layer represents exposure concentrations for benthic organisms. This depth is consistent with results from the sediment profile imaging (SPI) analyses conducted in the LDW for the Washington State Department of Ecology (Ecology 2007) and King County (King County 2007), as described in the RI (Windward 2010).[5] The 95% upper confidence limits (UCL95) on the mean of maximum sediment feeding void depths for benthic organisms (a conservative measure of the biologically active zone) used in the Ecology dataset was 11 cm with a mean of 10 cm. The King County dataset was even shallower (9 cm with a mean of 8 cm). The 10-cm depth is used as the STM and BCM assumptions of the active mixing layer.

[5] The assumption of 10 cm can be reasonably applied as the biologically active zone in the LDW based on several factors: representativeness of entire benthic community, relationship with void depths, and central tendency of void depths (Windward 2010).

5.2.3 Input Values to the BCM for Risk-Driver Chemicals

Concentrations of chemicals associated with the three sources or types of solids (i.e., upstream, lateral, and bed sediments) were estimated as inputs to the BCM. Samples from these three sources were analyzed for several chemicals over a period of years, and the resulting concentrations were selected for use in the BCM model based on summary statistics from compiled datasets, including a recommended value and upper and lower values, as described below. Recommended values and ranges for the BCM input values for total polychlorinated biphenyls (PCBs), arsenic, carcinogenic polycyclic aromatic hydrocarbons (cPAHs), and dioxins/furans are provided in Tables 5-1a through 5-1c. The ranges of observed concentrations reported from various data sources are provided in Tables 5-2a through 5-2d.

5.2.3.1 Chemical Concentrations Associated with Upstream Solids

Chemical concentrations associated with Green/Duwamish River solids were compiled from various data sources, which are described in Appendix C, Part 3. These data provide multiple lines of evidence that characterize the chemical concentrations associated with sediments entering the LDW from the Green/Duwamish River system. Data from the various studies were used to develop a range of input values for each risk-driver chemical (Table 5-1b).

The data sources evaluated included:

- Upstream whole-water samples collected by King County
- Upstream centrifuged suspended solids samples collected by Ecology
- Surface sediment samples (containing fines greater than 30%) collected by Ecology between RM 5.0 and 7.0
- Upstream surface sediment samples from RM 5.0 to 7.0 included in the RI dataset
- Core data collected by the USACE to characterize sediment prior to dredging in the navigation channel from RM 4.3 to 4.75, which represent the Green/Duwamish River bed load and suspended material that settles in the upper reach of the LDW.

The upstream King County whole-water concentrations were normalized to the value of the concurrently collected TSS, so that the concentration units were comparable with the sediment concentration units (i.e., both on a dry weight basis).[6]

[6] Normalizing to TSS likely produces a high estimate of the COC concentration on sediment particles because some of the COC mass is likely dissolved or on colloidal particles that do not settle in the LDW.

A subset of the Ecology upstream surface sediment data was developed by excluding samples that contained less than 30% fines. This approach accommodates the systematic differences in grain size distributions between upstream (e.g., mid-channel) data and average conditions in the LDW. Both the full dataset and the subset with fines greater than 30% were used as lines of evidence to develop the range of BCM upstream input parameters.

Upstream surface sediment samples from RM 5.0 to 7.0 included in the RI dataset were evaluated, but were not used in selecting BCM input values. The rationale for this approach is explained in Appendix C Part 3. Instead the more recent upstream surface sediment data collected by Ecology were used. The upstream surface sediment data had lower total PCB and cPAH concentrations than other upstream lines of evidence. This may reflect the coarser (i.e., sandier) material encountered during sampling that is characteristic of bed load[7] being transported down the Green/Duwamish River—very little of which is transported beyond the Upper Turning Basin. The surface sediments upstream of the LDW are generally coarser than those in the LDW because there is little net sedimentation upstream of the Upper Turning Basin as a result of higher stream velocities above RM 4.75.

The subsurface sediment cores collected by the USACE to characterize sediment prior to dredging in the navigation channel from RM 4.3 to 4.75 represent the Green/Duwamish River bed load and suspended material that settles in the upper reach of the LDW.[8] The Upper Turning Basin is a natural sink for incoming sediment loads from upstream and, because the navigation channel is dredged every 2 to 4 years from RM 4.0 to 4.75, this area is a good indicator of suspended solids settling in the upper reach of the LDW.

The recommended BCM values for upstream solids were based on these four datasets as values representing the best estimate concentrations of chemicals entering and settling in the LDW. Each dataset contains information that represents, to a degree, the chemical concentrations in sediment particles that enter and deposit within the LDW. As discussed below, these datasets are considered reasonable lines of evidence for developing incoming concentrations to the LDW from upstream, although each type of data collection tends to bias the results toward lower or higher values (e.g., low percent fines versus high percent fines; single collection events instead of seasonal collection events; potential influence of sources). In general, the value representing a mid-range of the various lines of evidence was considered for the recommended input value, and then values representing upper and lower bounds were selected for the high and low

[7] Bed load is heavier, sandier material that travels along the bed surface; it is not suspended in the water column and thus, typically travels shorter distances than do suspended solids.

[8] The RI summarized USACE cores in the Upper Turning Basin from RM 4.0 to 4.75. The FS screened this dataset to exclude the potential influence of sources (e.g., Hamm Creek) in the downstream portion between RM 4.0 and 4.3. The FS dataset also includes more recent data collected by USACE above RM 4.3.

sensitivity input values, respectively. One goal of including a range in the input values is to account for uncertainty in all the datasets representing upstream inputs and show how these data ranges affect the predictions of natural recovery for the remedial alternatives.

For total PCBs and cPAHs, the means of the LDW RM 4.3-4.75 USACE core data were used as the recommended upstream input value (35 microgram per kilogram dry weight [µg/kg dw] and 70 µg toxic equivalent [TEQ]/kg dw, respectively). To address sensitivity around the mid value for both total PCBs and cPAHs, the low upstream input values were the means of the Ecology upstream surface sediment samples containing fines greater than 30%. The high upstream input values were the UCL95s of the TSS-normalized King County whole-water datasets.

For arsenic, the recommended input value was the mean (9 milligrams per kilogram dry weight [mg/kg dw]) of the Ecology upstream samples containing fines greater than 30%. The mean of the LDW RM 4.3 to 4.75 USACE core data (7 mg/kg dw) was selected as the low sensitivity value. The high sensitivity value (10 mg/kg dw) was the UCL95 of the Ecology upstream sediment samples containing fines greater than 30%. King County surface water TSS-normalized data and Ecology centrifuged solids data were not used in the selection of BCM upstream values for arsenic because the UCL95 for both of these datasets would have resulted in much higher modeled surface sediment concentrations than in the LDW baseline dataset. It is likely that these two datasets, especially the surface water dataset, contain finer particulates with higher arsenic concentrations than those that deposit in the LDW. These finer particles mainly do not settle in the LDW (approximately 50% of the Green River solids do not settle in the LDW).

For dioxins/furans, the Ecology upstream sediment samples (containing fines greater than 30%) and the Ecology upstream centrifuged solids were the only datasets used for selecting the BCM input values; there were neither core data from RM 4.3 to 4.75 nor whole-water dioxin/furan data among the other datasets. Because of the limited datasets and the desire to evaluate a range of input values, a slightly different approach was used to select dioxin/furan BCM input values. The midpoint between the means of the two datasets is the recommended mid value (4 ng TEQ/kg dw); the low sensitivity value is the mean of the Ecology upstream sediment samples containing fines greater than 30% (2 ng TEQ/kg dw); and the high sensitivity value is the midpoint between the mean and UCL95 of the Ecology upstream centrifuged solids dataset (8 ng TEQ/kg dw).

Dry weight concentrations for COCs based on upstream surface sediment samples may be biased low and may under-represent the concentrations of chemicals associated with the fraction of solids entering the LDW that have finer grain size and higher organic carbon concentrations. Silt- and clay-sized suspended solids represent 67% of the sediment entering the LDW. As a result of the settling of most sand-sized particles in

Reach 3, silt- and clay-sized particles make up only about 35% of the sediment that settles in Reach 3, but more than 90% of the sediment that settles in Reaches 1 and 2. Case study literature and LDW data exist that support the relationship between chemical concentrations, organic carbon content, and particle size. The relationship between particle size and organic carbon content and the various methods to account for these relationships and their potential effect on results is explored in Section 5.3.3.

5.2.3.2 Chemical Concentrations Associated with Lateral Source Sediments

Chemical concentrations associated with storm drains and CSOs were evaluated to estimate chemical concentrations associated with lateral source sediments.[9] The storm drain solids and CSO data were collected as part of on-going source control programs for the LDW. All available storm drain data were compiled by Seattle Public Utilities (SPU) for source samples collected in areas draining to the LDW through June 2009 by SPU, the Boeing Company, and King County. These data included storm drain solids collected from on-site and right-of-way catch basins, in-line grab samples, and in-line sediment traps. The storm drain solids data were used to generate a range of lateral input concentrations for total PCBs, arsenic, and cPAHs for use in the BCM. Storm drain solids and sediment data collected near large stormwater outfalls draining urban areas in the greater Seattle area were used to establish BCM lateral input values for dioxins/furans. The King County CSO whole-water data were also considered and found to support the ranges of BCM lateral input values estimated from the storm drain solids dataset. Consequently, the same COC concentration values were used for both storm drains and CSOs and were also assumed for the stream inputs.

The lateral input values selected for use in the BCM are estimates, based on the assumption that chemical concentrations in storm drain solids will decrease as a result of source control efforts in the LDW drainage basin. The following assumptions were made for the BCM input values:

- The input, mid, or recommended value is a pragmatic assessment of what might be achieved in the next decade with anticipated levels of source control.
- The high sensitivity value is a conservative representation of future conditions assuming only modest success in source control (e.g., management of high priority sources).
- The low sensitivity value is an estimate of the best that might be achievable in 30 to 40 years with increased coverage and continued aggressive source control.

[9] Lateral source sediments include inputs from storm drains, CSOs, and streams discharging to the LDW.

The assumed level of source control was based on best professional judgment of the Source Control Work Group and what is currently known about the distributions of each COC within the LDW drainage basin and their on-going source(s). These reflect potential levels of source control that could occur over time. To simulate potential lateral inputs after implementing varying degrees of source control, the source tracing datasets were screened to remove all values above various concentrations already targeted for source control. Summary statistics were then generated for each level of assumed source control (high, medium, low). Table 5-1a presents the recommended BCM input values for lateral sources. The summary statistics for the four human health risk drivers (total PCBs, arsenic, cPAHs, and dioxins/furans) are provided in Tables 5-2a through 5-2d.

A general summary of the lateral input values selected for the BCM is presented below. The lateral sources memo (King County and SPU 2010) found in Appendix C, Part 3 describes the selection of the lateral input values in more detail. It should be noted that the high lateral input value is not intended to represent what sources could be throughout the drainage basins tributary to the LDW. This high value is used only to determine sensitivity of the model and the implications of inadequate source control at individual discharge locations; it is not an estimate of actual source loads or a target value for source control work.

Total PCBs

Prior to generating summary statistics for total PCBs, the data were flow-weighted, including data from Rainier Commons, North Boeing Field/Georgetown Steam Plant, Terminal 117, and Boeing Plant 2/Jorgensen Forge, to avoid skewing the summary statistics from these targeted and known source areas. Flow-weighting takes into account the relative contribution of a chemical by adjusting the concentration based on the land area and estimated annual runoff volume relative to the total contributing area in the LDW drainage basin. To reflect potential levels of source control that could occur over time, a range of screening concentrations was used to select the BCM lateral values for PCBs. The recommended BCM input value (300 µg/kg dw) is represented by the mean of data after excluding concentrations greater than 5,000 µg/kg dw.

Screening values of 2,000 and 10,000 µg/kg dw total PCBs were used to define the low and high BCM sensitivity values, respectively. If all samples with a total PCB concentration above a screening value of 2,000 µg/kg dw are removed from the dataset, the median of the remaining data is 100 µg/kg dw. This value was selected as the low BCM sensitivity value (100 µg/kg). When all samples with total PCB concentrations above a screening value of 10,000 µg/kg dw are removed from the dataset, the 90th percentile value of the remaining data is 1,000 µg/kg dw, which was selected as the high BCM sensitivity value.

cPAHs

Unlike total PCBs, cPAHs are expected to be difficult to control due to the petroleum-based economy, intensity of urbanization in the LDW, and a multitude of on-going sources. Consequently, a more cautious approach was taken with the source tracing dataset by excluding cPAH concentrations above a single source control level of 25,000 µg TEQ/kg dw. Data for cPAHs were not flow-weighted because cPAH concentrations in the storm drain solids samples do not show a distinct geographic distribution, and higher concentrations of cPAHs are found throughout the drainage basins tributary to the LDW, typically in on-site drainage structures (catch basins and oil/water separators) at sites engaged in transportation-related activities (e.g., bus and airport operations), maintenance facilities, service stations, foundries, and fast food facilities. The screening value of 25,000 µg TEQ/kg dw is considered an appropriate representation of effectiveness in controlling significant sources. The mean (1,400 µg TEQ/kg dw) of the data, excluding all samples with cPAH concentrations greater than 25,000 µg TEQ/kg dw, was selected as the recommended BCM input value; the median (500 µg TEQ/kg dw) was selected as the low sensitivity value; and the 90th percentile (3,400 µg TEQ/kg dw) was selected as the high BCM sensitivity value.

Arsenic

For arsenic, two different screening values (the SQS and cleanup screening level [CSL]) were used to reflect different potential levels of source control. The recommended BCM input value of 13 mg/kg dw was selected based on the mean of the dataset, excluding all samples with arsenic concentrations above a screening value of 93 mg/kg dw (the CSL). The 90th percentile of the same dataset is 30 mg/kg dw, and this value was selected to represent the high BCM sensitivity value. If all samples with arsenic concentrations above a screening value of 57 mg/kg dw (the SQS) are removed from the dataset, the median of the remaining data is 9 mg/kg dw. This value was recommended as the low BCM sensitivity value.

Dioxins/Furans

Available storm drain solids data for dioxins/furans were also used along with surface sediment sample data collected for the LDW RI in the vicinity of storm drains throughout the Greater Seattle metropolitan area to establish BCM lateral input values. By combining these two datasets (because the storm drain solids dataset was small compared to the other risk-driver datasets) and excluding one outlier, BCM lateral values were established for dioxins/furans. The mean of 20 ng TEQ/kg dw was selected as the BCM input value; the median of 10 ng TEQ/kg dw as the low BCM sensitivity value; and the UCL95 of 40 ng TEQ/kg dw as the high BCM sensitivity value. In addition, the UCL95 rather than the 90th percentile was used to establish the high BCM sensitivity value, because it resulted in a more reasonable upper end estimate for the sensitivity analysis.

King County CSO Whole-Water Samples

In addition to the storm drain solids dataset, whole-water samples collected from CSOs by King County for analyses of PCBs, arsenic, and cPAHs were also considered when developing BCM lateral values. For both total PCBs and cPAHs, whole-water concentrations were divided by their sample-specific TSS concentrations to calculate TSS-normalized concentrations. This gives a conservative estimate that is likely biased high because it is assumed that all of the PCBs and cPAHs are on the particulate fraction and none are in the dissolved or colloidal phases. For arsenic, paired total and dissolved concentrations were used to estimate the portions of the total arsenic concentrations associated with the particulate fraction. These were then divided by the sample-specific TSS concentrations to calculate a TSS-normalized concentration for arsenic. Whole-water samples collected from CSOs in the LDW had not been analyzed for dioxins/furans at the time this document was prepared. Summary statistics for CSO data are provided in the lateral source memo (King County and SPU 2010) found in Appendix C, Part 3.

5.2.3.3 Chemical Concentrations of Existing Bed Sediments

Existing bed sediment chemical concentrations were developed by spatially interpolating surface sediment data from the FS baseline dataset for total PCBs, arsenic, and cPAHs. An inverse distance weighting (IDW) algorithm was used to interpolate the data. The IDW methodology is documented in Appendix A.

Existing bed sediment concentrations for dioxins/furans were developed by applying Thiessen polygons to the surface sediment data from the FS baseline dataset. For other Washington State Sediment Management Standards (SMS) chemicals, SQS and CSL exceedances at surface sediment stations were also spatially applied using Thiessen polygons. In this case, actual dry weight or oc-normalized values were used as appropriate. The SMS data were also mapped as Thiessen polygons with a designation of "criteria pass, SQS exceedance, or CSL exceedance." For SMS chemicals, sediment toxicity results trumped SMS chemistry results. (For example, a Thiessen polygon with a chemistry CSL exceedance, but a toxicity pass, is coded as a pass).

Collectively, these risk-driver chemicals comprise the FS baseline dataset used to map "existing conditions" in the LDW. The FS baseline dataset spans about 18 years (1991 to 2009) of data collection efforts. Therefore, this analysis is considered conservative because it is likely that current concentrations of some COCs at stations sampled longer ago may now be lower than what is reflected in the FS baseline dataset (see Appendix F).

5.2.3.4 Post-Remedy Bed Sediment Replacement Values

In areas that would be actively remediated under different cleanup alternatives, the existing bed sediment concentration (C_{bed}) is replaced with a value representing near-term (0-2 years) conditions following the cleanup. The post-remedy surface sediment

conditions are influenced by multiple factors. This subsection describes the assumptions used to model the post-cleanup concentrations.

Experience at other sediment remediation sites has shown that chemical concentrations in the sediment bed shortly after the completion of dredging or capping cannot be assumed to be zero and are often above background (NRC 2007; EPA 2005; Anchor 2003). This occurs because some degree of residual surface contamination always exists from the resettling of contaminated sediments suspended during remedial activities; because material used for capping of subsurface sediment exposed after dredging contains low concentrations of these COCs; and because existing adjacent sediments can become resuspended and then deposited in remediated areas.

Post-remedy bed sediment replacement values within a remediated area reflect an assumed combination of clean backfill material (e.g., from capping or ENR, and using or not using post-dredge residuals management) and the average concentration of surrounding unremediated sediments. To derive a replacement value based on this assumption, estimates of both values are required. To estimate the clean backfill concentrations, the UCL95 of the 2008 EPA Puget Sound Ocean Survey Vessel (OSV) *Bold* survey (EPA OSV *Bold* survey) data were used. These data correspond to natural background estimates for Puget Sound.[10] However, the use of qualified maintenance dredged materials (e.g., materials dredged from the Upper Turning Basin) for capping would, in practice, lead to a higher range of post-remedy bed sediment replacement values than those calculated from the EPA OSV *Bold* survey data (EPA 2008).

However, once clean material is placed, other sediments start settling on the backfill. These sediments are some combination of upstream and lateral inputs, resuspended bed sediments, and dredge residuals. For the purposes of this FS, the average concentration of bed sediments that will not be actively remediated was assumed to be representative of this mixture of inputs onto the clean backfill. The average concentration of unremediated sediments was derived using the spatially-weighted average concentrations (SWACs) outside of remediated areas. The average concentrations remaining outside of AOPC 1 and outside AOPC 2 for Alternative 6 (see Section 6 for AOPCs and Section 8 for alternative footprints) were used in this analysis.

To calculate a range of post-remedy bed sediment replacement values for use in recommended and sensitivity analyses, the following ratios of clean material to remaining post-remedy average concentrations were assumed: 50:50 for the recommended BCM input value, 75:25 for the low sensitivity value, and 25:75 for the high sensitivity value.

Recommended post-remedy bed sediment replacement values for total PCBs, arsenic, cPAHs, and dioxins/furans are presented in Table 5-1c. The degree of residual

[10] Data were also collected from the Strait of Juan de Fuca and Strait of Georgia.

contamination is dependent on several factors, including the type of remedial activity, specific design elements, construction methods, best management practices, engineering controls, and contingency measures (discussed further in Section 7.1). Therefore, post-remedy bed sediment replacement values for use as input parameters to the BCM were developed as a range using the proportioning values described above and best professional judgment. The same post-remedy bed sediment replacement value is applied to areas that are to be dredged, capped, ENR, or have a thin-layer placement of sand for residuals management.

5.2.4 Inputs and Application of the BCM for Other SMS Chemicals

The BCM can also be used to estimate future SQS and CSL exceedances for SMS chemicals (i.e., representative SMS risk-driver chemicals). In the BCM, a particular chemical is selected for each point, and the BCM assigns that point into one of three categories in the future: below the SQS, SQS exceedance (but below the CSL), or CSL exceedance. The BCM equation (Equation 5-1) is used to estimate future conditions for any chemical, given upstream and lateral input values for that particular chemical. For the FS, these calculations were conducted on a subset of the SMS chemicals, termed "representative" chemicals. This subset was chosen from the full list of SMS chemicals because: 1) not every SMS chemical has lateral and upstream data available; 2) several chemicals had very low detection frequencies; and 3) indicator chemicals within a chemical class (e.g., PAHs) may well represent the behavior of that class of chemicals. The representative chemicals were identified by querying the database and counting the number of exceedances of each chemical above the SQS. The chemicals with the most frequently detected exceedances were selected to represent a chemical group/class (Table 5-3). The representative chemicals include bis(2-ethylhexyl)phthalate (BEHP) (phthalate group); chrysene, fluoranthene, and phenantherene (PAH group); and mercury and zinc (metal group). Arsenic and total PCBs were also included as representative chemicals to assess the spatial distribution of these risk-driver chemicals in a manner consistent with the other SMS chemicals. Detected SQS/CSL exceedances for total PCBs were assessed using sample-by-sample oc-normalizations to ensure that detected exceedances were not missed in the interpolated IDW maps based on dry weight (see Table 5-2b).

After the initial chemical list was established, locations were identified that exceeded the SQS for other chemicals, and additional chemicals were added to the list so that there were at least one representative chemical for each location. As a result, butylbenzyl-phthalate, phenol, acenaphthalene, and indeno(1,2,3-cd)pyrene were added. Table 5-3 lists these chemicals and the upstream and lateral values established for each.

For each location that had a detected SQS exceedance in the FS baseline dataset at the start of the modeling period, the maximum exceedance ratio above the SQS and the chemical responsible for that exceedance were determined. Typically, the chemical

responsible for the highest exceedance was one of the representative chemicals, with that representative chemical usually being total PCBs.[11] If the chemical with the maximum exceedance ratio was not in the representative chemical list, a representative chemical of the same chemical class that also exceeded the SQS at that location was used in the BCM. The BEHP concentration was also evaluated in the BCM for each location because this chemical is identified as a concern because of lateral sources.

5.2.4.1 Recommended Input Values for Representative SMS Chemicals

Lateral input values were determined by querying the City of Seattle's lateral source database (personal communication SPU 2010). Upstream input values were derived from the USACE Dredged Analysis Information System (DAIS) core database using data through 2009 (USACE 2009a, 2009b). For the City of Seattle data, all storm drain solids data were queried for each chemical of interest. The log-normal mean of the dataset was then calculated and used as the lateral inflow value for that chemical (Table 5-3) after outliers were removed. The USACE core data from the Upper Turning Basin, RM 4.3 to 4.75, were used to represent the incoming sediment load from upriver because that is the only upstream dataset analyzed for all SMS chemicals over a sufficient period of time. The data were screened to include only those collected after 1990 (prior data were excluded). The median of the dataset for each chemical was then calculated and used as the upstream value for that chemical. Table 5-3 lists the lateral and upstream inflow values used for each representative chemical. No post-remedy bed sediment replacement values were used for these points. If a point was located in an actively remediated area, it was considered to be remediated below the SQS and removed from further BCM modeling at that location.

5.2.4.2 BCM Equation Using Lateral and Upstream Input Parameters

For those locations where the concentration of any SMS chemical exceeded the SQS at the start of the modeling period, the BCM equation was run using Equation 5-1. The upstream and lateral input values discussed in Section 5.2.4.1 were employed for the chemical selected to represent that location. Equation 5-1 was also used to estimate exceedances at the end of 10 years for BEHP, a chemical that chronically exceeds the SQS and is generally associated with non-point source lateral discharges.

Because the lateral and upstream input parameters are on a dry weight basis, the BCM Equation 5-1 was run for the representative SMS chemicals using dry weight concentrations. For chemicals having oc-normalized SQS criteria, the resulting dry weight concentration after 10 years was compared to the starting dry weight concentration, yielding a percent reduction. The resulting percent reduction was then applied to the starting oc-normalized concentration. If the resulting value exceeded the SQS, then the station was considered to be an SQS exceedance at the end of the 10-year modeling period.

[11] Several locations were sampled only for PCBs.

5.2.5 BCM Output and Model Sensitivity

The output of the BCM is estimated chemical concentrations for each grid cell[12] at specified time intervals (i.e., 5, 10, 15, 20, 25, and 30 years). Summary statistics, such as LDW-wide and area-specific SWACs can be calculated for the distributions of chemical concentrations and used in assessing remedy effectiveness. Area-specific statistics can be defined to assess assumed beach play and potential clamming area-focused remedies. Sensitivity runs of the BCM are used to evaluate the effect of varying chemical concentrations associated with upstream and lateral source sediments and post-remedy bed sediment replacement values (in remediated areas) on bed sediment concentrations over time.

The sensitivity of the BCM was investigated by looking at how changes in input parameters affect the output (see Section 9).

5.3 Additional Analyses Related to Natural Recovery Potential

The STM and the BCM presented above address most of the processes that affect natural recovery. However, there are several processes not explicitly addressed in the RI (Windward 2010) and the Final STM report (QEA 2008) that are assessed in the FS. These include:

- The effect of tugs on sediments in berthing areas
- Additional model scenario runs using the calibrated STM to answer several specific FS questions
- Influence of grain size and organic carbon on sediment chemical concentrations.

The following is a discussion of these other processes that may affect natural recovery.

5.3.1 Propeller-Scour Model of Maneuvering Vessels

As discussed in Section 2, propeller scour from traveling tugs and barges in the LDW was evaluated in the STAR (Windward and QEA 2008). The analysis showed that the maximum scour from tugs transiting the navigation channel is approximately 3 cm in the navigation channel and approximately 5 cm on the benches. The higher potential scour on the benches is due to tugs traveling on the edge of the navigation channel adjacent to shallower depths on the benches.

This potential scour in the navigation channel and benches acts as a mixing process in the surface layer, augmenting the mixing induced by bioturbation (which is typically greatest within the top 10 cm of sediment). The STM assumes a 0- to 10-cm mixed layer

[12] The BCM analysis uses grid cell sizes of 10-ft by 10-ft, the same as those used for the IDW interpolation of surface sediment concentrations.

of sediment at the surface; hence, the effects of propeller scour associated with vessels moving in the channel are consistent with the STM assumptions.

However, the propeller scour analysis presented in the STAR is not applicable to tugs or vessels maneuvering in berthing areas where depths may be shallower than the navigation channel. Tugs may occasionally need to use more power while maneuvering barges in and out of berths, and tugs are present more frequently in berthing areas.

To analyze potential scour from tugs in berthing areas, two methods were considered. First, sun-illuminated bathymetric data were used to identify areas where there was visual evidence of tug-induced scour (see Section 2.2.1.1). The ridges and furrows identified from the bathymetry data were mapped into discrete areas (Figure 5-4) and used to help define what remedies were applicable within the AOPCs (Sections 6 and 8). Areas with higher or more frequent propeller scour are evident from the sun-illuminated bathymetric data. Furrows in the bed sediment take years to fill at sedimentation rates of only a few centimeters per year. Consequently, the sun-illumination data provide a historical record of areas affected by propeller scour.

Second, a modeling approach developed by the USACE was applied to the LDW. This model was developed with an analysis of currents and shear stresses induced by towboats and barges on the Mississippi River (Maynord 2000). The methods and model were used for computing bottom currents and shear stresses caused by moving barges and propeller scour in the LDW. A detailed discussion of the Maynord model is presented in Appendix C. Briefly, the model maps the velocity induced by the propellers that reaches the river bottom. The velocity and the sediment characteristics at the river bottom determine the amount of scour that will occur over a period of time. The velocity is related to the amount of power applied by the tug. However, tugs operate at higher power for shorter periods of time. The applied power under different operating conditions and durations was determined from interviews with tug operators. The analysis followed a similar approach as in the STAR (Windward and QEA 2008) using the same two tugs for model input parameters. The larger tug, *Sea Valiant*, operates downstream of the First Avenue bridge, while the smaller tug (*J.T. Quigg*) is able to operate in shallower water upstream of the bridge. Based on the analysis,[13] localized vessel scour as high as 25 cm may occur for tugs operating in shallow water and at higher power, as described by tug operators working under emergency conditions (see Appendix C). Vessel scour depth is strongly affected by water depth with substantially less scour in deeper water. For most berthing areas and operational conditions, the depth of scour is expected to be 10 cm or less, which would not necessarily expose buried concentrations.

[13] This analysis was limited to the vertical depth of the sedflume core data collected during the RI (about 30 cm).

Natural recovery over longer periods may still be occurring in areas with localized propeller scour. Propeller scour temporarily resuspends bed sediment, after which a portion of that material resettles in the same footprint with the coarser material more likely to resettle and fines more likely to be transported away depending on tides and currents. A constant source of incoming material from upstream also amends the bed sediment so that any exposed chemical concentrations are reduced over time. Regular maintenance dredging in active berthing areas indicates that net sedimentation is occurring and that sediment removal is required to maintain acceptable water depths for navigation. Empirical trends, where data are available, show that burial and sediment recovery are occurring in these scour areas (see Appendix F). Together with the fact that vessel power high enough to scour sediment deeper than 10 cm is used infrequently, MNR and ENR may be viable remedial technologies in these areas or where contaminated sediment is buried 25 cm or more. Berthing areas were considered on a case-by-case basis during development of technology assumptions.

5.3.2 Additional Special Scenario STM Runs

Six additional scenarios were run using the STM to further understand the movement of sediment particles within the LDW and the potential effects on the natural recovery analysis. The additional runs assessed:

1) Potential for recontamination of EAAs

2) Effect of more detailed distribution of discharges from lateral sources on the bed composition

3) Movement via tidal currents of resuspended sediment from reaches downstream of the Upper Turning Basin upstream into the Upper Turning Basin

4) Movement and deposition of sediment between Reaches 1, 2, and 3

5) Fate of sediment scoured from depths greater than 10 cm

6) Tracking of existing bed sediment movement.

A description of each of these scenarios and a summary of the results are presented in Table 5-4. A detailed accounting of these additional runs is presented in Appendix C. The findings of this work are generally consistent with the CSM (see Section 2) and support key assumptions and analyses inherent in the BCM and the assignment of remedial technologies (Section 8). The primary findings of the special scenario STM runs are discussed below.

5.3.2.1 Scenario 1: Potential Recontamination of EAAs

The purpose of this scenario was to assess the potential for remediated EAAs to be recontaminated over time by areas located outside of the EAA footprints that would be allowed to recover naturally. This may affect decisions concerning the timing and sequencing of remedial activities at specific EAAs.

The results of this analysis indicate it is unlikely that remediated areas will be recontaminated by unremediated areas unless the areas are adjacent to each other. Material resuspended from unremediated areas during storm events is expected to account for less than 5% of the material that settles in remediated EAA footprints over a 10-yr period[14] (see Figure 5-6). The BCM analysis on this scenario indicates that recontamination of EAAs above the SQS is more likely to occur near outfalls as a result of lateral source inputs than to scour and settling of bed sediment from outside EAAs.

5.3.2.2 Scenario 2: Distributed Discharges from Lateral Sources

This scenario examined certain simplifying assumptions that were used in the STM for lateral discharge locations (for storm drains, and streams), and refined those assumptions to better account for actual lateral discharge distribution. In the original STM (QEA 2008), all Duwamish watershed discharges were aggregated into 16 discharge points along the LDW. The discharge points consolidated total area runoff from storm drains to the major outfalls and did not include the more widely distributed smaller outfalls located along the shoreline. CSOs that discharge to the LDW were also included, but these were modeled at their actual locations.

In this distributed discharges modeling scenario, finer drainage basin delineations were used to more accurately reflect actual drainage subbasins and outfalls (pipe locations) of storm drains, resulting in 13 major storm drains, 9 CSOs, and 11 waterfront areas that discharge to the LDW through numerous small outfalls. The revised load estimates and drainage basins for storm drains, creeks, and City CSOs were presented in (SPU 2008) and are summarized in Appendix C. Because the distributed load simulation is considered to more accurately represent the distribution of lateral loads along the shoreline, it is therefore carried forward as the FS base case loading condition. The lateral loads used in the FS base case are shown in Figure 5-7.

5.3.2.3 Scenario 3: Movement of LDW Bed Sediment into the Upper Turning Basin

This scenario examined the degree to which bed sediments from elsewhere in the LDW may become resuspended, transported upstream, and deposit in the Upper Turning Basin (above RM 4.0). The Upper Turning Basin sediment composition and chemistry is only minimally affected (less than 0.01%) by sediment moving upstream with tidal currents (Figure 5-8). Figure 5-8 shows the geographic distribution of sediment settling

[14] Only a few grid cells have been indentified as having non-EAA source material in the range of 5 to 20% and most of these are in Reach 2. The average across the LDW is generally less than 5%.

in Reach 3 but originating from downstream of RM 4.0 (from Reaches 1 and 2). Only the area between RM 4.0 and 4.1, Slip 6, and a few other isolated grid cells in Reach 3 are estimated to have more than 0.01% sediment contribution from bed sediment downstream of RM 4.0, and even these areas are less than 0.05%. This estimate is in agreement with the 10-year sediment mass balance, which indicates that about 240 MT moves from Reaches 1 and 2 and is expected to deposit in Reach 3 (see Scenario 4). This is extremely small compared to the expected total sedimentation in Reach 3 of 2.3 million MT over 30 years; 99.99% of this sedimentation is from upstream sediments. Based on this analysis and the contribution from lateral loads (see Section 5.3.2.2), the sediment in the Upper Turning Basin and the navigation channel above RM 4.1 should not be adversely affected by sediments transported from other portions of the LDW. The BCM analysis for this scenario shows that the predicted COC concentrations in the Upper Turning Basin are for the most part below the SQS and negligibly affected by the amount of sediment deposited from downstream. This analysis also supports the use of Upper Turning Basin sediments in the navigation channel (RM 4.3 to 4.75) as representing the COC concentrations in sediments originating from the Green/Duwamish River.

5.3.2.4 Scenario 4: Movement of Bed Sediments between Reaches

This scenario examined the degree to which bed sediments in one reach of the river may be resuspended and transported to another reach. These results may be important in assessing recontamination potential between reaches and in assessing if locations would be important for sequencing the remedial alternatives. Sediment exchange (either upstream or downstream) is strongest between Reach 1 and Reach 2, while Reach 3 primarily contributes sediment to downstream reaches with very little sediment transported from downstream reaches back to Reach 3 (Figure 5-9). In addition, much of the bed sediment that is resuspended in a reach resettles in that same reach.

Reach 3 receives a large amount of sediment from the Green/Duwamish River as a combination of suspended load and bed load, the latter consisting mostly of sand. Sediment that settles in Reach 3 largely remains in Reach 3, with only about 22% of the solids resuspended and transported downstream. This reach is regularly dredged by the USACE, particularly in the Upper Turning Basin. Maintenance dredging has little effect on natural recovery as it removes sand that is not readily transported downstream and therefore is not a significant component of net sedimentation and natural recovery in Reaches 1 and 2.

5.3.2.5 Scenario 5: Sediment Scoured from Greater than 10 cm Depth

This analysis was conducted to show the fate of subsurface sediment scoured by an extreme high-flow event. Scour during a 100-year high-flow event was analyzed in the STM report as a 30-day simulation (QEA 2008). Scour in excess of 10 cm depth (up to

about 22 cm) occurs in portions of the LDW from RM 2.9 to RM 3.9 and in isolated areas between RM 4.2 and RM 4.7.

Sediment scoured from below 10 cm during a 100-year high-flow event was modeled over a 10-year period. In Figure 5-10a, the STM estimates that approximately 200,000 MT of sediment settles in the LDW during a 100-year high-flow event and of that amount, approximately 70,000 MT is eroded from the bed. However, as shown in Figure 5-10b, only about 6,600 MT of the sediment that settles is eroded from below 10 cm, which is only about 3% of the deposition during the 100-year high-flow event. Consequently, sediment eroded from below 10 cm during high-flow events, and mostly from Reach 2, makes a negligible contribution to sediment transport and deposition in the LDW during those high-flow events. About 50% of eroded material redeposits in the same reach and makes a very negligible contribution to the potential for redistribution of subsurface chemicals during high-flow events. Among sediment cores in these potential scour areas, very few had SQS exceedances and those with exceedances were located in or adjacent to EAAs (see Appendix C, Part 4).

The areas with greater than 10 cm of scour total about 22 acres. Core data indicate that only a few of these areas have chemical exceedances above the SQS or CSL. The total area with surface exceedances above the SQS in areas with more than 10 cm of scour during high-flow events is 5.4 acres; of that, 1.5 acres are in the EAAs. Given the small mass of sediment scoured from below 10 cm and the few exceedances of the SQS in these areas, any effect on sediment quality will be negligible.

5.3.2.6 Scenario 6: Movement of Existing Bed Sediment

This scenario was conducted to track the movement of sediment within the LDW. In the BCM, the COC concentration in the bed sediment at a given point is assumed to be unchanged through time. This means that the COC concentration changes at any given location are attributable only to the net sedimentation of upstream and lateral load sediments and mixing with bed sediments at that location. In actuality, bed sediments from other areas of the LDW are resuspended and settle throughout the waterway. The movement of resuspended bed sediment and its effect on COC concentrations was evaluated by separately tracking the deposition of resuspended bed sediment and original bed sediment over time. This allows the COC concentration to change due to deposition of bed sediment as well as deposition of upstream and lateral load sediments. The analysis results are presented in Appendix C, Part 5 (LDW STM Bed-tracking Scenario Simulation). This analysis was conducted with the assumption that remediation of the EAAs had been completed.

This analysis indicates that accounting for bed sediment movement produces either no change or a slightly lower total PCB SWAC at the end of 10 years, both on a site-wide and reach-wide basis (Table 5-5). The calculated PCB SWAC when this effect is considered is unchanged in Reaches 1 and 3, and 6% lower in Reach 2. Riverwide, the

change in calculated SWAC is approximately 1%. The changes are small because throughout the LDW, resuspended sediment that resettles in the LDW is a small component of the sediment mass balance. The resuspended bed sediment that settles in the LDW is only 5%, 12%, and 9% of the sediment mass balance in Reaches 1, 2, and 3, respectively. In Reach 2, which has the highest fraction of bed sediment that resettles, most of the sediment that resettles originates in Reach 3, where total PCB concentrations are generally lower than in the other reaches. Overall, this simulation shows that redistribution of existing bed sediment by storm events has a minor effect on recovery predictions, except in Reach 2. The approach used in the BCM base case analysis likely underestimates natural recovery in Reach 2 compared to a model that actually tracks the movement of individual sediment particles.

5.3.3 Influence of Grain Size and Organic Carbon on Sediment Chemistry

Hydrophobic compounds, such as PCBs, more readily adsorb to the organic substances attached to sediment particles rather than to the inorganic surface of sediment particles. As a result, the amount of organic carbon influences the potential adsorption of PCBs (and other hydrophobic COCs) to the particles. This phenomenon is well documented in the literature and can affect the distribution and bioavailability of chemicals. To account for this preferential partitioning, dry weight values are often normalized to the amount of organic carbon present in a sample (i.e., oc-normalization; Michelsen 1992). Many of the SMS chemicals have oc-normalized criteria.

The fraction of organic carbon (f_{oc}) of sediments typically varies as a function of the surface area to volume ratio; Hedges and Keil (1995) found f_{oc} is directly proportional to the surface area per gram of mineral. Comparison to empirical data demonstrated this differentiation by particle size/surface area (Wang and Kellor 2008). A study evaluating near-field deposition from outfalls (Fujisaki et al. 2009) used the particle size classes for upstream and lateral sources to calculate the settling velocities and f_{oc}, and then used the f_{oc} to settling velocity ratio to assign chemical concentration values to the particle size classes based on the relationships described above. The results showed higher concentrations among the finer particle fractions and lower concentrations associated with coarser sand fractions. The BCM could be used to incorporate either the effect of sediment particle size or surface area on natural recovery by assigning different concentrations to the different sediment classes from the STM. This may be particularly important in the LDW as the grain-size distribution gets finer from upstream to downstream (Figure 5-11). The potential for this effect can be seen by comparing concentrations of data that are not adjusted for carbon content or fines to those that have been adjusted in Table 5-6.

5.4 Empirical Trends and STM/BCM Reliability

The reliability of the STM to estimate net sedimentation rates, and of the BCM to predict changes in chemical concentrations, is supported by empirical trends (i.e., net

sedimentation rates from time markers in cores and changes in chemical concentrations over time). Consistency between empirically-derived net sedimentation rates and the STM and between the BCM and empirical trends in COC concentrations in surface sediments lends credibility to the STM/BCM prediction of MNR in the future. Chemical trends in surface sediments were evaluated both by changes in risk-driver chemical concentration by depth in cores and by changes in chemical concentrations over time at resampled surface sediment locations. Appendix F presents these empirical data and the methods by which these data were evaluated. This section summarizes the findings presented in Appendix F.

Net sedimentation rates calculated from time markers in cores support the rates estimated by the STM, while chemical trends in most cores and at most resampled surface sediment stations show reductions in chemical concentrations over time; both demonstrate that recovery is occurring (as discussed and presented below for total PCBs, cPAHs, and other SMS chemicals). In areas where these lines of evidence are not similar either to one another or to the STM outputs, or where recovery is not predicted by the BCM, more attention is given to ascertain the reasons for these differences (see Appendix F). In some small-scale areas, the empirical evidence may suggest that recovery is not occurring, and these lines of evidence are used to delineate recovery categories (see Section 6).

5.4.1 Net Sedimentation Rates

Net sedimentation rates were estimated using cores collected in the LDW where time markers could be identified. These markers provide evidence of new material being deposited in the LDW, showing that burial, the dominant recovery mechanism, is occurring. The time markers were used to validate the net sedimentation rates estimated by the STM, and this validation is discussed in Appendix F of the STAR report (Windward and QEA 2008). This analysis is also discussed in Appendix F of this FS. In the RI (Windward 2010), the depth of the peak total PCB concentration in each core was used to support the sedimentation rates estimated from the STM, and this analysis is discussed below in Section 5.4.1.1.

The core data indicate that net sedimentation rates are often higher than those estimated by the STM, and that the majority of the time, the STM underestimates actual net sedimentation in the LDW. Therefore, the model provides a conservative estimation of net sedimentation.

5.4.1.1 Vertical PCB Concentration Trends Compared to Net Sedimentation Rates

The PCB "peak" analysis presented in the RI (Windward 2010) combined information on depth patterns in PCB sediment chemistry (from sediment cores) with net sedimentation and erosion estimates from the STM to determine whether vertical patterns of total PCB concentrations are consistent with the STM's estimated net sedimentation rates and the CSM (Figure 5-13). Much of the sediment contamination in

the LDW, and particularly PCB contamination, is believed to have originated from historical sources in the LDW.[15] In undisturbed depositional areas with no on-going or recent sources, PCB concentrations should be higher in deeper core intervals than in shallower intervals. In areas with little or no deposition, localized disturbances, or on-going or recent secondary sources (e.g., erosion of contaminated upland soil), this pattern may be reversed, with higher PCB concentrations in the shallowest core intervals.

Assuming that an area is depositional and has not been disturbed, the depth of the maximum total PCB concentration within a core should be a function of both the time since peak PCB use and release and the estimated rate of net sedimentation (from the STM). As a result, the expected depth of peak (or maximum) total PCB concentration was estimated for each core using Equation 5-2.

$$D = (T_c - T_m) \times S \qquad \text{Equation 5-2}$$

Where:

- D = expected depth of peak total PCB concentration (cm)
- T_c = year of core collection
- T_m = assumed year of maximum concentration in surface sediment, corresponding to the assumed peak in PCB use and releases to the LDW
- S = net sedimentation rate (cm/yr) estimated from the STM for the grid cell containing the core (or the closest grid cell for cores outside the STM domain).

General uncertainties associated with estimating the depth of the peak total PCB concentration include uncertainties in the net sedimentation rate estimated by the STM and uncertainty in the estimate of the year of the peak release of PCBs. In addition, uncertainty is associated with identifying the exact depth of the peak total PCB concentration within a core because of compositing within each core section. Uncertainty is particularly high at locations where the core intervals analyzed were 3 feet (ft) or greater and is lowest at locations where the core was sectioned into 0.5-ft intervals. Location-specific uncertainties include the possibility of sediment disturbance near berthing areas or local structures, and the potential for localized PCB releases to continue after the peak use/release date. To address the uncertainty in the year of maximum historical PCB releases to the LDW, a range of estimated depths of the peak total PCB concentration was calculated for each core (i.e., estimated depths within each

[15] Peak PCB use was recorded in Puget Sound sediment cores between 1960 and 1970 (Van Metre and Mahler 2005; Battelle 1997); the commercial production of PCBs was banned in 1978, and they were subsequently phased out.

core were calculated by assuming maximum PCB releases in 1960, 1965, and 1974).[16] These depth estimates were then compared to the depth of the peak total PCB concentration in each core. If the observed depth of the peak total PCB concentration was at or deeper than the estimated depth, the core was considered to be consistent with the CSM, and with the STM's estimated net sedimentation rates.

Of the 366 cores available in the RI dataset, 157 cores were used in the analysis and 209 cores were not used because the type of information needed for the analysis was not available for those cores. Cores were excluded if at least one of the following conditions were met:

- Only one core interval was analyzed for total PCBs
- No core interval was analyzed within the depth range of the expected peak
- PCBs were not detected in any core interval
- The sediment was disrupted by dredging prior to sampling.

Of the 157 cores included in the analysis, 110 cores (70%) had peak total PCB concentrations at depths equal to or greater than the estimated depths, consistent with the STM's estimated net sedimentation rates. Forty-seven cores (30%) had maximum total PCB concentrations that were shallower than the estimated depth range based on net sedimentation rates from the STM, or the concentrations were too diffuse to detect a significant peak at depth. Thirty-two of these 47 cores were located in areas with either very low net sedimentation rates or in areas where source investigations have suggested the potential for on-going releases of PCBs.

However, even where the empirical data suggest sedimentation rates are lower than those estimated by the STM (or that sources were on-going longer than estimated), the empirical data are still demonstrating that sedimentation, and thus burial of PCB-contaminated sediments, is occurring.

5.4.2 Chemical Trends at Resampled Surface Sediment Locations

Generally, chemical trends in resampled surface sediment locations show that recovery is occurring site-wide, which supports the BCM findings of decreasing chemical concentrations over time. Resampled surface sediment locations are surface sediment samples collected at different times from the same station (within 10 ft of one another). The chemical concentrations in the LDW surface sediments are heterogeneous, but restricting the distance between older and newer locations to 10 ft reduces the uncertainty introduced by comparing samples from different locations. Appendix F

[16] The analysis used both nationwide trends for PCB peak release (1960 and 1965; Van Metre and Mahler 2004; Battelle 1997), and the year of a PCB spill in Slip 1 (1974; Blazevich et al. 1977).

describes the details, statistical results, and limitations associated with this type of comparison (analytical accuracy, etc.).

In the FS dataset, the data from 70 resampled stations (67 locations with 3 outliers excluded, and excluding those collected at the Norfolk Area and Duwamish/Diagonal EAA remediation sites) were grouped into two populations: older/resampled data and newer data (see Table 5-8). The statistical difference between total PCB concentrations in these two groups was evaluated to provide evidence of general LDW-wide trends using simple data distributions. The comparisons of total PCB concentrations between the older and newer data show a 23% decrease in the mean value. As shown in Table 5-8, the 25th and 90th percentiles of these datasets also decreased by 31% and 64%, respectively, revealing that, in general, the empirical data support the STM findings that the LDW is recovering (at least for PCBs). Table 5-8 also summarizes these trends for arsenic, cPAHs, and BEHP. These data demonstrate that, on average, chemical concentrations are decreasing over time (≥ 50% reduction in concentration) and arsenic is in equilibrium. Station-by-station results are presented in Appendix F for total PCBs, arsenic, cPAHs, BEHP, and SMS chemicals with detected exceedances in either the newer or older data.

5.5 Uncertainties Related to Predictive Modeling

The goal of an uncertainty analysis is to both qualitatively and quantitatively define the degree of confidence that exists with the site characterization data, both conceptual and predictive site models, and predictions of the results of remedial actions to the degree possible.[17] Bounding the certainty of estimates, especially in modeling, is a developing science. In accordance with an EPA guidance document (EPA 2005), the potential areas of uncertainty to be identified and addressed in an FS include the CSM, data uncertainty, temporal uncertainty, spatial variability, and quantitative uncertainty. Several elements of uncertainty related to the predictive models (STM and BCM) are described below.

5.5.1 Net Sedimentation Uncertainty

Extensive sensitivity analyses were conducted on the STM and are described in detail in the STM report (QEA 2008). Sensitivity analyses were conducted on both high-flow event simulations and long-term, net sedimentation simulations. The net sedimentation sensitivity analysis showed that the model was most sensitive to the upstream sediment load and the settling speed of the fine-grain sediment classes, which make up the

[17] Uncertainty analysis is separate from a sensitivity analysis. A sensitivity analysis looks at the effect of changing input values on the model results. The changes in input values are often extreme and may not be realistic, but are designed to stress the model and produce changes from the calibrated model results. Uncertainty analysis should be based on realistic and statistically defensible methods for developing a reasonable set of input parameters and conditions, which are then used to produce a range in model results for decision-making purposes.

majority of the incoming sediment load. The net sedimentation uncertainty analysis used the same input parameters and ranges as the sensitivity analysis and therefore is an extension of the sensitivity analysis. A more appropriate measure for uncertainty in model predictions and application in this FS is the spatial scale analysis (QEA 2008; see Figure 2-13 from the STM Report). This analysis examined the accuracy of the model with respect to estimating net sedimentation rates from the large scale (LDW-wide) to the small scale (location-specific areas). This analysis found that the capability of the model was not affected by spatial scale (minimal bias), and that on average, the model is able to estimate net sedimentation rates to within ±0.5 cm/yr on a typical net sedimentation of 1 cm/yr.

The incoming sediment load and depth of scour are affected by high-flow events. The STM used Green/Duwamish River flows from 1960 to 1989 as input flows. The maximum flow rate and upstream sediment loading for these years are shown on Figures 5-14a and 5-14b. The figure indicates that the upstream sediment load was below average for the first 10 years of the simulation. Consequently, the STM and BCM are conservatively predicting natural recovery through the first 10-year modeling period.

The flow period represented in the STM (1960 to 1989) and shown on Figures 5-14a and 5-14b is representative of current conditions. Annual precipitation since 1989 and up to the present has not changed significantly. Global warming is also not expected to change average annual precipitation significantly (Mote and Salathe 2009). By the late 1990s, when the USGS sediment loading study was conducted, the Green/Duwamish River basin was already under control by the Howard Hanson Dam and heavily developed among agricultural, urban, and suburban land uses. For these reasons, river flows and sediment loads are not expected to change substantially in the future as long as the river flow continues to be dam controlled in a manner generally consistent with historical water management practices.

5.5.2 STM Uncertainty – Lower and Upper Bound Simulations

The effects of uncertainty in STM inputs on model estimates were analyzed and quantified in the STM report (QEA 2008; see Section 2.8 and Appendix D.6). The results of the input parameter sensitivity analysis were used to generate "realistic" lower- and upper-bound limits on the base-case results, which are based on the calibration parameter set. The base-case simulations provide the best estimates of net sedimentation rate, but the lower- and upper-bound simulations provide an acceptable range of net sedimentation rates resulting from uncertainty in model inputs, with the "true" value of net sedimentation rate being within this range. However, it should be noted that the upper- and lower-bound simulations were shown to be significantly less accurate than the base case and that these bounded simulations would not be considered acceptable calibrations with respect to the data. Consequently, use of these

bounding simulations is only made to demonstrate the effect of model parameters on model results, but should not be used for predictive purposes or model error estimates.

To demonstrate the effect of model parameters on long-term changes in bed composition, the upper and lower bound results have been analyzed and used to estimate uncertainty in the predicted half-time of bed-source content in surface-layer (0-10 cm) sediment for the long-term, multi-year (e.g., 21-year calibration period) simulations. Half-time values of bed-source content in surface-layer sediment were estimated using relationships between net sedimentation rates and half-time values developed from model results presented in the STM report (QEA 2008). The approximate relationship between half-time of bed-source content and net sedimentation rate can be used to estimate the spatial distributions of half-time and recovery potential if the starting concentrations are known.

Generally, the half-time of bed-source content in surface-layer sediment tends to decrease as net sedimentation rate increases, see Section F.2 and Figure F-37 of the STM report (QEA 2008). In general, most areas have a half-time of less than 10 years based on net sedimentation rates of 1.0 cm/yr or more. This analysis indicated a general trend of decreasing half-life of bed-source content with an increasing net sedimentation rate. The spatial distributions of net sedimentation rate for the lower- and upper-bound simulations are shown in figures in Appendix C, Part 6. The best-fit model prediction from the bounding exercise is about 5 to 10 years (±5 years if the net sedimentation rate is more than 1 cm/yr and longer with lower net sedimentation rates). Because the bounding exercise does not represent the calibrated dataset, this characterization of uncertainty is more appropriate for those regions farther from the locations where the model was calibrated. Areas near calibrated locations have significantly lower levels of uncertainty. This level of uncertainty is acceptable for the FS. The uncertainty in the reasonable lower and upper bound STM runs and its effect on PCB concentrations are discussed in Section 5.5.4.

5.5.3 Uncertainty around the Recommended BCM Chemical Input Values

For the BCM, uncertainty exists in the assumptions about chemical concentrations in lateral and upstream sources (from both non-point and point sources). This uncertainty will exist well into the future based on the variable nature of these sources, but is managed by expressing BCM inputs as a range of concentrations (low, high, and best estimate values). These input values are based on actual data collected over the past 20 years. BCM uncertainty is managed by bracketing the best-estimate BCM value with lower- and upper-bound BCM input values representing the mean, UCL95, or percentiles of the existing data. For the lateral inputs, the low and high estimates are meant to capture a range of uncertainty associated with potential future source control measures.

These input values were generated by summary statistics from various datasets (surface water, surface sediment, in-line sediments, catch basin solids, etc.). Each dataset has some degree of sample uncertainty associated with it, relating to aspects such as the matrix from which the sample was collected, the location from which the sample was collected, the differences in TOC and grain size among the datasets, the time (season, river flow, portion of storm event [e.g., first flush]) of sample collection, on-going source control efforts, and other aspects that can affect chemical concentrations in a sample. The high end of the range (high lateral, high Green/Duwamish River, and high post-remedy bed sediment replacement values) is intended to capture variability in the source concentrations, worst-case recontamination potential, and regular, seasonal high flows from urbanized areas. The low end of the range (low lateral values, low Green/ Duwamish River, and low post-remedy bed sediment replacement values) represents a non-conservative set of assumptions that is considered likely to underestimate future chemical concentrations. The probability that site conditions will produce a high-high-high chemical concentration (lateral, Green/Duwamish, bed) is on the order of 0.001.[18] Similar probability of occurrence exists for the low-low-low end of the range.

Another source of uncertainty related to lateral inputs is the fact that lateral contributions to the LDW can come from many different sources, including storm drains, CSOs, overland sheet flow, surface water runoff, and atmospheric deposition anywhere along the LDW and in its drainage basin. These sources were aggregated into 11 waterfront areas and 16 discharge points to the LDW for the purposes of sediment transport modeling. Of these, only the CSOs have measured discharge flows; runoff flows are estimated for other discharges. Some localized discharge points may not be adequately characterized by the 11 general waterfront areas. In addition, CSO control plans will result in reduced flows in the future for many CSOs.

Similar uncertainty exists for the post-remedy bed sediment replacement values used as input in the BCM. These values represent the bed sediment chemical concentrations in the near-term (0 to 2 years) following completion of active remediation, including influence from multiple recontamination mechanisms. Evidence from other sediment sites shows that post-construction COC concentrations become higher than detection limits and natural background after this initial time frame. Limitations in the dredging/capping equipment leave behind dredging residuals that resettle within the remedial footprint. Residual COC concentrations are typically proportional to the average COC concentration of the dredged material, and typically higher than the COC concentration in surrounding sediments (see Section 9.8.3 for discussion on dredging

[18] As an example, the upstream input for total PCBs is based on the UCL95 for a data set that has some of the highest concentrations and the lateral load is based on a 90th percentile (excluding data where source control will likely reduce the highest observed concentrations). The bed replacement input assumes that remediated areas will be dominated by local sediments rather than by clean imported fill, which is an unlikely assumption. Assuming even a 20% probability for the high bed replacement value yields a probability of occurrence for the high-high-high input values at about 0.001.

residuals). Post-construction surface sediments in the LDW may come into equilibrium with the sediments surrounding the remediated area. The equilibrium concentration of COCs in the sediment bed may be higher than the COC concentration in upstream sediments because of increased urbanization as one moves downstream toward downtown Seattle (more cars, vessel traffic, non-point sources, air emissions, accidental spills, and storm drain runoff). To address this uncertainty, the best-estimate for the post-remedy bed sediment replacement value is bracketed by low and high BCM input values that are a combination of clean backfill material (based on natural background concentrations) and the surrounding unremediated sediments, assuming various proportioning percentages, as described in Section 5.2.3.4.

By using many lines of evidence and a range of input values derived from these data, some quantitative analysis of the uncertainty is provided, and confidence in the model representing long-term conditions over time is increased. However, it is also uncertain how these input concentrations may change over time. In summary, these BCM input values are considered adequate for the purposes of assembling remedial alternatives (Section 8) and evaluating the short- and long-term effectiveness of the alternatives (Section 9) in the FS.

5.5.4 Combined STM and BCM Uncertainty

Both the STM and BCM have uncertainty associated with model input values. Uncertainty in STM predictions that result from uncertainty in the input parameters was extensively examined in the STM report (QEA 2008). The uncertainty analysis in the STM report was used to develop reasonable and maximum reasonable upper and lower bounding simulations. These simulations provide a realistic range of net sedimentation rates for the LDW. The reasonable and maximum reasonable upper and lower bounding simulations were used to examine the effect of STM uncertainty on BCM results. The results from these bounding simulations are discussed in Section 5.5.2 above and in Appendix C, Part 6. Uncertainty in the BCM chemistry input values is discussed in Section 5.5.3.

The STM base-case composition results were taken at the end of the 10-year model run for reasonable and maximum reasonable upper and lower bounding simulations as input to the BCM to compute the total PCB SWAC for each simulation following remediation of the EAAs. This analysis is presented in Appendix C, Part 6. The reasonable lower to upper STM simulations produced a range in total PCB SWACs from 65 to 101 µg/kg dw or about -16% and +31% from the base case prediction, respectively (see Appendix C, Part 6, Table 5). Similarly, the maximum reasonable lower to upper STM simulations produced a range in total PCB SWACs from 62 to 104 µg/kg dw or about -19% and +35% from the base case prediction, respectively. However, the STM base case with lower to upper BCM input values produced a range in total PCB SWACs from 49 to 122 µg/kg or about -36% and +58% from the base case prediction, respectively. The analysis showed the total PCB SWAC is more sensitive to

the range of BCM chemistry input values than it is to the range of net sedimentation rates from the reasonable upper and lower or the maximum reasonable upper and lower bounding STM simulations. The range of total PCB SWAC values attributable to STM and BCM uncertainty is illustrated in Appendix C, Part 6, Figure 11.

5.5.5 BCM Input Values for Other SMS Chemicals

A total of 41 COCs with SMS criteria were identified for the protection of benthic infauna. It was not practical to run the BCM 41 times to evaluate recovery potential for every SMS chemical. Therefore, a smaller subset of representative chemicals was selected because:

- Many of these chemicals co-occur with other chemicals (e.g., PAHs)
- Groups of chemicals have similar modes of toxicity (e.g., phthalates)
- Lateral data have not been collected, or at least compiled, for every chemical
- Many of these COCs do not have widespread SQS exceedances in the LDW.

Application of the BCM using representative SMS chemicals is based on the fact that the representative chemicals account for the majority of the SQS exceedances and the assumption that all SMS chemicals within a group will behave/recover in a similar manner. Uncertainty exists with this simplifying assumption. In reality, each SMS chemical may have a different starting concentration, recovery and/or recontamination potential, sediment-water partitioning dynamics, bioavailability based on organic carbon content, and lateral and upstream sources. Estimated exceedances of the SQS and CSL at the end of the 10-year modeling period may be biased high or low relative to the representative chemical predictions. This uncertainty will be managed during remedial design and by refinement of the CSM for remedial areas.

5.5.6 Age and Spatial Extent of Chemical Data

Over the past 18 years, numerous site investigations have been conducted to determine the nature and extent of sediment contamination associated with past and present chemical releases. These investigations have included in-water site investigations involving surface and subsurface sediment sampling, toxicity testing, shoreline habitat inventories, seep surveys, and porewater sampling. These data have been aggregated into the FS baseline dataset. There is some remaining uncertainty associated with these data related to detection limits that exceed the screening criteria, especially in older data; chemical compositing with depth; and interpolation between sampling points. However, the largest source of uncertainty is the age of the data. Many of the surface sediment data comprising the FS baseline dataset are over 10 years old and do not represent true "current" conditions. Active remedial technologies are being assigned to particular areas based on surface sediment exceedances that may have improved (or worsened) over the past few years. Since the CSM and empirical data have shown that

the LDW is recovering (in many areas), there is likely a high bias introduced into the assembly of alternatives. Remedial alternatives are being assembled on fairly conservative assumptions that no recovery has occurred during the years since the data were collected to now. This source of uncertainty is being managed in two ways: 1) the modeling effort is conservative and does not account for 10 years or more of potential recovery from when the sample was collected; and 2) areas with older data, but which are expected to recover, will be subject to verification monitoring (see Section 6) to ensure compliance and recovery. Other sources of data uncertainty such as vertical and horizontal extent of contamination, elevated detection limits, and SMS compliance may also be refined during remedial design.

5.5.7 Chemical Degradation and Transport Processes

Many of the LDW risk-drivers (total PCBs, cPAHs, BEHP, arsenic, dioxins/furans, and other SMS chemicals) have similar fate and transport properties in that they are strongly bound to sediment particles and do not readily degrade. Compounds that readily degrade or desorb from sediments are not persistent in sediments because the concentration declines naturally over time. Persistent chemicals cause long-term sediment contamination. The following discussion focuses on PCBs because a large body of research exists for this COC at many sites across the country. However, for most of the COCs, degradation and desorption processes decrease the concentration of the chemical in sediment over time. By not accounting for these processes, the analysis is conservative with respect to sediment contamination and natural recovery because it will overestimate both long-term sediment concentrations and natural recovery.

PCBs, in particular, are stable compounds that do not degrade easily. Under certain conditions, they may be broken down by chemical, thermal, and biological processes (Erickson 1986). In the environment, photolysis (breakdown by light) is the only significant chemical degradation process, but it is not likely a significant means of PCB losses from sediments because of low PCB solubility and limited penetration of sunlight into the solid media (the sediment bed) (Hutzinger et al. 1974). Microbial processes are the main route of environmental degradation of PCBs in sediments. Reductions in the sediment concentrations of PCBs can happen via desorption from sediments into the overlying water column and volatilization. The breakdown of PCBs is generally discussed below, and implied for many other risk-driver chemicals; it is assumed to be occurring in the LDW although these processes have not been modeled in the FS. However, changes in PCB concentrations in the sediment bed can be translated to predicted concentrations of PCBs in fish and shellfish tissue via the PCB food web model developed for the LDW (Appendix D of the RI, Windward 2010). The food web model accounts for chemical fate and transport mechanisms within the food web and changes in seafood consumption risks.

5.5.7.1 Microbial Degradation

The viability of biodegradation as a natural method of sediment recovery for sediment-bound PCBs has been documented in several studies (RETEC 2002; Appendix F).

PCBs can undergo microbial degradation in natural environments under both aerobic (i.e., in the presence of oxygen) and anaerobic (i.e., in the absence of oxygen) conditions. PCBs are a class of 209 individual chemicals (PCB congeners), in which 1 to 10 chlorine atoms are attached to a biphenyl molecule. Most Aroclors (commercially produced groups of PCBs) contain 60 to 90 different PCB congeners, with varying numbers and positions of the chlorine atoms on the biphenyl rings.

Microbes degrade PCBs by breaking the carbon-to-carbon bond of PCBs, or by substituting the chlorine atoms with hydrogen atoms in the PCB molecule under aerobic and anaerobic conditions, respectively (McLaughlin 1994). The latter method results in the transformation of PCB congeners into other less chlorinated PCB congeners in a process called dechlorination (Abramowicz 1990). Aerobic degradation, on the other hand, results in a net PCB loss from a given PCB inventory. In river sediments, aerobic conditions are typically found in the top few centimeters of the sediment bed, while anaerobic conditions are found at greater depths below the sediment surface.

Aerobic Degradation

Even though laboratory studies have documented the existence of naturally occurring aerobic bacteria capable of degrading a large spectrum of PCB congeners, there is little direct evidence indicating that the aerobic degradation process is effective at reducing the PCB mass under field conditions. In laboratory studies of the Hudson River, PCB losses were highest in the less chlorinated congeners (43 to 47% reduction) and lowest in the more chlorinated congeners (17 to 5% reduction) (Harkness et al. 1993 and 1994). The in-field studies yielded similar results (less than 50% reduction). A study of PCB patterns in Green Bay sediments suggests that aerobic degradation is not a significant transformation mechanism for those sediments (McLaughlin 1994).

Anaerobic Dechlorination

Reduction through dechlorination (under anaerobic conditions) is generally viewed as a viable means of biodegradation for numerous compounds, including PCBs at higher concentrations. This process can alter the toxicity of these compounds and make them more readily degradable. The extent to which PCBs can degrade depends on several factors (Bedard and Quensen 1995), including the nature of the active microbial population, the type of chlorine substitution, the chlorine configuration, the initial PCB concentration, and the substrate conditions (temperature, redox conditions, ionic strength, amount of carbon, and presence of other oily contaminants, etc.). For example, no anaerobic dechlorination of PCBs was observed in the downstream deposits of the Fox River where the maximum PCB concentration was approximately 30 mg/kg dw

(limited effectiveness at lower concentrations). Dechlorination activity was limited to sediment PCB concentrations of 30 mg/kg dw or greater (McLaughlin 1994). The overall PCB loss due to microbial degradation in several Fox River sediment deposits was estimated to be less than 10% with respect to the original inventory of PCBs deposited in the river.

A similar threshold for degradation of 50 mg/kg dw was observed in Sheboygan River sediments (David 1990). For Grasse River sediments (Minkley et al. 1999a and 1999b), some dechlorination activity was suggested at total PCB concentrations below 7 to 10 mg/kg dw, but the statistical evidence of dechlorination was less strong than at higher concentrations. Attempts in a laboratory study to further dechlorinate Fox River sediments met with limited success and similar results, up to 10% dechlorination on a total chlorine basis (Hollifield et al. 1995).

In the Fox River, physical loss through desorption from sediments (into the water column) exceeded any biodegradation in the sediment. It was estimated that 33% of the original PCB mass originally deposited in the Lower Fox River was lost due to desorption.

5.5.7.2 Volatilization and Desorption

Volatilization and desorption remove contaminants from sediment particles without changing the chemical make-up of the contaminant. In desorption, the contaminant is removed from the sediment and becomes dissolved in water. Volatilization is the process of a contaminant going into the gaseous state and being released to the atmosphere.

Both of these processes are relatively weak for the COCs in the LDW. For instance, all of the inorganic compounds, with the exception of mercury and low molecular weight PCBs, generally do not undergo volatilization. For PCBs, volatilization into the air can be important in shallow arable soils, but less so for subsurface soils (Meijer et al. 2003). Limited volatilization of some organics could occur from exposed intertidal sediments at low tides, but this transport mechanism would be further limited by the high water content of the sediments. COCs may diffuse from sediment into porewater and then into the water column and/or atmosphere, but these transport pathways occur at very slow rates. Because subtidal sediments are covered with water and not in contact with the atmosphere, a very limited amount of volatilization occurs from dissolved PCBs in the water column, rather than directly from sediments. Consequently, volatilization is not considered a major process in the dynamics of PCBs or other COCs in LDW sediment.

Desorption is related to how strongly a contaminant binds to sediment or to organic carbon in sediment. All of the COCs in the LDW strongly bind to sediment. If the COCs did not bind strongly to sediments, they would have desorbed, become dissolved in surface water, and been discharged downstream, effectively removing them from LDW

sediments. Empirical evidence demonstrates the persistence of these chemicals with depth in the LDW. Many of the organic compounds, such as PCBs, PAHs, and dioxins/ furans, are referred to as hydrophobic compounds. That is, the compounds preferentially partition to solids rather than become dissolved in water.

Although desorption to the dissolved phase and volatilization to the atmosphere are processes that reduce the concentration of COCs with time, these processes are not likely to substantially affect COC concentrations in sediment over time (except that some low level equilibrium may be reached in the surface sediment and surface water from these processes and affect recovery potential). Furthermore, by not including these processes in the natural recovery analysis, estimated future chemical concentrations in sediment are conservative because both processes would slightly accelerate the predicted natural recovery in surface sediments.

5.5.8 Scour Potential

As discussed in Sections 5.3.1 and 5.3.2.5, the maximum estimated scour depth is about 22 cm during a 100-year high-flow event, and the upper bound of estimated scour is 36 cm, based on upper-bound erosion sensitivity simulations. Areas with subsurface sediment contamination located in potential scour areas are explored in Section 6 and are included in the AOPC footprint. Section 5.3.2.5 illustrates that potential exposure and transport of subsurface sediments during high-flow events is small compared to the incoming sediment loads. To explore the net effect of propeller scour events, Appendix F illustrates that empirical chemical trends from many of the resampled surface sediment stations and sediment cores have decreasing chemical trends (or trends in equilibrium) in scour areas. The FS conservatively assumes that scour potential (>10 cm) in areas with subsurface exceedances of SMS is of concern even if empirical evidence actually shows some recovery and scour areas with adequate net sedimentation rates and water depth may eventually recover. Uncertainty related to scour potential with subsurface exceedances is inherently accounted for in Section 6. Areas with subsurface exceedances in potential scour areas are included in the AOPC footprints for the FS, and these areas are given equal consideration as surface exceedances in the assembly of alternatives and assignment of remedial technologies to those areas (Section 8). Alternatives are inherently conservative by assigning active remediation to scour areas (within the depth of scour potential, typically chemical exceedances in the upper two ft) in the absence of empirical trends showing recovery.

A sensitivity analysis was conducted to evaluate uncertainty in STM predictions that may have resulted from uncertainty in model input parameters. The STM was most sensitive to the parameters that control erosion rates. Uncertainty in the extent of areas estimated to have erosion was less than ±50% within the area from RM 0.0 to 4.3, relative to the base-case simulation. Uncertainty in predicted sediment mass eroded ranged from about -50 to +75% within the area from RM 0.0 to 4.3 as well as in the east bench and navigation channel and ranged from -40 to +130% in the west bench. The

analysis showed that the predicted depth of scour, area of scour, and mass of sediment scoured are not very sensitive to erosion rate parameters used in the model.

5.5.9 Effects of Scour Potential on BCM Predictions

To evaluate the effect of vessel scour potential on BCM predictions (conditions unaccounted for by the STM), a worst case condition was evaluated assuming that no natural recovery occurs in potential scour areas. In this analysis, the initial bed concentrations in potential scour areas and berthing areas with low sedimentation were held constant for all BCM analysis throughout the 10-year period modeled in the BCM. This assumption is extremely conservative because it assumes there is no net sedimentation at any time over the 10-year period and that no upstream sediments mix with the original bed sediments in the top 10 cm of the bed. Areas held constant in this analysis are shown as propeller wash scour on Figure 2-7. In addition to vessel scour areas identified by the sun-illumination maps, the analysis also "held constant" berthing areas with net sedimentation rates less than 0.5 cm/yr (see Figure 2-8).

This analysis compared the site-wide and reach-wide total PCB SWACs between the base case and the case with constant bed sediment concentration in potential scour areas for a post-remedy test case.

10-Year Model Condition[a]	Total PCB SWAC (µg/kg dw)			
	Site-Wide	Reach 1	Reach 2	Reach 3
Base Case (includes modeled recovery in vessel scour areas)	62	68	61	39
Holding Cells Constant in vessel scour areas and berthing areas with net sedimentation rates <0.5 cm/yr	69	75	72	42

a Test case condition at 10 years following remedy completion of Alternative 3 using mid-range values.

The analysis shows that the estimates of total PCB SWAC are not very sensitive to effects that vessel scour may have in reducing rates of natural recovery on a site-wide scale. The holding cells constant case is on the order of 10 percent higher for site-wide and reach-wide total PCB SWAC, except in Reach 2, which is 18% higher. However, scour can be important in localized areas and will need to be factored into remedial design in potential scour areas (see Section 6).

5.5.10 Bathymetric Changes and Dredging of Upper Turning Basin Sediments

In the STM, a hydrodynamic model was used to generate flow velocities, which were then used in the sediment transport model. The hydrodynamic model was not revised for changes in bathymetry due to scour or net sedimentation. However, the STM does track the changes in bed elevation over time as sediment is scoured or deposited. Analysis of specific model cells in the navigation channel and on the benches show that the change in bed elevation in the first 10 years of the simulation is on the order of 10 cm (4 inches). This change in bathymetry would not be expected to affect the hydrodynamic model because the water depth is much greater than the change in bed elevation.

In Reach 3, the Upper Turning Basin has much more net sedimentation than Reaches 1 and 2. However, the Upper Turning Basin is regularly dredged. By ignoring the changes in bathymetry due to deposition in the Upper Turning Basin, the model essentially assumes that the Upper Turning Basin is continually dredged. If the hydrodynamic model and STM were modified for bathymetric changes between dredging events, the Upper Turning Basin would become shallower and more sediment would move downstream, resulting in higher net sedimentation rates downstream of the Upper Turning Basin. Consequently, the assumption that the bathymetry in the Upper Turning Basin does not change is consistent with expected long-term maintenance dredging in the LDW and is conservative with respect to the net sedimentation rate downstream from the Upper Turning Basin.

5.6 Modeling Summary and Conclusions

In summary, a predictive modeling tool is necessary for the FS to evaluate the value or effectiveness of remedial alternatives and the recovery potential of the system. Some alternatives will include MNR processes and others will not (see Section 8). The STM and BCM are valuable tools to guide decision-making regardless of which remedial alternative is selected. However, it is understood that both tools have some degree of uncertainty. For the purposes of the FS, a bounded margin of uncertainty is acceptable, but it is assumed that this uncertainty can be further managed during remedial design and future monitoring. Varying levels of confidence can be attached to these predictions depending on: 1) the COC (i.e., arsenic has a higher level of certainty compared to PAHs, which may have increasing concentration trends from urbanization), and 2) location in the LDW (areas with estimated net sedimentation greater than a few centimeters have a higher expectation that natural recovery will occur because the estimated net sedimentation is much greater than model error). Regardless, monitoring will be needed to confirm that recovery is occurring wherever it is proposed. In summary:

- The LDW is net depositional over time and its physical characteristics are well understood through fine-scale hydrodynamic and sediment transport modeling. The STM output has been supported by several lines of evidence, including chemistry profiles in sediment. Areas where the STM output doesn't match empirical data are generally found in locations where features are present that the STM didn't track (e.g., bridges and pilings). Three key outputs from the STM are used in the FS: net sedimentation rates, areas subject to scour from high-flow events, and bed composition. The third output provides the framework for predictive chemical modeling in the BCM.

- Sediment is continually depositing within the LDW. Almost all new sediment (99%) that enters the LDW originates in the Green/Duwamish River. The STM estimates that, on average, over 185,000 MT of sediment per

year enters the LDW, with approximately 100,000 MT depositing in the LDW. Approximately 90% of the total bed area in the LDW receives 10 cm of new sediment within 10 years or less. This sediment is mixed with the existing bed sediment through various processes, including bioturbation and propeller wash. On average, the annual volume dredged over the past 15 years is approximately 50,000 MT within the authorized navigation channel and 10,000 MT within the berthing areas, for a total annual dredge volume of about 60,000 MT.

- Overall, the maximum net erosion depth during a 100-year high-flow event is 22.2 cm, with most areas experiencing less than 10 cm of scour, while 82% of the LDW experiences net deposition rather than net erosion over the 30-year model period.
- 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. Ship-induced bed scour is viewed as an impulsive erosion-deposition process that tends to behave like an on-going mixing process for surficial bed sediment. Transiting ships in the navigation channel are not a major source of sediment transport or erosion in the LDW, except where slightly greater erosion depths (net erosion) are possible in shallower areas adjacent to the navigation channel. Maneuvering vessels in shallower areas may scour localized areas up to 25 cm in special circumstances where intense maneuvering is needed.
- The BCM is used to compute changes in chemical concentrations over time for the risk-driver chemicals. Output from the BCM includes chemical concentrations (point concentrations and area-based SWACs) at 5-year increments for 45 years.
- Empirical data show that, on average, LDW surface sediment concentrations are decreasing over time, consistent with BCM predictions of surface sediment concentrations approaching equilibrium over time. Appendix F shows specific locations where the empirical data demonstrate recovery.
- Chemical input values used in the BCM (lateral, Green/Duwamish River upstream, and post-remedy bed sediment replacement) were derived from actual input data (catch basin solids, sediment trap samples, upstream surface sediment and surface water data, USACE sediment cores). A range of values (high-medium-low) are used to address uncertainty and potential temporal variability in the range of chemical inputs associated with each source type.

- Both the BCM predictions and empirical chemical trends show that natural recovery is occurring in some areas of the LDW (see Appendix F). According to the BCM, MNR is a viable technology for many (but not all) areas of the LDW with moderate levels of contamination (below the CSL) and net sedimentation rates of more than 1 cm/yr. Even areas subject to periodic scour are showing some recovery based on empirical data.
- The BCM is a fairly conservative modeling tool for predicting recovery trends in the FS. It uses the FS baseline dataset (where the data are already more than 10 years old in some areas) and assumes no recovery or age-consideration for the older data in existing bed sediments; the chemical input values are conservative in that a certain amount of urban influence is assumed (which makes the time to achieve RAOs longer).
- Although the STM and BCM are not chemical fate and transport models, these predictive tools are conservative with respect to predicted sediment concentrations because they assume no chemical transformation or degradation over time. Changes in seafood consumption risks are evaluated via the PCB food web model developed as part of the RI (Windward 2010).
- The overall result is that the application of the BCM is inherently conservative with the exception of potential for COC concentrations in localized areas near active discharges to be underestimated. These localized areas should be evaluated for adequate source control during remedial design.
- Uncertainty in both the STM and BCM is recognized in sedimentation rates, erosion depths, scour areas, and chemical inputs over time. By using many lines of evidence and a range of input values derived from these data, the uncertainty is diminished. Overall, the uncertainty in BCM input parameters has a greater effect on predictions of natural recovery than does the uncertainty in sedimentation rates. Therefore the range of BCM input parameters is a useful tool to bracket uncertainties in the evaluation of FS alternatives.

In summary, the BCM analysis is considered adequate for estimating future chemical concentration in LDW sediments, assigning a range of suitable remedial technologies (Section 8), and evaluating short-term and long-term effectiveness of remedial alternatives (Section 9). However, model uncertainties must be accounted for when considering the predicted outcomes of the remedial alternatives; this uncertainty is also evaluated in Section 9. Spatial areas where model predictions agree or do not agree with empirical trends and physical site conditions are both accounted for in the FS in the designation of recovery categories (Section 6).

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Table 5-1a Recommended Bed Composition Model Lateral Input Parameters for Human Health Risk Drivers

Rationale

1. High – Conservative representation of current conditions assuming modest level of source control (e.g., management of high priority sources).
2. Input (Mid, Recommended) – Pragmatic assessment of what might be achieved in the next decade with anticipated levels of source control.
3. Low – Best that might be achievable in 30 to 40 years with increased coverage and continued aggressive source control.

Chemical	BCM Parameters			Basis for BCM Lateral Input and Sensitivity Values
	Input	Low	High	
Arsenic[a] (mg/kg dw)	13	9	30	Screened the source-tracing dataset to exclude concentrations above assumed SMS-based source control levels (93 and 57 mg/kg dw) Input: Mean excluding values >93 mg/kg (the CSL). High: 90th percentile excluding values >93 mg/kg (the CSL). Low: Median of all samples, excluding values >57 mg/kg (the SQS).[a]
Total PCBs[a] (µg /kg dw)	300	100	1,000	Used a range of screening concentrations to reflect potential levels of source control that could occur over time. Input: Mean of flow-weighted dataset excluding values >5,000 µg/kg dw (315 rounded to 300 µg /kg dw). High: 90th percentile of flow-weighted source tracing dataset excluding values >10,000 µg/kg dw (1,009 rounded to 1,000 µg /kg dw). Low: Median of flow-weighted source tracing dataset excluding values >2,000 µg/kg dw (102 rounded to 100 µg/kg dw).[a]
cPAH[a] (µg TEQ/kg dw)	1,400	500	3,400	Screened the source-tracing dataset to exclude concentrations above an assumed source control level. cPAHs are expected to be difficult to control due to the petroleum-based economy, intensity of urbanization in the LDW, and myriad on-going sources. Input: Mean of source-tracing dataset excluding values >25,000 µg TEQ/kg dw (1,370 rounded to 1,400 µg TEQ/kg dw). High: 90th percentile of source-tracing dataset excluding values >25,000 µg TEQ/kg dw (3,366 rounded to 3,400 µg TEQ/kg dw). Low: Median of source tracing dataset excluding values >25,000 µg TEQ/kg dw (490 rounded to 500 µg TEQ/kg dw). [a]
Dioxins and Furans[b] (ng TEQ/kg dw)	20	10	40	Based on combined Greater Seattle metropolitan sediment and SPU catch basin solids datasets.[b] Input: Mean (22 rounded to 20 ng TEQ/kg dw) High: UCL95 (41 rounded to 40 ng TEQ/kg dw). Low: Median (15 rounded to 10 ng TEQ/kg dw).

Notes:

a Used Lower Duwamish Waterway source tracing dataset (compiled by SPU) through June 2009 as the primary basis for establishing lateral BCM parameter values for arsenic, total PCBs, and cPAHs. The dataset was screened to remove concentrations using various source control practicability assumptions (best professional judgment by the Source Control Work Group). Total PCB data were flow-weighted before generating statistics because PCBs exhibit a distinct geographic distribution with hot spots identified at Terminal 117, North Boeing Field/Georgetown Steam Plant, Rainier Commons, and Boeing Plant 2/Jorgensen Forge. These four areas have been extensively sampled and make up a significant portion of the overall source tracing dataset. Therefore, the PCB source-tracing data were flow-weighted to avoid skewing the summary statistics used in the BCM. Arsenic and cPAH data were not flow-weighted prior to the statistical analysis because these chemicals lack a pronounced geographic dependency that would warrant flow-weighting. See Tables 5-2a through 5-2d for statistical summaries of supporting datasets.

b Parameter estimation for dioxins and furans was based on the Greater Seattle metropolitan area receiving sediment dataset collected as part of the RI (Windward 2010) and sediment and SPU catch basin solids datasets (City of Seattle 2009). The summary statistics used to estimate parameter values correspond to the combined datasets, as supported by statistical analysis, and include the removal of outliers. See Tables 5-2a through 5-2d for statistical summaries of supporting datasets.

BCM = bed composition model; cPAH = carcinogenic polycyclic aromatic hydrocarbon; CSL = cleanup screening level; FS = feasibility study; PCB = polychlorinated biphenyl; SPU = Seattle Public Utilities; TEQ = toxic equivalent; SQS = sediment quality standard; UCL95 = 95% upper confidence limit on the mean

Table 5-1b Recommended Bed Composition Model Upstream Input Parameters for Human Health Risk Drivers

Rationale

Range of concentrations considered representative of current and potential future conditions for solids entering and settling in the LDW from upstream. Four different datasets used to establish range of parameter values for upstream sources because of potential biases inherent to each.

Chemical	BCM Parameters			Basis for BCM Upstream Input and Sensitivity Values[a]
	Input	Low	High	
Arsenic (mg/kg dw)	9	7	10	Input: Mean of Ecology upstream sediment samples containing fines >30%. Low: Mean of LDW RM 4.3 to 4.75 DMMP (2001 – 2009) core data. High: UCL95 of Ecology upstream sediment samples with fines >30%.
Total PCBs (µg /kg dw)	35	5	80	Input: Mean of LDW RM 4.3 to 4.75 DMMP (2001 – 2009) core data (36 rounded to 35 µg /kg dw). Low: The mean of Ecology upstream sediment samples containing fines >30%. High: UCL95 of TSS-normalized King County (whole-water) (82 rounded to 80 µg /kg dw).
cPAHs (µg TEQ/kg dw)	70	40	270	Input: Mean of LDW RM 4.3 to 4.75 DMMP (2001 – 2009) core data (73 rounded to 70 µg TEQ/kg dw). Low: Mean of Ecology upstream sediment samples containing fines >30% (37 rounded to 40 µg TEQ/kg dw). High: UCL95 of TSS-normalized King County (whole-water) (269 rounded to 270 µg TEQ/kg dw).
Dioxins and Furans (ng TEQ/kg dw)	4	2	8	Input: Midpoint between mean of Ecology upstream centrifuged solids and mean of Ecology upstream sediment samples containing fines >30% Low: Mean of Ecology upstream sediment samples containing fines >30%. High: Midpoint between mean and UCL95 of Ecology centrifuged solids data.

Notes:

a Upstream BCM parameter values were revised using updated datasets and statistics reflective of current conditions (i.e., material entering the LDW from the Green/Duwamish River). The four primary datasets used for BCM parameterization are as follows (see Tables 5-2a through 5-2d for statistical summaries of supporting datasets):

- Ecology's 2008 upstream bed sediment chemistry data: This dataset was screened to exclude samples with ≤30% fines in consideration of the systematic differences in grain size distributions between upstream (e.g., mid-channel) data and average conditions in the LDW.
- TSS-normalized King County data: King County surface water data were normalized to solid fractions by dividing by the TSS in the individual sample.
- Ecology 2008 centrifuged suspended solids data: The Ecology samples are representative of sediments suspended mid-channel in the Duwamish/Green River that enter the LDW.
- Upper-reach USACE DMMP core data (RM 4.3 to 4.75): This dataset is representative of Green/Duwamish River suspended material that settles in the upper section of the LDW.

BCM = bed composition model; cPAH = carcinogenic polycyclic aromatic hydrocarbon; DMMP = Dredged Material Management Program; fines = sum of silt and clay grain size fractions; FS = feasibility study; PCB = polychlorinated biphenyl; RM = river mile; TEQ = toxic equivalent; TSS = total suspended solids; UCL95 = 95% upper confidence limit on the mean

Table 5-1c Recommended Bed Composition Model Post-Remedy Bed Sediment Replacement Values for Human Health Risk Drivers

Rationale

Range of concentrations considered representative of current and potential near-term (0-3 years) post-remedy surface sediment conditions influenced by multiple recontamination mechanisms. Values expected to vary spatially.[a]

Chemical	SWAC Outside of AOPC 1[b]	Clean Fill Material[c]	Input and Sensitivity Values					
			Proportioned Values Using SWAC Outside of AOPC 1[d]			Proportioned Values Using SWAC Outside of AOPC 2[d,e]		
			Input	Low Input	High Input	Input	Low Input	High Input
Arsenic (mg/kg dw)	12	7	10	9	11	9	8	10
Total PCBs (µg /kg dw)	120	2	60	30	90	20	10	40
cPAHs(µg TEQ/kg dw)	270	9	140	70	200	100	50	140
Dioxins and Furans (ng TEQ/kg dw)	7	2	4	2[f]	6	n/a	n/a	n/a

Notes:

a Actively remediated areas within the AOPC 1 footprint receive the higher input values. Actively remediated areas within AOPC 2 footprint would receive lower input values. See Section 6 for a definition of AOPCs.

b The SWAC outside of AOPC 1 is assumed representative of concentrations adjacent to remediated areas for arsenic, total PCBs, and cPAH. The representative dioxins and furans concentration outside of AOPC 1 is based on the arithmetic mean of the point values located outside of AOPC 1. See Section 6 for definition of AOPC 1.

c The chemical composition of clean fill material is based on the UCL95 of 2008 EPA OSV *Bold* Survey data. Use of qualified maintenance dredged materials (e.g. from the Upper Turning Basin) for capping would, in practice, lead to higher range of post-remedy bed-sediment replacement values than calculated in this table.

d Range of representative post-remedy bed sediment replacement values assumes combinations of clean backfill material (e.g., whether capping, ENR, or post-dredge residuals management) and surrounding representative bed sediment concentrations. Assumed proportioning percentages are as follows:

BCM Parameter	Post-Remedy Bed Sediment Replacement Value Proportioning Assumptions	
	% of Clean Import Material	% of SWAC Outside of AOPC 1
Input	50	50
Low	75	25
High	25	75

e As discussed in Section 6, a larger footprint referred to as AOPC 2 was developed. The remedial alternative that evaluates this footprint will use lower input values after all high to moderate PCB concentration areas have been remediated.

f In this case, the "low" value of 2 is recommended to maintain a reasonable range of concentrations. The adjustment is considered reasonable because of the small dataset available for calculating the concentration outside of AOPC 1.

AOPC = area of potential concern; BCM = bed composition model; cPAH = carcinogenic polycyclic aromatic hydrocarbon; DMMP = Dredged Material Management Program; ENR = enhanced natural recovery; FS = feasibility study; n/a = not available; PCB = polychlorinated biphenyl; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent; UCL95 = 95% upper confidence limit on the mean.

Table 5-2a BCM Parameter Line of Evidence Information for Arsenic (mg/kg dw)

Study/Source			*No. of Samples*	Mean	Median	90th Percentile	UCL95	Comments
Green/Duwamish River Inflow								
Green River Water Quality	King County Whole Water		*100*	37	29	73	47	Normalized to TSS; data from 2001 to 2006. All detected arsenic concentrations associated with TSS were calculated as the difference between whole-water (i.e., unfiltered) and filtered sample data.
	Ecology Centrifuged Solids		*7*	17	14	24	22	Data from 2008, downloaded from EIM database, stats calculated by AECOM.
Upstream Surface Sediment	LDW RI Data		*24*	7	5	11	8	Data from 1994 to 2005 between RM 5 and 7 included in the RI baseline dataset.
	Ecology	Fines >30%	*31*	9	9	11	10	Data from 2008, downloaded from EIM database, stats calculated by AECOM and screened to exclude samples ≤ 30% fines; unpublished.
		All	*74*	7	6	10	7	Data from 2008, downloaded from EIM database, stats calculated by AECOM.
	LDW RI and Ecology Data Combined		*98*	7	6	10	7	Calculation of all upstream surface sediment data by AECOM; unpublished.
USACE Upper Turning Basin Cores		RM. 4.5 – 4.75 (1991-2009)	*8*	5	5	7	7	Calculation of DAIS core data by AECOM; unpublished. 1990 data excluded.
		RM. 4.3 – 4.75 (1991-2009)	*18*	7	6	12	8	Calculation of DAIS core data by AECOM; unpublished. 1990 data excluded.
Lateral Inflow								
City of Seattle Storm Drain Data		Minus samples >57 mg/kg dw	*553*	12	9	29	—	Storm drain solids data screened to exclude samples >57 mg/kg dw; data collected through June 2009. SPU data provided by B. Schmoyer, 2010.
		Minus samples >93 mg/kg dw	*563*	13	10	30	—	Storm drain solids data screened to exclude samples >93 mg/kg dw; data collected through June 2009. SPU data provided by B. Schmoyer, 2010.
King County CSO Water Quality Data			*21*	9	11	13	—	TSS-normalized values of CSO water data provided by D. Williston, King County, 2010.
Post-Remedy Bed Sediment Replacement Value								
Post-Maintenance Dredge Surface Data		0 – 2 years after dredging	*8*	11	12	—	14	Calculation of post-maintenance dredge surface data by AECOM; unpublished.
Duwamish/Diagonal Post-Capping Data		Thick Cap	—	Mean = 3 (yr 0.5), 10 (yr 3)				Calculation of D/D post-capping data by AECOM; data available in King County monitoring reports (King County 2006; 2009)
		ENR	—	Mean = 2 (yr 0), 4 (yr 1), 8 (yr 2)				
EPA OSV *Bold* Survey			*70*	7	6	11	7	Calculation of Puget Sound Survey stats by AECOM.
Outside AOPC 1 Footprint			*n/a*	IDW interpolated SWAC = 12				Calculation of IDW interpolated SWAC by AECOM; unpublished. See Section 6 for AOPCs.
Outside AOPC 2 Footprint			*n/a*	IDW interpolated SWAC = 10				Calculation of IDW interpolated SWAC by AECOM; unpublished. See Section 6 for AOPCs.

Notes: See Table 5-2d for notes.

Table 5-2b BCM Parameter Line of Evidence Information for Total PCBs (µg/kg dw)

Study/Source			No. of Samples	Mean	Median	90th Percentile	UCL95	Comments
Green/Duwamish River Inflow								
Green River Water Quality	King County Whole Water		22	50	21	107	82	Normalized to TSS; data from 2005 to 2008, provided by King County.
	Ecology Centrifuged Solids		7	14	8	54	36	Data from 2008, downloaded from EIM database, stats calculated by AECOM.
	King County and Ecology Data Combined		29	42	11	120	127	Calculation of all upstream surface water data by AECOM; unpublished.
Upstream Surface Sediment	LDW RI Data		37	23	19	40	21	Data from 1994 to 2005 between RM 5 and 7 included in the RI baseline dataset.
	Ecology	Fines >30%	30	5	2	13	8	Data from 2008, downloaded from EIM database, stats calculated by AECOM, screened to exclude samples ≤ 30% fines; outlier excluded: 770 µg/kg dw; unpublished.
		All	73	3	3	6	3	Data from 2008, downloaded from EIM database; stats calculated by AECOM and outlier excluded: 770 µg/kg dw.
	LDW RI and Ecology Data Combined		110	8	3	23	13	Calculation of all upstream surface sediment data by AECOM and outlier excluded: 770 µg/kg dw; unpublished.
USACE Upper Turning Basin Cores	RM. 4.5 – 4.75 (1991-2009)		10	23	22	38	23	Calculation of DAIS core data by AECOM; unpublished.
	RM. 4.3 – 4.75 (1991-2009)		20	36	33	56	42	Calculation of DAIS core data by AECOM; unpublished.
Lateral Inflow								
City of Seattle Storm Drain Data	Minus samples >2,000 µg/kg dw		625	223	102	534	—	Flow-weighted average of storm drain solids data screened to exclude samples >2,000 µg/kg dw; data collected through June 2009. SPU data provided by B. Schmoyer, 2010.
	Minus samples >5,000 µg/kg dw		692	315	125	718	—	Flow-weighted average of storm drain solids data screened to exclude samples >5,000 µg/kg dw; data collected through June 2009. SPU data provided by B. Schmoyer, 2010.
	Minus samples >10,000 µg/kg dw		755	508	146	1,009	—	Flow-weighted average of storm drain solids data screened to exclude samples >10,000 µg/kg dw; data collected through June 2009. SPU data provided by B. Schmoyer, 2010.
King County CSO Water Quality Data			28	638	580	920	—	TSS-normalized values of CSO water data provided by D. Williston, King County, 2010. Estimates biased high because method assumes all PCBs in whole-water sample in particulate phase.
Post-Remedy Bed Sediment Replacement Value								
Post-Maintenance Dredge Surface Data	0 – 2 years after dredging		18	120	120	—	150	Calculation of post-maintenance dredge surface data by AECOM; unpublished.
Duwamish/Diagonal Post-Capping Data	Thick Cap		—	Mean = 45 (yr 0.5), 84 (yr 3)				Calculation of D/D post-capping data by AECOM; data available in King County monitoring reports (King County 2006; 2009)
	ENR		—	Mean = 6 (yr 0), 23 (yr 1), 62 (yr 2)				
Puget Sound Survey (OSV BOLD)			70	1	1	3	2	Calculation of Puget Sound Survey stats by AECOM.
Outside AOPC 1 Footprint			n/a	IDW interpolated SWAC = 120				Calculation of IDW interpolated SWAC by AECOM; unpublished. See Section 6 for AOPCs.
Outside AOPC 2 Footprint			n/a	IDW interpolated SWAC = 47				Calculation of IDW interpolated SWAC by AECOM; unpublished. See Section 6 for AOPCs.

Notes: See Table 5-2d for notes.

Table 5-2c BCM Parameter Line of Evidence Information for cPAHs (µg TEQ/kg dw)

Study/Source			No. of Samples	Mean	Median	90th Percentile	UCL95	Comments
Green/Duwamish River Inflow								
Green River Water Quality	King County Whole Water		*18*	151	74	354	269	Normalized to TSS; data from 2008, provided by King County.
	Ecology Centrifuged Solids		*7*	138	53	400	432	Data from 2008, downloaded from EIM database, stats calculated by AECOM.
	King County and Ecology Data Combined		*25*	135	58	330	266	Calculation of all upstream surface water data by AECOM; unpublished.
Upstream Surface Sediment	LDW RI Data		*16*	55	18	135	100	Data from 1994 to 2005 between RM 5 and 7 included in the RI baseline dataset.
	Ecology	Fines >30%	*31*	37	16	77	72	Data from 2008, downloaded from EIM database, stats calculated by AECOM and screened to exclude samples ≤30% fines.
		Fines >50%	*18*	50	44	91	75	Data from 2008, downloaded from EIM database, stats calculated by AECOM and screened to exclude samples ≤ 50% fines.
		All	*74*	18	9	57	43	Data from 2008, downloaded from EIM database, stats calculated by AECOM.
	LDW RI and Ecology Data Combined		*90*	25	10	73	55	Calculation of all upstream surface sediment data by AECOM; unpublished.
USACE Upper Turning Basin Cores		RM. 4.5 – 4.75 (1991-2009)	*9*	37	41	63	52	Calculation of DAIS core data by AECOM; outlier excluded: 1051.5 µg TEQ/kg dw; unpublished.
		RM. 4.3 – 4.75 (1991-2009)	*19*	73	57	180	134	Calculation of DAIS core data by AECOM; outlier excluded: 1051.5 µg TEQ/kg dw; unpublished.
Lateral Inflow								
City of Seattle Storm Drain Data (minus samples >25,000 µg TEQ/kg dw)			*533*	1,370	490	3,366	—	Storm drain solids data screened to exclude samples >25,000 µg TEQ/kg dw; data collected through June 2009. SPU data provided by B. Schmoyer (2010).
King County CSO Water Quality Data			*26*	1,051	714	2,728	—	TSS-normalized values of CSO water data provided by D. Williston, King County, 2010. Estimates biased high because method assumes all cPAHs in whole-water samples in particulate phase.
Post-Remedy Bed Sediment Replacement Value								
Post-Maintenance Dredge Surface Data		0 – 2 years after dredging	*8*	180	170	—	250	Calculation of post-maintenance dredge surface data by AECOM; unpublished.
Duwamish/Diagonal Post-Capping Data		Thick Cap	—	Mean = 63 (yr 0.5), 159 (yr 3)				Calculation of D/D post-capping data by AECOM; data available in King County monitoring reports(King County 2006; 2009)
		ENR	—	Mean = 11 (yr 0), 43 (yr 1), 89 (yr 2)				
Puget Sound Survey (OSV BOLD)			*70*	7	4	15	9	Calculation of Puget Sound Survey stats by AECOM.
Outside AOPC 1 Footprint			*n/a*	IDW interpolated SWAC = 270				Calculation of IDW interpolated SWAC by AECOM; unpublished. See Section 6 for AOPCs.
Outside AOPC 2 Footprint			*n/a*	IDW interpolated SWAC = 190				Calculation of IDW interpolated SWAC by AECOM; unpublished. See Section 6 for AOPCs.

Notes: See Table 5-2d for notes.

Table 5-2d BCM Parameter Line of Evidence Information for Dioxins/Furans (ng TEQ/kg dw)

Study/Source			*No. of Samples*	Mean	Median	90th Percentile	UCL95	Comments
Green/Duwamish River Inflow								
Green River Water Quality	Ecology Centrifuged Solids		*6*	6	3	13	10	Data from 2008, downloaded from EIM database, stats calculated by AECOM.
Upstream Surface Sediment	LDW RI Data		*4*	Range of Values (Median): 1.1 - 2.6 (1.7)				Data from 1994 to 2005 between RM 5 and 7 included in the RI baseline dataset.
	Ecology	Fines >30%	*31*	2	2	3	2	Data from 2008, downloaded from EIM database, stats calculated by AECOM and screened to exclude samples ≤ 30% fines; unpublished.
		Fines >50%	*18*	2	2	3	3	Data from 2008, downloaded from EIM database, stats calculated by AECOM and screened to exclude samples ≤ 50% fines; unpublished.
		All	*74*	1	0.3	3	2	Data from 2008, downloaded from EIM database, stats calculated by AECOM.
USACE Upper Turning Basin Cores RM 4.3 – 4. 75 (1991-2009)			*2*	2 and 2.8 ng TEQ/kg dw				Calculation of DAIS core data by AECOM; unpublished.
Lateral Inflow								
Greater Seattle Sediment and SPU Catch Basin Solids			*23*	22	15	48	41	Calculation of stats based on combined Greater Seattle sediment and SPU catch basin solids datasets by AECOM; outlier excluded: 187 ng TEQ/kg dw; unpublished.
Post-Remedy Bed Sediment Replacement Value								
Puget Sound Survey (OSV BOLD)			*70*	1	1	2	2	Calculation of Puget Sound Survey stats by AECOM.
Post- Maintenance Dredge Area Surface Data			*3*	Mean = 8.3 ng TEQ/kg dw				Calculation of post-maintenance dredge surface data by AECOM; unpublished.
Outside AOPC 1 Footprint			*18*	Mean = 7 ng TEQ/kg dw				Calculation of IDW interpolated SWAC by AECOM; unpublished. See Section 6 for AOPCs.
Outside AOPC 2 Footprint			*11*	Mean = 5 ng TEQ/kg dw				Calculation of IDW interpolated SWAC by AECOM; unpublished. See Section 6 for AOPCs.

Value(s) used for recommended central tendency BCM input value. (mid point between mean Ecology Centrifuged solids and mean upstream fines >30% used for Green/Duwamish River)

Value(s) used as basis for low-sensitivity BCM value.

Value(s) used as basis for high-sensitivity BCM value.(mid-point between mean and UCL95 Ecology Centrifuged Solids used for Green/Duwamish River)

Notes:
1. Statistics for these datasets were calculated using ProUCL 4.0, except that statistics for the City of Seattle Storm Drain Solids, King County CSO Water Quality, and Post-Remedy Bed Sediment Replacement Values datasets were calculated with Excel.
2. TEQs were calculated using one-half RL for undetected individual Dioxin/Furan congeners or PAH compounds.

'—' = not calculated; n/a = not available

BCM = bed composition model; cPAH = carcinogenic polycyclic aromatic hydrocarbon; dw = dry weight; EIM = Ecology Information Management Database; fines = sum of silt and clay grain size fractions; kg = kilogram; LDW = Lower Duwamish Waterway; µg = microgram; mg = milligram; ng = nanograms; PCB = polychlorinated biphenyl; RI = remedial investigation; RL = reporting limit; RM = river mile; SPU = Seattle Public Utilities; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent; TSS = total suspended solids; USACE = U.S. Army Corps of Engineers; UCL95 = 95 percent upper confidence limit on the mean.

Table 5-3 Chemical Input Values for Representative SMS Chemicals[a]

Chemical	Upstream Inflow (n = 22 to 23)		Lateral Inflow (n = 531 to 579)	
	BCM Input Value (µg/kg dw)[b]	Basis	BCM Input Value (µg/kg dw)[b]	Basis[b]
BEHP	120	Median of USACE Dredged Material Characterization Core Data (RM 4.3 to 4.75; USACE 2009a, 2009b)	15,475	Log-normal mean of City of Seattle source-tracing data through July 2009 with outliers removed[c] (City of Seattle 2010)
Chrysene	49		1,807	
Fluoranthene	190		3,989	
Phenanthrene	53		2,010	
Mercury (mg/kg dw)	0.1		0.14	
Zinc (mg/kg dw)	64		626	
Acenaphthalene	8		209	
Butylbenzyl-phthalate	11		972	
Indeno(1,2,3-cd)pyrene	31		675	
Phenol	10		237	

Notes:
a FS dataset used to generate summary statistics.
b Units are in µg/kg dw, unless otherwise noted. Input values are not flow-weighted.
c Values that were at least two times the next highest value were removed from the analysis as outliers.

BEHP = bis(2-ethylhexyl)phthalate; µg/kg dw ; micrograms per kilogram dry weight; mg/kg dw = milligrams per kilogram dry weight; n= number of; SMS = Sediment Management Standards; USACE = United States Army Corps of Engineers

Table 5-4 Results of Additional STM Special Scenario Runs

Purpose	Description	Results
1: Potential Recontamination of EAAs	An additional bed sediment class is added to differentiate sediment within EAAs from sediment outside of EAAs. This addition results in 16 sediment variables (four size classes for each of four sediment types): EAA bed sediments, non-EAA bed sediments, lateral source sediments, and upstream Green/Duwamish River source sediments). Model is run for 10-year period to predict how unremediated areas may contribute to recontamination of remediated area, assuming EAAs have been remediated	• Contribution from non-EAA areas to remediated EAAs is less than 5% of the surface sediments at most EAAs after 10 years.
2: Distributed Discharges from Lateral Sources	The STM input is modified to have the discharges from lateral sources distributed to more closely describe actual drainage distribution among shoreline outfalls. The updates primarily affect private nearshore drainage basins. The model is run for both 10-year and 30-year periods to compare what was reported in the STM report (QEA 2008)(the lateral load distributed via 21 outfalls) with the redistributed lateral loads used in the FS.	• Lateral source sediments are more widely distributed, often at lower percent composition, along the nearshore STM grid cells. • Lateral source sediments are more widely distributed throughout the LDW, but most of the changes only result in some areas increasing from <1.0% lateral load content to 1.0 - 2.0%. • The greatest changes were observed around Hamm Creek and between RM 2 and 3. • Updated load distribution used in all subsequent analyses; it was used in all STM base-case model runs.
3: Movement of LDW Bed Sediment into the Upper Turning Basin	10-year model run that tracks bed sediment from four sources: Upper Turning Basin, navigation channel from RM 4.0 to 4.3, bench areas upstream of RM 4.0, and all sediment downstream of RM 4.0. The model run predicts whether downstream LDW sediments resuspend and settle upstream in the Upper Turning Basin area.	• Contribution of downstream sediment to the Upper Turning Basin area is negligible (<0.1%). • Only 260 MT of sediment is transported upstream to Reach 3 from downstream areas over 10 years compared to over 800,000 MT that settles in Reach 3 from upstream. • Supports use of USACE sediment cores collected from RM 4.3 to 4.75 in navigation channel as one line of evidence of upstream solids (i.e., negligible input from downstream sediments)
4: Movement of Bed Sediments between Reaches	Evaluation of the mass balance of sediment originating from each reach that moves between reaches and out of the LDW. This scenario is conducted for the 30-year model period.	• Much of the sediment resuspended in a reach that resettles in the LDW settles within the same reach. • There is more of an exchange of sediments between Reach 1 and 2, than from Reach 1 and 2 to Reach 3. • Reach 3 sediments are widely distributed throughout the LDW, while very little sediment from Reach 1 or 2 resettles in Reach 3.

Table 5-4 Results of Additional STM Special Scenario Runs

Purpose	Description	Results
5: Sediment Scoured from Greater than 10-cm Depth	Areas that are estimated to scour greater than 10-cm depth are assigned a new variable to represent a new sediment class. The 100-year high-flow simulation is used to predict where these >10 cm scoured sediments resettle.	• Sediment eroded from below 10 cm makes up a very small fraction of the total sediment mass moving over a 100-year high-flow event. • Sediment eroded from below 10 cm is greatest in Reach 2 and lowest in Reach 1. • Most of the scour >10 cm occurs in localized navigation channel above about RM 2.9.
6: Movement of Existing Bed Sediment (bed-tracking)	An additional bed sediment class is added to differentiate bed sediment that was resuspended and redeposited into another model cell from original bed sediment over a 10-year period. This scenario tracks the movement of bed sediments with the LDW and its effect on bed composition and SWACs.	• Resuspended bed sediment makes up less than 30% of the total original + resuspended bed fraction, and typically less than 5 to 10%. • The BCM construct is considered appropriate for use in the FS

Note:
BCM = Bed Composition Model; cm = centimeter; EAA = early action area; FS = feasibility study; LDW = Lower Duwamish Waterway; MT = metric ton; RM = river mile; STM = sediment transport model; SWAC = spatially-weighted average concentration

Table 5-5 Comparison 10-year Total PCB SWACs between Bed Tracking Scenario and STM Base Case

Scenario	Total PCB SWACs (µg/kg dw)			
	Site-wide	Reach 1	Reach 2	Reach 3
Post-Alternative 1				
Year 0	188	199	240	57
Year 10 STM Base Case	75	87	70	40
Year 10 STM Bed Tracking with resuspended bed variable	74	87	66	40
Input Values to the Analysis				
Year 10 Distal Bed Input[a] (µg/kg dw)	n/a	192	126	58

Notes:

a The distal input refers to sediments that originate from the initial bed that settle on an STM model cell over time as opposed to original bed sediments that are not eroded over time. See Appendix C, Part 5. The distal input to the sediment bed for each reach is computed as the mass-weighted average concentration based on the mass of sediment that settles in a reach from all three reaches and the beginning (Year 0) Post-Alternative 1 SWAC in each reach. For example, the distal input for Reach 1 is computed as:

Distal input reach 1 = $(M_{1,1} * SWAC_1 + M_{1,2} * SWAC_2 + M_{1,3} * SWAC_3) / (M_{1,1} + M_{1,2} + M_{1,3})$

Where:

$M_{1,1}$ is the mass of sediment deposited in Reach 1 from Reach 1
$M_{1,2}$ is the mass of sediment deposited in Reach 1 from Reach 2
$M_{1,3}$ is the mass of sediment deposited in Reach 1 from Reach 3
$SWAC_1$, $SWAC_2$, and $SWAC_3$ are the beginning post-Alternative 1 SWACs in each reach

Greatest difference between bed tracking and STM base case

10-Yr Bed Tracking STM Equation

10-Yr Concentration = (Yr10 Bed $Distal_f$ * Yr0 Post Alternative 1 Reach-wide Mass-Weighted Average) + (Yr10 Bed $Local_f$ * Yr0 Post Alt 1 PCB) + (Yr10 Up_f * Up_c) + (Yr10 Lat_f * Lat_c)

Bed Tracking STM Chemical Inputs

1. Local Bed_c = Beginning RI Baseline IDW value or Mid RV of 60 µg/kg dw
2. Distal Bed_c = Beginning Post-Alternative 1 Reach-wide Mass-Weighted Average
3. $Upstream_c$ = Mid 35 µg/kg dw
4. $Lateral_c$ = Mid 300 µg/kg dw.

IDW = inverse distance weighting; µg/kg dw ; micrograms per kilogram dry weight; n/a = not applicable; PCB = polychlorinated biphenyl; STM = sediment transport model; SWAC = spatially-weighted average concentration;

Table 5-6 Summary of Correlation Analyses Relating Sediment Chemistry to Total Organic Carbon (TOC) and Percent Fines Using LDW RI/FS Datasets

Parameter	All LDW Surface Sediment		RM 4.0 to 4.75 Surface Sediment (Excluding Slip 6)		RM 4.0 to 4.75 Subsurface Sediment Cores		Upstream Surface Sediment	
	TOC	Percent Fines	TOC	Percent Fines	TOC	Percent Fines	TOC	Percent Fines
Total PCBs	Yes**	No	Yes**	No/Yes*	Yes*/No	Yes**	No	No
Arsenic	Yes**	Yes**	Yes**	Yes**	Yes**	Yes**	No	Yes**/Yes*
cPAHs	Yes**	Yes**	Yes*	Yes**	Yes**	Yes**	Yes*/No	Yes**
Dioxins/Furans	No/Yes*	No	n/a	n/a	n/a	n/a	n/a	n/a
TOC	n/a	Yes**	n/a	Yes**	n/a	Yes**	n/a	Yes**

Notes:
1. All distributions are non-parametric using ProUCL Goodness of Fit tests
2. Correlations tested for significance using Spearman's Rho and Kendall's concordance (PASW v.17)
3. Single table entries indicate same result using both Spearman's and Kendall's. Split entries indicate different Spearman's/Kendall's results.

** Correlation is significant at the p<0.01 level (2-tailed)

* Correlation is significant at the p<0.05 level (2-tailed)

cPAH = carcinogenic polycyclic aromatic hydrocarbons; LDW = Lower Duwamish Waterway; n/a = not applicable; PCB = polychlorinated biphenyl; RM = river mile; TOC = total organic carbon;

Table 5-7 Changes in Chemical Concentrations at Resampled Surface Sediment Stations

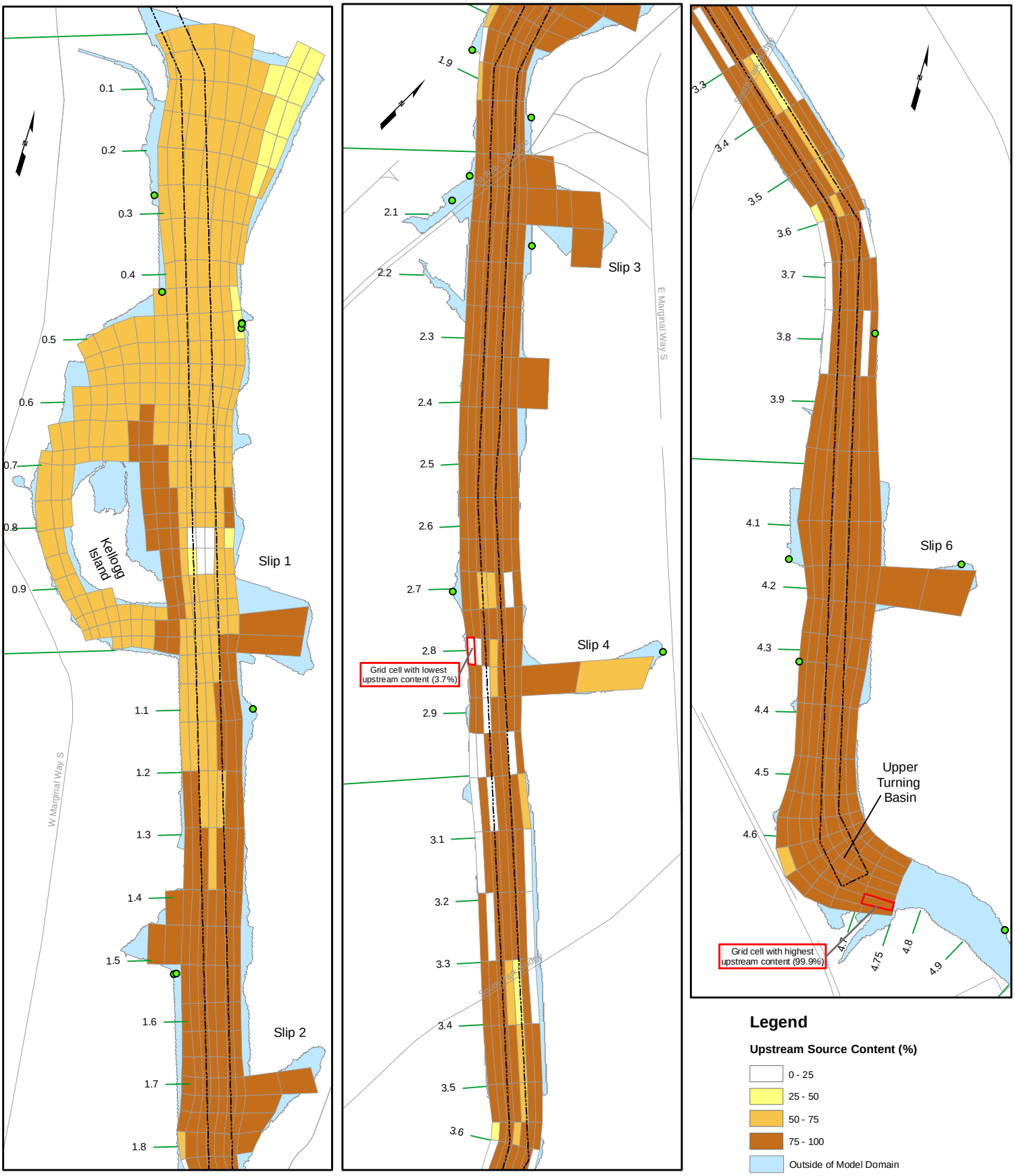
Chemical and Metric	Original/Older Data (1991–2006)	Newer (FS Baseline) Data (1998–2008)	Percent Decrease between Older and Newer Concentrations (%)
Total PCBs (µg/kg dw); N = 67			
25th Percentile	107	74	31
Mean	939	354	23
90th Percentile	2,141	776	58
Arsenic (mg/kg dw); N = 56			
25th Percentile	10	11	Minimal change; in equilibrium
Mean	40	35	
90th Percentile	41	40	
cPAHs (µg TEQ/kg dw); N = 53			
25th Percentile	200	145	28
Mean	1,534	437	72
90th Percentile	2,070	803	61
BEHP (µg/kg dw); N = 53			
25th Percentile	230	92	60
Mean	827	310	63
90th Percentile	1,570	606	61

Notes:

Newer data are co-located with older data (i.e., within 10 ft). Older data are not included in the FS baseline dataset.

1. Statistics calculated using ProUCL v.4.00.04.
2. Undetected data were set to the reporting limit.
3. Three PCB locations omitted to generate the n=67 dataset: LDW-SS110/SD-323-S; LDW-SS111/DR186; and SD-320-S/SD-DUW92. These are located within the Boeing Plant 2/Jorgensen Forge EAA.

Results on a station-by-station basis are provided in Appendix F.



Notes:
1. 10-year STM GIS shapefile dated Feb. 2009 (QEA Feb. 2009).
2. A grid cell with 75% sediment from upstream sources has 25% of the surface sediment from lateral and original bed sediment, totaling 100% bed composition (as solids).

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Percentage of Bed Sediment from Upstream Sources after 10 Years

DATE: 10/15/10 | DWRN:MVI/sea | Revision: 0

FIGURE 5-1a

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Legend

Upstream Source Content (%)

- 0 - 25
- 25 - 50
- 50 - 75
- 75 - 100
- Outside of Model Domain
- Discharge Location Modeled in STM
- Road
- Navigation Channel
- River Mile Marker

Notes:
1. 30-year STM GIS shapefile dated Feb. 2009 (QEA Feb. 2009).
2. A grid cell with 75% sediment from upstream sources has 25% of the surface sediment from lateral and original bed sediment, totaling 100% bed composition (as solids).

Feet
0 200 400 800

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Percentage of Bed Sediment from Upstream Sources after 30 Years

DATE: 10/15/10 | DWRN:MVI/sea | Revision: 0

FIGURE 5-1b 5-59

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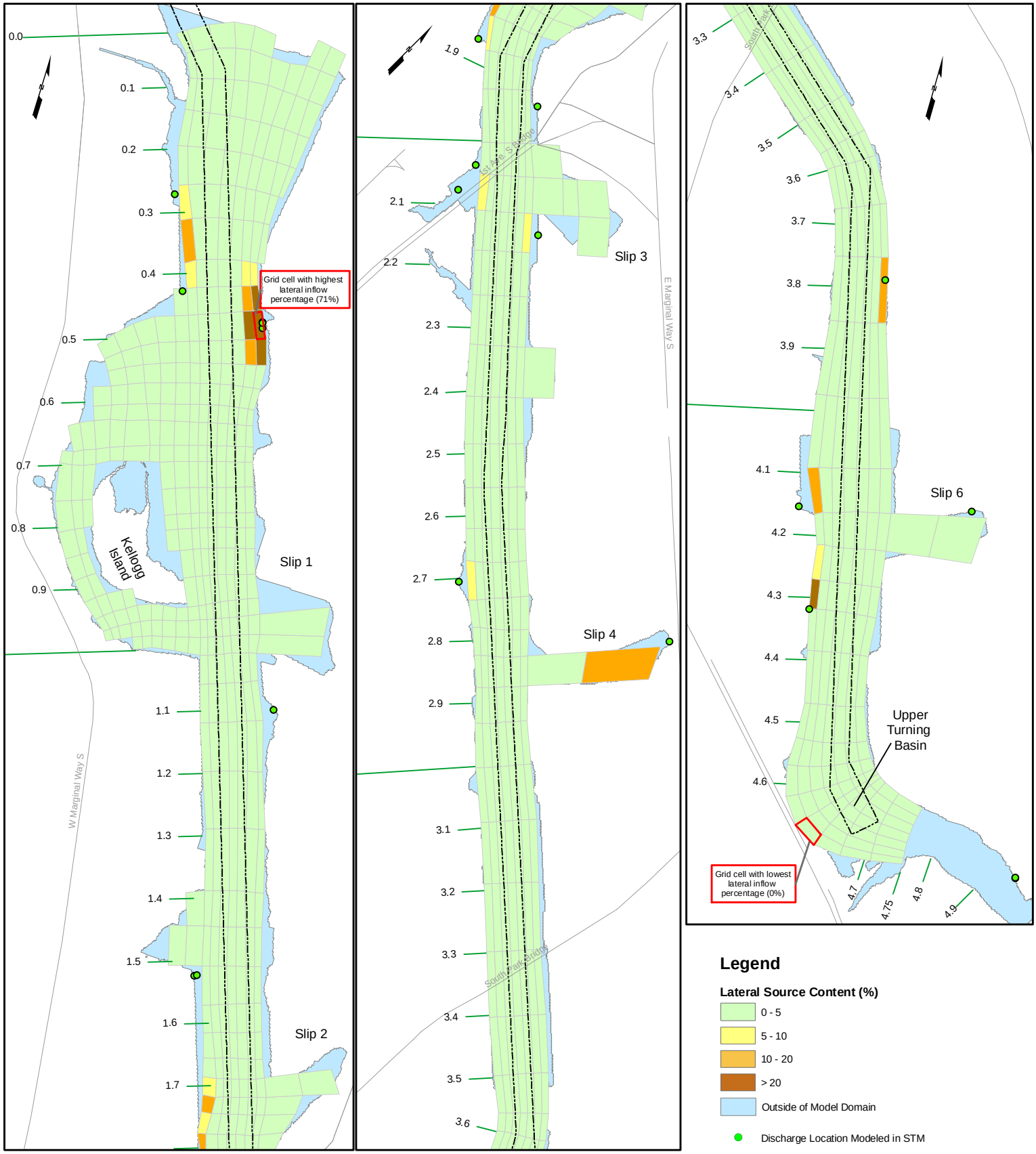

Notes:
1. 10-year STM GIS shapefile dated Feb. 2009 (QEA Feb. 2009).

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Percentage of Bed Sediment from Lateral Sources after 10 Years

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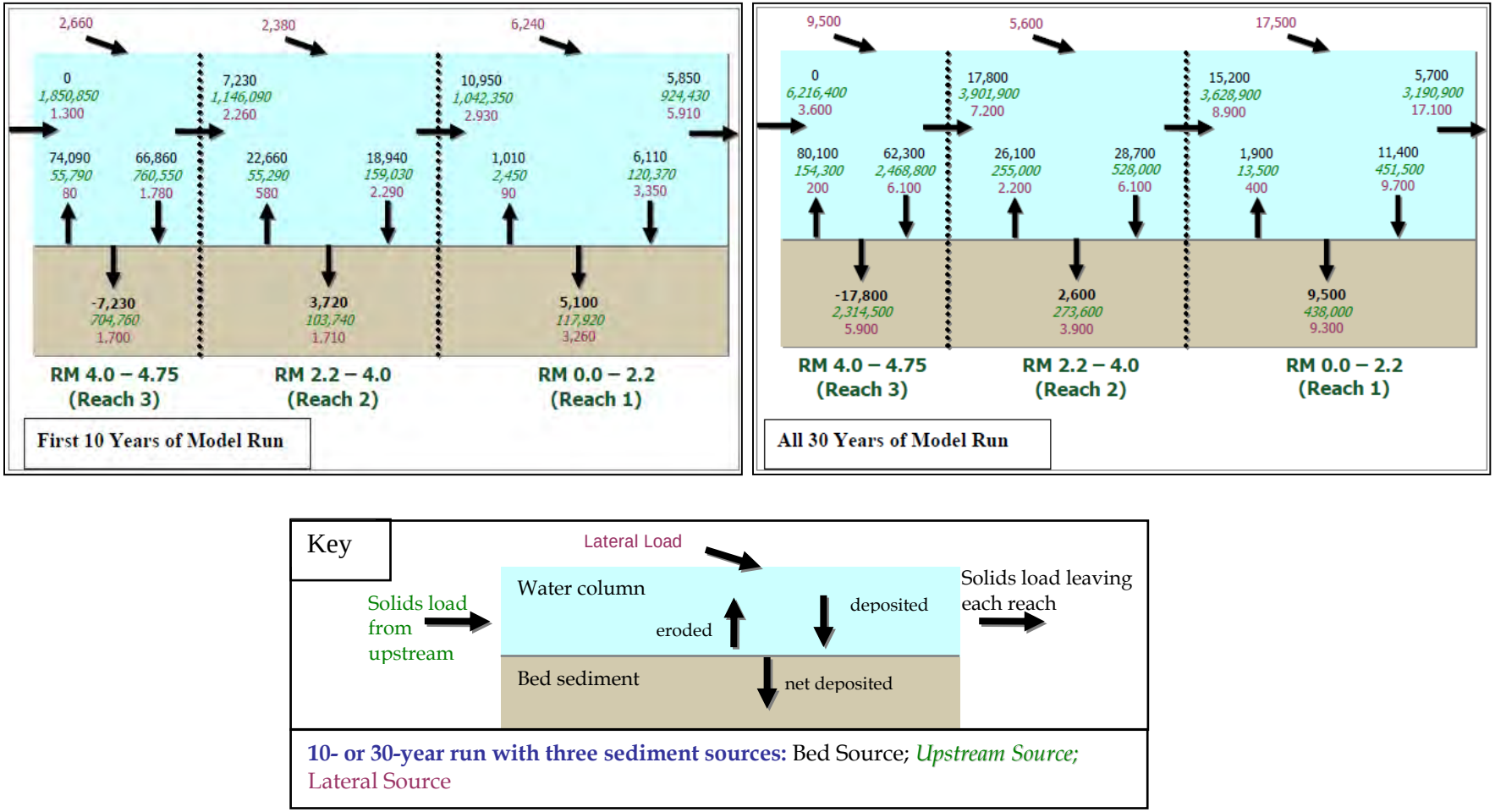
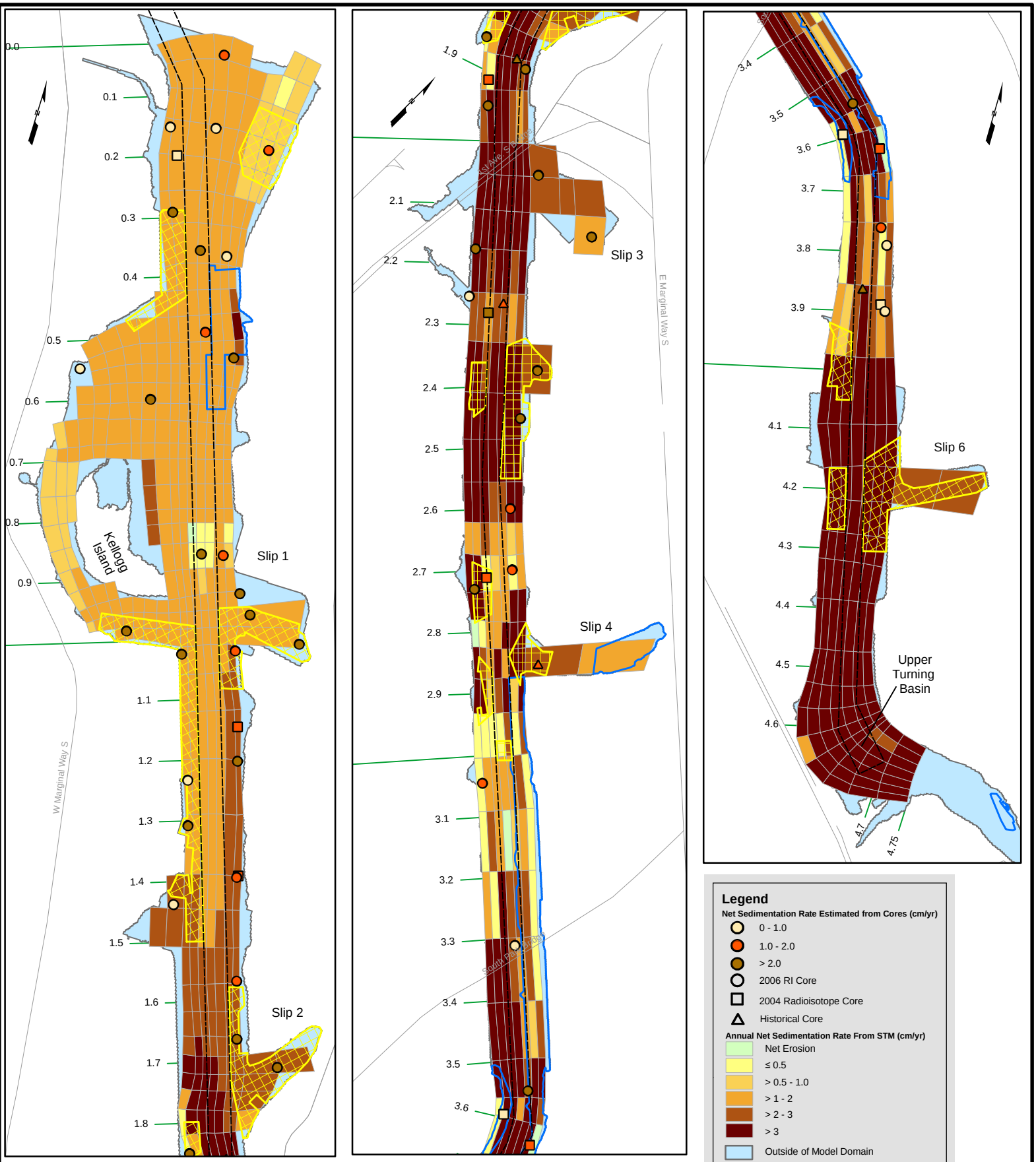
FIGURE 5-2

Figure 5-3 Sediment Loading To, Within, and Through the LDW Over Two STM Time Periods



Notes:
Loads are in metric tons over a 10- or 30-year model run.
Upper end of modeled reach extends to RM 4.75
RM= river mile.



Notes:
1. Net sedimentation rates estimated from radioisotope core data provided by QEA LLC; and 2006 core chemistry data and historical core data provided by Windward Environmental LLC.
2. Numerous time markers used to estimate net sedimentation rates are from radioisotope, physical, and chemical geochronology profiles.
3. Ranges shown are calculated from recovered depths.
4. STM GIS shapefile from 30-year run (QEA Feb. 2009).
5. High-flow scour of 10 cm or more over 30-year simulation (QEA 2008).

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Potential Scour Areas and Estimated Net Sedimentation Rates

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FIGURE 5-4

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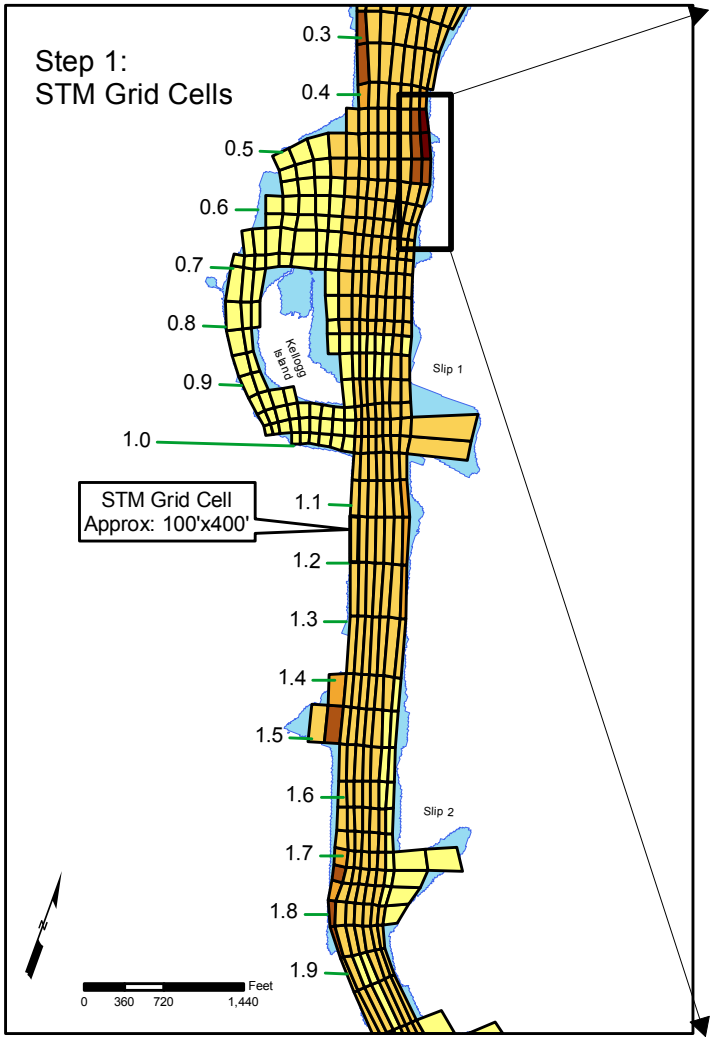

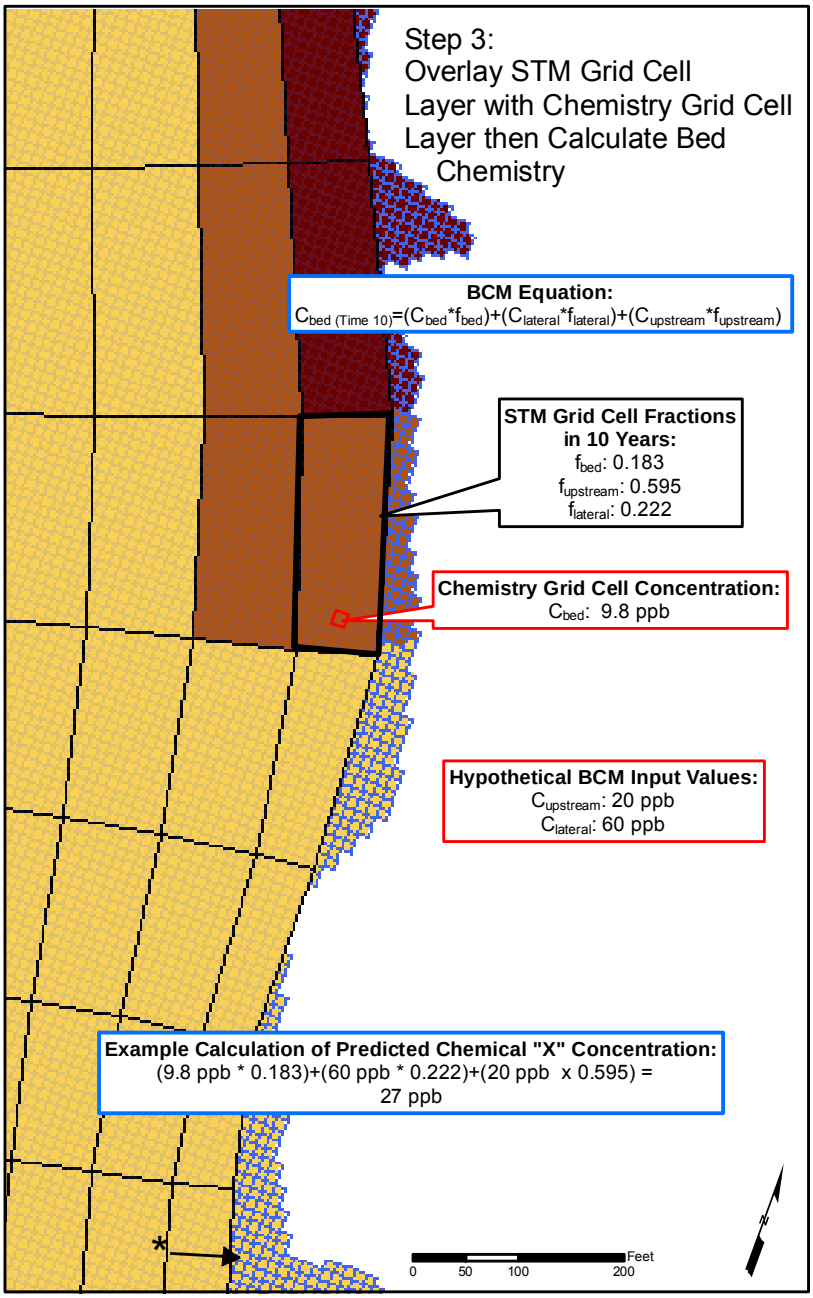

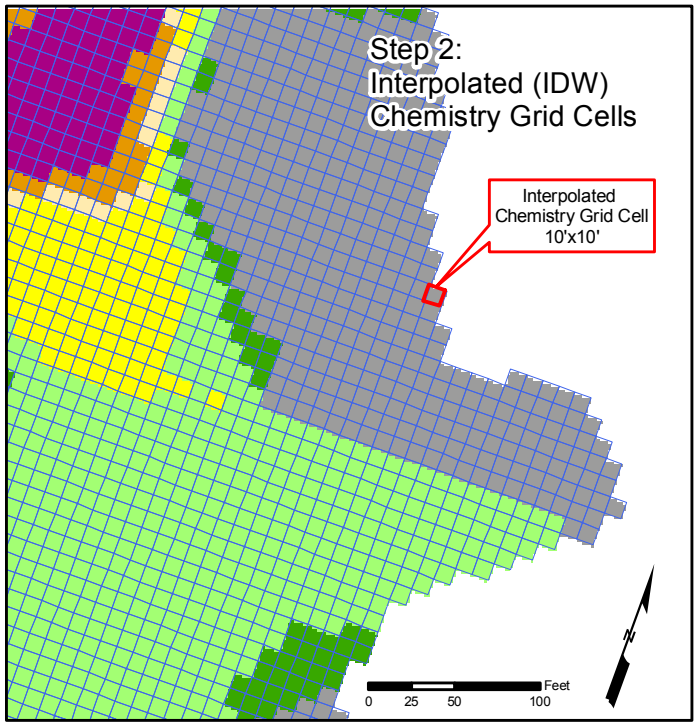

Legend

Estimated 10-Year Lateral Component of Composition from STM (Percent) (Step 1)

- ≤ 1
- > 1 - 5
- > 5 - 10
- > 10 - 25
- > 25
- Outside of Model Domain

Interpolated Total PCB Concentration (µg/kg dw) (Step 2)

- ≤ 60
- > 60 - 120
- > 120 - 240
- > 240 - 480
- > 480 - 720
- > 720 - 1,300
- > 1,300

River Mile Marker

Notes:
1. 10-year STM GIS shapefile (QEA June 2008) for illustrative purposes only.
2. The BCM equation is calculated for each 10'x10' grid cell.

* Data from closest STM grid cell was extrapolated towards shore to match chemistry grid cell layer footprint.
ppb= parts per billion.

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BCM Calculation in Model Grid Cells

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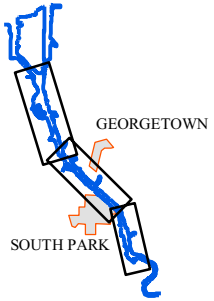
FIGURE 5-5

F:\PROJECTS\GIS\Lower Duwamish FS\Projects\FS\Section 5\Figure-xBCMCellCalcs.mxd

LOCATOR MAP



LEGEND

- Navigation Channel
- Shore Line
- River Miles
- Roads
- Hard Bottom
- Outside Model Domain
- Neighborhoods
- Non-EAA Area

Non-EAA Source Content (%)

- 0 - 1
- 1 - 5
- 5 - 20

LOWER DUWAMISH WATERWAY STUDY AREA SEATTLE, WA

Figure 5-6

Estimated percentage of surface (0-10 cm) sediments within EAAs originating from bed sediments outside the EAAs at the end of 10-year simulation

QEA Quantitative Environmental Analysis, LLC

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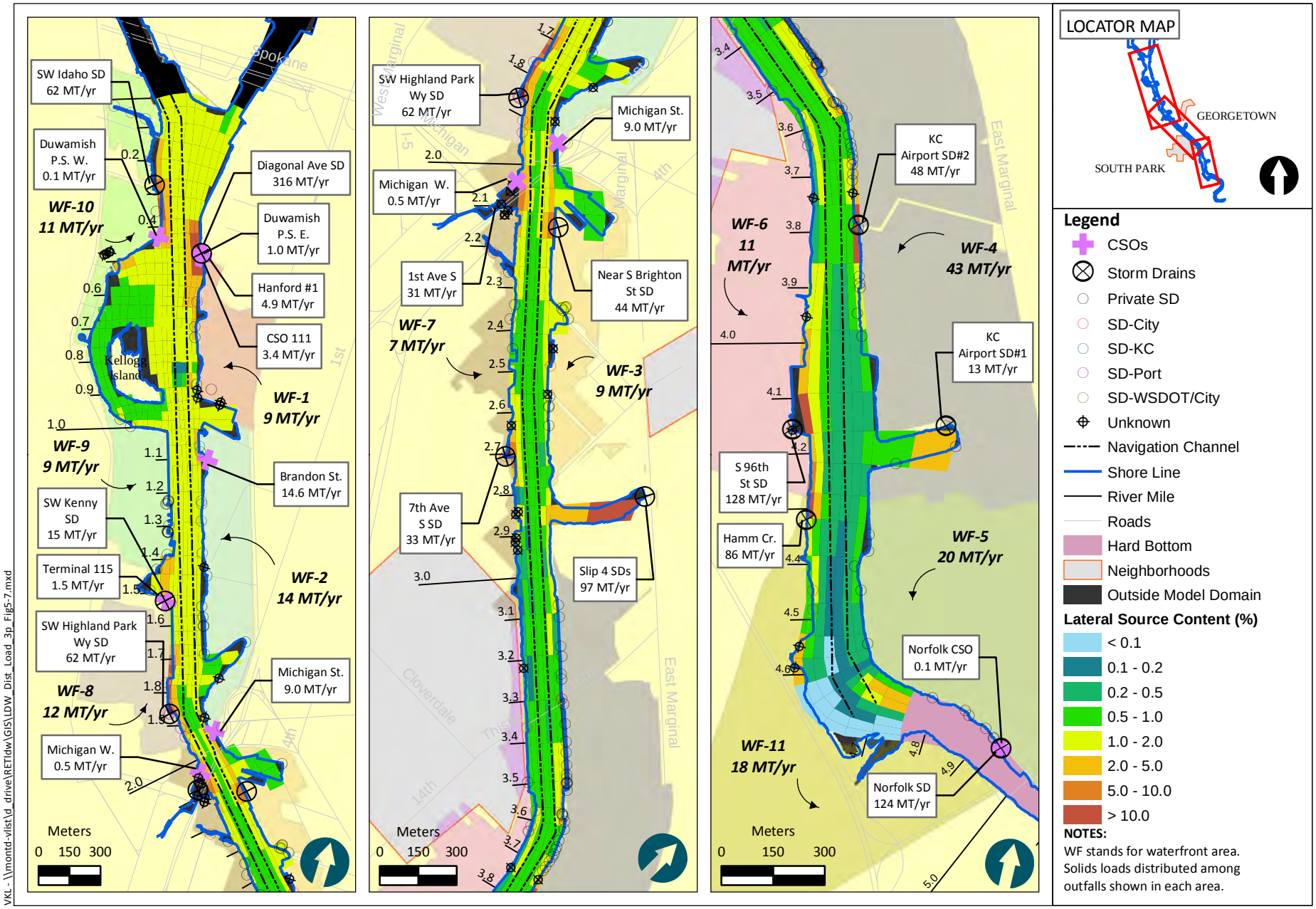
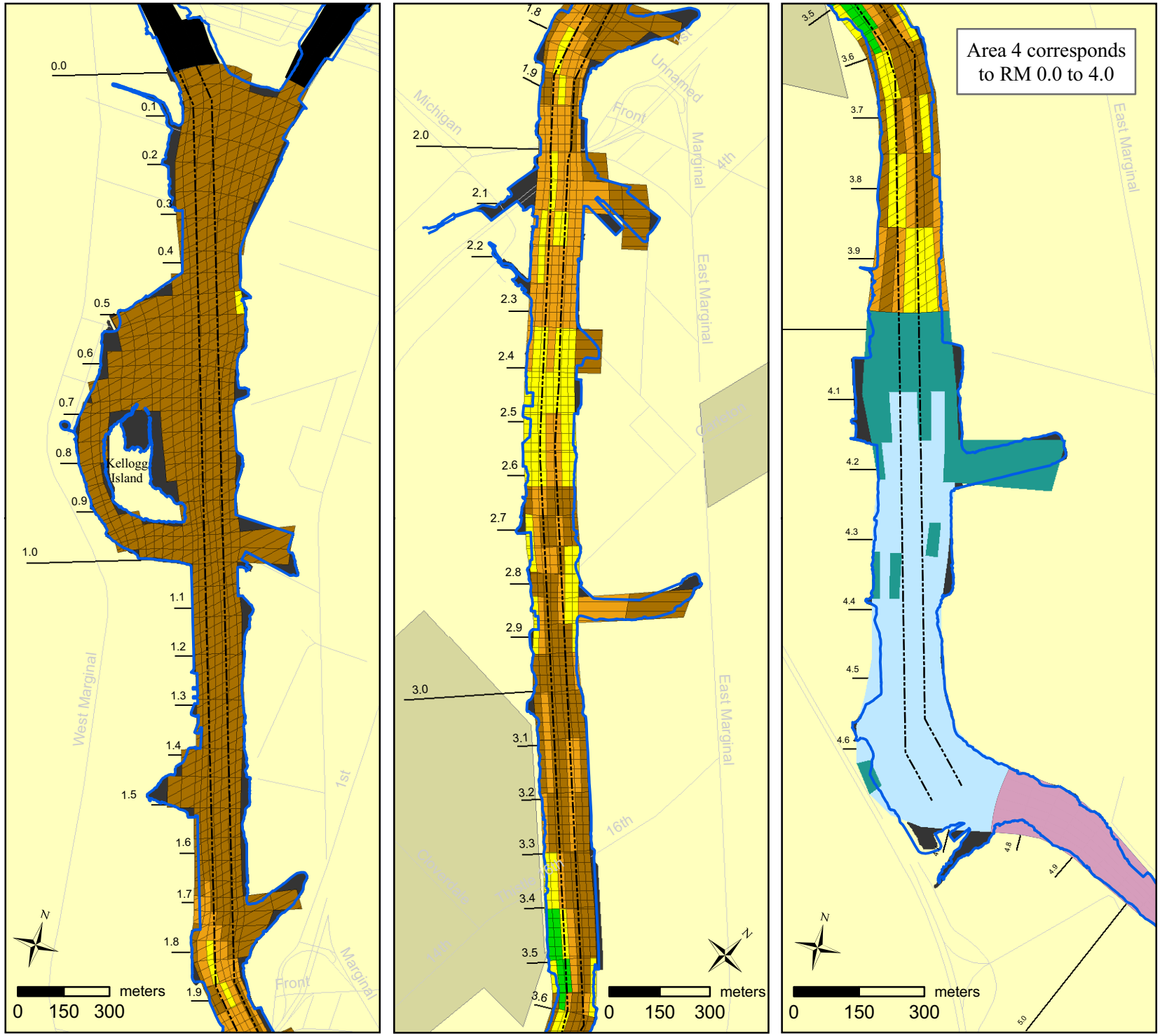


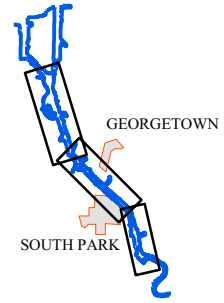
VKL - \\montd-vlist\d_drive\RETIdw\GIS\LDW_Dist_Load_3p_Fig5-7.mxd

Figure 5-7

Distributed lateral annual loads and lateral source content in surface (0-10 cm) sediments at end of 10-year simulation

QEA Quantitative Environmental Analysis, LLC





LEGEND

- Navigation Channel
- Shore Line
- River Miles
- Roads
- Hard Bottom
- Neighborhoods
- Outside Model Domain
- Area 4 Bed Source Location

Area 4 Bed Source Content (%)

- < 0.01
- 0.01 - 0.05
- 0.05 - 1
- 1 - 5
- 5 - 10
- > 10

LOWER DUWAMISH WATERWAY STUDY AREA SEATTLE, WA

Figure 5-8

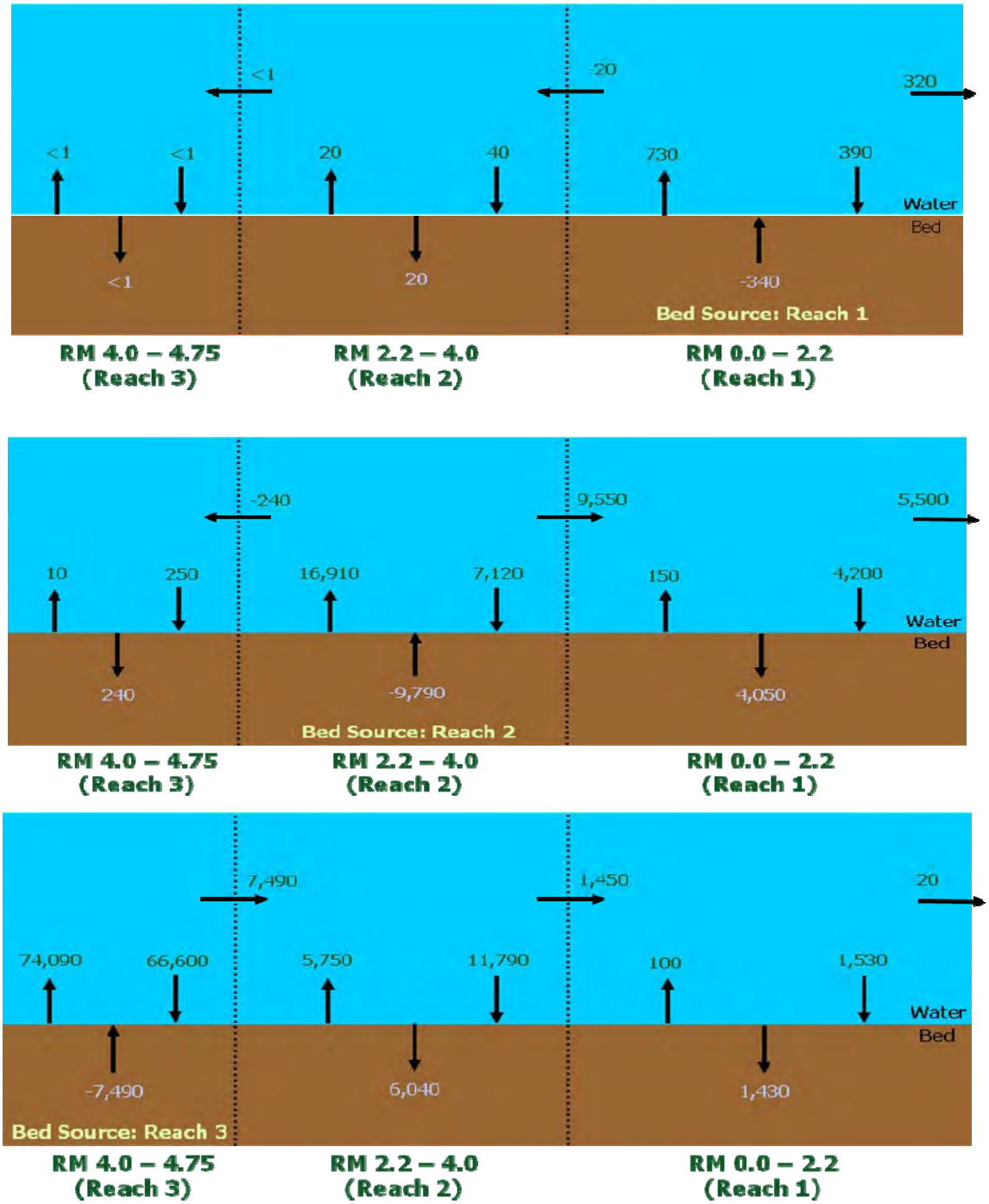
Estimated percentage of surface (0-10 cm) sediments resuspended from RM 0.0 to 4.0 and re-deposited in other LDW areas at the end of 10-year simulation

January 2009

QEA Quantitative Environmental Analysis, LLC

FC/JC- \\Jill\D_drive\Jobs\RETltw\Documents\Scenario_Memo\RETldw_tech_memo_fig_3-4_FS_fig_5-11.mxd

Figure 5-9 Mass Balances for Bed Sediment Originating from Reaches 1, 2, and 3 for 10-year STM Simulation



Note:
Sediment mass units are in metric tons, rounded to the nearest 100 metric tons.

Figure 5-10a Total Sediment Mass Balance for 100-year High-flow Event Simulation

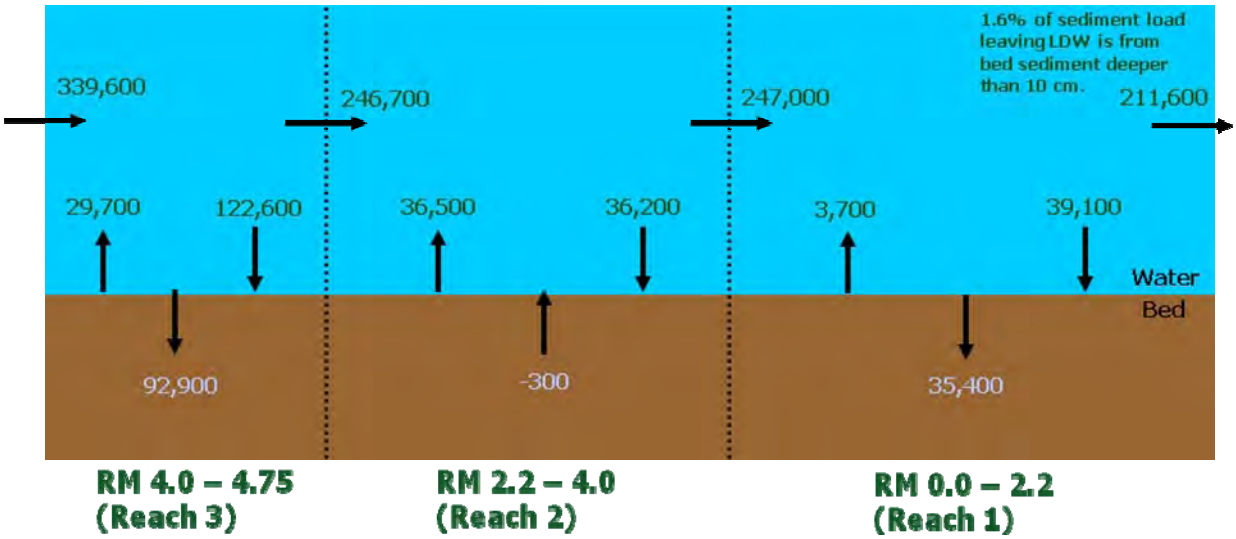
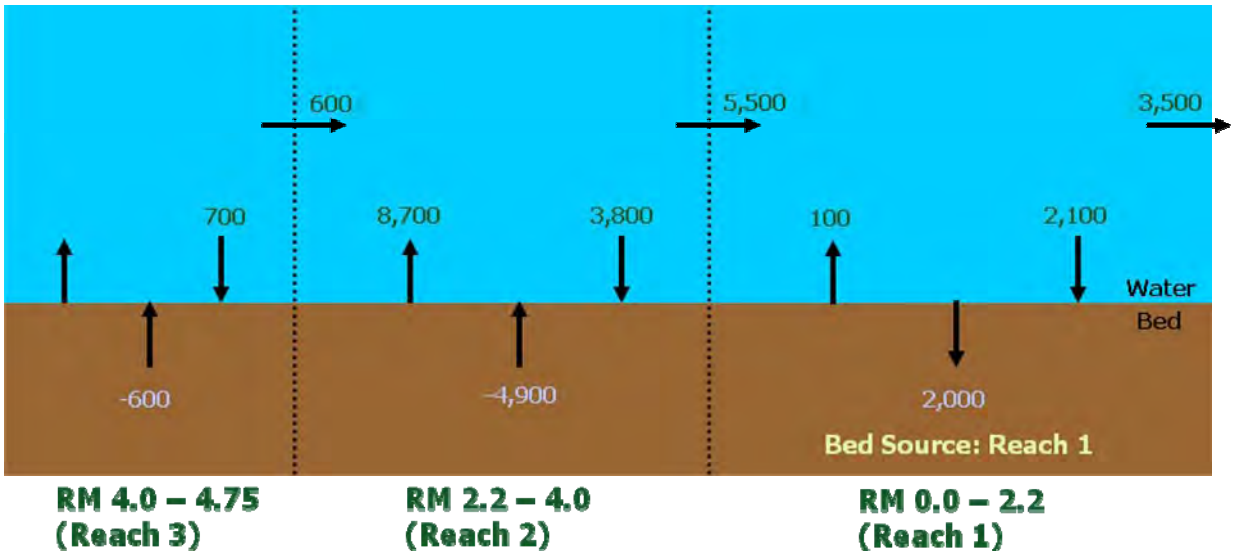
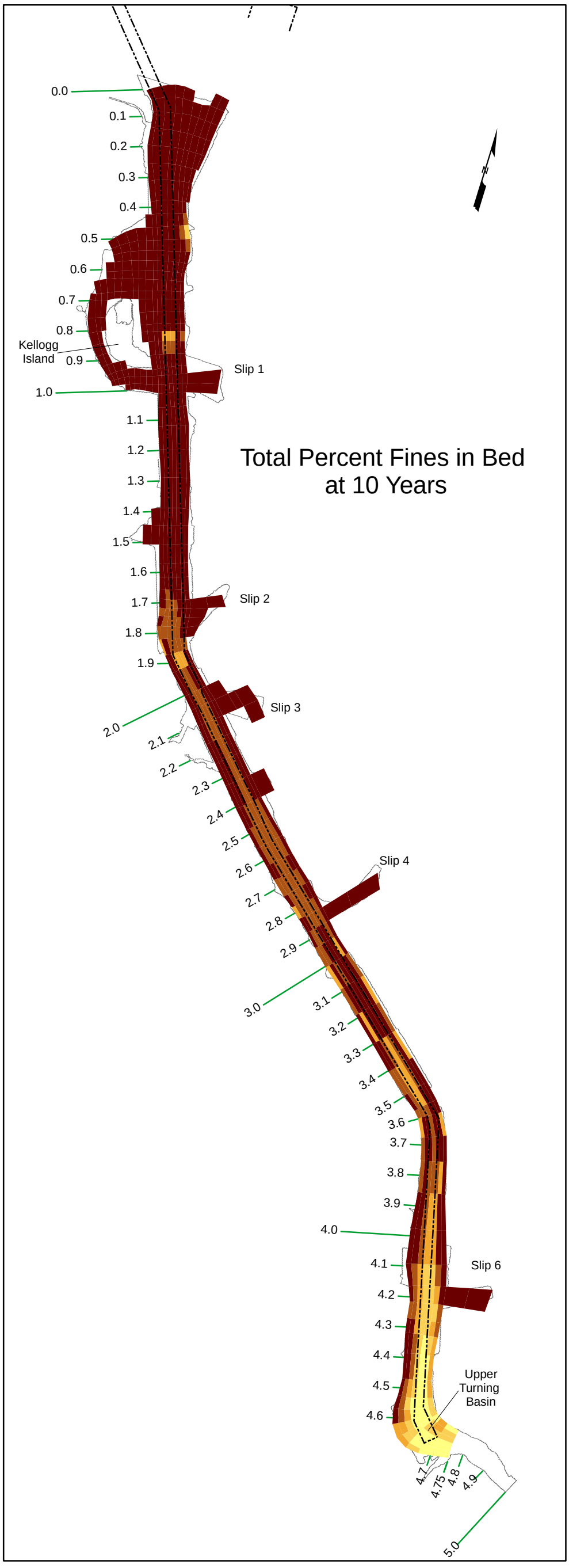
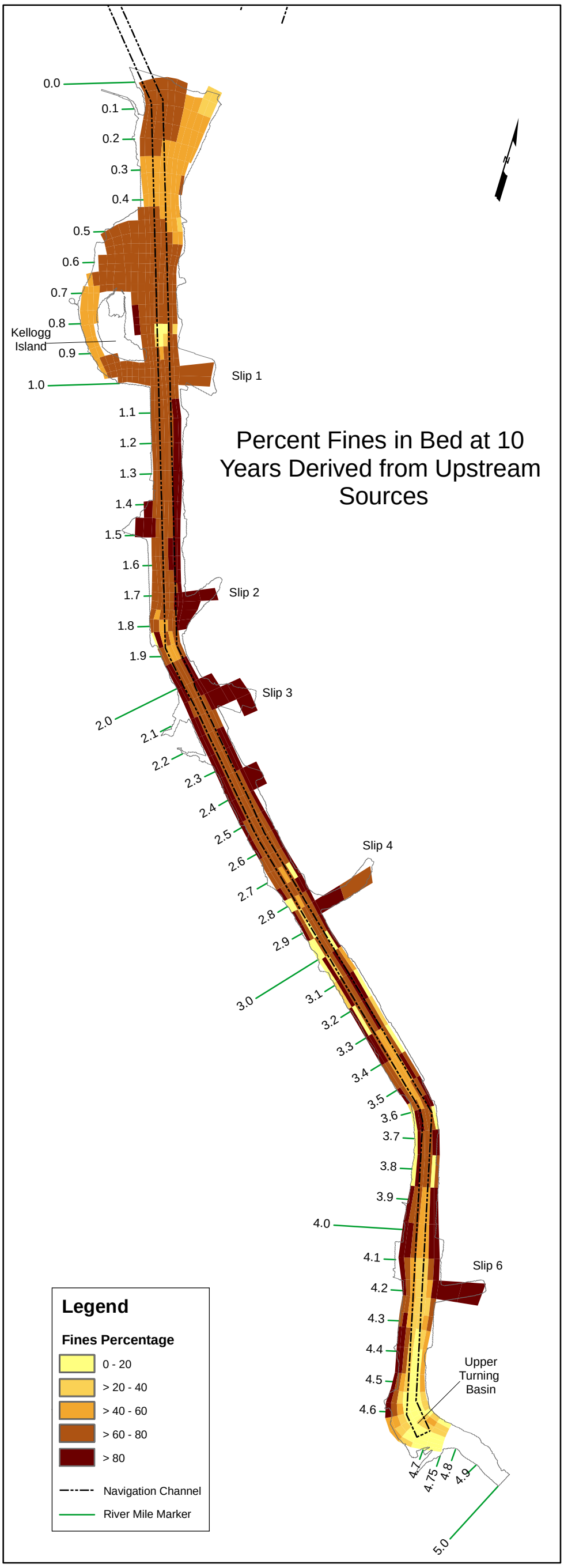


Figure 5-10b Mass Balance for Bed Sediment Originating from Deeper-than-10-cm Layer during 100-year High-flow Event Simulation



Note:
Sediment mass units are in metric tons, rounded to the nearest 100 metric tons.





Notes:
1. 10-year STM GIS shapefile (QEA Feb. 2009).
2. Total fines represents the sum of fine-grained sediment from bed, lateral, and upstream sources in each grid cell at 10 years.
3. Upstream fines represents the percentage of fine-grained sediment from upstream sources in each grid cell at 10 years.
4. Fine-grained sediment is the sum of grain size classes 1A and 1B modeled in the STM.

Feet
0 750 1,500 3,000

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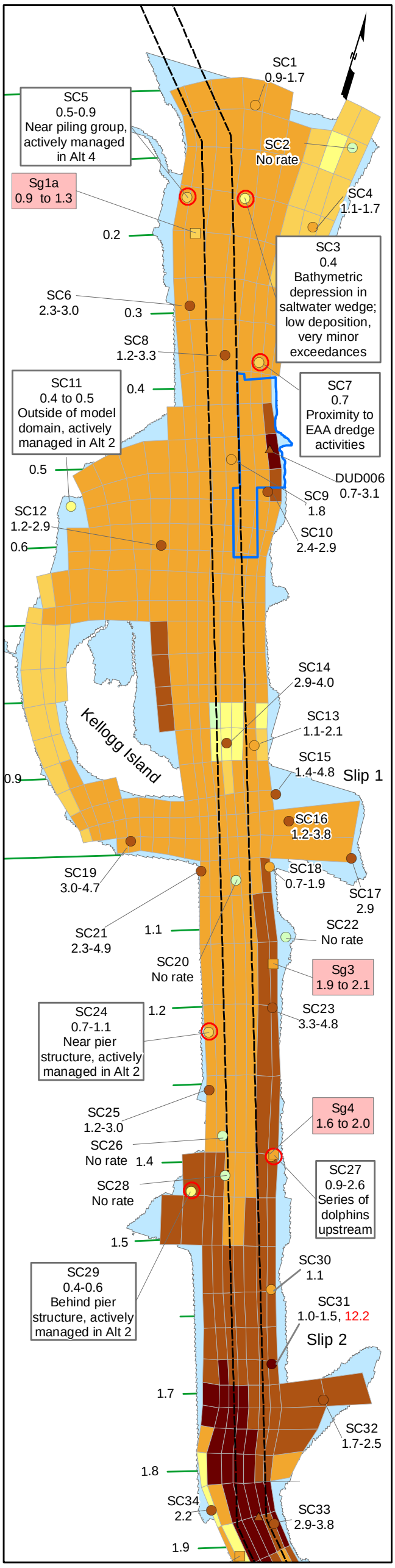
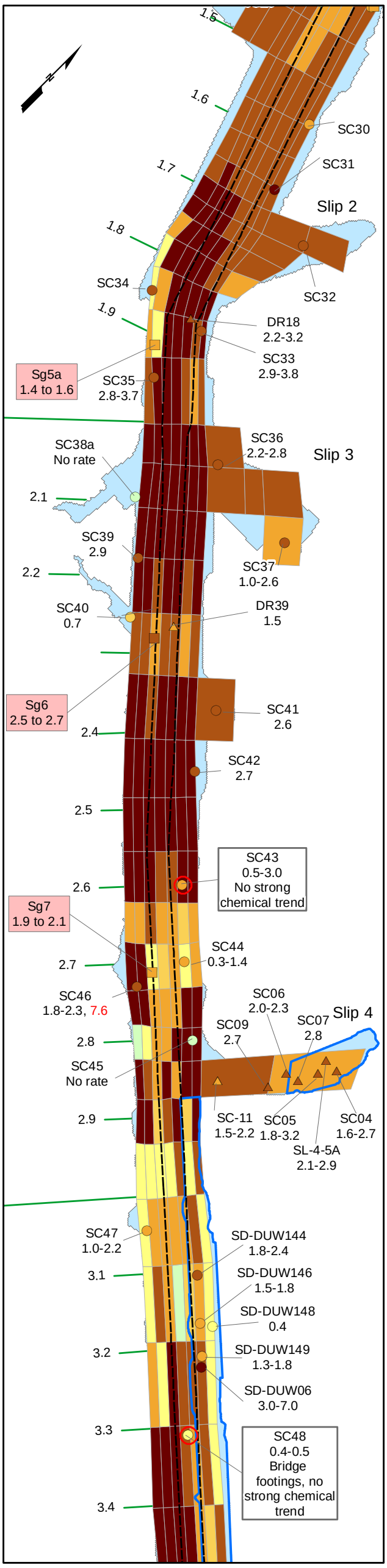
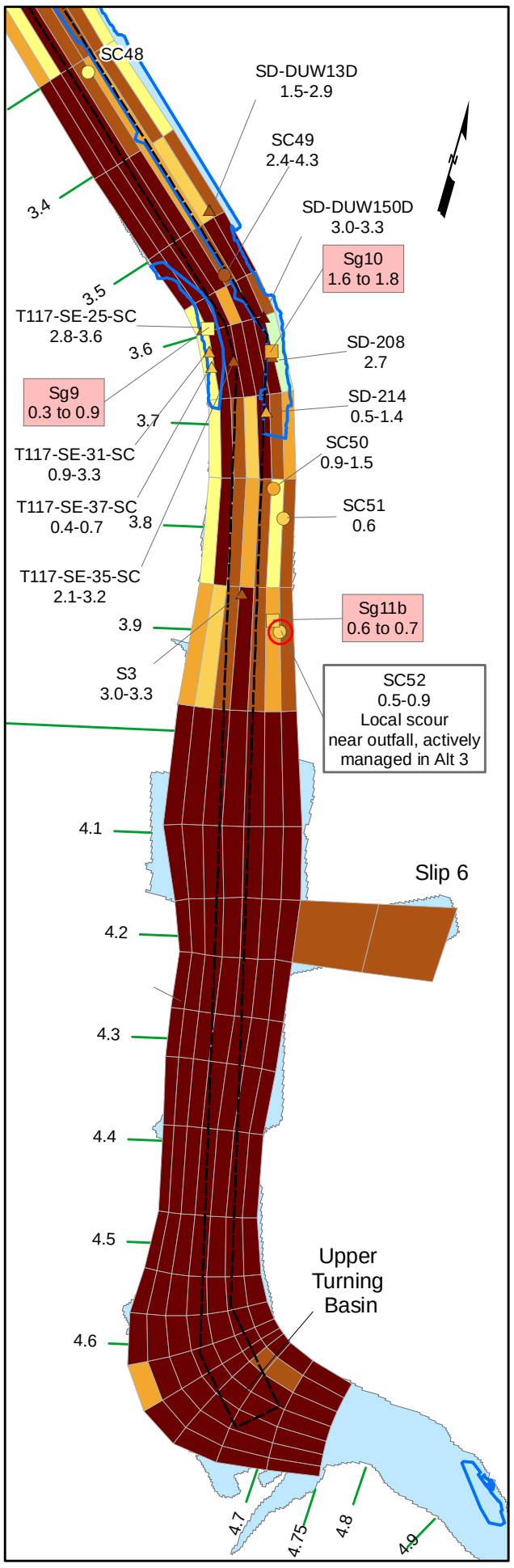
DATE: 10/15/10	DWRN: MVI/sea	Revision: 0	**FIGURE 5-11** 5-69

L:\Lower Duwamish FS\FS_GIS_01April2010\Section 5\MXDs\Figure5-xCombinedvsUpstreamFines.mxd







Legend

Annual Net Sedimentation Rate (cm/yr)

Rate (cm/yr)

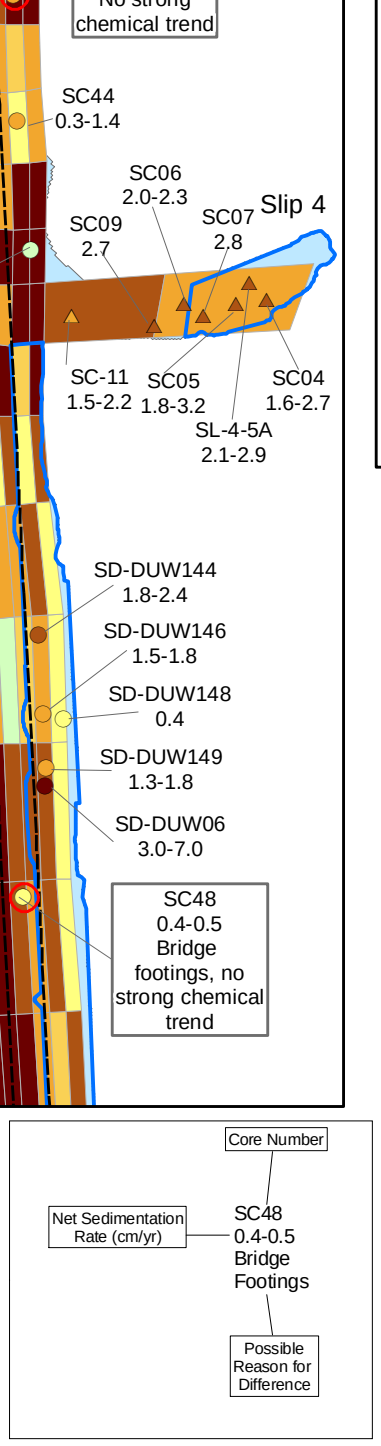
- Net Erosion
- 0 - 0.5
- > 0.5 - 1
- > 1 - 2
- > 2 - 3
- > 3

Rate Estimated from:

- SC8 ○ 2006 RI Core
- Sg1a □ 2004 Radioisotope Core
- DR39 △ Historical Core
- STM Grid Cell

- Net Sedimentation Rate Estimated from Core is Less than Rate from STM
- Outside Model Domain
- Early Action Area
- Navigation Channel
- River Mile Marker

Notes:
1. Net sedimentation rates estimated from radioisotope core data provided by QEA LLC; and 2006 core chemistry data and historical core data provided by Windward Environmental LLC.
2. Numerous time markers used to estimate net sedimentation rates are from radioisotope, physical, and chemical geochronology profiles.
3. Ranges shown are calculated from recovered depths.
4. Red font represents rate from dredging event marker outside range of other rates.
5. STM GIS shapefile from 30-year run (QEA Feb. 2009).
6. Seven RI cores for which rates could not be calculated are displayed as green circles.



0 400 800 Feet

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Comparison of Net Sedimentation Rates Estimated from the STM and from Sediment Cores

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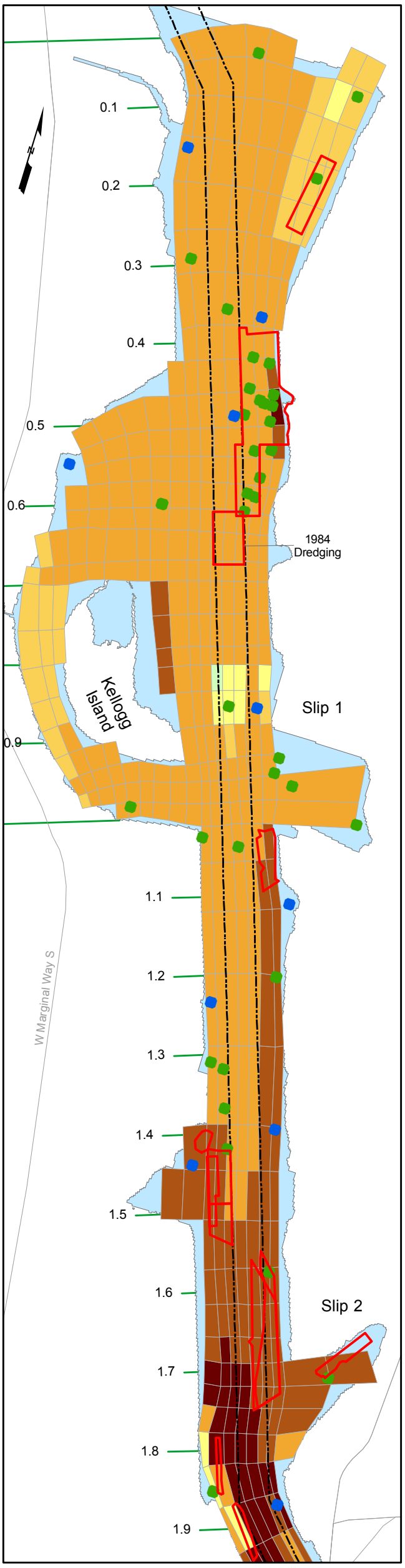

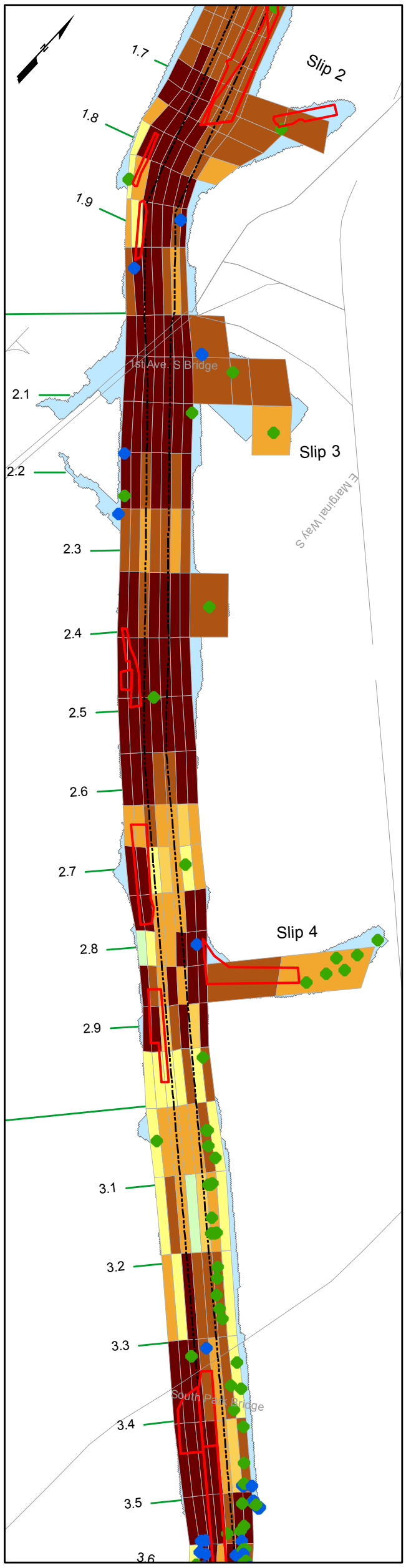

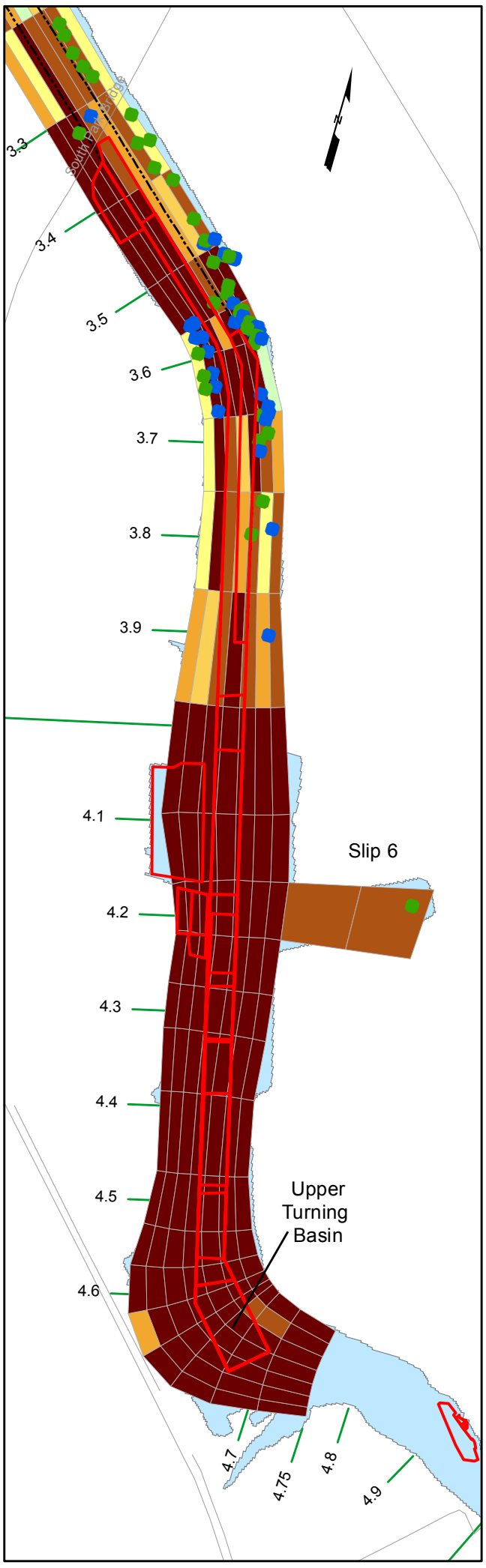

Legend

Interpretation of Subsurface Sediment PCB Profile

- Consistent with assumptions (peak total PCB concentration as deep or deeper than expected)
- Inconsistent with assumptions (peak total PCB concentration shallower than expected)

Annual Net Sedimentation Rate from STM (cm/yr)

- Net Erosion
- ≤ 0.5
- > 0.5 - 1
- > 1 - 2
- > 2 - 3
- > 3
- Outside of Model Domain
- Dredging Event within Last 30 Years
- Road
- Navigation Channel
- River Mile Marker

Notes:
1. Interpretation of total PCB profile from Final RI (Windward 2010). Interpretation identifies whether PCB peak assigned to 1965 is at a depth consistent with the net sedimentation rate from the STM annualized from a 30-year run.
2. Peak total PCB concentration at depth identified where concentration is at least two times concentration in surface interval.
3. 30-year STM GIS shapefile (QEA Feb. 2009).

Feet
0 200 400 800

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Lower Duwamish Waterway Draft Final Feasibility Study 60150279-14.8			Annual Net Sedimentation Rates and Empirical PCB Trends in Subsurface Core Data
DATE: 10/15/10	DWRN:MVI/sea	Revision: 0	FIGURE 5-13

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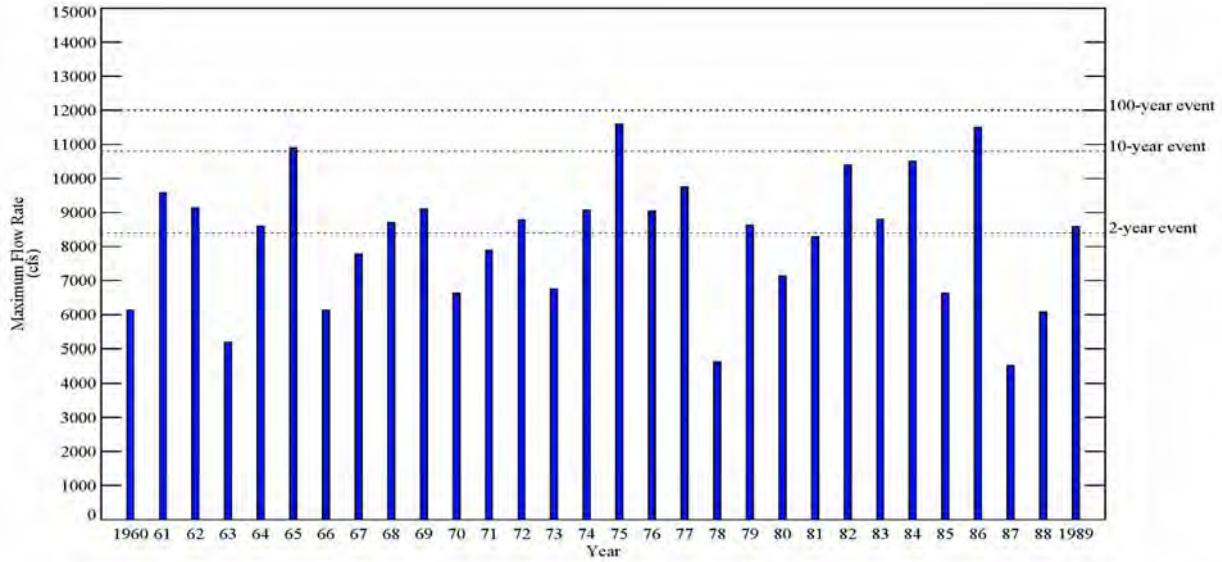

Figure 5-14a. Maximum flow rate during each year from 1960 to 1989.

Flow data: Fresh Water Discharge at USGS 12113000 (Green River).

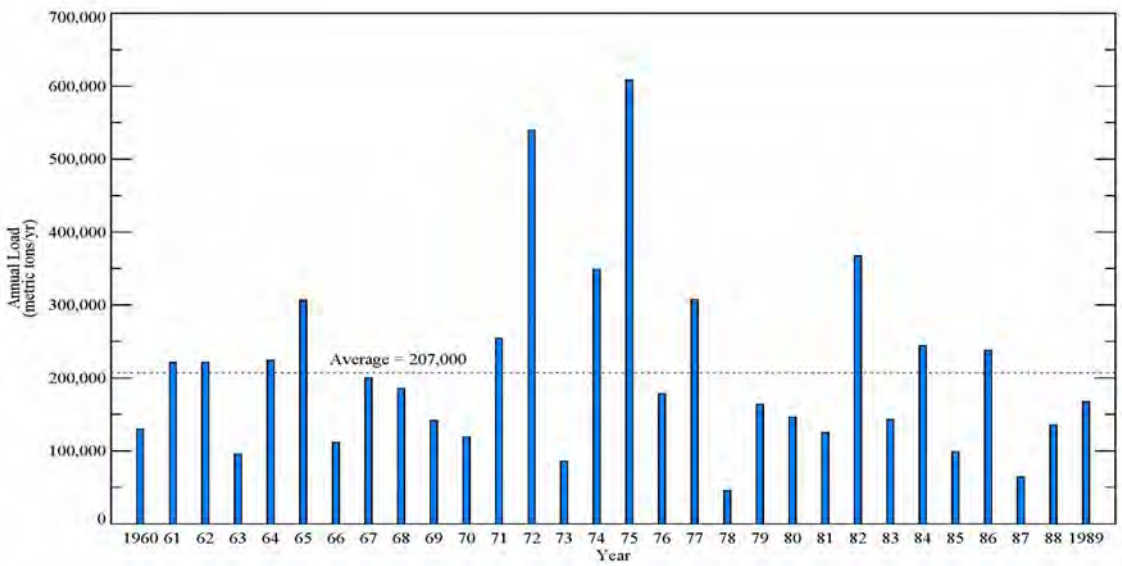

Figure 5-14b. Estimated annual total sediment load (suspended and bed load) in the Green River from 1960 through 1989.

Note: 207,000 MT is annual average sediment load over 30-yr period. The annual average sediment load over the first 10 years (1960 – 1969) is 185,000 MT.

6 Areas of Potential Concern, Remedial Action Levels, and Recovery Potential

This section defines the areas of potential concern (AOPCs) with potentially unacceptable risk based on the findings of the baseline risk assessments. This appendix also presents the remedial action levels (RALs) used in developing the remedial alternatives that address these risks. Lastly, this section presents categories of recovery potential for sediments in the LDW based on physical conditions and empirical chemical trends.

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Model Toxics Control Act (MTCA) require a feasibility study (FS) to identify volumes and areas of sediment where remedial action may be necessary and applied. Defining these areas requires

> *"…careful judgment and should include a consideration of not only acceptable exposure levels and exposure routes, but also site conditions and the nature and extent of contamination"* (EPA 1988).

For sites with both discrete hot-spot areas of contamination and low levels of wide-spread contamination, like the Lower Duwamish Waterway (LDW), the relationship between spatial location, areal extent, and concentrations of chemicals of concern (COCs) should be evaluated to determine the overall volumes and areas of sediments to be carried forward in the FS (EPA 1988 and 2005). Further, the extent to which natural recovery is potentially viable in areas of the LDW should also be evaluated, because it defines the upper end of the areal extent of the LDW that could potentially require active remedial actions (Ecology 1991).

Hence, important steps in the FS process for mapping cleanup areas at a complex sediment site like the LDW include:

- Delineate the areas that have potentially unacceptable risks based on the risk assessment findings that will likely require some consideration in the FS (e.g., active or passive remediation); this footprint, referred to as the AOPCs, is described in Section 6.1.
- Define a range of RALs that could be applied to the site to achieve preliminary remediation goals (PRGs). RALs are chemical-specific sediment concentrations that trigger the need for active remediation (e.g., dredging or capping). A RAL is equivalent to a "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). A range of possible RALs, which trigger

active remediation, is identified in this FS. The remedial action objectives (RAOs) can be achieved through combinations of this active remediation (triggered by the RALs), natural recovery, and institutional controls. This range of RALs is discussed in Section 6.2.

- Define areas within the AOPCs that have similar physical characteristics, engineering factors, and recovery potential for which particular remedial technologies may be applied. These areas are referred to as recovery categories and are discussed in Section 6.3.

Collectively, these evaluations are used in the assembly of the LDW-wide remedial alternatives in Section 8. For all FS-level analyses, various combinations of active and passive management of the AOPCs are evaluated relative to the RAOs. However, in many cases, the AOPC boundaries and the recovery potential within these boundaries will need to be refined during remedial design and even, perhaps, during implementation of the remedial alternative.

6.1 Delineating the Areas of Potential Concern (AOPCs)

The AOPCs represent the areas of sediment that have potentially unacceptable risks and will likely require application of active or passive remedial technologies. Defining the AOPC footprints requires understanding the types and levels of estimated risks in the LDW (see Section 3); the RAOs to address those risks and associated PRGs (see Section 4); and the conceptual site model, site conditions, and the data collection and analysis efforts over the past 20 years (see Section 2). The AOPC footprints defined for this FS are discussed in this section, along with a summary of the considerations used in deriving and evaluating these AOPCs. As shown in Table 6-1, the chemical values used to develop the AOPC footprints include detected concentrations of risk-driver chemicals above the PRGs from the FS baseline surface and subsurface sediment datasets, and toxicity data, when available (see Section 2).

The AOPCs do not include the early action areas (EAAs; 29 acres), which are addressed under existing cleanup programs. Evaluations used to define the AOPCs assume cleanup of the EAAs. Two AOPC footprints are shown in Figure 6-1 and are described below.

6.1.1 AOPC 1 Footprint

The AOPC 1 footprint defines the extent of areas that may require remediation (active or passive) to achieve the risk-driver chemical PRGs for RAOs 2, 3, and 4. AOPC 1 also addresses RAO 1 by reducing risk-driver chemical concentrations in sediments (although full achievement of RAO 1 will require measures in addition to sediment cleanup, as discussed in Section 8). The PRG for RAO 1 is natural background and, thus, is not expected to be achievable. AOPC 1 was delineated using the following criteria:

- Areas previously identified as EAAs are not included within the footprint.

- Areas where concentrations necessary to achieve area-based PRGs are exceeded in surface sediments (top 10 cm). These concentrations include:
  - Total polychlorinated biphenyls (PCBs) greater than 240 micrograms per kilogram dry weight (µg/kg dw) to achieve a reduction in seafood consumption risk and the point-based RAL of the sediment quality standard (SQS).
  - Arsenic greater than 57 milligrams per kilogram dry weight (mg/kg dw) (the SQS) to achieve the point-based RAL of the SQS.
  - Carcinogenic polycyclic aromatic hydrocarbons (cPAHs) greater than 1,000 µg toxic equivalent (TEQ)/kg dw to achieve reduction in seafood consumption risk.
  - Dioxins/furans greater than 25 nanograms (ng) TEQ/kg dw to achieve reduction in seafood consumption risk.
- Intertidal areas where concentrations necessary to achieve beach play direct contact PRGs and the tribal clamming PRGs[1] are exceeded within the upper 45 cm of sediment. These concentrations include:[2]
  - Arsenic greater than 28 mg/kg dw
  - cPAHs greater than 900 µg TEQ/kg dw
  - Assumed beach play areas where the cumulative (for all four human health risk-driver chemicals) direct contact risk exceeds 1×10^{-5}.
- Areas (by Thiessen polygon) that exceed the SQS chemical or toxicity criteria in surface sediment. Sediment toxicity data override chemical SQS or cleanup screening level (CSL) exceedances and chemical passes, as described in Section 2.
- Areas with SQS exceedances in the top two feet (ft) of subsurface sediment that are potentially subject to 100-year high-flow scour deeper than 10 centimeters (cm; as predicted by the Sediment Transport Model [STM]; see Figure 2-6) or are subject to vessel scour (see Figure 2-7). In an area with an SQS exceedance in the top two ft of a core, the areal extent was defined by the extent of the mapped high-flow scour or vessel scour around that core.

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1 The arsenic beach play and clamming PRGs are set to natural background, which can be achieved if natural background is the 90th percentile but below the 95% upper confidence limit of the natural background dataset for arsenic.

2 Total PCBs and dioxins/furans, which are also risk drivers for direct contact, are not listed for intertidal areas because the site-wide RALs of 240 µg/kg dw and 25 ng TEQ/kg dw, respectively address areas of concern for beach play and tribal clamming.

AOPC 1 represents the maximum extent of any exceedance delineated by the layers described above. Figure 6-1 presents the areal extent of the AOPC footprints. Overall, the AOPC 1 footprint (Figure 6-1) represents about 176 acres or about 40% of the entire LDW (441 acres).

For RAOs 1, 2, and 4, a series of GIS-interpolated chemical concentration maps for total PCBs, arsenic, cPAHs, and dioxins/furans was used to delineate the AOPC 1 footprint. As described in Section 2, inverse distance weighting (IDW) was used for the first three chemicals, and Thiessen polygons were used for dioxins/furans. A direct comparison of chemical point concentrations (measured at specific sample locations) to PRGs is not appropriate because the PRGs associated with RAO 1 (seafood consumption), RAO 2 (direct contact), and RAO 4 (wildlife consumption of prey) are area-based averages. Therefore, to determine the area needing remediation to achieve an area-based PRG (or to make progress toward achieving a PRG over time), a point concentration above which active remediation may be necessary was identified. In cases where the PRG is not achievable or natural recovery is used to achieve the PRG over time, remediation of these points yields maximum incremental progress toward achieving that PRG. To identify these point concentrations, each human health risk-driver chemical was evaluated in an iterative fashion. The chemical concentrations were ranked in descending order, and the values were sequentially replaced with a value representing post-cleanup conditions until the spatially-weighted average concentration (SWAC) achieves a target concentration (usually the PRG; expressed as either an LDW-wide or an area-wide SWAC). The boundary of AOPC 1 was defined by all of those areas identified as exceeding the point-based values.

Sediment Management Standard (SMS) criteria for RAO 3 were used in delineating AOPC 1 using point data coded by the maximum detected SQS exceedance (discussed in Section 2) and spatially represented as Thiessen polygons. The organic carbon (oc)-normalized concentrations were used for total PCBs and other non-polar organic compounds when the total organic carbon (TOC) content was within the appropriate range for oc-normalization; otherwise the dry weight apparent effects threshold (AET) value was used to code the point relative to the SMS criteria. SMS chemical point data were also evaluated relative to toxicity testing data collected from that same location. The FS dataset includes 76 locations with toxicity data, which override the SMS exceedance status assigned to the location based on chemical concentrations

The AOPC 1 footprint appropriately encompasses the areas that should be prioritized in the FS for remedial alternative development. Cleanup of the EAAs and all of AOPC 1, through some combination of active cleanup, verification monitoring, monitored natural recovery, and institutional controls, when complete, is projected to achieve the RAOs.

6.1.2 AOPC 2 Footprint

In addition to AOPC 1 shown on Figure 6-1, EPA and the Washington State Department of Ecology (Ecology) requested that a larger remedial footprint be evaluated that would achieve further reduction in risk-driver sediment concentrations through active remediation. This larger footprint, known as AOPC 2, adds approximately 123 acres to the AOPC 1 footprint, such that AOPC 2 encompasses 299 acres (or approximately 68% of the entire LDW study area). The extent of AOPC 2 is based on the feasibility considerations discussed below.

AOPC 2 was determined based on a best estimate of the areas that would need to be actively remediated to achieve site equilibrium.[3] Equilibrium is the long-term model-predicted average concentration for the LDW that incorporates urban influences. Achievement of natural background (at which some of the PRGs are set) is unlikely because additional remediation beyond AOPC 2 would not result in lower long-term COC concentrations. This is attributed to inputs from the Green/Duwamish River and lateral sources influenced by general urbanization of the LDW drainage basin. AOPC 2 was delineated to achieve site-wide SWACs that fell within the long-term model-predicted range of concentrations (i.e., concentrations the LDW will likely eventually equilibrate to following cleanup and associated source control).[4]

The AOPC 2 footprint was explored through a step-wise evaluation in which, active remediation of every point with a total PCB concentration above 100 µg/kg dw was assumed. Second, the effect of remediating this larger footprint was evaluated as site-wide SWACs for the other human health risk-driver chemicals. Based on this analysis, the AOPC 2 footprint was expanded to capture all arsenic points above 15 mg/kg dw and all dioxin/furan points above 15 ng TEQ/kg dw. Finally, the footprint was again expanded to include remaining sediment cores with detected SQS exceedances at any depth (regardless of scour potential).[5] The results of this analysis indicated that active remediation of AOPC 2, using the recommended post-remedy bed sediment replacement values for each risk-driver chemical would result in site-wide SWACs within the range of long-term model-predicted concentrations. This analysis demonstrates that:

1) Active remediation of the entire 299-acre AOPC 2 footprint would result in the lowest technically achievable SWAC, and further changes in

[3] Equilibrium is described as either the point when the rate of change (SWAC reduction per area) is small and the point at which minimal additional change in SWAC is expected to occur; or, when the asymptote of a recovery curve is reached.

[4] These concentrations are also referred to as the long-term range of model predictions.

[5] The exception is three cores collected from the Upper Turning Basin in 2009. Sediment in this area had not exceeded the SQS in previous samples. The samples were resubmitted to the laboratory several times (by USACE) for quality control issues, and the sediment represented by these cores was dredged in 2010.

SWAC over time after the cleanup through natural recovery are expected to be minimal (i.e., equilibrium would be reached).

2) Any further active remediation would not yield additional sustainable SWAC reduction or risk reduction, because upstream- and lateral- source sediments would continue to deposit onto remediated areas.

It is important to recognize that values used as post-remedy bed sediment replacement values for this analysis are uncertain. However, the sensitivity of these predictions is evaluated with a range of input parameters, described in Section 5, and based on this analysis, remediation of the AOPC 2 footprint is expected to reach long-term model-predicted concentrations. Remediation of any footprint larger than AOPC 2 would likely not result in lower site-wide or area-wide SWACs (concentrations are predicted to be within the range of the upstream inflows).

Cleanup of the EAAs and active remediation of the AOPC 2 (which includes AOPC 1) footprint is considered to represent the maximum feasible degree of SWAC risk reduction (for RAO 1) that can be achieved. The areas beyond the AOPCs are not considered for active cleanup in this FS (but may be subject to sampling and verification monitoring during remedial design).

In summary, the AOPC 2 footprint is considered appropriate to identify alternatives that achieve the RAOs. The footprints have been defined with enough rigor to facilitate a detailed evaluation of remedial alternatives (in Section 8) for the purposes of the FS. Finally, the remedial alternatives will include appropriate provisions (such as remedial design-level sampling) to manage the uncertainties inherent in this process.

6.2 Remedial Action Levels

RALs are surface sediment concentrations of specific chemicals that trigger the need for active remediation in the AOPCs to achieve a particular outcome. RALs are used to define the overall scope of active remediation for each remedial alternative (Section 8).

RALs are not the same as PRGs. PRGs are the long-term cleanup levels and goals for the project, whereas RALs are point-based values used to manage active remediation and are applicable only in the short term to define where active remedial actions are warranted. RALs can also be the compliance concentration used to verify that active remediation is complete, or successful, before equipment is demobilized from a site.

The development and use of RALs for this FS is based on two premises. First, once active remediation is complete (in areas where the RALs are exceeded), SWACs for human health risk drivers immediately following construction will be considerably lower than those for baseline conditions, such that some goal relative to the remedial alternative being considered is achieved. Second, after portions of the LDW are actively remediated, the remaining areas continue to undergo natural recovery processes,

largely through on-going sedimentation. In other words, remaining risk, or residual risk, in sediments may be estimated in terms of either COC concentrations at discrete locations or the SWAC in surface sediments as a function of time after the active remediation is complete. The evaluations of risk reduction over time, and the time to achieve the RAOs, are presented in Section 9.

For this FS, ranges of RALs are developed for the risk-driver chemicals (total PCBs, arsenic, cPAHs, dioxins/furans, and SMS chemicals [i.e., detected chemicals that exceeded the SQS in surface sediments]) for which PRGs were developed in Section 4 (see Figures 6-2a through 6-2d for the human health risk-driver chemicals). RALs are developed with the understanding that remediation of these risk-driver chemicals will also address the remaining COCs (see Table 3-9) that do not have PRGs.

6.2.1 Methods Used for Development of RALs

This section briefly summarizes the methods used to develop an array of RALs that bracket a wide range of active remedial footprints and expected outcomes. The range of RALs produces different areas/volumes of sediment to be actively remediated, levels of risk reduction immediately after construction, and time frames for achieving RAOs, allowing a broad array of remedial alternatives to be defined in Section 8. The residual risks remaining immediately after construction of each remedial alternative or after some additional recovery period are discussed in Sections 9 and 10 of this FS.

The RAL development is conservative because it looks only at individual chemicals without the context of commingled chemical occurrences or the spatial extent of such exceedances. Because many of the LDW COCs have some commingling and co-occurrence, it is reasonable to expect that by remediating an area to address one COC exceeding a RAL, some reduction in concentrations for other chemicals would also occur. Thus, the RALs may result in risk reduction not accounted for when only individual chemicals are evaluated. Following the active remediation of sediment exceeding each RAL, additional recovery is predicted with time, and thus each remedial alternative will achieve different degrees of risk reduction over time. This is evaluated in Section 9. The RALs were selected based on the following criteria and considerations:

- **Achievement of PRGs or ARARs.** Certain sediment PRGs or ARARs can directly translate into prospective RALs, such as SMS chemical criteria applied on a point basis and directly relate to protection of benthic receptors (RAO 3). RALs for RAO 3 were defined using two time points: at the end of construction and 10 years following completion of construction following SMS guidelines. Although not defined in the RAL development process, some RALs may achieve PRGs 20 years following completion of construction. PRGs (area-weighted) for certain direct contact scenarios are the basis for point-based RALs for this FS.

By definition, the RALs are point concentrations that exceed PRGs and require active remediation. However, a direct comparison of chemical point concentrations (at specific sample locations) to PRGs is not appropriate for all RAOs. This is because the PRGs associated with RAO 1 (seafood consumption), RAO 2 (direct contact), and RAO 4 (wildlife consumption of prey) are area-based averages. Therefore, each area-based average concentration goal needs to be "converted" to a not-to-exceed point concentration (RAL). To accomplish this "conversion" from SWACs to points, chemical concentrations were evaluated in an iterative fashion for each human health risk-driver chemical. The chemical concentrations were ranked from highest to lowest (using interpolated grid cells), and the highest values were sequentially replaced with a post-remedy bed sediment replacement value (in the bed composition model (BCM) excel worksheets) until the appropriate site-wide or area-based PRG was achieved. The highest remaining concentration becomes the RAL for the area-based target concentration.

- **SWAC Reduction for PRGs Set at Natural Background.** Certain PRGs, such as those for total PCBs for RAO 1 and arsenic for RAO 2, cannot be used directly as RALs because they are both set to natural background (Table 4-4). It would not be technically possible to implement a RAL set at natural background, because chemical concentrations associated with sediments continually entering the LDW from upstream exceed natural background concentrations. Therefore, a combination of technically feasible active remediation, natural recovery, and institutional controls must be used to achieve these PRGs. For PRGs set at natural background, two different approaches were used to identify prospective RALs. These approaches, described below, require a certain degree of best professional judgment and are considered useful for producing a range of remedial alternatives:
  - **Maximum Incremental Reduction.** Maximum incremental reduction in the average sediment concentration is a practicability assessment. It evaluates the maximum SWAC reduction for the least number of acres that can be achieved through active remediation of the highest concentrations. The maximum incremental reduction was explored for individual chemicals in a hill-topping manner, i.e., the highest concentration was replaced with the post-remedy bed sediment replacement value, and the SWAC was recalculated. This process was repeated until all baseline data were replaced. The incremental reduction was expressed as curves plotting the relationship between SWACs and acres, and identifying the "break in the curve" representing the optimized rate of change in SWAC. Figure 6-3 shows an example of how

the RAL for maximum incremental reduction was identified for total PCBs.

- **Point of Minimal Change in Concentration.** Natural background is unlikely to be reached, but rather, predicted concentrations will reach a point where minimal change in SWAC is expected to occur as more acres are remediated. This point is known as the asymptote. The estimated rate of change (SWAC reduction per acre) is expected to be so small after this point is reached that the site is considered to be "in equilibrium." It is expected that these values will also be within the range of upstream concentrations (see Table 5-1b). Figure 6-3 shows an example of this asymptote for total PCBs.

6.2.2 Range of Selected RALs

The array of RALs and how they relate to each RAO is summarized in the following subsections and in Table 6-2.

6.2.2.1 RAO 1 (Human Health Seafood Consumption) RALs

For this FS, progress toward achievement of RAO 1 (reduction of human health risks from seafood consumption) is assessed based on estimated reductions in the site-wide SWAC of total PCBs, arsenic, cPAHs, and dioxins/furans. For total PCBs, because the PRGs for RAO 1 is set at natural background, the RALs to address this objective aim to provide incremental reduction in the site-wide SWAC. The SWAC reduction is in turn expected to result in a commensurate incremental reduction in human health risks. For total PCBs, the RAL of 2,200 µg/kg dw achieves the maximum incremental reduction in the SWAC. A RAL of 1,300 µg/kg dw is defined based on the CSL[6] under RAO 3, and provides additional incremental SWAC reduction, decreasing human health risks. A RAL of 700 µg/kg dw is based on providing a well-spaced range of RALs, and provides additional incremental SWAC reduction, decreasing human health risks. A RAL of 240 µg/kg dw is defined based on the SQS[7] under RAO 3, and it provides additional incremental SWAC reduction, decreasing human health risks. The lowest total PCB RAL (100 µg/kg dw) is expected to yield minimal change in average concentration immediately after completion of construction. As discussed in Section 6.1.2, further active remediation would not appreciably lower the site-wide SWAC for total PCBs.

For dioxins/furans, because the PRG for RAO 1 is set at natural background, the RALs to address this objective aim to provide incremental reduction in the site-wide SWAC.

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[6] Assuming a total organic carbon content of 2% (the site-wide average), the total PCB dry weight equivalent of the CSL (65 mg/kg oc) is 1,300 µg/kg dw. If selected, actual implementation of this RAL would be based on the organic carbon-normalized criteria defined by the CSL.

[7] The total PCB dry weight equivalent of the SQS (12 mg/kg oc) is 240 µg/kg dw. If selected, actual implementation of this RAL would be based on the organic carbon-normalized criteria defined by the SQS.

The SWAC reduction is, in turn, expected to result in a commensurate incremental reduction in human health risks. For dioxins/furans, a RAL of 50 ng TEQ/kg dw is expected to achieve the maximum incremental reduction in the SWAC. RALs of 35 and 25 ng TEQ/kg dw are expected to achieve additional incremental reductions after construction is complete. The lowest dioxin/furan RAL (15 ng TEQ/kg dw) is expected to result in minimal change in the site-wide average concentration after construction is complete. Further active remediation would not appreciably lower the site-wide SWAC for dioxins/furans.

For cPAHs and arsenic, the relationship between concentrations in clam tissue and surface sediment is unclear. Remediating sediments may have little to no effect on reducing risks from seafood (clam) consumption. Because of co-occurrence with other chemicals, some reductions in cPAH and arsenic concentrations are expected to be achieved through management of other chemicals. To provide incremental reduction in the site-wide SWAC for cPAHs, the following array of RALs is used: 5,500, 3,800, and 1,000 µg TEQ/kg dw. For arsenic, the following array of RALs is used: 93, 57, 28, and 15 mg/kg dw. A RAL of 15 mg/kg dw for arsenic is expected to achieve a point of minimal change in average concentration after construction is complete. Further active remediation would not appreciably lower the site-wide SWAC for arsenic.

6.2.2.2 RAO 2 (Human Health Direct Contact) RALs

Achievement of RAO 2 is assessed on three spatial scales based on the three direct contact exposure scenarios. These spatial scales are site-wide for netfishing, area-wide within potential clamming areas for the tribal clamming scenarios , and area-wide within assumed beach play areas. In addition, future-use scenarios for beach play are assessed by evaluating all intertidal areas.

Netfishing

For total PCBs, cPAHs, and dioxins/furans, the netfishing site-wide PRGs are expected to be achieved immediately following remediation of the EAAs. All arsenic direct contact PRGs are set to natural background; therefore, they are not expected to be achieved. The arsenic array of RALs is set to achieve incremental SWAC reductions, with the lowest RAL set to achieve long-term model-predicted concentrations.

Assumed Beach Play Areas

As described in Section 3, the LDW has eight assumed beach play areas; note that these are not all necessarily areas where beach play currently occurs but that they were identified as such solely because public access is possible. Excess cancer risks for direct contact with sediment during beach play scenarios have been evaluated at each assumed beach play area, as well as in a subarea of Beach 5 (northerly section excluded) and in a subarea of Beach 4 (Trotsky Inlet excluded). The risks associated with the human health risk-driver chemicals are evaluated individually within each beach (risk

is calculated for each chemical) and as a cumulative total of these four risk-driver chemicals.

The PRGs for the beaches are area-weighted SWACs associated with the 10^{-5} total risk level for all human health risk drivers or with the 10^{-6} RBTCs for the individual risk drivers. An entire beach above a cumulative 10^{-5} risk, or a portion of the beach accounting for most of the risk, would require active remediation to achieve RAO 2. Total PCB beach play PRGs are expected to be achieved at the individual beaches after the EAAs have been actively remediated. The PRG for arsenic, which is equal to natural background because the 10^{-6} RBTC is below this value, is unlikely to be achieved. For cPAHs, the PRG falls within the range of upstream inputs, and therefore it is likely this PRG will not be achieved at all assumed beach play areas. Therefore, RALs for arsenic and cPAHs are set to the 10^{-5} RBTCs as points to ensure that, at a minimum, cumulative 10^{-5} risk goals are achieved on an average basis over the beaches. For arsenic, cPAHs, and dioxins/furans, RALs of 28 mg/kg dw (10^{-5} RBTC), 900 µg/kg dw (10^{-5} RBTC), and 28 ng TEQ/kg dw (10^{-6} RBTC), respectively, are applied in all intertidal areas, and hence, all potential current and future beach play areas.

Tribal Clamming Areas

All of the direct contact tribal clamming PRGs, except for arsenic, are expected to be achieved after the EAAs have been actively remediated (Figures 6-2a through 6-2d). An arsenic RAL of 93 mg/kg dw applied on a point basis is expected to achieve the tribal clamming 10^{-5} RBTC; the 10^{-6} RBTC is below natural background, and thus the PRG is set at natural background.

6.2.2.3 RAO 3 (Protection of Benthic Invertebrates) RALs

The RALs for any risk-driver chemical for RAO 3 are:

- **CSL10 –** achieves the CSL within 10 years after construction is complete. These values are estimated using the recommended BCM input parameters. The methods are described in Section 5.
- **CSL –** achieves the CSL by the time construction is complete.
- **SQS10 –** achieves the SQS within 10 years after construction is complete. These values are estimated using the recommended BCM input parameters. The methods are described in Section 5, and the locations predicted to still be SQS exceedances within 10 years are shown in Appendix F.
- **SQS –** achieves the SQS by the time construction is complete.

SMS criteria for total PCBs and the other non-polar organic compounds are on an oc-normalized basis. Total PCB RALs for RAO 3 are 12 and 65 mg/kg oc for the SQS and CSL, respectively, but may be expressed as dry-weight values in the FS for mapping

purposes and ease of discussion (240 and 1,300 µg/kg dw for SQS and CSL, respectively, assuming 2% TOC).

6.2.2.4 RAO 4 (Ecological Receptor Seafood Consumption) RALs

For RAO 4, total PCBs is the only risk–driver chemical. Achievement of the PRG (hazard quotient less than 1.0) is assessed on a site-wide basis. No separate RALs were defined for RAO 4 because the total PCB range of RALs described above for RAO 1 (2,200, 1,300, 700, 240, and 100 µg/kg dw) is expected to achieve RAO 4 immediately after construction or through a combination of active remediation and natural recovery.

6.3 Evaluating Recovery Potential of Sediments within the AOPCs

This section presents an evaluation of recovery potential intended to guide the final assembly of remedial alternatives (Section 8) within the AOPCs and to prioritize areas that likely require active remediation. This evaluation considers factors that affect the ability of areas to recover through natural processes,[8] including proximity to potential contaminant sources, net sedimentation rates, scour potential, and empirical trends.

The entire LDW was grouped into three categories with regard to recovery potential (Figures 6-4a and 6-4b). A recovery category represents areas of the LDW that share similar characteristics that could affect how well different remedial technologies would achieve the RAOs and how feasible they would be to implement. The recovery categories are:

- **Category 1** includes areas where recovery is presumed to be limited. It includes observed and predicted scour areas, net scour areas, and empirical data demonstrating increasing concentrations over time.
- **Category 2** includes areas where recovery is less certain. It includes areas with net sedimentation and mixed empirical chemical trends.
- **Category 3** includes areas where recovery is predicted. It includes areas with minimal to no scour potential, net sedimentation, and empirical trends of decreasing concentrations.

6.3.1 Mapping the Lines of Evidence for Evaluating Recovery Potential

To delineate the areas in each of these recovery categories, the following physical and chemical lines of evidence were considered (Table 6-3):

- Scour and deposition patterns:

[8] When reviewing empirical trends, proximity to contaminant sources, depth of contamination, and type of chemical exceedance were considered. Because the magnitude and direction of observed trends were often different (see Figure 6-4b and Appendix F) depending on the factors listed above, empirical trends were given equal weight to model predictions and site conditions. When source control is complete, recovery may be viable but not yet observed empirically.

  - Annual net sedimentation rates estimated by the STM averaged over the 30-year run
  - 100-year high-flow event scour areas predicted in the STM (maximum scour depth observed over the 30-year model period)
  - Empirical scour areas interpreted from 2003 bathymetry survey sun-illumination maps.
- Land and water use functions:
  - Berthing areas, former dredging events, and potential for disturbance by future dredging
  - Proximity to the toe of the slope along the navigation channel
  - Shoreline land use, public access, and outfall locations
  - Overwater structures
  - Habitat restoration areas, recreational shoreline access areas, and historical cleanup areas.
- Empirical evidence of recovery through chemical trends:
  - Chemical trends at resampled surface sediment stations
  - Chemical trends in the top two intervals (the shallowest two ft) of the cores.

Table 6-3 lists the key lines of evidence and the specific criteria used to delineate each recovery category, which are discussed below. The GIS base maps showing the extent of these features are presented in Section 2 and Appendix F. Other bulleted items (not listed in Table 6-3) were secondary considerations used to help interpret and evaluate empirical trends and to delineate layers in Table 6-3. For example, overwater structures and former dredging events were used to define active berthing areas. The following subsection describes how these features are overlaid to map recovery category areas. Recovery categories are defined only for the purposes of developing site-wide remedial alternatives and assigning remedial technologies (Section 8). Site-specific design considerations and new empirical data for these areas will be re-evaluated during the remedial design.

Figure 6-4a presents the three recovery categories. Figure 6-4b includes the empirical chemical trends with the recovery categories. A detailed analysis of this process by subarea is provided in Appendix D.

In addition, BCM predictions were used to evaluate the areas with recovery potential relative to the RALs (SQS within 10 years) for Alternative 4. See Appendix F for the 10-year BCM predictions. The BCM predicts future surface sediment concentrations based on STM net sedimentation rates, interpolated surface sediment concentrations,

and sediment loading from upstream and lateral sources. Predictions of exceedances of the SQS in 10 years are specifically used to inform remedial technology decisions for Alternative 4 and BCM predictions were not added to the recovery categories shown in Figure 6-4a.

6.3.1.1 Net Sedimentation

Natural recovery processes in the LDW include the natural deposition of cleaner sediment from upstream that is expected to reduce surface sediment COC concentrations.[9] Recovery is not considered viable if the STM estimates a potential for net scour (no sedimentation under average flow conditions); such areas are considered Category 1. Any positive rate of sedimentation indicates that an area may potentially be amenable to natural recovery, and thus this criterion places an area in Category 2 or 3 unless other lines of evidence suggest recovery is not occurring.

One additional check on the modeled sedimentation rates was to determine whether changes had occurred in bathymetric data between 2003 and 2008 in the navigation channel. Bathymetric data collected in the navigation channel by the USACE was paired with bathymetric data collected in 2003 by LDWG. Figure 6-5 displays these differences that sedimentation is occurring over broad spatial scales. Throughout most of the LDW, where there was data from both surveys, differences observed over this 5-year period suggest that sedimentation had occurred in subtidal areas.

6.3.1.2 High-flow Events

High-flow events increase the rate of erosion in certain areas of the LDW, which could reduce recovery potential. Scour depths deeper than 10 cm, as estimated by the STM as the maximum scour depth to occur any time during a 100-year high-flow event, are evidence that recovery may not be occurring (see Figure 2-6). A depth of 10 cm was selected because this is the depth of the biologically active zone.

6.3.1.3 Vessel Scour Areas

Vessel scour areas are locations with observed ridges and furrows (as determined using the sun-illuminated image of the 2003 bathymetric data) that may be caused by vessel traffic. These areas are assigned to Category 1 because of the possibility that deposited sediment is being eroded or sedimentation is being restricted. The bed forms observed in the sun-illuminated bathymetric data may actually represent stable conditions along established vessel traffic routes or steep slopes at the toe of the navigation channel. The mapping of this layer was restricted to areas where active berthing (vessels and overwater structures) was observed because they represent areas where vessels maneuvering into berthing areas may be causing scour or where spud placement

[9] Important mechanisms that reduce surface sediment contaminant concentrations are deposition of sediment sourced from upstream, followed by mixing and burial (see Section 2, Figure 2-8). These processes are described in greater detail in Section 5.

during vessel mooring may be disturbing the sediments. Bed forms identified outside of berthing areas could represent spud mounds (from vessels moored outside of mapped berthing areas), depressions from vessels resting in shallow water, debris, or shallow track lines from transiting vessels. However, these bed forms outside of known vessel use areas are relatively shallow and localized and are not expected to expose buried contamination or impede recovery. Vessel scour areas were limited to higher-traffic areas based on the presence of a pier/wharf face, documented maintenance dredging events, and/or operator interviews indicating that the area supports frequent vessel traffic (see Figure 2-7).

6.3.1.4 Berthing Areas

Berthing areas are locations in the LDW adjacent to observed overwater structures such as piers, wharves, pile groups, and dolphins (Figure 2-22 displays both overwater structures and berthing areas). These areas are assumed not to be viable for recovery if sedimentation rates are low, because of the possibility that vessel maneuvering erodes newly deposited sediment. Therefore the STM-estimated net sedimentation rate was used to characterize berthing areas for assignment as either Category 1 or Category 2. Berthing areas with net sedimentation rates of more than 1 cm/yr are assumed to exhibit recovery potential and thus can be in Category 2. Berthing areas with net sedimentation rates less than 1 cm/yr are placed in Category 1. The sedimentation criterion is based on the assumption that additional sedimentation helps to off-set vessel scour. In the absence of specific data regarding both vessel scour and the effect of sedimentation on vessel scour, a rate of more than 1 cm/yr was used to identify areas where new sediment would have an effect on the surface sediment conditions.

6.3.1.5 Empirical Trends

Empirical trends in sediment chemical concentrations were used to determine recovery categories by assigning the locations with observed trends into one of three categories: those with increasing chemical concentrations (more than 50% increases over previous or deeper data) are in Category 1; Category 2 represents locations with minimal change in chemical concentrations or contradictory results (by chemical); and Category 3 represents areas with decreasing chemical concentrations (more than 50% decreases from previous or deeper data). However, proximity to on-going sources is taken into account when evaluating empirical data relative to recovery categories. An area that was assigned to Category 3 based on physical conditions, but has increasing chemical trends and is near an on-going source, was assigned to Category 2. The physical conditions are such that sedimentation is occurring, and recovery will be expected once source control occurs. It is expected that sources will be controlled prior to conducting any remedial actions. This is discussed in greater detail in Section 8. The empirical data are discussed in greater detail in Appendix F.

6.4 Uncertainty Analysis of AOPCs and Recovery Potential

Uncertainties in the process of developing AOPC footprints and recovery potential categories are discussed below.

6.4.1 AOPC Uncertainty

This section examines the degree of confidence that exists with the estimate of the areal extent of the AOPC footprints using the criteria discussed in Section 6.1. The primary factors contributing to uncertainty in the AOPC footprints are:

- Age of the data
- Data mapping and interpolation.

These uncertainties are discussed below.

6.4.1.1 Age of Data

The FS baseline surface sediment dataset was used to map the AOPCs. One rule used to define the FS baseline dataset is the exclusion of older data at stations that were resampled (defined as falling within 10 ft of newer data). This evaluation was conducted on a chemical-by-chemical basis at each older station within 10 ft of a newer station. The intent of this effort was to use the most recent data available for defining the nature and extent of chemical contamination. However, because all of the older data were not co-located with newer data, the FS baseline surface sediment dataset is comprised of over 1,400 surface sediment samples spanning 20 years of data collection efforts (1990 to 2010). Many of the samples used in the mapping effort are now over 10 years old, and it is quite possible that surface conditions have changed in these sampled areas. In mapping the AOPCs, the FS accepts this level of uncertainty by assuming all data points are in essence the same age. Remedial alternatives are assembled around these predictions along with other lines of evidence described in Section 8. Sampling conducted during remedial design will resolve this uncertainty. To account for older data in the FS baseline dataset being used to evaluate RAL exceedances, areas of AOPC 1 with the following characteristics are assumed to be subject to verification monitoring in this FS:

- Relatively old data, i.e., sampled prior to 1998
- Low SQS exceedance ratios
- Isolated points (i.e., the area does not represent a group of data having RAL exceedances)
- Low potential for scour
- BCM predictions of recovery in 10 to 20 years.

It is expected that verification monitoring during remedial design will confirm whether the sediments in these areas exceed the RALs. Areas designated for verification monitoring are shown in Appendix D and are mapped separately in the remedial alternatives (Section 8).

6.4.1.2 Data Mapping and Interpolation

The FS baseline dataset contains data from numerous site investigations conducted over the past 20 years. These investigations have been used to determine the nature and extent of sediment contamination associated with past chemical releases. This extensive dataset was used to build the conceptual site model, map the nature and extent of contamination, and understand site processes for evaluating remedial alternatives. However, as with every environmental investigation, some uncertainty remains associated with the horizontal and vertical extent of sediment contamination, as discussed in the following points:

- **Laboratory Reporting Limits:** A portion of the uncertainty is related to reporting limits that exceed the screening criteria, especially in older data. Therefore, AOPC 1 was delineated using only detected SQS exceedances in the point data (expressed spatially as Thiessen polygons). In the *Baseline Ecological Risk Assessment* (Windward 2007a), an evaluation of the undetected data that exceeded the SQS found a low probability that these exceedances (by the reporting limits) would be of concern.
- **Sampling Design**: Another portion of the AOPC uncertainty is related to the design of the various past sampling programs represented in the FS baseline dataset. Some historical investigations have targeted specific areas (e.g., Boeing Plant 2) and therefore have much denser sampling coverage than other areas of the LDW. The experimental designs for collecting RI samples were developed in consultation with EPA and Ecology, and were largely designed to identify chemical hot spots and on-going sources.[10] Good spatial coverage exists throughout the LDW, but the frequency of sampling is not evenly distributed. For this reason, the areal extent of contamination remains somewhat uncertain, which is common in the feasibility study phase of any project. The delineation will be refined during remedial design.
- **Interpolation Methods:** Two interpolation methods were used to map surface sediment data (IDW and Thiessen polygons; see Appendix A). Each of these methods has inherent uncertainties, including the density of samples, influence of geomorphology on the distribution of contaminants,

[10] To refine the extent of known contaminated areas, additional sampling may be needed during remedial design. Thus, design sampling will be conducted to refine the areal extent of the cleanup area and vertical extent of contaminated sediments.

and influence of surrounding data. The uncertainty in these methods was minimized by conducting an extensive exploratory analysis and by optimizing the IDW parameters used for interpolating total PCBs, arsenic, and cPAHs. This parameterization simulates a best-fit estimate of the true concentration gradients of these chemical concentrations (Appendix A). The selected mapping techniques (i.e., IDW interpolation and Thiessen polygons) are well documented and widely used for managing contaminated sediments. The horizontal extent of chemical concentrations is expected to be refined during the remedial design phase when additional samples are collected.

- **Vertical Compositing**: The subsurface sediment dataset includes sediment cores that in most cases reached "native sediments," where concentrations were below the SQS. However, the interpreted bottom of contamination may not be the true bottom. Some of the vertical core samples were composited over 2-ft or longer lifts, such that the *in situ* bottom of contamination is not completely understood within the sample interval. This FS conservatively assumes that the bottom of the deepest sampling interval with a detected SQS exceedance is the bottom of contamination.

- **Vertical Extent of Contamination:** On a site-wide scale, the vertical extent of contamination (greater than SQS) has been interpolated into an isopach layer representing the bottom of this contamination (described in Appendix E). The native alluvium contact, which has also been interpolated into an isopach layer, can be used as a surrogate for the uncertainty in the extent of the bottom of contamination for this FS (see Appendix E). The native alluvium isopach layer is also assumed to be the vertical extent of any subsurface sediments with total PCB concentrations greater than 100 µg/kg dw (below this contact, sediments are assumed to exhibit native, pre-industrialized conditions). Because there are fewer cores than surface sediment samples, the interpolation of the subsurface contamination may not represent actual conditions as well as that for surface sediments. These estimates will need refinement during remedial design.

  Additionally, the cores were collected by many parties and can represent various sampling methods and compositing schemes. The data were not always accompanied by field and core processing logs that could be used to adjust recovered depths to *in situ* depths or to provide other useful information. Finally, not all intervals within each core were sampled, and within those samples, not all COCs were analyzed. If a sampling interval was not analyzed and the interval immediately above was contaminated, then the bottom of the contamination is assumed to be the bottom of the skipped interval.

Overall, the nature and extent of risk-driver chemicals are sufficiently understood to characterize risks, and develop reasonable estimates of the AOPCs and LDW-wide remedial alternatives for the FS. Uncertainty in the horizontal and vertical extent of sediment contamination above selected RALs will be refined during remedial design.

6.4.2 Recovery Potential Uncertainty

The recovery categories synthesize a large amount of information into a simple construct that can be used for managing uncertainty in technology assignments for this FS-level analysis. However, each criterion used in this analysis contains certain uncertainties and assumptions. Design-level analysis will provide additional information that will supersede many of the assumptions in this analysis. A few of the major assumptions and how they may affect an FS and remedial design-level analysis include:

- Berthing areas and navigation channel operations and future elevation needs may change.
- Further observations and analysis of location-specific vessel scour and its effect on recovery may change. Site-specific analysis of impacts may result in different conclusions on scour potential and may change technology selection.
- STM estimates may be combined with location-specific empirical data to refine sedimentation rates and scour potential.
- Additional data could refine location-specific chemical trends over time.
- Source control changes could affect the rate of observed natural recovery.

A point to be considered in decision-making for source control implementation, remedy design, and remedy implementation is whether areas of AOPC 1 located near certain outfalls may be subject to recontamination (to varying degrees). A premise of recent EPA sediment guidance is that active remediation should generally not be implemented until sources have been controlled (EPA 2005). Whether active or passive, the success of any remediation is affected by source control. This FS analysis is consistent with that principle. The FS accounts for source control by using a range of lateral input parameters in the BCM. The input parameters, described in Section 5, represent a range of potential concentrations given various levels of future source control actions.

Estimates of recovery potential should also include: 1) physical conditions that may preclude recovery; 2) predictive modeling that assumes lateral sources will be controlled, at least to some extent, in the future; 3) empirical trends demonstrating that recovery is underway, but that "final" recovery will require additional source control measures and time; and 4) recontamination potential from external sources (see Appendix J). All of these factors have been considered in this FS. However, remedial

design-level sampling and further evaluation of source control effectiveness will be necessary in certain areas before any remedial action is initiated. These data and model predictions will be essential in reassessing future recovery or recontamination of surface sediments after source controls are in place.

Table 6-1 COCs Considered When Defining the AOPCs

Criteria Used for Delineation of the AOPCs	Total Area (Acres)
EAAs	29
AOPC 1	
Beach where cumulative direct contact risk >1 × 10^{-5}	176
Total PCBs >240 µg/kg dw	
Arsenic >57 mg/kg dw (the SQS)	
Arsenic>28 mg/kg dw in intertidal areas	
cPAHs >1,000 µg TEQ/kg dw	
cPAHs>900 µg TEQ/kg dw in intertidal areas	
Dioxins/furans >25 ng TEQ/kg dw	
SMS chemicals >SQS (with toxicity override)	
Subsurface sediment >SQS in potential scour areas	
AOPC 2	
Total PCBs >100 µg/kg dw	123
Arsenic >15 mg/kg dw	
cPAHs: same as that for AOPC 1	
Dioxins/furans >15 ng TEQ/kg dw	
SMS chemicals: same as that for AOPC 1	
Any subsurface sediment >SQS	
Total cumulative area for AOPC 2 (with AOPC 1)	*299*

Notes:

1. Total acres in FS study area = 441. (The Early Action Areas [29 acres] are not considered part of the AOPC footprints.)
2. Of the 176 acres, 19 acres are designated for verification monitoring.

AOPC = area of potential concern; COC = chemical of concern; EAA = early action area; RAL = remedial action level; SMS = Sediment Management Standards; SQS = sediment quality standard; TEQ = toxic equivalent.

Table 6-2 Array of Remedial Action Levels

Risk-Driver Remedial Action Level	Rationale	RAO Addressed[a] (X = after construction; + = with time)			
		RAO 1	RAO 2	RAO 3	RAO 4
Total PCBs (µg/kg dw)					
2,200	• Maximum incremental SWAC reduction	+	Total PCB direct contact PRGs are achieved following remediation of EAAs	+ (achieves CSL with time)	+
1,300	• Dry weight equivalent of CSLb / incremental SWAC reduction	+		+	+
700	• Incremental SWAC reduction	+		X	+
240	• Dry weight equivalent of SQSb / incremental SWAC reduction	+		X	X
100	• Site-wide SWAC within range of upstream values and long-term model-predicted concentrations • Point of minimal change in SWAC	+		X	X
cPAHs (µg TEQ/kg dw)					
5,500	• Maximum incremental SWAC reduction	+	+	n/a	n/a
3,800	• 10^{-5} netfishing RBTC (applied as a point basis)	+	X	n/a	n/a
1,000 (site-wide)	• Site-wide SWAC within range of upstream values and long-term model-predicted concentrations	+	X	n/a	n/a
900 (intertidal areas)	• Beach play 10^{-5} RBTC (applied as point basis)	+	X	n/a	n/a
Dioxins/Furans (ng TEQ/kg dw)					
50	• Maximum incremental SWAC reduction	+	+	n/a	n/a
35 (site-wide)	• Incremental SWAC reduction	+	+	n/a	n/a
28 (intertidal areas)	• 10^{-6} beach play RBTC (applied as point basis)	+	X	n/a	n/a
25	• Incremental SWAC reduction	+	X	n/a	n/a
15	• Site-wide SWAC within range of upstream values and long-term model-predicted concentrations • Point of minimal change in SWAC	+	X	n/a	n/a
Arsenic (mg/kg dw)					
93	• CSL / Maximum incremental SWAC reduction	+	+	+	n/a
57 (site-wide)	• SQS / Incremental SWAC reduction	+	+	X	n/a
28 (intertidal areas)	• 10^{-5} beach play RBTC (applied as point basis)	+	+	X	n/a
15	• Site-wide SWAC within range of upstream values • Point of minimal change in SWAC	+	+	X	n/a

Table 6-2 Array of Remedial Action Levels

Risk-Driver Remedial Action Level	Rationale	RAO Addressed[a] (X = after construction; + = with time)			
		RAO 1	RAO 2	RAO 3	RAO 4
SMS Chemicals					
CSL at Year 10	• Achieve CSL 10 within years after completion of construction	n/a	n/a	CSL with time	n/a
CSL at Year 0	• Achieve CSL immediately after completion of construction	n/a	n/a	+	n/a
SQS at Year 10	• Achieve SQS 10 within years after completion of construction	n/a	n/a	SQS with time	n/a
SQS at Year 0	• Achieve SQS immediately after completion of construction	n/a	n/a	X	n/a

Notes:

a See Sections 8 and 9 for predicted outcomes and RALs by remedial alternative.

b Dry weight equivalents of the SQS and CSL SMS criteria of 12 and 65 mg/kg oc, assuming 2% TOC (average site-wide TOC value). If selected, actual implementation of this RAL would be based on carbon-normalized criteria defined by the SMS.

Year 0 = the point in time immediately following completion of construction.

Year 10 = the point in time 10 years after completion of construction.

+ = Partially achieves RAO or achieves RAOs over time. For RAO 1, institutional controls will be required to address residual seafood consumption risks regardless of the selected RAL.

X = Achieves RAO immediately following construction.

n/a = not applicable to the RAO

CSL = cleanup screening level; RAL = remedial action level; RAO = remedial action objective; RBTC = risk-based threshold concentration; SMS = sediment management standards; SQS = sediment quality standard; SWAC = spatially-weighted average concentration; total organic carbon = TOC.

Table 6-3 Criteria for Assigning Recovery Categories

Criteria		Recovery Categories		
		Category 1 Recovery Presumed to be Limited	Category 2 Recovery Less Certain	Category 3 Predicted to Recover
Physical Conditions	Vessel scour[a]	Observed vessel scour	No observed vessel scour	
	Berthing areas[b]	Berthing areas with <1 cm/yr net sedimentation	Berthing areas with >1 cm/yr net sedimentation	Not in a berthing area
Sediment Transport Model	STM-predicted 100-year high-flow scour (depth in cm)[c]	>10 cm	<10 cm	
	STM-derived net sedimentation rate[b] (cm/yr) using average flow conditions	Net scour	Net sedimentation	
Empirical Chemical Trend Criteria[d]	Resampled surface sediment locations	Increasing chemical concentrations (>50% increase)[e]	Equilibrium and mixed results (by chemical)	Declining chemical concentrations (>50% decrease)[e]
	Sediment cores (top 2 sample intervals in upper 2 ft)			
	Rules for applying criteria	Any one criterion in Category 1 results in the area achieving a Category 1 designation.	Conditions meet a mixture of Category 2 and 3 criteria	All conditions must meet the Category 3 criteria.

Notes:

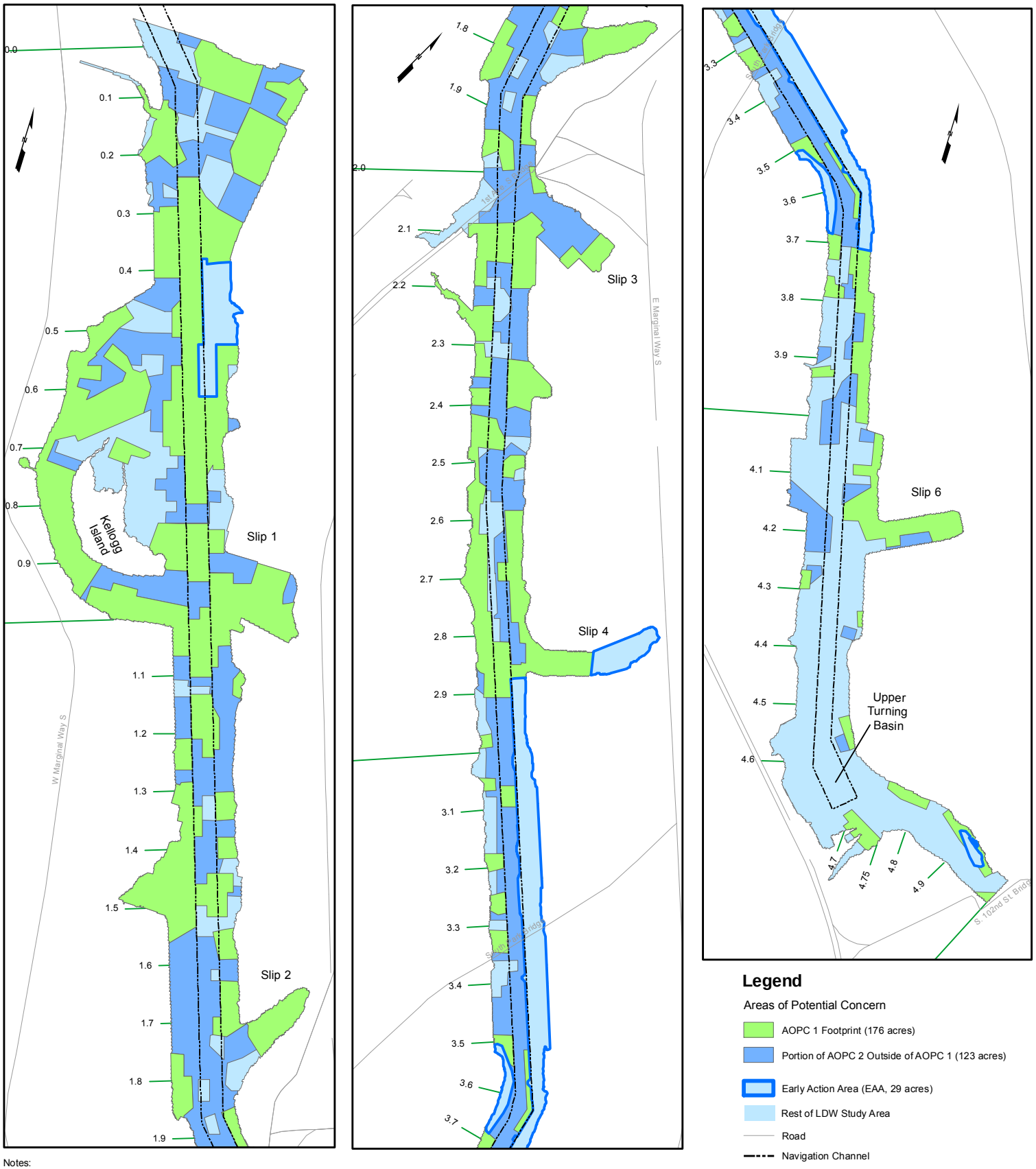
a Observed vessel scour areas are shown on Figure 2-7.

b Berthing areas are shown on Figure 2-21 and modeled net sedimentation rates are shown on Figure 2-8.

c High-flow scour areas are shown in Figure 2-6.

d Empirical trend data are described in Appendix F and summarized in Figure 6-4b.

e ±50% decrease is reasonable considering that analytical variability alone is 25%, and the difference in co-located field replicates ranges from 8% (arsenic) to 48% (cPAH).



Notes:
1. AOPC 1 was delineated using beaches with total excess cancer risk (all risk-driver chemicals combined) greater than 10^{-5}, subsurface SQS exceedances in scour areas, and surface sediments exceeding the following RALs: SQS for any chemical, total PCBs 240 µg/kg dw, arsenic 28 mg/kg dw in intertidal areas, cPAHs 1,000 µg TEQ/kg dw sitewide and 900 in intertidal areas, and dioxins/furans 25 ng TEQ/kg dw.
2. AOPC 2 was delineated using subsurface SQS exceedances and surface sediment exceeding the following RALs: total PCBs 100 µg/kg dw, arsenic 15 mg/kg dw, and dioxins/furans 15 ng TEQ/kg dw.
3. Verification monitoring areas (19 acres) are included in AOPC 1, but are presumed to be below the RAO 3 PRGs at the time of construction.

0 200 400 800 Feet

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The AOPC Footprints

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FIGURE 6-1

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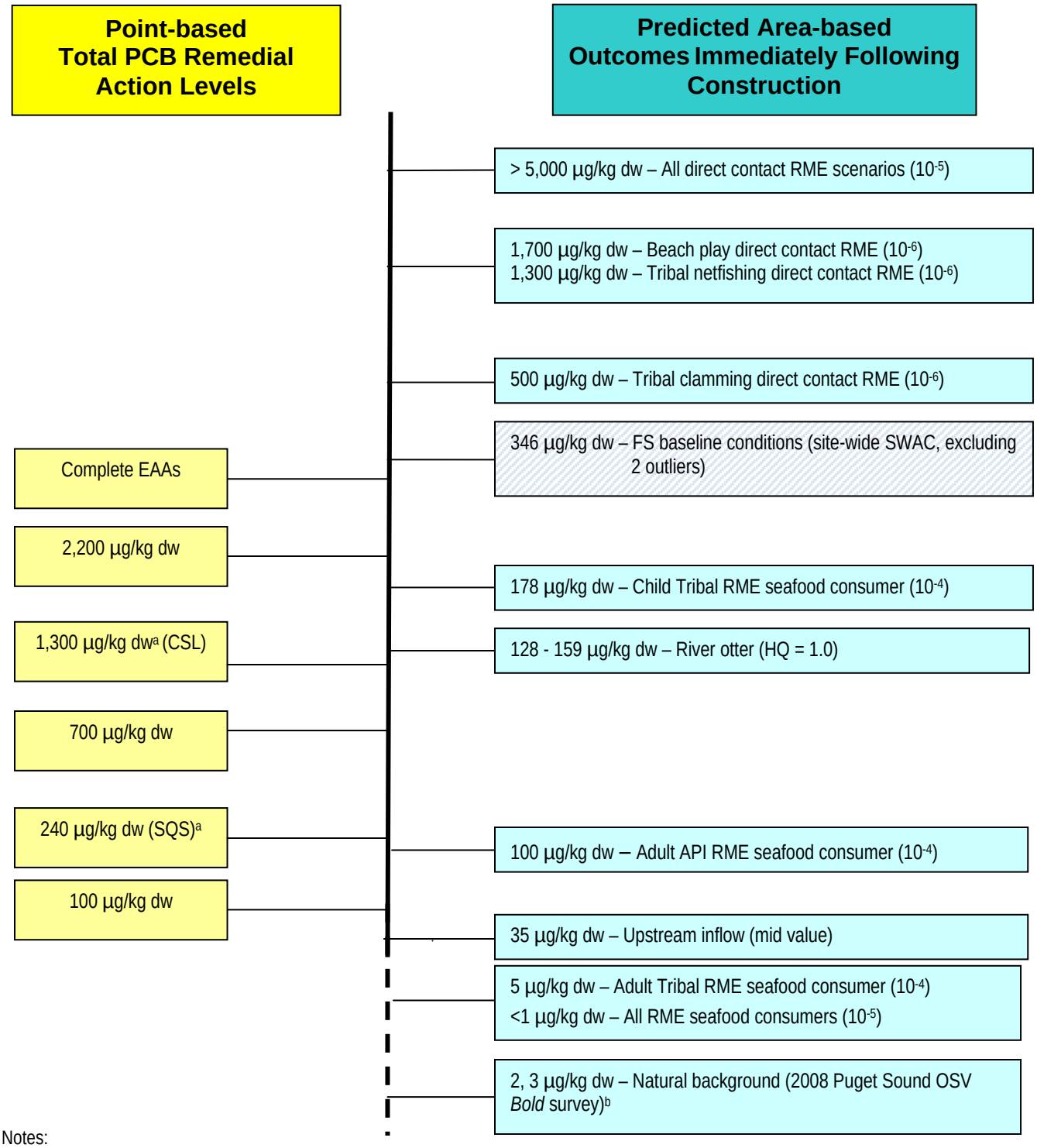
Figure 6-2a Total PCB Remedial Action Levels for Human and Ecological Health



Notes:

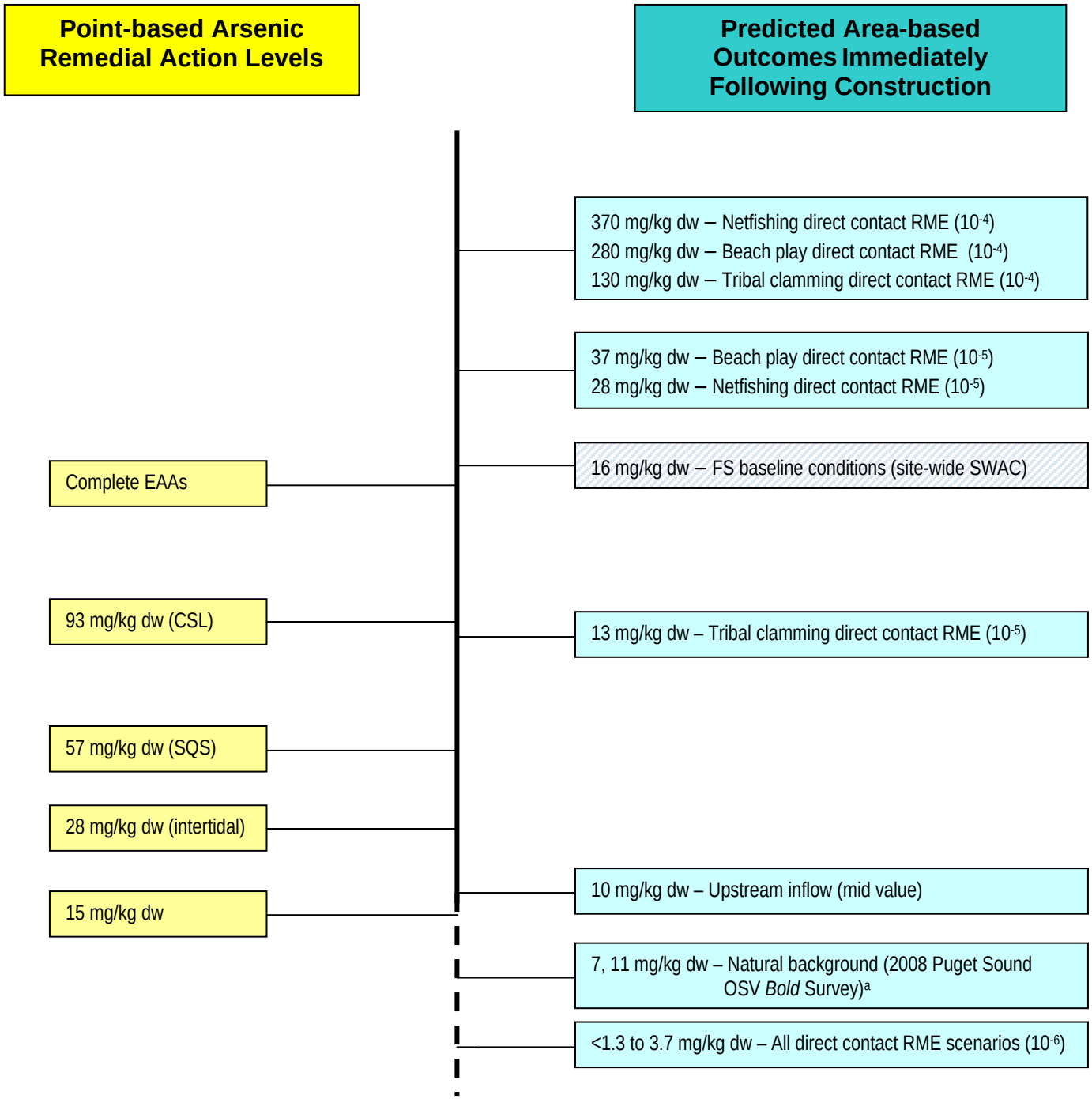
1. Year 10 prediction is from Bed Composition Model using recommended chemical input parameters. This value corresponds to the concentration immediately following construction that meets the CSL or SQS within 10 years following construction.

a Dry weight equivalents of the SQS and CSL SMS criteria of 12 and 65 mg/kg oc, assuming 2% total organic carbon (average LDW-wide TOC value).

b Two values are shown for natural background; the first is the UCL95 value and the second is the 90th percentile, both calculated from the EPA OSV *Bold* Survey dataset

10^{-5}= Risk of 1 additional cancer in 100,000 people over a lifetime; CSL = cleanup screening level; EAA = Early Action Area; HQ = hazard quotient; PCB = poly-chlorinated biphenyl; RME = reasonable maximum exposure; SWAC = spatially-weighted average concentration; SQS = sediment quality standard; TOC = total organic carbon; UCL = upper confidence limit.

Figure 6-2b Arsenic Remedial Action Levels for Human and Ecological Health

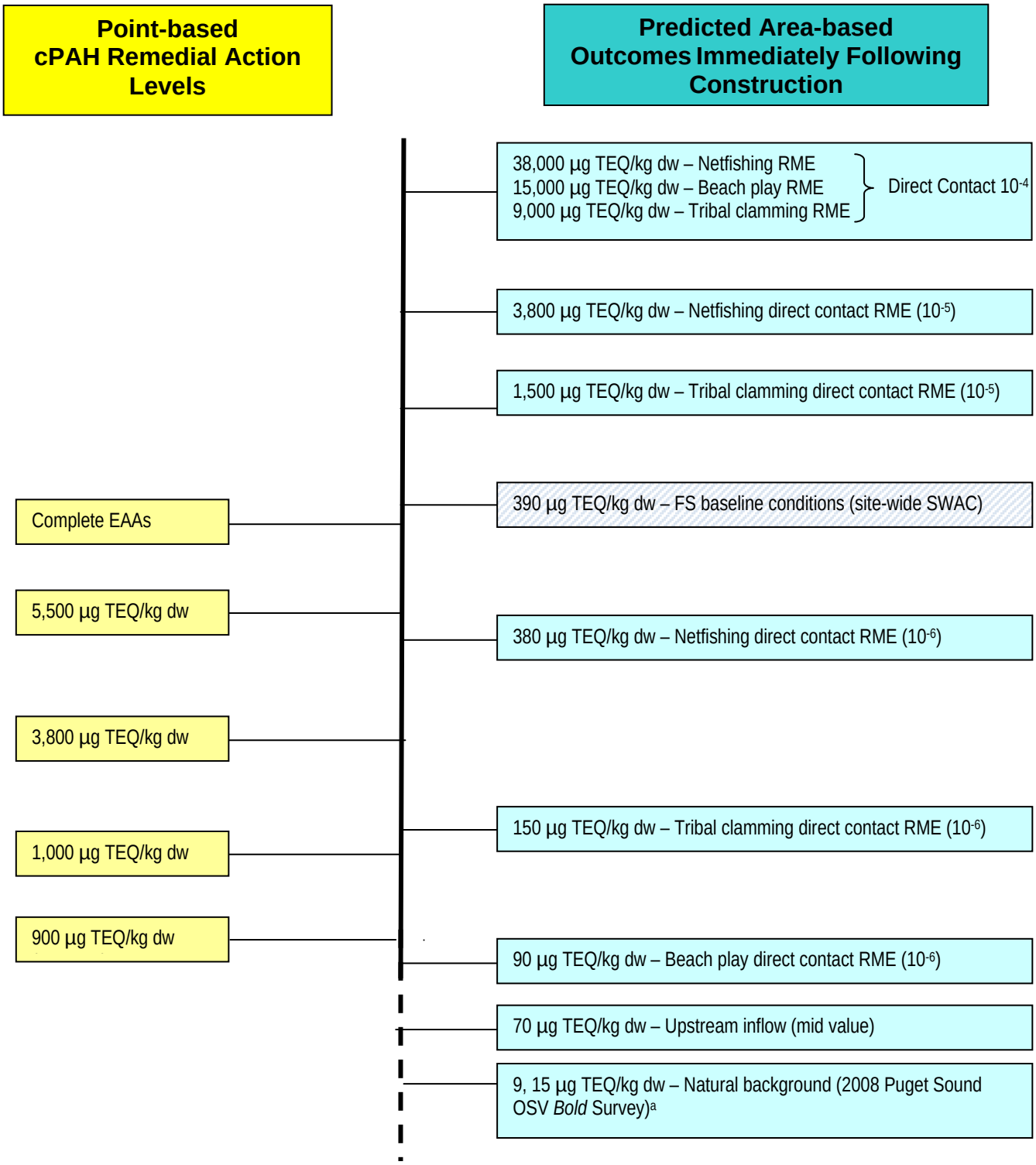


Notes:

a Two values are shown for natural background; the first is the UCL95 value and the second is the 90th percentile, both calculated from the EPA OSV *Bold* Survey dataset.

10^{-5} = Risk of 1 additional cancer in 100,000 people over a lifetime; CSL = cleanup screening level; EAA = Early Action Area; HQ = hazard quotient; RME = reasonable maximum exposure; SWAC = spatially-weighted average concentration; SQS = sediment quality standard; UCL = upper confidence limit.

Figure 6-2c cPAH Remedial Action Levels for Human Health

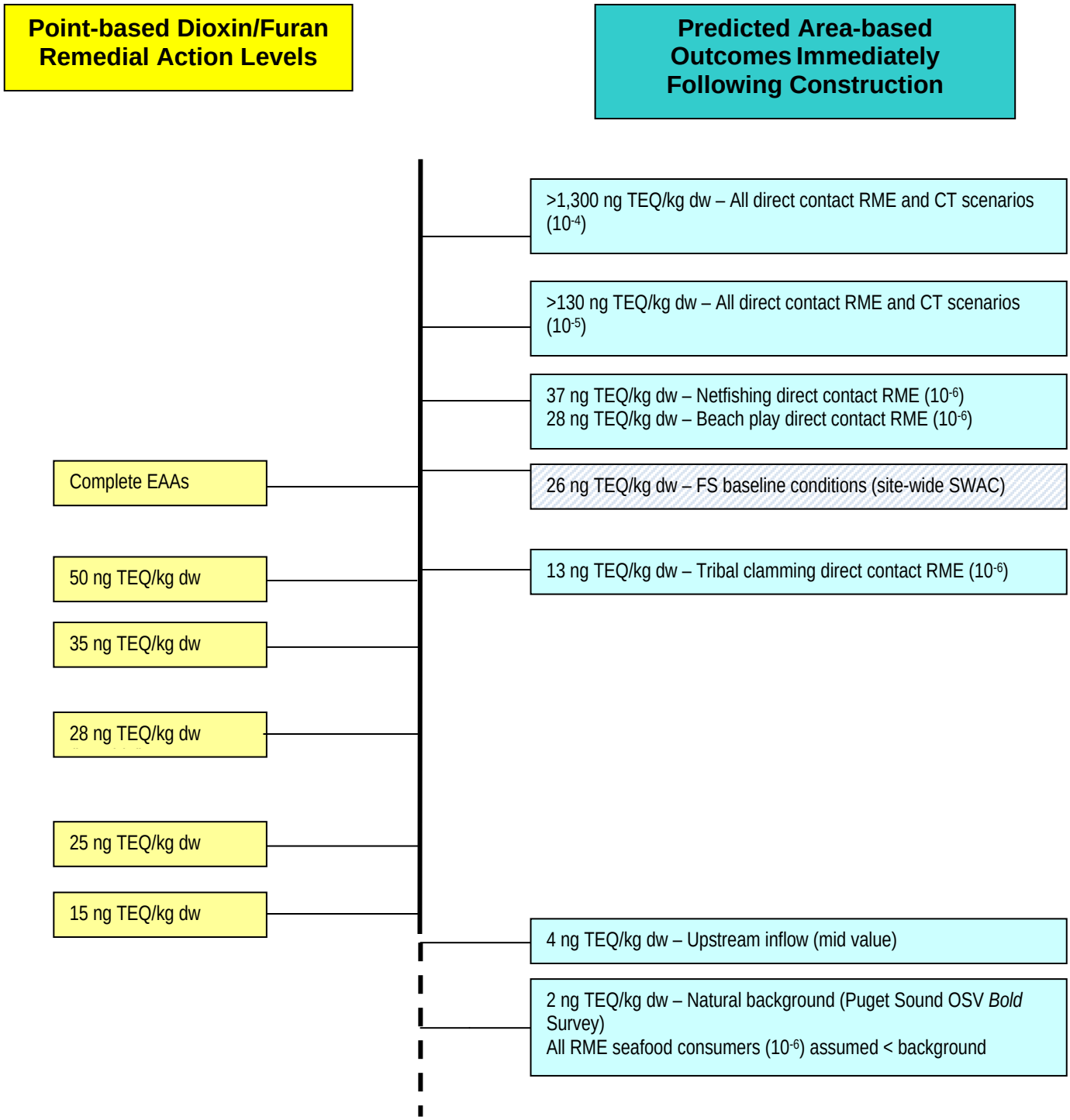


Notes:

a Two values are shown for natural background; the first is the UCL95 value and the second is the 90th percentile, both calculated from the EPA OSV *Bold* Survey dataset.

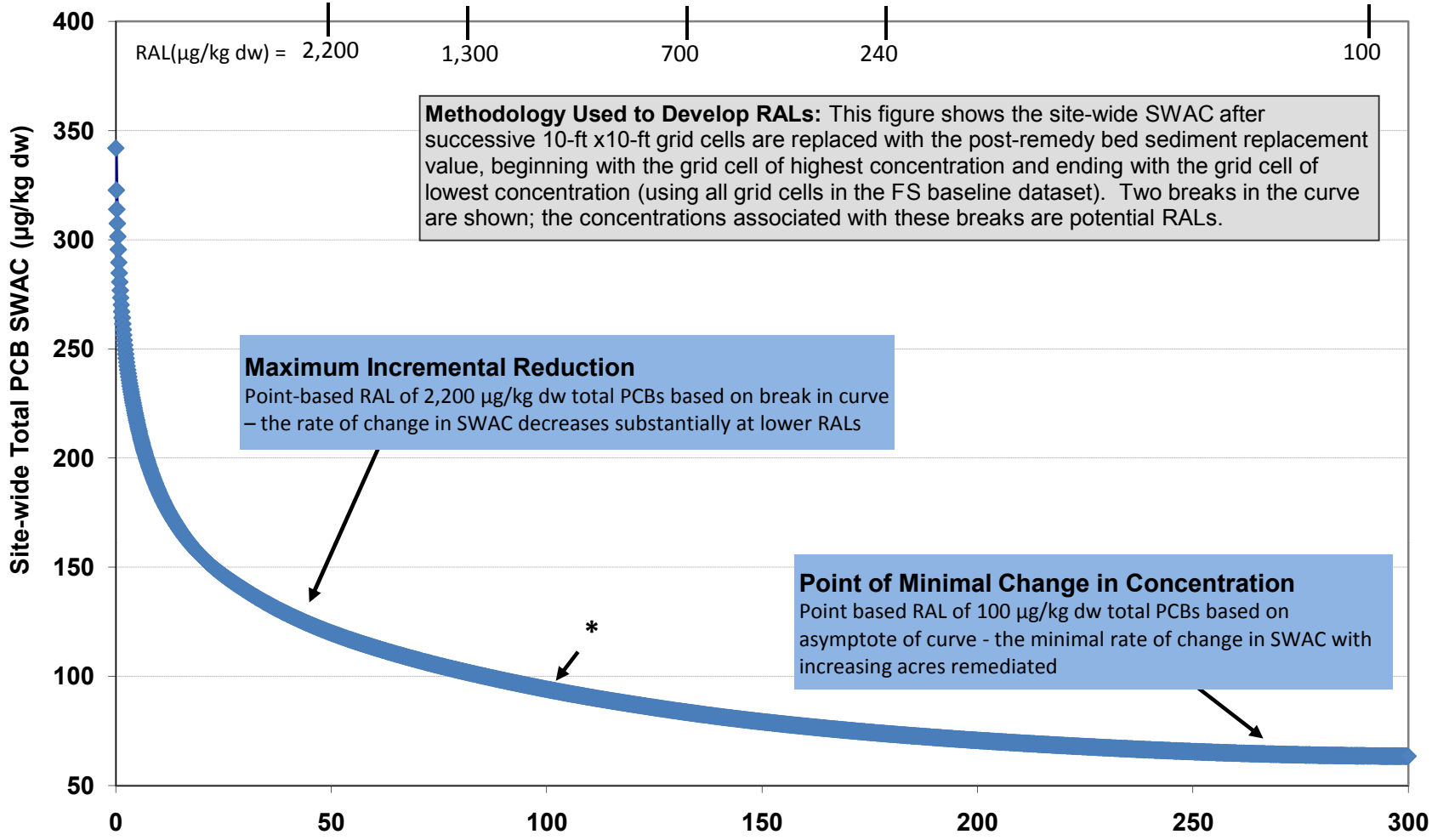
cPAH = carcinogenic polycyclic aromatic hydrocarbon; EAA = Early Action Area; RME = reasonable maximum exposure; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent; UCL = upper confidence limit.

Figure 6-2d Dioxin/Furan Remedial Action Levels for Human Health



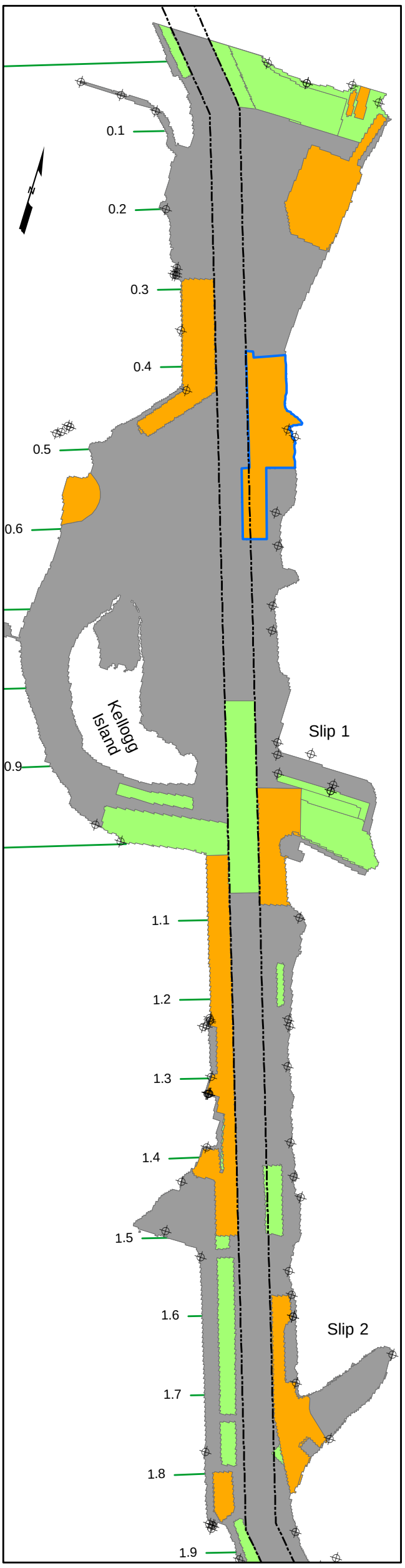
Notes:
CT = central tendency; EAA = Early Action Area; RME = reasonable maximum exposure; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent.

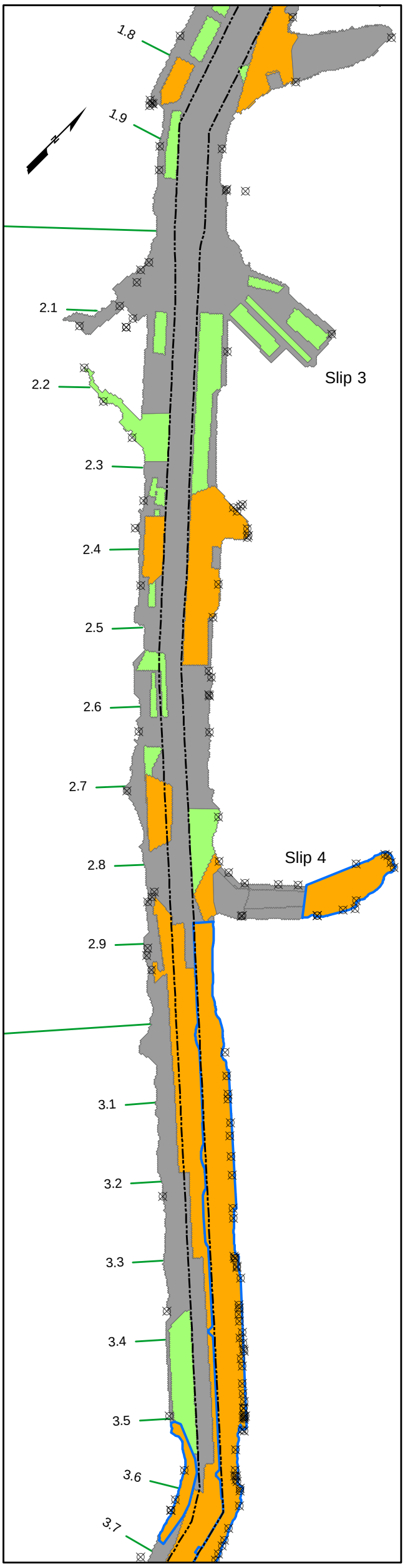
Figure 6-3 Example of Incremental Reduction and Minimal Change in Total PCB Concentrations

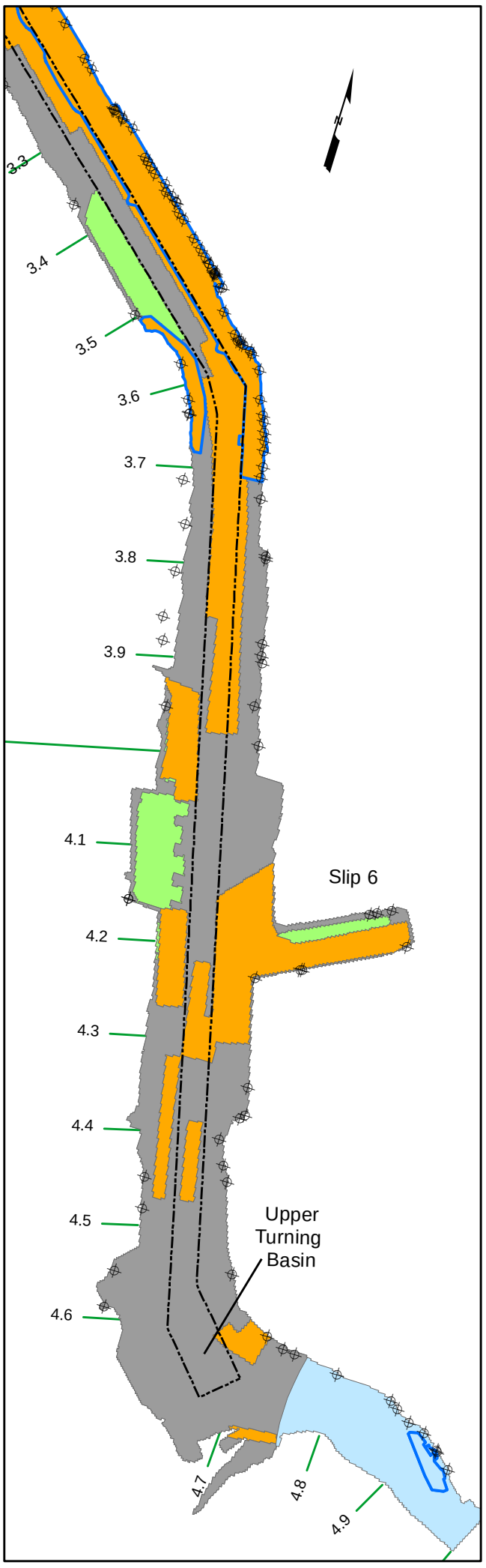


* Incremental reduction in SWAC is at some point between the maximum and minimum change in concentration.

RAL = remedial action level;
SWAC = spatially-weighted average concentration







Notes:
1. See Table 6-3 for recovery category criteria.
2. EAAs included in Category 1.
3. Total FS Study area is 441 acres, but STM domain is only 432 acres ending at RM 4.75.

Legend

Recovery Category

- Category 1: Recovery Presumed to be Limited (106 acres)
- Category 2: Recovery Less Certain (49 acres)
- Category 3: Predicted to Recover (277 acres)

- Early Action Area
- Outfall Location
- River Mile Marker
- Navigation Channel

Feet
0 200 400 800

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Recovery Categories

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FIGURE 6-4a

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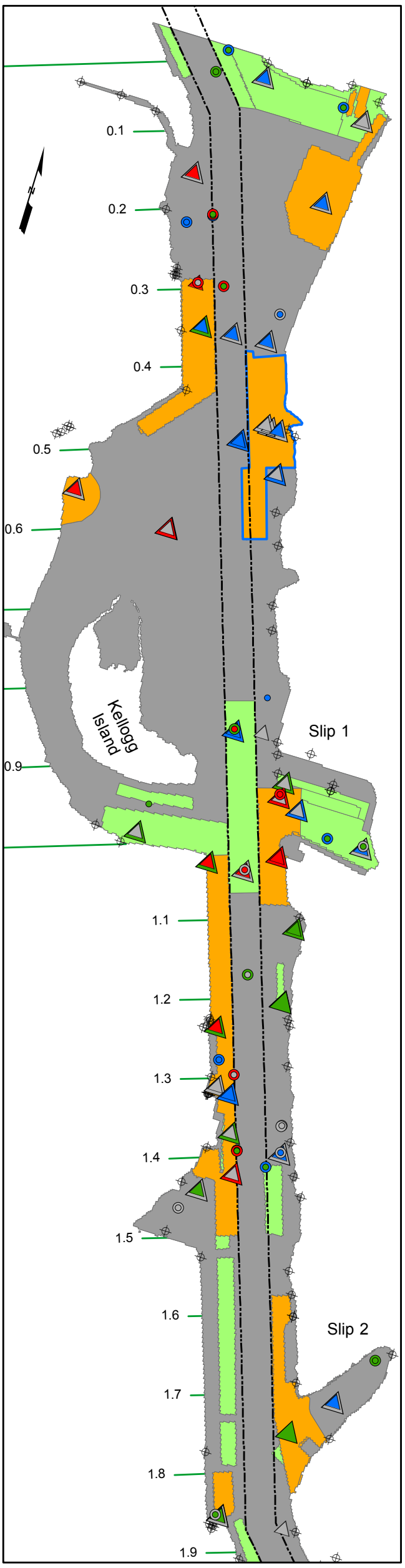

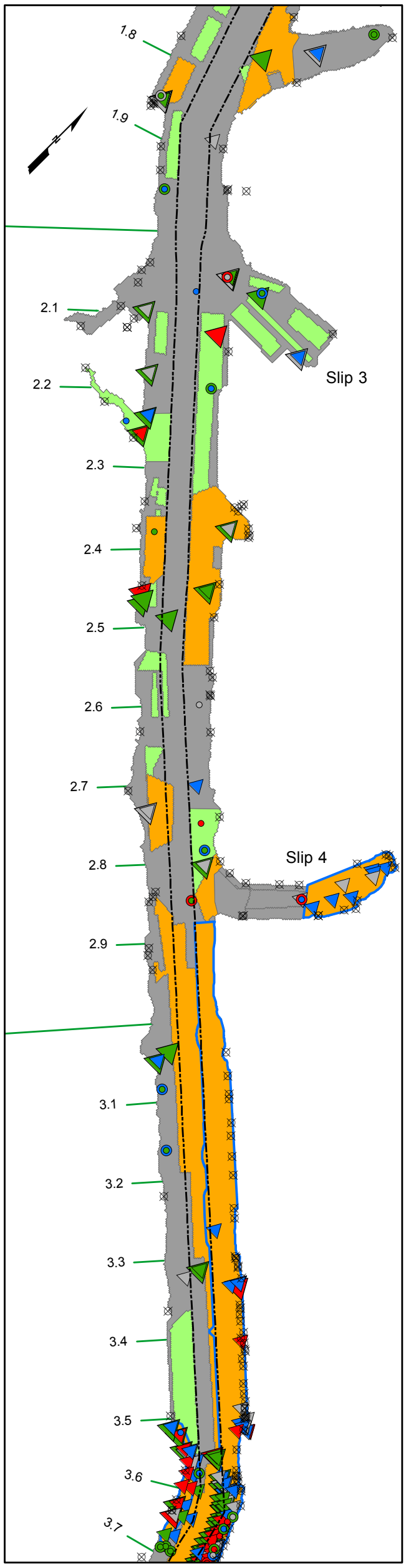

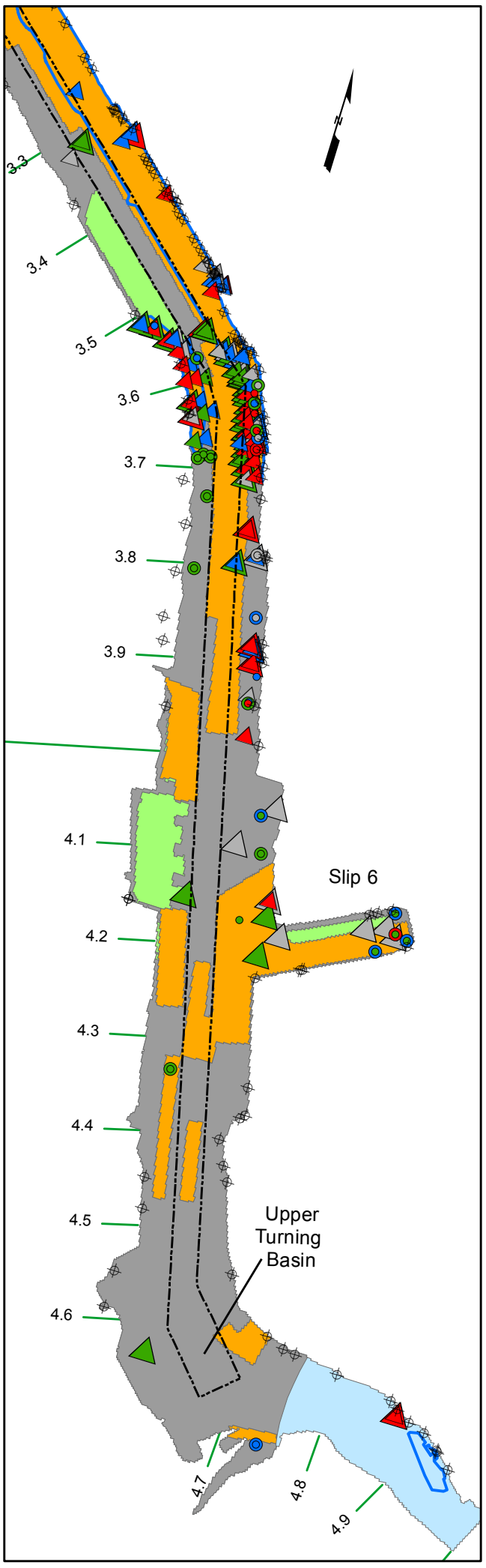

Notes:
1. Resampled surface sample locations include data trumped from both the RI and FS datasets.
2. See Table 6-3 for recovery catagory criteria.

Natural Recovery Empirical Data

Resampled Surface Sediment Location Total PCBs — Resampled Surface Sediment Location Other SMS Chemicals

Top Two Intervals in Cores Total PCBs — Top Two Intervals in Cores Other SMS Chemicals

Below SQS

Data that do not Support Recovery (≥50% Concentration Increase)

Data that Support Recovery (≥50% Concentration Decrease)

Station in Equilibrium or Mixed Result

Legend

Recovery Category

Category 1: Recovery Presumed to be Limited (106 acres)

Category 2: Recovery Less Certain (49 acres)

Category 3: Predicted to Recover (277 acres)

Early Action Area

Outfall Location

River Mile Marker

Navigation Channel

Feet
0 200 400 800

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Recovery Categories and Empirical Chemical Trends

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FIGURE 6-4b

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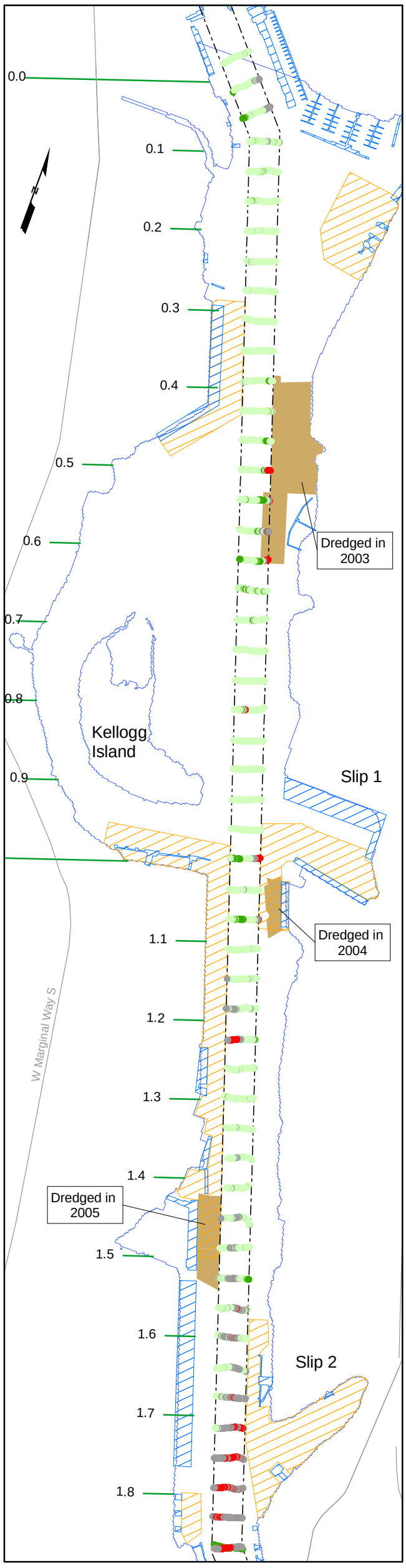

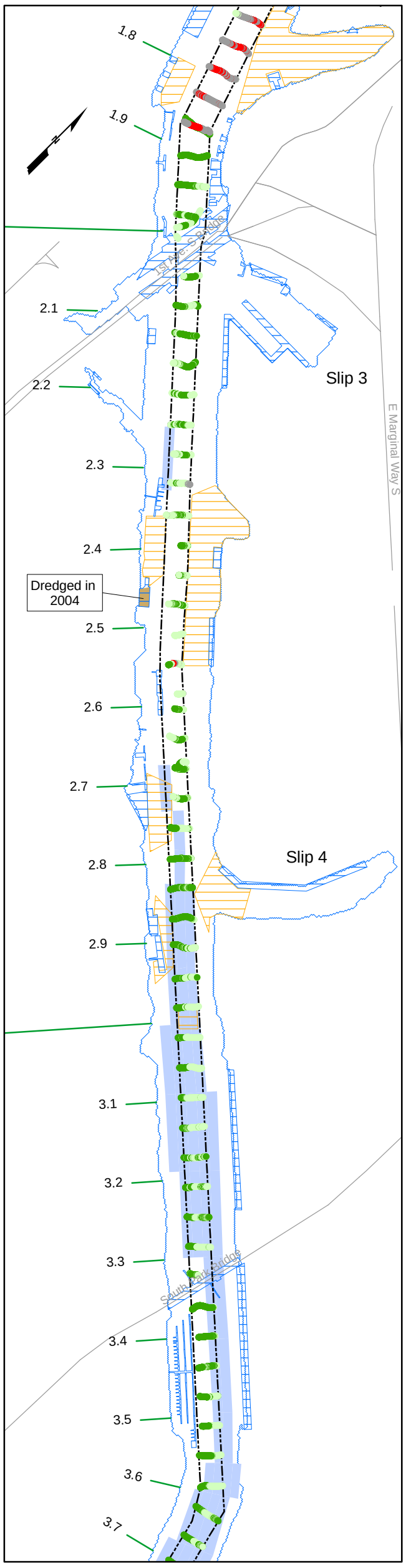

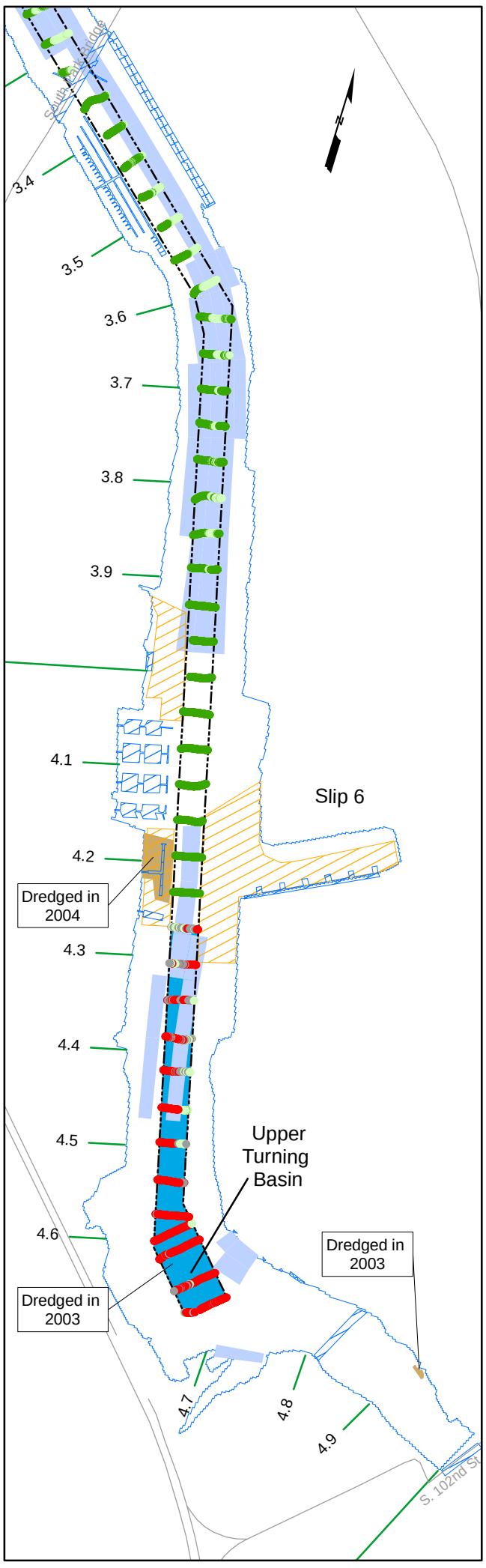

Notes:
1. 2008 bathymetry data from USACE in point format sounding.
2. 2008 Bathymetry survey completed 09/25/08.
3. Site-wide October 2003 bathymetric data in grid format from David Evans and Associates.
4. 2003 grid data was extracted into the 2008 points and the difference in elevation calculated.
5. Maximum scour depths from 100-year high-flow data dated June 2008 (QEA 2008).

Dredge Event Post 2002

- USACE Dredge Event
- Private Dredge Event

Legend

Bathymetric Change 2003-2008

Change in Elevation (ft)

- > 2.0 (deposition)
- > 0.5 to 2.0 (deposition)
- > -0.5 to 0.5 (minimal change)
- < -0.5 (scour, or dredging)
- STM Predicted High-flow Scour > 5 cm
- Overwater Structure
- Evidence of Propeller Wash Scour
- Road
- Navigation Channel
- River Mile Marker

0 200 400 800 Feet

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Bathymetric Change in Navigation Channel between 2003 and 2008

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FIGURE 6-5

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7 Identification and Screening of Remedial Technologies

This section identifies and screens remedial technologies consistent with the U.S. Environmental Protection Agency's (EPA) *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (EPA 1988). This step toward development of the remedial alternatives parallels and is consistent with Washington State's cleanup study requirements (Washington Administrative Code [WAC] 173-204-560(4)(k) and Model Toxics Control Act [MTCA] FS requirements WAC 173-340-350(8)).

The technology screening for the Lower Duwamish Waterway (LDW) was originally completed and issued as the *Candidate Technologies Memorandum* (CTM) (RETEC 2005).The CTM identified and screened a comprehensive set of general response actions, technology types, and process options that are potentially applicable to cleanup of contaminated sediments in the LDW. These three categories or tiers provide a systematic structure and method to identify and evaluate various physical, chemical, and administrative "tools" available for implementing remedial actions. General response actions describe in very broad terms the types of actions potentially applicable to cleanup of contaminated media. Each general response action may contain one or more technology type. For example, one general response action is physical removal of contaminated materials from the site, and two common technologies that can accomplish sediment removal are dredging and excavation. Process options are a further subdivision or tier in the technology screening procedure, and define the specific type of equipment used within a technology. For example, dredging may use a clamshell dredge, hydraulic dredge, or upland-based excavation equipment, such as backhoes.

The CTM evaluated remedial technologies and process options that could be carried forward for additional consideration in the FS. The screening evaluation was conducted using the effectiveness, implementability, and cost criteria consistent with EPA guidance (EPA 1988). Effectiveness refers to whether or not a technology can contain, reduce, or eliminate chemicals of concern (COCs) found in LDW sediments. Implementability refers to whether a technology can be operated under the physical and chemical conditions of the LDW, is commercially available, and has been used on sites similar in scale and scope to the LDW. The CTM contains complete descriptions of remedial technologies and process options and the supporting literature considered for alternative development in the FS.

In this section, technology recommendations from the CTM (RETEC 2005) are reviewed and updated to account for any recent technology developments or relevant experience at other cleanup sites. The Superfund Innovative Technology Evaluation (SITE) Program, the EPA Hazardous Waste Clean-up Information (CLU-IN) website, and the Federal Remediation Technologies Roundtable (FRTR) were reviewed for recent and

relevant information about innovative treatment technologies, including their cost and performance, results of technology development and demonstration, and technology optimization and evaluation. The complete screening process is summarized in tables as follows:

- Table 7-1 lists all of the candidate remedial technologies and process options that were evaluated in the CTM, along with an initial screening for potential applicability. Remedial technologies retained are shaded.
- Tables 7-2a through 7-2e provide the detailed screening of process options, which were presented previously in the CTM. These tables have been updated to include new technologies reviewed for the FS (e.g., spray cap).
- Table 7-3 summarizes the assessment of the effectiveness, implementability, and relative costs of the retained remedial technologies and process options.
- Table 7-4 provides the technologies and process options carried forward into alternative development as representative technologies and process options.

Finally, this section selects representative, effective, and implementable process options to carry forward for developing remedial alternatives. The selections consider information on past and current sediment remediation projects in the Puget Sound region, elsewhere in EPA Region 10, and nationally where appropriate. Selecting representative process options for the FS is consistent with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (EPA 1988) and MTCA (Ecology 2001) guidance. Reducing the number of process options does not preclude reexamination of other options during the remedial design/remedial action (RD/RA) phase of the cleanup project. Rather, it is a means to streamline the development and evaluation of the remedial alternatives (as described in Section 8) without sacrificing engineering flexibility. Representative technologies and process options used in the development of alternatives are shaded in Table 7-4.

Section 8 of this FS provides detailed descriptions of the technology types and process options that are assumed for cost estimating purposes under each remedial alternative.

7.1 Review and Selection of Representative Process Options

7.1.1 Dredging and Excavation

Removal is a common and frequently implemented general response action for sediment remediation nationwide and in the Puget Sound region. Mechanical dredging, mechanical excavator dredging, hydraulic dredging, and excavation using upland-based equipment (dry excavation) are the four representative process options available for removing contaminated sediments.

7.1.1.1 Removal Process Options

Mechanical Dredging

A mechanical dredge typically consists of a suspended or manipulated bucket that bites the sediment and raises it to the surface via a cable, boom, or ladder. The sediment is deposited on a haul barge or other vessel for transport to a disposal site. Under suitable conditions, mechanical dredges are capable of removing sediment at near *in situ* densities, with almost no additional water entrainment in the dredged mass and little free water in the filled bucket. Low water content is important if dewatering is required for sediment treatment or upland disposal.

Clamshell buckets (open, closed, hydraulic-actuated), backhoe buckets, dragline buckets, dipper (scoop) buckets, and bucket ladders are all examples of mechanical dredges. Clamshell dredges work best in water depths less than 100 feet (ft) to maintain production efficiency. Nominal bucket capacities (i.e., when full) for environmental applications typically range from less than 1 cubic yard (cy) to 10 cy. Clamshell buckets are most effective in consolidated sediments and are the devices of choice for sediments containing debris.

Environmental buckets, or specialty level-cut buckets, offer the advantages of a large footprint, a level cut, the capability to remove even layers of sediment. A level-cut bucket reduces the occurrence of ridges and winnows that are typically associated with conventional clamshell buckets. Environmental buckets are effective in unconsolidated sediments. They are not effective when digging in heavier sand or where a significant amount of debris may be present.

Mechanical dredging results in sediment excavation with near *in situ* density (water content), thereby reducing the need for substantial ancillary facilities and equipment to process wet dredged material. Mechanical dredging tends to minimize water entrainment by maintaining much of the *in situ* sediment structure (water entrainment ratio of approximately 2 parts water to one part dredged sediment). Material tends to be dewatered on the barge and then can be transloaded, transported, and managed at permitted off-site facilities that are authorized to handle wet sediments (these facilities are available to projects in this region). As a result, upland sediment processing and water treatment facilities require less acreage to handle mechanically dredged sediments.

Hydraulic Dredging

Hydraulic dredges remove and transport dredged material as a pumped sediment-water slurry. Large debris is typically removed by clamshell buckets prior to hydraulic dredging of sediments. Then, sediment is dislodged into the water column by mechanical agitation, cutterheads, augers, or high-pressure water or air jets. In very soft sediment, it may be possible to remove surface sediment by straight suction or by forcing the intake into the sediment without first mechanically dislodging the sediment. The majority of the loosened slurry is then captured by suction from pumps into an

intake pipe and transported through a dredge discharge pipeline to a handling/dewatering facility.

Hydraulic dredging requires substantial ancillary facility acreage (i.e., approximately 26 acres were utilized for Fox River Operable Unit 1 remediation) and equipment to process dredged sediments (dewatering) and to treat the wastewater before discharge. Hydraulic dredging entrains tremendous volumes of water, typically at 8 to 10 parts water to one part of dredged sediment. As a result, the upland area requirements to support sediment and water handling for hydraulic dredging are significantly greater than for mechanical dredging to handle the same volume of dredged sediment. In addition, the facilities handling the slurry need to be placed as close as possible to the dredging operations to enable pumping to the site to occur effectively.

Land available to site sediment processing equipment adjacent to the LDW is limited and consists mostly of small parcels (i.e., less than 5 to 10 acres). Areas large enough to site a facility capable of dewatering hydraulically dredged sediment with meaningful dredging production rates are not available. Hydraulic dredging may be viable for location-specific circumstances where the total volume of water generated is relatively small and controllable.

A prime example is using a diver-operated, hand-held, hydraulic dredge to remove materials under or around piers, pilings, or in other under-structure places where conventional dredging equipment is unable to reach. Using this technology, an otherwise unreachable location may be feasible to dredge, depending on circumstances. However, one must consider the diver's limited visibility, the overall safety of the diver potentially exposed to physical hazards and resuspended contaminants, and the reduced production rate compared to overall project volume requiring removal. As with other hydraulic dredges, the presence of debris limits the effectiveness of a diver-operated hydraulic dredge. Because under-pier areas typically include riprap and debris, incomplete removal of contaminated sediments can be expected even with a diver-operated hydraulic dredge, and thus capping would likely still be required following dredging.

Dry Excavation

Dry excavation using barge-mounted or upland-based precision excavators refers to the removal of sediments in the absence or limited presence (e.g., a few feet) of overlying water. This involves the removal of intertidal sediment under naturally-occurring low-tide (exposed) or shallow-water conditions. The fixed-arm, articulated arrangement of the precision excavators pushes the bucket into the sediment to the desired cut level without relying on the weight of the bucket for penetration. Engineered dewatering of an excavation area can also be undertaken to enable dry excavation. Dewatering methods include the use of earthen dams or sheet piling, often in combination with dewatering pump operations.

Upland-based removal of sediment using precision excavators can be employed on exposed shoreline and intertidal areas during low-tide conditions where access is feasible. To avoid the need for extensive upland dewatering treatment facilities, it is assumed that upland-based excavation is limited to elevations above –2 ft mean lower low water (MLLW) during low-tide conditions, and where access is practicable. -

7.1.1.2 Dredge Residuals

All in-water removal operations result in the release of a portion of the contaminants in the material being dredged and will leave behind some level of residual contamination in sediment after completion of dredging (USACE 2008a). Residual contamination can result from various causes that can be grouped into two categories:

- Undisturbed residuals are contaminated sediments found at the post-dredging surface that were not fully removed. The causes of undisturbed residuals include:
  - Incomplete characterization of depth-of-contamination in the remedial design, resulting in previously undocumented contaminated sediment being left in place.
  - Inaccuracies in meeting target dredge design elevation, resulting in contaminated sediment being left in place.
  - Furrows or ridges created by incomplete horizontal removal also leaving contaminated sediment in place.
- Generated residuals are contaminated post-dredging surface sediments that are dislodged or suspended by the dredging operation and subsequently redeposited on the bottom of the water body. Causes include:
  - Turbid flows from cut slope failures spreading sediment from adjacent areas on top of areas where dredging was completed or spreading it outside of the dredge boundaries.
  - Material resuspended by the bucket (mechanical dredging) during its bite or by the dredge cutterheads (hydraulic dredging) during its pass.
  - Material resuspended outward by the auger or cutterhead beyond the influence of the pump suction and left behind.
  - Vertical positioning of the auger or cutterhead at too great of a cut depth, resulting in material riding over the dredge head.
  - Material adhering to the outside of the bucket and washed off on its upward travel through the water column, then settling back down to the bottom.

- Material dripping from a partially closed or overfilled bucket on its upward travel through the water column, then settling back down to the bottom.
- Sloughing of material from steep cut banks spreading sediment from adjacent areas on top of areas where dredging was completed.
- Release of sediment contaminants dissolved in porewater when sediment is disturbed during dredging.

Although resuspension with subsequent resettling is one factor that can influence the residual concentrations of contaminants, other factors such as the type and size of dredging equipment, level of operator skill, positioning of equipment used during dredging, dredge sequencing, depth of dredge cut, type and volume of debris encountered, and the substrate type and bottom topography all combine to influence the degree of post-dredging residuals.

The nature and extent of dredging residuals dislodged or suspended by a dredging operation are not easily predicted. Most projects have based their post-dredging residual concentration by monitoring a specified surficial sediment thickness (e.g., 0 to 10 cm below mudline). By comparing the monitored thickness to the average concentration in the final production cut profile, it is possible to estimate the amount of residuals that will be generated by the project (USACE 2008a). Palermo and Patmont (2007) performed mass balance calculations for 11 project sites, demonstrating that generated residuals represented approximately 2 to 9 percent of the mass of contaminant dredged during the last production cut. The available data suggest that multiple sources contribute to generated residuals, including resuspension, sloughing, fall back, and other factors. However, on a mass basis, sediment resuspension from the dredge operations appears to explain only a portion of the observed generated residuals, suggesting that other sources such as cut slope failure and sloughing could be quantitatively more important.

The study also indicated that the presence of hardpan/bedrock, debris, and relatively low dry density sediment results in higher generated residuals. Numerous case studies have shown that the spatial extent of dredge residuals can extend beyond the footprint of the dredge prism. For this reason, it is appropriate to include residuals monitoring and management provisions in the remedial design phase that address adjacent areas as well as the dredge prism.

Dredge monitoring studies conducted over the last 10 years have estimated the rate of resuspension at 3 to 5% of PCBs by mass downstream (or as residuals) compared to the mass of material contained in a dredge prism (USACE 2008a; TetraTech 2010, Fox River; Connelly 2010, Hudson River). This loss of material is expected at all dredging sites regardless of the specific dredging process options, engineering controls, and best management practices used during dredging.

7.1.1.3 Recent Developments in Dredge Positioning Technology

Recent introduction and widespread use of real-time kinematic differential global positioning systems (RTK – DGPS), coupled with radio telemetry and data logging technology, has greatly improved the accuracy and operational flexibility of mechanical dredging. The latest generation of precision dredge and bucket guidance systems integrate RTK-DGPS, excavator and bucket inclinometer sensors, vessel motion sensors, electronic heading, and tide data to enable dredging accuracy generally to within less than 6 inches. Dredge operators are now able to visualize the location of the bucket cutting edge in relation to the target elevation, the bucket open/close status, and the horizontal position of the bucket through use of these advanced positioning and monitoring systems.

7.1.1.4 Dredging and Excavation Technology Summary

Mechanical dredging and excavation, the most commonly practiced forms of sediment removal in the Puget Sound region, are adopted in this FS as the representative primary removal process options for in-water work. Dry excavation using conventional earth-moving equipment is also retained for use in intertidal and embankment areas, but it is expected to be implementable only for a low percentage of the removal volume because of access limitations.[1] Representative dredging projects in the Puget Sound region are identified in Table 7-5. As noted from Table 7-5, approximately 90 percent of the projects completed in the Puget Sound region adopted mechanical dredging during implementation.

Mechanical dredging and excavation were selected as the primary in-water dredging options because several factors within the LDW favor mechanical dredging over hydraulic dredging:

- The LDW is a working industrial waterway and significant amounts of debris may be present in the sediments, the result of approximately 100 years of commercial and industrial activity. The presence of debris is a significant problem for hydraulic dredging. Although mechanical dredging is also adversely affected by debris, it is better suited to manage and accommodate debris removal.
- Two Subtitle D landfills in the region are permitted to accept wet sediment generated from mechanical dredging (see Section 7.1.3), thereby avoiding the need to dewater mechanically dredged solids.
- The environmental dredging literature contains no documented quantitative evaluations that distinguish between the resuspension and recontamination characteristics of mechanical and hydraulic

[1] Details regarding the range and type of dredge equipment available within the local/regional construction community are presented in Section 8 and Appendix I. Cost estimates prepared and presented in Appendix I are based on mechanical dredging, and barge-mounted excavators.

dredging under other than ideal debris-free site conditions (USACE 2008a).

Based on these considerations, the assumption of using mechanical dredging to conduct dredging is deemed suitably conservative for the FS. This assumption does not preclude other options from being considered during remedial design.

For the FS, partial dredging (diver-operated hydraulic dredging) and capping are assumed as the representative primary process option for under-pier work (see Section 7.1.4) because full removal is often difficult. Under-pier areas have limited access, limited maneuverability, accumulated debris, and riprap structures. This assumption does not preclude other options from being considered during remedial design. For example, a design decision could be made to remove a pier deck to allow access for mechanical excavation or capping, or to adopt diver-operated hydraulic dredging, or to apply a spray cap.

7.1.2 Treatment Technologies

Treatment technologies can potentially be applied to in-place sediment (*in situ* treatment) or to sediment after it has been physically removed from the aquatic system (*ex situ* treatment). The CTM presented a detailed evaluation of treatment technologies and their applicability for sediment cleanup in the LDW. The CTM also reviewed the extensive regulatory and industry efforts in Washington State and elsewhere to determine the viability of treatment in the context of centralized sediment management facilities. There are no viable *in situ* treatment technologies currently demonstrated or on the development/testing horizon for sediment containing complex mixtures of metals and bio-recalcitrant organic compounds.[2] For this reason, the discussion reviews only *ex situ* treatment approaches and their applicability to the LDW.

Ex situ treatment options with potential applicability to the LDW are conventional soil washing/particle separation, advanced soil washing (Biogenesis™), solidification, and thermal treatment. To date, *ex situ* treatment of sediments, while a subject of considerable interest nationwide, has been mostly limited to soil washing in full-scale sediment remediation projects.

Technologies that destroy or detoxify contaminants have been accepted at very few projects (i.e., Bayon Bonfouca) for cleanup at contaminated sediment sites for two reasons. First, it is difficult to balance treatment costs with a beneficial reuse outlet for the material; and second, upland and in-water disposal alternatives are much less expensive, particularly in this region. With the exception of the addition of cement-type materials to reduce free water content and mobility prior to upland disposal, no

[2] Reactive capping technology is discussed separately in Section 7.1.4.2.

contaminated sediment remediation projects in this region have utilized treatment or beneficial reuse of treated sediments.[3]

7.1.2.1 Soil Washing

Soil washing can be classified as conventional or advanced form of treatment. Conventional soil washing is a form of primary treatment that uses conventional and readily-available material handling unit processes to separate sediment particles, typically into coarse (sand and gravel) and fines (silt and clay) fractions (Figure 7-1). This treatment process separates the sediment particles using conventional equipment. These equipment systems have been derived largely from the mining and mineral processing industries, and include screening, gravity settling, flotation, and hydraulic classification (e.g., using hydrocyclones) (USACE-DOER 2000). Advanced soil washing, such as Biogenesis™, combines the physical separation aspects of conventional soil washing with additional treatment such as agitation, or the addition of surfactants, chemical oxidants, or chelating agents to the finer fraction of material.

Soil washing is a wet process and therefore generates wastewater that requires treatment and discharge. Depending on site conditions, the washed coarse fraction may be suitable for in-water placement (see Section 7.1.3.4 for beneficial uses of sediment) as a cap, enhanced natural recovery (ENR), or habitat creation/restoration medium. The finer fraction, which has higher concentrations of chemical contaminants, is typically dewatered, transported, and disposed of in a permitted upland landfill. Ideally, the net outcome of soil washing is a reusable coarse fraction and a reduced volume of contaminated material requiring additional treatment or direct disposal.

Sediments in portions of the LDW may be sufficiently coarse-grained to consider soil washing as a potentially viable treatment. One vendor has indicated that soil washing has the potential to be economical where the sediment contains greater than 30% sand (Boskalis-Dolman 2006). When the sediment contains less than 30% sand, treatment performance and economics deteriorate. Other factors affecting the economics and implementability of soil washing are:

- Physical and chemical properties of the sediment.
- Availability of an upland location for transloading sediment from barges.
- Availability of an upland location for sediment containment, storage, and operation of the soil washing facility. Although this facility may or may not be located at the transloading facility, it is assumed that it will be located within the transloading facility footprint for the purpose of cost estimating.

[3] Treatment to eliminate free liquids from dredged sediment is no longer required by two regional landfills servicing the Puget Sound area (see Section 7.1.3.2).

- Disposal costs for the fines fraction.
- Ability to commit to long-term (and continuous) high-volume sediment throughput (economies of scale).
- Ability to reuse washed coarse fraction beneficially and at low cost.

The last two factors are the most difficult to reconcile in a manner that promotes economic viability.

The following sections describe conventional and advanced soil washing techniques recently used at several sites.

Raritan River, Arthur Kill, and Passaic River, New Jersey - Soil Washing

Biogenesis™ is an advanced soil washing process that was used in a recently completed full-scale demonstration, which treated approximately 15,000 cy of contaminated sediments from the Raritan River, Arthur Kill, and Passaic River, New Jersey (Biogenesis 2009, Malcolm Pirnie 2007). The Biogenesis™ process combines the physical separation aspects of conventional soil washing with high-pressure agitation, surfactants, chemical oxidants (e.g., hydrogen peroxide), and chelating agents. This process uses equipment including but not limited to: truck-mounted washing units, sediment processor, sediment washing unit, hydrocyclones, shaker screens, water treatment equipment, tanks, water blasters, compressors, and earth moving equipment.

Important Biogenesis™ process steps include:

1) Dredged sediment is screened to remove oversized material and debris before transfer to the holding tanks.

2) High-pressure water, proprietary solvent, and physical agitation are combined to separate contaminants from the solids.

3) Treated sediment is then dewatered using a hydrocyclone and centrifuge. Some effluent water may be recycled through the system, but significant quantities of wastewater are generated that require treatment and disposal.

The process results in residual waste products, including sludge and organic material, that require disposal at a regulated landfill. Depending on the nature of the sediment and cleanup levels required, the sediment washing process may need to be repeated for multiple cycles.

The Biogenesis™ proprietary process is designed to separate and to destroy organic contaminants partially (through oxidation); metals are conserved but concentrated in the fines fraction. Results for treated sediment from the three different dredged material sites demonstrated significant reductions in dioxin concentrations (425 picograms per gram dry weight [pg/g dw] prior to treatment and 60 pg/g dw post treatment); however, it is uncertain from this study what portion of dioxins were actually released

into air or volatilized. Only slight decreases in polychlorinated biphenyl (PCB) concentrations were documented (450 micrograms/kilogram [µg/kg] dw prior to treatment and 380 µg/kg dw post treatment) (Biogenesis 2009). PAHs were not effectively removed or destroyed because of adsorption to, or sequestration within, the organic material mixed with the sediment. Approximately 13,000 tons of processed dredged material was loaded onto trucks and transported off site for beneficial reuse as fill material.

Fox River (Wisconsin) Soil Washing/Sediment Processing

In 2009, approximately 540,000 cy of PCB-contaminated sediments at Fox River (Operable Unit 1-OU1) were hydraulically dredged and pumped through a pipeline to a sediment processing facility equipped with particle-size separation, dewatering, and water treatment equipment (i.e., equivalent unit operations used in conventional soil washing). The sediment slurry passed over a vibrating screen enabling <0.5-inch material to pass through. The sand fraction of the slurry was then separated from the silt and clay fractions using a 150-micron (µm) coarse sand separation unit. The sand was polished in an up-flow clarifier, gravity dewatered, and temporarily stored on site for potential reuse. Average PCB concentration of dredged material was approximately 1,900 µg/kg dw (EPA 2009). Total PCB concentrations in the treated sand fraction were on the order of 300 µg/kg dw.

The remaining fine grained sediment (<60 µm) was mechanically filter-pressed to dewater it. The resulting filter cake, typically containing between 1,000 and 10,000 µg/kg total PCBs was then land-filled. Process wastewater was treated by sand-filtration and granular activated carbon adsorption. Treated water was returned to the Fox River. Discharge water was monitored for PCBs, mercury, lead, pH, ammonia, biochemical oxygen demand, and TSS.

It is important to note that the process used at Fox River does not destroy organic contaminants. Further, while one of the project goals was beneficial reuse of the processed sand fraction, the sole beneficial reuse to date for this material was using a portion of the sand fraction as fill material (spread in the upland portion of the project site) and as a fill behind the sheetpile bulkhead wall constructed at the site. No beneficial uses outside of the project have been identified (TetraTech 2010).

Hudson River (New York) Soil Washing/Sediment Processing

Phase 1 of the dredging operations was conducted at the Hudson River during 2009 (Anchor QEA 2010). Mechanical dredges with environmental clamshell buckets were used to remove approximately 278,000 cy of river sediments. Dredged material was transported by barges to a shore-based processing and transportation facility. Approximately 370,000 tons of PCB-contaminated sediments were processed to separate size fractions and dewater the solids in a similar fashion to that described above for the Fox River project. As a first step in processing the dredged material, debris and rock were removed and dredged sediments were processed through trammel screens and hydrocyclones to separate the material by size.

Approximately 40% of the sorted materials were fines and 60% were coarse material and wood. After coarse material separation, the slurry of fine sediments was mixed with a polymer in a gravity thickener and filter-pressed. Segregated debris and coarse solids and filter cake removed from the filter presses were temporarily stored in staging areas prior to rail transport and disposal at a permitted facility in Texas. Residual contaminant concentration in the coarse material precluded beneficial reuse of this material. All fractions of dredged material (debris, coarse and fine) were therefore transported to and disposed of at a permitted facility in Texas. The fine fraction was separated from the coarse fraction and processed through mechanical dewatering to decrease the water content, thereby reducing the transport and disposal costs. A water treatment plant with the capacity to handle 2 million gallons of water per day was built to treat the water collected during the dewatering process. Treated water (approximately 88 million gallons per season) was discharged to the Champlain Canal.

Potential Environmental Review and Permitting Requirements

Permitting requirements for a prospective soil washing operation are currently undetermined and are dependent on the extent of the CERCLA and MTCA LDW site jurisdictional area. If the soil-washing site was determined to be within or immediately adjacent to the CERCLA/MTCA site boundaries, all environmental review and permitting requirements would be treated as applicable or relevant and appropriate requirements (ARARs); substantive compliance must be demonstrated. However, individual permits would need to be secured if the treatment site was determined not to be within the CERCLA/MTCA site boundaries. Permits would also be required for any off-site disposition of treated CERCLA materials and waste streams, such as placement of treated material as off-site fill or discharge of wastewaters to the King County sanitary sewer system. Potential environmental review procedures and permits include:

- City of Seattle State Environmental Policy Act (SEPA) Checklist and Determination of Non-Significance (DNS). The SEPA Checklist would identify potential environmental, social, and economic impacts associated with the soil-washing operation. Based on analysis of the checklist and assuming the issues are not of major concern, the City of Seattle Department of Planning and Development (DPD) would issue a DNS. The DNS must be issued prior to DPD issuing any permits. Traffic impacts associated with trucking of contaminated sediment to the site, if located remotely, would be evaluated as part of this process.

- DPD Master Use Permit (MUP) for new uses (e.g., soil washing) located within appropriately zoned areas. If required, the MUP would also fully address and accommodate Washington State Shoreline Management Act requirements.

- NPDES Individual Permit issued by the Washington State Department of Ecology (Ecology) to allow for discharge of treated soil-washing wastewater into the LDW. Approval to discharge to the King County Metro sewer

system is considered improbable because of: 1) flow quantity (capacity) restrictions imposed to not overwhelm the County's wastewater treatment system, and 2) excessive total dissolved solids content, adversely affecting the secondary biological wastewater treatment process. Because the sediment source is located within brackish and saltwater areas, salinity is also expected to be a significant concern for King County.

7.1.2.2 Solidification

Solidification is a proven and effective technology that reduces the moisture content of dredged sediments and reduces the leachability (mobility) of metals. The process involves mechanical blending of the contaminated medium, in this case sediment, with an agent such as cement, cement kiln dust, other pozzalonic substance, or super-absorbent polymers. These agents react with moisture in the contaminated media and may produce a material that is much improved structurally (i.e., compressive strength) and can effectively reduce the leachability of contaminants. However, contaminants are not destroyed by solidification.

The major regional landfills (Allied Waste of Roosevelt, Washington, and Waste Management of Columbia Ridge, Oregon) are able to receive contaminated wet sediment at their sites in truck and rail containers (without requiring material to pass a Paint Filter Test [EPA 2008a]). These containers are lined to prevent loss of material (e.g., drainage) during transport.

Solidification does not adequately treat the COCs and solidified sediment would still require transport to a landfill for disposal. For this reason, solidification is not carried forward for alternative development in this FS, but it may be reconsidered during remedial design if moisture or leachability reduction is needed to comply with landfill operating permits.

7.1.2.3 Thermal Treatment

Thermal treatment involves elevating the temperature of sediment to levels that either volatilize the organic contaminants (for later destruction in an afterburner) or directly combust the contaminants (e.g., incineration). A number of different system configurations and operating principles have been developed and are available in the marketplace, as described in the CTM. Thermal treatment systems are generally effective for destroying a broad range of organic compounds. Metals are not destroyed by thermal treatment systems.

Thermal treatment facilities are not available either locally or regionally. Therefore, dredged sediment would need to be transported out of state (either to Idaho or Utah) to utilize an existing facility. Alternatively, a temporary on-site (i.e., adjacent to the LDW) facility is technically feasible to consider. Implementability considerations include general siting considerations and obtaining local permits (e.g., air).

The primary drawback to thermal treatment is that treated sediment is unlikely to achieve metal concentration limits for beneficial reuse and may thus still require upland landfill disposal. Studies (e.g., toxicity testing) would also be needed to ascertain whether treated sediment would have properties suitable for supporting benthic productivity before in-water placement of the treated material would be allowed. Thermal destruction processes also require monitoring and management of air releases of hazardous constituents, such as dioxins/furans. Dioxins/furans can be created and released in air emissions from some thermal treatment processes, and fulfilling all substantive permit requirements for managing these air emissions can be difficult and can affect implementability of on-site thermal treatment.

Cement-Lock® Technology is a thermo-chemical manufacturing process that decontaminates dredged material and converts it into Ecomelt®, a pozzolanic material, which when dried and finely ground can be used as a partial replacement for Portland cement in the production of concrete. In the Cement-Lock® process, a mixture of material and modifiers is charged to a rotary kiln at high temperatures, which yields a homogeneous melt with a manageable viscosity. All nonvolatile heavy metals originally present in the sediment are incorporated into the melt matrix via an ionic replacement mechanism. The melt then falls by gravity into water, which immediately quenches and granulates it. The resulting material, Ecomelt®, is removed from the quench granulator by a drag conveyor.

Preliminary pilot-scale results have shown that organic contaminants are partially destroyed, and inorganics (e.g., metals) are encapsulated within the Cement-Lock® matrix (i.e., Ecomelt®). The Cement-Lock® cement product passed the Toxicity Characteristic Leaching Procedure test for priority metals. The technology was recently demonstrated at a pilot-scale level for sediments dredged from the Stratus Petroleum site in upper Newark Bay (NJ) in 2006 and from the Passaic River (NJ) in 2006 and 2007. However, both demonstrations experienced equipment-related problems and were terminated (GTI 2008). In these studies, the Ecomelt product samples showed an average reduction in PCB concentrations from 2,800 µg/kg dw (pre-treatment) to 0.2 µg/kg dw (post-treatment), and from 170 pg/g dw (pre-treatment) to 0.8 pg/g dw (post-treatment) of 2,3,7,8-tetrachlorodibenzodioxin (TCDD) (GTI 2008).

Thermal treatment is not carried forward for further consideration in the FS because the process is unlikely to achieve the total metal concentration limits for beneficial reuse although a reduction in leaching potential could perhaps be achieved through use of one of the available technologies (e.g., Cement-Lock® technology).

7.1.2.4 Treatment Technology Summary

Conventional soil washing/particle separation and advanced soil washing has sufficient merit to carry this process forward in developing the LDW remedial alternatives. Soil washing is retained as a primary treatment process option because it has been applied at other contaminated sites in the United States and Europe, results in

volume reduction of treated dredged material, and may result in a sand fraction suitable for beneficial use in the LDW, or possibly reduce or eliminate the cost of disposal for the sand fraction. Significant engineering design would be required to specify soil washing site location(s), special equipment needs (e.g., cyclones, filters, water treatment systems, etc.), operational procedures, and environmental review and permitting requirements to implement soil-washing treatment.

It is assumed that soil-washing treatment would be located entirely within the transloading/dewatering facility and would consist of the following elements:

1) Physically wash the dredged material and separate the coarser grained (clean) sediment from the fine particle (contaminated) sediment.

2) Treat the wash water and discharge it to the LDW. Assume use of the following treatment train: collect and settle wastewater, flocculate, filter, analyze, and discharge.

3) Collect and stockpile the cleaned sediment in an on-site location separated from the soil-washing and wastewater treatment operations. Chemically analyze the sediment for COCs to confirm that remnant COC concentrations are less than sediment quality standards (SQS) or other applicable criteria and thereby are determined suitable for beneficial reuse.

4) Transfer the treated sands (processed material achieving target levels established for the project) off site and stockpile for assumed reuse as capping and ENR material for the project. Stockpile requirements need to address logistics and timelines for sand reuse. Specific requirements for sand quality and use need to be defined, including regulatory approvals.

5) Chemically analyze all remaining sediment to determine if treatment has magnified COC concentrations to be greater than landfill-designated hazardous waste concentrations.

6) Based on the chemical analytical results, load railcars with remaining sediment, transfer to the landfill, treat any excess wastewater, and dispose of the remaining sediment appropriately in either a Subtitle C or D landfill.

More advanced soil-washing technologies are not carried forward into the FS as the representative process option in the FS because conventional soil-washing techniques would likely produce the most value in terms of volume reduction for the cost. The expected post-treatment concentrations may preclude the material from beneficial reuse in Puget Sound. Solidification and treatment technologies were screened out for full-scale consideration in the FS as described above.

7.1.3 Disposal/Reuse of Contaminated Sediment

Several disposal options for dredged sediment were identified in the CTM and are reconsidered here for their applicability to cleanup of the LDW:

- On-site disposal
  - Contained aquatic disposal (CAD)
  - Confined disposal facility (CDF)
- Off-site disposal
  - Existing Subtitle C landfill (40 CFR Part 265, Subtitle C of RCRA)
  - Existing Subtitle D landfill (40 CFR Part 258, Subtitle D of RCRA)
- Open-water disposal
  - Dredged Material Management Program (DMMP) site
- Beneficial reuse.

The on-site disposal options retain the contaminated material in or very near the site in new, engineered facilities. The off-site disposal options pertain to upland disposal in existing regional landfills. Open-water disposal is also considered an applicable process option for some dredged material given the institutional and engineering framework embodied in the DMMP. All of these disposal alternatives have demonstrated effectiveness and have been successfully used in the Puget Sound region.

Beneficial reuse is often preferred to disposal, when feasible, although application can be limited by physical characteristics or contaminant concentrations.

7.1.3.1 On-Site Disposal

CAD and CDF are two potential on-site process options for disposal of dredged sediment. As discussed in the CTM (RETEC 2005), both disposal options confine contaminated sediment within an engineered structure, and differ primarily in location or setting. CAD facilities are located within a water body. CDFs are located nearshore or upland.

CAD Sites

CAD implementation, although a proven technology, is constrained in the LDW. Material is typically placed in horizontal layers, which requires locating the CAD site in a relatively flat area or depression to minimize excavation quantities during construction, and to prevent spread of contaminated sediment downslope. Potential CAD sites in the LDW are located within or near the defined navigation channel. To ensure that the authorized channel depths are maintained, the top surface of the CAD must be positioned below the authorized channel depth to allow for maintenance dredging. The federally-authorized navigation channel is a legal covenant that requires maintenance of a specified depth; remedial alternatives within the channel cannot

interfere with the authorized channel depth. Two locations in the LDW best satisfy these requirements:

- The deep area at the north end of the LDW directly south of Harbor Island, where the existing depth is well below the authorized navigation channel depth
- The southernmost portion of the LDW site, defined by the Upper Turning Basin and adjacent navigation channel.

An advantage of CAD over upland disposal is the overall project dredging production rate. When the CAD is sited (and excavated, if needed), sediment remediation dredging and disposal activity can proceed at a far greater rate than is possible with just upland disposal of the contaminated dredged sediment. This is because dredged sediment can be placed directly into bottom-dump barges for rapid movement to and placement into the CAD. Hence the dredging remediation would not be subject to the production rate constraints associated with transloading and transportation to a landfill. As result, the overall period of short-term dredging impacts could be reduced through use of CAD.

Numerous implementability issues would have to be addressed to implement CAD including:

- Logistical and timing considerations need to be planned for, including: 1) CAD construction (e.g., dredging and disposal of excavated sediment), 2) sequencing and timing to dredge and place contaminated sediment in the CAD, and 3) identification and coordination to secure and place capping material. In addition, capping (either interim or final) must be completed by the end of each in-water construction window to protect fish runs from disturbance by construction during migration.
- Barge dumping of contaminated sediment into a CAD site involves some dispersion of material as it falls through the water column and lands on the mudline. Unless care is taken, the dumped sediment can cause a "mud wave" when it strikes the bottom. This can cause contaminated sediment to move out of the CAD area and migrate onto adjacent surfaces. Models are available (e.g., STFATE) to assess this factor and engineering controls would need to be incorporated into the design to minimize or mitigate this factor. These engineering controls can include designing the CAD with features to limit mud waves, monitoring adjacent areas, and capping or implementing ENR for any affected adjacent areas.
- Propeller scour in the navigation channel as well as movement by tugs and other vessels accessing adjacent berthing areas could stir up exposed contaminants and move them into other areas before the

cap is installed. Modeling of propeller wash, along with appropriate navigation controls during the construction season can be used to minimize this potential.

A CAD could also potentially be located outside of the LDW (e.g., elsewhere in Puget Sound). However, this would be an off-site disposal action subject to permitting requirements. Because the administrative implementability of an off-site CAD is considered low, these possibilities are not explored in this FS.

CAD is being carried forward, and will be evaluated as a disposal alternative with the understanding that CAD capacity may not match the total volume of contaminated dredged sediment under some alternatives. However, regardless of which remedial alternative is selected, CAD may be considered during remedial design on a smaller-scale, location-specific basis, subject to agency approval.

CDF Sites

A nearshore or upland CDF (e.g., construction of a CDF in a slip) is a technically feasible option for the disposal of LDW dredged material, but is not carried forward as a primary in-water disposal technology for the FS. During engineering design, if a small-scale CDF potentially could be applicable, numerous hurdles would need to be overcome. Some of these hurdles include: identifying suitable available land/water sites for acquisition, providing compensatory habitat mitigation for lost aquatic habitat, and demonstrating appropriate economic development purposes for the upland facility in accordance with the Clean Water Act Section 404(b)(1) guidelines.

7.1.3.2 Off-Site Landfill Disposal

Sediments removed from the LDW are not expected to require disposal in a landfill permitted to receive Resource Conservation and Recovery Act (RCRA) hazardous waste or Toxic Substances Control Act (TSCA) waste (i.e., Subtitle C landfill). Nevertheless, a regional Subtitle C landfill (Waste Management, Inc. located at Arlington, Oregon) is available to receive material that exceeds the relevant RCRA or TSCA limits should such material be encountered during remediation. The NCP (40 CFR Section 300.430(a)(1)(iii)) states that EPA "generally shall consider the following expectations in developing appropriate remedial alternatives:

- .use treatment to address principal threats posed by a site, wherever practicable. Principal threats for which treatment is most likely to be appropriate include liquids, areas contaminated with high concentrations of toxic compounds, and highly mobile materials.
- …use engineering controls, such as containment, for waste that poses a relatively low long-term threat or where treatment is impracticable."

In guidance, EPA defines principal threat waste as a source material that is highly toxic or highly mobile that generally cannot be reliably contained or would present a significant risk to human health or the environment should exposure occur (EPA

1991a), such as drummed waste or pools of non-aqueous phase liquids. No non-aqueous phase liquids have been found in LDW sediments and most of the contaminated sediments in the LDW are low-level threat wastes[4].

Two regional Subtitle D landfills (Waste Management, Inc. located at Columbia Ridge, Oregon, and Allied Waste, Inc. located at Roosevelt, Washington) receive both municipal waste and solid nonhazardous contaminated media. Both facilities have been used for the majority of contaminated sediment projects in the Puget Sound region, including several projects in the LDW (Table 7-5). Further, both facilities are permitted to receive wet sediment (i.e., sediment that does not pass the paint filter test and therefore contains free liquid). These existing Subtitle D landfills are retained as representative disposal process options for remedial alternatives that call for sediment removal with disposal in an upland landfill.

7.1.3.3 Open-Water Disposal

In Puget Sound, the open-water disposal of sediments is managed and monitored under the DMMP, which is jointly administered by the USACE, the EPA, the Washington State Department of Natural Resources (WDNR), and Ecology. The DMMP User's Manual (USACE 2008b) details the sediment evaluation, testing, and disposal procedures for open-water disposal of dredged material at DMMP-designated disposal sites in Puget Sound. The DMMP non-dispersive deep water disposal site nearest to the LDW is in Elliott Bay. This facility has approximately 6.6 million cy of remaining capacity.[5]

Some of the LDW sediments that have been dredged from the navigation channel between river mile (RM) 3.8 and RM 4.8 and from private berthing areas outside of the navigation channel have previously been tested and accepted for open-water disposal. This suggests that at least some of the sediment removed during remediation may meet DMMP criteria. However, it is conservatively assumed that dredged sediments requiring remediation under CERCLA would not be approved for open-water disposal, although they are not specifically precluded from DMMP open-water disposal. This assumption is supported by the DMMP screening levels (SLs) for COCs that allow open-water disposal of dredged sediment per requirements similar to the SQS. Also, the DMMP maximum levels (MLs), above which sediments will not be approved for open-water disposal, are lower than the cleanup screening levels (CSL). Sediment with COC concentrations between the SL and ML must pass sediment toxicity tests (and potentially bioaccumulation testing) before open-water disposal is allowed.

[4] One sample located at the RM. 2.2 inlet (Trotsky area) measured 2,900 mg/kg dw PCBs, but the areal extent of this concentration is considered very small.

[5] Approximately 2.4 million cy of dredged material have been placed at the Elliott Bay disposal site between 1989 and 2007. With a capacity of 9.0 million cy, the site will be operational for about 50 more years, assuming about 130,000 cy of placement per year (USACE 2007a).

Open-water disposal may be considered in the remedial design phase for the following material if the sediment is demonstrated to achieve the DMMP criteria for open-water disposal:

- The clean sand fraction from conventional soil washing
- Suitable material dredged from areas during construction of a CAD facility
- Certain areas of comparatively clean, suitable material dredged as part of a CERCLA action under some alternatives.

7.1.3.4 Beneficial Use of Sediment (Clean and Treated)

Beneficial use of dredged sediment is preferred to its disposal, when feasible. However, contaminated and untreated sediment is generally not suitable for direct beneficial use applications because of the physical characteristics and the liability associated with using contaminated material and because the contaminant concentrations may exceed unrestricted state cleanup levels. Nonetheless, this subsection examines the potential beneficial use of:

- Clean dredged material generated by local navigation channel maintenance dredging projects
- Treated sand fraction of dredged contaminated sediments from the LDW.

It is noted that any potential in-water beneficial use application would need to meet associated material specifications to ensure an appropriate match between physical, chemical, and biological material properties and functionality in the aquatic environment.

Beneficial Use of Dredged Material from Navigation Projects

Regular USACE maintenance dredging of regional navigation channels in the LDW, Snohomish River, Swinomish Channel, and other rivers generates large volumes of sandy and silty sediments. In the Puget Sound region, this dredged material has been used beneficially for both remediation and habitat enhancement projects. Examples of projects in Elliott Bay that have used sediment from LDW Upper Turning Basin maintenance dredging activities include:

- **Denny Way Combined Sewer Overflow (CSO) Capping –** In 1990, King County and the USACE sponsored the Denny Way CSO capping project to test the feasibility of capping contaminated sediments in Elliott Bay. A 3-foot layer of sediment dredged from the LDW Upper Turning Basin was placed over a 3-acre area at the Denny Way CSO. Monitoring results over the last 15 years demonstrate that the cap is stable, is not eroding, and has

successfully isolated the underlying contaminated sediments (King County 2007a).

- **Pier 53-55 Capping –** In March 1992, about 22,000 cy of sediment dredged from the LDW Upper Turning Basin was placed offshore of Piers 53, 54, and 55 in Elliott Bay, to cap approximately 2.9 acres and ENR approximately 1.6 acres of contaminated sediments. Monitoring results indicate that the 3-foot cap and ENR areas are stable, and chemicals are not migrating from the underlying sediments up into the 3-foot cap or ENR area (King County 2009).
- **Bell Harbor Capping –** In March 1994, the Port of Seattle placed a thin-layer cap of sediment dredged from the LDW Upper Turning Basin over 3.9 acres of contaminated sediments at the former site of Pier 64/65 in Seattle. The site was also designed to incorporate habitat enhancement components, including rock corridors on top of the cap and gravel below the slope and between corridors. These substrata were specifically designed to serve as habitat for brown algae and juvenile rockfish. Subsequent monitoring has demonstrated the success of both actions (Erickson et al. 2005a and 2005b).
- **Pacific Sound Resources Superfund Site in West Seattle –** Approximately 66,000 cy of sediment dredged from the LDW Upper Turning Basin, along with over 200,000 cy of sediment dredged from the Snohomish River, was placed as a cap at the Pacific Sound Resources contaminated sediment site in West Seattle in 2004 (USACE 2007b).

It is assumed that upland-sourced materials (sand, gravel, and rock) will be purchased for use as cap materials and for ENR. However, the design process should consider the use of navigation channel and berthing area dredged materials determined suitable for beneficial use application as an alternative to upland-sourced materials. The EPA's Contaminated Sediment Technical Advisory Group (CSTAG) has recommended that the navigation channel and berthing area dredged material be considered for these uses in the remediation of the LDW (CSTAG 2006). However, significant administrative issues (including timing, contracting, and administrative approvals) are associated with procuring USACE and private party dredged materials.

Beneficial Use of Treated Contaminated Sediments

For contaminated sediments dredged as part of a cleanup action, treatment would be required before possible beneficial use. Treatment by soil washing followed by beneficial use of the sand fraction may be more cost-effective than treatment followed by disposal. The coarser (sand) product (processed material achieving target levels established for the project) from a soil washing process could potentially be reused

within the LDW for capping, habitat restoration, or grade restoration (i.e., to meet final bathymetry requirements) as part of the remedial action. However, a review of existing literature and local knowledge did not identify any examples of treated sediments being used beneficially in the Puget Sound region.

The sand produced from a soil washing process could also be reused in the uplands as construction fill or as material feedstock for other industrial or manufacturing applications (e.g., concrete or asphalt manufacture). Depending on the end use and associated exposure potential, it is not known whether the treated sand fraction would achieve appropriate chemical criteria for all LDW contaminants. Upland beneficial use would also require resolution of legal issues related to material classification, antidegradation, and administrative matters related to liability.

Remedial alternatives that include soil washing assume that the disposition of the washed material could result in a range of outcomes: 1) achieve the applicable chemical and physical requirements for in-water use and hence be used as on-site cap or ENR material with potential material cost savings; 2) be suitable for upland use as fill with no associated value or disposal cost; 3) be suitable for open-water disposal with a comparatively low disposal cost; or 4) require landfill disposal at significant cost.

7.1.4 Capping

In the CTM (RETEC 2005), capping was evaluated and retained as a containment technology that is considered both effective and implementable in the LDW. Capping is a well-developed and documented *in situ* remedial technology for sediment that isolates contaminants from the overlying water column and prevents direct contact with aquatic biota (Figures 7-2 and 7-3). Depending on the contaminants and sediment conditions present, a cap reduces risks through the following primary mechanisms (EPA 2005):

- Physical isolation of the contaminated sediment sufficient to reduce exposure through direct contact and to reduce the ability of burrowing organisms to move contaminants to the cap surface
- Stabilization of contaminated sediment and erosion protection of the sediment and cap sufficient to reduce resuspension and transport of contaminants into the water column
- Chemical isolation sufficient to prevent unacceptable risks of exposure to sediment contaminants that are solubilized and transported through the cap material and into the water column (e.g., via diffusion or groundwater advection).

7.1.4.1 Conventional Sand and Armored Caps

A large number of sediment caps have been successfully implemented in the Puget Sound region: One Tree Island Marina, Olympia 1987; St. Paul Waterway, Tacoma 1988; Georgia Pacific Log Pond, Bellingham 2000; East and West Eagle Harbor/Wyckoff,

Bainbridge Island, 1993-2002; Middle Waterway, Tacoma 2003; General Metals, Tacoma late 1990s; and others (RETEC 2002).

Within the LDW, a sand cap was constructed in 2005 in conjunction with the Duwamish/Diagonal early action area (EAA) sediment remediation project (EB/DRP 2005) (Figure 7-4). Preliminary monitoring results from 2007 to 2009 show trends indicating that the cap has successfully isolated underlying contamination. Following cap construction, total PCB concentrations in surface sediment have fluctuated around the SQS for total PCBs. However, because the Duwamish/Diagonal cap is located near an active storm drain and a CSO outfall, and is adjacent to other contaminated sediments, some degree of increase in chemical concentrations on the cap surface has been noted, highlighting the importance of source control.

The ability to implement capping technology is influenced greatly by physical constraints and engineering design. Capping may be suitable where navigation or other public uses would not be physically impeded, or in areas where it is impractical to remove all of the contaminated material because of slope or nearby structure stability concerns. If capping is chosen as part of the selected remedial alternative for the LDW, then bathymetric, hydrodynamic, slope stability, and biological conditions, as well as commercial/public land use would need to be considered. An engineered cap design specifies material types, gradation, thickness, armoring requirements, design elevation ranges, placement requirements, and other design parameters. For example, the cap design for deep depositional waters would be different from designs for intertidal and shallow subtidal areas of high habitat importance and areas that have the potential for appreciable episodic erosion.

7.1.4.2 Composite and Reactive Caps

A composite or reactive cap may be the desirable design solution in situations where:

- A reduced cap thickness is needed in navigation-constrained areas to avoid dredging.
- Standard sand capping would require excessive thickness for containment of a specific COC.
- Other contaminant migration pathways (e.g., more soluble chemicals, groundwater discharge) necessitate reducing contaminant flux over what is achievable with native materials.

Reactive cap technology refers to the inclusion of reactive amendments in the granular cap material or in manufactured mats. The additives are selected based on their ability to adsorb or react with contaminants migrating through the cap strata. Activated carbon, bentonite, apatite, AquaBlok™ (a commercial product designed to enhance chemical sequestering through organic carbon amendments to the cap, and to reduce permeability at the sediment-water interface), and coke are examples of reactive

amendment materials that have been investigated at the demonstration level or in full-scale applications.

The following paragraphs describe examples of composite or reactive cap demonstration level or full-scale application projects.

Carbon Amendment of Cap Materials (Various sites, Washington)
Sand with a carbon amendment was used or is planned for use in caps at the Upriver Dam PCB Sediments Site, Spokane, WA, Olympic View Resource Area, Tacoma, WA and Slip 4 EAA, Seattle, WA, (Schuchardt, personal communication 2009).

Activated Carbon – Reactive Core Mat (Stryker Bay, Duluth, Minnesota)
Stryker Bay in Duluth (MN) was heavily contaminated with tar and coke (Bell and Tracy 2007). Coal tar thicknesses under the water reached as much as 13 ft in some areas. Remediation involved placement of six inches of sand cap and a reactive core mat (RCM), followed by six inches of sand cap over the contaminated sediments. The activated carbon-based geotextile, a reactive cap, allowed for thinner cap thickness than a traditional sand cap, and provided stability and physical isolation.

Activated Clay Cap (Willamette River, Portland, Oregon)
In 2004, as part of the cleanup of the McCormick and Baxter Superfund site, the east bank and bed of the Willamette River in Portland (OR) were capped with an organoclay sediment layer to contain high concentrations of COCs including pentachlorophenol (PCP), creosote, chromium and arsenic (Aquatechnologies.com; Oregon Department of Environmental Quality 2005). Over most of the site, the cap consists of a 2-foot-thick layer of sand. In more highly contaminated areas, a 1-foot organoclay layer was placed beneath a 5-foot thick layer of sand. The organoclay consists of bentonite or hectorite clay modified to be hydrophobic, to have an affinity for non-soluble organics, and especially to prevent breakthrough of non-aqueous phase liquid through the cap. The design of the sediment cap incorporated different types of armoring to prevent erosion of the sand and organoclay layers.

Granular Bentonite, Sand/Soil/Bentonite Slurry, and Aquablok™ (Grasse River, Massena, New York)
Pilot studies conducted in 2001 in the Grasse River, Massena, (NY) evaluated capping with various materials as a cleanup alternative for the remediation of PCB-contaminated sediments (Quadrini et al. 2003). Materials such as a 1:1 sand/top soil mixture, granulated bentonite (clay), and AquaBlok™ were tested as single components or mixtures. Optimal results were achieved with a 1:1 sand/top soil cap applied via a clamshell attached to a barge-mounted crane. Few apparent short-term impacts were noted during the pilot project, as well as negligible water quality impacts. However, in 2003, cap monitoring data indicated significant loss of cap material, and in some cases, significant but localized scouring of underlying sediment (up to 2 ft), that translated into redistribution of the PCBs buried in the river sediments in the upper approximately 1.8 miles of the lower Grasse River. The possible cause was an ice jam that formed on the river during the spring ice breakup. Consequently, an ice breaking demonstration

project was conducted in 2007, the results of which were incorporated into the analysis of alternatives report to evaluate remedial options for the river (Alcoa 2007).

AquaBlok™/sand (Anacostia River, Washington, D.C.)

A major demonstration of several active-addition reactive cap designs has been conducted on the Anacostia River in Washington, DC (EPA 2007c). The objective of this demonstration project was to provide information on the design, construction, placement, and effectiveness of these augmented caps. Various cap technologies were evaluated, including sand (as a demonstration control), AquaBlok™, coke breeze (with potential to sequester and retard the migration of organic contaminants through sorption), and apatite (which encourages precipitation and sorption of metals). The performances of these caps were evaluated in terms of physical stability, hydraulic seepage, and impacts on benthic habitat and ecology. Monitoring of the caps over an approximately three-year period using a multitude of invasive and non-invasive sampling and monitoring tools was used in assessing performance. Results indicate that the AquaBlok™ was highly stable, and likely more stable than traditional sand capping material even under very high bottom shear stresses. The AquaBlok™ material was also characteristically more impermeable, and it is potentially more effective at controlling contaminant flux, than traditional sand capping material. However, the low permeability AquaBlok™ cap showed evidence of heaving because of methane accumulation and release. AquaBlok™ also appeared to be characterized by impacts (lack of colonization) to benthos and benthic habitat similar to traditional sand capping material (EPA 2007). Apatite results were not available for review in the EPA (2007) report.

In another demonstration in the Anacostia River in 2004, a RCM was designed to accurately place a 1.25-cm thick sorbent (coke) layer in an engineered sediment cap (McDonough et al. 2006; Figure 7-3). Twelve 3.1 m x 31 m sections of RCM were placed in the river and overlain with a 15-cm layer of sand to secure it and provide a habitat for benthic organisms to colonize without compromising the integrity of the cap. Placement of the RCM did not cause significant sediment resuspension or impact site hydrology. The RCM was shown to be an inexpensive and effective method to accurately deliver thin layers of difficult to place, high value, sorptive media into sediment caps. It can also be used to place granular reactive media that can degrade or mineralize contaminants.

7.1.4.3 - Capping and Overwater Structures

- Overwater or floating structures (e.g., docks, piers, marina floats) preclude conventional means of installing a cap using a material barge and excavator or clamshell-based equipment. Various alternative methods are available and have been successfully implemented under these circumstances: A belt-conveyor system that can be controlled for angle and speed spray-deposits sand under piers and between pile bents (Figure 7-5).

- Small construction equipment (e.g., skid loader) that fits between pile bents can directly apply cap materials during low tide and where surface conditions are sufficiently stable and access is adequate for maneuvering. This approach was used successfully at the Wyckoff/Eagle Harbor West Operable Unit remediation site in 1997.
- A discharge pipeline can hydraulically deposit a sand-slurry underneath or through the overwater structure. The latter may require removing some of the pier decking. This approach was used successfully at the Wyckoff/Eagle Harbor West Operable Unit remediation site in 1997.
- Pier decks can be removed temporarily to improve access for mechanical placement, as employed at Martinac Shipyard in the Thea Foss Waterway circa 2003.
- Grout-filled mats can be installed around pile bents, as employed in the Thea Foss Waterway circa 2003.

At intertidal locations where it is difficult to effectively place a sand cap by conventional means (e.g., where the slope is too steep or overhead obstructions exist), a shotcrete cap is an option. Shotcrete is typically composed of concrete or mortar and is pneumatically jettisoned from a nozzle at high velocity onto the surface to be coated at low tide. A shotcrete cap was installed during the Todd Shipyards sediment cleanup (McCarthy 2005). The shotcrete application at Todd Shipyards effectively encapsulated existing debris (slag) mounds (Figure 7-6). Shotcrete can be applied to various material types and surface orientations, including steep embankments.

7.1.4.4 Modeling of Cap Recontamination

The potential for a conventional *in situ* isolation sand cap to be recontaminated over time by the movement of chemicals through the cap from underlying sediments was analyzed using the approach presented by Lampert and Reible (2009). This approach uses a one-dimensional groundwater flux model that also includes net sedimentation on top of the cap. The modeling approach and the results of the analysis are presented in Appendix C, Part 8 (Modeling Contaminant Transport through a Sediment Cap).

The analysis showed that PCB breakthrough above the assumed performance goals is not expected to occur.[6] This is true even where the assumed conditions are unfavorable (high groundwater flow, low sedimentation, and low K_{oc}), because the sedimentation rate is always greater than the rate at which the contaminant front migrates through

[6] The assumed performance goals for cap modeling are: 1) sediment concentrations not exceeding 100 µg/kg dw total PCBs in the top 10 cm within 100 years, and 2) porewater concentrations below 0.03 µg/L at the sediment/water interface within 100 years.

both the cap and the new sediment layer that is continually added over time. The analysis showed that cPAHs behave similarly to PCBs and therefore would also not exceed similar performance goals.

In the complete absence of sedimentation, the results show that capping is still feasible, but that minimum organic carbon requirements for cap materials may need to be specified to achieve a cap design life of 100+ years. ENR is predicted to achieve assumed performance goals under average conditions, but may not be applicable in adverse conditions (high groundwater flow, no sedimentation, low K_{oc}).[7] Cap or ENR material specification and applicability of ENR would be evaluated during remedial design.

For the 45-cm clamming point of compliance direct contact scenario, the results show that capping with a 3-ft sand cap is feasible, even in the absence of sedimentation. However, minimum organic carbon requirements for cap materials may need to be specified to achieve a cap design life of 100+ years.

7.1.4.5 Capping Technology Summary

For developing and evaluating remedial alternatives in the FS, conventional sand cap and armored cap process options have been selected to represent the technology as a whole. Sand caps may be applied to net depositional areas, and armored caps may be applied to areas within the LDW subject to episodic erosion. Reactive caps, although not evaluated in this FS for LDW-wide application, may be appropriate and cost-effective depending on location-specific circumstances.

Section 8 of the FS surveys site-specific conditions and identifies areas suitable for capping. The analysis considers the potential for propeller scour, outfall scour, ship wakes, water depths required for vessel navigation and berthing, slopes, habitat requirements, and erosion associated with high-flow conditions in the LDW. Locations requiring armoring are also considered.

7.1.5 Monitored Natural Recovery (MNR)

Natural recovery of sediments refers to the ability of natural processes such as chemical and biological degradation as well as physical burial to reduce chemical concentrations over time (Figure 7-7 conceptual figure). Where conditions support natural recovery and natural recovery is included in the remedial alternative, a monitoring program will be instituted as a large component of MNR to assess if, and at what rate, risks are being reduced and whether progress is being made toward achieving the RAOs. The monitoring program associated with an MNR remedy generally combines physical, chemical, and possibly biological testing to track progress toward achieving the RAOs. As with any risk-reduction approach that takes time to reach remediation goals,

[7] Analysis of ENR generally assumes that placed ENR sand mixes with underlying sediment. This analysis assumed that a thin ENR sand layer (15 cm) did not mix with underlying sediment. Therefore, the analysis is exploratory.

remedies that include MNR frequently rely upon institutional controls, such as seafood consumption advisories, to control human exposure during the recovery period (EPA 2005). Importantly, contingency actions such as capping, ENR, or dredging are also typically identified as part of the MNR component. The contingencies can be implemented if the monitoring program indicates that the RAOs will not be achieved by MNR alone within an acceptable time frame.

As discussed in Section 5, there is appreciable burial of LDW sediments from deposition of new material transported into the LDW from upstream. This burial, combined with surficial mixing (both from bioturbation by benthic organisms and resuspension caused by physical processes), is the principal on-going natural recovery process within the LDW. The majority of COCs in LDW sediments are resistant to biodegradation and dissolution. Thus, it is reasonable to expect that the primary factor in determining how quickly natural recovery will occur (assuming sources are adequately controlled) is the burial or deposition rate. Recovery is expected to be more rapid in areas with intermediate to high net sedimentation rates and low where net sedimentation rates are low or where there is the potential for either significant scour or episodic erosion. The bed composition model (BCM) (see Section 5) was developed as a tool to enable predictions of recovery as a function of both location within the LDW and of the concentrations of chemicals coming into the LDW from upstream and lateral (e.g., stormwater) sources.

Data collected during the Duwamish/Diagonal EAA project (Anchor 2007) lends empirical support to natural recovery being operative in the LDW. This project involved a combination of removal (dredging), capping, and thin-layer sand placement. Surface sediment chemistry is being monitored on and adjacent to the actively remediated areas of the project site (Figure 7-4). Monitoring data associated with the cap and thin-layer sand placement are discussed below in Section 7.1.6. The data collected from stations peripheral to the actively remediated areas are plotted versus time in Figure 7-4 (center chart). The trends suggest that contamination from resuspension and dispersal during the dredging operation may have been responsible for total PCB concentrations remaining high and consistent with data generated during the investigative phase of the project in the mid-1990s. Since then, total PCB concentrations have declined, presumably as a result of natural recovery processes (see Appendix F). It should be noted that dispersion of some of the newly placed capping material appeared to have initially influenced some immediately adjacent noncapped areas, thereby contributing to the decrease in PCB concentrations seen in the first post-capping year.

Additional empirical support for natural recovery actively occurring in the LDW can be discerned from the Slip 4 surface sediment dataset, as shown in Figure 7-8. This figure shows where surface sediment samples were collected and analyzed for total PCBs within the Slip 4 EAA. These data were divided into two groups representing conditions observed before 1999, and conditions observed in 2004 (see Figure 7-8). The

two datasets were analyzed statistically and determined to be significantly different ($p<0.05$; Mann-Whitney two-sample test). The mean total PCB concentration in the 2004 dataset (830 µg/kg dw) is less than one-half the mean concentration of the pre-1999 dataset (3,200 µg/kg dw).

Natural recovery is expected to occur at varying rates at specific locations within the LDW, as illustrated in the examples above. Importantly, based on both modeling and empirical data, natural recovery is an ongoing process at the LDW-wide scale (see Appendix F). LDW-wide reductions in average concentrations of chemicals such as PCBs are necessary to reduce resident fish and shellfish tissue concentrations. Hence, MNR is evaluated as an LDW-wide "polishing step" for all of the remedial alternatives considered in this FS. In this context, MNR is expected to be a component of all large-scale sediment remediation projects with temporal goals (NRC 2007).

7.1.6 Enhanced Natural Recovery (ENR)

ENR refers to the application of thin layers of clean granular material, typically sand, to a sediment area targeted for remediation. Application thicknesses of approximately 6 inches are common, producing an immediate reduction in surface chemical concentrations (Figure 7-7). Essentially, ENR reduces the time to achieve RAOs over what is possible by relying solely on natural sediment deposition where burial is the principal recovery mechanism (EPA 2005). Thus, areas that are recovering naturally (albeit slowly) and are stable (not expected to erode), are candidates for ENR.

Unlike capping, which typically has a much greater application thickness, surface sediment chemical concentrations in areas that undergo remediation by ENR are expected to be influenced by benthic recolonization and associated bioturbation. These processes result in the mixing of underlying contaminated sediment with the cleaner near-surface material. This is important for remedial design where a surface sediment concentration threshold is typically established below which MNR is appropriate and above which other active technologies (e.g., dredging or capping) should be considered.

Examples of ENR sediment remediation projects are provided below.

Ketchikan Pulp Company, Ketchikan, Alaska

A thin-layer placement was successfully applied in 2001 over the sediments offshore of a former sulfite pulp mill (Ketchikan Pulp Company-KPC) in Ward Cove, Alaska (Merritt et al. 2009 and Becker et al. 2009). The primary chemicals of concern were ammonia and 4-methylphenol. These chemicals are not bioaccumulative. Diffusion of chemicals from underlying sediment was identified as the dominant mode of chemical transport responsible for toxicity to organisms in surface sediment.

The thin-layer cap of fine-grained to medium-grained sand was placed over 28 acres of native sediments to a thickness ranging from 15 to 30 cm (Merritt et al. 2009). In 2004 and 2007, the first and second monitoring events were conducted, and included evaluations of sediment chemistry, sediment toxicity, and benthic macroinvertebrate

communities. Concentrations of both COCs in the thin-layer strata were low in 2004, indicating ENR effectiveness. The clean sand placement material was not being noticeably affected by upward migration of the COCs from underlying native sediment; the concentrations of COCs remained low in 2007. For sediment toxicity, amphipod survival was about 93 to 96% in 2004 and remained high in 2007 (92 to 95%). Benthic communities had begun recolonization by 2004 and total abundance increased substantially in 2007 (Becker et al. 2009).

Bremerton Naval Complex, Puget Sound, Washington

The Puget Sound Bremerton Naval Shipyard Complex (PSNS), located on the Sinclair Inlet of Puget Sound at Bremerton (WA), is another site where ENR has been implemented as a component of a final site remedy (URS 2009, Merritt et al. 2009). The marine area of concern (Operable Unit B [OUB]) in the PSNS is a subtidal section of the inlet, with water depths generally less than 15 m. Baseline PCB concentrations in sediments within the area of concern exceeded the Washington State SQS of 12 mg/kg oc and mercury concentrations exceeded the SQS of 0.41 mg/kg dw.

One component of the remedy involved placement of a 15 to 20 cm layer of sediment over 16 acres of subtidal sediment within OUB that had surface sediment PCB concentrations greater than 6 mg/kg oc. The decision to adopt ENR for this area was guided by: 1) evidence that the system was gaining sediment through natural deposition, and 2) the comparatively low concentration of PCBs (<1 mg/kg oc) in sediments entering the system.

Benthic recolonization is actively occurring within the ENR zone, and mercury concentrations in surface sediments have decreased more significantly after thin-layer placement than have PCB concentrations. Continued monitoring in 2005 and 2007 showed that geometric mean sediment concentrations of PCBs and mercury, as well as the mean English sole PCB tissue concentrations, appeared to have declined from concentrations in 2003 (URS 2009, Merritt et al. 2009). However, the rate of recovery is slower than predicted by modeling.

Duwamish/Diagonal EAA Project, Seattle, Washington

In response to observed increases in surface sediment concentrations of total PCBs adjacent to a portion of the primary dredging and cap area at the Duwamish/Diagonal EAA, a thin layer of sand (9 inches, to ensure a minimum 6-inch coverage everywhere) was placed over 4 acres of sediment, providing immediate reduction in exposures, and reducing sediment concentrations to below cleanup goals (Figure 7-4) (Anchor 2006). Prior to dredging and capping, the adjacent ENR area had an average total PCB concentration of 46 mg/kg oc. Immediately following cap placement, that average tripled to 136 mg/kg oc. This increase in total PCB concentrations was attributed to resuspension and dispersal of contaminated sediment (i.e., dredging residuals) during the removal action. Within the ENR area, total PCB concentrations immediately

following thin layer placement were well below the SQS (at a mean of 7 µg/kg dw[8]) because of the clean material placed, achieving its goal of immediately reducing PCBs to below predredge surface sediment concentrations. Subsequent years have shown a slight increase in the PCBs concentrations; however, concentrations were not high enough to indicate that underlying sediment with higher concentrations of PCBs was being mixed into the sampled surface layer (0-10 cm) (Stern et al. 2009). The slight increase can be explained by resuspension of the surrounding sediments and by deposition of upstream and lateral load contributions according to the inputs to the area used in the STM. These monitoring data have also shown that the thin sand layer is acting more like a cap and not significantly mixing with the underlying sediment, and this is consistent with measured bioturbation depths (Stern et al. 2009).

A comparison of the 2008 and 2009 total PCB averages of 8 and 5 mg/kg oc, respectively, to the 2003 pre-dredging/capping average of 46 mg/kg oc (almost a six-fold decrease) demonstrates that ENR continues to maintain exposures below SMS values.

Based on diver probing surveys conducted in April 2009, the thickness of the ENR sand layer exhibited a minor decrease from 2006 to 2009. The estimated thickness of the ENR sand layer ranged between 5 and 10 inches at 11 different sampling locations, while 1 to 8 inches of silt were observed to have accumulated on the surface of the ENR layer. When silt and sand are considered together, the average thickness was 12.8 inches (Anchor QEA 2009). These results are consistent with deposition and bioturbation processes as originally anticipated in the ENR area, but also indicate the presence of a stable surface over a period of time. Post-placement bathymetric monitoring was also conducted and nearly all of the Duwamish/Diagonal cleanup area exhibited accretion over the 5-year period following completion of the ENR remedy.

7.1.6.1 ENR Technology Summary

ENR has sufficient merit and demonstration to carry this technology forward in developing LDW remedial alternatives. ENR may be applied to broad areas of the LDW with net sedimentation and where significant erosion is not a concern.

7.1.7 Institutional Controls

Institutional controls are non-engineered measures which may be selected as remedial or response actions either by themselves or in combination with engineered remedies, such as administrative and legal controls that minimize the potential for human exposure to contamination by limiting land or resource use (EPA 2000e). The National Contingency Plan sets forth the expectation that EPA will use institutional controls to supplement engineering controls as appropriate for short- and long-term management to prevent or limit exposure to hazardous substances, pollutants, or contaminants. It

[8] Total organic carbon content in the March 2005 sampling event was too low to calculate oc-normalized data.

states that institutional controls may not be used as a sole remedy unless active measures are determined not to be practicable, based on a balancing of trade-offs among alternatives (40 CFR 300.430 [a][1][iii]).

EPA recommends that where it may provide greater protection, multiple institutional controls should be used in combination in what the Agency calls "layering." Institutional controls may be an important part of the overall cleanup at a site, whenever contamination exists at concentrations that exceed cleanup levels. Institutional controls may be applied during remedy implementation to minimize the potential for human exposure (as temporary land use or exposure limitations). Similarly, they may extend beyond the end of construction and even after RAOs are achieved to ensure the long-term protectiveness of remedial actions (as more long-term or permanent limitations, e.g., protecting a contaminant barrier like a sediment cap from being accidentally breached).

Institutional controls potentially applicable to cleanup of the LDW site are identified and discussed below. It is important to note that, while this section describes specific individual controls in sufficient detail to allow for a comparison of remedial alternatives that include various types and degrees of reliance on institutional controls, an integrated Institutional Controls Implementation Plan is expected to be developed for the LDW that is more sensitive to and meets specific location and local community needs. These considerations are discussed further in the FS as part of the development and evaluation of remedial alternatives (Sections 8 and 9).

EPA guidance broadly lists four types of institutional controls: government controls, proprietary controls, enforcement tools, and informational devices. However, government controls such as the permitting of some (point source but not non-point source) discharges to, or dredging and filling of the LDW, as well as some enforcement controls, such as consent decrees or administrative orders under which settling parties implement remedies including institutional controls, are not discussed in this FS because they do not inform the choices among alternative remedies since they are, for remedy selection purposes, uniform across all alternatives and options. Therefore, the most important institutional controls for the development of remedial alternatives are more fully described below. Enforcement tools are discussed under the category of informational devices. It is important to note that some of these categories overlap (e.g., some proprietary controls have government enforcement mechanisms, and some informational devices can be related to governmental enforcement programs):

- Proprietary controls
- Informational devices
  - Monitoring and notification of waterway users
  - Seafood consumption advisories, public outreach, and education

- Enforcement tools
- Site registry.

These types of institutional controls are explained below.

7.1.7.1 Proprietary Controls

Proprietary controls are recorded rights or restrictions placed in property deeds or other documents transferring property interests that restrict or affect the use of property. Covenants are a grant or transfer contractual rights. Easements are a grant of property rights by an owner, often for a specific purpose (e.g., access, utility, and environmental, among other types of easements). Covenants and easements are essentially legal agreements between parties that allow access or restrict usage of property for a specific objective (i.e., habitat protection, protection of human health, etc.). They can be designed to survive the transfer of properties through real estate transactions. They can, for example, control or prevent owners from conducting or allowing activity that could result in the release or exposure of buried contamination. Potential activities controlled or prohibited may include in-water activities (e.g., anchoring, spudding, vessel or tug maneuvering) and construction activities (e.g., pile driving and pulling, dredging and filling) where buried contamination may become exposed as a result of the activity, as long as it is an activity the owner may legally control.

Traditionally, covenants or easements were only enforceable by whomever they were granted to, and their successors depending on how they are crafted. In the State of Washington, MTCA gave Ecology the right to enforce covenants created under MTCA. More recently, Washington passed its Uniform Environmental Covenants Act (UECA) which allows EPA as well as the state (in addition to the parties to an UECA covenant), to enforce environmental covenants. For this reason, UECA covenants are anticipated to be the primary proprietary control used in environmental cleanup actions selected by EPA.

Parties with sufficient ownership interests in aquatic land could grant UECA covenants that would help ensure that remedial measures (such as sediment caps) are not disturbed. UECA covenants are expected to be favored institutional controls, especially for privately-owned aquatic lands. However, UECA covenants may be not as effective for the publicly-owned, working industrial waterway portions of the LDW where access and use are more difficult to control. Further, limitations on property rights in those portions of the LDW may apply that could preclude use of the full range of controls commonly included in UECA covenants.

7.1.7.2 Informational Devices

Monitoring and Notification of Waterway Users

The cleanup decision document could include an enhanced notification, monitoring, and reporting program for areas of the LDW where contamination exceeding remedial

action levels remains in place following cleanup activities. Under such a program, the protection of areas where capping or CAD containment technology has been utilized could be enhanced. Such areas could be periodically monitored (by vessels and/or surveillance technology), with vessels performing the dual role of educating potential violators of the existence of activity restrictions, and promptly reporting violations of use restrictions to EPA and Ecology. Notification to waterway users could further be provided through enhanced signage and other forms of public notice, education and outreach. A mechanism for the review of any USACE dredging plans and other Joint Aquatic Resource Permit Application (JARPA) construction permitting activity could be established to identify any projects that may compromise containment remedies (cap or CAD), which would include a requirement to promptly notify EPA and Ecology during the permitting phase of any project that could affect containment remedies. This mechanism would serve as a backup to the Memorandum of Agreement between EPA and USACE for coordinating such permitting, especially if that agreement were to lapse or be discontinued for any reason by either agency into the future.

Additional measures could include: establishing a LDW cleanup hotline private citizens could call or email to report potential violations, with a requirement that reports to be investigated and conveyed to EPA and Ecology under specified protocols; and developing and implementing periodic seafood consumption surveys to identify, by population group, which fish species are consumed and in what quantities. This information would be used to update the Institutional Controls Implementation Plan as appropriate and improve seafood consumption advisories and associated public outreach and education. Additional monitoring of the effectiveness of these tools can be used to adapt this approach, as discussed in the next section. The effectiveness of all these measures could be re-evaluated periodically to assess which should be continued or be modified.

Seafood Consumption Advisories, Public Outreach, and Education

The Washington State Department of Health (DOH) publishes seafood consumption advisories in Washington. The DOH currently recommends no consumption of seafood other than salmon from the LDW. The DOH maintains a web site and provides publications and other educational forums that cover healthy eating and seafood consumption. In addition, the seafood consumption advisories are posted on signs at public access locations within the LDW. More information can be found at http://www.doh.wa.gov/ehp/oehas/fish/rma10.htm.

The Washington State Department of Fish and Wildlife (WDFW) develops and enforces seasonal restrictions on fishing and seasonal and daily catch limits for various seafood species per individual. This enhances the effectiveness of seafood consumption advisories. Everyone over 15 years of age must have a fishing license and comply with specific size, species, and seasonal restrictions on fishing for salmon, bottom-fish, clams and crabs throughout the Puget Sound region. These regulations also summarize the DOH seafood consumption advisories; however, they do not prohibit fishing or

shellfishing within the LDW. Thus, although it is not recommended, it is legal to collect and consume certain shellfish and bottom-fish from the LDW at certain times of the year.

Under all remedial alternatives, it is anticipated that some level of seafood consumption advisories will be necessary. Given the diversity of the community that can access the LDW, including tribal members, recreational users, low-income, and non-English-speaking people, additional measures beyond the current advisories may be necessary.

An approach called community-based social marketing has been adopted at the Palos Verdes Superfund site in California to address the limitations of seafood consumption advisories (EPA 2009a, 2009b). This technique, pioneered by Doug McKenzie-Mohr of St. Thomas University in Canada in 1999, as cited in EPA 2009a, can be summarized broadly as:

- Researching to establish and quantify baseline behaviors and size/demography of different populations and to identify culturally-specific barriers and benefits.
- Defining desired behaviors and understanding barriers to achieving those behaviors; definition of incentives for overcoming barriers and achieving behavior change.
- Creating effective messages/incentives and effective delivery and monitoring mechanisms.
- Implementing culturally-appropriate outreach to all target populations using brief, clear, tested messages and incentives.
- Following up on research after a time period to monitor and evaluate levels of behavior change and to modify the approach as needed.

Application of community-based social marketing concepts in the LDW, modeled after the program and experience-base developed for the Palos Verdes site, could improve the effectiveness of existing seafood consumption advisories for protecting human health.

A collaborative advisory group could be convened to develop an LDW-specific framework and technical approach. Likely participants would include EPA, Ecology, DOH, WDFW, and other interested federal, state and local government agencies such as the National Oceanic and Atmospheric Administration, the Seattle Department of Neighborhoods, and ethnically-specific community group leaders, as well as non-governmental environmental organization and settling parties. A key mandate of the advisory group would be the founding of a small, credible, and knowledgeable core team to facilitate the effort (e.g., develop and complete surveys to understand affected

populations [demographics], and potential incentives/barriers to improving the effectiveness of seafood consumption advisories).

The overarching goal of this effort would be to develop and implement a public outreach and education program that focuses on incentives and activities that research indicates have the greatest likelihood of adoption and would make the greatest substantive difference in environmental health. Ideally, the program would be coordinated with other health-based initiatives such as the City of Seattle's urban agriculture initiative.

Implementation of the outreach and education program could be accomplished in a number of ways, stressing culturally-appropriate teams, objective and credible participants, and a systematic approach to applying, documenting, and quantifying results of the approach. The advisory group would institutionalize program elements demonstrated to effect positive behavior change, and make appropriate programmatic changes as needed based on the evolution of monitoring and survey-based information. Example elements of the outreach and education program for enhancing the effectiveness of seafood consumption advisories are:

- Establish a website to provide up-to-date information on seafood tissue data and advisories.
- Increase use of signs containing advisory information at fishing locations.
- Conduct outreach efforts at fishing locations on a regular and periodic basis.
- Ensure all anglers receive seafood consumption advisory information when purchasing licenses.
- Disseminate advisory-related information at community health facilities, schools, and at community-based functions such as health fairs.
- Encourage health professionals to communicate risks to the public.

A significant difference between the Palos Verdes site and the LDW is the presence in the LDW of tribal fishing rights secured by treaties of the United States. Nothing in this section or anywhere in this FS is intended to suggest that exercise of such rights, or the cultural traditions underlying them, would be precluded by fish advisories and related programs to limit contaminated seafood consumption as part of LDW remedial action. For this reason, the seafood advisories, public outreach and education programs should be developed in consultation with affected tribes to develop accommodations for such tribes to the greatest extent practicable.

Enforcement Tools

Restricted Navigation Areas (RNAs) are created by the promulgation of formal rules by the United States Coast Guard. RNAs represent an enforceable means of protecting containment remedies and other areas from anchoring and other physical interference,

particularly where UECA covenants or other proprietary controls may not be achievable, such as within Commercial Waterway District #1.

To the extent that RNAs may potentially interfere with fish harvest activities, engineered or other alternative means of accommodating fish harvest should be devised (e.g., alternative means of allowing anchoring or tying off a net within a RNA-created no-anchor zone).

Although this option has the significant potential to regulate potential impacts associated with anchorage, barge spudding, and tugboat propeller wash, it also may preclude open commercial uses as those activities are generally necessary for construction, maintenance, and operation of commercial piers. Therefore, RNAs may only be useful in specific areas that are not available for maritime commerce now and in the future.

Site Registry

Additional informational devices could apply to areas with containment remedies (cap or CAD) in the LDW. Placement and maintenance of site information on the State Registry (Ecology's Hazardous Sites list and Site Register) would provide information regarding restrictions on the site-related property (RNAs and proprietary controls).

7.1.8 Monitoring

Monitoring is an important control and assessment technology for collecting data and is a requirement of remedial alternatives conducted under CERCLA and MTCA. Monitoring data are collected and used for various purposes pertaining to remedy implementation and evaluation of remedy effectiveness. The sampling and testing process options common to most sediment remediation projects are as follows:

- Sediment quality (e.g., chemistry, grain size distribution)
- Sediment toxicity
- Surface water quality (e.g., conventional parameters and contaminant concentrations)
- Fish and shellfish tissue chemical concentrations
- Physical (e.g., visual inspections, bathymetry).

Typically, these sampling and testing process options are prescribed components of project monitoring plans which, in turn, focus on different aspects of the remedial action. For example, monitoring during the construction phase of a remedial action has different objectives than the long-term monitoring that follows construction. Five different monitoring concepts that form the basis for individual or combined monitoring plans, depending on project-specific circumstances, are described below.

7.1.8.1 Baseline Monitoring

Baseline monitoring establishes a basis for comparing physical and chemical site conditions before and after a cleanup action. Baseline monitoring for the LDW will likely entail the sampling and analysis of sediment, surface water, and tissue samples in accordance with a sampling design that enables a statistical comparison of conditions before, during, and following the cleanup action.

7.1.8.2 Construction Monitoring

Construction monitoring during active remediation is area-specific and short-term and is used to evaluate whether the project is being constructed in accordance with plans and specifications (i.e., performance of contractor, equipment, and environmental controls). This type of monitoring evaluates water quality in the vicinity of the construction operations to determine whether contaminant resuspension and dispersion are adequately controlled.

Further, bathymetric monitoring data establish actual dredge prisms or the placement location and thickness of cap material.

7.1.8.3 Post-construction Performance Monitoring

Post-construction performance monitoring at the conclusion of in-water construction evaluates post-removal sediment conditions in dredging or containment areas. Both chemical and physical data are collected to determine whether the work complies with project specifications.

7.1.8.4 Long-term Operation and Maintenance Monitoring

Long-term operation and maintenance (O&M) monitoring refers to data collection for the purpose of tracking the long-term effectiveness and stability of individual sediment cleanup areas and project-specific disposal sites.

7.1.8.5 Long-term RAO Monitoring

Long-term RAO monitoring evaluates sediment, tissue, and water quality at the site for an extended period following the remedial action to assess achievement of RAOs.

7.1.8.6 Monitoring Summary

Monitoring is an essential element of remedial alternatives developed in this FS. Appendix K set forth key assumptions and an overall framework for monitoring using the process options and monitoring objectives described above. Appendix K also cross references these monitoring terms and concepts with those used in MTCA.

7.2 Ancillary Technologies

7.2.1 Barge Dewatering

Dewatering mechanically dredged sediment on transfer barges prior to additional sediment handling (e.g., off-loading and disposal) is an important interim management

step. Dewatering produces a more consolidated sediment load and reduces the volume of water that would otherwise need to be managed elsewhere (e.g., at a transloading facility or at a landfill). Typically, the dewatering step occurs on a transfer barge within the dredge operations area by gravity settling and separation. The separated water is decanted directly back to the receiving water without further treatment. This confines the release to the area that is already seeing elevated turbidity as a result of dredge operations. Barge dewatering in this manner is typical of sediment remediation projects conducted in the Puget Sound region and it is assumed to be part of the remedial alternatives for costing purposes in this FS.

Examples of Puget Sound region projects that used this technology are provided below. Each was implemented in compliance with project-specific water quality certifications.

Todd Shipyards, Seattle, Washington

A patented (General Construction Company) sloping drain barge was used on this project. The technique involved ballasting one end of the barge with ecology blocks to create a sloping deck surface, which in turn, promotes gravity drainage to the down-slope end of the barge (Figure 7-9). The down-slope end of the barge is equipped with an overflow weir. The separated water was released directly back into the receiving water without further treatment.

Denny Way and East Waterway Phase 1, Seattle, Washington

For these two projects, dredged material was placed on flat-deck barges equipped with fabric-lined scuppers to allow gravity drainage of sediment. Sediment was retained in the barge, while the separated water was decanted directly back into the receiving water through the scuppers without further treatment.

Hylebos Waterway Sediment Remediation, Tacoma, Washington

Dredged material was placed in hopper barges for gravity dewatering. Excess water from the hopper barge was decanted, treated to the water quality standards set for the project, and released back into the waterway. During the initial project phase, water treatment consisted of adding flocculants followed by routing the water through a series of weirs to enable suspended solids removal prior to discharging the water to the water body. During the final phase, a combination of flocculants and mixing tanks were used to treat the water prior to release to the water body.

7.2.2 Wastewater Treatment

Remedial alternatives that involve the removal and upland handling of contaminated sediment invariably generate wastewater that must be managed, treated, and discharged in a manner consistent with ARARs. Wastewater treatment technologies (e.g., for treatment of stormwater or industrial wastewater) are standard, myriad, and ubiquitous in their application to a wide variety of site-specific conditions. Treatment trains using conventional equipment are capable of treating water generated from sediment remediation projects to levels consistent with ARARs.

Section 8 assumes wastewater treatment would be required at a transloading facility to manage water generated within the upland transloading containment area. A representative treatment train is assumed to consist of gravity separation to remove suspended solids, media (e.g., sand) filtration, and adsorption on granular activated carbon (GAC) for removal of dissolved organic compounds. The assumption of a GAC adsorption unit operation is conservative, because treatment to effluent standards for turbidity may be sufficient to reduce solids-associated organic contaminants to acceptable concentrations. No specific treatment for dissolved metals is assumed, but such treatment is feasible, if warranted. Discharge of treated water, similar to the soil-washing water treatment discharge (Section 7.1.2.1), would likely be directly back to the LDW after treatment, and would be governed by an EPA CWA 401 water quality certification.

Discharge to the King County Metro sewer system could also be considered where the discharge meets flow and chemical parameter limits. This approach would be an off-site disposal action, potentially requiring pretreatment to achieve discharge criteria and comply with all permit requirements (e.g., daily discharge volume etc.).

7.2.3 Best Management Practices

Implementation of best management practices (BMPs) is widely considered essential to sediment cleanup projects (NRC 2007). BMPs are particularly important for environmental dredging to minimize release to the environment of contaminated material (sediment, water, debris) from the dredging footprint, and during barge transport, off-loading, and upland rehandling.

Environmental dredging to remove COCs also causes some residual sediment contamination (Palermo 2008). Contaminated sediments that are dislodged or suspended by the dredging operation are subsequently redeposited on the bottom either within or adjacent to the dredging footprint. The primary causes for this residual contamination are described in Section 7.1.1.2.

Resuspended residuals generally accumulate (settle) above the dredging cutline in thin layers, and are characterized by fine-grained sediment, being unconsolidated, having a high moisture content, and possibly existing as a fluid mud layer. The constituent COC concentrations in the residual layer can be approximated by the average dredge prism concentration (Hayes and Patmont 2004). The residual layer can be present within and adjacent to the dredge prism.

Potential BMPs to evaluate during design for dredging residuals and water quality management include:

- Minimize residuals generation by dredge control and design, such as carefully controlling depth, location, and cutting action to maximize sediment capture and minimize sloughing and bottom impacts.

Optimize the fill efficiency of a dredge bucket to minimize both free-water capture and overfill fallback.

- Control speed of bucket through the water column to minimize loss of adhered sediment.
- Allow sediment-filled bucket to drain before fully emerging above the water surface.
- Contain drippage during the overwater swing of a filled bucket (e.g., by placing an empty barge or apron under the swing path during offloading).
- Wash bucket prior to lowering back into the water column.
- Use environmental or sealed bucket if practicable and if proper sediment conditions exist.
- Start dredging in upslope areas and move downslope to minimize sloughing.
- Plan multiple dredge cuts: limit initial cut depths to avoid sloughing of the cut bank; plan initial cut(s) to remove most of the contamination; and design a final "cleanup" cut into subsurface "clean" sediment to lower the average dredge prism COC concentrations.
- Use floating and/or absorbent booms to capture floating debris or oil sheens.
- Use conventional construction stormwater BMPs to control and reduce the silt burden in runoff from barges or rehandling areas.
- Develop and implement a post-dredging residuals monitoring and management plan.
- Monitor natural recovery of dredged area.
- Place a thin-layer sand cover (ENR) to cover residuals.

The use of silt curtains around the dredging operations to reduce the transport of suspended solids is an engineering control that can be employed under certain circumstances. However, the effectiveness of a silt curtain is primarily determined by the hydrodynamic conditions at the site (usually relatively shallow, quiescent water, without significant tidal fluctuations are preferred), the quantity and type of suspended solids, the mooring method, and the characteristics of the barrier. Often, strong currents (greater than 2.5 ft/sec) are problematic, and any application and deployment of silt curtains for high velocities would require special design and engineering features

(USACE 2008a). In the Puget Sound region, silt curtains are not frequently used in areas where there are large tidal excursions, high-flow velocities, conflicts between dredging activities and navigation, or other technical limitations.

The specific array of BMPs or engineering controls implemented during cleanup will be location-specific and will be determined during design of the remedial alternative. Often, the remedial design specifications define certain BMPs along with performance requirements (such as water quality standards) to which the contractor must adhere. The contractor typically is required to provide additional details on specific BMPs in their work plans. Monitoring and adaptive management are common practices that will be used to refine and optimize BMPs throughout the duration of the project to ensure compliance with the project performance requirements. Representative BMPs have been identified as part of the FS remedial alternatives to develop cost estimates.

7.3 Summary of Representative Process Options for the FS

The shaded rows of Table 7-4 show the representative technology process options carried forward to Section 8 for potential development and evaluation of remedial alternatives. Consistent with CERCLA guidance, alternate process options may be considered during remedial design.

The suite of technologies and institutional controls is consistent with most of the sediment feasibility studies and cleanup projects conducted to date within the Puget Sound region and around the country. Further, it is consistent with recent deliberations and reports that have emerged from the sediment remediation community nationwide (NRC 2007). These reports conclude that a limited number of engineering approaches are available to address sediment cleanup and that some combination of dredging, disposal, capping, ENR, and MNR will invariably be at the core of almost every future major project.

Table 7-1 Initial Screening of Candidate Remedial Technologies

GRA	Technology Type	Process Option	Description
No action	None	Not applicable	No active remedy or monitoring.
Institutional controls	Proprietary controls and informational devices (EPA 2000)	Proprietary controls	Contractual mechanisms contained in a property deed or other document transferring property that restrict or affect the use of property
		Seafood Consumption Advisories, Education and Public Outreach	Public advisories to indicate that consumption of fish and shellfish and sediment contact in the LDW may present a health risk.
		Monitoring and notification of waterway users	Regulatory constraints on uses such as vessel wakes, anchoring, and dredging. Physical constraints, such as fencing and signs, placed on property access points that limit human access to areas that pose a health risk.
		Enforcement Tools	Signed order with agencies with details regarding implementation of institutional controls and monitoring
		Site Registry	Placement and maintenance of site information on the State Registry (Ecology's Hazardous Sites list and Site Register) would provide informational tools regarding restrictions on the property.
Monitoring	Physical and chemical assessment	Baseline Monitoring	Establishes a statistical basis for comparing site conditions before and after the cleanup action.
		Construction Monitoring	Short-term monitoring during remediation used to evaluate whether the project is being constructed in accordance with specifications (i.e., water quality monitoring, bathymetric surveys, discharge monitoring, inspection surveys, sediment monitoring)
		Post-construction Performance Monitoring	Post-construction performance monitoring evaluates post-removal surface and subsurface sediment conditions in dredging or containment areas to confirm compliance with project specifications.
		Long-term Operation and Maintenance Monitoring	Long-term operation and maintenance monitoring of dredging areas, containment and/or disposal sites (i.e., CAD sites, ENR and capping areas) required to ensure long-term effectiveness and continued stability of the structure.
		Long-term RAO Monitoring	Long-term RAO monitoring evaluates sediment, tissue and water quality at the site for an extended period following the remedial action.
Monitored natural recovery	Chemical/physical transport and degradation	Combination	Desorption, dispersion, diffusion, dilution, volatilization, resuspension, and transport.
	Biological degradation	COC metabolism	Chlorine atoms are removed from PCB molecules by bacteria; however, toxicity reduction is not directly correlated to the degree of dechlorination. PAHs may be partially or completely degraded.
	Physical-burial processes	Sedimentation	Contaminated sediments are buried (by naturally occurring sediment deposition) to deeper intervals that are less biologically available. (Resuspension and transport are minor components of MNR.)
Enhanced natural recovery	Thin-layer placement	Placement of thin layer to augment natural recovery	Application of a thin layer of clean sand and natural resorting, sedimentation, or bioturbation to mix the contaminated and clean sediments, resulting in acceptable chemical concentrations.
Containment	Capping	Conventional sand cap	Placement of clean sand over existing contaminated bottom to physically isolate contaminants.
		Conventional sediment / clay cap	Use of dredged fine-grained sediments or commercially obtained clay materials to achieve contaminant isolation.
		Armored cap	Coarse granular material such as: cobbles, pebbles, or larger material are incorporated into the cap to prevent erosion in high-energy environments or to prevent cap breaching by bioturbators (example: membrane gabions).
		Composite cap	Soil, media, and geotextile cap placed over contaminated material to inhibit migration of contaminated pore water and/or inhibit bioturbators.
		Spray cap	Placement of capping materials (usually concrete) by spraying concrete or mortar from a nozzle at high velocity onto a surface via pressure hoses with either a dry or wet mix process.
		Reactive cap	Incorporation of materials such as granular activated carbon or iron filings to provide chemical binding or destruction of contaminants migrating in porewater.
Removal	Dredging	Hydraulic dredging	Hydraulic dredges use a cutter head, and suction provided by an on-board pump(s) to agitate, entrain, and hydraulically transport sediment via pipeline to a land-based sediment handling facility or slurry discharge location.
		Mechanical dredging	A barge-mounted floating crane on a derrick barge maneuvers a dredging bucket. The bucket is lowered into the sediment; when the bucket is withdrawn, the jaws of the bucket are closed, retaining the dredged material.
		Mechanical dredging (excavator)*	Excavator dredges use a barge-mounted excavator with fixed arm linkages (boom and stick), instead of cables, to position the clamshell bucket at the target elevation for sediment removal.
	Excavating	Dry excavation	Sediment is removed by upland-based conventional excavation (backhoe) equipment. Removal during low tides may not require sheet-pile walls or cofferdams. This removal option may include erecting sheet-pile walls or a cofferdam around the contaminated sediments to dewater.
In Situ treatment	Biological*	*In situ* slurry biodegradation*	Anaerobic, aerobic, or sequential anaerobic/aerobic degradation of organic compounds with indigenous or exogenous microorganisms. Oxygen, nutrients, and pH are controlled to enhance degradation. Requires sheet piling around entire area and slurry treatment performed using aerators and possibly mixers.
		In situ aerobic biodegradation*	Aerobic degradation of sediment *in situ* with the injection of aerobic biphenyl enrichments or other co-metabolites. Oxygen, nutrients, and pH are controlled to enhance degradation.
		In situ anaerobic biodegradation*	Anaerobic degradation *in situ* with the injection of a methanogenic culture, anaerobic mineral medium, and routine supplements of glucose to maintain methanogenic activity. Nutrients and pH are controlled to enhance degradation.
		Imbiber Beads™*	A "cover blanket" of Imbiber Beads™ placed over contaminated sediments to enhance anaerobic microbial degradation processes and allow exchange of gases between sediments and surface water. The beads are spherical plastic particles that would adsorb PCB vapors generated.
	Chemical*	Aqua MecTool™ oxidation*	A caisson (18' by 18') is driven into the sediment and a rotary blade is used to mix sediment and add oxidizing agents such as ozone, peroxide, or Fenton's reagent. A bladder is placed in the caisson to reduce TSS and the vapors may be collected at the surface and treated.
		In situ oxidation*	Oxidation of organics using oxidizing agents such as ozone, peroxide, or Fenton's reagent.

Table 7-1 Initial Screening of Candidate Remedial Technologies

GRA	Technology Type	Process Option	Description
In Situ treatment (cont)		Electro-chemical oxidation*	Proprietary technology in which an array of single steel piles is installed and low current is applied to stimulate oxidation of organics.
	Physical-extractive processes*	Sediment flushing*	Water or other aqueous solution is circulated through contaminated sediment. An injection or infiltration process introduces the solution to the contaminated area and the solution is later extracted along with dissolved contaminants. Extraction fluid must be treated and is often recycled.
		In situ slurry oxidation*	An array of injection wells is used to introduce oxidizing agents such as ozone to degrade organics.
	Physical-immobilization*	Aqua MecTool™ stabilization*	A caisson (18' by 18') is driven into the sediment and a rotary blade is used to mix sediment and add stabilizing agents. A bladder is placed in the caisson to reduce TSS and the vapors may be collected at the surface and treated.
		Vitrification*	Uses an electric current *in situ* to melt sediment or other earthen materials at extremely high temperatures (2900-3650 °F). Inorganic compounds are incorporated into the vitrified glass and crystalline mass and organic pollutants are destroyed by pyrolysis. *In situ* applications use graphite electrodes to heat sediment.
		Ground freezing*	An array of pipes is placed *in situ* and brine at a temperature of -20 to -40°C is circulated to freeze soil. Recommended only for short duration applications and to assist with excavation.
Ex Situ treatment	Biological*	Landfarming/ Composting*	Sediment is mixed with amendments and placed on a treatment area that typically includes leachate collection. The soil and amendments are mixed using conventional tilling equipment or other means to provide aeration. Moisture, heat, nutrients, oxygen, and pH can be controlled to enhance biodegradation. Other organic amendments such as wood chips, potato waste, or alfalfa are added to composting systems.
		Biopiles*	Excavated sediments are mixed with amendments and placed in aboveground enclosures. This is an aerated static pile composting process in which compost is formed into piles and aerated with blowers or vacuum pumps. Moisture, heat, nutrients, oxygen, and pH can be controlled to enhance biodegradation.
		Fungal biodegradation*	Fungal biodegradation refers to the degradation of a wide variety of organopollutants by using fungal lignin-degrading or wood-rotting enzyme systems (example: white rot fungus).
		Slurry-phase biological treatment*	An aqueous slurry is created by combining sediment with water and other additives. The slurry is mixed to keep solids suspended and microorganisms in contact with the contaminants. Upon completion of the process, the slurry is dewatered and the treated sediment is removed for disposal (example: sequential anaerobic/aerobic slurry-phase bioreactors).
		Enhanced biodegradation*	Addition of nutrients (oxygen, minerals, etc.) to the sediment to improve the rate of natural biodegradation. Use of heat to break carbon-halogen bonds and to volatilize light organic compounds (example: D-Plus [Sinre/DRAT]).
	Chemical*	Acid extraction*	Contaminated sediment and acid extractant are mixed in an extractor, dissolving the contaminants. The extracted solution is then placed in a separator, where the contaminants and extractant are separated for treatment and further use.
		Solvent extraction(s)*	Contaminated sediment and solvent extractant are mixed in an extractor, dissolving the contaminants. The extracted solution is then placed in a separator, where the contaminants and extractant are separated for treatment and further use (example: B.E.S.T.™ and propane extraction process).
	Chemical/ Physical	Reduction/ Oxidation*	Reduction/oxidation chemically converts hazardous contaminants to nonhazardous or less toxic compounds that are more stable, less mobile, and/or inert. The oxidizing agents most commonly used are hypochlorites, chlorine, and chlorine dioxide.
		Slurry oxidation*	The same as slurry-phase biological treatment with the exception that oxidizing agents are added to decompose organics. Oxidizing agents may include ozone, hydrogen peroxide, and Fenton's reagent.
		Dehalogenation*	Dehalogenation process in which sediment is screened, processed with a crusher and pug mill, and mixed with sodium bicarbonate (base catalyzed decomposition) or potassium polyethylene glycol. The mixture is heated to above 630 °F in a rotary reactor to decompose and volatilize contaminants. Process produces biphenyls, olefins, and sodium chloride.
		Soil washing	Contaminants sorbed onto fine soil particles are separated from bulk soil in an aqueous-based system on the basis of particle size. The wash water may be augmented with a basic leaching agent, surfactant, pH adjustment, or chelating agent to help remove organics and heavy metals.
		Radiolytic dechlorination*	Sediment is placed in alkaline isopropanol solution and gamma irradiated. Products of this dechlorination process are biphenyl, acetone, and inorganic chloride. Process must be carried out under inert atmosphere.
	Physical	Particle Separation	Contaminated fractions of solids are concentrated through gravity, magnetic, or sieving separation processes.
		Solar detoxification*	Through photochemical and thermal reactions, the ultraviolet energy in sunlight destroys contaminants.
		Solidification	The mobility of constituents in a "solid" medium is reduced through addition of immobilization additives.
	Thermal	Incineration*	Temperatures greater than 1400°F are used to volatilize and combust organic chemicals. Commercial incinerator designs are rotary kilns equipped with an afterburner, a quench, and an air pollution control system.
		High Temperature Thermal Desorption*	Temperatures in the range of 600-1200°F are used to volatilize organic chemicals. These thermal units are typically equipped with an afterburner and baghouse for destruction of air emissions.
		Low Temperature Thermal Desorption*	Temperatures in the range of 200-600°F are used to volatilize and combust organic chemicals. These thermal units are typically equipped with an afterburner and baghouse for treatment of air emissions.
		Pyrolysis*	Chemical decomposition is induced in organic materials by heat in the absence of oxygen. Organic materials are transformed into gaseous components and a solid residue (coke) containing fixed carbon and ash.
		Thermal desorption*	Wastes are heated to volatilize water and organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system (examples: X*TRAX™, DAVES, Tacuik Process, and Holoflite™ Dryer).
		Vitrification*	Current technology uses oxy-fuels to melt soil or sediment materials at extremely high temperatures (2900-3650°F).
		High-pressure oxidation*	High temperature and pressure are used to break down organic compounds. Operating temperatures range from 150-600°C and pressures range from 2,000-22,300 MPa (examples: wet air oxidation and supercritical water oxidation).

Table 7-1 Initial Screening of Candidate Remedial Technologies

GRA	Technology Type	Process Option	Description
Disposal	On-site disposal	Level-bottom cap*	Relocation of contaminated sediment to discrete area and capping with a layer of clean sediments. Provides similar protection as capping, but requires substantially more sediment handling that may cause increased releases to surface water.
		Contained Aquatic Disposal (CAD)	Untreated sediment is placed within a lateral containment structure (i.e., bottom depression or subaqueous berm) and capped with clean sediment.
		Confined Disposal Facility (CDF)	Untreated sediment is placed in a nearshore CDF that is separated from the river by an earthen berm or other physical barrier and capped to prevent contact. A CDF may be designed for habitat purposes.
	Off-site Disposal	Subtitle D landfill	Off-site disposal at a licensed commercial facility that can accept nonhazardous sediment. Regional landfills can accept both dewatered and wet sediments.
		Subtitle C landfill	Off-site disposal at a licensed commercial facility that can accept hazardous dewatered sediment removed from dredging or excavation. Dewatering required to reduce water content for transportation.
		TSCA-licensed landfill*	Off-site disposal at a licensed commercial facility that can accept TSCA sediment. Dewatering required to reduce water content for transportation.
		DMMP open-water non-treated (if acceptable) disposal	Treated or separated sediment is placed at the Elliott Bay DMMP disposal site. Requires that the placed sediment be at, or below, DMMP disposal criteria for priority pollutants and potentially bioaccumulative chemicals.
		Upland MTCA confined fill (commercial/industrial – beneficial use)*	Treated or untreated sediment is placed at an off-site location. Requires that sediment be at, or treated to, MTCA cleanup levels at an off-site location and meet nondegradation standards. Location may require cap or other containment devices based on analytical data.
		Upland MTCA fill (residential/clean – beneficial use)*	Treated or untreated sediment is placed at an off-site location. Requires that sediment be at, or treated to, a concentration at or below MTCA cleanup levels for unrestricted land use and meet nondegradation standards.
		In-water beneficial use	Sediments treated to below DMMP guidelines may be beneficially reused for habitat creation, capping, or residual management.

Notes:

Shaded technologies and process options are retained as potentially feasible and carried forward to Table 7-2 series, where more detailed screening information is provided. These process options were retained in the detailed screening and are evaluated in Table 7-3 for applicability in the LDW.

*A detailed description of these process options is not included in the FS text. Details regarding these technology and process options are provided in the document *Identification of Candidate Cleanup Technologies for the Lower Duwamish Waterway* prepared by The RETEC Group Inc. (2005). These process options were eliminated in the detailed screening process shown in Table 7-2 series.

CAD = contained aquatic disposal; CDF = confined disposal facility; COC = chemical of concern; DMMP = Dredged Material Management Program; ENR = enhanced natural recovery; GRA = general response action; MTCA = Model Toxics Control Act; PAHA = polycyclic aromatic hydrocarbon; PCB = polychlorinated biphenyls; TSCA = Toxic Substances Control Act; TSS = total suspended solids

Table 7-2a Detailed Screening of Process Options: No Action, Institutional Controls, and Monitoring

GRA	Technology Type	Process Option	Effectiveness		Implementability			Screening Decision	Cost
			LDW COCs	Screening Decision	Site Conditions	Available and Demonstrated	Innovative Technology		
No Action	None	Not Applicable	—	Retained per NCP requirement	Technically implementable for conditions within the LDW.	—	—	Retained per NCP requirement	Low
Institutional Controls	Proprietary controls, and informational devices	Proprietary Controls	Can be effective for LDW COCs. Limited effectiveness if used as sole remedy, but effective when used in conjunction with active remedies.	Retained for further evaluation	Not implementable for the entire LDW. Active federally-authorized navigation channel and industrial uses limit applicability. Can be technically implemented for limited and specific portions.	Available and demonstrated, but industrial waterway uses and tribal fishing rights may preclude some applications.	—	Retained for further evaluation in the FS	Low
		Seafood Consumption Advisories, Education and Public Outreach	Effective for LDW COCs accumulated in fish or shellfish. Not effective for ecological receptors.	Retained for further evaluation	Technically implementable for conditions on the LDW. Requires commitment and cooperation of implementing agencies and Native Americans with treaty fishing rights.	Available and demonstrated, but must not preclude tribal treaty fishing rights.		Retained for further evaluation in the FS	Low
		Monitoring and Notification of Waterway Users	Can be effective for LDW COCs. Limited effectiveness if used as sole remedy, but effective when used in conjunction with active remedies	Retained for further evaluation	Not implementable for the entire LDW. Active federally-authorized navigation channel and industrial uses limit applicability. Can be technically implemented for limited and specific portions.	Available and demonstrated, but industrial waterway uses and tribal fishing rights may preclude some applications.	—	Retained for further evaluation in the FS	Low
		Enforcement Tools	Can be effective for LDW COCs.	Retained for further evaluation	Not implementable for the entire LDW. Active federally-authorized navigation channel and industrial uses limit applicability. Can be technically implemented for limited and specific portions.	Available and demonstrated.	—	Retained for further evaluation in the FS	Low
		Site Registry	Can be effective for LDW COCs. Limited effectiveness if used as sole remedy, but effective when used	Retained for further evaluation	Not implementable for the entire LDW. Active federally-authorized navigation channel and industrial uses limit applicability. Can be technically implemented for	Available and demonstrated, but industrial waterway uses and tribal fishing rights may preclude some applications.	—	Retained for further evaluation in the FS	Low

Table 7-2a Detailed Screening of Process Options: No Action, Institutional Controls, and Monitoring

GRA	Technology Type	Process Option	Effectiveness		Implementability			Screening Decision	Cost
			LDW COCs	Screening Decision	Site Conditions	Available and Demonstrated	Innovative Technology		
			in conjunction with active remedies.		limited and specific portions.				
Monitoring	Physical and Chemical Assessment	Baseline Monitoring	Can be effective for evaluating changes.	Retained for further evaluation	Technically implementable for conditions in the LDW.	Available and demonstrated	—	Retained for further evaluation in the FS	Moderate
		Construction Monitoring	Can be effective for evaluating changes.	Retained for further evaluation	Technically implementable for conditions in the LDW.	Available and demonstrated	—	Retained for further evaluation in the FS	Low
		Post-construction Performance Monitoring	Can be effective for evaluating changes	Retained for further evaluation	Technically implementable for conditions in the LDW.	Available and demonstrated	—	Retained for further evaluation in the FS	Low
		Long-term Operation and Maintenance Monitoring	Can be effective for evaluation and maintenance of LDW following remedial actions	Retained for further evaluation	Technically implementable for conditions in the LDW.	Available and demonstrated	—	Retained for further evaluation in the FS	Moderate
		Long-term RAO Monitoring	Can be effective for evaluating sediment, tissue and water quality over an extended period of time following remedial actions	Retained for further evaluation	Technically implementable for conditions in the LDW.	Available and demonstrated	—	Retained for further evaluation in the FS	Moderate to High

Note:

COC = chemical of concern; CTM = Candidate Technologies Memo; FS = feasibility study; GRA = general response action; NCP = National Contingency Plan

Table 7-be Detailed Screening of Process Options: Monitored Natural Recovery and Enhanced Natural Recovery

GRA	Technology Type	Process Option	Effectiveness Screening		Implementability				Cost
			LDW COCs	Screening Decision	Site Conditions	Available and Demonstrated	Innovative Technology	Screening Decision	
Monitored Natural Recovery	Chemical Degradation	Natural Désorption, Diffusion, Dilution, Volatilisation	Potentially effective for immobilizing COCs through TOC or sulfide sorption.	Retained for further evaluation	Technically implementable for conditions within the LDW	—	—	Retained for further evaluation in the FS	Moderate
Monitored Natural Recovery	Biological Degradation	COC Metabolism (aerobic and anaerobic)	Effective for SVOCs and PAHs but does not result in complete destruction of PCBs or TBT in acceptable time frame. Not applicable to metals.	Retained for further evaluation	Technically implementable for conditions within the LDW	—	—	Retained for further evaluation in the FS for SVOCs only	Moderate
Monitored Natural Recovery	Physical/Burial Processes	Natural Sedimentation and Burial (resuspension and transport are minor components of MNR)	Potentially effective for LDW COCs via deposition and reburial. Requires demonstration of long-term deposition and burial.	Retained for further evaluation	Technically implementable for conditions within the LDW	Preliminary results at some projects show some success.	—	Retained for further evaluation in the FS	Moderate
Enhanced Natural Recovery	Thin-layer Placement	Thin-layer Placement	Effective for all LDW COCs. Applicable: 1) at areas where MNR processes are demonstrated, but faster recovery is required; or 2) as a residual management tool after completion of a removal action.	Retained for further evaluation	Technically implementable for conditions within the LDW	Thin-layer placements for ENR and residuals management have been applied in multiple locations in Puget Sound and nationally.	—	Retained for further evaluation in the FS	Moderate

Note:

CTM = Candidate Technologies Memorandum; COC = chemical of concern; ENR = enhanced natural recovery; FS = feasibility study; GRA = general response action; MNR = monitored natural recovery; PAHA = polycyclic aromatic hydrocarbon; PCB = polychlorinated biphenyls; SVOC = semivolatile organic carbon; TOC = total organic carbon; TBT = tributyltin

Table 7-2c Detailed Screening of Process Options: Containment Process Options

GRA	Technology Type	Process Option	Effectiveness		Implementability				Cost
			LDW COCs	Screening Decision	Site Conditions	Available and Demonstrated	Innovative Technology	Screening Decision	
Containment	Capping	Conventional Sand Cap	Effective for contaminants with low solubility and high sorption where the main concern is resuspension and direct contact. Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants.	Retained for consideration throughout the LDW	Applicable to LDW conditions. Easily applied *in situ;* however, scouring must be considered. Decreased water depth may limit future uses of waterway and may impact flooding, stream bank erosion, navigation, and recreation.	Conventional sand caps have been applied in multiple locations in Puget Sound and nationally.	—	Retained for consideration in the FS for all areas of the LDW.	Low
		Conventional Sediment/Clay Cap	Effective for contaminants with low solubility and high sorption where the main concern is resuspension and direct contact. Sediment with silt and clay is effective in limiting diffusion of contaminants. Sediment caps are generally more effective than sand caps for containment of contaminants with high solubility and low sorption	Retained for consideration throughout the LDW	Generally applicable to LDW conditions. Placement of clay caps is considered in shallow water depth areas where minimal cap thickness is required. Special engineering controls will be needed to place clay cap in the LDW.	Conventional sediment caps using river-dredged sediments have been applied in multiple locations in Puget Sound and nationally. Application of clay caps is relatively new, but demonstrated.	—	Retained for consideration in the FS for all areas of the LDW.	Low
		Armored Cap	Applicable to LDW COCs. Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants.	Retained for limited use in high-energy sections of the LDW	Applicable to areas of LDW where increased velocities from river flow, or potential scouring associated with propeller wash might be expected. Decreased water depth may limit future uses of waterway and may impact flooding, stream bank erosion, navigation, and recreation. Limited use in intertidal areas that support clamming and recreational activities.	Armored caps have been implemented at several sites in Puget Sound and nationally.	—	Retained for limited use in the FS for high-energy sections of the LDW.	Low to Moderate
		Composite Cap (geotextile, HDPE)	Effective for LDW COCs. Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants. Can be used: 1) to limit cap thickness, 2) for low solids underlying sediments where additional floor-support is required, 3) as a bioturbation barrier, or 4) as a barrier for areas where methane generation may be an issue.	Retained for consideration throughout the LDW	Applicable to LDW site conditions. Application must consider that decreased water depth may limit future uses of waterway and impact flooding, stream bank erosion, navigation, and recreation. Limited use in intertidal areas that support clamming and recreational activities.	Application of composite capping is relatively new, but commercially demonstrated for projects with similar size and scope.	—	Retained for consideration in the FS for all areas of the LDW.	Low to Moderate
		Spray Cap	Confines COCs by encapsulating with shotcrete (usually concrete) placed over underlying surface.	Retained for consideration throughout the LDW	Applicable to hard to access areas under piers and wharves. Shotcrete cap reduces the habitat value of the intertidal sediment bed.	Shotcrete was used at the Todd Shipyards effectively encapsulating existing debris (slag) mounds under dock structures from the aquatic environment.	Demonstrated effective at recent Puget Sound region remediation project.	Retained for consideration in the FS for application to hard to access under piers or wharves structures.	Low to Moderate
		Reactive Cap	Effective for LDW COCs. Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants.	Retained	Reactive caps may be applicable to site conditions on the LDW. Limited use in intertidal areas that support clamming and recreational activities.	Addition of materials to increase sorptive capacity of cap has been implemented in Puget Sound. Long-term effectiveness data may be available during the LDW FS.	Reactive capping is an innovative technology that is in the demonstration phase on the Anacostia River. Results of those tests are expected during the LDW FS.	Retained for consideration in the FS as an innovative technology.	Low to Moderate

Notes:
COC = chemical of concern; FS = feasibility study; GRA = general response action; HDPE = High-density polyethylene

Table 7-2d Detailed Screening of Process Options: Removal Process Options

GRA	Technology Type	Process Option	Effectiveness		Implementability				Cost
			LDW COCs	Screening Decision	Site Conditions	Available and Demonstrated	Innovative Technology	Screening Decision	
Removal	Dredging	Hydraulic Dredging	Applicable to all LDW COCs	Retained for consideration throughout the LDW	Generally applicable to LDW in-water site conditions. Best suited to low density, high water solids with little debris. Requires nearshore dewatering facilities and right-of-way for slurry pipeline. Water treatment and disposal required.	Hydraulic environmental dredging is available and demonstrated in similar size projects, but is less frequently used for projects in Puget Sound.	—	Retained for consideration in the FS for all areas of the LDW.	Moderate
		Mechanical Dredging	Applicable to all LDW COCs	Retained for consideration throughout the LDW	Generally applicable to LDW in-water site conditions. Better suited for higher density, low water solids, and more effective at handling debris. Environmental buckets suitable for softer materials with low debris; clamshell buckets suitable for harder, dense sediments.	Mechanical environmental dredging is available and demonstrated in similar size projects, and is commonly employed for projects in Puget Sound.	—	Retained for consideration in the FS for all areas of the LDW.	Moderate
		Mechanical Dredging (Excavator)	Applicable to all LDW COCs	Retained for consideration throughout the LDW	Generally applicable to LDW in-water site conditions. Better suited for higher density, low water solids, and more effective at handling debris. Environmental excavators are suited for all materials (soft and dense), better able to handle debris, but may be depth limited.	In-water excavators are available and demonstrated in similar size projects, including projects in Puget Sound.	—	Retained for consideration in the FS for all areas of the LDW.	Moderate
	Dry Excavation	On-land or Intertidal excavator, backhoes, specialty equipment	Applicable to all LDW COCs. Effective for nearshore and/or intertidal areas where depths limit conventional dredging equipment	Retained for further consideration for intertidal or nearshore areas in the LDW	Limited in application to nearshore shallow and/or intertidal areas that can be reached from shore or by specialty equipment designed to work on soft unconsolidated sediments.	Equipment is commercially available and has been applied on projects of similar scope in Puget Sound.	—	Retained for consideration in the FS for shallow and/or intertidal areas of the LDW.	Moderate

Note:
COC = chemical of concern; FS = feasibility study; GRA = general response action

Table 7-2e Detailed Screening of Process Options: Treatment Process Options

GRA	Technology Type	Process Option	Effectiveness		Final Screening				Cost[1]
			LDW COCs	Screening Decision	Site Conditions	Available and Demonstrated	Innovative Technology	Screening Decision	
In Situ Treatment	Biological	*In Situ* Slurry Biodegradation	Biodegradation has not been demonstrated to effectively remediate metals, PCBs, or TBT within a reasonable time frame.	Eliminated	—	—	—	—	—
		In Situ Aerobic Biodegradation	Biodegradation has not been demonstrated to effectively remediate metals, PCBs, or TBT within a reasonable time frame.	Eliminated	—	—	—	—	—
		In Situ Anaerobic Biodegradation	Biodegradation has not been demonstrated to effectively remediate metals, PCBs, or TBT within a reasonable time frame.	Eliminated	—	—	—	—	—
		Imbiber Beads™	Potentially applicable to PCBs and SVOCs, not metals. No data on effectiveness with TBT. Not demonstrated for remediation of sediments. Removal and disposal of the blanket is not demonstrated.	Eliminated	—	—	—	—	—
	Chemical	Aqua MecTool™ Oxidation	Technology is effective for PCBs, SVOCs in soils. Process should be effective for TBT, but not metals.	Retained for further consideration	Could be applicable to conditions in LDW. Requires treating sediments in place using caisson and proprietary injectors.	Not demonstrated in pilot- or full-scale sediment projects. Technical difficulties in field trials injecting high air flows into caisson with standing water while preventing generation of TSS.	Not considered innovative or available during LDW FS.	Eliminated	—
		In Situ Oxidation	Has not been demonstrated to be effective for LDW COCs in sediments.	Eliminated	—	—	—	—	—
		Electro-chemical Oxidation	Applicability for use in water is not known. No demonstrated sediment application.	Eliminated	—	—	—	—	—
	Physical-Extractive Processes	Sediment Flushing	Bench scale effectiveness for all LDW COCs.	Retained for further consideration	Potentially applicable to LDW. Requires in-water steel piling around treatment area and extensive water quality monitoring outside piles.	No known pilot or full-scale applications.	Not considered innovative or available during LDW FS.	Eliminated	—
		In Situ Slurry Oxidation	Not demonstrated in full-scale applications effective for LDW COCs. Requires in-water steel piling around treatment area and extensive water quality monitoring outside piles.	Eliminated	—	—	—	—	—
	Physical-Immobilization	Aqua MecTool™ Stabilization	Proprietary technology that has been effective in stabilizing metals, PCBs and SVOCs in soil. No data available on TBT, but physical process likely to be effective on butyltins.	Retained for further consideration	Could be applicable to conditions in LDW. Requires treating sediments in place using caisson and proprietary injectors.	Proprietary technology that was tested in a pilot-scale application in Wisconsin with coal tar-contaminated sediments, and found to be not implementable. Previous trials with this technology created water treatment problems inside the caisson.	Not considered innovative or available during LDW FS.	Eliminated	—
		Vitrification	Effective at stabilizing COCs in soil applications, but requires less than 60% water content. Remaining sediment surface may not provide suitable habitat. No known sediment applications.	Eliminated	—	—	—	—	—
		Ground Freezing	Not permanently effective for LDW COCs. Long-term effectiveness in presence of standing water has not been demonstrated. Standing water likely provides a significant sink for cold temperatures and would substantially increase cost.	Eliminated	—	—	—	—	—

Table 7-2e Detailed Screening of Process Options: Treatment Process Options

GRA	Technology Type	Process Option	Effectiveness		Final Screening				Cost[1]
			LDW COCs	Screening Decision	Site Conditions	Available and Demonstrated	Innovative Technology	Screening Decision	
Ex Situ Treatment	Biological	Landfarming/ Composting	Not effective for metals, PCBs, dioxin or TBT. PAHs and some SVOCs are amenable to aerobic degradation.	Eliminated	—	—	—	—	—
		Biopiles	Not effective for metals, PCBs, dioxin or TBT. Used for reducing concentrations of petroleum constituents in soils. Applied to treatment of nonhalogenated VOCs and fuel hydrocarbons. Requires large upland area.	Eliminated	—	—	—	—	—
		Fungal Biodegradation	Not effective for metals, PCBs, dioxins or TBT. No known full-scale applications. High concentrations of contaminants may inhibit growth. The technology has been tested only at bench scale.	Eliminated	—	—	—	—	—
		Slurry-phase Biological Treatment	Not effective for metals, PCBs, dioxin or TBT. PAHs and some SVOCs are amenable to aerobic degradation. Large volume of tankage required. No known full-scale applications.	Eliminated	—	—	—	—	—
		Enhanced Biodegradation	Not effective for metals, PCBs, dioxin or TBT. PAHs and some SVOCs are amenable to aerobic degradation.	Eliminated	—	—	—	—	—
	Chemical/Physical	Acid Extraction	Suitable for sediments contaminated with metals, but not applicable to PCBs or SVOCs. No data on TBT.	Eliminated	—	—	—	—	—
		Solvent Extraction	Potentially effective for treating sediments containing PCBs, dioxins, or SVOCs. Not applicable to metals. No data on TBT. Extraction of organically-bound metals and organic contaminants creating residuals with special handling requirements. At least one commercial unit available.	Retained for further consideration	Potentially applicable to dewatered (dry) sediments on the LDW containing primarily organic contaminants such as PCBs. Extracted organic contaminants from the process will need to be treated or disposed. Requires pre-treatment that involves screening of sediments.	Equipment is commercially available, but has not been demonstrated on a project of similar scope and scale.	This technology has been used to demonstrate under the EPA SITE program, but there are no data for similar implementation of this technology for large-scale PCB-impacted sediment. No current or planned projects.	Eliminated	—
		Solvent extraction: Solvent Electron Technology (SET™)	Effective for SVOCs and PCBs, but not metals. No data on TBT. Full scale system commercially available for treatment. Mobile units can be set up to meet project requirements. Nationwide TSCA treatment permit for SET™ issued by EPA for mobile PCB chemical destruction in soils.	Retained for further consideration	Potentially applicable to dewatered (dry) sediments on the LDW. This technology results in destruction of PCBs and other organic contaminants. Operates on a closed loop system and does not produce secondary hazardous waste or off-gas.	Not demonstrated in pilot- or full-scale sediment projects.	—	Eliminated	—
		Solvent Extraction; Peroxide and Ferrous Iron Treatment	Oxidation using liquid hydrogen peroxide (H_2O_2) in the presence of native or supplemental ferrous iron (Fe^{+2}) produces Fenton's Reagent which yields free hydroxyl radicals (OH^-). These strong, nonspecific oxidants can rapidly degrade a variety of organics.	Retained for further consideration	Potentially applicable to LDW.	Technology is neither commercially available nor demonstrated on a project of similar size and scope.	This technology has been used for pilot studies for treating PAH-impacted sediment from Utica Harbor, but there are no data for similar implementation of this technology for PCB-impacted sediment. No current or planned projects.	Eliminated	—
		Solvent Extraction: High Energy Electron Beam Irradiation	Full-scale system commercially available for treatment of PCBs and SVOCs, and process is limited to slurried soils, sediments and sludges. Slurrying is a required pre-treatment for this technology. Not demonstrated to be effective in sediments. Pilot-scale testing has been performed to treat wastewaters with organic compounds. Metals are not amenable to treatment. No data on TBT.	Retained for further consideration	Potentially applicable to slurried sediments in the LDW consisting primarily of organic contaminants such as PBCs.	Equipment is commercially available, but has not been demonstrated on a project of similar scope and scale.	This technology has been used to demonstrate under the EPA SITE program to treat wastewater with organic compounds, but there are no data for similar implementation of this technology for PCB-impacted sediment. No current or planned projects.	Eliminated	—

Table 7-2e Detailed Screening of Process Options: Treatment Process Options

GRA	Technology Type	Process Option	Effectiveness		Final Screening				Cost[1]
			LDW COCs	Screening Decision	Site Conditions	Available and Demonstrated	Innovative Technology	Screening Decision	
Ex Situ Treatment (continued)	Chemical/ Physical	Dehalogenation	PCB and dioxin-specific technology. Generates secondary waste streams of air, water, and sludge. Similar to thermal desorption, but more expensive. Solids content above 80% is preferred. Technology is not applicable to metals.	Eliminated	—	—	—	—	—
		Slurry Oxidation	Applicable to SVOCs, but not PCBs or metals. TBT treatment unknown. Large volume of tankage required. No known full-scale applications. High organic carbon content in sediment will increase volume of reagent and cost.	Eliminated	—	—	—	—	—
		Reduction/ Oxidation	Target contaminant group for chemical redox is inorganics. Less effective for nonhalogenated VOCs, SVOCs, fuel hydrocarbons, and pesticides. Not cost-effective for high contaminant concentrations because of large amounts of oxidizing agent required.	Eliminated	—	—	—	—	—
		Soil Washing	Full-scale testing of Biogenesis™ Advanced washing process showed demonstrated effectiveness for metals, SVOCs and PCBs in sediments. Limited data suggests not effective for TBT. High recalcitrant (e.g., PCB) contaminant concentration, increased percentage of fines, and high organic content increases overall treatment costs.	Retained for further consideration	Potentially applicable to dewatered sediments on the LDW. Would require upland processing space, storage capacity for dredged sediments, wastewater treatment and discharge. Treated residuals would still require disposal.	Equipment is commercially available, but has not been demonstrated on a project of similar scope and scale. Tests to date have been on 15,000 cy.	Full-scale testing has been performed. Mobile units available for setup. Continuous flow process designed to process up to 40 cy of sediments per hour for the full-scale system.	Retained as innovative technology for further consideratio n in the FS.	Moderate to High
		Radiolytic Dechlorination	Only bench-scale testing has been performed. Difficult and expensive to create inert atmosphere for full-scale project.	Eliminated	—	—	—	—	—
	Physical	Particle Separation	Reduces volumes of COCs by separating sand from fine-grained sediments. Some bench scale testing has suggested that at high PCB concentrations, the sand fraction retains levels that still require landfilling.	Retained for further consideration	Potentially applicable dredged sediments in the LDW.	Separation technologies available and have been used in several programs of similar size and scope.	—	Retained for further consideratio n in the FS.	Low
		Solar Detoxification	The target contaminant group is VOCs, SVOCs, solvents, pesticides, and dyes. Not effective for PCBs, dioxins or TBT. Some heavy metals may be removed. Only effective during daytime with normal intensity of sunlight. The process has been successfully demonstrated at pilot scale.	Eliminated	—	—	—	—	—
		Solidification	Bench-scale studies have added immobilizing reagents ranging from Portland cement to lime cement, kiln dust, pozzolan, and proprietary agents with varying success. Dependent on sediment characteristics and water content. Lime is particularly effective at volatilizing PCBs in wet sediment (by a phase transfer mechanism).	Retained for further consideration	Potentially applicable to LDW.	Lime has been successfully added to dredged material at other projects. Considered for use during the dewatering operation to remove excess water and prepare material for disposal.	—	Retained for further consideratio n in the FS.	Moderate

Table 7-2e Detailed Screening of Process Options: Treatment Process Options

GRA	Technology Type	Process Option	Effectiveness		Final Screening				Cost[1]
			LDW COCs	Screening Decision	Site Conditions	Available and Demonstrated	Innovative Technology	Screening Decision	
Ex-situ Treatment (continued)	Thermal	Incineration	High temperatures result in generally complete decomposition of PCBs and other organic chemicals. Effective across wide range of sediment characteristics but fine grained sediment difficult to treat. Not effective for metals.	Retained for further consideration	Technically applicable to LDW site conditions. Especially effective and potentially required where COCs exceed TSCA limits (e.g., PCB >50 ppm). Only a small portion of LDW sediments are above TSCA.	Only one off-site fixed facility incinerator is permitted to burn PCBs and dioxins. Metals not amenable to incineration. No data on TBT, but should be effective. Mobile incinerators are available for movement to a fixed location in close proximity to the contaminated sediments.	—	Eliminated for the FS – may be evaluated during remedial design.	—
		High-temperature Thermal Desorption (HTTD) then Destruction	Target contaminants for HTTD are SVOCs, PAHs, PCBs, TBT and pesticides, which are destroyed by the heating process. Metals not destroyed.	Retained for further consideration	Technically applicable to LDW site conditions. Especially effective and potentially required where COCs exceed TSCA limits (e.g., PCB >50 ppm).	Technology readily available as mobile units that would need to be set up at a fixed location in close proximity to the contaminated sediments. Cement-Lock® Technology demonstration projects partially destroyed organics and encapsulated metals in the product matrix. The Cement-Lock® product passes the TCLP test for priority pollutants.	Cement-Lock® Technology -Two demonstration projects started. Both experienced equipment related problems and were shut down.	Eliminated for the FS – may be evaluated during remedial design.	—
		Low-temperature Thermal Desorption (LTTD)	Target contaminants for LTTD are SVOCs and PAHs. May have limited effectiveness for PCBs. Metals not destroyed. Fine-grained sediment and high moisture content will increase retention times. Widely-available commercial technology for both on-site and off-site applications. Acid scrubber will be added to treat off-gas.	Retained for further consideration	Potentially applicable to LDW.	Demonstrated effectiveness at several other sediment remediation sites. Vaporized organic contaminants that are captured and condensed need to be destroyed by another technology. The resulting water stream from the condensation process may require further treatment.	—	Eliminated for the FS – may be evaluated during remedial design.	—
		Pyrolysis	High moisture content increases treatment cost. Generates air and coke waste streams. Target contaminant groups are SVOCs and pesticides. It is not effective in either destroying or physically separating inorganics from the contaminated medium	Eliminated	—	—	—	—	—
		Vitrification	Thermally treats PCBs, SVOCs, TBT, and stabilizes metals. Successful bench-scale application to treating contaminated sediments in Lower Fox River, and in Passaic River.	Retained for further consideration	Potentially applicable to LDW.	Not commercially available or applied on similar site and scale.	No known pilot or full-scale applications in sediments planned.	Eliminated	—
		High-pressure Oxidation	Predominantly for aqueous-phase contaminants. Wet air oxidation is a commercially-proven technology for municipal wastewater sludges and destruction of PCBs is poor. Supercritical water oxidation has demonstrated success for PCB destruction.	Eliminated	—	—	—	—	—

Note:

1. Costs indicated here are relative to incineration costs.

COC = chemical of concern; CTM = Candidate Technologies Memorandum; cy = cubic yards; EPA = U.S. Environmental Protection Agency; FS = feasibility study; GRA = general response action; HTTD = high-temperature thermal desorption; LTTD = low-temperature thermal desorption; MNR = monitored natural recovery; NCP = National Contingency Plan; PAH = polycyclic aromatic hydrocarbon; PCB = polychlorinated biphenyls; SET™ = Sediment Electron Technology; SVOC = semivolatile organic carbon; TBT = tributyltin; TCLP = Toxicity Characteristic Leaching Procedure; TOC = total organic carbon; TSCA = Toxic Substances Control Act; TSS = total suspended solids

Table 7-3 Summary Assessment of Effectiveness, Implementability, and Cost for Retained Remedial Technologies and Process Options

GRA	Technology Type	Process Option	Effectiveness			Implementability			Cost[1]
			COCs	Advantages	Disadvantages	Site Conditions	Advantages	Disadvantages	
No Action	None	Required by NCP	Applicable to all LDW COCs.	Applicable to all COCs. Effective where risk assessment demonstrates low to no risk to human health and environment.	COCs remain in place.	Applicable throughout LDW where COC concentrations are low.	1) Readily implemented with no construction or monitoring requirements; 2) Minimal impact on industrial and shipping uses of waterway.	1) Requires source controls to be in place.	Low
Institutional Controls	Proprietary Controls and Informational Devices	Proprietary Controls	Applicable to all LDW COCs.	Can be effective for protecting human health in smaller tidal and subtidal areas where longer-term natural recovery is expected to occur, or where industrial waterway activities are expected to continue (e.g., under docks, active berths). Land use restrictions can be effective in maintaining the integrity of engineered structures such as caps or CAD sites.	1) Short-term impacts to human health may continue, and require use in conjunction with seafood consumption advisories and/or other site restrictions; 2) Not effective for ecological receptors because COCs remain in-place.	Applicable to all areas of the LDW.	1) Implemented through laws, zoning restrictions, and/or deed restrictions for upland and in-water uses; 2) Compatible with minimal impact on industrial and shipping uses of waterway; 3) Can be combined with other alternatives (e.g., MNR, ENR) as an interim measure until human health standards are achieved.	1) Deed restrictions may limit future development of water-related uses, or require removal of COCs by future developers. 2) May conflict with Tribal historical and cultural uses.	Low
		Seafood Consumption Advisories, Education, and Public Outreach	Applicable principally to bioaccumulative COCs such as PCBs and arsenic that pose human health risks through fish or shellfish consumption.	Experience at other sites has shown that seafood consumption advisories can be effective for well-educated public.	1) Less effective for subsistence ethnic groups who harvest fish or shellfish as a source of protein; 2) Not effective for ecological receptors because COCs remain in-place.	Applicable to all areas of the LDW.	1) Implemented through continuing health advisories, sign postings, regular and continued public notices, and enforcement; 2) Minimal impact on industrial and shipping uses of waterway.	1) Sign postings subject to theft and vandalism. Must also be printed in multiple languages to account for different ethnic uses of aquatic environment; 2) Requires long-term financial commitment to ensure continuing enforcement; (3) May conflict with Tribal treaty rights to harvest fish and shellfish in the LDW.	Low
		Monitoring and Notification of Waterway Users	Applicable to all LDW COCs.	Can be effective for protecting human health in smaller tidal and subtidal areas where longer-term natural recovery is expected to occur, or where industrial waterway activities are expected to continue (e.g., under docks, active berths).	1) Short-term impacts to human health may continue, and require use in conjunction with seafood consumption advisories and/or other site restrictions; 2) Not effective for ecological receptors because COCs remain in-place.	Applicable to all subtidal areas of LDW.	1) Implemented through laws, zoning restrictions, and/or deed restrictions for in-water uses; 2) Can be combined with other alternatives (e.g., MNR, ENR) as an interim measure until human health and ecological standards are achieved.	1) Waterway use restrictions for boating, marinas, anchoring, or other waterway-dependent activities for sub-tidal state lands may require Washington legislative action; 2) Waterway use restrictions could negatively impact current and future industrial waterway activities, prevent future development of water-related uses, or require removal of COCs by future developers.	Low
		Enforcement Tools	Applicable to all LDW COCs.	Can be effective for implementing ICs, long-term monitoring, and maintenance of remedial actions.	1) Short-term impacts to human health may continue, and require use in conjunction with seafood consumption advisories and/or other site restrictions; 2) Not effective for ecological receptors because COCs remain in-place.	Applicable to all areas of the LDW.	1) Implemented through agreed orders with EPA or Ecology, the UECA or WDFW.	1) Deed restrictions may limit future development of water-related uses, or require removal of COCs by future developers.	Low
		Site Registry	Applicable to all LDW COCs.	Can be effective for protecting human health in areas with containment remedies by filing deed notices.	1) Short-term impacts to human health may continue, and require use in conjunction with seafood consumption advisories and/or other site restrictions; 2) Not effective for ecological receptors because COCs remain in-place.	Applicable to all areas of the LDW.	1) Implemented through filing deed notices with County Recorder's office.	1) Deed restrictions may limit future development of water-related uses, or require removal of COCs by future developers.	Low
Monitoring	Physical and Chemical Assessment	Monitoring	Applicable to all LDW COCs.	Can be effective for evaluating changes during implementation phase and over the long-term	1) A lot of variability in data results, difficult to discern trends; 2) Relationships not well understood for some chemicals.	Applicable to all subtidal areas of LDW.	1) Readily implementable; 2) Minimal impact on industrial and shipping uses of waterway; 3) Good for risk communication to public.	1) Requires long-term financial commitment to ensure maintenance of engineered structures (i.e., cap, CAD) and monitoring/sampling.	Moderate

Table 7-3 Summary Assessment of Effectiveness, Implementability, and Cost for Retained Remedial Technologies and Process Options

GRA	Technology Type	Process Option	Effectiveness			Implementability			Cost[1]
			COCs	Advantages	Disadvantages	Site Conditions	Advantages	Disadvantages	
Monitored Natural Recovery	Chemical Degradation	Combination of natural desorption, diffusion, dilution, volatilization, resuspension, and transport	Effective principally to LDW organic COCs including SVOCs and PCBs. Inorganics not subject to degradation.	Effective where chemical degradation of COCs is demonstrated to occur in the short- and long-term.	1) Effective where risk assessment demonstrates low to no risk to human health and environment; 2) Physical/chemical degradation demonstrated for SVOCs, but less effective for metals, PCBs, TBT and pesticides; 3) Short-term impacts to human health may continue, and require use in conjunction with seafood consumption advisories and/or other site restrictions; 4) Potentially low level of short-term effectiveness for ecological receptors because COCs remain in place, but can provide adequate long-term protection; 5) Requires implementation of long-term monitoring study and risk assessment objectives.	Applicable to all areas of the LDW.	1) Readily implemented with no construction requirements; 2) Minimal impact on current or future industrial and shipping uses of waterway; 3) May be used in conjunction with other technologies in a combined alternative.	1) Must be implemented in conjunction with a well-designed, long-term monitoring program; 2) May require future active remediation where MNR risk-expectations are not achieved.	Low
Monitored Natural Recovery	Biological-Degradation	COC Metabolization (aerobic and anaerobic)	Effective principally to SVOCs. PCBs and TBT will degrade, but not within an acceptable time frame. Metals will not degrade.	Biodegradation is a demonstrated and proven remedial technology for volatiles and SVOCs. Effective where degradation of COCs are demonstrated to occur in the short- and long-term.	1) Biological degradation less effective for PCBs and TBT; 2) Short-term impacts to human health may continue, and require use in conjunction with seafood consumption advisories and/or other site restrictions; 3) Less effective for ecological receptors because COCs remain in place; 4) Requires implementation of long-term monitoring study and risk assessment objectives.	Applicable in areas with low concentrations of SVOCs in well-mixed sediments.	1) Readily implemented with no construction requirements; 2) Minimal impact on current or future industrial and shipping uses of waterway; 3) May be used in conjunction with other technologies in a combined alternative; 4) Implemented in areas with biodegradable COCs.	1) Must be implemented in conjunction with a well-designed long-term monitoring program; 2) May require future active remediation where MNR risk-expectations are not achieved.	Low
Monitored Natural Recovery	Physical Burial Processes	Sedimentation/ Burial Resuspension and Transport (minor components of MNR)	Effective for all LDW COCs where concentrations are low.	1) Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants; 2) Effective for contaminants with low solubility and high sorption where the main concern is resuspension and direct contact.	1) Requires implementation of long-term monitoring study and risk assessment objectives; 2) Short-term impacts to human health may continue, and require use in conjunction with seafood consumption advisories and/or other site restrictions; 3) Less effective for ecological receptors because COCs remain in place;4) COCs not actively removed and remain in place. 5) Facilitates PCB contamination of the marine food chain when resuspension and transport occur	Applicable where geochronological studies and hydrodynamic modeling demonstrate long-term sedimentation and burial processes are in-place.	1) Readily applied and demonstrated process; 2) Can be combined with institutional controls until long-term risk-objectives are demonstrated; 3) Minimal impact on industrial and shipping uses of waterway.	1) Requires long-term monitoring and continuing financial commitment until risk-objectives are achieved; 2) Associated institutional controls may limit future uses of waterway.	Low
Enhanced Natural Recovery	Enhanced Physical Burial	Thin-layer placement to augment natural sedimentation	Effective for all LDW COCs where MNR processes are demonstrated.	ENR dilutes COC concentrations while not resulting in the resuspension and transport of contaminants that occurs with dredging.	1) Requires implementation of long-term monitoring study and risk assessment objectives; 2) Short-term impacts to human and ecological health may continue, and require use in conjunction with seafood consumption advisories and/or other site restrictions; 3) COCs not actively removed, but attenuated by addition of clean sediments.	Applies where data and modeling indicate placement of a thin-layer of material, combined with natural recovery processes will result in achievement of risk-based sediment objectives. Particularly useful for critical habitat areas, and/or shallow intertidal areas where active remedial methods could result in unwanted habitat loss. Potentially suitable for management of dredge residuals.	1) Puget Sound-demonstrated technology with local construction knowledge; 2) Sediment for thin-layer placement readily available.	1) Requires long-term monitoring, institutional controls and continuing financial commitment until RAOs are achieved; 2) Institutional controls may limit future uses of waterway.	Low

Table 7-3 Summary Assessment of Effectiveness, Implementability, and Cost for Retained Remedial Technologies and Process Options

GRA	Technology Type	Process Option	Effectiveness			Implementability			Cost[1]
			COCs	Advantages	Disadvantages	Site Conditions	Advantages	Disadvantages	
Containment	Capping	Conventional Sand Cap	Applicable principally to PAHs, other SVOCs, metals, and PCBs; Limited applicability to VOCs.	1) Demonstrated effectiveness for isolating contaminants in the LDW; 2) Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants; 3) Capping does not result in the resuspension and transport of contaminants that occurs with dredging.	1) Sand cap may be subject to bioturbation and release of buried COCs; 2) Sand caps may be susceptible to propeller and/or flooding scour, methane generation, and earthquakes; 3) Changes in bed elevation may result in unacceptable ecological impacts to salmonid habitat; 4) Requires long-term monitoring, institutional controls and financial commitment.	Applicable to subtidal areas where sediments have sufficient bearing strength to support cap, and have low erosive potential. Not suitable for areas where groundwater can advect COCs into the clean cap surface.	1) Readily applied and demonstrated technology. Local construction experience; 2) Capping materials readily available from navigation dredging at the Upper Turning Basin.	1) Requires long-term maintenance and financial commitment; 2) May not be implementable for shallow, intertidal areas where elevation changes would result in unacceptable ecological impacts; 3) May require permanent institutional controls and limit future uses of waterway; 4) Impacts to flooding, stream bank erosion, navigation, and recreation must be addressed in design.	Low to Moderate
		Conventional Sediment/Clay Cap	Applicable principally to COCs with potentially higher solubilities and lower sorption.	1) Sediment with high fines (silt and clay) and or TOC is effective in limiting diffusion of contaminants. Sediment caps are generally more effective than sand caps for containment of contaminants with high solubility and low sorption; 2) Natural TOC present in conventional sediments more effective at adsorbing COCs such as PCBs.	1) Clay liners in caps are potentially more susceptible to breaches caused by methane generation through the cap; 2) Caps may be susceptible to propeller and/or flooding scour, methane generation, and earthquakes; 3) Changes in bed elevation may result in unacceptable ecological impacts to salmonid habitat; 4) Requires long-term monitoring, institutional controls and financial commitment.	Applicable in sections of LDW with low erosion potential and where placement of finer-grained material can be managed. May be useful in nearshore, or intertidal applications where thinner caps with higher sorbtive capacities are required. Sediments must still have sufficient bearing strength to support cap, and have low erosive potential. Not suitable for areas where groundwater can advect COCs into the clean cap surface.	1) Readily applied and demonstrated technology; 2) Placement of high TOC and/or high fine sediments minimizes thickness of cap in areas with shallow water depth; 3) Materials readily available through upland sources or from navigation dredging at other systems.	1) Requires long-term maintenance and financial commitment; 2) May not be implementable for shallow, intertidal areas where elevation changes would result in unacceptable ecological impacts; 3) May require permanent institutional controls and limit future uses of waterway; 4) Impacts to flooding, stream bank erosion, navigation, and recreation must be addressed in design; 5) Utilization of navigation dredged material for capping has potential logistical issues.	Low to Moderate
		Armored Cap	Applicable to all LDW COCs as described for sand and/or conventional caps.	Effective in combination with conventional caps to isolate contaminants and protect cap against physical erosion and/or bioturbation.	1) Changes in bed elevation may result in unacceptable ecological impacts to salmonid habitat; 2) Armor rock may be less productive habitat for benthic organisms. 3) Requires long-term monitoring, institutional controls and financial commitment.	Applicable in conjunction with other cap configurations in areas of LDW, but can be applied where erosion potentials are higher.	(1) Readily applied and demonstrated technology; 2) Armor placement can be used to minimizes thickness of cap in areas with shallow water depth; 3) Armor materials can be combined with habitat-enhancing materials (e.g., "Fish Mix").	1) Requires long-term maintenance and financial commitment; 2) May not be implementable for shallow, intertidal areas where elevation changes would result in unacceptable ecological impacts; 3) May require permanent institutional controls and limit future uses of waterway.	Low to Moderate
		Composite Cap	Applicable to all LDW COCs as described for sand and/or conventional caps.	1) Provides physical isolation of COCs from the overlying water column; 2) Assists in preventing bioturbation breaches of caps and prevents direct contact between aquatic biota and contaminants; 3) Rigid HDPE layers used in small areas to assist in NAPL containment, control hydraulic gradient, and methane containment and diffusion.	1) Composite caps at other sites have resulted in catastrophic breaches as a result of methane generation under the cap; 2) Rigid HDPE layers do not have long-term demonstrated effectiveness; 3) Use of geotextiles may not be necessary for contaminants with low solubility and high sorption where the main concern is resuspension and direct contact; 4) Geotextiles by themselves do not limit advective or diffusive flux of COCs; 5) Requires long-term monitoring, institutional controls and financial commitment.	Composite caps with impermeable layers such as HDPE are generally applicable where control of NAPL or groundwater movement is needed in a limited area. Composite caps may also be potentially applicable in intertidal areas where physical separation between receptors and COCs are required, but where minimal change to the slope or bathymetric configuration is needed.	1) Increasingly applied technology; 2) Placement of geotextile or rigid HDPE can be used to minimize thickness of cap in areas with shallow water depth.	1) Requires specialty equipment for placement, sinking, and securing to the sediment floor; 2) Tidal ranges in the LDW can affect ability to place materials; 3) Requires long-term monitoring and financial commitment.	Low to Moderate
		Spray Cap	Applicable to all LDW COCs as described for sand and/or conventional caps.	Good for application under hard to access areas such as piers and wharves. Provides good physical barrier between contaminants and overlying surfaces.	1) Creates a hard surface. If habitat surface values are required, habitat-suitable material would need to be placed on top of the shotcrete. 2) Must be applied in the dry with time to set. Areas of application are limited to high intertidal areas. 3) Requires long-term monitoring and maintenance, institutional controls, and a potential requirement for replacement habitat.	Labor intensive process to implement in difficult working conditions under docks and piers.	Good for application under hard to access areas such as piers and wharves.	1) Potentially dangerous work because of obstructions, slippage, and presence of contaminants next to workers applying the shotcrete. 2) Requires specialty equipment to place the shotcrete. 3) Tidal ranges can affect placement location.	High
		Reactive Caps	Potentially applicable to all LDW COCs as described for conventional sand and/or conventional sediment caps.	Similar to advantages described for other caps. Provides an additional level of contaminant-sorbing materials to caps.	Long-term effectiveness not demonstrated. Retained as innovative technology. Requires long-term monitoring, institutional controls, and financial commitment. Probably not acceptable in beach areas.	Applicable in conjunction with other cap configurations in areas of LDW.	Adds an additional level of environmental protection with contaminant sorbing materials. May allow for construction of thinner caps.	1) Requires specialty equipment for placement, sinking, and securing to the sediment floor; 2) Tidal ranges in the LDW can affect ability to place materials; 3) Requires long-term monitoring and financial commitment; 4) Long-term implementability not demonstrated. Retained as innovative technology.	Low to Moderate

Table 7-3 Summary Assessment of Effectiveness, Implementability, and Cost for Retained Remedial Technologies and Process Options

GRA	Technology Type	Process Option	Effectiveness			Implementability			Cost[1]
			COCs	Advantages	Disadvantages	Site Conditions	Advantages	Disadvantages	
Removal	Dredging	Hydraulic Dredging	Applicable to all LDW COCs at higher concentrations that either pose unacceptable risks to human health and the environment, and/or serve as sources for downstream recontamination.	1) Effective removal with lower resuspension and recontamination/residual rate relative to mechanical dredging; 2) Can be readily incorporated into treatment trains such as chemical and/or physical separation.	Requires management of contaminant residuals after dredging.	Applicable in areas with high volumes of low solid sediments, generally less than 20 ft. of water depth and low levels of debris.	(1) Various hydraulic dredges readily available on the West Coast and at least one dredging contractor has equipment on the LDW; (2) More effective lateral and vertical cut control may be achieved, relative to mechanical dredges; (3) High utility when used in conjunction with CDFs; (4) Local experience of use for the Sitcum and Blair Waterway projects.	1) Hydraulic dredges limited in heavy-debris environments; 2) Environmental hydraulic dredges are depth limited, and difficult to size to accommodate steady solids flow under varying tidal regimes; 3) Requires separation of solids from water, resulting in large volumes of water that may require treatment prior to discharge back to LDW; 4) Treatment facilities must be located near-waterway with enough land space to accommodate retention basins, mechanical dewatering equipment, sand and carbon filtration, and transfer of dewatered material to trucks or trains for transfer to regional landfill.	Moderate to High
		Mechanical Dredging	Applicable to all LDW COCs at concentrations that either pose unacceptable risks to human health and the environment, and/or serve as sources for downstream recontamination.	Effective for removal in areas with high debris and sediments with high sand or heavy clay content that require digging buckets.	Requires management of contaminant residuals after dredging.	Applicable in areas with high volumes of high percentage solids sediments, including areas with heavy debris, sand and clay. Mechanical dredging is not depth restricted, and not affected by tidal exchange.	1) Various mechanical dredges, including environmental buckets and clamshells readily available on the LDW and in Puget Sound; 2) Recent construction experience in LDW and Puget Sound with skilled operators; 3) Environmental buckets useful in softer, unconsolidated materials with low debris; 4) Digging buckets (e.g., clamshells) useful in harder clays or compacted sediments, or where debris is high; 5) Existing infrastructure for barge transport, off-loading, and transfer to railcars for transport to regional landfills; 6) Depth and tidal limitations within the LDW do not restrict use of mechanical buckets.	1) Not all river segments may be accessible to a barge-operated mechanical dredge; 2) Can result in potentially higher resuspension and residual rates than hydraulic dredges; 3) Lower vertical and horizontal operational control relative to hydraulic dredges.	Low to Moderate
		Mechanical Dredging (Excavator)	Applicable to all LDW COCs at concentrations that either pose unacceptable risks to human health and the environment, and/or serve as sources for downstream recontamination.	Effective for removal in areas with high debris and sediments with high sand or heavy clay content that require digging buckets.	Requires management of contaminant residuals after dredging.	Applicable in areas with high volumes of high percentage solids sediments, including areas with heavy debris, sand and clay. Mechanical dredging is not depth restricted, and not affected by tidal exchange.	1) Equipment is available to the Puget Sound region but to lesser extent than standard clamshell dredges; 2) Recent construction experience in LDW and Puget Sound with skilled operators; 3) Offer high level of vertical and horizontal control during dredging.	1) Not all river segments may be accessible to a barge-operated mechanical dredge; 2) Can result in potentially higher resuspension and residual rates than hydraulic dredges; 3) Lower vertical and horizontal operational control relative to hydraulic dredges.	Low to Moderate
	Excavating	Dry Excavating	Applicable to all LDW COCs. Effective for nearshore and/or intertidal areas where depths limit conventional dredging equipment	1) Contaminated sediments removed; 2) Residuals can be minimized or eliminated by dry excavation.	Effective only in relatively small and narrow shoreline areas of limited intertidal bands. Requires either only working during low tides, or using coffer dams or sheet pile walls to create a contained, dry area.	Limited in application to nearshore shallow and/or intertidal areas that can be reached from shore or by specialty equipment designed to work on soft, unconsolidated sediments.	Equipment and construction experience in Puget Sound.	1) Construction costs may involve contingencies to address potential spills and leaks	Low to Moderate
Ex Situ Treatment	Chemical/Physical	Soil Washing	Applicable to all LDW COCs. Principal application would be for high volumes of organic-contaminated sediments.	1) Full-scale testing demonstrated ability to take high concentrations of COCs and treat to equivalent of MTCA soil standards; 2) Potential beneficial reuse for residuals.	1) Tests to date have treated hazardous waste-level materials. No data on treatment of lower concentrations of contaminants; 2) Effective treatment when starting with high sands materials—lower effectiveness when treating low solids and high fine-grained sediments; 3) Solid-waste classification in Washington state unclear, which may require disposal of treated materials at a Subtitle D landfill.	Applicable to potential dredge areas containing organic and coarse-grained sediment.	1) Readily implementable, resulting in reduced contaminated sediment volume; 2) System could be coupled with hydraulic dredging for continuous treatment train; 3) Mobile units are available 4) Continuous flow process designed to process up to 40 cy of sediments per hour for the full-scale system; 5) May be available for potential beneficial reuse.	1) Waste streams include hydraulic-dredge decant water, reagents used in soil washing, and the treated residuals; 2) Water will require filtration and treatment prior to discharge; 3) Treated residuals may require off-site disposal; 4) Volume/long-term supply of sediments to be treated and local market for beneficial use products affect the economics of implementing this technology.	Moderate

Table 7-3 Summary Assessment of Effectiveness, Implementability, and Cost for Retained Remedial Technologies and Process Options

GRA	Technology Type	Process Option	Effectiveness			Implementability			Cost[1]
			COCs	Advantages	Disadvantages	Site Conditions	Advantages	Disadvantages	
Ex Situ Treatment (continued)	Physical	Particle Separation	Only applicable to adsorptive COCs that would adhere to the fine-grained soil. Offers greatest utility and cost saving benefits where concentrations of COCs would otherwise require incineration or Subtitle C disposal.	1) Demonstrated effectiveness for reduction in volume of highly contaminated sediments with a high percentage of sand-content; 2) Used to increase effectiveness of dewatering dredged material.	1) Not effective for contaminants with high concentrations and high organic content; 2) Previous work at other sites with PCB-contaminated sediments has shown that PCBs are retained on sand particles (as emulsion), requiring Subtitle D disposal.	Applicable to potential dredge areas containing higher sand content.	1) Readily implementable, resulting in reduced contaminated sediment volume; 2) Can be combined with soil washing to improve contaminant separation and/or destruction; 3) Mobile units are available; 4) Separated sand may be available for potential beneficial reuse, capping, or disposal at DMMP Elliott Bay site.	Will require disposal of separated waste stream at a Subtitle D landfill. Fines could also require Subtitle C disposal or incineration.	Moderate
		Solidification	Applicable to all LDW COCs. Principal application would be for high volumes of PCB-contaminated sediments that exceed hazardous waste criteria and would otherwise require incineration or Subtitle C disposal.	(1) Lime has been successfully added to dredged material at other projects; (2) Effective during the dewatering operation to remove excess water and prepare material for disposal.	High contaminant concentration and high water content results in higher project costs.	Applicable to all dredge areas of LDW.	(1) Readily implementable; (2) Reagent materials readily available.	1) Immobilizing reagents, ranging from Portland cement to lime cement, kiln dust, pozzolan, and proprietary agents, have been applied with varying success. Dependent on sediment characteristics and water content; 2) Contaminants remain in place. Stabilized product requires disposal in regulated landfill.	Moderate
Disposal	On-Site	Contained Aquatic Disposal (CAD)	Applicable to all LDW COCs below hazardous waste designations.	1) Demonstrated local experience and effectiveness in the LDW and Puget Sound; 2) Effective containment of metals, organics and PCBs; 3) Can be designed to include habitat enhancement for salmonids.	1) CADs must be engineered to withstand bioturbation, advective flux and release of buried COPCs, propeller and/or flooding scour, and earthquakes; 2) Changes in bed elevation may result in unacceptable ecological impacts to salmonid habitat; 3) Requires long-term monitoring, institutional controls and financial commitment.	Applicable to subtidal areas where sediments have sufficient bearing strength to support cap, and have low erosive potential. Not suitable for areas where groundwater can advect COPCs into the clean cap surface.	(1) Technically readily implemented within the LDW with contaminated sediments contained on-site; (2) Local construction experience; (3) Excavated clean pit-materials can be used for beneficial uses and/or to cap CAD; (4) Does not interfere with current industrial uses of LDW.	1) Volume-limited on LDW as a large area would be required to accommodate dredged sediments; 2) Requires long-term commitment to monitoring with the potential for additional actions if CAD fails; 3) Requires permanent institutional controls (e.g., deed restrictions, dredging moratorium) that may affect future development and uses of the LDW; (4) Requires concurrence with land owner.	Low to Moderate
		Confined Disposal Facility (CDF)	Applicable to all LDW COCs below hazardous waste designations.	1) Demonstrated local experience and effectiveness in Puget Sound; (2) Effective containment of metals, SVOCs and PCBs; 3) A subtidal CDF could be designed to include habitat enhancement for salmonids.	1) CDFs must be engineered to withstand advective flux and release of buried COCs, propeller and/or flooding scour, and earthquakes; 2) Filling of nearshore lands would result in unavoidable loss of aquatic lands that will require mitigation.	Requires large suitable near-shore or upland containment site. Former slips or similar in-water areas would be best suited to construct a CDF.	1) Puget Sound-demonstrated technology with local construction knowledge; 2) Cap sediments or soils readily available; 3) Could contain large volumes of contaminated sediments, depending upon site availability; 4) Beneficial upland industrial and/or residential reuse of filled site.	1) Site-limited on LDW. Few potential locations without other current uses; 2) Requires long-term commitment to monitoring with the potential for additional actions if CDF fails; 3) Requires permanent institutional controls (e.g., deed restrictions, dredging moratorium) that may affect future development and uses of the LDW; 4) Requires concurrence with land owner.	Moderate to High
	Off-Site	Subtitle D Landfill	Applicable to all LDW COCs below hazardous waste designations.	Subtitle D landfills highly effective for long term, permanent containment of contaminated materials.	COCs contained, but not permanently destroyed.	Applicable throughout LDW for both dewatered and wet sediments.	1) Several licensed landfills in Washington exist that can receive dredged materials in Puget Sound; 2) Transfer facilities for moving sediments from LDW to the landfills exist on-site; 3) Transport infrastructure in-place on the LDW; 4) Options exist for moving wet sediments - eliminating need for on-site dewatering facilities.	1) Transfer and barge offload facilities may not be present at the time the project is completed so a separate offload facility may need to be constructed; 2) Landfills in Eastern Washington and Eastern Oregon requires train transport with potential for spillage.	Moderate

Table 7-3 Summary Assessment of Effectiveness, Implementability, and Cost for Retained Remedial Technologies and Process Options

GRA	Technology Type	Process Option	Effectiveness			Implementability			Cost[1]
			COCs	Advantages	Disadvantages	Site Conditions	Advantages	Disadvantages	
Disposal (continued)	Off-Site	Subtitle C Landfill	Applicable to all LDW COCs exceeding hazardous waste designations.	Subtitle C landfills are federally-regulated facilities and are highly effective for long-term, permanent containment of highly contaminated materials.	1) COCs contained, but not permanently destroyed; 2) Requires dewatering of dredged sediments.	Applicable throughout LDW for dewatered sediments	Option for disposal of listed, hazardous wastes	Transport of hazardous materials to facility expensive.	High
		MTCA Reuse (upland or in-water beneficial reuse)	Applicable to all LDW COCs in sediments that are either below, or treated-to below the reuse standards for uplands and in-water.	Beneficial reuse of sediments	Some residual COCs may remain after treatment	Applicable throughout LDW	Potential use of sediments that meet the MTCA Level A soil requirements as upland fill, or other beneficial upland uses including daily landfill cover. Potential beneficial reuse as in-water ENR, capping material, and habitat enhancement. May be implementable for high volumes of materials with low concentrations of COCs, or for treated sediments.	No specific beneficial upland reuse has been identified. As such, requires the additional costs for transport of material and/or tipping fee to send to landfill.	None
		DMMP Open-Water Disposal	Applicable to all LDW COCs in sediments that are separated or treated to below the DMMP disposal standards.	DMMP is a well-established and effective program with a long-term track record of monitoring to verify environmental protectiveness.	None	Applicable throughout LDW	The DMMP disposal site is located in nearby Elliott Bay	Sediments that require remediation are not likely to meet the open-water disposal criteria.	Low

Notes:

1. Cost assessment is based on the relative cost of a process option in comparison to other process options within a given technology type.

CAD = contained aquatic disposal; CDF = confined disposal facility; CTM = Candidate Technologies Memorandum; COC = chemical of concern; cy = cubic yards; DMMP = Dredged Material Management Program; ENR = enhanced natural recovery; FS = Feasibility Study; GRA = general response action; HDPE = High-density polyethylene; HTTD = high-temperature thermal desorption; LTTD = low-temperature thermal desorption; MNR = Monitored Natural Recovery; MTCA = Model Toxic Control Act; NCP = National Contingency Plan; PCB = polychlorinated biphenyls; SVOC = semivolatile organic carbon; TBT = tributyltin; TOC = total organic carbon; TSCA = Toxic Substances Control Act; TSS = total suspended solids; UECA = Uniform Environmental Covenants Act

Table 7-4 Remedial Technologies and Process Options Retained for Potential Use in Developing Remedial Alternatives

General Response Action	Technology Type	Process Option	Comments Related to Technology Assumptions for the FS
No Action	None	Not Applicable	Per NCP requirements
Institutional Controls	Proprietary controls and Informational Devices (EPA 2000)	Proprietary Controls	Access to much of the LDW shoreline from the uplands is already restricted by general security measures put in place by private and public property owners. The LDW is a public waterway and public access to nearshore areas is generally not prohibited.
		Seafood Consumption Advisories, Education, and Public Outreach	Public advisories regarding fish and shellfish consumption are currently posted for the entire LDW. Public advisories regarding sediment contact risks are not currently posted. Advisories are a likely element of all remedial alternatives and will remain in place until monitoring data confirms that the advisories can be modified or removed entirely.
		Monitoring and Notification of Waterway Users	As needed, these will be tailored to specific remediation activities and site constraints.
		Enforcement Tools	CERCLA or MTCA agreed orders with EPA or Ecology will be required, as needed.
		Site Reporting	If considered, deed notices to be filed with the County office and information placed on the State Registry.
Monitoring	None	Baseline Monitoring	Establishes a statistical basis for comparing conditions before and after the cleanup action.
		Construction Monitoring	Short-term monitoring during remediation used to evaluate whether the project is being implemented in accordance with specifications (i.e., water quality monitoring, bathymetric surveys)
		Post-Construction Performance Monitoring	Post-construction performance monitoring evaluates post-removal surface and subsurface sediment conditions in dredging or containment areas to confirm compliance with project specifications.
		Long-term Operation and Maintenance Monitoring	Long-term operation and maintenance monitoring of dredging areas, containment and/or disposal sites (i.e., CAD sites, ENR and capping areas) required to ensure long-term effectiveness and continued stability of the structure.
		Long-term RAO Monitoring	Long-term monitoring evaluates sediment, tissue and water quality at the site for an extended period following the remedial action.
Monitored Natural Recovery (MNR)	Natural Physical, Biological, and Chemical Recovery	Multiple potential mechanisms: burial (sedimentation), immobilization, desorption, dispersion, diffusion, dilution, volatilization, resuspension, biological degradation.	Surface sediment chemistry is monitored over time to track recovery by multiple physical, chemical, and biological mechanisms that operate naturally in the estuarine environment of the LDW. Burial by the comparatively cleaner sediments coming into the LDW from the Green River is the principal mechanism for recovery in the LDW. Natural recovery is operative in the waterway as supported by analysis of the empirical data and predicted by the STM. Areas potentially suitable for MNR must be depositional, not subject to significant physical disturbances from high river flows, vessel propeller scour, anchor drag, and routine dredging. Future construction activity in MNR zones is not precluded; however, the applicant/owner must be prepared to appropriately handle any contaminants that may be encountered as part of the project.
Enhanced Natural Recovery (ENR)	Thin-layer Placement	Placement of a thin layer of granular media (e.g., sand) to augment natural recovery	ENR differs from MNR with respect to the modification of initial conditions (i.e., placing clean material onto the contaminated sediment surface). In other respects, siting, monitoring and future use restrictions and considerations are the same. Placement also can serve as a means of managing contaminated dredging sediment residuals, called thin-layer sand placement.
Containment	Capping	Conventional Sand Cap	Conventional capping is restricted to net deposition areas that are not subject to appreciable sustained or episodic erosion. Cap thickness must be sufficient to prevent reintroduction of buried contaminants into biologically active zone (upper 10 cm).
		Conventional Sediment/Clay Cap	Cap thickness must be sufficient to prevent reintroduction of buried contaminants into biologically active zone (upper 10 cm).
		Armored Cap	If capping is considered in erosion areas, armoring will likely be required to maintain the cap integrity.
		Spray Cap (Technology not addressed by CTM)	Shotcreting is potential approach for confining, isolating contaminants under dock or overwater structures. The shotcrete application at Todd Shipyards effectively encapsulated existing debris (slag) mounds from the aquatic environment.
		Composite Cap	Application would be site- and contaminant-specific where space or pollutant constraints indicate conventional sand capping is not adequate.
		Reactive Cap	Application would be site- and contaminant-specific where space or pollutant constraints indicate conventional sand capping is not adequate.
Removal	Dredging	Hydraulic Dredging (including diver-assisted dredging)	Hydraulic dredging has several constraints that limit its project-wide application: the cost and logistics of managing large volumes of water including large land area adjacent the dredging area; potential for water quality impacts; debris leads to operational difficulties and dredging inaccuracies; interruption of waterway use caused by placement of the hydraulic discharge pipeline in the LDW. Application of hydraulic dredging in the LDW may be appropriate on a small scale (e.g., diver-assisted dredging in under dock/pier areas) or on location-specific basis.
		Mechanical Dredging	Demonstrated effective in the Puget Sound region and nationwide sediment remediation projects. Readily available and least-cost dredging option in the Puget Sound region.
		Mechanical Dredging (Excavator)	Excavator dredges offer a high level of control in the placement of the dredge bucket because it uses fixed linkages instead of cables. This yields a higher degree of accuracy resulting in less volume of dredged sediment and reduced water quality impacts as compared to a conventional derrick barge. Often used for debris removal and/or shallow in-water dredging operations.
	Excavating	Dry Excavating	Generally applicable to nearshore areas above elevation -2.0 ft MLLW or 25 foot reach from top of bank.
Ex Situ Treatment	Chemical/ Physical	Soil Washing	Mechanically dredged sediment is screened to remove oversize debris and is then processed through a series of unit operations resulting in the following products or waste streams: wastewater, sludge (fines fractions), and sand/gravel. Wastewater requires treatment, the sludge is typically disposed (upland landfill), and the sand/gravel component may be reused for in-water applications if it tests suitable for beneficial use pursuant to the Washington State Sediment Management Standards (i.e., less than SQS criteria). Soil washing/particle separation is potentially effective and implementable in the LDW where the percentage of sand in the sediment exceeds ~ 30% by weight. It is anticipated that most of the COCs will concentrate on the remaining sludge (fines fraction) which will then need disposal. This concentrating process, if too great, could cause the sludge to be designated as hazardous waste.
	Physical	Separation	Presented as unit costs in FS.
		Solidification	If future designs require further water reduction methods and to remove free water prior to landfilling.

Table 7-4 Remedial Technologies and Process Options Retained for Potential Use in Developing Remedial Alternatives

General Response Action	Technology Type	Process Option	Comments Related to Technology Assumptions for the FS
Disposal	On-site Disposal	Contained Aquatic Disposal (CAD)	The overall space (volume) capacity for CAD is limited. However, adequate capacity may be available to contain substantial portion of the contaminated dredged sediment for those alternatives requiring the least amount of dredging. However, for most alternatives, CAD will not be adequate for project-wide application, but could serve to contain a portion of the contaminated sediment. Substantial implementability logistics issues need to be addressed with CAD. Also, constraints with long-term institutional controls (e.g., conflict if located within established dredging areas) and multiple agency approvals to authorize the site are a concern.
		Confined Disposal Facility (CDF)	Not applicable to LDW site-wide application because of limited locations (and capacity) without other current uses. May be applicable for smaller-scale location-specific application.
	Off-site Disposal	Beneficial Use (In-Water and Upland)	Sediment that tests suitable for beneficial use pursuant to the Washington State Sediment Management Standards (i.e., less than SQS criteria) may be beneficially reused for habitat creation, capping, or residual management. In case of treatment (e.g., soil washing), the sediment may qualify for beneficial reuse.
		Landfill (Subtitle D)	Applies specifically to sediment that is characterized as non-hazardous in accordance with federal or state regulations. Regional landfills that can accept nonhazardous sediment are Allied Waste Inc. (Roosevelt, Washington) and Waste Management (Arlington, Oregon).
		Landfill (Subtitle C)	Applies specifically to sediment that is characterized as hazardous or dangerous in accordance with federal or state regulations. This condition is not expected to occur on a large scale and more likely will be limited to localized hot spot removal areas, if triggered at all.
		Dredged Material Management Program (DMMP) Open-water Disposal	This is a potentially viable disposal option where the average concentration of COCs in the entire dredged material management unit is determined to be less than the DMMP disposal requirements.

Notes:

Representative site-wide process options included in the development of the remedial alternatives and cost estimates for this FS. Other process options may have location-specific applicability; but not site-wide applicability.

1. These technologies and process options were screened and retained in Tables 7-2a through 7-2e, and summarized in Table 7-3.

CAD = contained aquatic disposal; CDF = confined disposal facility; COCs = chemicals of concern; CTM = Candidate Technologies Memo; DMMP = Dredged Material Management Program; Ecology = Washington State Department of Ecology; ENR = enhanced natural recovery; EPA = U.S. Environmental Protection Agency; MNR = monitored natural recovery; MTCA = Model Toxics Control Act; MLLW = mean lower low water; NCP = National Contingency Plan; SQS = Sediment Quality Standards; STM = Sediment Transport Model.

Table 7-5 Sediment Dredging and Handling Methods Used on Representative Projects in the Puget Sound Region

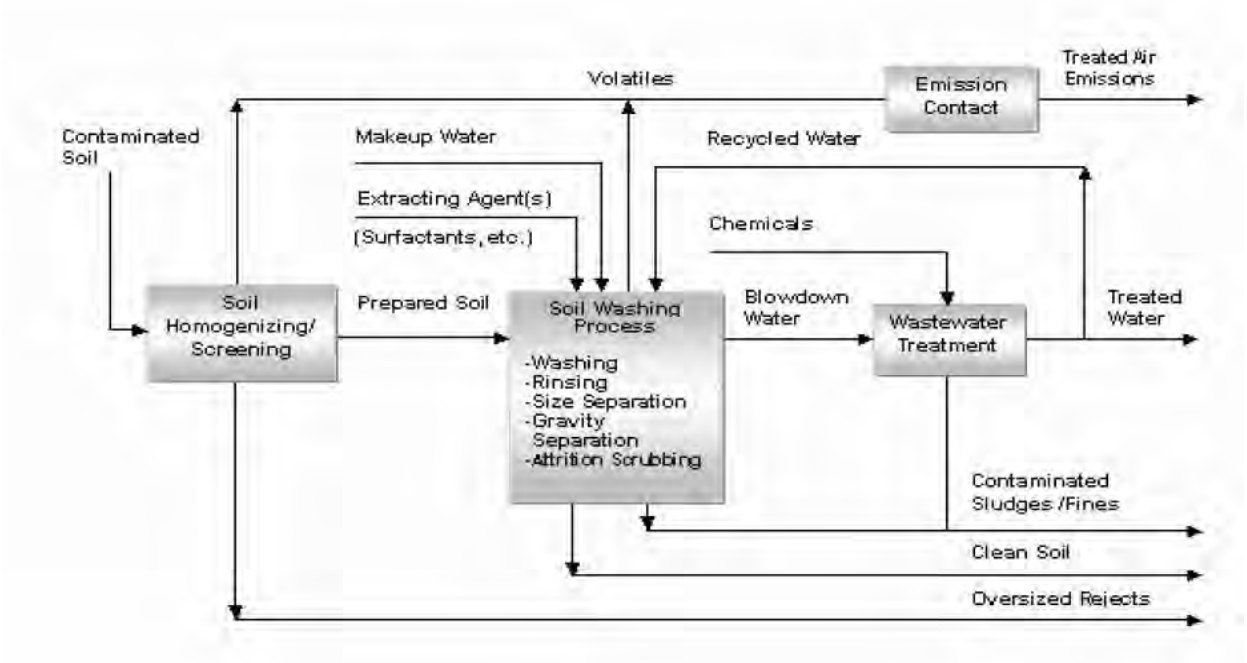
Sediment Remediation Project	Completed	Dredge Method	Disposal Method	Predicted Volume of Dredged Sediment (cubic yards)	Actual Volume of Dredged Sediment (cubic yards)
Wyckoff/Eagle Harbor West Operable Unit	1997	Mechanical	CDF	1,300 to 9,200	6,000
Norfolk Sediment Remediation	1999	Mechanical	Subtitle D landfill and Subtitle C landfill	4,050	5,190
Cascade Pole Site	2001	Mechanical	CDF	n/a	40,000
Puget Sound Naval Shipyard	2001	Mechanical	CAD	300,000	n/a
Weyerhaeuser	2002	Mechanical	Landfill	n/a	n/a
Hylebos Waterway – Area 5106	2003	Hydraulic	CDF	20,000	n/a
East Waterway	2004	Mechanical	Subtitle D landfill	n/a	n/a
Lockheed Shipyard	2004	Mechanical	Subtitle D landfill	46,625	70,000
Todd Shipyard	2004	Mechanical	Subtitle D landfill	116,415	220,000
Duwamish/Diagonal	2004	Mechanical	Subtitle D landfill	42,500	66,000
Middle Waterway	2004	Mechanical	CDF	75,000	109,000
Hylebos Waterway – Segments 3-5	2004	Mechanical	CDF	n/a	>100,000
Pacific Sound Resources	2004	Mechanical	Subtitle D landfill	3,500	10,000
Head of Hylebos Waterway	2005	Mechanical	Subtitle D landfill	217,000	419,000
Thea Foss – Wheeler Osgood Waterways	2005	Hydraulic	CDF	620,000[a]	422,535
Denny Way	2007	Mechanical	Subtitle D landfill	13,730	14,400

Notes:

a Volume from combined projects from Commencement Bay Nearshore/Tideflats Explanation of Significant Differences (EPA 2000)

CAD = contained aquatic disposal; CDF = confined disposal facility; n/a = not available

Figure 7-1 Soil Washing



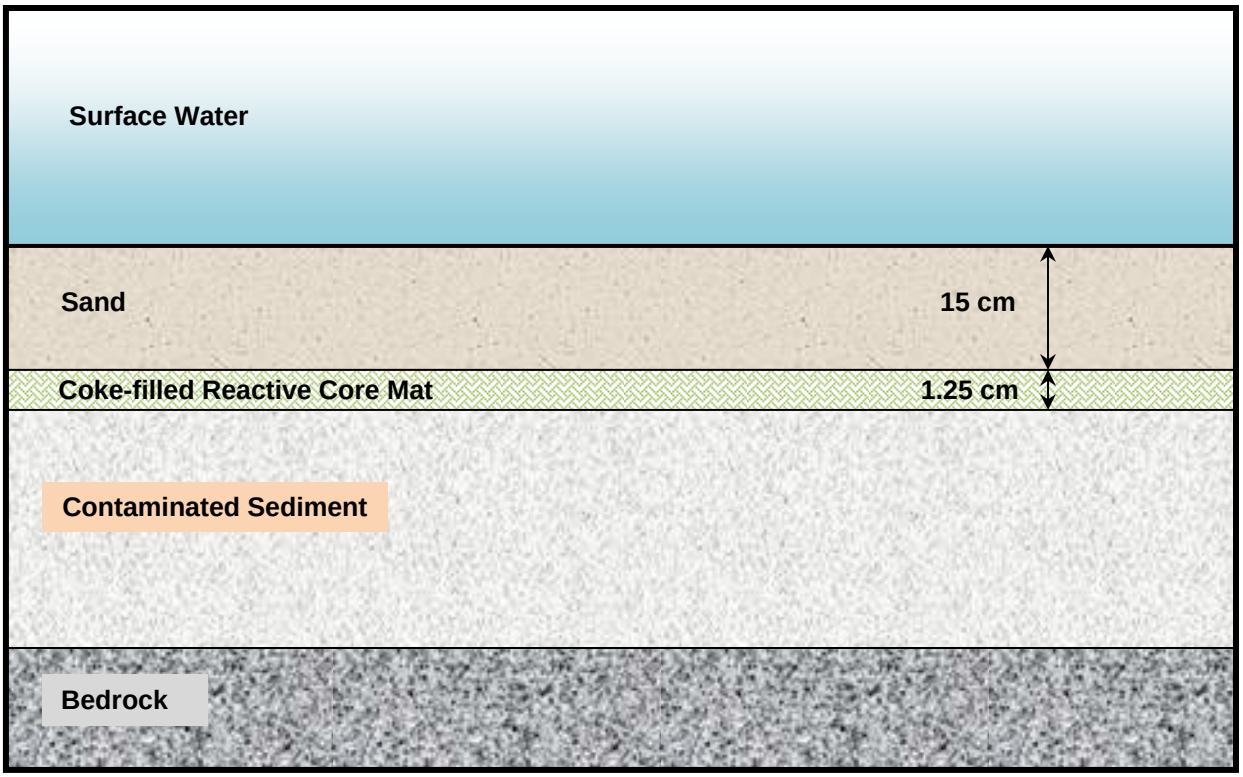
Process Diagram *http://www.frtr.gov/matrix2/section4/4-19.html*

Soil Washing. Miami River Soil /Sediment Separation Plant.
Source: Boskalis-Dolman 2006

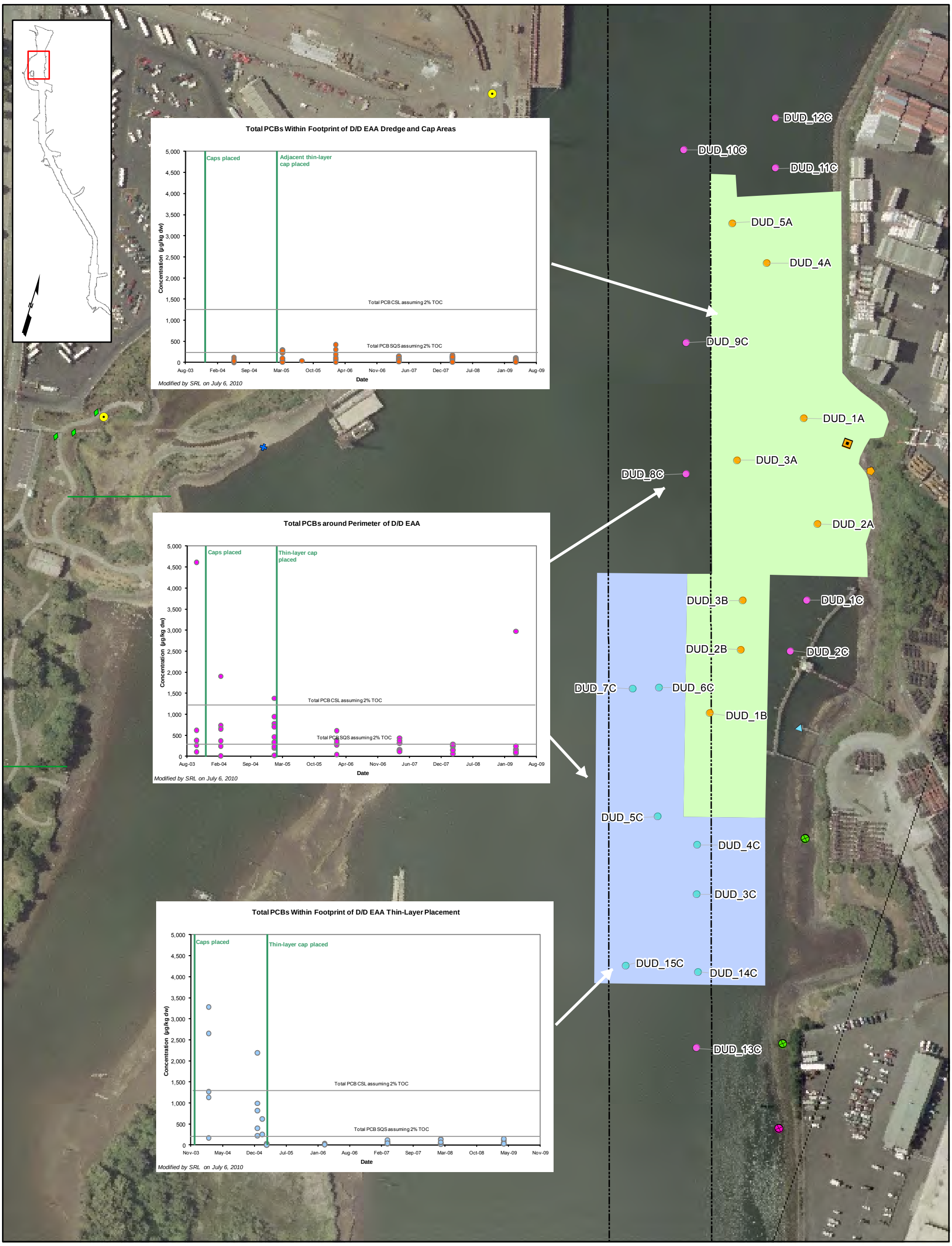
Figure 7-2 Mechanical Placement of Cap at Ward Cove, Alaska

Source: Candidate Technologies Memorandum, Retec 2007.

Figure 7-3 Schematic of Reactive Cap from Anacostia River



Note:
This reactive core mat (RCM) was designed to accurately place a 1.25-cm thick sorbent (coke) layer in an engineered sediment cap in twelve 3.1-m x 31-m sections. The RCM was overlain with a 15-cm layer of sand to secure it. It was placed in the Anacostia River (Washington D.C.) during the Anacostia River Active Capping demonstration project in April of 2004 (McDonough et al. 2006).



Notes:
1. USGS 2002 photograph provided by Windward Environmental.
2. Data provided by Windward Environmental in Access database accompanying Final Remedial Investigation (Windward 2010).
3. CSO= combined sewer overflow; EOF= emergency overflow.
4. 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 (NPDES) permit files and other relevant agency databases. These locations were later surveyed in the field. Review of agency files and interviews with agency and 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.

Outfall Location

- Private storm drain
- Permitted private storm drain
- Public storm drain
- CSO/storm drain
- EOF
- Stream, channel, or swale
- Abandoned
- Pipe of unresolved origin and/or use

0 120 240 480 Feet

Legend

- Dredge and Cap (2003-2004)
- Thin-layer Sand Placement (2005)

Sampling Location

- Dredging/Cap
- Thin-layer Sand Placement
- Perimeter
- River Mile Marker
- Navigation Channel

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

Lower Duwamish Waterway
Draft Final Feasibility Study
60150279-14.11

Surface Sediment Total PCB Trends at Duwamish/Diagonal EAA

DATE: 10/15/10 | DWRN:MVI/sea | Revision: 0

FIGURE 7-4

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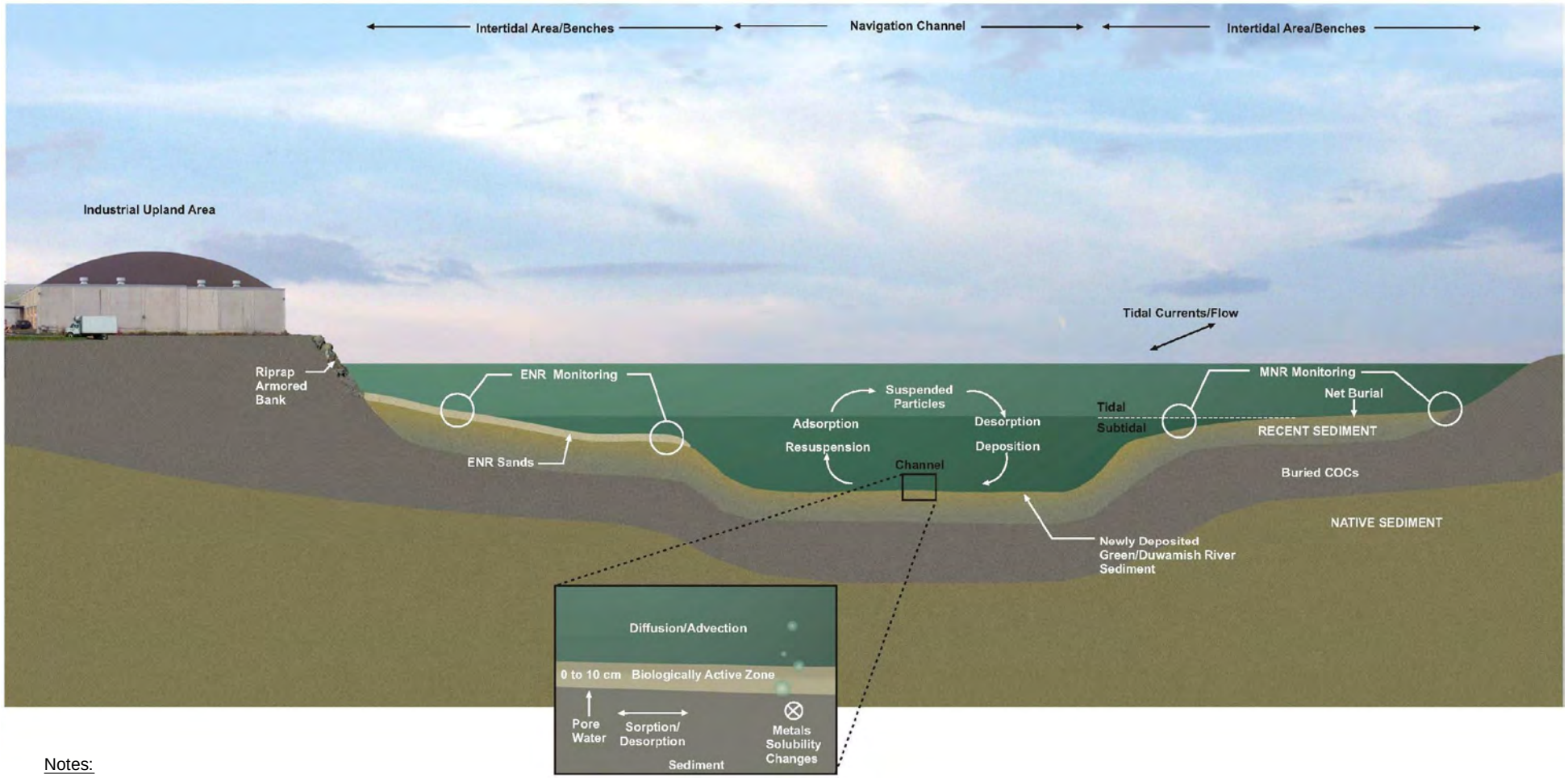
Figure 7-5 Placement of Under-pier Capping Sand between Bents by Sand Throwing Barge

Source: Interim Construction Completion Report, Todd Shipyards (McCarthy 2005)

Figure 7-6 Finished Shotcrete Surface on Debris Mound

Source: Interim Construction Completion Report, Todd Shipyards (McCarthy 2005)

Last revised 10-05-2010



Notes:

COCs = Chemicals of Concern
ENR = Enhanced Natural Recovery
MNR = Monitored Natural Recovery

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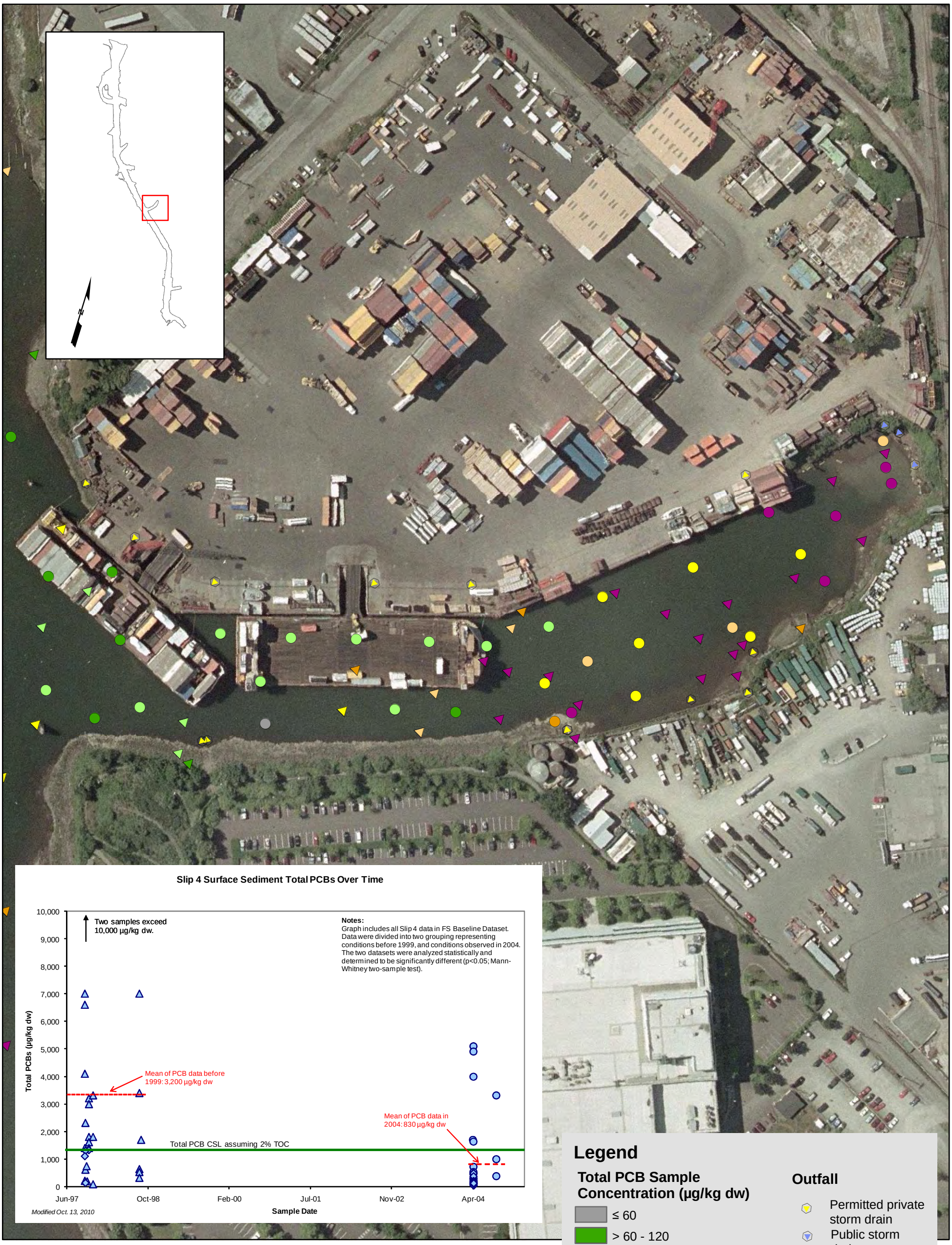
LOWER DUWAMISH WATERWAY DRAFT FINAL FEASIBILITY STUDY 60150279-14.11			CONCEPTUAL DIAGRAM OF MONITORED NATURAL RECOVERY AND ENHANCED NATURAL RECOVERY
DATE: 9/22/10	DRWN: E.M./SEA		FIGURE 7-7



Notes:
1. USGS 2002 photograph provided by Windward Environmental.
2. 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 (NPDES) permit files and other relevant agency databases. These locations were later surveyed in the field. Review of agency files and interviews with agency and 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.
3. SQS value of 240 µg/kg dw based on conversion of 12 mg/kg oc to a dry weight value using 2% TOC.

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

Lower Duwamish Waterway Feasibility Study 60150279-14.11			Surface Sediment Total PCB Trends in Slip 4
DATE: 10/15/10	DWRN:MVI/sea	Revision: 0	FIGURE 7-8

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Figure 7-9 Sloping Drain Barge

Source: interim Construction Completion Report, Todd Shipyards (McCarthy 2005)

8 Development of Remedial Alternatives

This section presents the rationale, assembly, and description of remedial alternatives for cleanup of the Lower Duwamish Waterway (LDW). The alternatives are assembled in a manner consistent with Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) guidance (EPA 1988) and the Model Toxics Control Act (MTCA) requirements. With the exception of Alternative 1 (no further action), each of the alternatives is designed to achieve the remedial action objectives (RAOs) (see Section 4).

Through the use of different remedial action levels (RALs) and types of remedial technologies, the remedial alternatives present a range in the spatial extent of active remediation,[1] time frames to achieve RAOs, volumes of sediment removed, and costs. These ranges of characteristics allow a comparison of the remedial alternatives in subsequent sections of the feasibility study (FS).

Twelve remedial alternatives have been developed (Table 8-1). The process used to develop the remedial alternatives is both sequential and iterative, and is outlined in the following sections:

- Section 8.1, Framework and Assumptions for Making Technology Assignments, describes the criteria and the approach to assigning remedial technologies for each alternative.
- Section 8.2, Common Elements for all Remedial Alternatives, describes elements applicable to all remedial alternatives, including source control, site preparation, staging, transloading, disposal, and additional details on the application of remedial technologies.
- Section 8.3, Detailed Description of Remedial Alternatives, presents the detailed elements of each remedial alternative, including actively remediated acres, volumes of dredged sediment, and numbers of years to implement.
- Section 8.4, Uncertainties, highlights specific instances where the assumptions used to develop remedial alternatives for this FS are likely to be refined during remedial design and remedial action.

[1] For the FS, "active remediation" refers to enhanced natural recovery (ENR), capping, dredging, or some combination of the three. "Passive remediation" refers to monitored natural recovery (MNR), site-wide monitoring, institutional controls, or some combination of the three.

The development of remedial alternatives is a culmination of the analyses and findings in previous sections of this FS. These include:

- **Regulatory requirements, RAOs**, and **preliminary remediation goals (PRGs)** as defined in Section 4.
- **Areas of potential concern (AOPCs),** as defined in Section 6, represent areas that exceed the PRGs**.** AOPC 1 represents the area exceeding PRGs for RAOs 2 through 4. AOPC 2 expands the AOPC 1 area to include the area[2] based on a best estimate of what areas would need to be actively remediated to achieve site equilibrium[3] (or to achieve a minimal rate of change in the SWAC immediately following remediation).
- **RALs** were developed in Section 6**.** The RALs form the primary basis for developing remedial alternatives. A RAL is defined as the point-based concentration above which an area is actively remediated using dredging, capping, enhanced natural recovery (ENR), or a combination of the three. The RALs for all risk-driver chemicals are grouped and assigned to the remedial alternatives.
- **Natural recovery potential and recovery categories** were evaluated in Sections 5 and 6**.** Predictive modeling, site conditions, and empirical trends help guide the development of remedial alternatives.
- **Representative remedial technologies** screened in Section 7 form the basis for the remedial alternatives. These include active remedial technologies: dredging, capping, upland disposal, contained aquatic disposal (CAD), treatment, ENR, and passive remedial technologies: monitored natural recovery (MNR), site-wide monitoring, and institutional controls.

Table 8-1 presents the remedial alternatives and the RALs. The remedial alternatives were developed based on the RALs developed in Section 6. In addition to a No Further Action alternative (Alternative 1), Alternatives 2 through 6 have been developed based on five groups of RALs (Table 8-1). These groups of RALs define the actively and passively remediated areas for the remedial alternatives. The bullets

[2] The long-term range of model-predicted concentrations is the point at which there is a minimal change in the site-wide average concentration, and it is considered in "equilibrium."

[3] Equilibrium is described as either the point when the rate of change (SWAC reduction per area) is small and the point at which minimal additional change in SWAC is expected to occur; or, it is when the asymptote of a recovery curve is reached.

below list the remedial alternatives and the goals that each alternative is designed, at a minimum, to achieve:[4]

- **Alternative 1 –** No further action following remediation of the early action areas (EAAs). This alternative provides a baseline against which to compare the other remedial alternatives; its inclusion is required by CERCLA.
- **Alternatives 2R and 2R-CAD –** Actively remediate 59 acres with chemical concentrations above the Alternative 2 RALs. These alternatives are designed to achieve, at a minimum:
  - Incremental risk reduction for RAO 1 (human health seafood consumption) through active remediation
  - RAO 2 (human health direct contact) PRGs within 10 years following construction
  - The cleanup screening levels (CSL) of the Washington State Sediment Management Standards (SMS) within 10 years following construction and the sediment quality standards (SQS) within 20 years following construction for RAO 3 (benthic)
  - RAO 4 (river otter) PRG within 10 years following construction.

  MNR is used where viable in areas with concentrations below the RALs to achieve RAOs following construction (e.g., SQS within 20 years following construction). For areas exceeding the RALs, Alternatives 2R and 2R-CAD emphasize removal (dredging) using upland and CAD disposal methods, respectively.
- **Alternatives 3R and 3C –** Actively remediate 86 acres with chemical concentrations above the Alternative 3 RALs. These alternatives are designed to achieve, at a minimum, the outcomes of Alternative 2, plus:
  - Achieve further incremental risk reduction for RAO 1 through active remediation
  - Achieve RAOs 2 and 4 immediately following construction, rather than 10 years following construction

[4] The model-predicted outcomes in Section 9 are different from the design outcomes in Section 8. This is mostly a result of BCM timing. For the assignment of remedial technologies discussed in Section 8, the starting point for the BCM is assumed to be after completion of construction. For the purpose of predicting remedial outcomes (Section 9), modeling is assumed to begin at the start of construction. Therefore, Section 9 assumes that natural recovery occurs concurrent with construction and Section 8 does not. Because of this small difference, Section 9 shows lower predicted chemical concentrations in LDW surface sediments.

- Achieve the CSL immediately following construction, rather than 10 years following construction for RAO 3.

MNR is used where viable in areas with concentrations below the RALs to achieve RAO 3 PRGs during a specified time frame following construction (i.e., SQS within 20 years following construction). For areas exceeding the RALs, Alternative 3R has a removal emphasis (i.e., dredging) and Alternative 3C uses a combined technology approach (i.e., capping and ENR).

- **Alternatives 4R and 4C –** Actively remediate 143 acres above the Alternative 4 RALs. These alternatives are designed to achieve, at a minimum, the outcomes of Alternative 3, plus:

  - Achieve further incremental risk reduction for RAO 1 through active remediation
  - Achieve the SQS for RAO 3 within 10 years following construction as opposed to 20 years following construction.

  MNR is used where viable in areas with concentrations below the RALs to achieve RAO 3 PRGs during a specified time frame following construction (i.e., SQS within 10 years following construction). Like Alternative 3, Alternative 4R emphasizes a removal technology approach and Alternative 4C uses a combined technology approach.

- **Alternatives 5R, 5R-Treatment, and 5C –** Actively remediate 186 acres above the Alternative 5 RALs. These alternatives are designed to achieve, at a minimum, the outcomes of Alternative 4, plus:

  - Achieve further incremental risk reduction for RAO 1 through active remediation
  - Achieve the SQS for RAO 3 immediately following construction as opposed to 10 years following construction.

  MNR is not used in this alternative; however, natural recovery outside of AOPC 1 contributes to risk reduction for RAO 1. For areas exceeding the RALs, Alternative 5R emphasizes removal with upland disposal, Alternative 5R-Treatment also emphasizes removal and adds soil-washing treatment, and Alternative 5C uses a combined technology approach.

- **Alternatives 6R and 6C –** Actively remediate 328 acres above the Alternative 6 RALs. These alternatives are designed to achieve, at a minimum, the outcomes of Alternative 5, plus:

- Achieve approximate equilibrium conditions immediately after construction for the human health risk drivers.

MNR is not used in this alternative. For areas exceeding the RALs, Alternative 6R emphasizes removal and Alternative 6C uses a combined technology approach.

The remedial technologies have been assembled into the 12 remedial alternatives (Alternatives 1, 2R, 2R-CAD, 3C, 3R, 4C, 4R, 5C, 5R, 5R-Treatment, 6C, and 6R) listed above. The various technologies are represented consistently among the remedial alternatives in the following way:

- All remedial alternatives rely on institutional controls to protect human health pursuant to achieving RAO 1. Additional institutional controls are used for long-term protection of engineered containment systems (e.g., caps or on-site CAD facilities) and ENR and MNR. All of the alternatives (except Alternative 1) include site-wide monitoring to assess risk reductions over time relative to RAO 1.

- Sediment removal (e.g., dredging) is incorporated into all active remedial alternatives. For the alternatives that emphasize removal (Alternatives 2R, 2R-CAD, 3R, 4R, 5R, 5R-Treatment, and 6R), dredging/excavation and disposal are the primary process options for active remediation. However, complete removal is unlikely to be feasible in some locations (particularly on banks and around structures), and thus these alternatives also include some isolation capping or partial dredging and capping. For the alternatives that use a combination of technologies (Alternatives 3C, 4C, 5C, and 6C), dredging and excavation are used when capping and ENR are not considered to be implementable.

- Upland disposal is incorporated into all remedial alternatives. In conjunction with upland disposal, CAD is incorporated into Alternative 2R-CAD and soil treatment is incorporated into Alternative 5R-Treatment. The CAD and soil treatment could be incorporated into any alternative, but are presented once to facilitate comparisons with other remedial technologies and disposal options in Sections 10 and 11.

- Capping and ENR are incorporated into the "combined technology" remedial alternatives (Alternatives 3C, 4C, 5C, and 6C), based on the decision criteria in Section 8.2. For these alternatives, ENR is used where considered feasible based on site conditions (e.g., scour potential, sediment chemistry), capping is used where ENR is not considered to be feasible, and partial dredging and capping are used when elevation constraints preclude capping.

- MNR is a key component of Alternatives 2 through 4. MNR is employed, where feasible, to allow recovery over time to achieve PRGs for RAOs 2, 3, and 4. Details on monitoring programs and contingency actions that are part of an MNR approach are provided in Sections 8.2.5 and 8.2.6.
- Natural recovery in areas below the RALs is a site-wide process that will continue to reduce surface sediment concentrations for all remedial alternatives.
- Site-wide monitoring is part of all remedial alternatives.

8.1 Framework and Assumptions for Making Technology Assignments

This section describes the criteria and assumptions used to guide the assignment of remedial technologies for the remedial alternatives. The criteria used for selection of remedial technologies were developed for the purposes of the FS and are subject to modification and refinement during remedial design, as discussed in Section 8.4. A two-step process was used for assigning technologies to the remedial alternatives.

First, the spatial extent of active and passive remediation is developed for each alternative (see Section 8.1.1 and Figure 8-1). This is based on the extent of RAL exceedances, taking into account recovery potential and constructability considerations. For the removal-emphasis alternatives (Alternatives 2R, 2R-CAD, 3R, 4R, 5R, 5R-Treatment, and 6R), the active remedial footprint indicates where removal will occur. For the combined technology alternatives (Alternatives 3C, 4C, 5C, and 6C), the active remedial footprint indicates where removal, capping, or ENR will occur. Outside of the active remedial footprints, passive remediation will occur, including MNR and/or institutional controls and site-wide monitoring.

Second, after the active and passive remedial footprints are established, remedial technologies are assigned (see Section 8.1.2 and Figures 8-1 and 8-2), based on whether the alternative is focused on removal or combined technologies. This is done by using a set of defined technology criteria assumptions based on the predicted effectiveness of the remedial technologies under various conditions in the LDW. These assignments apply to all remedial alternatives and are summarized in Tables 8-2 and 8-3.

8.1.1 Spatial Extent of Active and Passive Remediation

This section describes the development of the active and passive remedial footprints for the remedial alternatives (Figure 8-1). A RAL exceedance triggers the need for active remediation. The sediment concentrations were compared to the RALs in different ways depending on location. RAL exceedances site-wide and in localized areas (i.e., beaches, potential scour areas) were determined as follows:

- Site-wide, the point of compliance is the uppermost 10 cm of the sediment. Therefore, concentrations for all chemicals in the upper 10 cm of sediment were compared with the RALs. The spatial extent of RAL exceedances for individual risk-driver chemicals was defined by the interpolated area of the LDW with surface sediment concentrations exceeding the RALs (see Section 6 for interpolation methods).
- In areas where significant scour is possible (more than a 10-cm scour depth during a 100-year high-flow event, or observed vessel scour areas; see Sections 5 and 6), contaminated subsurface sediment could be uncovered and exposed. In these areas, the maximum chemical concentrations in cores in the upper 2 feet (ft) of sediment were compared to the RALs. The spatial extent of the RAL exceedance within potential scour areas was conservatively assumed to be the entire extent of the potential scour area if there was only a single subsurface sample within that area. If more than one core was located in a scour area, the spatial extent of the RAL exceedance was governed by the nearest core.
- In intertidal areas, the point of compliance for PCBs, arsenic, cPAHs, and dioxins/furans is established as the upper 45 cm of the sediment because of potential human direct contact during clamming or beach play. For SMS criteria, chemical concentrations within the upper 10 cm are compared to the RALs unless in an area with significant scour potential. For the FS, the maximum chemical concentration of the four human health risk drivers at any depth in the upper 45 cm of cores or in surface sediment samples[5] was compared to the intertidal RALs. The spatial extent of RAL exceedances in intertidal areas was based primarily on surface sediment concentrations (i.e., interpolated area or Thiessen polygons as described above) and core data, when available. In instances where core exceedances were outside areas represented by the surface grab exceedances, the active remedial footprint was expanded an appropriate amount based on analysis of the chemical and physical conditions at that location.
- In assumed beach play areas, the FS baseline cumulative (all risk-driver chemicals combined) excess cancer risk for each individual beach was compared with the 1×10^{-5} risk threshold to ensure that the active remedial footprint based on the RALs was sufficiently protective for each beach.

For all alternatives, the area with concentrations exceeding the RALs was assigned to the active remedial footprint. For Alternatives 2 and 4, the RALs for SMS chemicals (including polychlorinated biphenyls [PCBs]) are a range. In most locations, the upper

[5] In other words, if core data were not available, then the concentration in a 0-10 cm surface sediment sample was assumed to extend to 45 cm depth.

RAL was employed. In locations not predicted to achieve the CSL (Alternative 2) and SQS (Alternative 4) within 10 years following construction, the lower RAL was used (see Table 8-1). Specifically, the lower RAL was employed: a) in areas where the bed composition model (BCM) predicted concentration was greater than the CSL (Alternative 2) or SQS (Alternative 4) within 10 years; and b) in Recovery Categories 1 and 2 (see Section 8.1.2.4 for more detail on recovery categories).

For FS purposes, the spatial extent of the active remedial footprint was modified for constructability (e.g., minimum 100 ft x 100 ft constructible areas). The active remedial footprints will be refined during remedial design.

Passive remedial technologies are described in Section 8.2, including a discussion of adaptive management and potential contingency actions (Section 8.2.6). MNR is assigned to all areas within AOPC 1 that are not actively remediated (see Section 8.2.2.4). A subset of these areas is expected to be below the PRGs at the time of construction (data are isolated and more than 10 years old, or data indicate that natural recovery has occurred). These areas are designated for verification monitoring (VM) during remedial design. Institutional controls and site-wide monitoring apply to all alternatives, except Alternative 1. Monitoring for construction performance, maintenance, or achievement of RAOs also applies to all alternatives, except Alternative 1.

8.1.2 Assigning Remedial Technologies

Figures 8-1 and 8-2 describe the decision process for assigning active or passive remediation to an area for each alternative. The criteria used for technology assignments included chemical upper limits, contamination thickness, navigation and berthing elevation requirements, recovery categories, habitat, and overwater structures. Technology assignment criteria are described briefly in the following sections, and additional details regarding remediation are described in Section 8.2.

These technology assignments are preliminary to facilitate development and comparative analysis of remedial alternatives for this FS. Additional information on site characteristics and technology effectiveness may change the technology application during remedial design. Section 8.4.2 discusses uncertainties with respect to technology assignments and provides examples of how technology assignments and assumptions may change during remedial design.

8.1.2.1 Chemical Upper Limits

The chemical upper limit (UL) of each technology is the highest concentration that is assumed can be remediated under site conditions to achieve the identified goals for the technology. Removal and capping technologies do not have ULs. Site-wide, the UL for ENR is 3 times the RAL (3:1 ratio of mixing), except in intertidal areas, where it is limited to 1.5 times the RAL. The UL for MNR is, by definition, the RAL.

In intertidal areas, ENR is considered to be a viable remedial technology if the estimated average concentration for chemicals after ENR placement (6 inches of sand) is below the intertidal RAL over the 45 cm vertical compliance depth. Cap modeling (Appendix C) predicts no UL is needed for capping to protect the upper 45 cm of sediment for total PCBs or cPAHs.

The UL for effective ENR and capping depends on physical conditions such as net sedimentation rate and groundwater flux; therefore, location-specific analysis may change the ULs during design.

8.1.2.2 Contamination Thickness

For the combined technology alternatives, partial dredging and capping is warranted if more than 1 ft of contamination remains after partial dredging for cap placement. Partial dredging and capping is applicable in locations with topographic grade restriction, including habitat areas, berthing areas, and the navigation channel. For example, in habitat areas, if the contamination thickness is greater than 4 ft, then partial dredging and capping to accommodate a 3-ft thick cap is the assigned technology. The removal alternatives assume full removal is possible. The contamination thickness layer is developed in Appendix E and used to generate volume estimates as described in Section 8.2. The contaminated sediment thickness estimate will be refined during remedial design.

8.1.2.3 Navigation and Berthing Area Elevation Requirements

Authorized navigation channel depths and permitted depths for berthing areas influence technology implementation, with the goal that maintenance dredging should not compromise the integrity of a remedial action. Figure 2-21 identifies the authorized depths for the navigation channel and the permitted depths for berthing areas. For the FS, it is assumed that the post-construction cap or ENR elevation must be at least 3 ft below the authorized depth in the navigation channel, and at least 2 ft below the permitted depth in berthing areas. Because 18 inches is a typical vertical dredge tolerance for maintenance dredging, 2 ft of clearance is generally sufficient to ensure the integrity of the remedial action. Because the navigation channel is federally authorized, an additional 1-ft margin of safety was assumed to achieve the 3-ft clearance noted above. Final clearances in the navigation channel[6] or berthing areas will be determined in consultation with relevant parties during remedial design.

Elevation controls may also apply outside of the navigation channel or berthing areas. For example, the U.S. Army Corps of Engineers (USACE) horizontal dredge tolerance is typically 10 ft to either side of the navigation channel, so post-construction clearance elevations may apply in these areas. By extension, additional constraints may be placed

[6] In a letter to EPA, USACE is requesting 4-ft post-construction vertical clearance in the navigation channel after capping and a 10-ft buffer on either side of the channel (USACE 2010).

on capping side-slopes that angle from the navigation channel because of the possibility that maintenance dredging within the horizontal and vertical dredge tolerances may undermine the slope. These additional elevation considerations require detailed design analysis, and additional dredge volumes attributable to this consideration are assumed to be addressed by the dredge volume contingency (see Appendix E), but are not used in assigning remedial technologies.

Although the depth criteria above are sufficient for FS-level analyses of remedial alternatives, these are subject to change during remedial design (see Section 8.2.2.5). Both the dredge tolerance assumptions and the assumptions of the permitted depths in berthing areas are subject to refinement during remedial design.

8.1.2.4 Recovery Categories

Recovery categories are an FS-level surrogate for design level, location-specific analysis. The intent of using recovery categories for technology assignments is to apply more aggressive cleanup technologies (capping, dredging) in areas with less potential for natural recovery, and to optimize use of less aggressive cleanup technologies (ENR, MNR) in areas where recovery is predicted to occur more readily. Recovery categories were delineated in Section 6 to group areas of the waterway that have similar conditions with respect to predicted rates of natural recovery. The criteria used to delineate the recovery categories are developed in Section 6 and presented in Table 6-3. Figures 6-4a and 6-4b illustrate their spatial extent. Recovery categories are delineated independent of RAL exceedances or AOPCs. The factors that were incorporated into recovery categories include Sediment Transport Model (STM)-predicted high-flow event scour >10 cm depth, vessel scour, net sedimentation rates, berthing areas with low sedimentation rates, and empirical chemical trends.

Table 8-3 shows which remedial technologies are applicable within each recovery category. Table 8-4 relates the recovery categories to the RALs and remedial technologies for each remedial alternative. The following bullets describe how the recovery categories were used to make technology assignments:

- Recovery Category 1 represents areas where recovery is presumed to be limited. These areas are assumed to be candidates for dredging and capping, but are not candidates for either ENR or MNR(10) (see Table 8-3).
- Recovery Category 2 represents areas that have a less certain recovery potential. These areas are assumed to be candidates for dredging, capping, and ENR, but are not candidates for MNR(10) (see Table 8-3).
- Recovery Category 3 represents areas that are predicted to recover relatively quickly. These areas are therefore candidates for dredging, capping, ENR, and MNR.

8.1.2.5 Elevation Requirements in Habitat Areas

The maintenance of existing habitat area elevations in the LDW is an important aspect of all remedial alternatives. Intertidal and nearshore habitats are home to diverse communities of fish, birds, mammals, and invertebrate species. These areas are defined to be locations with an elevation greater than -10 ft mean lower low water (MLLW). For the FS, it is assumed that habitat within this zone (up to the approximate mean higher high water (MHHW) elevation, which is estimated to be +11.3 ft MLLW) will be managed in ways that approximately restore current elevations. Post-construction bathymetric elevation contours are assumed to be restored to the initial grade, and material placed in these areas will provide suitable habitat substrate. A sandy gravel material (referred to as "fish or habitat mix") is assumed to be applied as a top dressing in intertidal areas. For areas above -10 ft MLLW, the FS assumes that:

- Dredged or excavated sediment will be backfilled to original grade.
- Areas identified for isolation capping will be partially dredged to accommodate cap thickness. Caps that are sited in potential clamming areas may be designed with a greater thickness (e.g., 5 ft) such that the isolation functions of the cap are not affected by potential clamming activities; however, for this FS, a cap thickness of 3 ft is assumed in habitat areas.
- Elevations of habitat areas are assumed to be unaffected by ENR sand placement or MNR, regardless of location.

The assumptions above were employed in all areas above -10 ft MLLW with the exception of under-pier areas (see Section 8.1.2.6 for assumptions under piers). Not all intertidal areas are viable habitat areas (e.g., vertical bulkheads). Engineered slopes, bulkheads, and riprap shorelines are also present in the LDW and provide structural support to the shoreline; they may be more difficult to remediate and/or afford grade restoration (see shoreline conditions in Section 8.1.3). Below -10 ft MLLW, no grade restoration is assumed to be required. Additional opportunities to maintain or improve habitat areas may be evaluated during remedial design. For example, to create more intertidal acreage, some projects have placed an isolation cap on top of existing subtidal grades, or have over-excavated bank areas prior to capping.

8.1.2.6 Overwater Structures

Piers, dolphins, piling, and other overwater structures are important considerations in determining if capping and dredging can be implemented. Numerous overwater structures (generalized here by the term piers) exist along the shoreline of the LDW (Figure 2-22). These piers present special challenges for addressing contaminated sediment residing underneath and adjacent to these structures. All remedial actions under piers need to account for the potential structural ramifications of sediment removal or sediment addition (e.g., capping) and the difficulties of implementing remedial actions in limited access areas. For these and other reasons, under-pier areas

will require location-specific evaluation, but individual overwater structures are not evaluated for this analysis. Instead, a set of assumptions were used for developing and costing the site-wide remedial alternatives.

Because the Remedial Investigation (RI) dataset contains little information on sediment contamination under piers, the active remedial footprint below piers was defined by the sediment conditions adjacent to the piers and assumed to extend underneath.

For the removal alternatives, partial dredging and capping is assumed for all areas above RALs because it will be difficult to implement full removal in these limited access areas. For cost estimating, dredging is assumed to be performed by a means other than open-water dredging, such as diver-assisted hydraulic dredging or partial demolition of the pier structure to provide access (see Section 7.1.1). Where used, partial dredging, to the extent feasible, would then be followed by capping. For the combined technology alternatives, capping is assumed under piers in areas above RALs. In practice, various cap thicknesses may be viable in under-pier areas, ranging from a thin 6-inch cap to a thicker isolation cap. For cost estimating, 3 ft capping is assumed to be performed by a means other than open-water capping, such as casting of sand under piers using a belt conveyor, dry application using small construction equipment, or grout mats (see Section 7.1.4).

Each under-pier area will need to be evaluated during design. Additional design considerations include: the practicability of sediment removal or containment, the structural state and use of the pier, the hydrological and geological conditions under the pier, elevation restrictions, presence of debris, access, and the use of other remedial technologies (such as ENR).

8.1.2.7 Constructability and Best Professional Judgment Modifications

When the criteria described above are considered together, the resulting technology footprints include some small, irregular areas that may be impractical to remediate. Therefore, the remedial alternatives have slightly modified technology footprints to account for constructability and location-specific conditions.

Elements that went into the final modification of the remedial footprints include:

- Setting a minimum size of about 100 ft x 100 ft for technology areas.
- Evaluating berthing depths based on frequency of maintenance dredging, bathymetric survey data, and access issues.
- Evaluating chemical data and empirical time trends for recovery to ascertain potential pre-construction sediment concentrations relative to RALs (i.e. verification monitoring areas; see Appendix D).

Modifications to the remedial technology assignment areas are based on best professional judgment.

8.1.3 Other Considerations Not Addressed in Technology Assignments

This section addresses some additional considerations that need to be evaluated during remedial design, but were not used to assign remedial technologies. These include utilities, slope stability, and shoreline conditions.

Utilities

Utilities are important site features to understand and factor into remedial alternatives. Figure 2-22 maps known utility lines or corridors (in-water and overhead). More detailed utility information will be needed during remedial design. Site-specific evaluations will be needed regarding whether material can be placed over underwater utilities (i.e., capping and ENR), and what setback distances will be required when dredging in areas that contain utilities. For the FS, the presence of utilities (particularly in-water) is acknowledged as a consideration for implementation, but is not assumed to prevent the use of dredging, capping, or ENR technologies.

Slope Stability

Preliminary bearing capacity and slope stability engineering evaluations for capping feasibility were conducted to assess potential design impacts associated with the river bottom and bank slopes. These engineering evaluations determined that caps placed on slopes greater than 20 degrees can experience some amount of deformation under certain seismic loading conditions. Capping in these areas is not precluded, but requires a higher level of engineering design effort and appropriate long-term management controls to ensure long-term integrity.

Dredging in sloped areas needs to be carefully evaluated during remedial design to prevent sloughing and adverse impacts to engineered structures (e.g., slope armoring, piles, and bulkheads used to support docks, wharfs, and upland structures). In some cases, these considerations are expected to preclude complete removal of contaminated sediments in nearshore areas and areas with overwater structures, and capping or ENR would then be used to reduce exposure to the remaining contaminated sediment.

For the FS, slope stability is not incorporated into technology assignments for specific locations of the LDW, but is accounted for in the form of a cost premium in development of the remedial alternative. Approximately 10 acres of the LDW have slopes that are greater than 20 degrees. Up to 3 acres in these areas are designated for capping under the combined technology alternatives. For cost estimating, 10% was added to the total cap material volume to address the need to create flatter slopes where existing slopes are more than 20 degrees.

Shoreline Conditions

Shoreline conditions will have a large impact on nearshore remediation. Site features, such as the presence of riprap, sheetpile walls, upland infrastructure, overwater structures, limited access areas, or previously restored habitat areas will affect the remedial design and ability, or need, to fully remove contaminated sediments. For example, remediation must be conducted such that engineered and load-carrying walls and slopes are not compromised by sediment removal actions. General shoreline conditions (armored slope or riprap, vertical bulkhead, or exposed bank) mapped in the RI are shown on the alternative maps for reference; however, location-specific analysis was not performed as part of the development of site-wide remedial alternatives. The merits and difficulties of remediating these areas will be re-evaluated during remedial design.

Engineering challenges associated with shoreline conditions may result in additional costs. These additional costs are accounted for by adding a cost premium for technically challenging remediation areas. Technically challenging remediation areas are assumed to be 10% of the active remedial footprint for each remedial alternative (see Appendix I).

8.2 Common Elements for all Remedial Alternatives

This section provides additional details pertinent to all remedial alternatives. It includes common engineering assumptions (8.2.1), technology-specific engineering assumptions (8.2.2), remedial design investigations and evaluations (8.2.3), monitoring (8.2.4), adaptive management (8.2.5), and project sequencing (8.2.6). Source control is also a common element of all alternatives (see Section 2.4). It is assumed that source control work will be sufficiently complete before remediation begins and source control will be implemented in parallel with the sequencing of remedial actions.

8.2.1 Common Engineering Assumptions

This section discusses physical and logistical constraints related to implementation of all remedial alternatives and the engineering assumptions made to address them in the FS.

8.2.1.1 Site Preparation, Debris Removal, and Staging

Site preparation for sediment remediation projects is location-specific and generally limited to clearing the remediation areas of debris and other obstructions, as needed.

Debris of varying size and spatial density is likely in much of the LDW, given its long history of industrial and commercial use. The nature and extent of debris will be determined during remedial design. Standard practice in environmental dredging operations is to remove or “sweep” for debris (e.g., logs, concrete, sunken boats) concurrent with sediment removal and before beginning capping or ENR. Each alternative assumes that some degree of debris removal is required for dredging,

capping, and ENR projects, and that these sweeps will be conducted using a derrick barge and clamshell dredge. The debris is then barged and offloaded at a transloading facility for subsequent shipment to an upland landfill or for potential recycling (i.e., beneficial reuse). Side-scan sonar surveys, magnetometer surveys, and others methods may be used to assess the presence/absence of debris. If no debris is detected, a debris removal pass may not be required. The amount of debris clearance necessary could vary based on the remediation area and the type of technology employed. For the FS, debris removal is incorporated into the cost estimate by decreasing the open-water dredge production rate for 10% of the dredge footprint, and by adding a per acre unit cost for the entire ENR and capping footprint (see Appendix I for detailed cost estimates). The assumption of 10% for the dredge footprint area is adequate for FS cost estimating purposes, but the extent of debris in the LDW is not well known at this time and will need to be refined during remedial design.

Piling, dolphins, and other in-water infrastructure will be allowed to remain in place or will be removed prior to sediment remediation, depending on site-specific conditions. For this FS, dolphins are assumed to remain in place. Derelict piling and piers within actively remediated areas are assumed to be removed as part of the remediation. For cost estimating, pile and pier removal is not included as an independent line item; however, this cost is incorporated as an additional cost premium (assumed to be 10% of the LDW, see Appendix I). Piles are typically extracted or cut at the mudline, leaving any remaining pile stubs submerged in the mud where they will not impede boat traffic.

Staging for sediment remediation projects refers to upland operational areas that support material and equipment handling to and from the in-water project site. Upland staging areas are required to support land-based (dry) excavation operations. These staging areas are also needed to support the transloading of dredged sediment intended for upland landfill disposal (see Section 8.2.1.2). Other staging areas may be required for equipment and raw material transfers to barges. The LDW is a working industrial waterway serviced by multiple marine construction companies. Numerous docks, piers, and property, potentially suitable for various staging functions, flank the LDW, although the availability and suitability of these properties to support remedial construction activities is not known at this time.

For FS planning purposes, it is assumed that suitable land will be available adjacent to the LDW for staging and support activities. Specific staging areas have not been identified, and only rough assumptions have been made about specific staging area requirements. A line item is included in the cost estimates to account for leasing, site preparation, and set-up of an upland staging facility for the remedial alternatives (see Appendix I).

An additional facility cost is provided in the estimate for Alternative 5R-Treatment to account for staging of a soil washing treatment facility.

Because of likely access constraints, land-based excavation is anticipated to be feasible for only a small percentage of the LDW. It is assumed that excavation will typically occur via barge-mounted dredge or excavation equipment. Excavation of most banks is assumed to occur during the in-water work window, although a small percentage of bank areas could be excavated in the dry at low tide outside of the in-water work window, subject to EPA approval.

8.2.1.2 Transloading and Upland Disposal

The availability and capacity of transloading and transportation infrastructure to manage dredged material is an important factor in the production or dredging rate. Allied Waste Inc. has leasing arrangements with a private property owner along the LDW, and can perform transloading operations that involve direct transfers from a barge to lined bulk-material shipping containers. It is assumed that the containers would be trucked to the 3rd Avenue and Lander (Seattle, Washington) transfer facility (6 miles round trip), then transferred to rail (BNSF), and shipped to the Allied Waste Inc. landfill in Roosevelt, Washington (570 miles round trip see Appendix L). The transloading facility and rail operation capacity is expected to range between 1,000 and 2,000 tons/day based on the logistics of moving one train in/out of the LDW valley per day on existing rails, and providing temporary storage for daily dredged material (Casalini 2009; personal communication). One car contains approximately 75 tons and one train is approximately 22 cars. The construction time frames are based on the transloading capacity of 1,600 tons/day (see Appendix I for details). The construction time frame for all the remedial alternatives is based on the same transloading rate; however, an analysis of the remedial alternatives with double the transloading rate is performed in Section 10. Other methods of transloading sediment, such as direct container loading on barges, may also be considered during remedial design.

Additional hauling and disposal capacity is feasible but not currently available without significant infrastructure upgrades or securing an alternate location. Property ownership, current land uses, prospects for leasing, adjacency to road and rail services, and permitting are all factors in whether and when new or expanded capacity can be made available. Additional capacity or alternate staging locations have been assumed to be available along the LDW and will be identified as needed during remedial design. In addition, existing docking and land-based infrastructure is assumed to be sufficient to support these operations, requiring only modest upgrades. The logistics and actual sizing (capacity) of the transloading operations will be determined during remedial design.

8.2.1.3 Water Management

For the FS, it is assumed that dredged sediment will initially be dewatered on the dredge scows and allowed to discharge back to the LDW within the active dredge area. The dredge scows will be equipped with appropriate best management practices (BMPs) (e.g., hay bales, filter fabric, etc.) to filter runoff as necessary to maintain

compliance with applicable water quality criteria established for the dredging operations. Gravity drainage, filtering, and release of water drained from sediment on transfer barges consolidates the sediment load and reduces the volume of water that otherwise would need to be managed elsewhere (e.g., transloading facility or landfill). Common to most environmental dredging operations in the Puget Sound region, it is assumed that water quality permitting will allow release of this water within the defined limits of the dredge operating area, subject to compliance with water quality criteria. The cost estimate includes a contingency for discharge to the sewer and publicly owned treatment works (POTW) under permit with the King County Industrial Waste program.

Water management is a key component of dredged material transloading operations. Stormwater and drainage from sediments generated within the confines of the transloading facility are assumed to be captured, stored, treated, and either discharged to the local sanitary sewer under a King County Discharge Authorization or returned to the LDW. Dewatering is anticipated to be performed on a dewatering barge. Discharge into the LDW must comply with the substantive requirements of the Washington State National Pollutant Discharge Elimination System (NPDES) permitting regulations (Washington Administrative Code [WAC] 173-220) as administered by Ecology. Water management is included in the dewatering costs (Appendix I).

The two regional Subtitle D landfills (Allied Waste Inc., Roosevelt, Washington, and Waste Management, Arlington, Oregon) are both permitted to receive wet sediment (i.e., that does not pass the paint filter test). Once transferred to lined shipping containers, any additional consolidation of sediment and corresponding accumulations of free water are managed at the landfill facility.

8.2.1.4 Sea Level Rise

Climate change is expected to increase sea levels over the next several hundred years (National Assessment Synthesis Team 2000; Ecology 2006), and this is a potentially important design consideration for cleaning up high elevation (i.e., nearshore and intertidal) areas of the LDW. The predicted sea level rise in the vicinity of the LDW is approximately 8 to 18 inches over the next century, with a maximum potential rise of up to 27 inches (Glick et al. 2007). The magnitude of this change directly affects the corresponding shift in the elevations that define intertidal habitat and jurisdictional boundaries. Further, the design of engineered shoreline infrastructure (e.g., piers, bulkheads, habitat construction/preservation) may need to address the long-term effects of sea level rise. Sea level may factor into certain remedial design elements in intertidal areas, but is not considered to be a significant factor in the selection or the analysis of the alternatives in this FS.

8.2.1.5 Cost and Construction

Table 8-5 presents the volume and construction assumptions used in developing FS remedial costs. The detailed cost estimates are described in Appendix I, and have been developed consistent with CERCLA guidance (EPA 2000) with a target accuracy of +50% and -30%.

8.2.2 Technology-Specific Engineering Assumptions

This section presents the assumptions that were used site-wide in applying each remedial technology for the purpose of estimating cleanup time frames and costs for the FS. Figure 8-3 presents a schematic showing how removal and off-site disposal may be implemented within the LDW. Figure 8-4 presents a schematic showing how the combined technologies may be implemented within the LDW. Uncertainties associated with performance of remedial technologies and how these have been addressed in the FS are discussed in Section 8.4.

8.2.2.1 Removal

Removal technologies used in the FS rely on different mechanical equipment in nearshore and subtidal areas. These technologies are described below. Table 8-6 presents the assumptions used to develop production rate estimates.

Mechanical Dredging

For this FS, mechanical dredging using a clamshell dredge mounted on a derrick barge is assumed, where conditions allow. In difficult to access areas (e.g., under piers, dry shoreline areas with limited barge access), alternate removal methods such as diver-assisted hydraulic dredging could be considered. This would be determined during remedial design. Additional costs for under-pier remediation approaches are incorporated into the cost estimate assuming a 30% premium over open-water dredging. For cost estimating, it is assumed that all backfill materials used to restore the dredged areas to original grade carry the same unit costs.

Precision Excavation

The use of precision excavator equipment operated from a barge is assumed for removing contaminated sediment along exposed shoreline and intertidal areas. Conventional excavation is assumed to be restricted to surfaces at elevations above -2 ft MLLW and the equipment is assumed to reach up to 25 ft from the front of the excavator treads. Although longer reach equipment is available, the production rate diminishes as the reach is extended because of the need to reduce the bucket size in proportion to the reach. Depending on tides, schedules, and other logistics, a portion of the work may be excavated in-the-dry, working above the water level to reduce turbidity generation. Land-based excavation is recognized as an alternative method that may be more suitable under certain site-specific conditions, and is schematically shown

on Figure 8-4 for informational purposes, but it is not assumed for the FS (see Section 8.2.2.1).

All shoreline and intertidal excavation work would be conducted during the designated in-water work window, which is assumed to be October 1st to February 15th. This work window will be confirmed in formal consultation with the agencies before implementation. It may be possible to excavate certain areas in-the-dry at times outside this window (subject to permitting and agency approval); however, this approach is not relied upon in this FS because it would have limited benefit to the overall project schedule. The percent of sediment that could potentially be removed by dry excavation is a nominal amount (less than 1%) of the total removal volume for the alternatives. Therefore, an extended work schedule for dry excavation would result in minimal increases in site-wide seasonal production rates.

Volume Estimation

Approximation of sediment dredge volumes is necessary to support of cost estimates (Appendix I) and certain short-term impacts from construction (Appendix L). GIS-based triangulated irregular network (TIN) methods were used in conjunction with specific overdredge and contingency action assumptions for this purpose.

Chemical and physical data from all available surface sediment, subsurface sediment, and upland soil datasets within and adjacent to the LDW were used to develop two TINs: one to estimate the thickness of sediment that exceeds the SQS and one to estimate the thickness of sediment to the top of the lower alluvium. The SQS exceedance layer is assumed to approximate other risk-driver chemical exceedances above the RALs. This layer represents the best-estimate of the thickness of contaminated sediment. The sediment thickness to the top of the lower alluvium serves as an approximation for the maximum possible thickness of contamination. Using the TINs, neat-line, preliminary, and technology performance dredge volumes were estimated.

Neat-line dredge volumes were calculated by integrating the product of contaminant thickness and unit area across each remedial alternative's dredge footprint. For partial dredging and capping areas, 3 ft of dredging was assumed except in the navigation channel, berthing areas, and under piers. In the navigation channel and berthing areas, the partial dredge depth was the depth necessary to provide a 3-ft cap and an additional clearance below the authorized depth (3 ft in the navigation channel or 2 ft in berthing areas). In under-pier areas, 1 ft of removal was assumed. Additional partial dredging and capping areas are likely necessary to protect engineered shorelines and structures; however, these areas are assumed to be full removal for the FS. The dredging volume and the partial dredging volume were added together to calculate the total neat-line volume for each remedial alternative for each TIN.

Neat-line volumes under represent the amount of material removed under actual field conditions. Preliminary dredge volumes were estimated by applying specific overdredge factors to the neat-line volumes to account for:

- A 1.0 ft allowance over the depth, which is a common contracting approach that accounts for overdredging associated with operational characteristics of dredging equipment.
- An allowance to account for additional sediment characterization (i.e., presence of contaminants below the presently estimated depth of contamination).
- An allowance to account for clean-up passes for residuals management.
- Additional volumes required for constructability of dredge prisms, such as stable side slopes

To account for these multiple allowances, the neat-line volumes were increased by 50% for Alternatives 2 through 5. This adjustment for estimating preliminary dredge volumes is consistent with literature evaluations of previous FS volume estimates and actual removal volumes for large sediment remediation sites (Palermo 2009). The preliminary volume estimates for Alternatives 6C and 6R assumed a doubling of the neat-line volumes to the lower limit of SQS exceedances plus an additional 100%. A greater allowance for Alternative 6 is justified because the Alternative 6 RALs for total PCBs and arsenic are below the SQS values for these risk drivers. Further, it accounts for the greater difficulty of demonstrating compliance with low RALs (i.e., substantially lower than the SQS for PCBs and arsenic).

The remedial alternatives include technology performance assumptions (see also Appendix I) to acknowledge the potential for some areas of the waterway needing to convert from passive (e.g., MNR) to active (e.g., dredging) remediation. This can occur during remedial design or based on the results of long-term monitoring (i.e., adaptive management contingency actions). Base case performance volumes consist of the preliminary volumes plus the material generated from:

- 10% of capping, ENR, MNR, and VM areas being converted to dredging during remedial design.
- 15% of the remaining ENR and MNR areas being converted to dredging based on long-term RAO monitoring results demonstrating inadequate recovery performance.

In both cases, no specific location assumptions could be made for areas that convert to dredging and therefore the TIN information could not be used. Instead, the areas were

converted to approximate dredge volumes using a 4-ft average thickness of contamination plus 50%.

The technology performance dredge volumes provide the best-estimate, or "base case," dredge volumes for the remedial alternatives. To account for uncertainties in the volume estimate, a low-sensitivity and high-sensitivity volume estimate were also developed for each remedial alternative.

The low-sensitivity preliminary volume estimates were made using the same neat-line volumes as for the base case. However, here the overdredge allowances percentages were halved (i.e., to 25% for Alternative 2 through 5, and 50% for Alternative 6). Further, no technology performance adjustments were assumed for ENR and MNR during remedial design or monitoring.

The high-sensitivity volume estimates used the sediment thickness to the top of the lower alluvium, which serves as an approximation for the maximum possible thickness of contamination. For the preliminary dredge volume estimates, the neat-line volumes to the top of the lower alluvium without an additional allowance were used for all remedial alternatives, because the neat-line volume to the top of the lower alluvium was considered the reasonable maximum possible dredge volume. The high-sensitivity performance volumes consist of the preliminary volumes plus the material generated from:

- 20% of capping, ENR, MNR(10), and VM areas and 30% of MNR(20) areas being converted to dredging during remedial design.
- 30% of the remaining ENR and MNR areas being converted to dredging based on long-term RAO monitoring results demonstrating inadequate recovery performance.

Like the base-case, the areas were converted to approximate dredge volumes using a 4-ft average thickness of contamination plus 50%.

Production Rates

Table 8-6 presents two daily dredge production rate estimates for various configurations of dredge equipment: one based on 24 hour per day and 6 day per week operations; the other based on 12 hour per day and 5 day per week operations. Both are common operating regimes for projects in the Puget Sound region and are largely a function of project size and location as well as commercial and community concerns (nighttime noise and illumination). The calculations were prepared consistent with methodologies and efficiency factors set forth in USACE guidance (USACE 2008c).

Table 8-6 presents daily production rates for dredge equipment identified in this FS:

- Barge-mounted clamshell dredge for open-water operations

- Barge-mounted precision excavator for open-water operations (debris removal)
- Barge-mounted precision excavator for shallow-water operations.

Daily operating efficiency includes allowance for non-production activities such as equipment maintenance and repair, water quality management, agency inspections, testing, movement of dredges and barges, traffic, standby for navigation, and refueling.

The estimated daily production rates for 24-hour operations are 1,200 tons (800 cy)[7] for both types of open-water equipment and 900 tons (600 cy) for the precision excavator in shallow-water. The estimated daily production rates for 12-hour operations are 600 tons (400 cy) for both types of open-water equipment and 400 tons (270 cy) for the precision excavator in shallow water. Together, the estimated net annual dredge production rate for implementation of remedial alternatives is about 140,000 tons (95,000 cy) per construction season (see Table 8-7).

This estimate assumes two simultaneous dredging operations (one open-water and one shallow-water) for each season of construction. These operations are assumed to be evenly divided across the construction window between the 24-hour and 12-hour operating regimes, with the 12-hour regime assumed in areas with community or tribal fishing impacts and for smaller cleanup areas. For each construction season, the calculations account for five days of holidays and fifteen days of dredge downtime to accommodate debris sweep, ancillary construction (e.g., piling/dolphin, bulkhead, pier/dock related work), tribal fishing delays, weather and water quality related delays, and a dredging-free period near the end of the construction window for finishing residuals management, ENR, and capping. Thus, approximately 140,000 tons (95,000 cy) of sediment are estimated to be removed during each construction season, consisting of 88 net days of removal operations. This corresponds to an average removal rate of 1,600 tons (1,100 cy) per day, which is approximately equal to the throughput capacity of existing offloading/rail transport in the Duwamish corridor.

The FS makes the simplifying assumption that the total numbers of years required to completely implement any given alternative is indexed to the numbers of years corresponding to the remedial activity (i.e., open-water dredging or capping) that requires the longest time to implement. Based on the FS cost estimate, open-water dredging requires the longest time to implement for all the alternatives. Thus, for the FS, the total number of years to implement a given alternative corresponds to the open-water dredging duration for that alternative, plus a contingency of 25% added to the duration to account for additional time required for completing under-pier dredging, capping, and ENR construction during the season.

[7] For dredging and disposal purposes, the FS assumes an average of 1.5 tons per cubic yard of dredged material.

In-water Work Window

The nominal in-water construction window is October 1 to February 15. All in-water work is conducted during this period (e.g., dredging, excavation, capping, ENR).

In recent years, the Muckleshoot Tribe's netfishing activities within the LDW have sometimes extended through October and well into November. It is recognized that the tribe might not want these activities to be compromised by active construction that could otherwise occur during the first part of the construction window for in-water work. Although tribal fishing delays were one of several reasons for assuming a total of 15 days of dredging downtime in the calculations, more extensive netfishing during the construction window could reduce the net dredging days per season, and result in a lower net annual production rate than proposed herein. It is expected that EPA, Ecology, and the parties implementing the cleanup actions will work closely with the Muckleshoot Tribe during implementation to limit the conflicts between remediation and netfishing activities.

The construction time frame for each alternative was determined based on the in-water work window, the total base case preliminary dredge volume (open water, not including partial dredging under piers), and the net annual dredge production rate. The construction time frame equaled the total base case preliminary dredge volume divided by the net annual dredge production rate (taking into account the limited yearly work window). See "Production Rates" above for a discussion of construction time frame assumptions with regard to the remedial technologies used for each alternative.

Residuals Management

Dredging typically releases contaminated sediment that settles back onto the dredged surface or is transported outside the dredged area (see Section 7.2.3). Depending on site-specific conditions, these residuals may contain elevated concentrations of risk-driver chemicals. To manage residuals, numerous design and operational controls will be evaluated during remedial design.

For the purposes of the FS, active residuals management is incorporated using the following assumptions:

- Additional dredge passes, accounted for in the dredging volume estimates described above.
- Thin-layer placement of 9 inches of sand over an area equivalent to the entire dredged footprint, with the goal of achieving a minimum of 6 inches of coverage throughout the application area. In some cases, placement of 6 inches of sand over the dredged area footprint, with the goal of achieving 3 inches of cover, may be adequate. However, the cost estimates are based on a 9-inch thin-layer sand gross placement for the entire removal footprint.

This is sufficiently conservative to account for management of residuals that migrate outside of the immediate area of the dredge footprint.

8.2.2.2 Isolation Capping

For the FS, construction of conventional caps using appropriate material gradations (e.g., filter layers, isolation layers, armor layers, etc.) has been assumed. This assumption does not prevent the use of caps amended with sorptive or reactive materials (see Section 7.1.4), which may be appropriate for consideration during remedial design. The assumed restrictions on capping associated with water depths in the navigation channel or berthing areas are provided in Section 8.1.2.3. Assumed restrictions on capping associated with habitat issues are provided in Section 8.1.2.5.

The gradation of material selected for capping depends on factors such as habitat, erosion, and scour potential. Spatially defined judgments about material gradations have not been made for the FS because material unit costs generally differ within a very narrow range and therefore are not expected to have a significant impact on estimated costs. A sand cap thickness of 3 ft has been assumed in all areas. Thinner or thicker caps may be developed during remedial design for elevation considerations such as navigation depths or habitat.

Source material for isolation capping or ENR is assumed to be imported from commercial off-site vendors. Possible alternative material sourcing could include dredged materials excavated from the Upper Turning Basin or other Puget Sound maintenance dredging sites. For example, based on Upper Turning Basin dredging records from 1994 to 2010, approximately 32,000 cy of sediment is deposited each year in the Upper Turning Basin and is available for potential re-use. Challenges to beneficial use of this material include:

- Determining suitability of material gradation and chemical concentrations to meet the defined cap material specifications
- Coordinating contract requirements with the federally-procured USACE dredge contract
- Adjusting to mismatched production rates (e.g., maintenance dredged material may be generated at rates much less than or far exceeding cap placement rates)
- Accounting for rehandling needs and/or lack of suitable storage for dredged material awaiting beneficial use
- Working within the in-water construction window (e.g., maintenance dredging may occur near the end of the construction season, with no time for subsequent cap placement).

Coarse gravel or rock is required for engineered capping (i.e., armoring in areas prone to scour). These engineering requirements are designed within the assumed 3-ft cap thickness. A sandy gravel material (referred to as "fish or habitat mix") is assumed to be applied as a top dressing for riprap armoring in intertidal areas.

Cost assumptions for capping are presented in Appendix I. Cost estimates include contingencies for the repair of isolation caps.

8.2.2.3 Enhanced Natural Recovery

ENR, as used in this FS, means applying a thin layer of sandy material to accelerate the natural recovery processes of mixing and burial. This FS assumes ENR would involve spreading an average of 9 inches of sand (by clamshell from a material barge) with the goal of achieving a minimum 6 inches of coverage everywhere it is applied (King County 2005).

Material is assumed to be imported from off-site but could be obtained from local maintenance dredging, as discussed in Section 8.2.2.2.

Cost assumptions for ENR are presented in Appendix I. Cost estimates include contingencies for the repair of the ENR sand layer and for implementing adaptive management contingency actions, such as dredging, if ENR is not effective.

8.2.2.4 Monitored Natural Recovery

Monitored natural recovery (MNR), as a component of CERCLA or MTCA remedial actions, includes the establishment of cleanup levels and long-term goals, the assignment of a particular time frame for achieving those goals, the use of a monitoring program to track success, and a decision framework for implementing contingency actions if needed (adaptive management; EPA 2005). MNR is assigned to areas in the LDW that are well suited to natural recovery As discussed in Section 7 (and supported by data presented in Section 5 and Appendix F), there is appreciable burial of LDW sediments from the deposition of new material entering the LDW from upstream. Approximately 200,000 metric tons of material enters the LDW every year, approximately 100,000 of which is deposited onto the sediment bed (see Section 5). Empirical evidence shows that natural recovery is occurring in many areas of the LDW (see Appendix F) and is expected to continue in areas not subject to significant scour, assuming sources are adequately controlled.

Two types of MNR are defined for this FS, depending on the remedial goals and time to achieve RAOs for particular alternatives: MNR within 10 years ("MNR(10)") and MNR within 20 years ("MNR(20)"). MNR is assigned only in AOPC 1. MNR(10) applies to Alternatives 2 and 4 where the goal is to reach the CSL or SQS, respectively, within 10 years after active remediation. MNR(20) applies to Alternatives 2 and 3, where the goal is to achieve SQS on a time frame longer than 10 years. MNR(20) can also provide

incremental reduction in spatially-weighted average concentrations (SWACs) toward achieving other RAOs over time.

MNR(10) refers to monitoring to achieve alternative-specific 10-year post-construction target concentrations (e.g., the CSL for Alternatives 2R and 2R-CAD and the SQS for Alternatives 4R and 4C). The assumptions and criteria used for assigning MNR(10) are outlined in Table 8-1. These areas are expected to recover to below the SQS (Alternatives 4R and 4C) and to below the CSL (Alternatives 2R and 2R-CAD) within 10 years following remedy completion. Monitoring requirements are applicable at an appropriate area-specific scale over which the remedial technology is applied (see Long-term Operation and Maintenance Monitoring in Appendix K). This technology includes a commitment that the goals will be reached within 10 years after active construction is complete. Contingency actions for areas that do not achieve remediation goals include active remediation, additional investigation, and further monitoring. For cost estimating, this FS assumes that 15 percent of areas designated for MNR(10) would require active remediation based on monitoring results. For assigning remedial technologies in the FS, MNR(10) is assumed to be applicable in areas with no significant scour, empirical trends showing decreasing concentration trends when available, and where the BCM predicts recovery. These are Recovery Category 3 areas.

MNR(20) refers to monitoring to assess achievement of PRGs within 20 years. This is applicable to areas in Alternatives 2R, 2R-CAD, 3R, and 3C that are below the RALs but above the SQS. This technology includes a commitment to achieve PRGs on time scales to be determined, such as 20 years following construction (see Sections 9 and 10). Adaptive management is a key component of MNR(20). Contingency actions for areas that are not achieving remediation goals include active remediation, additional investigation, and further monitoring. For cost estimating, this FS assumes that 15 percent of areas designated for MNR(20) would require active remediation by dredging based on future monitoring results.

MNR is coupled with adaptive management (Section 8.2.5) to ultimately achieve the PRGs and RAOs. This is an important component for Alternatives 2, 3, and 4, which include MNR and will be influenced and directed by MNR monitoring results.

For FS purposes, it is assumed that MNR sampling events would occur at prescribed intervals (see Appendix K). Determination of the need for adaptive management may occur at any time during the monitoring period.

8.2.2.5 Verification Monitoring (VM)

VM areas were identified in Section 6 as areas with surface sediment concentrations above the PRGs for RAOs 2 through 4 in the FS baseline dataset, but which are expected to fall below the PRGs prior to remedial design. Therefore, these areas are included in the AOPC 1 footprint, but are not assumed to require active remediation for Alternatives 2 through 5 (they are actively remediated in Alternative 6). Generally,

these areas have isolated exceedances based on data that are greater than 10 years old; they are in Recovery Category 3; there are no cores in these areas to indicate increasing concentration trends; and the BCM predicts recovery within 10 years. The mouth of Slip 4 is considered to be a candidate VM area given that recent sediment samples indicate that concentrations are at or below the PRGs for RAOs 2 through 4. The area is included in AOPC 1 because of older data that are not co-located within 10 ft of newer data.

Active and passive remedial technology assignments in VM areas will be re-evaluated during remedial design. For cost estimating, this FS assumes that 10 percent of areas designated for verification monitoring would require active remediation by dredging based on the design-phase sampling results.

8.2.2.6 Institutional Controls

The two major types of institutional controls considered for this FS are: 1) proprietary controls; and 2) informational devices. Informational devices are further split into the following components: a) monitoring and notification of waterway users; b) seafood consumption advisories, public outreach, and education; c) enforcement tools; and d) site registry. These are discussed in Section 7.1.7.

All types of institutional controls apply to all remedial alternatives. Seafood consumption advisories, public outreach, and education would likely be similar in scope for all remedial alternatives. The other institutional controls, proprietary controls, monitoring and notification of waterway users, enforcement tools, and site registry, would likely vary in scope depending on the amount of contamination left on site. The degree to which each of these institutional controls is expected to be used for each remedial alternative is discussed in Section 8.3.

Costs for institutional controls are incorporated into the cost estimate for each remedial alternative in Appendix I.

8.2.3 Remedial Design Investigations and Evaluation

Remedial design investigations include location-specific sampling or testing for the purpose of refining the design and engineering assumptions for the selected remedy. Site-wide modeling and the associated data collection and testing that have been performed are useful for understanding overall site characteristics and making FS-level cleanup decisions, but additional testing and modeling may be needed for remedial design. It is anticipated that remedial design sampling will occur in conjunction with baseline sampling, and include verification monitoring. The purposes of these investigations include:

- Clarify the nature and extent of contaminated sediment in portions of the LDW being considered for remediation, including both the vertical and horizontal extent of contamination above the RALs. The nature and extent of contaminated sediment could affect the assignment of remedial

technologies. Areas subject to verification monitoring will be re-evaluated at this time based on chemical concentrations. Estimates of the volume of contaminated sediment to be removed will be refined.

- Assess source control and recontamination potential based on chemical data and location-specific conditions and data. This includes assessment of recontamination from buried contaminated sediment.
- Evaluate site-specific sediment stability using *in situ* observation such as settling plates, bathymetry surveys, or *ex situ* erosion testing such as SedFlume. These tests could be used to evaluate sediment stability under pre-design conditions or with stability enhancements such as ENR.
- Evaluate shoreline conditions, including structures, engineered slopes, and native slopes. Evaluate shoreline habitat enhancement opportunities.
- Collect surface sediment samples to confirm current concentrations and bathymetry data to evaluate current elevations and sedimentation.
- Collect chemical and radioisotope sediment core data to assess area-specific rates of sedimentation and recovery.
- Perform geotechnical testing on sediment cores for physical properties to assess, for example, recontamination potential associated with dredge residuals, material handling properties, and sediment strength for capping.
- Reassess remedial technology assignments and assumptions based on the investigations above.

These types of data would allow refinement of the selected remedial technologies and evaluation of their performance potential.

Costs and scope for remedial design sampling, baseline sampling, and verification monitoring are incorporated into remedial alternative costs as a portion of the total remedial design cost (see Appendix I).

8.2.4 Monitoring

Monitoring is a key assessment technology for sediment remediation. Numerous guidance documents highlight the need for monitoring to verify achievement of project RAOs (EPA 1998c; EPA 2005; NRC 2007). For contaminated sediment projects, monitoring can be grouped into five categories (EPA 2005):[8]

[8] Data collected as part of design-level investigations are another source of information that can overlap with or inform interpretation of other monitoring data (see Appendix K).

- Baseline monitoring – site-wide monitoring concurrent with remedial design studies, but separate in design and function[9]
- Construction monitoring – location-specific short-term monitoring during construction to ensure performance of the operations
- Post-construction performance monitoring – location-specific performance monitoring immediately following active remediation
- Long-term operation and maintenance (O&M) monitoring – area- and location-specific monitoring to confirm that technologies are operating as intended
- Long-term RAO monitoring – site-wide monitoring to confirm that the LDW is making progress toward and/or achieving the RAOs.

Baseline and long-term RAO monitoring have LDW-wide applications and are common to all alternatives, and are essentially the same in scope. They are used to assess the overall condition of the LDW in relation to RAOs and achievement of the cleanup levels set forth in the Record of Decision (ROD). The other three monitoring categories apply at the location- or project-specific level.

The monitoring results from each category inform and direct adaptive management activities to assure long-term remedy implementation and achievement of RAOs.

All five of these monitoring categories are included in the FS cost estimates (Appendix I) and described in Appendix K.

The terms used in this FS are generally consistent with compliance monitoring requirements described in MTCA (WAC 173-340-410), as shown in Table 8-8. MTCA specifies three types of monitoring requirements for site cleanup and monitoring:

- Protection monitoring confirms that human health and the environment are adequately protected during construction (called construction monitoring in this FS).
- Performance monitoring confirms that remedial actions have achieved the cleanup standards or other performance standards (called post-construction performance monitoring in this FS; could also be called RAO monitoring if the remedy has temporal goals).
- Confirmational monitoring confirms the long-term effectiveness of a remedial action after the performance standards or remediation levels

[9] Costs and scope for baseline monitoring, remedial design sampling, and verification monitoring are not included in this FS as separate line item costs. Both are incorporated into the capital costs for each remedial alternative as part of 20% of the total capital costs for remedial design (see Appendix I).

have been achieved. This would include monitoring of disposal, isolation, or containment sites to ensure protection (called long-term O&M and RAO monitoring in this FS).

For specific application to contaminated sediments and the sediment cleanup decision process, the *Sediment Cleanup Standards Users Manual* (Ecology 1991, WAC 173-204-600) lists three general types of monitoring. The first, source control monitoring, is conducted prior to and following active cleanup to determine how on-going sources may affect the success of active cleanup and natural recovery. The second, compliance monitoring for sediments, is considered to be long-term monitoring that is conducted following cleanup actions that include containment of contaminated sediments, or is conducted to assess the progress of natural recovery and to evaluate possible recontamination of the area. The third, closure monitoring, follows active cleanup to demonstrate successful cleanup of a site before delisting or site closure.

8.2.5 Adaptive Management

Adaptive management is the use of data collected during and after remediation to optimize further remedial actions. Because remediation in the LDW will span many years under all remedial alternatives and because of uncertainties in the LDW system, adaptive management will be important for achieving the long-term project objectives. In the context of the assignment of remedial technologies, adaptive management would be used to refine the areas in which remedial technologies are applied and to refine the methods employed during construction. Data collected during monitoring will be used to make location-specific and project-wide remedial decisions through adaptive management. Some of the ways that adaptive management may affect the implementation of specific remedial technologies are discussed below.

In dredge areas, data collected during construction monitoring may be used to more effectively employ BMPs while performing active remediation to reduce short-term environmental impacts. Post-construction performance monitoring provides information on whether RALs were achieved, which could result in managing dredge residuals. Long-term O&M and RAO monitoring could result in additional source control efforts or additional remediation.

In capping areas, data collected during construction may be used to more effectively apply BMPs during active remediation to reduce impacts to the ecosystem during construction. Post-construction performance monitoring will immediately assess whether the cap has been affected by residuals. Long-term O&M monitoring will assess cap stability and effectiveness. The monitoring results may be used to improve capping designs for subsequent remedial action areas within the site, identify the need for supplemental sand placement, or change technology assignments in other parts of the LDW. Long-term RAO monitoring will assess the need for further remediation.

In ENR areas, post-construction performance monitoring will be used to assess whether ENR has successfully achieved RALs. Long-term RAO monitoring will be used to assess the progress toward achieving RAOs.

In MNR areas, long-term RAO monitoring on timescales of 5 to 20 years will provide important information on the natural recovery potential in the LDW. Monitoring data will be used to inform remediation choices in the area being monitored, including the potential need to trigger use of contingency active cleanup technologies if MNR is not progressing as expected. Long-term monitoring may also help to assess the applicability of MNR in other areas of the LDW (see Section 8.2.2.4).

The following identifies three hypothetical MNR scenarios and example adaptive management contingency actions:

- MNR sampling results over a 10-year period are trending toward or have demonstrated that natural recovery occurred (i.e., achievement of PRGs in AOPC 1). Where improvement is documented by the monitoring results and recovery is progressing appropriately to predicted recovery within 10 years, MNR would continue until recovery is complete and documented. MNR would be discontinued and no further monitoring would occur whenever the monitoring results document that recovery has been achieved.
- MNR sampling results over a 10-year period indicate that an area is not recovering adequately. These results would trigger adaptive management review to determine appropriate response actions to more readily achieve RAO 3 PRGs. Contingency actions may include modifications to the MNR sampling program or active remediation.
- MNR sampling results over a 20-year period indicate that an area is not recovering adequately to achieve the SQS for RAO 3. These results would trigger an adaptive management review and the potential need for additional remedial actions, source control, or monitoring to achieve the RAO within 20 years after construction is complete.

Site-wide monitoring will inform future source control actions and progress toward achieving RAOs, regardless of the remedial technology being used, and help inform remedial decisions in the future.

8.2.6 Project Sequencing

Project sequencing refers to the order in which individual areas are remediated for a given alternative. Sequencing of sediment remediation with source control is an important consideration from a recontamination perspective. The timing of individual source control actions is expected to influence when it is appropriate for specific areas to undergo remediation (e.g., near some outfalls) (Section 8.3.1). However, the potential

number and complexity of upland source areas and associated programmatic difficulties of sequencing individual in-water cleanup projects in a specific order is a major area of uncertainty (see Section 8.5).

In this FS, it is assumed that project sequencing starts with active management of the most contaminated areas. Active remediation is modeled in 5-year increments in the BCM. Each successive alternative fully captures and embeds the previous alternative's RALs within its RALs because the highest exceedances are managed first, followed by successively lower RAL exceedance areas. This provides a "continuum" of actions that results in successive areas of progressively lower concentrations being addressed. This assumption is incorporated in the BCM sequencing, as discussed in Section 9.

8.3 Detailed Description of Remedial Alternatives

This section describes the site-wide remedial alternatives. Figures 8-5 through 8-17 present the remedial footprints for Alternatives 1 through 6, showing the spatial extent of active and passive technology assignments. Alternatives 2 through 5 address the AOPC 1 footprint. Alternative 6 addresses the AOPC 2 footprint, which includes all of AOPC 1. Appendix D presents additional physical and chemical considerations that affected the recovery category assignments, and hence the technology assignments. Appendix G presents a plan-view map of each alternative showing the location of surface sediment concentrations above the RALs and "stick maps" showing subsurface sediment core contamination designated to be dredged, capped, or remain in place. Figure 8-18 is a generalized flow diagram of the active technology assignments that apply to any of the remedial alternatives. Table 8-9 presents a summary of areas and volumes associated with each remedial alternative.

8.3.1 Alternative 1 – No Further Action (Completion of EAAs)

Alternative 1 consists of completing removal actions at the EAAs (29 acres) (Figure 8-5). The EAAs were previously identified as containing some of the highest levels of contamination in the LDW. This alternative is not formulated with specific risk reduction goals in mind. However, it does provide a basis to compare the relative effectiveness of the other alternatives (see Section 10). Under CERCLA, a no action alternative is required as a baseline for comparison with the other alternatives. For this reason, Alternative 1 is included in the FS and considered in the evaluation and comparative analysis presented in Sections 9 and 10, respectively.

Although natural recovery processes are expected to continue as the Green/Duwamish River delivers new sediment to the LDW, recovery and eventual achievement of RAOs is not ensured for Alternative 1. In addition, no project-related monitoring or adaptive management contingency actions would be undertaken, even if recovery did not occur as expected.

Regulatory goals, management approaches, and associated RALs for this alternative will be developed specific to each individual EAA and not by this FS. The volume of sediment removed from EAAs is not incorporated into sediment volume calculations in the FS. Nevertheless, removal actions for some of the identified "hot spots" (i.e., areas of noted high levels of contamination) will be completed as part of the EAAs, resulting in overall LDW-wide SWAC reduction for all risk-driver chemicals. These outcomes are presented in Section 9. Contaminant reduction outside of the EAAs will occur only to the degree achieved by on-going natural recovery processes. Under Alternative 1, monitoring would not occur to track changes in sediment or tissue concentrations beyond that currently undertaken by the Puget Sound Ambient Monitoring Program. Completion of the actions at the EAAs is assumed to be a common element of all subsequent alternatives, but costs for these actions have not been included in the FS alternative cost estimates. A summary of the status of the EAAs is provided in Section 2.7.

8.3.2 Alternatives 2R and 2R-CAD

Alternatives 2R and 2R-CAD are designed, at a minimum, to achieve RAO 1 through a combination of active remediation, MNR, and institutional controls; achieve the PRGs for RAOs 2 and 4 within 10 years following construction; and achieve the minimum cleanup level (i.e., CSL) for RAO 3 within 10 years following construction and the SQS within 20 years following construction. Model-predicted outcomes are presented in Section 9.

Alternatives 2R and 2R-CAD are designed to comply with the minimum "threshold requirements" discussed in Sections 10 and 11. The regulatory basis for achieving the CSL within 10 years following construction for RAO 3 is WAC 173-204-570(3):

> *"Minimum cleanup level. The minimum cleanup level is 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."*

The regulatory basis for achieving the cleanup objective (i.e., SQS) is defined in WAC 173-204-570(2)), although it is recognized that a longer restoration time frame to achieve the cleanup objective may be appropriate per WAC 173-204-580(3)(b).

Alternative 2R emphasizes removal and upland disposal of sediment within the designated active remediation areas. Alternative 2R-CAD emphasizes removal with disposal in one or more CAD facilities to be constructed within the LDW, although, because of capacity limitations, some material would go to upland disposal. Both remedial alternatives have the same active remedial footprint and technology assignments. Section 8.2 describes the assumptions common to all the remedial alternatives. The following subsections describe the details of Alternatives 2R and 2R-CAD.

8.3.2.1 Alternative 2R – Removal Emphasis with Upland Disposal

Alternative 2R addresses the AOPC 1 footprint (176 acres), by actively remediating 30 acres (in addition to the 29 acres in the EAAs) and passively remediating 146 acres. Figure 8-6 illustrates the estimated areas to be remediated under Alternative 2R and Table 8-9 summarizes the remedial areas for all alternatives. The primary elements of Alternative 2R are as follows:

- **Dredging and upland disposal:** 27 acres would be dredged to the full depth of contamination exceeding the SQS. In dredged areas, residuals management would be used as needed to achieve a final surface sediment concentration below the SQS. Areas with existing elevations above -10 ft MLLW would be backfilled to grade.
- **Partial dredging and capping:** 3 acres (under-pier areas) would be partially dredged and covered with an isolation cap.
- **MNR(10):** 20 acres are predicted to recover to below the CSL within 10 years following remedy construction. Areas that did not recover to below the CSL within 10 years would be subject to active remediation. For cost estimating, this FS assumes that 15% of these areas would require active remediation by dredging based on long-term RAO monitoring. These areas would also be monitored for eventual recovery to the SQS within 20 years following construction.
- **MNR(20):** 107 acres are conservatively predicted to recover to the SQS within 20 years following construction. Alternative 2 includes contingent active remediation as needed to ensure that the SQS is achieved by year 20. For cost estimating, this FS assumes that 15% of these areas would require active remediation by dredging, based on long-term RAO monitoring.
- **VM:** 19 acres are predicted to have already recovered to below the SQS by the time of remedy implementation. If these areas are determined to be above the SQS during remedial design, they would be assigned to an appropriate active or passive remedial technology based on chemical and physical conditions. For cost estimating, this FS assumes that 10% of these areas would require active remediation by dredging based on remedial design sampling.
- **Institutional controls:** The types of institutional controls are discussed in Section 7.1.7 and summarized in Section 8.2.2.6. Alternative 2R applies the following:
  - Seafood consumption advisories, public outreach, and education – these apply LDW-wide.

- Proprietary controls, monitoring and notification of waterway users, enforcement tools, and site registry – these would apply in proportion to the area of the site remediated by technologies other than dredging: 3 acres of engineered caps and 127 acres of MNR.
- Institutional controls specific to the EAAs would also continue, as defined by the Institutional Controls plan developed for each EAA.

♦ **Site-wide monitoring, adaptive management, and periodic reviews.** Monitoring and adaptive management are integral components of Alternative 2R. The basic monitoring elements are described in Appendix K and summarized in Section 8.2.4. For this alternative, the scope of monitoring elements is summarized as:

- Baseline monitoring would occur site-wide concurrently with remedial design investigations and verification monitoring
- Construction monitoring would apply during the estimated 4 years of construction.
- Long-term operations and maintenance monitoring would apply to the estimated 3 acres of engineered caps and 127 acres of MNR.
- Long-term RAO monitoring would apply until RAOs are achieved.

Adaptive management would apply to the estimated 127 acres of MNR. All areas of the LDW would be required to achieve the CSL within 10 years following construction. Based on monitoring results, additional active remediation would be implemented as needed to achieve the CSL within 10 years following construction and to achieve the SQS within 20 years following construction. Adaptive management for all remedial alternatives is described in Section 8.2.5.

Because this alternative would result in some contaminated sediments remaining on site at levels that do not allow unrestricted use, EPA and/or Ecology would review the effectiveness of the remedial alternative a minimum of every 5 years. These periodic reviews can inform adaptive management decisions, as required to achieve the RAOs.

Estimated Quantities Construction Time Frames, and Cost

As shown in Table 8-9, Alternative 2R would remove approximately 620,000 cy of contaminated sediment (not including the EAAs) by dredging and excavation, assuming dredging to the extent of the active footprint and vertically to the full depth of contamination as defined by the SQS. Partial dredging of one foot and capping are assumed under overwater structures. Approximately 110,000 cy of sand, gravel, and rock would be needed to manage dredge residuals, restore habitat areas to grade, and provide cap material in partial dredging and capping areas.

The estimated construction time frame is 4 years, assuming an annual open-water (i.e., excluding under piers) dredging rate of approximately 95,000 cy.[10] The estimated costs for Alternative 2 are $230 million (base case), $120 million (low sensitivity), and $360 million high sensitivity. Indirect construction[11] costs are approximately 12% of the total estimated costs. See Appendix I for cost estimate details.

8.3.2.2 Alternative 2R-CAD – Removal Emphasis with CAD

Alternative 2R-CAD is identical to Alternative 2R in terms of areas remediated (30 acres actively remediated and 146 acres passively remediated) and volume of sediment removed (620,000 cy). The main difference between the two alternatives is that Alternative 2R-CAD includes the construction and use of CAD facilities within the LDW, as shown in Figures 8-7, 8-8, and 8-9. Alternative 2R-CAD is the only alternative with a CAD option. However, a CAD could be incorporated into any remedial alternative during remedial design. Alternative 2R and 2R-CAD have the exact same technology assignments so that the CAD alternative can be directly compared to the non-CAD alternative in subsequent sections of the FS.

It is assumed that CAD construction would occur concurrently with remediation and does not affect the overall construction time frame of the remedial alternative. However, it is possible that CAD construction could extend the construction time frame for this alternative. The primary elements of Alternative 2R-CAD are as follows:

- **Dredging, Partial Dredging and Capping, MNR, and VM:** Alternative 2R-CAD remediates the same acreages using the same technologies as described for Alternative 2R above.
- **Capping:** The completed CAD facilities would encompass approximately 23 acres of capped contaminated sediment.
- **Institutional controls:** The types of institutional controls are the same as described for Alternative 2R except the following:
  - Proprietary controls, monitoring and notification of waterway users, and enforcement tools would apply to 26 acres of engineered caps as opposed to 3 acres of engineered caps
  - Site registry would also apply to 26 acres of engineered caps as opposed to 3 acres of engineered caps.

[10] Nearshore and underpier activities are assumed to be concurrent with open-water dredging; therefore, the construction time is based on the open-water activities plus 25% time added for non-concurrent activities (i.e., dredge residuals management at end of season, difficult under pier work). This assumption applies to all the remedial alternatives except Alternative 6R, which does not add any additional percentage because it uses dredging exclusively to remediate the AOPC 2 footprint.

[11] Indirect construction costs include operations and maintenance, long-term monitoring, and institutional controls. These costs are described in detail in Appendix I.

- **Site-wide Monitoring, Adaptive Management, and Periodic Reviews:** The type for monitoring is the same as described for Alternative 2R with the exception that long-term operations and maintenance monitoring would apply to an estimated additional 23 acres of the engineered caps covering the CAD cells. Adaptive management and periodic reviews would be the same as described for Alternative 2R.

Estimated Quantities, Construction Time Frames, and Cost

The removal volume and the estimated construction time for active management of contaminated sediment above the RALs are the same as those for Alternative 2R. Plus, the construction of the CAD facilities is estimated to require the removal of 370,000 cy of clean sediment, which is assumed to be disposed at the Dredged Material Management Program open-water disposal site in Elliott Bay. The completed CAD facilities would have a capacity of 310,000 cy of contaminated sediment[12] and require approximately 74,000 cy of capping material. Additional details on the construction of the CAD facilities are provided below.

The estimated costs for Alternative 2R-CAD are $210 million (base case), $93 million (low sensitivity), and $330 million (high sensitivity). Monitoring costs are approximately 14% of the total estimated costs. See Appendix I for cost estimate details.

Potential CAD Sites

Two potentially suitable CAD sites, located within the LDW, have been conceptually developed for the FS (Figures 8-7, 8-8, and 8-9). One site is located just south of Harbor Island (river mile [RM] 0.1 to 0.5; northern site) and the other is located near the Upper Turning Basin (RM 4.4 to 4.8; southern site).

The northern site is a deep-water area partially within the authorized navigation channel. Preliminary estimates suggest that a CAD site in this area could have a net storage capacity of 210,000 cy, assuming removal of 140,000 cy of sediment to prepare the site, and 44,000 cy of capping material to construct the final cap. A subsurface core collected from this area shows surficial contamination but no subsurface contamination. The sediment stratigraphy below the surface is dense, native alluvium.

The southern site is located within the authorized navigation channel and Upper Turning Basin. Preliminary estimates suggest a net storage capacity of 100,000 cy. In this case, 230,000 cy of sediment would need to be removed to prepare the site, and 30,000 cy of sand capping material would be required to confine the contaminated sediment.

CAD site construction and operation assumptions include the following:

[12] Volume refers to the *in situ* volume of dredged sediment that would fit in the CAD facilities.

- Sediment sampling and analysis of the sediment within the CAD prism would be required. This sampling would determine suitability of the dredged sediment for disposal at the Elliott Bay open-water disposal site and for beneficial reuse.
- Some excavated material from the CAD construction could potentially be reused on site as CAD cap cover or sand capping material; however, it has been assumed that 100% of this material will be taken to the Elliott Bay open-water disposal site. This disposal would require permitting by the Dredged Material Management Program agencies because it is an off-site action.
- Total disposal capacity of the northern and southern CAD sites is 310,000 cy.
- The operation/logistics for CAD site preparation and filling is sequential by season. It is assumed that the CAD construction would occur concurrently with remediation, so that the total construction time frame of four construction seasons is the same as for Alternative 2R. The northern CAD would be constructed first. Material excavated from the CAD would be sent to open-water disposal, if suitable. Concurrently, contaminated dredged material would be sent to upland disposal until the CAD is prepared to take contaminated sediment. Once the northern CAD is filled with contaminated sediment, material would be excavated from the southern CAD site, and potentially used as cover material for the northern CAD facility. When excavation of the southern CAD site is completed, the remaining areas would be dredged and dredged material sent to the southern CAD site for disposal. The CAD site would be covered with imported clean sand material. Excavated CAD development sediment not used for capping or other beneficial use would be disposed of at the Elliott Bay open-water site or at an upland off-site disposal facility.
- The same guidelines used for capping would be applied for CAD development (see Sections 8.1.2.3 and 8.1.2.5). For the purpose of this FS, the final CAD cap would be 3 ft below the authorized navigation channel elevation, with a 3:1 side slope outside of the channel. Nearshore habitat would be preserved.

Significant engineering remedial design effort would be required to develop and implement CAD at these sites. Key remedial design considerations include:

- Sediment sampling and analyses, as discussed above
- Determination of whether dredged sediments are suitable to prepare the CAD sites

- Development of a detailed dredging plan
- Engineering evaluation of: CAD capacities, bulking of the sediment resulting from dredging, subsequent compaction after placement and settling in the CAD site, and slope stability
- Residuals and contaminated sediment controls when placing contaminated dredged sediment into the CAD site
- Determination of the impact of the activities on navigation and commercial activities, including the potential for contaminant spread resulting from vessel propeller wash, and required navigation controls during construction activities
- Administrative and substantive requirements for siting a CAD facility in the LDW, including long-term monitoring and maintenance responsibilities and implementation of land use restrictions.

8.3.3 Alternatives 3R and 3C

Similar to Alternatives 2R and 2-CAD, Alternatives 3R and 3C are designed, at a minimum, to achieve RAO 1 through a combination of active remediation, MNR, and institutional controls; and would achieve the PRGs for RAOs 2 and 4 and the minimum cleanup level (i.e., CSL) for RAO 3 immediately following construction (rather than within 10 years following construction). Similar to Alternatives 2R and 2R-CAD, Alternatives 3R and 3C are designed to achieve the cleanup objective (i.e., SQS) within 20 years following construction. Model-predicted outcomes are presented in Section 9.

Alternative 3R emphasizes removal and upland disposal of sediment from the actively remediated areas. Alternative 3C emphasizes using combined technologies—dredging with upland disposal, capping, and ENR where appropriate. Both remedial alternatives have the same active remedial footprint and the same passive remedial technology assignments. Section 8.2 describes the assumptions common to all the remedial alternatives. The following subsections describe the details of Alternatives 3R and 3C.

8.3.3.1 Alternative 3R – Removal Emphasis with Upland Disposal

Alternative 3R addresses the AOPC 1 footprint (176 acres) by actively remediating 57 acres (in addition to the 29 acres in the EAAs), and passively remediating 119 acres. Figure 8-10 illustrates the estimated areas to be remediated under Alternative 3R, and Table 8-9 summarizes the acres managed. The primary elements of Alternative 3R are as follows:

- **Dredging and upland disposal:** 52 acres would be dredged to the full depth of contamination exceeding the SQS. Other details are identical to Alternative 2R.

- **Partial dredging and capping:** 5 acres (under-pier areas) would be partially dredged and covered with an isolation cap.
- **MNR(20):** 100 acres are predicted to recover to below the SQS within 20 years following construction. For other MNR(20) details, see Alternative 2R. For cost estimating, this FS assumes that 15% of these areas would require active remediation by dredging based on long-term RAO monitoring.
- **Verification monitoring:** Applies to the same 19 acres as described for Alternative 2R.
- **Institutional controls:** The types of institutional controls are discussed in Section 7.1.7. Alternative 3R applies the following:
  - Seafood consumption advisories, public outreach, and education – these apply LDW-wide.
  - Proprietary controls, monitoring and notification of waterway users, enforcement tools, and site registry – these would apply in proportion to the area of the site remediated by technologies other than dredging: 5 acres of engineered caps and 100 acres of MNR.
  - Institutional controls specific to the EAAs would also continue, as defined by the Institutional Controls plan developed for each EAA.
- **Site-wide monitoring, adaptive management, and periodic reviews.** Monitoring and adaptive management are integral components of Alternative 3R. The basic monitoring elements are described in Appendix K and summarized in Section 8.2.4. For this alternative, the scope of monitoring elements is summarized as:
  - Baseline monitoring would occur site-wide concurrently with remedial design investigations and verification monitoring
  - Construction monitoring would apply during the estimated 6 years of construction.
  - Long-term operations and maintenance monitoring would apply to the estimated 5 acres of engineered caps and 100 acres of MNR.
  - Long-term RAO monitoring would apply until RAOs are achieved.
  - Adaptive management applies within the estimated 100 acres of MNR. Based on the monitoring results, additional active remediation would be implemented as needed to achieve the SQS within 20 years following construction.
  - Periodic reviews would be the same as described for Alternative 2R.

Estimated Quantities, Construction Time Frame, and Cost

As shown in Table 8-9, Alternative 3R would remove approximately 790,000 cy of contaminated sediment (not including the EAAs) by dredging and excavation, assuming dredging to the extent of the active footprint and vertically to the full depth of contamination, as defined by the SQS. Partial dredging and capping are assumed under overwater structures. Approximately 240,000 cy of sand, gravel, and rock would be needed to manage dredge residuals, restore habitat areas to grade, and for partial dredging and capping.

The estimated construction time frame is 6 years, assuming an annual open-water dredging rate of approximately 95,000 cy, plus 25% to complete other remedial activities. The estimated costs for Alternative 3R are $290 million (base case), $190 million (low sensitivity), and $460 million (high sensitivity). Indirect construction costs are approximately 9% of the total estimated costs. See Appendix I for cost estimate details.

8.3.3.2 Alternative 3C – Combined Technology

Similar to Alternative 3R, Alternative 3C addresses the AOPC 1 footprint (176 acres) by actively remediating 57 acres (in addition to the 29 acres in the EAAs), and passively remediating 119 acres. Figure 8-11 illustrates the estimated areas to be remediated under Alternative 3C and Table 8-9 summarizes the acres managed. The primary elements of Alternative 3C are as follows:

- **Dredging and upland disposal:** 29 acres would be dredged to the full depth of contamination above the SQS. In dredged areas, residuals management would be used as needed to achieve a final surface sediment concentration below the SQS. Areas with existing elevations above -10 ft MLLW would be backfilled to grade.
- **Partial dredging and capping:** 9 acres would be partially dredged to the necessary depth based on elevation constraints, and covered with an isolation cap.
- **Capping:** 10 acres of contaminated sediment would be contained with an isolation cap.
- **ENR:** 9 acres of contaminated sediment would be remediated with a layer of ENR sand.
- **MNR(20):** same area (100 acres) as for Alternative 3R.
- **Verification monitoring:** Applies to the same 19 acres as described for Alternative 2R.

- **Institutional Controls:** Alternative 3C includes the same institutional controls as described for Alternative 3R, except for the following differences:
  - Proprietary controls, monitoring and notification of waterway users, enforcement tools, and site registry – these would apply in proportion to the area of the site remediated by technologies other than dredging: 19 acres of engineered caps, 9 acres of ENR, and 100 acres of MNR.
- **Site-wide monitoring, adaptive management, and periodic reviews.** These elements would be the same as described for Alternative 3R, except for the following differences:
  - Construction monitoring during implementation would apply during the estimated 4 years of construction.
  - Long-term operations and maintenance monitoring would apply to the estimated 19 acres of engineered caps, 9 acres of ENR, and 100 acres of MNR.
  - Adaptive management applies to the 100 acres of MNR as described for Alternative 3R.
  - Periodic reviews would be the same as described for Alternative 2R.

Estimated Quantities, Construction Time Frame, and Cost

As shown in Table 8-9, Alternative 3C would remove approximately 570,000 cy of contaminated sediment (not including the EAAs) by dredging and excavation, assuming dredging to the extent of the active footprint and vertically to the full depth of contamination, as defined by the SQS, and partial dredging and capping to the depth necessary based on elevation constraints. Approximately 260,000 cy of sand, gravel, and rock would be needed to manage dredge residuals, restore habitat areas to grade, cap, and place ENR sand.

The estimated construction time frame is 4 years, assuming an annual open-water dredging rate of approximately 95,000 cy, plus 25% to complete other remedial activities. The estimated costs for Alternative 3C are $220 million (base case), $120 million (low sensitivity), and $360 million (high sensitivity). Indirect construction costs are approximately 12% of the total estimated costs. See Appendix I for cost estimate details

8.3.4 Alternatives 4R and 4C

Similar to Alternatives 3R and 3C, Alternatives 4R and 4C are designed, at a minimum, to achieve RAO 1 through a combination of active remediation, MNR, and institutional controls; achieve the PRGs for RAOs 2 and 4 immediately following construction; but achieve the PRG (i.e., SQS) for RAO 3 within 10 years following construction (instead of within 20 years for Alternatives 3R and 3C). Areas with potential scour (Recovery

Category 1 areas) are actively remediated to the SQS (PRG for RAO 3 is achieved immediately following construction in Recovery Category 1 areas). Model-predicted outcomes are presented in Section 9.

The technology differences between Alternatives 4R and 4C are similar to the technology differences between Alternatives 3R and 3C. Alternative 4R emphasizes removal and upland disposal of the actively remediated areas. Alternative 4C emphasizes combined technologies where appropriate.

8.3.4.1 Alternative 4R – Removal Emphasis with Upland Disposal

Alternative 4R addresses the AOPC 1 footprint (176 acres) by actively remediating 114 acres (in addition to the 29 acres in the EAAs), and passively remediating 62 acres. Figure 8-12 illustrates the estimated areas to be remediated under Alternative 4R and Table 8-9 summarizes the acres managed. The primary elements of Alternative 4R are as follows:

- **Dredging and upland disposal:** 103 acres would be dredged to the full depth of contamination above the SQS. Other details are identical to Alternative 2R.
- **Partial dredging and capping:** 11 acres (under-pier areas) would be partially dredged and covered with an isolation cap.
- **MNR(10):** 43 acres are predicted to recover to below the SQS within 10 years following remedy construction. Areas that did not recover to the SQS within 10 years would be subject to active remediation. For cost estimating, this FS assumes that 15% of these areas would require active remediation by dredging based on long-term RAO monitoring results.
- **Verification monitoring:** Applies to the same 19 acres as described for Alternative 2R.
- **Institutional Controls:** The types of institutional controls are discussed in Section 7.1.7. Alternative 4R applies the following:
  - Seafood consumption advisories, public outreach, and education – these apply LDW-wide.
  - Proprietary controls, monitoring and notification of waterway users, enforcement tools, and site registry – these would apply in proportion to the area of the site remediated by technologies other than dredging: 11 acres of engineered caps and 43 acres of MNR.
  - Institutional controls specific to the EAAs would also continue, as defined by the Institutional Controls plan developed for each EAA.

- **Site-wide monitoring, adaptive management, and periodic reviews.** Monitoring and adaptive management are integral components of Alternative 4R. The basic monitoring elements are described in Appendix K and summarized in Section 8.2.4. For this alternative, the scope of monitoring elements is summarized as:
  - Baseline monitoring would occur site-wide concurrently with remedial design investigations and verification monitoring
  - Construction monitoring would apply during the estimated 13 years of construction.
  - Long-term operations and maintenance monitoring would apply to the estimated 11 acres of engineered caps and 43 acres of MNR.
  - Long-term RAO monitoring would apply until RAOs are achieved.
  - Adaptive management applies within the estimated 43 acres of MNR. Based on the monitoring results, additional active remediation would be implemented as needed to achieve the SQS within 20 years following construction.
  - Periodic reviews would be the same as described for Alternative 2R.

Estimated Quantities, Construction Time Frame, and Cost

As shown in Table 8-9, Alternative 4R would remove approximately 1,200,000 cy of contaminated sediment (not including the EAAs) by dredging and excavation, assuming dredging to the extent of the active footprint and vertically to the full depth of contamination, as defined by the SQS. Partial dredging and capping are assumed under overwater structures. Approximately 410,000 cy of sand, gravel, and rock would be needed to manage dredge residuals, restore habitat areas to grade, and for partial dredging and capping.

The estimated construction time frame is 13 years, assuming an annual open-water dredge rate of approximately 95,000 cy, plus 25% to complete other remedial activities. The estimated costs for Alternative 4R are $440 million (base case), $350 million (low sensitivity), and $630 million (high sensitivity). Indirect construction costs are approximately 5% of the total estimated costs. See Appendix I for cost estimate details.

8.3.4.2 Alternative 4C – Combined Technology

Similar to Alternative 4R, Alternative 4C addresses the AOPC 1 footprint (176 acres) by actively remediating 114 acres (in addition to the 29 acres in the EAAs) and passively remediating 62 acres. Figure 8-13 illustrates the estimated areas to be remediated under Alternative 4C and Table 8-9 summarizes the acres managed. The primary elements of Alternative 4C are as follows:

- **Dredging and upland disposal:** 51 acres would be dredged to the full depth of contamination above the SQS. In dredged areas, residuals management would be used as needed to achieve a final surface sediment concentration below the SQS. Areas with existing elevations above -10 ft MLLW would be backfilled to grade.
- **Partial dredging and capping:** 25 acres would be partially dredged to the necessary depth based on elevation constraints and covered with an isolation cap.
- **Capping:** 23 acres of contaminated sediment would be contained with an isolation cap.
- **ENR:** 15 acres of contaminated sediment would be remediated with a layer of ENR sand.
- **MNR(10):** Applies to 43 acres as described for Alternative 4R.
- **Verification monitoring:** Applies to the same 19 acres as described for Alternative 2R.
- **Institutional Controls:** Alternative 4C includes the same institutional controls as described for Alternative 4R, except for the following differences:
  - Proprietary controls, monitoring and notification of waterway users, enforcement tools, and site registry – these would apply in proportion to the area of the site remediated by technologies other than dredging: 48 acres of engineered caps, 15 acres of ENR, and 43 acres of MNR.
- **Site-wide monitoring, adaptive management, and periodic reviews.** These elements would be the same as described for Alternative 4R, except for the following differences:
  - Construction monitoring would apply during the estimated 7 years of construction.
  - Long-term operations and maintenance monitoring would apply to the estimated 48 acres of engineered caps and 43 acres of MNR.
  - Adaptive management applies to the 43 acres of MNR as described for Alternative 4R.
  - Periodic reviews would be the same as described for Alternative 2R.

Estimated Quantities, Construction Time Frame, and Cost

As shown in Table 8-9, Alternative 4C would remove approximately 740,000 cy of contaminated sediment (not including the EAAs) by dredging and excavation,

assuming dredging to the extent of the active footprint and vertically to the full depth of contamination, as defined by the SQS, and partial dredging and capping to the depth necessary based on elevation constraints. Approximately 510,000 cy of sand, gravel, and rock would be needed to manage dredge residuals, restore habitat areas to grade, cap, and place ENR sand.

The estimated construction time frame is 7 years, assuming an annual open-water dredging rate of approximately 95,000 cy, plus 25% to complete other remedial activities. The estimated costs for Alternative 4C are $290 million (base case), $210 million (low sensitivity), and $410 million (high sensitivity). Indirect construction costs are approximately 7% of the total estimated costs. See Appendix I for cost estimate details.

8.3.5 Alternatives 5R, 5R-Treatment and 5C

Similar to Alternatives 4R and 4C, Alternatives 5R, 5R-Treatment, and 5C are designed, at a minimum, to achieve RAO 1 through a combination of active remediation, natural recovery, and institutional controls; achieve the PRGs for RAOs 2 and 4 immediately following construction; and achieve the PRG for RAO 3 immediately following construction (instead of within 10 years for Alternatives 4R and 4C). Model-predicted outcomes are presented in Section 9.

The technology differences between Alternatives 5R and 5C are the same as the differences in the technologies between Alternatives 4R and 4C. Alternative 5R-Treatment has the same technology assignments as Alternative 5R, except it includes treatment of sediment from actively remediated areas using soil washing, in addition to upland disposal.

8.3.5.1 Alternative 5R – Removal Emphasis with Upland Disposal

Alternative 5R addresses the AOPC 1 footprint (176 acres) by actively remediating 157 acres (in addition to the 29 acres in the EAAs), and passively remediating 19 acres. Figure 8-7 illustrates the estimated areas to be remediated under Alternative 5R and Table 8-9 summarizes the acres managed. The primary elements of Alternative 5R are as follows:

- **Dredging and upland disposal:** 145 acres would be dredged to the full depth of contamination above the SQS. Other details are identical to Alternative 2R.
- **Partial dredging and capping:** 12 acres (under-pier areas) would be partially dredged and covered with an isolation cap.
- **Verification monitoring:** Applies to the same 19 acres as described for Alternative 2R.

- **Institutional Controls:** The types of institutional controls are discussed in Section 7.1.7. Alternative 5R applies the following:
  - Seafood consumption advisories, public outreach, and education – these apply LDW-wide.
  - Proprietary controls, monitoring and notification of waterway users, enforcement tools, and site registry – these would apply in proportion to the area of the site remediated by technologies other than dredging: 12 acres of engineered caps.
  - Institutional controls specific to the EAAs would also continue, as defined by the Institutional Controls plan developed for each EAA.
- **Site-wide monitoring, adaptive management, and periodic reviews.** Institutional controls and site-wide monitoring apply to the rest of the AOPC 2 footprint (outside of the AOPC 1 footprint that is actively managed) and the rest of the LDW. For Alternative 5R, the scope of monitoring elements is summarized as:
  - Baseline monitoring would occur site-wide concurrently with remedial design investigations and verification monitoring
  - Construction monitoring would apply during the estimated 19 years of construction.
  - Long-term operations and maintenance monitoring would apply to the estimated 12 acres of engineered caps.
  - Long-term RAO monitoring would apply until RAOs are achieved.
  - Adaptive management for all remedial alternatives is described in Section 8.2.5.
  - Periodic reviews would be the same as described for Alternative 2R.

Estimated Quantities, Construction Time Frame, and Cost

As shown in Table 8-9, Alternative 5R would remove approximately 1,500,000 cy of contaminated sediment (not including the EAAs) by dredging and excavation, assuming dredging to the extent of the active footprint and vertically to the full depth of contamination, as defined by the SQS. Partial dredging and capping are assumed under overwater structures. Approximately 550,000 cy of sand, gravel, and rock would be needed to manage dredge residuals, restore habitat areas to grade, and for partial dredging and capping.

The estimated construction time frame is 19 years, assuming an annual open-water dredge rate of approximately 95,000 cy, plus 25% to complete other remedial activities. The estimated costs for Alternative 5R are $550 million (base case), $460 million (low

sensitivity), and $800 million (high sensitivity). Indirect construction costs are approximately 3% of the total estimated costs. See Appendix I for cost estimate details.

8.3.5.2 Alternative 5R-Treatment – Removal Emphasis with Soil Washing Treatment

Alternative 5R-Treatment is identical to Alternative 5R in terms of active and passive remedial footprints, monitoring requirements, institutional controls, quantities, and time frames. The only difference between the two alternatives is that Alternative 5R-Treatment includes the construction and use of a soil washing facility that could reduce the quantity of contaminated sediment sent to the landfill. The following provides additional details regarding the soil washing facility for treating dredged material.

Soil Washing Facility Details

The soil washing facility is assumed to be located within a single transloading/ dewatering facility used for all dredged sediment. The soil washing operations are expected to require up to approximately 7 acres and would be sited entirely within an expanded transloading facility footprint.

All dredged/excavated material generated for this alternative would be handled at the transloading/treatment facility. To optimize the effectiveness of soil technology, this alternative would need to be sequenced in a manner that would allow targeted dredging of areas with relatively coarser grained sediments that are more amenable to treatment.

Once the dredged/excavated materials are delivered to the transloading/treatment facility, the soil washing process is as follows:

1) Physically wash the dredged sediment and separate coarse-grained (cleaner sand) from fine particle (contaminated) sediment. As addressed in Section 7.1.2.1, it is assumed that soil washing is feasible for those areas that contain more than 30% sand. Approximately 750,000 cy of material are assumed to undergo soil washing in Alternative 5R-Treatment, generating approximately 375,000 cy of sand fraction and 375,000 cy of waste fines fraction (filter cake) (see Section 7).

2) Treat the wash water and discharge it to the LDW. The FS assumes the following treatment train will be used: collect and settle, flocculate, filter, analyze, and discharge wastewater. Chemically analyze the water to confirm that concentrations meet discharge limits.

3) Collect and stockpile the cleaner sand fraction in an on-site location. Chemically analyze the sand to confirm that concentrations are suitable for beneficial reuse.

4) Transfer the treated sands off-site and stockpile for reuse or disposal.

5) Chemically analyze all remaining fine-grained sediment to determine appropriate handling and disposal requirements.

6) Based on the analytical results, treat any excess wastewater and load railcars with remaining sediment for transport to an appropriate Subtitle C or D landfill for disposal.

The potential disposition of the treated sand fraction is uncertain and has considerable implications for implementation and cost, as discussed in Section 7. Four potential outcomes for the treated sand fraction are listed below in order from the least costly to the most costly:

- Meet the applicable chemical and physical requirements for in-water beneficial reuse, and hence be used in the remedial actions as on-site cap or ENR material with potential material cost savings.
- Be suitable for upland use as fill with no associated value or disposal cost.
- Be suitable for open-water disposal with a comparatively low disposal cost.
- Require landfill disposal at significant cost.

The FS assumes the treated sand fraction has no associated value or disposal cost (e.g., cost neutral). Section 9 further explores cost sensitivity analyses for other possible disposal options. The approximate raw material production rate for the soil-washing treatment system is assumed to be 40 to 45 tons per hour. Assuming that only the sand portion of the sediment is recoverable and all other sediment would need to be disposed of in a Subtitle D landfill, approximately 375,000 cy of sediment would be potentially available for beneficial reuse. The remaining 375,000 cy of material would be disposed of in the regional Subtitle D landfill, along with the estimated 750,000 cy of sediment not suitable for treatment because the fines fraction is too high for effective soil-washing. The volume of treated material may require a large temporary storage area until permits for viable reuse are obtained (or equivalency is demonstrated), and viable reuse options are identified. Soil washing would result in a maximum reduction of about 25% of the material otherwise destined for the landfill.

Estimated Quantities, Construction Time Frame, and Cost

Alternative 5R-Treatment is assumed to have the same volume of sediment removed, volume of material placed, and construction time frame as Alternative 5R.

The estimated costs for Alternative 5R-Treatment are $600 million (base case), $500 million (low sensitivity), and $940 million (high sensitivity). Indirect construction costs are approximately 3% of the total estimated costs. See Appendix I for cost estimate details.

8.3.5.3 Alternative 5C – Combined Technology

Similar to Alternative 5R, Alternative 5C addresses the AOPC 1 footprint (176) by actively remediating 157 acres (in addition to the 29 acres in the EAAs) and passively remediating 19 acres (verification monitoring). Figure 8-8 illustrates the estimated areas to be remediated under Alternative 5C and Table 8-9 summarizes the acres managed. The primary elements of Alternative 5C are as follows:

- **Dredging and upland disposal:** 54 acres would be dredged to the full depth of contamination above the SQS. For other details, see Alternative 2R.
- **Partial dredging and capping:** 29 acres would be partially dredged to the necessary depth based on elevation constraints and covered with an isolation cap.
- **Capping:** 24 acres of contaminated sediment would be contained with an isolation cap.
- **ENR:** 50 acres of contaminated sediment would be remediated with a layer of ENR sand.
- **Verification monitoring:** Applies to the same 19 acres as described for Alternative 2R.
- **Institutional Controls:** Alternative 5C includes the same institutional controls as described for Alternative 5R, except for the following differences:
  - Proprietary controls, monitoring and notification of waterway users, enforcement tools, and site registry – these would apply in proportion to the area of the site remediated by technologies other than dredging: 53 acres of engineered caps and 50 acres of ENR.
- **Site-wide monitoring, adaptive management, and periodic reviews.** These elements would be the same as described for Alternative 5R, except for the following differences:
  - Construction monitoring during implementation would apply during the estimated 8 years of construction
  - Long-term operations and maintenance monitoring would apply to the estimated 53 acres of engineered caps and 50 acres of ENR.
  - Adaptive management for all remedial alternatives is described in Section 8.2.5.
  - Periodic reviews would be the same as described for Alternative 2R.

Estimated Quantities, Construction Time Frame, and Cost

As shown in Table 8-9, Alternative 5C would remove approximately 770,000 cy of contaminated sediment (not including the EAAs) by dredging and excavation, assuming dredging to the extent of the active footprint and vertically to the full depth of contamination, as defined by the SQS, and partial dredging and capping to the depth necessary based on elevation constraints. Approximately 620,000 cy of sand, gravel, and rock would be needed to manage dredge residuals, restore habitat areas to grade, cap, and place ENR sand.

The estimated construction time frame is 8 years, assuming an annual open-water dredge rate of approximately 95,000 cy, plus 25% to complete other remedial activities. The estimated costs for Alternative 5C are $310 million (base case), $230 million (low sensitivity), and $450 million (high sensitivity). Indirect construction costs are approximately 6% of the total estimated costs. See Appendix I for cost estimate details.

8.3.6 Alternatives 6R and 6C

Similar to Alternatives 5R, 5R-Treatment, and 5C, Alternatives 6R and 6C are designed to achieve, at a minimum, RAO 1 through a combination of active remediation and institutional controls; and achieve the PRGs for RAOs 2, 3, and 4 immediately following construction. In addition, Alternatives 6R and 6C are designed to achieve the range of long-term, model-predicted concentrations immediately following construction. Model-predicted outcomes are presented in Section 9.

The technology differences between Alternatives 6R and 6C are the same as the differences in technology assignments between Alternatives 5R and 5C. Alternative 6R emphasizes removal and upland disposal of the actively remediated areas. Alternative 6C emphasizes using combined technologies when applicable.

8.3.6.1 Alternative 6R – Removal Emphasis with Upland Disposal

Alternative 6R addresses the AOPC 2 footprint, which encompasses all of AOPC 1. This remedial alternative actively remediates the entire footprint of 299 acres (in addition to the 29 acres in the EAAs) and is estimated to achieve equilibrium conditions following construction. The verification monitoring areas are actively remediated in Alternative 6. Figure 8-7 illustrates the estimated areas to be remediated under Alternative 6R and Table 8-9 summarizes the acres managed. The primary elements of Alternative 6R are as follows:

- **Dredging and upland disposal:** 271 acres would be dredged to the full depth of contamination to the depth to RALs (estimated by the depth to SQS plus an additional 50% contingency to account for the lower RALs). In dredged areas, residuals management would be used as needed to achieve a final surface below the Alternative 6 RALs, and areas with existing elevations above -10 ft MLLW would be backfilled to grade.

- **Partial dredging and capping:** 28 acres (under-pier areas) would be partially dredged and finished with an isolation cap.
- **Institutional Controls:** Alternative 6R includes:
  - Seafood consumption advisories, public outreach, and education – these apply LDW-wide.
  - Proprietary controls, monitoring and notification of waterway users, enforcement tools, and site registry – these would apply in proportion to the area of the site remediated by technologies other than dredging: 28 acres of engineered caps.
  - Institutional controls specific to the EAAs would also continue, as defined by the Institutional Controls plan developed for each EAA.
- **Site-wide monitoring, adaptive management, and periodic reviews.** For Alternative 6R, the scope of monitoring elements is summarized as:
  - Baseline monitoring would occur site-wide concurrently with remedial design investigations and verification monitoring
  - Construction monitoring would apply during the estimated 38 years of construction.
  - Long-term operations and maintenance monitoring would apply to the estimated 28 acres of engineered caps.
  - Long-term RAO monitoring would apply until RAOs are achieved.
  - Adaptive management for all alternatives is described in Section 8.2.5.
  - Periodic reviews would be the same as described for Alternative 2R.

Estimated Quantities, Construction Time Frame, and Cost

As shown in Table 8-9, Alternative 6R would remove approximately 3,600,000 cy of contaminated sediment (not including the EAAs) by dredging and excavation, assuming dredging to the extent of the active footprint and vertically to the full depth of contamination as defined by the depth to the base of SQS exceeding sediments, plus a contingency of 50% for overdredge, constructability, and additional characterization, and an additional contingency of 50% to account for lower RALs for Alternative 6. Partial dredging and capping are assumed under overwater structures. Approximately 1,100,000 cy of sand, gravel, and rock would be needed to manage dredge residuals, restore habitat areas to grade, and for partial dredging and capping.

The estimated construction time frame is 38 years, assuming an annual open-water dredge rate of approximately 95,000 cy. The estimated costs for Alternative 6R are $1,300 million (base case), $970 million (low sensitivity), and $1,500 million (high

sensitivity). Indirect construction costs are approximately 2% of the total estimated costs. See Appendix I for cost estimate details.

8.3.6.2 Alternative 6C – Combined Technology

Similar to Alternative 6R, Alternative 6C addresses the AOPC 2 footprint, which encompasses all of AOPC 1. This remedial alternative actively remediates the entire footprint of 299 acres (in addition to the 29 acres in the EAAs) and is estimated to achieve equilibrium conditions immediately following construction. Figure 8-7 illustrates the estimated areas to be remediated under Alternative 6C and Table 8-9 summarizes the acres managed. The primary elements of Alternative 6C are as follows:

- **Dredging and upland disposal:** 106 acres would be dredged to the full depth of contamination above the RALs (estimated by the depth to SQS plus a contingency of 50% for overdredge, constructability, lower RALs, and additional characterization). In dredged areas, residuals management would be used as needed to achieve a final surface below the Alternative 6 RALs, and areas with existing elevations above -10 ft MLLW would be backfilled to grade.
- **Partial dredging and capping:** 50 acres would be partially dredged to the necessary depth based on elevation constraints, and finished with an isolation cap.
- **Capping:** 51 acres of contaminated sediment would be isolation capped.
- **ENR:** 92 acres of contaminated sediment would be remediated with a layer of ENR sand.
- **Institutional Controls:** Alternative 6C includes the same institutional controls as described for Alternative 6R, except for the following differences:
  - Proprietary controls, monitoring and notification of waterway users, enforcement tools, and site registry – these would apply in proportion to the area of the site remediated by technologies other than dredging: 101 acres of engineered caps and 92 acres of ENR.
- **Site-wide monitoring, adaptive management, and periodic reviews.** These elements would be the same as described for Alternative 6R, except for the following differences:
  - Construction monitoring would apply during the estimated 18 years of construction.
  - Long-term operations and maintenance monitoring would apply to the estimated 101 acres of engineered caps and 92 acres of ENR.

Estimated Quantities, Construction Time Frame, and Cost

As shown in Table 8-9, Alternative 6C would remove approximately 1,700,000 cy of contaminated sediment (not including the EAAs) by dredging and excavation, assuming dredging to the extent of the active footprint and vertically to the base of contamination as defined by SQS, and partial dredging and capping to the depth necessary based on elevation constraints. Approximately 1,200,000 cy of sand, gravel, and rock would be needed to manage dredge residuals, restore habitat areas to grade, cap, and place ENR sand.

The estimated construction time frame is 18 years, assuming an annual open-water dredge rate of approximately 95,000 cy, plus 25% to complete other remedial activities. The estimated costs for Alternative 6C are $650 million (base case), $450 million (low sensitivity), and $820 million (high sensitivity). Indirect construction costs are approximately 4% of the total estimated costs. See Appendix I for cost estimate details.

8.4 Uncertainties

Sufficient data collection and analyses have been completed to develop and evaluate the LDW conceptual site model and remedial alternatives presented therein. Overall, the remedial alternatives are considered to be sufficiently defined to allow a detailed evaluation against the CERCLA criteria (Section 9), to perform a comparative analysis in accordance with CERCLA criteria (Section 10), to perform a disproportionate cost analysis in accordance with the MTCA criteria (Section 11), and to support remedial decision-making. However, inherent to the conceptual nature of the FS process, key uncertainties remain regarding certain assumptions made in development of the remedial alternatives. These uncertainties include, but are not limited to, the following:

- Adequacy and timing of source control
- Volume estimates
- Remedial technology assignments and expected performance
- Extent and rate of on-going natural recovery processes
- Considerations of other technologies
- Future land and waterway uses.

These uncertainties are discussed below.

8.4.1 Adequacy and Timing of Source Control

To assess potential pathways and sources of contamination to the LDW, the Source Control Work Group, led by Ecology, has identified a total of 24 source control areas. According to the most recent progress report (Ecology 2009), all Tier 1 source control areas have completed Source Control Action Plans (SCAPs), and half of the Tier 2 and 3

areas have completed SCAPs. The completion of the remaining SCAPs depends on funding. Each of the completed SCAPs identifies action items for each source control area, prioritizing those that need to be completed before sediment cleanup begins. Ecology (2009) indicates that all source control areas still have outstanding high priority action items without definitive time lines for completion. Ecology currently estimates that source control actions will be completed by 2019. The development of the remedial alternatives for the FS assumes that source control work will be sufficiently completed before construction in specific areas of the LDW, or that remedial actions will be sequenced in accordance with source control in prioritized areas. However, the progress of source control work could impact the timing and method of sediment remediation.

In accordance with EPA guidance and prudent practice, remedial actions should not commence until appropriate source control measures have been implemented and their performance verified. Remedial actions need to be carefully coordinated with the source control work and SCAPs. Ecology and others have invested significant effort in regulating discharges to the LDW. Nevertheless, uncertainty remains as to whether these and planned future source control actions will be completed prior to implementing the selected remedy, and whether these actions will be sufficiently protective to prevent recontamination of LDW sediment. These uncertainties were not addressed in estimates of construction time frames for the remedial alternatives, except that Alternatives 2 through 6 are not initiated until five years after issuance of the decisions documents to allow sufficient time for progress in source control efforts by other parties outside of the LDW CERCLA action. During this five-year period, baseline sampling and remedial design sampling will also occur; results should help to determine when source control is sufficient to commence remediation of contaminated sediment in a given area.

Following remediation, the effectiveness of source control will continue to be assessed. Based on these assessments, additional source control (or other actions) may be performed as needed under an adaptive management approach.

8.4.2 Volume Estimates

The horizontal and vertical extent of sediment concentrations exceeding RALs is a key uncertainty in this FS, and the key sensitivity parameter for the cost and duration of remedial actions. Uncertainty in FS sediment characterization stems from the age of some data and the spatial coverage of sampling, especially in the subsurface. This uncertainty is accounted for with a dredge volume contingency factor of 50%, which is added to the FS neat-line dredge prism volume. This value was empirically determined based on the volume increase from FS to implementation for 19 large sediment remediation projects (Palermo 2009). “Volume creep” commonly results from additional dredging resulting from the design of constructible dredge prisms with flat box cuts and side slopes, overdredging, additional characterization of sediments, and

management of dredge residuals. In addition, Appendix E (volume estimates) calculates a conservative volume beyond the measured depth of contamination, down to the native alluvium. This native stratum was used as the basis to develop a reasonable upper limit for the volume estimates used in the FS cost estimates.

Remedial design sampling will refine the estimated extent of sediment exceeding the RALs and the PRGs and confirm or modify the technology assignments identified in the FS. Despite this uncertainty, the assumptions used to define the remedial areas and volumes set forth in this section are reasonable and appropriate for an FS-level alternatives development process.

8.4.3 Remedial Technologies Assignments and Expected Performance

The remedial alternatives have been assembled using a set of assumptions about the applicability and effectiveness of remedial technologies (Section 8.1). Some of these are rather straight-forward, such as the assumption that capping is not applicable in the navigation channel without enough post-construction vertical clearance to allow for future maintenance dredging. Other criteria are based on general assumptions that would require confirmation during remedial design.

In addition, some location-specific attributes of the LDW were not used for technology assignments for assembling site-wide remedial alternatives. For example, shoreline structures such as pilings and riprap will affect the viability of full removal of contaminated sediment; therefore, partial dredging and capping may be necessary in more places than indicated in these locations. In total, all of these assessments could result in refinements and changes to the mix of technologies during remedial design. Similar sources of uncertainty exist for all remedial technologies; see below for examples.

8.4.3.1 Capping, ENR and MNR Uncertainty

The effectiveness of capping is uncertain with respect to waterway conditions. This uncertainty was addressed through contaminant transport modeling in Appendix C, and by a cost contingency for capping areas reverting to dredging. Uncertainty regarding the long-term stability of cap material was addressed by including an additional cost for maintenance and repair of sediment caps.

The assumption that ENR is viable in Recovery Category 2 and 3 areas but not viable in Recovery Category 1 areas is appropriate for FS-level analysis, but would require re-evaluation during remedial design. The Recovery Categories are based on a set of assumptions about the conditions of the waterway (e.g., that the STM base-case accurately represents conditions in the waterway), and about how these conditions relate to ENR (e.g., that >10 cm scour during a high-flow event would preclude effective ENR, but <10 cm scour would not). Both of these sets of assumptions would be revisited and refined during remedial design. This could involve empirical studies of

the use of ENR in the LDW or other waterways, bathymetric surveying, additional modeling, location-specific scour modeling or measurement, and others.

The effectiveness of MNR is a key uncertainty for Alternatives 2 through 4. Uncertainty in the rate of natural recovery is discussed in Section 8.4.4. Like ENR, MNR uncertainty was accounted for by limiting MNR based on a set of assumptions (e.g., no MNR in Recovery Categories 1 or 2), and by assuming that a percentage of the MNR areas will require contingency actions. Time-trend analysis and adaptive management would account for this uncertainty during remedy implementation.

These sources of uncertainty were accounted for in the FS by incorporating adaptive management components into the cost estimate. For example, for ENR these sources of uncertainty were addressed by assuming that 10% of the ENR area is re-assigned to dredging during remedial design and 15% is re-assigned to dredging following implementation due to adaptive management. Similar adjustments are made for capping and MNR (see Appendix I for details). These adjustments account for changes in remedy implementation triggered by new information gathered during design, implementation, and following implementation.

8.4.3.2 Treatment Uncertainty

Significant uncertainty exists with the treatment option, soil washing. If soil washing is employed, there would need to be bench-and pilot-scale testing to confirm the assumption that sand-size material can be treated to an acceptable level for beneficial reuse. Additional permitting requirements may limit the reuse of sand. Water quality criteria may limit the effectiveness of water management or require additional water treatment.

8.4.3.3 Dredging Uncertainty

When dredging is employed, potential sediment resuspension and plume migration will need to be understood in order to develop an effective residual management plan. The management of dredge residuals is an uncertain activity in practice. Based on empirical data cited by the National Resource Council (NRC 2007), 13 out of 14 sites could not account for all the mass of contaminated sediment, which may have been lost to the waterway as dredge residuals. The NRC document also states (p. 164, 2007):

> "dredging alone is unlikely to be effective in reaching short-term or long-term goals where sites exhibit one of more unfavorable conditions. Where unfavorable conditions exist, increased contaminant resuspension, release, and residuals will tend to limit ability to meet cleanup levels and delay the achievement of remedial action objectives unless managed through a combination of remedies or alternative remedies."

The unfavorable site conditions often include: presence of debris, bedrock, or other physical obstructions that prevent full removal; side slopes; piers and other obstacles; strong currents; scour potential; and on-going sources. Pilot studies, experienced contractors, best management practices, a monitoring program, and a good

understanding of site conditions and its limitations, can help improve the likelihood that dredging will be successful. However, there is a "general lack of evidence that dredging projects have led to the achievement of long-term remedial success and did so within the expected time frames" (NRC 2007, p90). Of the 21 dredging projects reviewed, about half of the projects have not achieved their RAOs or did not have adequate monitoring to evaluate success. Insufficient time has elapsed at another 25% of the sites. The expected performance of dredging as a remedial alternative has its limitations in reaching long-term RAOs. These sources of uncertainty are accounted for in the FS by incorporating contingency actions into the remedial alternatives.

In summary, uncertainties are inevitable and must be managed appropriately. Many short-term uncertainties will be addressed during remedial design and implementation; however, long-term uncertainties will remain following implementation of the selected remedial action. Collectively, these uncertainties will be addressed through the use of long-term monitoring and adaptive management to ensure protectiveness of the selected remedial action.

8.4.4 Extent and Level of On-Going Natural Recovery Processes

Natural recovery is occurring within the LDW, but the extent and level of recovery is uncertain, in large part because of the lack of time trend data and the difficulty in predicting future conditions. Natural recovery parameters have uncertainty associated with: concentrations of particles entering the LDW from upstream, sedimentation rates, resuspension rates, scour depth, dispersion rates, groundwater flow rates, degree of contaminant mobility, and degree of source control. Empirical time trends can be confounded by spatial heterogeneity and variations in the behavior or degree of source control for various contaminants.

For the FS, the rate of natural recovery was predicted using the BCM (Section 5) and empirical time trend data (Section 6). To address concerns of the possibility that the BCM may over-estimate rates of natural recovery and miss some key parameters affecting natural recovery (for example, vessel scour), the recovery categories were constructed to conservatively identify areas of the LDW with higher or lower potential for natural recovery (Section 6). These were compared with empirical data in an attempt to improve natural recovery predictions. Appendix F includes specific examples of empirical time trend data used to evaluate natural recovery in the LDW.

The BCM was conservatively employed in the assembly of remedial alternatives in two ways. First, by including any location that exceeded PRGs within the AOPC boundary, regardless of the date the location was sampled, natural recovery was not incorporated into that delineation. While this is a conservative approach to ensure adequate remediation of those locations, it likely overestimates risk-driver concentrations because it does not take into account recovery during the period from the time the sediment was sampled to the time that active remediation begins. Second, the MNR predictions for

the development of remedial alternatives do not assume any natural recovery until the end of construction. Therefore, they did not account for natural recovery occurring from the time of sampling through remedial design and construction. Section 9 accounts for this uncertainty by assuming that natural recovery occurs concurrently with active remediation.

To summarize, these uncertainties are managed by calibrating the STM and BCM, using empirical trends where available, and using conservative technology assignment assumptions. In total, while uncertainty exists, the conceptual recovery model for the LDW is based on all the lines of evidence in Appendix F and represents the best estimate of conditions in the LDW. In addition, considerably less uncertainty exists in site-wide analysis of the LDW than in smaller scale analysis of specific locations within the LDW.

The best way to assess chemical trends is through direct measurement. Therefore, remedial design sampling (including verification monitoring), MNR monitoring, site-wide monitoring, and long-term RAO monitoring, combined with adaptive management, are crucial to the long-term success and effectiveness of remediation of the LDW.

8.4.5 Consideration of Other Technologies

The alternatives presented in this FS use technologies that, with the exception of soil washing, are common to most sediment remediation projects undertaken worldwide. Investigation and development of new technologies for sediment cleanup continues within the sediment management practice. The FS recognizes that new technologies should not be discounted for consideration in the cleanup of the LDW. In part, this recognition is because of the very real potential that complete cleanup of the LDW could potentially span an appreciable period of time (e.g., up to 20 or more years from the date of this document).

Advances in dredging and capping amendments have the potential to improve cleanup of the LDW and should be considered at the remedial design stage.

Although not retained in the development of site-wide alternatives, other on-site options (e.g., nearshore CAD, upland landfill within the project boundary) are potentially viable options for disposal of dredged material. Although these disposal options are not considered to be LDW-wide options because of insufficient capacity, lack of available land, permitting, and mitigation difficulties, these options may be determined to be viable and reasonable on a site-specific basis during remedial design. Depending on the specifics of such a proposal, a CERCLA Explanation of Significant Differences and associated public process may be required for these disposal options to be included in a site-specific design.

8.4.6 Future Land and Waterway Uses

Future changes in upland land use or changes to in-water uses of the LDW have the potential to impact remedial design decisions. To identify and evaluate potential future use changes, existing legal zoning and on-going planning activities that address future uses were investigated in this FS. Findings are summarized below.

8.4.6.1 Land Uses

Land bordering the majority of the LDW is zoned for industrial/manufacturing uses. Three local jurisdictions border the LDW: the City of Seattle, the City of Tukwila, and King County. These jurisdictions have established planning priorities and goals for the LDW that are described in the following planning documents:

- City of Seattle Comprehensive Plan 2005 http://www.seattle.gov/DPD/Planning/Seattle_s_Comprehensive_Plan/Overview/
- City of Seattle Shoreline Master Program Updates 2008 http://www.seattle.gov/dpd/Planning/ShorelineMasterProgramUpdate/Overview/
- City of Tukwila Comprehensive Plan 2005http://www.ci.tukwila.wa.us/dcd/dcdcompplan.html and update to the Shoreline element 2009 http://www.ci.tukwila.wa.us/dcd/shoreline/materials/Ord_2270.pdf
- City of Tukwila Shoreline Master Program Update 2010 http://www.ci.tukwila.wa.us/dcd/shoreline.html
- King County Comprehensive Plan 2008 http://www.kingcounty.gov/property/permits/codes/growth/CompPlan/2008.aspx.

In general, these documents call for land surrounding the LDW to remain zoned primarily for industrial and manufacturing activities into the future. Existing neighborhoods adjacent to the LDW are zoned residential and are also expected to remain as such. These plans have a universal goal to improve the habitat value of the LDW corridor and to increase public access. Where technically feasible and consistent with current property use, additional public access and shoreline/habitat restoration is encouraged through these municipal planning priorities.

The City of Seattle Shoreline Master Program Updates establish policies and regulations that govern development and uses of adjoining shorelines. An overarching objective of the updates is natural resource protection with the adopted standard of preventing any net loss of environmental function. A component of the updates is a restoration plan that identifies specific habitat restoration opportunities along the Lower Duwamish

River. The updates are scheduled to be adopted by the Seattle City Council in 2010, and adopted by Ecology in the spring or summer of 2011.

8.4.6.2 Waterway Uses

The National Oceanic and Atmospheric Administration and the Lower Duwamish River Natural Resource Trustees prepared the *Lower Duwamish River Draft Restoration Plan and Programmatic Environmental Impact Statement* (RP/PEIS; NOAA 2009) to identify general types of restoration projects that will be used to compensate for natural resource damage. The plan also considers the unique characteristics of different segments of the river and how they influence the restoration strategy. The Draft RP/PEIS was released for public comment on May 22, 2009.

A community planning project to create a long-range vision for the Duwamish River and its surroundings was led and recently completed by the Duwamish River Cleanup Coalition (DRCC). The project was a comprehensive, community-based, visioning endeavor involving workshops, mapping, and interviews, engaging people who live in, work in, or visit the Duwamish Valley. The project compiled the community's ideas, concerns, and visions of the future Duwamish Valley into a comprehensive map and report (DRCC 2009, available online at www.duwamishcleanup.org). The DRCC is the formal community advisory group recognized by EPA for this project.

Figure 2-3 shows existing shoreline restoration areas and public access points along the LDW. Specific land and waterway uses or practices may be expected to change over time. Land or waterway changes that physically alter a remedy component (e.g., construction in the location of an existing sediment cap) would need to consider the remedial component during planning and construction. Under these circumstances, it would be the responsibility of the project sponsor to design and construct the remedial action in a manner that is generally acceptable to EPA and Ecology. The sponsor would need to appropriately manage contaminated material encountered during construction, and comply with all required post-construction maintenance and monitoring.

On July 7, 2009, the Port of Seattle Commission adopted the Lower Duwamish River Habitat Restoration Plan (Port of Seattle 2009), which establishes a long-range framework to guide restoration of aquatic and riparian habitat on Port property along the shoreline. The plan identifies sites where natural habitat can be enhanced or restored to coexist with commerce that relies on the LDW for navigation. Prior to adoption of the plan, the Port undertook a comprehensive outreach process that engaged numerous stakeholders, including area businesses, community and environmental groups, Native American tribes, and key public agencies.

At present, the Port of Seattle does not forecast a change in the vessel draft or authorized navigation channel depths in the LDW in the foreseeable future (Hotchkiss 2010). The existing ship and vessel traffic usage is expected to remain unchanged, and any changes to these assumptions will be addressed during remedial design or in the

future. Currently, vessel speed regulations are in force to reduce personal injuries and property damage. The speed limit for vessels is 7 knots within the navigation channel of the LDW. Because of congestion, vessel speeds are often much slower.

In general, existing zoning and habitat enhancement planning activities are not expected to conflict with potential active and passive remediation activities on a site-wide basis. However, any potential conflicts will be addressed during remedial design.

Table 8-1 Remedial Alternatives and Associated Remedial Technologies, Remedial Action Levels, and Actively Remediated Acres

Remedial Alternatives and Technologies[a]	Brief Description and Expected Outcomes	Remedial Action Levels for Risk Drivers					Actively Remediated Area (Acres)
		Total PCBs (µg/kg dw)[b]	cPAHs (µg TEQ/kg dw)[c]	Dioxins/ Furans (ng TEQ/kg dw)	Arsenic (mg/kg dw)	Benthic SMS(41 Chemicals)[d]	
Alternative 1 No Further Action after removal or capping of Early Action Areas	CERCLA baseline alternative used for comparison to other alternatives.	n/a	n/a	n/a	n/a	n/a	29 acres
Alternative 2 (2R) – dredge emphasis with upland disposal/MNR Alternative 2 with CAD (2R-CAD) – dredge emphasis with contained aquatic disposal/MNR	Actively remediate hotspots and other areas to achieve the CSL, cumulative 1×10^{-5} direct contact risks, and river otter risks within 10 years following construction. Achieve the CSL immediately following active remediation in areas not expected to recover naturally (Categories 1 and 2). MNR to achieve the SQS in a greater than 10-year time frame. More reliance on MNR to reduce risk-driver concentrations associated with human health risks attributable to seafood consumption. Additional actions will be taken if SQS not achieved within 30 years.	1,300[b] to 2,200[b]; 10-yr post-construction target: 1,300[b]	5,500	50	93	CSL to 3 × CSL[c] 10-yr post-construction target: CSL	30 acres (plus 29 acres EAAs)
Alternative 3 removal (3R) – dredge emphasis with upland disposal/MNR Alternative 3 combined technologies (3C) – ENR/cap/MNR where appropriate, otherwise dredge with upland disposal	Actively remediate areas to achieve the CSL, cumulative 1×10^{-5} direct contact risks, individual risk-driver chemicals in the 10^{-5} or 10^{-6} direct contact magnitude risk[e], HQ <1 for non-cancer direct contact risks, and river otter risks HQ <1 immediately following construction. Use MNR to achieve SQS in a greater than 10-year time frame. More reliance on active remediation to reduce risk-driver concentrations associated with human health risks attributable to seafood consumption than previous alternative. Additional actions will be taken if SQS not achieved within 20 years.	1,300[b]	3,800 (site-wide) 900 (intertidal)	35 (site-wide) 28 (intertidal)	93 (site-wide) 28 (intertidal)	CSL toxicity or chemistry	57 acres (plus 29 acres EAAs)
Alternative 4 removal (4R) – dredge emphasis with upland disposal/MNR Alternative 4 combined technologies (4C) – ENR/cap/MNR where appropriate, otherwise dredge with upland disposal	Actively remediate areas to achieve the SQS within 10 years following construction and incremental reduction in the site-side SWAC for total PCBs (RAO 1). Achieve the SQS immediately following active remediation in areas not expected to recover naturally (Categories 1 and 2). Use MNR in other areas to achieve the SQS within 10 years. More reliance on active remediation to reduce risk-driver concentrations associated with human health risks attributable to seafood consumption than previous alternative. Additional actions will be taken if SQS not achieved within 10 years.	240 to 700[b]; 10-yr post-construction target: 240[b]	1,000 (site-wide) 900 (intertidal)	25	57 (site-wide) 28 (intertidal)	SQS to CSL[c] 10-yr post-construction target: SQS	114 acres (plus 29 acres EAAs)
Alternative 5 removal (5R) – dredge emphasis with upland disposal Alternative 5 removal with treatment (5R-T) – dredge with soil washing treatment and disposal/re-use [f,g] Alternative 5 combined technologies (5C) – ENR/cap where appropriate, otherwise dredge with upland disposal	Active remediate areas to achieve the SQS and incremental reduction in the site-wide SWAC for total PCBs (RAO 1) immediately following construction. More reliance on active remediation to reduce risk-driver concentrations associated with human health risks attributable to seafood consumption than previous alternative	240[b]	1,000 (site-wide) 900 (intertidal)	25	57 (site-wide) 28 (intertidal)	SQS toxicity or chemistry	157 acres (plus 29 acres EAAs)
Alternative 6 removal (6R) – dredge emphasis with upland disposal Alternative 6 combined technologies (6C) – ENR/cap where appropriate, otherwise dredge with upland disposal	Reduction in PCB SWAC to achieve approximate long-term range of model-predicted concentrations immediately following construction. Most reliance on active remediation to reduce risk-driver concentrations associated with human health risks attributable to seafood consumption.	100	1,000 (site-wide) 900 (intertidal)	15	15	SQS toxicity or chemistry	299 acres (plus 29 acres EAAs)

Notes:

a Alternatives 2 through 6 include institutional controls and site-wide monitoring.

b Total PCBs concentrations of 1,300 µg/kg dw and 240 µg/kg dw are dry weight approximations of the 65 mg/kg oc (CSL) and 12 mg/kg oc (SQS) values assuming 2% oc. Compliance with SMS (RAO 3) will be evaluated using carbon normalized data as appropriate.

c Individual cPAH compounds are also incorporated in benthic RALs.

d The RALs for SMS chemicals (excluding arsenic) are a range for Alternatives 2 and 4. The upper RALs are used where conditions for recovery are predicted to be more favorable (Recovery Category 3); and the lower RALs are used where conditions for recovery are predicted to be less certain (Recovery Category 2); or where the BCM does not predict recovery or where recovery is presumed to be limited (Recovery Category 1).

e Direct contact excess cancer risks attributable to individual chemicals are less than 1×10^{-6} for cPAHs, PCBs, and dioxins/furans, and less than 1×10^{-5} for arsenic (1×10^{-6} excess cancer risk levels are below natural background for arsenic).

f Treatment technology could be used in conjunction with any alternative. Treatment unit costs are presented in Section 11.

AOPC = area of potential concern; BCM = bed composition model; C = combined technology; CAD = contained aquatic disposal; CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act; cPAH = carcinogenic polycyclic aromatic hydrocarbon; CSL = cleanup screening level; dw = dry weight; EAA = early action area; ENR = enhanced natural recovery; MNR = monitored natural recovery; n/a = not applicable; oc = organic carbon; PCB = polychlorinated biphenyl; R = removal emphasis; RAL = remedial action level; RAO = remedial action objective; R-T = removal with physical treatment; SMS = Sediment Management Standards; SQS = sediment quality standard; SWAC = spatially-weighted average concentration TBD = to be determined; TEQ = toxic equivalent; TOC = total organic carbon

Table 8-2 Technology Applicability Assumptions for the FS

Technology[a, b]	Active or Passive Technology[c]	Sediment Chemical Concentration[d]	Physical Conditions (Scour, Berthing, Sedimentation Rate, Under Piers, Slope Stability)	Elevation Requirements (Habitat, Navigation Channel, Berthing Areas)[e]
Removal	Active	No upper concentration limit. Vertical extent is to the depth of SQS exceedances. A 50% volume adjustment factor is added to the neat volume for Alternatives 2 through 5. An adjustment of 100% is added for Alternative 6. Post-dredge residuals management in all dredge areas with 6 inches of thin-layer sand placement.	Removal Alternatives: partially viable under piers. In those areas, assume partial dredging and capping under piers. Applicable in all other areas.	Habitat areas: (i.e., elevations >10 ft MLLW), assume backfill to grade to maintain habitat. Dry excavate above depths of -2 ft MLLW. Navigation channel and berthing areas: no restrictions.
Partial Dredging and Capping	Active	No upper concentration limit. If <1 foot of contamination is predicted to remain below the cap, assume complete removal (e.g., if contaminant thickness is <4 ft for a 3-ft removal). Dredge vertically to the depth necessary to fit a 3-ft cap and comply with post-construction elevation assumptions.	Applicable in all areas. Engineered capping as necessary in scour areas, berthing areas, under piers, and in areas with >20 degree slopes (greater than 2.7:1 slopes). Partial dredging and capping is the default active technology under-piers for the removal-emphasis alternatives.	Habitat areas: partial dredge 3 ft and sand cap to grade. Finish with habitat suitable substrate. Navigation channel and berthing areas: partial dredge to provide 3 ft and 2 ft clearance respectively post-construction.
Capping	Active	No upper concentration limit.	Applicable in all areas. Engineered capping as necessary in scour areas, berthing areas, under piers, and in areas with >20 degree slopes. Capping is the default active technology under-piers for the combined-technology alternatives.	Habitat areas: partial dredge and cap (see above). Navigation channel and berthing areas: Applicable in areas with 6 ft and 5 ft pre-construction clearance respectively (depth necessary to fit a 3-ft cap).
ENR	Active	Upper limit for ENR is 3 x RAL for all alternatives, and 1.5 x intertidal RAL for human health risk drivers in the intertidal areas.	Not applicable in Recovery Category 1 areas (Table 8-3).	Habitat area: ENR is not restricted based on habitat. Navigation and berthing areas: ENR is viable if >3 ft and >2 ft pre-construction clearance, respectively.[f]
MNR(10)[g,h]	Passive	Upper limit for MNR(10) is RAL by definition. Applicable in areas above the 10-year post-construction target for only Alternatives 2R and 2R-CAD (CSL) and 4R and 4C (SQS).	Not applicable in Recovery Category 1 and 2 areas (Table 8-3).	Not restricted based on habitat.
MNR(20)[i]	Passive	MNR(20) applies to areas below the RALs.	Applies to all areas of the LDW. Assume areas adaptively managed using monitoring to achieve long-term targets.	Applies to all areas of the LDW. Assume areas adaptively managed using monitoring to achieve long-term targets.

Table 8-2 Technology Applicability Assumptions for the FS

Technology[a, b]	Active or Passive Technology[c]	Sediment Chemical Concentration[d]	Physical Conditions (Scour, Berthing, Sedimentation Rate, Under Piers, Slope Stability)	Elevation Requirements (Habitat, Navigation Channel, Berthing Areas)[e]
Verification Monitoring	Passive	Areas with concentrations >Alternative 5 RALs (as bounded by AOPC 1), but at concentrations expected to be below the Alternative 5 RALs by the time of construction based on recovery potential, empirical trends, and age of data.	Not applicable in Recovery Category 1 and 2 areas (Table 8-3).	Not applicable in Recovery Category 1 and 2 areas (Table 8-3).
Institutional Controls & Site-wide Monitoring[j]	Passive	Apply to all areas of the LDW.	Apply to all areas of the LDW.	Apply to all areas of the LDW.

Notes:

a Criteria and assumptions are for the FS and may be changed during remedial design.

b Capping and ENR are applicable only to the combined technology alternatives.

c Active technology applicable above the RALs. Passive technologies are applicable below the RALs.

d Sediment concentration in the upper 10 cm is compared to alternative specific RALs throughout the site. In intertidal areas, the RALs for human health risk drivers are compared to both surface sediment and to the vertical average of the upper 45 cm in intertidal areas. In scour areas (areas with observed vessel scour of >10 cm scour during high-flow events), alternative-specific RALs are compared to both surface sediment and the maximum concentration in the upper 2 ft of cores.

e Habitat areas are defined as nearshore areas with bathymetric elevations greater than -10 ft MLLW. Navigational channel and berthing areas have water depth requirements to ensure safe passage of vessels.

f As a conservative assumption, the assignment of ENR was limited based on the similar navigation channel and berthing area clearance requirements as capping. However, ENR may not have clearance requirements in the navigation channel or berthing areas.

g Active remediation (dredging, capping, ENR, or a combination) is required for Alternatives 2 and 4 in areas not predicted to recover to below the 10-year post construction target concentration (i.e., the lower RAL).

h MNR(10) is monitoring to achieve the 10-year post-construction target concentrations (applicable to Alternatives 2 and 4).

i MNR(20) is monitoring to achieve PRGs for RAOs 2 through 4 within 20 years after construction is complete. MNR(20) is applicable in all recovery categories because these areas are adaptively managed for long-term compliance. Recovery categories are likely to change based on additional information during monitoring. The time to achieve PRGs for RAOs 2 through 4 may be considerably less than 20 years; see Section 9 for predicted outcomes.

j Institutional controls in the form of seafood consumption advisories apply site-wide for all alternatives. Ranges of institutional controls and monitoring apply to specific actions and areas, such as areas where buried contamination is contained on site. Site-wide monitoring will assess long-term progress toward the remedial action objectives for all alternatives.

AOPC = area of potential concern; C = combined technology; CAD = contained aquatic disposal; CSL = cleanup screening level; ENR = enhanced natural recovery; LDW = Lower Duwamish Waterway; MLLW = mean lower low water; MNR = monitored natural recovery; n/a = not applicable; PRG = preliminary remediation goal; R = removal emphasis; RAL = remedial action level; RAO = remedial action objective; SWAC = spatially-weighted average concentration; SQS = sediment quality standard.

Table 8-3 Recovery Categories and Technology Assignment Assumptions

Feasibility Study Technology	Recovery Categories[a]		
	Category 1[b] Recovery Is Presumed to be Limited	Category 2[c] Recovery Less Certain	Category 3[d] Recovery Predicted
Dredging	Applicable	Applicable	Applicable
Capping	Applicable	Applicable	Applicable
ENR	Not Applicable	Applicable	Applicable
MNR(10)[e]	Not Applicable	Not Applicable	Applicable
MNR(20)[f]	Applicable	Applicable	Applicable
Institutional Controls and Site-wide Monitoring	Applicable	Applicable	Applicable

Notes:

a Recovery categories represent areas with similar predicted rates of chemical natural recovery and similar characteristics with regard to predicted remedial technology effectiveness. See Section 6 and Table 6-4 for definitions.

b Recovery Category 1 – Recovery Is Presumed to be Limited: Potential sediment instability attributable to maintenance dredging, flow scour, or vessel scour; potentially slow recovery attributable to low sedimentation; or empirical chemical evidence for no natural recovery attributable to sediment instability.

c Recovery Category 2 – Recovery Less Certain: Sediment may be stable, but recovery may be slow because of low sedimentation rates, berthing areas with >1 cm/yr net sedimentation; or empirical chemical evidence for slow natural recovery (or source-control related).

d Recovery Category 3 – Recovery Predicted: Sediment is stable and naturally recovering based on available evidence.

e MNR(10) is monitoring to achieve the 10-year post-construction target concentrations (applicable to Alternatives 2 and 4). Includes verification monitoring areas.

f MNR(20) is monitoring to achieve SQS and PRGs for RAOs 2 through 4 within AOPC 1 within 20 years (applicable to Alternatives 2R, 2R-CAD, 3R, and 3C). MNR(20) is applicable in all recovery categories because these areas are adaptively managed for long-term compliance, and recovery categories are likely to change based on additional information during monitoring.

AOPC = area of potential concern; ENR = enhanced natural recovery; MNR = monitored natural recovery

Table 8-4 Conceptual Technology Assignments for Remedial Alternatives

Alternative 2: Removal Emphasis

RALs[c]	Footprint	Recovery Category[a,b] 1 Dredge/Cap Viable	2 ENR Viable	3 MNR Viable	Acres (not including EAAs)
>Alt 2 RALs	AOPC 1	Dredge			30
>Alt 3 RALs	AOPC 1	Dredge[d]	Dredge[d]	MNR(10)[e]	127 (MNR)
>Alt 4 RALs	AOPC 1	MNR(20)[f]			
>Alt 5 RALs	AOPC 1	MNR(20)[f]			
>Alt 6 RALs	AOPC 2	Institutional controls and site-wide monitoring			255
n/a	Rest of LDW	Institutional controls and site-wide monitoring			255

Alternative 2: Removal with CAD

RALs[c]	Footprint	Recovery Category[a,b] 1 Dredge/Cap Viable	2 ENR Viable	3 MNR Viable	Acres (not including EAAs)
>Alt 2 RALs	AOPC 1	Dredge			30
>Alt 3 RALs	AOPC 1	Dredge[d]	Dredge[d]	MNR(10)[e]	127 (MNR)
>Alt 4 RALs	AOPC 1	MNR(20)[f]			
>Alt 5 RALs	AOPC 1	MNR(20)[f]			
>Alt 6 RALs	AOPC 2	Institutional controls and site-wide monitoring			255
n/a	Rest of LDW	Institutional controls and site-wide monitoring			255

Alternative 3: Removal Emphasis

RALs[c]	Footprint	Recovery Category[a,b] 1 Dredge/Cap Viable	2 ENR Viable	3 MNR Viable	Acres (not including EAAs)
>Alt 2 RALs	AOPC 1	Dredge			57
>Alt 3 RALs	AOPC 1	Dredge			57
>Alt 4 RALs	AOPC 1	MNR(20)[f]			100
>Alt 5 RALs	AOPC 1	MNR(20)[f]			100
>Alt 6 RALs	AOPC 2	Institutional controls and site-wide monitoring			255
n/a	Rest of LDW	Institutional controls and site-wide monitoring			255

Alternative 3: Combined Technology

RALs[c]	Footprint	Recovery Category[a,b] 1 Dredge/Cap Viable	2 ENR Viable	3 MNR Viable	Acres (not including EAAs)
>Alt 2 RALs	AOPC 1	Cap/Dredge			48
>Alt 3 RALs	AOPC 1	Cap/Dredge	ENR		9 (ENR)
>Alt 4 RALs	AOPC 1	MNR(20)[f]			100
>Alt 5 RALs	AOPC 1	MNR(20)[f]			100
>Alt 6 RALs	AOPC 2	Institutional controls and site-wide monitoring			255
n/a	Rest of LDW	Institutional controls and site-wide monitoring			255

Table 8-4 Conceptual Technology Assignments for Remedial Alternatives *(continued)*

Alternative 4: Removal Emphasis

RALs[c]	Footprint	Recovery Category[a,b] 1 Dredge/Cap Viable	2 ENR Viable	3 MNR Viable	Acres (not including EAAs)
>Alt 2 RALs	AOPC 1	Dredge			114
>Alt 3 RALs					
>Alt 4 RALs					
>Alt 5 RALs		Dredge[d]		MNR[e]	43 (MNR)
>Alt 6 RALs	AOPC 2	Institutional controls and site-wide monitoring			255
n/a	Rest of LDW				

Alternative 4: Combined Technology

RALs[c]	Footprint	Recovery Category[a,b] 1 Dredge/Cap Viable	2 ENR Viable	3 MNR Viable	Acres (not including EAAs)
>Alt 2 RALs	AOPC 1	Cap/Dredge			99
>Alt 3 RALs					
>Alt 4 RALs		Cap/Dredge[d]	ENR		15 (ENR)
>Alt 5 RALs			ENR[d]	MNR[e]	43 (MNR)
>Alt 6 RALs	AOPC 2	Institutional controls and site-wide monitoring			255
n/a	Rest of LDW				

Alternative 5: Removal and Alternative 5-Removal with Treatment Emphasis

RALs[c]	Footprint	Recovery Category[a,b] 1 Dredge/Cap Viable	2 ENR Viable	3 MNR Viable	Acres (not including EAAs)
>Alt 2 RALs	AOPC 1	Dredge			157
>Alt 3 RALs					
>Alt 4 RALs					
>Alt 5 RALs					
>Alt 6 RALs	AOPC 2	Institutional controls and site-wide monitoring			255
n/a	Rest of LDW				

Alternative 5: Combined Technology

RALs[c]	Footprint	Recovery Category[a,b] 1 Dredge/Cap Viable	2 ENR Viable	3 MNR Viable	Acres (not including EAAs)
>Alt 2 RALs	AOPC 1	Cap/Dredge			107
>Alt 3 RALs					
>Alt 4 RALs					
>Alt 5 RALs		Cap/Dredge		ENR	50 (ENR)
>Alt 6 RALs	AOPC 2	Institutional controls and site-wide monitoring			255
n/a	Rest of LDW				

Table 8-4 Conceptual Technology Assignments for Remedial Alternatives *(continued)*

Alternative 6: Removal Emphasis

RALs[c]	Footprint	Recovery Category[a,b] 1 Dredge/Cap Viable	2 ENR Viable	3 MNR Viable	Acres (not including EAAs)
>Alt 2 RALs	AOPC 1	Dredge			299
>Alt 3 RALs					
>Alt 4 RALs					
>Alt 5 RALs					
>Alt 6 RALs	AOPC 2				
n/a	Rest of LDW	Institutional controls and site-wide monitoring			113

Alternative 6: Combined Technology

RALs[c]	Footprint	Recovery Category[a,b] 1 Dredge/Cap Viable	2 ENR Viable	3 MNR Viable	Acres (not including EAAs)
>Alt 2 RALs	AOPC 1	Cap/Dredge			207
>Alt 3 RALs					
>Alt 4 RALs					
>Alt 5 RALs					
>Alt 6 RALs	AOPC 2	Cap/Dredge	ENR		92 (ENR)
n/a	Rest of LDW	Institutional controls and site-wide monitoring			113

Notes:

a Technology assumptions apply to the Feasibility Study for developing comparable alternatives; technology assignments may change during remedial design. See Section 6 for a description of recovery categories.

b The tables provide a conceptual schematic of the remedial alternatives. Additional details are used to make location-specific technology assignments. For example, removal alternatives include partial dredge and cap in difficult-to-access areas such as overwater structures. The alternative-specific maps (8-5 through 8-17) illustrate these details.

c Red RALs show all concentrations above which active remediation occurs.

d Active remediation to the lower RALs to achieve the 10-year post-construction target concentrations in areas not predicted to recover naturally (Recovery Categories 1 and 2).

e MNR(10) is monitoring to achieve at a minimum the 10-year post-construction target concentrations (applicable to Alternatives 2 and 4).

f MNR(20) is monitoring to achieve at a minimum PRGs for RAOs 2 through 4 in more than 10 years. MNR(20) is applicable in all recovery categories because these areas are adaptively managed for long-term compliance, and recovery categories are likely to change based on additional information during monitoring.

g Verification monitoring acres are included with acres of institutional controls and site-wide monitoring for Alternatives 2 through 5 in this presentation.

AOPC = area of potential concern; CAD = contained aquatic disposal; EAA = early action area; ENR = enhanced natural recovery; LDW = Lower Duwamish Waterway; MNR = monitored natural recovery; n/a = not applicable; RAL = remedial action level; SQS = sediment quality standard

Table 8-5 Area-specific Construction Assumptions for the FS Summarized from Appendix I

Elevation or Geographic Limits[a]	Applicable Active Remedial Technologies[b]	Volume Estimating Assumptions and Construction Assumptions
Native or Eroding Banks; MHHW to -2 ft MLLW	Excavate using land-based or barge-mounted excavator, cap, ENR	For cost estimating, excavation, capping, and ENR are performed by barge-mounted precision excavator. Excavation is performed to a stable slope vertically to the maximum depth of contamination. Excavation areas are restored to original grade with sand and habitat substrate.[c] Capping areas are assumed to be partially dredged to 3 ft below mudline and capped to grade with sand habitat substrate. ENR areas are assumed to be covered with 6 inches of sand and habitat substrate without partial removal. During design, additional engineering considerations in native or eroding bank areas could include the use of land-based excavation and placement applied with a 25-ft maximum lateral reach from top of bank,[d] the use of thicker or thinner caps or the use of capping materials other than sand, and additional considerations to account for bank stability.
Engineered Banks; MHHW to -2 ft MLLW	Excavate using barge-mounted excavator, cap, ENR	For cost estimating purposes, engineered banks are assumed to have the same removal, backfill, capping, and ENR volume assumptions as native or eroding banks (see above). Additional engineering considerations for engineered banks are incorporated into the cost estimate as a 10 percent contingency for areas with additional engineering challenges. During design, additional considerations will be necessary for engineered banks that will ensure the structural integrity of the bank. Engineered surface (e.g., riprap or bulkhead) will remain during removal; partial removal with capping may be necessary. Removal adjacent to vertical sheetpile may not be feasible because of geotechnical stability; partial removal with capping may be necessary. Land-based excavation and placement may be applicable with a 25-ft maximum lateral reach from top of bank.[c]
Under Piers and Overwater Structures	Partial dredge using diver-assisted hydraulic dredge, cap	For cost estimating purposes, partial dredging and capping is assigned in the active remedial footprint for the removal-emphasis alternatives and capping is assigned in the active remedial footprint for the mixed technology alternatives. Removal is assumed to be 1 ft and capping is assumed to be 3 ft after partial removal. Removal would occur by a method higher in cost than open water dredging (such as diver-assisted dredging), and capping would occur by casting material laterally under the structure. The remediation of under pier areas is assumed to occur concurrently with open-water remediation; however, the project duration has been increased by 30% to account for the remediation of these and other areas (see Appendix I). During design, many additional engineering considerations will need to be addressed, including the use of specialized equipment for dredging or capping, partial demolition and replacement of structures, slope stability improvements, casting of cap material, structural or utility work, and additional logistical and access constraints, such as temporary relocation of moorage/marina facilities. Caps thinner than 3 ft and use of ENR may also be considered during design.
-2 ft MLLW to -10 ft MLLW	Dredge or partial dredge and cap, ENR	For cost estimating purposes, habitat areas are assumed to be >-10 ft MLLW. Removal and placement would occur via barge-mounted precision excavator. Habitat would be maintained by conserving bathymetric elevation, and appropriate habitat substrate would be used. During design, additional options for improving habitat may be considered.

Table 8-5 Area-specific Construction Assumptions for the FS Summarized from Appendix I

Elevation or Geographic Limits[a]	Applicable Active Remedial Technologies[b]	Volume Estimating Assumptions and Construction Assumptions
Below -10 ft MLLW	Dredge or partial dredge and cap, cap, ENR	For cost estimating purposes, removal and placement are performed via barge-mounted precision excavator. Capping requires armoring in high-flow event scour or vessel scour areas. For the FS, the cost for armoring is assumed to be the same as a full sand cap. Active remediation adjacent to the navigation channel is assumed to account for USACE maintenance dredge tolerance and sloping from the navigation channel. During design, additional considerations include the use of capping materials other than sand, and additional elevation considerations in the navigation channel or berthing areas.
Additional site-wide assumptions	Removal	For cost estimating purposes, 6-inch layer of sand placed in all dredge areas to manage residuals. Removal volume equals the neat volume to >SQS, plus 50% volume that accounts for overdredge, side slopes, box cuts (i.e., design of constructible dredge prisms), and additional characterization, and more removal in intertidal areas for Alternatives 2 through 5. For Alternative 6, removal volume equals the neat volume >SQS plus 100% to account for the factors above, and the lower RAL for Alternative 6. Production rate assumed to be 1,600 tons/day (1,100 cy/day). Debris sweep is assumed for 10% of dredging areas, resulting in a lower production rate. Debris removal includes side-scan survey and debris disposal at a construction debris landfill. See Appendix I for cost details.
	Capping/ENR	For cost estimating purposes, 3.5 ft of capping material is assumed to achieve a goal of a minimum 3-ft cap, and 9 inches of sand is assumed to achieve a 6-in ENR layer. Additional material (10%) is assumed to be necessary to account for material required in steep slope areas (>20 degree slopes) to address slope stability. Debris sweep is assumed for all capping and ENR areas. Cap and ENR maintenance is included on a cost-per-acre basis. See Appendix I for cost details.

Notes:

a FS assumed intertidal and habitat range extends from -10 ft MLLW to the approximate MHHW elevation. -2 ft MLLW is the approximate lowest elevation considered to be practical for excavation using land-based equipment.

b The process options listed in this table are primary options with site-wide applicability. Other options discussed in Section 7 may also be appropriate, as determined on a site-specific basis at time of remedial design.

c Backfill and restoration to original grade are assumed for all removal actions between MHHW and -10 ft MLLW. ENR does not require restoration to original grade.

d Longer reaches than 25 ft are possible but bucket size diminishes with longer reach equipment. Also, some areas may be sufficiently accessible by water for nearshore removal operations.

cy = cubic yards; ENR = enhanced natural recovery; FS = feasibility study; MHHW = mean higher high water; MLLW = mean lower low water; MNR = monitored natural recovery; RAL = remedial action level; SWAC = spatially-weighted average concentration; SQS = sediment quality standard; USACE = U.S. Army Corps of Engineers.

Table 8-6 Assumptions for Dredge Production Rate Estimates

Parameter	Derrick Barge/Clamshell (Open Water)	Barge-mounted Precision Excavator (Open Water)	Barge-mounted Precision Excavator (Shallow Water)
24 Hours/Day, 6 Days/Week			
Cycle Time (min)	3.5	3	2.5
Bucket Capacity (cy)	6	5	3
Effective Bucket Capacity (@ 55%; cy)[a]	3.3	2.75	1.65
Operating Day (hours/day)	24	24	24
Weekly Operating Days (days/week)	6	6	6
Operating Efficiency (%)[b]	60%	60%	60%
Daily Average Dredge Production (cy/day)	815	792	570
Daily Average Dredge Production (tons/day)[c]	1,200	1,200	900
12 Hours/Day, 5 Days/Week			
Cycle Time (min)	3.5	3	2.5
Bucket Capacity (cy)	6	5	3
Effective Bucket Capacity (@ 55%; cy)[a]	3.3	2.75	1.65
Operating Day (hours/day)	12	12	12
Weekly Operating Days (days/week)	5	5	5
Operating Efficiency (%)[b]	60%	60%	60%
Daily Average Dredge Production (cy/day)	407	396	285
Daily Average Dredge Production (tons/day)[c]	600	600	400

Note:
Both 24 hours/day and 12 hours/day dredge operations were assumed to accommodate a range of project sizes, duration, complexity, and tribal and community concerns (e.g., noise, lights).

a USACE 2008d. *Technical Guidelines for Environmental Dredging of Contaminated Sediments*. ERDC/EL TR-08-29.

b *ibid*. Operating efficiency includes allowance for non-production activities such as equipment maintenance/repair, water quality management, navigation systems, agency inspections, waiting for test results, moving dredges/barges, traffic, standby for navigation, and refueling.

c Assumes average sediment bulk density of 1.5 tons/cy. See Table 8-7 for the blended average production rate estimates used in this FS.

Table 8-7 Recommended Dredge/Excavation Scenario and Net Annual Production Rate Estimate

Item	Value(s)	Notes
No. of dredges/excavators operating simultaneously	2	One open-water dredge/precision excavator and one shallow-water excavator
Dredge operating regimes	50% @ 24 hours/day, 6 days/week 50% @ 12 hours/day, 5 days/week	Operations during the construction window average an equal split between 24 hours/day, 6 days/week and 12 hours/day, 5 days/week equipment operations. Both operating regimes are typical for projects in the Puget Sound region and depend on project size, duration, complexity, and tribal and community concerns (e.g., noise, light).
In-water construction window	Oct.1 to Feb. 15	USACE Seattle District
Total number of calendar days in construction window (days)	138	
Holidays (days)	5	Thanksgiving (2 days), Christmas (2 days), and New Year's Day
Other dredging downtime (days)	15	Accounts for dredging downtime or slowed production to accommodate debris sweep, ancillary construction (e.g., piling/dolphin, bulkhead, pier/dock related work), tribal fishing delays, weather and water quality related delays, and a dredging-free period near the end of the construction window for finishing residuals management, ENR, and capping.
Net dredging days per season (days)	49 @ 24 hours/day; 39 @ 12 hours/day	Total net dredging days split between 24 hours/day, 6 days/week and 12 hours/day, 5 days/week operations
Net annual production rate (tons/year)	140,000	Equates to approximately 1,600 tons/day average blended dredge production rate over the 88 net days of dredging (equates to approximately 95,000 cy/year). See Appendix I for cost estimating details.

Notes:

See Appendix I for cost estimating details. The blended average dredge production rate assumes a combination of operating regimes and is calculated with unrounded numbers; therefore, hand-calculation of the rounded numbers cited for dredge production may differ from the total shown in the table above.

ENR = enhanced natural recovery; USACE = United States Army Corps of Engineers

Table 8-8 Comparison of Monitoring Criteria and Terminologies Used for Sediment Sites

Monitoring Objective	Type of Monitoring Included in FS The selected monitoring type is based, in part, on EPA contaminated sediment remediation guidance for hazardous wastes sites (EPA 2005) and EPA guidance for monitoring at hazardous waste sites: framework for monitoring plan development and implementation (EPA 2004)	Type of MTCA Compliance Monitoring "…shall be required until residual hazardous substances concentrations no longer exceed site cleanup levels established under WAC 173-340 through 173-340-760" [173-340-410][a]
Establish baseline conditions for future compliance monitoring	Baseline monitoring	n/a
Refine the nature and extent of contaminated areas after the FS; confirm recovery processes	Remedial design sampling and verification monitoring[b]	n/a
Protect human health and the environment during construction	Construction monitoring (short-term monitoring during construction)	Protection monitoring
Verify that remedial action levels or remediation levels have been achieved before demobilizing from the site	Post-construction performance monitoring	Performance monitoring
Confirm that natural recovery processes are occurring as predicted to achieve cleanup goals	Long-term O&M monitoring	Performance monitoring
Monitor the stability of a cap or ENR area to ensure isolation and containment	Long-term O&M monitoring	Confirmational monitoring
Monitor surface sediments over time for potential recontamination	Long-term RAO monitoring	Confirmational monitoring
Monitor tissues over time to evaluate risk reduction	Long-term RAO monitoring	Confirmational monitoring
Determine how on-going sources at or near a site may affect the success of active cleanup and/or natural recovery	Source control evaluation – in parallel to baseline, remedial design, and long-term monitoring. Not part of the CERCLA remedy.	Source control monitoring (not a component of compliance monitoring)

Notes:

a Demonstrating the ability to meet cleanup standards involves the point of compliance, how long it takes to meet cleanup levels (restoration time frame), and monitoring to ensure that cleanup standards have been met and will continue to be met in the future [WAC 173-340-700]

b These are not identified as separate costs but are included in the general scope of remedial design costs, which are 20% of the total project cost.

Included in FS cost estimates in Appendix I. Remedial design sampling included in the capital costs of each alternative.

CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act; ENR = enhanced natural recovery; EPA = U.S. Environmental Protection Agency; FS = feasibility study; MTCA = Model Toxics Control Act; O&M = operations & maintenance; RAO = remedial action objective; WAC = Washington Administrative Code

Table 8-9 Remedial Alternative Areas and Volumes

Site-wide Remedial Alternative	Remedial Alternative Technology and Areas												Base-case Preliminary Dredge Volume (cy)[c]	Base-case Performance Dredge Volume (cy)[d]	Total Placement Volume (Capping, ENR, Dredge Residuals, Habitat) (cy)	Construction Time Frame (years)[e]	Cost		
	EAAs (acres)	Dredge (acres)	Partial Dredge and Cap (acres)	Cap (acres)	ENR (acres)	MNR(10)[a] (acres)	MNR(20)[b] (acres)	VM (acres)	Institutional Controls and Site-wide Monitoring (acres)	Rest of LDW (acres)	Total Active (acres)	Total Study Area (acres)					Low Sensitivity Cost ($MM)[h]	Base-case Cost ($MM)[i]	High Sensitivity Cost ($MM)[j]
1 No Further Action (EAAs)	29	0	0	0	0	0	0	0	0	412	29	441	0	n/a	n/a	n/a	$66	$66	$66
2 Removal[f]	29	27	3	0	0	20	107	19	123	113	30	441	310,000	620,000	110,000	4	$120	$230	$360
2 Removal with CAD[f]	29	27	3	0	0	20	107	19	123	113	30	441	310,000	620,000	180,000	4	$93	$210	$330
3 Removal	29	52	5	0	0	0	100	19	123	113	57	441	540,000	790,000	240,000	6	$190	$290	$460
3 Combined Technology	29	29	9	10	9	0	100	19	123	113	57	441	280,000	570,000	260,000	4	$120	$220	$360
4 Removal	29	103	11	0	0	43	0	19	123	113	114	441	1,100,000	1,200,000	410,000	13	$350	$440	$630
4 Combined Technology	29	51	25	23	15	43	0	19	123	113	114	441	540,000	740,000	510,000	7	$210	$290	$410
5 Removal[g]	29	145	12	0	0	0	0	19	123	113	186	441	1,500,000	1,500,000	550,000	19	$460	$550	$800
5 Removal with Treatment[g]	29	145	12	0	0	0	0	19	123	113	157	441	1,500,000	1,500,000	550,000	19	$500	$600	$940
5 Combined Technology	29	54	29	24	50	0	0	19	123	113	157	441	590,000	770,000	620,000	8	$230	$310	$450
6 Removal	29	271	28	0	0	0	0	0	0	113	299	441	3,600,000	3,600,000	1,100,000	38	$970	$1,300	$1,500
6 Combined Technology	29	106	50	51	92	0	0	0	0	113	299	441	1,400,000	1,700,000	1,200,000	18	$450	$650	$820

Notes:

1. Areas are rounded to the nearest acre as shown. Volumes in this table are rounded to two significant figures. Volumes are calculated in a spreadsheet prior to rounding; therefore, hand-calculated values may differ slightly from those shown. Acres and volumes shown for Alternatives 2 through 6 do not include the EAAs.

a MNR(10) is monitoring designed to achieve the 10-year post-construction target concentrations within 10 years (applicable to Alternatives 2 and 4).

b MNR(20) is monitoring to achieve SQS within 20 years after construction is complete (applicable to Alternatives 2R, 2R-CAD, 3R, and 3C).

c The base-case preliminary dredge volume estimate is the neat volume to the maximum depth of SQS plus 50% for Alternatives 2 through 5 to account for overdredging, additional sediment characterization, cleanup passes for residuals management, and additional volumes for constructability (e.g., stable side slopes). The base-case preliminary dredge volume estimate is the neat volume of the maximum depth of SQS plus 100% to account for the factors listed above and additional removal required to achieve the Alternative 6 RALs, some of which are less then SQS.

d The base-case performance dredge volume is the preliminary dredge volume plus additional volume for technology assignment and performance-based contingency assumptions (e.g., 15% of MNR areas are assumed to require dredging based on long-term RAO monitoring results).

e Construction time frame estimated based on preliminary dredge volumes.

f The removal with upland disposal alternative has same areas/dredge volumes as the removal with CAD alternative.

g The removal with upland disposal alternative has same areas/dredge volumes as the removal with treatment alternative.

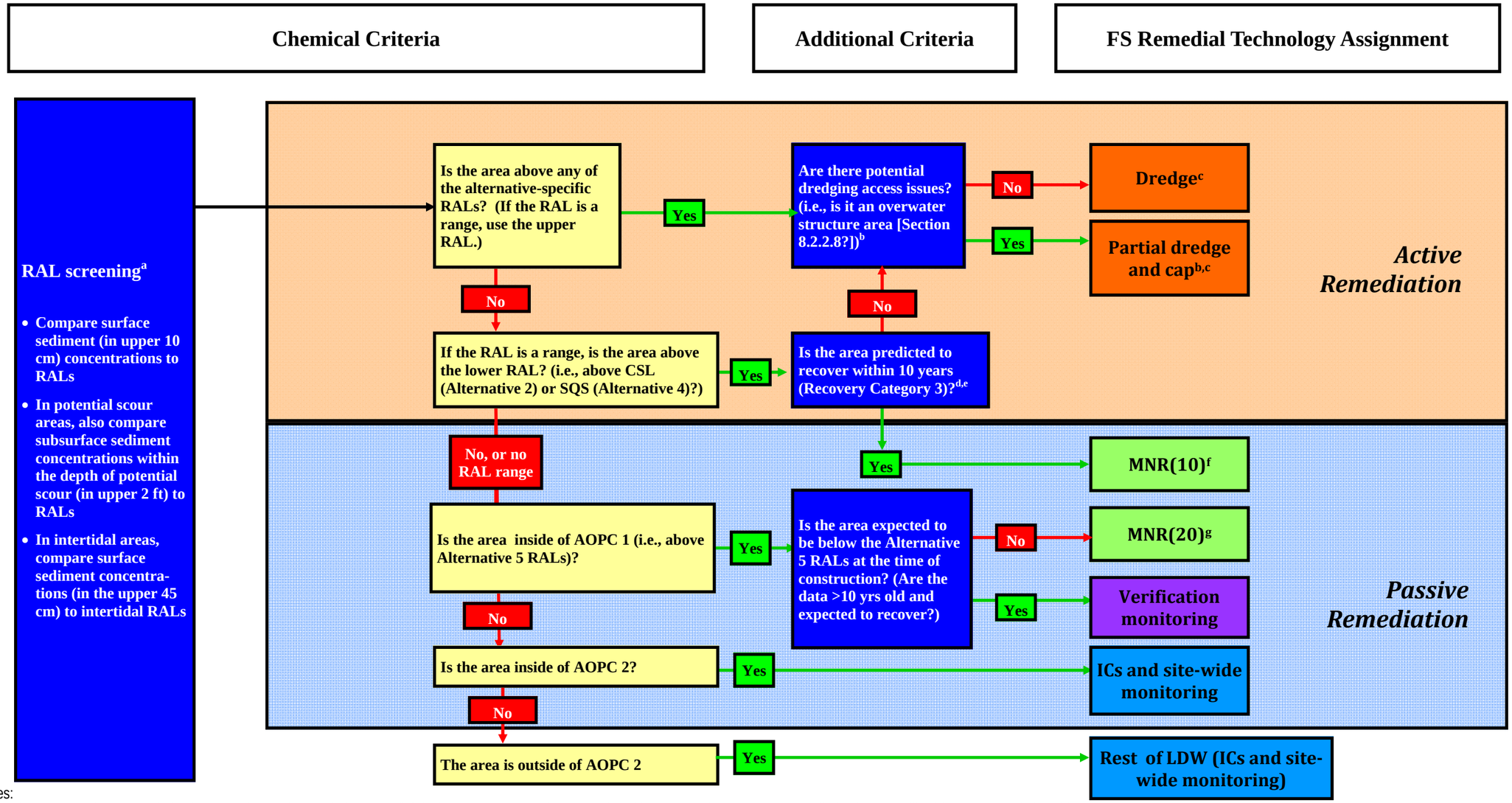
h The volume basis for the low sensitivity cost estimate is explained in Appendix I and Section 8.2.2.1.

i Base-case costs estimates based on base-case performance dredge volumes.

j The volume basis for the high sensitivity cost estimate is explained in Appendix I and Section 8.2.2.1.

CAD = contained aquatic disposal; EAA = early action area; ENR = enhanced natural recovery; LDW = Lower Duwamish Waterway; MNR = monitored natural recovery; n/a = not applicable; R = removal emphasis; SQS = sediment quality standard; VM = verification monitoring

Figure 8-1 Flow Chart for Technology Assignments for Removal Emphasis Alternatives (Alternatives 2R, 2R-CAD, 3R, 4R, 5R, 5R-T, 6R)



Notes:

Technology assumptions are only for the FS and may change during remedial design. Some areas of the LDW (outside AOPCs) do not require remediation but are still subject to ICs and site-wide monitoring.

a See Section 8.2.1 for additional details. See Table 8-1 for the array of RALs for each alternative. All RAL screening bullets apply to all yellow boxes.

b Under-pier areas are assigned partial dredging and capping for the R alternatives for cost estimating purposes; however, these areas have engineering challenges that require location-specific analysis. Various remedial technologies may be employed during design.

c The spatial extent of the remedial footprints is slightly modified in the FS for constructability considerations and detailed interpretation of the chemical data and trends (See Appendix D). See Table 8-3 for dredge depth assumptions.

d Recovery Category 1—recovery presumed to be limited; Recovery Category 2—Recovery less certain; Recovery Category 3—Predicted to recover.

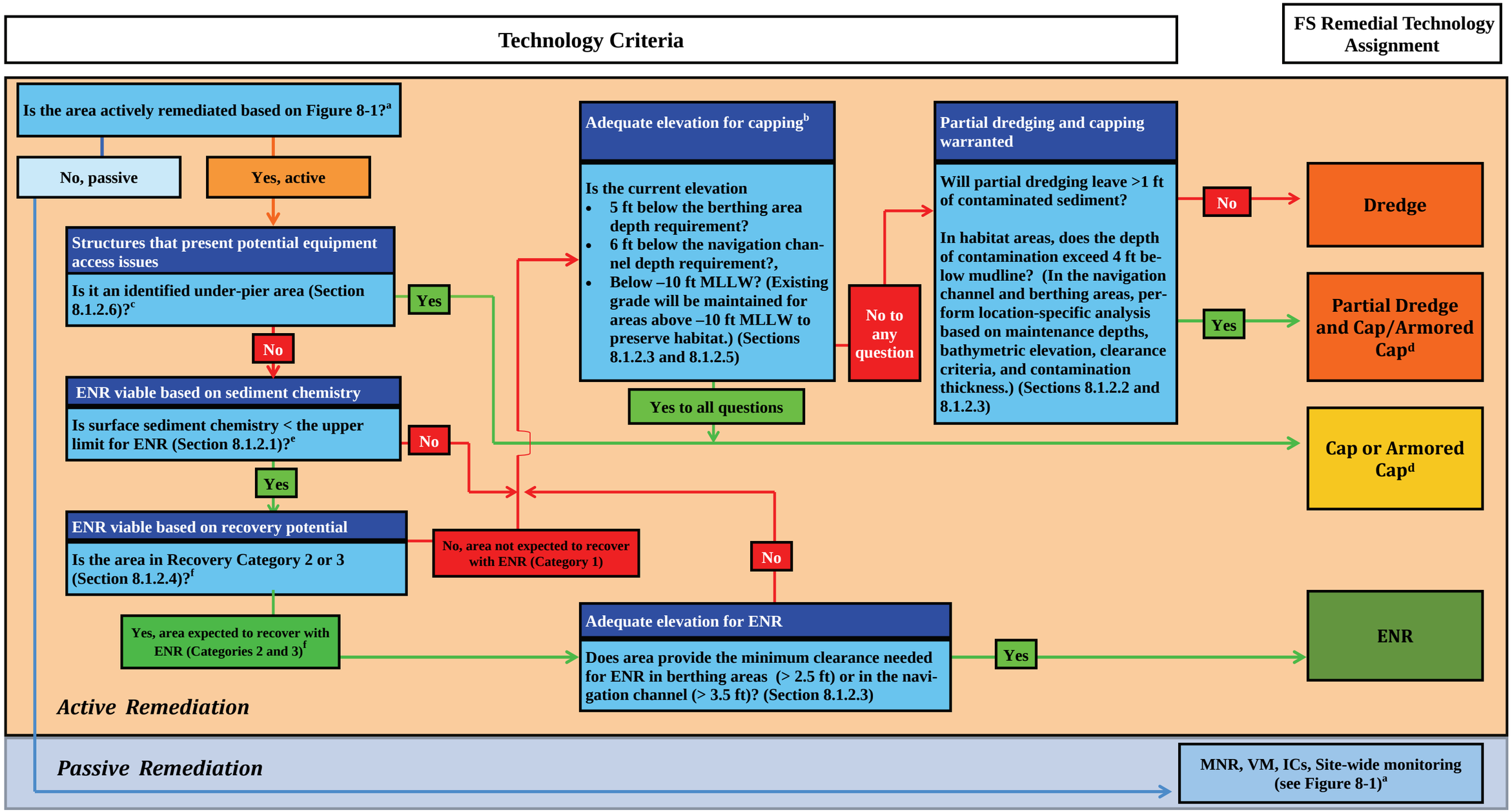
e Recovery criteria are based on recovery categories and BCM predictions. For this analysis, "No" means Recovery Categories 1 or 2 , OR areas where BCM does not predict recovery within 10 years following construction to concentrations below the CSL (Alternative 2) or SQS (Alternative 4). 'Yes" means Recovery Category 3 AND areas where BCM predicts recovery to below the CSL or SQS within 10 years.

f MNR(10) is monitoring to attain the 10-year post-construction target concentrations (applicable to Alternatives 2 and 4).

g MNR(20) is monitoring to attain PRGs for RAOs 2 through 4 on an unspecified timeframe (applicable to Alternatives 2 and 3).

AOPC = area of potential concern; BCM = bed composition model; ICs = institutional controls; MNR = monitored natural recovery; RALs = remedial action levels.

Figure 8-2 Flow Chart for Technology Assignments for Combined Technology Alternatives (Alternatives 3C, 4C, 5C, 6C)



Notes:

1. Technology assumptions are only for the FS and may change during remedial design. Some areas of the LDW (outside AOPCs) do not require remediation but are still subject to ICs and site-wide monitoring.

[a] See Figure 8-1 for details on the RALs screening and passive remedial technologies.

[b] The construction of a cap thicker or thinner than 3 ft would change the elevation requirement shown.

[c] Under-pier areas are assigned capping for the R alternatives for cost estimating purposes, however, these areas have engineering challenges that require location-specific analysis. A variety of remedial technologies may be employed during design.

[d] Armor capping is assumed to be necessary in potential scour areas.

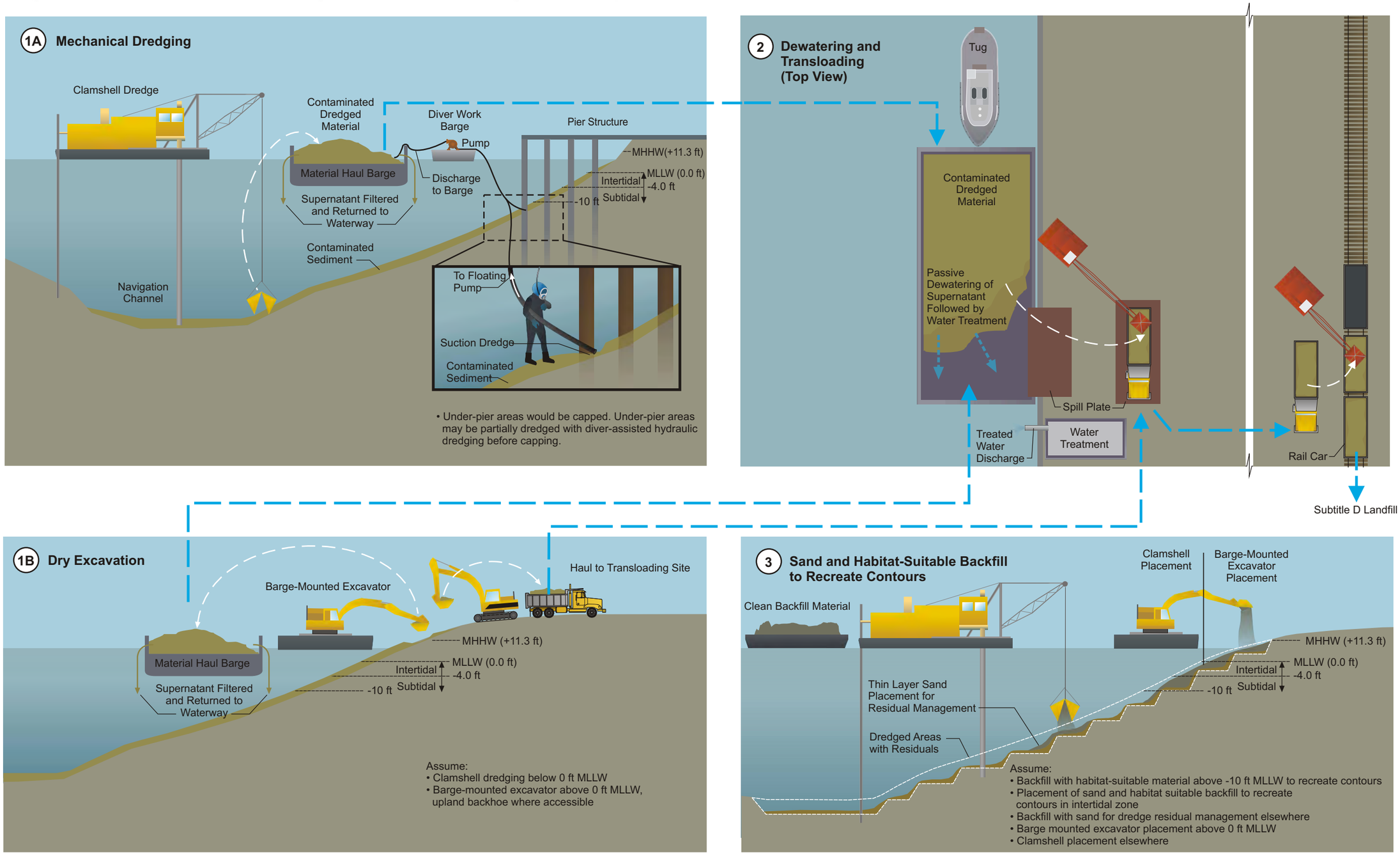
[e] Upper concentration limit is 3 times the alternative-specific RALs site-wide and 1.5 times the alternative-specific intertidal RALs in intertidal areas. See Table 8-1 for array of RALs for each alternative.

[f] Recovery Category 1—recovery presumed to be limited; Recovery Category 2—Recovery less certain; Recovery Category 3—Predicted to recover. For the FS, ENR is assumed to be viable in Recovery Categories 2 ad 3 but ENR viability may be reevaluated during design.

ENR = enhanced natural recovery; ICs = institutional controls; FS = feasibility study; MNR = monitored natural recovery; VM = verification monitoring.

Dark blue—design issue
Light blue—FS assumption and criteria

Figure 8-3 Schematic of Dredge and Partial Dredge and Cap for Removal Alternatives



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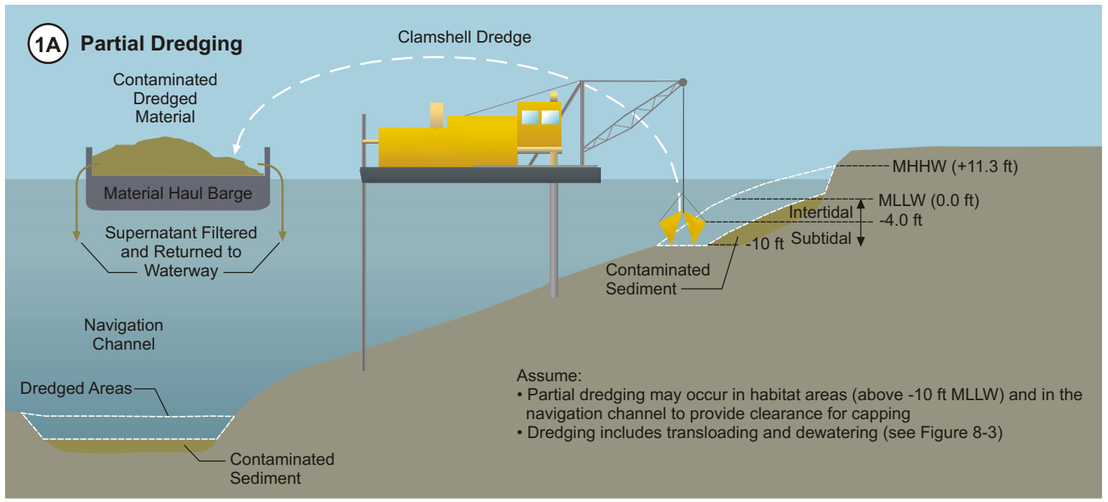
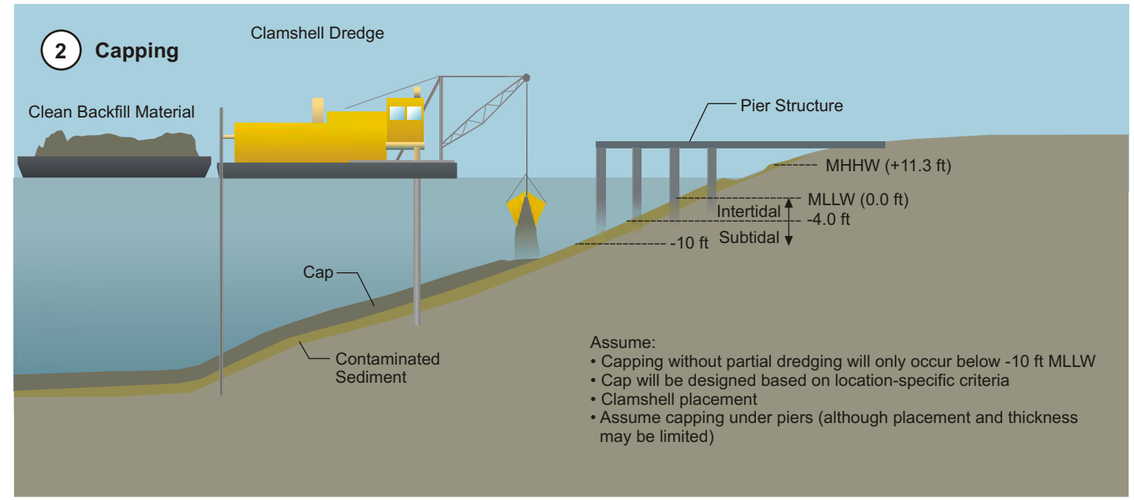
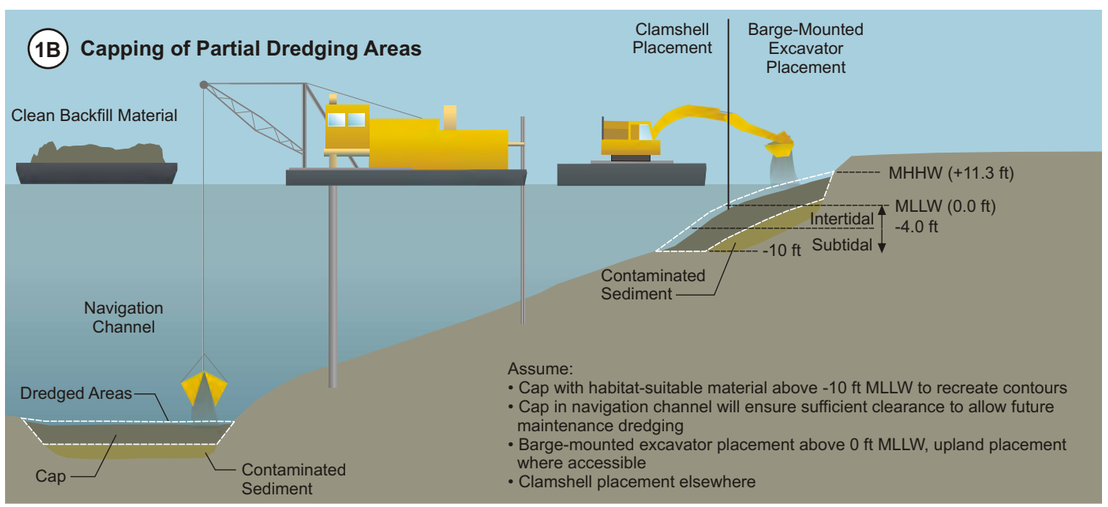
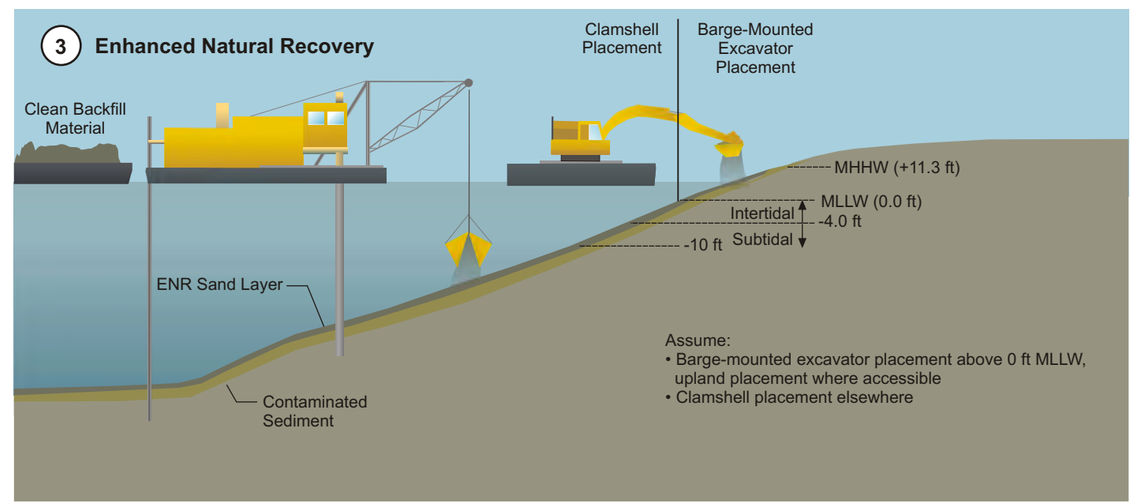
Note:
1. Use of upland backhoe and excavation equipment may be possible in localized areas, but not assumed for this FS. Nearshore intertidal areas will be accessed from in-water barges.

Figure 8-4 Schematic of Partial Dredge and Cap, Cap, and ENR for Combined Alternatives









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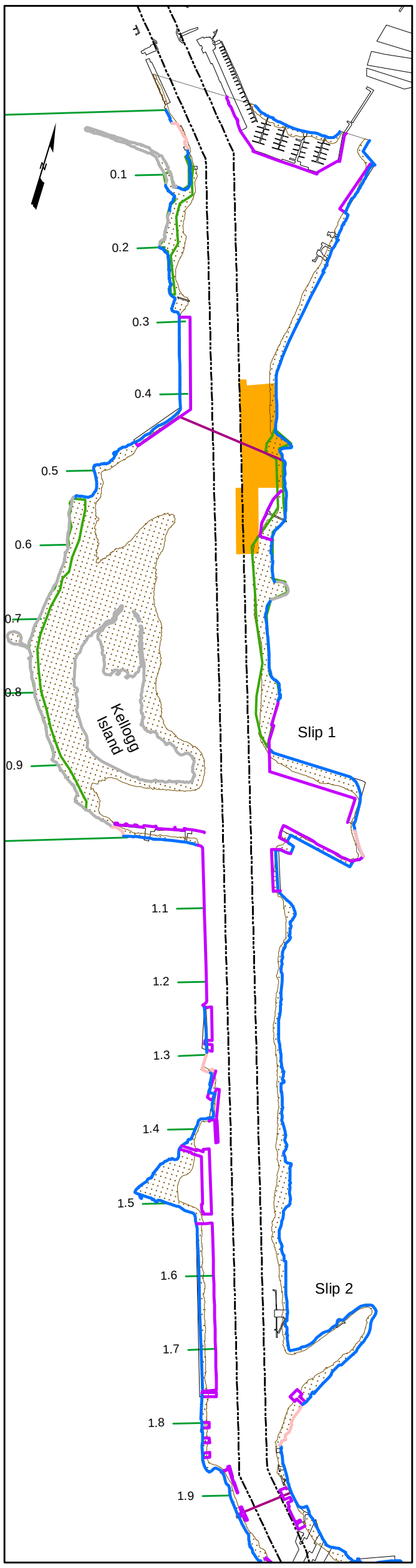
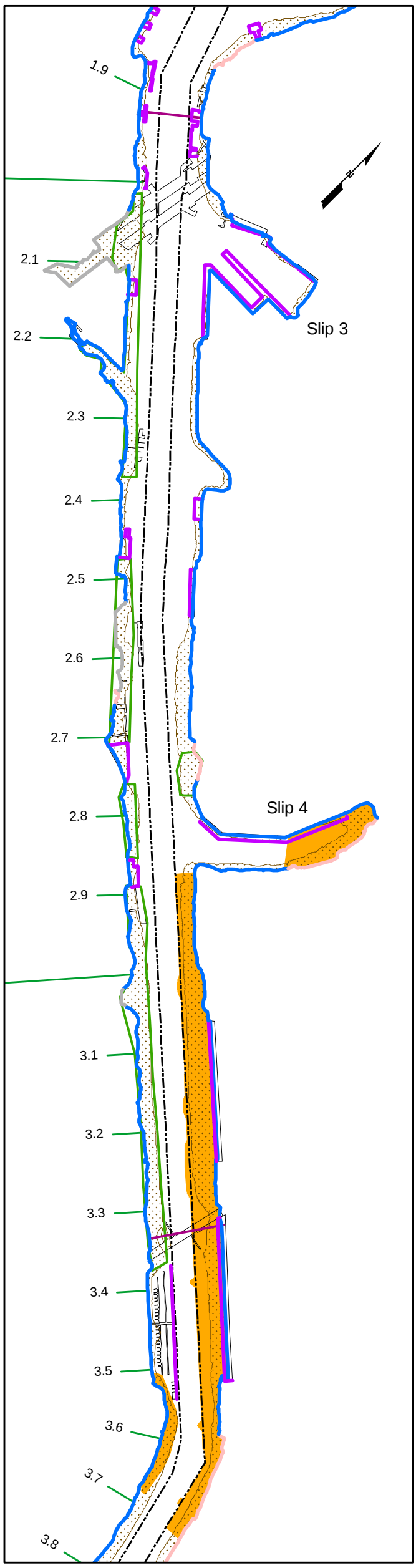
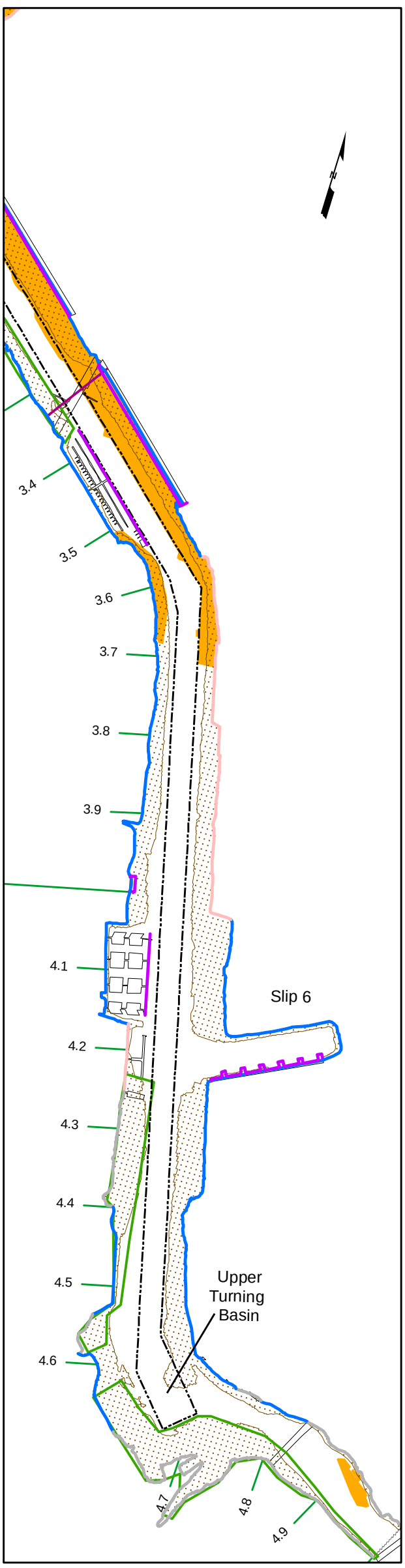
Note:
1. Use of upland backhoe and excavation equipment may be possible in localized areas, but not assumed for this FS. Nearshore intertidal activities will be accessed from in-water barges.







Notes:
1. Alternative 1, No Further Action, is the CERCLA baseline alternative used for comparison to other alternatives.

Technology Assignment

- Dredge, Cap, or Partial Dredge and Cap (Early Action Areas: 29 acres)
- Remaining Study Area (412 acres)

Legend

- Overwater Structure
- Assumed Beach Play Area
- Intertidal Area > -4 ft MLLW

Shoreline Structure

- Armored Slope (10.1 miles)
- Vertical Bulkhead (1.0 miles)
- Exposed Bank (3.7 miles)
- Dock Face (4.9 miles)
- Underwater Utility
- Navigation Channel
- River Mile Marker

Feet
0 200 400 800

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Alternative 1 No Further Action

DATE: 10/15/10 | DWRN:MVI/sea | Revision: 0

FIGURE 8-5

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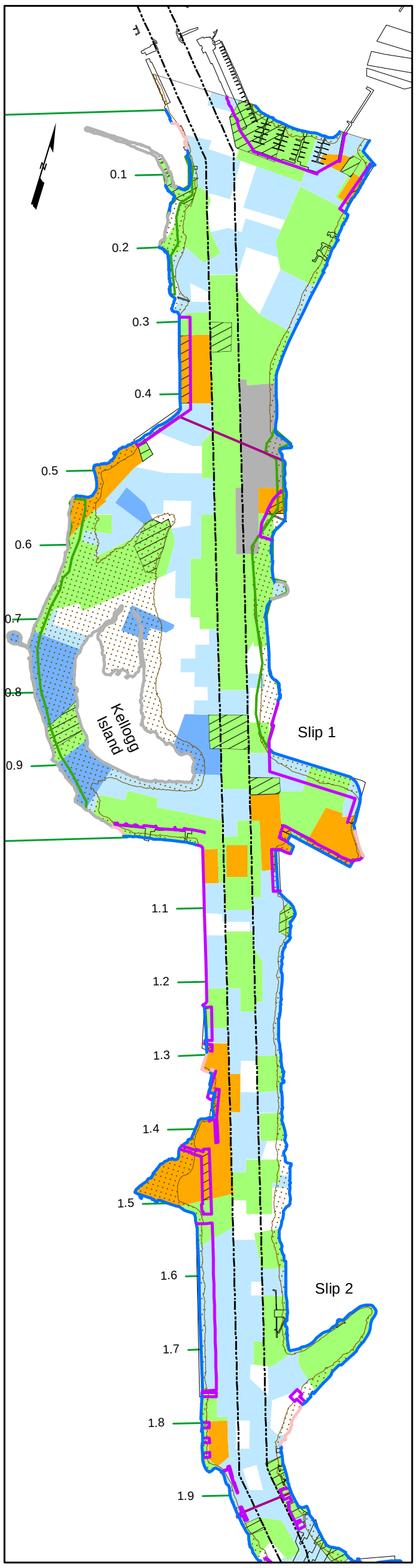

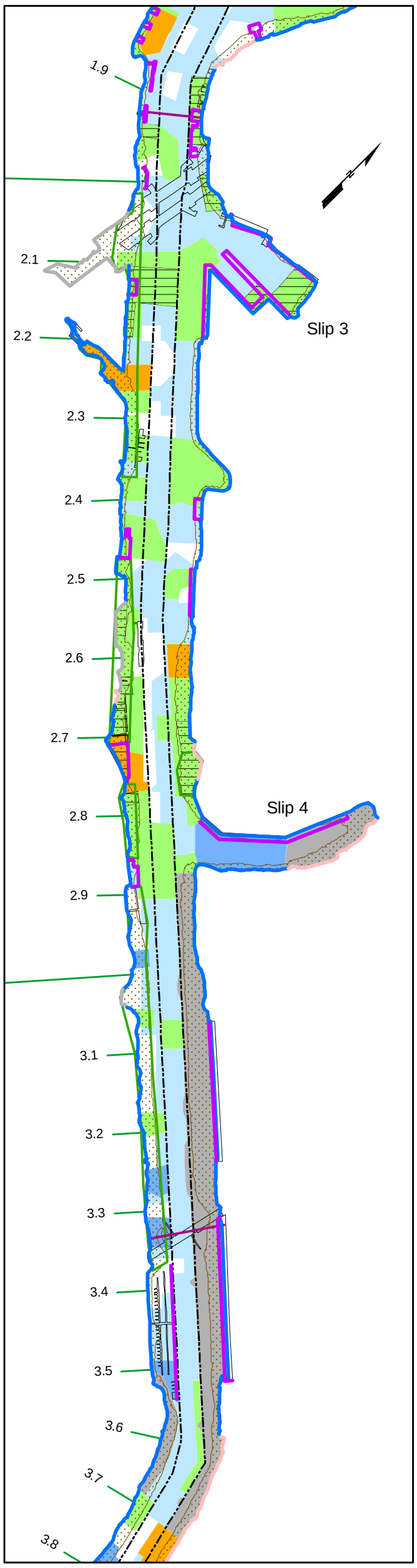

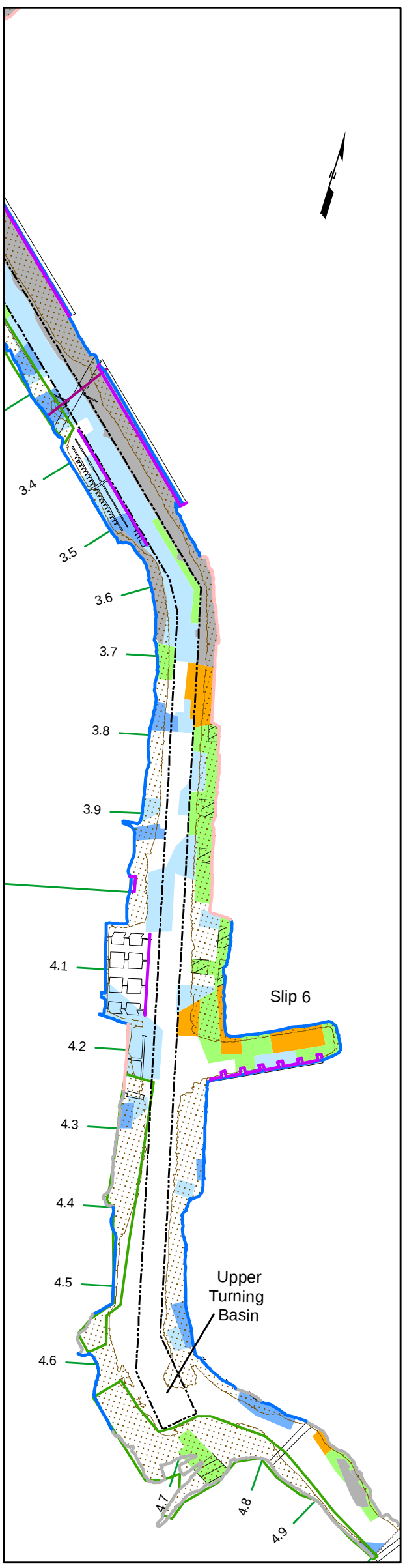

Notes:
1. Technology assignments are for the FS and may change based on additional data.
2. AOPC 1 represents the area > Alternative 5 RALs
3. AOPC 2 represents the area > Alternative 6 RALs
4. The total FS study area is 441 acres.
5. MNR(10) is the area predicted to achieve the post-construction target (CSL for Alternative 2, SQS for Alternative 4) through natural recovery within 10 years.
6. MNR(20) is the area predicted to achieve the PRGs for RAOs 2, 3, and 4 through natural recovery within 20 years.
7. Verification monitoring areas will be confirmed during remedial design and are expected to be below the SQS (Alternative 5 RALs).

Technology Assignment

AOPC 1
- Dredge (27 acres)
- Partial Dredge and Cap (3 acres)
- Cap (0 acres)
- ENR (0 acres)
- Monitored Natural Recovery (10) (20 acres)
- Monitored Natural Recovery (20) (107 acres)
- Verification Monitoring Area (19 acres)
- AOPC 2 Outside of AOPC 1 (Institutional Controls and Site-wide Monitoring) (123 acres)
- Remaining Study Area (Institutional Controls and Site-wide Monitoring) (113 acres)

Feet
0 200 400 800

Legend

- Early Action Area (29 acres)
- Overwater Structure
- Assumed Beach Play Area
- Intertidal Area > -4 ft MLLW

Shoreline Structure

- Armored Slope (10.1 miles)
- Vertical Bulkhead (1.0 miles)
- Exposed Bank (3.7 miles)
- Dock Face (4.9 miles)
- Underwater Utility
- Navigation Channel
- River Mile Marker

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Alternative 2 Removal Technology Assignments

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FIGURE 8-6

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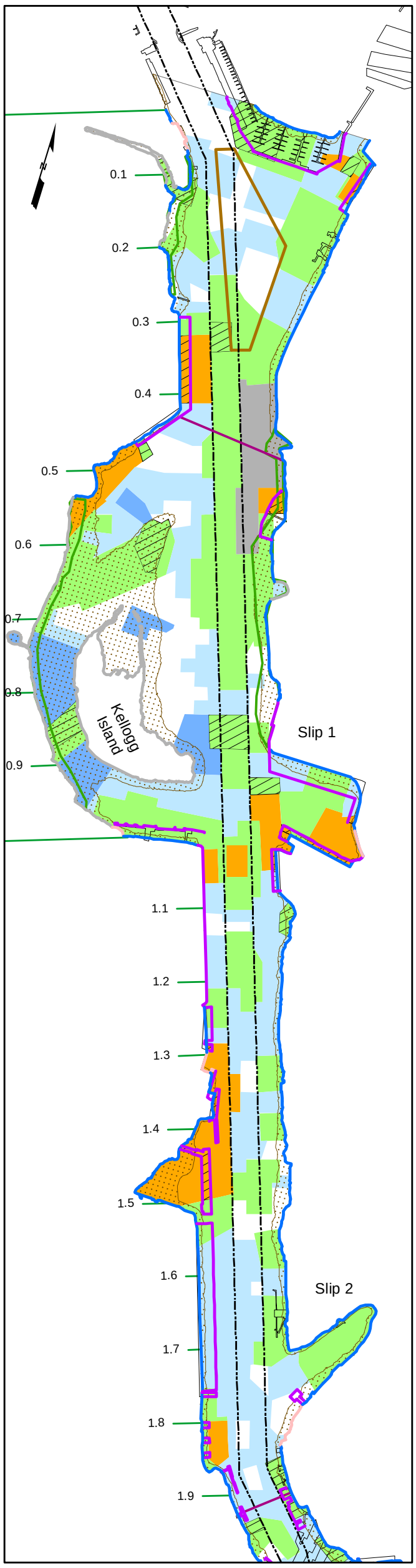

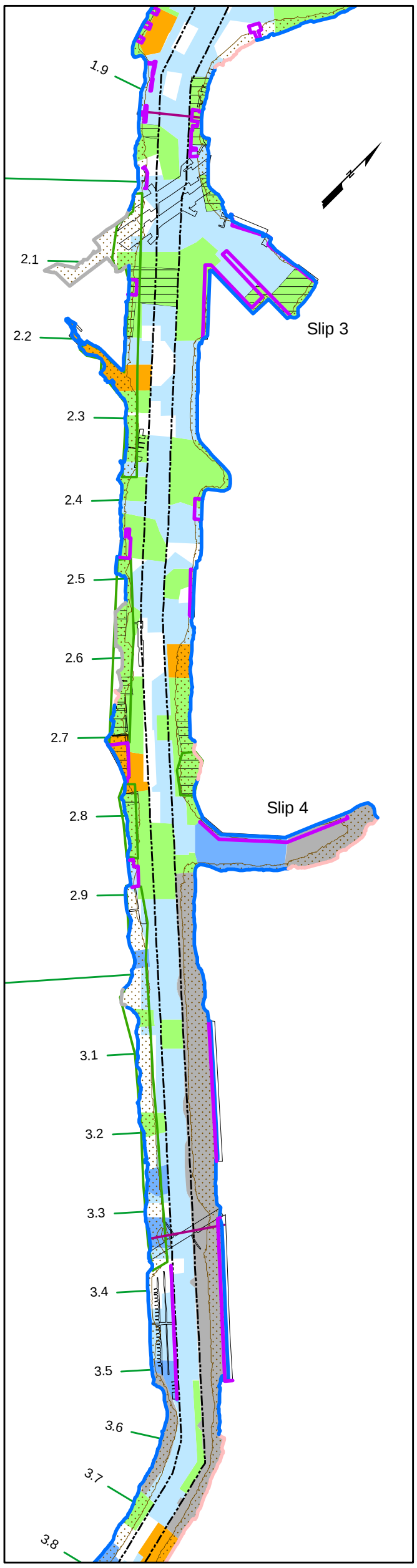

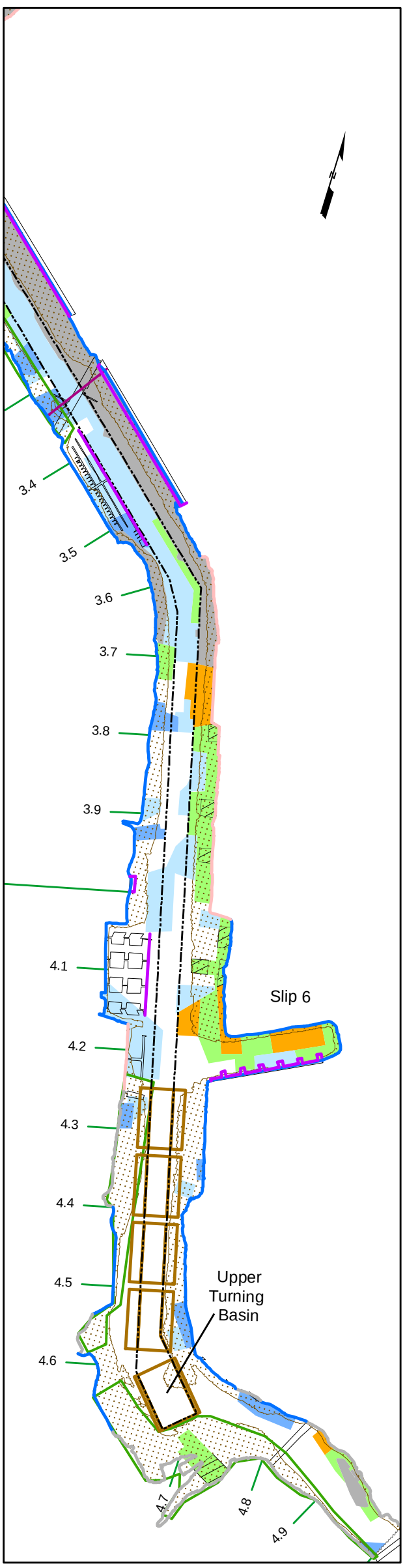

Notes:
1. Northern CAD area is expected to hold 340,000 cubic yards of contaminated sediment. The southern CAD areas are expected to hold 73,000 cubic yards of contaminated sediment.
2. Technology assignments are for the FS and may change based on additional data.
3. AOPC 1 represents the area > Alternative 5 RALs
4. AOPC 2 represents the area > Alternative 6 RALs
5. The total FS study area is 441 acres.
6. MNR(10) is the area predicted to achieve the post-construction target (CSL for Alternative 2, SQS for Alternative 4) through natural recovery within 10 years.
7. MNR(20) is the area predicted to achieve the PRGs for RAOs 2, 3, and 4 through natural recovery within 20 years.
8. Verification monitoring areas will be confirmed during remedial design and are expected to be below the SQS (Alternative 5 RALs).

Technology Assignment

- Dredge (27 acres)
- AOPC 1:
  - Partial Dredge and Cap (3 acres)
  - Cap (0 acres)
  - ENR (0 acres)
  - Monitored Natural Recovery (10) (20 acres)
  - Monitored Natural Recovery (20) (107 acres)
- Verification Monitoring Area (19 acres)
- AOPC 2 Outside of AOPC 1 (Institutional Controls and Site-wide Monitoring) (123 acres)
- Remaining Study Area (Institutional Controls and Site-wide Monitoring) (113 acres)

0 200 400 800 Feet

Legend

- Early Action Area (29 acres)
- Overwater Structure
- Assumed Beach Play Area
- Intertidal Area > -4 ft MLLW
- Confined Aquatic Disposal Area

Shoreline Structure

- Armored Slope (10.1 miles)
- Vertical Bulkhead (1.0 miles)
- Exposed Bank (3.7 miles)
- Dock Face (4.9 miles)
- Underwater Utility
- Navigation Channel
- River Mile Marker

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Alternative 2 Removal With CAD Technology Assignments

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FIGURE 8-7

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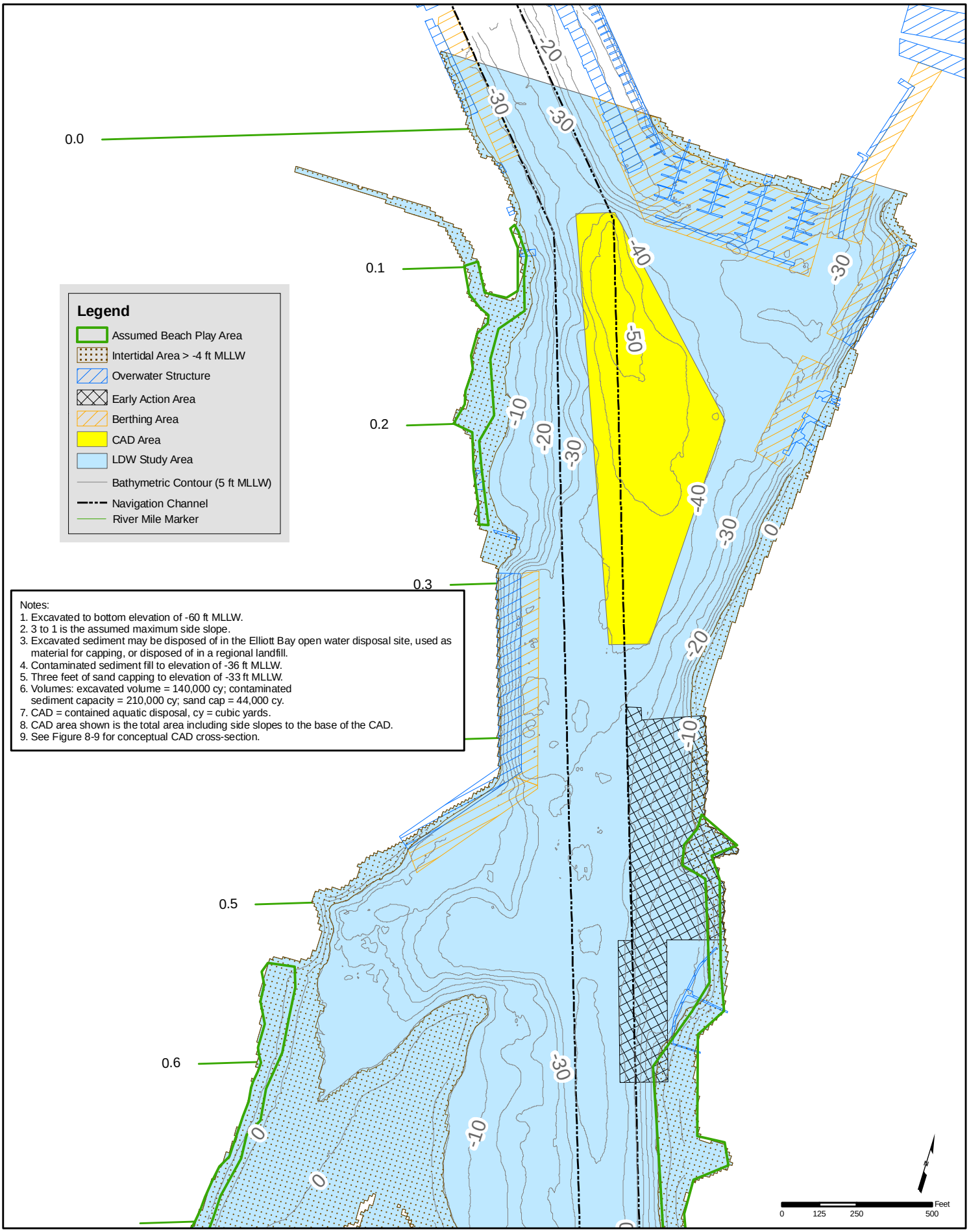

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Alternative 2
Northern CAD Area

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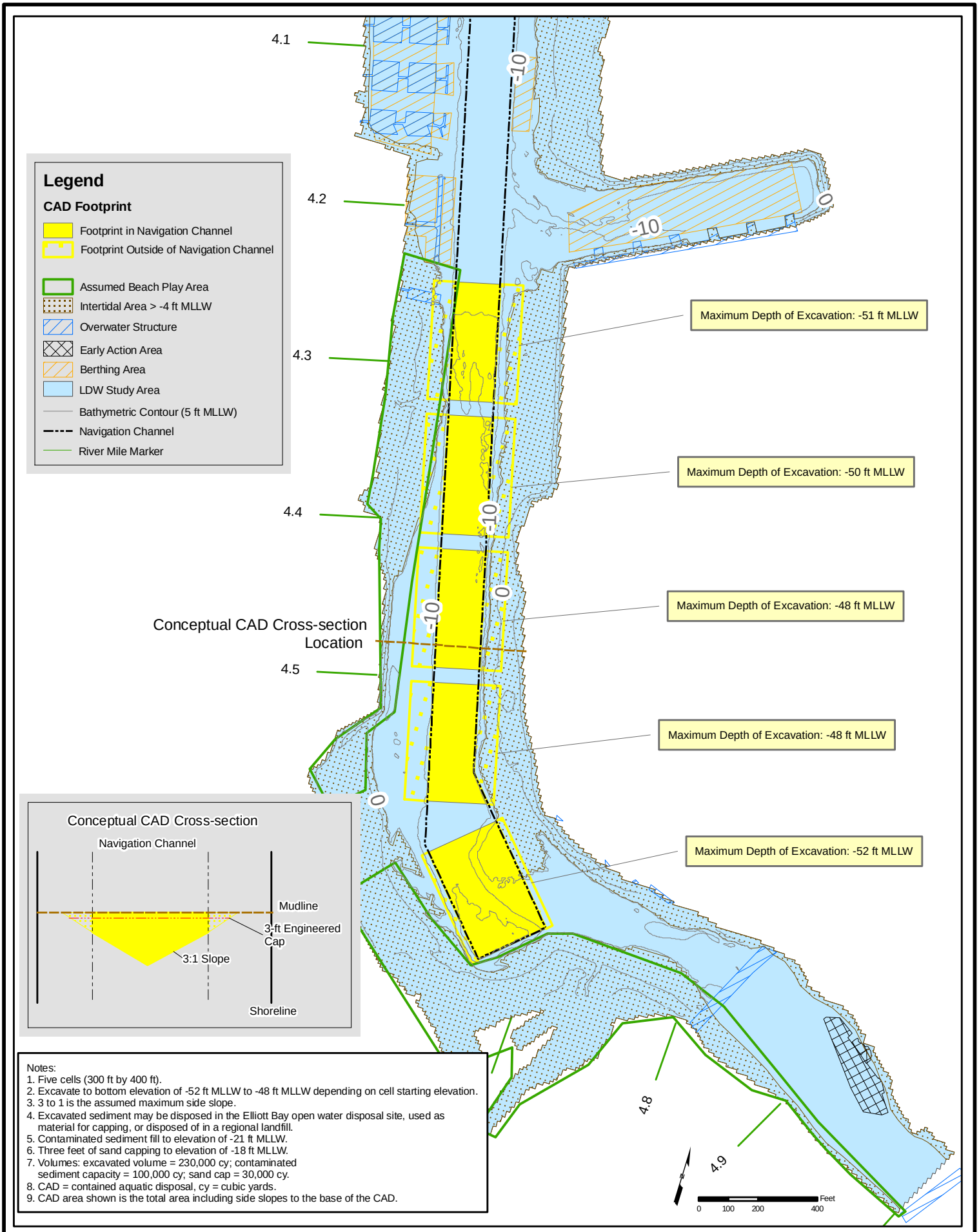
FIGURE 8-8



Notes:
1. Five cells (300 ft by 400 ft).
2. Excavate to bottom elevation of -52 ft MLLW to -48 ft MLLW depending on cell starting elevation.
3. 3 to 1 is the assumed maximum side slope.
4. Excavated sediment may be disposed in the Elliott Bay open water disposal site, used as material for capping, or disposed of in a regional landfill.
5. Contaminated sediment fill to elevation of -21 ft MLLW.
6. Three feet of sand capping to elevation of -18 ft MLLW.
7. Volumes: excavated volume = 230,000 cy; contaminated sediment capacity = 100,000 cy; sand cap = 30,000 cy.
8. CAD = contained aquatic disposal, cy = cubic yards.
9. CAD area shown is the total area including side slopes to the base of the CAD.

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Alternative 2
Southern CAD Areas

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FIGURE 8-9

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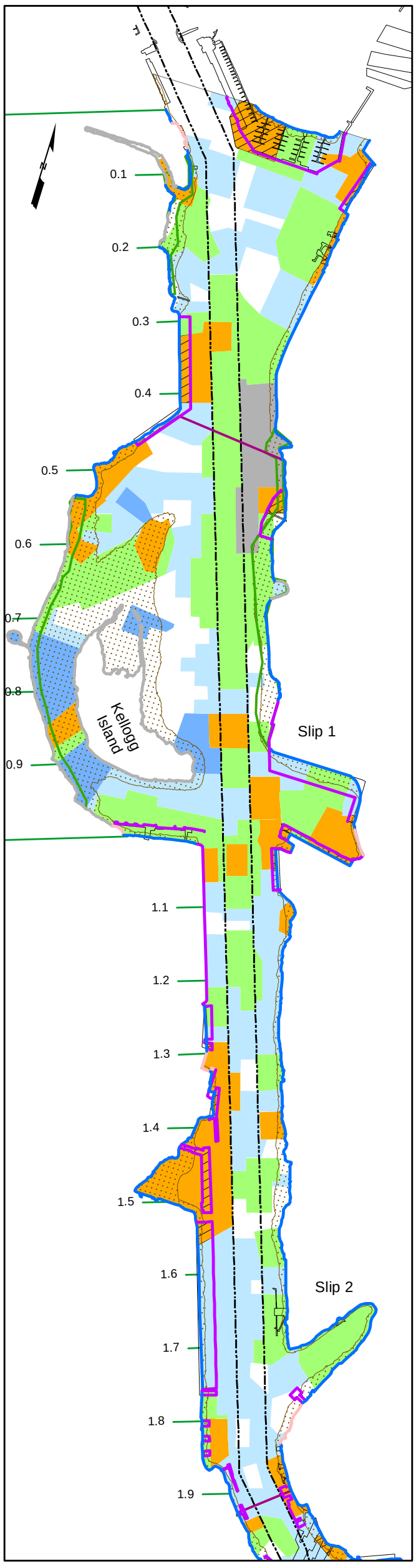

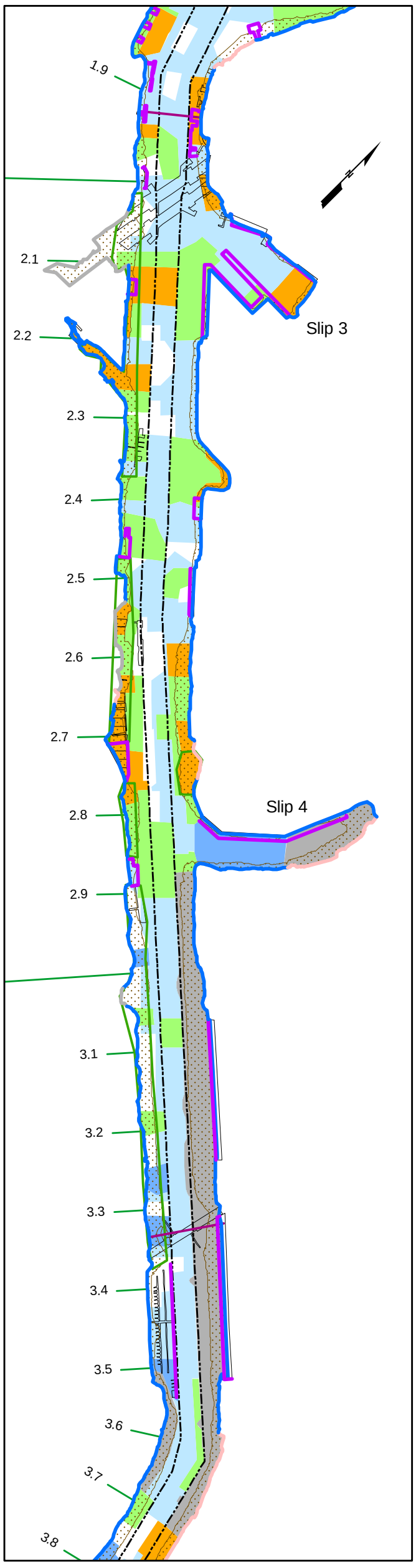

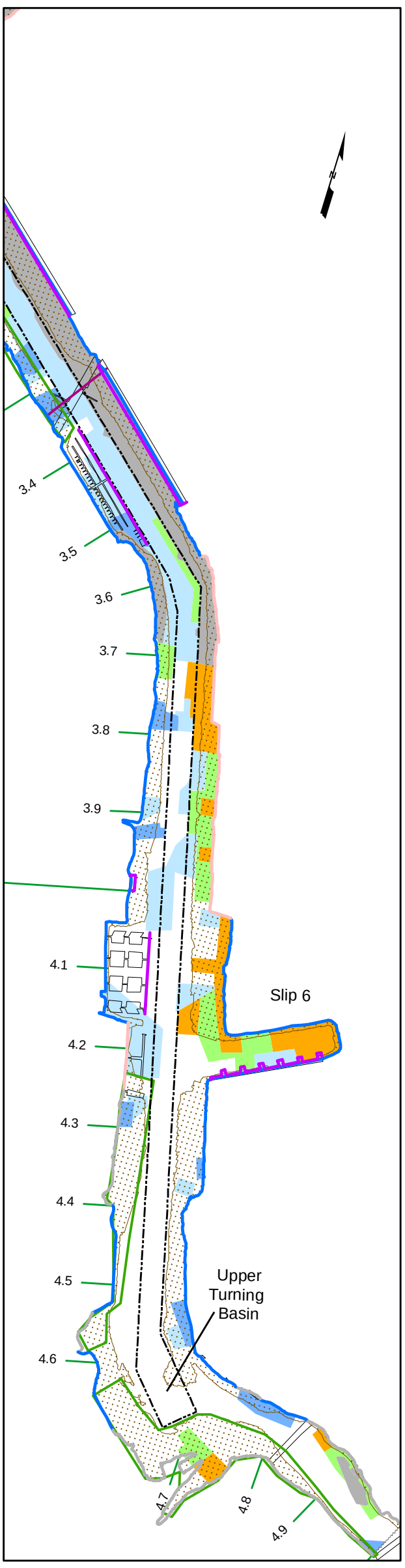

Notes:
1. Technology assignments are for the FS and may change based on additional data.
2. AOPC 1 represents the area > Alternative 5 RALs
3. AOPC 2 represents the area > Alternative 6 RALs
4. The total FS study area is 441 acres.
5. MNR(10) is the area predicted to achieve the post-construction target (CSL for Alternative 2, SQS for Alternative 4) through natural recovery within 10 years.
6. MNR(20) is the area predicted to achieve the PRGs for RAOs 2, 3, and 4 through natural recovery within 20 years.
7. Verification monitoring areas will be confirmed during remedial design and are expected to be below the SQS (Alternative 5 RALs).

Technology Assignment

AOPC 1
- Dredge (52 acres)
- Partial Dredge and Cap (5 acres)
- Cap (0 acres)
- ENR (0 acres)
- Monitored Natural Recovery (10) (0 acres)
- Monitored Natural Recovery (20) (100 acres)
- Verification Monitoring Area (19 acres)

- AOPC 2 Outside of AOPC 1 (Institutional Controls and Site-wide Monitoring) (123 acres)
- Remaining Study Area (Institutional Controls and Site-wide Monitoring) (113 acres)

Feet
0 200 400 800

Legend

- Early Action Area (29 acres)
- Overwater Structure
- Assumed Beach Play Area
- Intertidal Area > -4 ft MLLW

Shoreline Structure

- Armored Slope (10.1 miles)
- Vertical Bulkhead (1.0 miles)
- Exposed Bank (3.7 miles)
- Dock Face (4.9 miles)
- Underwater Utility
- Navigation Channel
- River Mile Marker

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Alternative 3 Removal Technology Assignments

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FIGURE 8-10

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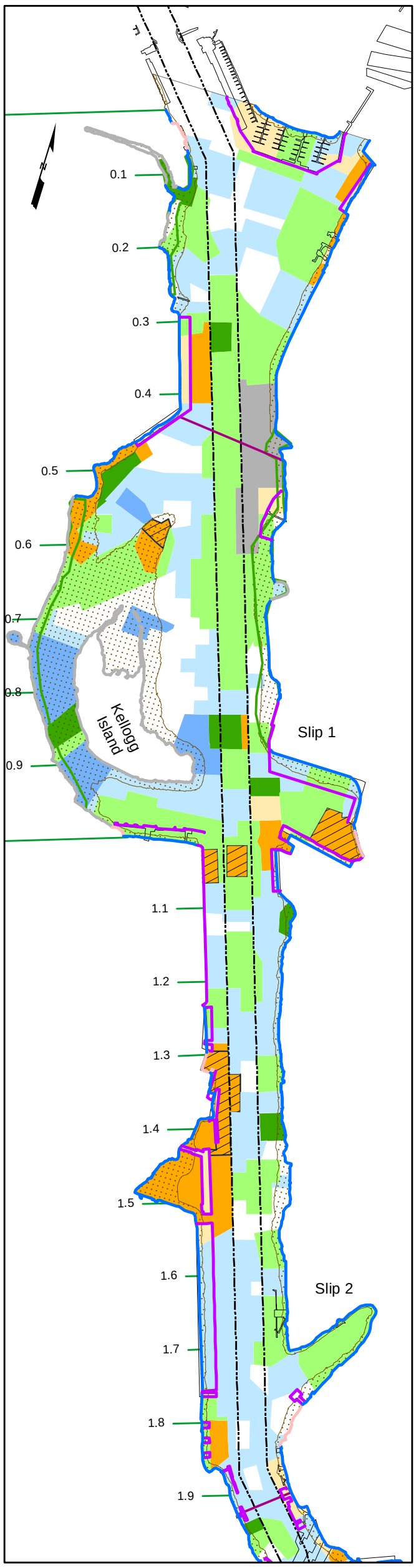

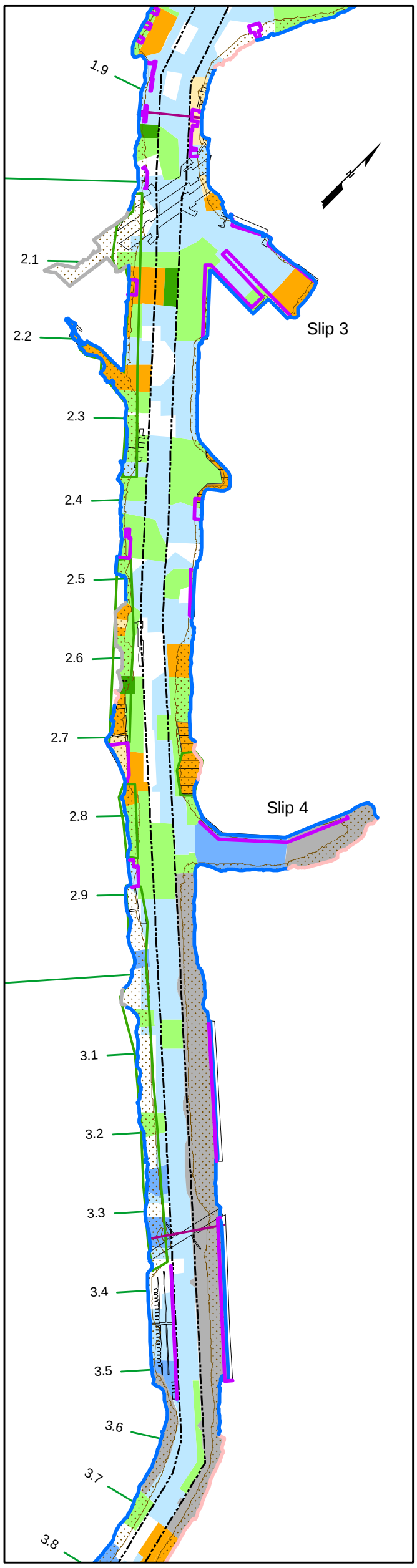

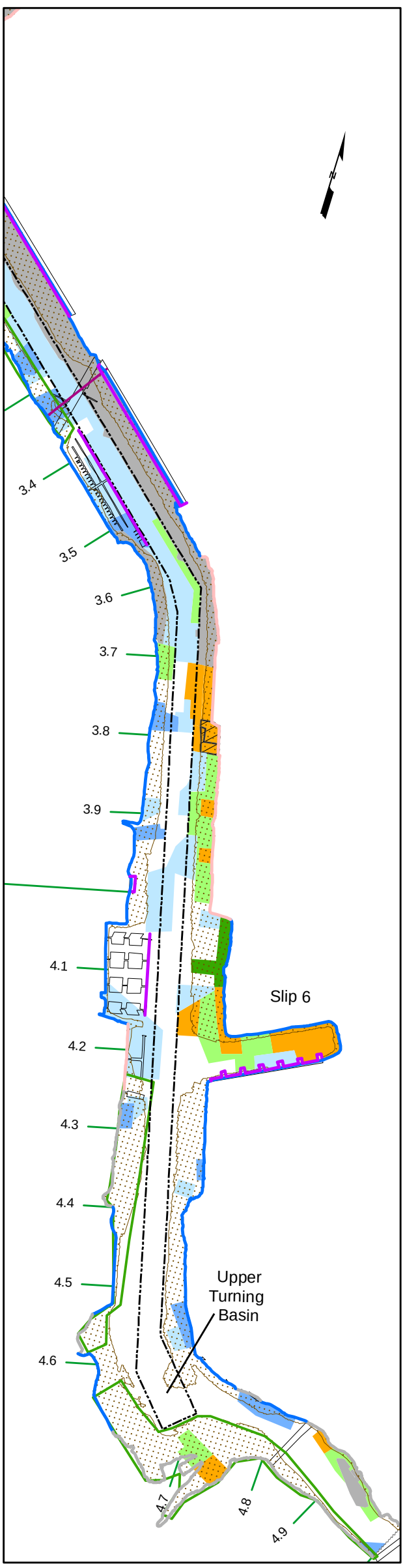

Notes:
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2. AOPC 1 represents the area > Alternative 5 RALs
3. AOPC 2 represents the area > Alternative 6 RALs
4. The total FS study area is 441 acres.
5. MNR(10) is the area predicted to achieve the post-construction target (CSL for Alternative 2, SQS for Alternative 4) through natural recovery within 10 years.
6. MNR(20) is the area predicted to achieve the PRGs for RAOs 2, 3, and 4 through natural recovery within 20 years.
7. Verification monitoring areas will be confirmed during remedial design and are expected to be below the SQS (Alternative 5 RALs).

Technology Assignment

AOPC 1
- Dredge (29 acres)
- Partial Dredge and Cap (9 acres)
- Cap (10 acres)
- ENR (9 acres)
- Monitored Natural Recovery (10) (0 acres)
- Monitored Natural Recovery (20) (100 acres)
- Verification Monitoring Area (19 acres)

- AOPC 2 Outside of AOPC 1 (Institutional Controls and Site-wide Monitoring) (123 acres)
- Remaining Study Area (Institutional Controls and Site-wide Monitoring) (113 acres)

Feet
0 200 400 800

Legend

- Early Action Area (29 acres)
- Overwater Structure
- Assumed Beach Play Area
- Intertidal Area > -4 ft MLLW

Shoreline Structure

- Armored Slope (10.1 miles)
- Vertical Bulkhead (1.0 miles)
- Exposed Bank (3.7 miles)
- Dock Face (4.9 miles)
- Underwater Utility
- Navigation Channel
- River Mile Marker

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Alternative 3 Combined Technology Assignments

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FIGURE 8-11

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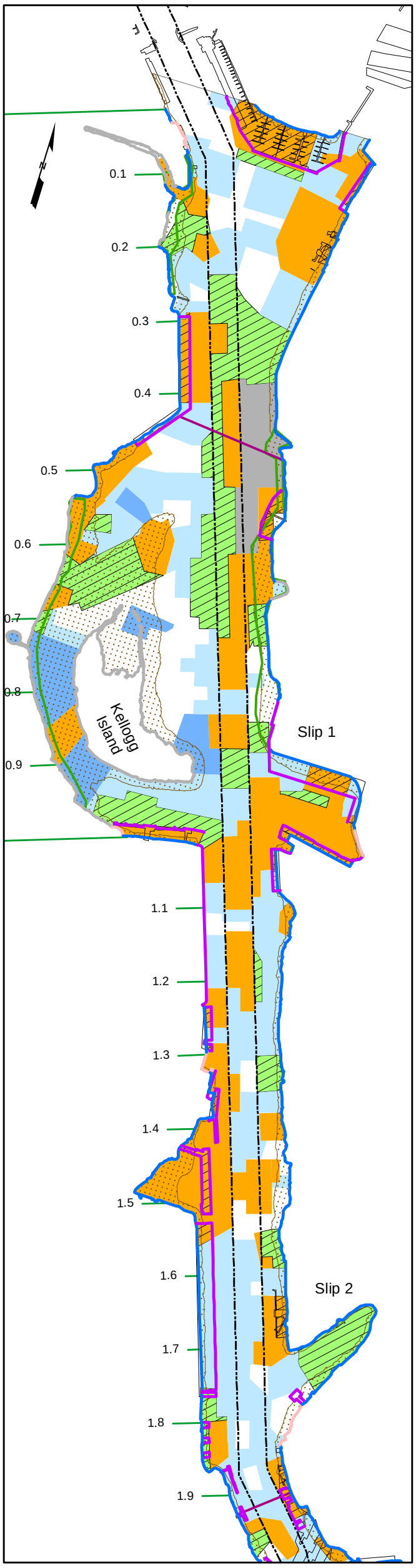

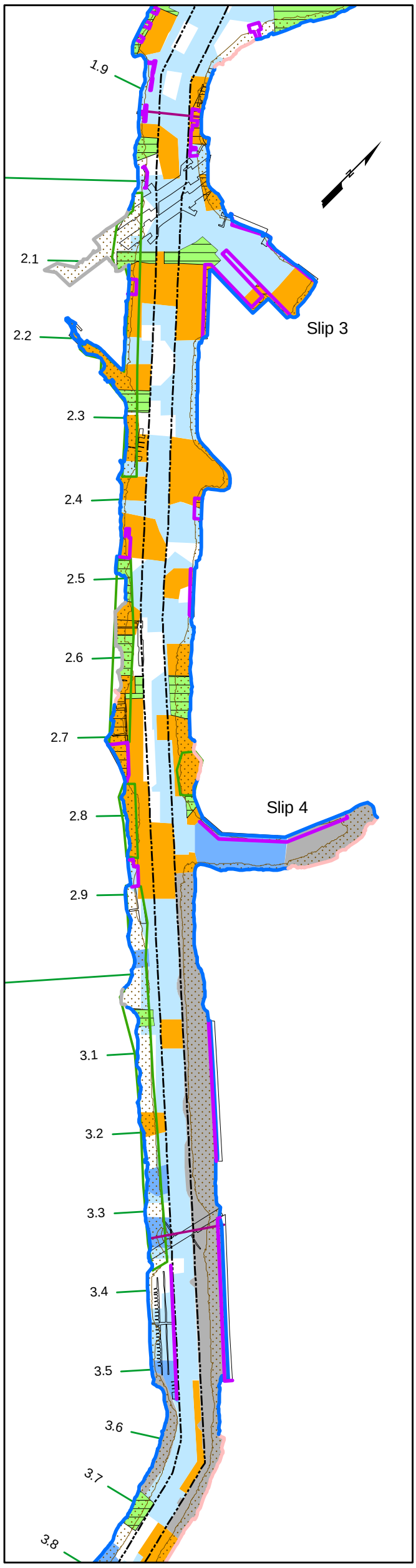

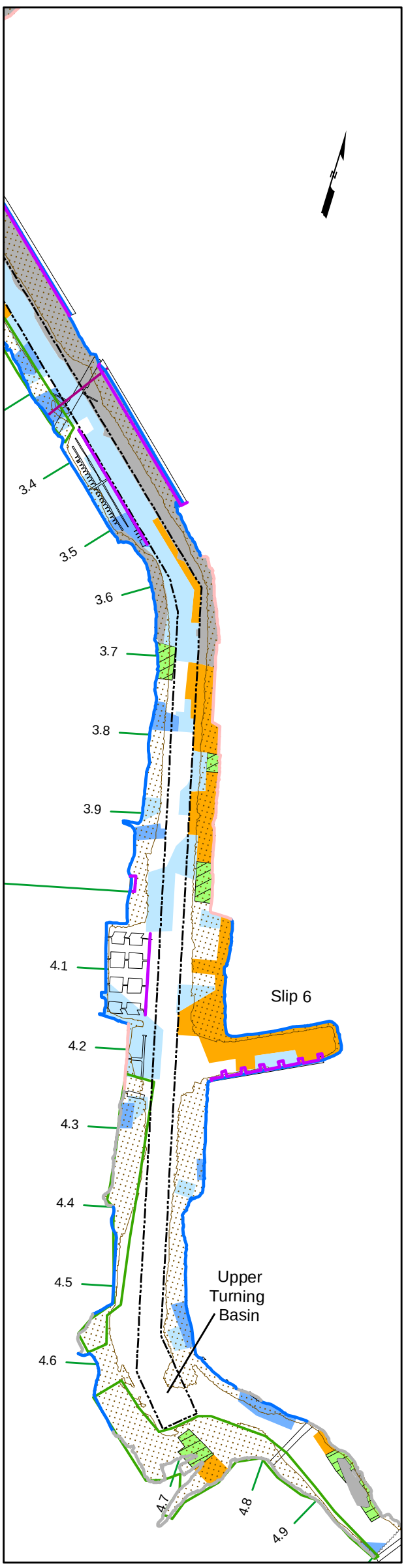

Notes:
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2. AOPC 1 represents the area > Alternative 5 RALs
3. AOPC 2 represents the area > Alternative 6 RALs
4. The total FS study area is 441 acres.
5. MNR(10) is the area predicted to achieve the post-construction target (CSL for Alternative 2, SQS for Alternative 4) through natural recovery within 10 years.
6. MNR(20) is the area predicted to achieve the PRGs for RAOs 2, 3, and 4 through natural recovery within 20 years.
7. Verification monitoring areas will be confirmed during remedial design and are expected to be below the SQS (Alternative 5 RALs).

Technology Assignment

AOPC 1
- Dredge (103 acres)
- Partial Dredge and Cap (11 acres)
- Cap (0 acres)
- ENR (0 acres)
- Monitored Natural Recovery (10) (43 acres)
- Monitored Natural Recovery (20) (0 acres)
- Verification Monitoring Area (19 acres)

AOPC 2 Outside of AOPC 1 (Institutional Controls and Site-wide Monitoring) (123 acres)

Remaining Study Area (Institutional Controls and Site-wide Monitoring) (113 acres)

Feet
0 200 400 800

Legend

- Early Action Area (29 acres)
- Overwater Structure
- Assumed Beach Play Area
- Intertidal Area > -4 ft MLLW

Shoreline Structure

- Armored Slope (10.1 miles)
- Vertical Bulkhead (1.0 miles)
- Exposed Bank (3.7 miles)
- Dock Face (4.9 miles)
- Underwater Utility
- Navigation Channel
- River Mile Marker

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Alternative 4 Removal Technology Assignments

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FIGURE 8-12

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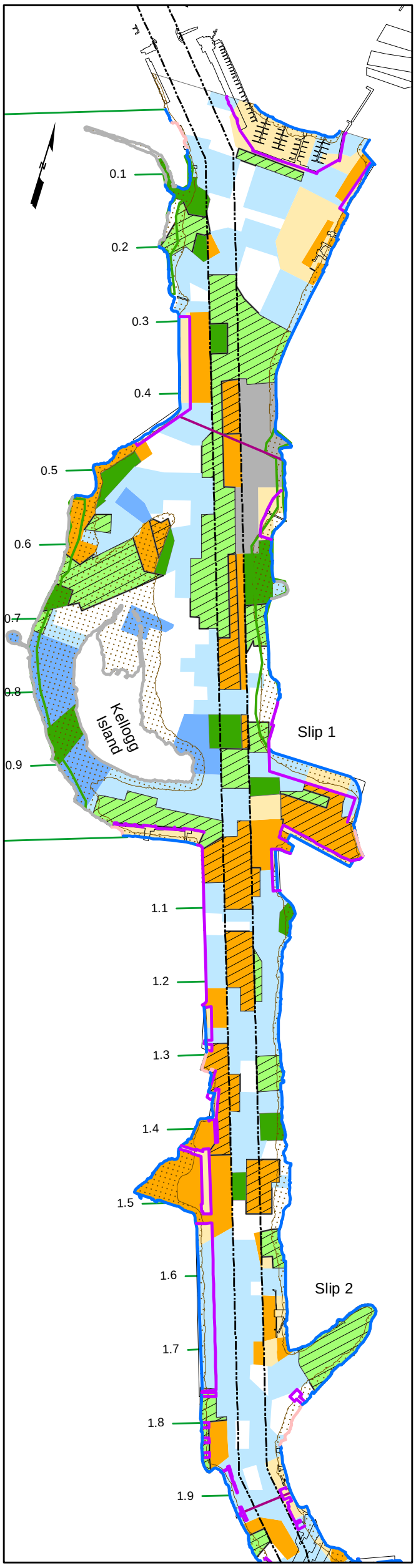

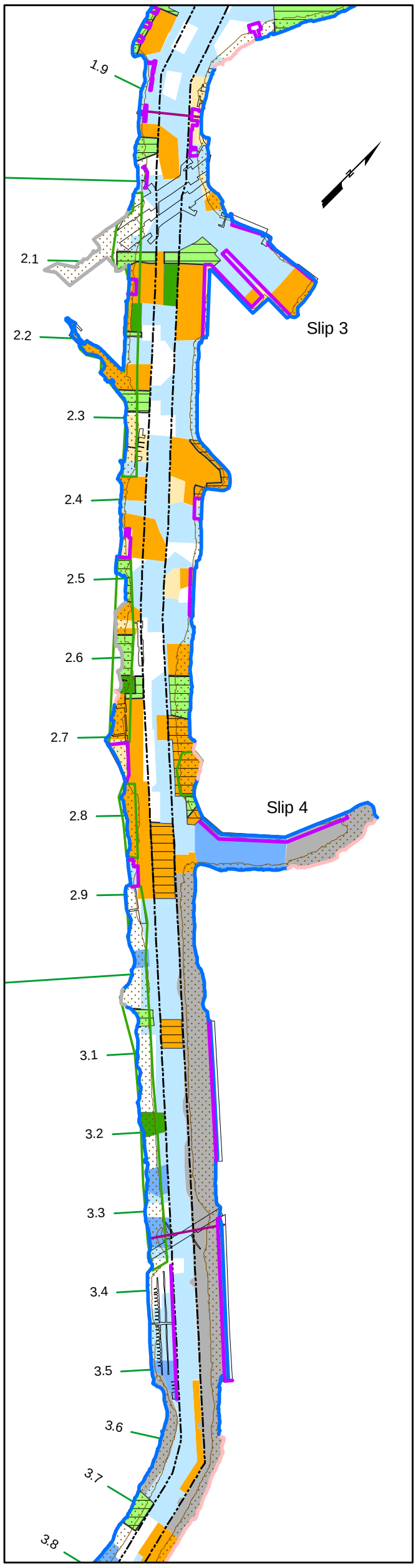

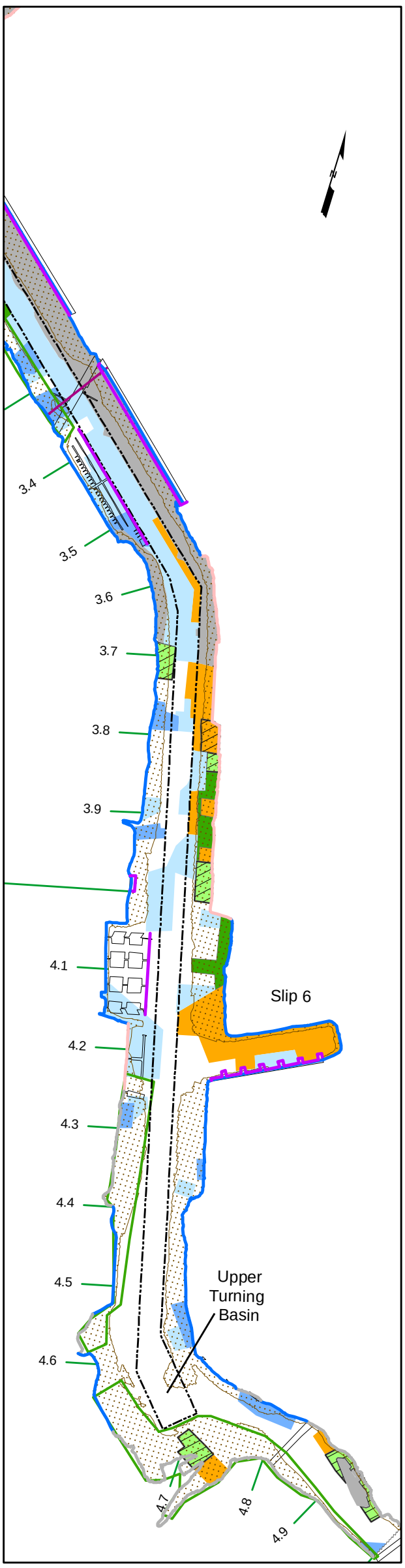

Notes:
1. Technology assignments are for the FS and may change based on additional data.
2. AOPC 1 represents the area > Alternative 5 RALs
3. AOPC 2 represents the area > Alternative 6 RALs
4. The total FS study area is 441 acres.
5. MNR(10) is the area predicted to achieve the post-construction target (CSL for Alternative 2, SQS for Alternative 4) through natural recovery within 10 years.
6. MNR(20) is the area predicted to achieve the PRGs for RAOs 2, 3, and 4 through natural recovery within 20 years.
7. Verification monitoring areas will be confirmed during remedial design and are expected to be below the SQS (Alternative 5 RALs).

Technology Assignment

AOPC 1
- Dredge (51 acres)
- Partial Dredge and Cap (25 acres)
- Cap (23 acres)
- ENR (15 acres)
- Monitored Natural Recovery (10) (43 acres)
- Monitored Natural Recovery (20) (0 acres)
- Verification Monitoring Area (19 acres)

AOPC 2 Outside of AOPC 1 (Institutional Controls and Site-wide Monitoring) (123 acres)

Remaining Study Area (Institutional Controls and Site-wide Monitoring) (113 acres)

Feet
0 200 400 800

Legend

- Early Action Area (29 acres)
- Overwater Structure
- Assumed Beach Play Area
- Intertidal Area > -4 ft MLLW

Shoreline Structure

- Armored Slope (10.1 miles)
- Vertical Bulkhead (1.0 miles)
- Exposed Bank (3.7 miles)
- Dock Face (4.9 miles)
- Underwater Utility
- Navigation Channel
- River Mile Marker

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Alternative 4 Combined Technology Assignments

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FIGURE 8-13

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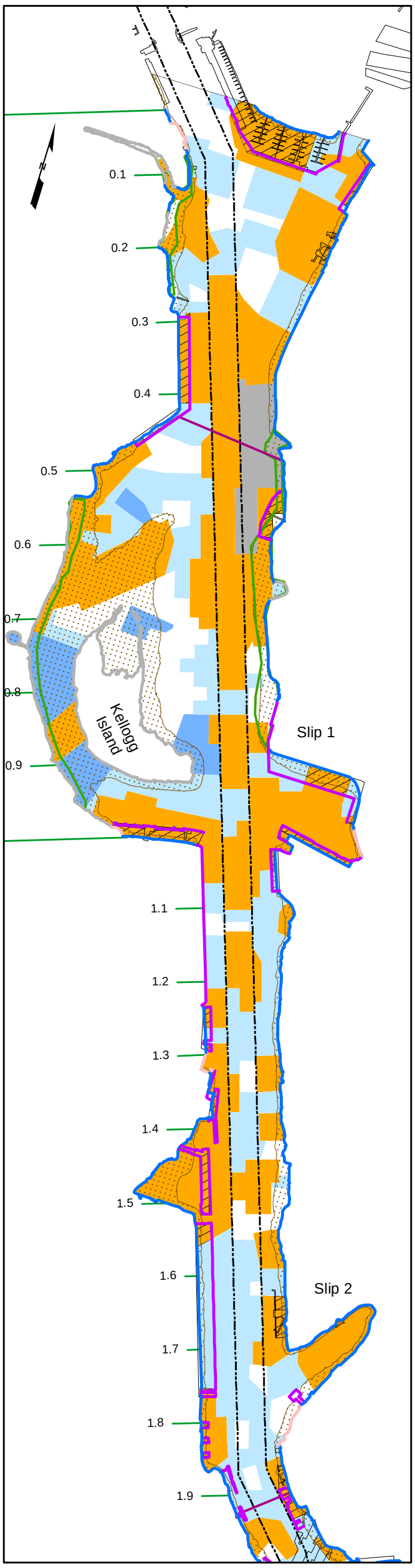

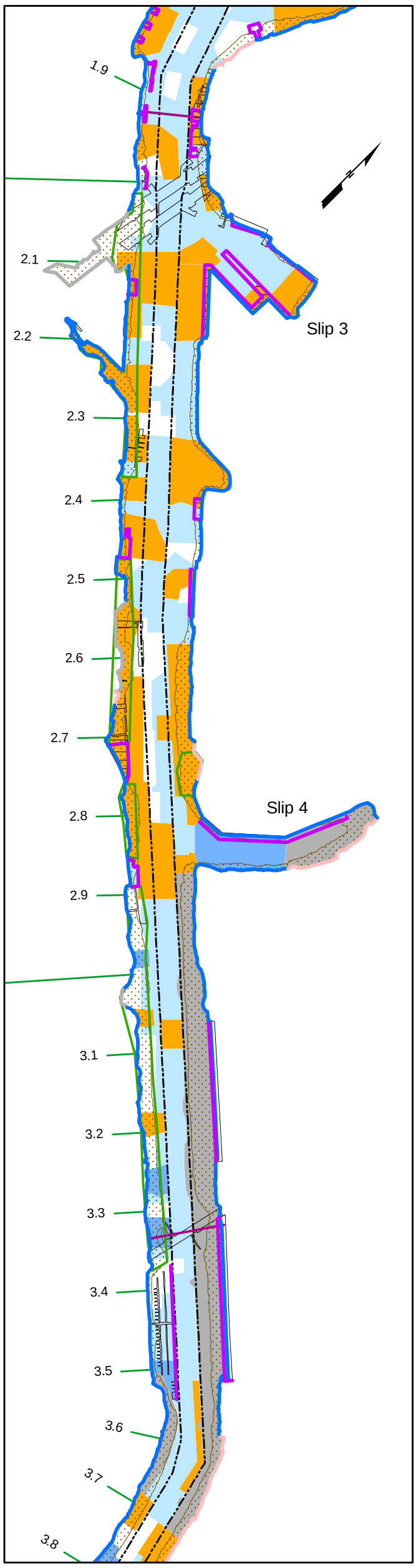

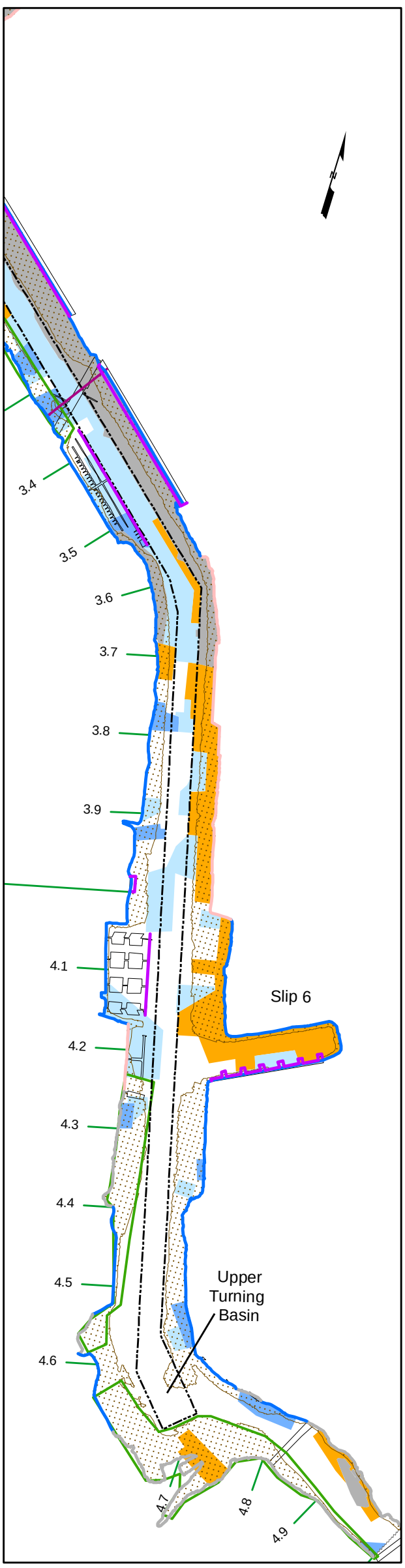

Notes:
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6. MNR(20) is the area predicted to achieve the PRGs for RAOs 2, 3, and 4 through natural recovery within 20 years.
7. Verification monitoring areas will be confirmed during remedial design and are expected to be below the SQS (Alternative 5 RALs).

Technology Assignment

AOPC 1
- Dredge (145 acres)
- Partial Dredge and Cap (12 acres)
- Cap (0 acres)
- ENR (0 acres)
- Monitored Natural Recovery (10) (0 acres)
- Monitored Natural Recovery (20) (0 acres)
- Verification Monitoring Area (19 acres)

AOPC 2 Outside of AOPC 1 (Institutional Controls and Site-wide Monitoring) (123 acres)

Remaining Study Area (Institutional Controls and Site-wide Monitoring) (113 acres)

Feet
0 200 400 800

Legend

- Early Action Area (29 acres)
- Overwater Structure
- Assumed Beach Play Area
- Intertidal Area > -4 ft MLLW

Shoreline Structure

- Armored Slope (10.1 miles)
- Vertical Bulkhead (1.0 miles)
- Exposed Bank (3.7 miles)
- Dock Face (4.9 miles)
- Underwater Utility
- Navigation Channel
- River Mile Marker

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Alternative 5 Removal and Alternative 5 Removal with Treatment Technology Assignments

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FIGURE 8-14

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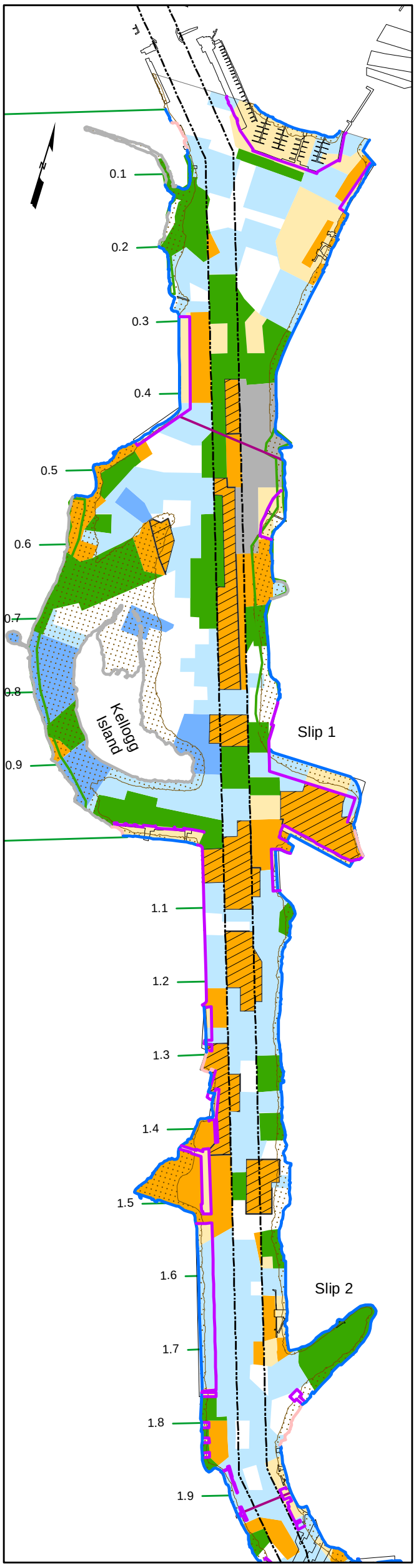

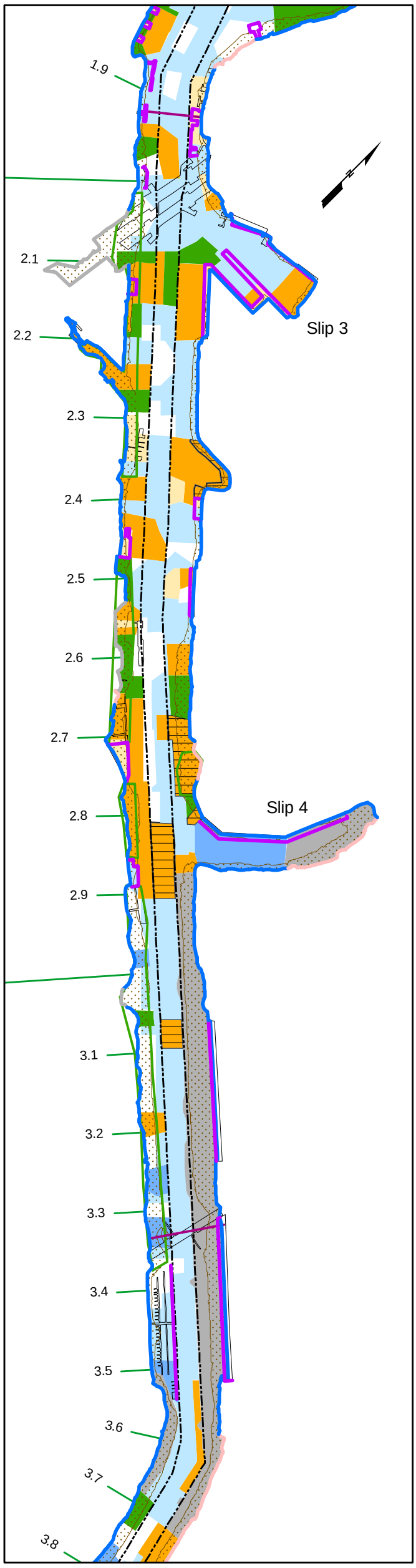

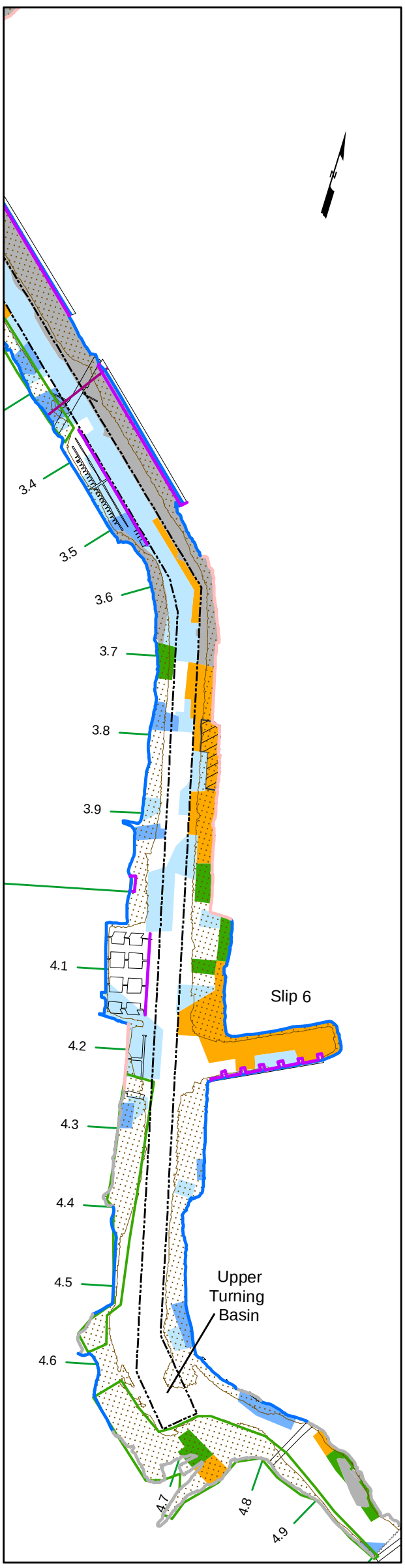

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7. Verification monitoring areas will be confirmed during remedial design and are expected to be below the SQS (Alternative 5 RALs).

Technology Assignment

AOPC 1
- Dredge (54 acres)
- Partial Dredge and Cap (29 acres)
- Cap (24 acres)
- ENR (50 acres)
- Monitored Natural Recovery (10) (0 acres)
- Monitored Natural Recovery (20) (0 acres)
- Verification Monitoring Area (19 acres)

AOPC 2 Outside of AOPC 1 (Institutional Controls and Site-wide Monitoring) (123 acres)

Remaining Study Area (Institutional Controls and Site-wide Monitoring) (113 acres)

Feet
0 200 400 800

Legend

- Early Action Area (29 acres)
- Overwater Structure
- Assumed Beach Play Area
- Intertidal Area > -4 ft MLLW

Shoreline Structure

- Armored Slope (10.1 miles)
- Vertical Bulkhead (1.0 miles)
- Exposed Bank (3.7 miles)
- Dock Face (4.9 miles)
- Underwater Utility
- Navigation Channel
- River Mile Marker

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Alternative 5 Combined Technology Assignments

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FIGURE 8-15

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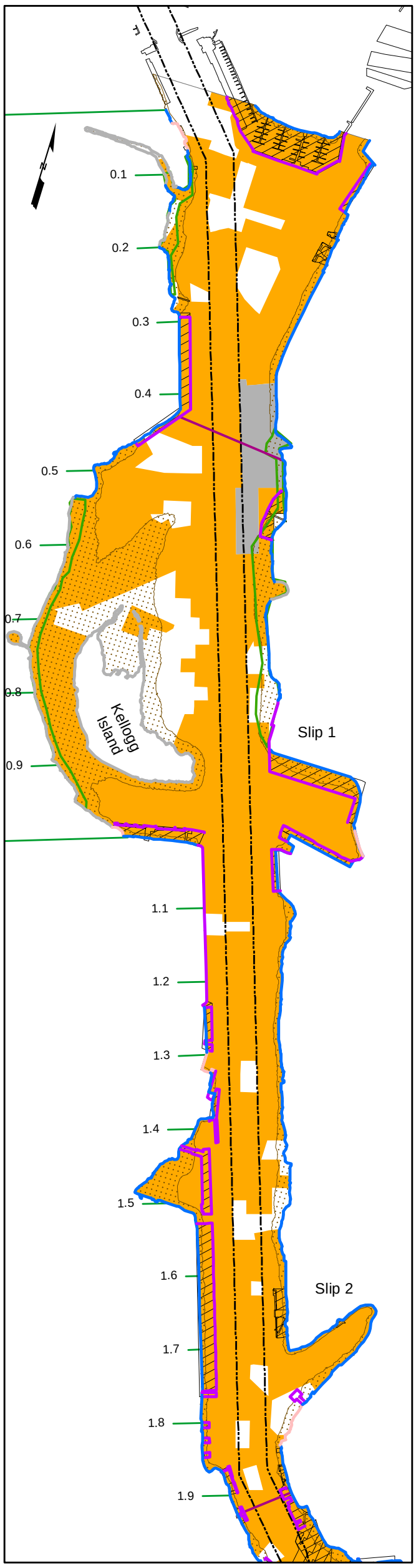

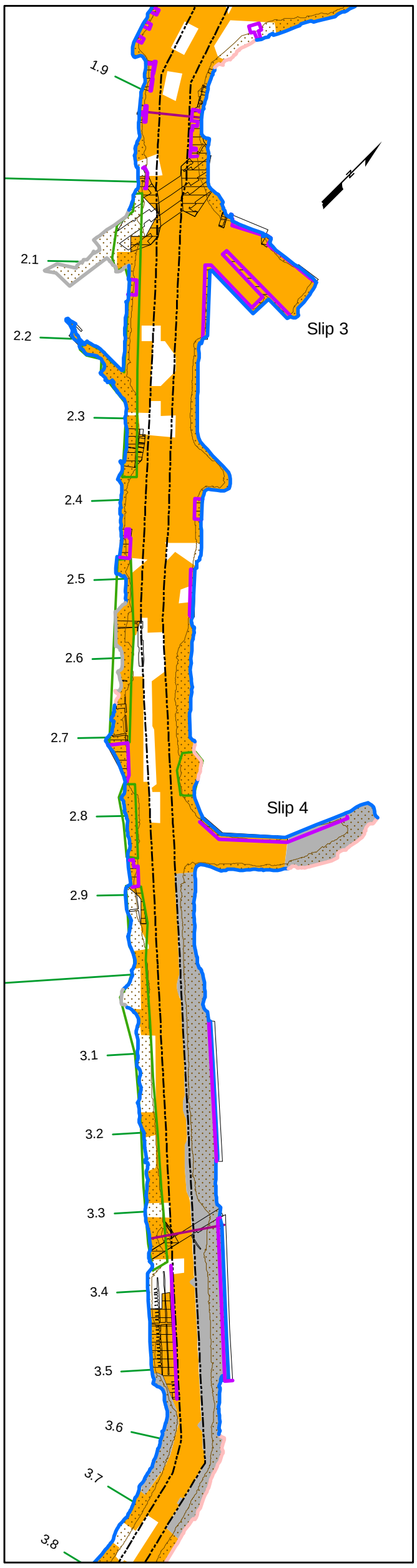

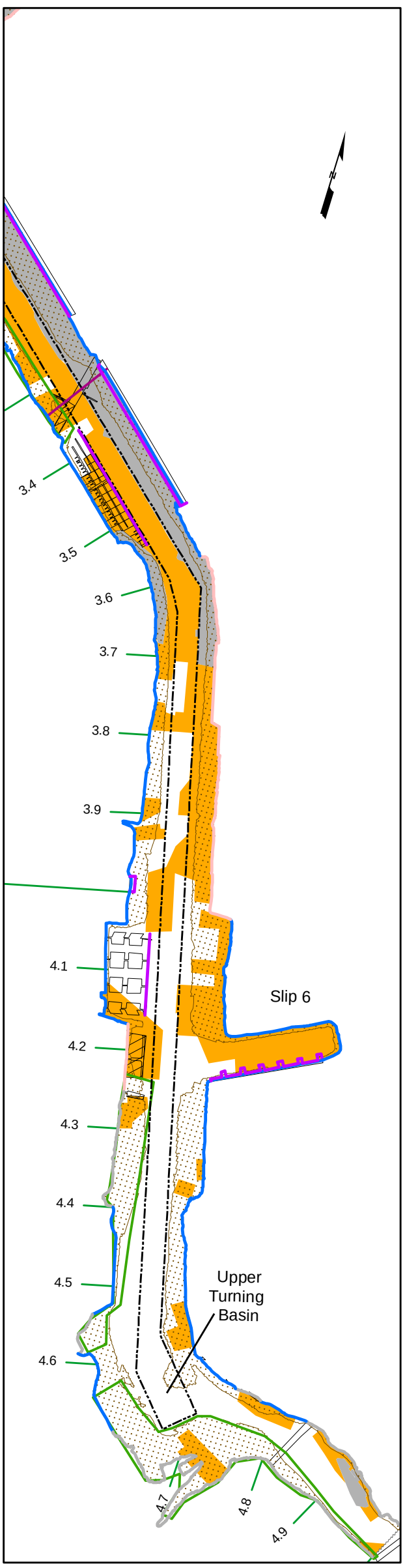

Notes:
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7. Verification monitoring areas will be confirmed during remedial design and are expected to be below the SQS (Alternative 5 RALs).

Technology Assignment

AOPC 2
- Dredge (271 acres)
- Partial Dredge and Cap (28 acres)
- Cap (0 acres)
- ENR (0 acres)
- Monitored Natural Recovery (10) (0 acres)
- Monitored Natural Recovery (20) (0 acres)
- Verification Monitoring Area (0 acres)

Remaining Study Area (Institutional Controls and Site-wide Monitoring) (113 acres)

Feet
0 200 400 800

Legend

- Early Action Area (29 acres)
- Overwater Structure
- Assumed Beach Play Area
- Intertidal Area > -4 ft MLLW

Shoreline Structure

- Armored Slope (10.1 miles)
- Vertical Bulkhead (1.0 miles)
- Exposed Bank (3.7 miles)
- Dock Face (4.9 miles)
- Underwater Utility
- Navigation Channel
- River Mile Marker

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Lower Duwamish Waterway
Draft Final Feasibility Study
60150279-14.12

Alternative 6 Removal Technology Assignments

DATE: 10/15/10 | DWRN:MVI/sea | Revision: 0

FIGURE 8-16

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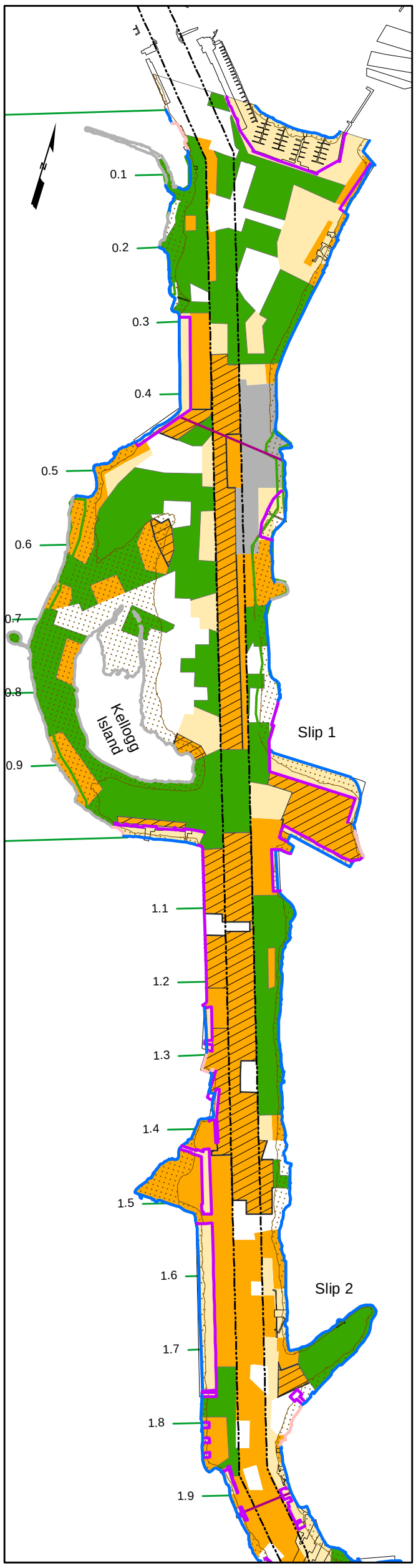

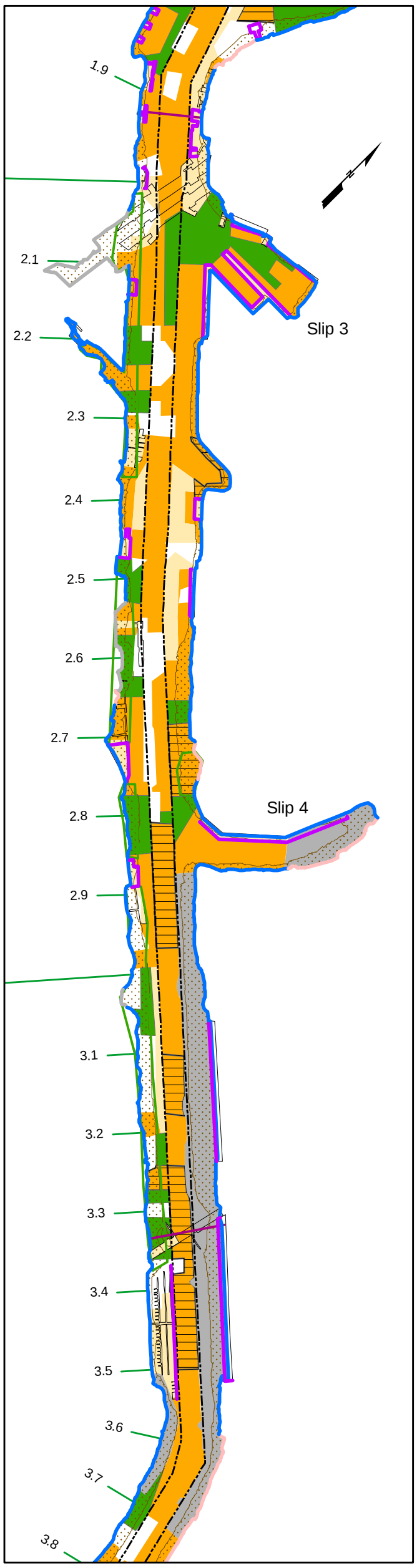

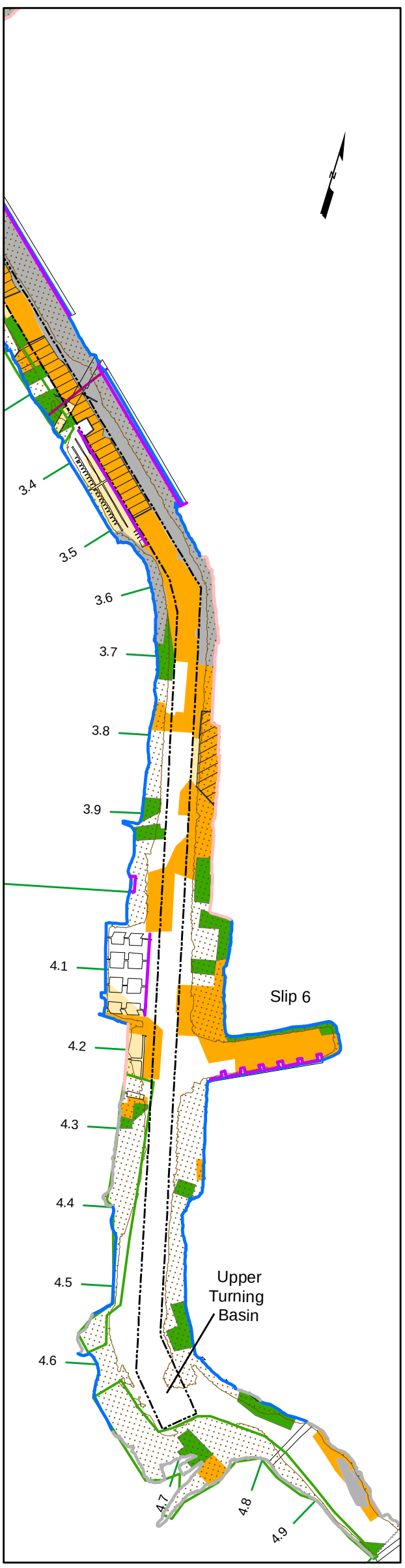

Notes:
1. Technology assignments are for the FS and may change based on additional data.
2. AOPC 1 represents the area > Alternative 5 RALs
3. AOPC 2 represents the area > Alternative 6 RALs
4. The total FS study area is 441 acres.
5. MNR(10) is the area predicted to achieve the post-construction target (CSL for Alternative 2, SQS for Alternative 4) through natural recovery within 10 years.
6. MNR(20) is the area predicted to achieve the PRGs for RAOs 2, 3, and 4 through natural recovery within 20 years.
7. Verification monitoring areas will be confirmed during remedial design and are expected to be below the SQS (Alternative 5 RALs).

Technology Assignment

AOPC 2
- Dredge (106 acres)
- Partial Dredge and Cap (50 acres)
- Cap (51 acres)
- ENR (92 acres)
- Monitored Natural Recovery (10) (0 acres)
- Monitored Natural Recovery (20) (0 acres)
- Verification Monitoring Area (0 acres)

Remaining Study Area (Institutional Controls and Site-wide Monitoring) (113 acres)

Feet
0 200 400 800

Legend

- Early Action Area (29 acres)
- Overwater Structure
- Assumed Beach Play Area
- Intertidal Area > -4 ft MLLW

Shoreline Structure

- Armored Slope (10.1 miles)
- Vertical Bulkhead (1.0 miles)
- Exposed Bank (3.7 miles)
- Dock Face (4.9 miles)
- Underwater Utility
- Navigation Channel
- River Mile Marker

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Alternative 6 Combined Technology Assignments

DATE: 10/15/10 | DWRN:MVI/sea | Revision: 0

FIGURE 8-17

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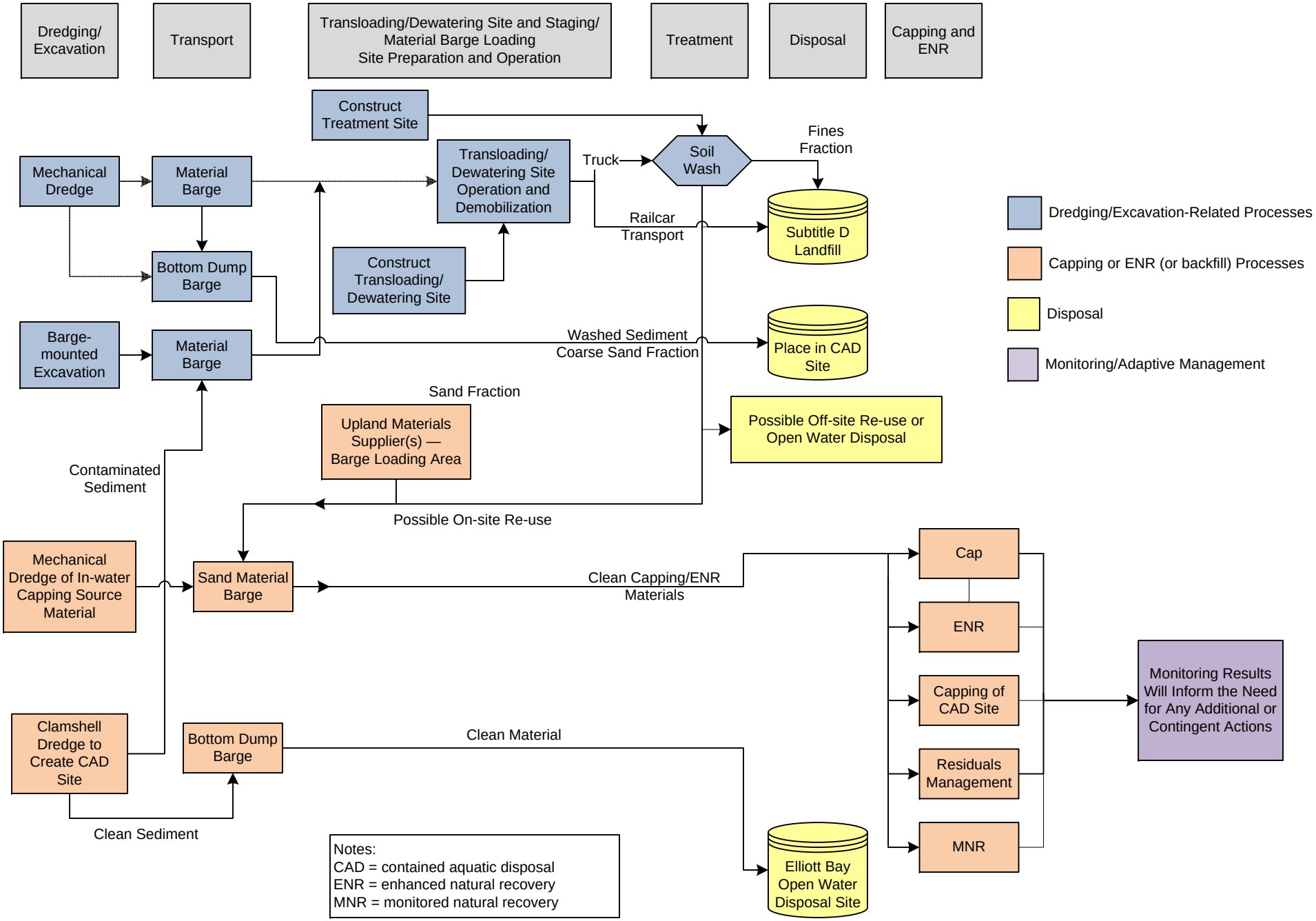
Figure 8-18 Generalized Process Flow Diagram of Active Remedy Elements



Notes:
CAD = contained aquatic disposal
ENR = enhanced natural recovery
MNR = monitored natural recovery

9 Detailed Analysis of Individual Remedial Alternatives

This section presents a detailed analysis of the remedial alternatives, using the feasibility study (FS) criteria outlined in the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the National Contingency Plan (NCP), and other relevant guidance. As discussed in Section 8, these alternatives cover the range of potential remedial actions considered to be feasible for cleanup of the Lower Duwamish Waterway (LDW). A comparative evaluation of the remedial alternatives under CERCLA occurs in Section 10 of this FS. Evaluation of the remedial alternatives under the Washington State Model Toxics Control Act (MTCA) occurs in Section 11 of this FS.

9.1 Overview of NCP Evaluation Criteria

The National Oil and Hazardous Substances Contingency Plan (EPA 2002b) and the U.S. Environmental Protection Agency (EPA) guidance for conducting feasibility studies under CERCLA (EPA 1988) require consideration of nine evaluation criteria to address the CERCLA statutory requirements (Table 9-1).

The first two criteria are categorized as threshold criteria:

- Overall protection of human health and the environment
- Compliance with applicable or relevant and appropriate regulations (ARARs).

For any alternative, these two criteria must be met to be considered viable as a remedy for cleanup in the LDW. The next five criteria are considered to be balancing criteria:

- Long-term effectiveness and permanence
- Reduction of toxicity, mobility, or volume through treatment
- Short-term effectiveness
- Implementability
- Cost.

These five balancing criteria are weighed within the context of evaluating an alternative as a whole. These five criteria are grouped together and with the threshold criteria form the basis for the detailed evaluation. The last two criteria are considered to be modifying criteria:

- State/Tribal acceptance
- Community acceptance.

These are typically assessed following agency and public comment on the FS in development of EPA's proposed plan and then again on the proposed plan itself. Community and Tribal stakeholders have been kept informed and have provided input during development of the FS. In this section of the FS, the CERCLA criteria are used to evaluate each remedial alternative. The key ideas and concepts embodied by the criteria are presented in the following subsections.

9.1.1 Threshold Criteria

CERCLA prescribes threshold criteria that must be met by a remedial alternative. This section discusses how an alternative meets these criteria. It serves as a summary of how the alternative achieves the remedial action objectives (RAOs), and what expected statutory or other relevant requirements must be achieved during implementation of the remedial action.

9.1.1.1 Overall Protection of Human Health and the Environment

This criterion addresses whether a remedial alternative provides adequate protection of human health and the environment. The evaluation focuses on how a specific remedial alternative achieves adequate protection, especially with regard to long- and short-term effectiveness. The assessment of protection includes a description of how site risks posed through each pathway addressed in this FS is eliminated, reduced, or controlled through treatment, engineering, or institutional controls.

9.1.1.2 Compliance with ARARs

ARARs for cleanup of the LDW were presented and discussed previously in Section 4. Of the ARARs listed in Table 4-1, only three were used in determining compliance of the remedial alternatives:

- Surface Water Quality Standards (RCW 90-48; WAC 173-201A).
- Sediment Management Standards (SMS) (WAC 173-204)
- Model Toxics Control Act (WAC 173-340-700 (5)(d))

The other ARARs listed in Table 4-1 are not discussed explicitly as part of evaluating the remedial alternatives. The remedial alternatives are assumed to comply with these ARARs; the rationale being that none of the ARARs are likely to cause a fatal flaw and that the required engineering design and agency review process will ensure that the selected remedy complies with those ARARs. For example, the construction elements for the remedial alternatives are similar in nature and scope to sediment remediation projects previously implemented in the Puget Sound region and elsewhere around the country. It is therefore anticipated that all of the alternatives can be designed and implemented in compliance with ARARs pertaining to management and disposal of generated materials (e.g., contaminated sediment, wastewater, and solid waste). These ARARs are all largely procedural and influence how materials are handled and disposed. The ARARs may

affect implementation but do not have a marked effect on whether a remedial alternative is fundamentally viable. Further, the remedial design phase can address the various land use and resource protection ARAR requirements (e.g., habitat preservation, mitigation).

Surface Water Quality Standards

Compliance with surface water quality ARARs is both a short-term and long-term requirement. Dredging is the remedial technology with the greatest potential for exceeding water quality parameters in the short-term.[1] However, contaminated sediment dredging projects in and near the LDW have historically been issued water quality certifications with stipulated measures to minimize construction-related impacts.

Active remedial measures for the water column are not technically feasible and are therefore not included as part of the remedial alternatives. While significant water quality improvements are anticipated from sediment remediation and source control, it may not be possible for any alternative to meet certain federal or state ambient water quality criteria or standards, particularly those based on human consumption of bioaccumulative contaminants that magnify through the food chain. Further, it is difficult to account for watershed-wide source control efforts, particularly changes in water and sediment quality entering the LDW from the Green/Duwamish River system. For this reason, more definitive statements on whether, and to what extent, certain water quality criteria will be met or potentially waived (based on technical impracticability) cannot be made at this time.

Sediment Management Standards

The SMS are an ARAR under CERCLA and a requirement under MTCA. Cleanup standards under the SMS are established on a location-specific basis within an allowable range of concentrations. The upper end of this range is the minimum cleanup level (MCUL) established at a level not to be exceeded 10 years after completion of the active cleanup actions. The MCUL is the same numerical value as the cleanup screening level (CSL), which defines the upper end of minor adverse effects for benthic organisms. The lower end is the cleanup objective and is equivalent to the sediment quality standards (SQS). Site-specific cleanup standards are to be as close as practicable to the cleanup objective. The SMS defines the sediment cleanup objective as the elimination of adverse effects on biological resources and significant health threats to humans from sediment contamination (WAC 173-204-570). Factors considered for identification of site-specific sediment cleanup standards include environmental effects, technical feasibility, and cost. Longer times to achieve RAOs may also be approved for some sites, where it is not practicable to achieve the RAOs within a 10-year period.

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[1] Placement of granular material in the context of backfilling, capping, and ENR can also cause water quality impacts depending on material gradation and application method and rate. Chemical-specific water quality impacts are much more likely during dredging than during placement of granular material.

For this FS, a remedial alternative's ability to comply with the SMS (and therefore achieve RAO 3) is semi-quantitatively assessed based on the following metrics:

- More than 98% of FS dataset stations are predicted to comply with the SMS.
- More than 98% of the site surface area is predicted to comply with the SMS.[2]

These metrics acknowledge that the SMS has flexibility in defining cleanup standards and, further, that the SMS allow for consideration of environmental effects, technical feasibility, and cost (WAC 173-204-200(19)). In addition, the FS recognizes that, given the uncertainty in predictions of future chemical concentrations based on model- and chemical-specific assumptions, achievement of 100% compliance with the SMS may be an overly stringent expectation. Cleanup standards will be established in the final decision documents. In this context, small numbers of SQS exceedances may represent no more than isolated minor adverse effects on the benthic community, and those may not merit further action based on a number of factors such as bioavailability and sediment toxicity test results. It is important to note that adaptive management measures (e.g., verification monitoring, contingency actions) may become necessary, consistent with the technical feasibility provisions of the SMS, in response to isolated or localized exceedances of the cleanup standards.

Model Toxics Control Act

MTCA regulations governing the selection of cleanup standards are ARARs under CERCLA and a requirement under MTCA. MTCA provides that sediment cleanup levels cannot be set at concentrations lower than natural background when risk-based threshold concentrations (RBTCs; based on 1×10^{-6} excess cancer risk threshold) are below natural background (WAC 173-340-705(6)). For the LDW, this applies to total PCBs and dioxins/furans for the human seafood consumption scenario and arsenic for all direct contact scenarios. The associated preliminary remediation goals (PRGs) for these chemicals and scenarios were defined in Section 4 based on estimates of natural background using the 2008 EPA Puget Sound Ocean Survey Vessel (OSV) *Bold* survey dataset (EPA OSV *Bold* survey; EPA 2008). EPA has recommended using the 95% upper confidence limit on the mean (UCL95) to estimate natural background.

All of the alternatives leave contaminated sediment on site above the estimated natural background cleanup levels for total PCBs and dioxins/furans. They comply with the MTCA ARAR by a combination of reducing concentrations of total PCBs and dioxins/furans and using institutional controls designed to reduce human consumption of resident fish and shellfish (WAC 173-340-360 and 370).

[2] Estimated areas are based on the sum of Thiessen polygon-derived areas for predicted station exceedances following remediation and are referenced to the total surface area of the site (441 acres).

The MTCA regulations define natural background using the 90th percentile of the dataset (WAC 173-340-709) although the Washington State Department of Ecology (Ecology) may approve alternate statistical metrics. For arsenic, using the 90th percentile results in a range of 7 mg/kg dw (UCL95) to 11 mg/kg dw (90th percentile). For FS evaluation purposes, arsenic concentrations of 11 mg/kg dw are considered MTCA cleanup levels.

9.1.2 Balancing Criteria

Table 9-1 presents the five primary balancing criteria under CERCLA and a summary of the evaluation factors used to assess each one. These criteria and their evaluation are described in detail in the following subsections.

9.1.2.1 Long-Term Effectiveness and Permanence

This balancing criterion assesses the magnitude and type of residual risk that would remain at the site after RAOs are achieved. In addition, the criterion assesses the adequacy and reliability of the controls that are used to manage treatment residuals or manage contaminated media remaining at the site (e.g., in the subsurface).

Magnitude and Type of Residual Risk

Residual risks to humans, wildlife, and the benthic community from surface sediment concentrations remaining on-site at the completion of active remediation (and further in time as a result of additional natural recovery) are estimated using output from the bed composition model (BCM), as described later in this section.

The other form of residual risk described in CERCLA guidance is that "…from untreated waste or treatment residuals at the conclusion of remedial activities." Guidance further states that the "…potential for this risk may be measured by the volume or concentration of contaminants in waste, media, or treatment residuals remaining on the site." Evaluation of this form of residual risk following achievement of RAOs focuses on the potential for exposure of sediments remaining in the subsurface that contain chemicals of concern (COCs) above protective levels. This requires an understanding of:

- The magnitude of subsurface contamination.
- The potential for re-exposure.
- The mechanisms (pathways) of re-exposure.

The magnitude of subsurface total PCB, arsenic, and cPAH contamination remaining under each remedial alternative was evaluated using summary statistics of subsurface sediment data from FS dataset cores located outside of early action areas (EAAs) and dredged areas for each remedial alternative (Figures 9-1a, 9-1b, and 9-1c). Insufficient core data were available to prepare summary statistics for dioxins/furans. The FS dataset core data were queried and sorted into two depth intervals: ≤3 feet (ft) and >3 ft. This is a

conservative estimated depth at which re-exposure of contaminants could occur over time by the mechanisms discussed below.[3]

Residual median and average total PCB concentrations show little difference in response to the various remedial alternatives (Figure 9-1a). The median total PCB concentrations remaining in subsurface sediments are 2 to 3 times the SQS (240 µg/kg dw assuming 2% organic carbon) and the averages are either below or less than a factor of 2 above the CSL (1,300 µg/kg dw assuming 2% organic carbon). These results are the same regardless of the alternative up to Alternative 6R, which by definition, is designed to remove any known subsurface contamination. More variability is evident in the carcinogenic polycyclic aromatic hydrocarbon (cPAH) summary statistics (Figure 9-1b) but the same general insensitivity to remedial alternative applies. The median cPAH concentrations range from approximately 100 to 400 µg toxic equivalent (TEQ)/kg dw and the averages range from about 500 to 1,000 µg TEQ/kg. From a PRG perspective, the netfishing PRG for cPAH is 380 µg TEQ/kg dw. Median arsenic concentrations in the less than 3-ft interval (Figure 9-1c) are generally within a factor of 2 to 3 of the estimated natural background concentration.

The core data statistics provide a reasonable approximation of arsenic, total PCB, and cPAH concentrations remaining in the subsurface but are limited for approximating the potential for re-exposure. Re-exposure potential was qualitatively gauged using the following factors:

- The number of sediment cores in the FS dataset with concentrations above SMS criteria (i.e., SQS and CSL) and that are located within areas that are either capped or undergo natural recovery (enhanced natural recovery [ENR] or monitored natural recovery [MNR]).
- Surface areas within Area of Potential Concern 1 (AOPC 1) that are either capped or undergo natural recovery (ENR or MNR).[4]

In both cases, the results are grouped by recovery category. Recovery Category 1 areas are presumed to have limited recovery potential because of scour. Recovery Category 2 areas have less certain recovery potential. Recovery Category 3 areas are predicted to recover. Natural recovery can be expected to improve and stabilize surface sediment over time in areas designated as either Recovery Category 2 or Recovery Category 3.

Mechanisms for re-exposing subsurface sediment are episodic disturbances such as high-flow scour, propeller wash, construction activities,[5] and seismic events. The majority of

[3] The upper (shallow) end of the core sample interval was used to assign data to the 0 to 3 ft or >3 ft populations. Summary statistics for FS dataset cores remaining outside of EAAs and dredge areas, and also outside, partial dredge and cap and cap areas were prepared for arsenic, total PCBs, and cPAHs grouped into the two depth intervals and presented in Table M-1 in Appendix M.

[4] AOPC 1 is an approximation of the known extent of contamination.

disturbances are likely to be localized and have a low potential for increasing spatially-weighted average concentrations (SWACs) sufficiently to compromise associated RAOs (e.g., RAOs 1, 2, and 4). On the other hand, acute, yet spatially intermittent impacts to the benthos from episodic disturbances could occur. The potential for such impacts diminishes in severity and duration as natural recovery (i.e., burial) progresses. Earthquakes could cause recontamination either from ground disturbances and related impacts to sediment caps, or from tsunami scour. Seismic stability of caps on slopes would be a factor to be considered in design. The potential for recontamination from all of these mechanisms generally decreases with the depth of contamination and as the surface area containing subsurface contamination decreases.

The construct for gauging the re-exposure potential of subsurface sediment assesses available information on number of cores, chemical concentration, recovery category, and surface area that is remediated by capping, ENR, or MNR. This information is used as follows. First, the re-exposure potential is not equal between cap and natural recovery areas. Caps are engineered systems in which the cap thickness and material are selected based on well-understood design principles and experience gained through widespread use at other sites. Caps are designed to handle location-specific conditions up to predetermined design thresholds. Areas undergoing ENR or MNR do not have the same degree of protectiveness as caps, because they are not designed to ensure isolation. Thus, the potential for subsurface sediment to be exposed by scour or future uncontrolled human disturbance is greater beneath MNR and ENR areas than in capped areas. Second, the re-exposure potential of surfaces undergoing ENR and MNR is assumed to decrease as the remaining number of cores with SMS exceedances decrease and as the number of cores remaining in Recovery Category 1 decrease. In the first case, lower numbers of remaining cores with chemical exceedances reflect an expansion of the dredge footprint and thus removal of more subsurface contamination. Also, a limited number of the RI cores were randomly located. For the most part, cores were located to delineate the vertical extent of contamination in areas where available evidence confirmed surface sediment contamination, suggested a nearby source, or historic release. Thus, reduced core counts remaining after remediation are an indicator of reduced subsurface contamination.[6] Also, cores and surface area undergoing ENR and MNR that are located

[5] Construction-related recontamination, from future projects unrelated to the remedy selected for this project, is manageable through institutional controls. Within the institutional controls, a monitoring element associated with the waterway use and permit application process serves to identify and alert EPA and Ecology of projects that are being proposed in areas with residual contamination. The agencies can then track and influence the design (e.g., specifying use of construction-related best management practices (BMPs) and monitoring). An additional and related consideration is the degree to which technologies such as MNR and ENR could require a more active form of remediation (i.e., dredging) based on monitoring results that suggest impaired performance. This is discussed in terms of costs in Section 9.1.2.5.

[6] Additional cores will be collected during remedial design to verify subsurface conditions in areas targeted for remediation.

in Recovery Categories 2 and 3 have a low potential for re-exposure compared to those located in Recovery Category 1.

Adequacy and Reliability of Controls

This factor assesses the adequacy and reliability of controls used to manage contaminated sediment that remains at the site. For this FS, the assessment focuses on monitoring, maintenance, and institutional controls. Alternative 1 is assumed to have none of these controls beyond those specific to the EAAs.

The intensity and duration of monitoring and maintenance is assumed to increase in proportion to the area undergoing remediation by capping, ENR, and MNR. In particular, MNR requires extensive monitoring to enable accurate tracking of surface sediment conditions over time until contaminant concentrations reach acceptable levels (e.g., PRGs or long-term values below which further decline is impracticable). Areas that are dredged or capped yield immediate and more permanent concentration and risk reduction. Therefore, these areas require less monitoring compared to MNR. In all cases, visual and bathymetric surveys coupled with monitoring data will be used to determine the condition of the remedy. As needed, repairs would likely consist of thin-layer sand applications but could, in limited situations, involve localized engineered cap repair or removal of contaminated sediment.

Institutional controls are a required element of Alternatives 2 through 6. As discussed in Section 7, an Institutional Controls plan for the LDW will include seafood consumption advisories, public outreach, and education programs. This is because none of the alternatives can achieve the total PCB and dioxin/furan PRGs that are set to natural background for the human seafood consumption scenario. The cleanup decision document could also include an enhanced notification, monitoring, and reporting program for areas of the LDW where contamination exceeding remedial action levels remains in place following cleanup activities. A third Institutional Controls plan element is the use of restrictive covenants, the primary proprietary control used in environmental remediation actions (see Section 7.1.7.1). The covenant controls (or prevents) the owners of the property subject to the covenant from conducting (or allowing to be conducted) any unconditioned or uncontrolled activity that could result in the release or exposure to the environment of buried contamination.

For FS evaluation purposes, the adequacy and reliability of the controls (monitoring, maintenance, institutional controls) are considered proportional to the area remediated by capping, ENR, and MNR).

9.1.2.2 Reduction of Toxicity, Mobility, or Volume through Treatment

This criterion assesses the degree to which site media are treated to reduce the toxicity, mobility, or volume of site contaminants permanently and significantly. This assessment is accomplished by analyzing the destruction of toxic contaminants, the reduction of the total mass of toxic contaminants, the irreversible reduction in contaminant mobility, or

the reduction in total volume of contaminated material that is accomplished by one or more treatment components of the remedial alternative.

The NCP (40 CFR Section 300.430(a)(1)(iii)) states that EPA "generally shall consider the following expectations in developing appropriate remedial alternatives:

- …use treatment to address principal threats posed by a site, wherever practicable. Principal threats for which treatment is most likely to be appropriate include liquids, areas contaminated with high concentrations of toxic compounds, and highly mobile materials.
- …use engineering controls, such as containment, for waste that poses a relatively low long-term threat or where treatment is impracticable."

EPA guidance defines principal threat waste as a source material that is highly toxic or highly mobile that generally cannot be reliably contained or would present a significant risk to human health or the environment should exposure occur, such as drummed waste or pools of non-aqueous phase liquids (EPA 1991a). No non-aqueous phase liquids have been found in LDW sediments and EPA has determined that most of the contaminated sediments in the LDW are low-level threat wastes.[7]

The maximum concentrations detected for the four human health risk-driver chemicals in surface and subsurface sediment are: 2,100 ng TEQ/kg dw for dioxins/furans, 890,000 µg/kg dw for total PCBs,[8] 2,000 mg/kg dw for arsenic, and 11,000 µg TEQ/kg dw for cPAHs. Direct contact risks are low relative to seafood consumption risks (maximum direct contact reasonable maximum exposure [RME] excess cancer risk is 2×10^{-4}, as compared to excess cancer risk of 3×10^{-3} for seafood consumption, see Tables 3-3a and 3-5a).

Most of the contaminated sediments in the LDW are low-level threat wastes. Alternative 5R-Treatment contains a treatment technology (soil washing) and is therefore the primary alternative evaluated under this criterion in keeping with CERCLA guidance.[9]

The main elements of the remedial alternatives are removal and disposal, capping, ENR, and MNR, which are not categorized as treatment technologies under CERCLA.[10] These

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[7] One sample collected from the Trotsky area contained 2,900 mg/kg total PCBs. This sample corresponds to a small volume of oily material that could be considered for treatment after better characterization in the remedial design phase, but it is of insufficient quantity (and cost) to influence the overall development and evaluation of alternatives. The area in question would be remediated in Alternatives 2 through 6.

[8] Excluding two ouliers, the highest of which was 2,900 µg/kg dw PCBs (see Section 2.3.2.3).

[9] Costs are provided in Appendix I to add treatment by soil washing to any alternative. (see also Section 11, Table 11-8).

technologies reduce mobility and toxicity even though they do not address the NCP criterion for treatment of principal threat wastes. For example, once contaminated sediment is disposed at a landfill, LDW receptors (humans, fish, and wildlife) cannot come into contact with the material. Capping physically and chemically contains the contaminant thereby reducing mobility and exposure potential. Similarly, ENR and MNR reduce surface sediment concentrations through burial, which in turn reduces mobility and toxicity.

While not explicitly evaluated in the detailed analysis of alternatives, amended capping was a process option variant retained in the Section 7 technology screening analysis. Amendment technology has the potential to reduce contaminant mobility and toxicity (e.g., bioavailability) and may be applied in cleanup of the LDW during the remedial design phase.

9.1.2.3 Short-term Effectiveness

Short-term effectiveness addresses how an alternative affects its surroundings primarily during the construction phase of the remedial action. These effects include considering protection of workers and the community during construction, environmental impacts that might result from construction and the length of time until the RAOs are achieved. Environmental impacts are evaluated, in part, based on habitat disturbance, consumption of natural resource materials (e.g., for capping), landfill capacity utilization, transportation mileage, particulate matter, and gas emissions (including carbon dioxide [CO_2], nitrogen oxides [NO_x] and sulfur oxides [SO_x]). The degree of habitat disturbance is measured as the amount of active remediation in intertidal and shallow subtidal areas above -10 ft mean lower low water (MLLW). Transportation mileage, particulates (PM_{10}), and gas emissions are used to evaluate potential short-term impacts to the community and workers. Estimates for gas emissions based on heavy equipment use and transportation are provided in Appendix L. In addition, general disruptions and inconveniences to the public and commercial community (e.g., noise and lights from night-time operations, traffic, and temporary waterway restrictions) can be expected to increase with the duration of construction. Fish and shellfish tissue concentrations are also assumed to increase and remain elevated during the course of the multi-year construction periods and for some time thereafter, based on documented experience at other sites (City of Tacoma and Floyd | Snider 2007b, BBL 1995a and 1995b, Bauman and Harshbarger 1998).

For FS evaluation purposes, the conditions assumed necessary for achieving RAOs and for estimating the time to achieve RAOs are as follows:

[10] Some biodegradation and dechlorination of organic compounds can be expected to occur in sediments over the long term. This mechanism is considered to yield limited risk reduction for more recalcitrant chemicals compared to the primary recovery mechanism of burial.

- **RAO 1 (Seafood Consumption):** The remedial alternatives cannot achieve the total PCB and dioxin/furan PRGs for the seafood consumption scenario. These PRGs are based on natural background. Therefore, two time periods are considered. First, the remedial alternative's implementation period, at the end of which all alternatives reduce the Adult Tribal RME seafood consumption risk to the lowest magnitude achievable in the long term (i.e., 10^{-4}; see Section 9.3.2). The multi-layered program of monitoring and institutional controls (advisories, public outreach, and education) is required at this point for all alternatives to further reduce seafood consumption exposures (see Section 10.2.1.2). All alternatives are predicted to achieve a risk magnitude of 10^{-4} for Adult Tribal and Adult API RME seafood consumption scenarios immediately following the completion of the implementation period (Table 9-6a). Risks of either 4×10^{-5} or 5×10^{-5} are predicted for the Child Tribal RME scenario immediately following the completion of the implementation for Alternatives 2 through 6.

  The second time component is the predicted time for risk-driver concentrations to achieve long-term model-predicted concentration ranges. Further incremental reductions in risk-driver concentrations are expected to occur over time after implementation is complete as a result of source control and natural recovery processes (see Section 9.3.1).

- **RAO 2 (Direct Contact):** Cumulative risk of $\leq 1 \times 10^{-5}$ (netfishing, tribal clamming, and assumed beach play areas).

- **RAO 3 (Benthic):** At least 98% of FS surface sediment dataset stations predicted to comply with the SMS and more than 98% of the LDW surface area predicted to comply with the SMS.

- **RAO 4 (Ecological):** LDW-wide total PCB surface sediment SWAC is ≤128 µg/kg dw.

In this FS, SWACs are compared to those PRGs that have a spatially-weighted basis. It is recognized that, for determining compliance, other statistical metrics (e.g., upper confidence limits) may be applied to empirical surface sediment data collected during remedy implementation and subsequent monitoring.

9.1.2.4 Implementability

This criterion assesses the technical and administrative feasibility of implementing a remedial alternative and the availability of services and materials required for implementation. Technical feasibility encompasses the complexity and uncertainties associated with the alternative, the reliability of the technologies, the ease of undertaking additional remedial actions if necessary, and monitoring requirements.

Administrative feasibility includes the activities required for coordination with other offices and agencies (e.g., obtaining permits for off-site activities or rights-of-way for construction). For example, a key administrative feasibility factor for the LDW is that in-water construction is not allowed year round. The in-water work window is assumed to be October 1 to February 15, a period that will be confirmed in formal consultation with the agencies and Tribes before implementation.

Availability of services and materials includes the availability of necessary equipment and specialists, the ability to obtain competitive bids, and the availability of prospective technologies. Dredging and capping are mature technologies. Similar remedial and non-remedial (maintenance, construction) actions have been implemented in the LDW and elsewhere in the Puget Sound region. Services, equipment, and materials (e.g., sand and aggregate) are locally or regionally available. Regional upland landfills are authorized to receive contaminated sediment and have done so on several recent projects in or near the LDW. Debris is expected to complicate but is not likely to significantly delay construction efforts.

One significant technical implementability challenge is remediation under piers and other above-water structures. For example, diver-assisted hydraulic dredging is difficult to implement and a potentially dangerous activity from a worker health and safety perspective. A suite of potential remedial actions was described in Section 8 that, based on location-specific engineering evaluations, can be implemented in areas under and around overwater structures. Maintaining flexibility in construction methods through the remedial design phase is an important consideration for these areas.

The LDW is a working industrial waterway that has the necessary infrastructure to support sediment remediation activities. Nevertheless, careful coordination will be required among government agencies and private entities to design, schedule, and construct the cleanup actions. Further, it will be important to evaluate whether source controls have been implemented to a sufficient degree before or as a part of remedy construction (e.g., to stabilize erodible embankments) to limit recontamination potential.

Metrics used to gauge the relative magnitude of technical and administrative implementability of the alternatives include the surface areas actively managed (dredging and all active technologies) and the dredge volumes, because areas and volumes are considered proportional to the degree of difficulty to implement and manage them. One exception is the long-term administrative efforts needed to maintain and track MNR remediation.

9.1.2.5 Cost

The cost criterion evaluates the capital and long-term operations, monitoring, and maintenance (OM&M) costs of each remedial alternative.[11] OM&M costs include long-

[11] See Appendix I for detailed cost estimates.

term maintenance, repair, and monitoring costs for dredging, capping, ENR, and MNR. They also include costs for long-term RAO monitoring and institutional controls. Costs for contingency actions are included in the OM&M to account for the potential that some areas assumed in the FS as suitable for no action or less aggressive technologies (e.g., ENR or MNR) will require dredging based on information gained during remedial design or monitoring. Consistent with CERCLA guidance, the cost estimates were prepared in the absence of detailed engineering design information and have a target level of accuracy ranging from +50% to -30%.

It is important to recognize that the scale, complexity, and uncertainties associated with a large sediment remediation project, such as for the LDW, may contribute to cost estimation inaccuracies beyond those typically encountered in a CERCLA FS for smaller, less complex projects. The actual costs of the sediment cleanup in the LDW depend on the final scope of the remedial action, the implementation schedule, actual labor and material costs at the time of implementation, competitive market conditions, and other variable factors that may affect project costs.

The cost estimates developed in this FS are expressed in current (2010) dollars, and are calculated using discount factors consistent with CERCLA cost estimation guidance. Discount factors take into account the time value of money and the difference between the expected rate of return on funds and the expected rate of inflation. The duration of the construction and monitoring phases of many remedial alternatives presented herein is likely to span a lengthy period (e.g., more than 10 years), which could see significant inflationary pressures depending on economic conditions. In particular, fuel prices and landfill tipping fees are not likely to remain at current levels. Increases in fuel prices will translate into higher construction, transportation, and disposal costs. With these considerations, the discount factor is assumed to be zero for construction costs and 3% for operation and maintenance (O&M) costs.[12]

The estimated total cost to complete the in-water work for the EAAs (Alternative 1) is $66 million. This cost is not included in the estimated costs for Alternatives 2 through 6 because those actions are not part of the alternatives being evaluated in this FS. However, it is important to recognize that completion of the EAAs alone contributes substantively toward risk reduction and overall cleanup of the LDW (see Section 9.2) while impacting overall costs. Further, the cost estimates for Alternatives 2 through 6 do not include any investments in upland source control or habitat mitigation. Discussions of cost uncertainty and sensitivity related to key cost factors (e.g., dredged material volume) are presented in Appendix I.

[12] Construction costs are assumed to inflate at approximately the rate of return on investment and thus a discount factor of zero is used in present value calculations.

9.1.3 Modifying Criteria

The final two detailed evaluation criteria are the modifying criteria: state and tribal acceptance and community acceptance. Outreach and educational efforts were conducted during preparation of the FS, consisting of quarterly meetings with resource agencies, community technical advisory groups, and tribal representatives. These criteria cannot be fully assessed until the FS is released for regulatory and public review. However, community and stakeholder comments and concerns have been and will continue to be considered by EPA and Ecology. In addition, because the State of Washington is actively involved in the project through Ecology, state acceptance of the remedial alternatives is implicit in the FS-approval process. EPA will evaluate state, tribal, and community acceptance in the final decision document following the public comment period on the FS and on EPA's proposed plan.

9.2 Tools Used to Estimate Contaminant Reduction over Time

Performance of the remedial alternatives is, in part, evaluated based on reductions in contaminant concentrations (and therefore risks) over time. The BCM allows prediction of changes over time in surface sediment concentrations of COCs resulting from sediment deposition, surficial mixing, and burial, the primary mechanism of natural recovery in the LDW. Section 5 provides a description of the model, its relationship to the sediment transport model (STM), and chemical concentrations associated with incoming sediments (e.g., upstream and lateral). The framework for applying the BCM to each remedial alternative is discussed herein. An important element of the BCM framework is how each remedial alternative is sequenced both spatially and temporally. Later in this section, surface sediment concentrations modeled using the BCM are presented and discussed for each remedial alternative.

9.2.1 Temporal Concepts

In the following discussion of remedial alternatives, time is referenced in a number of ways that are interrelated, sometimes overlap, and yet have specific meanings (Figure 9-2). The signing of EPA and Ecology decision documents, which follows completion of the LDW FS and a public comment period on the draft decision documents, is the assumed starting point from which the following time periods are indexed:

- **Construction period –** The time assumed necessary for construction of the remedial alternative.[13] Construction of Alternatives 2 through 6 is assumed to begin 5 years following issuance of final decision documents. During this period, the following occurs: completion of the EAAs (i.e., Alternative 1), priority source control, negotiation of orders, initial remedial alternative

[13] In-water construction work spans multiple seasons following the production assumptions described in Section 8.

design/planning, baseline monitoring, and verification monitoring in higher priority areas.

- **Implementation period –** The time that transpires between issuance of the final decision documents and the end of construction.
- **Natural recovery estimation period –** The time that transpires between start of construction and achievement of RAOs, individually or comprehensively.
- **MTCA restoration time frame –** The time between the end of construction and achievement of RAOs, individually or comprehensively. (This is discussed in the context of the MTCA evaluation in Section 11).
- **Time to achieve RAOs –** The time between signing of the decision documents and achievement of RAOs.

9.2.2 BCM Framework Adopted for the Remedial Alternatives

The BCM uses STM output in 5-year increments across a 30-year hydrograph of the Green/Duwamish River (Section 5). This section discusses how the 5-year temporal output is reconciled with the estimated construction periods of the remedial alternatives. In particular, the BCM framework adopts specific assumptions to enable modeling with as much temporal and spatial consistency as practicable.

Figure 9-3 depicts the BCM framework for the remedial alternatives developed in Section 8. The framework produces output in 5-year intervals commensurate with the STM results, which were also provided in 5-year intervals.[14] The estimated construction periods for each alternative are shown in the second column of Figure 9-3. The construction periods are estimated to the nearest year and, therefore cannot be matched exactly with the 5-year BCM intervals. The construction periods and the 5-year model intervals are reconciled by using the 5-year BCM output nearest the construction period as described in the following examples:

- Alternatives 2R and 3C both have estimated construction periods of 4 years. For this case, the 5-year BCM output for the gridded area outside the actively remediated footprint and replacement values applied within the actively remediated footprint are used to calculate SWACs for each exposure area. These SWACs approximate surface sediment conditions at the end of construction. This time frame reconciliation method results in a slight (1-year) calculation bias. That is, the end of construction SWACs for these alternatives reflect one additional year of natural recovery outside the actively remediated footprint, and neglect one year's worth of natural recovery within the actively

[14] Conducting the analysis in shorter (e.g., 1-year) intervals confers an unjustified level of accuracy to the model.

remediated footprint that would theoretically occur if the replacement values could be applied at Year 4 instead of Year 5.

- Similarly, Alternative 4C has an estimated construction period of 7 years. Again, the 5-year BCM output for the gridded area outside the actively remediated footprint and replacement values applied within the actively remediated footprint are used to calculate SWACs for each exposure area and are used to approximate surface sediment conditions at the end of construction. However, in this case, the time frame reconciliation results in a 2-year calculation bias wherein the end of construction SWACs neglect two years of natural recovery outside the actively remediated footprint, and reflect an additional two year's worth of natural recovery within the actively remediated footprint than would theoretically occur if the replacement values could be applied at Year 7 instead of Year 5.

In all cases, this method of reconciling the construction and model output periods results in no more than a 2-year bias. This is well within construction period and model uncertainties and, as becomes apparent later in this section and Section 10, has a negligible effect on the evaluation of the alternatives in terms of effectiveness and time to achieve RAOs.

A second important feature of the model is the assumed temporal sequencing or allocation of each remedial alternative's actively remediated footprint. Because it is impossible to predict the actual sequencing of multi-year remediation projects, sequencing was consistent across the remedial alternatives to the extent practicable. This simplifies the BCM analysis and allows for a comparable analysis across alternatives. The sequencing has two elements:

- The combined and removal alternatives are, respectively, sequenced such that alternatives with smaller footprints (e.g., Alternative 3C) are assumed to be remediated first and constitute the basis for larger alternatives (e.g., Alternative 5C). In this manner, the larger footprint alternatives build upon the smaller ones and all alternatives therefore remove higher priority areas first.
- After the sequencing of previous alternatives, the remaining area is spatially sequenced from upstream to downstream in 5-year increments defined using dredge production rate assumptions.

Thus, specific areas identified for active remediation as part of two different remedial alternatives are assumed to be remediated at the same time in the BCM framework; for Alternative 5C, the framework assumption is that the Alternative 3C footprint is actively remediated in the first 5-year interval and the remainder of the Alternative 5C footprint is next. Similarly, Alternative 6C is constructed over an 18-year period and spans four BCM intervals. The first 10 years is sequenced exactly as for Alternative 5C. At this point,

Alternative 6C is approximately half complete. The framework assumption for the balance of Alternative 6C is to incrementally progress from the head of the waterway (near the Upper Turning Basin) to the mouth of the waterway (Reach 1), upstream to downstream. This sequencing is illustrated in Figure 9-4. The more complex sequencing of Alternative 6R is shown in Figure 9-5. The latter more clearly shows the assumed progression of active remediation from upstream to downstream. It is important to note that this sequencing aspect of the BCM framework is assumed only to lend consistency to the FS evaluation of remedial alternatives and is not intended to constitute or represent a specific sequencing recommendation. It is also important to recognize that the assumed sequencing from higher to lower concentrations in the BCM framework predicts a more optimal decline in SWACs from what would occur if the remedial actions were coordinated and sequenced differently.

At EPA's direction, The BCM framework models natural recovery from the beginning of construction but only for those areas that are not being actively remediated. Therefore, in any 5-yr period, all areas of the LDW that are not undergoing active remediation are being modeled for sediment inputs to the existing bed. Areas outside of the active footprint are modeled using the full complement (30 years) of STM output in 5-year output intervals. Areas that undergo active remediation and that are then modeled into the future after construction use STM output that excludes contributions to bed composition during the 5-yr period assumed for construction. This is indicated in Figure 9-3 by the subscripted numeric values associated with each 5-year interval. For example, the active portion of Alternative 3 is remediated in the first 5-year period. This area receives the post-remedy bed sediment replacement value at the end of the 5-year period (see Section 5) and the BCM predicts changes in chemical composition from that point forward. At Year 10 of the hydrograph, the BCM calculation for this same area uses STM output representing conditions between Years 5 and 10 of the hydrograph. This is indicated by the symbol 10_5.[15] Also, in cases where active remediation for a given area begins five or more years into the overall construction period, the BCM is applied to that specific footprint both before and after construction.

Finally, it is important to recognize that surface sediment chemical concentrations at the start of construction (and BCM modeling) for Alternatives 2 through 6 assume post-remedy bed sediment replacement values in the EAA areas. Concentrations across the remainder of the site are interpolated values from the FS baseline surface sediment dataset (Appendix A). This is a conservative assumption on two fronts. It does not account for the approximately 20-year period over which much of the data were collected and during which some level of natural recovery has occurred. It also does not account for natural recovery during the period of remedial design, priority source control, and

[15] Because Alternative 6R has an estimated construction period that exceeds 30 years (i.e., the span of the hydrograph used in the STM), the hydrograph and associated STM output are repeated (starting over at year zero) through the end of BCM modeling.

EAA remediation, all of which are presumed to occur in a 5-year period before the start of construction of any of the other alternatives.

9.3 Site-wide and Area SWAC and Risk Reductions

Tables 9-2a and 9-3 compile predicted concentrations for risk-drivers (arsenic, total PCBs, cPAHs and dioxins/furans) in surface sediment during and following implementation of each remedial alternative. The estimated concentrations are provided for time intervals that begin with the issuance of final decision documents (see Figures 9-2 and 9-3). Table 9-2b provides estimates of the number of the FS baseline surface sediment sampling locations predicted to exceed the SMS criteria (SQS and CSL), the percentage of all FS baseline surface sediment sampling locations predicted to comply with the SMS, and the percentage of the entire LDW surface area predicted to comply with the SMS at time intervals following issuance of the final decision documents.[16]

9.3.1 Changes in Sediment Bed Concentrations

Some general findings and observations regarding the information in Tables 9-2a, 9-2b and 9-3 are presented here to help familiarize the reader with the contents and, in turn, facilitate an understanding of the detailed evaluations for the remedial alternatives. These summary findings are:

- **Table 9-2a:**
  - Long term, concentrations (SWACs) for all four risk-driver chemicals reach very similar values regardless of alternative, a consequence of burial by upstream (Green/Duwamish River) sediments.
  - All alternatives reduce total PCB and dioxin/furan concentrations below the direct contact PRGs for all exposure scenarios.
  - All alternatives reduce cPAH concentrations below the PRGs established for netfishing and tribal clamming.
  - The PRG for the beach play scenario (90 µg TEQ/kg dw) is closely approached by all alternatives for all beaches combined but is not achieved in the long term. However, all alternatives reduce cPAH concentrations

[16] As discussed in Section 5, the BCM was applied on a point basis to SMS risk-driver chemicals. An approach using representative chemicals was adopted (see Section 5.2 and Table 5-3). The representative chemicals were phthalates, metals, and individual polycyclic aromatic hydrocarbon (PAH) compounds. Each SQS exceedance location was assigned a representative chemical for BCM estimation. The representative chemical corresponded to the one responsible for the maximum exceedance ratio of the sample and for which upstream and lateral data were available to establish input values. Application of the BCM in this manner assumes that the representative chemical for any given sample provides a conservative estimate of recovery at that location. Further, it assumes that all SMS chemicals within a group exhibit a similar recovery trend.

below a concentration of 140 µg TEQ/kg dw (MTCA Method B unrestricted soil direct contact; WAC 173-340-740 (3)).

- All alternatives achieve a long-term site-wide total PCB SWAC well below the PRG (128 µg/kg dw) for protection of the river otter.
- None of the alternatives are predicted to reach total PCB or dioxin/furan PRGs for the human seafood consumption scenario. Both PRGs are based on natural background concentrations.
- The direct contact PRG for arsenic, based on the natural-background value of 7 mg/kg dw, cannot be achieved under any remedial alternative or exposure area scenario. However, all remedial alternatives reduce arsenic concentrations below the assumed MTCA cleanup level of 11 mg/kg dw (based on a 90th percentile of the natural background dataset).

♦ **Table 9-2b:**

- Alternatives 4C, 4R, 5R, 5C, 6C, and 6R are predicted to comply with the SMS (SQS or CSL) before or at the end of the implementation period (as shown in Figures 9-6a and 9-6b)
- Alternatives 2R and 3C are predicted to comply with the SMS within 10 years following the end of construction.
- Alternative 1 is predicted to require more than 10 years following the end of construction to comply with the SMS.

♦ **Table 9-3:**

- The PRG for the beach play scenario (90 µg TEQ/kg dw) is closely approached,[17] and in some cases achieved, by all alternatives and for each individual beach, except Beach 3. Beach 3 model results are influenced by an adjacent outfall that discharges directly to a portion of the assumed beach play area.
- All alternatives reduce cPAH concentrations below a concentration of 140 µg TEQ/kg dw (MTCA Method B unrestricted soil direct contact; WAC 173-340-740 (3)) for each individual beach, except Beach 3.
- All remedial alternatives reduce arsenic concentrations below the assumed MTCA cleanup level concentration of 11 mg/kg dw.

[17] All alternatives are predicted to achieve 1×10^{-6} excess cancer risks for cPAHs in all beaches, except Beach 3 (Appendix M, Table M-8c).

Figures 9-7a through 9-7h chart the site-wide SWAC BCM output from Table 9-2a for each of the four risk-driver chemicals as a function of time beginning with the issuance of the final decision documents. The combined-technology and removal-technology alternative results are shown on separate charts. Excluding Alternative 1, it is evident that the decline in SWACs is similar among the remedial alternatives: the curves converge over time, and 15 years represents a reasonable approximation of when the trends flatten out and yield very little additional reduction with more time. In all cases and for all risk-driver chemicals, the long-term model-predicted SWAC closely approaches the assumed BCM upstream input value. This is the expected outcome because in the long term, incoming sediment from upstream dominates the chemical composition of surface sediment in the LDW.

The core set of BCM results plotted in Figures 9-7a through 9-7h are based on BCM input parameters for upstream, lateral, and post-remedy bed sediment replacement values that represent best estimates of what will influence LDW chemical concentrations over time (see Section 5.2.3). However, in recognition of uncertainties in the input parameter values, calculations were also performed using a broader range of chemical input parameters (Table 9-4). Uncertainty bounding of the trends in these figures is represented using the Alternative 6R BCM output. The uppermost curve is based on using all high input parameters and the lowermost curve is based on using all low input parameters.[18]

Results based on using all high parameter values represent a very conservative (worst-case) scenario in which the effectiveness of source control is low, efforts to control recontamination during construction are ineffective, and incoming sediment concentrations from upstream closely match the highest estimates using data on incoming (Green/Duwamish River) suspended solids. Results based on using all low parameter values are an optimistic representation of what may be achievable in the long term, primarily as a result of very effective source control (over a 30- to 40-year period) and incoming sediment concentrations from upstream being more represented by the upstream surface sediment in RM 5.0 to 7.0 rather than the other weights-of-evidence considerations.

As mentioned earlier, the long-term model-predicted SWACs approach the assumed BCM upstream input value for each risk driver. Assuming reasonably effective source control, an outcome represented by the upper-bound curve has a low likelihood of occurring. By the same token, the lower-bound curve is likely over-optimistic based on the various lines of evidence. However, inputs of all chemicals and how they affect the LDW are variable and difficult to predict beyond the level of analysis included in the FS. Future monitoring would use empirical data to evaluate actual changes in the long-term concentrations achieved following active remediation.

[18] Refer to Table 9-4 for bounding results for each individual alternative

As discussed in Section 4, analysis indicates that no alternative can achieve the PRGs for total PCBs and dioxins/furans that have been established in this FS for RAO 1. Further, risks to humans from consumption of seafood exposed to sediments containing the other three risk drivers could not be quantified. Therefore, it is of interest in the evaluation of alternatives to understand what might be the best achievable or best practicable result. Table 9-5 presents differences among the alternatives using long-term, BCM-predicted, site-wide SWACs from Alternative 6R (the most aggressive of the remedial alternatives) as the basis for comparison.[19] The results are based on using the mid (base case) BCM input values (Table 9-2a). The alternatives converge to the same approximate SWACs over time. Differences among the alternatives compared to the "base" (Alternative 6R) for arsenic, cPAHs, and dioxins/furans are very insensitive to time and descend to low single digit percentages in 20 to 30 years. Differences for total PCBs are slightly more pronounced. For example, the total PCB SWACs for Alternatives 2R, 3C, 3R, 4C, 4R, 5C, and 5R are within 25% of the long-term Alternative 6R value in 20 years and decline slowly to about a 10% difference by the end of the model run (45 years). Based on this analysis, risk-driver concentrations are assumed to reach long-term values when the site-wide PCB SWAC reduces to the range of 40 to 50 µg/kg dw.

9.3.2 Risk Reduction for Human and Ecological Health

The SWAC predictions discussed above can be used to estimate the risks associated with total PCBs for human health seafood consumption (RAO 1), the risks associated with all four risk drivers for human health direct contact (RAO 2), and risks associated with total PCBs for river otter (RAO 4). These estimates are relevant to evaluating the effectiveness of the remedial alternatives.

9.3.2.1 Cancer Risks

Table 9-6a summarizes estimates of excess human cancer risks from consuming seafood that contains total PCBs for all remedial alternatives at various times. Tissue concentrations estimated by the food web model (Windward 2010), using site-wide total PCB SWACs in surface sediments, were used to estimate risks. Quantitative risk estimates from the four risk drivers combined are not possible. However, the majority of the risk associated with the consumption of resident fish and crabs in the LDW is believed to be attributable to total PCBs (see Appendix B, Section B.4) and therefore, total excess cancer risk from seafood consumption (specifically resident fish and crabs) in the LDW is likely of the same magnitude as the risk from total PCBs.

[19] Additional estimated risk-driver chemical concentrations in surface sediment during and following implementation of each remedial alternative and for other areas/grouping of the LDW are available in Appendix M. Table M-2 compiles sediment concentrations by reaches 1, 2, and 3, while Table M-3 summarizes SWACs for intertidal areas.

All three RME seafood consumption scenarios evaluated in the RI are represented in Table 9-6a.[20] Effectiveness of the remedial alternatives is discussed in this section for the three RME scenarios. Results for the non-RME scenarios (see Appendix M) provide additional context for purposes of risk communication. Color shading in Table 9-6a identifies excess cancer risk, which is rounded to the nearest order of magnitude for each calculated value. Figures 9-8a through 9-8c present the residual total PCB seafood consumption risks for the three RME scenarios at the end of construction and 10 years after construction for each remedial alternative. Note that the seafood consumption excess cancer risk corresponding to the Adult Tribal RME scenario is similar in the long term among Alternatives 2 through 6, is uniformly of magnitude 10^{-4} (between 1×10^{-4} to 4.49×10^{-4}), and does not decrease further regardless of the remedial alternative (Table 9-6a). Excess cancer risk is also similar among alternatives for the Child Tribal RME scenario (risks from 3×10^{-5} to 4×10^{-5}) and the Adult API RME scenario (risks of 5×10^{-5} to 6×10^{-5}).

Site-related risks (total risk minus contributions from upstream) are presented in Appendix M for each alternative. In the long term, a 93 to 95% percent reduction in site-related risks is achieved based on the Adult Tribal RME scenario (Table M-5).[21]

9.3.2.2 Non-cancer Risks

Table 9-6b[22] summarizes estimates of non-cancer hazard quotient (HQ) risks to humans based on RME scenarios and river otters from consuming seafood that contains total PCBs. For the river otter, all remedial alternatives are predicted to result in HQs of less than 1. Figures 9-9a through 9-9c show the human health residual seafood consumption HQs for total PCBs at the end of construction and 10 years after construction.[23] The Adult Tribal RME non-cancer seafood consumption HQs associated with total PCBs exceed 1 for all alternatives. In the long term, Alternatives 2 through 6 are predicted to have an HQ of 4 or 5 and do not decrease further regardless of the remedial alternative. Following remediation, much of the residual non-cancer risk is attributable to the upstream contribution.[23]

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[20] See Appendix M (Table M-4) for the non-RME (informational) seafood consumption scenarios.

[21] Appendix M (Table M-5) provides estimates of site-related excess cancer risks remaining after remediation. The site-related risks were approximated by subtracting out the portion of total residual risks associated with background seafood tissue concentrations, which were estimated using the food web model and the total PCB concentrations found in upstream (Green/Duwamish River) sediment. Assumed upstream Green/Duwamish River sediment concentrations equal the mid (BCM input) value.

[22] See Appendix M (Table M-6) for the non-RME (informational) seafood consumption scenarios.

[23] Appendix M (Table M-7) provides estimates of site-related non-cancer risks remaining after remediation. Background risks are based on the assumed upstream total PCB concentration of 35 µg/kg dw; (mid BCM input value).

9.3.2.3 Direct Contact Risks

Cumulative direct contact excess cancer risks for the four human health risk drivers are presented in Table 9-7, Figures 9-10a through 9-10c, and Figure 9-11. All alternatives are predicted to reach a cumulative excess cancer risk of 1×10^{-5} or less for all exposure scenarios. This meets CERCLA residual risk expectations. Direct contact excess cancer risks from total PCBs and dioxins/furans are reduced by all alternatives to less that 1×10^{-6} (the MTCA ARAR) for all exposure scenarios (Tables M-8c). All alternatives reduce arsenic below the assumed MTCA cleanup level of 11 mg/kg dw. For cPAHs, long-term predicted risks are less than 1×10^{-6} (the MTCA ARAR) for netfishing (site-wide) and tribal clamming. For cPAHs, excess cancer risks at the individual beaches are predicted to be at 1×10^{-6} with one exception, Beach 3 (Beach 3 is actively remediated, but recontamination is predicted).

Under baseline conditions, unacceptable direct contact non-cancer risks were predicted from total PCBs at Beach 4 only (Section 3.2.2). This area is actively remediated by Alternative 2 and therefore no non-cancer risks are expected for any direct contact scenario for Alternatives 2 through 6.

9.3.2.4 Tissue Concentrations

Finally, Table 9-8 presents future fish and shellfish tissue concentrations for total PCBs predicted using the food web model with future LDW-wide total PCB SWACs. The most pronounced reduction in tissue total PCB concentrations occurs between baseline and completion of the EAAs (e.g., edible sole fillet has total PCB tissue concentration of 1,200 µg/kg ww at baseline and a tissue concentration of 420 µg/kg ww after completion of the EAAs). Among the other alternatives, further reductions for total PCBs show considerably smaller decline in tissue concentration from that achieved by Alternative 1. Tissue concentrations are not shown during the period of construction because tissue levels will likely be influenced (elevated) as a result of dissolved concentrations released to and solids suspended in the water column during in-water construction activities.

9.4 Detailed Analysis of Alternative 1: No Further Action

Alternative 1 consists of completing removal actions at the EAAs (29 acres) (Table 9-9). This alternative is not formulated with specific risk reduction goals in mind. However, it does provide a basis to compare the relative effectiveness of the other alternatives (see Section 10).[24]

9.4.1 Overall Protection of Human Health and the Environment

The EAAs were previously identified as containing some of the highest levels of sediment contamination in the LDW. Cleanups have already been conducted at two of the EAAs and three others are in the final planning stages; it is assumed that cleanups of these

[24] Alternative 1 is the designated CERCLA "no action" alternative.

remaining EAAs will be completed, regardless of which of the remedial alternatives is selected for the remainder of the LDW. Contaminant reduction outside of the EAAs will occur only to the degree achieved by on-going natural recovery processes. However, no project-specific monitoring, engineering, or institutional controls are assumed for areas outside of the EAAs.

Alternative 1 provides the least protection of human health and the environment. It does not achieve any of the RAOs because it includes no provisions for LDW-wide monitoring and institutional controls from which to ascertain the levels of protection achieved, to identify need for contingency actions, and to reduce exposures to residual risks.

9.4.2 Compliance with ARARs

Alternative 1 does not satisfy the threshold requirement of complying with ARARs.

9.4.3 Long-term Effectiveness and Permanence

9.4.3.1 Magnitude and Type of Residual Risk

The residual excess cancer risk to humans consuming seafood that contains total PCBs is predicted to be 2×10^{-4} (Adult Tribal RME). The cumulative (all chemicals combined) direct contact excess cancer risk in each exposure area is predicted to be less than or equal to 1×10^{-5}. Risks to the benthic community are predicted to be reduced to levels compliant with the SMS. Finally, the residual hazard quotient for wildlife consumption of seafood containing total PCBs is predicted to be less than 1.

Alternative 1 leaves all sediment in place outside of the EAAs and therefore has a high re-exposure potential from physical disturbances.

9.4.3.2 Adequacy and Reliability of Controls

Monitoring and controls applied under Alternative 1 are not assumed to extend to areas outside the EAA boundaries. This geographic limitation of monitoring and controls would not be adequate for managing residual risks elsewhere at the site.

9.4.4 Reductions in Toxicity, Mobility, or Volume through Treatment

Certain treatment elements may be incorporated into individual EAA designs but are not specifically evaluated in this FS. For example, the Slip 4 capping design includes carbon amendment to reduce the mobility of contaminants (Integral 2007).

9.4.5 Short-term Effectiveness

9.4.5.1 Community and Worker Protection

Risks to the community and workers were not specifically evaluated for Alternative 1. Some of the EAA work has been completed (Diagonal/Duwamish and Norfolk Combined Sewer Overflow [CSO]). Work at the other EAAs is pending. The risks to complete the EAAs are assumed to be manageable and acceptable given the common

nature of the measures likely to be taken at the remaining EAAs and the types of planning/operational measures available to provide community and worker protection. Risks to seafood consumers will remain elevated during construction before starting to decline to levels similar to other alternatives.

9.4.5.2 Environmental Impacts

Environmental impacts associated with implementation of Alternative 1 were not estimated. The impacts are assumed to be manageable and acceptable given the common nature of the remedial actions taken (and likely to be taken) and the types of planning/operational measures available to limit impacts.

9.4.5.3 Time to Achieve RAOs

Alternative 1 does not achieve PRGs for RAO 1 that are based on natural background. Further it does not achieve the cPAH PRG in the majority of individual assumed beach play areas. Alternative 1 is predicted to achieve the PRGs for RAO 3 (i.e., the SQS) in slightly more than 10 years. It is also predicted to achieve the total PCB PRG of 128 µg/kg dw associated with RAO 4 within 10 years. However, Alternative 1 also lacks the monitoring, engineering, and institutional controls to determine if, in fact, it will achieve its targets over time, or manage the residual risks if it does not, and thus cannot be determined to achieve the RAOs.

9.4.6 Implementability

Alternative 1 is administratively implementable. A portion of the EAA work has been completed (i.e., Norfolk and Duwamish/Diagonal). Slip 4 design work is completed and Terminal 117 and Boeing Plant 2/Jorgensen Forge design work is nearing completion. The on-going design work has not identified any insurmountable technical or administrative challenges other than the need to adequately complete source controls before in-water construction work commences.

9.4.7 Cost

Estimated total costs to implement Alternative 1 are $66 million based on documented costs for the Diagonal/Duwamish and Norfolk projects and projected engineering and construction costs for Terminal 117, Slip 4, and Boeing Plant 2/Jorgensen Forge. These estimated costs do not include anticipated costs for associated upland remediation or source control efforts, which could be significant.

9.4.8 State, Tribal, and Community Acceptance

Alternative 1 is unlikely to be acceptable to the state, tribes, and community. Stakeholder comments and concerns have and will continue to be considered by EPA and Ecology. EPA will fully evaluate state, tribal, and community acceptance in the final decision documents following the public comment period on the Remedial Investigation/ Feasibility Study (RI/FS) and on EPA's proposed plan.

9.5 Detailed Analysis of Alternative 2

Scope, performance, and cost summaries for Alternatives 2R and 2R with contained aquatic disposal (2R-CAD) are presented in Table 9-10.

9.5.1 Overall Protection of Human Health and the Environment

The technology application areas and dredge removal volumes presented in Table 9-10 illustrate the physical extent to which these alternatives rely on engineering controls and natural recovery to reduce risk. Alternative 2R and 2R-CAD emphasize removal and disposal of sediment from the actively remediated areas. Alternative 2R-CAD disposes a portion of dredged material in one or more CAD facilities whereas all contaminated sediment that is dredged by Alternative 2R goes to upland landfill disposal. Both alternatives have the same active remedial footprint and a large MNR footprint (127 acres). The alternatives have an estimated construction period of 4 years.

Alternatives 2R and 2R-CAD are predicted to achieve all four RAOs. Residual risks from surface sediment are predicted to be the same for both alternatives as discussed below in Section 9.5.3. Estimated times to achieve the RAOs (from issuance of final decision documents) are shown in the lower panel of Table 9-10. Both the implementation period and the predicted time to achieve long-term modeled concentration ranges for risk drivers are considered.

Neither remedial alternative can achieve the total PCB and dioxin/furan PRGs for the seafood consumption scenario. Institutional controls including programs of advisories, outreach, and education are implemented to reduce seafood consumption exposures to achieve RAO 1. Further, LDW-wide recovery processes are monitored to assess long-term human health risk reduction.

The potential for re-exposure of subsurface contaminated sediment following active remediation is primarily from areas managed by MNR. Alternatives 2R and 2R-CAD remediate 127 acres through natural recovery. An estimated 20 acres of this area is located in Recovery Category 1 and the remainder is located in Recovery Categories 2 and 3 (Table 9-11).

Risks to workers and the community from the general physical hazards of construction, noise, particulate emissions, and elevated fish and shellfish tissue concentrations are similar for both alternatives. In both cases, protection of workers and the community from physical injury are manageable with appropriate planning and standard construction practices. Institutional controls are required to protect consumers of resident LDW seafood during construction.

Long-term monitoring, maintenance, and institutional controls are required and are considered to be reliable for both alternatives. The level of effort associated with these activities is expected to be greater for Alternative 2R-CAD because, while both

alternatives use capping and MNR over a surface area of 130 acres, 2R-CAD has an additional 23 acres for the CAD to monitor and maintain.

9.5.2 Compliance with ARARs

Alternatives 2R and 2R-CAD are expected to comply with ARARs except as follows:

- The alternatives are unlikely to achieve the total PCB and dioxin/furan PRGs for seafood consumption (by humans). These PRGs are based on natural background, and it is not practicable to achieve natural background concentrations for these chemicals in the LDW. Compliance with the MTCA ARARs is achieved by reducing concentrations and by using institutional controls designed to reduce human exposure to resident fish and shellfish.
- Surface water quality in the LDW is expected to improve as a result of sediment remediation and upland source control. However, compliance with some water quality standards may not be feasible, particularly those based on human consumption of bioaccumulative contaminants that magnify through the food chain, such as PCBs.
- Model results suggest that the beach play direct contact PRG for cPAHs cannot be achieved at all beaches although risks are projected to achieve 1×10^{-6}. (Note: The MTCA Method B unrestricted soil direct contact level of 140 µg TEQ/kg dw is above predicted cPAH concentrations in all assumed beach play areas except Beach 3 where additional focused source control measures may be needed).

ARAR waivers based on technical impracticability may be required for one or more of the above conditions depending on what cleanup levels are established in the remedy decision documents and on long-term monitoring results.

The level of performance achieved by Alternatives 2R and 2R-CAD is considered, for FS evaluation purposes, to be sufficient for achieving RAO 3. The percentage of SMS stations in the FS dataset predicted to be below the SQS and the percentage of the LDW area predicted to be below the SQS within 10 years after construction are both above the thresholds established in this FS for demonstrating compliance (see Table 9-2b). Ecology would have to set a cleanup standard that is either above the SQS for a few chemicals or includes a longer time frame (e.g., more than 10 years) for compliance.

9.5.3 Long-term Effectiveness and Permanence

9.5.3.1 Magnitude and Type of Residual Risk

Once RAOs are achieved by Alternatives 2R and 2R-CAD, the residual risks from surface sediment are predicted to be the same. The residual excess cancer risk to humans consuming seafood that contains total PCBs is 2×10^{-4} (Adult Tribal RME). The cumulative direct contact excess cancer risk in each exposure area is less than or equal to

1×10^{-5}. Residual excess cancer risks for direct contact are predicted to be 1×10^{-6} or less for total PCBs, dioxins/furans, and cPAHs for all areas except for cPAHs at Beach 3 (Appendix M, Table M-8). Arsenic concentrations are below the MTCA natural-background (WAC 173-340-709). Risks to the benthic community are reduced to levels compliant with the SMS. Finally, the residual hazard quotient for wildlife consumption of seafood containing total PCBs is less than 1.

Alternatives 2R and 2R-CAD actively remediate the same 30 acres of the site. The potential for re-exposure is small for the 3 acres of partially dredged and capped area in both alternatives. The majority of re-exposure potential derives from the 127 acres that both alternatives monitor for natural recovery. Table 9-11 shows the allocation of the 127 acres by recovery category and also tallies the associated FS dataset cores remaining. The majority of the MNR area is located in Recovery Categories 2 and 3. Under both alternatives, 20 acres identified as Recovery Category 1 are remediated by natural recovery. These 20 acres have a higher re-exposure potential and also are more likely to require dredging based on data collected during remedial design or monitoring. Alternative 2 leaves 37 core stations in place that exceed the CSL and are located within the area remediated by natural recovery. The majority of these cores are in Recovery Categories 2 and 3.

9.5.3.2 Adequacy and Reliability of Controls

The scope and duration of the long-term monitoring and maintenance requirement is proportional to the aggregate surface area remediated by capping and MNR (130 acres). Alternative 2R-CAD has additional monitoring and maintenance requirements associated with the 23-acre CAD facility. The potential for caps (3 acres) needing to be replaced in the future is considered to be low. Controls for MNR include monitoring of MNR performance and provisions for contingency actions if monitoring data indicate unacceptable performance.[25] In the long term, the effectiveness of source control for the LDW and inputs from the Green/Duwamish River are the primary factors governing surface sediment concentrations.

Both Alternatives 2R and 2R-CAD require an Institutional Controls plan of similar scope and duration because: 1) the PRGs for RAO 1 cannot be achieved, and 2) subsurface contaminated sediment above protective levels remains in place (Section 9.5.3.1). The Institutional Controls plan consists of:

- Seafood consumption advisories, public outreach, and education.
- Monitoring of in-water construction permit applications, waterway uses, and notification of waterway users.

[25] 15% percent of the MNR area of Alternatives 2R and 2R-CAD (approximately 19 acres) are assumed to require dredging based on O&M monitoring results, with the probability being higher in area located in Recovery Category 1 than in Recovery Categories 2 or 3.

- Restrictive covenants for areas with residual contamination above protective levels.

The combination of monitoring, maintenance, institutional controls, formal 5-year reviews, and contingency actions (if required), is considered adequate for ensuring remedy integrity. As a whole, these devices will enable the remedial alternatives to be adaptively managed, as needed, based on new information.

9.5.4 Reductions in Toxicity, Mobility, or Volume through Treatment

Neither Alternatives 2R nor Alternative 2R-CAD treat contaminated sediment. Although these remedial alternatives do not include treatment, for informational purposes other technology components of these remedial alternatives that reduce mobility and/or exposure potential are summarized in Table 9-10.

9.5.5 Short-term Effectiveness

9.5.5.1 Community and Worker Protection

Appropriate planning and adherence to standard health and safety practices provide some protection to both workers and the community during the estimated 4-year construction period. Fish and shellfish tissue concentrations are predicted to remain elevated during construction and for some time thereafter, resulting in increased seafood consumptions risks for that additional time.

Local transportation impacts (traffic, noise) from implementation of these alternatives are proportional to the number of truck/train miles (Alternative 2R: 400,000/106,000 and Alternative 2R-CAD: 200,000/53,000) estimated for support of material hauling operations (Appendix L). The particulate matter generated from all combustion activity (PM_{10}) is estimated to be 25 metric tons for both alternatives (Appendix L).

9.5.5.2 Environmental Impacts

Resuspension of contaminated sediment is inevitable during environmental dredging operations. This material re-settles primarily onto the dredged surface and areas just outside the dredge footprint (near-field). Fine-grained material that is slow to re-settle can be transported well beyond the dredge operating area (far-field). Dredging also releases contaminants into the dissolved phase (i.e., the water column). These mass transfer mechanisms are difficult to quantify and cannot be prevented. Release of contaminated sediment that settles back onto the dredged surface or to areas just outside the dredge footprint are assumed to be managed through application of a thin-layer of sand (9 inches with the goal of achieving a minimum of 6 inches of coverage; 27 acres of coverage).

Estimates of air-borne gas emissions associated with Alternative 2R are presented in Appendix L. Implementation of this alternative would result in approximately 25,000 tons of CO_2 emitted to the atmosphere. Alternative 2R-CAD has estimated CO_2 emissions of 20,000 metric tons. The similarity in emission estimates for the two alternatives is because

of the additional dredging required for the CAD site(s). These emissions are primarily the result of using fossil fuels for activities such as dredging and transportation. Appendix L describes best management practices (BMPs) for reducing this "carbon footprint," such as using alternative fuels. Estimated reductions associated with BMPs are less than 10% because the majority of these emissions are associated with large equipment that is not suited to the use of alternative fuels.

For Alternatives 2R and 2R-CAD, approximately 12 acres of intertidal and shallow subtidal habitat above -10 ft MLLW are actively remediated (Table 9-10). Another 61 acres above -10 ft MLLW is left undisturbed and monitored for natural recovery.

The alternatives consume regional resources primarily in the form of quarry material (sand, gravel, and rock) and landfill space. An estimated 180,000 cubic yards (cy) (Alternative 2R-CAD) and 110,000 cy (Alternative 2R) of granular material is used for all imported material requirements: capping, management of dredge residuals, habitat restoration, and backfilling of dredged intertidal areas original grade. The landfill capacity consumed by Alternative 2R is proportional to the volume of material removed and disposed of in the landfill (750,000 cy). Alternative 2R-CAD reduces consumption of landfill capacity to 370,000 cy because half of the dredged material is disposed of in the CAD(s).

9.5.5.3 Time to Achieve RAOs

Alternatives 2R and 2R-CAD are estimated to take 4 years to construct and thus have an implementation period of 9 years. Predicted times to achieve RAOs are reported in the lower panel of Table 9-10. In summary, RAOs 2 and 4 are achieved immediately after implementation is complete. RAO 3 requires additional natural recovery and is achieved in 19 yrs. Given the inability of any remedial alternative to reach the PRG for the seafood consumption scenario (RAO 1), the minimum expectation is that immediately after implementation is complete, the Adult Tribal RME seafood consumption risk is reduced to the lowest magnitude achievable in the long term (i.e., 10^{-4}) and institutional controls are in place to reduce exposures. After approximately 24 years, all four risk drivers reach long-term model-predicted concentration ranges site-wide, achieving some incremental seafood consumption risk reduction. Continued use of institutional controls is necessary to reduce exposure. The time to reach long-term surface sediment concentration predictions is subject to uncertainties largely associated with source control in the Green/Duwamish River inputs and natural recovery beyond the project implementation period.

9.5.6 Implementability

The CAD component of Alternative 2R-CAD is considered a significant administrative challenge from the standpoints of locating, using, and maintaining one or more CAD facilities. These include obtaining permission from the landowner, sequencing remedial projects for effective CAD use; potential disruption of navigation and tribal fisheries

throughout construction, filling, and closure; obtaining agreements among multiple parties for CAD use; costs; maintenance; and liability.

Alternative 2R has a construction period of only 4 years, actively remediates only 30 acres, and thus is considered to have a low potential for technical difficulties that could lead to schedule delays. The elevated RALs limit the potential for additional actions being required as a result of recontamination, although inadequate removal of contaminated inventory or significant residuals could require additional administrative efforts to determine the need for additional actions. On the other hand, Alternative 2R relies significantly on natural recovery to achieve all RAOs. Some of the natural recovery (20 acres) occurs in area designated Recovery Category 1, which is more vulnerable to re-exposure of buried contaminated sediment than areas designated Recovery Categories 2 and 3. For this reason, some additional future remedial actions are assumed likely for Alternative 2R based on monitoring data indicating inadequate performance in achieving all RAOs. Additional administrative efforts would be required to accomplish the potential future remedial actions.

9.5.7 Cost

Total present value costs for Alternatives 2R and 2R-CAD are $230 million and $210 million, respectively (see Appendix I for details). The 2R-CAD costs are slightly lower because less volume is travelling to off-site disposal. OM&M costs for both are an estimated $27 and $29 million, respectively. The sensitivity of cost to key factors (e.g., dredge volume) resulted in a range of estimates from $93 to $330 million for Alternative 2R-CAD and $120 to $360 million for Alternative 2R.

9.5.8 State, Tribal, and Community Acceptance

See Section 9.1.3.

9.6 Detailed Analysis of Alternative 3: Combined and Removal

Scope, performance, and cost summaries for Alternatives 3C and 3R are presented in Table 9-12.

9.6.1 Overall Protection of Human Health and the Environment

The technology application areas and dredge removal volumes presented in Table 9-12 illustrate the physical extent to which these alternatives rely on engineering controls and natural recovery to reduce risk. Alternative 3C emphasizes a combination of active remedial technologies—dredging with upland disposal, capping, and ENR, where appropriate. Alternative 3R emphasizes removal and upland disposal of sediment from the actively remediated areas. Both alternatives have the same active remedial footprint and the same passive remedial technology assignments. The construction periods for Alternatives 3C and 3R are estimated at 4 and 6 years, respectively.

Alternatives 3C and 3R are predicted to achieve all four RAOs. Residual risks from surface sediment are predicted to be the same for both alternatives as discussed below in Section 9.6.3. Estimated times to achieve RAOs (from issuance of final decision documents) are shown in the lower panel of Table 9-12. Both the implementation period and the predicted time to achieve long-term modeled concentration ranges for risk drivers are considered.

Neither remedial alternative can achieve the total PCB and dioxin/furan PRGs for the seafood consumption scenario. Institutional controls including programs of advisories, outreach, and education are implemented to reduce seafood consumption exposures and achieve RAO 1. Further, LDW-wide recovery processes are monitored to assess long-term human health risk reduction.

The potential for re-exposure of subsurface contaminated sediment following active remediation is primarily from areas managed by MNR and ENR. Both alternatives monitor 100 acres for natural recovery and Alternative 3C remediates an additional 9 acres with ENR. In both cases, an estimated 19 acres of MNR/ENR area is located in Recovery Category 1 and the remainder is located in Recovery Categories 2 and 3 (Table 9-13).

Risks to workers and the community from the general physical hazards of construction, noise, particulate emissions, and elevated fish and shellfish tissue concentrations are higher for Alternative 3R. In both alternatives, protection of workers and the community from physical injury are manageable with appropriate planning and standard construction practices. institutional controls are required to protect consumers of resident LDW seafood during construction.

Long-term monitoring, maintenance, and institutional controls are required and are considered to be reliable for both alternatives. The scope of monitoring and maintenance is higher for Alternative 3C because it has about 28 acres more of capping, ENR, and MNR to monitor and maintain. The Institutional Controls programs for both are of similar scope and duration.

9.6.2 Compliance with ARARs

Alternative 3C and 3R have the same limitations as Alternative 2R for achieving the total PCB and dioxin/furan PRGs based on natural background, the assumed beach play direct contact PRG for cPAHs, and surface water quality ARARs (see Section 9.5.2).

The levels of performance achieved by Alternatives 3C and 3R are, for FS evaluation purposes, sufficient for achieving RAO 3. The percentage of SMS stations in the FS dataset predicted to be below the SQS and the percentage of the LDW area predicted to be below the SQS within 10 years after construction are both above the thresholds established in this FS for demonstrating compliance (see Table 9-2b).

9.6.3 Long-term Effectiveness and Permanence

9.6.3.1 Magnitude and Type of Residual Risk

Once RAOs are achieved by Alternatives 3C and 3R, the types of residual risks from surface sediment are predicted to be the same as discussed previously for Alternative 2R (Section 9.5.3.1).

Alternatives 3C and 3R actively remediate the same 57 acres of the site with different combinations of technology. Alternative 3R leaves less subsurface contaminated sediment in place because of its greater reliance on dredging; 52 acres versus 29 acres for Alternative 3C (Table 9-12). However, the potential for re-exposure in areas that are either capped outright or are partially dredged and capped is considered low (19 acres for Alternative 3C and 5 acres for Alternative 3R). Greater re-exposure potential derives from the 100 acres that are monitored for natural recovery under both alternatives and the additional 9 acres remediated by ENR under Alternative 3C.

For reference, Table 9-13 summarizes the non-dredging technology application areas by recovery category and also tallies the associated FS dataset cores remaining in place. Under both alternatives, 19 acres are monitored for natural recovery in areas identified as Recovery Category 1. These 19 acres have a higher re-exposure potential; therefore, these areas have a greater potential to require some form of contingency action (e.g., dredging) as a result of additional sampling either during remedial design or monitoring. The majority of the ENR and MNR areas are located in Recovery Categories 2 and 3 where re-exposure potential is lower. Alternative 3C leaves 28 core stations in place within ENR and MNR areas that contain sediment exceeding the CSL. Alternative 3R leaves behind 20. In both cases, the majority of these cores are in Recovery Categories 2 and 3.

9.6.3.2 Adequacy and Reliability of Controls

Alternative 3R dredges a larger area (52 acres) than Alternative 3C (29 acres) thereby requiring a proportionately larger effort to manage dredging residuals. Alternative 3C has slightly broader scope and higher long-term monitoring and maintenance requirements than Alternative 3R based on the aggregate surface areas remediated by capping, ENR, and MNR (128 acres for Alternative 3C and 105 acres for Alternative 3R). The potential for caps needing to be replaced in the future is considered to be low because of the engineering involved in location-specific design. The ENR and MNR areas have the potential of requiring dredging based on monitoring data showing unacceptable performance. Both alternatives manage 19 acres using these technologies in areas that are designated Recovery Category 1.[26] In the long term, the effectiveness of source control for

[26] An important assumption underlying development of the remedial alternatives is that 15% percent of the total ENR and MNR areas of the alternatives (approximately 15 acres for Alternatives 3C and 3R) are assumed to require dredging based on O&M monitoring results.

the LDW and inputs from the Green/Duwamish River are the primary factors governing surface sediment concentrations.

Both Alternatives 3C and 3R require an Institutional Controls plan of similar scope and duration because: 1) the PRGs for RAO 1 cannot be achieved, and 2) subsurface contaminated sediment above protective levels remains in place (Section 9.6.3.1). The institutional controls plan consists of:

- Seafood consumption advisories, public outreach, and education.
- Monitoring of in-water construction permit applications, waterway uses, and notification of waterway users.
- Restrictive covenants for areas with residual contamination above protective levels.

The combination of monitoring, maintenance, and institutional controls, formal 5-year reviews, and contingency actions (if required), is considered adequate for ensuring remedy integrity. As a whole, these devices will enable the remedial alternatives to be adaptively managed, as needed, based on new information.

9.6.4 Reductions in Toxicity, Mobility, or Volume through Treatment

Neither Alternative 3C nor Alternative 3R treat contaminated sediment. Although these alternatives do not include treatment, for informational purposes other technology components of these remedial alternatives that reduce mobility and/or exposure potential are summarized in Table 9-12.

9.6.5 Short-term Effectiveness

9.6.5.1 Community and Worker Protection

Appropriate planning and adherence to standard health and safety practices provide some protection to both workers and the community during the construction periods of Alternatives 3C and 3R. The construction period of Alternative 3R (6 years) is two years longer than that for Alternative 3C (4 years). Therefore, risks to workers and the community are assumed to be higher for Alternative 3R by a similar degree. Also, fish and shellfish tissue concentrations are predicted to remain elevated during the additional years of construction for Alternative 3R and for some time thereafter, resulting in increased seafood consumptions risks for that additional time.

Local transportation impacts (traffic, noise) from implementation of these alternatives are proportional to the number of truck/train miles (Alternative 3C: 364,000/97,000 and Alternative 3R: 505,000/134,000) estimated for support of material hauling operations (Appendix L). The particulate matter generated from all combustion activity (PM_{10}) is estimated to be 24 and 34 metric tons for Alternative 3C and Alternative 3R respectively (Appendix L).

9.6.5.2 Environmental Impacts

Resuspension of contaminated sediment is inevitable during environmental dredging operations and would be managed as described for Alternative 2 (see Section 9.5.5.2). The dredged areas (and volumes) of Alternatives 3C and 3R differ by a factor of about 2 (Table 9-12). Thus, Alternative 3R would generate approximately twice the amount of dredge residuals as Alternative 3C.

For Alternative 3C, approximately 27 acres of intertidal and shallow subtidal habitat areas (i.e., above -10 ft MLLW) are actively remediated (Table 9-12). Another 46 acres above -10 ft MLLW are left undisturbed and are monitored for natural recovery. The alternative consumes regional resources primarily in the form of quarry material (sand, gravel, and rock) and landfill space. An estimated 260,000 cy of imported granular material is used for capping, ENR, and backfilling of dredged areas where return to grade is assumed. The landfill capacity consumed by Alternative 3C is proportional to the volume of dredged material removed and disposed of in the landfill (680,000 cy).

For Alternative 3R, approximately 27 acres of intertidal and shallow subtidal habitat area (i.e., above -10 ft MLLW) are actively remediated (Table 9-12). Another 46 acres above -10 ft MLLW are left undisturbed and are monitored for natural recovery. An estimated 240,000 cy of imported granular material is used for capping, management of dredge residuals, habitat restoration, and backfilling of dredged areas where restoration to grade is assumed. The landfill capacity consumed by the alternative is proportional to the volume of dredged material removed and disposed of in the landfill (940,000 cy).

Estimates of air-borne gas emissions associated with Alternative 3C are presented in Appendix L. Implementation of this alternative would result in approximately 25,000 tons of CO_2 emitted to the atmosphere. These emissions are primarily the result of using fossil fuels for activities such as dredging and transportation. Appendix L describes BMPs for reducing this "carbon footprint," such as using alternative fuels.

Alternative 3R has estimated CO_2 emissions of 33,000 tons. As with Alternative 3C, limited reductions in the carbon footprint of this alternative are possible through the use of BMPs.

9.6.5.3 Time to Achieve RAOs

Alternatives 3C and 3R are estimated to take 4 and 6 years to construct and thus have implementation periods of 9 and 11 years, respectively. Predicted times to achieve RAOs are reported in the lower panel of Table 9-12. In summary, RAOs 2 and 4 are achieved immediately after implementation is complete. RAO 3 requires additional natural recovery and is achieved in 14 years for Alternative 3C, and in 16 years for Alternative 3R (i.e., approximately 5 years after construction is complete). Given the inability of any remedial alternative to reach the PRG for the seafood consumption scenario (RAO 1), the minimum expectation is that immediately after implementation is complete, the Adult Tribal RME seafood consumption risk is reduced to the lowest magnitude achievable in

the long term (i.e., 10^{-4} to 10^{-5} risk range) and institutional controls are in place to reduce exposures. After approximately 24 and 26 years for Alternatives 3C and 3R respectively, all four risk drivers reach long-term model-predicted concentration ranges site-wide, achieving some incremental seafood consumption risk reduction. Continued use of institutional controls is necessary to reduce exposure. The time to reach long-term surface sediment concentration predictions is subject to uncertainties largely associated with source control in the LDW, Green/Duwamish River, and natural recovery beyond the project implementation period.

9.6.6 Implementability

Alternatives 3C and 3R have construction periods of 4 and 6 years, respectively, actively remediate 57 acres, and are administratively implementable. Alternative 3R dredges approximately twice the area and sediment volume than Alternative 3C, has a longer construction period, and therefore is subject to more technical or administrative delays. The potential for recontamination above RALs is considered low. Alternatives 3C and 3R rely significantly on natural recovery to achieve all RAOs. Some of the natural recovery (19 acres) occurs in areas designated as Recovery Category 1, which is more vulnerable to re-exposure of subsurface contaminated sediment than areas designated as Recovery Categories 2 and 3. For this reason, some additional actions are assumed likely for Alternatives 3C and 3R based on monitoring data indicating inadequate performance in achieving all RAOs.

9.6.7 Cost

Total present value costs for Alternatives 3C and 3R are $220 million and $290 million, respectively (see Appendix I for details). OM&M costs for both are approximately $26 and $25 million, respectively. The sensitivity of cost to key factors (e.g., dredge volume) resulted in a range of estimates from of $120 to $360 million for Alternative 3C and $190 to $460 million for Alternative 3R.

9.6.8 State, Tribal, and Community Acceptance

See Section 9.1.3.

9.7 Detailed Analysis of Alternative 4: Combined and Removal

Scope, performance, and cost summaries for Alternatives 4C and 4R are presented in Table 9-14.

9.7.1 Overall Protection of Human Health and the Environment

The technology application areas and dredge removal volumes presented in Table 9-14 illustrate the physical extent to which these alternatives rely on engineering controls and natural recovery to reduce risk. Alternative 4C emphasizes a combination of active remedial technologies—dredging with upland disposal, capping, and ENR, where appropriate. Alternative 4R emphasizes removal and upland disposal of sediment from

the actively remediated areas. Both alternatives have the same active remedial footprint and the same area monitored for natural recovery. The alternatives have estimated construction periods of 7 and 13 years, respectively.

Alternatives 4C and 4R are predicted to achieve all four RAOs. Residual risks from surface sediment are predicted to be the same for both alternatives as discussed below in Section 9.7.3. Estimated times to achieve RAOs (from issuance of final decision documents) are shown in the lower panel of Table 9-14 and discussed in greater detail below (Section 9.7.5.3). Both the implementation period and the predicted time to achieve long-term modeled concentration ranges for risk drivers are considered.

Neither remedial alternative can achieve the total PCB and dioxin/furan PRGs for the seafood consumption scenario. Institutional controls including programs of advisories, outreach, and education are implemented to reduce seafood consumption exposures and achieve RAO 1. Further, LDW-wide recovery processes are monitored to assess long-term human health risk reduction.

The potential for re-exposure of subsurface contaminated sediment following active remediation is primarily from areas managed by MNR and ENR. Alternatives 4C and 4R include monitoring of 58 and 43 acres, respectively, for a combination of ENR and MNR. All of these areas are located in Recovery Categories 2 and 3 (Table 9-15).

Risks to workers and the community from the general physical hazards of construction, noise, particulate emissions, and elevated fish and shellfish tissue concentrations are higher for Alternative 4R. In both alternatives, protection of workers and the community from physical injury is manageable with appropriate planning and standard construction practices. Institutional controls are required to protect consumers of resident LDW seafood during construction.

Long-term monitoring, maintenance, and institutional controls are required and are considered to be reliable for both alternatives. Although both alternatives use capping (including partial dredge and cap areas), ENR, and MNR, Alternative 4C would have a higher level of effort with a total surface area of approximately 106 acres and Alternative 4R would have a lower level of effort with a total of 54 acres.

9.7.2 Compliance with ARARs

Alternative 4C and 4R have the same limitations as Alternatives 2R, 3C, and 3R for achieving the total PCB and dioxin/furan PRGs based on natural background, surface water quality ARARs, and the beach play direct contact PRG for cPAHs (see Sections 9.5.2 and 9.6.2).

The levels of performance achieved by Alternatives 4C and 4R are, for FS evaluation purposes, sufficient for achieving RAO 3. The percentage of SMS stations in the FS dataset predicted to be below the SQS and the percentage of the LDW area predicted to be below

the SQS at the completion of construction are both above the thresholds established in this FS for demonstrating compliance (see Table 9-2b).

9.7.3 Long-term Effectiveness and Permanence

9.7.3.1 Magnitude and Type of Residual Risk

Once RAOs are achieved by Alternatives 4C and 4R, the types of residual risks from surface sediment are predicted to be the same as discussed previously for Alternative 2R (Section 9.5.3.1).

Alternatives 4C and 4R actively remediate the same 114 acres of the site. Alternative 4R leaves less subsurface contaminated sediment in place because of its greater reliance on dredging; 103 acres versus 51 acres for Alternative 4C (Table 9-14). The potential for re-exposure in areas that are either capped outright or are partially dredged and capped is considered low (48 acres for Alternative 4C and 11 acres for Alternative 4R). Greater re-exposure potential derives from the 43 acres that are monitored for natural recovery under both alternatives and the additional 15 acres remediated by ENR under Alternative 4C.

For reference, Table 9-15 summarizes the non-dredging technology application areas by recovery category and also tallies the associated FS dataset cores remaining. Under both alternatives, ENR and MNR are applied only in Recovery Categories 2 and 3 areas where re-exposure potential is lower. Alternative 4C leaves 20 core stations in place within ENR and MNR areas that exceed the CSL. Alternative 4R leaves behind 9 core stations. In both cases, the cores are located in Recovery Categories 2 and 3.

9.7.3.2 Adequacy and Reliability of Controls

Alternative 4R dredges almost twice the area as Alternative 4C, thereby requiring a proportionately larger effort to manage dredge residuals (Table 9-14). Alternative 4C has a broader scope and almost twice the duration of the long-term monitoring and maintenance requirements of Alternative 4R based on the aggregate surface areas remediated by capping, ENR, and MNR (106 acres for Alternative 4C and 54 acres for Alternative 4R). The potential for caps needing to be replaced in the future is considered to be low because of the engineering involved in location-specific design. The ENR and MNR components have the potential of requiring dredging based on monitoring data showing unacceptable performance. Of the total ENR and MNR areas of these alternatives, approximately 15% percent (9 acres for Alternative 4C and 6 acres for Alternative 4R) are assumed to require dredging based on O&M monitoring results. These two technologies are not used to manage any areas identified as Recovery Category 1 (Table 9-15). In the long term, the effectiveness of source control for the LDW and inputs from the Green/Duwamish River are the primary factors governing surface sediment concentrations.

Both Alternatives 4C and 4R require an Institutional Controls plan of similar scope and duration because: 1) the PRGs for RAO 1 cannot be achieved, and 2) subsurface contaminated sediment above protective levels remains in place (Section 9.7.3.1). The Institutional Controls plan consists of:

- Seafood consumption advisories, public outreach, and education.
- Monitoring of in-water construction permit applications, waterway uses, and notification of waterway users.
- Restrictive covenants for areas with residual contamination above protective levels.

The combination of monitoring, maintenance, and institutional controls, formal 5-year reviews, and contingency actions (if required), is considered adequate for ensuring remedy integrity. As a whole, these devices will enable the remedial alternatives to be adaptively managed, as needed, based on new information.

9.7.4 Reductions in Toxicity, Mobility, or Volume through Treatment

Neither Alternatives 4C nor Alternative 4R treat contaminated sediment. Although these alternatives do not include treatment, for informational purposes other technology components of these remedial alternatives that reduce mobility and/or exposure potential are summarized in Table 9-14.

9.7.5 Short-term Effectiveness

9.7.5.1 Community and Worker Protection

Appropriate planning and adherence to standard health and safety practices provide some protection to both workers and the community during the construction period. The construction period for Alternative 4R (13 years) is about twice that for Alternative 4C (7 years). Therefore, risks to workers and the community are assumed to be higher for Alternative 4R by a similar degree. Also, fish and shellfish tissue concentrations are predicted to remain elevated during the additional years of construction for Alternative 4R and for some time thereafter, resulting in increased seafood consumptions risks for that additional time.

Local transportation impacts (traffic, noise) from implementation of these alternatives are proportional to the number of truck/train miles (Alternative 4C: 475,000/126,000 and Alternative 4R: 779,000/206,000) estimated for support of material hauling operations (Appendix L). The particulate matter generated from all combustion activity (PM_{10}) is estimated to be 35 and 56 metric tons for Alternative 4C and Alternative 4R respectively (Appendix L).

9.7.5.2 Environmental Impacts

Resuspension of contaminated sediment is inevitable during environmental dredging operations and would be managed as described for Alternative 2 (see Section 9.5.5.2). The dredged areas (and volumes) of Alternatives 4C and 4R differ by a factor of about 2 (Table 9-14). Thus, Alternative 4R would generate approximately twice the amount of dredge residuals as Alternative 4C.

For Alternative 4C, approximately 42 acres of intertidal and shallow subtidal habitat areas (i.e., above -10 ft MLLW) are actively remediated (Table 9-14). Another 31 acres above -10 ft MLLW are left undisturbed and are monitored for natural recovery. The alternative consumes regional resources primarily in the form of quarry material (sand, gravel, and rock) and landfill space. An estimated 510,000 cy of imported granular material is used for capping, ENR, management of dredge residuals, habitat restoration, and backfilling of dredged areas where restoration to original grade is assumed. The landfill capacity consumed by this alternative is proportional to the volume of material removed and disposed of in the landfill (890,000 cy).

For Alternative 4R, approximately 42 acres of intertidal and shallow subtidal habitat area (i.e., above -10 ft MLLW) are actively remediated (Table 9-14). Another 31 acres above -10 ft MLLW are left undisturbed and monitored for natural recovery. An estimated 410,000 cy of imported granular material is used for capping, management of dredge residuals, habitat restoration, and backfilling of dredged areas where restoration to grade is assumed. The landfill capacity consumed by the alternative is proportional to the volume of dredged material removed and disposed of in the landfill (1,500,000 cy).

Estimates of air-borne gas emissions associated with Alternative 4C are presented in Appendix L. Implementation of this alternative would result in approximately 34,000 tons of CO_2 emitted to the atmosphere. These emissions are primarily the result of using fossil fuels for activities such as dredging and transportation. Alternative 4R has estimated CO_2 emissions of 52,000 metric tons. As described for Alternative 2R, limited reductions in the carbon footprint of less than 10% are possible through the use of BMPs for both alternatives.

9.7.5.3 Time to Achieve RAOs

Alternatives 4C and 4R are estimated to take 7 and 13 years to construct and thus have implementation periods of 12 and 18 years. Predicted times to achieve RAOs are reported in the lower Panel of Table 9-14. In summary, RAOs 2, 3, and 4 are achieved before (e.g., RAO 2) or immediately after implementation is complete. Given the inability of any remedial alternative to reach the PRG for the seafood consumption scenario (RAO 1), the minimum expectation is that immediately after implementation is complete, the Adult Tribal RME seafood consumption risk is reduced to the lowest magnitude achievable in the long term (i.e., 10^{-4} to 10^{-5}) and institutional controls are in place to reduce exposures. After approximately 22 and 18 years for Alternatives 4C and

4R, respectively, all four risk drivers are predicted to reach long-term model-predicted concentration ranges site-wide, achieving some incremental seafood consumption risk reduction. Continued use of institutional controls is necessary to reduce exposure. The time to reach long-term surface sediment concentration predictions is subject to uncertainties largely associated with source control in the LDW, Green/Duwamish River, and natural recovery beyond the project implementation period.

9.7.6 Implementability

Alternatives 4C and 4R have construction periods of 7 and 13 years, respectively, actively remediate 114 acres, and are administratively implementable. Alternative 4R dredges approximately twice the area and sediment volume than Alternative 4C, has a longer construction period, and therefore is subject to more technical or administrative delays. The potential for recontamination above RALs is considered low. Alternatives 4C and 4R rely on some natural recovery to achieve all RAOs. All of the natural recovery occurs in areas designated as Recovery Categories 2 and 3, which are less vulnerable to re-exposure of subsurface contaminated sediment. For this reason, no additional actions need to be assumed for these alternatives to indicate inadequate performance in achieving all RAOs.

9.7.7 Cost

Total present value costs for Alternatives 4C and 4R are $290 million and $440 million, respectively (see Appendix I for details). OM&M costs for both are approximately $22 and $20 million, respectively. The sensitivity of cost to key factors (e.g., dredge volume) resulted in a range of estimates from of $210 to $410 million for Alternative 4C and $350 to $630 million for Alternative 4R.

9.7.8 State, Tribal, and Community Acceptance

See Section 9.1.3.

9.8 Detailed Analysis of Alternative 5: Combined, Removal and Removal with Treatment

Scope, performance, and cost summaries for Alternatives 5C, 5R, and 5R-Treatment are presented in Table 9-16.

9.8.1 Overall Protection of Human Health and the Environment

The technology application areas and dredge removal volumes presented in Table 9-16 illustrate the physical extent to which these alternatives rely on engineering controls and to reduce risk. Alternative 5C emphasizes a combination of active remedial technologies: dredging with upland disposal, capping, and ENR, where appropriate. Alternative 5R emphasizes removal and upland disposal of sediment from the actively remediated areas. Alternative 5R-Treatment applies soil washing treatment to a portion of the dredged material. All three alternatives have the same active remedial footprint. These alternatives do not employ MNR, but nevertheless, they rely on source control and natural recovery

after construction outside of the AOPC footprint to achieve long-term model-predicted concentration ranges. The construction periods for Alternatives 5C and 5R/5R-Treatment are estimated at 8 and 19 years, respectively.

Alternatives 5C, 5R, and 5R-Treatment are predicted to achieve all four RAOs. Soil washing (Alternative 5R-Treatment) does not provide additional overall protection to human health and environment than that which can be achieved by Alternative 5R. Residual risks from surface sediment are predicted to be the same for these alternatives as discussed below in Section 9.8.3. Estimated times to achieve the RAOs (from issuance of final decision documents) are shown in the lower panel of Table 9-16. Both the implementation period and the predicted time to achieve long-term modeled concentration ranges for risk drivers are considered.

The potential for re-exposure of subsurface contaminated sediment following active remediation is primarily from areas managed by ENR. Alternative 5C remediates 50 acres with ENR. All of these areas are located in Recovery Categories 2 and 3 (Table 9-17). Alternatives 5R and 5R-Treatment do not employ ENR.

Risks to workers and the community from the general physical hazards of construction, noise, particulate emissions, and elevated fish and shellfish tissue concentrations are higher for Alternatives 5R and 5R-Treatment. The long construction periods and large areas of disturbance (especially above -10 ft MLLW) associated with these alternatives lead to significant ecological impacts to intertidal and shallow subtidal habitat areas and environmental impacts from emissions and resource consumption. Institutional controls are required to protect consumers of resident LDW seafood during construction.

Long-term monitoring, maintenance, and institutional controls are required and are considered reliable for these alternatives. The level of effort associated with these activities is expected to be lower for Alternative 5R (5R-Treatment) because it has only 12 acres of capping and no ENR as compared to 103 acres of capping and ENR combined for Alternative 5C.

9.8.2 Compliance with ARARs

Alternatives 5C, 5R, and 5R-Treatment have the same limitations as Alternatives 2R, 3C, 3R, 4C, and 4R for achieving the total PCB and dioxin/furan PRGs based on natural background, surface water quality ARARs, and the beach play direct contact PRG for cPAHs (see Sections 9.5.2, 9.6.2, and 9.7.2).

The level of performance achieved by Alternatives 5C, 5R, and 5R-Treatment is considered, for FS evaluation purposes, to be sufficient for achieving RAO 3. The percentage of SMS stations in the FS dataset predicted to be below the SQS and the percentage of LDW area predicted to be below the SQS at the completion of construction are both above the thresholds established in this FS for demonstrating compliance (see Table 9-2b).

9.8.3 Long-term Effectiveness and Permanence

9.8.3.1 Magnitude and Type of Residual Risk

Once RAOs are achieved by Alternatives 5C, 5R, and 5R-Treatment, the types of residual risks from surface sediment are predicted to be the same as discussed previously for Alternative 2R (Section 9.5.3.1).

Alternatives 5C and 5R (5R-Treatment) actively remediate the same 157 acres of the site. Alternatives 5R and 5R-Treatment leave less subsurface contaminated sediment in place than Alternative 5C because of their greater reliance on dredging; 145 acres versus 54 acres for Alternative 5C (Table 9-16). However, the potential for re-exposure in areas that are either capped outright or are partially dredged and capped is considered low (53 acres for Alternative 5C and 12 acres for Alternatives 5R and 5R-Treatment). Greater re-exposure potential derives from the 50 acres that are remediated by ENR under Alternative 5C.

For reference, Table 9-17 summarizes the non-dredging technology application areas by recovery category and also tallies the associated FS dataset cores remaining in place. Under Alternative 5C, ENR is applied only in Recovery Category 2 and 3 areas where re-exposure potential is lower. Alternative 5C leaves 16 core stations in place within the ENR footprint that exceed the CSL.

9.8.3.2 Adequacy and Reliability of Controls

Alternatives 5R and 5R-Treatment dredges almost three times the area as Alternative 5C, thereby requiring a proportionately larger effort to manage dredge residuals (Table 9-16). Alternative 5C has a broader scope and a substantially higher long-term monitoring and maintenance requirements compared to Alternatives 5R and 5R-Treatment, based on the aggregate surface areas remediated by capping and ENR (103 acres for Alternative 5C and 12 acres for Alternatives 5R and 5R-Treatment).[27] The potential for caps needing to be replaced in the future is considered to be low because of the engineering involved in location-specific design. The ENR component of Alternative 5C has the potential of requiring dredging based on monitoring data showing unacceptable performance. ENR is not used for any areas that are in Recovery Category 1 (Table 9-17).[28] In the long term, the effectiveness of source control for the LDW and inputs from the Green/Duwamish River are the primary factors governing surface sediment concentrations.

Alternatives 5C, 5R, and 5R-Treatment require an Institutional Controls plan consisting primarily because: 1) the PRGs for RAO 1 cannot be achieved, and 2) subsurface contaminated sediment above protective levels remains in place (Section 9.8.3.1). The institutional controls plan consists of:

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[27] Alternatives 5C, 5R, and 5R-Treatment do not remediate any area by MNR.

[28] 15% percent of the total ENR area of Alternative 5C (approximately 8 acres) is assumed to require dredging based on O&M monitoring results.

- Seafood consumption advisories, public outreach, and education.
- Monitoring of in-water construction permit applications, waterway uses, and notification of waterway users (Alternative 5C only).
- Restrictive covenants for areas with residual contamination above protective levels.

Monitoring of in-water construction permit applications, waterway use, and notification of waterway users may not be needed for Alternatives 5R and 5R-Treatment or at least can be assumed of much reduced scope because no cores with subsurface contamination remain following completion of construction. For the same reason, the number of restrictive covenants needed for Alternatives 5R and 5R-Treatment is relatively small in keeping with the small area (12 acres) that uses partial dredge and cap.

The combination of monitoring, maintenance, and institutional controls, formal 5-year reviews, and contingency actions (if required), is considered adequate for ensuring remedy integrity. As a whole, these devices will enable the remedial alternatives to be adaptively managed, as needed, based on new information.

9.8.4 Reductions in Toxicity, Mobility, or Volume through Treatment

Neither Alternatives 5C nor Alternative 5R treat contaminated sediment. Although these alternatives do not include treatment, for informational purposes other technology components of these remedial alternatives that reduce the mobility and/or exposure potential of contaminated sediments in the LDW are summarized in Table 9-16.

Alternative 5R-Treatment includes soil washing as a treatment component. Half of the estimated 1,500,000 cy of dredged sediment is expected to have sufficiently high sand content to warrant soil washing; hence, 750,000 cy would be taken to a soil washing facility for treatment. Assuming that only the sand portion of the sediment is recoverable and all other sediment would need to be disposed of in a Subtitle C or D landfill, it is estimated that approximately 375,000 cy of sediment would be potentially available for beneficial reuse.[29] The remaining 375,000 cy of fine-grained material would be disposed of in a regional landfill, along with the estimated 750,000 cy of sediment not suitable for treatment because it has too high a fine fractions for effective soil-washing. In summary, treatment by soil washing has the potential to decrease the volume of material requiring landfill disposal by roughly 375,000 cy if a viable reuse option can be identified. In addition, the treatment process generates and additional waste stream from process water that, while treated, releases large quantities of trace concentrations of dissolved contaminants back into the LDW. This treatment therefore increases the toxicity or mobility of contaminants.

[29] As discussed in Section 9.8.5, implementability concerns may limit the ability to reuse the cleaner sands, which could lead to the need for disposal of the cleaner sands in a landfill.

9.8.5 Short-term Effectiveness

9.8.5.1 Community and Worker Protection

Appropriate planning and adherence to standard health and safety practices provide some protection to both workers and the community during the construction period. The construction period of Alternatives 5R and 5R-Treatment (19 years) is more than twice that for Alternative 5C (8 years). Therefore, risks to workers and the community are assumed to be higher for Alternatives 5R/5R-Treatment by a similar degree. Also, fish and shellfish tissue concentrations are predicted to remain elevated during the additional years of construction for Alternatives 5R/5R-Treatment and for some time thereafter, resulting in increased seafood consumption risks for that additional time. Local transportation impacts (traffic, noise) from implementation of these alternatives are proportional to the number of truck/train miles (Alternative 5C: 498,000/132,000, Alternative 5R: 987,000/262,000, and Alternative 5R-Treatment: 741,000/196,000) estimated for support of material hauling operations (Appendix L). The particulate matter generated from all combustion activity (PM_{10}) is estimated to be 37, 73, and 65 metric tons for Alternatives 5C, 5R, and 5R-Treatment, respectively (Appendix L).

9.8.5.2 Environmental Impacts

Resuspension of contaminated sediment is inevitable during environmental dredging operations and would be managed as described for Alternative 2 (see Section 9.5.5.2). The dredged areas (and volumes) of Alternatives 5C and 5R/5R-Treatment differ by a factor of about 3 (Table 9-16). Thus, Alternatives 5R and 5R-Treatment would generate approximately three times the amount of dredge residuals as Alternative 5C.

For Alternative 5C, approximately 59 acres of intertidal and shallow subtidal habitat areas (i.e., above -10 ft MLLW) are actively remediated (Table 9-16). Another 14 acres above -10 ft MLLW are left undisturbed. The alternative consumes regional resources primarily in the form of quarry material (sand, gravel, and rock) and landfill space. An estimated 620,000 cy of imported granular material is used for capping, ENR, management of dredge residuals, habitat restoration, and backfilling of dredged areas where restoration to original grade is assumed. The landfill capacity consumed by this alternative is proportional to the volume of material removed and disposed of in the landfill (930,000 cy).

For both Alternatives 5R and 5R-Treatment, approximately 59 acres of intertidal and shallow subtidal habitat areas (i.e., above -10 ft MLLW) are actively remediated (Table 9-16). An estimated 550,000 cy of imported granular material are used for capping and backfilling of dredged areas where return to grade is assumed. The landfill capacity consumed by the alternative is proportional to the volume of dredged material removed and disposed of in the landfill (1,800,000 and 1,400,000 cy for Alternatives 5R and 5R-Treatment, respectively).

Estimates of air-borne gas emissions associated with Alternative 5C are presented in Appendix L. Implementation of this alternative would result in approximately 37,000 metric tons of CO_2 emitted to the atmosphere. These emissions are primarily the result of using fossil fuels for activities such as dredging and transportation. Alternatives 5R and 5R-Treatment have estimated CO_2 emissions of 66,000 and 54,000 metric tons, respectively. As described for Alternative 2R, limited reductions in the carbon footprint are possible through the use of BMPs for these alternatives.

9.8.5.3 Time to Achieve RAOs

Alternatives 5C and 5R/5R-Treatment are estimated to take 8 and 19 years to construct and thus have an implementation period of 13 and 24 years. Predicted times to achieve RAOs are reported in the lower panel of Table 9-16. In summary, RAOs 2, 3, and 4 are achieved before (RAO 2) or immediately after implementation is complete. Given the inability of any remedial alternative to reach the PRG for the seafood consumption scenario (RAO 1), the minimum expectation is that immediately after implementation is complete, the Adult Tribal RME seafood consumption risk is reduced to the lowest magnitude achievable in the long term (i.e., 10^{-4} to 10^{-5}) and institutional controls are in place to reduce exposures. After approximately 18 and 24 years for Alternatives 5C and 5R/5R-Treatment, respectively, all four risk drivers reach long-term model-predicted concentration ranges site-wide, achieving some incremental seafood consumption risk reduction. Continued use of institutional controls is necessary to reduce exposure. The time to reach long-term surface sediment concentration predictions is subject to uncertainties largely associated with source control in the LDW, Green/Duwamish River, and natural recovery beyond the project implementation period.

9.8.6 Implementability

Alternatives 5C and 5R have construction periods of 8 and 19 years, respectively, actively remediate 157 acres, and are administratively implementable. Alternative 5R-Treatment poses challenges related to locating, permitting, and operating the soil washing facility. In addition, there are administrative implementability concerns associated with finding an acceptable beneficial re-use of the treated sand fraction. Alternatives 5R and 5R-Treatment dredge approximately twice the area and sediment volume as Alternative 5C, have a longer construction period, and therefore are subject to more technical or administrative delays. The longer construction periods, larger and more complex project scopes, and potential for low RALs triggering significant additional actions because of recontamination, are important implementability considerations for these alternatives. Alternative 5C is more flexible in the use of technologies, in that it utilizes ENR to remediate 50 acres. The latter aspect makes Alternative 5C somewhat more susceptible to contingency actions should ENR not perform adequately.

9.8.7 Cost

Total present value costs for Alternatives 5C, 5R and 5R-Treatment are $310 million, $550 million, and $600 million respectively (see Appendix I for details). OM&M costs for all three are approximately $20 million (Alternative 5C) and $17 million (Alternatives 5R and 5R-Treatment). The sensitivity of cost to key factors (e.g., dredge volume) resulted in a range of estimates from of:

- 5C – $230 to $450 million
- 5R – $460 to $800 million
- 5R-Treatment - $500 to $940 million,

9.8.8 State, Tribal, and Community Acceptance

See Section 9.1.3.

9.9 Detailed Analysis of Alternative 6: Combined and Removal

Scope, performance, and cost summaries for Alternatives 6C and 6R are presented in Table 9-18.

9.9.1 Overall Protection of Human Health and the Environment

The technology application areas and dredge removal volumes presented in Table 9-18 illustrate the physical extent to which these alternatives rely on engineering controls and natural recovery to reduce risk. Alternative 6C emphasizes a combination of active remedial technologies—dredging with upland disposal, capping, and ENR, where appropriate. Alternative 6R emphasizes removal and upland disposal of sediment from the actively remediated areas. Both alternatives have the same active remedial footprint. None of these alternatives employ MNR but nevertheless rely on source control to preserve risk reductions achieved by construction. The alternatives have estimated construction periods of 18 and 38 years, respectively.

Alternatives 6C and 6R are predicted to achieve all four RAOs. Residual risks from surface sediment are predicted to be the same for both alternatives as discussed below in Section 9.9.3. Estimated times to achieve the RAOs (from issuance of final decision documents) are shown in the lower panel of Table 9-18. Both the implementation period and the predicted time to achieve long-term modeled concentration ranges for risk drivers are considered.

The potential for re-exposure of subsurface contaminated sediment following active remediation is primarily from areas managed by ENR (neither alternative uses MNR). Alternative 6C uses ENR to remediate 47 acres in AOPC 1 and 45 acres in AOPC 2, all of which are located in Recovery Categories 2 and 3 (Table 9-19). Alternative 6R does not employ ENR.

Risks to workers and the community from the general physical hazards of construction, noise, particulate emissions, and elevated fish and shellfish tissue concentrations are higher for Alternative 6R. The long construction period and large areas of disturbance (especially above -10 MLLW) lead to significant ecological impacts to intertidal and shallow subtidal habitat areas and environmental impacts from emissions and resource consumption. Institutional controls are required to protect consumers of resident LDW seafood during construction.

Long-term monitoring, maintenance, and institutional controls are required and are considered to be reliable for both alternatives. The level of effort associated with these activities is lower for Alternative 6R because of the low RALs, reliance on removal, and there being only 28 acres of capped surface area to manage. Alternative 6C has 193 acres of surface that are either capped or that undergo remediation by ENR.

9.9.2 Compliance with ARARs

Alternatives 6C and 6R have the same limitations as Alternatives 2R through 5R for achieving the total PCB and dioxin/furan PRGs based on natural background, surface water quality ARARs, and the beach play direct contact PRG for cPAHs (see Sections 9.5.2, 9.6.2, 9.7.2, and 9.8.2).

The percentage of SMS stations in the FS dataset predicted to be below the SQS and the percentage of the LDW area predicted to be below the SQS at the completion of construction are both above the thresholds established in this FS for demonstrating compliance (see Table 9-2b).

9.9.3 Long-term Effectiveness and Permanence

9.9.3.1 Magnitude and Type of Residual Risk

Once RAOs are achieved by Alternatives 6C and 6R, the types of residual risks from surface sediment are predicted to be the same as discussed previously for Alternative 2R (Section 9.5.3.1).

As discussed in Section 9.1.2.1, another type of residual risk following achievement of RAOs derives from the potential for re-exposure of remaining subsurface sediments that contain COCs above protective levels. For reference, Table 9-19 summarizes the technology application areas and remaining FS dataset cores. Alternatives 6C and 6R actively remediate the same 299 acres of the site. The greater potential for re-exposure is from the area that is either capped outright or partially dredged and capped (101 acres for Alternative 6C and 28 acres for Alternative 6R), but Alternative 6C manages an additional 92 acres by ENR. Table 9-19 shows the allocation of these areas by recovery category and also tallies the associated FS dataset cores remaining. Under Alternative 6C, all of the area managed by ENR is located in Recovery Categories 2 and 3. Alternative 6C leaves 7 core stations in place within ENR areas that exceed the CSL at depth, located outside of the dredged and capped areas. These cores did not have CSL exceedances at the surface and

are not located in potential scour areas. Alternative 6R does not leave any cores (>SQS) behind. In the case of Alternative 6C, the 7 cores are in Recovery Categories 2 and 3.

9.9.3.2 Adequacy and Reliability of Controls

Alternative 6R dredges more than twice the area of Alternative 6C, thereby requiring a proportionately larger effort to manage dredge residuals (Table 9-18). Alternative 6C has a broader scope and a substantially higher long-term monitoring and maintenance requirements compared to Alternative 6R, based on the aggregate surface areas remediated by capping and ENR (193 acres for Alternative 6C and 28 acres for Alternative 6R).[30] The potential for caps needing to be replaced in the future is considered to be low because of the engineering involved in location-specific design. The ENR component of Alternative 6C has the potential of requiring dredging based on monitoring data showing unacceptable performance. The areas managed by ENR are located in Recovery Categories 2 and 3; none are located in potential scour areas (Table 9-19).[31] In the long term, the effectiveness of source control for the LDW and inputs from the Green/Duwamish River are the primary factors governing surface sediment concentrations.

Alternatives 6C and 6R require an Institutional Controls plan because the PRGs for RAO 1 cannot be achieved. The Institutional Controls plan consists of:

- Seafood consumption advisories, public outreach, and education (both alternatives)
- Monitoring of in-water construction permit applications, waterway uses, and notification of waterway users (only for Alternative 6C, as Alternative 6R leaves no cores behind with subsurface contamination following completion of construction)
- Restrictive covenants for areas with residual contamination above protective levels (both alternatives).

The combination of monitoring, maintenance, and institutional controls, formal 5-year reviews, and contingency actions (if required), is considered adequate for ensuring remedy integrity. As a whole, these devices will enable the remedial alternatives to be adaptively managed, as needed, based on new information.

9.9.4 Reductions in Toxicity, Mobility, or Volume through Treatment

Neither Alternative 6C nor Alternative 6R treat contaminated sediment. Although these alternatives do not include treatment, for informational purposes other technology

[30] Alternatives 6C and 6R do not remediate any area by MNR.

[31] 15% percent of the total ENR area of Alternative 6C (approximately 14 acres) are assumed to require dredging based on O&M monitoring results.

components of these remedial alternatives that reduce the mobility and/or exposure potential of contaminated sediments in the LDW are summarized in Table 9-18.

9.9.5 Short-term Effectiveness

9.9.5.1 Community and Worker Protection

Appropriate planning and adherence to standard health and safety practices provide some protection to both workers and the community during the construction period. The construction period of Alternative 6R (38 years) is more than twice that for Alternative 6C (18 years). Therefore, risks to workers and the community are assumed to be higher for Alternative 6R by a similar degree. Also, fish and shellfish tissue concentrations are predicted to remain elevated during the additional years of construction for Alternative 6R and for some time thereafter, resulting in increased seafood consumption risks for that additional time.

Local transportation impacts (traffic, noise) from implementation of these alternatives are proportional to the number of truck/train miles (Alternative 6C: 1,086,000/288,000 and Alternative 6R: 2,322,000/616,000) estimated for support of material hauling operations (Appendix L). Also, approximately 84 and 168 metric tons of particulate matter, as PM_{10}, are predicted to be emitted by the two alternatives.

9.9.5.2 Environmental Impacts

Resuspension of contaminated sediment is inevitable during environmental dredging operations and would be managed as described for Alternative 2 (see Section 9.5.5.2). The dredged areas (and volumes) of Alternatives 6C and 6R differ by more than a factor 2 (Table 9-18). Thus, Alternative 6R would generate approximately twice the amount of dredge residuals as Alternative 6C.

For Alternative 6C**,** approximately 98 acres of intertidal and shallow subtidalhabitat areas (i.e., above -10 ft MLLW) are actively remediated (Table 9-18). No areas above -10 ft MLLW are passively remediated. The alternative consumes regional resources primarily in the form of quarry material (sand, gravel, and rock) and landfill space. An estimated 1,200,000 cy of imported granular material are used for capping, ENR, management of dredge residuals, habitat restoration, and backfilling of dredged areas where restoration to original grade is assumed. The landfill capacity consumed by this alternative is proportional to the volume of material removed and disposed of in the landfill (2,000,000 cy).

For Alternative 6R, approximately 98 acres of intertidal and shallow subtidal habitat area (i.e., above -10 ft MLLW) are actively remediated (Table 9-18). No areas above -10 ft MLLW are passively remediated. An estimated 1,100,000 cy of imported granular material are used for capping, management of dredge residuals, habitat restoration, and backfilling of dredged areas where restoration to grade is assumed. The landfill capacity

consumed by the alternative is proportional to the volume of dredged material removed and disposed of in the landfill (4,300,000 cy).

Estimates of air-borne gas emissions associated with Alternative 6C are presented in Appendix L. Implementation of this alternative would result in approximately 78,000 tons of CO_2 emitted to the atmosphere. These emissions are primarily the result of using fossil fuels for activities such as dredging and transportation. Alternative 6R has estimated CO_2 emissions of 153,000 tons. As described for Alternative 2R, only small reductions in the carbon footprint are possible through the use of BMPs for these alternatives.

9.9.6 Time to Achieve RAOs

Alternatives 6C and 6R are estimated to take 18 and 38 years to construct and thus have an implementation period of 23 and 43 years, respectively. Predicted times to achieve RAOs are reported in the lower panel of Table 9-18. In summary, RAOs 2, 3, and 4 are achieved before (RAO 2) or immediately after implementation is complete. Given the inability of any remedial alternative to reach the PRG for the seafood consumption scenario (RAO 1), the minimum expectation is that immediately after implementation is complete, the Adult Tribal RME seafood consumption risk is reduced to the lowest magnitude achievable in the long term (i.e., 10^{-4} to 10^{-5}) and institutional controls are in place to reduce exposures. After implementation the concentration of all four risk drivers are, by definition, consistent with long-term model-predicted concentrations site-wide. Beyond implementation, long-term surface sediment concentrations are subject to uncertainties largely associated with source control in the LDW and Green/Duwamish River.

9.9.7 Implementability

Alternatives 6C and 6R have construction periods of 18 and 38 years, respectively, actively remediate 299 acres, and are administratively implementable. Alternative 6R dredges more than twice the area and sediment volume as Alternative 6C, has a much longer construction period, and therefore has a higher potential for technical or administrative delays. Alternative 6C is more flexible in the use of technologies, in that it utilizes ENR. The latter aspect makes Alternative 6C somewhat more susceptible to contingency actions should ENR not perform adequately.

The much longer construction periods, larger and more complex project scopes, and potential for low RALs triggering significant additional actions from recontamination, are important implementability considerations for these alternatives.

9.9.8 Cost

Total present value costs for Alternatives 6C and 6R are $650 million and $1,300 million respectively (see Appendix I for details). OM&M costs are approximately $26 million for Alternative 6C and are $20 million for Alternative 6R. The sensitivity of cost to key factors

(e.g., dredge volume) resulted in a range of estimates from of $450 to $820 million for Alternative 6C and $970 to $1,500 million for Alternative 6R.

9.9.9 State, Tribal, and Community Acceptance

See Section 9.1.3.

9.10 Summary of the Detailed Analysis of Remedial Alternatives

Table 9-20 presents a summary of the expected long-term model-predicted outcomes of the remedial alternatives for RAOs 1, 2, 3, and 4. Except for Alternative 1, the remedial alternatives satisfy the threshold criteria of protecting human health and the environment and complying with ARARs. Alternatives 2 through 6 eventually reach the same outcomes but vary significantly in the time required to achieve the RAOs.

The information presented in this section serves as the basis for a comparative evaluation of the remedial alternatives presented in Section 10.

9.11 Managing COCs Other Than the Risk Drivers

In addition to the risk-driver chemicals, additional COCs were identified in both the human health and ecological risk assessments (Table 3-9) (Windward 2007a and 2007b). As summarized in Section 3, COCs were defined as detected chemicals with hazard quotients greater than one (for the risk assessments) or excess cancer risk estimates greater than 1×10^{-6} (for human health). The risks associated with these other COCs were very small compared to the risks associated with the risk-driver chemicals. This section evaluates how concentrations of these other COCs would change following implementation of the various remedial alternatives and how these changes would achieve the applicable RAOs.

9.11.1 Human Health

In addition to the four human health risk-driver chemicals, 3 semivolatile organic compounds (SVOCs), 2 metals, and 10 organochlorine pesticides were identified as COCs for human health seafood consumption scenarios in the RI (Windward 2010). These COCs were not designated as risk drivers for establishing PRGs in the FS because of their limited contribution to overall risk and because of uncertainties associated with the risk estimates for these chemicals (see Section 3). Table 9-21 summarizes the estimated risks associated with these COCs and the expected management of these risks through sediment remediation. In general, these chemicals are not expected to pose significant residual human health risks after remediation of LDW sediments primarily because: 1) detection frequencies in either sediment or tissue were low (e.g., <5%); 2) baseline cumulative risk is within the EPA target risk range and is not expected to increase when these individual chemical risks are added; or 3) baseline concentrations are close to background.

The three SVOC COCs not designated as risk drivers are bis(2-ethylhexyl)phthalate (BEHP), pentachlorophenol, and carbazole. BEHP was rarely detected in tissues and generally had low concentrations when detected. This chemical will be reduced in sediment largely as a result of source control and removal of hot spots identified for remediation by the Alternative 2 RALs. Further, BEHP is an SMS chemical and Alternatives 2 through 6 are designed to comply with the SMS. Pentachlorophenol was rarely detected in LDW tissue samples. Re-analyses of tissue samples suggest that the initial analyses were biased high and pentachlorophenol may not have been present. Risks from carbozole are within the EPA target risk range.

The two metal COCs not designated as risk drivers are vanadium and tributyltin (TBT) (an organometal). Vanadium concentrations in LDW sediment are consistent with natural background and therefore sediment remediation is not likely to reduce concentrations in the long term. Risk estimates for TBT were driven primarily by concentrations in clams. Several clam sampling locations will be remediated as part of completing the EAAs (Alternative 1), which may reduce TBT concentrations in clams. Finally, TBT discharges to LDW sediments peaked in the 1970s and 1980s and current industrial uses are strictly controlled. Concentrations of this compound are expected to decline as a result of natural recovery processes.

Ten organochlorine pesticides (i.e., dichlorodiphenyl-trichloroethanes [DDTs], aldrin, alpha-benzene hexachloride (alpha-BHC), beta-BHC, total chlordane, dieldrin, gamma-BHC, heptachlor, heptachlor epoxide, and hexachlorobenzene) were COCs for seafood consumption scenarios. Most of the organochlorine pesticides had low detection frequencies in sediment and tissue from the LDW (Table 9-21). Also, many of the sample results for these compounds had high reporting limits. As discussed in the RI, the high reporting limits are most likely attributable to analytical interference from PCB congeners.[32] The low level of detections, while not fully independent of the analytical issue described above, align with the similarly low detection frequencies reported throughout the Puget Sound region. Further, the existing conservatively estimated risks are all within the EPA target risk range of 10^{-4} to 10^{-6}. Remediation of the EAAs (Alternative 1) and hot spots (Alternative 2) are expected to effectively manage the majority of sample locations with detected levels of total chlordane, total DDTs, TBT, beta-BHC, and dieldrin. Finally, as with PCBs, many of the organochlorine pesticides have been banned from use and therefore are expected to decline due to natural recovery processes.

Toxaphene is the only other chemical that was identified in the RI (Windward 2010) as a COC for direct contact. It had a detection frequency in surface sediment of 1% (based on the RI baseline dataset) and an estimated risk of 6×10^{-6}, well within the EPA target risk

[32] A detailed discussion of PCB interference with quantitation of organochlorine pesticides is given in Section B.6.1.1.3 of the HHRA (Windward 2007a) and summarized here.

range. Both detected results (2 total) were JN-qualified (estimated concentration tentatively identified compound) because of analytical interference.

9.11.2 Ecological Health

In addition to the 41 SMS chemicals identified as risk-driver chemicals, nickel, total DDTs, and total chlordane were identified as COCs for benthic invertebrates. A majority of the detected values for these three COCs were located in EAAs and therefore will be managed under all alternatives (Table 9-22); hence, these chemicals are not considered to pose significant residual risks.

In addition to PCBs for river otter, several other COCs were identified in the RI for ecological receptors. These COCs were not designated as risk drivers for establishing PRGs in the FS because of uncertainties in exposure and effects data, based on comparisons to regional natural background concentrations in sediment, and based on the likely magnitude of residual risks following planned sediment remediation within EAAs in the LDW.

Table 9-22 summarizes the estimated risks associated with these COCs and the expected management of these risks through sediment remediation.

Many of the ecological COCs are metals (chromium, copper, lead, mercury, and vanadium) and present a risk to the spotted sandpiper in only specific sandpiper exposure areas. All lowest-observed-adverse-effect level (LOAEL)-based hazard quotients (HQs) for these metals were less than 2.0, except for a LOAEL-based HQ of 5.5 for lead in one area. The hazard quotients for several metals (copper, lead [one of two areas], and mercury) are expected to be reduced to less than 1.0 in these habitat areas as a result of completing the planned actions in the EAAs (Alternative 1). LOAEL-based HQs for cadmium and fish are also expected to be reduced to less than 1.0 as a result of Alternative 1. In the case of vanadium, existing concentrations are consistent with Puget Sound Ambient Monitoring Program rural Puget Sound background, and therefore sediment remediation is not likely to reduce concentrations in the long term.

Table 9-1 National Contingency Plan Evaluation Criteria for Detailed Analysis of LDW Remedial Alternatives

Criteria		FS Evaluation Factors
Threshold	1. Overall Protection of Human Health and the Environment	Controls used to reduce risks
		Effectiveness summary
	2. Compliance with ARARs	Location, chemistry, and action
Balancing	3. Long-Term Effectiveness and permanence	Magnitude and type of residual risk
		Adequacy and reliability of controls
	4. Reduction in Toxicity, Mobility, or Volume Through Treatment (applies only to Alternative 5R-Treatment)	Treatment process used
		Amount of hazardous material destroyed or treated
		Reduction in toxicity, mobility, or volume
		Treatment irreversibility
		Nature and quantity of post-treatment residuals
	5. Short-Term Effectiveness	Community protection
		Protection of workers
		Environmental impacts
		Time to achieve RAOs
	6. Implementability	Ability to construct and operate technology
		Reliability of the technology
		Ease of undertaking additional remedial actions
		Monitoring considerations
		Ability to coordinate and obtain approval from agencies
		Availability of transloading and offsite disposal services and capacity
		Availability of technology, equipment, and specialists
	7. Cost	Capital
		Operations, maintenance, and monitoring
		Total net present value
Modifying	8/9. State, Tribal, and Community Acceptance	Will be evaluated in the ROD following the public comment period on the RI/FS

Source: Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA, EPA 1988

Table 9-2a Effectiveness Evaluation – Predicted Post-Construction Arsenic, Total PCB, cPAH, and Dioxin/Furan Concentrations (SWACs)

Arsenic (mg/kg dw) (RAO 2)

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Implemen-tation Period (years)	Netfishing Direct Contact Baseline = 16 10^{-6} RBTC = 3.7 PRG = Background = 7.0 [a], 90th percentile = 11									Tribal Clamming Direct Contact Baseline = 13 10^{-6} RBTC = 1.3 PRG = Background = 7.0 [a], 90th percentile = 11									Beach Play Direct Contact Baseline = 15 10^{-6} RBTC = 2.8 PRG = Background = 7.0 [a], 90th percentile = 11								
				Time from Issuance of Remedy Decision Documents (years)									*Time from Issuance of Remedy Decision Documents (years)*									*Time from Issuance of Remedy Decision Documents (years)*								
				5 [b]	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [b]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [b]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
EAA-Alternative 1	29	<5	<5	16	12	11	10	10	9.7	9.7	9.5	9.5	13	11	11	11	11	11	11	10	10	15	12	11	11	10	10	10	10	10
Alternative 3C	86	4	9	16	10	9.7	9.4	9.3	9.2	9.2	9.2	9.1	13	9	9.3	9.2	9.2	9.2	9.2	9.2	9.2	15	10	9.4	9.3	9.2	9.2	9.2	9.2	9.2
Alternative 4C	143	7	12	16	10	9.6	9.3	9.2	9.2	9.2	9.1	9.1	13	10	9.3	9.3	9.2	9.2	9.2	9.2	9.2	15	10	9.4	9.3	9.2	9.2	9.2	9.2	9.2
Alternative 5C	186	8	13	16	10	9.6	9.3	9.2	9.2	9.2	9.2	9.1	13	10	9.4	9.3	9.3	9.2	9.2	9.2	9.2	15	10	9.5	9.3	9.3	9.2	9.2	9.2	9.2
Alternative 6C	328	18	23	16	10	9.6	9.3	9.1	9.1	9.1	9.1	9.1	13	10	9.4	9.3	9.2	9.2	9.2	9.1	9.2	15	10	9.5	9.3	9.2	9.2	9.2	9.2	9.2
Alternative 2R	59	4	9	16	10	9.8	9.4	9.3	9.2	9.2	9.2	9.2	13	9	9.3	9.3	9.2	9.2	9.2	9.2	9.2	15	10	9.5	9.3	9.3	9.2	9.2	9.2	9.2
Alternative 3R	86	6	11	16	10	9.7	9.4	9.3	9.2	9.2	9.2	9.1	13	9	9.3	9.2	9.2	9.2	9.2	9.2	9.2	15	10	9.4	9.3	9.2	9.2	9.2	9.2	9.2
Alternative 4R	143	13	18	16	10	9.7	9.4	9.3	9.2	9.2	9.2	9.1	13	9	9.3	9.3	9.2	9.2	9.2	9.2	9.2	15	10	9.4	9.3	9.3	9.2	9.2	9.2	9.2
Alternative 5R	186	19	24	16	10	9.7	9.4	9.3	9.2	9.2	9.2	9.2	13	9	9.3	9.3	9.3	9.3	9.2	9.2	9.2	15	10	9.4	9.3	9.3	9.3	9.2	9.2	9.2
Alternative 6R	328	38	43	16	10	9.7	9.4	9.3	9.2	9.2	9.1	9.1	13	9	9.3	9.3	9.3	9.2	9.2	9.2	9.2	15	10	9.4	9.3	9.3	9.2	9.2	9.2	9.2

Total PCBs (µg/kg dw)(RAOs 1, 2 and 4)

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Implemen-tation Period (years)	Site-wide Baseline = 346 Netfishing Direct Contact: PRG = 10^{-6} RBTC = 1,300 Seafood Consumption - Human: PRG = Background = 2 Seafood Consumption - Ecological (otter): PRG = 128 - 159									Tribal Clamming Direct Contact Baseline = 540 10^{-6} RBTC = 500 PRG = 500									Beach Play Direct Contact Baseline = 500 10^{-6} RBTC = 1,700 PRG = 1,700								
				Time from Issuance of Remedy Decision Documents (years)									*Time from Issuance of Remedy Decision Documents (years)*									*Time from Issuance of Remedy Decision Documents (years)*								
				5 [b]	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [b]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [b]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
EAA-Alternative 1	29	<5	<5	180	103	73	56	52	49	48	45	45	190	95	68	55	52	50	49	47	47	180	93	67	54	51	50	49	47	47
Alternative 3C	86	4	9	180	86	65	52	49	46	45	44	43	190	66	56	50	48	47	46	45	45	180	68	57	50	48	47	47	45	45
Alternative 4C	143	7	12	180	75	58	49	47	45	44	43	43	190	61	53	48	46	45	45	44	44	180	63	54	48	46	46	46	44	45
Alternative 5C	186	8	13	180	75	55	47	46	44	44	43	43	190	61	53	47	46	45	45	44	44	180	63	53	47	46	45	45	44	44
Alternative 6C	328	18	23	180	75	55	42	38	39	41	41	41	190	61	53	45	41	41	42	42	42	180	63	53	44	41	42	43	42	43
Alternative 2R	59	4	9	180	91	68	54	50	48	47	45	44	190	72	60	52	50	48	47	46	46	180	74	60	52	49	48	48	46	46
Alternative 3R	86	6	11	180	86	65	52	49	46	45	44	43	190	66	56	50	48	47	46	45	45	180	68	57	50	48	47	47	45	45
Alternative 4R	143	13	18	180	86	64	50	47	45	45	43	43	190	66	56	48	47	46	45	44	44	180	68	56	49	47	46	46	44	45
Alternative 5R	186	19	24	180	86	64	50	48	45	45	43	43	190	66	56	48	48	46	46	44	44	180	68	56	49	48	46	46	45	45
Alternative 6R	328	38	43	180	86	64	50	48	42	41	40	39	190	66	56	48	48	44	44	42	41	180	68	56	49	48	44	44	42	41

Table 9-2a Effectiveness Evaluation – Predicted Post-Construction Arsenic, Total PCB, cPAH, and Dioxin/Furan Concentrations (SWACs)

cPAHs (µg TEQ/kg dw) (RAO 2)

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Implemen-tation Period (years)	Netfishing Direct Contact Baseline = 390 10^{-6} RBTC = 380 PRG = 380									Tribal Clamming Direct Contact Baseline = 380 10^{-6} RBTC = 150 PRG = 150									Beach Play Direct Contact Baseline = 410 10^{-6} RBTC = 90 PRG = 90								
				Time from Issuance of Remedy Decision Documents (years)									*Time from Issuance of Remedy Decision Documents (years)*									*Time from Issuance of Remedy Decision Documents (years)*								
				5 [b]	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [b]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [b]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
EAA-Alternative 1	29	<5	<5	360	220	160	130	120	110	110	107	107	300	190	150	130	120	120	120	110	110	330	210	160	130	120	120	120	110	120
Alternative 3C	86	4	9	360	180	140	120	109	105	107	104	104	300	130	120	107	107	106	106	104	105	330	140	130	110	110	109	110	107	109
Alternative 4C	143	7	12	360	170	130	110	106	104	106	103	103	300	130	120	107	106	105	106	103	105	330	140	120	110	109	108	110	107	109
Alternative 5C	186	8	13	360	170	130	109	105	103	106	103	103	300	130	120	107	107	106	107	104	105	330	140	120	109	109	108	110	107	109
Alternative 6C	328	18	23	360	170	130	109	102	101	104	102	102	300	130	120	106	107	105	106	103	105	330	140	120	108	108	107	109	107	108
Alternative 2R	59	4	9	360	200	150	120	110	108	109	105	105	300	170	140	120	120	110	110	107	108	330	180	150	120	120	110	110	110	110
Alternative 3R	86	6	11	360	180	140	120	109	105	107	104	104	300	130	120	107	107	106	106	104	105	330	140	130	110	110	109	110	107	109
Alternative 4R	143	13	18	360	180	140	110	108	104	106	103	103	300	130	120	107	107	106	107	104	105	330	140	130	110	110	108	110	107	109
Alternative 5R	186	19	24	360	180	140	110	110	106	107	104	104	300	130	120	107	110	108	108	104	106	330	140	130	110	110	110	110	108	109
Alternative 6R	328	38	43	360	180	140	110	110	106	107	104	103	300	130	120	107	110	107	107	104	106	330	140	130	110	110	109	110	108	109

Dioxins/Furans (ng TEQ/kg dw) (RAOs 1 and 2)

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Implemen-tation Period (years)	Site-wide Baseline = 26 Netfishing Direct Contact: PRG = 10^{-6} RBTC = 37 Seafood Consumption - Human: PRG = Background = 2									Tribal Clamming Direct Contact Baseline = 32 10^{-6} RBTC = 13 PRG = 13									Beach Play Direct Contact Baseline = 29 10^{-6} RBTC = 28 PRG = 28								
				Time from Issuance of Remedy Decision Documents (years)									*Time from Issuance of Remedy Decision Documents (years)*									*Time from Issuance of Remedy Decision Documents (years)*								
				5 [b]	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [b]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [b]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
EAA-Alternative 1	29	<5	<5	24	13	7.9	5.5	4.9	4.6	4.6	4.5	4.4	30	15	8.5	5.6	4.9	4.6	4.6	4.5	4.4	27	13	8.1	5.5	4.9	4.7	4.6	4.5	4.5
Alternative 3C	86	4	9	24	5.9	5.2	4.7	4.5	4.5	4.5	4.4	4.4	30	5.4	5.0	4.6	4.5	4.4	4.4	4.4	4.4	27	5.3	5.0	4.6	4.5	4.4	4.4	4.4	4.4
Alternative 4C	143	7	12	24	5.3	4.9	4.5	4.4	4.4	4.4	4.4	4.4	30	5.3	4.9	4.5	4.4	4.4	4.4	4.4	4.4	27	5.2	4.9	4.5	4.5	4.4	4.4	4.4	4.4
Alternative 5C	186	8	13	24	5.3	4.6	4.4	4.4	4.4	4.4	4.4	4.4	30	5.3	4.7	4.4	4.4	4.4	4.4	4.3	4.4	27	5.2	4.6	4.4	4.4	4.4	4.4	4.4	4.4
Alternative 6C	328	18	23	24	5.3	4.6	4.3	4.3	4.3	4.4	4.3	4.4	30	5.3	4.7	4.4	4.3	4.3	4.3	4.3	4.3	27	5.2	4.6	4.4	4.3	4.3	4.4	4.4	4.4
Alternative 2R	59	4	9	24	6.1	5.3	4.7	4.6	4.5	4.5	4.4	4.4	30	5.7	5.2	4.7	4.5	4.5	4.4	4.4	4.4	27	5.7	5.2	4.7	4.6	4.5	4.5	4.4	4.4
Alternative 3R	86	6	11	24	5.9	5.2	4.7	4.5	4.5	4.5	4.4	4.4	30	5.4	5.0	4.6	4.5	4.4	4.4	4.4	4.4	27	5.3	5.0	4.6	4.5	4.4	4.4	4.4	4.4
Alternative 4R	143	13	18	24	5.9	5.1	4.5	4.4	4.4	4.4	4.4	4.4	30	5.4	5.0	4.5	4.4	4.4	4.4	4.4	4.4	27	5.3	4.9	4.5	4.5	4.4	4.4	4.4	4.4
Alternative 5R	186	19	24	24	5.9	5.1	4.5	4.4	4.4	4.4	4.4	4.4	30	5.4	5.0	4.5	4.4	4.3	4.4	4.3	4.4	27	5.3	4.9	4.5	4.4	4.4	4.4	4.4	4.4
Alternative 6R	328	38	43	24	5.9	5.1	4.5	4.4	4.3	4.4	4.3	4.3	30	5.4	5.0	4.5	4.4	4.3	4.3	4.3	4.3	27	5.3	4.9	4.5	4.4	4.3	4.4	4.4	4.4

Notes:

1. BCM predictions use base case STM outputs revised June 2010 (Appendix C).
2. Arsenic BCM inputs (mg/kg dw): upstream 9, lateral 13, and post-remedy bed sediment replacement value 10 (AOPC 1) and 9 (AOPC 2).
3. Total PCB BCM inputs (µg/kg dw): upstream 35, lateral 300, and post-remedy bed sediment replacement value 60 (AOPC 1) and 20 (AOPC 2).
4. cPAH BCM inputs (µg TEQ/kg dw): upstream 70, lateral 1,400, and post-remedy bed sediment replacement value 140 (AOPC 1) and 100 (AOPC 2).
5. Dioxin/furan BCM inputs (ng TEQ/kg dw): upstream 4, lateral 20, and post-remedy bed sediment replacement value 4 (AOPC 1).
6. BCM model area = 430 acres and FS study area = 441 acres

a Background value based on UCL95.

b This is the start of construction for Alternatives 2 through 6. The 5-year model-predicted intervals associated with the BCM SWAC output are indexed to issuance of remedy decision documents. Activities during the assumed 5-year period between signing of the documents and start of construction are completion of EAAs, priority source control, negotiations, and initial remedial design. Implementation period starts from the issuance of remedy decision documents through the end of construction.

End of construction period.

Acronyms

AOPC = area of potential concern
BCM = bed composition model
EAA = early action area
FS = feasibility study
PRG = preliminary remediation goal
RAO = remedial action objective
RBTC = risk-based threshold concentration
STM = sediment transport model
SWAC = spatially-weighted average concentration
TEQ = toxic equivalent

Table 9-2b Effectiveness Evaluation – Predicted Post-Construction Exceedances of SMS Criteria (CSL and SQS) (RAO 3)

Remaining CSL Chemistry Station Counts; Total Baseline Station Count = 1,395

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Implemen-tation Period (years)	Time from Issuance of Remedy Decision Documents (years)																					10 Years Following End of Construction		
				5 yr (Start of Construction)[a]			10 yr			15 yr			20 yr			25 yr			30 yr			35 yr					
				Number of Stations	% of Stations < CSL	% of Area < CSL	Number of Stations	% of Stations < CSL	% of Area < CSL	Number of Stations	% of Stations < CSL	% of Area < CSL	Number of Stations	% of Stations < CSL	% of Area < CSL	Number of Stations	% of Stations < CSL	% of Area < CSL	Number of Stations	% of Stations < CSL	% of Area < CSL	Number of Stations	% of Stations < CSL	% of Area < CSL	Number of Stations	% of Stations < CSL	% of Area < CSL
EAA-Alternative 1	29	<5	<5	65	95%	94%	34	98%	98%	24	98%	99%	11	99%	>99%	8	99%	>99%	10	99%	>99%	13	99%	>99%	24	98%	99%
Alternative 3C	86	4	9	65	95%	94%	7	99%	>99%	3	>99%	>99%	2	>99%	>99%	1	>99%	>99%	1	>99%	>99%	2	>99%	>99%	2	>99%	>99%
Alternative 4C	143	7	12	65	95%	94%	4	>99%	>99%	2	>99%	>99%	1	>99%	>99%	1	>99%	>99%	1	>99%	>99%	1	>99%	>99%	1	>99%	>99%
Alternative 5C	186	8	13	65	95%	94%	4	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%
Alternative 6C	328	18	23	65	95%	94%	4	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%
Alternative 2R	59	4	9	65	95%	94%	12	99%	>99%	8	99%	>99%	4	>99%	>99%	2	>99%	>99%	2	>99%	>99%	4	>99%	>99%	4	>99%	>99%
Alternative 3R	86	6	11	65	95%	94%	7	99%	>99%	3	>99%	>99%	2	>99%	>99%	1	>99%	>99%	1	>99%	>99%	2	>99%	>99%	2	>99%	>99%
Alternative 4R	143	13	18	65	95%	94%	7	99%	>99%	3	>99%	>99%	1	>99%	>99%	1	>99%	>99%	1	>99%	>99%	1	>99%	>99%	1	>99%	>99%
Alternative 5R	186	19	24	65	95%	94%	7	99%	>99%	3	>99%	>99%	1	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%
Alternative 6R	328	38	43	65	95%	94%	7	99%	>99%	3	>99%	>99%	1	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%

Remaining SQS Chemistry Station Counts; PRG = compliance with SQS; Total Baseline Station Count = 1,395

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Implemen-tation Period (years)	Time from Issuance of Remedy Decision Documents (years)																					10 Years Following End of Construction		
				5 yr (Start of Construction)[a]			10 yr			15 yr			20 yr			25 yr			30 yr			35 yr					
				Number of Stations	% of Stations < SQS	% of Area < SQS	Number of Stations	% of Stations < SQS	% of Area < SQS	Number of Stations	% of Stations < SQS	% of Area < SQS	Number of Stations	% of Stations < SQS	% of Area < SQS	Number of Stations	% of Stations < SQS	% of Area < SQS	Number of Stations	% of Stations < SQS	% of Area < SQS	Number of Stations	% of Stations < SQS	% of Area < SQS	Number of Stations	% of Stations < SQS	% of Area < SQS
EAA-Alternative 1	29	<5	<5	234	83%	82%	115	92%	91%	71	95%	96%	49	96%	97%	34	98%	98%	29	98%	99%	34	98%	99%	71	95%	96%
Alternative 3C	86	4	9	234	83%	82%	50	96%	95%	29	98%	98%	21	98%	99%	14	99%	99%	10	99%	>99%	11	99%	>99%	21	98%	99%
Alternative 4C	143	7	12	234	83%	82%	22	98%	98%	10	99%	99%	9	99%	99%	5	>99%	>99%	4	>99%	>99%	5	>99%	>99%	9	99%	99%
Alternative 5C	186	8	13	234	83%	82%	22	98%	98%	0	>99%	99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%
Alternative 6C	328	18	23	234	83%	82%	22	98%	98%	0	>99%	99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%
Alternative 2R	59	4	9	234	83%	82%	71	95%	94%	43	97%	97%	30	98%	98%	22	98%	99%	18	99%	99%	21	98%	99%	30	98%	98%
Alternative 3R	86	6	11	234	83%	82%	50	96%	95%	29	98%	98%	21	98%	99%	14	99%	99%	10	99%	>99%	11	99%	>99%	21	98%	99%
Alternative 4R	143	13	18	234	83%	82%	50	96%	95%	29	98%	98%	9	99%	99%	5	>99%	>99%	4	>99%	>99%	5	>99%	>99%	4	>99%	>99%
Alternative 5R	186	19	24	234	83%	82%	50	96%	95%	29	98%	98%	9	99%	99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%
Alternative 6R	328	38	43	234	83%	82%	50	96%	95%	29	98%	98%	9	99%	99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%

= Predicted percentage of baseline stations or LDW surface area below CSL or SQS is ≥ 98%

Notes:

1. FS study area = 441 acres. BCM model area = 430 acres
2. Chemical predictions use BCM input parameters for SMS chemicals described in Section 5.
3. Points falling within the actively remediated footprint of each remedial alternative are not counted after construction is completed for that alternative. However, recontamination potential analysis shows that 23 STM grid cells (out of >700) have the potential to recontaminate above the SQS for BEHP 10 years after remedy completion. These counts do not factor into that recontamination potential.
4. In some locations, the BCM predicts point concentrations above the SQS, but recent chemical data and trend analysis suggest sediment concentrations below the SQS. Therefore, the assignment of remedial technologies may not be consistent with BCM point-counts. This apparent discrepancy will be resolved during remedy implementation through design sampling, monitoring, and adaptive management.
5. Many of the predicted SQS exceedances remaining 10 years after construction of Alternative 3 (BCM Year 15) are located on the edges of areas to be actively remediated and will likely be re-characterized during remedial design sampling. Other locations are in areas expected to recover (based on other factors used to define the recovery categories) and were assigned to MNR during the BPJ assignments.
6. The % of LDW area below SMS criteria is calculated by dividing the polygon-derived areas associated with predicted exceedances by the total area of the LDW (441 acres).
7. The % of stations below SMS criteria is calculated by dividing the predicted number of station exceedances by the number of FS baseline stations (n = 1,395 points).
8. Estimated construction period for Alternative 6R is 38 years; results are only shown through 35 years.

a This is the start of construction for Alternatives 2 through 6. The 5-year model-predicted intervals are indexed to issuance of remedy decision documents. Activities during the assumed 5-year period between signing of the documents and start of construction are completion of EAAs, priority source control, negotiations, and initial remedial design. Implementation period starts from the issuance of remedy decision documents through the end of construction.

Acronyms

BCM = bed composition model
BEHP = bis 2-ethylhexyl phthalate
BPJ = best professional judgement
CSL = cleanup screening level
EAA = early action area
LDW = Lower Duwamish Waterway
MNR = monitored natural recovery
PRG = preliminary remediation goal
RAO = remedial action objective
RBTC = risk-based threshold concentration
SQS = sediment quality standard

Table 9-3 Effectiveness Evaluation – Predicted Post-Construction Risk Driver Concentrations (SWACs) at Individual Beaches

Arsenic (mg/kg dw), Beach Play Direct Contact, PRG = 7[a], 10^{-6} RBTC = 2.8

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Implemen-tation Period (years)	Beach 1 Baseline = 8.3									Beach 2 Baseline = 13									Beach 3 Baseline = 11								
				Time from Issuance of Remedy Decision Documents (years)									*Time from Issuance of Remedy Decision Documents (years)*									*Time from Issuance of Remedy Decision Documents (years)*								
				5[b]	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5[b]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5[b]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
EAA-Alternative 1	29	<5	<5	8.3	8.7	8.9	9.1	9.1	9.1	9.1	9.1	9.1	13	11	11	9.9	9.5	9.3	9.3	9.2	9.1	11	10	9.9	9.7	9.8	9.8	9.8	9.7	9.7
Alternative 3C	86	4	9	8.3	8.0	8.5	8.9	9.0	9.1	9.1	9.1	9.1	13	10	10	9.6	9.4	9.3	9.2	9.2	9.1	11	10	9.8	9.7	9.8	9.8	9.8	9.7	9.7
Alternative 4C	143	7	12	8.3	8.0	8.5	8.9	9.0	9.1	9.1	9.1	9.1	13	11	10	9.7	9.4	9.3	9.2	9.2	9.1	11	10	10	9.9	9.8	9.8	9.8	9.7	9.7
Alternative 5C	186	8	13	8.3	8.0	9.2	9.2	9.1	9.1	9.1	9.1	9.1	13	11	10	9.9	9.5	9.3	9.3	9.2	9.1	11	10	10	9.8	9.8	9.8	9.8	9.7	9.7
Alternative 6C	328	18	23	8.3	8.0	9.2	9.2	9.1	9.1	9.1	9.1	9.1	13	11	10	9.9	9.1	9.1	9.1	9.1	9.1	11	10	10	9.8	9.8	9.8	9.8	9.7	9.7
Alternative 2R	59	4	9	8.3	8.7	8.9	9.1	9.1	9.1	9.1	9.1	9.1	13	11	10	9.7	9.4	9.3	9.2	9.2	9.1	11	10	9.8	9.7	9.8	9.8	9.8	9.7	9.7
Alternative 3R	86	6	11	8.3	8.0	8.5	8.9	9.0	9.1	9.1	9.1	9.1	13	10	10	9.6	9.4	9.3	9.2	9.2	9.1	11	10	9.8	9.7	9.8	9.8	9.8	9.7	9.7
Alternative 4R	143	13	18	8.3	8.0	8.5	8.9	9.0	9.1	9.1	9.1	9.1	13	10	10	9.8	9.5	9.3	9.2	9.2	9.1	11	10	9.8	10	9.9	9.8	9.8	9.7	9.7
Alternative 5R	186	19	24	8.3	8.0	8.5	8.9	9.3	9.2	9.2	9.2	9.2	13	10	10	9.8	9.7	9.4	9.3	9.2	9.2	11	10	9.8	10	10	9.9	9.9	9.7	9.7
Alternative 6R	328	38	43	8.3	8.0	8.5	8.9	9.3	9.2	9.2	9.2	9.2	13	10	10	9.8	9.7	9.4	9.3	9.2	9.1	11	10	9.8	10	10	9.9	9.9	9.7	9.7

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Implemen-tation Period (years)	Beach 4 Baseline = 7.5									Beach 5 Baseline = 9.1									Beach 6 Baseline = 12								
				Time from Issuance of Remedy Decision Documents (years)									*Time from Issuance of Remedy Decision Documents (years)*									*Time from Issuance of Remedy Decision Documents (years)*								
				5[b]	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5[b]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5[b]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
EAA-Alternative 1	29	<5	<5	7.5	8.7	9.0	9.1	9.1	9.1	9.0	9.1	9.1	9.1	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	12	9.5	9.1	9.1	9.1	9.1	9.1	9.0	9.0
Alternative 3C	86	4	9	7.5	9.0	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	8.8	8.7	8.7	8.7	8.7	8.7	8.8	8.7	12	10	9.3	9.2	9.1	9.1	9.1	9.1	9.1
Alternative 4C	143	7	12	7.5	9.2	9.2	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	8.9	8.9	8.9	8.9	8.9	8.9	8.9	12	10	9.3	9.2	9.1	9.1	9.1	9.1	9.1
Alternative 5C	186	8	13	7.5	9.2	9.3	9.2	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	8.9	8.9	8.9	8.9	8.9	8.9	12	10	9.3	9.2	9.1	9.1	9.1	9.1	9.1
Alternative 6C	328	18	23	7.5	9.2	9.3	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.0	9.0	8.9	8.9	8.9	8.9	12	10	9.3	9.2	9.1	9.1	9.1	9.1	9.1
Alternative 2R	59	4	9	7.5	9.0	9.1	9.1	9.1	9.1	9.0	9.1	9.1	9.1	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	12	9.5	9.1	9.1	9.1	9.1	9.1	9.0	9.0
Alternative 3R	86	6	11	7.5	9.0	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	8.8	8.7	8.7	8.7	8.7	8.7	8.8	8.7	12	10	9.3	9.2	9.1	9.1	9.1	9.1	9.1
Alternative 4R	143	13	18	7.5	9.0	9.3	9.1	9.1	9.1	9.1	9.1	9.1	9.1	8.8	9.0	8.9	8.9	8.9	8.9	8.9	8.9	12	10	9.3	9.2	9.1	9.1	9.1	9.1	9.1
Alternative 5R	186	19	24	7.5	9.0	9.3	9.1	9.2	9.1	9.1	9.1	9.1	9.1	8.8	9.0	8.9	9.1	8.9	8.9	8.9	8.9	12	10	9.3	9.2	9.1	9.1	9.1	9.1	9.1
Alternative 6R	328	38	43	7.5	9.0	9.3	9.1	9.2	9.1	9.1	9.1	9.1	9.1	8.8	9.0	8.9	9.1	9.0	9.0	8.9	8.9	12	10	9.3	9.2	9.1	9.1	9.1	9.1	9.1

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Implemen-tation Period (years)	Beach 7 Baseline = 8.4									Beach 8 Baseline = 8								
				Time from Issuance of Remedy Decision Documents (years)									*Time from Issuance of Remedy Decision Documents (years)*								
				5[b]	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5[b]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
EAA-Alternative 1	29	<5	<5	8.4	9.0	9.1	9.1	9.1	9.1	9.2	9.1	9.1	8.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Alternative 3C	86	4	9	8.4	9.0	9.1	9.1	9.1	9.1	9.2	9.1	9.1	8.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Alternative 4C	143	7	12	8.4	9.0	9.1	9.1	9.1	9.1	9.2	9.1	9.1	8.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Alternative 5C	186	8	13	8.4	9.0	9.1	9.1	9.1	9.1	9.2	9.1	9.1	8.0	9.0	9.1	9.0	9.0	9.0	9.0	9.0	9.0
Alternative 6C	328	18	23	8.4	9.0	9.1	9.0	9.1	9.1	9.1	9.1	9.1	8.0	9.0	9.1	9.0	9.0	9.0	9.0	9.0	9.0
Alternative 2R	59	4	9	8.4	9.0	9.1	9.1	9.1	9.1	9.2	9.1	9.1	8.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Alternative 3R	86	6	11	8.4	9.0	9.1	9.1	9.1	9.1	9.2	9.1	9.1	8.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Alternative 4R	143	13	18	8.4	9.0	9.1	9.1	9.1	9.1	9.2	9.1	9.1	8.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Alternative 5R	186	19	24	8.4	9.0	9.1	9.1	9.1	9.1	9.2	9.1	9.1	8.0	9.0	9.0	9.0	9.1	9.0	9.0	9.0	9.0
Alternative 6R	328	38	43	8.4	9.0	9.1	9.1	9.1	9.1	9.1	9.1	9.1	8.0	9.0	9.0	9.0	9.1	9.0	9.0	9.0	9.0

Table 9-3 Effectiveness Evaluation – Predicted Post-Construction Risk Driver Concentrations (SWACs) at Individual Beaches

Total PCBs (µg/kg dw), Beach Play Direct Contact, PRG = 10^{-6} RBTC = 1,700

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Implemen-tation Period (years)	Beach 1 Baseline = 51									Beach 2 Baseline = 280									Beach 3 Baseline = 170								
				Time from Issuance of Remedy Decision Documents (years)									*Time from Issuance of Remedy Decision Documents (years)*									*Time from Issuance of Remedy Decision Documents (years)*								
				5 [b]	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [b]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [b]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
EAA-Alternative 1	29	<5	<5	51	49	47	44	43	43	42	43	44	280	190	130	86	64	54	49	45	43	104	93	80	66	64	63	65	65	65
Alternative 3C	86	4	9	51	47	46	45	43	43	43	44	44	280	110	86	66	53	48	45	43	41	104	88	77	65	63	63	65	65	65
Alternative 4C	143	7	12	51	47	46	45	43	43	43	44	44	280	85	69	57	48	44	43	41	40	104	71	69	63	62	63	65	65	65
Alternative 5C	186	8	13	51	47	53	47	44	44	44	45	45	280	85	68	56	47	44	43	41	40	104	71	70	63	62	63	66	66	65
Alternative 6C	328	18	23	51	47	53	47	41	42	43	44	44	280	85	68	56	33	35	36	36	37	104	71	70	63	61	62	65	65	65
Alternative 2R	59	4	9	51	49	47	44	43	43	42	43	44	280	140	104	74	57	50	47	44	42	104	88	77	65	63	63	65	65	65
Alternative 3R	86	6	11	51	47	46	45	43	43	43	44	44	280	110	86	66	53	48	45	43	41	104	88	77	65	63	63	65	65	65
Alternative 4R	143	13	18	51	47	46	45	43	43	43	44	44	280	110	86	58	49	45	43	41	40	104	88	77	66	64	64	66	66	65
Alternative 5R	186	19	24	51	47	46	45	48	46	45	45	45	280	110	86	58	51	46	44	42	41	104	88	77	66	66	65	67	66	66
Alternative 6R	328	38	43	51	47	46	45	48	46	45	45	42	280	110	86	58	51	46	44	37	33	104	88	77	66	66	65	67	66	64

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Implemen-tation Period (years)	Beach 4 Baseline = 1,100									Beach 5 Baseline = 123									Beach 6 Baseline = 450								
				Time from Issuance of Remedy Decision Documents (years)									*Time from Issuance of Remedy Decision Documents (years)*									*Time from Issuance of Remedy Decision Documents (years)*								
				5 [b]	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [b]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [b]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
EAA-Alternative 1	29	<5	<5	1100	290	110	55	56	51	44	43	44	123	70	60	59	58	58	58	54	55	450	120	67	55	57	53	46	41	40
Alternative 3C	86	4	9	1100	69	51	43	44	44	40	42	43	123	64	58	58	57	57	57	53	54	450	60	43	41	39	39	39	38	38
Alternative 4C	143	7	12	1100	61	48	43	43	43	40	42	43	123	59	53	52	52	51	51	49	50	450	60	43	41	39	39	39	38	38
Alternative 5C	186	8	13	1100	61	49	43	43	43	41	42	43	123	59	55	52	51	51	51	49	49	450	60	43	41	39	39	39	38	38
Alternative 6C	328	18	23	1100	61	49	40	42	43	42	43	43	123	59	55	41	44	44	44	43	43	450	60	43	41	39	39	39	38	38
Alternative 2R	59	4	9	1100	70	51	43	44	44	39	42	43	123	69	60	59	58	58	58	54	55	450	120	67	55	57	53	46	41	40
Alternative 3R	86	6	11	1100	69	51	43	44	44	40	42	43	123	64	58	58	57	57	57	53	54	450	60	43	41	39	39	39	38	38
Alternative 4R	143	13	18	1100	69	51	43	43	43	40	42	43	123	64	54	52	52	51	51	49	50	450	60	43	41	39	39	39	38	38
Alternative 5R	186	19	24	1100	69	51	43	45	44	41	42	43	123	64	54	52	54	51	52	49	49	450	60	43	41	39	39	39	38	38
Alternative 6R	328	38	43	1100	69	51	43	45	44	39	42	43	123	64	54	52	54	42	44	43	43	450	60	43	41	39	39	39	38	38

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Implemen-tation Period (years)	Beach 7 Baseline = 46									Beach 8 Baseline = 49								
				Time from Issuance of Remedy Decision Documents (years)									*Time from Issuance of Remedy Decision Documents (years)*								
				5 [b]	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [b]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
EAA-Alternative 1	29	<5	<5	46	41	42	40	41	41	46	41	41	49	35	35	35	36	35	35	35	35
Alternative 3C	86	4	9	46	41	42	40	41	41	46	41	41	49	37	35	35	35	35	35	35	35
Alternative 4C	143	7	12	46	41	42	40	41	41	46	41	41	49	37	35	35	35	35	35	35	35
Alternative 5C	186	8	13	46	41	42	40	41	41	46	41	41	49	37	38	35	35	35	35	35	35
Alternative 6C	328	18	23	46	41	42	36	41	40	43	41	41	49	37	38	35	35	35	35	35	35
Alternative 2R	59	4	9	46	41	42	40	41	41	46	41	41	49	35	35	35	36	35	35	35	35
Alternative 3R	86	6	11	46	41	42	40	41	41	46	41	41	49	37	35	35	35	35	35	35	35
Alternative 4R	143	13	18	46	41	42	40	41	41	46	41	41	49	37	35	35	35	35	35	35	35
Alternative 5R	186	19	24	46	41	42	40	41	41	46	41	41	49	37	35	35	38	35	35	35	35
Alternative 6R	328	38	43	46	41	42	40	41	37	43	41	41	49	37	35	35	38	35	35	35	35

Table 9-3 Effectiveness Evaluation – Predicted Post-Construction Risk Driver Concentrations (SWACs) at Individual Beaches

cPAHs (µg TEQ/kg dw), Beach Play Direct Contact, PRG = 10[-6] RBTC = 90

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Implemen-tation Period (years)	Beach 1 Baseline = 400									Beach 2 Baseline = 750									Beach 3 Baseline = 510								
				Time from Issuance of Remedy Decision Documents (years)									*Time from Issuance of Remedy Decision Documents (years)*									*Time from Issuance of Remedy Decision Documents (years)*								
				5[b]	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5[b]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5[b]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
EAA-Alternative 1	29	<5	<5	400	300	220	160	130	120	110	120	120	750	490	320	200	140	120	107	99	93	380	340	290	240	240	240	250	240	240
Alternative 3C	86	4	9	400	110	120	110	106	108	107	110	120	750	130	110	102	92	89	89	87	86	380	320	280	240	240	240	250	240	240
Alternative 4C	143	7	12	400	110	120	110	106	108	107	110	120	750	130	120	105	93	90	89	88	87	380	310	280	230	240	240	250	240	240
Alternative 5C	186	8	13	400	110	130	120	109	110	110	120	120	750	130	120	107	95	91	90	88	87	380	310	260	230	230	240	250	240	240
Alternative 6C	328	18	23	400	110	130	120	107	109	110	120	120	750	130	120	107	97	92	92	89	88	380	310	260	230	230	240	250	240	240
Alternative 2R	59	4	9	400	300	220	160	130	120	110	120	120	750	260	190	140	110	100	96	92	89	380	320	280	240	240	240	250	240	240
Alternative 3R	86	6	11	400	110	120	110	106	108	107	110	120	750	130	110	102	92	89	89	87	86	380	320	280	240	240	240	250	240	240
Alternative 4R	143	13	18	400	110	120	110	106	108	107	110	120	750	130	110	109	96	92	91	89	87	380	320	280	240	240	240	250	240	240
Alternative 5R	186	19	24	400	110	120	110	120	110	110	120	120	750	130	110	109	103	96	94	91	89	380	320	280	240	240	240	250	240	240
Alternative 6R	328	38	43	400	110	120	110	120	110	110	120	120	750	130	110	109	103	96	94	94	93	380	320	280	240	240	240	250	240	240

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Implemen-tation Period (years)	Beach 4 Baseline = 380									Beach 5 Baseline = 385									Beach 6 Baseline = 530								
				Time from Issuance of Remedy Decision Documents (years)									*Time from Issuance of Remedy Decision Documents (years)*									*Time from Issuance of Remedy Decision Documents (years)*								
				5[b]	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5[b]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5[b]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
EAA-Alternative 1	29	<5	<5	380	170	130	103	110	110	87	104	110	385	165	118	103	107	104	100	95	96	530	190	130	120	120	110	98	91	92
Alternative 3C	86	4	9	380	140	120	103	108	109	91	105	110	385	117	105	98	99	98	98	94	96	530	140	96	90	87	86	87	83	84
Alternative 4C	143	7	12	380	130	120	103	107	109	93	105	110	385	115	106	99	101	100	102	97	99	530	140	96	90	87	86	87	83	84
Alternative 5C	186	8	13	380	130	120	104	108	109	99	107	110	385	115	109	99	101	101	102	97	100	530	140	96	90	87	86	87	83	84
Alternative 6C	328	18	23	380	130	120	104	108	109	103	108	110	385	115	109	100	99	98	100	96	98	530	140	96	90	87	86	87	83	84
Alternative 2R	59	4	9	380	160	130	103	109	110	89	104	110	385	160	118	103	104	101	100	95	96	530	190	130	120	120	110	98	91	92
Alternative 3R	86	6	11	380	140	120	103	108	109	91	105	110	385	117	105	98	99	98	98	94	96	530	140	96	90	87	86	87	83	84
Alternative 4R	143	13	18	380	140	120	102	108	109	93	105	110	385	117	108	99	102	100	102	97	99	530	140	96	90	88	86	87	83	84
Alternative 5R	186	19	24	380	140	120	102	110	110	100	107	110	385	117	108	99	106	101	102	97	100	530	140	96	90	88	86	87	83	84
Alternative 6R	328	38	43	380	140	120	102	110	110	102	107	110	385	117	108	99	106	101	101	96	98	530	140	96	90	88	86	87	83	84

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Implemen-tation Period (years)	Beach 7 Baseline = 74									Beach 8 Baseline = 180								
				Time from Issuance of Remedy Decision Documents (years)									*Time from Issuance of Remedy Decision Documents (years)*								
				5[b]	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5[b]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
EAA-Alternative 1	29	<5	<5	74	97	102	93	101	98	130	100	102	180	76	74	72	73	73	72	71	71
Alternative 3C	86	4	9	74	97	102	93	101	98	130	100	102	180	81	74	72	73	73	72	71	71
Alternative 4C	143	7	12	74	97	102	93	101	98	130	100	102	180	81	74	72	73	73	72	71	71
Alternative 5C	186	8	13	74	97	102	93	101	98	130	100	102	180	81	81	72	73	73	72	71	71
Alternative 6C	328	18	23	74	97	102	88	101	98	110	99	102	180	81	81	72	73	73	72	71	71
Alternative 2R	59	4	9	74	97	102	93	101	98	130	100	102	180	76	74	72	73	73	72	71	71
Alternative 3R	86	6	11	74	97	102	93	101	98	130	100	102	180	81	74	72	73	73	72	71	71
Alternative 4R	143	13	18	74	97	102	93	101	98	130	100	102	180	81	74	72	73	73	72	71	71
Alternative 5R	186	19	24	74	97	102	93	101	98	130	100	102	180	81	74	72	80	73	73	71	71
Alternative 6R	328	38	43	74	97	102	93	101	91	110	99	102	180	81	74	72	80	73	73	71	71

Table 9-3 Effectiveness Evaluation – Predicted Post-Construction Risk Driver Concentrations (SWACs) at Individual Beaches

Dioxins/Furans (ng TEQ/kg dw), Beach Play Direct Contact, PRG = 10^{-6} RBTC = 28

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Implemen-tation Period (years)	Beach 1 Baseline = 5.3									Beach 2 Baseline = 23									Beach 3 Baseline = 30								
				Time from Issuance of Remedy Decision Documents (years)									*Time from Issuance of Remedy Decision Documents (years)*									*Time from Issuance of Remedy Decision Documents (years)*								
				5 [b]	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [b]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [b]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
EAA-Alternative 1	29	<5	<5	5.3	5.1	4.8	4.6	4.5	4.5	4.4	4.5	4.5	23	16.0	11.0	7.7	6.0	5.3	5.0	4.7	4.5	7.2	6.8	6.4	5.8	5.8	5.8	5.9	5.9	5.9
Alternative 3C	86	4	9	5.3	4.6	4.6	4.5	4.4	4.5	4.4	4.5	4.5	23	7.7	6.5	5.5	4.9	4.7	4.5	4.4	4.3	7.2	5.9	6.0	5.7	5.8	5.8	5.9	5.9	5.9
Alternative 4C	143	7	12	5.3	4.6	4.6	4.5	4.4	4.5	4.4	4.5	4.5	23	7.1	6.1	5.2	4.8	4.6	4.5	4.4	4.3	7.2	5.8	5.9	5.6	5.8	5.8	6.0	5.9	5.9
Alternative 5C	186	8	13	5.3	4.6	4.3	4.4	4.4	4.4	4.5	4.5	4.6	23	7.1	5.5	4.9	4.6	4.4	4.4	4.3	4.3	7.2	5.8	5.8	5.6	5.7	5.8	6.0	5.9	5.9
Alternative 6C	328	18	23	5.3	4.6	4.3	4.4	4.4	4.4	4.5	4.5	4.6	23	7.1	5.5	4.9	4.1	4.1	4.1	4.2	4.2	7.2	5.8	5.8	5.6	5.7	5.8	6.0	5.9	5.9
Alternative 2R	59	4	9	5.3	5.1	4.8	4.6	4.5	4.5	4.4	4.5	4.5	23	8.5	7.0	5.7	5.1	4.7	4.6	4.5	4.4	7.2	5.9	6.0	5.7	5.8	5.8	5.9	5.9	5.9
Alternative 3R	86	6	11	5.3	4.6	4.6	4.5	4.4	4.5	4.4	4.5	4.5	23	7.7	6.5	5.5	4.9	4.7	4.5	4.4	4.3	7.2	5.9	6.0	5.7	5.8	5.8	5.9	5.9	5.9
Alternative 4R	143	13	18	5.3	4.6	4.6	4.5	4.4	4.5	4.4	4.5	4.5	23	7.7	6.5	5.2	4.8	4.6	4.5	4.4	4.3	7.2	5.9	6.0	5.5	5.7	5.8	5.9	5.9	5.9
Alternative 5R	186	19	24	5.3	4.6	4.6	4.5	4.3	4.4	4.4	4.5	4.5	23	7.7	6.5	5.2	4.6	4.4	4.4	4.3	4.3	7.2	5.9	6.0	5.5	5.7	5.8	5.9	5.9	5.9
Alternative 6R	328	38	43	5.3	4.6	4.6	4.5	4.3	4.4	4.4	4.5	4.5	23	7.7	6.5	5.2	4.6	4.4	4.4	4.2	4.1	7.2	5.9	6.0	5.5	5.7	5.8	5.9	5.9	5.9

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Implemen-tation Period (years)	Beach 4 Baseline = 47									Beach 5 Baseline = 5.8									Beach 6 Baseline = 8.3								
				Time from Issuance of Remedy Decision Documents (years)									*Time from Issuance of Remedy Decision Documents (years)*									*Time from Issuance of Remedy Decision Documents (years)*								
				5 [b]	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [b]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [b]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
EAA-Alternative 1	29	<5	<5	47	14.0	7.2	4.9	5.0	4.8	4.4	4.5	4.5	5.8	4.2	4.0	3.8	3.8	3.8	3.8	3.9	3.9	8.3	5.4	5.1	5.1	5.1	5.1	4.6	4.4	4.5
Alternative 3C	86	4	9	47	5.0	4.7	4.4	4.5	4.5	4.3	4.4	4.5	5.8	3.5	3.7	3.6	3.6	3.6	3.6	3.7	3.7	8.3	4.0	4.1	4.1	4.1	4.1	4.2	4.1	4.2
Alternative 4C	143	7	12	47	4.7	4.6	4.4	4.5	4.5	4.3	4.4	4.5	5.8	3.5	3.7	3.5	3.6	3.6	3.7	3.7	3.7	8.3	4.0	4.1	4.1	4.1	4.1	4.2	4.1	4.2
Alternative 5C	186	8	13	47	4.7	4.5	4.4	4.5	4.5	4.4	4.4	4.5	5.8	3.5	3.6	3.5	3.6	3.6	3.7	3.8	3.7	8.3	4.0	4.1	4.1	4.1	4.1	4.2	4.1	4.2
Alternative 6C	328	18	23	47	4.7	4.5	4.3	4.4	4.5	4.4	4.5	4.5	5.8	3.5	3.6	3.7	3.8	3.8	3.8	3.9	3.9	8.3	4.0	4.1	4.1	4.1	4.1	4.2	4.1	4.2
Alternative 2R	59	4	9	47	5.2	4.7	4.4	4.5	4.5	4.2	4.4	4.5	5.8	4.1	3.9	3.8	3.8	3.8	3.8	3.9	3.9	8.3	5.4	5.1	5.1	5.1	5.1	4.6	4.4	4.5
Alternative 3R	86	6	11	47	5.0	4.7	4.4	4.5	4.5	4.3	4.4	4.5	5.8	3.5	3.7	3.6	3.6	3.6	3.6	3.7	3.7	8.3	4.0	4.1	4.1	4.1	4.1	4.2	4.1	4.2
Alternative 4R	143	13	18	47	5.0	4.6	4.4	4.5	4.5	4.3	4.4	4.5	5.8	3.5	3.6	3.6	3.6	3.6	3.7	3.7	3.7	8.3	4.0	4.1	4.1	4.1	4.1	4.2	4.1	4.2
Alternative 5R	186	19	24	47	5.0	4.6	4.4	4.4	4.5	4.3	4.4	4.5	5.8	3.5	3.6	3.6	3.6	3.6	3.7	3.8	3.7	8.3	4.0	4.1	4.1	4.1	4.1	4.2	4.1	4.2
Alternative 6R	328	38	43	47	5.0	4.6	4.4	4.4	4.5	4.3	4.4	4.5	5.8	3.5	3.6	3.6	3.6	3.8	3.8	3.9	3.9	8.3	4.0	4.1	4.1	4.1	4.1	4.2	4.1	4.2

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Implemen-tation Period (years)	Beach 7 Baseline = 2.5									Beach 8 Baseline = 3.8								
				Time from Issuance of Remedy Decision Documents (years)									*Time from Issuance of Remedy Decision Documents (years)*								
				5 [b]	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [b]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
EAA-Alternative 1	29	<5	<5	2.5	4.2	4.3	4.2	4.3	4.3	4.6	4.4	4.4	3.8	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Alternative 3C	86	4	9	2.5	4.2	4.3	4.2	4.3	4.3	4.6	4.4	4.4	3.8	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Alternative 4C	143	7	12	2.5	4.2	4.3	4.2	4.3	4.3	4.6	4.4	4.4	3.8	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Alternative 5C	186	8	13	2.5	4.2	4.3	4.2	4.3	4.3	4.6	4.4	4.4	3.8	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Alternative 6C	328	18	23	2.5	4.2	4.3	4.1	4.3	4.3	4.5	4.4	4.4	3.8	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Alternative 2R	59	4	9	2.5	4.2	4.3	4.2	4.3	4.3	4.6	4.4	4.4	3.8	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Alternative 3R	86	6	11	2.5	4.2	4.3	4.2	4.3	4.3	4.6	4.4	4.4	3.8	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Alternative 4R	143	13	18	2.5	4.2	4.3	4.2	4.3	4.3	4.6	4.4	4.4	3.8	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Alternative 5R	186	19	24	2.5	4.2	4.3	4.2	4.3	4.3	4.6	4.4	4.4	3.8	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Alternative 6R	328	38	43	2.5	4.2	4.3	4.2	4.3	4.2	4.5	4.4	4.4	3.8	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0

Notes:

1. BCM predictions use base case STM outputs revised June 2010 (Appendix C).
2. Arsenic BCM inputs (mg/kg dw): upstream 9, lateral 13, and post-remedy bed sediment replacement value 10 (AOPC 1) and 9 (AOPC 2).
3. Total PCB BCM inputs (µg/kg dw): upstream 35, lateral 300, and post-remedy bed sediment replacement value 60 (AOPC 1) and 20 (AOPC 2).
4. cPAH BCM inputs (µg TEQ/kg dw): upstream 70, lateral 1,400, and post-remedy bed sediment replacement value 140 (AOPC 1) and 100 (AOPC 2).
5. Dioxin/Furan BCM inputs (ng TEQ/kg dw): upstream 4, lateral 20, and post-remedy bed sediment replacement value 4 (AOPC 1).
6. BCM model area = 430 acres and FS study area = 441 acres

a Background value based on UCL95. The 90th percentile for arsenic is 11 mg/kg dw.

b This is the start of construction for Alternatives 2 through 6. The 5-year model-predicted intervals associated with the BCM SWAC output are indexed to issuance of remedy decision documents. Activities during the assumed 5-year period between signing of the documents and start of construction are completion of EAAs, priority source control, negotiations, and initial remedial design. Implementation period starts from the issuance of remedy decision documents through the end of construction.

BCM = bed composition model; EAA = early action area; PRG = preliminary remediation goal; RBTC = risk-based threshold concentration; STM = sediment transport model; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent.

End of construction period.

Table 9-4 Sensitivity of LDW Arsenic, Total PCB, cPAH, and Dioxin/Furan SWACs to BCM Chemical Input Values

Arsenic Site-Wide Predicted SWACs (mg/kg dw) Based on Range of BCM Parameter Value Sets; Baseline Arsenic SWAC = 16 mg/kg dw

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Implemen-tation Period (years)	Recommended (Mid, Mid, Mid)									Sensitivity (Low, Low, Low)									Sensitivity (High, High, High)									Sensitivity (Mid (Bed), Mid (Up), High (Lat))								
				Time from Issuance of Remedy Decision Documents (years)									*Time from Issuance of Remedy Decision Documents (years)*									*Time from Issuance of Remedy Decision Documents (years)*									*Time from Issuance of Remedy Decision Documents (years)*								
				5 [a]	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [a]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [a]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [a]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
EAA-Alternative 1	29	<5	<5	16	12	11	10	10	9.7	9.7	9.5	9.5	16	11	9.2	8.3	8.1	7.8	7.8	7.6	7.5	16	13	12	11	11	11	11	11	11	16	12	11	10	10	10	10	9.9	9.9
Alternative 3C	86	4	9	16	10	9.7	9.4	9.3	9.2	9.2	9.2	9.1	16	9.0	8.1	7.6	7.4	7.3	7.2	7.2	7.1	16	11	11	10	10	10	10	10	10	16	10	9.9	9.6	9.5	9.5	9.5	9.5	9.5
Alternative 4C	143	7	12	16	10	9.6	9.3	9.2	9.2	9.2	9.1	9.1	16	8.9	8.0	7.6	7.4	7.3	7.2	7.2	7.1	16	11	11	10	10	10	10	10	10	16	10	9.9	9.6	9.5	9.5	9.5	9.5	9.5
Alternative 5C	186	8	13	16	10	9.6	9.3	9.2	9.2	9.2	9.2	9.1	16	8.9	8.0	7.6	7.4	7.3	7.2	7.2	7.1	16	11	11	10	10	10	10	10	10	16	10	9.9	9.6	9.5	9.5	9.5	9.5	9.5
Alternative 6C	328	18	23	16	10	9.6	9.3	9.1	9.1	9.1	9.1	9.1	16	8.9	8.0	7.7	7.4	7.3	7.2	7.2	7.1	16	11	11	10	10	10	10	10	10	16	10	9.9	9.5	9.4	9.4	9.5	9.5	9.5
Alternative 2R	59	4	9	16	10	9.8	9.4	9.3	9.2	9.2	9.2	9.2	16	9.1	8.2	7.6	7.4	7.3	7.3	7.2	7.2	16	11	11	11	10	10	11	10	10	16	11	10	9.7	9.6	9.5	9.6	9.5	9.5
Alternative 3R	86	6	11	16	10	9.7	9.4	9.3	9.2	9.2	9.2	9.1	16	9.0	8.1	7.6	7.4	7.3	7.2	7.2	7.1	16	11	11	10	10	10	10	10	10	16	10	9.9	9.6	9.5	9.5	9.5	9.5	9.5
Alternative 4R	143	13	18	16	10	9.7	9.4	9.3	9.2	9.2	9.2	9.1	16	9.0	8.1	7.6	7.4	7.3	7.3	7.2	7.2	16	11	11	11	10	10	10	10	10	16	10	10	9.6	9.5	9.5	9.5	9.5	9.5
Alternative 5R	186	19	24	16	10	9.7	9.4	9.3	9.2	9.2	9.2	9.2	16	9.0	8.1	7.6	7.6	7.4	7.3	7.2	7.2	16	11	11	11	11	10	11	10	10	16	10	10	9.6	9.6	9.5	9.6	9.5	9.5
Alternative 6R	328	38	43	16	10	9.7	9.4	9.3	9.2	9.2	9.1	9.1	16	9.0	8.1	7.6	7.6	7.4	7.4	7.3	7.3	16	11	11	11	11	10	10	10	10	16	10	10	9.6	9.6	9.5	9.5	9.5	9.4

BCM input parameters (mg/kg dw arsenic)
low: upstream = 7; lateral = 9; replacement value = 9 (AOPC 1), 8 (AOPC 2)
mid: upstream = 9; lateral = 13; replacement value = 10 (AOPC 1), 9 (AOPC 2)
high: upstream = 10; lateral = 30; replacement value = 11 (AOPC 1), 10 (AOPC 2)

Total PCBs Site-Wide Predicted SWACs (µg/kg dw) Based on Range of BCM Parameter Value Sets; Baseline Total PCB SWAC = 346 µg/kg dw

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Implemen-tation Period (years)	Recommended (Mid, Mid, Mid)									Sensitivity (Low, Low, Low)									Sensitivity (High, High, High)									Sensitivity (Mid (Bed), Mid (Up), High (Lat))								
				Time from Issuance of Remedy Decision Documents (years)									*Time from Issuance of Remedy Decision Documents (years)*									*Time from Issuance of Remedy Decision Documents (years)*									*Time from Issuance of Remedy Decision Documents (years)*								
				5 [a]	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [a]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [a]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [a]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
EAA-Alternative 1	29	<5	<5	180	103	73	56	52	49	48	45	45	180	83	46	27	22	17	16	13	12	180	140	120	106	104	103	104	103	103	180	110	86	67	64	61	63	60	60
Alternative 3C	86	4	9	180	86	65	52	49	46	45	44	43	180	64	37	23	18	15	13	11	10	180	120	110	101	101	100	102	101	102	180	101	77	62	61	59	60	59	59
Alternative 4C	143	7	12	180	75	58	49	47	45	44	43	43	180	51	30	19	16	13	12	10	10	180	109	105	98	99	99	101	101	101	180	87	70	59	58	58	59	58	58
Alternative 5C	186	8	13	180	75	55	47	46	44	44	43	43	180	51	26	17	15	13	12	10	9.3	180	109	101	96	98	99	101	101	101	180	87	75	57	58	57	59	58	58
Alternative 6C	328	18	23	180	75	55	42	38	39	41	41	41	180	51	26	15	10	9.3	9.1	8.3	8.2	180	109	101	86	84	91	96	98	99	180	87	75	50	47	51	55	56	57
Alternative 2R	59	4	9	180	91	68	54	50	48	47	45	44	180	70	41	25	20	16	15	12	11	180	130	110	103	103	102	103	102	102	180	106	80	64	62	60	61	60	60
Alternative 3R	86	6	11	180	86	65	52	49	46	45	44	43	180	64	37	23	18	15	13	11	10	180	120	110	101	101	100	102	101	102	180	101	77	62	61	59	60	59	59
Alternative 4R	143	13	18	180	86	64	50	47	45	45	43	43	180	64	36	20	16	13	12	10	10	180	120	110	98	99	99	101	101	101	180	101	85	71	59	58	59	58	58
Alternative 5R	186	19	24	180	86	64	50	48	45	45	43	43	180	64	36	20	17	14	12	10	10	180	120	110	98	98	99	101	101	101	180	101	85	71	70	58	59	58	58
Alternative 6R	328	38	43	180	86	64	50	48	42	41	40	39	180	64	36	20	17	12	11	10	8.7	180	120	110	98	98	93	94	93	93	180	101	85	71	70	54	55	54	53

BCM input parameters (µg/kg dw total PCBs)
low: upstream = 5; lateral = 100; replacement value = 30 (AOPC 1), 10 (AOPC 2)
mid: upstream = 35; lateral = 300; replacement value = 60 (AOPC 1), 20 (AOPC 2)
high: upstream = 80; lateral = 1,000; replacement value = 90 (AOPC 1), 40 (AOPC 2)

Table 9-4 Sensitivity of LDW Arsenic, Total PCB, cPAH, and Dioxin/Furan SWACs to BCM Chemical Input Values

cPAHs Site-Wide Predicted SWACs (µg TEQ/kg dw) Based on Range of BCM Parameter Value Sets; Baseline cPAH SWAC = 390 µg TEQ/kg dw

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Implemen-tation Period (years)	Recommended (Mid, Mid, Mid)									Sensitivity (Low, Low, Low)									Sensitivity (High, High, High)									Sensitivity (Mid (Bed), Mid (Up), High (Lat))								
				Time from Issuance of Remedy Decision Documents (years)									*Time from Issuance of Remedy Decision Documents (years)*									*Time from Issuance of Remedy Decision Documents (years)*									*Time from Issuance of Remedy Decision Documents (years)*								
				5 [a]	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [a]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [a]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [a]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
EAA-Alternative 1	29	<5	<5	360	220	160	130	120	110	110	107	107	350	190	120	85	73	66	64	59	57	360	360	350	330	330	330	340	340	340	360	250	200	160	150	150	150	150	150
Alternative 3C	86	4	9	360	180	140	120	109	105	107	104	104	350	150	101	74	65	60	59	55	54	360	310	330	310	320	320	330	340	340	360	200	180	140	140	140	150	150	150
Alternative 4C	143	7	12	360	170	130	110	106	104	106	103	103	350	120	88	67	62	58	57	54	54	360	290	320	310	320	320	330	330	340	360	180	170	140	140	140	150	150	150
Alternative 5C	186	8	13	360	170	130	109	105	103	106	103	103	350	120	81	64	60	57	57	54	53	360	290	300	300	310	320	330	330	340	360	180	160	140	140	140	150	150	150
Alternative 6C	328	18	23	360	170	130	109	102	101	104	102	102	350	120	81	61	54	53	54	52	52	360	290	300	280	280	300	320	330	330	360	180	160	130	130	130	150	140	150
Alternative 2R	59	4	9	360	200	150	120	110	108	109	105	105	350	170	110	79	69	63	61	57	56	360	330	340	320	320	330	330	340	340	360	220	190	150	150	140	150	150	150
Alternative 3R	86	6	11	360	180	140	120	109	105	107	104	104	350	150	101	74	65	60	59	55	54	360	310	330	310	320	320	330	340	340	360	200	180	140	140	140	150	150	150
Alternative 4R	143	13	18	360	180	140	110	108	104	106	103	103	350	150	100	68	62	58	57	54	54	360	310	320	300	310	320	330	330	340	360	200	180	140	140	140	150	150	150
Alternative 5R	186	19	24	360	180	140	110	110	106	107	104	104	350	150	100	68	62	58	57	54	54	360	310	320	300	300	320	330	330	340	360	200	180	140	140	140	150	150	150
Alternative 6R	328	38	43	360	180	140	110	110	106	107	104	103	350	150	100	68	62	57	56	54	52	360	310	320	300	300	300	310	310	310	360	200	180	140	140	140	140	140	140

BCM input parameters (µg TEQ/kg dw cPAHs)
low: upstream = 40; lateral = 500; replacement value = 70 (AOPC 1), 50 (AOPC 2)
mid: uptream = 70; lateral = 1,400; replacement value = 140 (AOPC 1), 100 (AOPC 2)
high: upstream = 270; lateral = 3,400; replacement value = 200 (AOPC 1), 140 (AOPC 2)

Dioxin/Furan Site-Wide Predicted SWACs (ng TEQ/kg dw) Based on Range of BCM Parameter Value Sets; Baseline Total PCB SWAC = 26 ng TEQ/kg dw

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Implemen-tation Period (years)	Recommended (Mid, Mid, Mid)									Sensitivity (Low, Low, Low)									Sensitivity (High, High, High)									Sensitivity (Mid (Bed), Mid (Up), High (Lat))								
				Time from Issuance of Remedy Decision Documents (years)									*Time from Issuance of Remedy Decision Documents (years)*									*Time from Issuance of Remedy Decision Documents (years)*									*Time from Issuance of Remedy Decision Documents (years)*								
				5 [a]	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [a]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [a]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*5 [a]*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
EAA-Alternative 1	29	<5	<5	24	13	7.9	5.5	4.9	4.6	4.6	4.5	4.4	24	11	6.2	3.6	2.9	2.6	2.5	2.4	2.3	24	15	11	9.2	8.8	8.7	8.7	8.7	8.7	24	13	8.3	5.8	5.2	5.0	5.0	4.9	4.9
Alternative 3C	86	4	9	24	5.9	5.2	4.7	4.5	4.5	4.5	4.4	4.4	24	4.5	3.4	2.7	2.5	2.4	2.4	2.3	2.3	24	8.4	8.6	8.4	8.5	8.5	8.6	8.6	8.6	24	6.1	5.5	4.9	4.9	4.8	4.9	4.8	4.8
Alternative 4C	143	7	12	24	5.3	4.9	4.5	4.4	4.4	4.4	4.4	4.4	24	3.7	3.0	2.5	2.4	2.3	2.3	2.3	2.2	24	7.7	8.3	8.2	8.4	8.5	8.6	8.6	8.6	24	5.5	5.2	4.8	4.8	4.8	4.8	4.8	4.8
Alternative 5C	186	8	13	24	5.3	4.6	4.4	4.4	4.4	4.4	4.4	4.4	24	3.7	2.7	2.4	2.4	2.3	2.3	2.2	2.2	24	7.7	7.9	8.1	8.3	8.4	8.5	8.6	8.6	24	5.5	4.9	4.7	4.7	4.7	4.8	4.8	4.8
Alternative 6C	328	18	23	24	5.3	4.6	4.3	4.3	4.3	4.4	4.3	4.4	24	3.7	2.7	2.3	2.2	2.2	2.2	2.2	2.2	24	7.7	7.9	7.7	7.8	8.2	8.4	8.5	8.6	24	5.5	4.9	4.6	4.5	4.6	4.8	4.8	4.8
Alternative 2R	59	4	9	24	6.1	5.3	4.7	4.6	4.5	4.5	4.4	4.4	24	4.7	3.6	2.8	2.6	2.5	2.4	2.3	2.3	24	8.6	8.7	8.5	8.5	8.5	8.6	8.6	8.7	24	6.3	5.6	5.0	4.9	4.9	4.9	4.9	4.9
Alternative 3R	86	6	11	24	5.9	5.2	4.7	4.5	4.5	4.5	4.4	4.4	24	4.5	3.4	2.7	2.5	2.4	2.4	2.3	2.3	24	8.4	8.6	8.4	8.5	8.5	8.6	8.6	8.6	24	6.1	5.5	4.9	4.9	4.8	4.9	4.8	4.8
Alternative 4R	143	13	18	24	5.9	5.1	4.5	4.4	4.4	4.4	4.4	4.4	24	4.5	3.3	2.5	2.4	2.3	2.3	2.3	2.2	24	8.4	8.4	8.1	8.3	8.4	8.5	8.6	8.6	24	6.1	5.5	4.8	4.8	4.8	4.8	4.8	4.8
Alternative 5R	186	19	24	24	5.9	5.1	4.5	4.4	4.4	4.4	4.4	4.4	24	4.5	3.3	2.5	2.4	2.3	2.3	2.2	2.2	24	8.4	8.4	8.1	8.0	8.3	8.5	8.5	8.6	24	6.1	5.5	4.8	4.7	4.7	4.8	4.8	4.8
Alternative 6R	328	38	43	24	5.9	5.1	4.5	4.4	4.3	4.4	4.3	4.3	24	4.5	3.3	2.5	2.4	2.3	2.2	2.2	2.2	24	8.4	8.4	8.1	8.0	8.1	8.2	8.3	8.3	24	6.1	5.5	4.8	4.7	4.7	4.7	4.7	4.7

BCM input parameters (ng TEQ/kg dw dioxins/furans)
low: upstream = 2; lateral = 10; replacement value = 2 (AOPC 1)
mid: upstream = 4; lateral = 20; replacement value = 4 (AOPC 1)
high: upstream = 8; lateral = 40; replacement value = 6 (AOPC 1)

Notes:
1. BCM predictions use base case STM outputs revised June 2010 (Appendix C).
2. BCM model area = 430 acres and FS study area = 441 acres

a This is the start of construction for Alternatives 2 through 6. The 5-year model-predicted intervals associated with the BCM SWAC output are indexed to issuance of remedy decision documents. Activities during the assumed 5-year period between signing of the documents and start of construction are completion of EAAs, priority source control, negotiations, and initial remedial design. Implementation period starts from the issuance of remedy decision documents through the end of construction.

End of construction period.

BCM = bed composition model; cPAH = carcinogenic polycyclic aromatic hydrocarbon; EAA = early action area; FS = feasibility study; STM = sediment transport model; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent.

Table 9-5 Site-wide Arsenic, Total PCB, cPAH, and Dioxin/Furan Predicted SWACs Compared to Alternative 6 Predicted SWAC

Arsenic (mg/kg dw)

Alternative	Time from Issuance of Remedy Decision Documents (years)								Inter-alternative Change in SWAC[a]						
	10	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*15 yr*	*20 yr*	*25 yr*	*30 yr*	*35 yr*	*40 yr*	*45 yr*
Alternative 3C	10	9.7	9.4	9.3	9.2	9.2	9.2	9.1	6%	3%	2%	1%	1%	1%	0%
Alternative 4C	10	9.6	9.3	9.2	9.2	9.2	9.1	9.1	5%	2%	1%	1%	1%	0%	0%
Alternative 5C	10	9.6	9.3	9.2	9.2	9.2	9.2	9.1	5%	2%	1%	1%	1%	1%	0%
Alternative 6C	10	9.6	9.3	9.1	9.1	9.1	9.1	9.1	5%	2%	0%	0%	0%	0%	0%
Alternative 2R	10	9.8	9.4	9.3	9.2	9.2	9.2	9.2	7%	3%	2%	1%	1%	1%	1%
Alternative 3R	10	9.7	9.4	9.3	9.2	9.2	9.2	9.1	6%	3%	2%	1%	1%	1%	0%
Alternative 4R	10	9.7	9.4	9.3	9.2	9.2	9.2	9.1	6%	3%	2%	1%	1%	1%	0%
Alternative 5R	10	9.7	9.4	9.3	9.2	9.2	9.2	9.2	6%	3%	2%	1%	1%	1%	1%
Alternative 6R	10	9.7	9.4	9.3	9.2	9.2	9.1	9.1	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Total PCBs (µg/kg dw)

Alternative	Time from Issuance of Remedy Decision Documents (years)								Inter-alternative Change in SWAC[a]						
	10	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*15 yr*	*20 yr*	*25 yr*	*30 yr*	*35 yr*	*40 yr*	*45 yr*
Alternative 3C	86	65	52	49	46	45	44	43	40%	25%	20%	15%	13%	11%	9%
Alternative 4C	75	58	49	47	45	44	43	43	33%	20%	17%	13%	11%	9%	9%
Alternative 5C	75	55	47	46	44	44	43	43	29%	17%	15%	11%	11%	9%	9%
Alternative 6C	75	55	42	38	39	41	41	41	29%	7%	-3%	0%	5%	5%	5%
Alternative 2R	91	68	54	50	48	47	45	44	43%	28%	22%	19%	17%	13%	11%
Alternative 3R	86	65	52	49	46	45	44	43	40%	25%	20%	15%	13%	11%	9%
Alternative 4R	86	64	50	47	45	45	43	43	39%	22%	17%	13%	13%	9%	9%
Alternative 5R	86	64	50	48	45	45	43	43	39%	22%	19%	13%	13%	9%	9%
Alternative 6R	86	64	50	48	42	41	40	39	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Table 9-5 Site-wide Arsenic, Total PCB, cPAH, and Dioxin/Furan Predicted SWACs Compared to Alternative 6 Predicted SWAC

cPAHs (µg TEQ/kg dw)

Alternative	Time from Issuance of Remedy Decision Documents (years)								Inter-alternative Change in SWAC[a]						
	10	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*15 yr*	*20 yr*	*25 yr*	*30 yr*	*35 yr*	*40 yr*	*45 yr*
Alternative 3C	180	140	120	109	105	107	104	104	26%	14%	6%	2%	4%	1%	1%
Alternative 4C	170	130	110	106	104	106	103	103	21%	6%	3%	1%	3%	0%	0%
Alternative 5C	170	130	109	105	103	106	103	103	21%	6%	2%	0%	3%	0%	0%
Alternative 6C	170	130	109	102	101	104	102	102	21%	6%	-1%	-2%	1%	-1%	-1%
Alternative 2R	200	150	120	110	108	109	105	105	31%	14%	6%	5%	6%	2%	2%
Alternative 3R	180	140	120	109	105	107	104	104	26%	14%	6%	2%	4%	1%	1%
Alternative 4R	180	140	110	108	104	106	103	103	26%	6%	5%	1%	3%	0%	0%
Alternative 5R	180	140	110	110	106	107	104	104	26%	6%	6%	3%	4%	1%	1%
Alternative 6R	180	140	110	110	106	107	104	103	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Dioxin/Furan (ng TEQ/kg dw)

Alternative	Time from Issuance of Remedy Decision Documents (years)								Inter-alternative Change in SWAC[a]						
	10	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*15 yr*	*20 yr*	*25 yr*	*30 yr*	*35 yr*	*40 yr*	*45 yr*
Alternative 3C	5.9	5.2	4.7	4.5	4.5	4.5	4.4	4.4	17%	9%	4%	4%	4%	2%	2%
Alternative 4C	5.3	4.9	4.5	4.4	4.4	4.4	4.4	4.4	12%	4%	2%	2%	2%	2%	2%
Alternative 5C	5.3	4.6	4.4	4.4	4.4	4.4	4.4	4.4	7%	2%	2%	2%	2%	2%	2%
Alternative 6C	5.3	4.6	4.3	4.3	4.3	4.4	4.3	4.4	7%	0%	0%	0%	2%	0%	2%
Alternative 2R	6.1	5.3	4.7	4.6	4.5	4.5	4.4	4.4	19%	9%	7%	4%	4%	2%	2%
Alternative 3R	5.9	5.2	4.7	4.5	4.5	4.5	4.4	4.4	17%	9%	4%	4%	4%	2%	2%
Alternative 4R	5.9	5.1	4.5	4.4	4.4	4.4	4.4	4.4	16%	4%	2%	2%	2%	2%	2%
Alternative 5R	5.9	5.1	4.5	4.4	4.4	4.4	4.4	4.4	16%	4%	2%	2%	2%	2%	2%
Alternative 6R	5.9	5.1	4.5	4.4	4.3	4.4	4.3	4.3	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Notes:

1. SWACs reported are base case (mid input values) BCM outputs (Table 9-2a).
2. Year 5 is the start of construction for Alternatives 2 through 6. The 5-year model-predicted intervals associated with the BCM SWAC output are indexed to issuance of remedy decision documents. Activities during the assumed 5-year period between signing of the documents and start of construction are completion of EAAs, priority source control, negotiations and initial remedial design. Implementation period starts from the issuance of remedy decision documents through the end of construction.

a Inter-alternative change in SWAC is calculated using Alternative 6 Removal at the end of construction (year 45)

BCM = bed composition model; EAAs = early action areas; n/a = not applicable; SWAC = spatially-weighted average concentration

Percent reduction in SWAC from alternative to Year 45 Alternative 6 SWAC between 20 and 25%

Percent reduction in SWAC from alternative to Year 45 Alternative 6 SWAC equal or less than 20%

Table 9-6a Seafood Consumption Excess Cancer Risk Associated with Residual Surface Sediment Total PCB Concentrations for RME Scenarios Over Time

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Implemen-tation Period (years)	Adult Tribal RME (Tulalip data)							Child Tribal RME (Tulalip data)							Adult API RME						
				Time from Issuance of Remedy Decision Documents (years) [a]							*Time from Issuance of Remedy Decision Documents (years)* [a]							*Time from Issuance of Remedy Decision Documents (years)* [a]						
				10	*15*	*20*	*25*	*30*	*35*	*45*	*10*	*15*	*20*	*25*	*30*	*35*	*45*	*10*	*15*	*20*	*25*	*30*	*35*	*45*
EAA-Alternative 1	29	<5	<5	4×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	nc	7×10^{-5}	5×10^{-5}	4×10^{-5}	4×10^{-5}	4×10^{-5}	4×10^{-5}	nc	1×10^{-4}	7×10^{-5}	6×10^{-5}	6×10^{-5}	6×10^{-5}	6×10^{-5}	nc
Alternative 3C	86	4	9		2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	nc		4×10^{-5}	4×10^{-5}	4×10^{-5}	3×10^{-5}	3×10^{-5}	nc		7×10^{-5}	6×10^{-5}	6×10^{-5}	6×10^{-5}	6×10^{-5}	nc
Alternative 4C	143	7	12		2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	nc		4×10^{-5}	4×10^{-5}	4×10^{-5}	3×10^{-5}	3×10^{-5}	nc		6×10^{-5}	6×10^{-5}	6×10^{-5}	6×10^{-5}	5×10^{-5}	nc
Alternative 5C	186	8	13			2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	nc			4×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}	nc			6×10^{-5}	6×10^{-5}	5×10^{-5}	5×10^{-5}	nc
Alternative 6C	328	18	23					2×10^{-4}	2×10^{-4}	2×10^{-4}					3×10^{-5}	3×10^{-5}	3×10^{-5}					5×10^{-5}	5×10^{-5}	5×10^{-5}
Alternative 2R	59	4	9		2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	nc		4×10^{-5}	4×10^{-5}	4×10^{-5}	4×10^{-5}	4×10^{-5}	nc		7×10^{-5}	6×10^{-5}	6×10^{-5}	6×10^{-5}	6×10^{-5}	nc
Alternative 3R	86	6	11		2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	nc		4×10^{-5}	4×10^{-5}	4×10^{-5}	3×10^{-5}	3×10^{-5}	nc		7×10^{-5}	6×10^{-5}	6×10^{-5}	6×10^{-5}	6×10^{-5}	nc
Alternative 4R	143	13	18				2×10^{-4}	2×10^{-4}	2×10^{-4}	nc				4×10^{-5}	3×10^{-5}	3×10^{-5}	nc				6×10^{-5}	6×10^{-5}	6×10^{-5}	nc
Alternative 5R	186	19	24					2×10^{-4}	2×10^{-4}	nc					3×10^{-5}	3×10^{-5}	nc					6×10^{-5}	6×10^{-5}	nc
Alternative 6R	328	38	43							2×10^{-4}							3×10^{-5}							5×10^{-5}

Notes:
1. Risks estimated using the food web model (Windward 2010), alternative-specific total PCB concentrations in surface sediment (Table 9-2a), and assumed surface water dissolved concentrations of 0.6 ng/L, except Year 10 for Alternative 1 (0.9 ng/L).
2. Significant figures are displayed in accordance with the conventions established in the risk assessments.
3. Risks were not estimated for construction period because of uncertainties in PCB exposure concentrations during construction.
4. Residual risks corresponding to non-RME exposure scenarios are provided in Appendix M.

a Construction starts at year 5 for Alternatives 2 through 6. The 5-year model-predicted intervals associated with the BCM SWAC output are indexed to issuance of remedy decision documents. Activities during the assumed 5-year period between signing of the documents and start of construction are completion of EAAs, priority source control, negotiations, and initial remedial design. Implementation period starts from the issuance of remedy decision documents through the end of construction.

10^{-4}	Colored cells correspond to residual risk rounded to the nearest order of magnitude.
10^{-5}	
	Grey indicates construction period.

BCM Chemical Input Values (recommended)				
Chemical	Unit	Post-remedy Bed Sediment Replacement	Lateral	Upstream
PCB	µg/kg dw	20/60	300	35

API = Asian Pacific Islander; BCM = bed composition model; EAA = early action area; nc = not calculated; RME = reasonable maximum exposure; SWAC = spatially-weighted average concentration

Table 9-6b Seafood Consumption Non-Cancer Risk Associated with Residual Sediment Total PCB Concentrations for Human Health Scenarios and River Otter Over Time

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Implemen-tation Period (years)	Adult Tribal RME (Tulalip data)							Child Tribal RME (Tulalip data)							Adult API RME						
				Time from Issuance of Remedy Decision Documents (years) [a]							*Time from Issuance of Remedy Decision Documents (years)* [a]							*Time from Issuance of Remedy Decision Documents (years)* [a]						
				10	*15*	*20*	*25*	*30*	*35*	*45*	*10*	*15*	*20*	*25*	*30*	*35*	*45*	*10*	*15*	*20*	*25*	*30*	*35*	*45*
EAA-Alternative 1	29	<5	<5	9	6	5	5	5	5	nc	19	13	11	11	10	10	nc	6	4	4	3	3	3	nc
Alternative 3C	86	4	9		6	5	5	5	5	nc		12	11	10	10	10	nc		4	3	3	3	3	nc
Alternative 4C	143	7	12		5	5	5	5	5	nc		12	10	10	10	10	nc		4	3	3	3	3	nc
Alternative 5C	186	8	13			5	5	5	5	nc			10	10	10	10	nc			3	3	3	3	nc
Alternative 6C	328	18	23					4	4	4					9	9	9					3	3	3
Alternative 2R	59	4	9		6	5	5	5	5	nc		13	11	11	10	10	nc		4	4	3	3	3	nc
Alternative 3R	86	6	11		6	5	5	5	5	nc		12	11	10	10	10	nc		4	3	3	3	3	nc
Alternative 4R	143	13	18				5	5	5	nc				10	10	10	nc			3	3	3	3	nc
Alternative 5R	186	19	24					5	5	nc					10	10	nc				3	3	3	nc
Alternative 6R	328	38	43							4							9							3

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Implemen-tation Period (years)	Otter LOAEL-based HQ – with Juvenile Fish							Otter LOAEL-based HQ – without Juvenile Fish						
				Time from Issuance of Remedy Decision Documents (years) [a]							*Time from Issuance of Remedy Decision Documents (years)* [a]						
				10	*15*	*20*	*25*	*30*	*35*	*45*	*10*	*15*	*20*	*25*	*30*	*35*	*45*
EAA-Alternative 1	29	<5	<5	0.7	0.5	0.4	0.4	0.4	0.4	nc	0.9	0.6	0.5	0.5	0.5	0.5	nc
Alternative 3C	86	4	9		0.5	0.4	0.4	0.4	0.4	nc		0.6	0.5	0.5	0.5	0.4	nc
Alternative 4C	143	7	12		0.4	0.4	0.4	0.4	0.4	nc		0.5	0.5	0.5	0.4	0.4	nc
Alternative 5C	186	8	13			0.4	0.4	0.4	0.4	nc			0.5	0.5	0.4	0.4	nc
Alternative 6C	328	18	23					0.4	0.4	0.4					0.4	0.4	0.4
Alternative 2R	59	4	9		0.5	0.4	0.4	0.4	0.4	nc		0.6	0.5	0.5	0.5	0.5	nc
Alternative 3R	86	6	11		0.5	0.4	0.4	0.4	0.4	nc		0.6	0.5	0.5	0.5	0.4	nc
Alternative 4R	143	13	18				0.4	0.4	0.4	nc				0.5	0.4	0.4	nc
Alternative 5R	186	19	24					0.4	0.4	nc					0.4	0.4	nc
Alternative 6R	328	38	43							0.4							0.4

Notes:
1. Risks estimated using the food web model (Windward 2010), alternative-specific total PCB concentrations in surface sediment (Table 9-2a), and assumed surface water dissolved concentrations of 0.6 ng/L, except Year 10 for Alternative 1 (0.9 ng/L).
2. All tabulated risk units are Hazard Quotients.
3. Risks were not estimated for construction period because of uncertainties in PCB exposure concentrations during construction.
4. Residual risks corresponding to non-RME exposure scenarios are provided in Appendix M.

a Construction starts at year 5 for Alternatives 2 through 6. The 5-year model-predicted intervals associated with the BCM SWAC output are indexed to issuance of remedy decision documents. Activities during the assumed 5-year period between signing of the documents and start of construction are remediation of EAAs, priority source control, negotiations, and initial remedial design. Implementation period starts from the issuance of remedy decision documents through the end of construction.

HQ >1	Colored cells correspond to residual risk.
HQ ≤1	
	Grey indicates construction period.

BCM Chemical Input Values (mid)				
Chemical	Unit	Post-remedy bed sediment replacement	Lateral	Upstream
PCB	µg/kg dw	20/60	300	35

API = Asian Pacific Islander; BCM = bed composition model; EAA = early action area; HQ = hazard quotient; LOAEL = lowest observed adverse effect level; nc = not calculated; RME = reasonable maximum exposure; SWAC = spatially-weighted average concentration.

Table 9-7 Cumulative Excess Cancer Risks for Direct Contact Based on Predicted SWACs

Combined Alternatives

	Risk for Each Alternative																				
	EAAs-Alternative 1							Alternative 3 Combined (9 years[a])							Alternative 4 Combined (12 years[a])						
	Time from Issuance of Remedy Decision Documents (years)							*Time from Issuance of Remedy Decision Documents (years)*							*Time from Issuance of Remedy Decision Documents (years)*						
Receptor Group	*5[b]*	*10*	*15*	*20*	*25*	*30*	*35*	*5[b]*	*10*	*15*	*20*	*25*	*30*	*35*	*5[b]*	*10*	*15*	*20*	*25*	*30*	*35*
Site-wide Netfishing	6×10^{-6}	4×10^{-6}	4×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	6×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	6×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}
Tribal Clamming	1×10^{-5}	1×10^{-5}	1×10^{-5}	9×10^{-6}	9×10^{-6}	9×10^{-6}	9×10^{-6}	1×10^{-5}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	1×10^{-5}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}
Total Beach Play Area	7×10^{-6}	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 1	8×10^{-6}	7×10^{-6}	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	8×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	8×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 2	1×10^{-5}	1×10^{-5}	8×10^{-6}	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	1×10^{-5}	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	1×10^{-5}	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 3	8×10^{-6}	8×10^{-6}	7×10^{-6}	6×10^{-6}	6×10^{-6}	6×10^{-6}	7×10^{-6}	8×10^{-6}	7×10^{-6}	7×10^{-6}	6×10^{-6}	6×10^{-6}	6×10^{-6}	7×10^{-6}	8×10^{-6}	7×10^{-6}	7×10^{-6}	6×10^{-6}	6×10^{-6}	6×10^{-6}	7×10^{-6}
Beach 4	4×10^{-6}	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	9×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	9×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}
Beach 5	8×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}
Beach 6	1×10^{-5}	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	1×10^{-5}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	1×10^{-5}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}
Beach 7	4×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 8	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}

	Risk for Each Alternative													
	Alternative 5 Combined (13 years[a])							Alternative 6 Combined (23 years[a])						
	Time from Issuance of Remedy Decision Documents (years)							*Time from Issuance of Remedy Decision Documents (years)*						
Receptor Group	*5[b]*	*10*	*15*	*20*	*25*	*30*	*35*	*5[b]*	*10*	*15*	*20*	*25*	*30*	*35*
Site-wide Netfishing	6×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	6×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}
Tribal Clamming	1×10^{-5}	9×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	1×10^{-5}	9×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}
Total Beach Play Area	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 1	8×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	8×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 2	1×10^{-5}	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	1×10^{-5}	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}
Beach 3	8×10^{-6}	7×10^{-6}	7×10^{-6}	6×10^{-6}	6×10^{-6}	6×10^{-6}	7×10^{-6}	8×10^{-6}	7×10^{-6}	7×10^{-6}	6×10^{-6}	6×10^{-6}	6×10^{-6}	7×10^{-6}
Beach 4	9×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	9×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 5	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}
Beach 6	1×10^{-5}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	1×10^{-5}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}
Beach 7	4×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 8	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}

Table 9-7 Cumulative Excess Cancer Risks for Direct Contact Based on Predicted SWACs

Removal Alternatives

Receptor Group	Risk for Each Alternative																				
	Alternative 2 Removal (9 years[a])							Alternative 3 Removal (11 years[a])							Alternative 4 Removal (18 years[a])						
	Time from Issuance of Remedy Decision Documents (years)							*Time from Issuance of Remedy Decision Documents (years)*							*Time from Issuance of Remedy Decision Documents (years)*						
	5[b]	*10*	*15*	*20*	*25*	*30*	*35*	*5[b]*	*10*	*15*	*20*	*25*	*30*	*35*	*5[b]*	*10*	*15*	*20*	*25*	*30*	*35*
Site-wide Netfishing	6×10^{-6}	4×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	6×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	6×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}
Tribal Clamming	1×10^{-5}	9×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	1×10^{-5}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	1×10^{-5}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}
Total Beach Play Area	6×10^{-6}	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 1	8×10^{-6}	7×10^{-6}	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	8×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	8×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 2	1×10^{-5}	7×10^{-6}	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	1×10^{-5}	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	1×10^{-5}	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 3	8×10^{-6}	7×10^{-6}	7×10^{-6}	6×10^{-6}	6×10^{-6}	6×10^{-6}	7×10^{-6}	8×10^{-6}	7×10^{-6}	7×10^{-6}	6×10^{-6}	6×10^{-6}	6×10^{-6}	7×10^{-6}	8×10^{-6}	7×10^{-6}	7×10^{-6}	7×10^{-6}	7×10^{-6}	7×10^{-6}	7×10^{-6}
Beach 4	9×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	9×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	9×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 5	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}
Beach 6	1×10^{-5}	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	1×10^{-5}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	1×10^{-5}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}
Beach 7	4×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 8	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}

Receptor Group	Risk for Each Alternative													
	Alternative 5 Removal (24 years[a])							Alternative 6 Removal (43 years[a])						
	Time from Issuance of Remedy Decision Documents (years)							*Time from Issuance of Remedy Decision Documents (years)*						
	5[b]	*10*	*15*	*20*	*25*	*30*	*35*	*5[b]*	*10*	*15*	*20*	*25*	*30*	*35*
Site-wide Netfishing	6×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	6×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}
Tribal Clamming	1×10^{-5}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	1×10^{-5}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}
Total Beach Play Area	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	7×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 1	8×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	8×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 2	1×10^{-5}	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	1×10^{-5}	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 3	8×10^{-6}	7×10^{-6}	7×10^{-6}	7×10^{-6}	7×10^{-6}	7×10^{-6}	7×10^{-6}	8×10^{-6}	7×10^{-6}	7×10^{-6}	7×10^{-6}	7×10^{-6}	7×10^{-6}	7×10^{-6}
Beach 4	9×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	9×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 5	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 6	1×10^{-5}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	1×10^{-5}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}
Beach 7	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 8	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}

Notes:

1. Cumulative excess cancer risks include only the risk driver chemicals (arsenic, cPAH, total PCB, and dioxin/furan).
2. Significant figures are displayed in accordance with the conventions established in the risk assessments.
3. The BCM chemical input values used to predict concentrations at 5, 10, 15, 20, 25, and 30 years after start of construction are as follows:

Chemical	Unit	Upstream	Lateral
Total PCBs	µg/kg dw	35	300
Arsenic	mg/kg dw	9	13
cPAHs	µg TEQ /kg dw	70	1,400
Dioxins/Furans	ng TEQ /kg dw	4	20

4. PRGs for arsenic are set to natural background because 1×10^{-6} risk threshold is below this level.
5. Estimated implementation period for Alternative 6R is 43 years; results are only shown through first 35 years.

a Implementation period.

b This is the start of construction for Alternatives 2 through 6. The 5-year intervals associated with the BCM SWAC output are indexed to issuance of remedy decision documents. Activities during the assumed 5-year period between signing of the documents and start of construction are completion of EAAs, priority source control, negotiations, and initial remedial design. Implementation period starts from the issuance of remedy decision documents through the end of construction.

EAA = early action area; BCM = bed composition model; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent

Table 9-8 Predicted Total PCB Tissue Concentrations (µg/kg ww)

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Implemen-tation Period (years)	Clam Baseline = 110							Dungeness Crab Whole-Body (calculated) Baseline = 1,117							Dungeness Crab Edible Meat (calculated)[a] Baseline = 155						
				Time from Issuance of Remedy Decision Documents (years)[b]							*Time from Issuance of Remedy Decision Documents (years)[b]*							*Time from Issuance of Remedy Decision Documents (years)[b]*						
				10	*15*	*20*	*25*	*30*	*35*	*45*	*10*	*15*	*20*	*25*	*30*	*35*	*45*	*10*	*15*	*20*	*25*	*30*	*35*	*45*
EAA-Alternative 1	29	<5	<5	42	29	25	24	23	23	nc	479	329	290	281	274	272	nc	67	46	40	39	38	38	nc
Alternative 3C	86	4	9		27	24	23	22	22	nc		311	281	274	268	265	nc		43	39	38	37	37	nc
Alternative 4C	143	7	12		25	23	23	22	22	nc		295	274	270	265	263	nc		41	38	38	37	37	nc
Alternative 5C	186	8	13			23	22	22	22	nc			270	268	263	263	nc			38	37	37	37	nc
Alternative 6C	328	18	23					21	21	21					251	256	256					35	36	36
Alternative 2R	59	4	9		28	24	23	23	23	nc		318	286	277	272	270	nc		44	40	38	38	38	nc
Alternative 3R	86	6	11		27	24	23	22	22	nc		311	281	274	268	265	nc		43	39	38	37	37	nc
Alternative 4R	143	13	18				23	22	22	nc				270	265	265	nc				38	37	37	nc
Alternative 5R	186	19	24					22	22	nc					265	265	nc					37	37	nc
Alternative 6R	328	38	43							21							254							35

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Implemen-tation Period (years)	Perch Baseline = 1,436							Sole Whole-Body Baseline = 2,282							Sole Fillet (calculated)[a] Baseline = 1,200						
				Time from Issuance of Remedy Decision Documents (years)[b]							*Time from Issuance of Remedy Decision Documents (years)[b]*							*Time from Issuance of Remedy Decision Documents (years)[b]*						
				10	*15*	*20*	*25*	*30*	*35*	*45*	*10*	*15*	*20*	*25*	*30*	*35*	*45*	*10*	*15*	*20*	*25*	*30*	*35*	*45*
EAA-Alternative 1	29	<5	<5	539	374	316	302	292	288	nc	799	558	458	435	418	412	nc	420	293	241	229	220	217	nc
Alternative 3C	86	4	9		347	302	292	281	278	nc		511	435	418	400	394	nc		269	229	220	210	207	nc
Alternative 4C	143	7	12		323	292	285	278	274	nc		470	418	406	394	388	nc		247	220	214	207	204	nc
Alternative 5C	186	8	13			285	281	274	274	nc			406	400	388	388	nc			214	210	204	204	nc
Alternative 6C	328	18	23						264	264						371	371					189	195	195
Alternative 2R	59	4	9		357	309	295	288	285	nc		528	447	423	412	406	nc		278	235	223	217	214	nc
Alternative 3R	86	6	11		347	302	292	281	278	nc		511	435	418	400	394	nc		269	229	220	210	207	nc
Alternative 4R	143	13	18				285	278	278	nc				406	394	394	nc				214	207	207	nc
Alternative 5R	186	19	24					278	278	nc					394	394	nc					207	207	nc
Alternative 6R	328	38	43							261							365							192

Notes:

1. Tissue concentrations were estimated using the FWM (Windward 2010) and the alternative-specific total PCB concentrations in sediment, and assumed surface water dissolved concentrations of 0.6 ng/L, excep Year 10 for Alternative 1 (0.9 ng/L). For comparative purposes, baseline risk estimates were calculated using the food web model and the FS baseline dataset. These differ from the HHRA baseline risk estimates, which were based on actual tissue data and 95UCL.
2. Tissue concentrations were not estimated for construction period because of uncertainties in PCB exposure concentrations during construction.
3. Seafood consumption advisories based on Washington Department of Health methodology, which uses non-cancer effects to develop the advisory

a The FWM estimated total PCB concentrations in whole-body organisms. In the HHRA, some of the seafood ingestion scenarios included the consumption of edible meat (crabs) or fillet (English sole). Therefore conversion factors were developed. The conversion factors used to convert total PCB concentrations in whole-body organisms to lower concentrations in edible meat or fillet concentrations were 0.295 for slender crabs, 0.139 for Dungeness crabs, and 0.526 for English sole. These conversion factors were based on the ratio of whole-body to edible-meat concentrations detected in individual LDW fish tissue samples and detected in composite crab edible meat and hepatopancreas samples collected as part of the LDW RI

b Construction starts at year 5 for Alternatives 2 through 6. The 5-year model-predicted intervals associated with the BCM SWAC output are indexed to issuance of remedy decision documents. Activities during the assumed 5-year period between signing of the documents and start of construction are completion of EAAs, priority source control, negotiations, and initial remedial design. Implementation period starts from the issuance of remedy decision documents through the end of construction

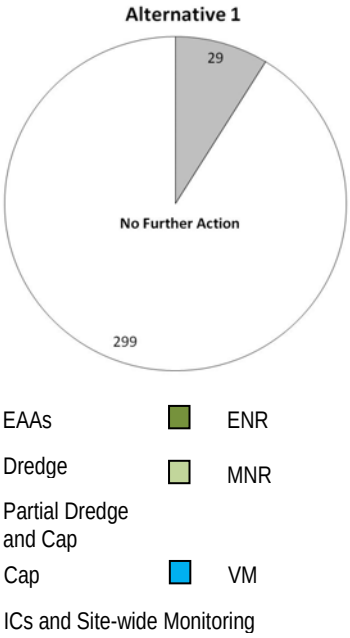
BCM = bed composition model; EAA = early action area; FS = feasibility study; FWM = food web model; HHRA = human health risk assessment; nc = not calculated; SWAC = spatially-weighted average concentration; UCL = upper confidence limit on the mean

Seafood Consumption Advisory	Total PCBs (µg/kg dw)
No limit	<43
One meal/week (four meals/month)	43 – 68
Two meals/month (one meal every other week)	69 – 140
One meal/month	141 – 187
No consumption (< one meal/month)	>187

Grey indicates construction period.

Table 9-9 Remedial Alternative 1: Scope, Costs, and Performance Summary

		1
Technology Application Summary		
Early Action Areas (acres)		29
Actively Remediated Area (acres)	Dredge	0
	Partial Dredge and Cap	0
	Cap	0
	ENR	0
	Habitat Area	(n/a)
Passively Remediated Area (acres)	MNR	0
	Verification Monitoring	0
	Habitat Area	(n/a)
Active/Passive/Total Managed Area (acres)		0/0/0
Institutional Controls and Site-wide Monitoring (acres)		n/a
Performance Dredging Volume (1,000s cy)		n/a
Construction Time (years)		n/a
Implementation Time Frame (years)		5
Cost Summary		
Costs (MM$)	Capital	0
	OM&M	0
	Total	66
Performance Summary – Time Frames for Achieving RAOs		
RAO	Risk Threshold Achieved	Years Post-Decision Documents
1 (Human Seafood Consumption)	Adult Tribal RME (10^{-4})	Not Estimated
	Time to reach long-term model-predicted concentration range in surface sediment	Not Estimated
2 (Human Direct Contact)	Cumulative ($\leq 1 \times 10^{-5}$)	Not Estimated
3 (Benthic Organisms)	CSL (>98%)	Not Estimated
	SQS (>98%)	
4 (Ecological)	River Otter (HQ <1)	Not Estimated



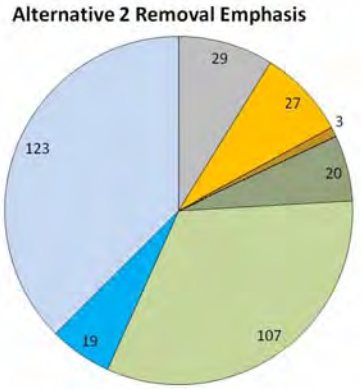
Note: numbers in pie chart represent acres.

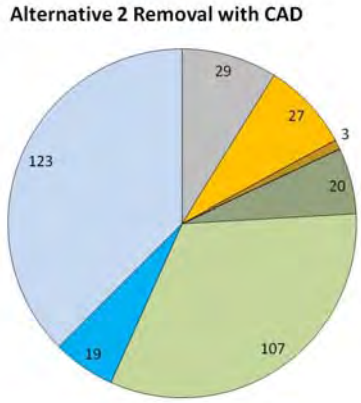
Notes:
Time frames for achieving RAOs were not estimated for Alternative 1 because it is not expected to achieve any of the RAOs.

AOPC = area of potential concern; CSL = cleanup screening level; EAA = early action area; ENR = enhanced natural recovery; MLLW = mean lower low water; MNR = monitored natural recovery; n/a = not applicable; OM&M = operations, maintenance and monitoring; RAO = remedial action objective; RME = reasonable maximum exposure; SMS = Sediment Management Standards; SQS = sediment quality standard.

Table 9-10 Remedial Alternatives 2R and 2R with CAD: Scope, Costs, and Performance Summaries

		2R	2R-CAD
Technology Application Summary			
Early Action Areas (acres)		29	29
Actively Remediated Area (acres)	Dredge	27	27
	Partial Dredge and Cap	3	3
	Cap	0	0
	ENR	0	0
	Habitat Area[a]	(12)	(12)
Passively Remediated Area (acres)	MNR(10)[b]	20	20
	MNR(20)[c]	107	107
	Verification Monitoring	19	19
	Habitat Area[a]	(61)	(61)
Active/Passive/Total Managed Area (acres)[d]		30/146/176	30/146/176
Institutional Controls and Site-wide Monitoring (acres)[e]		123	123
Performance Dredging Volume (1,000 cy)[f]		620	620
Construction Time (years)		4	4
Implementation Time Frame (years)		9	9
Cost Summary			
Costs (MM$)[g]	Capital	204	177
	OM&M	27	29
	Total	230	210
Performance Summary – Time to Achieve RAOs			
RAO	Risk Threshold Achieved	Years Post-Decision Documents	
1 (Human Seafood Consumption)	Adult Tribal RME (10^{-4})	9	9
	Time to reach long-term model-predicted concentration range in surface sediment	24	24
2 (Human Direct Contact)	Cumulative ($\leq 1 \times 10^{-5}$)	10	10
3 (Benthic Organisms)	CSL (>98%)	9	9
	SQS (>98%)	19	19
4 (Ecological)	River Otter (HQ <1)	9	9





EAAs
Dredge
Partial Dredge and Cap
Cap
ICs and Site-wide Monitoring
ENR
MNR (10)
MNR (20)
VM

Note: numbers in pie charts represent acres.

Notes:

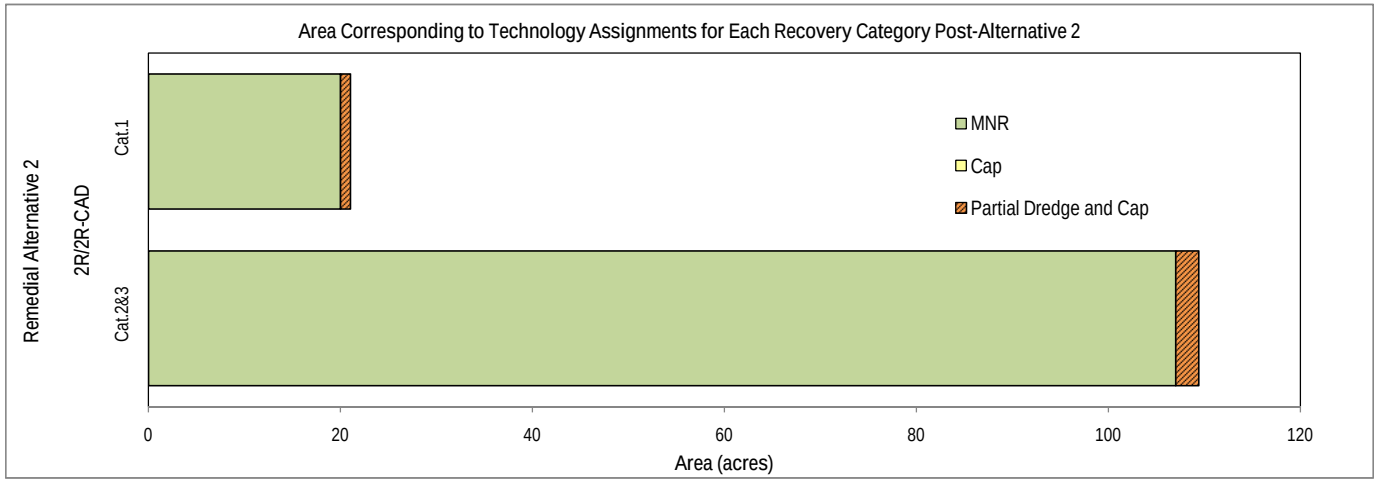
1. Remedial action levels for Alternatives 2 Removal and 2 Removal with CAD are as follows: arsenic: 93 mg/kg dw; total PCBs: 2,200 µg/kg dw; cPAHs: 5,500 µg TEQ/kg dw, dioxins/furans: 50 ng TEQ/kg dw, and benthic SMS (41 chemicals): CSL 10 (achieve CSL within 10 years).
2. The EAA costs and the costs of upland cleanup and source control are not included in cost estimates.

a Habitat areas (above -10 ft MLLW) require special management and are shown for reference only.
b MNR(10) is the area expected to be less than CSL (Alternative 2) within 10 years.
c MNR(20) is the area expected to be less than SQS in 20 years (applicable to areas below the RALs).
d The area remediated by the EAAs (29 acres) is not included in the active and total managed areas, but is nonetheless remediated and accounted for in terms of estimating the time frames.
e Additional 113 acres are outside of AOPC 2 and would need institutional controls and site-wide monitoring.
f The base-case performance dredge volume is the preliminary dredge volume (neat volume to maximum depth of SQS plus 50%) plus additional volume for technology assignment and performance-based contingency assumptions.
g Capital and OM&M costs are rounded to three significant figures, and total costs are rounded to two significant figures.

AOPC = area of potential concern; C = combined; CAD = contained aquatic disposal; CSL = cleanup screening level; EAA = early action area; ENR = enhanced natural recovery; MLLW = mean lower low water; MNR = monitored natural recovery; n/a = not applicable; OM&M = operations, maintenance and monitoring; R = removal; RAO = remedial action objective; RME = reasonable maximum exposure; SMS = Sediment Management Standards; SQS = sediment quality standard; TEQ = toxic equivalent; VM = verification monitoring.

Table 9-11 Remediated Surface Areas Outside the EAA and Dredge Footprint and Associated Number of Core Stations with SMS Chemistry Exceedances – Alternative 2

Remedial Alternative 2	Recovery Category	Cap / Partial Dredge and Cap			MNR		
		Station Counts		Surface Area (acres)	Station Counts		Surface Area (acres)
		> CSL	< CSL, > SQS		> CSL	< CSL, > SQS	
Removal	1	6	0	1	5	14	20
	2 and 3	4	0	2	32	8	107



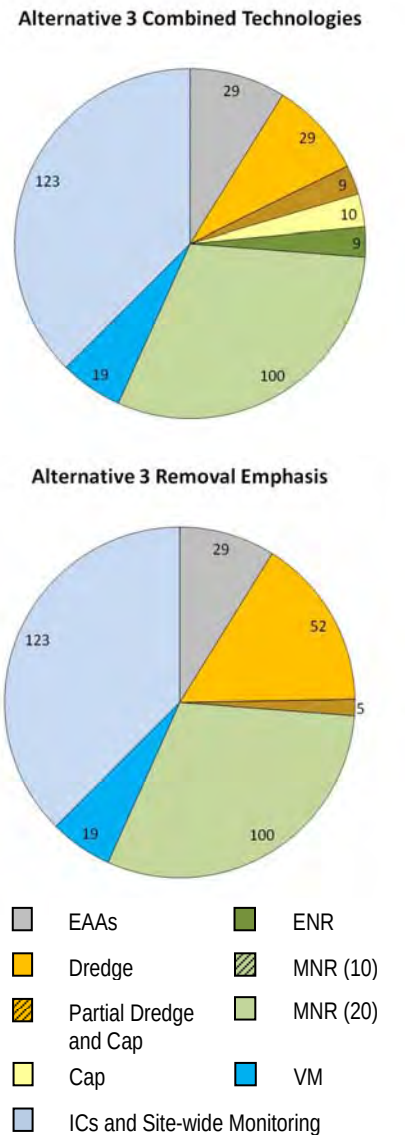
Notes:

1. Recovery Categories 1, 2, and 3 are all areas of the LDW, regardless of AOPCs and RAL exceedances, that are based on the predicted ability to recover naturally. Recovery Category 1 areas are presumed to have limited recovery potential. Recovery Category 2 areas have less certain recovery potential. Recovery Category 3 areas are predicted to recover.
2. Core counts may be conservative because some of the material at these locations may have been dredged. It is unconfirmed whether all contamination was removed and, in some instances, whether dredging actually occurred at these locations. Therefore, all remaining cores were included in the core counts.

AOPC = area of potential concern; CSL = cleanup screening level; MNR = monitored natural recovery; RAL = remedial action level; SQS = sediment quality standard

Table 9-12 Remedial Alternatives 3C and 3R: Scope, Costs, and Performance Summaries

		3C	3R
Technology Application Summary			
Early Action Areas (acres)		29	29
Actively Remediated Area (acres)	Dredge	29	52
	Partial Dredge and Cap	9	5
	Cap	10	0
	ENR	9	0
	Habitat Area[a]	(27)	(27)
Passively Remediated Area (acres)	MNR(10)[b]	0	0
	MNR(20)[c]	100	100
	Verification Monitoring	19	19
	Habitat Area[a]	(46)	(46)
Active/Passive/Total Managed Area (acres)[d]		57/119/176	57/119/176
Institutional Controls and Site-wide Monitoring (acres)[e]		123	123
Performance Dredging Volume (1,000s cy)[f]		570	790
Construction Time (years)		4	6
Implementation Time Frame (years)		9	11
Cost Summary			
Costs (MM$)[g]	Capital	197	267
	OM&M	26	25
	Total	220	290
Performance Summary – Time Frames for Achieving RAOs			
RAO	Risk Threshold Achieved	Years Post-Decision Documents	
1 (Human Seafood Consumption)	Adult Tribal RME (10^{-4})	9	11
	Time to reach long-term model-predicted concentration range in surface sediment	24	26
2 (Human Direct Contact)	Cumulative ($\leq 1 \times 10^{-5}$)	10	10
3 (Benthic Organisms)	CSL (>98%)	9	11
	SQS (>98%)	14	16
4 (Ecological)	River Otter (HQ <1)	9	11



Note: numbers in pie charts represent acres.

Notes:

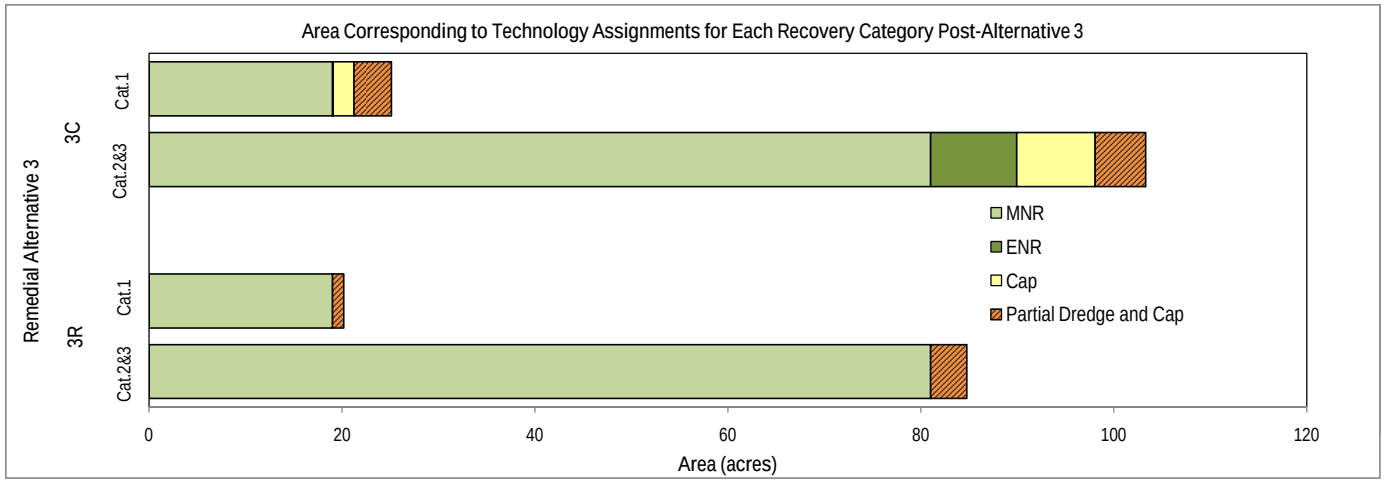
1. Remedial action levels for Alternatives 3 Combined and 3 Removal are as follows: arsenic: 93 and 28 (intertidal) mg/kg dw; total PCBs: 1,300 µg/kg dw; cPAHs: 3,800 and 900 (intertidal) µg TEQ/kg dw, dioxins/furans: 35 and 28 (intertidal) ng TEQ/kg dw, and benthic SMS (41 chemicals): CSL toxicity or chemistry.
2. The EAA costs and the costs of upland cleanup and source control are not included in cost estimates.

a Habitat areas (above -10 ft MLLW) require special management and are shown for reference only.
b Not applicable for Alternatives 3C and 3R.
c MNR(20) is the area expected to be less than SQS in 20 years (applicable to areas below the RALs).
d The area remediated by the EAAs (29 acres) is not included in the active and total managed areas, but is nonetheless remediated and accounted for in terms of estimating the time frames.
e Additional 113 acres are outside of AOPC 2 and would need institutional controls and site-wide monitoring.
f The base-case performance dredge volume is the preliminary dredge volume (neat volume to maximum depth of SQS plus 50%) plus additional volume for technology assignment and performance-based contingency assumptions.
g Capital and OM&M costs are rounded to three significant figures, and total costs are rounded to two significant figures.

AOPC = area of potential concern; C = combined; CSL = cleanup screening level; EAA = early action area; ENR = enhanced natural recovery; MLLW = mean lower low water; MNR = monitored natural recovery; n/a = not applicable; OM&M = operations, maintenance and monitoring; R = removal; RAO = remedial action objective; RME = reasonable maximum exposure; SMS = Sediment Management Standards; SQS = sediment quality standard; TEQ = toxic equivalent; VM = verification monitoring.

Table 9-13 Remediated Surface Areas Outside the EAA and Dredge Footprint and Associated Number of Core Stations with SMS Chemistry Exceedances – Alternative 3

Remedial Alternative 3	Recovery Category	Cap / Partial Dredge and Cap			ENR / MNR		
		Station Counts		Surface Area (acres)	Station Counts		Surface Area (acres)
		> CSL	< CSL, > SQS		> CSL	< CSL, > SQS	
Combined	1	6	0	6	5	11	19
	2 and 3	9	1	13	23	7	90
Removal	1	0	0	1	5	11	19
	2 and 3	1	0	4	15	5	81



Notes:

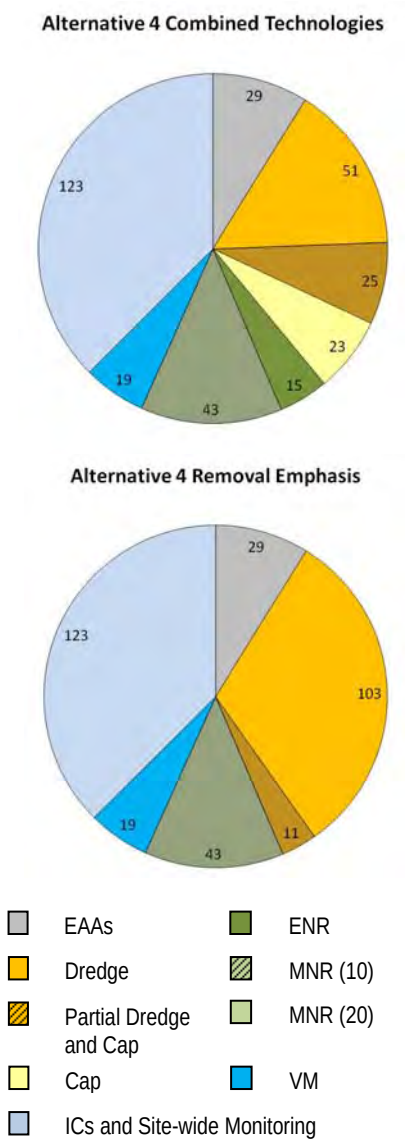
1. Recovery Categories 1, 2, and 3 are all areas of the LDW, regardless of AOPCs and RAL exceedances, that are based on the predicted ability to recover naturally. Recovery Category 1 areas are presumed to have limited recovery potential. Recovery Category 2 areas have less certain recovery potential. Recovery Category 3 areas are predicted to recover.

2. Core counts may be conservative because some of the material at these locations may have been dredged. It is unconfirmed whether all contamination was removed and, in some instances, whether dredging actually occurred at these locations. Therefore, al

AOPC = area of potential concern; CSL = cleanup screening level; ENR = enhanced natural recovery; MNR = monitored natural recovery; RAL = remedial action level; SQS = sediment quality standard

Table 9-14 Remedial Alternatives 4C and 4R: Scope, Costs, and Performance Summaries

		4C	4R
Technology Application Summary			
Early Action Areas (acres)		29	29
Actively Remediated Area (acres)	Dredge	51	103
	Partial Dredge and Cap	25	11
	Cap	23	0
	ENR	15	0
	Habitat Area[a]	(42)	(42)
Passively Remediated Area (acres)	MNR(10)[b]	43	43
	MNR(20)[c]	0	0
	Verification Monitoring	19	19
	Habitat Area[a]	(31)	(31)
Active/Passive/Total Managed Area (acres)[d]		114/62/176	114/62/176
Institutional Controls and Site-wide Monitoring (acres)[e]		123	123
Performance Dredging Volume (1,000s cy)[f]		740	1,200
Construction Time (years)		7	13
Implementation Time Frame (years)		12	18
Cost Summary			
Costs (MM$)[g]	Capital	272	424
	OM&M	22	20
	Total	290	440
Performance Summary – Time Frames for Achieving RAOs			
RAO	Risk Threshold Achieved	Years Post-Decision Documents	
1 (Human Seafood Consumption)	Adult Tribal RME (10^{-4})	12	18
	Time to reach long-term model-predicted concentration range in surface sediment	22	18
2 (Human Direct Contact)	Cumulative ($\leq 1 \times 10^{-5}$)	10	10
3 (Benthic Organisms)	CSL (>98%)	10	15
	SQS (>98%)	12	15
4 (Ecological)	River Otter (HQ <1)	12	18



Note: numbers in pie charts represent acres.

Notes:

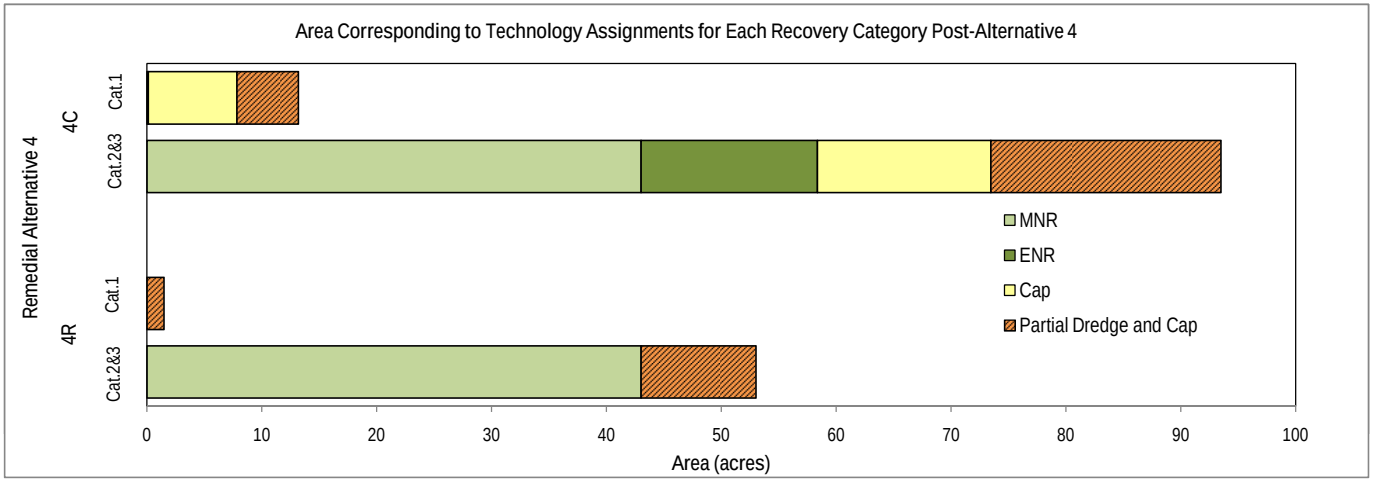
1. Remedial action levels for Alternatives 4 Combined and 4 Removal are as follows: arsenic: 57 and 28 (intertidal) mg/kg dw; total PCBs: 700 µg/kg dw; cPAHs: 1,000 and 900 (intertidal) µg TEQ/kg dw, dioxins/furans: 25 ng TEQ/kg dw, and benthic SMS (41 chemicals): SQS 10 (achieve SQS within 10 years).
2. The EAA costs and the costs of upland cleanup and source control are not included in cost estimates.

a Habitat areas (above -10 ft MLLW) require special management and are shown for reference only.
b MNR(<10) is the area expected to be less SQS (Alternative 4) within 10 years.
c Not applicable for Alternatives 4C and 4R.
d The area remediated by the EAAs (29 acres) is not included in the active and total managed areas, but is nonetheless remediated and accounted for in terms of estimating the time frames.
e Additional 113 acres are outside of AOPC 2 and would need institutional controls and site-wide monitoring.
f The base-case performance dredge volume is the preliminary dredge volume (neat volume to maximum depth of SQS plus 50%) plus additional volume for technology assignment and performance-based contingency assumptions.
g Capital and OM&M costs are rounded to three significant figures, and total costs are rounded to two significant figures.

AOPC = area of potential concern; C = combined; CSL = cleanup screening level; EAA = early action area; ENR = enhanced natural recovery; MLLW = mean lower low water; MNR = monitored natural recovery; n/a = not applicable; OM&M = operations, maintenance and monitoring; R = removal; RAO = remedial action objective; RME = reasonable maximum exposure; SMS = Sediment Management Standards; SQS = sediment quality standard; TEQ = toxic equivalent; VM = verification monitoring.

Table 9-15 Remediated Surface Areas Outside the EAA and Dredge Footprint and Associated Number of Core Stations with SMS Chemistry Exceedances – Alternative 4

Remedial Alternative 4	Recovery Category	Cap / Partial Dredge and Cap			ENR / MNR		
		Station Counts		Surface Area (acres)	Station Counts		Surface Area (acres)
		> CSL	< CSL, > SQS		> CSL	< CSL, > SQS	
Combined	1	8	2	13	0	0	0
	2 and 3	9	1	35	20	5	58
Removal	1	0	0	1	0	0	0
	2 and 3	1	0	10	9	3	43



Notes:

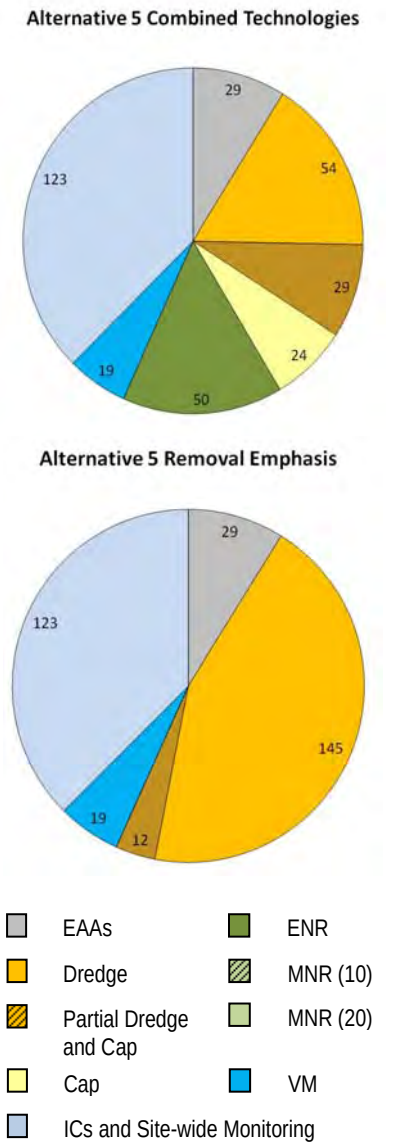
1. Recovery Categories 1, 2, and 3 are all areas of the LDW, regardless of AOPCs and RAL exceedances, that are based on the predicted ability to recover naturally. Recovery Category 1 areas are presumed to have limited recovery potential. Recovery Category 2 areas have less certain recovery potential. Recovery Category 3 areas are predicted to recover.

2. Core counts may be conservative because some of the material at these locations may have been dredged. It is unconfirmed whether all contamination was removed and, in some instances, whether dredging actually occurred at these locations. Therefore

AOPC = area of potential concern; CSL = cleanup screening level; ENR = enhanced natural recovery; MNR = monitored natural recovery; RAL = remedial action level; SQS = sediment quality standard

Table 9-16 Remedial Alternatives 5C and 5R/5R-T: Scope, Costs, and Performance Summaries

		5C	5R/5R-T
Technology Application Summary			
Early Action Areas (acres)		29	29
Actively Remediated Area (acres)	Dredge	54	145
	Partial Dredge and Cap	29	12
	Cap	24	0
	ENR	50	0
	Habitat Area[a]	(59)	(59)
Passively Remediated Area (acres)	MNR(10)[b]	0	0
	MNR(20)[c]	0	0
	Verification Monitoring	19	19
	Habitat Area[a]	(14)	(14)
Active/Passive/Total Managed Area (acres)[d]		157/19/176	157/19/176
Institutional Controls and Site-wide Monitoring (acres)[e]		123	123
Performance Dredging Volume (1,000s cy)[f]		770	1,500
Construction Time (years)		8	19
Implementation Time Frame (years)		13	24
Cost Summary			
Costs (MM$)[g]	Capital	294	538/588
	OM&M	20	17/17
	Total	310	550/600
Performance Summary – Time Frames for Achieving RAOs			
RAO	Risk Threshold Achieved	Years Post-Decision Documents	
1 (Human Seafood Consumption)	Adult Tribal RME (10^{-4})	13	24
	Time to reach long-term model-predicted concentration range in surface sediment	18	24
2 (Human Direct Contact)	Cumulative ($\leq 1 \times 10^{-5}$)	10	10
3 (Benthic Organisms)	CSL (>98%)	10	10
	SQS (>98%)	12	15
4 (Ecological)	River Otter (HQ <1)	13	24



Note: numbers in pie charts represent acres.

Notes:

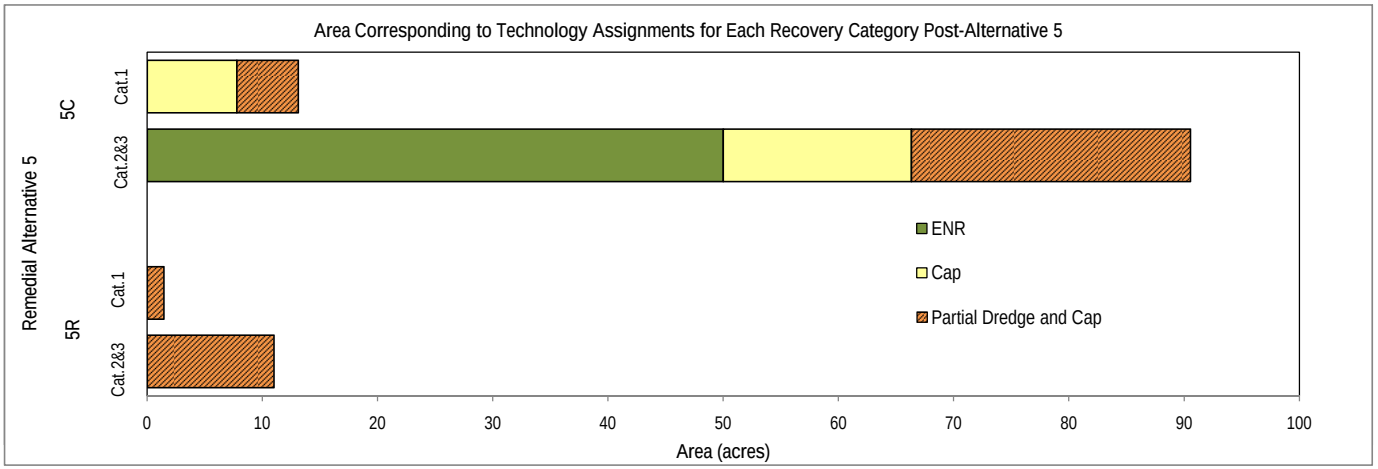
1. Remedial action levels for Alternatives 5 Combined and 5 Removal/5 Removal with Treatment are as follows: arsenic: 57 and 28 (intertidal) mg/kg dw; total PCBs: 240 µg/kg dw; cPAHs: 1,000 and 900 (intertidal) µg TEQ/kg dw, dioxins/furans: 25 ng TEQ/kg dw, and benthic SMS (41 chemicals): SQS toxicity or chemistry.
2. The EAA costs and the costs of upland cleanup and source control are not included in cost estimates.

a Habitat areas (above -10 ft MLLW) require special management and are shown for reference only.
b Not applicable for Alternatives 5C and 5R.
c Not applicable for Alternatives 5C and 5R.
d The area remediated by the EAAs (29 acres) is not included in the active and total managed areas, but is nonetheless remediated and accounted for in terms of estimating the time frames.
e Additional 113 acres are outside of AOPC 2 and would need institutional controls and site-wide monitoring.
f The base-case performance dredge volume is the preliminary dredge volume (neat volume to maximum depth of SQS plus 50%) plus additional volume for technology assignment and performance-based contingency assumptions.
g Capital and OM&M costs are rounded to three significant figures, and total costs are rounded to two significant figures.

AOPC = area of potential concern; C = combined; CSL = cleanup screening level; EAA = early action area; ENR = enhanced natural recovery; MLLW = mean lower low water; MNR = monitored natural recovery; n/a = not applicable; OM&M = operations, maintenance and monitoring; R = removal; RAO = remedial action objective; RME = reasonable maximum exposure; SMS = Sediment Management Standards; SQS = sediment quality standard; TEQ = toxic equivalent; VM = verification monitoring.

Table 9-17 Remediated Surface Areas Outside the EAA and Dredge Footprint and Associated Number of Core Stations with SMS Chemistry Exceedances – Alternative 5

Remedial Alternative 5	Recovery Category	Cap / Partial Dredge and Cap			ENR		
		Station Counts		Surface Area (acres)	Station Counts		Surface Area (acres)
		> CSL	< CSL, > SQS		> CSL	< CSL, > SQS	
Combined	1	8	2	13	0	0	0
	2 and 3	12	1	40	16	5	50
Removal	1	0	0	1	0	0	0
	2 and 3	1	0	11	0	0	0



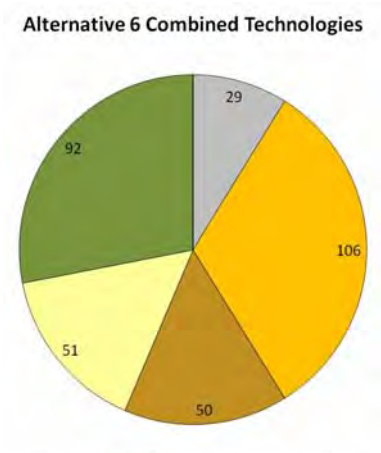
Notes:

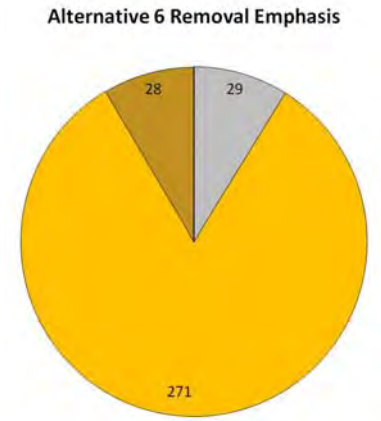
1. Recovery Categories 1, 2, and 3 are all areas of the LDW, regardless of AOPCs and RAL exceedances, that are based on the predicted ability to recover naturally. Recovery Category 1 areas are presumed to have limited recovery potential. Recovery Category 2 areas have less certain recovery potential. Recovery Category 3 areas are predicted to recover.
2. Core counts may be conservative because some of the material at these locations may have been dredged. It is unconfirmed whether all contamination was removed and, in some instances, whether dredging actually occurred at these locations. Therefore, all

AOPC = area of potential concern; CSL = cleanup screening level; ENR = enhanced natural recovery; RAL = remedial action level; SQS = sediment quality standard

Table 9-18 Remedial Alternatives 6C and 6R: Scope, Costs, and Performance Summaries

		6C	6R
Technology Application Summary			
Early Action Areas (acres)		29	29
Actively Remediated Area (acres)	Dredge	106	271
	Partial Dredge and Cap	50	28
	Cap	51	0
	ENR	92	0
	Habitat Area[a]	(98)	(98)
Passively Remediated Area (acres)	MNR(10)[b]	0	0
	MNR(20)[c]	0	0
	Verification Monitoring	0	0
	Habitat Area[a]	(0)	(0)
Active/Passive/Total Managed Area (acres)[d]		299/0/299	299/0/299
Institutional Controls and Site-wide Monitoring (acres)[e]		0	0
Performance Dredging Volume (1,000s cy)[f]		1,700	3,600
Construction Time (years)		18	38
Implementation Time Frame (years)		23	43
Cost Summary			
Costs (MM$)[g]	Capital	621	1,250
	OM&M	26	20
	Total	650	1,300
Performance Summary – Time Frames for Achieving RAOs			
RAO	Risk Threshold Achieved	Years Post-Decision Documents	
1 (Human Seafood Consumption)	Adult Tribal RME (10^{-4})	23	43
	Time to reach long-term model-predicted concentration range in surface sediment	23	43
2 (Human Direct Contact)	Cumulative ($\leq 1 \times 10^{-5}$)	10	10
3 (Benthic Organisms)	CSL (>98%)	10	10
	SQS (>98%)	12	15
4 (Ecological)	River Otter (HQ <1)	23	43





EAAs
ENR
Dredge
MNR (10)
Partial Dredge and Cap
MNR (20)
Cap
VM
ICs and Site-wide Monitoring

Note: numbers in pie charts represent acres.

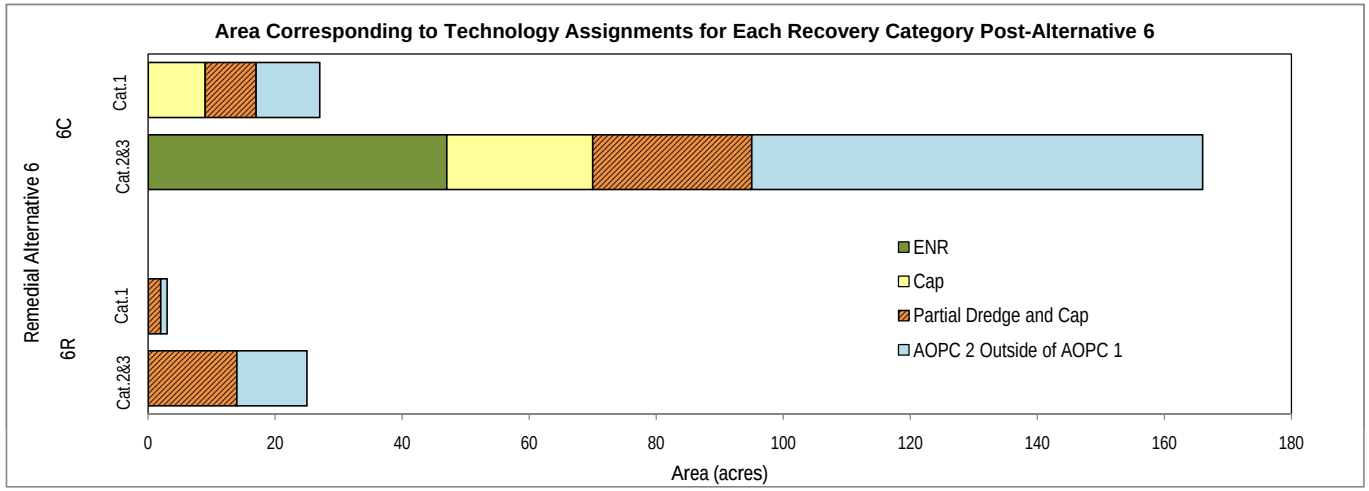
Notes:
1. Remedial action levels for Alternatives 6 Combined and 6 Removal are as follows: arsenic: 15 mg/kg dw; total PCBs: 100 µg/kg dw; cPAHs: 1,000 and 900 (intertidal) µg TEQ/kg dw, dioxins/furans: 15 ng TEQ/kg dw, and benthic SMS (41 chemicals): SQS toxicity or chemistry.
2. The EAA costs and the costs of upland cleanup and source control are not included in cost estimates.

a Habitat areas (above -10 ft MLLW) require special management and are shown for reference only.
b Not applicable for Alternatives 6C and 6R.
c Not applicable for Alternatives 6C and 6R.
d The area remediated by the EAAs (29 acres) is not included in the active and total managed areas, but is nonetheless remediated and accounted for in terms of estimating the time frames.
e Additional 113 acres are outside of AOPC 2 and would need institutional controls and site-wide monitoring.
f The base-case performance dredge volume is the preliminary dredge volume (neat volume to maximum depth of SQS plus 100%) plus additional volume for technology assignment and performance-based contingency assumptions.
g Capital and OM&M costs are rounded to three significant figures, and total costs are rounded to two significant figures.

AOPC = area of potential concern; C = combined; CSL = cleanup screening level; EAA = early action area; ENR = enhanced natural recovery; MLLW = mean lower low water; MNR = monitored natural recovery; n/a = not applicable; OM&M = operations, maintenance and monitoring; R = removal; RAO = remedial action objective; RME = reasonable maximum exposure; SMS = Sediment Management Standards; SQS = sediment quality standard; TEQ = toxic equivalent; VM = verification monitoring.

Table 9-19 Remediated Surface Areas Outside the EAA and Dredge Footprint and Associated Number of Core Stations with SMS Chemistry Exceedances - Alternative 6

Remedial Alternative 6	Recovery Category	Cap / Partial Dredge and Cap			ENR		
		Station Counts		Surface Area (acres)	Station Counts		Surface Area (acres)
		> CSL	< CSL, > SQS		> CSL	< CSL, > SQS	
Combined	1	8	4	26	0	0	0
	2 and 3	18	2	75	7	7	92
Removal	1	0	0	3	0	0	0
	2 and 3	0	0	25	0	0	0



Notes:

1. Recovery Categories 1, 2, and 3 are all areas of the LDW, regardless of AOPCs and RAL exceedances, that are based on the predicted ability to recover naturally. Recovery Category 1 areas are presumed to have limited recovery potential. Recovery Category 2 areas have less certain recovery potential. Recovery Category 3 areas are predicted to recover.

2. Core counts may be conservative because some of the material at these locations may have been dredged. It is unconfirmed whether all contamination was removed and, in some instances, whether dredging actually occurred at these locations. Therefore, all remaining cores were included in the core counts.

3. AOPC 2 outside of AOPC 1 includes partial dredging, capping, or ENR (low risk of exposing buried contamination >SQS).

AOPC = area of potential concern; CSL = cleanup screening level; ENR = enhanced natural recovery; RAL = remedial action level; SQS = sediment quality standard

Table 9-20 Remedial Alternatives, Remedial Action Levels, and Model Predicted Long-term Outcomes

Remedial Alternative and Implementation Period[a]	Remedial Action Levels	Remedial Alternatives and Predicted Outcomes			
		RAO 1: Human Health – Seafood Consumption for PCBs[b] (see Tables 9-5 and 9-6a)	RAO 2: Human Health – Direct Contact[c] (see Tables 9-3, 9-7, and M-8)	RAO 3: Ecological Health – Benthic[d] (see Table 9-2b)	RAO4: Ecological Health – Seafood Consumption – River Otter (see Table 9-6b)
Alternative 1 No Further Action after removal or capping of EAAs (5 years)	n/a	Incremental risk reduction.	Incremental direct contact risk reduction.	Incremental reduction in CSL and SQS exceedances.	Incremental HQ reduction.
Alternative 2 – removal emphasis with upland disposal/MNR (9 years) Alternative 2 with CAD – dredge emphasis with contained aquatic disposal/MNR (9 years)	Total PCBs: 1,300 to 2,200 µg/kg dw cPAHs: 5,500 µg TEQ/kg dw Dioxins/Furans: 50 ng TEQ/kg dw Arsenic: 93 mg/kg dw SMS chemicals: achieve CSL within 10 years	Immediately following implementation (9 yrs): Predicted to achieve 10^{-4} magnitude risk for adult tribal, child tribal and adult API. Seafood consumption exposures further reduced through a multi-layered program of advisories, outreach, and education. River-wide recovery processes monitored to assess long-term human health risk reduction. 5 years post-implementation (14 yrs): Predicted to achieve 10^{-5} magnitude risk for child tribal. 15 years post-implementation (24 yrs): All four risk drivers predicted to reach modeled long-term concentration ranges site-wide. Modeled long-term non cancer risk; HQ >1	Immediately following implementation (9 yrs): Predicted to achieve 1×10^{-5} cumulative risk and HQ <1 for netfishing (site-wide), tribal clamming, and assumed beach play areas (each beach); achieves 1×10^{-6} risk for dioxins/ furans and total PCBs in all areas. Predicted to achieve 10^{-6} magnitude risk for arsenic for netfishing (site-wide) and beach play and 10^{-5} magnitude risk for tribal clamming. Predicted to achieve 1×10^{-6} risk for cPAHs netfishing (site-wide) and tribal clamming and 10^{-6} magnitude risk for beach play. Predicted to achieve MTCA natural background for arsenic for all exposure areas. 15 years post-implementation (24 yrs): Predicted to achieve MTCA unrestricted cleanup level for cPAHs for all beaches except Beach 3.	Immediately following implementation (9 yrs): predicted to achieve CSL 10 years post-implementation (19 yrs): predicted to achieve SQS. Note: Recovery Category 1 areas subject to natural recovery in Alternative 2; therefore, modeled times may be under-predicted.	Immediately following implementation (9 yrs): Predicted to achieve HQ <1.
Alternative 3 removal emphasis (3R) – dredge with upland disposal/MNR (11 years) Alternative 3 combined technology (3C) – ENR/cap/MNR where appropriate, otherwise dredge with upland disposal (9 years)	Total PCBs: 1,300 µg/kg dw cPAHs: 3,800 µg TEQ/kg dw 900 µg TEQ/kg dw (intertidal) Dioxins/Furans: 35 ng TEQ/kg dw 28 ng TEQ/kg dw (intertidal) Arsenic: 93 mg/kg dw 28 mg/kg dw (intertidal) SMS chemicals: CSL toxicity or chemistry	Immediately following implementation (9 yrs 3C; 11 yrs 3R): Predicted to achieve 10^{-4} magnitude risk for adult tribal, child tribal and adult API. Seafood consumption exposures further reduced through a multi-layered program of advisories, outreach, and education. River-wide recovery processes monitored to assess long-term human health risk reduction. 5 years post-implementation (14 yrs 3C; 16 yrs 3R): Predicted to achieve 10^{-5} magnitude risk for child tribal. 15 years post-implementation (24 yrs 3C; 26 yrs 3R): All four risk drivers predicted to reach modeled long-term concentration ranges site-wide. Modeled long-term non cancer risk; HQ >1	Immediately following implementation (9 yrs 3C; 11 yrs 3R): Predicted to achieve 1×10^{-5} cumulative risk and HQ <1 for netfishing, tribal clamming, and assumed beach play areas (each beach); achieves 1×10^{-6} risk for dioxins/ furans and total PCBs in all areas. Predicted to achieve 10^{-6} magnitude risk for arsenic for netfishing (site-wide) and beach play and 10^{-5} magnitude risk for tribal clamming. Predicted to achieve 1×10^{-6} risk for cPAHs netfishing (site-wide) and tribal clamming and 10^{-6} magnitude risk for beach play. Predicted to achieve MTCA natural background for arsenic for all exposure areas. 5 years post-implementation (14 yrs 3C; 16 yrs 3R): Predicted to achieve MTCA unrestricted cleanup level for cPAHs for all beaches except Beach 3.	Immediately following implementation (9 yrs 3C; 11 yrs 3R): Predicted to achieve CSL 5 years post-implementation (14 yrs 3C; 16 yrs 3R): Predicted to achieve SQS.	Immediately following implementation (9 yrs 3C; 11 yrs 3R): Predicted to achieve HQ <1.
Alternative 4 removal emphasis (4R) – dredge with upland disposal/MNR (18 years) Alternative 4 combined technology (4C) – ENR/cap/MNR where appropriate, otherwise dredge with upland disposal (12 years)	Total PCBs: 240 to 700 µg/kg dw cPAHs: 1,000 µg TEQ/kg dw 900 µg TEQ/kg dw (intertidal) Dioxins/Furans: 25 ng TEQ/kg dw Arsenic: 57 mg/kg dw 28 mg/kg dw (intertidal) SMS chemicals: achieve SQS within 10 years	Immediately following implementation (12 yrs 4C; 18 yrs 4R): predicted to achieve 10^{-4} risk magnitude for adult tribal, child tribal and adult API. Seafood consumption exposures further reduced through a multi-layered program of advisories, outreach, and education. River-wide recovery processes monitored to assess long-term human health risk reduction. All four risk drivers predicted to reach modeled long-term concentration ranges site-wide by Alternative 4R. 5 years post-implementation (17 yrs 4C; 23 yrs 4R): Predicted to achieve 10^{-5} magnitude risk for child tribal. 10 years post-implementation (22 yrs 4C): All four risk drivers predicted to reach modeled long-term concentration ranges site-wide by Alternative 4C. Modeled long-term non cancer risk; HQ >1	Immediately following implementation (12 yrs 4C; 18 yrs 4R): Predicted to achieve 1×10^{-5} cumulative risk and HQ <1 for netfishing, tribal clamming, and assumed beach play areas (each beach); achieves 1×10^{-6} risk for dioxins/ furans and total PCBs in all areas. Predicted to achieve 10^{-6} magnitude risk for arsenic for netfishing (site-wide) and beach play and 10^{-5} magnitude risk for tribal clamming. Predicted to achieve 1×10^{-6} risk for cPAHs netfishing (site-wide) and tribal clamming and 10^{-6} magnitude risk for beach play. Predicted to achieve MTCA natural background for arsenic for all exposure areas. Predicted to achieve MTCA unrestricted cleanup level for cPAHs for all beaches except Beach 3.	Immediately following implementation (12 yrs 4C; 18 yrs 4R): Predicted to achieve SQS.	Immediately following implementation (12 yrs 4C; 18 yrs 4R): Predicted to achieve HQ <1.

Table 9-20 Remedial Alternatives, Remedial Action Levels, and Model Predicted Long-term Outcomes

Remedial Alternative and Implementation Period[a]	Remedial Action Levels	Remedial Alternatives and Predicted Outcomes			
		RAO 1: Human Health – Seafood Consumption for PCBs[b] (see Tables 9-5 and 9-6a)	RAO 2: Human Health – Direct Contact[c] (see Tables 9-3, 9-7, and M-8)	RAO 3: Ecological Health – Benthic[d] (see Table 9-2b)	RAO4: Ecological Health – Seafood Consumption – River Otter (see Table 9-6b)
Alternative 5 removal emphasis (5R) – dredge with upland disposal (24 years) Alternative 5 removal with treatment (5RT) – dredge with soil washing treatment and disposal/re-use[d] (24 years) Alternative 5 combined technology (5C) – ENR/cap where appropriate, otherwise dredge with upland disposal (13 years)	Total PCBs: 240 µg/kg dw cPAH s: 1,000 µg TEQ/kg dw 900 µg TEQ/kg dw (intertidal) Dioxins/Furans: 25 ng TEQ/kg dw Arsenic: 57 mg/kg dw 28 mg/kg dw (intertidal) SMS chemicals: SQS toxicity or chemistry	Immediately following implementation (13 yrs 5C; 24 yrs 5R): Predicted to achieve 10^{-4} magnitude risk for adult tribal and adult API, and 10^{-5} risk range for child tribal. Seafood consumption exposures would be further reduced through a multi-layered program of advisories, outreach, and education. River-wide recovery processes would be monitored to assess long-term human health risk reduction. All four risk drivers predicted to reach modeled long-term concentration ranges site-wide by Alternative 5R. 5 years post-implementation (18 yrs 5C): All four risk drivers predicted to reach modeled long-term concentration ranges site-wide by Alternative 5C. Modeled long-term non cancer risk; HQ >1	Immediately following implementation (13 yrs 5C; 24 yrs 5R): Predicted to achieve 1×10^{-5} cumulative risk and HQ<1 for netfishing, tribal clamming, and assumed beach play areas (each beach); achieves 1×10^{-6} risk for dioxins/ furans and total PCBs in all areas. Predicted to achieve 10^{-6} magnitude risk for arsenic for netfishing (site-wide) and beach play and 10^{-5} magnitude risk for tribal clamming. Predicted to achieve 1×10^{-6} risk for cPAHs netfishing (site-wide) and tribal clamming and 10^{-6} magnitude risk for beach play. Predicted to achieve MTCA natural background for arsenic for all exposure areas. Predicted to achieve MTCA unrestricted cleanup level for cPAHs for all beaches except Beach 3.	Immediately following implementation (13 yrs 5C; 24 yrs 5R): Predicted to achieve SQS.	Immediately following implementation (13 yrs 5C; 24 yrs 5R): Predicted to achieve HQ<1.
Alternative 6 removal emphasis (6R) – dredge with upland disposal (43 years) Alternative 6 combined technology (6C) – ENR/cap where appropriate, otherwise dredge with upland disposal (23 years)	Total PCBs: 100 µg/kg dw cPAHs: 1,000 µg TEQ/kg dw 900 µg TEQ/kg dw (intertidal) Dioxins/Furans: 15 ng TEQ/kg dw Arsenic: 15 mg/kg dw SMS chemicals: SQS toxicity or chemistry	Immediately following implementation (23 yrs 6C; 43 yrs 6R): Predicted to achieve 10^{-4} magnitude risk for adult tribal and adult API and 10^{-5} magnitude risk for child tribal. All four risk drivers predicted to reach modeled long-term concentration ranges site-wide. Seafood consumption exposures further reduced through a multi-layered program of advisories, outreach, and education. River-wide recovery processes monitored to assess long-term human health risk reduction. Modeled long-term non cancer risk; HQ >1	Immediately following implementation (23 yrs 6C; 43 yrs 6R): achieve 1×10^{-5} cumulative risk and HQ <1 for netfishing, tribal clamming, and assumed beach play areas (each beach) achieves 1×10^{-6} risk for dioxins/furans and total PCBs in all areas. Predicted to achieve 10^{-6} magnitude risk for arsenic for netfishing (site-wide) and beach play and 10^{-5} magnitude risk for tribal clamming. Predicted to achieve 1×10^{-6} risk for cPAHs netfishing (site-wide) and tribal clamming and 10^{-6} magnitude risk for beach play. Predicted to achieve MTCA natural background for arsenic for all exposure areas. Predicted to achieve MTCA unrestricted cleanup level for cPAHs for all beaches except Beach 3.	Immediately following implementation (23 yrs 6C; 43 yrs 6R): Predicted to achieve SQS.	Immediately following implementation (23 yrs 6C; 43 yrs 6R): Predicted to achieve HQ<1.

Notes:

a Alternatives 2 through 6 include institutional controls and site-wide monitoring. Implementation period = 5 years from remedy decision documents plus construction period (see Figure 9-2).

b Only risks from total PCBs are discussed for human health seafood consumption because sediment to tissue relationships could not be developed for the other three risk drivers. No alternative can meet the natural background PRGs for total PCBs (2 µg/kg dw) or dioxins/furans (2 ng TEQ/kg dw). Model-predicted long-term (25 years) and site-wide outcomes for all four risk-driver chemicals and all alternatives, excluding Alternative 1, are approximately: 40 to 50 µg/kg dw (total PCBs), 9 to 10 mg/kg dw (arsenic), 100 to 110 mg TEQ/kg dw (cPAHs), and 4 to 5 ng TEQ/kg dw (dioxins/furans).

c All alternatives are predicted to achieve the cumulative direct contact risk of 1×10^{-5} in beach play areas. All beaches are below the 90th percentile (WAC 173-340-709 (3)) but above the UCL95 of the natural background dataset for arsenic. All beaches except Beach 3 are below a concentration of 140 µg TEQ/kg dw (MTCA Method B unrestricted soil direct contact; WAC 173-340-740 (3)) and thereby comply with the MTCA ARAR. The BCM model output for Beach 3 is influenced by a lateral source.

d Reduction of SQS and CSL exceedances sufficient to meet the RAO 3 criteria is dependent on adequate source control and natural recovery during construction. Achievement may take a few years longer if these two factors are not considered. Localized recontamination is expected (see Appendix J) but not accounted for in the results presented in this table.

AOPC = area of potential concern; API = Asian Pacific Islander; ARAR = applicable or relevant and appropriate requirements; BCM = bed composition model; CAD = contained aquatic disposal; CERCLA = Comprehensive Environmental Response; Compensation; and Liability Act; CSL = cleanup screening level; ENR = enhanced natural recovery; HQ = hazard quotient; MNR = monitored natural recovery; MTCA = Model Toxics Control Act; n/a = not applicable; PCB = polychlorinated biphenyl; RAO = remedial action objective; SMS = Sediment Management Standards; SQS = sediment quality standard; TEQ = toxic equivalent; UCL = upper confidence limit on the mean

Table 9-21 Remaining Human Health Chemicals of Concern for Consideration in FS and Expected Risk Outcomes

Human Health Chemical of Concern		Risk Estimate[a]	Additional Considerations[b]	Expected Outcome
Semivolatile Organics	bis(2-ethylhexyl) phthalate (BEHP)	6×10^{-6}	Infrequently detected (15%) in LDW tissue samples. RLs were elevated in the initial analysis because of sample dilution requirements. A subset of samples was reanalyzed, and lower RLs were achieved, suggesting that initial analysis results were biased high. Approximately 80% of the surface sediment locations with BEHP concentrations above the SQS also had PCB concentrations above the SQS. Thus, remediation of PCBs in areas with these SQS exceedances will reduce BEHP concentrations in surface sediment.	Baseline risk is within EPA target risk range.
	Pentachloro-phenol	9×10^{-5}	Rarely detected (6%) in LDW tissue samples. A subset of samples was reanalyzed, and much lower RLs were achieved. Also, the only two original detected results that were reanalyzed were not confirmed, suggesting that the results of the initial analysis were biased high and pentachlorophenol may not have been present. Also rarely detected (2%) in sediment samples.	Baseline risk is within EPA target risk range.
	Carbazole	5×10^{-5}	Not detected in sediment. Tissue sample results were JN qualified because of analytical interference, but only 1% of the samples had detectable concentrations.	Baseline risk is within EPA target risk range.
Metals	Tributyltin (TBT)	3 (HQ)[c]	Risk estimate is driven primarily by concentrations in clams. Several clam sampling locations will be remediated as part of early actions, which may reduce TBT concentrations in clams.	Legacy compound expected to be managed by natural recovery.
	Vanadium	2 (HQ)[c]	Exposure concentration in LDW surface sediment (average of 58 mg/kg dw) was less than PSAMP rural Puget Sound concentration (64 mg/kg dw [90th percentile]).	Baseline concentrations are below background.
Organochlorine pesticides	Aldrin	5×10^{-5}	Rarely detected (2%) at very low concentrations (2 µg/kg or less) that were likely biased high because of interference from PCBs.	Baseline risk is within EPA target risk range.
	alpha-BHC	2×10^{-5}	Rarely detected (2%) at very low concentrations (2 µg/kg or less) that were likely biased high because of interference from PCBs.	Baseline risk is within EPA target risk range.
	beta-BHC	6×10^{-6}	Rarely detected (2%) at concentrations that were likely biased high because of interference from PCBs. The highest concentration in surface sediment was detected at the head of Slip 4, which is an EAA.	Baseline risk is within EPA target risk range.

Table 9-21 Remaining Human Health Chemicals of Concern for Consideration in FS and Expected Risk Outcomes

Human Health Chemical of Concern		Risk Estimate[a]	Additional Considerations[b]	Expected Outcome
Organochlorine pesticides	Total chlordane	6×10^{-6}	Detected concentrations in surface sediment were likely biased high because of interference from PCBs. The two highest concentrations in surface sediment were at the head of Slip 4, which is an EAA.	Baseline risk is within EPA target risk range.
	Total DDTs	2×10^{-5}	Although DDT and its isomers were frequently detected in surface sediment and tissue samples, DDT concentrations may have been biased high because of PCB interference. Tissue data were JN-qualified.	Baseline risk is within EPA Target Risk Range.
	Dieldrin	1×10^{-4}	Rarely detected (4%) at concentrations that were likely biased high because of interference from PCBs. The highest concentration in surface sediment was detected at the head of Slip 4, which is an EAA.	Managed by Alternatives 1 and 2.
	gamma through BHC	6×10^{-6}	Rarely detected (6%) at low concentrations (7 µg/kg or less) that were likely biased high because of interference from PCBs.	Baseline risk is within EPA target risk range.
	Heptachlor	1×10^{-5}	Rarely detected (3%) at very low concentrations (5 µg/kg or less) that were likely biased high because of interference from PCBs.	Baseline risk is within EPA target risk range.
	Heptachlor-epoxide	3×10^{-5}	Rarely detected (3%) at very low concentrations (5 µg/kg or less) that were likely biased high because of interference from PCBs.	Baseline risk is within EPA target risk range.
	Hexachloro-benzene	1×10^{-5}	Rarely detected (6%) at concentrations that were likely biased high because of interference from PCBs.	Baseline risk is within EPA target risk range.
	Toxaphene	6×10^{-6}	Rarely detected (1%) in sediment.	Baseline risk is within EPA target risk range.

Notes:

a Risk estimates are from the HHRA (Windward 2008b) and are for seafood consumption with one exception, toxaphene, which is for direct contact (tribal netfishing). The seafood consumption excess cancer risk estimates are for the Adult Tribal RME seafood consumption scenario (using Tulalip data). Adult Tribal RME had the highest cancer risk estimates among the RME seafood consumption scenarios. The direct contact risk estimate presented for toxaphene is the highest risk estimate for any direct contact scenario for toxaphene reported in the RI (Windward 2010).

b Detection frequency and concentrations in tissue are based on data in the RI baseline dataset.

c HQs were below 1 for the Adult Tribal RME scenario based on Tulalip data. HQs listed in table are for the Child Tribal RME seafood consumption scenario based on Tulalip data.

EAA = early action areas; EPA = U.S. Environmental Protection Agency; HHRA = human health risk assessment; HQ = hazard quotient; JN = tentatively identified compound present; LDW = Lower Duwamish Waterway; PSAMP = Puget Sound Ambient Monitoring Program; RL = reporting limit; RME = reasonable maximum exposure; SQS = sediment quality standard

Table 9-22 Remaining Ecological Chemicals of Concern for Consideration in FS and Expected Outcomes

Ecological Chemical of Concern		Receptor of Concern	Maximum NOAEL-Based Hazard Quotient[a]	Maximum LOAEL-Based Hazard Quotient[a]	Additional Considerations[b]	Expected Outcome
Metals	Cadmium	juvenile chinook salmon, English sole, Pacific staghorn sculpin	6.1	1.2	The site-wide average concentration of cadmium will likely be reduced through remediation of EAAs to concentrations corresponding to a LOAEL-based HQ of less than 1.0.	Managed by Alternative 1
	Chromium	spotted sandpiper; Area 2[c]	8.8	1.8	The LOAEL-based HQ was greater than 1.0 in only one area (Area 2 of sandpiper habitat). The HQ would have been less than 1.0 if the single anomalously high benthic invertebrate tissue sample from RM 3.0 West was excluded. This sample was collected from the beach just south of Slip 4 on the western shoreline. Chromium concentrations in surface sediment were low in this area. This area is a candidate for verification monitoring during remedial design.	May require verification monitoring
	Copper	spotted sandpiper; Area 3[c]	1.5	1.1	The LOAEL-based HQ was greater than 1.0 in only one area (Area 3 of sandpiper habitat). The HQ will likely be reduced to less than 1.0 following remediation of EAAs (Alternative 1). Also, the average concentration in surface sediment (57 mg/kg dw)[b] from Area 3 was similar to PSAMP rural Puget Sound concentrations (50 mg/kg dw [90th percentile]). Thus, Alternative 1 is considered sufficient for addressing protection of spotted sandpiper for exposure to copper.	Managed by Alternative 1
	Lead	spotted sandpiper; Area 2[c]	19	5.5	The LOAEL-based HQ was greater than 1.0 in only one area (Area 2 of sandpiper habitat). The HQ would have been less than 1.0 if the single anomalously high benthic invertebrate tissue sample from RM 3.0 West was excluded. This sample was collected from the beach just south of Slip 4 on the western shoreline. Lead concentrations in surface sediment were low in this area. This area is a candidate for verification monitoring during remedial design.	May require verification monitoring
		spotted sandpiper; Area 3[c]	5.0	1.5	The LOAEL-based HQ was greater than 1.0 in only one area (Area 3 of sandpiper habitat). The HQ will likely be reduced to less than 1.0 following remediation of EAAs (Alternative 1).	Managed by Alternative 1

Table 9-22 Remaining Ecological Chemicals of Concern for Consideration in FS and Expected Outcomes

Ecological Chemical of Concern		Receptor of Concern	Maximum NOAEL-Based Hazard Quotient[a]	Maximum LOAEL-Based Hazard Quotient[a]	Additional Considerations[b]	Expected Outcome
Metals (continuded)	(Mercury	spotted sandpiper; Area 3[d]	5.3	1.0	The LOAEL-based HQ was greater than 1.0 in only one area (Area 3 of sandpiper habitat). The HQ will likely be reduced to less than 1.0 following remediation of EAAs (Alternative 1).	Managed by Alternative 1
	Vanadium	English sole, Pacific staghorn sculpin	5.9	1.2	Average concentrations in LDW surface sediment (58 mg/kg dw)[b] were less than the PSAMP rural Puget Sound concentration (64 mg/kg dw [90th percentile]).	Levels were within PSAMP background range
		spotted sandpiper – all exposure areas	2.0 – 2.7	1.0 – 1.4	Mean surface sediment concentrations in sandpiper exposure areas ranged from 49 to 57 mg/kg dw[b] and were lower than the PSAMP rural Puget Sound background concentration of 64 mg/kg dw (90th percentile).	Levels were within PSAMP background range
	Nickel	benthic invertebrates	6.6	2.5	The LOAEL-based HQ was exceeded at four locations in the LDW;[b] all were located within EAAs.	Managed by Alternative 1
Pesticides	Total DDTs	benthic invertebrates	5.1	2.7	The LOAEL-based HQ was exceeded at one location,[b] which was located within an EAA.	Managed by Alternative 1
	Total chlordane	benthic invertebrates	82	48	The LOAEL-based HQ was exceeded at 14 locations in LDW;[b] all but one of these locations were within EAAs.	Managed by Alternative 1

Notes:

1. PCBs were designated as a risk-driver chemical for river otter. LOAEL-based HQs were also greater than or equal to 1.0 for crabs (1.0), English sole (0.98 – 5.0), Pacific staghorn sculpin (0.3 – 3.8), and spotted sandpiper (0.18 – 1.5, on a TEQ basis).
2. HQs for fish are the highest HQs in cases where more than one approach was used.

a HQs were calculated in the ERA using the baseline surface sediment dataset available at that time. The RI baseline surface sediment dataset included additional samples collected in 2006 during Round 3 of the RI sediment sampling.

b Concentrations in surface sediment are based on the RI baseline dataset. Comments regarding the HQs are based on the ERA baseline dataset; these comments would not change if the RI baseline dataset had been used.

c Both high and poor quality foraging habitat.

d Only high quality foraging habitat.

EAA = early action area; ERA = Ecological Risk Assessment; HQ = hazard quotient; LOAEL = lowest-observed-adverse-effect level; NOAEL = no observed adverse effect level; PSAMP = Puget Sound Ambient Monitoring Program; RI = remedial investigation; RM = river mile

Figure 9-1a Total PCB Summary Statistics for Cores Remaining Outside of the Early Action Areas and Dredged Areas for Each Remedial Alternative

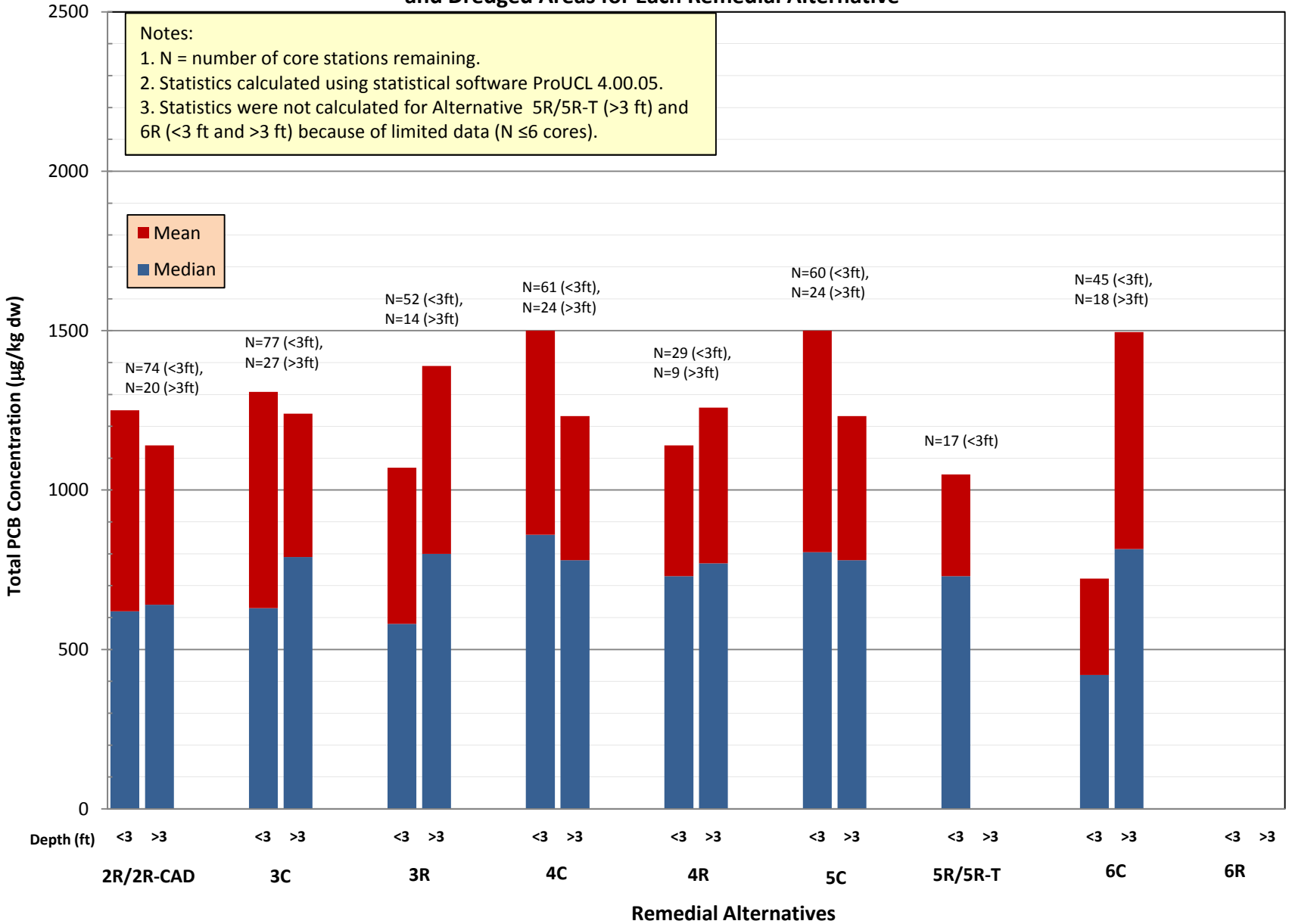


Figure 9-1b cPAH Summary Statistics for Cores Remaining Outside of the Early Action Areas and Dredged Areas for Each Remedial Alternative

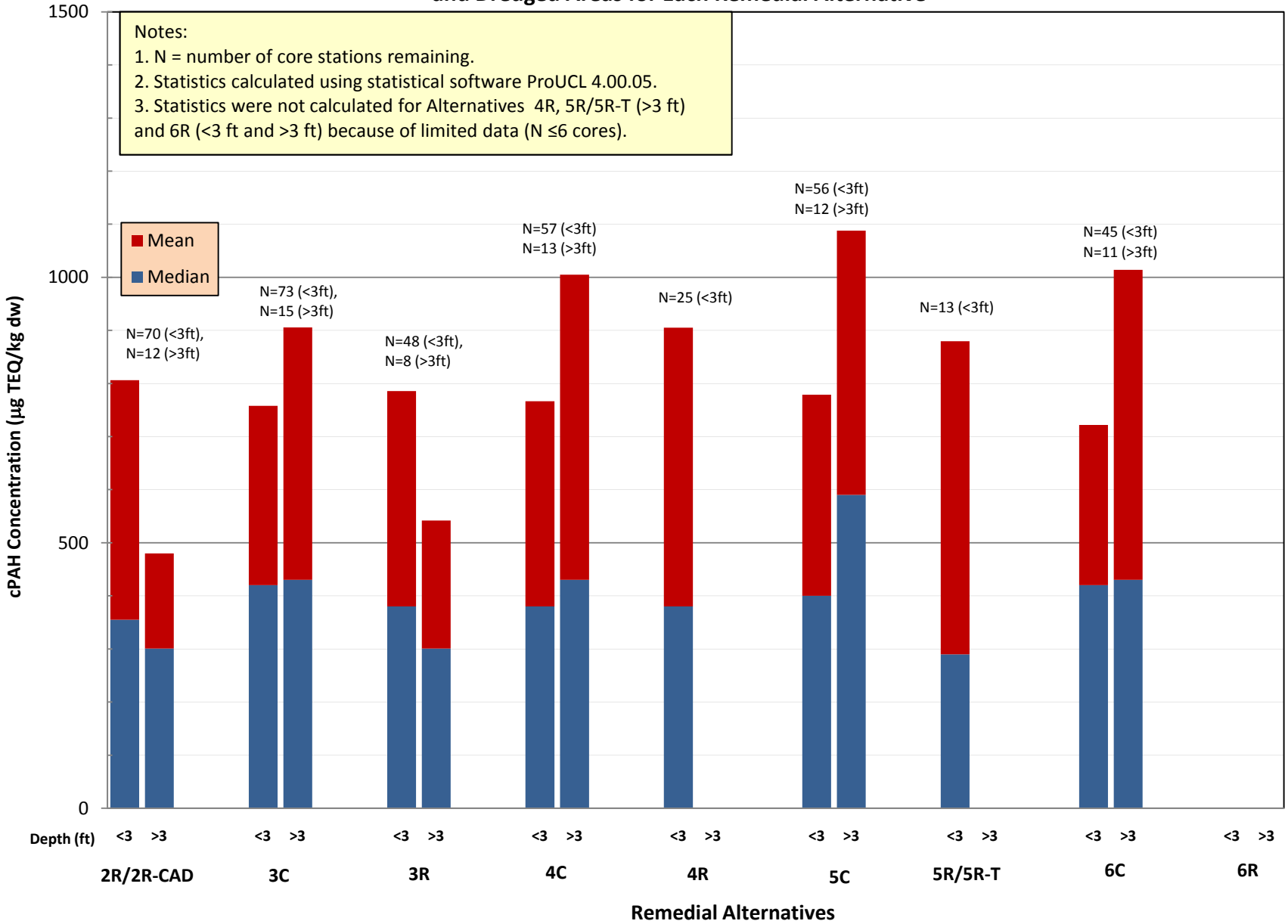


Figure 9-1c Arsenic Summary Statistics for Cores Remaining Outside of the Early Action Areas and Dredged Areas for Each Remedial Alternative

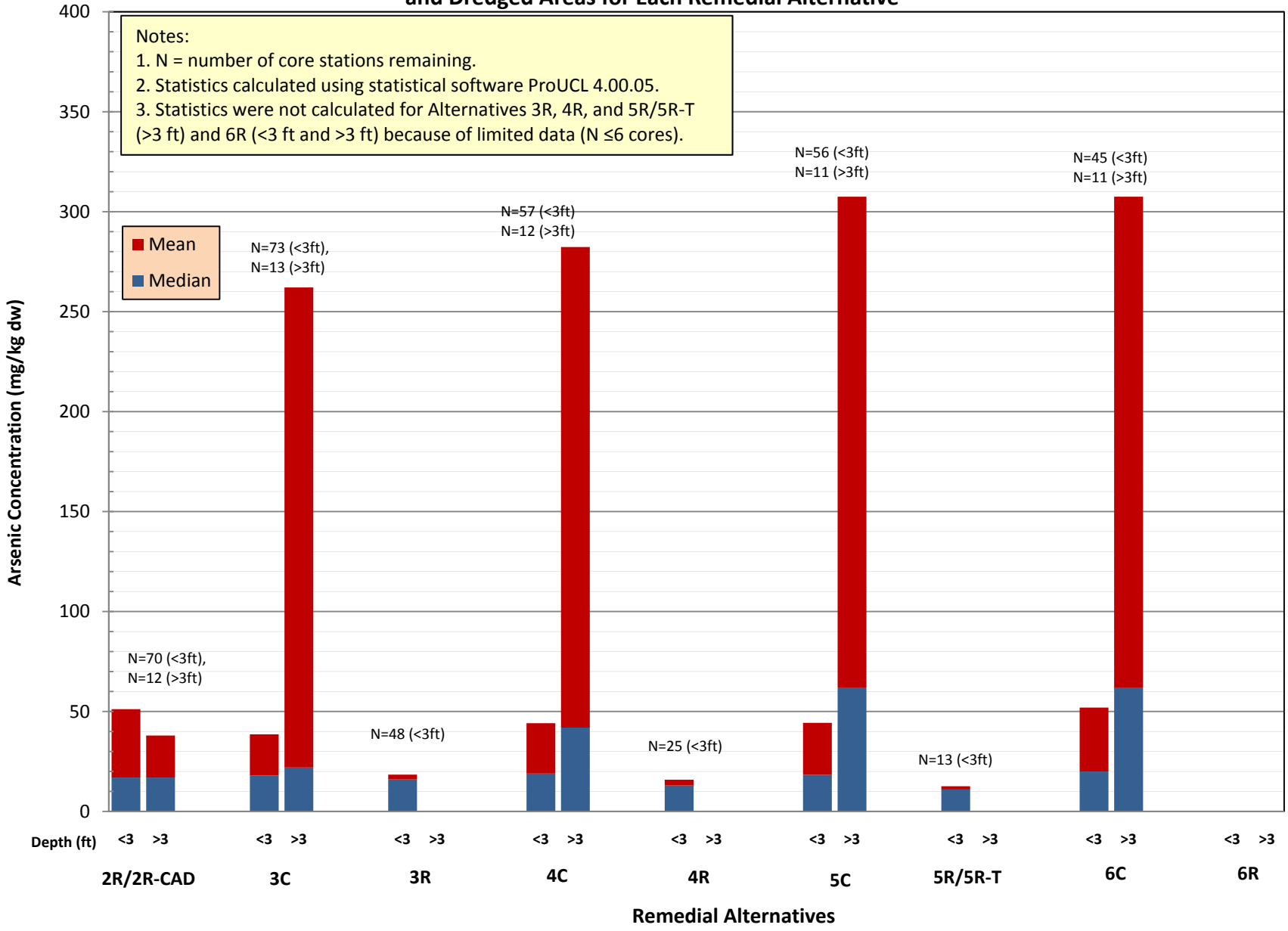
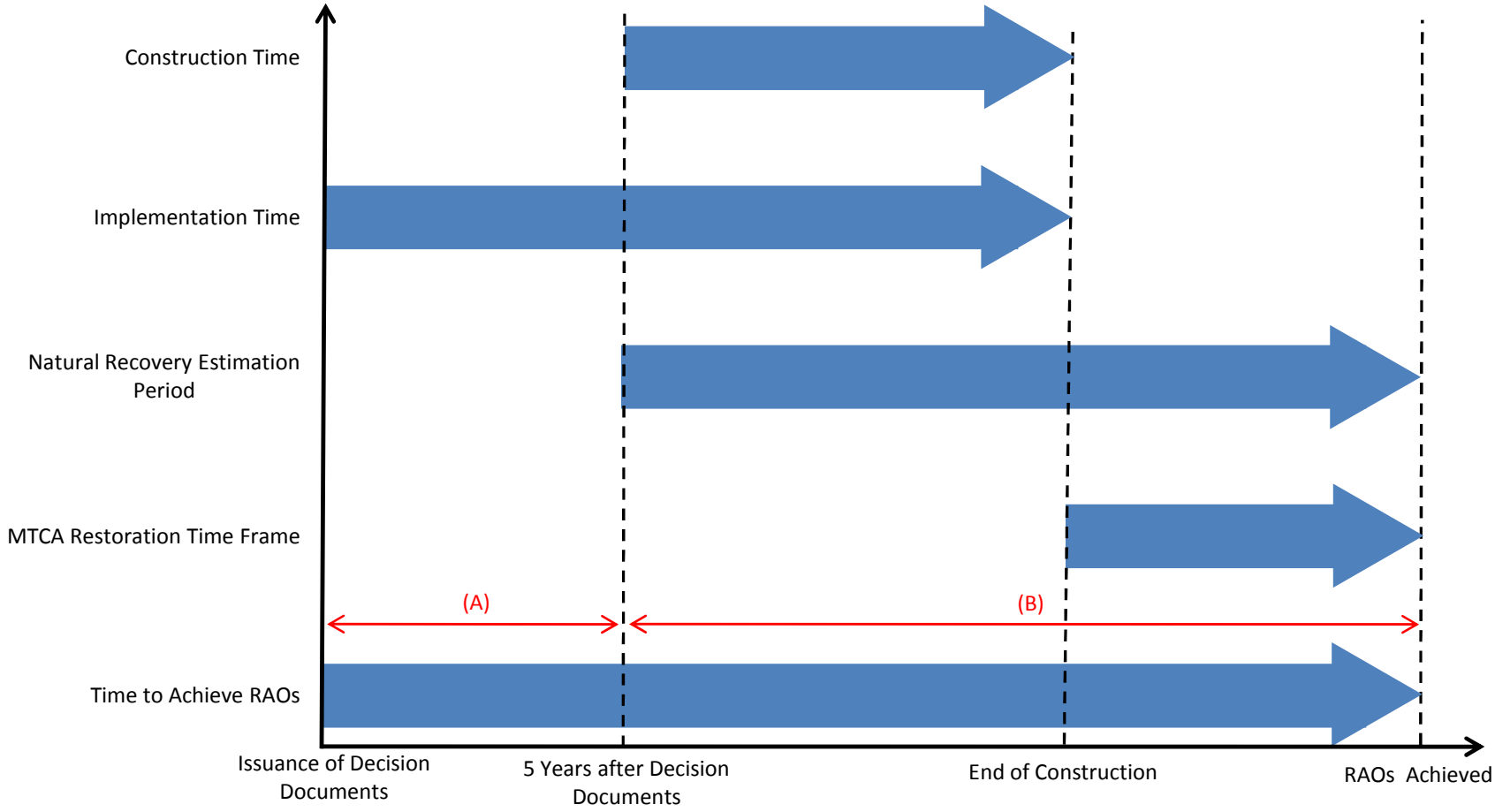


Figure 9-2 Conceptual Relationships Among Time Frames Used in the Evaluation of the Remedial Alternatives



Notes:
(A): Assume 5 years after issuance of decision documents: EAAs are managed (Alt. 1), initial design period for other remedy components, priority source control, baseline monitoring, and verification monitoring.
(B): The BCM is used during this period to model future conditions before, during, and after construction for each of the remedial alternatives.
BCM = bed composition model; EAA = early action area; MTCA = Model Toxics Control Act; RAO = remedial action objective.

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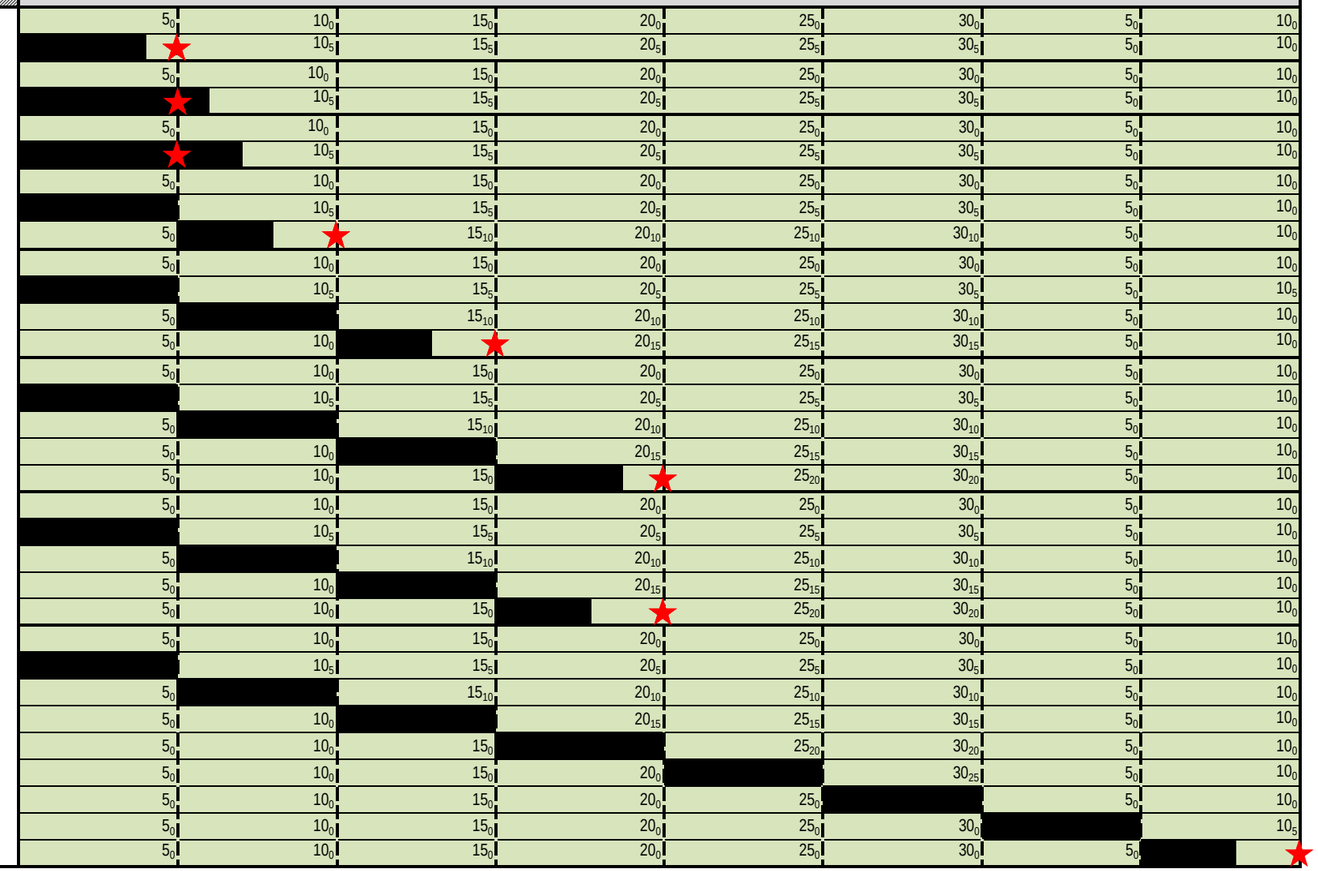
Figure 9-3 Time Frame and Base-Case BCM Modeling Framework for the Remedial Alternatives

Remedial Alternative	Construction Years/ Implementation Years	Remedial Alternative Construction Footprint Assumptions for BCM Calculations
2R, 2R-CAD and 3C	4/9	Outside active footprint
		Active footprint
3R	6/11	Outside active footprint
		Active footprint
4C	7/12	Outside active footprint
		Active footprint
5C	8/13	Outside active footprint
		Alternative 4C
		Remaining active footprint
4R	13/18	Outside active footprint
		Alternative 3R
		Upstream 1/2 of Alternative 4R
		Remaining active footprint
5R and 5R-T	19/24	Outside active footprint
		Alternative 3R
		Upstream 1/2 of Alternative 4R
		Downstream 1/2 of Alternative 4R
		Remaining active footprint
6C	18/23	Outside active footprint
		Alternative 4C
		Alternative 5C
		Upstream 1/2 of Alternative 6C
		Remaining active footprint
6R	38/43	Outside active footprint
		Alternative 3R
		Upstream 1/2 of Alternative 4R
		Downstream 1/2 of Alternative 4R
		Alternative 5R
		1st upstream 1/4 of Alternative 6R
		2nd upstream 1/4 of Alternative 6R
		3rd upstream 1/4 of Alternative 6R
		Remaining active footprint

Activities during 5-year period between signing of the final decision documents and start of construction: EAAs remediated, priority source control, and remedial design.

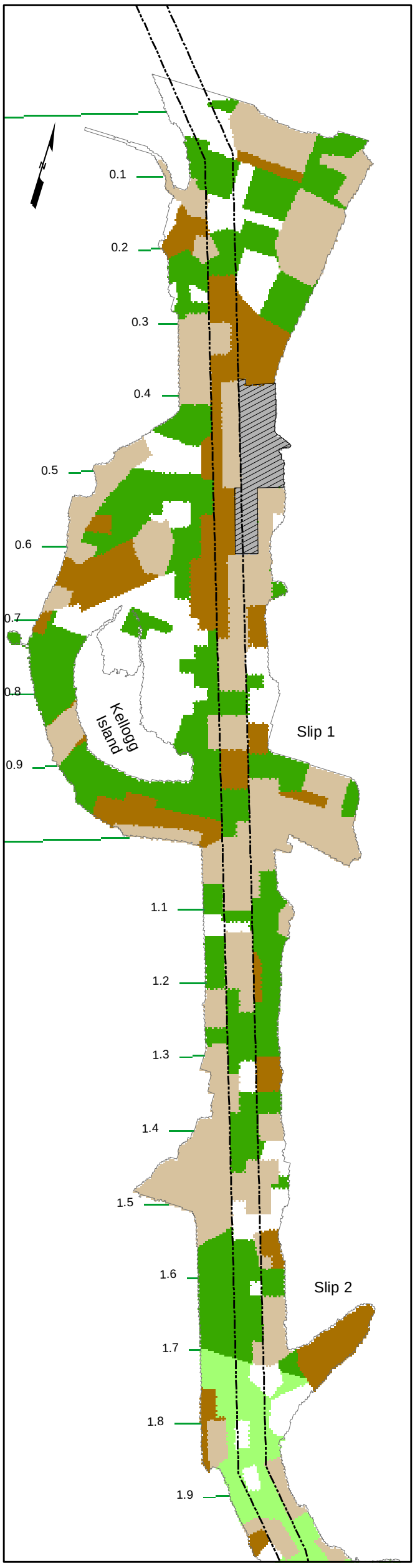


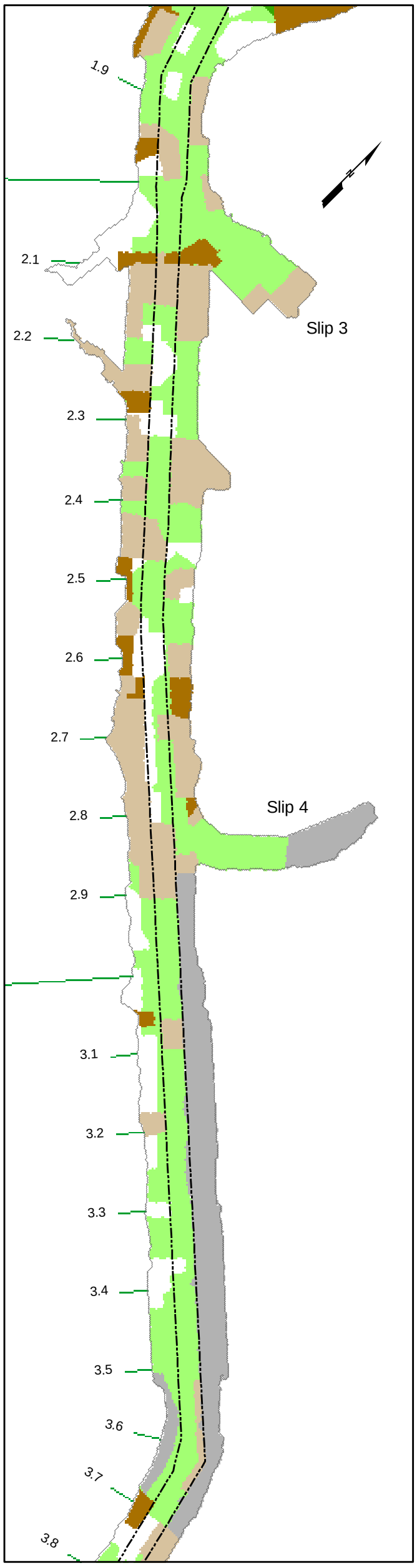
= construction

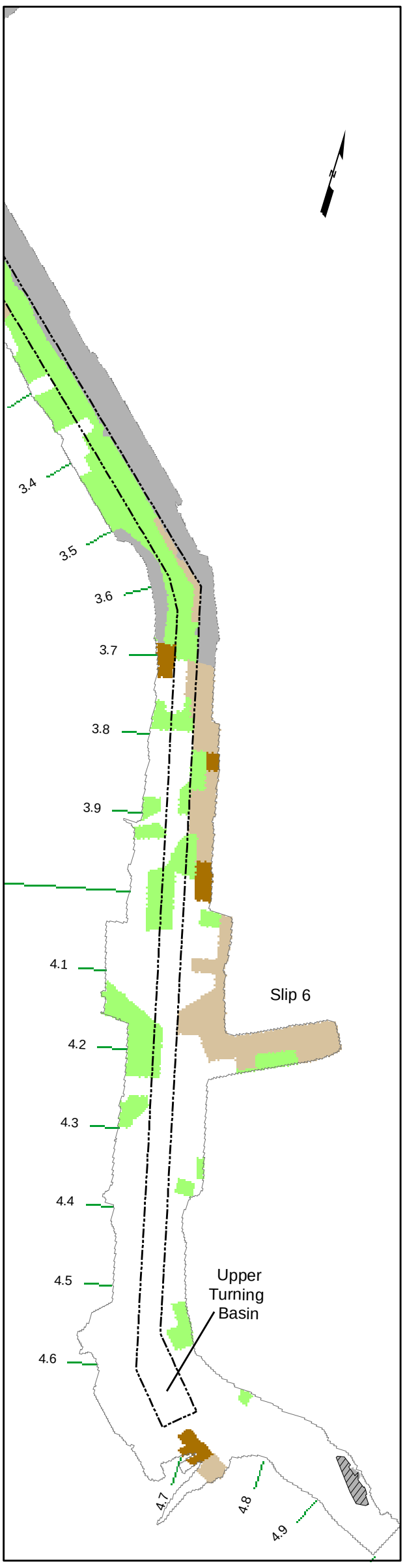
Notes:

1. Estimated construction times listed for the alternatives (first column) are represented on the chart as horizontal black bars.
2. Estimated construction times are based on the time required for open-water dredging + 25% (see dredge production rate assumptions; Appendix I).
3. Construction times are not multiples of 5. Reconciliation of construction periods and the 5-year model intervals is accomplished by applying the nearest 5-year BCM output to the end of construction for each alternative. This is symbolized with a ★. For example, output from model-year 5 is used at the end of construction for Alternatives 2 and 3C, which have construction times of 4 years. Similarly, model-year 5 output is used at the end of construction for Alternative 4C, which has an estimated construction period of 7 years.
4. The alternatives progressively build or integrate their respective footprints in 5-year intervals (i.e., 3R to 6R in succession) lending spatial consistency to the BCM calculations.
5. BCM calculations for fractional "remaining active footprints" assume construction begins at the head of the waterway (Reach 3) and works toward the mouth of the waterway (Reach 1).
6. BCM calculations use STM base case run with distributed lateral loads.
7. Example table notation: 15_5 means BCM output for Year 15 excluding Years 0 to 5 of the hydrograph.
8. The temporal bias refers to the difference between the end of the estimated construction time and when the post-remedy bed sediment replacement value is assigned to coincide with a 5-year model interval. Implementation and restoration time frames adjust for this bias.

BCM = bed composition model; C = combined technology alternative; CAD = contained aquatic disposal; R = removal emphasis alternative; STM = sediment transport model; T = treatment







Legend

Designations of Areas Assumed to be Actively Remediated during Indicated Time Period

- Remaining EAAs
- Completed EAAs
- 0 to 5 Years (Alternatives 2, 3, and 4)
- 5 to 10 Years (Alternative 5 Combined)
- 10 to 15 Years (Upstream Portion of Alternative 6)
- 15 to 20 Years (Downstream Portion of Alternative 6)
- No Action
- Navigation Channel
- River Mile Marker

Notes:
1. Construction time frames rounded to nearest 5-year interval.
2. Sequencing prioritized with higher concentrations first (previous alternatives remediated first), then upstream to downstream.
3. Remaining EAAs are assumed to be completed in the first 5 years after the issuance of the decision document(s).
4. Five-year intervals are indexed to the start of construction.
5. Areas upstream of RM 4.75 are not sequenced in the BCM because they are outside of the STM domain.
6. BCM = bed composition model, EAA = early action area, STM = sediment transport model.

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Temporal Sequencing of Actively Remediated Areas for BCM Calculations: Alternative 6 Combined

DATE: 10/15/10 | DWRN:MVI/sea | Revision: 0

FIGURE 9-4

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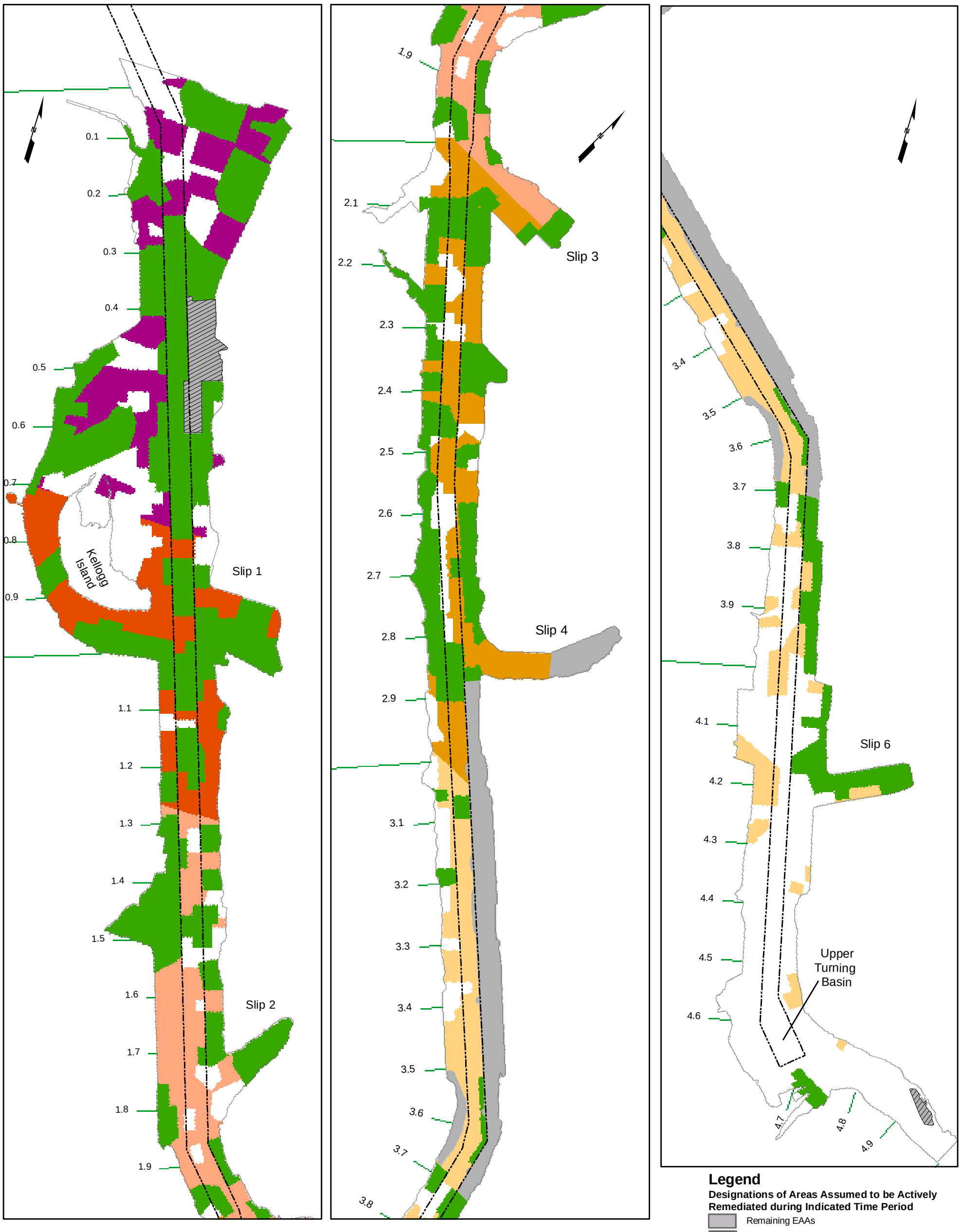

Notes:
1. Construction time frames rounded to nearest 5-year interval.
2. Sequencing prioritized with higher concentrations first (previous alternatives remediated first), then upstream to downstream.
3. Remaining EAAs are assumed to be completed in the first 5 years after the issuance of the decision document(s).
4. Five-year intervals are indexed to the start of construction.
5. Areas upstream of RM 4.75 are not sequenced in the BCM because they are outside of the STM domain.
6. BCM = bed composition model, EAA = early action area, STM = sediment transport model.

Legend

Designations of Areas Assumed to be Actively Remediated during Indicated Time Period

- Remaining EAAs
- Completed EAAs
- 0 to 20 Years (Alternative 5 Removal)
- 20 to 25 Years
- 25 to 30 Years
- 30 to 35 Years
- 35 to 40 Years
- 40 to 45 Years
- No Action
- Navigation Channel
- River Mile Marker

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Draft Final Feasibility Study
60150279-14.12

Temporal Sequencing of Actively Remediated Areas for BCM Calculations: Alternative 6 Removal

DATE: 10/15/10 | DWRN:MVI/sea | Revision: 0

FIGURE 9-5

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Figure 9-6a Comparative Evaluation of Residual Benthic Risk (RAO 3) for Remedial Alternatives – Predicted Percentage of Baseline Stations in Compliance with SMS Criteria after Remediation

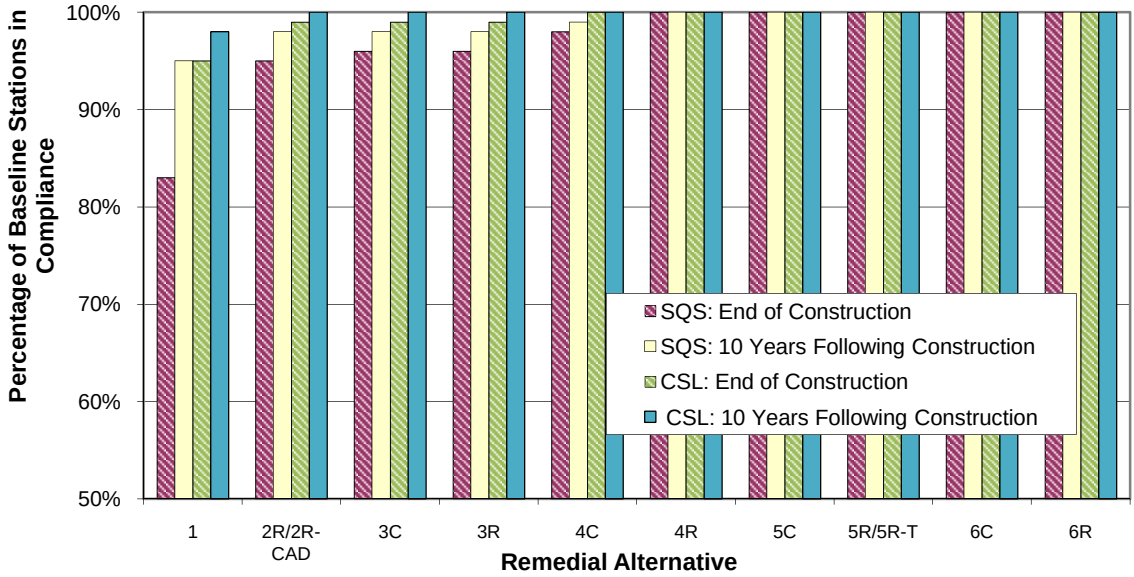
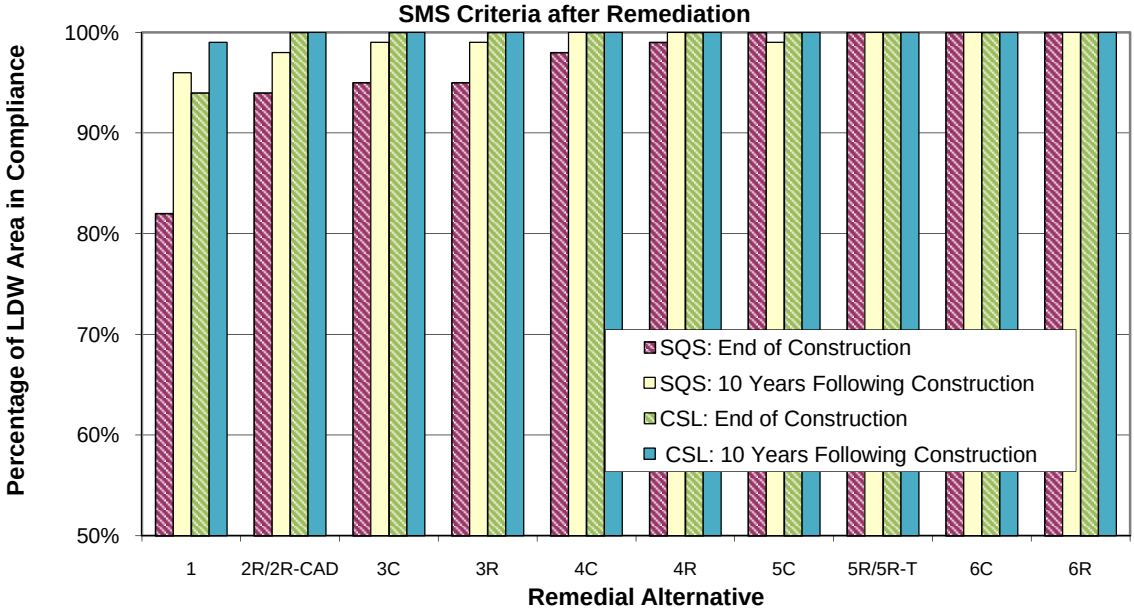


Figure 9-6b Comparative Evaluation of Residual Benthic Risk (RAO 3) for Remedial Alternatives – Predicted Percentage of LDW Area in Compliance with SMS Criteria after Remediation



Notes:

1. The % of SMS point exceedances shown is calculated by dividing the SQS/CSL exceedances by the total FS baseline station counts of the LDW (n=1,395).
2. The % of LDW area shown for SMS exceedances is calculated by dividing the acreages associated with SQS/CSL exceedances by the total area of the LDW (441 acres).

C= combined; CAD: contained aquatic disposal; CSL = cleanup screening level; SMS = Sediment Management Standards; SQS = sediment quality standard; T = treatment.

Figure 9-7a Site-wide Arsenic SWAC Versus Time - Removal Alternatives

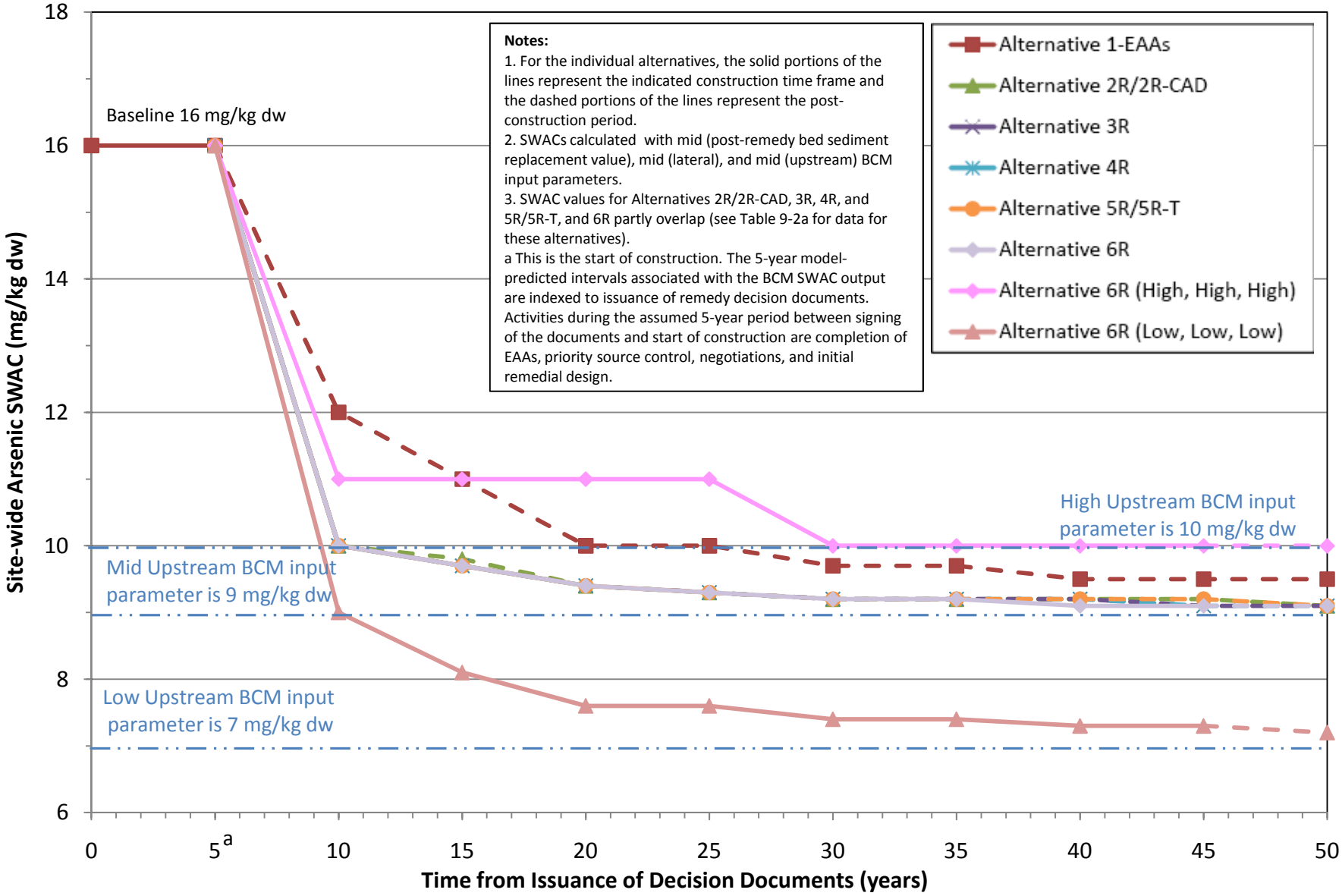


Figure 9-7b Site-wide Arsenic SWAC Versus Time - Combined Alternatives

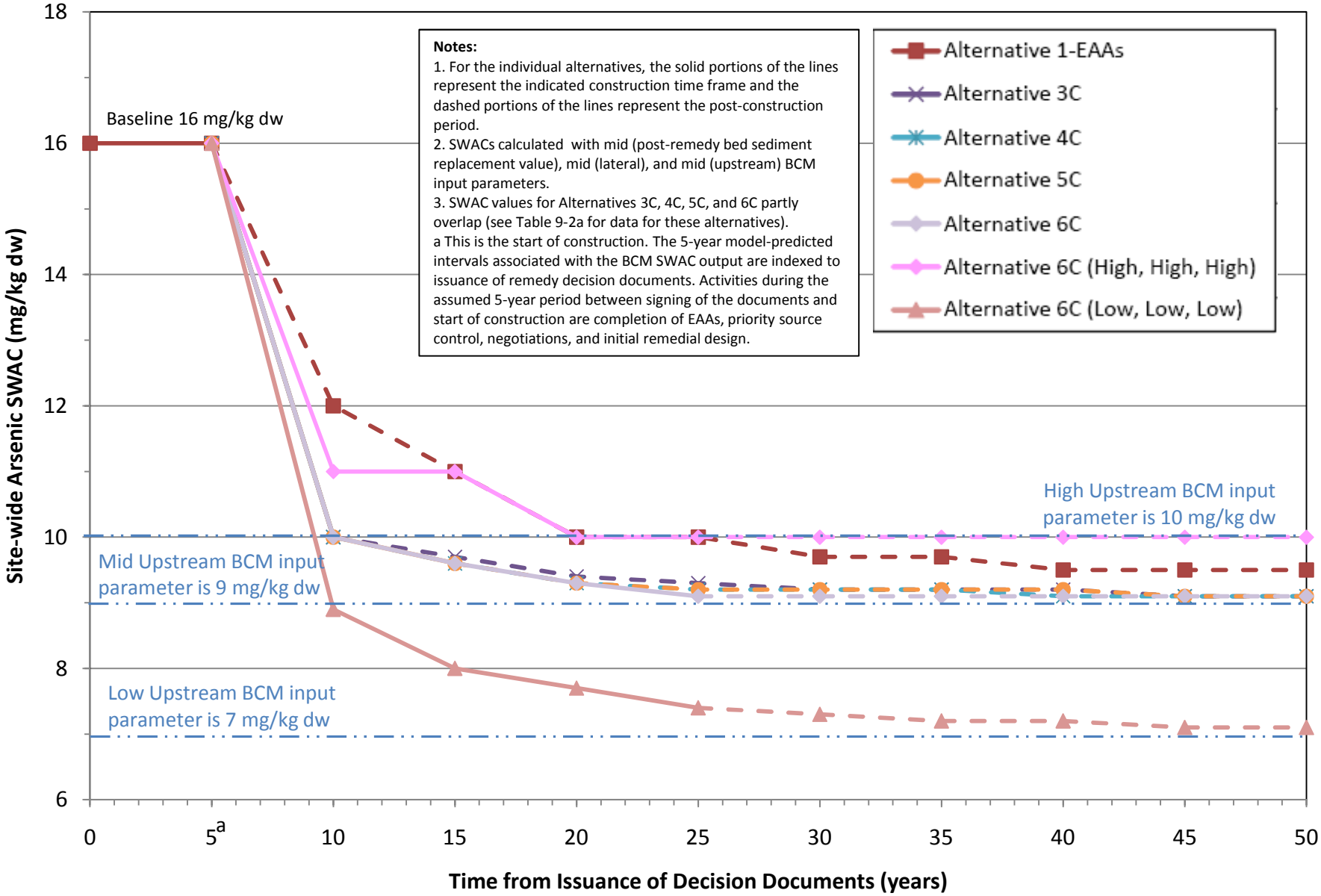


Figure 9-7c Site-wide Total PCB SWAC Versus Time - Removal Alternatives

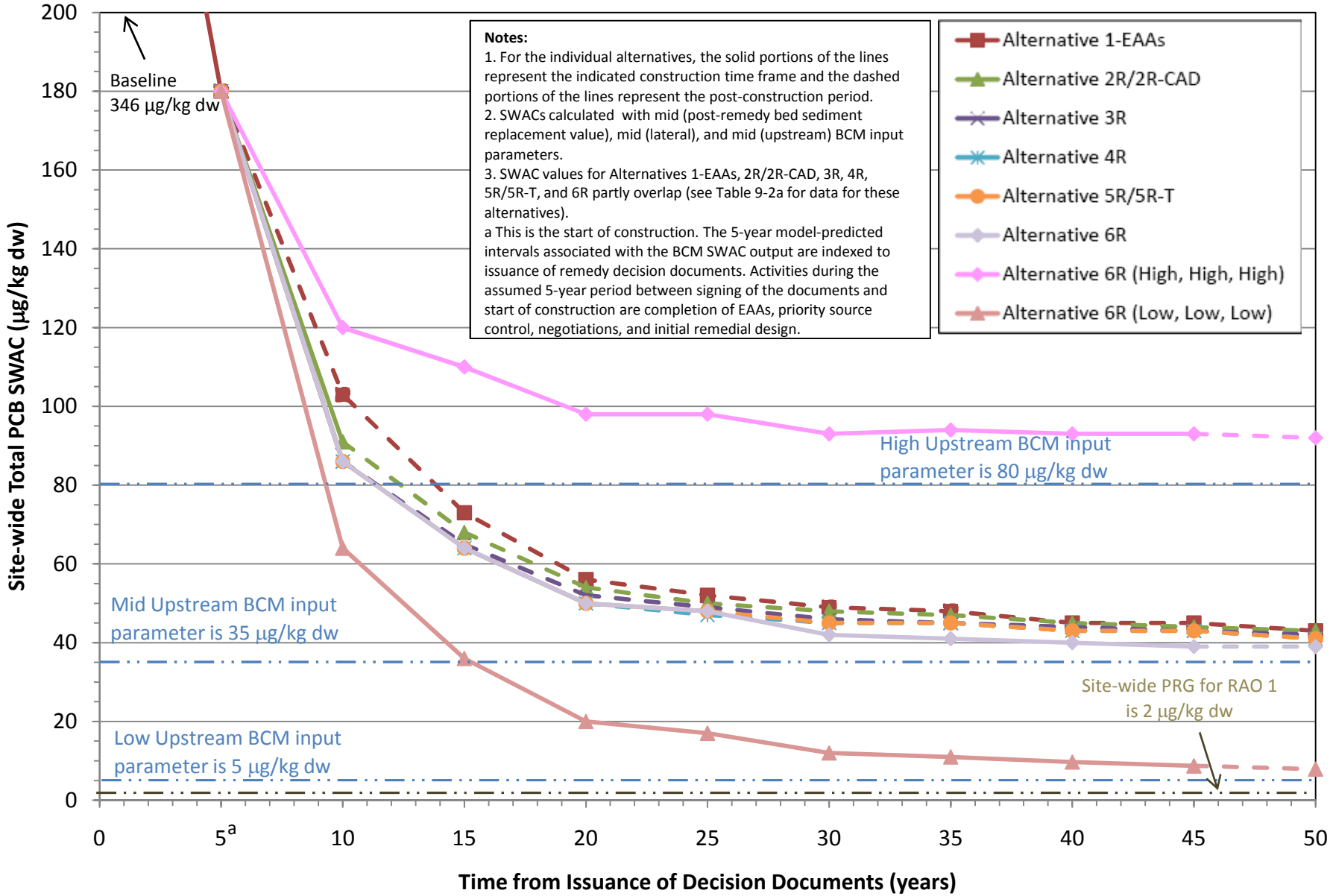


Figure 9-7d Site-wide Total PCB SWAC Versus Time - Combined Alternatives

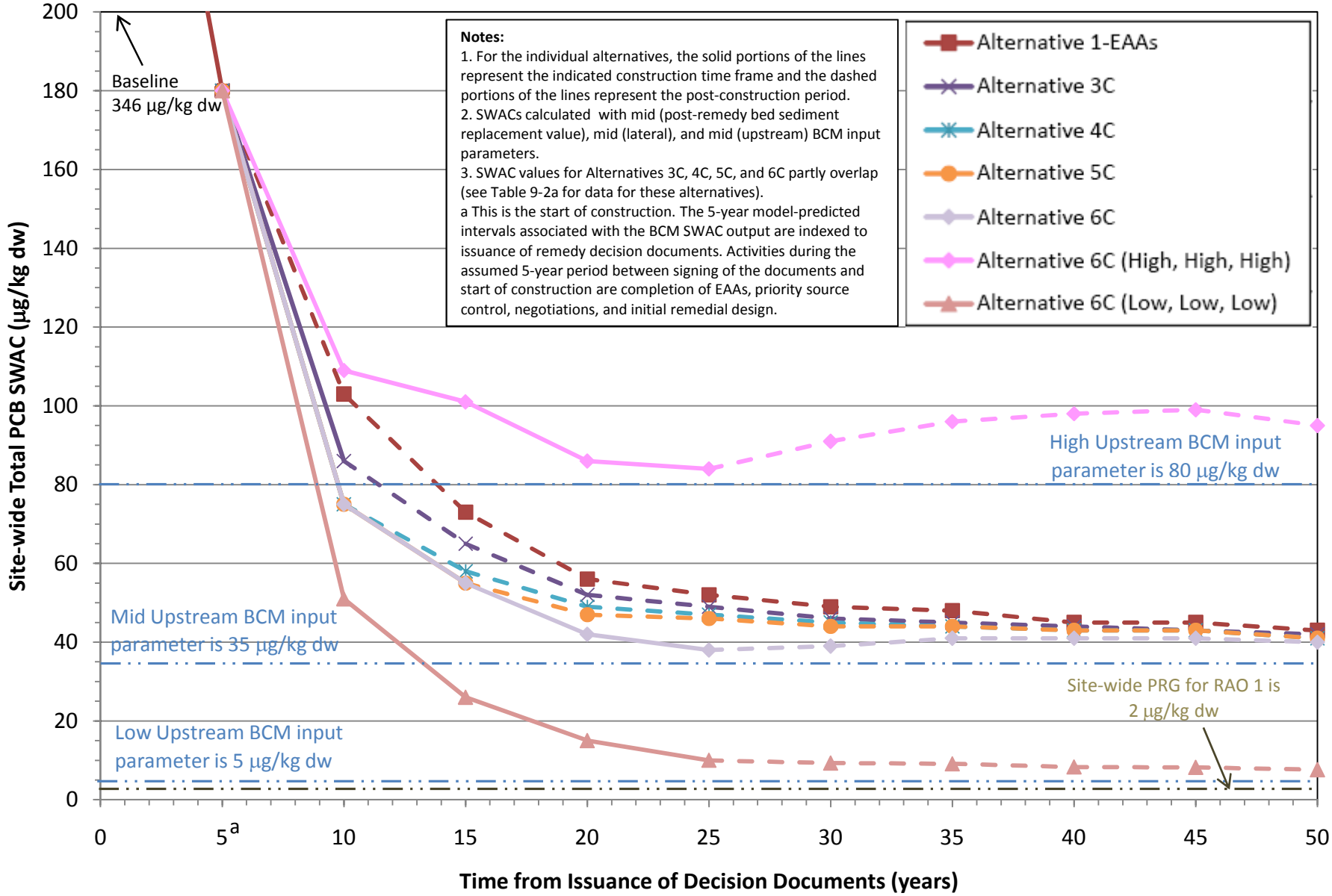
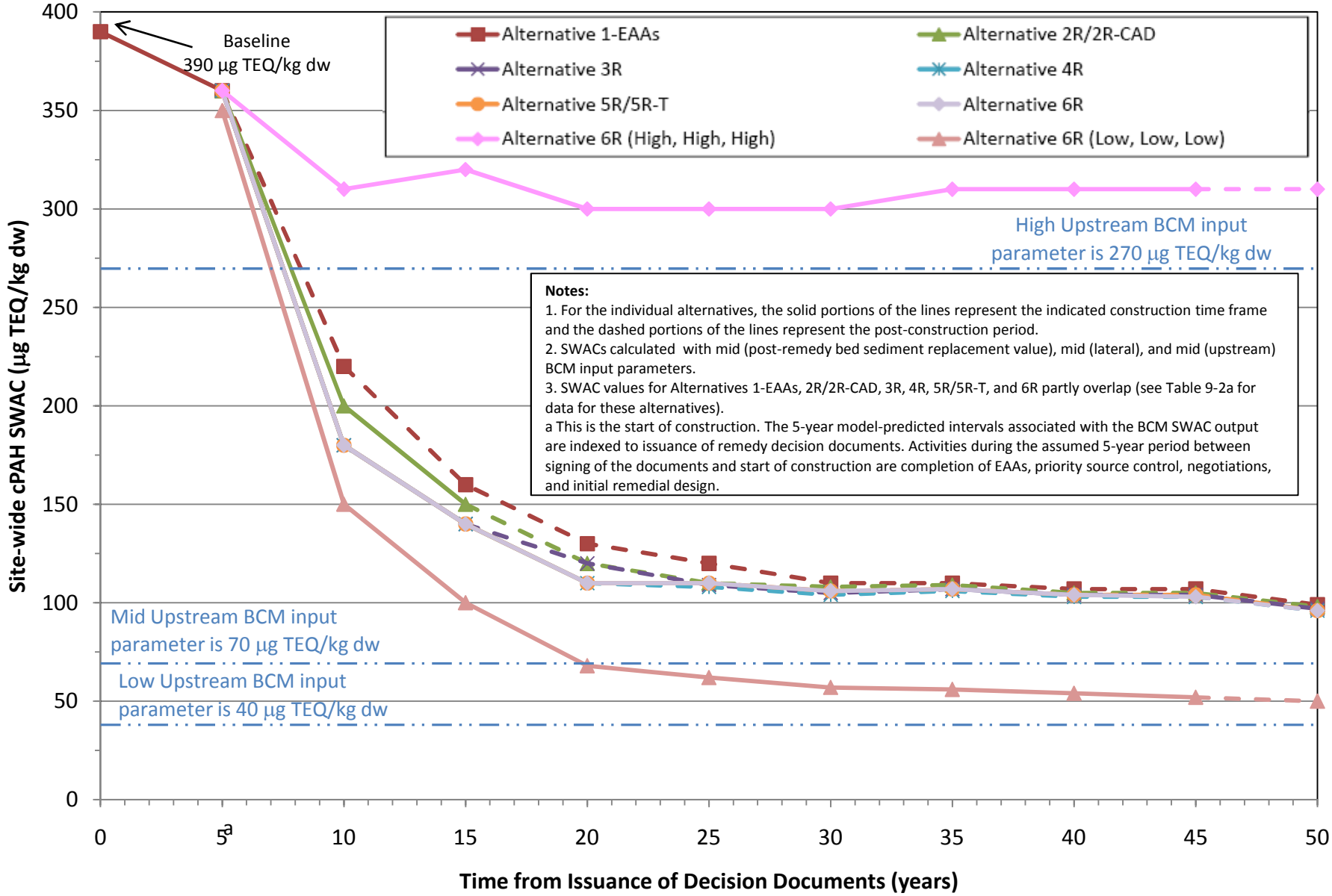
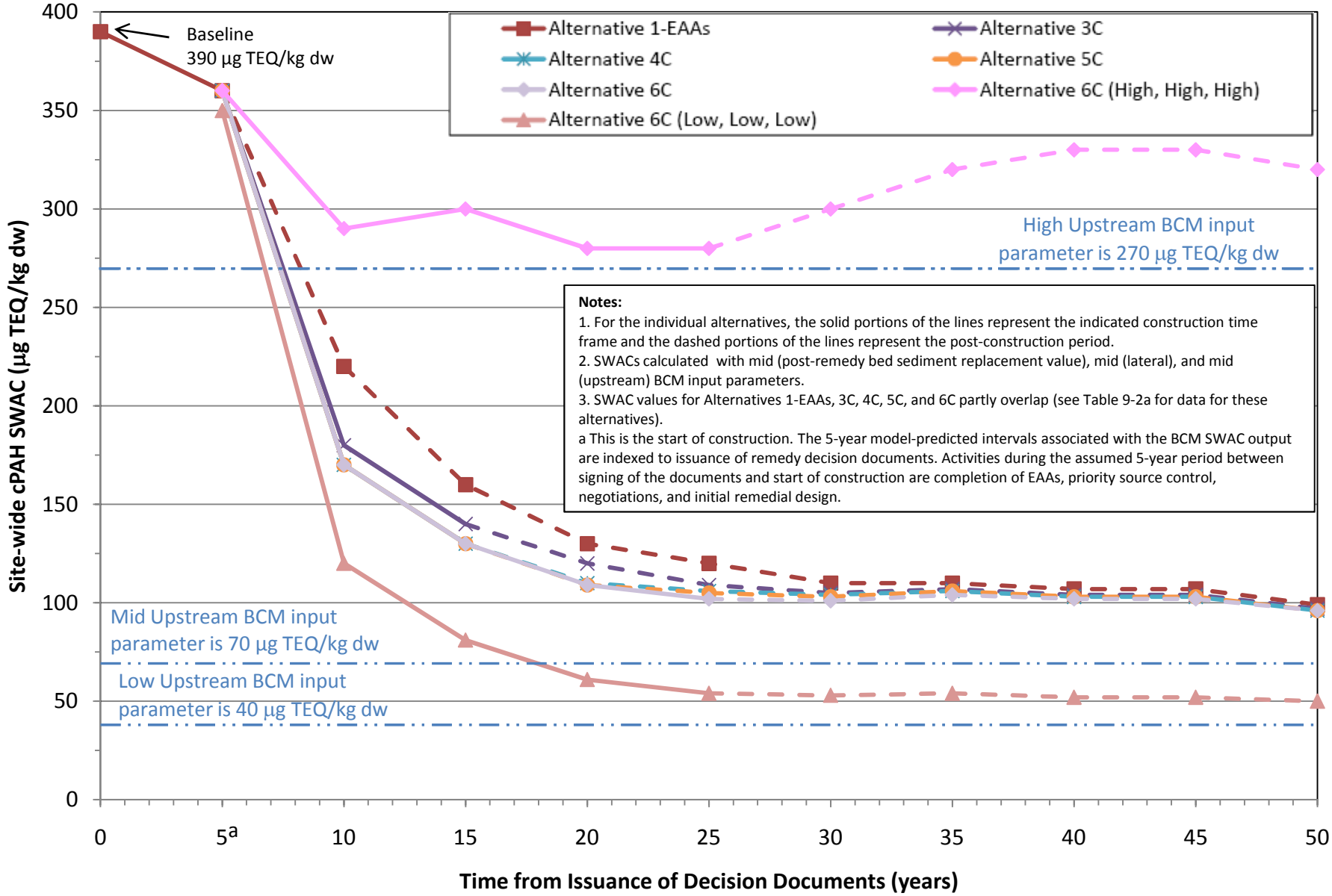


Figure 9-7e Site-wide cPAH SWAC Versus Time - Removal Alternatives



Notes:
1. For the individual alternatives, the solid portions of the lines represent the indicated construction time frame and the dashed portions of the lines represent the post-construction period.
2. SWACs calculated with mid (post-remedy bed sediment replacement value), mid (lateral), and mid (upstream) BCM input parameters.
3. SWAC values for Alternatives 1-EAAs, 2R/2R-CAD, 3R, 4R, 5R/5R-T, and 6R partly overlap (see Table 9-2a for data for these alternatives).
a This is the start of construction. The 5-year model-predicted intervals associated with the BCM SWAC output are indexed to issuance of remedy decision documents. Activities during the assumed 5-year period between signing of the documents and start of construction are completion of EAAs, priority source control, negotiations, and initial remedial design.

Figure 9-7f Site-wide cPAH SWAC Versus Time - Combined Alternatives



Notes:
1. For the individual alternatives, the solid portions of the lines represent the indicated construction time frame and the dashed portions of the lines represent the post-construction period.
2. SWACs calculated with mid (post-remedy bed sediment replacement value), mid (lateral), and mid (upstream) BCM input parameters.
3. SWAC values for Alternatives 1-EAAs, 3C, 4C, 5C, and 6C partly overlap (see Table 9-2a for data for these alternatives).
a This is the start of construction. The 5-year model-predicted intervals associated with the BCM SWAC output are indexed to issuance of remedy decision documents. Activities during the assumed 5-year period between signing of the documents and start of construction are completion of EAAs, priority source control, negotiations, and initial remedial design.

Figure 9-7g Site-wide Dioxin/Furan SWAC Versus Time - Removal Alternatives

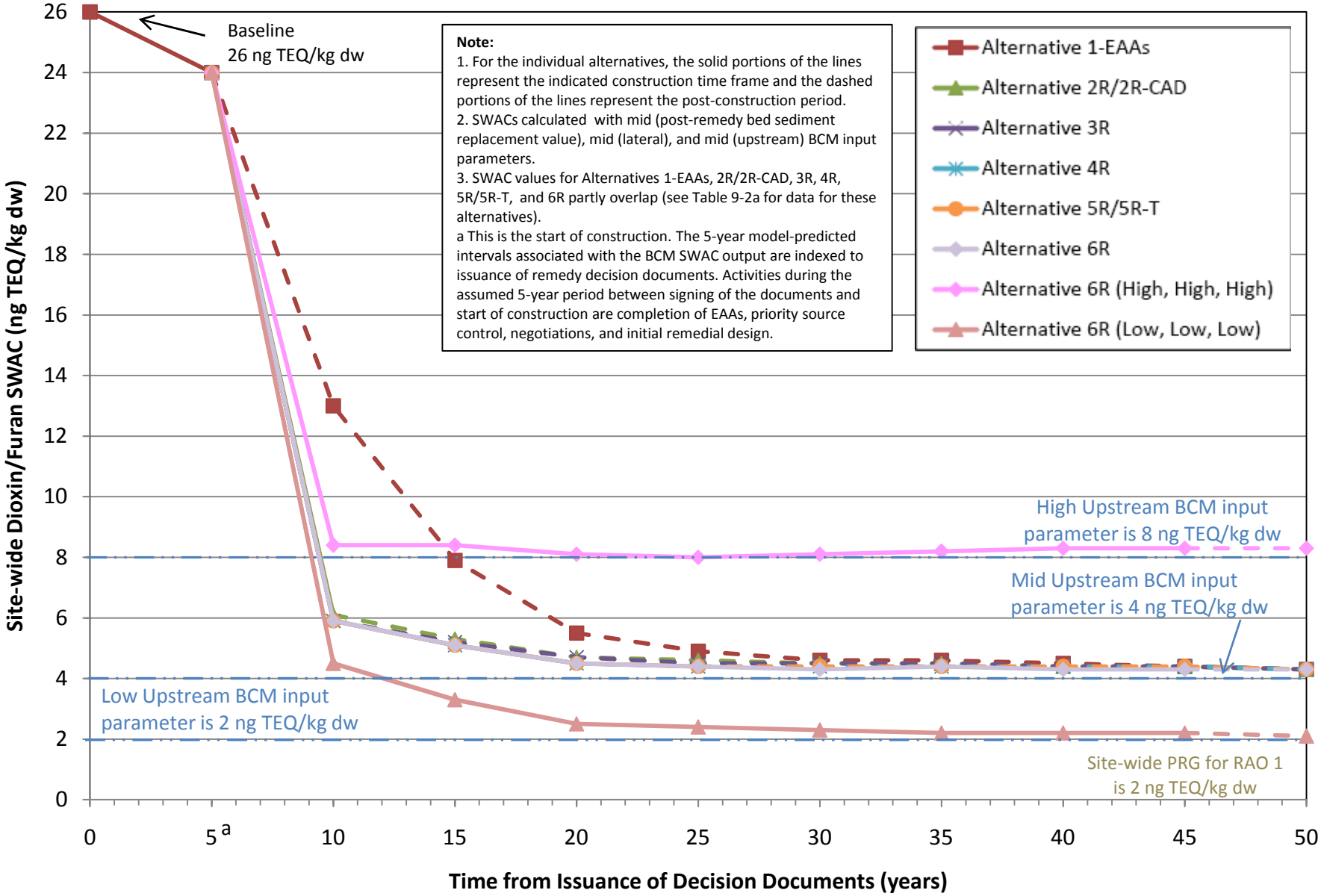


Figure 9-7h Site-wide Dioxin/Furan SWAC Versus Time - Combined Alternatives

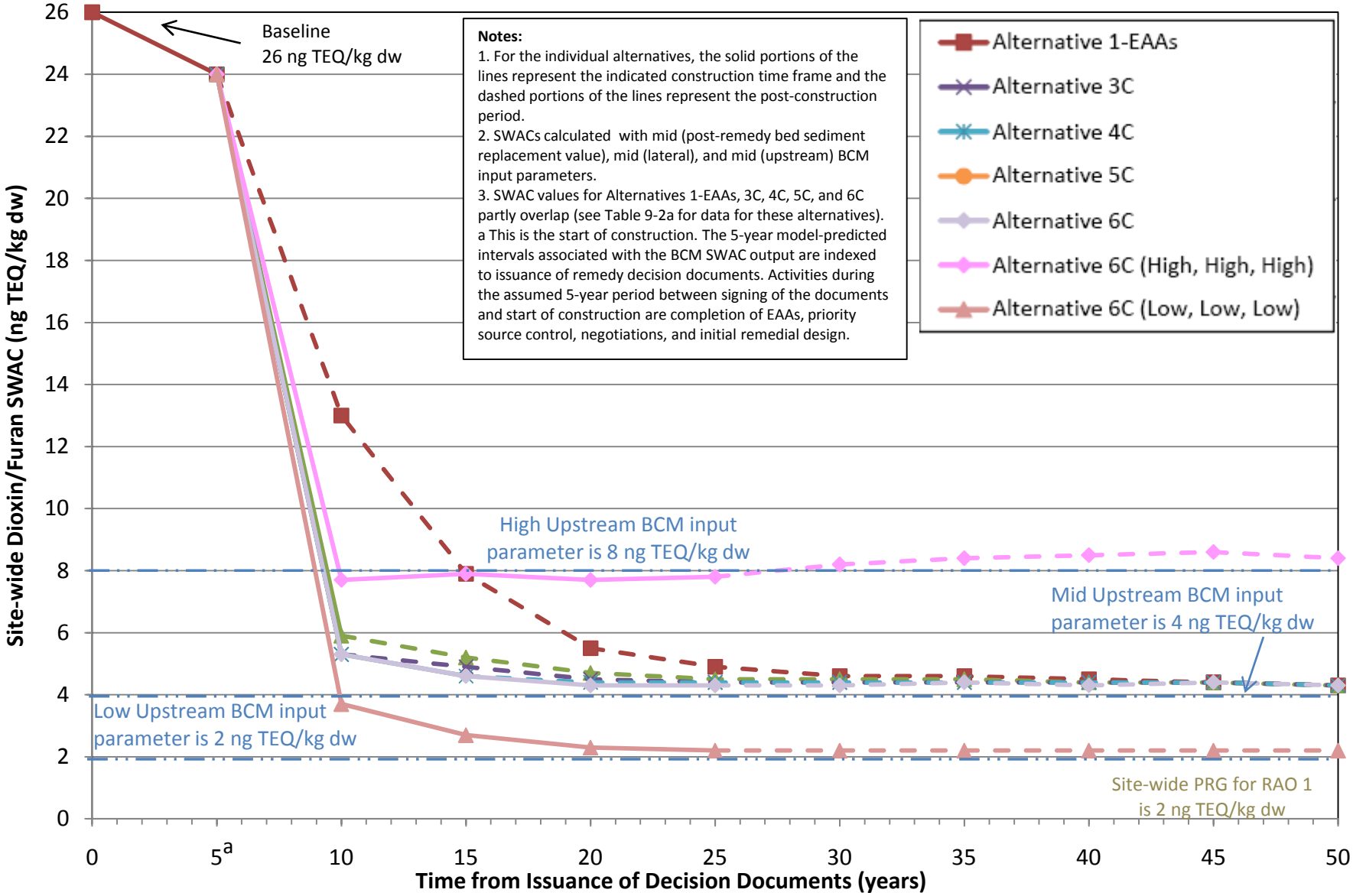
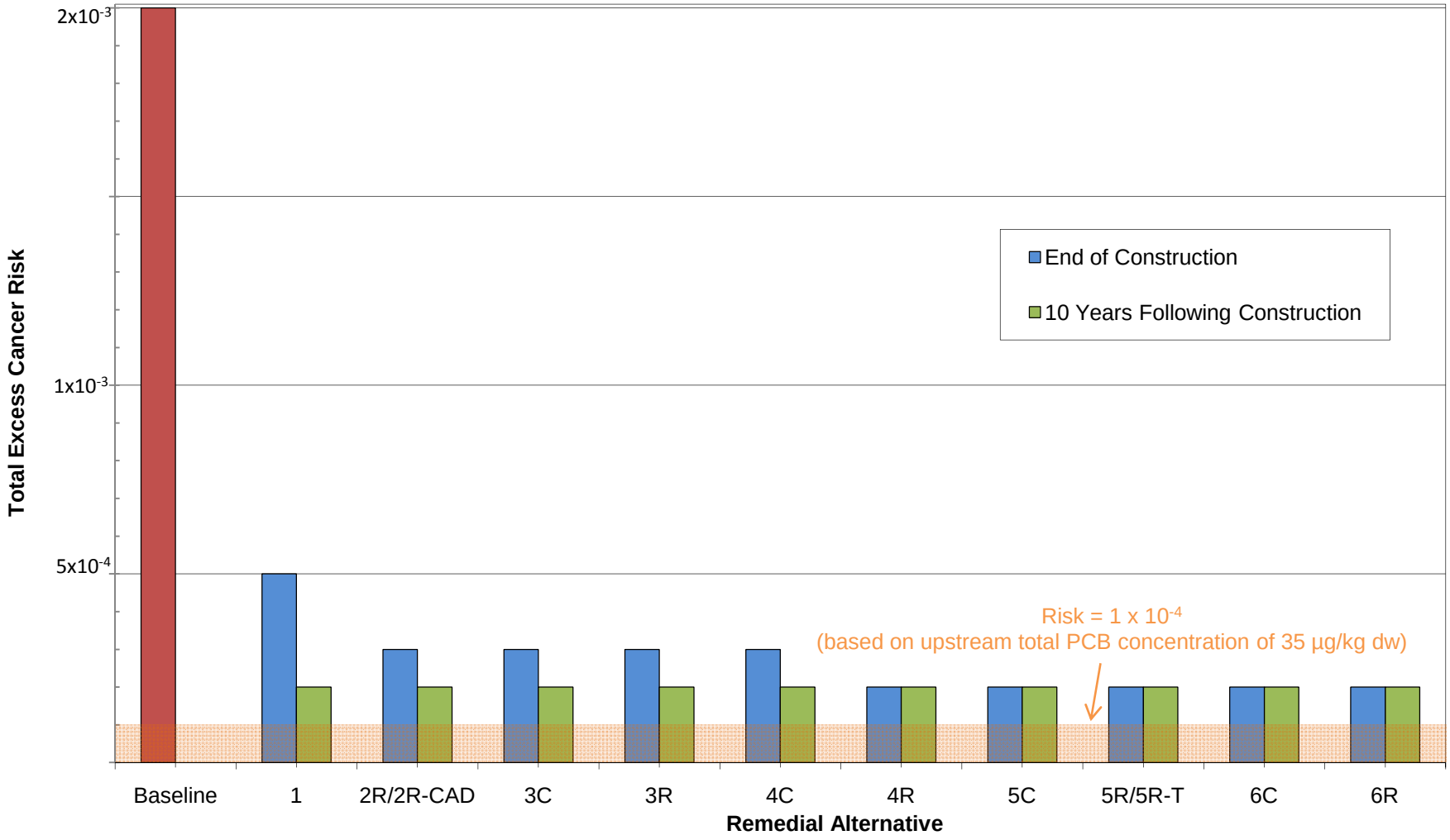


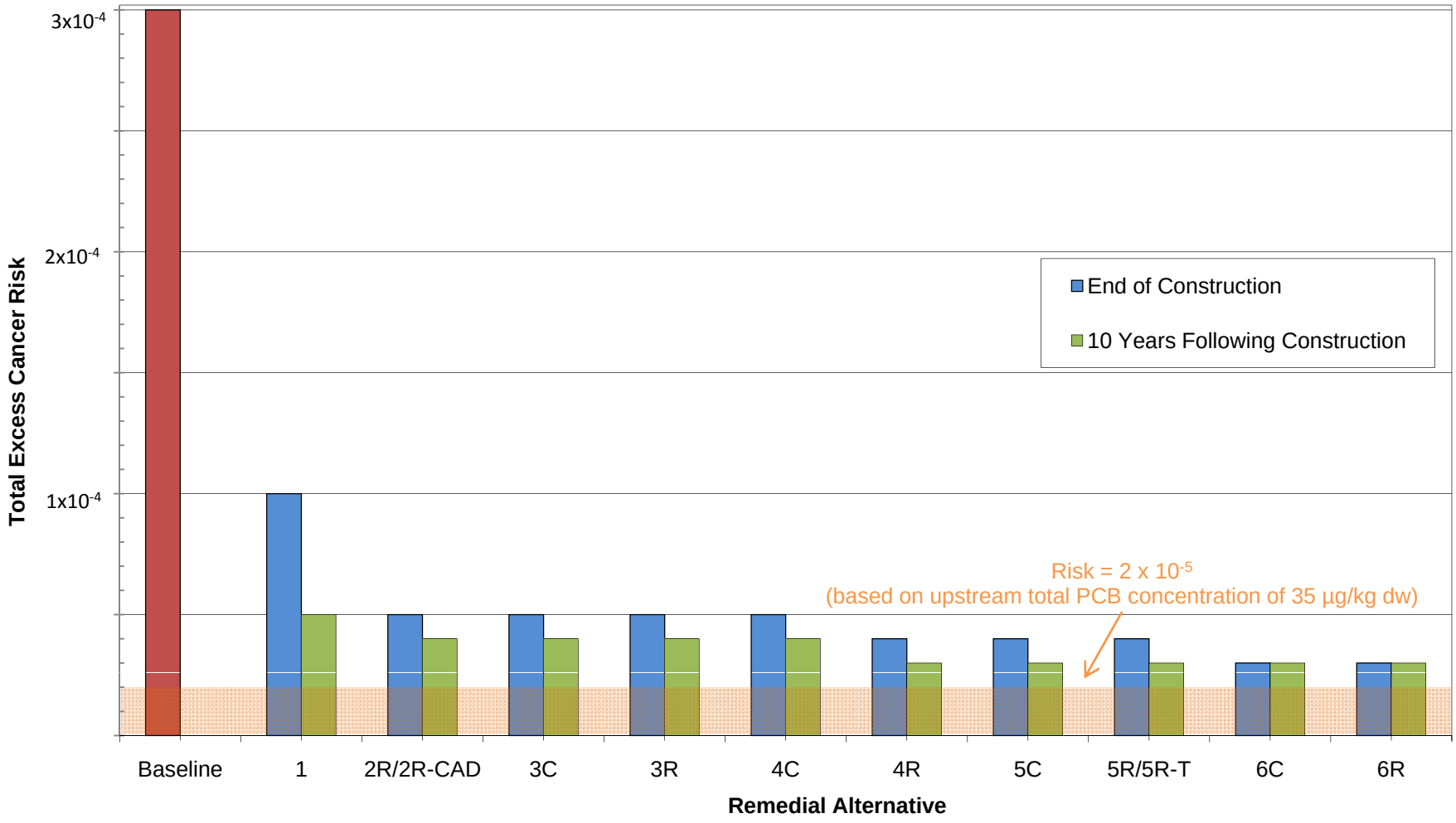
Figure 9-8a Residual Adult Tribal Reasonable Maximum Exposure Seafood Consumption Risk (RAO 1) for Total PCBs After Remediation



Notes:

1. Risk values shown for the alternatives are also presented in Table 9-6a.

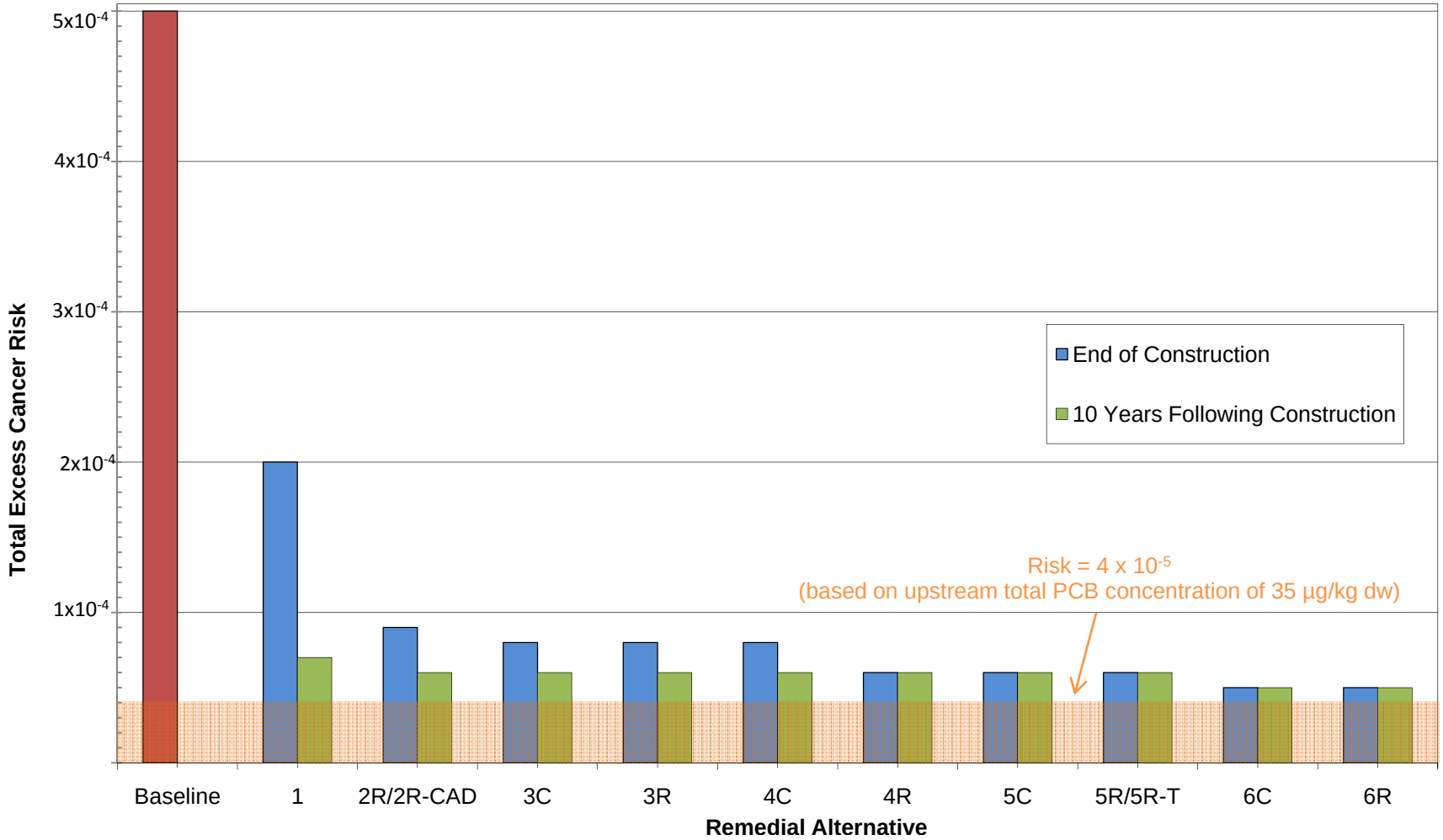
Figure 9-8b Residual Child Tribal Reasonable Maximum Exposure Seafood Consumption Risk (RAO 1) for Total PCBs After Remediation



Notes:

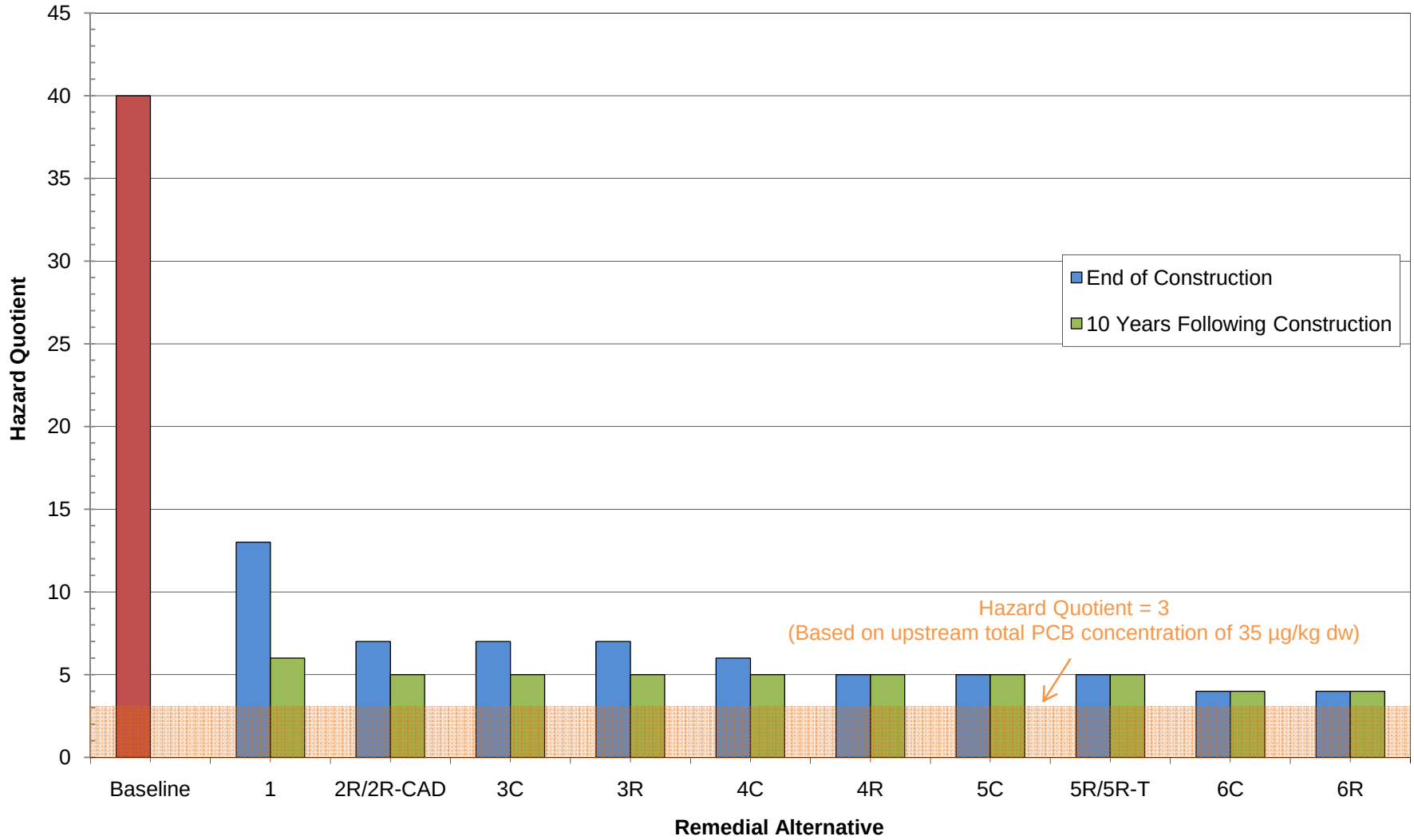
1. Risk values shown for the alternatives are also presented in Table 9-6a.

Figure 9-8c Residual Adult Asian Pacific Islander Reasonable Maximum Exposure Seafood Consumption Risk (RAO 1) for Total PCBs After Remediation



Notes:
1. Risk values shown for the alternatives are also presented in Table 9-6a.

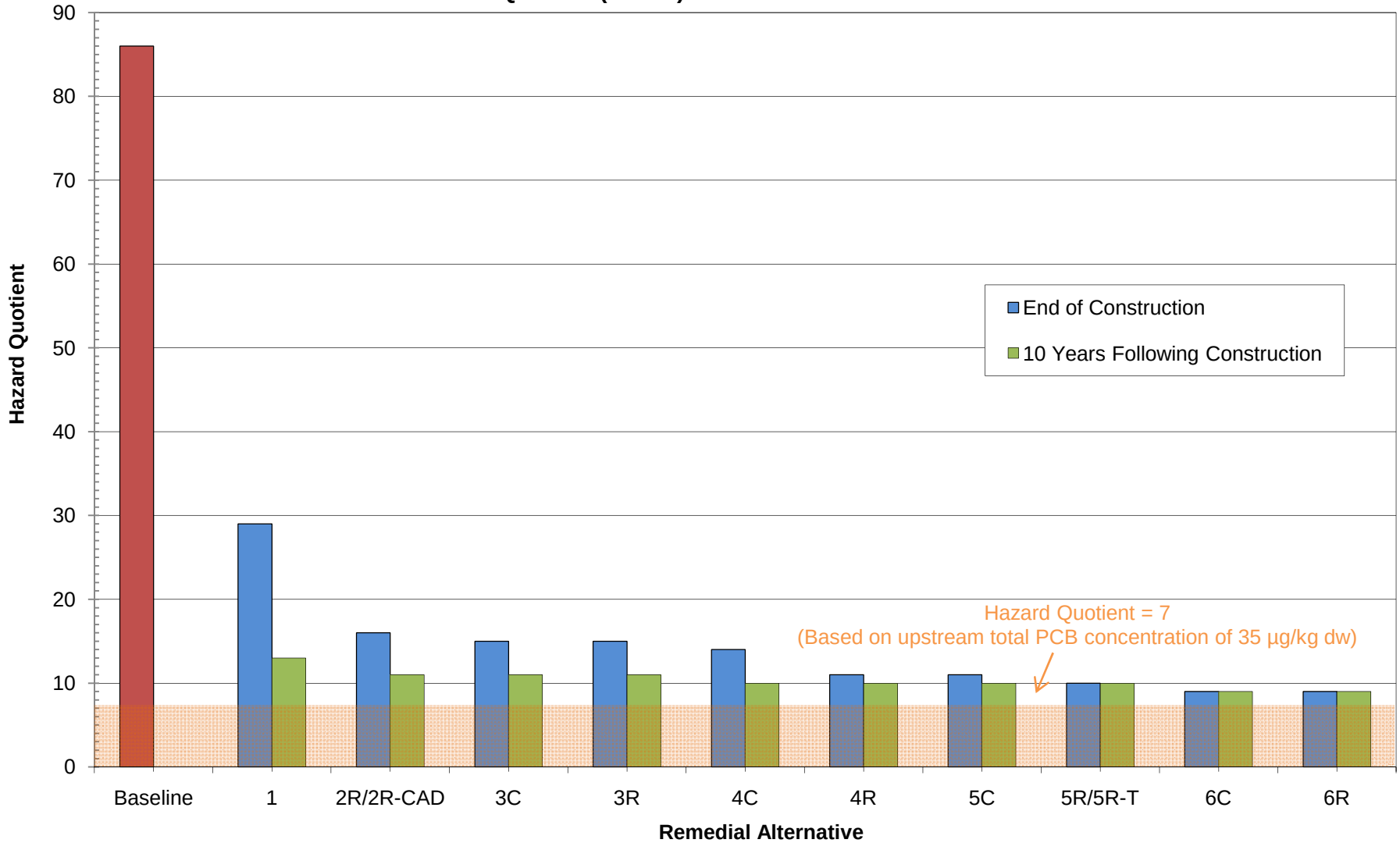
Figure 9-9a Residual Adult Tribal Reasonable Maximum Exposure Seafood Consumption Hazard Quotient (RAO 1) for Total PCBs After Remediation



Notes:

1. Risk values shown for the alternatives are also presented in Table 9-6b.

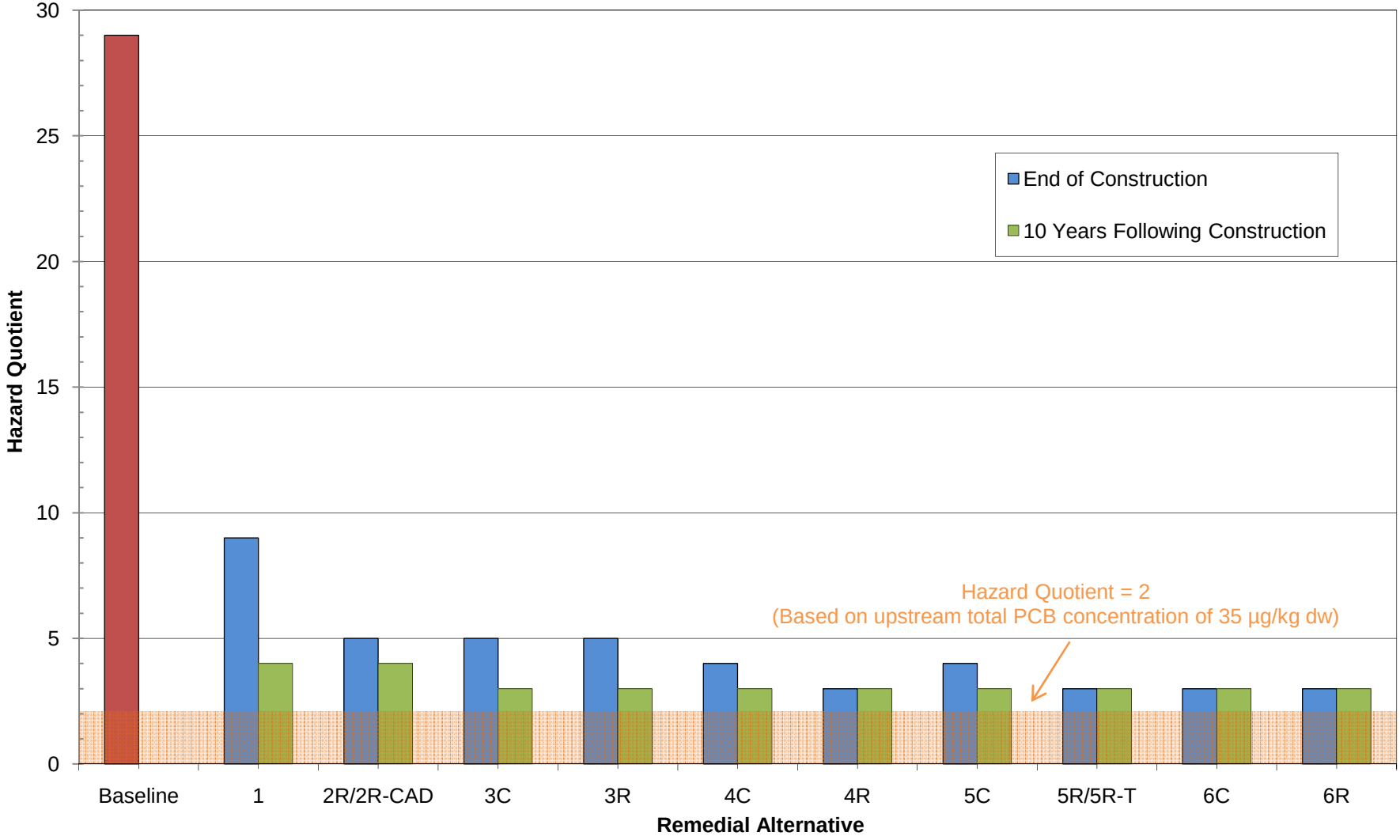
Figure 9-9b Residual Child Tribal Reasonable Maximum Exposure Seafood Consumption Hazard Quotient (RAO 1) for Total PCBs After Remediation



Notes:

1. Risk values shown for the alternatives are also presented in Table 9-6b.

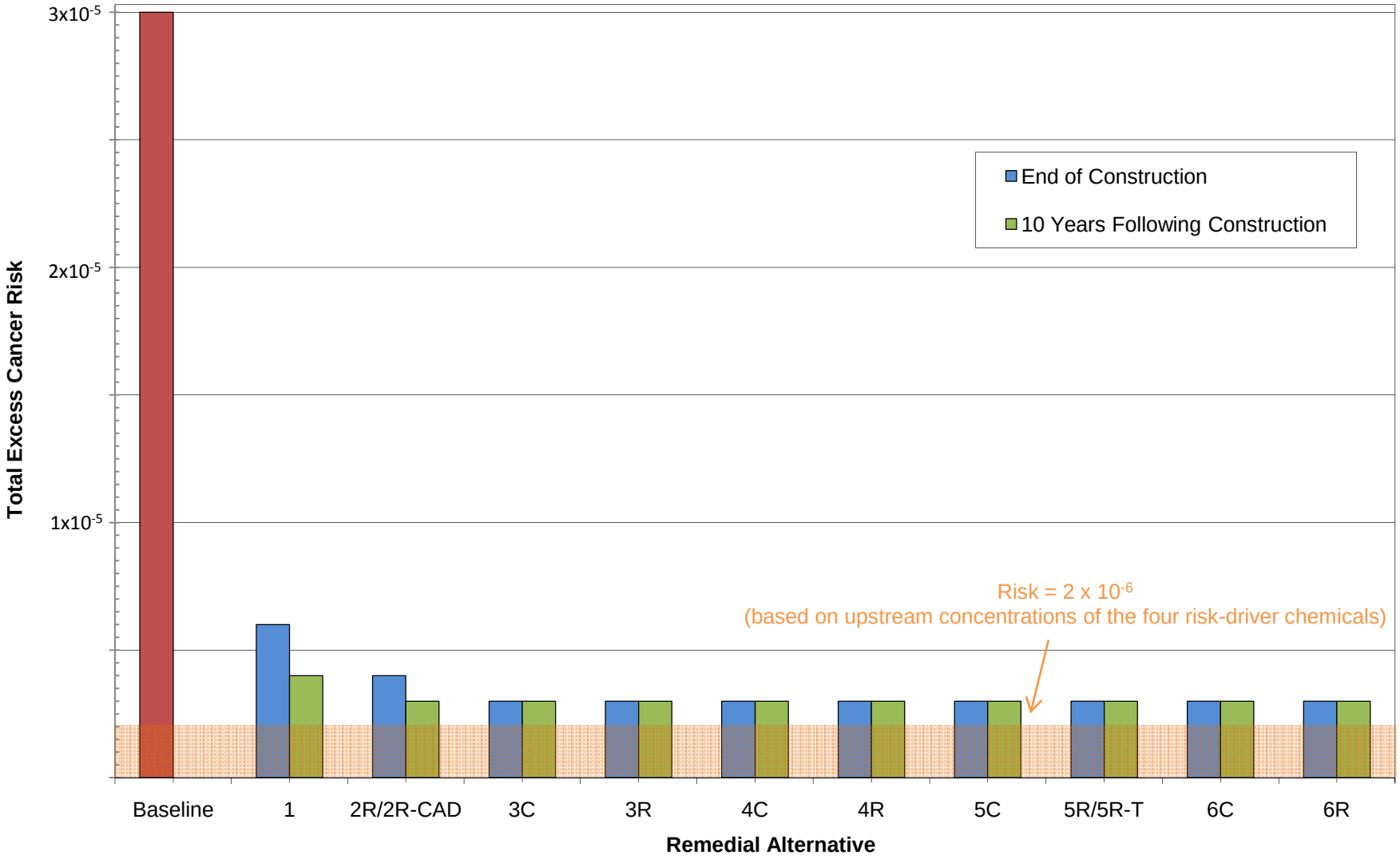
Figure 9-9c Residual Adult Asian Pacific Islander Reasonable Maximum Exposure Seafood Consumption Hazard Quotient (RAO 1) for Total PCBs After Remediation



Notes:

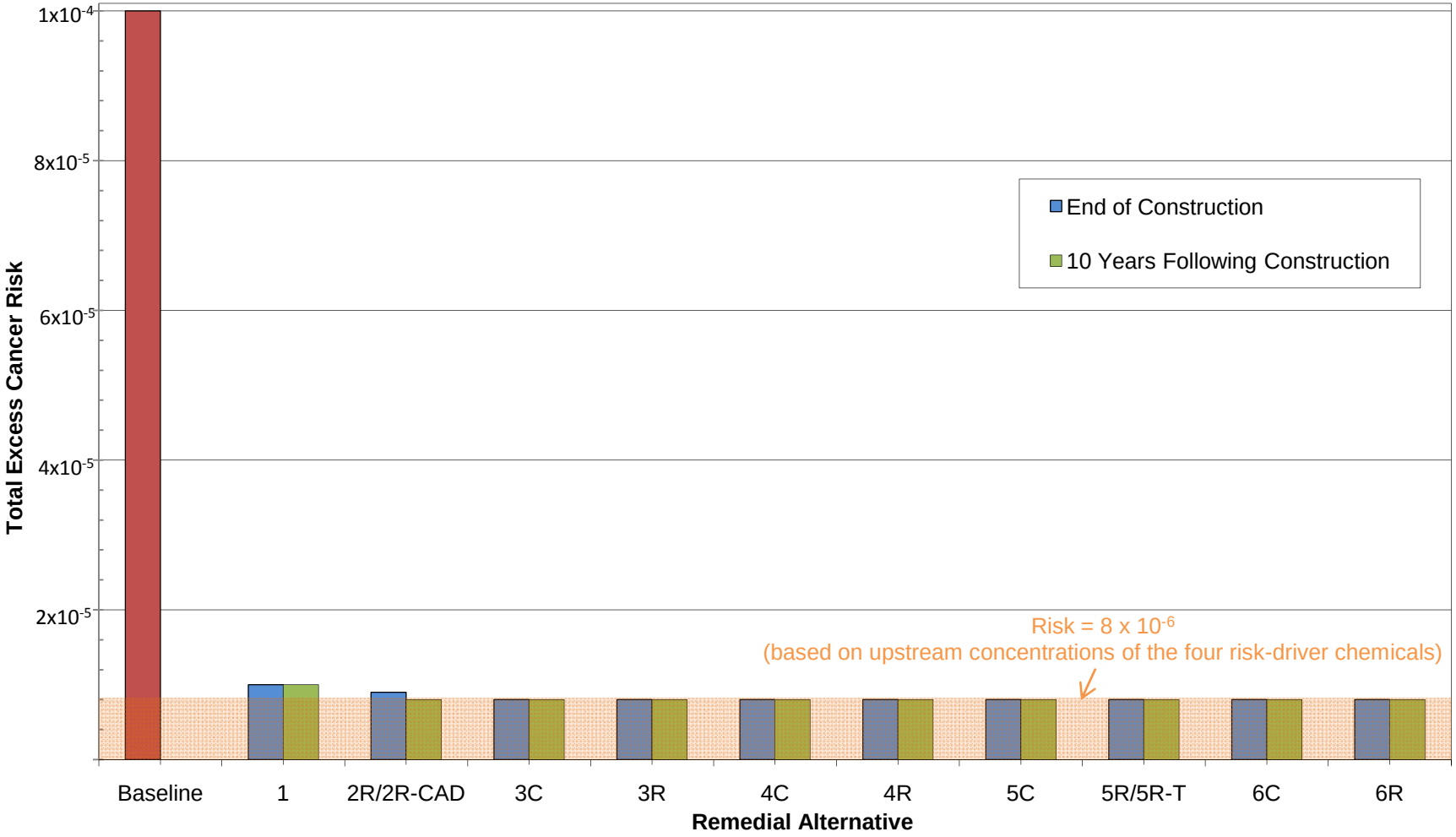
1. Risk values shown for the alternatives are also presented in Table 9-6b.

Figure 9-10a Site-wide (Netfishing) Cumulative Direct Contact Risk (RAO 2) After Remediation



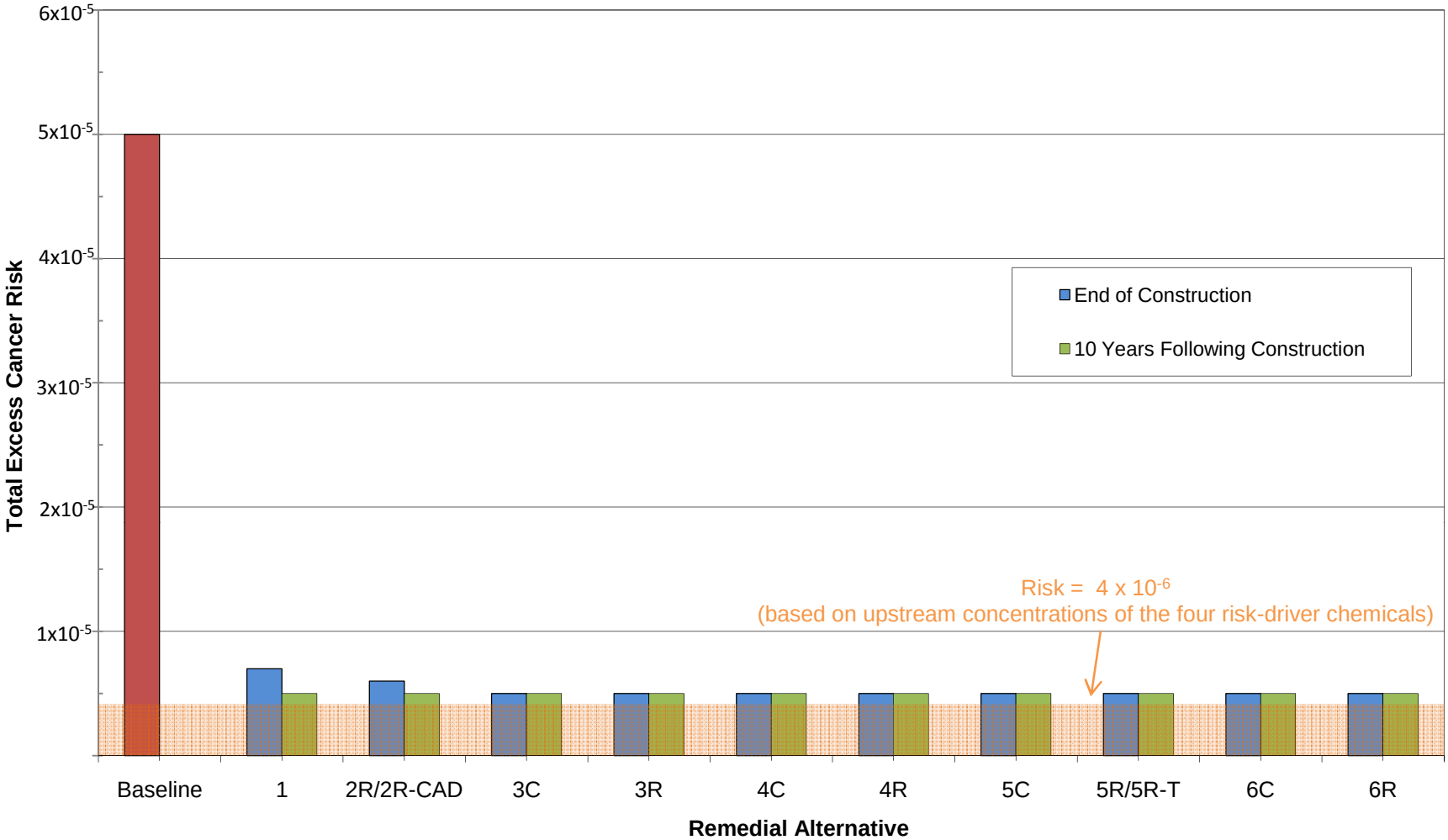
Notes:
1. Cumulative risks include only the risk-driver chemicals (arsenic, cPAHs, total PCBs, and dioxins/furans).
2. Risk values shown for the alternatives are also presented in Table 9-7.
3. Orange bar represents the upstream risk estimate for the netfishing direct contact RME scenario.

Figure 9-10b Tribal Clamming Cumulative Direct Contact Risk (RAO 2) After Remediation



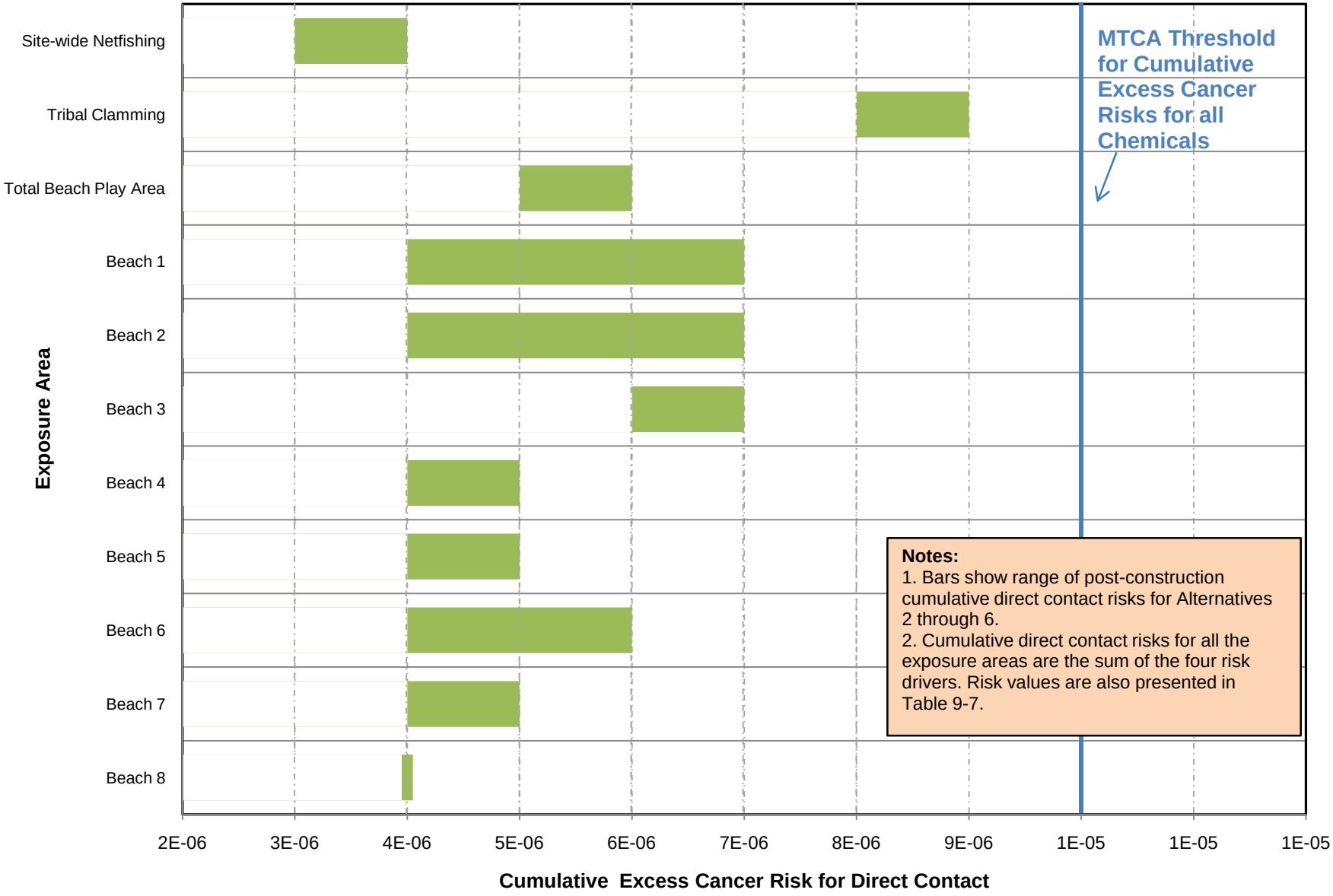
Notes:
1. Cumulative risks include only the risk-driver chemicals (arsenic, cPAHs, total PCBs, and dioxins/furans).
2. Risk values shown for the alternatives are also presented in Table 9-7.
3. Orange bar represents the upstream risk estimate for the tribal clamming direct contact RME scenario.

Figure 9-10c Total Beach Play Area Cumulative Direct Contact Risk (RAO 2) After Remediation



Notes:
1. Cumulative risks include only the risk-driver chemicals (arsenic, cPAHs, total PCBs, and dioxins/furans).
2. Risk values shown for the alternatives are also presented in Table 9-7.
3. Orange bar represents the upstream risk estimate for the total beach play area direct contact RME scenario.

Figure 9-11 Range of Post-Construction Cumulative Excess Cancer Risks for Direct Contact for Alternatives 2 Through 6



Updated by NCO on 10-13-10

10 CERCLA Comparative Analysis

This section compares the Lower Duwamish Waterway (LDW) remedial alternatives that were developed in Section 8 and evaluated individually in Section 9. This comparative analysis of alternatives uses the same set of Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) criteria that were used to evaluate each alternative in Section 9. Table 10-1 consolidates the pertinent narrative and quantitative information discussed herein. The alternatives are first evaluated for whether they meet or do not meet threshold criteria. For the CERCLA balancing criteria, the table ranks the alternatives using a 5-star relative ranking scale: one star (★) is the lowest relative rank and five stars (★★★★★) is the highest relative rank. A comparative evaluation of alternatives under the Washington State Model Toxics Control Act (MTCA) is provided in Section 11.

10.1 Threshold Criteria

The alternatives were compared, as discussed in this section, for their ability to satisfy the two threshold criteria designated by CERCLA. The threshold criteria include: 1) overall protection of human health and the environment and 2) compliance with applicable or relevant and appropriate requirements (ARARs).

10.1.1 Overall Protection of Human Health and Environment

Dredging, landfill disposal, capping, enhanced natural recovery (ENR), and monitored natural recovery (MNR) form the primary suite of technologies around which Alternatives 2 through 6 are developed. As the remedial action levels (RALs) are lowered through this series of alternatives (and the remedial footprints increase), engineering controls (active remediation) are relied on more and natural recovery is relied on less to achieve the remedial action objectives (RAOs). In addition, Alternative 2R-contained aquatic disposal (2R-CAD) substitutes on-site CAD for upland landfill disposal. Alternative 5R-Treatment uses soil washing to treat a fraction of the dredged material.

All alternatives require institutional controls. In particular, seafood consumption advisories, public education, and outreach are needed to reduce human exposures to resident LDW seafood, because none of the alternatives are capable of lowering total polychlorinated biphenyls (PCBs) and dioxins/furans in surface sediment to their respective preliminary remediation goals (PRGs), which are set at natural background.

Alternative 1 provides the least protection of human health and the environment. It does not achieve any of the RAOs primarily because it does not provide adequate monitoring, engineering and institutional controls to ensure that the PRGs are achieved or to apply contingency actions if they are not achieved. All of the remaining alternatives (2 through 6) meet the threshold criterion for overall protection of human

health and the environment because they achieve the four RAOs and provide monitoring to ensure they are achieved. Long-term residual risks are the same for these alternatives (Table 10-1). As discussed later in this section, the times required to reach these residual risks differ among the alternatives.

Differences in overall protectiveness of Alternatives 2 through 6 are largely in the context of short-term and long-term effectiveness. Combined technology alternatives can be implemented more quickly than removal-based alternatives with the same RALs. Also, alternatives with higher RALs can be implemented more quickly than those with lower RALs. Shorter construction periods translate into lower impacts to workers, the community, and the environment during implementation. Conversely, longer construction periods result in higher short-term impacts. As discussed under short-term effectiveness, these impacts include traffic, noise, emissions, resource depletion, habitat disturbance, elevated fish tissue concentrations and time to achieve RAOs. Alternatives 2, 3, 4C, and 5C have construction periods ranging from 4 to 8 years and generally have lower short-term impacts. Alternatives 4R, 5R, and 6C have construction periods ranging from 13 to 19 years and thus, have much greater short-term impacts. Alternative 6R is anticipated to require almost 40 years to construct and thus, has the greatest short-term impacts.

In the long term, remedial alternatives with higher RALs, and therefore smaller dredge and cap footprints, leave more subsurface contamination in place that could potentially be re-exposed by physical disturbance mechanisms (e.g., high-flow scour, propeller wash, and construction). This is acknowledged and addressed in the development of the remedial alternatives with the assumption that portions of the site designated for natural recovery (ENR and MNR) are likely to require more active remediation (dredging or capping) based on data collected during both remedial design or as a result of future monitoring. Also, reliance on institutional controls is expected where subsurface contamination remains above protective levels to reduce the potential for re-exposure (e.g., restrictive covenants, monitoring and notification of waterway users). Re-exposure of subsurface contamination is primarily a matter of concern in the context of RAO 3, which has a point-based compliance standard and is therefore more influenced by localized re-exposures. Re-exposure is less of a concern for maintaining RAOs 1, 2, and 4. The PRGs for these are all based on spatially-weighted average concentration (SWAC) metrics and are therefore less subject to influence by localized or small-scale re-exposures.

In summary, Alternatives 2 through 6 each achieve the threshold criterion of Overall Protection of Human Health and the Environment. Alternative 1 does not achieve this threshold criterion.

10.1.2 Compliance with ARARs

The three most important ARARs in terms of evaluating the remedial alternatives are: the Washington State Sediment Management Standards (SMS; WAC 173-204); Surface Water Quality Standards (RCW 90-48; WAC 173-201A); and MTCA cleanup level selection requirements. Other ARARs listed in Table 4-1 (Section 4) were not discussed explicitly as part of the detailed evaluation of remedial alternatives in Section 9. As described below, broad compliance with ARARs is considered to be feasible, for the remedial alternatives at the feasibility study (FS)-level of analysis. Experience on similar projects has shown that a rigorous yet flexible engineering and agency design review can ensure that any of the remedial alternatives (with the exception of Alternative 1) can be designed to comply with ARARs.

SMS Compliance

Cleanup standards under the SMS are established by the Washington State Department of Ecology (Ecology) on a site-specific basis within an allowable range of concentrations. The upper end is a minimum cleanup level (MCUL) established at a level not to be exceeded 10 years after completion of the active cleanup actions. The lower end is the cleanup objective and is equivalent to the sediment quality standards (SQS). Site-specific cleanup standards are to be as close as practicable to the cleanup objective. Factors considered for the site-specific sediment cleanup standards include environmental effects, technical feasibility, and cost. Longer time frames for achieving RAOs may be required and approved for some sites, where cleanup standards cannot be achieved within 10 years following construction of the remedial alternative.

Alternative 1 is not expected to comply with the SMS. Alternatives 2 through 6 are considered compliant with the SMS, and rely to varying degrees on the flexibility provided within the SMS regulations for setting cleanup standards and for achieving them within a reasonable time frame. Section 4 of this FS identifies the SQS as the PRG for sediments under RAO 3. Cleanup standards will be established in the final decision documents consistent with the SMS.

Water Quality Standards Compliance

All of the remedial alternatives must comply substantively with Surface Water Quality Standards (WAC 173-201A) during construction. Dredging and capping projects previously implemented in the LDW have complied with the requirements of the project-specific water-quality certification requirements. Thus, compliance with these certification requirements can be expected regardless of the remedial alternative selected, provided that dredging methods include best management practices (BMPs) to ensure that dissolved and/or suspended releases (e.g., of total suspended solids [TSS] and PCBs) do not result in exceedances of water quality standards (EPA 2005; NRC 2007; USACE 2008a). It is noted that implementing multiple projects simultaneously and in relative proximity to one another could increase the risk of violating short-term

water quality compliance, a consideration that should be factored into project sequencing and production rate decisions. Careful planning, production rate controls, and the use of BMPs is warranted in all cases to reduce short-term water quality impacts.

RAO 1 includes compliance with water quality standards for protection of human health (i.e., risk-based standards based on the seafood consumption pathway under WAC 173-201A). Cleanup of sediments, along with source control actions, are expected to reduce concentrations of chemicals of concern (COCs) in the water column following cleanup actions. Other factors not related to releases from the site also contribute to chemical concentrations in water. Monitoring will assess whether this ARAR can be attained in the long term or a waiver would be required. To the extent that surface waters are deemed to be impaired following the remedial action, they will continue to be addressed through separate regulatory programs under the Clean Water Act (CWA).

MTCA Cleanup Level Selection Compliance

For this FS, EPA determined that achieving certain natural background concentrations is a MTCA ARAR. This applies to PRGs for PCBs and dioxins/furans (for RAO 1) and arsenic (for RAO 2). EPA established natural background concentrations for these risk drivers based on the 95th upper confidence limit on the mean for the 2008 EPA Puget Sound Ocean Survey Vessel (OSV) *Bold* survey dataset (EPA 2008). However, based on current knowledge of sediment loads to the LDW, and regardless of the effectiveness of source control, achievement of these PRGs is considered technically infeasible. Importantly, MTCA considers other statistical metrics (e.g., the 90th percentile) for estimation of natural background. Alternatives 2 through 6 comply with a natural background PRG (i.e., MTCA cleanup level) for arsenic based on the latter metric. Also, Alternatives 2 through 6 comply with the MTCA ARAR and achieve RAO 1 through a combination of active cleanup to reduce concentrations and application of institutional controls designed to reduce exposure.

For RAO 2 (human health direct contact), all MTCA requirements are achieved for cumulative excess cancer risks (at or below 1×10^{-5}) and for individual excess cancer risks (at or below 1×10^{-6}) for total PCBs and dioxins/furans. Concentrations of carcinogenic polycyclic aromatic hydrocarbons (cPAHs) at most of the individual beaches are predicted to remain above the PRG of 90 micrograms toxic equivalent per kilogram dry weight (µg TEQ/kg dw). However, beaches are predicted to have excess cancer risks of 1×10^{-6} for cPAHs for all assumed beach play areas, except Beach 3 (Appendix M, Table M-8c). In addition, the MTCA Method B unrestricted soil direct contact cleanup level for cPAHs is 140 µg TEQ/kg dw (WAC 173-340-740 (3)) and cPAH concentrations at all beaches, except Beach 3, are predicted to be reduced below this level, thus complying with the MTCA ARAR but not the PRG. The bed composition

model (BCM) model output for Beach 3 is influenced by a lateral source, indicating the importance of source control for complying with the MTCA ARAR at all beaches.

Compliance with other ARARs

The construction elements for the remedial alternatives are similar in nature and scope to ARAR-compliant sediment remediation projects previously implemented in the Puget Sound region. It is therefore anticipated that all of the remedial alternatives can be designed and implemented to comply with ARARs pertaining to:

- **Management and disposal of generated materials (e.g., contaminated sediment, wastewater, and solid waste).** These are all largely procedural and influence the handling and disposal of materials. The ARARs may complicate implementation but have negligible likelihood of influencing whether a remedial alternative is fundamentally viable.
- **Resource protection requirements (e.g., habitat preservation, mitigation).** These do not pose a fundamental obstacle to the design and implementation of the remedial alternatives. Each alternative can be designed to result in no net loss of aquatic habitat area over time. Short-term damage to benthic habitat will occur with increased dredging and capping footprints in existing habitat areas. Thus, more intensive active remediation in intertidal and nearshore locations will carry an increased design burden for accommodating ecological habitat issues and tribal concerns.

CWA 404 dredge and fill requirements can be met for all remedial alternatives. As with previous regional CERCLA remediation projects, the EPA would evaluate the selected alternative for substantive compliance with 404(b)(1) and Rivers and Harbors Act Section 10 requirements. Specific design elements would ensure these requirements are satisfied.

Alternative 5R-Treatment may require construction and operation of a treatment facility located outside of the Superfund site, in which case, all permit requirements related to the facility would need to be satisfied. Off-site placement of any treated sand under Alternative 5R-Treatment, if determined to be legally and commercially viable, would also need to obtain regulatory approvals.

Alternative 2R-CAD includes off-site open-water disposal of clean sediments excavated from CAD pits. This disposal would be subject to full administrative compliance (including permitting) under the dredged material management program (DMMP) process, and such compliance is considered feasible.

Summary of Compliance with ARARs

Alternative 1 does not satisfy the threshold requirement of complying with ARARs. Alternatives 2 through 6 comply with ARARs.

Natural background PRGs for PCBs and dioxins/furans (for RAO 1) in sediment are ARARs under MTCA for protection of human health via the seafood consumption pathway. The alternatives are not expected to achieve concentrations at or below these PRGs. Compliance with the MTCA ARARs is achieved by using institutional controls designed to reduce human exposure to resident fish and shellfish.

CERCLA requires that all ARARs be met or waived on any one or more of six bases upon completion of remedial actions. In addition, compliance with some water quality standards may not be feasible, particularly those based on human consumption of bioaccumulative contaminants that magnify through the food chain, such as PCBs. By far the most common waiver is for technical impracticability. The goal in all instances where predictions are that ARARs may not be achieved is to get as close as technically practicable to the ARAR, and apply a waiver only to the extent necessary. Because future conditions are difficult to predict, actual data available upon completion of the remedial action will underlie the basis for any such waivers, which are formally documented and issued by EPA. For this reason, more definitive statements on whether, and perhaps more significantly to what extent, ARARs such as sediment PRGs for PCBs and dioxins/furans, or certain water quality criteria based on bioaccumulation of contaminants through the food chain will be achieved or potentially waived cannot be made at this time, but must be made at the completion of cleanup and source control work at the site.

10.2 Balancing Criteria

The alternatives were compared with regard to their ability to satisfy the five balancing criteria designated by CERCLA. The subsections below present the comparison.

10.2.1 Long-term Effectiveness and Permanence

This balancing criterion assesses the magnitude and type of residual risk that would remain at the site after RAOs are achieved. The primary focus of this evaluation is the extent and effectiveness of the controls that may be required to manage the risks posed by residual contamination.

10.2.1.1 Magnitude of Residual Risk

The remedial alternatives were evaluated for two types of residual risk. One type is the risk predicted to remain on-site from exposure to surface sediment containing residual concentrations of risk-driver chemicals. The other form of residual risk described in CERCLA guidance is that "…from untreated waste or treatment residuals at the conclusion of remedial activities." Evaluation of this form of residual risk following

achievement of RAOs considers the potential for re-exposure of sediments remaining in the subsurface that contain COCs above protective levels.

Residual risks to humans, wildlife, and the benthic community from surface sediment concentrations remaining on-site once RAOs are achieved were estimated as described in Section 9 and are summarized in the first several rows of Table 10-1. All of these alternatives achieve similar residual surface sediment risk levels. Alternative 1 does not provide adequate monitoring, engineering and institutional controls to enable an RAO compliance assessment.

Evaluation of residual risks in the context of contamination remaining on site considered the potential for re-exposure of subsurface contamination under caps or located in areas monitored for natural recovery or ENR. Table 10-1 contains the following semi-quantitative metrics for each alternative:

- Total area dredged (in acres)
- Total area capped, including partial dredge and cap (in acres)
- ENR and MNR surface area (in acres) grouped by recovery categories[1]
- The number of core stations in the FS dataset that contain concentrations greater than cleanup screening levels (CSL) and reside: 1) under caps; and 2) all other locations – i.e., ENR, MNR, and the rest of the LDW.

In general, remedial alternatives that emphasize removal and upland disposal of subsurface contaminated sediments from the LDW have a lower re-exposure potential than alternatives emphasizing capping, ENR, and MNR. This is because removal and upland disposal in a regional landfill physically removes contaminated sediment from the LDW thereby eliminating any residual risk to the LDW from that material. The potential for re-exposure is considered slightly higher for capped sediment than for dredged sediment primarily because the material remains in the LDW. However, the potential is only slightly higher because caps are engineered to remain structurally stable under site-specific conditions. In comparison to capped areas, residual contamination beneath ENR and MNR areas has greater potential for re-exposure because these technologies are not engineered to ensure isolation of buried contaminated sediments.

[1] As defined in Section 6, Recovery Category 1 has a high potential for scour or a high re-exposure potential; recovery is presumed to be limited. Recovery Categories 2 and 3 are either stable or expected to recover over time and thus have a lower re-exposure potential than Recovery Category 1 areas.

From a recovery category perspective, limiting ENR and MNR to areas in Recovery Categories 2 and 3 reduces the potential for re-exposure of deeper buried contaminated sediment from episodic physical disturbances (e.g., high-flow event scour, general waterway use, seismic events, and development-related construction). ENR and MNR are not assigned to any area in Recovery Category 1 in Alternatives 4, 5, and 6.[2] The remaining FS dataset cores containing sediment with concentrations greater than CSL are either capped or are located in less energetic or more depositional areas found in Recovery Categories 2 or 3.

In the long-term, re-exposure of buried contamination by mechanical disturbances would generally be confined to small, localized areas. Localized risks to benthic organisms could occur in these instances. It is unlikely that such disturbances would significantly increase residual risks that are based on SWACs (i.e., direct contact and seafood consumption risks). Risks from resuspension of material in the water column were not evaluated, but are believed also to be of short-term duration. Finally, with the passage of time, the magnitude of chemical impacts to sediment from episodic and shallow physical disturbances can be expected to diminish as a result of the dynamic burial and mixing mechanisms that reduce heterogeneity naturally.

As shown in Table 10-1 and in Figure 10-1, Alternatives 2 (127 acres) and 3 (100 to 109 acres) remediate the largest portion of Area of Potential Concern 1 (AOPC 1) using ENR and MNR. In both cases, approximately 20 acres reside in Recovery Category 1. Alternatives 4C, 4R, 5C, and 6C remediate much smaller areas in AOPC 1 using these technologies (43 to 58 acres), all of which are located in either Recovery Categories 2 or 3. These alternatives have a much lower potential for re-exposure of buried contaminated sediment. Alternatives 5R and 6R have the lowest potential for re-exposure because they rely fully on the dredging and capping technologies.

The CAD component of Alternative 2R-CAD has a slightly higher re-exposure potential compared to disposal in an upland landfill. However, the risk of re-exposure of sediments placed in the CAD is low because the CAD cell and engineered sediment cap would be designed, monitored, and maintained for long-term stability. The CAD is therefore considered similar to other caps for re-exposure potential.

10.2.1.2 Adequacy and Reliability of Controls

This factor assesses the adequacy and reliability of controls used to manage contaminated sediment that remains on-site after implementation. Residual sediment contamination can stem from dredge residuals, uncontrolled sources, or from the

[2] Also, in recognition that remedial design information could change technology assignments and that the potential for scour is an important determinant, the alternatives assume that 10% percent of the base area designated for cap, ENR, MNR, VM, institutional controls, and site-wide monitoring will require dredging during remedial design.

intentional leaving behind of material in the subsurface as part of the remedy.[3] The remedial alternatives (with the exception of Alternative 1) require long-term monitoring, maintenance, and institutional controls to manage residual risks and the potential for recontamination. The relative magnitude and importance of these control components vary somewhat among the alternatives and are related to the re-exposure potential of subsurface contaminated sediment under caps and in areas managed for natural recovery (MNR and ENR). Information gathered from these activities is used to assess the need to replace technical components of the alternative (e.g., a cap) and the exposure pathway/risks posed should the remedial action need replacement or repair.

Control of Dredge Residuals

All dredging projects leave behind some level of residual contamination immediately after completion of in-water work (USACE 2008a). Dredge residuals are produced by the resettling of sediments suspended during dredging, subsequent disturbance and transport of the material as fluidized mud layers along the bottom, or material left behind (not removed from) in the dredge prism (USACE 2008a). Remediated surface sediments in the LDW will be affected by dredge residuals. The inevitability of dredge residuals was acknowledged in the development of remedial alternatives (Section 8) with a specific assumption that dredging is followed by a thin-layer application of sand; an engineering control for residuals.[4]

Source Control

Uncontrolled sources contribute to and influence remediated surface sediment concentrations. In general, areas near stormwater and combined sewer overflow (CSO) outfalls have a higher potential for being recontaminated than areas that are distant from such outfalls.[5] The same can be said of areas adjacent to contaminated and erodible bank soils and areas near the discharge zones of contaminated groundwater. A more intractable problem to quantify and control is the immediate urban, broader regional and even global sources and transport mechanisms (e.g., PCBs, dioxins/furans). Control of upland sources of contamination to the LDW is therefore an important factor for limiting recontamination of sediments. Predicting the benefits of source control in terms of reduced recontamination potential is chemical-specific and subject to considerable uncertainty. Legacy compounds such as PCBs can be expected to diminish over time both as a result of source control and because the chemicals are no longer being manufactured and used within the United States. However, global use and

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[3] Potential for re-exposure of subsurface contamination was discussed above in Section 10.2.1.1.

[4] Also, the post-remedy bed sediment replacement values assigned to remediated surfaces following construction were developed, in part, to account for the effects of dredge residuals.

[5] Monitoring at the Duwamish/Diagonal EAA and the Norfolk area show decreasing overall trends, but continue to produce some exceedances above the SQS for a few chemicals.

global transport of PCBs through atmospheric deposition will continue to influence long-term concentrations (see Appendix J). In addition, PCBs at diffuse levels will continue to be present in construction materials. Other chemicals (e.g., cPAHs and phthalates) continue to be generated and released into the environment. Empirical data trends for PCBs and other chemicals in Puget Sound (Appendix J) show that recontamination is expected in an urban environment. Zero discharge of any of these chemicals is neither a practicable nor achievable goal. The FS assumes that an adequate level of source control occurs before active remediation is undertaken. It is also anticipated that each remedial design effort will specifically address the adequacy of or need for additional control of near-field sources that could impact the cleanup.

Monitoring

Monitoring of sediment and surface water quality will be required regardless of the remedial alternative selected for cleanup of the LDW. Monitoring methodologies are considered reliable for tracking remedy performance, achievement, and maintenance of RAOs. Monitoring data would also be used to assess whether and to what extent sediment recontamination is occurring. In the short term, monitoring data would be used to identify the need for management of dredge residuals. Depending on the risks posed by the residuals and the regulatory approach to cleanup at a particular site, accumulations of residual contaminated material could trigger a need for additional actions (Bridges et al. 2008). Additional actions could be necessary if concentrations exceed action levels (e.g., RALs). This latter point is discussed further as part of the implementability criterion (Section 10.2.4).

Once RAOs are achieved, differences in the adequacy and reliability of monitoring are minor among the alternatives. However, scope and duration of monitoring do differ among the alternatives. For example, the MNR and ENR components of the combined alternatives require the collection of more project-specific operations and maintenance (O&M) monitoring data than the removal-based alternatives to achieve equivalent data quality objectives.

The entire LDW will require monitoring under all remedial alternatives. To differentiate among the alternatives, the monitoring evaluation factor is qualitatively assessed in terms of whether the remedial alternatives have large, moderate, or small surface areas that require technology-specific monitoring (i.e., cap, ENR, and MNR) during the O&M period (Table 10-1). Alternatives 2, 3C, 3R, 4C, 5C, and 6C have comparatively large areas to monitor, with Alternatives 2, 3C, and 3R having the largest areas to monitor. The monitoring requirement for Alternative 4R is moderate. Alternatives 5R and 6R have low monitoring requirements because they have the least area remediated by capping, and neither ENR nor MNR is used for these two alternatives.

Maintenance

Following achievement of RAOs, the primary form of maintenance, when needed, consists of placing additional granular material (of varying types and quantities) to repair caps and ENR areas. To a lesser degree, localized removal and disposal could also be undertaken. Long-term RAO monitoring, repair, and adaptive management responses (including contingency actions where appropriate, such as spot removals) would decrease the residual risk of future exposure to buried contaminated sediment once RAOs are achieved. Reliability differences among the alternatives become less discernable after the RAOs have been achieved.

The maintenance technologies are drawn from the same set of technologies used to develop the remedial alternatives. The primary maintenance devices are dredging or application of granular material (e.g., to repair a cap or ENR area). These are performed using the same marine construction technologies that are used during remedy construction. These technologies are as reliable for maintenance as when employed in constructing the alternatives themselves, assuming that the engineering, planning, and execution of the repairs are done with a similar level of proficiency. Maintenance records are available for previously completed capping projects that have been in place for more than 15 years (e.g., a number of estuarine caps constructed throughout the Puget Sound region). A review of several completed projects show the caps have been successful in containing the contaminated sediments and are performing as designed (see Sections 7.1.3.4 and 7.1.4).

Alternatives emphasizing removal have a reduced level of effort for maintenance compared to alternatives emphasizing containment and natural recovery. ENR and MNR areas are assumed to have a higher maintenance requirement (i.e., per unit area) compared to capping.[6] The maintenance evaluation factor is qualitatively assessed in terms of whether the remedial alternatives have large, moderate, or small surface areas to maintain (Table 10-1). Therefore, the comparison of alternatives is the same as previously discussed for monitoring.

Institutional Controls

None of the alternatives achieve the RAO 1 PRGs for total PCBs or dioxins/furans. Thus, remaining risks to the community from seafood consumption must be managed by institutional controls in all cases. The institutional controls that manage human health risks from seafood consumption are seafood consumption advisories and a

[6] The long-term O&M monitoring that occurs in natural recovery areas before goals are achieved will identify performance-related issues in specific project areas and enable decision-making on whether contingency actions are warranted before goals are achieved. The alternatives assume that 15% percent of ENR and MNR areas will require dredging based on long-term O&M monitoring results. Therefore, most long-term maintenance needs will be to address small areas affected by localized scour.

public education/outreach program. The Washington State Department of Health publishes seafood consumption advisories in Washington State. These are informational devices. The alternatives do not differ in the scope and duration of this control once RAOs are achieved. The public education/outreach effort would be developed and administered by the settling parties with participation from local governments, Tribes, and other community stakeholders.

The other important informational device is monitoring and notification of waterway users. The essential components of this institutional control, as developed in Section 7.1.7, could include:

- Conduct periodic seafood consumption surveys to identify, by population group, which species are consumed and in what quantities. Information is used to update the Institutional Control Implementation Plan and to improve seafood consumption advisories and the associated public outreach and education.
- Review USACE dredging plans and other Joint Aquatic Resource Permit Application (JARPA) construction permitting activity to identify any projects with the potential to compromise containment remedies (cap or CAD). EPA and Ecology are notified during the permitting phase of any project that could affect containment remedies.[7]
- Using signs and other forms of public notice, notify waterway users of use restrictions where subsurface contamination remains above protective levels.
- Establish a sediment cleanup hotline for private citizens to call or e-mail information on potential violations. EPA and Ecology are notified of any issues, as appropriate. The agencies have authority to order performing parties to assess or correct any damage to the remedy based on this information.
- Conduct periodic vessel-based surveys, in which the vessel operator educates potential violators of the existence of the LDW use or activity restrictions. Potential violations of use restrictions would be reported to Ecology and EPA.

Private owners of LDW properties that have contamination remaining above protective levels following remediation (e.g., in the subsurface) would be required to file a restrictive covenant on the property deed. It is assumed that a standardized restrictive

[7] This function is currently in place in the form of a Memorandum of Agreement between EPA and USACE, and the existing mechanism could either be funded or assumed by the settling parties.

covenant would be developed and used for this purpose. Restrictive covenants will be needed for all alternatives. For comparative purposes, the impact on development of restrictive covenants is assumed to be similar for all alternatives and is not analyzed in detail. The magnitude and duration of institutional controls, and their overall importance to managing residual risk, would be slightly greater for alternatives that emphasize capping, ENR, and MNR. With respect to the latter two technologies, the importance of controls is primarily for areas where subsurface contamination exceeds RALs and could be re-exposed by mechanical disturbances.

10.2.1.3 Summary of Long-term Effectiveness and Permanence

With the exception of Alternative 1, the residual risks from surface sediment are similar among the alternatives based on model-predicted outcomes. Active remediation alone (i.e., ignoring any contribution from natural recovery) is responsible for the majority of progress toward achievement of the residual risk levels for all alternatives. However, Alternatives 2, 3, and 4 rely more on natural recovery and thus have more uncertainty associated with: 1) the rate of natural recovery and 2) the potential for re-exposure of buried subsurface contamination. Ultimately, surface sediment concentrations are expected to converge to levels similar to the quality of incoming sediment from the Green/Duwamish River, resulting in similar levels of risk over time for all remedial alternatives. In the long term, the effectiveness of source control for the LDW and inputs from the Green/Duwamish River are the primary factors governing surface sediment concentrations.

With the exception of Alternative 1, each alternative requires monitoring, maintenance, and institutional controls, with contingency actions and periodic reviews (e.g., every 5 years) to manage remaining contamination. Differences in the level of effort and reliability of these control mechanisms among the alternatives, once RAOs are achieved, are related primarily to the magnitude of subsurface contamination remaining.

Adequate controls to manage dredge residuals deposited in the near-field can be included in engineering design requirements and are an assumed element of the remedial alternatives developed in this FS. Some residuals will escape the dredge operational area and contribute to far-field recontamination. Finally, it is also worth noting that removal-emphasis alternatives will necessarily have a more extensive dredge residuals management component than the combined alternatives.

Adequate source control will be important for limiting the potential for recontamination. For FS purposes, upland source control is assumed to occur in advance of remedy implementation to an extent sufficient to preclude significant additional actions in the long term. Nevertheless, any recontamination would ultimately be identified and assessed through the monitoring program.

Long-term O&M monitoring is a reliable control. Sampling methods and analytical techniques are sufficiently advanced to enable collection of representative data for purposes of assessing long-term remedy performance following achievement of RAOs. Differences among the alternatives are in the scope and duration of long-term O&M monitoring and not reliability. The scope and duration of long-term O&M monitoring diminishes in proportion to the total surface area designated for capping, ENR, and MNR. The remedial alternatives explicitly assume that 15% of the designated ENR and MNR area of any given remedial alternative will require dredging as an effectiveness-based contingency action in response to long-term O&M monitoring data indicating less than adequate performance.

The need for maintenance of remediated areas would be based on physical inspection and monitoring information. Inspections and monitoring can provide reliable information for this purpose. Alternatives emphasizing removal have a reduced level of maintenance compared to alternatives emphasizing capping and ENR. The differences are more a matter of the cost of maintenance rather than of inherent reliability.

All remedial alternatives require institutional controls. The program for institutional controls varies in scope and duration depending on the alternative:

- All alternatives have similar seafood consumption advisories and a public education/outreach program sponsored by the settling parties.
- Alternatives 2R through 6R require the waterway user and notification institutional control sponsored by the settling parties.
- Restrictive covenants are applied to private properties within the LDW that have subsurface contamination remaining above RALs following construction.

In general terms, the alternatives that rely to a large extent on monitored natural recovery to achieve the RAOs (Alternatives 2 and 3) are ranked lower for long-term effectiveness and permanence than Alternatives 4 through 6 due to:

- Need to evaluate the reliability and protectiveness of these remedies
- Potential need for implementing maintenance and occasional contingency actions.

Alternative 1 has the lowest relative rank (★) for long-term effectiveness and permanence because it does not provide any long-term monitoring to ensure reliability of controls and leaves the largest amount of subsurface contamination in place. The removal alternatives, 2R through 6R, have progressively increasing relative ranks (★★ to ★★★★★) because they progressively remove more contaminated sediment from potential scour areas, have fewer restrictive controls, and require less maintenance.

Alternatives 5R/5R-Treatment and 6R, rank the highest (★★★★★) because they leave the least amount of subsurface contamination in the LDW and require the least amount of monitoring and maintenance. Alternatives 4R, 4C, 5C, and 6C (★★★★) rank slightly below Alternatives 5R and 6R, because they leave an incrementally larger area managed by ENR and MNR and have greater monitoring and maintenance requirements. Alternatives 2R (★★), 3C, and 3R (★★★) rank low to moderate because they have even larger areas managed by ENR and MNR. The monitoring and maintenance requirements are greater in general for the combined alternatives than for the corresponding removal-emphasis alternatives throughout the implementation phase. However, once any necessary contingency actions are undertaken (e.g., MNR or ENR areas requiring dredging) and RAOs are achieved, monitoring, maintenance, and O&M efforts are not substantially different between the alternatives.

10.2.2 Reduction in Toxicity, Mobility, or Volume through Treatment

This criterion assesses the degree to which site media are treated to permanently and significantly reduce the toxicity, mobility, or volume of site contaminants. CERCLA guidance specifically applies this criterion to cleanups involving principal threat wastes. EPA has determined that most of the contaminated sediment within the LDW are low-level threat wastes (Section 9.1.2.2).

Alternative 5R-Treatment is the only alternative that includes a treatment technology (soil washing).[8] Soil washing decreases the volume of sediment containing contaminants (i.e., dredged material), but does not decrease the actual mass of chemicals. The residuals from soil washing are distributed into the separated fine-grained material containing the majority of the contaminants; the treated sand fraction contains low residual contaminant concentrations; and a large amount of wastewater contains low particulate and dissolved contaminant concentrations. The treated sand fraction would require testing to quantify residual contaminant concentrations and to assess the suitability for potential beneficial reuse. The process wastewater requires treatment to reduce residual contaminants prior to discharge back into the LDW. Depending on how these materials are handled, residual contaminants may pose a different exposure potential to human health and the environment.

Removal and disposal, capping, ENR, and MNR are not categorized as treatment technologies under CERCLA. However, these remedial actions can provide reductions in mobility, toxicity, or volume even though the reductions are not achieved by

[8] Carbon-amended or other reactive caps were not specifically evaluated but amended caps may be considered during remedial design. Amended caps have toxicity and mobility reduction characteristics and have been successfully used in a number of regional capping projects, including the Olympic View Resource Area and Thea Foss Waterway in Tacoma, and Upriver Dam in Spokane, and are included in the design for the Slip 4 EAA.

treatment. Any alternative could be modified to incorporate treatment into the remedy (i.e., carbon amendments). Also, if principal threat waste material were identified during design, a treatment component could be added to address this material.

Based on these considerations, all the remedial alternatives, except for Alternative 5R-Treatment, have low ranks (★) because they don't treat contaminated sediment. Alternative 5R-Treatment ranks slightly higher (★★) than the others because it is the only alternative that provides treatment. However, while potentially reducing the volume of sediment that must otherwise be disposed of in a landfill, the treatment does not reduce the chemical mass or toxicity.

10.2.3 Short-term Effectiveness

This evaluation criterion addresses the effects of the alternative during the construction and implementation phase until RAOs are achieved (e.g., a cleanup target has been achieved). Under this criterion, alternatives are evaluated with respect to their effects on human health and the environment during implementation of the remedial action including impacts on: the community, workers, and the environment. This criterion also considers the time required for each alternative to achieve the RAOs.

10.2.3.1 Protection of Workers and Community during Construction

This aspect of short-term effectiveness addresses risks from implementation of the alternatives. Short-term impacts to both workers and the community are largely proportional to the construction period (Table 10-1). That is, longer construction equates to greater relative impacts.

For workers, activities on the construction job site (from operation of heavy equipment) pose the greatest risk of physical injury. Risk to workers from exposure to site-related contaminants is generally considered low and manageable through established health and safety requirements for hazardous materials site work. Nevertheless, in both cases, the potential for exposure and injury increases in proportion to the duration of construction. Diver-operated dredging poses unique hazards to workers, and may be used to a greater degree to address under-pier areas under the removal-based alternatives.

Similarly, impacts to the community increase with the amount and duration of construction. The potential for physical injury is primarily a function of accidents associated with road-transport of contaminated sediment and clean import material to and from the site. This potential is related to the amount of truck and train traffic anticipated. Table 10-1 summarizes estimates of truck and train miles traveled under each alternative. Truck-miles are estimated according to the amount of dredged material generated, recognizing that the configuration and location of potential transloading facilities will affect the truck miles. Train miles are estimated based on an

assumed round trip of 568 miles to the landfill. Transportation-related impacts would be managed in part with traffic control plans developed during remedial design.

Other community impacts from transportation and heavy equipment operations are air emissions (e.g., PM_{10}, a respiratory irritant), noise, and nighttime illumination of operations. Also, seafood consumption that occurs during construction presents short-term risks to the community because concentrations of COCs in resident seafood are likely to be higher during construction as a result of contaminated sediment resuspension and biological uptake.

Alternatives 2R, 2R-CAD, 3C, 3R, 4C, and 5C have relatively short construction periods (4 to 8 years) and therefore lower short-term risks to workers and the community. Alternative 4R has a significantly longer construction period (13 years) and therefore moderate impacts for this factor. Alternatives 5R/5R-Treatment, 6C, and 6R have the longest construction periods (19, 18, and 43 years respectively), the most dredging, and thus, the highest short-term impacts to the community and workers.

10.2.3.2 Protection of the Environmental During Construction

Cleaning up the LDW will have environmental impacts that can be grouped into the categories of atmospheric emissions, ecological impacts, and resource consumption. In general, longer duration alternatives and those that emphasize removal have greater short-term impacts in all of these categories than similarly scaled alternatives that emphasize containment (see Table 10-1).

Larger actively remediated footprints increase the areal extent of short-term disturbances to the existing benthic community and other resident aquatic life. Concentrations of bioaccumulative chemicals (e.g., total PCBs) are likely to increase in the tissues of aquatic organisms during the construction phase of removal-intensive alternatives and the organisms that feed on them such as river otters. Finally, damage or destruction of the benthic community reduces food sources for other organisms.

Longer construction time frames increase air emissions and noise. Air emissions include components with local environmental impacts (e.g., S_{ox}, N_{ox}), those which can cause respiratory problems (PM_{10}) and those with global impacts (CO_2 and other greenhouse gases).

The remedial alternatives consume quarry materials (sand, gravel) to satisfy the varying requirements for capping, backfilling (for habitat restoration), ENR, and management of dredge residuals (Table 10-1). Removal alternatives generally consume less material than their combined-technology counterparts. Alternative 2R-CAD has a relatively high material demand for construction of the CAD cap. Alternative 6C has by far the greatest material demand primarily because the remediation footprint is expanded into AOPC 2.

All of the alternatives dredge some volume of material and therefore consume landfill space (Table 10-1). Alternative 2R-CAD and Alternative 5R-Treatment reduce utilization of landfill capacity to the extent that:

- The CAD capacity reduces the volume of dredged material requiring landfill disposal.
- A beneficial use can be identified for the treated coarse-grained material from the soil washing component of Alternative 5R-Treatment.

Otherwise the removal alternatives consume more landfill space than their combined-technology counterparts and alternatives with larger active footprints place a higher demand on landfill space.

Alternatives 5R, 6C, and 6R take the longest to construct, consume the greatest amount of natural resources, generate the most transportation-related impacts, produce the greatest emissions, create the longest periods of bioaccumulation and exposure in resident species, and disturb the largest surface area of benthic community and higher value habitat types (i.e., above -10 MLLW). These alternatives rank relatively low because the short-term community and environmental impacts last for a longer time period compared to other alternatives. At the other end of the spectrum, Alternatives 1, 2R, 2R-CAD, and 3C rank relatively high because the short-term community and environmental impacts last for a much shorter time. Between these, are Alternatives 3R, 4R, 4C, and 5C, all of which have a moderate ranking for environmental impacts.

10.2.3.3 Time to Achieve RAOs

Table 10-1 and Figure 10-2 present predicted time frames to achieve each RAO for each alternative, as defined below:

- **RAO 1:** The remedial alternatives cannot achieve the total PCB and dioxin/furan PRGs for the seafood consumption scenario. These PRGs are based on natural background. Therefore, two time periods are considered. First is the implementation period, at the end of which, all alternatives reduce the Adult Tribal RME seafood consumption risk to the lowest magnitude achievable in the long term (i.e., 10^{-4}). The multi-layered program of monitoring and institutional controls (advisories, public outreach, and education) is required at this point for all alternatives to further reduce seafood consumption exposures (see Section 10.2.1.2). All remedial alternatives are predicted to achieve a risk magnitude of 10^{-4} for Adult Tribal and Adult API RME seafood consumption scenarios immediately following the completion of the implementation period (Table 9-6a). Risks of either 4×10^{-5} or 5×10^{-5} are predicted for the Child Tribal

RME scenario immediately following the completion of implementation for Alternatives 2 through 6.

The second time component is the predicted time to achieve long-term modeled concentration ranges. Incremental reductions in risk-driver concentrations are expected to occur over time as a result of source control and natural recovery processes. These incremental concentration reductions are more pronounced for the lower numbered alternatives (i.e., those with smaller active footprints) that rely more on natural recovery (Figure 10-3). Risk drivers ultimately reach long-term model-predicted surface sediment concentration ranges site-wide for all alternatives. At that predicted time, risks for the Adult Tribal and Adult API RME seafood consumption scenarios remain at the 10^{-4} magnitude (Table 9-6a). Excess cancer risks for the Child Tribal RME seafood consumption scenario are predicted to be no lower than 3×10^{-5}. The time to reach long-term, predicted surface sediment concentrations is subject to uncertainties largely associated with source control in the LDW, Green/Duwamish River inputs, and natural recovery beyond the project implementation period.

- **RAO 2:** Alternatives 2 through 6 are predicted to achieve a cumulative excess cancer risk of $\leq 1 \times 10^{-5}$ for all direct contact reasonable maximum exposure (RME) scenarios within 10 years from issuance of the remedy decision documents.
- **RAO 3**: Alternatives 3C through 6R are predicted to comply with the SMS and thereby achieve RAO 3 within 10 to 15 years from issuance of the remedy decision documents. Alternatives 2R and 2R-CAD are predicted to take almost 20 years.
- **RAO 4**: All of the alternatives are predicted to achieve the site-wide PRG of 128 µg/kg dw for the protection of the river otter (total PCBs site-wide). The time to achieve this RAO is predicted to be immediately following the end of implementation.

Alternatives 3C, 4C, and 5C achieve all four RAOs (not including long-term model-predicted concentrations) in the shortest time frames of 14, 12, and 13 years respectively. Alternatives 2R, 2R-CAD, 3R, and 4R take moderately longer times to achieve the RAOs of 19, 16, and 18 years respectively. Alternatives 5R, 6C, and 6R take the longest time to achieve RAOs (24, 23, and 43 years respectively), by virtue of their long implementation periods, and the on-going impacts to fish tissue concentrations during construction. Time to achieve long-term model-predicted concentration ranges is shortest for Alternatives 4R and 5C (18 years).

The rates of construction and sequencing of remedial actions are uncertainty factors that influence the time to achieve RAOs as discussed below. The basis for establishing the years of construction for each alternative was detailed in Section 8 and Appendix I. Numerous technical and administrative factors determine the net rate of construction ultimately achieved by the selected remedy. Given the pace of a majority of sediment remediation mega-projects elsewhere in the country, longer, not shorter, construction periods than those developed in this FS (particularly for the lower numbered alternatives) are possible. Also, the remediation footprint sequencing assumptions made for the BCM framework may not be realized in practice given the numerous factors that can affect individual project time lines.

If the construction rate was able to be increased appreciably from that assumed for this FS, the effect on time to achieve all RAOs would be most pronounced for alternatives that are designed to rely predominately on active remediation alone (e.g., Alternatives 5R and 6R). Faster construction would have a negligible effect on the time to achieve all RAOs for alternatives that require additional time beyond construction to reach long-term risk-driver concentrations via natural recovery (e.g., Alternatives 2, 3, and 4).

Another source of uncertainty stems from how the overall cleanup project is sequenced. Sequencing assumptions made for the BCM framework used in the FS may not be realized in practice given the numerous factors that will affect individual project time lines. To explore the potential magnitude of this uncertainty, a simple upstream to downstream remediation sequence, which eliminates the hot-spot prioritization aspect inherent to the BCM framework, was evaluated using Alternative 6R. This evaluation extended the time to reach the model-predicted range of surface sediment concentrations by 5 to 10 years (see Table 10-2). This resulted in a predicted 20% increase in the site-wide total PCB SWAC at the end of construction. The net effect would be higher SWAC concentrations and a longer time to achieve RAOs, if the sequencing of remedial actions is not optimized from highest to lowest concentrations. If the worst areas are not prioritized first, then some recontamination can be expected in areas that have already been remediated.

10.2.3.4 Summary of Short-term Effectiveness

Alternatives with longer construction times present proportionately larger risks to workers, the community, and the environment. Longer construction periods increase equipment and vehicle emissions, noise, and other resource use. Larger actively remediated footprints increase the short-term disturbance of the existing benthic community and other resident aquatic life and generate more releases of bioavailable chemicals over a longer period of time.

Alternatives 2 through 6 are predicted to achieve the RAOs at completion of or within 10 years of construction completion. The alternatives differ significantly in their construction time period. Alternatives that emphasize removal have longer construction

times than the combined alternatives. As an example, Alternative 6R has a construction time of 38 years versus 18 years for Alternative 6C.

Alternatives 3C, 4C, and 5C are predicted to achieve all four RAOs in the shortest time frames (14, 12, and 13 years respectively). Alternatives 2, 3R, and 4R have moderately long time frames (19, 16, and 18 years respectively) to achieve the RAOs. Alternatives 4R and 5C are predicted to achieve the long-term model-predicted concentrations in the shortest time (18 years). The other alternatives have longer time frames (22 to 43 years) for achieving the long-term model-predicted concentrations.

The limiting factors in achieving the RAOs and long-term model-predicted concentrations are different for each remedial alternative. For example, Alternatives 2 and 3R require time beyond the construction period to achieve RAO 3 through natural recovery, whereas the limitation for Alternative 4R is the construction period. Natural recovery and construction timing estimates both have uncertainty. Alternatives 5R, 6C, and 6R have the longest predicted times to achieve the RAOs (24, 23, and 43 years respectively), by virtue of their long construction periods.

Alternatives 2R and 2R-CAD rank low (★★) for short-term effectiveness, primarily because of their long time for achieving RAOs, which relies primarily on natural recovery. Alternatives 5R, 5R-Treatment, 6C, and 6R also rank low (★ or ★★) because of their high short-term impacts and long time to achieve RAOs that stem from the long construction periods and the persistence of elevated fish-tissue concentrations during construction. Alternatives 3C, 3R, 4C, and 5C are ranked relatively high (★★★★), because of their short construction period, comparatively low construction-related environmental impacts, and shorter time for achieving RAOs. Alternative 4R has a moderate relative ranking of (★★★) that results from a moderate construction period (13 years) and the short-term impacts from dredging.

10.2.4 Implementability

Technical feasibility, administrative feasibility, and availability of services and materials are factors considered under this criterion. The implementability evaluation focuses primarily on the first two factors because, with the exception of Alternative 5R-Treatment, the alternatives use the same types of technologies or the same types of equipment and methods, all of which are available and for which expertise exists in the Puget Sound region.

10.2.4.1 Technical Implementability during Construction

In general, the potential for technical problems and schedule delays increases in direct proportion to duration (complexity) and inversely to RALs. Alternatives with low RALs are more complex and have lengthy construction undertakings that require more administrative coordination than do alternatives with higher RALs and shorter

construction periods. Less complexity and shorter duration of construction reduces the overall level of difficulty both technically and administratively (e.g., coordination with agencies) and the potential for technical problems leading to schedule delays. This is reflected in Table 10-1 using actively remediated area and dredge volume as metrics. Thus, alternatives with larger active footprints that are designed to remove large volumes of material have a comparatively higher potential for problems and delays than the alternatives with smaller active footprints. Similarly, dredge residuals become an increasing detriment to reliability as RALs decrease whether by requiring additional passes or by expanding the geographic reach of residuals management. In addition, alternatives with the lowest RALs (Alternatives 5C/5R and 6C/6R) have a greater potential for triggering additional actions if source control is inadequate and portions of the site are recontaminated to levels that exceed RALs. There is a lack of precedence for achieving and maintaining similarly low RALs at other complex sediment sites.

The CAD component of Alternative 2R-CAD is considered a significant administrative challenge from the standpoints of locating, using, and maintaining one or more CAD facilities. Implementing CAD will involve obtaining permission from the landowner, sequencing remedial projects for effective CAD use; potential disruption of navigation and tribal fisheries throughout construction, filling, and closure; obtaining agreements among multiple parties for CAD use; costs; maintenance; and liability.

The soil washing component of Alternative 5R-Treatment also has technical and administrative challenges associated with locating and permitting an upland soil washing facility (particularly if the facility is not located on or directly adjacent to the CERCLA site). Negotiating standards and other requirements for treatment and discharge of wastewater could be a significant administrative hurdle. Treatability studies would be required to verify the suitability of soil washing as a viable treatment technology. Further, the ability to reuse the treated cleaner sand fraction of the sediment is not assured.

Technology reliability and the relative ease of undertaking additional remedial actions are also important to consider in the comparative evaluation of alternatives. Thus, additional implementability considerations come into play following the planned/designed construction and must be balanced against those discussed above. Alternatives that rely more on MNR to achieve PRGs have an increased potential for requiring actions in the future (e.g., more dredging). This results in an increased technical and administrative burden of evaluating monitoring data over time, considering the need for contingency actions if cleanup levels are not achieved in the predicted time frame, and implementing contingency actions. In this context, alternatives that rely to a greater extent on active construction to achieve PRGs are more favorable.

10.2.4.2 Administrative Implementability and Contingency Actions

Future remedial actions that may need to be undertaken draw from the same technologies used in the remedial alternatives (i.e., dredging, capping, and thin-sand placement) and are inherently implementable. Further, the associated technical and administrative difficulties of undertaking additional remedial actions, while difficult to predict, would likely increase with the magnitude of these undertakings. The need for additional actions will likely be triggered by monitoring data that show inadequate cleanup performance particularly in areas undergoing natural recovery. Thus, alternatives with higher RALs and larger MNR footprints have a higher potential for requiring additional actions.

The degree to which the remedial alternatives rely on natural recovery to achieve RAOs can therefore provide insight on the potential magnitude and difficulty associated with additional actions.[9] Table 10-3 shows predicted site-wide concentrations (SWACs) at the end of construction for Alternatives 2 through 6 and for the three risk exposure areas (site-wide [netfishing], clamming and total beach play) ignoring any contribution from natural recovery. The SWAC estimates were calculated by assigning post-remedy bed sediment replacement values to the active construction footprint and preserving the original FS-dataset interpolated concentrations outside of the active footprint.[10] The key outcomes reflected in this table are:

- Alternatives 2 through 6 with active remediation alone reduce the site-wide total PCB SWAC sufficiently to be within the 10^{-4} magnitude of excess cancer risk for the Adult Tribal RME seafood consumption scenario (RAO 1) based on total PCB site-wide SWACs (see Figure 10-3). Alternatives 2 through 5 require an additional period of natural recovery to reach long-term model-predicted concentration ranges.
- Alternatives 2 through 6 are predicted to achieve RAO 2 for all three exposure scenarios (based on achieving a cumulative excess cancer risk of $\leq 1 \times 10^{-5}$). Most of the individual chemical PRGs are predicted to be achieved as well, except cPAHs.
- For RAO 3, Alternatives 5C, 5R, 6C, and 6R are predicted to achieve the SQS by active remediation alone. Alternatives 2R, 2R-CAD, 3C, and 3R bring 90%

[9] A specific assumption was made in the development of remedial alternatives that 15% of designated ENR and MNR areas of any given remedial alternative will require dredging as a contingency action based on monitoring data for this very reason.

[10] The construction-only results are influenced by the post-remedy bed sediment replacement values (especially as the active footprint increases) that were developed in Section 5. The post-remedy bed-sediment replacement values are independent of natural recovery. They acknowledge and represent a partial rebound in contaminant concentrations following active cleanup.

or more of the site into compliance with the SQS and therefore require an additional period of natural recovery to fully achieve RAO 3. Similarly, Alternatives 4C and 4R bring approximately 95% of the site into compliance with the SQS.

- Alternatives 4 through 6 achieve the RAO 4 PRG (128 µg/kg dw total PCBs) by active remediation alone; Alternative 3 is predicted to be just slightly above the PRG as a result of active remediation and requires a very small incremental reduction in the site-wide total PCB concentration.

Figures 10-3 and 10-4 provide additional perspective on the relative contributions of active remediation (i.e., from Table 10-3) and that from modeled natural recovery. Incremental contributions to SWAC reduction are shown for cleanup of the EAAs (Alternative 1), active remediation alone, modeled natural recovery during the construction period, and lastly, recovery from the end of construction through the end of the model period (40 years). The trends illustrated in Figures 10-3 and 10-4 suggest that the potential for future remedial actions and associated difficulties of undertaking such actions may be relatively low and diminish progressively from the smaller active remedial footprints to the larger active remedial footprints.

10.2.4.3 Summary of Implementability

Alternatives 5R-Treatment and 6R receive the lowest rank (★) relative to the other alternatives. Alternative 5R-Treatment is ranked low relative to the other alternatives because of the administrative and technical difficulties associated with the soil washing technology as well as the long construction time and complex scope. Alternative 6R also is ranked low due to its having by far the lengthiest construction period and largest construction scope. Alternative 1 is given a low implementability rank (★★) because it cannot achieve RAOs, will therefore trigger a substantial amount of additional actions, and provides no monitoring from which to evaluate continuing exposure risks. The administrative issues of the CAD are responsible for the low ranking of 2R-CAD (★★). Alternatives 5R and 6C rank low (★★) because of longer construction periods, larger and more complex project scopes, and potential for low RALs triggering significant additional actions from recontamination. Alternatives 2R, 3R, 3C, and 5C (★★★) receive a higher rank because they are technically reliable, administratively feasible, and have a moderate potential for additional remedial actions. The potential for additional remedial actions for Alternative 5C are moderate and attributable to recontamination exceeding RALs during implementation. For Alternatives 2R, 3R, and 3C, the potential for additional remedial actions is also moderate but for a different reason—the potential for MNR and ENR areas to require additional actions based on performance results. Alternatives 4C and 4R are highly implementable (★★★★) because they are technically reliable and administratively feasible, and the large actively remediated surface area equates to a low potential for triggering additional actions.

10.2.5 Costs

This assessment evaluates the capital and operations, maintenance, and monitoring (OM&M) costs of each alternative. Detailed cost estimates for each remedial alternative are presented in Appendix I, and summarized in Table 10-4 and Figure 10-5. These estimated costs include assumptions for long-term monitoring, institutional controls, and contingency actions; however, they do not include anticipated costs for upland remediation or source control efforts. The total estimated cost for Alternative 1 is approximately $66 million. This cost is not included in the estimated costs for Alternatives 2 through 6 because those actions are not part of the alternatives being evaluated in this FS. The base case or "best estimate" cleanup costs for Alternatives 2 through 6 range from a low of $210 million (Alternative 2R-CAD) to a high of $1,300 million (Alternative 6R), not including the EAA costs reflected in Alternative 1.

Table 10-4 and Figure 10-5 also present information pertaining to cost sensitivity. Variation in the volume and scope of each remedial alternative is a significant contributing factor to cost uncertainty. Changes in the volume of sediment dredged and disposed of has a much greater influence on cost than changes of a proportionately similar magnitude in an area remediated using containment-oriented technologies (i.e., capping). Cost sensitivity was evaluated by changing three key factors: the nature and extent of contamination (volume); the extent of remedy failure during design; and subsequent monitoring that requires additional active remediation (via removal or placement of additional sand). Figure 10-5 illustrates differences in the best estimates of total present value (capital plus OM&M) for the remedial alternatives and includes, as error bars, the sensitivity range for each. The cost sensitivity exercise suggests that differences between the best estimate and actual costs are more likely to reflect an overall increase than decrease, and this has historically been the case at large sediment remediation sites. Further, as the dredge footprint increases, the magnitude of the cost sensitivity (i.e., length of the bars in Figure 10-5) increases.

The sensitivity analysis does not consider uncertainties associated with treatment operations, which would likely be logistically difficult and costly. Only base costs have been assumed for siting a facility, issuing permits, exceeding monitoring standards, and finding beneficial reuse options. Actual time and expenses could be much higher than assumed in this FS. It is also important to recognize that the cost estimates do not consider inflation, an assumption consistent with CERCLA cost estimation guidance. The duration of the construction and monitoring phases of many of the remedial alternatives presented herein is likely to span a lengthy period (e.g., more than 10 years), which, depending on economic conditions, could see significant inflationary pressures, thereby resulting in increased overall construction costs. In particular, fuel prices and landfill tipping fees are not likely to remain at current levels. Increases in fuel prices will translate into higher construction, transportation, and disposal costs.

Alternative 6R has the highest base case cost ($1,300 million) and therefore ranks lowest for this criterion (★). Alternatives 4R, 5R, 5R-Treatment, and 6C are assigned the next lowest rank (★★).[11] Base costs for these alternatives range from approximately $440 to $650 million. Alternatives 3R, 4C, and 5C receive a three-star ranking with costs from approximately $290 to $310 million. Alternatives 2R, 2R-CAD and 3C are next at approximately $230 million, $210 million, and $220 million, respectively (★★★★). Alternative 1 at $66 million (★★★★★) has the highest ranking for cost.

10.3 Modifying Criteria – State/Tribal and Community Acceptance

EPA and Ecology have engaged with the tribes and community to review and comment on the remedial investigation/feasibility study (RI/FS) documents. The framework for tribal and community involvement is detailed in a community involvement plan for the site.[12] This plan was developed based on interviews with community members, EPA, and Ecology. EPA awarded a technical assistance grant to the community advisory group for the site, The Duwamish River Cleanup Coalition. This organization reviews information about the site and shares it with community members. EPA outreach and educational efforts conducted during preparation of the FS have consisted of quarterly meetings with resource agencies, the community advisory group, and tribal representatives. Additional involvement of other stakeholders and the broader community is anticipated prior to finalizing this FS.

The proposed alternative for cleanup of the LDW will be identified in the EPA and Ecology-issued proposed plan, and that document will also identify the formal public comment period. Input from the tribes, the citizen advisory group, local landowners, and others in the community will be considered by EPA in their decision-making on the proposed alternative. EPA and Ecology will consider and respond to public comments in their decision document(s). For these reasons Table 10-1 does not include relative to alternative ranks for the State/Tribal and Community Acceptance criteria.

10.4 Managing Uncertainty

Decision-making and successful implementation of remedial actions for a site the size and complexity of the LDW requires acknowledgement and accommodation of uncertainty. As discussed previously, surface sediment concentrations are ultimately expected to converge to levels similar to the quality of incoming sediment from the Green/Duwamish River and other inputs, resulting in similar levels of risk over time.

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[11] Recall that Alternative 5R-Treatment has the additional cost uncertainty associated with whether a beneficial use can be identified for the treated material.

[12] EPA and Ecology developed and published a community involvement plan in October 2002 for the Lower Duwamish Waterway Site.

The actual numeric values of these concentrations and the time it will take to reach them are difficult to predict and are where the greatest uncertainties exist.

Several factors emerge as particularly important for managing uncertainty relative to the time predicted for achieving RAOs and the anticipated performance of the alternatives including: 1) the quality of incoming sediment from the Green/Duwamish River, 2) the rate of natural recovery, 3) actual performance of remedial technologies, and 4) the potential for re-exposure of buried subsurface contamination. While future conditions and actual concentrations are not certain (e.g., depending on the effectiveness of watershed-wide source control efforts), it is likely that conditions will be similar in the long term, regardless of alternative. However, it is important to place these uncertainties in the context of how much the remedial alternatives achieve by active remediation alone, and to what extent they rely on natural recovery to achieve RAOs (see Section 10.2.4 and Figure 10-3). Much is accomplished toward achieving all RAOs among the lower numbered alternatives by active remediation alone, which suggests that, while still important, the uncertainties are less critical to overall success than would be the case for a marginally depositional sediment site.

The alternatives are predicted to reach similar surface sediment concentrations over a period of approximately two decades from issuance of the final decision documents. However, long-term predictions of the effectiveness of the alternatives are subject to various uncertainty factors. Several sources of quantitative uncertainty were discussed in Section 9. These include:

- Assumption of no optimized sequencing from more contaminated to less contaminated areas (discussed in Section 10.2.3.3).
- Assumption of no natural recovery. This was explored at two scales: in potential scour areas and in all unremediated areas during construction or following construction (discussed in Section 10.2.4.2).
- BCM and sediment transport model (STM) predictions and the BCM input parameter values.
- Influence of on-going lateral sources.
- Influence of dredge residuals during construction in unremediated areas.
- Methods used for spatial interpolation and LDW-wide SWAC calculations.

The overall effect of uncertainties suggests a 20 to 40% range on long-term achievable SWAC predictions (Figure 10-6; shown for PCBs). Such scale of uncertainty is larger than the range of differences in SWAC predictions among alternatives. Therefore, more uncertainty exists in the long-term achievable concentrations for any alternative regardless of the factor investigated (sequencing, natural recovery, dredging) than

exists in estimates among the various alternatives themselves. The time required to reach the long-term range of model-predicted outcomes for risk-driver chemicals could increase by several years depending on these factors. As discussed in Section 10.2.4, this is particularly relevant for longer duration alternatives (e.g., Alternatives 5R and 6R), if the remedial actions are not sequenced to remove the most contaminated material first. Figure 10-6 illustrates how these uncertainties compare to the base case estimates presented in this FS.

Collectively, the base case predicted result could easily have more than a 20% difference in the LDW-wide SWAC calculation depending on the method and tool used to derive it, especially at smaller scales. To account for the inherent uncertainty built into the model predictions and site assumptions, a 25% difference in the long-term predicted concentration was assumed to be acceptable (and indistinguishable). Therefore the "time to achieve RAOs" for each alternative was calculated to be when long-term achievable concentrations came within 25% of the lowest predicted long-term achievable concentrations (Alternative 6R).

At a smaller scale, the technology performance and episodic re-exposure of buried contamination from mechanical disturbances will also contribute to localized variations in surface sediment concentrations. These uncertainties were addressed in the FS by ensuring that the majority of areas with known significant scour potential and subsurface contamination are prioritized for active remediation in Alternatives 4 through 6. Re-exposure potential will be managed during remedial design and through monitoring and adaptive management. Contingency actions will be taken as needed (e.g., dredging, capping, or more monitoring).

Table 10-1 Comparative Evaluation and Relative Ranking of Remedial Alternatives[a]

Evaluation Criteria					Remedial Alternative											
					1	2R	2R-CAD	3C	3R	4C	4R	5C	5R	5R-T	6C	6R
Overall Protection of Human Health and the Environment	Summary of Long-term Effectiveness and Permanence (See Long-term Effectiveness section below for details)	Magnitude of Residual Risk (based on time to reach modeled long-term model-predicted concentration range in surface sediment)	RAO 1: Residual risk from total PCBs – Adult Tribal RME[b,c]	Excess cancer risk	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}
				Non-cancer risk (HQ)	5	5	5	5	5	5	5	5	5	5	4	4
			RAO 2: Residual direct contact excess cancer risk – cumulative[d]		$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$
			RAO 3: Benthic	Stations predicted to comply with SQS as percent of total FS surface sediment stations (n=1,395; Table 9-2b)	98%	>98%	>98%	>98%	>98%	>98%	>98%	>98%	>98%	>98%	>98%	>98%
				LDW surface area predicted to comply with SQS as percent of total study area (441 acres; Table 9-2b)	>98%	>98%	>98%	>98%	>98%	>98%	>98%	>98%	>98%	>98%	>98%	>98%
			RAO 4: HQ for consumption of seafood (without juvenile fish) by the river otter		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
			Achievement of RAOs		Not expected to achieve all RAOs.	All RAOs achieved.										
			Potential for Re-exposing Remaining Subsurface Contamination		Largest amount of subsurface contamination and greatest potential for re-exposure.	Moderate potential for re-exposure. Localized impacts unlikely to affect SWACs	Same as for 2R plus: majority of contaminated sediment remains on-site in CAD.	Moderate potential for re-exposure. Localized impacts unlikely to affect SWACs	Same as for 3C plus: Lower residual subsurface contamination than 3C.	Low potential for re-exposure. Localized impacts unlikely to affect SWACs	Same as for 4C plus: lower residual subsurface contamination than 4C.	Low potential for re-exposure. Localized impacts unlikely to affect SWACs	No designated ENR and MNR areas. Very low potential for re-exposure. Lower residual subsurface contamination than 5C.	Same as for 5R.	Large ENR area but low potential for re-exposure. Localized impacts unlikely to affect SWACs	No designated ENR and MNR areas. Least amount of residual subsurface contamination. Very low potential for re-exposure.
		Adequacy & Reliability of Controls	Institutional Controls, Monitoring and Maintenance (based on area remediated by capping, ENR and MNR)		No ICs implemented. Only EAAs monitored.	ICs are required for all remedial alternatives to manage residual seafood consumption risks.										
						Large area to monitor and maintain (130 acres)	Large area to monitor and maintain (130 + 23 acres of CAD)	Large area to monitor and maintain (128 acres)	Large area to monitor and maintain (105 acres)	Large area to monitor and maintain (106 acres)	Moderate area to monitor and maintain (54 acres)	Large area to monitor and maintain (103 acres)	Small area to monitor and maintain (12 acres)	Small area to monitor and maintain (12 acres)	Large area to monitor and maintain (113 in AOPC 1[r] and 80 in AOPC 2)	Small area to monitor and maintain (16 in AOPC 1[r] and 12 in AOPC 2)
	Summary of Short-term Effectiveness				Low short-term impacts during construction but contamination remains above protective levels.	Low short-term impacts during construction but long time to achieve RAOs.	Low short-term impacts during construction but long time to achieve RAOs.	Low short-term impacts during construction and moderate time to achieve RAOs.	Low short-term impacts during construction and moderate time to achieve RAOs.	Moderate short-term impacts during construction and moderate time to achieve RAOs.	High short-term impacts during construction and moderate time to achieve RAOs.	Moderate short-term impacts during construction and moderate time to achieve RAOs.	High short-term impacts during construction and long time to achieve RAOs.	High short-term impacts during construction and long time to achieve RAOs.	High short-term impacts during construction and long time to achieve RAOs.	High short-term impacts during construction and long time to achieve RAOs.
	Summary of Overall Protection of Human Health and the Environment				Does not provide adequate overall protection to human health and the environment.	Alternatives 2 through 6 provide adequate overall protection to human health and the environment. All achieve the four RAOs and can be implemented in a manner that protects workers, the community, and the environment. Alternatives with longer construction periods have proportionately greater short-term impacts. Alternatives that dredge or cap a larger surface area have a lower potential for subsurface contamination to be re-exposed by natural or mechanical disturbances (e.g., scour). Re-exposure of subsurface contaminated sediment is likely to be localized and have limited effect on SWACs.										
Comply with or Waive ARARs	Compliance with ARARs	Water Quality Standards			No active remedial measures are feasible or anticipated for the water column although significant water quality improvements are anticipated from sediment remediation and source control. It is not anticipated that any alternative will comply with all federal or state ambient water quality criteria or standards, particularly those based on human consumption of bioaccumulative contaminants that magnify through the food chain. Similar long-term water quality improvements are expected for all alternatives.											
		Sediment Management Standards			Not expected to comply.	Alternatives 2R and 2R-CAD are predicted to achieve the SQS within 10 years following implementation but may require higher cleanup standards and longer time to achieve RAOs based on model uncertainty.		Alternatives 3C and 3R are predicted to achieve the SQS within 5 years following implementation.		Alternatives 4 through 6 are predicted to achieve the SQS immediately following implementation.						
		MTCA	Human Health Seafood Consumption		Not expected to comply.	Alternatives 2 through 6 require engineering and institutional controls to comply with MTCA because the MTCA requirement to achieve natural background is not achievable.										
			Human Health Direct Contact		Not expected to comply.	Alternatives 2 through 6 achieve the cumulative direct contact goal of 1×10^{-5}. The alternatives also achieve individual chemical risk thresholds of 1×10^{-6} for total PCBs and dioxins/furans. All beaches are below the 90th percentile but above the UCL95 of the natural background dataset for arsenic (the arsenic PRG is natural background). All exposure areas (except Beach 3) are at or below an individual cPAH risk of 1×10^{-6}. BCM predictions for Beach 3 are influenced by a lateral source.										
	Summary of ARARs				Not expected to comply.	Alternatives 2 through 6 comply.										
Achieve Threshold Requirements					No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 10-1 Comparative Evaluation and Relative Ranking of Remedial Alternatives[a]

Evaluation Criteria				Remedial Alternative 1	2R	2R-CAD	3C	3R	4C	4R	5C	5R	5R-T	6C	6R
Long-term Effectiveness and Permanence	Magnitude of Residual Risk (Contaminated sediment remaining in the subsurface)	Total dredge area (acres)		Not estimated	27	27	29	52	51	103	54	145	145	106	271
		Total cap and partial dredge/cap application area (acres)		n/c	3	3	19	5	48	11	53	12	12	65 in AOPC 1[f] and 36 outside of AOPC 1	16 in AOPC 1[f] and 12 outside of AOPC 1
		Total ENR and MNR application area (in Category 1/Categories 2 & 3 combined; acres)[e]		n/c	20 / 107	20 / 107	19 / 90	19 / 81	0 / 58	0 / 43	0 / 50	0 / 0	0 / 0	0/47 in AOPC 1 and 0/45 outside of AOPC 1	0/0 in AOPC 1 and 0/0 outside of AOPC 1
		Post-construction number of core stations remaining >CSL in the FS dataset (under caps/ all other locations)[f]		n/c	10/41	10/41	15/32	1/24	17/24	1/13	20/20	1/4	1/4	26/7	0/0
		Summary		Largest amount of subsurface contamination and greatest potential for re-exposure.	Large ENR and MNR area. Moderate potential for re-exposure.	Large ENR and MNR area. Moderate potential for re-exposure	Large ENR and MNR area. Moderate potential for re-exposure	Large ENR and MNR area. Moderate potential for re-exposure	Moderate ENR and MNR area. Low potential for re-exposure.	Moderate ENR and MNR area. Low potential for re-exposure.	Moderate ENR and MNR area. Low potential for re-exposure.	No designated ENR and MNR areas. Very low potential for re-exposure.	No designated ENR and MNR areas. Very low potential for re-exposure.	Large ENR area. Low potential for re-exposure.	No designated ENR and MNR areas. Very low potential for re-exposure.
	Adequacy and Reliability of Controls[g]	Relative amount of monitoring and maintenance required (based on total cap, ENR and MNR area – see number of acres above).		Low – only EAAs monitored	Large area to monitor and maintain (130 acres)	Large area to monitor and maintain (130 + 23 acres of CAD)	Large area to monitor and maintain (128 acres)	Large area to monitor and maintain (105 acres)	Large area to monitor and maintain (106 acres)	Moderate area to monitor and maintain (54 acres)	Large area to monitor and maintain (103 acres)	Small area to monitor and maintain (12 acres)	Small area to monitor and maintain (12 acres)	Large area to monitor and maintain (113 in AOPC 1[f] and 80 outside of AOPC 1)	Small area to monitor and maintain (16 in AOPC 1[f] and 12 outside of AOPC 1)
		Magnitude and Duration of Institutional Controls	Monitoring and notification of waterway users (based on total cap, ENR, and MNR area; acres)	No institutional controls	Same relative rankings as for monitoring and maintenance (see above).										
			Seafood consumption advisories, public outreach, and education	No outreach or education	Seafood consumption advisories, public outreach, and education are required for the entire LDW and are of similar magnitude and duration regardless of alternative.										
			Summary	No institutional controls	The need for monitoring and maintenance is higher for combined alternatives and less for removal alternatives with the same RALs. Seafood consumption advisories, public outreach, and education are required and of similar magnitude/duration regardless of alternative. Monitoring of waterway permitting and use activities is highest for combined alternatives. Removal alternatives require less monitoring and notification activity as RALs are reduced because less subsurface contaminated sediment remains in place.										
	Summary			Low – only EAAs remediated. Not expected to achieve all RAOs.	Lower numbered alternatives leave a greater amount of contaminated subsurface sediment in place than the higher numbered alternatives and also have greater monitoring and maintenance requirements. Removal alternatives have fewer FS dataset cores >CSL remaining after construction than their combined technology counterparts. Monitoring, maintenance, and ICs are considered adequate and reliable for Alternatives 2 through 6.										
	Relative ranking (★ = Lowest for long-term effectiveness and permanence)			★	★★	★★	★★★	★★★	★★★★	★★★★	★★★★	★★★★★	★★★★★	★★★★	★★★★★
Reduction of Toxicity, Mobility, or Volume through Treatment	Summary			No treatment	Alternatives 2, 3, 4, 5C, and 5R could include treatment in certain circumstances if required in design [h]								Treatment by soil washing to potentially reduce volume of waste requiring landfill disposal	Alternative 6 could include treatment in certain circumstances if required in design[h]	
	Relative ranking based on amount of material managed[i] (★ = Lowest for Reduction of Toxicity, Mobility or Volume)			★	★	★	★	★	★	★	★	★	★★	★	★

Table 10-1 Comparative Evaluation and Relative Ranking of Remedial Alternatives[a]

Evaluation Criteria			Remedial Alternative											
			1	2R	2R-CAD	3C	3R	4C	4R	5C	5R	5R-T	6C	6R
Short-term Effectiveness	Protection or Workers, Community, and Environment during Construction	Period of community exposure, worker exposure and ecological disturbance (years of construction)[j]	<5	4	4	4	6	7	13	8	19	19	18	38
		Transportation – (truck miles/train miles)[k]	Not calculated	400,000 / 106,000	200,000 / 53,000	364,000 / 97,000	505,000 / 134,000	475,000 / 126,000	779,000 / 206,000	498,000 / 132,000	987,000 / 262,000	741,000 / 196,000	1,086,000 / 288,000	2,322,000 / 616,000
		Ecological – Habitat area above -10 ft MLLW disturbed (dredging/partial dredge and cap/capping)	Not estimated	12	12	27	27	42	42	59	59	59	98	98
		Greenhouse gas emissions (CO_2; metric tons)	Not calculated	25,000	20,000	25,000	33,000	34,000	52,000	37,000	66,000	54,000	78,000	153,000
		Other air pollutants (NO_x/SO_x ; metric tons)	Not calculated	482 / 15	324 / 17	461 / 14	622 / 19	624 / 20	967 / 30	665 / 21	1,231 / 38	981 / 35	1,429 / 46	2,871/ 89
		Particulate matter emissions (PM_{10}; metric tons)	Not calculated	25	25	24	34	35	56	37	73	65	84	168
		Depleted natural resources (sand/gravel for in-water placement; cy)	Not calculated	110,000	180,000	260,000	240,000	510,000	410,000	620,000	550,000	550,000	1,200,000	1,100,000
		Landfill capacity used (1.2 × dredge vol; MMcy)	Not estimated	0.75	0.37	0.68	0.94	0.89	1.5	0.93	1.8	1.4	2.0	4.3
	Time Until RAOs are Achieved (years) [l]	RAO 1: 10^{-4} magnitude risk (Adult Tribal RME)[m]	Not estimated	9	9	9	11	12	18	13	24	24	23	43
		RAO 1: Predicted time for risk drivers to reach long-term model-predicted concentration range in surface sediment[m]	Not estimated	24	24	24	26	22	18	18	24	24	23	43
		RAO 2: Cumulative risk ≤1 x 10^{-5} (All exposure scenarios)[n]	Not estimated	10	10	10	10	10	10	10	10	10	10	10
		RAO 3: Benthic invertebrates (>98% compliance with SMS)[o]	Not estimated	19	19	14	16	12	15	12	15	15	12	15
		RAO 4: Ecological – river otter (HQ<1)[p]	Not estimated	9	9	9	11	12	18	13	24	24	23	43
	Summary		Low short-term impacts during construction but contamination remains above protective levels.	Low short-term impacts during construction. Moderate time to achieve RAOs and high uncertainty.	Low short-term impacts during construction. Moderate time to achieve RAOs and high uncertainty.	Low short-term impacts during construction and low time to achieve RAOs and moderate uncertainty.	Low short-term impacts during construction and moderate time to achieve RAOs and moderate uncertainty.	Moderate short-term impacts during construction and moderate time to achieve RAOs with low uncertainty.	High short-term impacts during construction and moderate time to achieve RAOs with low uncertainty.	Moderate short-term impacts during construction and moderate time to achieve RAOs with very low uncertainty.	High short-term impacts during construction and long frame to achieve RAOs with very low uncertainty.	High short-term impacts during construction and long time to achieve RAOs with very low uncertainty.	High short-term impacts during construction and long time to achieve RAOs with very low uncertainty.	High short-term impacts during construction and long time to achieve RAOs with very low uncertainty.
	Relative Ranking (★= Lowest for short-term effectiveness)		★	★★	★★	★★★★	★★★★	★★★★	★★★	★★★★	★★	★★	★★	★

Table 10-1 Comparative Evaluation and Relative Ranking of Remedial Alternatives[a]

Evaluation Criteria			Remedial Alternative											
			1	2R	2R-CAD	3C	3R	4C	4R	5C	5R	5R-T	6C	6R
Implementability	Technical and Administrative Feasibility	Total actively remediated area (acres; Alter natives 2 through 6 values do not include EAAs)	29	30	30	57	57	114	114	157	157	157	299	299
		Performance dredge volume; MMcy	Not estimated	0.62	0.62	0.57	0.79	0.74	1.2	0.77	1.5	1.5	1.7	3.6
		During construction	Short construction period. Low potential for technical/ administrative difficulties and schedule delays.	Short construction period. Low potential for technical/ administrative difficulties and schedule delays.	Same as 2R plus significant administrative issues associated with siting, use, maintenance, and liability of CAD.	Short construction period. Low potential for technical/ administrative difficulties and schedule delays.	Short construction period. Low potential for technical/ administrative difficulties and schedule delays.	Short construction period. Low potential for technical/ administrative difficulties and schedule delays.	Moderate construction period. Moderate potential for technical/ administrative difficulties and schedule delays.	Short to moderate construction period. Moderate potential for technical/ administrative difficulties and schedule delays.	Long construction period. High potential for technical/ administrative difficulties and schedule delays.	Same as 5R plus significant administrative issues associated with permitting facility and reusing treated material.	Long construction period. High potential for technical/ administrative difficulties and schedule delays.	Long construction period. Very high potential for technical/ administrative difficulties and schedule delays.
		Technical and administrative burden of evaluating monitoring data, considering and implementing contingency actions.	Significant additional actions needed to comply with CERCLA requirements LDW-wide.	Low recontamination potential above RALs. High potential for additional actions in MNR and ENR areas.	Same as 2R	Low recontamination potential above RALs. Moderate to high potential for additional actions in MNR and ENR areas.	Low recontamination potential above RALs. Moderate to high potential for additional actions in MNR and ENR areas.	Low recontamination potential above RALs. Moderate potential for additional actions in MNR and/or ENR areas.	Low recontamination potential above RALs. Low potential for additional actions in MNR areas.	Moderate to high potential for recontamination above RALs. Low potential for additional actions in ENR areas.	Moderate potential for recontamination above RALs.	Same as 5R	High potential for recontamination above RALs.	High potential for recontamination above RALs.
	Summary		Low	Moderate	Low	Moderate	Moderate	High	High	Moderate	Low	Very Low	Low	Very Low
	Relative ranking (★= Lowest for implementability)		★★	★★★	★★	★★★	★★★	★★★★	★★★★	★★★	★★	★	★★	★
Costs	Total (MM$) [q]		66	230	210	220	290	290	440	310	550	600	650	1,300
	Relative ranking (★= highest for cost)		★★★★★	★★★★	★★★★	★★★★	★★★	★★★	★★	★★★	★★	★★	★★	★

Notes:

a Relative ranking compares alternatives to one another using a one star (★= low ranking) to five star (★★★★★= high ranking) system. See specific criteria for guide to interpreting star rankings.

b Risk estimate based on use of the total PCB SWAC (using base case [mid input values] BCM output) in the food web model. Total excess cancer risks (all carcinogens combined) are expected to be similar to total PCB risks for the consumption of resident fish and crab.

c See Table 9-6a for other RME risk scenarios. See Appendix M for site-related risk reduction calculations.

d Base case (mid input values) BCM output used for cumulative (i.e., contributions of all four risk-driver chemicals) risk estimation. Cumulative risks lower than 1×10^{-5} are within the acceptable CERCLA risk range.

e Recovery categories: Category 1 – presumed to be limited; Category 2 – less certain; Category 3 – predicted to recover.

f Remaining cores grouped by those located under caps and those located anywhere else at the site after construction.

g This analysis evaluates the reliability of controls after RAOs are achieved. The construction periods for the alternatives differ (see Short-term Effectiveness) and various controls will also be required during construction.

h Other treatment technologies could be adopted at remedial design to address principal threat wastes (should they be encountered) or as a component of cap design (i.e., amended cap).

i All alternatives remove and dispose of some volume of contaminated sediment. Also, the combined alternatives reduce exposure potential using various combinations of capping, ENR, and MNR (see remaining subsurface contamination under long-term effectiveness above). These contribute to reductions in toxicity, mobility, or volume. Alternative 5R includes a treatment technology (soil washing) that is intended to reduce the volume of contaminated sediment but does not destroy the mass of contaminants.

j Construction period rounded to nearest year. Additional time beyond construction required for ecologically sensitive areas to recover. Also, fish and shellfish tissue contaminant concentrations may require additional time after construction to recover.

k Sediment is assumed to be disposed of by trucking from a transloading area to an intermodal station, where it is loaded onto train cars for transport to a landfill in Eastern Washington or Eastern Oregon. Trucking miles are estimated using an average 28 tons/truck and 12 miles to the intermodal station. Train miles are estimated assuming 568 miles (round trip) to the landfill and assuming that each train can carry 5,000 tons of dredged material.

l The predicted time to achieve RAOs beginning with issuance of final remedy decision documents.

m Two time frames are considered for RAO 1. First is the remedial alternative's implementation time, at which point all alternatives reduce the Adult Tribal RME seafood consumption risk to the lowest risk magnitude (10^{-4}) achievable in the long term. The multi-layered program of monitoring and ICs (advisories, outreach, and education) is required at this point for all alternatives to further reduce seafood consumption exposures (see Section 10.2.1.2). The second time component is the predicted time for risk-driver concentrations to achieve long-term modeled concentration ranges. The food web model relationship between sediment and fish tissue concentrations is assumed to not apply during construction. Fish tissue concentrations are assumed to remain elevated as a result of resuspension and release of total PCBs into the water column. None of the alternatives reduce the human non-cancer seafood consumption HQ to less than 1.

n Alternatives 3C and 3R specifically address direct contact risks and achieve a cumulative direct contact risk of $\leq 1 \times 10^{-5}$ for all exposure scenarios. It is assumed that the Alternative 3 actions occur in the first 5 years of Alternatives 4, 5, and 6 and therefore the same rounded time to achieve RAO 2 (10 years) is applied to Alternatives 3 through 6. Alternative 2 does not specifically address direct contact risks. However, surface sediments in potential tribal clamming and assumed beach play areas are $\leq 1 \times 10^{-5}$ following construction of EAAs and are expected to continue recovering naturally over time.

o The time to achieve RAO 3 is when at least 98% of FS surface sediment dataset stations are predicted to comply with the SMS and more than 98% of the LDW surface area is predicted to comply with the SMS.

p The time to achieve RAO 4 is when wildlife seafood consumption non-cancer risk of HQ <1 is achieved based on the site-wide total PCB SWAC following implementation.

q Estimated cost of $66 million for Alternative 1 (EAAs) is not included in cost totals for the other alternatives.

r The total number of acres includes 19 acres of verification monitoring in AOPC 1 that are actively remediated in Alternative 6.

AOPC = area of potential concern; BCM = bed composition model; C = combined alternative; CAD = contained aquatic disposal; CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act; CSL = cleanup screening level; cy = cubic yards; EAA = early action area; ENR = enhanced natural recovery; HQ = hazard quotient; IC = institutional control; MLLW = mean low lower water; MM = million; n/a = not applicable; MNR = monitored natural recovery; PCB = polychlorinated biphenyls; R = removal alternative; RAL = remedial action level; RAO = remedial action objective; RME = reasonable maximum exposure; R-T = removal alternative with treatment; SMS = Sediment Management Standards; SQS = sediment quality standard; UCL95 = 95 percent upper confidence limit on the mean.

Table 10-2 Uncertainty in Site-wide SWAC and Time Frame Associated with non-Optimized Sequencing of Remedial Actions

Sequencing Assumption	Alternative	Site-wide Total PCB SWAC (µg/kg dw)									Model Year When total PCB SWAC is within 40 to 50 µg/kg dw	Difference in Years (between sequencing assumptions)
		Time From Issuance of Final Decision Documents (years)										
		5[a]	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*		
Upstream to Downstream	Alternative 6 Removal	330	187	108	62	52	49	50	47	46	30	5
	Alternative 6 Combined	330	145	82	59	48	45	45	43	43	25	5
Optimized as Worst First	Alternative 6 Removal	180	86	64	50	48	42	41	40	39	25	
	Alternative 6 Combined	180	75	55	42	38	39	41	41	41	20	

Sequencing Assumption	Alternative	Site-wide Arsenic SWAC (mg/kg dw)									Model Year When Arsenic SWAC is within 8 to 10 mg/kg dw	Difference in Years (between sequencing assumptions)
		Time From Issuance of Final Decision Documents (years)										
		5[a]	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*		
Upstream to Downstream	Alternative 6 Removal	15.8	12.3	10.4	9.7	9.5	9.4	9.4	9.4	9.3	20	5
	Alternative 6 Combined	15.8	11.7	10.5	9.6	9.5	9.3	9.3	9.2	9.2	20	5
Optimized as Worst First	Alternative 6 Removal	16.0	10.0	9.7	9.4	9.3	9.2	9.2	9.1	9.1	15	
	Alternative 6 Combined	16.0	10.0	9.6	9.3	9.1	9.1	9.1	9.1	9.1	15	

Sequencing Assumption	Alternative	Site-wide cPAH SWAC (µg TEQ/kg dw)									Model Year When cPAH SWAC is within 100 to 125 µg TEQ/kg dw	Difference in Years (between sequencing assumptions)
		Time From Issuance of Final Decision Documents (years)										
		5[a]	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*		
Upstream to Downstream	Alternative 6 Removal	394	245	173	129	116	112	116	112	108	25	5
	Alternative 6 Combined	394	239	167	128	113	107	110	105	104	25	5
Optimized as Worst First	Alternative 6 Removal	360	180	140	110	110	106	107	104	103	20	
	Alternative 6 Combined	360	170	130	109	102	101	104	102	102	20	

Table 10-2 Uncertainty in Site-wide SWAC and Time Frame Associated with non-Optimized Sequencing of Remedial Actions *(continued)*

Sequencing Assumption	Alternative	Site-wide Dioxin/Furan SWAC (ng TEQ/kg dw)									Model Year When Dioxin/Furan SWAC is within 4 to 6 ng TEQ/kg dw	Difference in Years (between sequencing assumptions)
		Time From Issuance of Final Decision Documents (years)										
		5[a]	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*		
Upstream to Downstream	Alternative 6 Removal	26	13.9	8.4	5.6	4.8	4.5	4.4	4.3	4.2	20	10
	Alternative 6 Combined	26	13.5	8.2	5.4	4.4	4.4	4.3	4.3	4.2	20	10
Optimized as Worst First	Alternative 6 Removal	24	5.9	5.1	4.5	4.4	4.3	4.3	4.3	4.3	10	
	Alternative 6 Combined	24	5.3	4.6	4.3	4.3	4.3	4.4	4.3	4.4	10	

Notes:

= Construction Time Frame

1. Construction is assumed to begin at the upstream end of the BCM domain (RM 4.75) and sequentially work downstream towards the mouth (RM 0).
2. Construction is equally divided over 20 or 45 years for the combined and removal alternatives, respectively. The construction sequencing of "optimized as worst first" is used in the FS.
3. Model runs assume natural recovery during construction, larger differences are likely if no recovery is assumed during construction.
4. Remedial actions include dredging, capping, and ENR.

a This is the start of construction for all the alternatives. The 5-year model-predicted intervals associated with the BCM SWAC output are indexed to issuance of final decision documents.

cPAH = carcinogenic polycyclic aromatic hydrocarbons; µg/kg dw = micrograms per kilogram dry weight; mg/kg dw = milligrams per kilogram dry weight; PCBs = polychlorinated biphenyls; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent

Table 10-3 Predicted SWAC and SMS Exceedance Outcomes for Alternatives 2 through 6 by Active Remediation Only

Alternative	Site-Wide SWAC				Potential Tribal Clamming Area SWAC				Assumed Beach Play Area SWAC				SMS			
	Arsenic (mg/kg dw)[a]	Total PCBs (µg/kg dw)	cPAHs (µg TEQ/ kg dw)	Dioxins/ Furans (ng TEQ/ kg dw)	Arsenic (mg/kg dw)	Total PCBs (µg/kg dw)	cPAHs (µg TEQ/ kg dw)	Dioxins/ Furans (ng TEQ/ kg dw)	Arsenic (mg/kg dw)	Total PCBs (µg/kg dw)	cPAHs (µg TEQ/ kg dw)	Dioxins/ Furans (ng TEQ/ kg dw)	% of Stations <CSL	%LDW Area <CSL	% of Stations <SQS	% of Area <SQS
Predicted Outcomes without Natural Recovery																
2R/ 2R-CAD	12	140	310	7.9	9.5	108	250	6.8	8.9	104	270	5.3	98	98	88	85
3R/3C	11	130	270	7.4	9.3	89	160	6.1	8.8	82	180	4.6	99	99	91	88
4R/4C	11	106	230	6.3	9.3	76	160	5.9	8.9	65	160	4.3	99	100	96	95
5R/ 5R-T/5C	11	92	210	5.6	9.4	69	150	5.2	9.1	62	150	4.1	100	100	100	99
6R/6C	10	46	140	4.3	9.1	48	140	4.3	9.0	46	140	3.9	100	100	100	99
Remedial Action Objective PRGs																
RAO 1 PRGs	n/a	2	n/a	2	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
RAO 2 PRGs [a]	7, 11	1,300	380	37	7, 11	500	150	13	7, 11	1,700	90	28	n/a	n/a	n/a	n/a
RAO 3 PRGs	n/a	128	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	SQS, but up to the CSL			
RAO 4 PRG	n/a	128	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Notes:

1. Results shown are predicted conditions immediately at the end of alternative construction using post-remedy bed sediment replacement values in the actively remediated footprint and baseline (FS dataset). This analysis assumes no natural recovery during remediation; no changes over time in chemical concentrations from baseline conditions outside of the actively remediated footprint.
2. Refer to Table 9-2a footnotes for additional information on replacement values and calculation methodologies.

a Two natural background values are shown for arsenic (x,x). The first value is the UCL95 and the second value is the 90th percentile. Both values are calculated using the EPA OSV *Bold* survey dataset.

C = combined technologies alternative; CAD = contained aquatic disposal; cPAH = carcinogenic polycyclic hydrocarbons; CSL = cleanup screening level; dw = dry weight; kg = kilograms; µg = micrograms; mg = milligrams; n/a = not applicable; PCB = polychlorinated biphenyl; PRG = preliminary remediation goal; R = removal emphasis alternative; RAO = remedial action objective; R-T = removal emphasis with treatment; SMS = Sediment Management Standards; SQS = sediment quality standard; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent

Table 10-4 Summary of Costs – Sensitivity Analysis

BASE CASE[a]

Alternative Number	1	2R	2R-CAD	3R	3C	4R	4C	5R	5R-Treatment	5C	6R	6C
Capital Cost	$0	$204,000,000	$177,000,000	$267,000,000	$197,000,000	$424,000,000	$272,000,000	$538,000,000	$588,000,000	$294,000,000	$1,250,000,000	$621,000,000
Indirect Construction Cost	$0	$27,100,000	$28,500,000	$25,100,000	$26,400,000	$19,900,000	$21,600,000	$16,800,000	$16,800,000	$20,100,000	$20,100,000	$26,300,000
Total Cost	$66,000,000[b]	$230,000,000	$210,000,000	$290,000,000	$220,000,000	$440,000,000	$290,000,000	$550,000,000	$600,000,000	$310,000,000	$1,300,000,000	$650,000,000

Notes:

1. Base case preliminary dredge volumes for Alternatives 2 through 5 are the neat volume to base of contamination plus 50%. Alternative 6 is neat volume plus 100%.
2. Assume 10% of VM areas require to active remediation (dredging).
3. Assume 10% of cap, ENR, and MNR areas require dredging due to technology assignment uncertainty.
4. Assume 15% of ENR and MNR areas require dredging based on future monitoring.
5. Assume no disposal cost for treated sand from soil washing operations.
6. Capital costs and indirect construction costs are rounded to three significant digits. Total costs are rounded to two significant digits. All volumes are calculated by a spreadsheet prior to rounding.

LOW SENSITIVITY[a]

Alternative Number	1	2R	2R-CAD	3R	3C	4R	4C	5R	5R-Treatment	5C	6R	6C
Capital Cost	$0	$96,100,000	$64,200,000	$164,000,000	$96,600,000	$326,000,000	$184,000,000	$445,000,000	$488,000,000	$208,000,000	$946,000,000	$422,000,000
Indirect Construction Cost	$0	$27,100,000	$28,500,000	$25,100,000	$26,200,000	$19,900,000	$21,600,000	$16,800,000	$16,800,000	$19,000,000	$20,100,000	$26,300,000
Total Cost	$66,000,000[b]	$120,000,000	$93,000,000	$190,000,000	$120,000,000	$350,000,000	$210,000,000	$460,000,000	$500,000,000	$230,000,000	$970,000,000	$450,000,000

Notes:

1. Low sensitivity preliminary dredge volumes for Alternatives 2 through 5 are the neat volume to base of contamination plus 25%. Alternative 6 is neat volume plus 50%.
2. Assume 0% of VM areas require active remediation (dredging).
3. Assume 0% of cap, ENR, and MNR areas require dredging due to technology assignment uncertainty.
4. Assume 0% of ENR and MNR areas require dredging based on future monitoring.
5. Assume no disposal cost for treated sand from soil washing operations.
6. Capital costs and indirect construction costs are rounded to three significant digits. Total costs are rounded to two significant digits. All volumes are calculated by a spreadsheet prior to rounding.

HIGH SENSITIVITY[a]

Alternative Number	1	2R	2R-CAD	3R	3C	4R	4C	5R	5R-Treatment	5C	6R	6C
Capital Cost	$0	$333,000,000	$306,000,000	$436,000,000	$337,000,000	$608,000,000	$392,000,000	$786,000,000	$924,000,000	$426,000,000	$1,480,000,000	$798,000,000
Indirect Construction Cost	$0	$27,100,000	$28,500,000	$25,100,000	$26,200,000	$19,900,000	$21,600,000	$16,800,000	$16,800,000	$20,100,000	$20,100,000	$26,300,000
Total Cost	$66,000,000[b]	$360,000,000	$330,000,000	$460,000,000	$360,000,000	$630,000,000	$410,000,000	$800,000,000	$940,000,000	$450,000,000	$1,500,000,000	$820,000,000

Notes:

1. High sensitivity preliminary dredge volumes for Alternatives 2 through 6 are based on depth to alluvium dredge volumes.
2. Assume 20% of VM areas require active remediation (dredging).
3. Assume 30% of cap, ENR, and MNR areas require dredging due to technology assignment uncertainty.
4. Assume 30% of ENR and MNR areas require dredging based on future monitoring.
5. Assume $60/ton disposal cost for treated sand from soil washing operations.
6. Capital costs and indirect construction costs are rounded to three significant digits. Total costs are rounded to two significant digits. All volumes are calculated by a spreadsheet prior to rounding.

a See Appendix I, Table I-3 for volume and technology performance assumptions used in the cost sensitivity analysis. Capital costs include construction contingency, sales tax, project management and remedial design, construction management, and agency oversight. Indirect construction costs include operations and maintenance (dredging, capping, ENR, and MNR), institutional controls, and long-term RAO monitoring.

b Costs for early action areas (EAAs) are shown here for completeness. Decisions on those cleanups have been made and are not part of the decision process represented in this FS. EAA in-water work is estimated at $66 million. Substantial additional costs are expected for upland cleanup and source control. The EAA costs and the costs of upland cleanup and source control are not included in cost estimates shown for Alternatives 2 through 6.

C= combined technology alternative; ENR = enhanced natural recovery; MNR = monitored natural recovery; R = removal emphasis alternative; R-CAD = removal with contained aquatic disposal; R-Treatment = removal with treatment; SQS = sediment quality standard; VM = verification monitoring.

Figure 10-1 Areas that are not Dredged Corresponding to Technology Assignments for Each Recovery Category

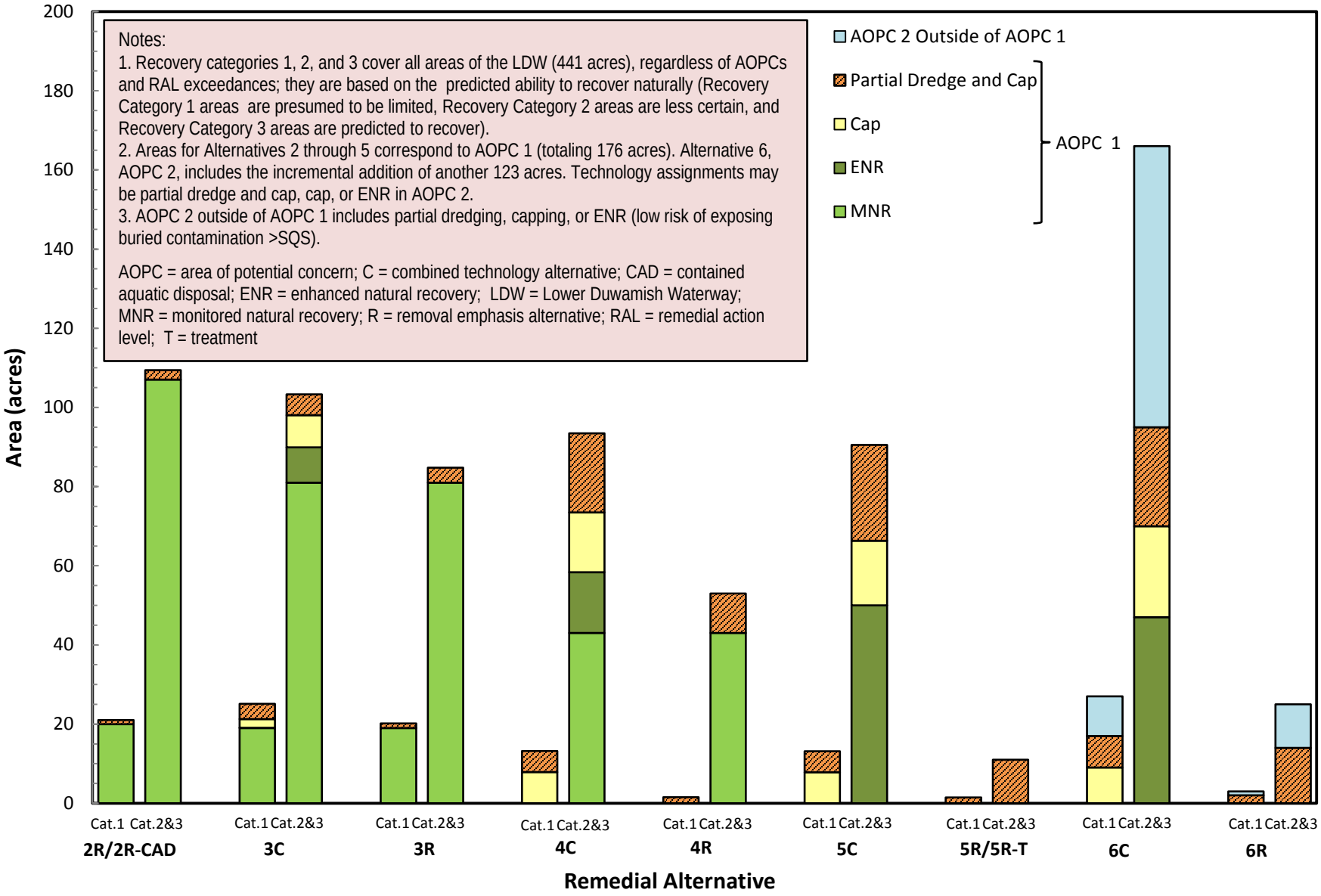


Figure 10-2 Predicted Time to Achieve Remedial Action Objectives (RAOs) for Protection of Human Health and the Environment

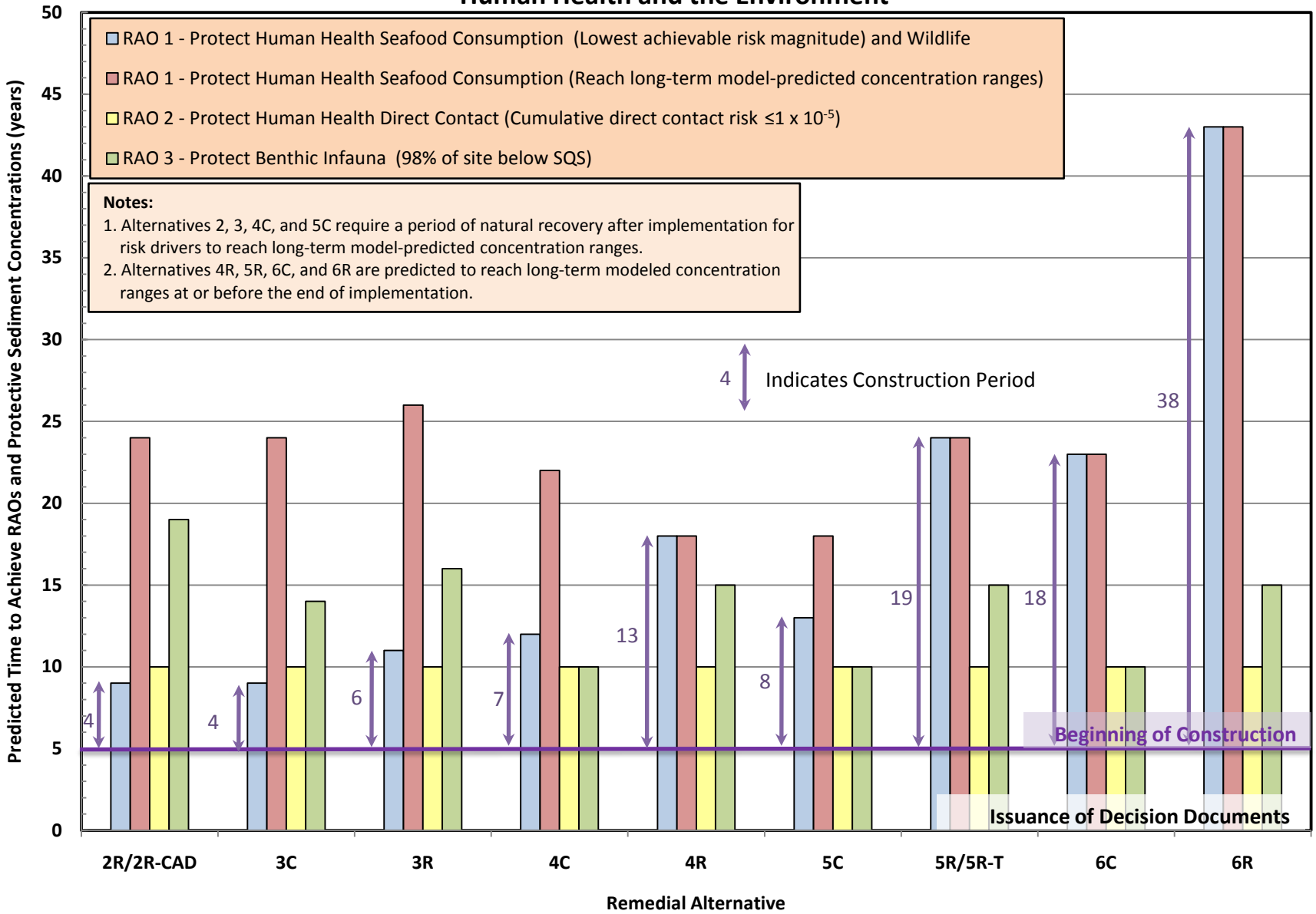


Figure 10-3 Contributions to Reduction in Total PCB Spatially-Weighted Average Concentration (SWAC) by Active Remediation and Natural Recovery

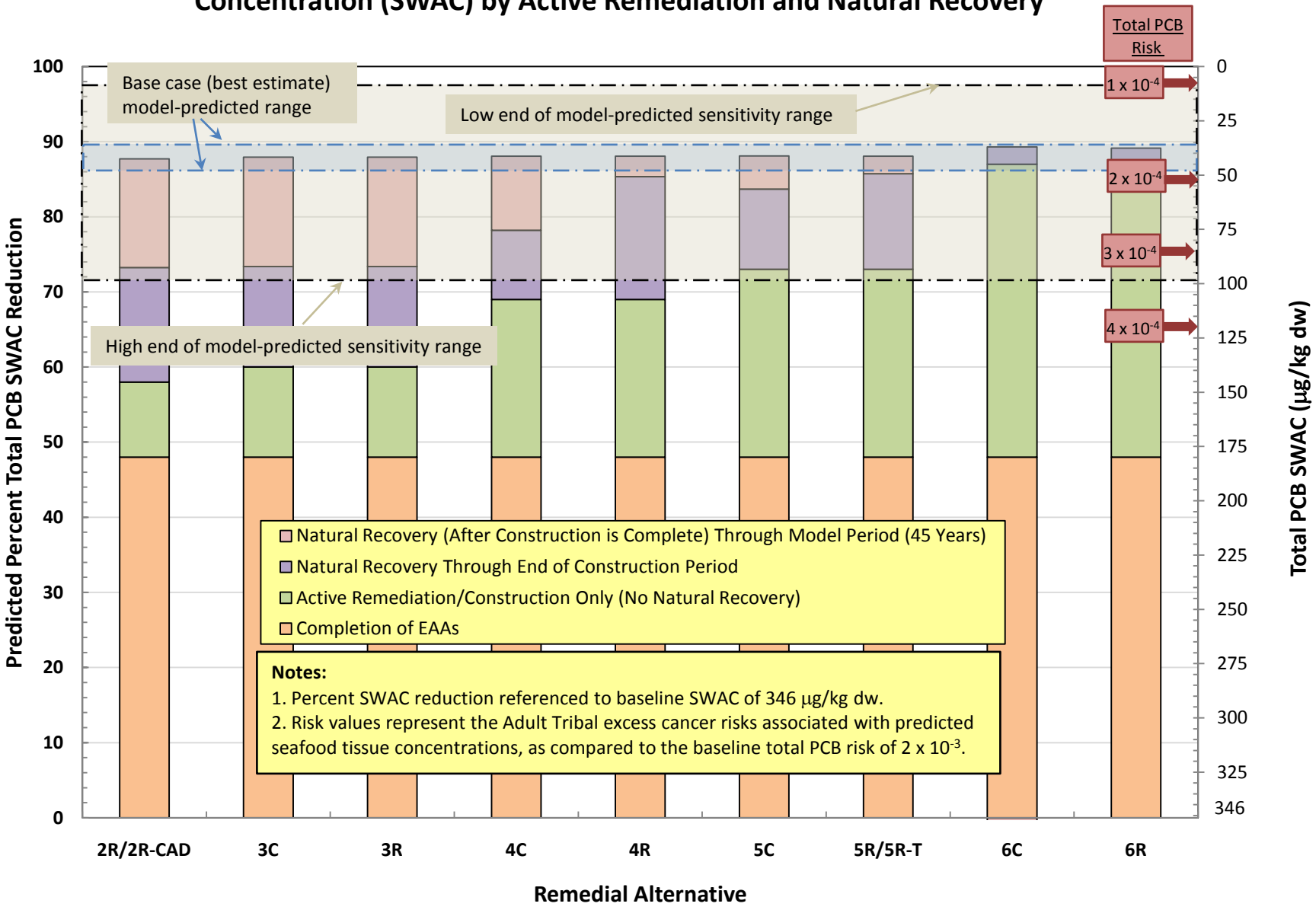


Figure 10-4 Contributions to Achievement of RAO 3 by Active Remediation and Natural Recovery

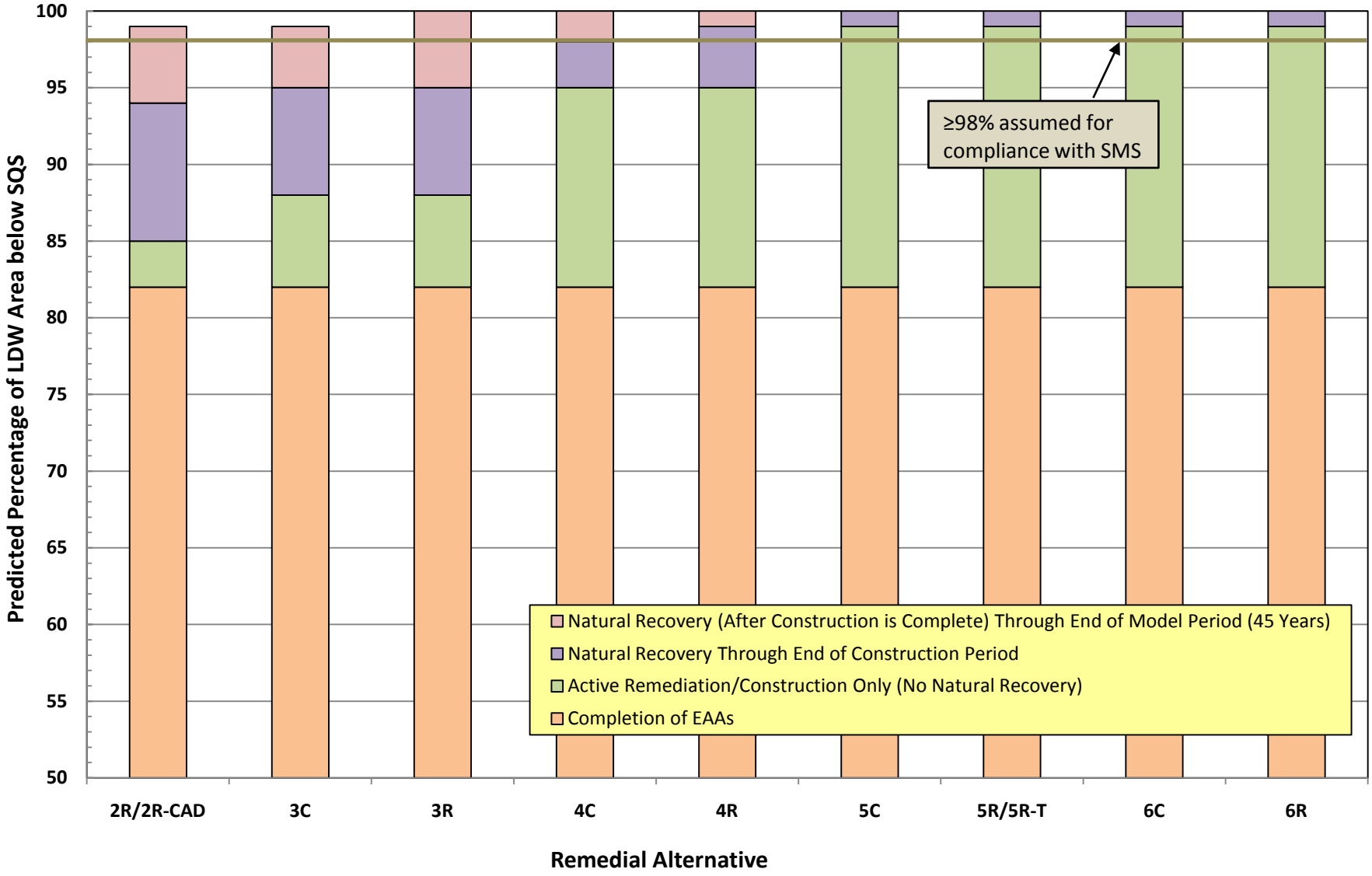


Figure 10-5 Estimated Total Costs of the Remedial Alternatives

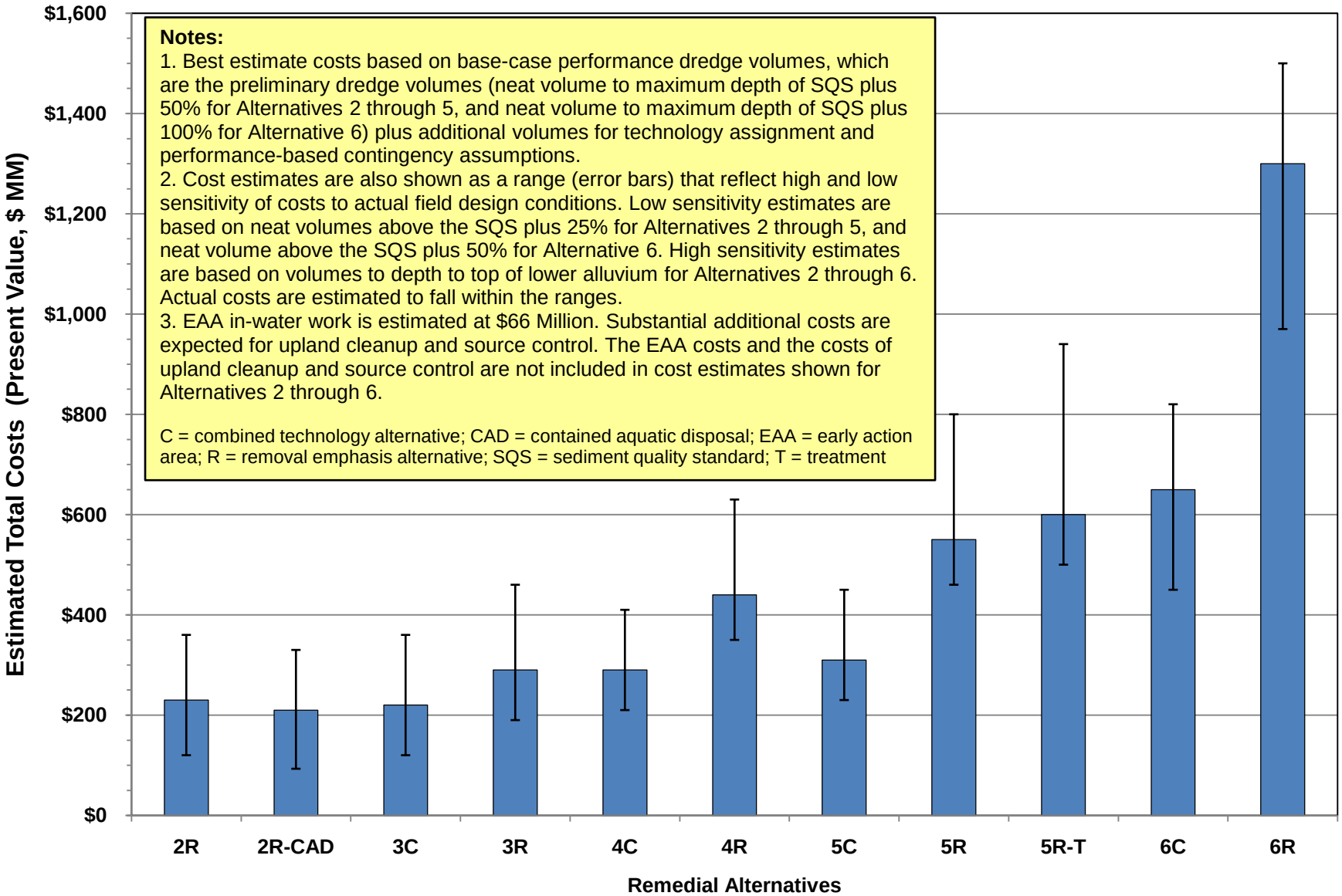
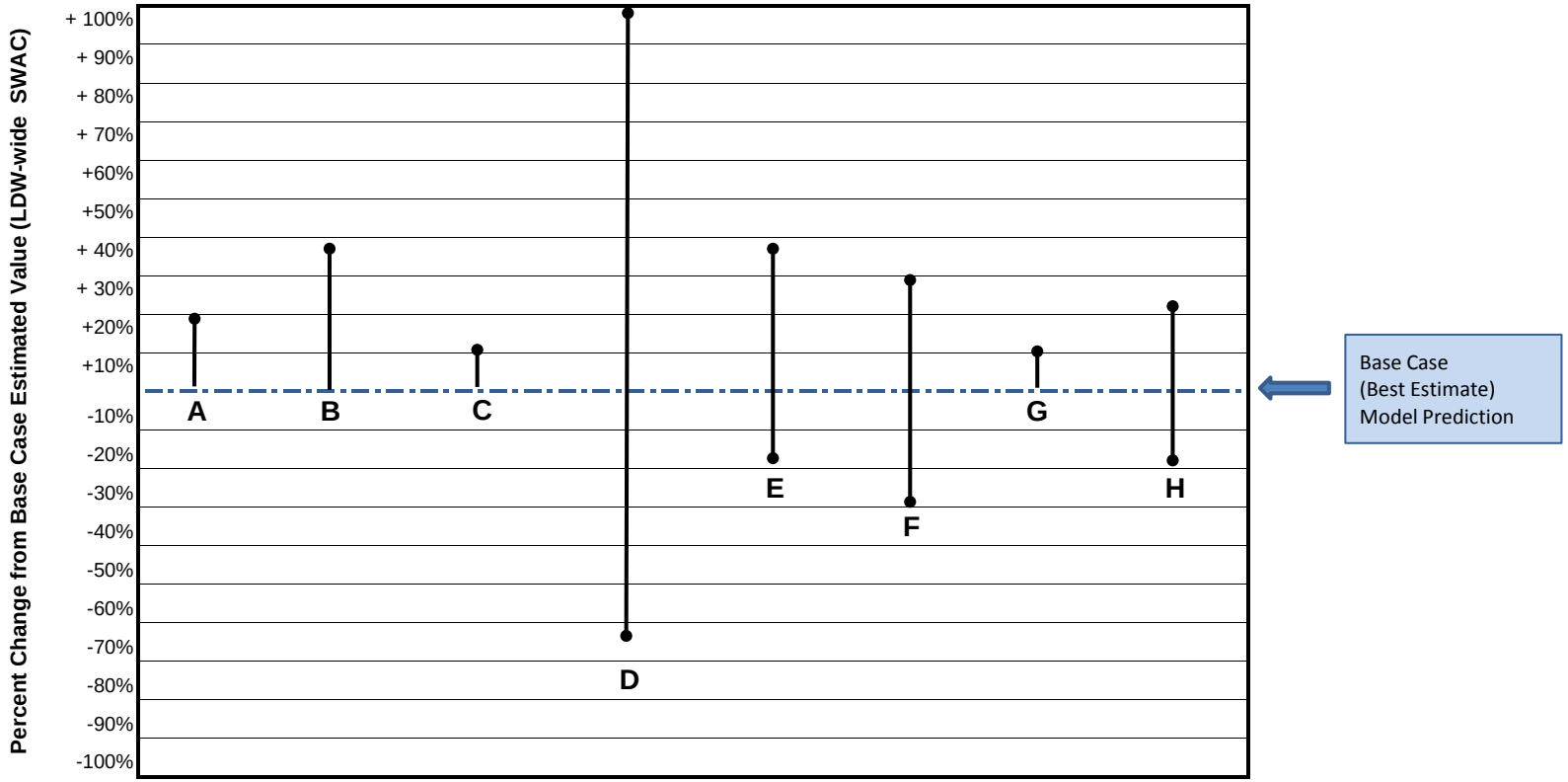


Figure 10-6 Approximate Magnitude and Range of Uncertainties in SWAC Estimation



Definitions:

A - Do not sequence remedial actions by alternative; instead remediate Alternative 6 footprint from upstream to downstream (Section 10.2.3.3).

B - Do not account for natural recovery predicted by the BCM; estimate SWACs after construction using the post-remedy bed sediment replacement value (Section 10.2.4).

C - Hold cells constant (no natural recovery) in Category 1 scour areas: Compare against 10-year base case results (Appendix C).

D - BCM sensitivity, 30-year results (range from all low input parameters to all high input parameters; Table 9-4).

E - STM bounding runs; +/- net sedimentation rate of 1 cm/year from STM 10-year base case results. (Appendix C and Section 5).

F - BCM sensitivity for lateral values (mid input values for upstream and post-remedy bed sediment replacement value, high input value for lateral): Compare 30-year output (Table 9-4 with natural recovery, and Appendix J without natural recovery during construction).

G - Resuspension and redeposition of total PCBs during active dredging (literature-based estimate).

H - Spatial interpolation method uncertainty (Appendices A and H).

Notes:

1. Uncertainty evaluation based on total PCBs.
2. SWAC = spatially-weighted average concentration

11 MTCA Evaluation of Remedial Alternatives

This section of the feasibility study (FS) evaluates the remedial alternatives[1] under the State of Washington Model Toxics Control Act (MTCA) requirements for conducting a FS. As stated within the Washington Administrative Code (WAC) 173-340-350, the purpose of an FS is to develop and evaluate remedial alternatives that will enable a remedial action to be selected for the site. This is the same purpose for conducting an FS under the Comprehensive Environmental Response, Conservation, and Liability Act (CERCLA) of 1980. The Washington State Department of Ecology (Ecology) is responsible for actions under MTCA. The U.S. Environmental Protection Agency (EPA) is responsible for actions under CERCLA. Both Ecology and EPA are reviewing the FS and will select the remedial alternative for the Lower Duwamish Waterway (LDW).

The LDW FS is structured using the CERCLA guidance framework for developing, evaluating, and presenting the analysis of remedial alternatives. This approach is appropriate because MTCA and CERCLA are similar in many respects. However, there are differences. This section evaluates information developed and presented elsewhere in the FS, but uses the methodology and criteria set forth in MTCA (WAC 173-340-360). This evaluation is similar to the CERCLA comparative analysis evaluation in Section 10.

11.1 MTCA Requirements for Content of the FS

The general content and requirements under MTCA for an FS are outlined within WAC 173-340-350 and include:

- Develop cleanup standards applicable to the site. These standards are similar to preliminary remediation goals (PRGs) presented in Section 4.
- Assemble remedial alternatives that protect human health and the environment by eliminating, reducing, or otherwise controlling risks posed through each exposure pathway and migration route identified for the site. Remedial alternatives were assembled in Section 8. Section 9 presented the predicted outcomes of each remedial alternative.
- Use remediation levels to define when particular remedial alternative components will be used. Remedial action levels (RALs), which are similar to remediation levels, are developed in Section 6. RALs are reviewed relative to MTCA criteria in Section 11.2.

[1] MTCA refers to remedial alternatives as cleanup action alternatives. For consistency with the rest of the FS, the term "remedial alternatives" is retained in this section.

- Use remedial action components that provide for on-site or off-site disposal of the hazardous substances in an engineered, lined, and monitored facility; on-site isolation or containment of the hazardous substances with attendant engineering controls, institutional controls, and monitoring. The remedial alternatives incorporate a reasonable array of remedial technologies as screened in Section 7.
- Develop a reasonable number and type of alternatives, taking into account the characteristics and complexity of the LDW, including current site conditions and physical constraints. Twelve remedial alternatives were developed in Section 8 using 5 sets of RALs (Alternatives 2 through 6), two sets of technology options (combined technology ["C"]) and removal emphasis ["R"]), two disposal options (upland disposal [default disposal option for all alternatives], one treatment option (soil washing), and contained aquatic disposal (CAD). The complete set of alternatives is: 1, 2R, 2R-CAD, 3C, 3R, 4C, 4R, 5C, 5R, 5R-Treatment, 6C, and 6R.
- Evaluate the residual threats that would accompany each remedial alternative to determine if alternatives are protective of human health and the environment. The risk-based outcomes and restoration time frames for each alternative are described in Section 9 and are incorporated into Sections 11.4 and 11.5.
- Use a standard point of compliance for alternatives unless it is not practicable, and use, as appropriate, alternatives with conditional points of compliance. Points of compliance for each alternative were discussed in Section 8 and are summarized in Section 11.3.
- Evaluate alternatives, using the "minimum requirements," which include "threshold requirements," "other requirements," additional minimum requirements, and the disproportionate cost analysis (DCA). Sections 11.2 through 11.5 present the MTCA evaluation of the remedial alternatives.

11.2 MTCA Minimum Requirements for Remedial Actions

Under MTCA, remedial alternatives are evaluated within the framework of minimum requirements, including threshold requirements, other requirements, and additional minimum requirements as specified in WAC 173-340-360. Table 11-1 provides a schematic of the MTCA remedy selection process, which illustrates the process of screening the remedial alternatives against minimum requirements, and then comparing them using a DCA. Table 11-2 cross-references the minimum requirements to sections of the FS where relevant information and analyses are presented.

11.2.1 Threshold Requirements

WAC 173-340-360(2)(a) lists four threshold requirements for remedial actions. All remedial actions must:

- Protect human health and the environment
- Comply with cleanup standards
- Comply with applicable state and federal laws
- Provide for compliance monitoring.

An evaluation of the remedial alternatives against these threshold requirements is presented in Section 11.3.

11.2.2 Other Requirements

Under MTCA, alternatives that achieve the threshold requirements must also achieve the following "other requirements" (WAC 173-340-360(2)(b)):

- Provide for a reasonable restoration time frame
- Use permanent solutions to the maximum extent practicable as determined by the DCA
- Consider public concerns.

Each of these "other requirements" is described below.

11.2.2.1 Reasonable Restoration Time Frame

MTCA requires that remedial alternatives provide for a reasonable restoration time frame (i.e., time to achieve cleanup standards). MTCA provides no specific time requirement but allows for a comparison of these restoration time frames among the remedial alternatives. The Washington State Sediment Management Standards (SMS) requires an evaluation of the practicability of achieving a 10-year restoration time frame following construction, but allows restoration time frames to exceed 10 years where it is not practicable to achieve the cleanup standards within 10 years. The term "time to achieve remedial action objectives (RAOs)" used in Sections 9 and 10 is equivalent to the term "restoration time frame" used in this section. However, restoration time frame is defined in Sections 7 and 9 (Figure 9-2) as the time frame required to achieve RAOs after remedial actions have been completed to specifically address SMS.

11.2.2.2 Disproportionate Cost Analysis (DCA)

MTCA specifies that, when selecting a remedial alternative, preference shall be given to actions that are permanent solutions to the maximum extent practicable. Multiple approaches to achieving cleanup standards are possible for the LDW. Identifying an alternative that is permanent to the maximum extent practicable requires weighing the

costs and benefits of each. MTCA defines this weighting process as a "disproportionate cost analysis" (WAC 173-340-360(3)(e)). The following criteria, which are used to evaluate and compare remedial alternatives when conducting a DCA under WAC 173-340-360(3)(f), are further defined under MTCA as:

- Protectiveness
- Permanence
- Long-term effectiveness
- Short-term risk management
- Implementability
- Potential for community concerns
- Cost.

This DCA provides a means to screen out alternatives for which the implementation costs are disproportionate to the benefits achieved. According to WAC 173-340-360(3)(e)(i), costs are considered disproportionate to benefits when the incremental costs of the alternative exceed the incremental benefits achieved by the alternative compared to that achieved by other lower-cost alternatives.

11.2.2.3 Consider Public Concerns

MTCA requires that public concerns solicited throughout the cleanup process pursuant to WAC 173-340-660 be considered. Consideration of community acceptance (including concerns of individuals, community groups, local governments, tribes, and federal and state agencies) cannot be fully assessed until after the FS is released for regulatory and public review. This criterion, therefore, should be evaluated in the final decision document, which will also include a formal responsiveness summary to public comments.

11.2.3 Additional Minimum Requirements

Additional minimum requirements are described in MTCA as relevant for comparing and evaluating alternatives. These are described below and listed in Table 11-2.

11.2.3.1 Institutional Controls

All of the alternatives presented in Section 8 rely in part on institutional controls to achieve cleanup standards, because none of the alternatives can achieve the total polychlorinated biphenyls (PCB) and dioxin/furan cleanup levels (PRGs) that are set to natural background for the human seafood consumption scenario. Institutional controls may also be required to protect certain elements of the remedial alternatives (e.g., engineered caps).

MTCA (WAC 173-340-360(2)(e) and 173-340-440) requires that remedial alternatives that include institutional controls satisfy the following three provisions:

- Remedial alternatives shall meet each of the minimum requirements in WAC 173-340-360 (2).
- The institutional controls should demonstrably reduce risks to ensure a protective remedy.
- Remedial alternatives shall not rely primarily on institutional controls and monitoring where it is technically possible to implement a more permanent remedial alternative for all or a portion of the site.

Section 11.3 addresses the first provision and evaluates the alternatives against the minimum requirements. Section 7 of this FS provides a detailed discussion of institutional controls, including a discussion of how they will reduce risk. The third provision is addressed within the DCA presented in Section 11.5.

11.2.3.2 Releases and Migration

Remedial alternatives shall prevent or minimize present and future releases and migration of hazardous substances in the environment (WAC 173-340-360(2)(f)). Pertinent factors that are considered for this evaluation include:

- Releases during implementation (e.g., during dredging or contained aquatic disposal)
- Releases associated with treatment residuals
- Potential future releases from scour in passive remediation and enhanced natural recovery (ENR) areas
- Potential future releases from failure of engineered containment remedies (e.g., caps).

Construction best management practices and proper residuals management are designed into the engineering and construction management of the remedial alternatives to limit resuspension of contaminated sediment and recontamination of adjacent areas. Although minimized to the maximum extent practicable, resuspension from dredging still figures significantly in the short-term risk impacts. Capping with appropriately engineered armoring is considered in locations where there is the potential for significant erosion from high flows or vessel traffic. Capping limits the potential for future exposure of buried contaminated sediment. ENR and monitored natural recovery (MNR) are avoided in areas with potential scour. In addition, a preliminary analysis of contaminant migration through isolation caps (Section 7.1.4), shows that capping would achieve full isolation in areas with low rates of sedimentation (>0 cm/year), and that caps can be engineered to

achieve isolation for 100 years or more in the absence of sedimentation (see Appendix C, Part 8). Maintenance and monitoring of the remedial actions will continue in an effort to minimize future releases.

Source control and potential on-going releases from sources are key considerations in all alternatives (see Section 2.4 and Section 8.4.1).

11.2.3.3 Dilution and Dispersion

Remedial alternatives shall not rely primarily on dilution and dispersion unless the incremental costs of any active remedial measure over the costs of dilution and dispersion grossly exceed the incremental degree of benefits of active remedial measures over the benefits of dilution and dispersion (WAC 173-340-360(2)(g)).

The alternatives presented in this FS do not rely primarily on dilution and dispersion.

11.2.3.4 Remediation Levels

The term "remediation levels" is synonymous with "remedial action levels (RALs)" used in previous sections of this document. Remedial alternatives that use remediation levels shall meet the following requirements:

- Remedial alternatives shall meet each of the minimum requirements in WAC 173-340-360 (2), including a determination that the remedial action is protective of human health and the environment
- Selection of a remedial alternative that uses remediation levels requires a determination that a more permanent remedial alternative is not practicable based on the DCA.

Each alternative uses RALs developed in Section 6 and institutional controls to protect human health and the environment.

11.3 Evaluation of Alternatives against Threshold Requirements

This section evaluates each of the remedial alternatives with respect to the threshold requirements set forth in MTCA, Ch. 70.105D RCW (WAC 173-340-360). Table 11-3 summarizes the evaluation of remedial alternatives against the threshold and other requirements. For any alternative, the four threshold criteria must be met to be considered viable as a remedial alternative for the LDW and carried forward in the evaluation. As indicated in Table 11-3, Alternatives 2 through 6 satisfy the four threshold requirements.

11.3.1 Protect Human Health and the Environment

Protection of human health and the environment is measured by each alternative's ability to achieve MTCA cleanup standards, while considering related short-term impacts to human health and the environment that result from active remediation (e.g., benthic community and habitat loss, increased fish tissue concentrations of risk-driver chemicals

during dredging and resulting increased risk to seafood consumers and river otters, community impacts from traffic, noise, and emissions).

In the LDW, risk reduction is measured by the achievement of the MTCA cleanup standards (Table 11-3). Detailed chemical and risk-based predicted outcomes are provided in Section 9 and Appendix M. Tables 9-2a and 9-3 present predicted human health risk-driver chemical concentrations achieved over time by the alternatives. Tables 9-6a, 9-6b, 9-7, and Appendix M present the expected human health risks for each remedial alternative. Tables M-8a through M8-d present additional expected risk for individual chemicals for direct contact scenarios.

As indicated in Table 11-3, RAOs 1 through 4 are achieved for Alternatives 2 through 6 through a combination of active remediation, natural recovery, and institutional controls to reduce exposures. As discussed in Sections 9 and 10, the overall improvement in the quality of the LDW aquatic environment for Alternatives 2 through 6 is similar over the 10- to 30-year time frame.

Remedy construction can result in related environmental risks, such as those posed by the mobilization of chemicals during dredging (see Table 10-1). Dredging activities are associated with a relatively higher risk of water quality inputs, elevated concentrations of chemicals in fish tissue, and potential sediment recontamination, compared to other remedial technologies such as capping, ENR, and MNR. Dredging-related risks include the introduction of residuals into areas that were not previously contaminated. Some short-term risks can be reduced through prudent design practices and best management practices during construction. Other short-term risks, such as impacts due to traffic, are generally proportional to the scale of the remedial alternatives (i.e., construction time frame).

Alternatives 2 through 6 pass the threshold criteria of protecting human health and the environment because the alternatives achieve the RAOs. Long-term risks and short-term (i.e., construction-related) risks are further evaluated as part of the DCA in Section 11.5.

11.3.2 Comply with Cleanup Standards

For remedial alternatives to be considered viable, the alternatives must comply with cleanup standards. Cleanup standards have two components: cleanup level and point of compliance. Cleanup standards will be set by EPA and Ecology in the final decision document. For this FS, the cleanup levels are the PRGs or the calculated MTCA method equivalent when assessing MTCA compliance. The point of compliance throughout the LDW is 10 cm depth, except in potential clamming and assumed beach play areas when addressing PRGs for direct contact pathways. In these areas, the point of compliance is 45 cm depth to protect against direct contact exposures (RAO 2).

The PRGs developed in Section 4 considered MTCA requirements for cleanup levels. MTCA requires that cleanup levels achieve a cumulative hazard quotient of 1 or less and

a cumulative excess cancer risk of 1×10^{-5} or less. MTCA stipulates that the individual chemical excess cancer risk must be 1×10^{-6} or less. MTCA also allows an upward adjustment of the cleanup level to natural background or the practical quantitation limit (PQL), whichever is greater, if the cleanup level is below natural background or the PQL. All PRGs and the basis for each are listed in Table 4-4.

Table 11-3 summarizes predicted outcomes for the remedial alternatives with respect to the RAOs and PRGs, based on the information presented in Section 9. Most PRGs are achieved following construction or within 10 years following construction, depending on the alternative. Risk reduction is achieved for RAO 1 through a combination of active remediation, natural recovery, and institutional controls (e.g., seafood advisories) to reduce exposures (as discussed in Section 9).

The arsenic PRG established in Section 4 for all direct contact scenarios (7 mg/kg dw), which is based on natural background, cannot be achieved by any remedial alternative. However, the standard methodology for calculating natural background specified in MTCA (WAC 173-240-709) differs slightly from that used in prior sections of the FS. For a lognormal dataset deemed representative of natural background conditions, the natural background concentration is the minimum of the 90th percentile and four times the 50th percentile. Based on the 90th percentile of the 2008 EPA Puget Sound OSV *Bold* survey dataset (EPA 2008), the arsenic natural background value is 11 mg/kg dw (Table 11-4).[2] Comparing this value to the predicted arsenic spatially-weighted average concentrations (SWACs) for all direct contact exposure areas (e.g., each beach) for RAO 2 in Tables 9-2a and 9-3 shows that Remedial Alternatives 1 through 6 are predicted to achieve the MTCA natural background value for arsenic of 11 mg/kg dw.[3]

The cPAH PRG for the beach play direct contact scenario (90 µg TEQ/kg dw) is not predicted to be achieved by any remedial alternative.[4] This PRG is based on achieving 1×10^{-6} risk or less for assumed beach play areas, but the method for calculating risk specified in MTCA differs slightly from the method used in the RI. Using the MTCA Method B standard equation (WAC 173-340-740), a risk threshold of 1×10^{-6} for cPAH corresponds to a concentration of 140 µg TEQ/kg dw.[5] Comparing this value to the

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[2] A value of 11 mg/kg dw was calculated as the 90th percentile of the OSV *Bold* survey dataset using ProUCL. Using MTCAStat, the 90th percentile of the OSV *Bold* survey dataset is 12 mg/kg dw.

[3] The comparison of predicted SWACs to the cleanup level is sufficient for this analysis; however, compliance with cleanup standards would be based on the 95% confidence limit on the true mean concentration with no single sample above two times the cleanup level (WAC 173-340-740(7)(d)(i)(A).

[4] Although 90 µg TEQ/kg dw is not predicted to be achieved in beaches, the excess cancer risk threshold of 1×10^{-6} is predicted to be achieved in all but Beach 3.

[5] The MTCA Method B standard equation includes a 365 days per year exposure scenario and does not include an adjustment for early life exposure. Based on a preliminary analysis, adjusting the equation for a 65 days per year exposure scenario and for early life would lower the risk-based threshold

predicted outcomes in Table 9-3 shows that Alternatives 3 through 6 achieve this level immediately following construction, or before construction is complete for all assumed beach play areas except Beach 3, which is likely influenced by lateral sources. Alternatives 1 and 2 are predicted to achieve this level within 20 years following the issuance of the final decision documents (approximately 15 and 10 years following the end of construction, respectively). The cPAH SWAC of 140 µg TEQ/kg dw is not practicable for Beach 3 for any of the remedial alternatives because of lateral loading from nearby outfalls. However, the cumulative risk for all risk-driver chemicals achieves the cumulative direct contact risk of 1×10^{-5} for Beach 3. As shown in Table 9-7, all remedial alternatives achieve 1×10^{-5} cumulative direct contact risk for all beaches.

11.3.3 Comply with Applicable State and Federal Laws

This criterion is discussed in Section 9.1.1.2. With the exception of Alternative 1, all remedial alternatives would comply with the applicable state and federal laws.

11.3.4 Provide for Compliance Monitoring

Section 8.2.4 describes the MTCA requirements for protection, performance, and confirmation monitoring. The monitoring program included in Alternatives 2 through 6 allows the progress toward achieving cleanup standards to be assessed on a periodic basis. The conceptual monitoring program as presented in Appendix K complies with the MTCA requirements and Table 8-8 cross-references the MTCA terms with the CERCLA monitoring terms used in this FS.

With the exception of Alternative 1, all the remedial alternatives include compliance monitoring. The remedial alternatives are expected to ultimately achieve compliance with cleanup standards. However, the estimated time required to achieve compliance varies among the alternatives. Alternatives 2 through 6 incorporate the compliance monitoring required to evaluate whether cleanup standards are being achieved.

11.4 Provide for a Reasonable Restoration Time Frame

MTCA defines restoration time frame as the period of time needed to achieve the required cleanup levels at the points of compliance established for the site. The SMS (WAC 173-204-570) establishes the expectation that the minimum cleanup level (i.e., CSL) is the maximum allowed chemical concentration and the level of biological effects permissible at the cleanup site 10 years after completion of active remediation. The sediment cleanup standards are established on a location-specific basis and can range between the sediment quality standards (SQS) and the CSL.

concentration (RBTC) from 140 µg TEQ/kg dw to 130 µg TEQ/kg dw. This change would not affect compliance with cleanup standards for RAO 2.

Table 11-3 summarizes the restoration time frames based on the analysis in Section 9. The values for "restoration time frame" are identical to the values for "time to achieve RAOs" presented in Section 9. Alternatives 3C, 4C, and 5C achieve all four RAOs in the shortest time frames of 14, 12, and 13 years, respectively, but take another 5 to 15 years to reach long-term model-predicted concentrations. Alternatives 2R, 2R-CAD, 3R, and 4R take moderately longer to achieve the RAOs (19, 16, and 18 years, respectively). Alternatives 5R, 6C, and 6R take the longest time to achieve the RAOs (24, 23, and 43 years, respectively, and take another 5 to 15 years to reach long-term model-predicted concentrations), by virtue of their long implementation periods, and the ongoing impacts to fish tissue concentrations during construction.

As discussed elsewhere in this FS, some uncertainties are associated with the estimated restoration time frames. These uncertainties are managed through compliance monitoring, coupled with an adaptive management approach, as described in Sections 8.2.4 and 8.2.5. This approach provides information during the implementation of remediation and allows for appropriate assessments of risk and progress toward achieving the MTCA cleanup levels. This monitoring allows for feedback, reassessments, and adjustments to provide adequate methods and levels of protection. These adaptive management measures are included in Alternatives 2 through 6 and will allow additional areas to be identified and managed as needed, including areas that may still exceed SMS criteria after 10 years.

11.5 Disproportionate Cost Analysis

MTCA requires that remedial alternatives use permanent solutions to the maximum extent practicable. This determination is made based on the DCA process in which: 1) the most practicable, permanent remedial alternative serves as the baseline; and 2) the benefits to human health and the environment of the remedial alternatives are evaluated and compared to the costs. This analysis uses the evaluation criteria listed in WAC 173-340-360(3)(f). Both quantitative measures and more qualitative best professional judgments are used in assessing benefits (WAC 173-340-360(3)(e)(ii)(C)). The metrics used in the DCA are described in Table 11-5. Results of the DCA are summarized in Table 11-6. Table 11-7 provides the detailed metrics and scoring for each evaluation criterion.

11.5.1 Weighting of MTCA Evaluation Criteria

The MTCA evaluation criteria presented in WAC 173-340-360 (3)(f) were weighted in consultation with Ecology (Table 11-5). The weightings emphasize the core purpose of protecting human health and the environment and reflect site-specific considerations, such as the size, complexity, and potential time frames involved in the remedial alternatives. The sum of the weightings equal 100%.

"Protectiveness" represents the ultimate objective of implementing a remedial alternative. Therefore, overall protectiveness ratings were weighted 30%.

A weighting of 20% was assigned to the "permanence" criterion. In evaluating the alternatives under this criterion, MTCA focuses on the degree that the toxicity, mobility, or volume of hazardous substances is reduced.

"Effectiveness over the long term" is an important requirement because it addresses how well the remedy reduces risks and whether controls are adequate to maintain protection against exposures to contamination left in place in the long term. This criterion therefore received a weighting of 20%.

A weighting of 15% was assigned to the "management of short-term risk" criterion. This weighting considers the relatively long durations of most of the remedial alternatives. Because of the extended implementation times for alternatives with larger active remediation footprints, short-term risks to workers, the community, and the environment can extend for many years. Generally, short-term risks are actively monitored during the period the risks exist.

A weighting of 15% was assigned to the "technical and administrative implementability" criterion. This weighting reflects the fact that implementability is less associated with environmental concerns than with the relative difficulty and uncertainty of implementing the project. It includes both technical factors and the administrative factors associated with permitting and completing the cleanup.

Consideration of public concerns is another criterion in the MTCA DCA; however, this criterion was not evaluated in the DCA because public outreach will not be completed until after release of the FS for comment. This criterion will be evaluated by EPA and Ecology in the Proposed Plan after release of the final FS and the opportunity to review public comments.

Cost is not a weighted benefit, but is used in the DCA to evaluate the benefit of each alternative relative to the cost.

11.5.2 DCA Evaluation for Remedial Alternatives

Table 11-6 provides a summary of how well the remedial alternatives rate on a scale from 0 to 10 for each MTCA criterion. The following evaluations provide the basis for the numerical ratings in the DCA. These ratings are then weighted and summed for an overall measure of the benefits achieved by the alternatives, presented in Table 11-6, along with the cost estimates (as net present value) for each remedial alternative. Table 11-7 provides the metrics used to develop the ratings summarized in Table 11-6. Each metric includes the unit used for each alternative (e.g., years, cubic yards, acres, or risk), as well as the representative value that would receive a score from 0 to 10. In general, a score of 0 represents a poor-performing alternative for that metric, and a score of 10 represents the best-performing alternative for that metric. Note that depending on the basis for a metric's scale, the alternatives may not always cover the full range (0 to 10) if they all have less than optimal results for that measure.

The goal of Table 11-7 is to select benefit metrics for each DCA evaluation criterion such that the benefit metrics reasonably reflect the DCA criteria. As a result, each statement within each criterion description is reflected as a separate metric, unless otherwise noted in Table 11-7. Some metrics appear more than once because the selected metric is a surrogate measure of the value statement for each line item in the DCA, or because the same metric is directly applicable to multiple MTCA-defined criteria. This ensures that each DCA criterion is quantified and contributes to the overall benefit scoring.

A significant number of choices were made in selecting each metric and selecting the scoring range (defining what 0 and 10 represent). These choices were made using best professional judgment; however, scoring the "benefit" of each remedial alternative is somewhat subjective. These scores provide a useful tool for comparing remedial alternatives, but do not provide an absolute or precise measurement of benefit. Small differences in overall benefit scores should therefore be considered to have limited significance.

The following subsections describe the MTCA DCA criteria as defined by WAC 173-340-360 and the metrics that were used to evaluate each alternative's performance relative to that metric in the DCA.

11.5.2.1 Protectiveness

Protectiveness is determined to be equally based on: 1) the degree to which existing site risks are reduced, 2) the time required to reduce these risks and to achieve cleanup standards, 3) on-site and off-site risks resulting from implementing the alternative, and 4) improvement of the overall environmental quality.

Degree to which Existing Risks are Reduced

The degree to which LDW-wide residual risks are reduced is based on the ability of a remedial alternative to achieve the four RAOs at the end of the model period. To assess this criterion for each remedial alternative, the excess cancer risk or hazard quotient exceedance (for non-cancer) predicted by the BCM was compared to the FS baseline excess cancer risk or hazard quotient exceedances for each RAO. If the risk is reduced to below the threshold criteria for the RAO, it scores a 10; if the risk is not reduced from baseline conditions, it scores a 0.

Alternatives 2 through 6 perform similarly over the long term because they achieve RAOs 1 through 4 established for human and ecological receptors.[6] Because the rate of risk-reduction for Alternatives 2 through 6 is similar (e.g., see Figure 9-7), these alternatives all scored similarly.

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[6] All alternatives rely on institutional controls to achieve RAO 1 because the PRGs are set at natural background and it is unlikely this goal will be achieved based on upstream inputs and general urban inputs to the LDW.

Time Required to Reduce Risk

For this analysis, the time required to reduce risk was measured starting from the issuance of the final decision documents. Construction of Alternatives 2 through 6 is assumed to begin 5 years following issuance of final decision documents. During this period, the following activities are expected to occur: completion of the EAAs (i.e., Alternative 1), priority source control, negotiating orders, initial remedial design/ planning, baseline monitoring, and verification monitoring in higher priority areas. Five years was selected as the fastest possible restoration time frame (score 10), and 45 years was selected as the maximum allowable time frame (score 0). The achievement of each RAO is considered equally important and each one is weighted equally.

The scores indicate a balance between reliance on natural recovery to reduce risks and reliance on active remediation to reduce risks. In general, the combined alternatives score better than the removal alternatives because active remediation (i.e., construction time frame) is longer for the removal alternatives. For the removal alternatives, Alternative 3R scores the highest because it actively remediates more than Alternative 2R, and the construction time frame is significantly shorter than for the other removal alternatives. For the combined alternatives, Alternative 4C scores the highest because it achieves all RAOs slightly faster than Alternative 3C and 5C due to a shorter construction time frame than Alternative 5C and less reliance on natural recovery than Alternative 3C.

On-site and Off-site Risks from Implementation

As noted in Section 11.3.1, implementing the remedial alternatives causes construction-related environmental risks such as mobilization of chemicals of concern during construction. Risks to the community, construction workers, and the environment are simplified into one metric (based on volume of material handled) that represents several applicable metrics:

- Estimated number of truck and train miles for transporting sediment and capping materials (community risks)
- Estimated construction time required for each alternative and associated increased risks to people who consume resident seafood during that period (community risks)
- Quantitative impacts to the environment from air pollution generated and depletable resources consumed, as well as the expected short-term increases of contaminant concentrations within fish tissue and disruptions to aquatic habitat (environmental risks).

The implementation risks to the community are largely due to the increased construction-related traffic through local communities, along with risks to those people who choose to consume resident seafood that will have elevated tissue concentrations during the

construction period. The latter can be reduced by using institutional controls to reduce exposure through seafood consumption advisories.

The evaluation of environmental risks includes the quantitative impacts to the environment from air pollution generated by construction activities and depletable resources consumed, as well as the expected short-term increases of contaminant concentrations within fish tissue and physical disruptions to aquatic habitat. Increased resuspension of sediment associated with dredging is anticipated to result in higher contaminant concentrations in fish tissue during construction. In addition, the recovery time of habitat in areas may be heavily affected by the degree to which the existing sediment habitat is disrupted, the total area disrupted, and to what degree the impacted habitats are contiguous.

For the purposes of this analysis, all of these on-site and off-site risks are assumed to be directly proportional to the quantity of material handled during construction. The sediment handled is generally equivalent to the removal volume plus the placed volume (for capping, ENR, backfilling, or managing residuals), including additional removal necessary for CAD construction (Alternative 2R-CAD), and including additional handling of approximately 50% of dredged sediment necessary for soil washing (Alternative 5R-Treatment). The handling volumes are scored inversely proportional to a very large maximum handling volume (5 million cy = score 0) and no handling volume (0 cy = score 10). Handling volumes and relative ratings are shown in Table 11-7.

For this metric, Alternatives 1 through 6 score progressively lower, and removal alternatives score lower than combined alternatives, indicating increased risks during implementation for the removal-focused alternatives with larger active footprints.

Improvement of Overall Environmental Quality

Improvement of overall environmental quality was considered to be the achievement of the long-term risk-reduction, balanced by short-term risks during implementation. Therefore, this metric is scored by averaging the scores for the two metrics: degree to which existing risks are reduced, and on-site and off-site risks from implementation.

Overall Scores for Protectiveness

When the preceding four metrics are averaged, the combined alternatives score slightly higher than the removal alternatives because they achieve comparable risk reduction in shorter time frames with fewer implementation risks. The alternatives with smaller active footprints tend to score higher than alternatives with larger active footprints (e.g., Alternative 2R versus Alternative 6R) for the same reasons.

11.5.2.2 Permanence

MTCA defines permanence as the degree to which the alternative permanently reduces the toxicity, mobility, or volume of hazardous substances, including the adequacy of the alternative in destroying hazardous substances, the reduction or elimination of hazardous

substance releases and sources of releases, the degree of irreversibility of waste treatment process, and the characteristics and quantity of waste residuals generated.

For the LDW, rating the alternatives for permanence is not straightforward because no remedial alternative destroys contaminants; rather, they contain the contaminated material, move it to a landfill (all alternatives in varying degrees), move it to a CAD (Alternative 2R-CAD), or segregate it into more and less contaminated fractions before sending the higher contaminated material to the landfill and placing the lower contaminated material back into the environment (soil washing in Alternative 5R-Treatment).

For this analysis, two metrics were selected to represent permanence. The first is volume of sediment removed from the LDW. This metric was scaled from 0 cy (score 0), based on no sediment removal, to 4 million cy (score 10), based on complete removal of material above the Alternative 6 RAL. For this metric, the removal alternatives score significantly higher than the combined alternatives, and alternatives with larger active footprints score higher than alternatives with smaller active footprints (e.g., Alternative 6R versus Alternative 2R).

The second metric ranks the reduction in contaminant mobility in the LDW based on the acres of each remedial technology used. For this analysis, dredging and capping were assumed to reduce mobility more than the other technologies (score 9), ENR was assumed to reduce mobility a moderate amount (score 5), and MNR and verification monitoring (VM) were assumed to reduce mobility to a lesser degree (score 3). The mechanism by which ENR, MNR, and VM reduce mobility is through burial; monitoring and adaptive management (i.e., contingency actions) ensure that contaminated sediment is immobilized sufficiently. This metric scores similar to the previous metric: the removal alternatives score significantly higher than the combined alternatives, and the alternatives with larger active footprints score higher than the alternatives with smaller active footprints.

These metrics are considered adequate for rating permanence; however, several aspects are missing from these metrics that should be noted here. First, the mass removal of contaminated sediment does not take into account the diminishing risk-driver chemical concentrations of the sediment removed for alternatives with lower RALs (e.g., Alternative 6). In other words, Alternatives 6R and 5R may be rated artificially high because they remove a large volume of sediment, but the volumes don't equate to a proportional reduction in mass of contamination. Second, the mobility of contaminants in the LDW will likely increase as a result of contaminants being resuspended and released during dredging. Third, treatment does not receive credit for potential reduction in contaminated sediment volume sent to the landfill. Finally, the expected destruction of organic contaminants from natural processes (i.e., biotransformations) that may be a component of ENR and MNR or the reduction in mobility and toxicity that would result from any potential use of carbon amendment in capping or ENR are not accounted for within these ratings.

11.5.2.3 Effectiveness over the Long Term

The effectiveness of the remedial alternative over the long term is determined by averaging the score of the following components:

- Degree of certainty that the remedy will be successful
- Reliability of the alternative over the period during which risk-driver chemicals remain on site (including subsurface contamination) at concentrations higher than PRGs (or cleanup levels)
- The magnitude of residual risk
- Reliability of institutional controls and engineering controls used to manage risks
- Cleanup and disposal methods hierarchy listed in WAC 173-340-360(3)(f)(iv).

These evaluation components are summarized in Tables 11-6 and 11-7, and are discussed below.

Degree of Certainty in the Success of Remedial Alternatives

As noted elsewhere in the FS, the predicted outcomes and success of remediation for all remedial alternatives have some uncertainty. These uncertainties include the effectiveness of source control, the rates of natural recovery, concentrations of incoming sediment from upstream and lateral sources, and the effectiveness of remedial technologies (see discussion in Section 8.4). Many of these uncertainties are the same for all remedial alternatives, such as the concentrations of upstream sediment. However, uncertainties related to the use of specific remedial technologies differ among alternatives. Therefore, the remedial alternatives were scored based on the remedial technologies employed.

For this metric, each remedial technology is weighted based on professional judgment. It is assumed that the remedial technologies that depend on construction only (i.e., capping and dredging) have a higher degree of certainty of success than remedial technologies that depend on natural recovery (i.e., ENR and MNR). Dredging scores a 9 because, while it would remove a significant degree of contamination from the LDW, removal would not be perfect in practice and significant contamination would be left following dredging (e.g., due to dredge residuals or losses during dredging). Capping scores 9 because it would isolate contaminated sediment, but contaminated sediment would remain on site with a chance of re-exposure. ENR scores 5 because it depends on natural recovery, but also achieves additional protectiveness with a thin layer of sand. MNR and VM score 3 because they depend on natural recovery; however, monitoring and adaptive management ensure that areas that do not achieve performance goals are actively managed. The remedial alternatives are scored based on the weighted average of the acreage of each technology used in AOPC 1. For example if an alternative assigned dredging to all of AOPC 1, then the alternative would score a 9, and if the alternative

assigned MNR to all of AOPC 1, it would score a 3. Half dredging and half MNR would score a 6.

Table 11-7 shows the scores for the remedial alternatives. The removal alternatives score higher than the combined alternatives, and the alternatives with larger active footprints score higher than the alternatives with smaller active footprints (e.g., Alternative 6 scores higher than Alternative 2).

Reliability of the Alternatives during the Period of Time that Hazardous Substances Remain On-Site at Concentrations Exceeding Cleanup Levels

The evaluation of reliability is assumed to refer to the reliability of the alternative to contain remaining subsurface contamination following remediation. All remedial alternatives leave subsurface contamination behind and manage it through isolation by capping, ENR, or passive remediation (e.g., MNR and VM) in conjunction with institutional controls. The risk that subsurface sediment will recontaminate surface sediment is in part related to the remedial technology employed. Dredging scores 9 because subsurface contamination is removed. Dredging does not score a 10 because of releases and residuals that will occur during implementation. Capping scores 9 because it fully contains contaminated sediment under an engineered cap, ENR scores 5, and MNR and VM score 3 because these remedial technologies are more likely to incorporate mixing between subsurface contamination and surface contamination. Note that for all remedial alternatives, monitoring and adaptive management (i.e., contingency actions) will be used to reduce risk in areas where contaminated sediment is left in place and could potentially be re-exposed such that RAOs would be compromised. The remedial alternatives are scored by multiplying the acres of each technology by the score for each, then dividing that score by the area with subsurface contamination (AOPC 1). A score of 10 would represent an alternative with all dredging, and a score of 0 would represent passive remediation without monitoring and adaptive management.

For this metric, the removal alternatives score higher than the combined alternatives, and the alternatives with larger active footprints score higher than the alternatives with smaller active footprints (e.g., Alternative 6 scores higher than Alternative 2).

Magnitude of Residual Risk

The magnitude of residual risk in surface sediment is predicted using the BCM after completion of remedial alternatives. This determination uses the same metric as that for the "Degree to Which Risks are Reduced" under the criterion *Protectiveness*. For this evaluation, risk-reduction scores are effectively the same as the magnitude of residual risk in the surface sediment. As discussed above, all remedial alternatives scored approximately the same for this metric.

Reliability of Institutional Controls and Engineering Controls Used to Manage Risks

The reliability of controls has two components. The first component, institutional controls, includes seafood consumption advisories, public outreach, and education, as described in Section 7. Alternatives 2 through 6 all score the same for this metric because all alternatives rely on institutional controls to address the same amount of residual risk (see Table 11-7). Fish advisories will remain in effect for all remedial alternatives.

The second component, engineering controls, is necessary for managing and monitoring "waste" remaining on site. This metric is scored as a proportion of the surface area where buried contamination potentially remains on site. For this metric, the acres with caps, ENR, MNR, and VM in Area of Potential Concern 1 (AOPC 1) are summed for each alternative. Alternative 2R-CAD includes the CAD area. The metric is scored from none of AOPC 1 removed (score 0) to all of AOPC 1 removed (score 10). The removal alternatives score higher than the combined technologies alternatives for this metric, and the alternatives with larger active footprints score higher than the alternatives with smaller active footprints.

Hierarchy of Cleanup and Disposal Technologies Used

The hierarchy of cleanup and disposal methods is listed in WAC 173-340-360(3)(f)(iv) and can be used as a guide for evaluating effectiveness over the long term. Within this hierarchy, technologies are ranked in descending order. The ranking of MTCA technologies, the point value assigned to each, and the way that technologies are assigned are listed below:

- Reuse and recycle (weight 9 points; a slightly higher rank for soil-washing treatment [Alternative 5R-Treatment]; however, beneficial reuse of treated sediment is highly uncertain)
- Destruction or detoxification (not applicable to any of the remedial alternatives)
- Immobilization or solidification (not applicable to any of the remedial alternatives)
- Removal/upland disposal (weight 7 points; proportional to dredge area)
- On-site containment (weight 5 points; includes contained aquatic disposal and capping)
- Institutional controls and monitoring (weight 3 points; ENR, MNR, and verification monitoring areas).

The hierarchy of remedial alternatives is scored in Table 11-7 by assigning a weight from 0 to 10 for each item of the hierarchy. Then, the area is computed for each technology for each remedial alternative. The area for each alternative is multiplied by the weighting

factor, and then divided by the total area (AOPC 1). A theoretical alternative with 100% reuse and recycle would score 9 points. Areas, weightings, and scores are provided in Table 11-7.

For this metric, the removal alternatives score higher than the combined alternatives, and the alternatives with larger active footprints score higher than the alternatives with smaller active footprints. Alternative 5R-Treatment scores the highest owing to its potential to generate soil for beneficial reuse, although the reuse of treated dredged material is still highly uncertain (see Section 7).

Overall Score for Effectiveness over the Long Term

When the preceding five criteria are averaged to score *Effectiveness over the Long Term*, the result is that the removal alternatives score slightly higher than the combined alternatives, and the alternatives with larger active footprints score slightly higher than the alternatives with smaller active footprints.

11.5.2.4 Management of Short-term Risk

Short-term risks to human health and the environment occur during construction and remedy implementation. This criterion uses two components: the risks presented by the implementation of the remedial alternative and the effectiveness of the protective measures utilized to manage those short-term risks.

Implementation Risks

Implementation risks are assumed to be equivalent to the metric On-site and Off-site Risks from Implementation discussed in Section 11.2.5.1.

Effectiveness of Protective Measures to Manage Short-term Risks

The second criterion rates the effectiveness of protective measures such as institutional controls and best management practices that would be used to mitigate the risks associated with the remedial alternatives during construction.

For this analysis, it is assumed that the same types of protective measures are used for all alternatives; therefore, the effectiveness of these protective measures is proportional to the construction time frame of the remedial alternative. The alternatives with the shortest construction time frame ranked the highest and those with the longest construction time frames ranked the lowest.

The construction time frames and relative rankings of the alternatives are shown in Table 11-7. Alternatives rate progressively lower from Alternatives 2 through 6 and rate lower for removal alternatives than for combined alternatives.

11.5.2.5 Technical and Administrative Implementability

Implementability has several criteria, including technical feasibility; availability of necessary off-site facilities, services, and materials; administrative and regulatory

requirements; scheduling, size, and complexity; monitoring requirements; access for construction and operations and maintenance monitoring; and integration with existing facility operations and other remedial actions. Each criteria has its own metric and ranking. The metrics selected for scoring these aspects of implementation were developed elsewhere in the disproportionate cost analysis (DCA) or were based on best professional judgment. For clarity, the evaluation criteria number from Table 11-7 is listed beside each metric.

- **Technical feasibility (Evaluation Criteria 5a), and scheduling size, and complexity (Evaluation Criteria 5d):** the scale of cleanup is assumed to be proportional to the amount of material handled. This metric is developed and scored in the same manner as described in Section 11.5.2.1 (Evaluation Criteria 1c – On-site and off-site risks from implementation). Although all alternatives are considered technically feasible, the degree of technical challenge for each alternative is roughly proportional to the amount of material handled. Additional technical challenges associated with treatment (Alternative 5R-Treatment) and CAD (Alternative 2R-CAD) are accounted for in this metric because treatment requires double handling of 50% of dredged sediment, and construction of CAD cells requires significant sediment removal.

- **Availability of necessary off-site facilities, services and materials; access for construction operations and monitoring (Evaluation Criteria 5b);** and **integration with existing facility operations and other remedial actions Evaluation Criteria 5g):** all alternatives are assumed to have access to necessary off-site resources, and to integrate with current LDW operations, but the degree to which these resources are used by remedial activities is proportional to construction time frame. Therefore, the remedial alternatives score is proportional to its construction time frame. This metric is developed in the same manner as described in Section 11.5.2.4 (Evaluation Criteria 4b – effectiveness of protective measures to measure short term risk).

- **Administrative and regulatory requirements (Evaluation Criteria 5c):** are scored using best professional judgment. Alternatives 2R-CAD, 5R-Treatment, and 6R are rated lowest because they are considered more challenging to implement; Alternative 2R-CAD because of the difficulty of placing contaminated sediment into CADs; Alternative 5R-Treatment because of the difficulty of treating and reusing contaminated sediment; and Alternative 6R because of the very large scope of remediation. Alternatives 4R, 5R, and 6C are rated in the middle because of the relatively large scope of cleanup, and Alternatives 2R, 3C, 3R, 4C, and 5C score higher (score 8, 8, 7, 7, and 6 respectively) because of the relatively smaller scope of cleanup.

- **Monitoring requirements (Evaluation Criteria 5e):** requirements are assumed to be proportional to the surface area remediated by capping, ENR, MNR, and VM. This metric is developed and scored in the same manner as described in Section 11.5.2.3 (Evaluation Criteria 3d – reliability of Institutional controls and engineering controls used to manage risk).
- **Access for construction operations and monitoring (Evaluation Criteria 5f):** access is assumed to be available for all remedial alternatives and used in proportional to the restoration time frame. This metric is developed and scored in the same manner as described in Section 11.5.2.1 (Evaluation Criteria 1b – time required to reduce risk).

The volumes, areas, times, and relative rankings of the alternatives are shown in Table 11-7. Because technical and administrative implementability is the average of multiple aspects that can score opposite to one another (e.g., alternatives that score high in technical feasibility score low in monitoring requirements, and vice versa), all alternatives score fairly similarly to one another for this criterion, except for Alternative 6R (which scores lower). In general, the average score for technical and administrative implementability is lower for alternatives with more removal and longer time frames (the removal alternatives and the alternatives with larger active footprints), and higher for alternatives with less sediment removal and shorter time frames (the combined alternatives and the alternatives with smaller active footprints).

11.5.2.6 Consideration of Public Concerns

The public involvement process under MTCA and CERCLA is used to identify public preferences and concerns regarding the remedial alternatives. This includes concerns raised by individuals, community groups, local governments, local businesses, tribes, federal and state agencies, and other organizations that may have an interest in or knowledge of the site. The extent to which an alternative addresses the concerns identified by the public is considered as part of the remedy selection process that occurs after the FS is completed.

Issuance of this FS and of the Proposed Plan will provide an opportunity for identifying public comments, concerns, and feedback. This criterion will ultimately be evaluated by EPA and Ecology in the selection of the preferred alternative with the issuance of the final decision document. Therefore, this criterion is not used within the DCA evaluation.

11.5.2.7 Costs

Estimated costs to implement the remedial alternatives are presented in Appendix I. These cost estimates and their associated total weighted benefits can be used by the agencies to determine whether a remedial alternative's costs are disproportionate to the benefits provided by the alternative. The costs are presented in Tables 11-3 and 11-6 and are shown with the total benefits ratings on Figures 11-1 through 11-4.

11.5.3 Relative Benefits and Costs for Treatment Technology

By comparing Alternative 5R with Alternative 5R-Treatment, a direct comparison of upland landfill disposal and soil washing treatment can be made. A review of the scoring of the two alternatives shows that Alternative 5R scores slightly higher for benefit and is slightly lower in cost, indicating that soil washing treatment benefits may be disproportionate to costs.

For informational purposes, the estimated additional cost associated with adding soil washing treatment to all alternatives is shown in Table 11-8.

11.5.4 Summary of DCA Results

Table 11-6 summarizes the DCA and calculated cost/benefit ratios for Alternatives 2 through 6. Considering all of the rating criteria, the total benefit scores for the remedial alternatives range from 4.8 to 6.4. This narrow range is attributable primarily to two key factors: 1) the predicted outcomes are similar for all alternatives; and 2) differences between the alternatives for individual criteria are diminished when those criteria are averaged to calculate total benefit. The results demonstrate the fundamental difference between the alternatives. More dredging has other effects that do not result in higher overall scores. More reliance on isolation has other benefits that result in higher scores.

Weighted benefits that differ by small amounts should be considered equivalent because of the degree to which best professional judgment plays a role in the analysis. Small differences in the total weighted benefits can be attributed to issues of judgment both in the weighting of the importance of the various evaluation criteria, and the assigned scoring under each criterion.

A series of figures are provided that interpret the results of the DCA. Figure 11-1 shows the weighted benefit score for each alternative with an overlay of cost. The weighted benefits for the alternatives range from approximately 4.8 to 6.4, indicating that the more expensive alternatives do not necessarily show proportional increases in overall benefit.

Figure 11-2 plots benefits versus the cost for the alternatives. This graphic shows the same benefit rankings as Figure 11-1, but provides a visual representation of the spread of costs. This figure also indicates that added cost does not translate to proportional overall benefits.

Figure 11-3 shows the benefit per unit cost for the alternatives, and demonstrates a general trend for declining cost/benefit ratio as the alternative's costs increase. This is expected because all alternatives score similarly in benefit regardless of cost. The combined technology alternatives have slightly greater benefit per unit cost than similarly priced removal-emphasis alternatives. Alternative 3C provides the greatest overall benefit per dollar spent.

Figure 11-4 plots benefits versus the cost for the alternatives, similar to Figure 11-3, but normalizes the benefits and costs from the lowest to the highest of the remedial alternatives on a scale from 1 to 10. For example, the least expensive alternative, Alternative 2R-CAD ($210 million), are shown as a 0, and the most expensive alternative, Alternative 6R ($1,300 million), is shown as a 1. The other alternatives are plotted on the same 1 to 10 scale. One may expect that the remedial alternatives would follow the trend of increased benefit per increased cost. However, this figure shows that the benefit and cost relationship between the remedial alternatives does not follow the trend of increased benefit per unit cost.

The analysis presented in this section is intended to support Ecology in its evaluation of the remedial alternatives relative to MTCA. Figures 11-1 through 11-4 provide various approaches to identify where costs may be disproportionate to benefits. The final identification of the remedial alternative that uses "permanent solutions to the maximum extent practicable" will be made by EPA and Ecology after the FS is finalized and after the agencies consider public comments.

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Table 11-1 Schematic of the MTCA Remedy Selection Process

MTCA Minimum Requirements for Cleanup Actions (WAC 173-340-360(2)	MTCA Cleanup Regulation	Description and Applicability	Evaluation Procedure
Threshold Requirements			Alternatives are initially screened against "threshold requirements"
Protect human health and the environment	WAC 173-340-360(2)(a)(i)	Threshold requirements are the initial screening of remedial alternatives. Threshold requirements are addressed in Section 11.3.	
Comply with cleanup standards	WAC 173-340-360(2)(a)(ii)		
Comply with applicable state and federal laws	WAC 173-340-360(2)(a)(iii)		
Provide for compliance monitoring	WAC 173-340-360(2)(a)(iv)		
Other Requirements (except using permanent solutions to the maximum extent practicable, which is evaluated last)			Alternatives are screened against the additional "minimum requirements"
Provide for a reasonable restoration time frame	WAC 173-340-360(2)(b)(ii)	Remedial alternatives are screened for reasonable restoration time frame in addressed in Section 11.4.	
Consider public concerns	WAC 173-340-360(2)(b)(iii)	Considerations of public concerns are included in the MTCA process and are not addressed in a separate part of Section 11. The FS will be open to public comment for a period following publication, and public concerns will be incorporated into the final decision documents.	
Additional Minimum Requirements			
Groundwater cleanup actions	WAC 173-340-360(2)(c)	Not applicable to the FS.	
Soil at residential areas, schools, and child care centers	WAC 173-340-360(2)(d)		
Institutional controls	WAC 173-340-360(2)(e)	These additional minimum requirements serve to screen remedial alternatives and are addressed in Sections 11.2.3 through 11.2.5.	
Releases and migration	WAC 173-340-360(2)(f)		
Dilution and dispersion	WAC 173-340-360(2)(g)		
Remediation levels	WAC 173-340-360(2)(h)		
Additional Other Requirement (DCA) (evaluated last)			Alternatives that pass other "minimum requirements" are compared using the DCA.
Use of permanent solutions to the maximum extent practicable – disproportionate cost analysis (DCA)	WAC 173-340-360(2)(b)(i)	The DCA provides a tool for the comparison of alternatives that pass the other "minimum requirements," and is addressed in Section 11.5.	

Notes:

DCA = disproportionate cost analysis; FS = feasibility study; MTCA = Model Toxics Control Act; WAC = Washington Administrative Code.

Table 11-2 Cross Reference of MTCA Threshold and Other Minimum Requirements to Sections of the FS

MTCA Minimum Requirements for Remedial Alternatives (WAC 173-340-360(2))	MTCA Evaluation Factors	FS Section in Which Requirement is Evaluated
Threshold Requirements (WAC 173-340-360 (2)(a))		
i. Protect human health and the environment WAC 173-340-360(3(f)(i)	• Degree to which existing risks are reduced • Time required to reduce risks and achieve cleanup standards • On-site and off-site risks from implementing alternative • Improvement in overall environmental quality	• Alternatives are evaluated in Section 11.3 • Tables 9-2 through 9-6 and alternative summary tables and figures in Section 9 provide the predicted numerical reductions in risk-driver concentrations for each alternative over time. • Section 9 contains evaluations of on-site and off-site risks, as well as time to achieve RAOs
ii. Comply with cleanup standards WAC 173-340-760	• Remediation levels (WAC 173-340-355) • No significant health risk to humans (site specific) (173-340-320 (4)) SMS criteria: • Cleanup objective 173-204-570 (2) • No adverse effects on biological resources (173-204-320 (2)) • Minimum Cleanup Level (173-204-570(3))	• Alternatives are evaluated in Section 11.3 • RAOs and PRGs are presented and discussed in Section 4. • RALs developed in Section 6 are used to develop alternatives in Section 8. • Section 11.2 discusses MTCA cleanup standards, and remediation levels compared to PRGs and RALs.
iii. Comply with applicable state and federal laws. WAC 173-340-710	• ARARs	• Alternatives are evaluated in Section 11.3 • ARARs are discussed in Section 9.1.1.2
iv. Provide for compliance monitoring WAC 173-340-410 and 173-340-760	• Protection Monitoring • Performance Monitoring • Confirmational Monitoring	• Alternatives are evaluated in Section 11.3 • Conceptual monitoring scope is developed in detail in Appendix K for costing purposes, and discussed in Section 8 for each remedial alternative.

Table 11-2 Cross Reference of MTCA Threshold and Other Minimum Requirements to Sections of the FS

MTCA Minimum Requirements for Remedial Alternatives (WAC 173-340-360(2))	MTCA Evaluation Factors	FS Section in Which Requirement is Evaluated
Other Requirements (WAC 173-340-360(2)(b)		
i. Use permanent solutions to the maximum extent practicable	• Disproportionate Cost Analysis 173-340-360(3)(e)	• Discussed in Section 11.6 "Practicability" determined through the Disproportionate Cost Analysis (DCA).
ii. Provide for a reasonable restoration time frame	• 173-340-360(4)(b) • Potential risks posed by the site • Practicability of achieving a shorter restoration time frame • Uses & resources that are or may be affected by releases from the site • Effectiveness & reliability of institutional controls • Ability to control and monitor migration • Toxicity of the hazardous substances at the site • Natural processes that reduce concentration and have been documented to occur at the site or under similar site conditions	• Restoration time frame is evaluated in Section 11.4 • Potential baseline site risks are summarized in Section 3. • Restoration time frames are discussed in Section 9 and presented in Table 11-3. • The potential for elevated fish and shellfish tissue concentrations during and following construction activities is discussed in "Short-term Effectiveness" headings for each alternative in Section 9. • Institutional controls, monitoring, and adaptive management are discussed in detail in Appendix K and Section 7, and discussed in Section 8 for each alternative • Time to achieve RAOs for alternatives that rely on MNR under "Long-term Effectiveness" headings for each alternative in Section 9. The BCM (Section 5) is used to predict recovery potential.
iii. Consider public concerns	• Consideration of public concerns is part of the FS process and will be formally evaluated during development of the final decision document.	• Discussed in Section 9.1.3

Notes:

ARAR = applicable or relevant and appropriate requirements; DCA = disproportionate cost analysis; MNR = monitored natural recovery; MTCA = Model Toxics Control Act; PRG = preliminary remediation goal; RAL = remedial action levels; RAO = remedial action objectives; SQS = sediment quality standards; STM = sediment transport model; WAC = Washington Administrative Code

Table 11-3 Compliance with Minimum Requirements

	Analysis Parameters			Remedial Alternative											
				1	2R	2R-CAD	3C	3R	4C	4R	5C	5R	5R-T	6C	6R
Threshold Requirements	Protect human health and the environment, and compliance with cleanup standards														
	Risk Pathway Category		Preliminary Cleanup Standard [a]	Compliance											
	Human Health	RAO 1: Human Health – Seafood Consumption	Preliminary CULs = PRGs (possible adjustment upward due to natural background calculation) with a POC of the upper 10 cm of sediment site-wide	Not achieved	PRGs are not achieved for any alternative; however, the RAO is achieved through a combination of active remediation, natural recovery, and institutional controls. See Section 9.										
	Human Health	RAO 2: Human Health – Direct Contact	Preliminary CULs = PRGs (except 11 mg/kg dw for arsenic[b]) with a POC of the upper 45 cm of sediment in beaches and potential clamming areas, and upper 10 cm of sediment site-wide	Not achieved	Predicted to achieve within 15 years following the beginning of construction based on BCM predictions in Table 9-2a [c]		Predicted to achieve following construction completion [a]								
	Environment	RAO 3: Ecological Health – Benthic	Preliminary CULS = PRGs (SQS) with a POC upper 10 cm of sediment site-wide	Not achieved	Predicted to achieve SQS within 10 years following construction, based on BCM predictions in Table 9-2b		Predicted to achieve SQS within 5 years following construction, based on BCM predictions in Table 9-2b		Predicted to achieve SQS immediately following construction, based on BCM predictions in Table 9-2b						
	Environment	RAO4: Ecological Health – Seafood Consumption – River Otter	Preliminary CULS = PRGs with a POC upper 10 cm of sediment site-wide	Not achieved	Predicted to achieve immediately following construction based on BCM predictions in Table 9-6b										
	Compliance with applicable local, state and federal laws			Not achieved	Complies with all applicable local, state, and federal laws; see Section 9 for discussion.										
	Provide for compliance monitoring			Not achieved	Conceptual monitoring plan for Remedial Alternatives 2 through 6 is provided in Appendix K.										
	Achieves threshold requirements?			No	Yes										
Other Requirements	*Restoration Time Frames (RTF – years)* [d]														
	Duration of construction period			n/a	4	4	4	6	7	13	8	19	19	18	38
	Implementation period from issuance of the final decision document (construction period plus 5 yrs)				9	9	9	11	12	18	13	24	24	23	43
	RAO 1	Predicted years to complete construction and implement institutional controls [e]			9	9	9	11	12	18	13	24	24	23	43
	RAO 2	Predicted years to achieve cumulative risk $\leq 1 \times 10^{-5}$ (all exposure scenarios) [f]			10	10	10	10	10	10	10	10	10	10	10
	RAO 3	Predicted years to achieve >98% of area remediated to <SQS [g]			19	19	14	16	12	15	12	15	15	12	15
	RAO 4	Predicted years to reach ecological HQ<1 for all scenarios [h]			9	9	9	11	12	18	13	24	24	23	43
	Additional risk reduction (RAO 1)	Time for risk drivers to reach modeled long-term concentration range in surface sediment, which provides nominal incremental risk reduction			24	24	24	26	22	18	18	24	24	23	43
	Consideration of public concerns			n/a	Determined during development of final decision document										
Additional Minimum Requirements	*Groundwater cleanup actions*			n/a	Not applicable to FS										
	Soil at residential areas, schools, and child care centers				Not applicable to FS										
	Institutional controls				Achieved										
	Releases and migration				Achieved										
	Dilution and dispersion				Achieved										
	Remediation levels				Achieved										
DCA	Weighted Benefit Points (score from Table 11-6) [i]			n/a	6.1	5.7	6.2	6.2	6.4	6.3	6.4	6.3	5.9	5.6	4.8
	Cost ($millions net present value)				230	210	220	290	290	440	310	550	600	650	1,300
	Benefit points/cost ($billions)				27	27	28	21	22	14	21	12	10	9	4

Notes:

a Preliminary cleanup levels are considered to be equivalent with PRGs with the exception of those based on natural background, as discussed in Section 11.2.

b A value of 11 mg/kg dw was calculated as the 90th percentile of the EPA OSV *Bold* survey dataset using ProUCL. Using MTCAStat, the 90th percentile of the EPA OSV Bold survey dataset is 12 mg/kg dw

c Achieves cumulative direct contact risk of 1×10^{-5} for all scenarios. PCBs and dioxins/furans achieve direct contact excess cancer risk of 10^{-6} for all scenarios. Arsenic achieves MTCA background concentrations. cPAH exceed 1×10^{-6} for Beach 3 due to lateral loads.

d Estimated RTF is time from the issuance of the final decision documents; 5 years are added to the construction time to estimate the time to complete the EAAs, baseline monitoring, and remedial design.

e Two time frames are considered for RAO 1. First is the remedial alternative's implementation time, at which point all alternatives reduce the Adult Tribal RME seafood consumption risk to the lowest risk magnitude (10) achievable in the long term. The multi-layered program of monitoring and ICs (advisories, outreach, and education) is required at this point for all alternatives to further reduce seafood consumption exposures (see Section 10.2.1.2). The second time component is the predicted time for risk-driver concentrations to achieve long-term modeled concentration ranges. The food web model relationship between sediment and fish tissue concentrations is assumed to not apply during construction. Fish tissue concentrations are assumed to remain elevated as a result of resuspension and release of total PCBs into the water column. None of the alternatives reduce the human non-cancer seafood consumption HQ to less than 1.

f Alternatives 3C and 3R specifically address direct contact risks and achieve a cumulative direct contact risk of $\leq 1 \times 10^{-5}$ for all exposure scenarios. It is assumed that the Alternative 3 actions occur in the first 5 years of Alternatives 4, 5, and 6, and therefore the same rounded time frame to achieve RAO 2 (10 years) is applied to Alternatives 3 through 6. Alternative 2 does not specifically address direct contact risks through active remediation. However, surface sediments in potential clamming and assumed beach play areas are expected to recover naturally over time.

g The RAO 3 RTF is assumed to range between when the MCUL is met (<1 acre associated with remaining point exceedances) and when remaining SQS points correspond to fewer than 2% of the LDW surface area. Within this range, conditions are reached when it is no longer technically practicable to manage isolated point exceedances with any certainty of a net environmental benefit.

h RTF for RAO 4 is based on the longer of: 1) wildlife seafood consumption non-cancer risks to HQ <1 based on the site-wide total PCB SWAC, and 2) end of construction. The food web model relationship between sediment and fish tissue concentrations is assumed not to apply during construction. Fish tissue concentrations are assumed to remain elevated above equilibrium values as a result of and release of total PCBs into the water column.

I Weighted benefit points are based on Table 11-7.

C = combined technology alternatives; CUL = cleanup level; HQ = hazard quotient; MCUL = minimum cleanup level; MTCA = Model Toxics Control Act; n/a = not applicable; POC = point of compliance; PRGs = preliminary remediation goals; R = removal-emphasis alternatives with upland disposal; RAO = remedial action objective; R-CAD = removal-emphasis alternative with contained aquatic disposal; RME = reasonable maximum exposure; R-T = removal-emphasis alternative with soil washing; RTF = restoration time frame; SMS = sediment management standards; SQS = sediment quality standards; TBD = to be determined

Table 11-4 MTCA Cleanup Levels and Preliminary Remediation Goals for Total PCBs, Arsenic, cPAH, and Dioxins/ Furans

Analyte	Spatial Scale of Exposure [a]	MTCA Sediment Cleanup Levels and Preliminary Remediation Goals for LDW			
		Value	Basis	Statistical Metric[b]	Spatial Scale
Total PCBs (µg/kg dw)	Site-wide	2 (RAO 1)	bg[c]	SWAC	Site-wide
		3 (RAO 1)	MTCA bg[d]		
		1,300 (RAO 2)	10^{-6} RBTC		
		128 – 159 (RAO 4)[e]	HQ <1		
	Tribal Clamming	500	10^{-6} RBTC	SWAC	Clamming Areas
	Beach Play	1,700	10^{-6} RBTC	SWAC	Individual Beaches
	Point	12 (mg/kg oc) (RAO 3)	RBTC (SMS)	Point Concentration or Toxicity Test Pass	Point
Arsenic (mg/kg dw)	Site-wide[f]	7 (RAO 2)	bg [c]	SWAC	Site-wide
		11 (RAO 2)	MTCA bg[d]		
	Tribal Clamming	7 (RAO 2)	bg [d]	SWAC	Clamming Areas
		11 (RAO 2)	MTCA bg [d]		
	Beach Play	7 (RAO 2)	bg [c]	SWAC	Individual Beaches
		11 (RAO 2)	MTCA bg [d]		
	Point	57 (RAO 3)	RBTC (SMS)	Point Concentration or Toxicity Test Pass	Point
cPAHs (µg TEQ/kg dw)	Site-wide[f]	380 (RAO 2) [c]	10^{-6} RBTC	SWAC	Site-wide
	Tribal Clamming	150	10^{-6} RBTC	SWAC	Clamming Areas
	Beach Play	90	10^{-6} RBTC	SWAC	Individual Beaches
		140	MTCA Method B		
	Point	n/a [g]	n/a	n/a	n/a
Dioxins/Furans (ng TEQ/kg dw)	Site-wide	2 (RAO 1)	bg [c]	SWAC	Site-wide
		2 (RAO 1)	MTCA bg [d]		
		37 (RAO 2)	10^{-6} RBTC		
	Tribal Clamming	13	10^{-6} RBTC	SWAC	Clamming Areas
	Beach Play	28	10^{-6} RBTC	SWAC	Individual Beaches
	Point	n/a	n/a	n/a	n/a

Notes:

a The spatial scale of site-wide exposure is RAO-specific: seafood consumption for RAO 1 and RAO 4; netfishing for RAO 2.

b Predicted SWAC is compared to the cleanup levels in this analysis, However, in practice, compliance under MTCA would include additional criteria specified in 173-340-740(7)(d)(i)(B), such as the comparison of spatially-weighted UCLs to the cleanup levels and the allowance of a maximum point concentration to 2 times the cleanup level.

c Natural background values are 95 UCL of the mean value from the 2008 EPA OSV *Bold* survey dataset using ProUCL.

d MTCA natural background values are 90th percentile values from the 2008 EPA OSV *Bold* survey dataset using ProUCL. Using MTCAStat, the 90th percentile values would be 12 mg/kg dw for arsenic, 2 µg/kg dw for total PCBs, and 3 ng TEQ/kg dw for dioxins/furans.

e Values represent best-fit estimates for two different dietary scenarios as reported in the RI (Windward 2010). No value calculated for other receptors (i.e., fish and sandpiper).

f Arsenic and cPAH PRGs are undefined for the human health seafood consumption pathway (RAO 1). Unacceptable seafood consumption excess cancer risks for these two risk drivers were based on the consumption of clams. There is no credible relationship, based on site data, relating cPAH or arsenic concentrations in sediment to concentrations in clam tissue (Section 8 of the RI, Windward 2010).

g Low- and high-molecular weight PAHs are addressed by the SMS. Criteria are set for both groupings and for individual compounds.

bg = natural background; cPAH = carcinogenic polycyclic aromatic hydrocarbon; CSL = cleanup screening level; dw = dry weight; LDW = Lower Duwamish Waterway; kg = kilogram; µg = micrograms; mg = milligrams; n/a = not applicable; ng = nanograms; oc = organic carbon; PAH = polycyclic aromatic hydrocarbon; PCB = polychlorinated biphenyl; PRG = preliminary remediation goal; RAO = remedial action objective; RBTC = risk-based threshold concentration; SMS = Sediment Management Standards; SQS = sediment quality standard; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent; UCL = upper confidence limit on the mean.

Table 11-5 Framework and Weighting of Factors in the MTCA Disproportionate Cost Analysis

Evaluation Criterion and WAC Citation	Benefit Weighting Percentages and Rationale	Rating Metrics Used
Protectiveness: WAC 173-340-360(3)(f)(i)	30%: Protectiveness has a high weighting because it represents the ultimate goal of the cleanup.	• Reduction in LDW-wide residual risk. • Time required to reduce risk from the issuance of the final decision document. • On-site and off-site risks from alternative implementation. • Improvement of overall environmental quality (not used).
Permanence WAC 173-340-360(3)(f)(ii)	20%: Permanence receives a relatively high weighting value because it addresses the degree to which the remedial alternatives reduce exposure potential in the LDW.	• Volume of sediment removed from the LDW. • Amount of contaminants immobilized.
Effectiveness over the long term: WAC 173-340-360(3)(f)(iv)	20%: This category receives a relatively high weighting value because it addresses how well the remedy reduces risks and whether controls are adequate to maintain protection against exposures to contamination left in place in the long term.	• Degree of certainty in success of the alternatives • Reliability of the alternative during the period in which contaminants remain higher than cleanup levels. • Magnitude of residual risks • Reliability of institutional and engineering controls. • Hierarchy of cleanup and disposal methods.
Management of short-term risk: WAC 173-340-360(3)(f)(v)	15%: This category receives a relatively low weighting value because impacts to both human health and the environment are predictable and manageable. However, these risks are of significant magnitude for remedial alternatives that extend over long durations.	• Implementation risks (to the community, workers, environment). • Effectiveness of protective measures used to manage risks.
Technical and administrative implementability: WAC 173-340-360(3)(f)(vi)	15%: This category receives a relatively low weighting value because it is not directly related to the goals of the environmental cleanup. Further, the alternatives are all considered to be implementable.	• Degree of technical complexity (access, size, availability of materials) and administrative (legal, regulatory, and monitoring) requirements
Consideration of Public Concerns: WAC 173-340-360(3)(f)(vii)	n/a	• Public concerns will be evaluated in the final decision document.
Costs (see Appendix I): WAC 173-340-360(3)(f)(iii)	This criterion is used to compare against the benefits for the disproportionate cost analysis.	• Net present value; see Appendix I.

Notes:

CAP = corrective action plan; ROD = record of decision; SMA = sediment management area

Table 11-6 Summary of Disproportionate Cost Analysis – Alternative Benefits Scores

	Evaluation Criteria	Remedial Alternatives and Scores[a]										
		2R	2R–CAD	3C	3R	4C	4R	5C	5R	5R– T	6C	6R
1	**Protectiveness – total weighting factor: 30%[b]**	**8.1**	**7.8**	**8.1**	**7.9**	**7.8**	**7.4**	**7.7**	**6.8**	**6.3**	**6.2**	**4.1**
1a	Degree to which existing risks are reduced	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	7.9	7.9
1b	Time required to reduce risk	7.7	7.7	8.0	7.6	7.9	7.3	8.0	6.4	6.4	6.7	3.6
1c	On-site and off-site risks from implementation	8.5	7.7	8.3	7.9	7.5	6.8	7.2	5.9	4.4	4.2	0.6
1d	Improvement of the overall environmental quality	8.3	7.9	8.2	8.0	7.8	7.4	7.6	7.0	6.2	6.1	4.3
2	Permanence – total weighting factor: 20%[b]	2.9	2.4	3.2	3.6	4.4	5.3	4.7	6.5	6.5	6.3	9.5
2a	Reduction in volume of contaminated sediment	1.6	0.8	1.4	2.0	1.9	3.0	1.9	3.8	3.8	4.3	9.0
2b	Reduction in mobility of contaminants	4.2	4.0	4.9	5.2	6.8	7.5	7.5	9.2	9.2	8.3	9.9
2c	Reduction in toxicity, adequacy of alternative in destroying hazardous substances, reduction or elimination of hazardous substance releases and sources or releases, the degree of irreversibility of waste treatment processes, and the characteristics and quantity of treatment residuals generated – MTCA criteria not used											
3	Effectiveness Over the Long Term – total weighting factor: 20%[b]	3.4	3.3	3.7	3.9	4.5	5.0	4.8	5.9	6.2	5.1	6.2
3a	Degree of certainty that remedy will be successful	4.0	4.0	4.7	4.9	6.5	6.9	7.2	8.4	8.4	7.9	9.0
3b	Reliability of the alternatives during the time that sediment above PRGs remain on site	4.0	4.0	4.7	4.9	6.5	6.9	7.2	8.4	8.4	7.9	9.0
3c	Magnitude of residual risk	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	7.9	7.9
3d	Reliability of ICs and engineering controls used to manage risk	0.8	0.1	0.9	1.5	1.5	3.0	1.6	4.1	4.1	1.9	4.6
3e	Hierarchy of cleanup and disposal technologies used	3.6	3.4	3.9	4.2	4.7	5.4	4.8	6.4	8.3	5.2	6.8
4	Management of Short-term Risk – total weighting factor: 15%[b]	8.8	8.4	8.7	8.2	7.9	6.8	7.6	5.6	4.9	4.9	0.6
4a	Implementation risks	8.5	7.7	8.3	7.9	7.5	6.8	7.2	5.9	4.4	4.2	0.6
4b	Effectiveness of protective measures to manage short-term risks	9.0	9.0	9.0	8.5	8.3	6.8	8.0	5.3	5.3	5.5	0.5
5	Technical and Administrative Implementability – total weighting factor: 15%[b]	7.5	6.2	7.5	7.2	7.1	6.5	6.8	6.0	5.1	5.0	2.4
5a	Technical feasibility	8.5	7.7	8.3	7.9	7.5	6.8	7.2	5.9	4.4	4.2	0.6
5b	Availability of necessary off-site facilities, services and materials	9.0	9.0	9.0	8.5	8.3	6.8	8.0	5.3	5.3	5.5	0.5
5c	Administrative and regulatory requirements	8.0	2.0	8.0	7.0	7.0	5.0	6.0	5.0	2.0	5.0	2.0
5d	Scheduling, size, and complexity	8.5	7.7	8.3	7.9	7.5	6.8	7.2	5.9	4.4	4.2	0.6
5e	Monitoring requirements	1.6	0.2	1.7	3.0	2.9	5.9	3.1	8.2	8.2	3.7	9.1
5f	Access for construction operations and monitoring	7.7	7.7	8.0	7.6	7.9	7.3	8.0	6.4	6.4	6.7	3.6
5g	Integration with existing facility operations and other remedial actions	9.0	9.0	9.0	8.5	8.3	6.8	8.0	5.3	5.3	5.5	0.5
6	Consideration of Public Concerns (not factored into the cost benefit analysis) – to be decided in the final decision documents											
7	Total Weighted Benefits	6.1	5.7	6.2	6.2	6.4	6.3	6.4	6.3	5.9	5.6	4.8
8	Cost ($millions)	230	210	220	290	290	440	310	550	600	650	1300
9	Benefit/cost (Benefit /$billions)	27	27	28	21	22	14	21	11	10	9	4

Notes:

a A score of 0 represents the lowest benefit, or a poor performing alternative for the given metric. A score of 10 represents the highest benefit, or an excellent performing alternative for the given metric. Scores of 0 and 10 do not represent the lowest and highest alternatives in the suite of alternatives, but represent the high and low values shown in the Scale of Benefit columns on Table 11-7. The alternatives are scored on a linear scale between these end points.

b Categorical ratings for each alternative are averaged scores from each of the subcriteria listed underneath the shaded headings.

AOPC = area of potential concern; BPJ = best professional judgement; C = combined technology; cy = cubic yards; EAA = early action area; ENR = enhanced natural recovery; ICs = institutional controls; MNR = monitored natural recovery; MTCA = Model Toxics Control Act; R = removal focused; RAO = remedial action objective; R-CAD = removal-emphasis alternative with contained aquatic disposal; R-T = removal-emphasis alternative with treatment (soil washing)

Table 11-7 Disproportionate Cost Analysis – Alternative Benefits Metrics and Scores

MTCA Evaluation Criteria			Units	Scale of Benefit (Scoring Basis)[a] Score 0	Score 10	Remedial Alternatives and Scores[b] 2R	2R-CAD	3C	3R	4C	4R	5C	5R	5R-T	6C	6R
1	Protectiveness – total weighting factor: 30%		Benefit	Average score of 1a, 1b, 1c, 1d		8.1	7.8	8.1	7.9	7.8	7.4	7.7	6.8	6.3	6.2	4.1
1a	Degree to which existing risks are reduced	Average benefit score of all RAOs weighted equally	benefit	Average score of RAOs		8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	7.9	7.9
	RAO 1[c,d]	Excess residual cancer risk from total PCBs – Adult Tribal RME	benefit	9×10^{-4} (baseline)	1×10^{-5}	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
			risk at end of the model period			2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}
		Non-cancer risk (HQ) – Adult Tribal RME	benefit	24 (baseline)	1	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.3	1.3
			HQ at end of the model period			5	5	5	5	5	5	5	5	5	4	4
	RAO 2[e]	Residual Direct Contact Risk – Cumulative (for net fishing, clamming, and beach play scenarios)	benefit	1×10^{-4}	1×10^{-5} for all areas	10	10	10	10	10	10	10	10	10	10	10
			total risk at the end of the model period			$\leq 1 \times 10^{-5}$ for all areas	$\leq 1 \times 10^{-5}$ for all areas	$\leq 1 \times 10^{-5}$ for all areas	$\leq 1 \times 10^{-5}$ for all areas	$\leq 1 \times 10^{-5}$ for all areas	$\leq 1 \times 10^{-5}$ for all areas	$\leq 1 \times 10^{-5}$ for all areas	$\leq 1 \times 10^{-5}$ for all areas	$\leq 1 \times 10^{-5}$ for all areas	$\leq 1 \times 10^{-5}$ for all areas	$\leq 1 \times 10^{-5}$ for all areas
	RAO 3	SQS exceedances remediated as percentage of total FS surface sediment dataset stations (n=1,395; see Table 9-2b)	benefit	Approx. 65% (baseline)	98%	10	10	10	10	10	10	10	10	10	10	10
			% of points remediated 10 years after construction			98%	>98%	>98%	>98%	>98%	>98%	>98%	>98%	>98%	>98%	>98%
		LDW area associated with SQS exceedances as percent of total study area (441 acres; see Table 9-2b)	benefit	Approx. 65% (baseline)	98%	10	10	10	10	10	10	10	10	10	10	10
			% of area remediated 10 years after construction			>98%	>98%	>98%	>98%	>98%	>98%	>98%	>98%	>98%	>98%	>98%
	RAO 4	HQ for consumption of seafood (without juvenile fish) by the river otter	benefit	2 (baseline)	1	10	10	10	10	10	10	10	10	10	10	10
			HQ at the end of the model period			<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
1b	Time required to reduce risk[f]	Average benefit score of all RAOs weighted equally	benefit	Average score of RAOs and additional risk reduction		7.7	7.7	8.0	7.6	7.9	7.3	8.0	6.4	6.4	6.7	3.6
	RAO 1[g]	Years to complete construction and implement of institutional controls	benefit	45 years	5 years	9.0	9.0	9.0	8.5	8.3	6.8	8.0	5.3	5.3	5.5	0.5
			years from issuance of final decision documents			9	9	9	11	12	18	13	24	24	23	43
	RAO 2[h]	Years to achieve cumulative risk $\leq 1 \times 10^{-5}$ (all exposure scenarios)	benefit	45 years	5 years	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8
			years from issuance of final decision documents			10	10	10	10	10	10	10	10	10	10	10
	RAO 3[i]	Years to achieve >98% of area remediated to <SQS	benefit	45 years	5 years	6.5	6.5	7.8	7.3	8.3	7.5	8.3	7.5	7.5	8.3	7.5
			years from issuance of final decision documents			19	19	14	16	12	15	12	15	15	12	15
	RAO 4	Years to reach ecological HQ <1 for all scenarios	benefit	45 years	5 years	9.0	9.0	9.0	8.5	8.3	6.8	8.0	5.3	5.3	5.5	0.5
			years from issuance of final decision documents			9	9	9	11	12	18	13	24	24	23	43
	Additional risk reduction for RAO 1	Time for risk drivers to reach long-term model-predicted concentration ranges in surface sediment	benefit	45 years	5 years	5.3	5.3	5.3	4.8	5.8	6.8	6.8	5.3	5.3	5.5	0.5
			years from issuance of final decision documents			24	24	24	26	22	18	18	24	24	23	43
1c	On-site and off-site risks from implementation	Assume implementation risks are proportional to volume of material handled[j]	benefit	5 million cy	0 cy	8.5	7.7	8.3	7.9	7.5	6.8	7.2	5.9	4.4	4.2	0.6
	Total volume of material handled including dredging (base-case performance volume), CAD construction (2R–CAD) (0.37 MM cy), treatment (5R–T) (50% of performance volume), backfill, ENR, residuals management, and capping volume (total placement volume).		million cy			0.73	1.2	0.83	1.03	1.3	1.6	1.4	2.1	2.8	2.9	4.7
1d	Improvement of the overall environmental quality	Overall improvement is assumed to be proportional to risk reduction benefit minus implementation risks (average #1a and #1c above)	benefit	see #1a and #1c above		8.3	7.9	8.2	8.0	7.8	7.4	7.6	7.0	6.2	6.1	4.3

Table 11-7 Disproportionate Cost Analysis – Alternative Benefits Metrics and Scores

	MTCA Evaluation Criteria		Units	Scale of Benefit (Scoring Basis)[a] Score 0	Score 10	Remedial Alternatives and Scores[b] 2R	2R-CAD	3C	3R	4C	4R	5C	5R	5R-T	6C	6R
2	Permanence – total weighting factor: 20%		benefit	Average score of 2a, 2b		2.9	2.4	3.2	3.6	4.4	5.3	4.7	6.5	6.5	6.3	9.5
2a	Reduction in volume of contaminated sediment		benefit	0 cy	4 million cy	1.6	0.8	1.4	2.0	1.9	3.0	1.9	3.8	3.8	4.3	9.0
		Volume removed from LDW (base case performance volume estimate)[k]	million cy			0.62	0.31	0.57	0.79	0.74	1.20	0.77	1.50	1.50	1.70	3.60
2b	Reduction in mobility of contaminants	Immobility rating based on the weighted benefit of areas and type of technology applied in AOPC 1	benefit	score total of weighted average: (acres of technology) * (weighting) / (total acres (176 = AOPC 1))		4.2	4.0	4.9	5.2	6.8	7.5	7.5	9.2	9.2	8.3	9.9
		dredge	acres of AOPC 1	weighting: 10		27	3	29	52	51	103	54	145	145	64	160
		cap/ partial dredge and cap (Alternative 2R–CAD includes 24 acres of CAD area; that acreage is subtracted from the dredge area)	acres of AOPC 1	weighting: 9		3	27	19	5	48	11	53	12	12	65	16
		ENR	acres of AOPC 1	weighting: 5		0	0	9	0	15	0	50	0	0	47	0
		MNR and VM	acres of AOPC 1	weighting: 3		146	146	119	119	62	62	19	19	19	0	0
2c	Reduction in toxicity, adequacy of alternative in destroying hazardous substances, reduction or elimination of hazardous substance releases and sources or releases, the degree of irreversibility of waste treatment process, and the characteristics and quantity of treatment residuals generated – MTCA criteria not used															
3	Effectiveness Over the Long Term – total weighting factor: 20%		benefit	Average score of 3a, 3b, 3c, 3d, 3e		3.4	3.3	3.7	3.9	4.5	5.0	4.8	5.9	6.2	5.1	6.2
3a	Degree of certainty that remedy will be successful[l]	Degree of certainty rating based on weighted benefit of remedial technologies below	benefit	score total of weighted average: (acres of technology) * (weighting) / (total acres (176 = AOPC 1))		4.0	4.0	4.7	4.9	6.5	6.9	7.2	8.4	8.4	7.9	9.0
		dredge	acres of AOPC 1	weighting: 9		27	3	29	52	51	103	54	145	145	64	160
		cap/ partial dredge and cap (Alternative 2R–CAD includes 24 acres of CAD area; that acreage is subtracted from the dredge area)	acres of AOPC 1	weighting: 9		3	27	19	5	48	11	53	12	12	65	16
		ENR	acres of AOPC 1	weighting: 5		0	0	9	0	15	0	50	0	0	47	0
		MNR and VM	acres of AOPC 1	weighting: 3		146	146	119	119	62	62	19	19	19	0	0
3b	Reliability of the alternatives during the time that sediment above PRGs remain on site	Reliability rating based on weighted benefit of remedial technologies	benefit	see #3a above		4.0	4.0	4.7	4.9	6.5	6.9	7.2	8.4	8.4	7.9	9.0
3c	Magnitude of residual risk	Proportional to the degree to which existing risks are reduced (see #1a above)	benefit	see #1a above		8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	7.9	7.9
3d	Reliability of ICs and engineering controls used to manage risk	Assume that the reliability of controls is proportional to the degree to which they are used	benefit			0.8	0.1	0.9	1.5	1.5	3.0	1.6	4.1	4.1	1.9	4.6
	Seafood consumption advisory	Assume reliability is based on the degree of seafood advisories in effect	benefit	no	yes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			fish advisory remains in effect?			yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
	Reliability of O&M monitoring, relative amounts of maintenance required, relative monitoring and notification of waterway users	Assume reliability is inversely proportional to acres of caps, ENR, MNR, VM in AOPC 1. Alternative 2R–CAD includes 24 acres of CAD area	benefit	176 acres (AOPC 1)	0 acres	1.6	0.2	1.7	3.0	2.9	5.9	3.1	8.2	8.2	3.7	9.1
			acres of AOPC 1			149	173	147	124	125	73	122	31	31	112	16
3e	Hierarchy of cleanup and disposal technologies used	Weighted average of acres for each achieved (assume acres remediated is a proxy for volume remediated)	benefit	score total of weighted average: (acres of technology) * (weighting) / (total acres (176 = AOPC 1))		3.6	3.4	3.9	4.2	4.7	5.4	4.8	6.4	8.3	5.2	6.8
		Reuse and recycle (assume 25% of acres of dredging for Alternative 5RT is reused sediment)	acres of AOPC 1	weighting: 9		0	0	0	0	0	0	0	0	38	0	0
		Destruction and detoxification	acres of AOPC 1	weighting: n/a		0	0	0	0	0	0	0	0	0	0	0
		Immobilization and solidification	acres of AOPC 1	weighting: n/a		0	0	0	0	0	0	0	0	0	0	0
		On-site or off-site disposal (dredge)	acres of AOPC 1	weighting: 7		27	3	29	52	51	103	54	145	145	64	160
		On-site isolation or containment (cap + PDC) (Alternative 2R–CAD includes 24 acres of CAD area; that acreage is subtracted from the dredge area)	acres of AOPC 1	weighting: 5		3	27	19	5	48	11	53	12	12	65	16
		Institutional controls and monitoring (ENR, MNR, VM)	acres of AOPC 1	weighting: 3		146	146	128	119	77	62	69	19	19	47	0

Table 11-7 Disproportionate Cost Analysis – Alternative Benefits Metrics and Scores

	MTCA Evaluation Criteria		Units	Scale of Benefit (Scoring Basis)[a] Score 0	Score 10	Remedial Alternatives and Scores[b] 2R	2R-CAD	3C	3R	4C	4R	5C	5R	5R-T	6C	6R
4	Management of Short-term Risk – total weighting factor: 15%		benefit	Average score of 4a, 4b		8.8	8.4	8.7	8.2	7.9	6.8	7.6	5.6	4.9	4.9	0.6
4a	Implementation risks	Implementation risks are assumed to be equivalent to on-site and off-site risks due to implementation (see #1c above)	benefit	see #1c above		8.5	7.7	8.3	7.9	7.5	6.8	7.2	5.9	4.4	4.2	0.6
4b	Effectiveness of protective measures to manage short-term risks	Proportional to the construction time frame	benefit	40 years	0 years	9.0	9.0	9.0	8.5	8.3	6.8	8.0	5.3	5.3	5.5	0.5
		Construction time frame	years			4	4	4	6	7	13	8	19	19	18	38
5	Technical and Administrative Implementability – total weighting factor: 15%		benefit	Average score of 5a, 5b, 5c, 5d, 5e, 5f, 5g		7.5	6.2	7.5	7.2	7.1	6.5	6.8	6.0	5.1	5.0	2.4
5a	Technical feasibility	All alternatives are assumed be technically feasible. Treatment (5RT) is scored lower because of additional technical challenges.	benefit	see #1c above		8.5	7.7	8.3	7.9	7.5	6.8	7.2	5.9	4.4	4.2	0.6
5b	Availability of necessary off-site facilities, services and materials	Assume off-site resources are available; they are used in proportion to the construction time frame (see #4b above)	benefit	see #4b above		9.0	9.0	9.0	8.5	8.3	6.8	8.0	5.3	5.3	5.5	0.5
5c	Administrative and regulatory requirements	Evaluated using BPJ assuming that alternatives with longer construction time frames will have additional requirements, and CAD and treatment	benefit	BPJ		8.0	2.0	8.0	7.0	7.0	5.0	6.0	5.0	2.0	5.0	2.0
5d	Scheduling, size, and complexity	Assume size is proportional to removal and handling volume (see #1c above)	benefit	see #1c above		8.5	7.7	8.3	7.9	7.5	6.8	7.2	5.9	4.4	4.2	0.6
5e	Monitoring requirements	Assume monitoring is proportional to cap, ENR, and MNR area (see #3d above)	benefit	see #3d above		1.6	0.2	1.7	3.0	2.9	5.9	3.1	8.2	8.2	3.7	9.1
5f	Access for construction operations and monitoring	Assume access is available; and access is needed in proportion to the restoration time frame (see #1b above)	benefit	see #1b above		7.7	7.7	8.0	7.6	7.9	7.3	8.0	6.4	6.4	6.7	3.6
5g	Integration with existing facility operations and other remedial actions	Assume integration is possible, and integration challenges are in proportion to the construction time frame (see #4b above)	benefit	see #4b above		9.0	9.0	9.0	8.5	8.3	6.8	8.0	5.3	5.3	5.5	0.5
6	Consideration of Public Concerns	Not factored into the cost benefit analysis – TBD in the final decision documents														
7	Total Weighted Benefits					6.1	5.7	6.2	6.2	6.4	6.3	6.4	6.3	5.9	5.6	4.8
8	Cost ($millions)					230	210	220	290	290	440	310	550	600	650	1,300
9	Benefit/cost (Benefit /$billions)					27	27	28	21	22	14	21	11	10	9	4

Notes:

a A score of 0 represents the lowest benefit, or a poor performing alternative for the given metric. A score of 10 represents the highest benefit, or an excellent performing alternative for the given metric. Scores of 0 and 10 do not represent the lowest and highest alternatives in the suite of alternatives, but represent the high and low values shown in the Scale of Benefit columns. The alternatives are scored on a linear scale between these end points.

b Categorical ratings for each alternative are averaged scores from each of the subcriteria listed underneath the shaded headings.

c Risk estimate based on use of the total PCB SWAC (using base case [mid input values] BCM output) in the food web model. Total excess cancer risks (all carcinogens combined) are expected to be similar to total PCB risks for the consumption of resident fish and crab because most of the seafood consumption risk for these seafood types is from PCBs.

d See Table 9-6a for other RME risk scenarios and site-related risk reduction calculations.

e Base case (mid input values) BCM output used for cumulative (i.e., contributions of all four risk-driver chemicals) risk estimation. Cumulative risks lower than 1×10^{5} comply with one component of MTCA cleanup standards. Clamming risk is selected as baseline because it is the highest baseline risk of the direct contact scenarios.

f The estimated time frames to achieve RAOs start at the issuance of final remedy decision documents. Final remedy decision documents are estimated to precede the beginning of remedial construction by 5 years.

g Restoration time frame for RAO 1 is based on the longer of: 1) reducing seafood consumption risks to the 10^{4} risk magnitude based on the site-wide total PCB SWAC, and 2) end of construction. The food web model relationship between sediment and fish tissue concentrations is assumed not to apply during construction. Fish tissue concentrations are assumed to remain elevated above equilibrium values as a result of construction-stimulated releases of total PCBs into the water column.

h Alternatives 3C and 3R specifically address direct contact risks and attain a cumulative direct contact risk of $\leq 1 \times 10^{-5}$ for all exposure scenarios. It is assumed that the Alternative 3 actions occur in the first 5 years of Alternatives 4, 5, and 6 and therefore the same rounded time frame to achieve RAO 2 (10 years) is applied to Alternatives 3 through 6. Alternative 2 does not specifically address direct contact risks. However, surface sediments in potential clamming and assumed beach play areas are expected to recover because of remediation of sediment above the site-wide RALs and naturally over time.

i The RAO 3 restoration time frame is assumed to range between when the MCUL is achieved (<1 acre associated with remaining point exceedances) and when remaining SQS points correspond to fewer than 2% of the LDW surface area. Within this range, conditions are reached when it is no longer technically practicable to manage isolated point exceedances with any certainty of a net environmental benefit.

j On-site and off-site risks due to implementation include release of residual contamination into the water column during dredging, landfill usage, environmental impacts due to transportation of material and mining of sand, worker safety, greenhouse gas emissions, particulate emissions, and others such as landfill space and carbon footprint. For the purpose of this metric, the volume of material handled is used as a proxy for these risks.

k CAD volumes for Alternative 2R-CAD are assumed to remain in the LDW.

l The remediation of all risk-driver chemicals is subject to uncertainty. PCBs are used as a surrogate for uncertainty for all risk-driver chemicals. HHH stands for high lateral, bed replacement, and upstream values, MMM stands for mid lateral, bed replacement, and upstream values, and LLL stands for low lateral, bed replacement, and upstream values.

AOPC = area of potential concern; BCM = bed composition nodel; BPJ = best professional judgment; C = combined technology; CAD = contained aquatic disposal; cy = cubic yards; EAA = early action area; ENR = enhanced natural recovery; HQ = hazard quotient; ICs = institutional controls; MCUL = minimum cleanup level; MNR = monitored natural recovery; MTCA = Model Toxics Control Act; O&M = operations and maintenance; PDC = partial dredge and cap; PRGs = preliminary remediation goals; R = removal focused; RAO = remedial action objective; R-CAD = removal-emphasis alternative with contained aquatic disposal; RME = reasonable maximum exposure; R–T = removal-emphasis alternative with treatment (soil washing); SQS = sediment quality standard; SWAC = spatially-weighted average concentration; TBD = to be decided; VM = verification monitoring.

Table 11-8 Estimated Additional Costs for Soil Washing for All Remedial Alternatives

Remedial Alternative	Baseline Estimated Cost ($millions net present value)	Removal Volume (million cy)	Estimated Additional Cost for Treatment with Beneficial Reuse[a] ($millions net present value)	Estimated Additional Cost for Treatment without Beneficial Reuse ($millions net present value)
1	n/a	n/a	n/a	n/a
2R	230	0.62	25	50
2R-CAD	210	0.62	n/a	n/a
3C	220	0.57	23	47
3R	290	0.79	29	62
4C	290	0.74	28	59
4R	440	1.2	41	91
5C	310	0.77	29	61
5R	550	1.5	49	111
5R-T	600	1.5	n/a	111
6C	650	1.7	55	125
6R	1300	3.6	107	257

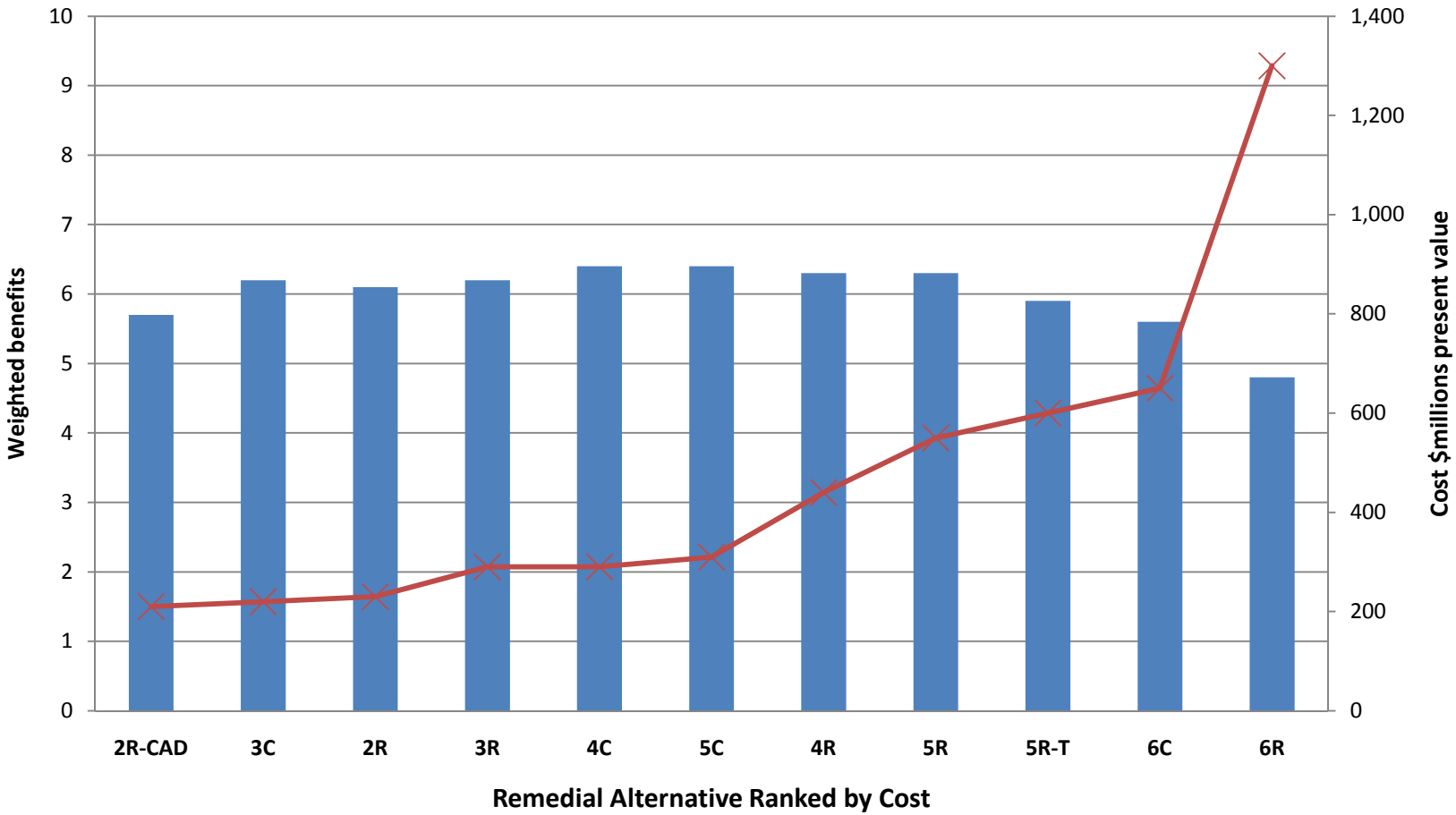
Notes:

a Cost for treatment with beneficial reuse assumes the cost for mobilization, soil washing treatment operations including water management, upland disposal of fine fraction of treated sediment, and reuse of sand fraction at no cost. 50% of dredged sediment is assumed to be viable for soil washing.

b Cost for treatment without beneficial reuse assumes the cost for mobilization, soil washing treatment operations including water management, and upland disposal of both fine fraction and sand fraction of treated sediment. 50% of dredged sediment is assumed to be viable for soil washing.

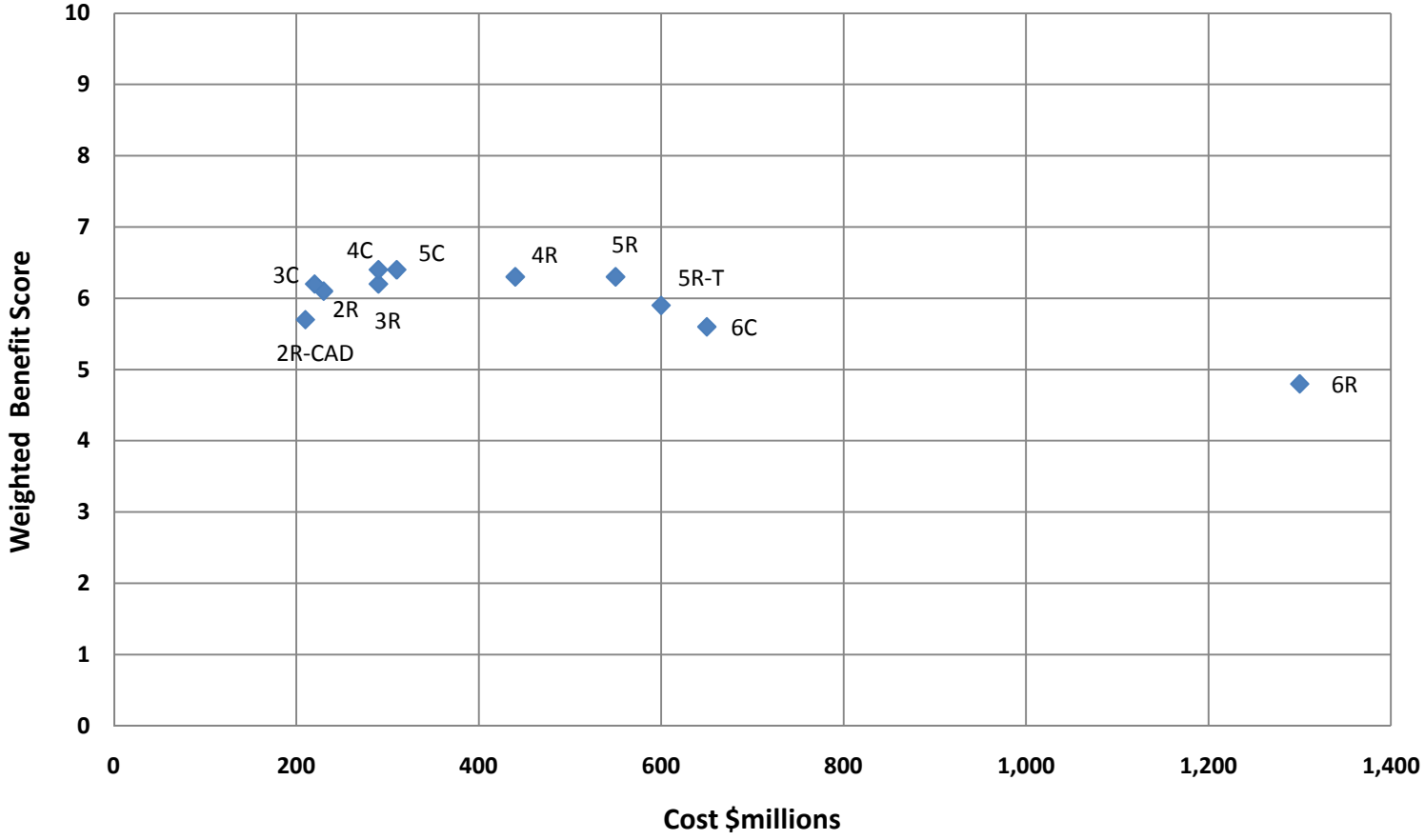
C= combined technology alternative; cy = cubic yard; n/a = not applicable; R = removal emphasis alternative. R-CAD = removal alternative with contained aquatic disposal; R-T = removal alternative with treatment

Figure 11-1 Benefits and Costs for Remedial Alternatives (Ranked by Cost)



Notes:
C = combined technology alternatives
R = removal-emphasis alternatives with upland disposal
R-CAD = removal-emphasis alternative with contained aquatic disposal
R-T = removal-emphasis alternative with soil washing treatment

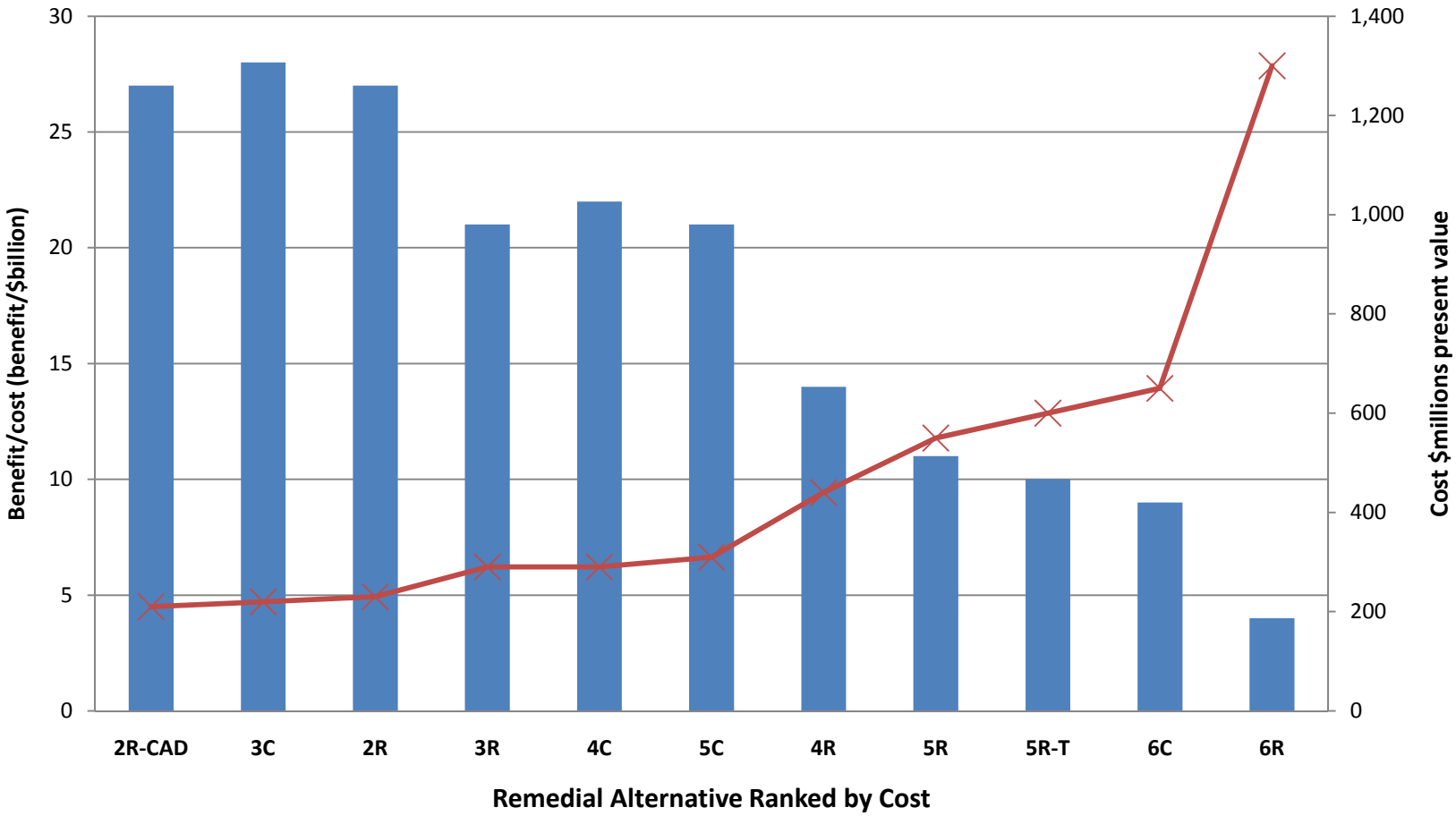
Figure 11-2 Benefits vs. Costs for Remedial Alternatives



Notes:

C = combined technology alternative; R = removal-emphasis alternatives with upland disposal; R-CAD = removal-emphasis alternative with contained aquatic disposal; R-T = removal-emphasis alternative with soil washing treatment.

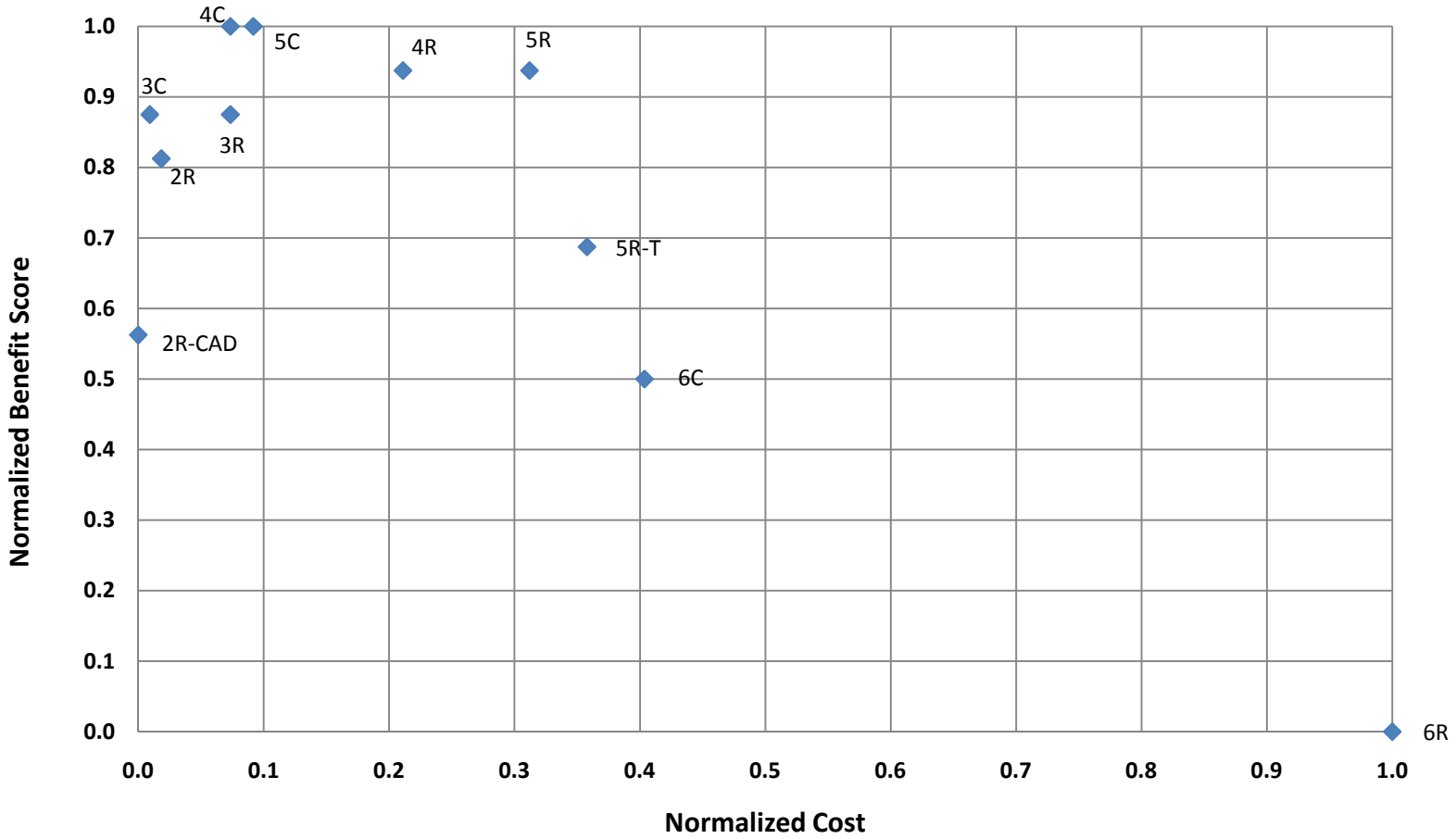
Figure 11-3 Benefits per Unit Costs for Remedial Alternatives (Ranked by Cost)



Notes:
R = removal-emphasis alternatives with upland disposal
R-CAD = removal-emphasis alternative with contained aquatic disposal
R-T = removal-emphasis alternatives with soil washing treatment
C = combined technology alternatives

MM - millions

Figure 11-4 Normalized Benefits vs. Normalized Costs for Remedial Alternatives



Notes:
Costs and benefits were normalized from the lowest score or value of all the alternatives to the highest score or value of all the alternatives.
R = removal-emphasis alternatives with upland disposal; R-CAD = removal-emphasis alternative with contained aquatic disposal; R-T = removal-emphasis alternative with soil washing treatment; C = combined technology alternatives

Normalized value = ((value)-(min alt))/((max alt)-(min alt))

12 Conclusions

Cleanup of the Lower Duwamish Waterway (LDW) is a complex, large scale undertaking that seeks to accomplish important human health and environmental objectives in a challenging urban/industrial setting. Several factors are estimated and evaluated in this FS to develop and compare a full range of remedial alternatives for the LDW that are protective over the long term. These include quantifying the deposition of new sediment from upstream and their associated chemical concentrations, forecasting the timing and future results of upland source control in numerous locations along the LDW, estimating dredge volumes and costs, and predicting the time needed to implement the cleanup and reach the cleanup objectives (remedial action objectives [RAOs]). However, uncertainties exist in each of these factors.

A recent report by the National Research Council (NRC 2007) on sediment cleanups at large Superfund sites identifies similar challenges at sites elsewhere in the country, and suggests how to move forward in selecting remedies for sites as large and complex as the LDW. The report concludes with the following excerpt:

> *If there is one fact on which all would agree, it is that the selection and implementation of remedies at contaminated sediment sites are complicated. Many large and complex contaminated sediment sites will take years or even decades to remediate and the technical challenges and uncertainties of remediating aquatic environments are a major obstacle to cost-effective cleanup.*
>
> *Because of site-specific conditions – including hydrodynamic setting, bathymetry, bottom structure, distribution of contaminant concentrations and types, geographic scale, and remediation time frames – the remediation of contaminated sediment is neither simple nor quick, and the notion of a straightforward "remedial pipeline" that is typically used to describe the decision-making process for Superfund sites is likely to be at best not useful and at worst counterproductive.*
>
> *The typical Superfund remedy-selection approach, in which site studies in the remedial investigation and feasibility study establish a single path to remediation in the record of decision, is not the best approach to remedy selection and implementation at these sites owing to the inherent uncertainties in remedy effectiveness. At the largest sites, the time frames and scales are in many ways unprecedented. Given that remedies are estimated to take years or decades to implement and even longer to achieve cleanup goals, there is the potential – indeed almost a certainty – that there will be a need for changes, whether in response to new knowledge about site conditions, to changes in site conditions from extreme storms or flooding, or to advances in technology (such as improved dredge or cap design or in situ treatments). Regulators and others will need to adapt continually to evolving conditions and environmental responses that cannot be foreseen.*
>
> *These possibilities reiterate the importance of phased, adaptive approaches for sediment management at megasites. As described previously, adaptive management*

does not postpone action, but rather supports action in the face of limited scientific knowledge and the complexities and unpredictable behavior of large ecosystems.

In that context, this section discusses:

- Some of the key conclusions related to protecting human health and the environment by comparing remedial alternatives to the Compliance with Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Model Toxics Control Act (MTCA) criteria for remedial alternative selection
- A comparison of the analysis in this FS to the most recent national guidance of remedy selection for contaminated sediment sites
- Uncertainties identified and addressed in the LDW as referenced in the NRC (2007) study.

Similarities and differences among the alternatives and how they compare under MTCA and CERCLA are described in Section 12.1, along with the key findings. Risk managements principles and national guidance are discussed next in Section 12.2. Section 12.3 briefly describes the uncertainties associated with the alternatives and their predicted outcomes. The final section, 12.4 discusses the next steps in the process for selecting the remedy for the LDW in coordination with other LDW cleanup activities.

12.1 Summary of the Comparative Analysis under MTCA and CERCLA

Twelve alternatives were individually evaluated against the CERCLA criteria in Section 9, compared to each other in Section 10, and evaluated against the MTCA criteria in Section 11 including a disproportionate cost analysis. CERCLA provides a set of prescribed criteria against which the remedial alternatives are evaluated (Table 9-1). MTCA has a similar framework for evaluating alternatives, with a few important distinctions (Tables 11-1 and 11-2) that have been incorporated into the following discussions.

Table 12-1 summarizes each alternative's remedial technologies, the size of the active remedial footprint, the volumes and costs, the time frame predicted for achieving the RAOs, and residual risks (predicted outcomes). Differences in overall protectiveness of Alternatives 2 through 6 are largely in the context of short-term and long-term effectiveness. The lower numbered/smaller alternatives rely more on natural recovery to achieve the RAOs, while higher numbered/larger alternatives rely more on engineering controls such as dredging, capping, and enhanced natural recovery (ENR). The major differences among the alternatives with the same remedial action levels (RALs) are the reliance on dredging for the active portion of the "R" alternatives versus a combination of technologies (dredging, capping, and ENR) for the active portion of the "C" alternatives.

Figure 12-1 presents a summary of the comparative analysis under the CERCLA evaluation criteria. Alternative 1 failed to meet CERCLA threshold criteria but was retained for comparative purposes as the No Action Alternative. A high ranking (full red dot) means that the alternative ranks relatively high compared to other alternatives, whereas a low ranking (full black dot) means the alternative ranks low compared to other alternatives. In many cases, the evaluation did not identify substantial differences among the alternatives and therefore they are ranked the same.

Figure 12-2 presents a summary of the comparative analysis under the MTCA evaluation criteria. Overall, the MTCA analysis yielded results similar to the CERCLA analysis. However, MTCA has specific differences in the factors that were considered under each evaluation criterion and, unlike CERCLA, the metrics used in the comparative analysis are converted to numerical scores. These scores are combined for a total benefit score, then are compared with the cost of each alternative as a means of comparing the benefit of each alternative relative to its cost (called the disproportionate cost analysis, or DCA).

The following sections summarize the key points of the comparative analyses and performance of the remedial alternatives related to both the CERCLA and MTCA requirements. The following discussion is organized by the nine CERCLA criteria (two threshold criteria, five balancing criteria, and two modifying criteria). However, the last two modifying criteria, state/tribal and community acceptance, are not discussed below; they will be evaluated by EPA and Ecology after the FS in completed and include consideration of formal public comments on the proposed plan

12.1.1 Overall Protection of Human Health and the Environment

Alternatives that rely more on dredging have higher impacts to human health and the environment in the short term; they maintain elevated seafood tissue contaminant concentrations over the duration of active remediation. Construction times are longer for dredging than for other active technologies over a similar area. However, they also leave less subsurface contamination in place and therefore have a reduced potential for material to become re-exposed in the future.

Residual risks for each alternative are provided below:

- Alternatives 2 through 6 are predicted to achieve similar levels of residual excess cancer risks, in the range of 1 in 10,000 (10^{-4} magnitude risk) or less, depending on the exposure pathway (Table 12-1; Figure 12-3). These risks are within the acceptable risk range for CERLCA, but none of the alternatives reach the MTCA threshold risk of 1×10^{-6} for individual chemicals for the seafood consumption pathway. The alternatives are predicted to reduce risks to humans who consume resident LDW seafood to a lifetime excess cancer risks in the range of 10^{-4} based on Adult Tribal and API consumption rates (RAO 1). Lifetime excess cancer risks for the Child

Tribal scenario are reduced to the range of 10^{-5}. Alternatives 2 through 5 rely to a certain extent on natural recovery to achieve this result.

- It is not technically feasible for the alternatives to achieve the total PCB and dioxin/furan PRGs for the human seafood consumption pathway because they are set at natural background concentrations. Instead, Alternatives 2 through 6 are predicted to achieve long-term model-predicted concentrations over time (Table 12-1). These concentrations represent the lowest surface-weighted concentrations that are achievable based on modeling assumptions. Seafood consumption advisories are expected to remain in effect in the LDW, no matter which alternative is selected.
- Alternatives 2 through 6 are predicted to reduce surface sediment concentrations to levels that protect humans from adverse effects associated with direct contact with sediment (RAO 2). In all cases, active remediation alone reduces cumulative excess cancer risks from all four risk drivers and all exposure scenarios to no higher than 1 in 100,000 (1×10^{-5}). However, the individual risk posed by arsenic is greater than 1 × 1,000,000 (1×10^{-6}) because the natural background concentration of arsenic yields greater risks.
- Alternatives 2 through 6 are predicted to comply with MTCA/Sediment Management Standards (SMS) requirements for protection of the benthic community (RAO 3). Alternatives 2 through 4 rely to a certain extent on natural recovery to achieve this result.
- Alternatives 2 through 6 are predicted to protect wildlife (RAO 4) by reducing total PCB concentrations below levels that corresponds to a non-cancer HQ <1 for wildlife that consume resident seafood; these PRGs are predicted to be achieved immediately following construction for Alternatives 4, 5, and 6.
- Alternatives that rely more on dredging have higher impacts in the short term and maintain high seafood tissue chemical concentrations over the implementation time frames. Implementation time frames are longer for dredging than for other active technologies over a similar area. However, the removal emphasis alternatives also leave less subsurface contamination in place and therefore have a reduced potential for material to become re-exposed in the future.

Achievement of RAOs and estimated residual risks are primarily based on the future predictions of spatially-weighted average concentrations (SWAC) in surface sediment. Uncertainties associated with SWAC calculations are discussed in Section 10.4.

12.1.2 Compliance with ARARs

Because this FS is being conducted under a joint CERCLA and MTCA order, provisions of MTCA and the SMS are considered to be ARARs under CERCLA and governing requirements under MTCA/SMS.

- Alternative 1 provides the least protection of human health and the environment and does not satisfy the threshold requirement of complying with ARARs. It is not expected to comply with the SMS requirement to achieve site cleanup standards within 10 years after construction.
- All other alternatives are considered protective of human health and the environment and comply with ARARs to the extent practicable. Natural background for PCBs and dioxins/furans (for RAO 1) in sediment are ARARs under MTCA because human health risk-based thresholds for seafood consumption are lower than natural background concentrations. None of the alternatives are expected to comply with these ARARs without reliance on institutional controls designed to reduce human exposure to resident fish and shellfish.
- Significant water quality improvements are anticipated from sediment remediation and source control. Water quality is likely to be variable throughout the LDW, depending on the extent of local sources. Generally, the more quickly and thoroughly sources are controlled, the more quickly water quality improvements should occur. It is not anticipated that any alternative will comply with all the federal or state ambient water quality criteria or standards, particularly those based on human consumption of bioaccumulative contaminants that magnify through the food chain, such as PCBs, because upstream concentrations exceed those criteria or standards.

CERCLA requires that all ARARs be met or waived upon completion of remedial action. By far the most common waiver is for technical impracticability. The goal in all instances where alternatives are not predicted to comply with ARARs, is to get as close as technically practicable to the ARAR, and apply a waiver only to the extent necessary. Because future conditions are difficult to project, actual data collected upon completion of the remedial action will underlie the basis for any such waivers, which are formally documented and issued by EPA. For this reason, more definitive statements on whether, and perhaps more significantly to what extent, ARARs will be met or potentially waived cannot be made at this time, but must be made at the completion of cleanup and source control work at the site.

12.1.3 Long-term Effectiveness and Permanence

Long-term effectiveness and permanence considers the residual risks that remain on site after the RAOs have been achieved, and the controls that can be used to manage these residual risks. The comparative analysis found:

- With the exception of Alternative 1, residual risks from surface sediment are similar among the alternatives based on model-predicted outcomes. They are predicted to achieve similar risk endpoints once RAOs have been achieved. Active remediation alone (i.e., ignoring any contribution from natural recovery) is responsible for the majority of progress toward achieving the residual risk levels for all alternatives. However, Alternatives 2, 3, and 4 rely more on natural recovery and thus have more uncertainty in the outcomes.
- A 50 to 90% reduction in site-wide concentrations for risk-driver chemicals is predicted over time for all alternatives compared to baseline conditions; about 50% of this reduction is expected after cleanup of early action areas (EAAs) (Figure 12-3).
- Uncertainty in the residual risk from surface sediment is largely associated with the quality of incoming sediment from the Green/Duwamish River. Ultimately, surface sediment chemical concentrations are expected to converge to levels similar to the quality of incoming sediment from upstream combined with other inputs, resulting in similar levels of risk over time.
- Differences in the level of effort and reliability of the control mechanisms, once RAOs are achieved, are related primarily to the areal extent of remaining subsurface contamination. The remedial alternatives differ in the amount of contaminated subsurface sediment remaining with concentrations above protective levels, which, if re-exposed or brought to the surface, could pose human health and/or ecological risks. Alternatives that dredge across a greater surface area leave less contaminated subsurface sediment behind, which, in turn, reduces the risk of potential future exposures (e.g., by high-flow events or vessel scour). More capped surface area translates into lower risk from subsurface sediments than areas addressed by ENR or MNR because caps are engineered to withstand scour or other disturbance under location-specific conditions.
- Each of Alternatives 2 through 6 requires a set of controls consisting of monitoring, maintenance, and institutional controls, with contingency actions and periodic reviews (e.g., every 5 years). All of the alternatives have seafood consumption advisories and other public outreach designed to increase seafood consumers' awareness of risks and to reduce unacceptable exposures. Outreach and notification to waterway users, review of USACE construction permit applications, and where appropriate, the use of restrictive covenants or similar controls to avoid disturbance of subsurface contamination will be required to varying degrees depending on the remedial alternative.

Alternatives 2 through 6 progressively rank from low to high for long-term effectiveness and permanence, and the combined technology "C" alternatives rank lower than the removal emphasis "R" alternatives. Key differences in the rankings are based on the amount of contaminated sediment managed in place (or removed) and the degree to which institutional controls and monitoring are needed to manage the remaining material.

12.1.4 Reductions in Mobility, Toxicity, or Volume through Treatment

This criterion considers the reduction of contaminant mobility, toxicity, or volume achieved through treatment. Treatment is generally preferred to address principal threat wastes (e.g., highly toxic or highly mobile waste) that are not found in the LDW; however, use of other institutional and engineering controls is also acceptable for the low-level threats present in the LDW (40 CFR Section 300.430 (a)(1)(iii)).

- Alternative 5R-Treatment is the only alternative that includes a treatment technology (soil washing). Soil washing could decrease the volume of dredged sediment requiring upland disposal but not the mass of chemicals. Removal and disposal, capping, ENR, and MNR are not categorized as treatment technologies under CERCLA. Thus, each alternative, except Alternative 5R-Treatment, is ranked equally. Alternative 5R-Treatment ranks slightly higher because the volume of contaminated sediment requiring disposal may be reduced.
- Other alternatives could include treatment of material after dredging; FS-level unit costs for the addition of treatment (soil washing) to each alternative are shown in Table 11-8.
- All of the alternatives include some combination of removal, disposal, containment, and natural recovery. While none of these technologies actually treat contaminated sediment, they do reduce the toxicity, mobility, and volume of chemicals remaining in the LDW compared to Alternative 1.

12.1.5 Short-term Effectiveness

Short-term effectiveness is a measure of the time required to achieve the RAOs and the risks and impacts that may occur during that implementation. Alternatives are evaluated for their ability to protect the community, workers, and the environment during implementation. The evaluation had these key results:

- Alternatives with longer construction times and greater dredge volumes present proportionately larger risks to workers, the community, and the environment and therefore generally rank lower for these short-term effectiveness factors. Longer construction periods increase equipment and vehicle emissions, noise, and other resource use. Larger actively remediated footprints increase the short-term disturbance of the existing benthic

community and other resident aquatic life and generate more releases of bio-available chemicals over longer construction time frames.

- Alternatives 2 through 6 are predicted to achieve the RAOs at or within 10 to 15 years of construction completion. The alternatives differ significantly in their construction time period. Alternatives that emphasize removal have longer construction times than the combined alternatives. The construction times vary from about 4 years (Alternative 2) to 18 years (Alternative 6C) and 38 years (Alternative 6R).
- Alternatives 3C, 4C, and 5C are predicted to achieve all 4 RAOs in the shortest time frames (14, 12, and 13 years, respectively, after issuance of remedy decision documents), but will require an additional 5 to 10 years to achieve long-term model-predicted concentrations for RAO 1.
- Alternatives 2, 2-R CAD, 3R, and 4R have moderately long time frames (19, 16, and 18 years, respectively) to achieve the RAOs, but Alternatives 2 and 3R will require an additional 5 years to achieve long-term model-predicted concentrations for RAO 1.
- Alternatives 5R, 6C, and 6R have the longest predicted time frames to achieve the RAOs (24, 23, and 43 years respectively) by virtue of their long construction periods.
- When viewed collectively, Alternatives 4R and 5C are predicted to achieve all 4 RAOs, including the long-term model-predicted concentrations, in the shortest time frames (18 years).

Alternatives 3C, 3R, 4C, and 5C are ranked relatively high compared to other alternatives for short-term effectiveness. Key differences in these rankings are based on the construction periods (shorter construction periods for active remediation have lower impacts) and the time to achieve RAOs.

12.1.6 Implementability

This criterion considers both the technical and administrative ability to implement each alternative. Each of the alternatives involves various combinations of technologies that have been successfully implemented at numerous sites in the Puget Sound region and throughout the country. The required equipment and appropriately skilled personnel are readily available and coordination of the activities among agencies can be achieved. Based on the comparative analysis:

- Alternatives with shorter construction periods are easier to implement through the end of the construction period than those with longer construction periods. This reduces the overall level of difficulty both technically and administratively (e.g., coordination with agencies) and the potential for technical problems leading to schedule delays. In this context,

Alternative 1 is the most implementable of the alternatives. Some of the required approvals have already been obtained for Alternative 1 and the cleanup actions have either been completed or are expected to be initiated soon.

- As the RALs decrease, the active remediation footprint also increases, thereby raising the potential for technical problems and administrative delays (e.g., water quality monitoring, protection of fish migration windows, coordination with vessel traffic). Therefore, Alternatives 5 and 6 rank lower than Alternatives 3 and 4. The lowered numbered alternatives have relatively short construction periods and are flexible in terms of the technology mix. The latter is important in terms of reducing technical problems that could lead to schedule delays.
- The CAD (2R-CAD) and treatment (5R-Treatment) alternatives have technical and administrative challenges associated with siting and operating either CAD facilities or a soil washing facility, and for Alternative 5R-Treatment, finding an acceptable use for treated sediment.
- Alternatives that rely more on MNR to achieve PRGs have an increased potential for requiring actions in the future (e.g., more dredging or capping). This results in an increased technical and administrative burden of evaluating monitoring data over time, considering the need for contingency actions if cleanup levels are not achieved in the predicted time frame, and implementing contingency actions. In this context, alternatives that rely to a greater extent on active construction to achieve PRGs are more favorable and may have greater administrative implementability.

Alternatives 4C and 4R receive the highest rankings because they represent the best balance of the implementability factors.

Project sequencing is an important consideration from a recontamination perspective. The larger dredging alternatives (4R, 5R and 6R) are more difficult to sequence in a specific order, because of the difficulties in coordinating multiple remediation projects and source control actions, administrative delays, and associated programmatic difficulties. Section 12.4 discusses an adaptive management approach for managing the sediment cleanup, and Section 10.2.3.3 evaluates the potential effects that sequencing may have on predicted site-wide sediment concentrations.

12.1.7 Cost

In terms of cost, the comparative analysis concluded that the alternatives differ significantly in costs:

- Alternative 6R has the highest costs ($1.3 billion) and therefore ranks the lowest for this criterion (Table 12-1). The estimated costs for remaining

alternatives range from Alternative 2R with the lowest cost and highest rank ($210 million) after Alternative 1, up to Alternative 6C ($650 million).[1]

- Alternatives with a focus on combined technologies for a large portion of the active remediation ("C" alternatives) have lower costs than the corresponding alternatives that rely on dredging (removal) for active remediation ("R" alternatives) for the same remedial action level.
- Based on the MTCA analysis, comparing benefit scores to costs indicates that additional costs do not necessarily add proportional benefit for the remediation of contaminated sediment in the LDW. Specifically, Alternatives 2R, 2R-CAD, 3R, 3C, 4C, and 5C have a relatively similar benefit-to-cost relationship, while the remaining alternatives show a pattern of diminishing benefits per incremental cost (Figure 11-3).

Although sufficient for the purposes of this FS, uncertainties in these cost estimates are considerable, as shown in Table 12-1 and discussed in Section 10.2.5.

12.2 Risk Management Principles and National Guidance

The LDW is not the only large and complex site in the country, and many other regions are addressing similar issues and uncertainties. In response, the U.S. Environmental Protection Agency (EPA) released the *Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites (*2002) which can be found in Appendix A of the *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (2005). Many of the recommendations in these documents have been integrated into the FS process to develop and evaluate the alternatives for the LDW. It is recommended that the following 11 risk management principles from EPA (2005) be incorporated into risk management decisions.

These principles are reviewed below in the context of the LDW alternatives:

1) **Control Sources Early:** The Washington State Department of Ecology (Ecology) is leading the source control program currently underway in the LDW. Implementation of this program is a long-term effort, and there are uncertainties as to how effective the program can be at preventing recontamination from diffuse sources in an urban watershed. Nevertheless, modeling efforts and empirical data collected to date show that the effects of lateral loadings are localized, once reasonable source control is attained. However, model predictions estimate a range of long-term chemical concentrations that are above some PRGs (natural background) and influenced by on-going urban inputs. Model predictions are supported by

[1] The estimated EAA (Alternative 1) cost of $66 million and costs associated with upland cleanup and source control (not estimated) are not included in the cost estimates for Alternatives 2 through 6.

empirical trends observed in the LDW and other urban and non-urban water bodies.

2) **Involve the Community Early and Often:** An extensive outreach effort has been conducted during the course of the RI/FS. The baseline risk assessments evaluated potential site uses by local populations, including community members, tribal members, and Asian and Pacific islanders. These risk results have been factored into developing the long-term cleanup goals for the LDW. As the remedial alternative decision draws near, LDWG and the agencies will seek input from all affected parties, including the local landowners and businesses, the neighborhoods, and the broader ratepayer and taxpayer community who may fund some of these cleanups.

3) **Coordinate with States, Local Governments, Tribes, and Natural Resource Trustees:** This FS is conducted under a joint order with Ecology so state coordination is ensured. The tribes and the National Oceanic and Atmospheric Administration have all been closely involved in the studies completed to date on the LDW. EPA and Ecology have instituted a regular series of meetings with them, and LDWG has participated actively in sharing the concepts and key issues related to the cleanup. The input received from these parties has been very helpful in developing the FS.

4) **Develop and Refine a Conceptual Site Model that Considers Sediment Stability:** Empirical data and modeling have been used to develop a conceptual site model (CSM) of the LDW, which is summarized in Section 2 and detailed in the RI (Windward 2010). The CSM indicates that the LDW is a net depositional system with more than 100,000 metric tons of sediment deposited within the LDW each year. Relatively small areas are subject to episodic scouring as a result of high-flow events or localized vessel activity. These areas have been accounted for in developing the alternatives, and are part of the areas designated for active management in Alternatives 2 through 6.

5) **Use an Iterative Approach in a Risk-based Framework:** Recent studies by the NRC (2007), and other independent, scientific peer reviews of sediment sites throughout the country (USACE 2008a; Cannon 2006) conclude that there are substantial uncertainties related to cleanup of complex sites such as the LDW and point to the necessity of using adaptive management strategies. Remedial alternatives that rely primarily on dredging to achieve risk-based goals may have practical limitations as a result of the effects of sediment resuspension and recontamination. The time frames for completing source control and sediment cleanup in the LDW may span decades. Performance of passive remedial technologies such as MNR may be slower than predicted. These limitations suggest that selection of the

remedial alternative for the LDW should include an iterative approach (see below).

6) **Evaluate the Assumptions and Uncertainties Associated with Site Characterization Data and Site Models:** A multimillion dollar study, completed over the past nine years, has been conducted and includes extensive site characterization and a state-of-the-art model for evaluating sediment stability and long-term recovery in the LDW. The investigation studies and modeling completed to date indicate that the LDW is recovering naturally in many areas and focused remedial actions can increase the rate of recovery. As with any set of studies, their predictive ability has many limitations that can be improved during the remedial design and implementation phases as new information is developed. These uncertainties have been considered in evaluating the alternatives and the effects of these uncertainties have been discussed in the comparative analysis of the alternatives.

7) **Select Site-specific, Project-specific, and Sediment-specific Risk Management Approaches that Will Achieve Risk-Based Goals:** As part of assembling the alternatives, a range of remedial actions and RALs have been presented. These have been used to evaluate the reduction in risks that may be achievable under each alternative. None of the alternatives are predicted to achieve PRGs based on natural background. However, the results illustrate that a combination of cleanup methods, including selective removal actions at targeted locations and various containment technologies, when coupled with natural recovery, are predicted to be the most cost-effective approach for achieving the RAOs (with institutional controls needed to manage residual risks). All alternatives are predicted to achieve the same risk levels but at different points in time. The alternatives have been compared to one another considering temporal and spatial aspects of the LDW and the overall risk reduction achieved under each alternative. The results indicate that a combination of technologies is likely to be the most effective site-, project-, and sediment-specific risk management approach.

8) **Ensure that Sediment Cleanup Levels are Clearly Tied to Risk Management Goals:** The RAOs developed for the LDW are based on the results of the baseline human health and ecological risk assessments (Windward 2007a and 2007b). The final cleanup levels will be determined by EPA and Ecology; this FS presents PRGs that form the starting point for establishing the cleanup levels. The sediment PRGs associated with each RAO are based both on the results of the risk assessments and on background concentrations. Alternatives 2 through 6 share the same PRGs and ultimately have the same risk management goals. The alternatives differ in the type and extent of active versus passive remediation, and hence have

different estimated time frames to reach these goals with proportional short-term effects.

9) **Maximize the Effectiveness of Institutional Controls and Recognize Their Limitations:** To be fully protective, the alternatives will all require similar institutional controls (including seafood consumption advisories). Seafood consumption advisories and institutional controls will be especially important during construction, when seafood tissue concentrations are predicted to increase as a result of dredging. Additional actions to improve the effectiveness of seafood consumption advisories have been evaluated and discussed in this FS; recommended actions are similar regardless of the alternative selected. Alternatives that include significant containment components (such as capping) that leave contaminated sediment in place at depth will require additional institutional controls, such as restrictions on activities that could disturb the affected area. These controls have been successfully implemented at a wide range of sites regionally and nationally.

10) **Select Remedies that Minimize Short-term Risks while Achieving Long-term Protection:** Alternatives have been developed that achieve similar long-term risk-reduction goals. The alternatives differ significantly in short-term risks to the community and workers and environmental impacts associated with remediation construction. Short-term risks during construction include worker safety, transportation-related impacts on communities, habitat disruption, and increased chemical concentrations in fish and shellfish tissue during dredging. Related short-term environmental impacts include greenhouse gas emissions and other air pollutants, consumption of landfill space, and consumption of aggregate materials such as sand for capping. Both the duration and magnitude of most of these short-term risks are closely tied to the dredging volumes associated with each alternative. In contrast, the long-term effectiveness and permanence of the remedial alternatives is considered to be greater for alternatives that remove larger volumes of contaminated sediments. Results of the MTCA DCA show that Alternatives 2 through 6, excluding Alternative 6R, score in the same range (5.7 to 6.4 total benefit points), and Alternative 6R scores lower (4.8) when these factors are collectively considered. When a remedy is selected, the short-term effectiveness considerations of the remedial alternatives will need to be considered alongside the long-term effectiveness and permanence considerations.

11) **Monitor During and After Sediment Remediation to Assess and Document Remedy Effectiveness:** Alternatives 2 through 6 include extensive short-term and long-term monitoring programs (see Appendix K conceptual monitoring plan) and the cost estimates assume contingency actions based on monitoring results. Alternatives that include a substantial

natural recovery component have monitoring programs that can be used to adapt the remedial alternative as new information becomes available. Monitoring data can be evaluated against performance metrics, and contingency actions (such as active dredging, capping, or ENR) may be implemented as identified in the final decision documents.

12.3 Managing the Key Uncertainties

Decision-making on a site of the size and complexity of the LDW, in an environment that is changing over time, means accommodating areas of uncertainty. This FS has relied on the best information and science available at this time, and where necessary, made reasonable assumptions to evaluate different remedial alternatives. The remaining sources of uncertainty in these analyses must be factored into the selection and implementation of a remedial alternative for the LDW.

The following factors emerge as particularly important for managing uncertainty relative to the time predicted for achieving RAOs and the anticipated performance of the alternatives:

- Uncertainty in the residual risk conclusions is largely of three kinds: 1) the quality of incoming sediment from the Green/Duwamish River, 2) the rate of natural recovery, and 3) the potential for re-exposure of buried subsurface contamination. Ultimately, surface sediment concentrations are expected to converge to levels similar to the quality of incoming sediment from the Green/Duwamish River and other inputs, resulting in similar levels of risk over time. While future conditions and actual concentrations are not certain (e.g., depending on the effectiveness of source control efforts), it is likely that conditions will be similar in the long term, regardless of the alternative.
- A sensitivity analysis was conducted to evaluate uncertainties associated with net sedimentation rates, which will affect the rate at which recovery occurs; and the concentrations of incoming sediment. Despite the uncertainties in predicting the long-term sediment concentrations, the analysis concluded that the final long-term, model-predicted concentrations are largely insensitive to the range of RALs evaluated in Alternatives 2 through 6. Results showed that variability in the chemical input parameters was more important to the recovery than sedimentation, although localized sedimentation and scour effects could be important. Areas with significant scour potential and contamination were prioritized for remedial action in the FS.
- As the RAL becomes lower (i.e., for higher-numbered, larger alternatives such as Alternatives 6C and 6R), the chance for recontamination from continuing urban inputs becomes higher. The highest probability of recontamination will be in localized areas, likely located near outfalls (see

Appendix J). Collectively, these localized areas are predicted to have an effect on the site-wide average concentrations that can be achieved long term.

- The bed composition model developed for this FS allows for a semi-quantitative evaluation of source control effects on sediments. Location-specific analyses and coordination with the source control program will be required during the remedial design phase to ensure that source control is in place. Long-term monitoring and source control measures will be necessary, regardless of the remedial alternative selected. This uncertainty can affect the predicted time frame to achieve RAOs.
- The performance of each remedial technology has some uncertainty associated with it. It is well documented that dredging produces dredge residuals that will elevate surface sediment and tissue concentrations over the short term. Capping and ENR may need periodic repairs and continued maintenance. MNR performance may be slower (or faster) than predicted and may require additional monitoring or contingency actions based on monitoring results. Many of these potential uncertainties have been incorporated into the cost estimates as contingency actions, repairs, and/or additional monitoring.
- Recent projects have shown that actual dredging volumes can be much higher than those estimated during the FS or remedial design phase. Conservative volume estimates have been used in this FS based on engineering experience. However, uncertainty remains and is managed in this FS by presenting a range of contaminated sediment volumes and including these ranges in the cost estimates (Table 12-1) and construction times.

12.4 Next Steps

This FS provides the basis for obtaining input from many interested parties. EPA, Ecology, and LDWG intend to solicit input from the public, including a broad range of stakeholders, and incorporate this input into the Final FS, which will be available in 2011. EPA and Ecology will then issue a proposed plan that identifies a preferred remedial alternative for the LDW. Formal public comment will be received on the proposed plan. After public comments on the proposed plan are received and evaluated, EPA and Ecology will select the final remedial alternative and publish the decision.

The overall goals, RALs, and sequencing of cleanup actions will be specified in the final decision document, after seeking state concurrence. It may also specify interim (e.g., 5-year) goals and final post-construction goals for passively remediated areas. After the final decision document is issued, the first 5-year period is expected to include

completing any remaining early actions; conducting extensive source identification and control activities; completing pre-design investigations and remedial design for the highest priority areas; and developing both a compliance monitoring program for active cleanup areas and a long-term O&M monitoring program. The long-term plan will be designed to assess achievement of RAOs, performance of the technologies, and trigger contingency actions, and adaptive management steps as needed.

In the end, the CERCLA sediment cleanup actions will be part of a larger adaptive management program intended to improve the overall quality of the LDW and the surrounding watershed. This program is multi-disciplinary, and will include coordinated efforts by EPA, Ecology, King County, the City of Seattle, the City of Tukwila, the Port of Seattle, the Washington State Department of Health, affected industries in the LDW watershed, and a number of other parties with particular interests in the LDW. The efforts are three-fold and will include: cleanup of the EAAs; remediation and adaptive management of the sediments in the LDW beyond the EAAs; and on-going source control efforts. Each of these efforts is discussed below.

12.4.1 Cleanup of the EAAs

There are five designated EAAs in the LDW. The parties responsible for the five EAAs have conducted an intensive study of each one, and cleanup has occurred at two of the five EAAs: the Duwamish/Diagonal EAA by King County in 2003 and 2004; and the Norfolk EAA by King County in 1999 and The Boeing Company in 2003. Three other EAAs are in the planning stages under cleanup agreements with EPA. Together, these five EAAs cover 29 acres, representing some of the highest levels of sediment contamination in the LDW. It is anticipated that cleanup of the EAAs will be completed prior to initiating any of the cleanup alternatives in the FS.

Additional agreed orders have been negotiated, or are being negotiated, with upland property owners along the Duwamish that have adjacent contaminated sediments. Ecology has over 20 agreed orders pending with site owners or users (see Section 2.7). The scope of work included in these agreed orders often includes upland, shoreline, and sediment investigations, evaluation of sources to the LDW surface water and sediments including near-field recontamination modeling, and an evaluation of remedial alternatives.

12.4.2 On-going Source Control Efforts

Controlling sources is critical to the long-term success of any remedial action (EPA 2002). On-going sources of contamination to the LDW need to be controlled to the extent practicable to protect cleanup of the LDW and achievement of the RAOs. Ecology is the lead agency for managing activities that identify and address sources of chemicals contributing to ongoing contamination of the LDW. Ecology developed a source control strategy (Ecology 2004) to identify and manage sources of contaminants to LDW sediments that coordinates with the sediment cleanups addressed in the EAAs and in

this FS. The strategy and associated Source Control Action Plans (SCAPs) for 24 individual drainage basins around the LDW provide the framework and process for identifying source control issues and implementing practical control of contaminant sources.

It is important to note that in some localized areas, some recontamination may occur even with aggressive source control because of the difficulty in identifying and completely controlling all potential sources of certain contaminants that are widely released by urban activities. EPA's (2002) sediment guidance recommends "control sources early, before sediment cleanup begins", but that may not be practical (see below). Delaying sediment cleanup until all sources have been identified and controlled, regardless of their contribution in terms of contaminant loading, may delay achieving many of the benefits that sediment cleanup alone can accomplish.

The LDW source control efforts have been developed in parallel with the RI and FS and will continue before, during, and after the implementation of the remedial alternatives discussed in this FS.

Source tracing and control efforts include:

- Mapping of storm drain systems and chemical analyses of samples collected therein
- Management of discharges from storm drains and combined sewer overflows (CSOs)
- Inspections of local businesses that discharge or otherwise contribute to storm drains, CSOs, or directly to the LDW, and implementation of best management practices
- Upland cleanups, including remediating contaminated soils, groundwater, and storm drain solids.

Ecology chairs the Source Control Work Group (SCWG), consisting of the primary public agencies responsible for source control for the LDW: Ecology, the City of Seattle, King County, Port of Seattle, City of Tukwila, and EPA. SCAPs document and prioritize source control activities for each source control area. Ecology's first priority is to address sources contributing to contamination in EAAs. Because of the dynamic nature of many source control activities, it is essential to maintain flexibility when adapting source control efforts to specific needs within source control areas. The success of source control depends on cooperation of all members of the SCWG and the active participation of businesses that must make changes to accomplish source control goals. This adaptive strategy for prioritizing source control work will continue throughout selection, design, and implementation of the long-term remedy for the LDW.

12.4.3 Adaptive Management for In-Water Sediment Remediation (Beyond the EAAs)

The approach taken for remediation of contaminated sediments in the LDW under CERLCA should focus on cleaning up the most contaminated areas first to reduce risks the fastest. Next, learning from each incremental cleanup experience, further actions should be adjusted based on what has been learned. The cleanup process of the LDW should:

1) Remediate the most contaminated sediment areas first
2) Continue source control efforts, sequenced to the sediment remediation
3) Actively continue resolving uncertainties, and provide flexibility in the design elements as more data becomes available
4) Monitor performance and changing conditions in both the remediation and source control efforts
5) Implement contingency actions that may become needed over time.

Experiences at other complex sediment sites point to the necessity of using adaptive management strategies, as recommended by EPA guidance (EPA 2005), the National Academy of Sciences (NRC 2007), and other independent, scientific peer reviews of sediment sites throughout the country (USACE 2008; Cannon 2006). For adaptive management to be valuable, a long-term monitoring plan will need to be established with metrics, analyses, and detection limit goals to which future data can be compared. For the LDW, the plan would be designed to generate data needed to assess achievement of the cleanup levels, as well as achieve the RAOs. Collecting monitoring information during and after cleanup will help evaluate the effectiveness of the selected remedial alternative, and trigger contingency actions as needed. A baseline monitoring event should be conducted prior to beginning the initial remedial activities to establish a benchmark for evaluating the effectiveness of the remediation.

EPA will evaluate the effectiveness of the selected remedial alternative no less frequently than once every five years. The 5-year reviews can integrate a comprehensive review of seafood consumption advisories, source control status, overall waterway health, and the need for contingency actions as necessary. These periodic reviews can be used by EPA to identify the need for any additional course corrections in the cleanup.

Table 12-1 Summary of Alternatives: Costs, Technologies, and Predicted Time to Achieve Overall Protection of Human Health and the Environment

	Analysis Parameters	Site-wide Remedial Alternative											
		1	2R	2R-CAD	3C	3R	4C	4R	5C	5R	5R-T	6C	6R
Quantities and Costs	Capital & O&M Costs (net present value, in $Millions)	*66*	*230*	*210*	*220*	*290*	*290*	*440*	*310*	*550*	*600*	*650*	*1,300*
	Estimated Range of Costs (in $Millions)[a]	*n/e*	*130 – 300*	*110 – 280*	*130 – 310*	*200 – 420*	*220 – 400*	*370 – 650*	*240 – 420*	*500 – 1,000*	*600 – 1,200*	*480 – 780*	*1,100 – 1,600*
	Remediation Footprint (area in acres)												
	Dredge	n/a	27	27	29	52	51	103	54	145	145	106	271
	Partial Dredge and Cap; Cap	n/a	3	38	19	5	48	11	53	12	12	101	28
	ENR	n/a	0	0	9	0	15	0	50	0	0	92	0
	MNR	n/a	127	127	119	100	43	43	0	0	0	0	0
	Verification Monitoring	n/a	19	19	19	19	19	19	19	19	19	0	0
	Total Active Area (acres) excluding 29 EAA acres[b]	29	30	30	57	5	114	114	15	157	157	299	299
	Total Performance Volume Dredged (1,000s cubic yards)	n/a	620	620	570	790	740	1,200	770	1,500	1,500	1,700	3,600
Overall Protection of Human Health and the Environment	*Construction Period, Time to Achieve RAOs in Years, and Risk Reduction*												
	Construction Period	n/e	4	4	4	6	7	13	8	19	19	18	38
	Implementation Time Frame from Issuance of Final Decision Documents	5	9	9	9	12	12	18	13	24	24	23	43
	Predicted Time to Achieve RAOs / Long-term model-predicted concentrations (RAO 1)	n/a	19 / 24	19 / 24	14 / 24	16 / 26	12 / 22	18	13 / 18	24	24	23	43
	RAO 1 Seafood Consumption 2×10^{-4} excess cancer risk for total PCBs (Adult Tribal RME)	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}
	RAO 2 Direct contact: cumulative excess cancer risk $\leq 1 \times 10^{-5}$ (All exposure scenarios)	n/e	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}
	RAO 3 Ecological Protection: of benthic invertebrates (>98% compliance with SQS)	95%	> 98%	> 98%	> 98%	> 98%	> 98%	> 98%	> 98%	> 98%	> 98%	> 98%	> 98%
	RAO 4 Ecological Protection: seafood consumption for wildlife – river otter (HQ <1)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
	Does the alternative meet threshold criteria?	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Risk Reduction: predicted % of PCB SWAC reduction from baseline attributable to construction only (active remediation)	48%	58%	58%	62%	62%	69%	69%	73%	73%	73%	87%	87%
	Amount of Material Left In place: Monitoring and notification of waterway users based on total cap, ENR, and MNR area (acres)	No ICs	130	153 (23 CAD)	128	105	106	54	103	12	12	113 (in AOPC 1)[d]	16 (in AOPC 1)[d]
	Short-term Effectiveness												
	Impacts due to construction: transportation, truck, train miles[C]	n/e	510,000	250,000	460,000	640,000	600,000	990,000	630,000	1,250,000	940,000	1,370,000	2,940,000

Notes:

a The estimated range of costs are related only to the sediment cleanup actions; potential upland source control costs could be significant but are not included; EAA costs are also not included in Alternatives 2 through 6.

b The total managed area is 176 acres in AOPC 1 and 299 acres in AOPC 2, excluding 29 EAA acres.

c Short-term impacts to workers, the community, and the environment are proportional the volume of material managed and the length of construction. Transportation (truck and train miles) is a surrogate for total volume managed. It is one particular metric that affects the community. See Table 10-1 for other short-term metrics.

d Includes 19 acres of verification monitoring that are actively remediated in Alternative 6.

AOPC = area of potential concern; ARARs = applicable or relevant and appropriate requirement; BCM = bed composition model; C = combined technology; CAD = contained aquatic disposal; EAA = early action area; ENR = enhanced natural recovery; HQ = hazard quotient; ICs = institutional controls; MNR = monitored natural recovery; n/a = not applicable; n/e = not estimated; O&M = operations and maintenance; PCB = polychlorinated biphenyl; PRG = preliminary remediation goal; RAO = remedial action objective; RME = reasonable maximum exposure; R = removal emphasis; SQS = sediment quality standards; SWAC = spatially-weighted average concentration; T = treatment.

Figure 12-1 Comparative Analysis of Remedial Alternatives

Remedial Alternative	Cost (Net Present Value)	CERCLA Evaluation of Alternatives[a]					
		Meets Threshold Criteria[b]	Reduction in Toxicity, Mobility & Volume through Treatment [c]	Long-term Effectiveness	Short-term Effectiveness	Implementability	Cost [d]
1	$66 M	No	●	●	●	◒	◉
2R-CAD	$210 M	Yes	●	◒	◒	◒	◓
2R	$230 M	Yes	●	◒	◒	○	◓
3C	$220 M	Yes	●	○	◓	○	◓
3R	$290 M	Yes	●	○	◓	○	○
4C	$290 M	Yes	●	◓	◓	◓	○
4R	$440 M	Yes	●	◓	○	◓	◒
5C	$310 M	Yes	●	◓	◓	○	○
5R	$550 M	Yes	●	◉	◒	◒	◒
5R-Treatment	$600 M	Yes	◒	◉	◒	●	◒
6C	650 M	Yes	●	◓	◒	◒	◒
6R	$1,300 M	Yes	●	◉	●	●	●

Notes:

1. State, tribal, and community acceptance will be evaluated following formal public comment on the FS and EPA's proposed plan.

a Ratings based on rankings shown in Table 10-1.

b Threshold criteria are: 1) Overall Protection of Human Health and the Environment and 2) Compliance with ARARs.

c Treatment (soil washing) is a component of only Alternative 5R-T.

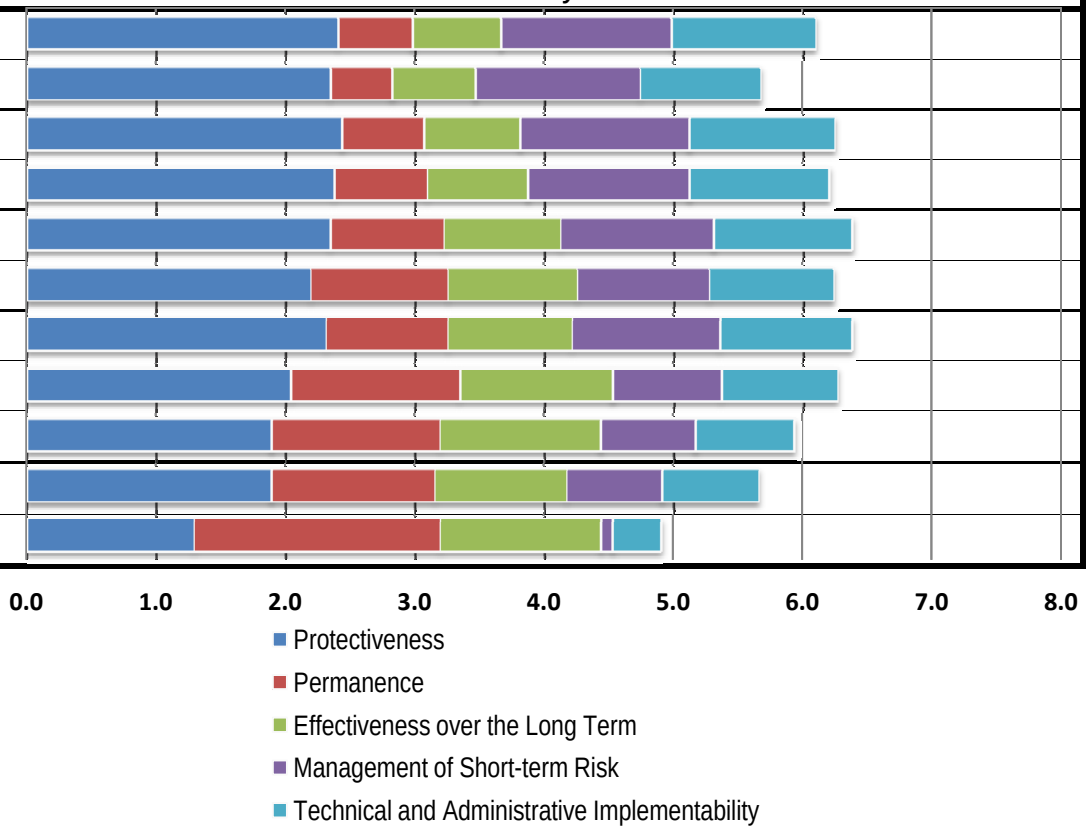
d Low costs are given a high rank and high costs are given a low rank.

◉ - Ranks very high compared to other alternatives
◓ - Ranks relatively high compared to other alternatives
○ - Ranks moderate compared to other alternatives
◒ - Ranks low-moderate compared to other alternatives
● - Ranks low compared to other alternatives

CAD = contained aquatic disposal; C = combined technologies; LDW = Lower Duwamish Waterway; R = removal emphasis

Figure 12-2 MTCA DCA Weighted Benefits for Individual Evaluation Criteria

Remedial Alternative	Actively Remediated Area (acres)[b]	Weighted Ratings and Benefits Under MTCA[a]	
		Benefit Score	Total Benefits by Criteria
2R	59	6.1	
2R-CAD	59	5.7	
3C	86	6.1	
3R	86	6.2	
4C	143	6.4	
4R	143	6.3	
5C	186	6.4	
5R	186	6.3	
5R-Treatment	186	5.9	
6C	328	5.6	
6R	328	4.8	



Notes:

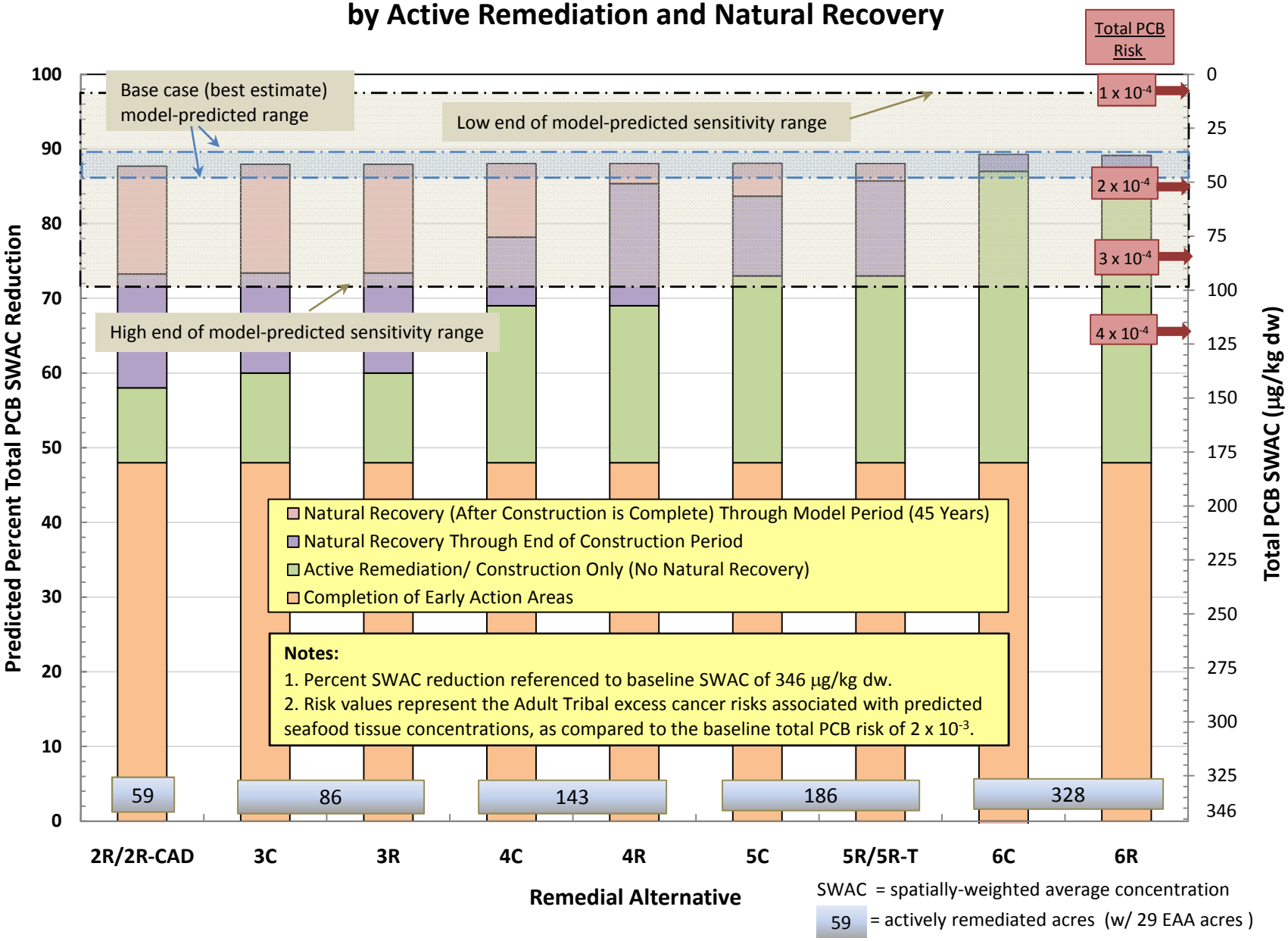
1. See Section 11 for details.

a Ratings based on rankings shown in Table 10-1.

b Includes 29 EAA acres.

C = combined technologies alternative; CAD = contained aquatic disposal; DCA = disproportionate cost analysis; MTCA = Model Toxics Control Act; R = removal emphasis.

Figure 12-3 Contributions to Reduction in Total PCB SWAC by Active Remediation and Natural Recovery



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