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

FINAL FEASIBILITY STUDY WORK PLAN
Lower Duwamish Waterway
Seattle, Washington

For Submittal to:

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

The Washington State Department of Ecology
Northwest Regional Office
Bellevue, WA

May 4, 2007

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Lower Duwamish Waterway
Seattle, Washington

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List of Acronyms

AOC	Administrative Order on Consent
AOPC	area of potential concern
ARAR	Applicable or Relevant and Appropriate Requirement
CAP	cleanup action plan
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System
CFR	Code of Federal Regulations
COC	chemical of concern
CSL	cleanup screening level
CSM	conceptual site model
CSO	combined sewer overflow
CTM	Candidate Technologies Memorandum
DRCC	Duwamish River Cleanup Coalition
DRET	dredging elutriate test
EAA	Early Action Area
EBDRP	Elliott Bay/Duwamish Restoration Program
Ecology	Washington State Department of Ecology
EFDC	Environmental Fluid Dynamics Code
ENR	enhanced natural recovery
EPA	United States Environmental Protection Agency
FS	feasibility study
FSWP	Feasibility Study Work Plan
ft	foot/feet
GIS	geographic information system
IDW	inverse distance weighting
LDW	Lower Duwamish Waterway
LDWG	Lower Duwamish Waterway Group
m	meter
MLLW	mean lower low water
MNR	monitored natural recovery

List of Acronyms

MTCA	Model Toxics Control Act
NCP	National Oil and Hazardous Substances Pollution Contingency Plan (referred to as the National Contingency Plan)
PCB	polychlorinated biphenyl
PPA	Potential Priority Area
PQL	practical quantitation limit
PRG	preliminary remediation goal
PSA	preliminary screening of alternatives
QEA	Quantitative Environmental Analysis LLC
RAL	remedial action level
RAO	remedial action objective
RBTC	risk-based threshold concentration
RCRA	Resource Conservation and Recovery Act
RETEC	The RETEC Group, Inc.
RI	remedial investigation
RI/FS	remedial investigation/feasibility study
RM	river mile
ROD	Record of Decision
SMA	sediment management area
SMS	Sediment Management Standards
SQS	sediment quality standard
SSPA	S.S. Papadopoulos and Associates, Inc.
SWAC	spatially weighted average concentration
TBC	to be considered
TSS	total suspended solids
USGS	U.S. Geological Survey
WAC	Washington Administrative Code
Windward	Windward Environmental LLC

1 Introduction

This document is the Feasibility Study Work Plan (FSWP) for the Lower Duwamish Waterway (LDW) Superfund Site in Seattle, Washington (Figure 1-1). The FSWP identifies the tasks that will be completed as part of the feasibility study (FS) for the LDW, as described in the Statement of Work for the study area (LDWG 2000).

The LDW is a saltwater wedge-type estuary influenced by river flow and tidal effects, both of which fluctuate seasonally. The LDW study area encompasses approximately 429 acres extending from the southern tip of Harbor Island (river mile [RM] 0.0) to just upstream of the upper turning basin (Figure 1-1). The LDW is approximately 5 miles (8 kilometers) long and has an average width of 440 feet (ft) (134 meters [m]). The LDW includes a federally maintained navigation channel; the authorized water depth within the navigation channel ranges from -30 ft mean lower low water (MLLW) near the mouth to -15 ft MLLW near RM 4.8 at the upper turning basin. Outside of the navigation channel, the LDW consists of shallow and deep bench areas; intertidal areas; recreational and habitat areas; and many shoreline structures, including bulkheads, banks armored with riprap, and over-water piers and buildings. Industrial land uses dominate the downstream areas of the LDW; some mixed commercial and recreational uses also occur. Land uses in the upstream areas of the LDW are mixed commercial and residential/ recreational. Remnant tidal marshes (totaling 5 acres) and intertidal mudflats (totaling 54 acres) are dispersed throughout the LDW, including several nearshore restoration areas.

1.1 Background and Regulatory Context

In December 2000, the City of Seattle, King County, the Port of Seattle, and the Boeing Company—collectively referred to as the Lower Duwamish Waterway Group (LDWG)—signed an Administrative Order on Consent (AOC) with the United States Environmental Protection Agency (EPA) and the Washington State Department of Ecology (Ecology) to conduct a remedial investigation/feasibility study (RI/FS) for the LDW. The LDW was subsequently added to EPA's National Priorities List (also known as Superfund) on September 13, 2001 (Comprehensive Environmental Response, Compensation, and Liability Information System [CERCLIS] No. WA0002329803). The LDW was added to Ecology's Hazardous Sites List on February 26, 2002 (FS ID 4297743).

In 2003, a Phase 1 remedial investigation (RI) was prepared based on existing information (Windward 2003a). The Phase 1 RI included both a preliminary human health risk assessment and a preliminary ecological risk assessment. In the following years, additional data were collected to address RI/FS data needs. The Phase 2 RI, which will include baseline human health and ecological risk assessments and the draft final *Sediment Transport Analysis Report* (Windward Environmental LLC [Windward] and Quantitative Environmental Analysis LLC [QEA] 2007), is currently being developed. To meet the project schedule, this FSWP is being developed before the Phase 2 RI tasks are complete.

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 potential response actions identified in the FS must comply with both the federal and state acts. The specific documents defining the conduct of the overall FS process include the following:

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

- Clarification of Feasibility Study Requirements (LDWG 2003), a clarification letter from LDWG to EPA and Ecology dated December 4, 2003.

In addition, the following regulations and guidance documents are relevant to the FS process:

- CERCLA

    - National Oil and Hazardous Substances Pollution Contingency Plan (40 Code of Federal Regulations [CFR] Part 300), referred to herein as the National Contingency Plan (NCP)

    - *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (EPA 1988)

    - *A Guide on Remedial Actions at Superfund Sites with PCB Contamination* (EPA 1990)

    - *Risk Assessment Guidance for Superfund: Volume 1—Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals)* (EPA 1991a)

    - *Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions* (EPA 1991b)

    - *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)
  - ► *Supplemental Guidance to RAGs: Region 4 Bulletins, Human Health Risk Assessment Bulletins* (EPA 2000a)
  - ► *A Risk Management Strategy for PCB-Contaminated Sediments* (NRC 2001)
  - ► *Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites* (EPA 2002a)
  - ► *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (EPA 2005)
- MTCA
  - ► MTCA regulations for the selection of cleanup actions and content of an FS, including: (1) the *Model Toxics Control Act Cleanup Regulation*, Washington Administrative Code (WAC) Chapter 173-340 (Ecology 2001), and (2) the *Sediment Management Standards* (SMS), WAC 173-204 (Ecology 1995)
  - ► *Sediment Cleanup Standards User Manual* (Ecology 1991).

In addition to the above-listed documents, various documents related to engineering evaluation/cost analysis, remedial design, permitting, and construction/post-construction monitoring have been prepared for early and final remedial actions within and adjacent to the LDW. These documents, including those prepared for the Norfolk, Boeing Plant 2, Terminal 117, Slip 4, Duwamish/Diagonal, Lockheed Shipyard, Todd Shipyard, and East Waterway areas, are also relevant to the conduct of the FS[1].

The FS will address the LDW as a whole (i.e., on a waterway-wide basis), as indicated in the December 4, 2003 clarification letter. The FS will identify and screen remedial alternatives based on the general range of LDW sediment characteristics, LDW conditions, and the chemicals of concern (COCs) refined in the Phase 2 RI. This detailed analysis of remedial alternatives will provide the information necessary to formulate a proposed cleanup plan for public comment.

EPA and Ecology will select a final cleanup remedy for the site. Pursuant to WAC 173-340-380, Ecology must issue a cleanup action plan (CAP) whereas

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[1] Documents from all these projects may contain relevant engineering information, although not all the projects were performed under MTCA or CERCLA orders. The Boeing Plant 2 sediment remediation work was done under a RCRA order. The Norfolk and Duwamish/Diagonal sediment remediation projects were done as part of the Elliot Bay/Duwamish Restoration Program (EBDRP), as interim cleanup actions under the MTCA voluntary cleanup program.

under 40 CFR 300.430, EPA must document its decision in a Record of Decision (ROD). A MTCA CAP and a CERCLA ROD are functionally equivalent, and EPA and Ecology could combine the CAP and the ROD into one decision document for the LDW.

1.2 Definitions for the Feasibility Study

Key terms used in the FS to discuss chemical concentrations and various spatial areas are defined below. Some of these terms are site-specific definitions but most are directly from CERCLA or MTCA regulations or guidance documents. Where new definitions are presented, references to similar terms are provided when applicable.

1.2.1 Regulatory Terms

Cleanup levels represent COC concentrations in environmental media and are required under both CERCLA and MTCA for each COC, receptor, and exposure pathway identified in the human health and ecological risk assessments. 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. The terms that will be used in the FS are presented below along with the appropriate CERCLA or MTCA regulatory citation. Appendix A provides a comparison of the regulatory terms under CERCLA and MTCA.

Chemicals of Concern (COCs) are a defined subset of the chemicals of potential concern that were quantitatively evaluated in the risk assessments 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 will use 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). Following CERCLA guidance, natural background concentrations will be used in the evaluation of cleanup levels as a lower limit below which cleanup levels cannot be achieved (EPA 2005). Similarly, MTCA cleanup levels are not set at concentrations below natural background concentrations (WAC 173-340-705(6)).

Area Background is a term specific to MTCA used to represent those concentrations 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; the cleanup action is then considered an interim action until cleanup levels are attained. 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. This FS will use the term area background.

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 be modified based on "factors related to technical limitations such as detection/quantification limits for contaminants." The term PQL is synonymous with quantitation limit and reporting limit.

Remedial Action Objectives (RAOs) describe what the proposed sediment cleanup 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 risk assessments and are based on the exposure pathways and receptors and the identified COCs. Narrative RAOs form the basis for establishing preliminary remediation goals (PRGs; defined below). RAO is a common CERCLA term. There is no comparable term under MTCA, although the specified exposure conditions used to develop RAOs may also be applied to develop a "modified Method B cleanup level" under MTCA if the criteria specified in WAC 173-340-708 are met. The FS will present draft RAOs; final RAOs will be identified by EPA and Ecology in the ROD.

Risk Drivers are used in the FS to indicate the subset of COCs identified in the risk assessments as accounting for the principal risks[2]. Risk drivers as used herein 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).

Preliminary remediation goals (PRGs) will be developed only for the risk drivers. Other COCs not designated as risk drivers may be evaluated in one or more of the following ways: (1) assessment of reductions in sediment concentrations or residual risks from these chemicals following the identification of the recommended remedial alternative in the FS; (2) review

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

of any new toxicological effects data, as part of the 5-year review that is conducted once a CERCLA cleanup of completed; and (3) consideration of these chemicals in the post-cleanup monitoring program.

Preliminary Remediation Goals (PRGs) are specific statements of the 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 preliminary site information (EPA 1997b).

PRGs are intended to be protective of human health and the environment and comply with chemical-specific applicable or relevant and appropriate requirements (ARARs) (EPA 1991a). PRGs specify the desired endpoint concentration or risk level (EPA 1997b) and provide numerical concentrations or ranges of concentrations in environmental media that are designed to protect a particular exposure pathway and receptor. For the FS, PRGs will be expressed as sediment concentrations for the risk drivers and will be established considering risk-based threshold concentrations (RBTCs), ARARs, background concentrations, PQLs, and the sediment quality standards (SQS) and cleanup screening levels (CSLs) of the SMS. PRG is a term under CERCLA that has no specific parallel in MTCA other than the previously referenced "modified Method B cleanup level." PRGs will be presented in the FS and will be finalized into cleanup levels (defined below) by EPA and Ecology in the ROD.

Remedial Action Levels (RALs) are chemical-specific sediment concentrations that might trigger the need for *active* remediation (e.g., dredging or capping). Under CERCLA, RALs are defined as the "not-to-exceed" level (EPA 2000a) or the concentration above which remedial action would be needed to reduce concentrations in sediment sufficiently to reach a target risk level within a specified restoration time frame. This term will be used in the FS and have the same meaning as **remediation level** under MTCA, 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 plan" (except that MTCA includes monitored natural recovery under remediation levels). For the purposes of this FS, a range of RALs will be developed for risk drivers, such as total polychlorinated biphenyls (PCBs). Different areas of the LDW may have different RALs depending on the magnitude of risk, rate of natural recovery, and land use (e.g., a high-value shoreline area with recreational access). In addition, different RALs may be identified for different types of remedial actions, such as dredging or enhanced natural recovery (ENR).

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 ten after completion of the active cleanup action" (WAC 173-204-570(3)). The term cleanup level may be used in the FS, but final cleanup levels will be defined in the ROD by EPA and Ecology.

1.2.2 Application of Regulatory Terms

EPA and Ecology will select the final, chemical-specific sediment RAOs and cleanup levels after considering the analyses presented in the FS and public comments (EPA 1999). RAOs, PRGs, and cleanup levels are normally dependent upon each other and represent three steps in the continuum leading from RI/FS scoping to the selection of a final cleanup action that will be protective of human health and the environment, meet ARARs, and provide the best balance among the FS evaluation criteria (EPA 2005). The agencies' selection of RAOs and cleanup levels will likely involve weighing a number of site factors, including:

- Uncertainty factors
- 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 SMS (WAC 173-204)
- Selection factors provided in the *Sediment Cleanup Standards User Manual* (Ecology 1991; note: this guidance is under revision).

1.2.3 Sediment Concentrations

Sediment concentrations will be expressed and evaluated in the FS in two ways: as individual point concentrations or as spatially weighted average concentrations (SWACs). Risk-based threshold concentrations (RBTCs) will be developed in the Phase 2 RI and may be expressed as either point concentrations or SWACs.

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., benthic organisms with small home ranges). Point concentrations usually pertain to smaller-scale management areas for the protection of benthic communities under the SMS.

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, waterway-wide SWACs may be appropriate for estimating risks attributable to human consumption of English sole, but not for risks from consumption of clams (which are present only in certain areas) or for risks from direct human contact with sediments during clamming or beach play (which have smaller exposure areas). 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.

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 will be derived from the risk assessments and presented in the Phase 2 RI. RBTCs will be used along with other site information to set PRGs (defined above) in the FS.

1.2.4 Spatial Areas

Relevant definitions of different spatial areas that have been used previously in the LDW RI/FS process are described below, along with definitions that will be used moving forward in the FS. These definitions are used to describe areas likely to require remediation.

Early Action Areas (EAAs) are areas where active management is required to reduce unacceptable risks in surface sediments. Candidate EAAs were initially identified by LDWG (Windward 2003b) early in the RI/FS process and are listed below:

- Duwamish/Diagonal
- Slip 4
- Terminal 117
- Boeing Plant 2
- Norfolk Area
- RM 2.2 west
- RM 3.8 east.

These EAAs are being addressed either as sediment restoration projects under the Elliott Bay/Duwamish Restoration Program (EBDRP) (Duwamish/ Diagonal); as a voluntary cleanup program action under MTCA (the Boeing South Storm Drain within the Norfolk Area); as non-time-critical removal actions under CERCLA (Slip 4 and Terminal 117); as a corrective action under the Resource Conservation and Recovery Act (RCRA) (Boeing Plant 2); and/or as part of the FS.

In addition, EBDRP implemented a sediment restoration project at the Norfolk combined sewer overflow (CSO) area, which is within the Norfolk Area. This effort was completed in 1999 before the LDW was listed as a Superfund site, and therefore the Norfolk CSO sediment restoration project was not included as an EAA. The larger Norfolk Area encompasses the Norfolk CSO, the Boeing South Storm Drain, and any remaining areas immediately adjacent to these cleanup actions. All EAAs are included in this FS as part of the overall CERCLA effort. However, remedial alternatives for EAAs that either have been already addressed or are currently being addressed will not be evaluated to the same level of detail in the FS, because they were previously evaluated in either engineering evaluation/cost analysis reports, Corrective Measures Studies, or other similar documents (e.g., Integral 2006; King County 2000, 2003; MCS Environmental, Inc. and Floyd|Snider, Inc. 2006; The RETEC Group, Inc. [RETEC] 2006a; Project Performance Corporation 2003). Areas outside of the boundaries of cleanups or current cleanup plans for the EAAs will be addressed in the FS.

The two EAAs that have not been addressed, RM 2.2 west and RM 3.8 east, will be considered areas of potential concern (AOPCs; defined below) for further analysis in the FS. Depending on the evaluation of the Phase 2 RI data, their boundaries may be refined in the FS. Remedial actions for these two EAAs will be evaluated in the FS.

Potential Priority Areas (PPAs) are similar to EAAs but were not defined at the time the EAAs were identified (Windward 2003b). Instead, the PPAs were identified in the draft *Preliminary Screening of Alternatives Memorandum* (PSA; RETEC 2006b) as areas with unacceptable risks, based on criteria similar to those used earlier to identify the EAAs. PPAs will likely become AOPCs (defined below) in the FS following the outcome of the RAO and PRG process. Moving forward, the term AOPC will be used in the FS.

Areas of Potential Concern (AOPCs) represent the areas of surface sediment with unacceptable risks. AOPCs will be delineated using sediment PRGs and other applicable risk information (e.g., current or future exposure pathways). In the FS, AOPCs may include the EAAs identified at RM 2.2 west and RM 3.8 east, the areas previously identified in the draft PSA (RETEC 2006b) as PPAs, and any additional areas identified through the Phase 2 RI data compilation and the baseline human health and ecological risk assessments (and taking into consideration the sediment transport modeling results) as representing unacceptable risks that will likely require some form of remediation.

Sediment Management Areas (SMAs) are defined as areas and volumes of contaminated sediment (EAAs, individual AOPCs, or portions of AOPCs) to which one type of management method will be applied. SMAs are equivalent to “site units” under SMS (WAC 173-204-200(25)). Each management method employed at an SMA will be selected based on physical, chemical, biological, and engineering factors (EPA 1988, Ecology 1991). Although the same RALs will be applied throughout a given SMA, different SMAs may have different RALs applied to them depending on different factors, such as the level of risks, sediment stability, land use considerations, and expected recovery time. SMAs may be further divided into smaller units based on design-level data regarding physical site conditions; however, these subdivisions are beyond the scope of this waterway-wide FS.

1.3 Road Map through the FS Process

The purpose of an FS is to develop and evaluate a number of alternative methods for achieving the RAOs at a contaminated site. This process lays the groundwork for proposing a selected remedy that best eliminates, reduces, or controls risks to human health and the environment. The road map through this process includes several FS 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 Phase 2 RI, the human health and ecological risk assessments, and related documents, as well as refining the physical conceptual site model (CSM) as part of the FS

- Establishing RAOs and associated PRGs

- Estimating volumes and areas of sediment with COC concentrations above RALs that are appropriate for the application of sediment remedial approaches

- Identifying and screening general response actions, remedial technology types, and specific process options best suited to site conditions

- Assembling the technology types and process options into site-wide remedial alternatives and then completing the screening and final assembly of remedial alternatives

- Completing a detailed evaluation and comparative analysis of retained remedial alternatives, concluding with a recommended preferred remedy.

Many of the important work products needed to complete the required technical memoranda and the FS are described in the Lower Duwamish Waterway AOC including Attachment A, the *Lower Duwamish Waterway Remedial Investigation/Feasibility Study Statement of Work* (EPA Docket No. CERCLA 10-2001-0055 and Ecology Docket No. 00TCPNR-1895), and the

Remedial Investigation/Feasibility Study Integration Memorandum (RETEC 2005a). Section 2.1 summarizes these work products and describes how they integrate into the FS report. Figure 1-2 outlines the general information flow from the Phase 2 RI into the FS. Table 1-1 lists the key CERCLA and MTCA steps in the FS process and the FS documents that address each step. Section 4.3 lists key FS deliverables.

1.3.1 Integration of CERCLA and MTCA

The RI/FS is being conducted under both CERCLA and MTCA authorities. Any potential response action identified in the FS must comply with both acts. In addition, MTCA regulations incorporate the SMS regulations by reference, and the SMS will also be applied in developing RAOs and PRGs for the site.

Table 1-2 compares the major criteria used to select a remedial action under CERCLA with the corresponding requirements under MTCA. Additional comparisons are provided in the tables in Appendix A. Although many CERCLA requirements have MTCA counterparts, there are some important differences. Both CERCLA and MTCA have threshold requirements that must be met by a remedial or cleanup action — namely, that such an action must be protective of human health and the environment and that it must comply with ARARs, cleanup standards, and relevant state and federal laws. However, in addition to these shared threshold criteria, MTCA requires a specific demonstration that the proposed remedy provides for compliance monitoring. Compliance monitoring is also required for remedial actions under CERCLA; however, it is only required whenever hazardous substances remain on site at levels that do not allow unrestricted use or unrestricted exposure. MTCA's implementing regulations require a specific discussion of the nature of that monitoring in making a cleanup decision.

CERCLA and MTCA also share the same balancing criteria for choosing a remedial/cleanup action, but the frameworks for considering those criteria are different under the two acts. For instance, CERCLA prescribes five balancing criteria: long-term effectiveness and permanence; reduction of toxicity, mobility, or volume through treatment; short-term effectiveness; implementability; and cost. In effect, these five criteria are to be balanced in making a remedial decision. In contrast, MTCA requires that cleanup actions use permanent solutions to the maximum extent practicable and also requires a long-term monitoring plan. When making a determination of whether a cleanup action uses permanent solutions to the maximum extent practicable under MTCA, a disproportionate cost analysis is applied that takes into account criteria that are essentially the five CERCLA balancing criteria identified above.

CERCLA also contains two modifying criteria: (1) state and tribal acceptance, and (2) community acceptance. MTCA provides for consideration of local, state, federal, tribal, and community acceptance as part of the disproportionate cost analysis.

In addition, MTCA prescribes one additional requirement—providing for a reasonable restoration time frame. Under CERCLA, this consideration is evaluated under the *short-term effectiveness* criterion specifically as the estimated time to achieve RAOs. Therefore, in conducting an FS that complies with both MTCA and CERCLA, the requirement for a reasonable restoration time frame could be analyzed and met using a synthesis of existing data and analyses contained in other parts of the FS.

Appendix A presents a detailed comparison of CERCLA and MTCA criteria, as well as SMS criteria where they apply.

1.3.2 Pre-Feasibility Study Work Plan Memoranda

Three FS memoranda were produced before this FSWP:

- *Remedial Investigation/Feasibility Study Integration Memorandum for the Lower Duwamish Waterway Superfund Site* (referred to herein as the RI/FS Integration Memorandum) (RETEC 2005a)
- *Identification of Candidate Cleanup Technologies Memorandum for the Lower Duwamish Waterway Superfund Site* (referred to herein as the Candidate Technologies Memorandum, or the CTM) (RETEC 2005b)
- The *Preliminary Screening of Alternatives Memorandum, Lower Duwamish Waterway Superfund Site, Draft* (referred to herein as the draft PSA) (RETEC 2006b).

Each of these documents is briefly summarized below.

RI/FS Integration Memorandum

The *RI/FS Integration Memorandum* (RETEC 2005a) provides a road map to the FS process and demonstrates how specific activities, memoranda, and decision points associated with the Phase 2 RI, the FSWP, and the FS will be conducted. It identifies where the FS process can be advanced while data collection and analyses for the Phase 2 RI are ongoing. It presents the process for providing FS-related input to the Phase 2 RI; describes the CTM, PSA, and FSWP; and outlines the technical sections of the FS. EPA approved the *RI/FS Integration Memorandum* on June 7, 2005.

Candidate Technologies Memorandum

The CTM (RETEC 2005b) presents an initial evaluation and screening of remedial technologies and their applicability to the LDW based on the criteria of implementability and effectiveness. Both *in situ* and *ex situ* remedial technologies were compiled and evaluated in the CTM, reflecting a wide range of preliminary sediment cleanup technologies that are consistent with both CERCLA and MTCA guidance. Preliminary candidate technologies identified in the CTM included isolation capping, reactive caps, partial dredging and capping, ENR, and monitored natural recovery (MNR). Potential candidate treatment technologies included solidification; stabilization; high-temperature thermal desorption; vitrification; solvent extraction; and segregation, separation, and consolidation technologies.

Additional detailed review of one technology, the Biogenesis™ process, was done as part of the CTM (RETEC 2005b) and the T-117 Engineering Evaluation/Cost Analysis (Windward; Dalton, Olmstead and Fugelvand; and Onsite Enterprises, Inc. 2005). The Biogenesis™ process is a patented soil washing process that the Duwamish River Cleanup Coalition (DRCC) has recommended for use in the LDW. A separate evaluation entitled *Technical and Policy Issues Associated with the Use of the Biogenesis™ Process of the Treatment of LDW Sediment* was submitted to EPA and Ecology (RETEC and Integral 2005). That paper summarized the technical and policy considerations related to the possible use of the Biogenesis™ process for the treatment of contaminated sediments that are dredged from the LDW, with an emphasis on upcoming early actions at T-117 and Slip 4. In addition, a public meeting was held in June 2006 that included Eric Stern of the EPA's NY/NJ Harbor Sediment Decontamination Program, Dr. Charles Wilde of the Biogenesis Corporation, EPA, Ecology, LDWG, the Corps of Engineers, DRCC, and other interested parties.

EPA approved the CTM on December 14, 2005. Although the CTM has been approved, the FS will incorporate any new, relevant information developed after the CTM approval date in its evaluation of cleanup technologies (e.g., results from the NY/NJ Harbor sediment decontamination studies) as appropriate.

Draft Preliminary Screening of Alternatives

The draft PSA (RETEC 2006b) assembles potentially applicable technologies retained in the CTM into a set of representative site-wide remedial alternatives. The draft PSA builds on the CTM and generally follows CERCLA and MTCA guidance for selecting and screening representative remedial alternatives considering their implementability, effectiveness, and cost. The draft PSA acknowledges that site conditions used to delineate these remedial alternatives may vary, particularly in intertidal areas, and that different remedial technologies or alternatives may be more or less appropriate at specific areas of the site.

The draft PSA used a preliminary (December 2005) dataset to map chemical concentrations and identify approximate remedial areas under various remediation scenarios. The draft PSA fulfilled the AOC's requirement for development and preliminary screening of alternatives, as established in the *RI/FS Integration Memorandum* (RETEC 2005a).

The draft PSA identified several site-wide remedial alternatives that should be carried forward and refined in the FS. A draft version of this memorandum was submitted to EPA on September 27, 2006. Although the draft PSA will not be finalized, its contents will be further developed through the FS process.

1.3.3 Post-Feasibility Study Work Plan Deliverables

As discussed in Section 1.1, information generated in the Phase 2 RI and risk assessments has been and will continue to be iteratively incorporated into a series of technical memoranda and/or discussions that will culminate in a draft FS. The next step in the FS process is to develop a set of ARARs, RAOs, and PRGs in accordance with CERCLA and MTCA requirements that can be used to define preliminary RALs and SMAs. Following that step, remedial alternatives will be assembled to address recommended RALs at the individual SMAs. The remedial alternatives will be evaluated against the nine CERCLA FS criteria (EPA 1988) and the MTCA requirements for selection of a cleanup action (WAC 173-340-360). These steps will be described in the following additional FS deliverables:

- A draft RAO memorandum, which will be finalized in the FS
- A draft Sediment Transport Modeling Report, which will be finalized in the FS and used in the FS to evaluate sediment stability and restoration time frames
- A draft and final FS report.

The contents of these deliverables are described in Sections 2.4 through 2.10 relative to the FS process. The associated format and schedule are described in Sections 4.3 and 5 of this FSWP. An additional deliverable, the Development, Screening, and Final Assembly of Alternatives Memorandum, which was originally described in the *RI/FS Integration Memo,* has been removed from the list of FS deliverables by agreement with EPA and Ecology. Instead, LDWG, EPA, and Ecology have agreed to a series of meetings to discuss key milestones in the FS process (i.e., PRGs, RALs, and SMA development). These meetings will provide feedback to the FS process.

Four milestone meetings are planned at key check-in points in the FS process to ensure that EPA and Ecology's concerns and input are discussed. Each milestone meeting will be preceded by submittal of an agenda and draft technical supporting data, such as tables and maps. Figure 1-3 illustrates the timing of the four milestone meetings and the anticipated topics of discussion at each (see also Table 1-1). Figure 1-3 also shows two additional technical meetings that will be used to present specific findings to EPA and Ecology in a timely manner.

In addition to the milestone and technical meetings, EPA, Ecology, and LDW stakeholders will have quarterly meetings throughout the FS process. LDWG will present technical data at these meetings to brief the stakeholders on work that is under way. The draft RAO memorandum, the draft Sediment Transport Modeling report, and the draft FS will be available to the stakeholders concurrent with the submittal of those documents to EPA and Ecology.

1.3.4 Feasibility Study Objectives and Tasks

This FSWP presents tasks and procedures for developing the FS. Concepts and data derived from the pre-FSWP memoranda (Section 1.3.2) provide the basis for the design and scope of the FSWP. The following key tasks will be completed in developing the FS:

1) Identify ARARs and develop RAOs and associated PRGs

2) Identify AOPCs and volumes using the results of the ongoing Phase 2 RI and risk assessment work

3) Taking into consideration net environmental benefits, estimated restoration time frames, and costs, evaluate a range of PRGs and alternatives that are implementable and that satisfy remedial action objectives, as generally defined in the NCP, MTCA, SMS, and the *Sediment Cleanup Standards User Manual* (Ecology 1991)

4) Evaluate the effectiveness of the potential remedial alternatives and the potential for natural recovery and recontamination using appropriate predictive models and empirical evidence

5) Identify SMAs and RALs that consider site risks, practicability, estimated restoration time frames, technical feasibility, net environmental effects and benefits, cost-effectiveness, and future land use needs, as described in the NCP, MTCA, SMS, and the *Sediment Cleanup Standards User Manual* (Ecology 1991)

6) Complete the final assembly of remedial alternatives using the information developed during the above-listed Tasks 1 through 5 and the alternatives retained in the draft PSA (RETEC 2006b)

7) Present a detailed evaluation and comparative analysis of the retained remedial alternatives, considering the remedy evaluation criteria in CERCLA and MTCA.

The CSM, PRGs, and preliminary RALs will continue to be refined throughout the FS process, and final determination of RAOs, cleanup levels, and RALs will be made in the ROD.

Section 2 presents the scope of work for completing the FS tasks. As part of the RI/FS integration process for this project, Section 3 presents the anticipated FS data needs associated with these tasks. The data necessary to complete these evaluations will be presented in the Phase 2 RI, the risk assessments, and the draft Sediment Transport Modeling Report. All field data collected under the AOC to date, including the additional Round 3 surface sediment data that resulted from a sampling event that was conducted in October 2006, have been reported in separate data reports.

1.4 Document Organization

The remainder of this document is organized as follows:

- Section 2 presents the scope of work and process for completing the FS tasks
- Section 3 presents an updated physical CSM and an evaluation of data needs for the FS
- Section 4 presents the project management plan for the FS, including major deliverables
- Section 5 summarizes the schedule of activities, major deliverables, and milestones
- Section 6 presents the references cited in this document
- Appendix A presents a comparative analysis of remedy selection criteria under CERCLA and MTCA
- Appendix B presents a technical memorandum developed by LDWG outlining the proposed scope of work for additional modeling and the draft Sediment Transport Modeling Report
- Tables and figures appear at the end of the sections in which they are first discussed.

Table 1-1 Feasibility Study Steps and Key Deliverables

CERCLA and MTCA RI/FS Steps	LDW RI/FS Work Products								
	Phase 2 RI, HHRA, and ERA (in progress)	**CTM***	**PSA***	**FSWP**	**Draft RAO Memo**	**Technical and Milestone Meetings**	**Sediment Transport Analysis Report****	**Draft Sediment Transport Modeling Report*****	**Feasibility Study Report**
Characterize the nature and extent of chemical contamination	**X**								
Evaluate site risks	**X**								
Develop and refine the conceptual site model	**X**						**X**	**X**	**X**
Screen technologies		**X**							**(1)**
Preliminarily screen alternatives			**X**						**X**
Document scope of FS and evaluate FS data needs				**X**					
Develop ARARs and RAOs					**X**	**X**			**X**
Develop PRGs						**X**			**X**
Evaluate sediment transport/stability and incoming sediment deposition						**X**		**X**	**X**
Identify AOPCs						**X**			**X**
Identify RALs						**X**			**X**
Identify SMAs						**X**			**X**
Evaluate natural recovery						**X**			**X**
Assemble final remedial alternatives						**X**			**X**
Conduct detailed evaluation of remedial alternatives									**X**

Table 1-1 Feasibility Study Steps and Key Deliverables

CERCLA and MTCA RI/FS Steps	LDW RI/FS Work Products								
	Phase 2 RI, HHRA, and ERA (in progress)	**CTM***	**PSA***	**FSWP**	**Draft RAO Memo**	**Technical and Milestone Meetings**	**Sediment Transport Analysis Report****	**Draft Sediment Transport Modeling Report*****	**Feasibility Study Report**
Conduct comparative analysis of remedial alternatives						X			X
Identify a preferred remedy						X			X

Notes:

Definitions: ARAR = Applicable or Relevant and Appropriate Requirement; CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act; CTM = Candidate Technologies Memorandum; ERA = ecological risk assessment; FS = feasibility study; FSWP = Feasibility Study Work Plan; HHRA = human health risk assessment; MTCA = Model Toxics Control Act; PRG = Preliminary Remediation Goal; PSA = Preliminary Screening of Alternatives Memorandum; RAL = Remedial Action Level; RAO = Remedial Action Objective; RI = remedial investigation; RI/FS = remedial investigation/feasibility study; SMA = Sediment Management Area

* = document already submitted to agencies (pre-FSWP deliverables)

** = draft final document submitted in January 2007

*** = output from this modeling will be used in the AOPC development and MNR analysis of the FS.

(1)The FS may present revisions to the technology screening if significant new information has become available since the CTM was published.

Table 1-2 Comparison of CERCLA and MTCA Remedial Alternative Screening Criteria

	CERCLA[1] Requirement		MTCA Requirement[2]
MTCA Minimum Requirements and CERCLA Threshold Criteria	Overall protection of human health and the environment 40 CFR 300.430(e)(9)(iii)(A)	• How alternative provides human health and environmental protection	The first threshold requirement under MTCA is to protect human health and the environment (WAC 173-340-360(2)(a)(i)); also a component of setting cleanup levels (WAC 173-340-700(2)).
	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 guidances	MTCA's second threshold requirement is compliance with cleanup standards, and the third requirement is compliance with state and federal laws (WAC 173-340-360(2)(a)(ii)-(iii)).
	Compliance Monitoring	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)).
MTCA Other Requirements and CERCLA Primary Balancing Criteria	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)). Practicability is determined using a disproportionate cost analysis (WAC 173-360-340(3)(e)). Part of the disproportionate cost analysis is evaluating "effectiveness over the long term," which includes the same criteria used under CERCLA for evaluating long-term effectiveness and permanence (WAC 173-340-360(3)(f)(iv)).
	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 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)(ii)). MTCA's individual criteria in evaluating permanence correspond to CERCLA's criteria on evaluating the reduction of toxicity, mobility, or volume — following CERCLA's requirements should cover MTCA's requirements.

Table 1-2 Comparison of CERCLA and MTCA Remedial Alternative Screening Criteria

	CERCLA[1] Requirement		MTCA Requirement[2]
MTCA Other Requirements and CERCLA Balancing Criteria	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	Provide for a reasonable restoration time frame WAC 173-340-360 (2)(b)(ii) 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)(ii)).
	Implementability 40 CFR 300.430(3)(9)(F)(1)-(3) (technical feasibility, administrative feasibility, availability of services and materials)	• 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 other agencies • 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)).
	Cost 40 CFR 300.430(e)(9)(G)(1)-(2)	• Capital costs, direct and indirect • Operating and maintenance costs • Net present value of capital and O&M cost	MTCA includes similar cost considerations in the disproportionate cost analysis. However, MTCA provides a bit more detail in its requirements, including breaking out the pretreatment, analytical, labor, and waste management costs associated with treatment technologies and taking into account the design life of a cleanup action, including the costs to replace or repair major elements (WAC 173-340-360(3)(f)(iii)).

Table 1-2 Comparison of CERCLA and MTCA Remedial Alternative Screening Criteria

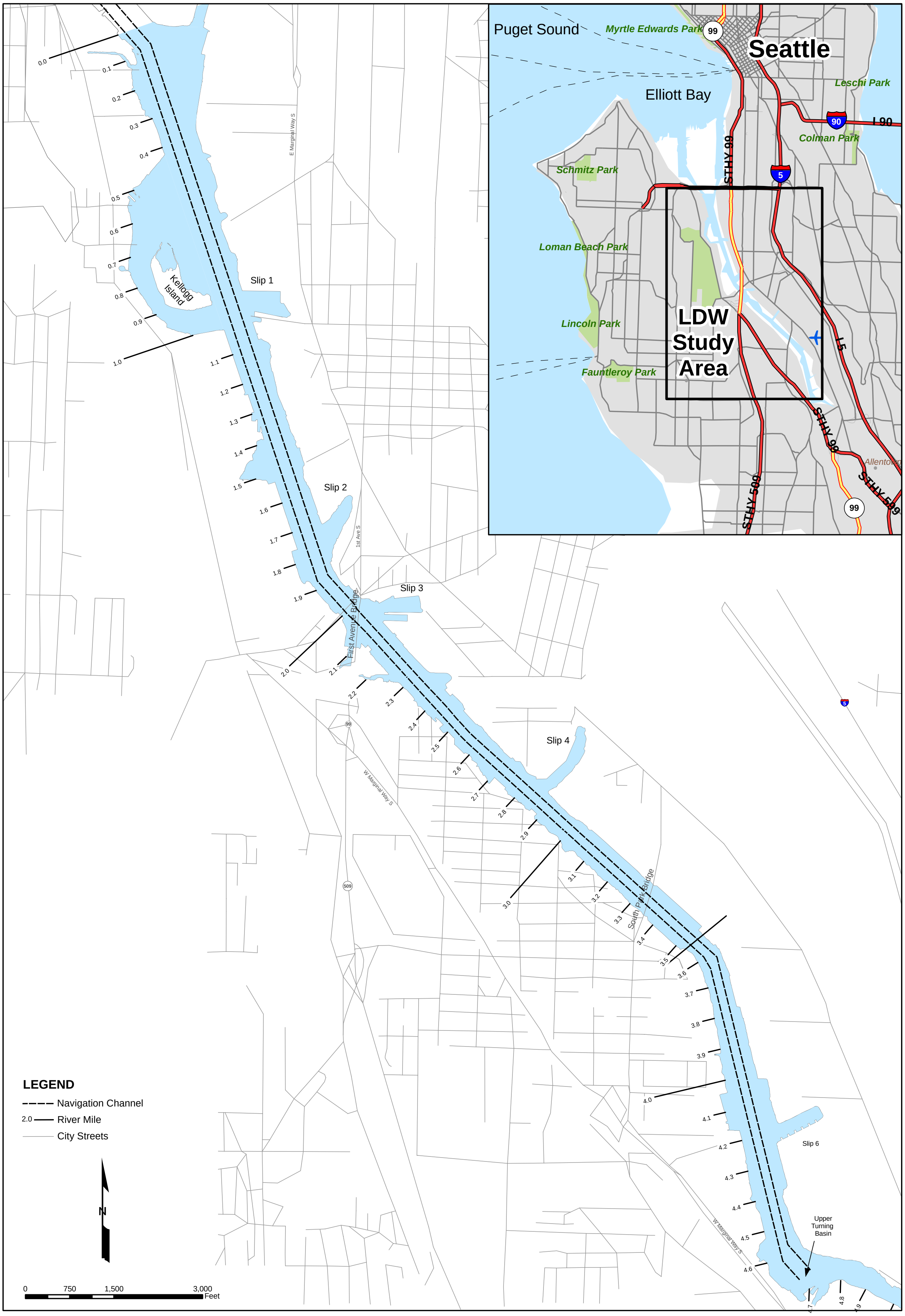
	CERCLA[1] Requirement		**MTCA Requirement[2]**
CERCLA Modifying Criteria	Community acceptance 40 CFR 300.430(e)(9)(I)	Completed after the public comment period but may be discussed in the proposed plan issued for public comment.	MTCA requires consideration of public concerns solicited throughout the 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)
	State and Tribal acceptance 40 CFR 300.430(e)(9)(H)		

Notes:

CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act; CFR = Code of Federal Regulations; MTCA = Model Toxics Control Act; O&M = operations and maintenance; WAC = Washington Administrative Code

Sources:

1. EPA 1988. *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA*. Interim Final. EPA/540/G-89/004. October 1988.
2. Ecology 2001. *Model Toxics Control Act Cleanup Regulation*. Chapter 173-340. Amended February 12, 2001.



1. Basemap provided by Windward Environmental, LLC and ESRI StreetMap USA.

D

RETEC

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

LDW
DRAFT FEASIBILITY STUDY WORK PLAN
(PORS5-18220-623)

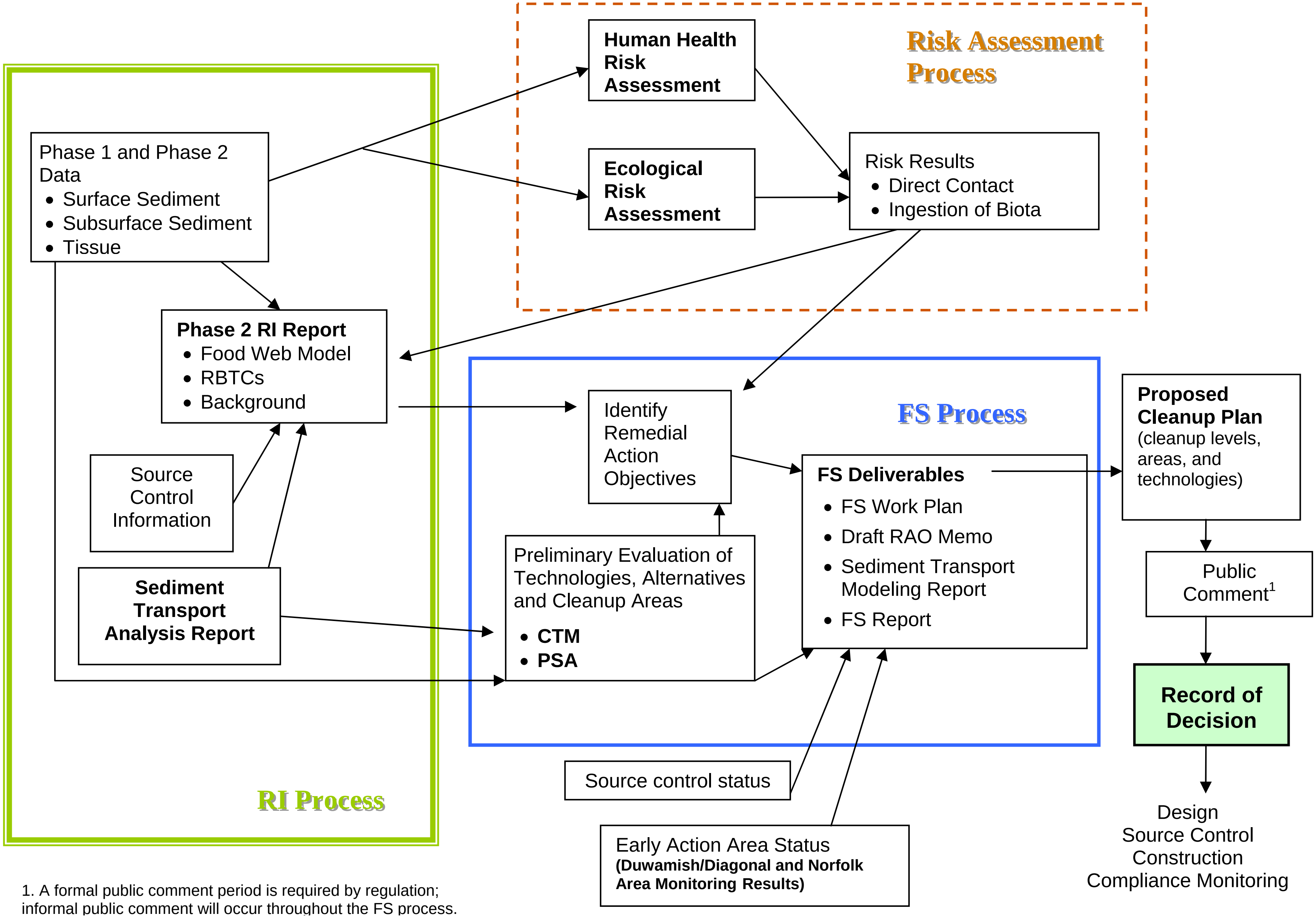
LOWER DUWAMISH WATERWAY REMEDIAL INVESTIGATION AND FEASIBILITY STUDY AREA

DATE: 10/16/06 | DWN. BY: KBL/ftc

FIGURE 1-1

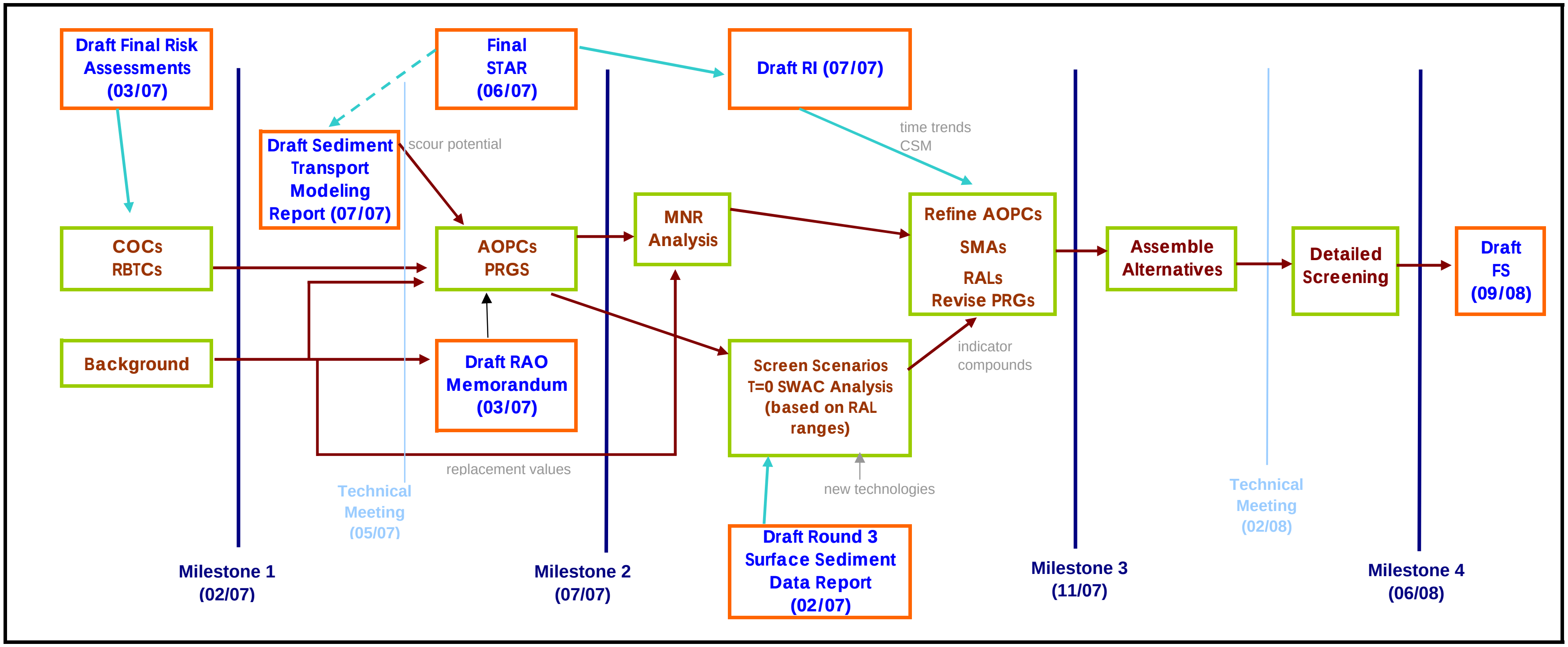
FILE: T:/LDWG_Duwamish/Projects/FSworkplan/GeneralLayout.MXD

Figure 1-2 RI/FS Process Flow Chart and Integration of LDWG Data



1. A formal public comment period is required by regulation; informal public comment will occur throughout the FS process.

Figure 1-3 FS Process Flow Chart and Milestone Meetings



FS FS or RI Deliverable (month/year to agencies)

RAOs FS Step

━ milestone meeting with the EPA, Ecology, and LDWG

─ other technical meeting

→ RI input

→ FS flow

Acronyms: AOPC - area of potential concern; COC- chemical of concern; CSM - conceptual site model; FS- feasibility study; MNR - monitored natural recovery; PRG - preliminary remediation goal; RAL- remedial action level; RAO - remedial action objectives

2 Scope of Work for the Feasibility Study

This section describes in greater detail the process and scope of work for the FS outlined in Section 1.3. Figure 2-1 presents the FS framework and shows how work conducted for the Phase 2 RI supports the FS. The framework also shows the linkages among the FS technical memoranda, other reports required under the AOC, and proposed Sections 1 through 10 of the FS report. The process illustrated on Figure 2-1 is designed to allow completion of FS activities as additional data, memoranda, and reports become available from the Phase 2 RI and risk assessments. Figure 2-1 also shows the expected timeline relative to FS tasks for the draft baseline human health and ecological risk assessments, the Phase 2 RI deliverables, and the sequencing of the draft FS technical products.

Section 2.1 presents an overview of the FS process by report sections. The remainder of Section 2 describes the scope of work for each of the major FS steps, which will ultimately culminate in a preferred remedial alternative for site-wide application in the LDW.

2.1 Feasibility Study Report Outline

The following discussion briefly summarizes the content of each FS section and describes how the information developed in the pre- and post-FSWP memoranda will be integrated to fill critical data and decision steps. Figure 2-1 shows the linkage among these FS sections, which are configured to summarize all of the key Phase 2 RI and risk assessment documents, and also include the sediment transport and natural recovery analyses. Sections of the draft FS report will be developed in cooperation with EPA and Ecology on elements critical to this document. The contents of Sections 2 through 10 of the FS report are described in more detail in Sections 2.2 through 2.10, in parallel structure to the FS report sections.

- **Section 1: Introduction** will present an overview of the FS purpose and report organization.

- **Section 2: Summary of Existing Information and the Conceptual Site Model** will summarize the Phase 2 RI, including the site hydrologic conditions; bathymetric contours; area uses (commercial and recreational); and the nature, extent, and, if possible, sources of sediment COCs. Section 2 will also provide a brief overview of the sediment transport modeling and will identify areas of potential scour.

- **Section 3: Summary of the Baseline Risk Assessments** will briefly describe the pathways, COCs, risk drivers, and receptors identified from the baseline human health and ecological risk assessments as having unacceptable levels of risk.

- **Section 4: Remedial Action Objectives** will include ARARs, narrative RAOs, background and analytical considerations, and numerical PRGs. This information will draw on results from the Phase 2 RI, risk assessments, comments received from the agencies on the draft RAO memo, and discussions at milestone meetings.

- **Section 5: Identification and Preliminary Screening of Remedial Technologies and Alternatives** will delineate the preliminary AOPCs based on the PRGs and assemble a preliminary set of site-wide remedial alternatives based on the technologies identified in the CTM (RETEC 2005b) and draft PSA (RETEC 2006b) documents. The CTM retained several remedial technologies, including ENR, MNR, institutional controls, removal, capping, treatment, and disposal. Based on new information, the refined CSM, the defined RAOs, and comments received on the draft PSA, this section will rescreen the alternatives in accordance with CERCLA and MTCA requirements regarding implementability, effectiveness, and cost.

- **Section 6: Sediment Transport Modeling and Natural Recovery Analysis** will discuss the results of additional sediment transport modeling to predict areas of potential scour and net deposition and will present the results of post-modeling analyses to estimate natural recovery rates. Sediment modeling will address current and future distributions of contaminants.

- **Section 7: Remedial Action Levels** will be developed based on the analyses in Sections 4, 5, and 6 of the FS report and information produced in the Phase 2 RI and risk assessments.

- **Section 8: Final Assembly of Remedial Alternatives** will delineate SMAs based on RALs and AOPCs, estimate the areas and volumes of sediments potentially requiring remediation, and summarize the status of source control activities. This section will then construct and define a set of specific site-wide remedial alternatives.

- **Section 9: Detailed Analysis of Remedial Alternatives** will evaluate the retained set of remedial alternatives using the CERCLA and MTCA threshold and balancing criteria, with the intention of achieving the CERCLA FS cost-estimating goal for accuracy of -30 to +50 percent. After the ROD is issued, more detailed design cost estimates may be developed by the performing party or parties in conjunction with remedial designs for specific SMAs.

- **Section 10: Comparative Analysis of Remedial Alternatives** will present a comparative analysis of the retained remedial alternatives in accordance with EPA guidance and MTCA regulations. It will also identify a recommended remedial alternative.

2.2 Summary of Existing Information and the Conceptual Site Model

Section 2 of the FS will describe existing site information relevant for the FS, including hydrologic conditions, bathymetric contours, results of the final *Sediment Transport Analysis Report* (final expected in July 2007; the draft final was submitted January 18, 2007), area uses (commercial and recreational), topographic features and structures, and the distribution of sediment COCs. Section 2 will summarize the nature and extent of chemical contamination described in the Phase 2 RI. Results from the Round 3 surface sediment sampling (Windward 2007) will be used along with the baseline surface sediment dataset in the Phase 2 RI to map the areal extent of COCs. This section will also summarize empirical physical and chemical time trends (changing conditions over time), which may be useful in evaluating sediment stability and may provide a line of evidence when evaluating the potential for natural recovery.

Essential elements of the CSM generally include information about sources, transport pathways, exposure pathways, and receptors. The CSM can be a valuable tool for evaluating the potential effectiveness of cleanup alternatives and will be updated during the conduct of the FS. Two particular elements of the CSM, the exposure pathways and the transport pathways, are discussed below in Sections 2.3 and 2.6, respectively, because these issues have direct bearing on the development of PRGs and SMAs.

The physical, chemical, and biological CSM is derived from existing site data and knowledge gained from other sites that provide a simple understanding of the site based on available data. As EPA (2005) describes in the *Contaminated Sediment Remediation Guidance*, the CSM is a representation of the environmental system and the physical, chemical, and biological processes that determine the transport of contaminants or other substances of concern from sources to receptors. For sediment sites, perhaps even more so than for other types of sites, the physical CSM can be an important element for evaluating risk reduction approaches.

Two important steps will be conducted to update the physical CSM. First, the draft final *Sediment Transport Analysis Report* (Windward and QEA 2007) will be revised to incorporate comments received from EPA and Ecology, and resubmitted to the agencies for final approval. Second, additional sediment transport modeling will be conducted to evaluate sediment stability, the movement of sediment in and out of the LDW, and sedimentation. Results of this modeling effort will be presented in the draft *Sediment Transport Modeling Report* and summarized in Sections 2 and 6 of the FS report. The final *Sediment Transport Analysis Report* will be an appendix to the *Sediment Transport Modeling Report*. The scope of this modeling effort is summarized in Appendix B and described below in Section 2.6. The chemical and biological components of the CSM, including sources, pathways, and receptors, initially developed in the Phase 1 RI (Windward 2003a), will be updated in the Phase 2 RI and summarized in this section of the FS.

2.3 Summary of the Baseline Risk Assessments

Section 3 of the FS will summarize the major findings of the baseline human health and ecological risk assessments and the Phase 2 RI as they pertain to the FS. The findings will include the COCs, the risk drivers, the major pathways and receptors of concern, and the RBTCs associated with the receptors and pathways of concern.

Two draft risk assessments have been submitted to EPA and Ecology: the *Draft Baseline Ecological Risk Assessment* (Windward 2006b) and the *Draft Baseline Human Health Risk Assessment* (Windward 2006a). These risk assessments will be revised based on comments received from EPA and Ecology. The *Draft Baseline Human Health Risk Assessment* characterized risks to people from site-related exposures for site COPCs through two pathways of exposure: seafood consumption and direct contact with sediment and surface water. The *Draft Baseline Ecological Risk Assessment* evaluated risks from site-related exposures to the benthic invertebrate community, crabs, fish (including juvenile chinook salmon), birds, and mammals. A brief discussion of risks related to current conditions (i.e., post remediation of completed EAAs) will also be included.

2.4 Remedial Action Objectives

Section 4 of the FS will identify the ARARs and develop RAOs and PRGs in accordance with the requirements of CERCLA and MTCA. CERCLA requires the development of ARARs, RAOs, and PRGs as the basis for establishing the need for remedial actions and defining the objectives and goals of those actions (EPA 1988). MTCA requires that cleanup standards for the site include consideration of cleanup levels, points of compliance, and other regulatory requirements (similar to ARARs). The process for identifying ARARs and developing RAOs and numerical PRGs is described in general below and shown on Figure 2-2. The specific process for each of these elements is discussed in the following subsections: Section 2.4.1, RAO Memorandum; Section 2.4.2, ARARs; Section 2.4.3, RAOs; and Section 2.4.4, PRGs.

The preliminary content of this FS report section will be submitted in advance of the FS report in a separate draft RAO memorandum. Comments received from the agencies on this memorandum will be discussed in milestone meetings and addressed in Section 4 of the FS report, which will include ARARs, narrative RAOs, and numerical PRGs that draw on results from the Phase 2 RI, risk assessments, and any updates to the physical CSM. In accordance with EPA's CERCLA RI/FS guidance (EPA 1988) and MTCA regulations, ARARs are directly applicable to developing a set of RAOs. The numerical PRGs will follow directly from the RAOs and will consider chemical-specific ARARs.

2.4.1 RAO Memorandum

A draft RAO memorandum will be submitted in advance of the FS section to facilitate discussion among LDWG, EPA, and Ecology on the appropriate ARARs and narrative RAOs and the process for identifying the PRGs to be used in the FS. The actual PRGs will not be identified in the RAO memorandum but will be presented in a milestone meeting along with revised RAOs and ARARs developed on the basis of EPA and Ecology comments on the draft RAO memorandum. The specific items that will be addressed in the RAO memorandum include:

- Identification of preliminary COCs, risk drivers, pathways, and receptors from the risk assessments
- Presentation of narrative RAOs that address the identified risks
- Identification of ARARs and other non-promulgated criteria or guidance to be considered (referred to as TBCs)
- Application of the SMS
- The approach to developing and using RBTCs
- The approach to developing and using background concentrations of certain risk drivers such as PCBs, dioxins/furans, arsenic, and possibly carcinogenic polycyclic aromatic hydrocarbons
- Discussion of analytical reporting limits/PQLs for risk drivers
- The approach to developing PRGs for the RAOs, based on the risk drivers, RBTCs, background, and analytical reporting limits.

Because the draft RAO memorandum will be presented to EPA and Ecology before the draft Phase 2 RI, the ARARs and RAOs in the RAO memorandum will be considered draft and subject to refinement with input from EPA and Ecology. Comments received from EPA and Ecology will be incorporated into deliverables for milestone meetings as relevant tables and figures and then in Section 4 of the FS; the RAO memorandum will not be finalized as a separate document.

2.4.2 Applicable or Relevant and Appropriate Requirements

A preliminary set of potential ARARs and TBCs was presented in the Phase 1 RI (Windward 2003a). Three categories of ARARs and TBCs influence RAOs, PRGs, and the selection and application of remedial alternatives for the FS:

- **Chemical-specific** requirements, which may define acceptable exposure levels and therefore are considered in establishing PRGs
- **Location-specific** requirements, which may set restrictions on activities within specific locations, such as floodplains or wetlands
- **Action-specific** requirements, which may set controls or restrictions for particular construction, operation, and disposal activities related to in-water construction or the management of hazardous wastes.

In addition to the ARARs listed in the Phase 1 RI (Windward 2003a), the ARARs to be presented in the RAO memorandum will be drawn from, and are expected to be similar to, those compiled for other recent CERCLA projects in the Duwamish River (e.g., Lockheed, Todd Shipyard, Slip 4, and Terminal 117), Puget Sound (e.g., Puget Sound Naval Shipyard, Pacific Sound Resources, Hylebos Waterway, and Thea Foss Waterway), EPA Region 10 (e.g., Portland Harbor, Oregon), and PCB-contaminated sediment sites of national importance (e.g., Hudson River, New York). Therefore, updated ARARs will be presented in the RAO memorandum and refined as necessary, based on comments received from EPA and Ecology, in Section 4 of the FS.

2.4.3 Developing Remedial Action Objectives

RAOs will be developed based on the findings of the baseline human health and ecological risk assessments in accordance with both EPA RI/FS guidance (EPA 1988) and SMS (WAC 173-204-570(2)). The overarching goal for cleanup of the LDW will be to reduce or eliminate unacceptable adverse effects on biological resources and unacceptable health threats to people from COC concentrations in sediment or seafood. RAOs will be developed for those COCs, exposure pathways, and receptors for which an unacceptable risk was identified in the risk assessments. RAOs will also be informed by the CSM and revised as needed as the CSM evolves throughout the FS process. Where appropriate, additional RAOs may be developed based on other considerations, such as access to public/recreational areas, cultural uses, the commercial/industrial nature of the site, the physical river system, and integration with habitat restoration activities. As discussed above, narrative RAOs will first be presented in the RAO memorandum and will be revised as needed in the FS following discussions among LDWG, EPA, and Ecology.

RAOs are intended to provide the link between the risk assessments and the level or degree of cleanup required, i.e., the PRGs. The guidance states that RAOs should be as detailed as possible without limiting the range of possible remedial alternatives (EPA 1988). For the LDW, the RAOs will be narrative statements based on risk management principles.

For protection of human health, RAOs will be developed when the cumulative site risks to an individual based on reasonable maximum exposures for either current or future land or resource uses exceed regulatory thresholds. For protection of the environment, SMS regulations are part of the requirements of MTCA and include criteria for both chemical concentrations and biological effects that will be considered in defining RAOs and PRGs for the protection of the benthic community. For other ecological receptors, RAOs will be developed to address those receptors and pathways that are of concern.

2.4.4 Developing Preliminary Remediation Goals

Draft PRGs will be presented in a milestone meeting in advance of the FS to ensure continuing discussions among LDWG, EPA, and Ecology on the appropriate RAOs and PRGs to be used in the FS. The numerical PRGs will be developed from the objectives identified in the RAO memorandum, as modified by EPA and Ecology comments on that memorandum.

Numerical PRGs for the LDW will be expressed as sediment concentrations of individual risk drivers developed for each RAO, as appropriate. These values will reflect the final lists of risk drivers, receptors, and exposure pathways. The PRGs will be developed on the basis of chemical-specific ARARs and TBCs, the SMS, RBTCs, natural and area background concentrations, and analytical considerations. PRGs are initial guidelines; they do not dictate that cleanup is warranted to meet those goals (EPA 1991b). The PRGs remain preliminary throughout the FS process and are finalized as cleanup levels by EPA and Ecology in the ROD.

Sediment Management Standards

The SMS criteria will be the principal consideration in developing PRGs for the protection of the benthic invertebrate community (sediment-dwelling ecological receptors). These values include both the SQS and the CSL chemical and biological criteria developed for Puget Sound marine sediments (WAC 173-204). For the benthic community, risks from COCs that are not addressed by the SMS, other chemical-specific ARARs, and TBCs may also be considered during the development of benthic invertebrate community PRGs.

Risk-Based Threshold Concentrations

When a PRG cannot be established based on ARARs or TBCs, PRGs may be developed based on background, PQLs or risk-based considerations. To develop risk-based PRGs, RBTCs will be developed for each risk driver and the corresponding receptor, and pathway. RBTCs for human health will consider both the direct sediment contact and seafood consumption pathways. RBTCs for ecological receptors will consider protection of both the benthic invertebrate community and higher trophic level organisms.

For RBTCs that are based on the human consumption of seafood, a tissue-based RBTC will be established first by using the standard human health equations and solving the equation for tissue concentrations associated with acceptable risk levels. To determine the corresponding sediment concentration, chemical-specific methods will be used. Translation of tissue RBTCs into sediment RBTCs using either a food web model or a sediment-tissue regression is subject to considerable uncertainty. Therefore, if sediment RBTCs are calculated based on seafood consumption scenarios, those RBTCs may be expressed as ranges, as appropriate, to account for the associated uncertainty. The methodology that will be used to derive RBTCs will be presented in the RAO Memorandum and further developed in consultation with EPA and Ecology.

Background Concentrations

Background concentrations (previously defined in Section 1.2.1) are relevant to setting PRGs because cleanup levels are not set at concentrations below natural background levels under either MTCA or CERCLA. The reasons for this approach include cost-effectiveness, technical practicability, and the potential for recontamination of remediated areas by surrounding areas exhibiting background concentrations (EPA 2002b). In addition, both natural and area background values need to be adequately understood to establish realistic risk reduction goals (EPA 2002b).

Both area and natural background will be evaluated in setting PRGs. A process for calculating these background values will be presented in the RAO memorandum, and the calculated values will be presented and discussed in a milestone meeting. Types of data that may be considered in the background analysis include sediment quality data from locations upstream of the LDW boundaries or from Puget Sound (excluding other CERCLA or MTCA sites), soil background values, and certain data from non-point sources such as atmospheric deposition or urban run-off.

Preliminary Remediation Goals

PRGs will generally be set at the lowest sediment-based RBTC or chemical-specific ARAR, unless the background concentration is higher; in that case, the background concentration may become the *de facto* PRG. EPA guidance and MTCA also allow for consideration of PQLs in setting PRGs (EPA 1991b; WAC 173-340-707).

Table 2-1 provides an example of how unacceptable risk pathways identified in the risk assessments may be developed into RAOs, RBTCs, and PRGs and potentially into RALs. Both EPA and Ecology set a PRG for excess cancer risks of one in one million (10^{-6}) as a point of departure and a hazard index for non-cancer risks of less than one (EPA 1991b, Ecology 1997). PRGs are idealized goals and may not always be achievable given the constraints of implementability and practicability/cost-effectiveness. As such, a range of RBTCs associated with risks from 10^{-6} to 10^{-4} will be evaluated for carcinogenic chemicals.

Both point- and SWAC-based PRGs may be developed. A point-based PRG is a concentration or condition that must be met at each individual location or group of locations. Examples of point-based PRGs are the chemical criteria under SMS; an example of a SWAC-based PRG is an area-wide average sediment concentration that is protective of seafood consumers. In addition, certain PRGs may be applicable only to specific locations or areas, such as valuable habitats or access and other spatial exposure areas deemed important in the risk assessments.

Section 4 of the FS will present the PRGs and will also address EPA and Ecology comments on the draft RAO memorandum, the PRG discussion that will occur in a milestone meeting, results of the Phase 2 RI, and results of the food web model for the LDW. Any updates to the background conditions and equilibrium conditions expected after remedy completion might also be considered.

2.5 Preliminary Screening of Remedial Technologies and Alternatives

Section 5 of the FS will delineate preliminary AOPCs based on the PRGs to form the basis for describing the scope of the remedial alternatives. This section will draw on the CTM (RETEC 2005b) and the draft PSA (RETEC 2006b). The conclusions of these reports will be updated as necessary based on the refined physical CSM, as well as on any new, relevant technological data. The CTM (RETEC 2005b) evaluated a comprehensive range of potential technologies within the general response action, categories of ENR, MNR, institutional controls, removal, containment, treatment, and disposal. Based on the CERCLA and MTCA screening criteria of effectiveness, implementability, and cost, a number of potentially applicable technologies within each general response action category were selected for possible incorporation into site-wide alternatives. In the draft PSA (RETEC 2006b), these retained technologies were further screened using the CERCLA and MTCA criteria of implementability, effectiveness, and cost to select representative technologies. These technologies were then assembled into preliminary site-wide alternatives, which were defined as a range of hypothetical RALs for PCBs. Section 5 of the FS report will re-evaluate these alternatives based on new information, the refined physical CSM, the defined RAOs, and comments received on the draft PSA (RETEC 2006b), based on the following steps:

- Delineating AOPCs
- Identifying the general response actions and remedial technologies
- Conducting preliminary screening of remedial alternatives.

Section 5 will conclude with a set of retained remedial alternatives, AOPCs, and a range of potential RALs that will be carried forward into the natural recovery analysis (Section 6) and the assembly and detailed evaluation of remedial alternatives (Sections 8 and 9, respectively). These alternatives will be compared to CERCLA and MTCA baseline alternatives, as described in Section 2.5.3.

2.5.1 Delineation of Areas of Potential Concern

Delineation of AOPCs will be an iterative process involving the use of multiple overlays. Areas previously identified as EAAs will form one overlay. Areas that exceed point-based PRGs will then be mapped, with each PRG map added as another overlay. Surface sediment sampling stations failing sediment toxicity tests will be another overlay. This process will include mapping of areas with buried COCs that exceed PRGs and could be exposed as a result of future scour events. Additional overlays will include relevant exposure areas identified in the baseline risk assessments and associated SWAC-based PRGs. Overlays may use differing interpolation techniques (e.g., inverse-distance weighting, Theissen polygons, grid cells or kriging). These maps will be the subject of a milestone meeting with EPA and Ecology.

This mapping exercise will include all COCs identified as risk drivers in the risk assessments. Co-occurrence of chemicals will be evaluated, and use of a reduced list of indicator COCs (such as total PCBs and arsenic) may be proposed to represent COC risks in future mapping scenarios.

From these maps of AOPCs, areas and volumes of contaminated sediment will be estimated and carried forward into the preliminary screening of remedial alternatives, similar to the process conducted in the draft PSA (RETEC 2006b).

2.5.2 General Response Actions and Representative Technologies

This step of the FS process is essentially complete but will be modified based on comments on the draft PSA (RETEC 2006b) and any new information developed between the time of the draft PSA and the draft FS report. The remedial technologies and general response actions retained in the CTM (RETEC 2005b) and the draft PSA (RETEC 2006b) will be brought into and evaluated in the FS. These include no action, no further action, active management (i.e., dredging, capping, treatment, and ENR), and passive management (i.e., monitoring, institutional controls and MNR). The technologies retained at the conclusion of the draft PSA were selected as representative technologies for site-wide application and do not necessarily preclude the use of other technologies, such as treatment, later in the FS or in the design process. Combinations of these general response actions and remedial technologies will then be assembled into remedial alternatives.

2.5.3 Screening Preliminary Remedial Alternatives Carried Forward from the Draft PSA

Section 5 will build upon the technologies and remedial alternatives retained in the CTM (RETEC 2005b) and the draft PSA (RETEC 2006b). It will update the information in the draft PSA as necessary based on the refined physical CSM, new technological developments, and the conclusions from the Phase 2 RI and risk assessments.

The technologies retained in the draft PSA (RETEC 2006b) were combined into the following preliminary remedial alternatives:

- No further action (defined as no actions other than those already completed or under way at the EAAs)
- Dredging with upland disposal of sediments from the PPAs[3] and other areas of interest[4] exceeding the hypothetical RALs (dredge to the maximum extent practicable)
- Dredging and upland disposal of sediments from the AOPCs[3] coupled with a combination of removal, ENR, and MNR for the remaining areas[4] exceeding the hypothetical RALs
- Capping (to the maximum extent practicable) and dredging (where capping is not practicable) sediments from AOPCs[3] exceeding the hypothetical RALs
- Dredging and treatment of sediments from a subset of the AOPCs[3] coupled with ENR and MNR for the remaining areas[4] exceeding the hypothetical RALs

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[3] In the draft PSA, PPAs are areas exceeding CSL criteria; these areas will be referred to as AOPCs in the FS.

[4] In the draft PSA, areas of interest are remaining areas outside the PPAs based on interpolations of total PCBs; these areas will be referred to as AOPCs in the FS and will be revised to include other COCs.

- One or more combined alternatives that may include some combination of dredging, capping, treatment, ENR, and MNR of sediments from the AOPCs[3] and that may include location-specific remedial actions or RALs.

Both CERCLA and MTCA require use of a baseline alternative for comparative analysis with other cleanup alternatives. Therefore, the FS will also include:

- A No Action alternative (the CERCLA baseline alternative), which is defined as the conditions evaluated in the risk assessments and assumes no remediation in the EAAs

- Identification of the alternative that provides the most practicable, permanent solution (the MTCA baseline alternative).

The alternatives will be ranked for permanence (as defined by WAC 173-340-200). The MTCA baseline alternative will be identified as the alternative that provides the most practicable, permanent solution. This alternative will be considered for conducting the disproportionate cost analysis defined in WAC 173-340-360.

These remedial alternatives and technologies will be revised in the FS as appropriate, based on conclusions from the Phase 2 RI report, the risk assessments, and additional sediment transport modeling. Similar to the draft PSA (RETEC 2006b), Section 5 will evaluate the changes in SWAC and number of SQS/CSL point exceedances at various action levels for different alternatives immediately following remedy completion (time 0). These results will be useful in evaluating RALs in Sections 6 and 7 of the FS report.

2.6 Sediment Transport Modeling and Natural Recovery Analysis

Sections 2 and 6 of the FS report will present an evaluation of sediment transport processes, a summary of the sediment transport modeling, and an analysis of the potential for scour and for natural recovery in the LDW.

Sediment resuspension and sedimentation processes are active to varying degrees in the LDW. These processes are expected to be an integral component in evaluating the ability of remedial alternatives to achieve the long-term remediation goals for the LDW. As an example, the location, areal extent, and duration of hydraulic scour will influence whether: (1) subsurface contaminants no longer present a risk because of their complete and permanent burial, or (2) subsurface contaminants have the potential to become exposed during episodic erosion events, potentially presenting a direct risk or affecting surface conditions in the waterway.

Sedimentation rates in areas that are either stable or subject to scour will both influence restoration time frames and inform the evaluation of RALs, AOPCs, and SMAs in the FS. To determine which areas with subsurface contamination are of concern and the degree to which natural recovery can contribute to overall management of the LDW, the FS will evaluate the rate at which the LDW can recover and assess whether currently buried COCs will remain in place. The hydrodynamic properties of the LDW, which directly control the issues of erosion and deposition, are discussed in the draft final *Sediment Transport Analysis Report* (Windward and QEA 2007). While that report provides an important understanding of hydraulic forces acting on the sediments, additional data and information are needed for the FS pertaining to the following four questions:

1) Where, under what conditions, and to what depth could scour occur during episodic events that could lead to the long–term exposure and/or resuspension of buried contaminated sediments?

2) What is the approximate time period over which the contaminated sediments at depth could potentially be exposed before the area recovers by sediment deposition?

3) What are appropriate estimates of both short-term and long-term post-remedial conditions in areas actively cleaned up (e.g., including consideration of dredging residuals)?

4) What areas of the LDW can be considered suitable for natural recovery and what are the rates of recovery (i.e., what is the estimated restoration time frame[5] to achieve a specified PRG)?

Questions 1 and 2 (sediment transport and stability) will be evaluated primarily for those areas where surface sediment concentrations do not exceed the PRGs (i.e., areas not already defined as AOPCs), but where concentrations of subsurface COCs may exceed the PRGs. This evaluation may also be applied to potential capping areas to assess long-term stability of capping material. Hydrodynamic modeling will be evaluated (see Section 3.3) to address those questions and areas. Areas where scour does not occur to the depth that would expose contaminated sediments would not be designated as AOPCs. Areas where scour to the depth of contaminated sediments might occur may be designated as AOPCs, but will also require additional evaluation to determine the duration and frequency of exposure.

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[5] *Restoration time frame* is defined as the number of years required for a surface sediment COC concentration to fall below the PRG. MTCA specifies a maximum restoration time frame of 10 years unless a longer restoration time frame is authorized by Ecology.

The model will qualitatively assess risks associated with total suspended solids (TSS) loads (and exposure) to the water column during scour events by estimating the length of time the solids remain in suspension.

Questions 3 and 4 (sediment recovery potential) will be evaluated for all areas of the LDW. Natural recovery by burial of contaminants with cleaner materials is expected to be an important remedial component in the achievement of long-term cleanup levels for the LDW as a whole and for individual SMAs. The degree to which MNR may be applied to an area depends on the erosional and depositional conditions at an SMA and on the potential for contaminant loading. SMAs that are potentially erodable or predicted to be subject to significant contaminant loading based on modeling or empirical data are unlikely candidates for natural recovery. For areas that are depositional, it will be important to determine the rate of deposition and the estimated restoration time frame. This is information that will be used to define actions within SMAs and evaluate potential remedial alternatives.

In addition, the analyses discussed above may be useful in assessing the potential for ongoing sources to cause sediment concentrations to exceed PRGs after remedy completion (i.e., source control evaluation). A range of chemical concentrations will be applied to incoming sediment loads to evaluate the influence of those loads on recovery and recontamination potential. This exercise may also provide insights regarding the extent to which source control will be important in attaining PRGs. In addition, deposition from specific lateral loads near major discharge locations will be considered in evaluating the potential for natural recovery, or the potential for recontamination, using output from the site-wide model. These analyses will inform both the remedy selection in these areas and the ongoing, coordinated source control efforts.

Long-term predictions for the LDW will rely on several lines of evidence, one of which is a sediment transport model that is capable of predicting both intermittent scour under time-varying flow conditions and the time period for exposed contaminated sediments to be reburied. The sediment transport modeling is discussed in Section 2.6.1. The other lines of evidence include geochronology cores, high-resolution 6-inch subsurface sediment chemistry data, bathymetry surveys, Sedflume analyses, stratigraphic profiles, prior sediment transport studies, and temporal changes in surface sediment chemistry.

Questions concerning scour potential and sediment stability will be addressed by evaluating outputs from the model (in consultation with EPA and Ecology). This evaluation is discussed in Section 2.6.2. Questions concerning natural recovery and recontamination will be addressed by evaluating changes in chemical concentrations over time as necessary to inform the FS coupled with the modeling. This is discussed further in Section 2.6.3.

2.6.1 Additional Sediment Transport Modeling

Sediment transport modeling will be conducted for the purpose of predicting the effect of episodic erosion events on the sediment bed, the spatial distribution of sedimentation rates, and sediment mixing between existing and incoming sediments. The model will be constructed using the Environmental Fluid Dynamics Code (EFDC), which was developed by Dr. John Hamrick at the Virginia Institute of Marine Science at the College of William and Mary (Hamrick 1996). This model code was modified by QEA and used to conduct the hydrodynamic simulations of the LDW for the draft final Sediment Transport Analysis Report (Windward and QEA 2007). The overall goal of the sediment transport modeling, as agreed to by LDWG and the agencies that formed the Sediment Transport Modeling Work Group, is to develop a quantitative tool that can be used to evaluate sediment transport processes in the LDW. Specific goals of the modeling effort relative to long-term multi-year periods and episodic high-flow events are listed in Appendix B. The selected model can be used to address the questions posed above and may be used to predict sediment transport from the LDW downstream to the East and West Waterways. However, the model is not a full fate and transport model and therefore can only be used to predict contaminant transport within the limitations of certain assumptions. For instance, the export of sediment from the Green River to the LDW and lateral inflows of sediment to the LDW (e.g., storm drains, CSOs, overland flow and tributary creeks) can be directly predicted by the model. However, to estimate the chemical loads associated with these sources of sediment, the chemical concentration on these sediments must be estimated.

In the proposed natural recovery analysis, chemical substitution values will be applied to sediment inputs from the Green River and various lateral inflows. The substitution values will represent a range of possible chemical concentrations that may be associated with the sediment inputs from the Green River and lateral inflow sediments. Consequently, a range of export values associated with lateral inflow and Green River sediments can be computed.

The situation is more complicated with respect to existing bed sediments. While the model computes resuspension of sediments within the LDW and can compute the amount of resuspended sediments that are exported from the LDW, the model does not track where these sediments originated. Consequently, it is difficult to identify a chemical concentration associated with sediments resuspended from the sediment bed.

The model will incorporate sediment inflow from the Green River as measured by the U.S. Geological Survey (USGS) near Highway 405 in Tukwila, Washington, and from lateral inflows along the LDW (e.g., storm drains, CSOs, overland flow and tributary creeks). The model will simulate sediment deposition, scour, and resuspension and predict the movement of sediment within the LDW. It also could be used to predict the discharge of TSS out of the LDW study area. To support the FS, the model will be applied to river flow and storm event simulations to predict future sediment conditions in the LDW, as described below. Simulations will be used to predict (1) bed elevation changes, and (2) mixing or dilution of existing LDW sediments with incoming sediments.

A detailed discussion of the modeling scope and approach is presented in Appendix B. The scope of work described in the appendix consists of five steps:

1) Model development
2) Model calibration
3) Model validation
4) Sensitivity analysis
5) Application of the calibrated model.

The scope of the modeling effort will be further refined in a series of collaborative technical meetings of the Sediment Transport Modeling Work Group members; refinements will be documented in meeting summaries reviewed by the work group.

Model Development, Calibration, and Validation

Model development is the process of both constructing a model of the LDW and developing the model input parameters. Model construction includes determining the model area, developing the numerical grid to cover the model area (Arega and Hayter 2004), and determining the model boundaries (i.e., upstream and downstream limits and inflows to and outflows from the model area). This step defines the initial conditions of the LDW model area and the processes that are simulated in the model. Initial conditions include bed elevation, distribution of sediment size in the sediment bed, initial water flow and stage height, and concentration of TSS. Three sediment classes will be simulated, representing: (1) silt and clay (cohesive sediment), (2) fine sand (non-cohesive sediment), and (3) medium to coarse sand (non-cohesive sediment). Process parameters include bed sediment properties (grain size distribution and bulk density), erosion rate parameters, and particle settling speeds.

Model calibration and validation is the process of applying the model to different datasets, then comparing the results among datasets to determine how well the model simulates LDW conditions. The model will be calibrated to simulate varying hydrodynamic and sedimentation processes based on existing data from the LDW.

Successful model validation lends credibility to the predictive ability of the model. The primary focus of model validation will be an evaluation of the model's ability to predict sedimentation in the bench areas of the LDW. The datasets that will be used to conduct this evaluation will likely include geochronology core data and sedimentation rates estimated based on those cores, subsurface core profile data (chemistry and lithology), and other relevant data yet to be determined.

Sensitivity Analysis

In a sensitivity analysis, model input parameters are varied to demonstrate how model results may change because of uncertainty in those parameters. Input parameters to be included in the sensitivity analysis will be determined after the model calibration process is complete; an understanding of the behavior of the model with respect to input parameters will be developed during model calibration. The results of the sensitivity analyses will be quantitatively compared to the initial results.

Application of the Calibrated Model

Once the model is adequately calibrated and validated, the model will be applied to predictive simulations. Flow conditions in the future will be based on the historical record of flows within the Duwamish-Green River system[6]. Application of the model will focus on estimating two key characteristics of the LDW:

- The effect of high-flow events on bed scour and the potential for re-exposing sediments with elevated chemical concentrations buried at depth in the bed

- The rate of natural recovery.

To estimate these characteristics, the modeling results will be used in the FS in two ways. First, changes in bed elevation and predicted scour during high-flow events will be used to identify areas where episodic scour could expose contaminated sediments. The model will also be used to predict the time for those sediments to be reburied, as described in Section 2.6.2. Second, the sediment dilution analysis will be used to estimate the sources of the bedded sediment over time. This will be accomplished by using the results of the sediment dilution analysis to compute the distribution of sediment particles derived from various sources (i.e., existing bed, upstream, or lateral inputs) within specific grid cells over time. The model results can be presented as maps of particle origins at various time intervals that will be used to derive MNR estimates, as described in Section 2.6.3.

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[6] The modeling report will present the time-frame of historical data used (approximate 20-year calibration period). The model may consider flow changes from the South (Renton) wastewater treatment plant, which began operations in 1965 and discharged treated effluent (limit: 10-15 mg/L total suspended solids) to the Duwamish River upstream of the LDW, accounting for about 25% of the flow in the Duwamish River during low-flow periods. By 1987, the effluent from this wastewater treatment plant was diverted to Puget Sound.

2.6.2 Evaluation of Scour Potential

The sediment transport modeling will also be used to predict: (1) bed elevation changes (i.e., net sedimentation rates and bed scour depths), and (2) distribution of solids mass balances over various time periods. In addition, the effect of high-flow events on sediment bed stability will be evaluated using short-term simulations to analyze the effect of a 100-year flow event under varying tidal conditions.

These simulations will determine the effective depth to which episodic events can scour and the time frame over which subsurface sediments would be exposed before reburial. Model results will map areas of net deposition and episodic scour. These will be compared to maps of surface and subsurface contamination to determine which areas in the LDW could be at risk from episodic scour events. These estimates and areal maps will be useful in evaluating RALs and specific actions at the various SMAs in Sections 7 and 8 of the FS report.

The best use of the model with respect to discharge of sediment from the LDW is to look at the fraction of sediment discharge that originates from the sediment bed, as opposed to Green River and lateral inflow sediments and how this fraction changes over time. Because existing bed sediments are mixed with or buried by inflow sediments, the model will show how much of the sediment export out of the LDW originates from existing bed sediments versus inflow sediments and how the proportion of each changes with time.

2.6.3 Evaluation of Natural Recovery

Following active remediation, natural recovery is expected to further reduce chemical concentrations in bed sediments over time to varying degrees in different locations. To estimate the potential for and rate of natural recovery after active remediation, chemical concentrations can be assigned to the various sediment particle fractions depositing on the bed (sediment particle dilution)[7] as follows:

- The bed sediment fractions can be assigned interpolated chemical concentrations representing post-cleanup bed concentrations under different remedial scenarios.
- The upstream and lateral-derived sediment fractions may be modeled separately or as one combined fraction of “new” sediments. These two fractions can be assigned chemical

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[7] Multi-year simulations will be conducted to predict the dilution of existing sediments in the LDW with incoming sediments. Output from the sediment transport model will result in two grid cell maps: (1) change in bed elevation, and (2) change in composition of the bed (ratio of incoming sediment versus bedded sediment). The latter map will be used in the natural recovery analysis by assigning the modeled bed composition with associated chemical concentrations of each particle type at selected time simulations.

> concentrations based on other existing information, which may include several types of data such as surface water, area background, sediment trap, or lateral inflow data.

With this approach, surface sediment contaminant concentrations can be estimated for each cell in the grid (providing localized or SMA-specific MNR estimates) for various times in the future. The results can also be averaged to derive LDW-wide SWAC estimates of natural recovery over time. This approach is valid only for contaminants such as PCBs that are strongly sorbed to the sediment particles and do not degrade over time; however, this approach is conservative with respect to other contaminants that degrade. These MNR estimates will be useful in evaluating RALs and specific actions at the various SMAs in Sections 7 and 8 of the FS report.

In addition to the dilution calculation, the model may be used to predict: (1) bed elevation changes to estimate net sedimentation rates, (2) depth and areal extent of bed scour, (3) TSS concentrations in the water column, (4) TSS load balances over various time periods, and (5) discharge of TSS to the East and West Waterways. Sediment mass balances are useful for understanding the amount of sediment entering the LDW from different sources and how much of that incoming sediment is deposited in the LDW and how much leaves the LDW.

This approach will be used to predict natural recovery under a range of post-cleanup scenarios. For example, natural recovery estimates may be made for conditions following active cleanup to the various prospective RALs explored in Section 5 of the FS report. In addition to predictive modeling, empirical time trends observed in the data may also be used to evaluate natural recovery potential.

2.7 Remedial Action Levels

Section 7 of the FS report will present a range of selected RALs to be carried forward in the FS. Preliminary RALs will be evaluated first in Section 5 during the preliminary screening of alternatives. From the analysis presented in Section 5, a range of RALs will be evaluated in Section 6 as part of the natural recovery analysis. Section 7 of the FS report will analyze the results of Sections 5 and 6 and select a range of RALs that will be used to assemble remedial alternatives. Factors considered will include an evaluation of natural recovery potential (from Section 6) and the ability to achieve the RAOs practicably, cost-effectively, and within a reasonable restoration time frame.

Factors to be considered in proposing the RALs will include the PRGs; the distribution of COCs; the potential for erosion, sediment transport, and natural recovery in the LDW; and other relevant factors, such as implementability, restoration time frames, and cost-effectiveness of different RALs consistent with NCP and MTCA guidance.

2.8 Final Assembly of Remedial Alternatives

Section 8 of the FS report will integrate the information developed in the risk assessments, the Phase 2 RI, the CTM (RETEC 2005b), the draft PSA (RETEC 2006b), the RAO memorandum, and in previous sections of the FS report. The objectives of this step will be to:

- Identify SMAs and sediment volumes (from the PRGs) that take into consideration results from the draft Sediment Transport Modeling Report
- Refine the boundaries of the SMAs and the RALs that will apply to them
- Assemble a detailed set of LDW-wide remedial alternatives that meet the RAOs.

Meetings and discussions with EPA and Ecology on the content of Sections 4, 5, and 6 of the FS report will be used to refine PRGs, RALs, and SMAs for the final assembly of remedial alternatives. This section will present a final set of assembled remedial alternatives that will be carried forward into the detailed and comparative analysis of alternatives (Sections 9 and 10 of the FS report).

2.8.1 Identification of SMAs

SMAs will be identified from the RAOs, PRGs, RALs, and AOPCs and will consider other factors such as land use, recovery potential, and habitat type. Maps delineating SMAs will be reviewed by and discussed with EPA and Ecology in a milestone meeting before the alternatives are evaluated in detail. The process will build on the analyses presented in the draft PSA (RETEC 2006b) and will discuss how the RAOs and PRGs are incorporated. Figure 2-3 summarizes this generalized approach. The SMAs for the FS can be classified into two categories:

- EAAs that are under way and where one or more individual LDWG members have made a commitment to complete removal actions (Windward 2003b)
- Other SMAs, based on exceedances of the PRGs, which were previously identified as AOPCs. In general, these areas exceed SMS chemical or biological criteria or other ARAR/TBC-defined PRGs. They may be expressed as point-based, area-based, or SWAC-based SMAs.

The SMAs will be further refined into areas requiring active management versus areas amenable to passive management or MNR. This step will be accomplished by overlaying the SMAs with maps of sediment stability, net sedimentation rates, scour potential (relative to buried subsurface deposits of contaminated sediment), and natural recovery potential (discussed above).

Early Action Areas

The first remedial actions in the LDW will be undertaken at the five EAAs (Figure 2-4) where one or more individual LDWG members have committed to conduct remedial actions. These five EAAs in the LDW total approximately 31 acres[8] (Table 2-2). The following activities are either completed or planned:

- The Diagonal/Duwamish removal action was conducted in 2003/2004 as part of EBDRP. A 4-acre thin layer placement was conducted in February 2005 as an enhanced natural recovery interim measure.
- A CERCLA non-time-critical removal action is planned for Slip 4.
- A CERCLA non-time-critical removal action is planned for the in-water portion of Terminal 117.
- Sediment remediation, to be undertaken as a RCRA corrective action, is planned for Boeing Plant 2.
- Sediment remediation in the Norfolk Area, consisting of a sediment removal action at the Boeing Developmental Center South Storm Drain was completed in 2003 under the MTCA Voluntary Cleanup Program.

The FS will not evaluate remedial alternatives in detail for these five EAAs, but will examine the selected remedies to see if the EAAs are consistent with cleanup alternatives being evaluated for the non-EAA areas. The FS will also review available monitoring data from completed actions and will include these areas in long-term simulations to assess site-wide SWAC reductions and recontamination potential. Areas outside of the boundaries of all the EAAs will be addressed in the FS. Completed EAAs will be carried forward into the FS for evaluation of pre- and post-remedial conditions, long-term monitoring requirements, requirements for institutional controls to ensure the long-term integrity of the caps, the overall cost of remedial actions, and overall compliance with the threshold requirements for a final remedy.

For example, Figure 2-5 shows areas where COC concentrations in surface sediments exceed the SQS of the SMS after remediation of the EAAs and PPAs (identified in the draft PSA; RETEC 2006b). These areas were

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[8] Although the cleanup at the Norfolk CSO discharge area conducted in 1999 is part of the Norfolk Area, it does not have remediation acres associated with it because the area was remediated before the LDW AOC.

delineated as interpolations of total PCBs (shown as contours on the maps created by inverse distance weighting [IDW] interpolation) and other chemicals of potential concern (shown as polygons for other chemicals exceeding the SQS of the SMS). The baseline surface sediment dataset (Windward 2006c) will be used for delineation of these areas. The five EAAs listed above are considered administratively complete; that is, individual parties have committed to completing remediation in these areas.

SMAs Exceeding the PRGs

The PRGs will be used to identify additional SMAs where remediation will be considered. The process for identifying preliminary SMAs will include several mapping steps. First, results from the AOPC evaluation will be evaluated to delineate areas with similar or co-occurring risk drivers or indicator COCs, if appropriate**.** Second, the RALs carried forward from Section 6 will be evaluated spatially in the LDW. Lastly, physical factors, such as grain size, site access, bathymetry, and navigation requirements, and sediment stability factors, such as net sedimentation rates, scour potential, and natural recovery potential, will then be used to refine the SMA boundaries. Physical factors will also affect the selection of remedial alternatives appropriate for those SMAs.

2.8.2 Evaluate SMA Boundaries and Design Conditions

The delineation of preliminary SMAs described above will be based primarily on chemical or biological exceedances of the PRGs, as appropriate. However, both the CERCLA and MTCA guidance contain provisions for considering other lines of evidence when developing SMA boundaries. This evaluation will occur in Section 8 of the FS report and will build upon analyses in the draft PSA (RETEC 2006b). The specific objectives of this exercise will be to:

1) Identify SMA boundaries as those areas where surface sediments exceed the PRGs

2) Estimate the depth of contaminated sediments within the boundaries defined by the SMAs

3) Evaluate the SMAs relative to the revised physical CSM using the results of the Phase 2 RI and the Sediment Transport Modeling Report

4) Estimate which, if any, SMAs may be suitable for MNR based on predictions of achieving the short- and long-term RAO restoration time frames. Criteria for MNR suitability include (but are not necessarily limited to): limited scour potential, limited potential for disturbance by dredging, and a modeled prediction of achieving PRGs within a reasonable restoration time frame. SMAs that

appear suitable for MNR will also be actively remediated under some alternatives

5) Define which SMAs will require active remedial actions

6) Evaluate and subdivide the preliminary SMAs relative to the physical and use conditions in the LDW.

The output from this activity will be the grouping of SMAs that have similar physical, hydraulic, and potential management characteristics. Specific to the LDW, the physical factors will include two primary site-wide conditions:

- Land use functions (i.e., the navigation channel, active marinas and berthing areas, intertidal habitat restoration and enhancement areas, and recreational shoreline access areas)

- Sediment stability and natural recovery potential (i.e., potential scour of subsurface deposits of contaminated sediment and net deposition areas from the draft *Sediment Transport Analysis Report* [Windward and QEA 2006]), areas undergoing burial by cleaner material, and areas with ongoing sources).

The delineated SMAs and groupings of SMAs will provide the spatial and location-specific basis for assembling technologies and process options into site-wide remedial alternatives. Different RALs may be applied to different SMAs depending on the expected rate of natural recovery over time, sediment stability, and initial chemical concentrations in the surface sediments. This step forms a basis for key FS analyses; therefore, delineation of SMAs will be discussed with EPA and Ecology before the remedial alternatives are screened in detail.

2.8.3 Develop Remedial Alternatives

The site-wide remedial alternatives will include a range of appropriate general response actions, technologies, and process options for individual SMAs. Different RALs and/or remedial actions may be considered for particular SMAs depending on the land use and sediment recovery potential, as described above.

The general response actions that will be considered during the final assembly of remedial alternatives include no action (assumes that remediation of the EAAs has not occurred), no action beyond the five EAAs that are completed or under way, active management (i.e., dredging, capping, treatment, disposal, and ENR), and passive management (e.g., monitoring, institutional controls, and MNR). Assembled alternatives may employ a combination of these general response actions, including both active and passive management.

The final step in assembling the remedial alternatives will be the grouping of SMAs and application of RALs considering their ability to achieve the RAOs. The evaluation used in the draft PSA (RETEC 2006b) will be refined using updated site information. Several factors, such as physical, hydraulic, and functional conditions at the site, may determine not only the selection of an RAL, but also the application of the RAL at a specific SMA. For example, more aggressive RALs and actions may be required for some areas (e.g., the navigation channel or public access) while less aggressive RALs may be applicable where natural recovery processes are already occurring.

2.8.4 Source Control Activities

Source control is generally defined as “those efforts taken to eliminate or reduce, to the extent practicable, the release of contaminants from direct and indirect continuing sources to the water body under investigation” (EPA 2005). Ecology is the lead agency for source control in the LDW.

Initial lines of evidence collected during the Phase 2 RI suggest that many of the original sources of contamination have already been controlled, but ongoing sources may include stormwater and CSO discharges, erosion of contaminated shoreline soils, and overland surface water flow from contaminated surface soils. Atmospheric deposition also contributes to contaminant loads in storm drains and the river upstream of the LDW.

These potential sources were initially inventoried in the Phase 1 RI (Windward 2003a) and will be addressed again in the upcoming Phase 2 RI. Section 8 of the FS report will briefly summarize the status of ongoing source identification and source control activities within the LDW. This section of the FS report will also present the results of sediment transport modeling and any associated insights regarding the potential impact of continuing sources of COCs to the LDW. In addition, deposition from specific lateral loads near major discharge locations will be considered in evaluating the potential for natural recovery, or the potential for recontamination, using output from the site-wide model. These analyses will inform both the remedy selection in these areas and the ongoing, coordinated source control efforts.

This section of the FS will summarize the progress and findings of the LDW Source Control Work Group, which includes Ecology as the lead, EPA, King County, the City of Seattle, the City of Tukwila, and the Port of Seattle. Source control efforts are implemented by the Source Control Work Group through a tiered approach, beginning with basins, shoreline, and nearshore facilities that discharge to: (1) high-priority areas associated with priority sediment cleanups (e.g., EAAs), (2) areas associated with longer-term cleanup levels, and (3) basins that may not drain directly to an identified sediment cleanup area. In addition, the work group will focus source control efforts to address any recontamination identified by the monitoring of completed sediment cleanup areas (Ecology 2004).

2.9 Detailed Analysis of Remedial Alternatives

Section 9 of the FS report will present a detailed evaluation of each remedial alternative relative to both the nine CERCLA criteria and the MTCA minimum requirements. This evaluation will be followed by a comparative evaluation of the alternatives in Section 10 relative to these same criteria. Table 2-3 lists the criteria to be used for the detailed evaluation of remedial alternatives. This section will also evaluate potential contributions from ongoing sources (i.e., source control evaluation) as a component of the evaluation of remedial alternatives.

As described in Section 1.3.1, the requirements for evaluating remedial alternatives are similar under both CERCLA and MTCA. Both acts require that a comparative analysis of remedial alternatives be completed by considering both threshold requirements and balancing criteria; modifying criteria (i.e., state and community acceptance) will be addressed in the ROD as part of the final remedy selection. A comparison of the CERCLA and MTCA criteria is presented in Appendix A and a brief overview follows.

The CERCLA and MTCA minimum threshold requirements are:

- Protect human health and the environment
- Comply with cleanup standards (WAC 173-340-700–760)
- Comply with applicable local, state, and federal laws (ARARs under CERCLA)
- Provide for compliance monitoring (WAC 173-340-410 and 173-340-720–760) (MTCA only).

The CERCLA balancing criteria are similar to the MTCA disproportionate cost analysis:

- Short-term effectiveness
- Long-term effectiveness
- Reduction in mobility, toxicity, or volume through treatment
- Implementability
- Cost.

In addition, MTCA requires that the selected cleanup action shall:

- Use permanent solutions to the maximum extent practicable (as defined in WAC 173-340-360, Subsection 3)
- Provide for a reasonable restoration time frame (as defined in WAC 173-340-360, Subsection 4)

- Consider public concerns (per WAC 173-340-600).

Whether a remedial alternative uses permanent solutions to the maximum extent practicable is evaluated through a disproportionate cost analysis (WAC 173-340-360[3][e]), which provides for comparison of the costs and benefits of the cleanup action alternatives using the following evaluation criteria (similar to the CERCLA balancing criteria):

- **Protectiveness.** Overall protectiveness of human health and the environment

- **Permanence.** The degree to which the remedial alternative permanently reduces the toxicity, mobility, or volume of hazardous substances

- **Cost.** The cost to implement the remedial alternative, including the cost of long-term monitoring

- **Long-Term Effectiveness.** The degree of certainty of success, the reliability of the remedial alternative, the magnitude of residual risks, and the effectiveness of controls

- **Management of Short-Term Risks.** The risks to human health and the environment associated with construction and implementation of the remedial alternative

- **Technical and Administrative Implementability.** Technical feasibility of the remedial alternative and administrative requirements, including costs and implementability of institutional controls

- **Consideration of Public Concerns.** Whether the community has concerns regarding the remedial alternative and, if so, the extent to which the alternative addresses those concerns. This criterion for government and public acceptance will be addressed in the ROD following EPA and Ecology review and stakeholder/public comment on the FS and proposed plan.

Table 2-3 presents the criteria for evaluating remedial alternatives and factors to consider under each regulatory program. A detailed analysis of the remedial alternatives that meet the MTCA and CERCLA requirements will be developed in the FS based on the above criteria.

2.10 Comparative Analysis of Remedial Alternatives

The last section of the FS report, Section 10, will present a comparative evaluation of the remedial alternatives to assess the relative performance of each alternative with respect to the MTCA and CERCLA evaluation criteria described above and detailed in Appendix A. The comparative analysis presented in Section 10 of the FS report will focus on synthesizing the evaluation in Section 9 into readily accessible summaries for decision making. The purpose of the comparative analysis is to identify the advantages and disadvantages of each remedial alternative relative to one another so that key tradeoffs among alternatives can be identified. Examples of key questions addressed in this analysis include:

- What is the near-term, post-remediation benefit of risk reduction to human health and ecological receptors?
- What are the short-term effects of the remediation on workers, the community, and the environment?
- What is the estimated restoration time frame; that is, how long after remediation is completed will it take to achieve sediment concentrations that result in reduced risks to humans and ecological receptors?
- What is the cost of implementing each remedial alternative?
- Which alternative provides the most practical permanent solution in terms of its ability to meet the cleanup standards without further action being required, i.e., which alternative is the MTCA baseline alternative?
- What is the relative cost of each remedial alternative? How does it compare to the MTCA and CERCLA baseline alternatives? How does the cost of each alternative compare to its benefits? Which alternative(s) has (have) an incremental cost that is not proportionate to the incremental benefits (i.e., MTCA disproportionate cost analysis)?

Based on the comparative analysis, Section 10 will identify a recommended remedial alternative that will achieve the RAOs and provide the best balance of tradeoffs among the nine CERCLA criteria and the MTCA minimum and other requirements. A preferred remedy will be identified at the conclusion of the FS report.

Based on the FS, EPA and Ecology will issue a proposed plan for cleanup for formal public comment. Based on the public comments, the ROD will evaluate the modifying criteria of state and community acceptance. Final selection of a remedy will be made by EPA and Ecology, and the selected remedy will be identified in the ROD.

Table 2-1 Example Process Flow Chart for Developing RAOs and PRGs

Risk Assessment →	Statutory Evaluations →	Risk-Based Threshold Concentrations (RBTCs) →	Chemical-Specific ARARs/TBCs →	RAOs →	PRGs →	RALs
HH Receptors/Pathways with "actionable risks"	***Human Health Evaluations***	***Human Health RBTCs***	***Human Health ARARs***	***Example Human Health RAOs***	***Human Health Sediment PRGs***	***Human Health Sediment RALs***
Identification of cancer and non-cancer risks for specified receptors and pathways	Identification of "unacceptable" risk based on regulatory requirements (MTCA/CERCLA)	Determination of sediment concentrations protective of human health	Identification of concentrations in other standards and criteria to protect human health	Description of goals to reduce risk to human health	PRGs for human health are selected based on consideration of: - RBTCs - ARARs or TBCs (chemical-specific) - Background Levels - PQLs	Use of list of risk drivers for determining RALs
Ecological Receptors/Pathways with "remediable risks"	***Ecological Evaluations***	***Ecological RBTCs***	***Ecological ARARs & TBCs***	***Example Ecological RAOs***	***Ecological Sediment PRGs***	***Ecological Sediment RALs***
Identification of ecological risks for specified receptors and pathways	Determination of "unacceptable" risk based on regulatory requirements (i.e., Sediment Management Standards)	Determination of sediment concentrations protective of ecological resources	Identification of concentrations in other standards and criteria to protect ecological resources	Description of goals to reduce risk to ecological resources	PRGs for ecological receptors are selected based on consideration of: - SMS chemical and biological criteria - RBTCs - ARARs or TBCs - Background levels - PQLs	to be determined

Table 2-2 List of Early Action Areas Where Cleanup Is Under Way or Completed

Identified Areas	River Mile	Acres	Rationale for Selection
Duwamish/Diagonal	0.5 E	11	Identified EAA in the *Identification of Candidate Sites for Early Action* (Windward 2003b).
Slip 4	2.8 E	3.6	
Boeing Plant 2	3.4 E	14.9	
Terminal 117	3.6 W	2.2	
Norfolk Area: Boeing Developmental Center South Storm Drain 2003	4.9 E	0.04	Identified EAA. Cluster of PCB CSL exceedances. This EAA is part of a larger area collectively called the Norfolk Area.
Norfolk Area: Norfolk CSO 1999	4.9 E	0.74	The Norfolk CSO remediation area is within the Norfolk Area, but because this remediation was completed before the LDW AOC, samples collected within this area before remediation are not included in the baseline surface sediment dataset. This area will be looked at in the FS in its current, post-cleanup condition

Notes:

AOC = Administrative Order on Consent; CSL = cleanup screening level; CSO = combined sewer overflow; E = east; EAA = Early Action Area; FS = feasibility study; LDW = Lower Duwamish Waterway; PCB = polychlorinated biphenyl; W = west.

Table 2-3 Feasibility Study Criteria for Evaluation of Remedial Alternatives

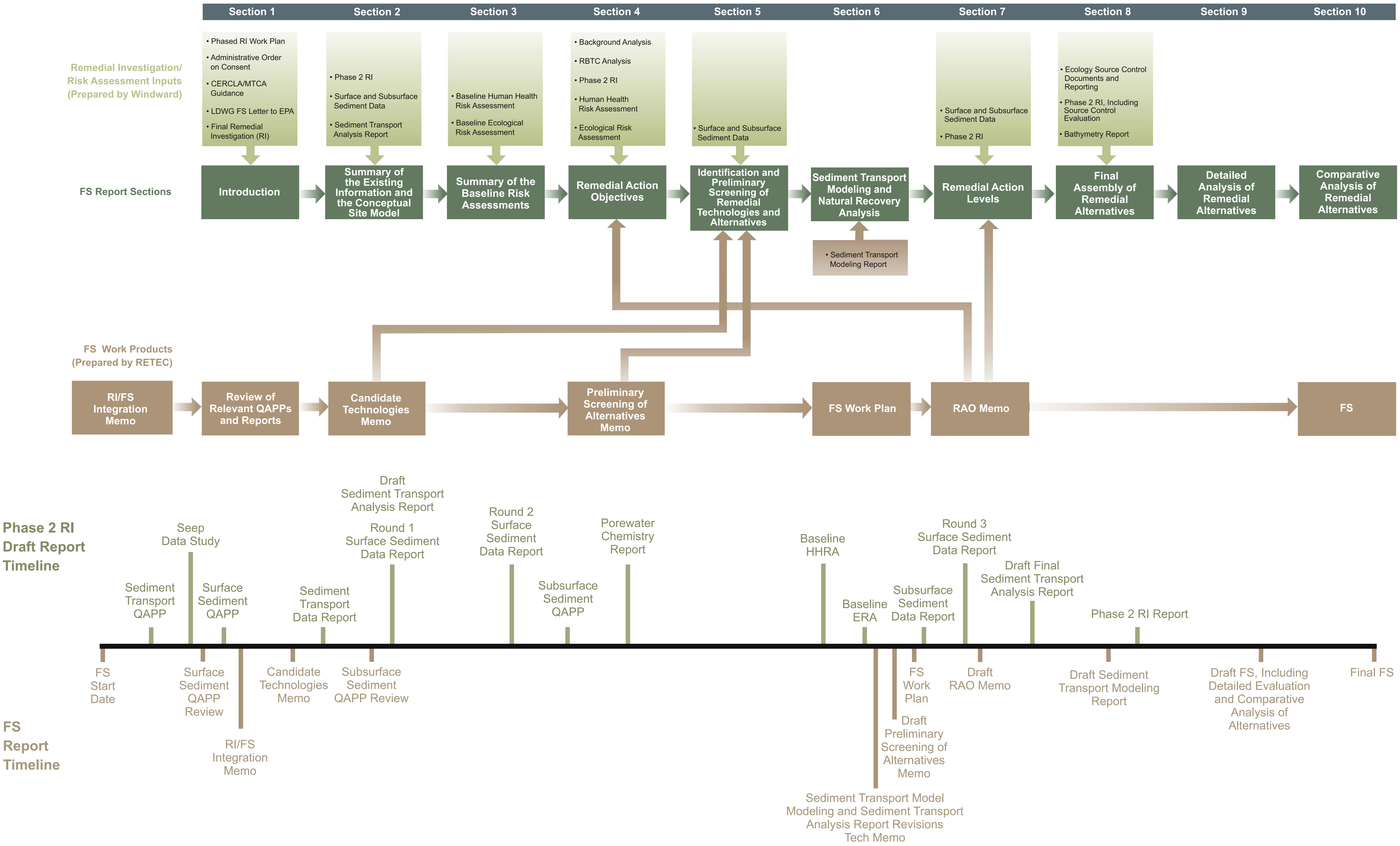
	Overall Protection of Human Health and the Environment*	Compliance with ARARs	MTCA Additional
Threshold Criteria	How remedial alternative provides human health and environmental protection by eliminating, reducing, or otherwise controlling risks posed through each exposure pathway and migration route. Consider risk resulting from implementing the remedial alternative in proportion to overall improvement of environmental quality.	• Compliance with chemical-specific ARARs • Compliance with action-specific ARARs • Compliance with location-specific ARARs • Compliance with other criteria, advisories, and guidance • Compliance with source control requirements	• Time required to attain state SMS cleanup standards • Provide for compliance monitoring (considered in balancing criteria under CERCLA)

	Long-Term Effectiveness and Permanence*	Reduction of Toxicity, Mobility, and Volume through Treatment*	Short-Term Effectiveness*	Implementability*	Cost
Balancing Criteria	• Magnitude of residual risk • Adequacy and reliability of controls • Compliance with cleanup standards over the long-term performance of the remedy	• 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 recycling, reuse, and waste minimization are employed	• Protection of community during remedial actions • Protection of workers during remedial actions • Environmental impacts • Disposal site risks • Effectiveness of measures to manage risk • Time until remedial action objectives are achieved / restoration time frame	• Ability to construct and operate the technology • Landowner cooperation • Integration with existing facility operations and other current or potential cleanup actions • Reliability of the technology • Ease of undertaking additional remedial actions, if necessary • Ability to monitor effectiveness of remedy • Ability to obtain approvals from other agencies • Ability to obtain permitting and funding • 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	• Capital costs, direct and indirect costs • Design and construction costs • Operating and maintenance costs • Net present value • Costs of institutional controls • Long-term monitoring costs

	State Acceptance*	Community Acceptance*
Modifying Criteria	The degree to which state concerns are addressed.	The degree to which community concerns are addressed.

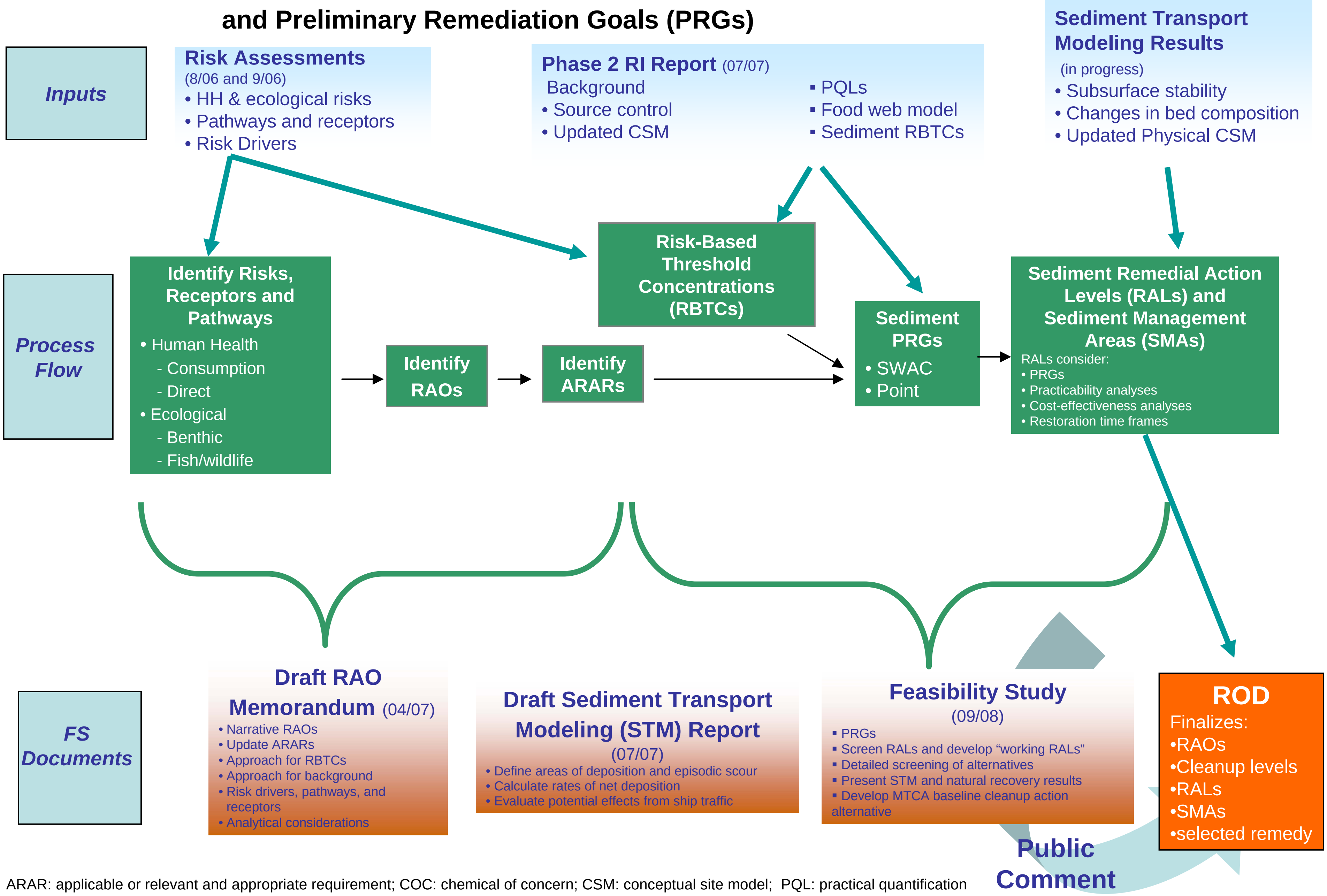
Notes:
ARARs = Applicable or Relevant and Appropriate Requirements; CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act; MTCA = Model Toxics Control Act; SMS = Sediment Management Standards
* Disproportionate cost analysis performed on these criteria.
Sources:
1. EPA 1988. Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA. Interim Final. EPA/540/G-89/004. October 1988.
2. MTCA: Ecology 2001. Model Toxics Control Act Cleanup Regulation, Chapter 173-340 WAC, Section 360, Selection of cleanup actions. Amended February 12, 2001.
3. SMS: Ecology 1991. Sediment Cleanup Standards User Manual. First Edition. December, 1991.

Figure 2-1 Feasibility Study Outline, Scope of Work, and Schedule



Retec/Duwamish/2007/January/Figure 2-1

Figure 2-2 Process for Developing Remedial Action Objectives (RAOs) and Preliminary Remediation Goals (PRGs)



Inputs

Risk Assessments
(8/06 and 9/06)
- HH & ecological risks
- Pathways and receptors
- Risk Drivers

Phase 2 RI Report (07/07)
Background
- Source control
- Updated CSM
- PQLs
- Food web model
- Sediment RBTCs

Sediment Transport Modeling Results
(in progress)
- Subsurface stability
- Changes in bed composition
- Updated Physical CSM

Process Flow

Identify Risks, Receptors and Pathways
- Human Health
  - Consumption
  - Direct
- Ecological
  - Benthic
  - Fish/wildlife

Identify RAOs

Identify ARARs

Risk-Based Threshold Concentrations (RBTCs)

Sediment PRGs
- SWAC
- Point

Sediment Remedial Action Levels (RALs) and Sediment Management Areas (SMAs)
RALs consider:
- PRGs
- Practicability analyses
- Cost-effectiveness analyses
- Restoration time frames

FS Documents

Draft RAO Memorandum (04/07)
- Narrative RAOs
- Update ARARs
- Approach for RBTCs
- Approach for background
- Risk drivers, pathways, and receptors
- Analytical considerations

Draft Sediment Transport Modeling (STM) Report
(07/07)
- Define areas of deposition and episodic scour
- Calculate rates of net deposition
- Evaluate potential effects from ship traffic

Feasibility Study
(09/08)
- PRGs
- Screen RALs and develop "working RALs"
- Detailed screening of alternatives
- Present STM and natural recovery results
- Develop MTCA baseline cleanup action alternative

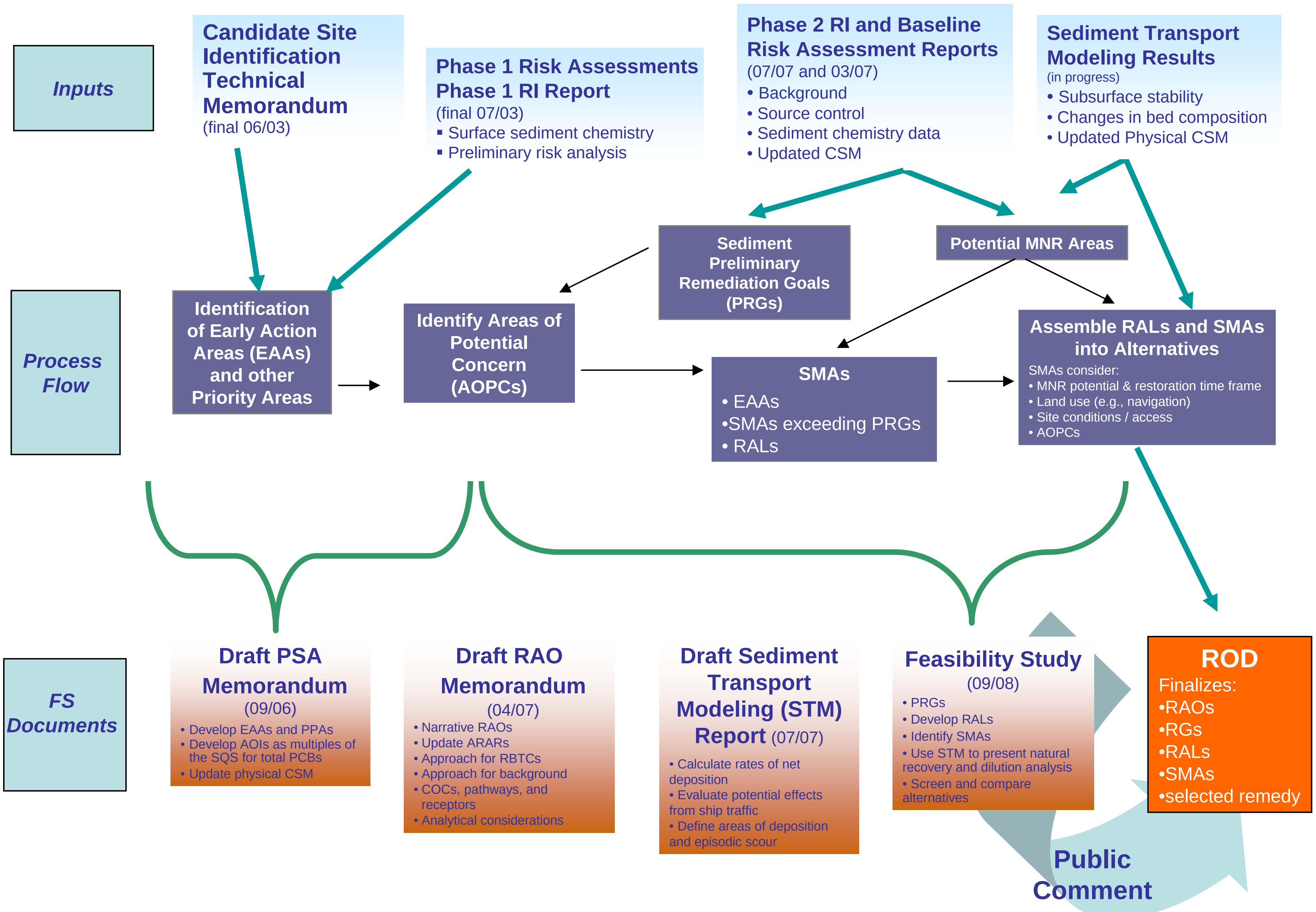
Public Comment

ROD
Finalizes:
- RAOs
- Cleanup levels
- RALs
- SMAs
- selected remedy

ARAR: applicable or relevant and appropriate requirement; COC: chemical of concern; CSM: conceptual site model; PQL: practical quantification limit; PRG: preliminary remedial goal; RI: remedial investigation; RAL: remedial action level; RAO: remedial action objective; RBTC: risk based threshold concentration; SMA: sediment management area; STM: sediment transport modeling; SWAC: spatially weighted average concentration.

Dates represent current schedule for first draft deliverables to agencies.

Figure 2-3 Process for Developing Sediment Management Areas (SMAs)



Inputs

Candidate Site Identification Technical Memorandum
(final 06/03)

Phase 1 Risk Assessments
Phase 1 RI Report
(final 07/03)
- Surface sediment chemistry
- Preliminary risk analysis

Phase 2 RI and Baseline Risk Assessment Reports
(07/07 and 03/07)
- Background
- Source control
- Sediment chemistry data
- Updated CSM

Sediment Transport Modeling Results
(in progress)
- Subsurface stability
- Changes in bed composition
- Updated Physical CSM

Process Flow

Identification of Early Action Areas (EAAs) and other Priority Areas

Identify Areas of Potential Concern (AOPCs)

Sediment Preliminary Remediation Goals (PRGs)

Potential MNR Areas

SMAs
- EAAs
- SMAs exceeding PRGs
- RALs

Assemble RALs and SMAs into Alternatives
SMAs consider:
- MNR potential & restoration time frame
- Land use (e.g., navigation)
- Site conditions / access
- AOPCs

FS Documents

Draft PSA Memorandum
(09/06)
- Develop EAAs and PPAs
- Develop AOIs as multiples of the SQS for total PCBs
- Update physical CSM

Draft RAO Memorandum
(04/07)
- Narrative RAOs
- Update ARARs
- Approach for RBTCs
- Approach for background
- COCs, pathways, and receptors
- Analytical considerations

Draft Sediment Transport Modeling (STM) Report (07/07)
- Calculate rates of net deposition
- Evaluate potential effects from ship traffic
- Define areas of deposition and episodic scour

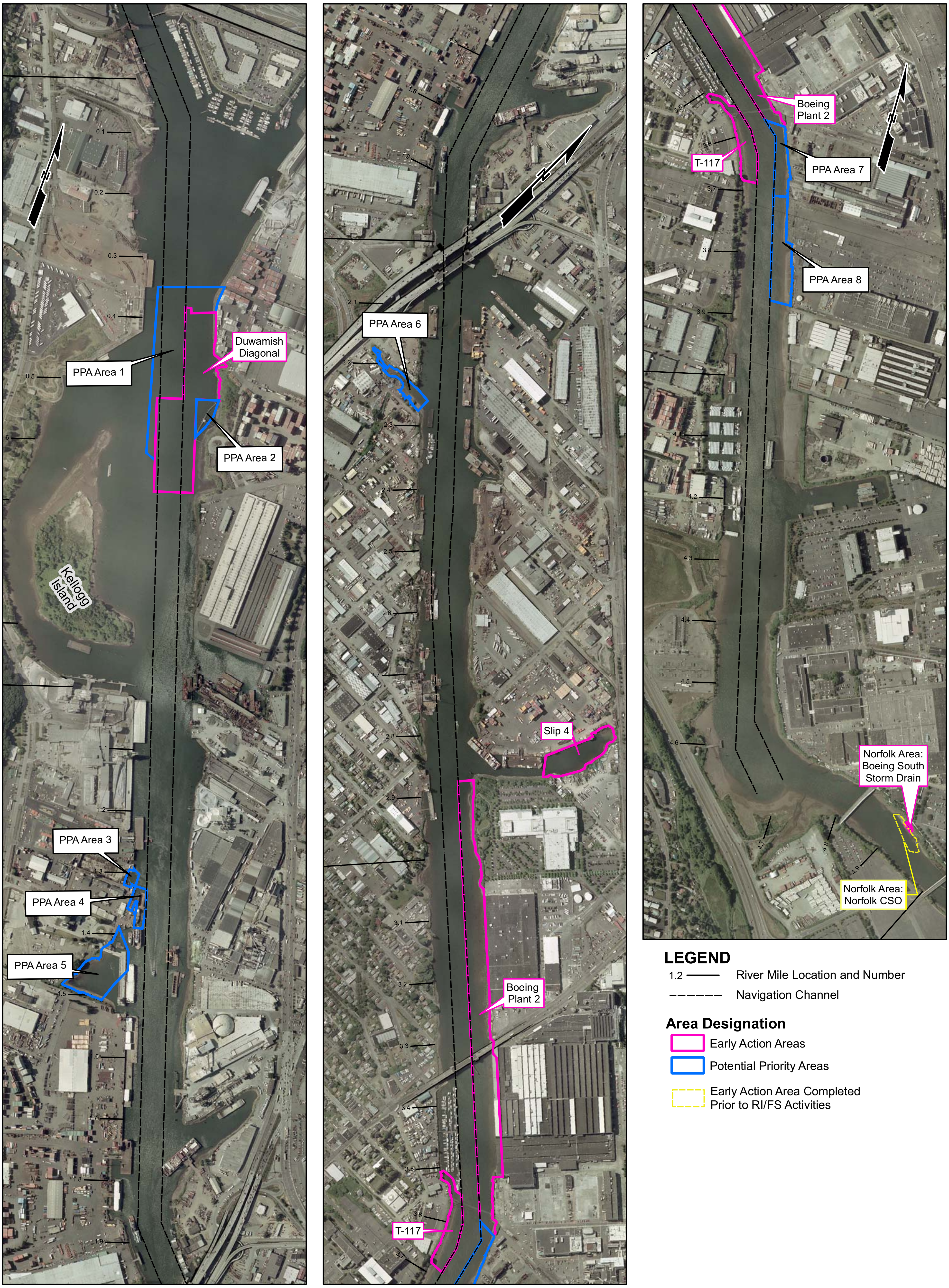
Feasibility Study
(09/08)
- PRGs
- Develop RALs
- Identify SMAs
- Use STM to present natural recovery and dilution analysis
- Screen and compare alternatives

ROD
Finalizes:
- RAOs
- RGs
- RALs
- SMAs
- selected remedy

Public Comment

AOI: area of interest; COC: chemical of concern; CSM: conceptual site model; MNR: monitored natural recovery; PCB: polychlorinated biphenyl; PPA: Potential Priority Area; RALs: remedial action levels; RAO: remedial action objective; RBTC: risk based threshold concentration; RG: remediation goal; RM: river mile; ROD: record of decision; SMS: sediment management standards; SQS: sediment quality standard; STM: sediment transport modeling.

Dates represent current schedule for first draft deliverables to agencies.



LEGEND

1.2 —— River Mile Location and Number

– – – – – – Navigation Channel

Area Designation

▭ Early Action Areas

▭ Potential Priority Areas

⬚ Early Action Area Completed Prior to RI/FS Activities

1. USGS 2002 photograph provided by Windward Environmental LLC.
2. Early Action Areas are areas where one or more individual LDWG members have made a commitment to conduct remedial actions.
3. Potential Priority Areas are areas that are likely to require remediation; however, no commitment to conduct remedial actions has been made.

0 400 800 Feet

RETEC

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

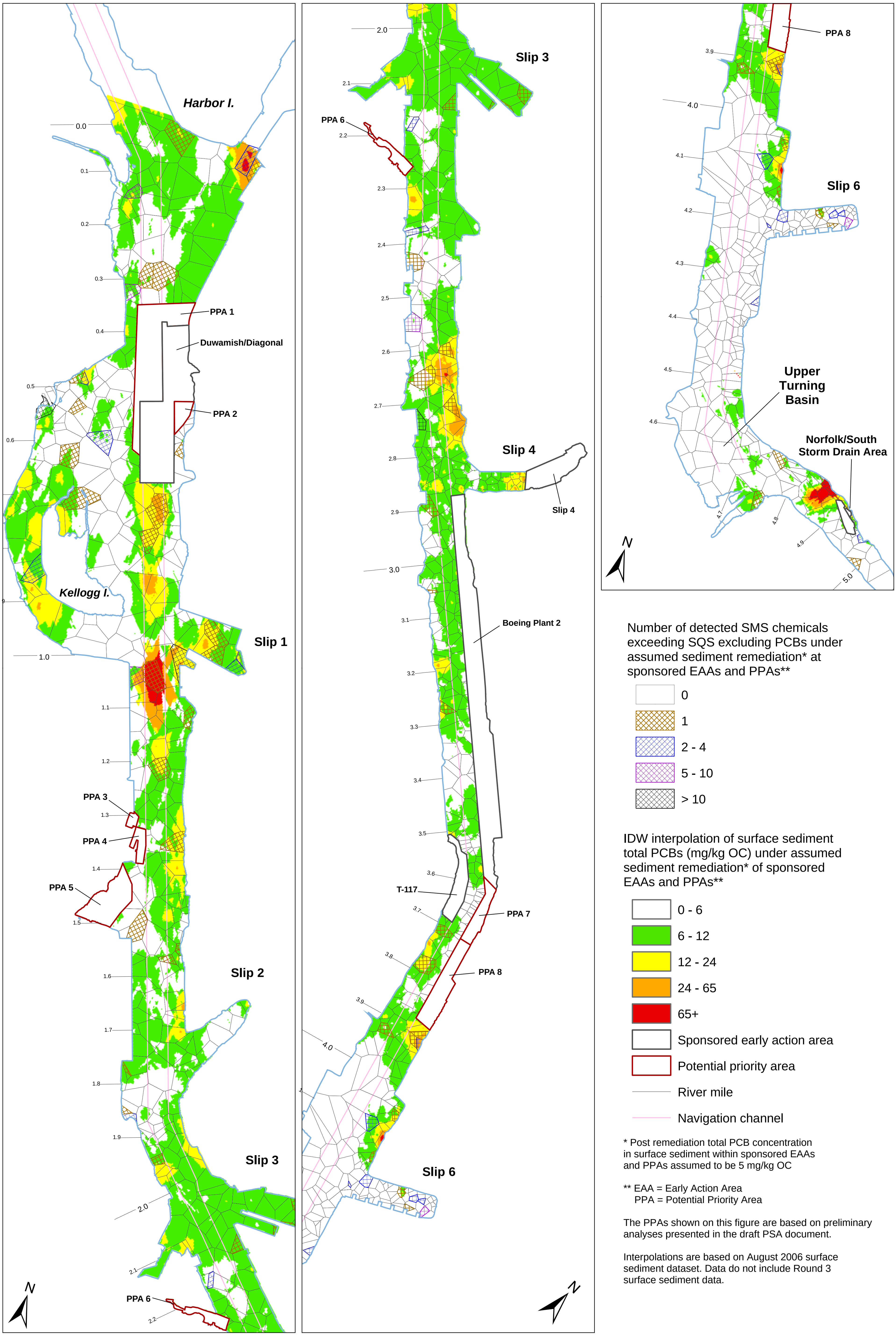
LDW
DRAFT FEASIBILITY STUDY WORK PLAN
(PORS5-18220-622)

LOCATION OF EARLY ACTION AREAS
AND POTENTIAL PROBLEM AREAS
IDENTIFIED IN THE DRAFT PSA

DATE: 1/30/07 | DWN. BY: MI/Sea

FIGURE 2-4

FILE: T:/LDWG_Duwamish/Projects/FSworkplan_V6_Aug06/EAAs.MXD



* Post remediation total PCB concentration in surface sediment within sponsored EAAs and PPAs assumed to be 5 mg/kg OC

** EAA = Early Action Area
PPA = Potential Priority Area

The PPAs shown on this figure are based on preliminary analyses presented in the draft PSA document.

Interpolations are based on August 2006 surface sediment dataset. Data do not include Round 3 surface sediment data.

Windward environmental LLC

0 0.1 0.2 Miles
0 0.1 0.2 Kilometers

Scale is the same for each inset map

Figure 2-5. IDW interpolation of surface sediment Total PCBs and number of chemical exceedances (excluding PCBs) under assumed sediment remediation* at sponsored EAAs and PPAs**

Prepared by CEH 05/30/06, revised 07/07/06, 10/13/06, 04/10/07; Map 2388; W:\Projects\00-08-06_Duwamish_RI\data\gis\Subsurface\Feasibility Study Retec

3 Feasibility Study Data Needs

The process described in Section 2 for completing the FS provides a basis for determining what additional information beyond that collected for the Phase 2 RI will be needed. Consistent with the organizing road map presented in Section 1.3, Section 3 compares the available data against the following information needs:

- What additional information is needed to update the CSM in terms of evaluating sediment transport?
- What information is needed to identify ARARs and develop RAOs and PRGs?
- Are sufficient data available to evaluate sediment transport and natural recovery potential, estimate natural recovery rates, and estimate restoration time frames?
- Are sufficient data available to identify the areal extent and estimated sediment volumes for SMA delineation?
- Is there a sufficient amount of data to develop, screen, and assemble a final set of remedial alternatives, then conduct a detailed evaluation of those alternatives? Are treatability studies needed to develop certain remedial alternatives? Can the costs of the remedial alternatives be reasonably estimated to within the CERCLA accuracy range of -30 to +50 percent? Are cost data adequate to perform the MTCA disproportionate cost analysis?

An evaluation of data needs in response to these questions is presented in Sections 3.1 through 3.6. The schedule for these activities is presented in Section 5.

3.1 Updating the Conceptual Site Model during the FS

The preliminary CSM presented in the Phase 1 RI report (Windward 2003a) included potential sources, possible migration pathways, and receptors. The CSM has been revised in light of new data developed and presented in the risk assessments and the draft final *Sediment Transport Analysis Report* (Windward and QEA 2007). The updated CSM will be presented in the Phase 2 RI report and summarized in the FS report.

The physical CSM presented in the draft PSA (RETEC 2006b) was used as a basis for formulating remedial alternatives in that document. Figure 3-1 graphically displays this CSM as three distinct reaches with similar hydrodynamic characteristics, as described below. Data needed to revise the physical, chemical, and biological components of the CSM are briefly discussed below. The CSM remains an important FS element that needs to be completed before remedial alternatives are formulated.

3.1.1 Physical Conceptual Site Model

Numerous sources of data were used to revise the physical CSM for the LDW. Most of these data were collected, presented, and analyzed in the draft final *Sediment Transport Analysis Report* (Windward and QEA 2007) conducted as part of the Phase 2 RI. A compilation of the components used to develop the current physical CSM (Figures 3-1 through 3-4) and the lines of evidence being used to update the CSM in various stages of the RI/FS include:

- LDW geomorphology
- Sediment mass balance for the 1960 to 1980 time period (extent of available data)
- Observed areas of sedimentation in navigation channel (documented by bathymetry and dredging records)
- Analysis of geochronology cores and subsurface sediment core stratigraphy
- Analysis of depositional rates (sediment transport modeling)
- Analysis of potential effects of natural events (hydrodynamic modeling)
- Site-specific erosion property data (Sedflume cores)
- Analysis of temporal and spatial variations in scour potential (sediment transport modeling)
- Analysis of potential effects of ship-induced bed scour.

Briefly, the current physical CSM describes the LDW in terms of three reaches and nine distinct segments. To derive the nine segments, the three reaches were determined on the basis of combinations of characteristics that include location, water depth, erosion potential, and site use. The three reaches were each then further segmented into shallow and deep bench areas (intertidal and subtidal) and the navigation channel, resulting in a total of nine segments. The physical CSM describes the three reaches as follows:

- **Reach 1: RM 0.0 to 2.0.** The downstream reach of the LDW is net depositional in both the navigation channel and the adjacent bench areas. The navigation channel is classified as higher net depositional, and the bench areas are classified as intermediate net depositional. Empirical data show that the intertidal areas have relatively low net sedimentation rates, on the order of 0.5 cm/year. This reach is occupied by the saltwater wedge under all flow conditions. This reach would not likely be subject to scour during the 100-year, spring-tide, high-flow event except in localized areas.

- **Reach 2: RM 2.0 to 3.0.** The middle reach of the LDW is net depositional on annual time scales[9]. The navigation channel is classified as higher net depositional, and the bench areas are classified as primarily intermediate net depositional, but variable with some small bench areas being lower net depositional and some higher net depositional (on the order of 0.5 to >2 cm/year). This middle reach is a transitional zone between the upper and lower reaches, with the saltwater wedge being pushed downstream of this reach (to RM 1.8) only under extreme flow events (100-year, high-flow event and greater).

- **Reach 3: RM 3.0 to 5.0.** The upstream reach of the LDW is net depositional on annual time scales. The data indicate that the navigation channel has higher net depositional rates than other areas of the LDW. In the bench areas, sedimentation rates are variable, with some areas being lower, intermediate, and higher net depositional. Greater episodic erosion may occur in this reach than in the other reaches during high-flow events. This reach is occupied by the saltwater wedge during low flow and average flow conditions. According to the draft final *Sediment Transport Analysis Report*, average river flows are estimated to be 1,350 cubic feet per second, while river flows during the 100-year events are about 13,000 cubic feet per second (Windward and QEA 2007).

A considerable body of data and information supports the physical CSM and the designation of the three reaches. Figure 3-1 presents a plan view of the three reaches. Schematic cross-sections of the three reaches are presented on Figures 3-2 through 3-4. These figures illustrate the various critical physical characteristics, site use considerations, and scour potential that affect the selection of appropriate remedial technologies.

However, for the purposes of formulating and evaluating remedial alternatives, uncertainty remains in the physical conditions in the CSM, including: (1) the potential for exposure of subsurface contaminated sediment during episodic erosion events, (2) the locations and the length of time of

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[9] Net depositional from year to year, although periods of scour may occur during high-flow events.

episodic exposure, (3) the rate of natural recovery of sediments (the restoration time frame), and (4) the potential for recontamination of remediated areas. These four elements will be assessed using a weight-of-evidence approach. Additional sediment transport modeling will be conducted for the LDW to refine the CSM and improve the ability to predict future conditions (see Section 2.6 and Appendix B). The results from that effort and refinement of the current CSM will be documented in the FS report.

3.1.2 Chemical and Biological Conceptual Site Model

The chemical and biological components of the CSM will be considered complete with the inclusion of source, pathway, and spatial extent information developed in the Phase 2 RI, including the additional chemical sampling described in Section 3.4 and findings presented in the human and ecological risk assessments.

3.2 Data Needs for RAOs and PRGs

A preliminary RAO memorandum (discussed in Section 2.4.1) will be submitted in advance of the draft FS to facilitate discussion among LDWG, EPA, and Ecology on the appropriate ARARs, narrative RAOs, and the process for identifying the PRGs to be used in the FS. The actual PRGs will not be identified in the RAO memorandum.

The principal information requirements that will need to be developed among LDWG, EPA, and Ecology are the appropriate methods to derive and apply both background concentrations and PQLs in developing PRGs. Because these methods will be presented and discussed as part of the RAO memorandum, any additional information needs will be presented there.

A preliminary list of ARARs and TBCs was presented in the Phase 1 RI (Windward 2003a). Any additions to or deletions from that preliminary list will be made as needed. As discussed in Section 2.4, the ARARs/TBCs identified in the RAO memorandum are expected to be similar to those compiled in the Phase 1 RI (Windward 2003a) for the LDW and similar to those compiled for other regional and national CERCLA projects.

RAOs will be developed in an iterative process with EPA and Ecology. PRGs will be developed considering RBTCs developed as part of the Phase 2 RI, chemical-specific ARAR/TBC values, analytical considerations, and background values.

While no additional site data or other information are likely to be needed to develop the ARARs, RAOs, and PRGs, if any additional information is identified it will be discussed in a milestone meeting and presented as part of the RAO memorandum.

3.3 Data Needs for Evaluating Natural Recovery

Natural recovery processes are active to varying degrees in all areas of the LDW and are expected to be an integral component of all remedies to achieve the long-term remediation goals for the LDW. The degree to which natural recovery can contribute to overall management of the LDW requires the ability to estimate the rate at which the LDW can recover, assess whether COCs currently buried will remain in place, and understand the role of source control in the evaluation of recontamination potential. As described in Section 2.6, long-term predictions for natural recovery in the LDW may be improved by implementing the sediment transport modeling and natural recovery analysis discussed in Section 2.6 and in Appendix B.

Based on a series of meetings with EPA and Ecology, the modeling path includes application of the EFDC sediment transport module with the hydrodynamic module, coupled with a bed elevation/chemical concentration change model to predict areas of sediment stability and natural recovery potential (see Appendix B). Modeling results from this analysis will be used to estimate natural recovery rates by assigning chemical concentration values to the primary sediment components of the model (i.e., existing sediment bed, incoming upstream particle loads, and lateral particle loads).

Assumptions regarding costs for a long-term compliance monitoring plan will be included in the detailed analysis of alternatives. Long-term monitoring would be used to verify natural recovery and achievement of RAOs.

3.3.1 Sediment Transport Analysis

The sediment transport model will be used as described in Section 2.6. Input parameters required for model application were developed in a series of meetings among LDWG, EPA, and Ecology.

Existing data to be used as key model input parameters and for calibration and validation are summarized in Table 3-1. The physical processes to be modeled are presented in Table 3-2. When taken in conjunction with the available empirical data, these tools, data, and model output can provide a means of assessing long-term changes in LDW sediments.

Data needs for the model include sediment loading rates, erosion rates, sediment properties (grain size and density), and particle settling speeds. These model inputs will be derived either from existing site-specific data or from literature values. The recently formed Sediment Transport Modeling Work Group, which includes representatives of LDWG, EPA, Ecology, and the U.S. Army Corps of Engineers, is reviewing the data adequacy for sediment transport modeling. The group currently believes that the existing data are adequate for the purposes of the FS, but the group will be finalizing this assessment over the next few months. Therefore, it is presumed that collection of additional data is not needed to support the model. Table 3-3 summarizes the existing sources of LDW model input data. Types of existing data include water column TSS and particle size distribution data, lateral inflow TSS and particle size distribution data, upstream TSS and particle size distribution data, sediment trap data (albeit limited), LDW surface and subsurface sediment grain size and geotechnical data, radioisotope profiles, and Sedflume core data.

Uncertainty introduced from the variability in site-specific values and in the literature values will be evaluated through a model sensitivity analysis (see Appendix B).

3.3.2 Natural Recovery Rate Estimates

The model output (grid cell maps showing surface sediment particle composition over time) will be used in the FS to estimate natural recovery by assigning appropriate contaminant concentrations to the sediment particle sources (sediment bed, upstream loads, and lateral loads) as described in Section 2.6. The data needed to translate the sediment transport model results into predicted natural recovery rates are the estimated sediment contaminant concentrations for each sediment type (upstream-derived, lateral-derived, and sediment bed).

Upstream-derived sediments and lateral inflow sediments can be assigned chemical concentrations from a range of potential data sources or data types, which can be modeled separately or as a combined fraction of “new” sediments. The types of existing data that may be used in a weight-of-evidence approach include, but are not limited to, chemical data from surface water (unfiltered) from LDW, lateral inflow (e.g., storm drain, surface water runoff, CSOs), and upstream surface water sampling stations; in-line storm drain traps and catch basins; in-water sediment traps (limited data exist from south of Harbor Island); subsurface sediment core data from LDW; and area background sediment concentration estimates (approach to be described in the RAO memorandum).

Sediment bed concentrations can be assigned interpolated chemical concentrations representing post-cleanup bed concentrations for different remediation scenarios. In the FS, a sensitivity analysis around natural recovery potential may be evaluated by substituting a range of chemical concentrations (from the area background analyses, for example) into the MNR model to predict site-wide changes in the sediment bed concentrations over time. The area background analysis will be presented in the Phase 2 RI. Based on the availability of existing data (from the Phase 2 RI) to assign sediment chemistry concentrations, additional data are not required for estimating rates of natural recovery in the FS.

In addition to sediment transport modeling, empirical lines of evidence may be used in the FS to improve confidence in the net sedimentation rate estimates calculated from the geochronology cores and natural recovery potential. These lines of evidence, added as an appendix to the draft final *Sediment Transport Analysis Report* (Windward and QEA 2007), include chemical concentration profiles, physical time markers, distribution of sediment grain sizes, and chemical time markers. In addition, changes in bed elevations and surface sediment chemistry over time may be evaluated through historical datasets as additional empirical evidence for evaluating sediment transport and long-term changes in bed elevations. When these lines of evidence are evaluated collectively, a well-defined picture of net sedimentation, erosion potential, and natural recovery is expected to emerge.

3.4 Data Needs for Delineating Sediment Management Areas

SMAs will be developed from the PRGs and AOPCs following the process described in Section 2.8. Identification of SMAs depends on having: (1) a sufficient number of stations to define[10] the extent of COCs in the surface and subsurface sediments, and (2) a completed CSM around which to evaluate remedial alternatives for the SMAs. Table 3-4 presents the data needs associated with defining SMAs. In summary, SMAs will be developed using the following information from the Phase 2 RI and risk assessments:

- Spatial delineation (horizontal and vertical extent) of contaminated sediments (AOPCs) that pose unacceptable risks to ecological and human health receptors, based on PRGs
- Refinements to the CSM related to the evaluation of natural recovery in terms of sediment transport in areas where the surface concentrations may appear acceptable but the subsurface concentrations are higher, as well as scour potential, net deposition, and surface sediment recovery over time
- Refinements to the CSM related to the physical environment and land use (e.g., bed elevation and slope, location of saltwater wedge, land ownership, and navigation)
- Initial identification of SMAs potentially subject to recontamination from ongoing, localized sources.

Consideration of these risk-based concentrations, chemical extent, sediment transport and scour potential, and land use functions will be an essential

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[10] It is acknowledged that after remedy selection, pre-design investigations will develop more site-specific data within individual SMAs. SMA boundaries could be refined or further subdivided during design based on those data.

element of the FS when refining the SMAs and developing remedial alternatives. Most of these data have been collected in previous phases of the Phase 2 RI and risk assessments. Additional FS data needs associated with these considerations are discussed below.

3.4.1 Spatial Extent of AOPCs

Horizontal Extent

Since 1990, more than 1,300 surface sediment samples have been collected (to identify the nature and extent of contaminants in the LDW[11]. These samples form the basis for the Phase 2 RI and baseline risk assessments, and data from these samples will be used to identify the areal extent of SMAs for the FS. The distance between sampling stations is typically less than 400 ft (120 m) and is often less than 100 ft (30 m) in particular areas of interest. In general, surface sediment samples are well distributed throughout the study area.

A quality assurance project plan for the collection of Round 3 surface sediment samples (Windward 2006e) was developed and approved by EPA and Ecology to address uncertainties associated with the horizontal extent of surface sediment contamination. The field work was completed in October 2006. The data report was submitted to EPA and Ecology in February 2007 and finalized in March 2007 (Windward 2007). After compilation of the Round 3 surface sediment data, surface sediment conditions will be adequately characterized to identify and delineate AOPCs. No additional surface sediment data will be needed to complete the FS.

Vertical Extent of COCs

Approximately 350 historical sediment cores have been collected in the LDW to define the vertical extent of contamination[12]. In March 2006, additional subsurface sediment samples were collected, as described in the *Quality Assurance Project Plan: Subsurface Sediment Sampling for Chemical Analyses* (Windward 2006d). In total, 56 core locations were sampled in consultation with EPA and Ecology based on distributions of COCs in surface sediments, spatial coverage, and a review of historical industrial/commercial activity along the LDW corridor. The final subsurface sediment data report (Windward and RETEC 2007) documents the chemical profiles and depth of exceedances.

Preliminary analysis of these sediment cores is being used to vertically profile the major sediment units observed in the LDW. The analysis shows that the

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[11] About 300 of the 1,300 samples were collected from EAAs that are completed or underway. The samples that are representative (i.e., the 1000+ remaining samples, the Round 3 Phase 2 RI data, and monitoring data from completed EAAs) will be used in the FS.

[12] About 140 of the 403 sediment cores were collected from EAAs that are completed or underway. Only subsurface samples that are representative of current conditions (i.e., post-dredge or remedial events) will be used in the FS.

major sediment units (i.e., recent deposits, upper alluvium, and lower alluvium) are present throughout the LDW and that the LDW appears to be net depositional, as described in the CSM. These units may vary in localized areas where shoreline or dredging activities have occurred. The vertical depth of contaminated sediment and volumes will be refined in Sections 6 and 8 of the FS report using the existing subsurface data.

LDWG believes that the available core samples are adequate to sufficiently characterize the nature, extent, and potential depth of remediation within the SMAs based on: (1) an initial review of chemistry data, (2) consistencies observed among stratigraphic units, (3) visual observations, and (4) the apparent correlation between chemistry and stratigraphy. No additional subsurface sediment data will be needed to complete the FS.

3.4.2 Evaluation of Bed Scour and Net Deposition

Based on numerous discussions with EPA and Ecology, additional sediment transport modeling will be conducted to address sediment stability and natural recovery potential. The scope of work and anticipated data needs for this modeling effort are discussed in Section 3.3. Modeling results may be used in the delineation of SMAs.

3.4.3 Future Land Use

Land use functions within the physical environment of the LDW will be considered during delineation of SMAs. These functions include ecologically significant habitat areas, potential restoration areas, recreational land use and access areas, current and future tribal use (subsistence and commercial resource harvesting as well as spiritual and cultural uses), and continued maintenance of the navigation channel (i.e., active berthing areas for commercial and recreational vessels). These types of data have been identified and inventoried in the Phase 1 RI (Windward 2003a) and the draft PSA (RETEC 2006b) and will be revised as necessary in the Phase 2 RI. No additional data are needed to complete the FS.

Potential data needs related to source control are discussed in Section 3.5.5.

3.5 Data Needs for Assembly and Screening of Remedial Alternatives

After filling the information needs described in the previous sections, the final FS consideration will be whether the information is sufficient to allow estimation of costs for the remedial alternatives to within -30 to +50 percent and to support the MTCA disproportionate cost analyses. Table 3-5 describes the physical information needed to assemble, screen, and evaluate remedial alternatives, as well as the sources for those data and the status of data needs. Table 3-6 presents the status of sediment cleanup actions at the EAAs where work has been completed or is currently under way and other remedial actions in the LDW.

3.5.1 Site Conditions and Sediment Properties

Recent projects completed on the LDW point to the need to have a good understanding of the over-water, in-water, and subsurface structures and debris present in the LDW to adequately assess remedial alternatives and their estimated costs. Over-water structures include those piers built out over the waterway on pilings that affect accessibility.

In-water and subsurface structures include active and abandoned pilings, utility and cable corridors, and bridge footings that affect dredging efficiency. Surface and subsurface in-water debris, such as wood, concrete, sheet steel, steel cables, tires, welding rods, and various other debris, may impact the implementability and effectiveness of remedial alternatives, including natural recovery. In the latter case, several recent projects on the LDW have encountered debris that impeded remedial activities and drove up final remedial costs. Table 3-5 evaluates FS data needs related to site conditions and sediment properties needed to develop remedial alternatives such as dredging and capping.

For example, visual inspections, bathymetry surveys, debris surveys, side-scan sonar surveys, and sub-bottom profiling surveys are tools commonly used to evaluate substrate conditions that often impact remedial alternatives and costs. While most of these detailed surveys will occur during the individual site remedial design/remedial action phase, a basic understanding of these conditions is needed to meet the CERCLA cost criteria. Lessons learned from the two EAAs completed in the LDW and other remedial actions completed in the West and East Waterways will be used to supplement our understanding of these conditions for the FS. Assumptions will be built into the FS cost structure (for example, an assumed 20 percent of the area requiring remediation will require a detailed pre-dredge debris removal sweep). Additional FS data needs include:

- **Over-Water Structures Survey.** An observational survey (field observations and site visits along the LDW) of over-water structures will be used as a quality control check of the existing National Oceanic and Atmospheric Administration survey map.

- **Sediment Properties.** No new field data are needed, but existing geotechnical and grain size data from existing core samples will be evaluated and used to revise the cost estimate assumptions regarding sediment properties as they relate to dredging, capping, or treatment.

3.5.2 Development of Remedial Action Levels

No additional field data are anticipated to be needed to develop RALs. This effort is primarily an administrative and technical process. The administrative aspect of this process requires risk management decision making in consideration of the identified risks to human health and the environment, background conditions, acceptable time frames for recovery, cost-effectiveness, and the extent to which institutional controls will be allowed. The technical aspect of this process requires bed mapping using a geographic information system (GIS), data analysis, and predictive tools to determine the long-term recovery potential of the system and the relationship between RALs and sediment recovery (see Sections 2.6 and 2.7).

3.5.3 Incorporating Data from Early Actions

As sediment remediation projects are completed in the LDW over the course of this RI/FS (e.g., Duwamish/Diagonal CSO/storm drain in 2004), relevant information regarding sediment properties, dredging, and capping performance, monitoring results, and design studies may be considered in the FS during development of remedial alternatives.

The Duwamish/Diagonal and Norfolk Areas are both currently being monitored for cap integrity and recovery. For example, five years of post-monitoring data for the sediment cleanup at the Norfolk CSO are available for consideration in the FS. Time trends of changing surface sediment concentrations in these monitoring areas may be used during consideration of equilibrium conditions, RALs, and alternatives. The status of these completed remedial actions and monitoring results are summarized in Table 3-6, along with the status of the other EAAs where work is currently underway. As data become available, results from the monitoring efforts will be incorporated into the FS.

In addition, the actual costs of implementing the completed EAAs and the estimated costs of implementing the selected remedies for the EAAs where cleanup is underway will be included in the analysis of the comprehensive LDW-wide remedial alternatives.

3.5.4 Treatability Studies

The potential need for treatability studies is discussed in the AOC, but such studies are required only when it is demonstrated that this information is needed to understand how various treatment technologies will be applied to LDW sediments. Various *in situ* and *ex situ* treatment technologies were compiled and evaluated in the CTM (RETEC 2005b). In response to EPA, Ecology, and public comments regarding that memorandum, LDWG also produced a treatment white paper evaluating the efficacy of specific treatment technologies, such as Biogenesis™ (RETEC and Integral 2005).

Bench-scale treatability testing of contaminated sediments is typically conducted in a laboratory equipped to test the capacity of chemicals to move in and out of the material and how the physical properties of the material change during dredging, capping, dewatering, settling, or treatment. Many of these tests are specifically designed to evaluate the performance of sediment during application of a particular remedial technology. Relevant sediment properties are discussed below.

Properties for Soil Washing

Soil washing was retained as the representative treatment technology in the draft PSA (RETEC 2006b). Sufficient information on the expected performance and cost of soil washing is available to allow decision making regarding potential selection of a soil washing alternative. It is expected that if soil washing is chosen as either a remedy, remedy option, or contingent remedy, pilot-scale treatability testing could occur in the design phase to refine operating parameters of the system(s).

A significant uncertainty regarding the evaluation of cost and performance of soil washing in the FS is based on the distribution of percent fines in the LDW system. To determine the influence of organic matter on the grain size results (measured as a higher percentage of sand than actually present), a limited number of the subsurface samples will be combusted to remove the organic fraction, then reanalyzed for grain size and Atterberg limits. If the after-burn results are minimally different from the pre-burn results, then the percent coarse fraction in the samples is more certain. If the testing results are substantially different, then the estimated 30 percent sand fraction needed to viably conduct soil washing treatment in the LDW will be re-evaluated. The estimated cut-off may become more conservative (e.g., 40 percent sand) to ensure adequate volumes of sand fraction for treatment and removal. No other treatability studies are currently envisioned for the FS.

Other Sediment Properties

For the purposes of the FS, many of the geotechnical parameters used to evaluate technology performance (grain size, specific gravity, total solids, density, porosity, and Atterberg limits) were already assessed during the 2006 subsurface sampling event. Additional parameters (i.e., compressive shear strength, consolidation properties, particle settling properties) can be extrapolated from earlier studies in the LDW or other riverine sites with similar grain sizes and site conditions and from the remedial actions already completed in the LDW. No other geotechnical parameters or treatability studies, beyond the retesting of grain size results described above, are needed at this time for the FS. Table 3-5 presents an evaluation of data needs related to treatability testing.

3.5.5 Source Control Evaluation

The concept of recontamination by ongoing sources is subtly different from natural recovery. However, both processes relate to long-term effectiveness and long-term changes in surface sediment concentrations. The remedial technology associated with natural recovery is MNR. MNR represents ongoing natural processes where monitoring is conducted to verify that a site will continue to improve after contaminated sediments (above a specified action level) have been managed. Recontamination potential, on the other hand, relates to source control and possible unacceptable increases in sediment contaminant concentrations after completion of a cleanup. Source control pertains to potential ongoing point and non-point sources that are independent of remedial actions for sediments. Source control often pertains to other media and pathways (surface water, suspended solids, atmospheric deposition, and deleterious substances) on the fringes of the study area and often requires coordination with other agencies and stakeholders for management.

One key question for implementing any remedial alternative is, “What is the potential for recontamination and to what degree can sites become recontaminated after remediation?” As part of the Phase 2 RI, existing data from the LDW and its environs will be identified regarding potential sources, pathways, and source control activities. Results of this compilation will be used in the FS to identify SMAs where recontamination potential may be higher. This preliminary assessment may be used by Ecology, the Source Control Work Group, and other relevant parties to help prioritize source control efforts.

In the FS, recontamination potential to the LDW may be further evaluated in three ways: (1) as an empirical but semi-quantitative review of existing data in terms of chemical profiles and changes in sediment chemistry over time in localized areas of the LDW, (2) review of existing information on upstream-derived, lateral inflow-derived, or atmospheric deposition-derived chemical data to the LDW, and (3) through assessment of lateral contaminant loading using output from the sediment transport model. Existing chemistry data will be compiled to assess potential recontamination after remedy completion. These types of data are considered adequate to conduct these analyses; no new field data are anticipated to be collected for the FS.

To the extent practicable, source controls need to be in place before sediment remediation can begin. This assessment will be accomplished during the design phase for individual SMAs. The FS will assume that source control efforts, monitoring, and implementation of best management practices by Ecology, the Source Control Work Group, and other relevant parties will continue. Therefore, future sediment bed concentrations (i.e., chemical concentrations) will only improve through time as source control efforts continue.

3.6 Feasibility Study Supplemental Studies

Based on the information and data needs described above, the Sediment Transport Modeling Work Group held collaborative discussions outlining data gaps and defining a path forward for additional sediment transport modeling. These discussions resulted in a draft technical memorandum (see Appendix B) that outlines the scope of work and approach for conducting additional sediment transport modeling and for revising the draft *Sediment Transport Analysis Report* (Windward and QEA 2006). The memorandum also outlines the input parameters and the output needed to analyze changes in bed composition over time in order to evaluate scour potential, restoration time frames, and natural recovery for selected areas of the LDW. This analysis will be conducted in response to comments from the agencies on the draft *Sediment Transport Analysis Report* (Windward and QEA 2006).

Results of the sediment transport modeling will be presented in the draft *Sediment Transport Modeling Report*, and then finalized as an appendix to the FS after receipt of EPA and Ecology comments. After completion of the additional modeling described in the technical memorandum referred to above, a natural recovery analysis will be conducted using the model outputs; that analysis will be summarized in Section 6 of the FS.

Table 3-1 Key Input Parameters to Predictive Sediment Transport Models and Natural Recovery Analysis

Parameters (typical units shown)		**Environmental Fluid Dynamics Code (EFDC) Sediment Transport Model**		
		Sediment Transport Inputs	**Data Source**	**Comment**
Water Column Properties	Flow Through Water Column (m^3/year)	**X**	USGS water gauge data	Daily flow rates.
	Water Depth of Model Area (m)	**X**	Various bathymetric surveys	
	Surface Area of Model Area (m^2)	**X**	User-specified area calculated using GIS	—
	Sediment TSS Concentration in Inflow (mass/volume)	**X**	King County water quality and USGS data	Two sets of USGS data (from 1960s and 1990s)
	Suspended Solids Chemical of Concern (COC) Concentration (mg/L)*	—	King County water quality data	Two surface water stations: one upstream, one in Elliott Bay. Monthly data for just over a year. Infer COC concentration on the solid phase from the water results.
	Total Organic Carbon (TOC) Fraction of TSS*	—	King County water quality data	Two surface water stations: one upstream, one in Elliott Bay. Monthly data for just over a year.
Sediment Properties	Active Layer Thickness (m)	**M**	Calculated by sediment transport model	—
	Active Layer Density (g/m^3)	—	Extrapolate from bulk density	—
	Sediment Layer Thickness – below mixed layer (m)	—	User-specified	Depth selected to prevent scour to bottom model layer
	Sediment Layer Density (g/m^3)	**X**	Extrapolate from bulk density	—
	Rate of Mass Accumulation of Solid Material in Sediments (g/cm^2/yr)	**M**	—	—
	Total Net Accumulation of Sediments in Surface Mixed Layer (g/cm^2)	**M**	—	—
	Contaminant Concentration and TOC in mixed layer**	—	Sediment chemistry from surface grabs and top of core samples	Data interpolated over LDW

Parameters **(typical units shown)**		**Environmental Fluid Dynamics Code (EFDC) Sediment Transport Model**		
		Sediment Transport Inputs	**Data Source**	**Comment**
Sediment Properties	Contaminant Concentration and TOC in subsurface layers**	—	Sediment chemistry from subsurface cores	Data extrapolated from nearby cores
	Resuspension Velocity (m/yr)	**M**	Model-calculated using erosion rates and shear stress from hydrodynamic model	—
	Burial Velocity (m/yr)	**M**	Calculated by sediment transport model	—
	Settling Velocity of Solids (m/s)	**O**	May be estimated during calibration, or from literature-derived values	—
System Properties	Critical shear stress for deposition (Pa)	**X**	User-specified, but based on literature values	—
	Critical shear stress for erosion (Pa)	**X**	Sediment Transport Study	—
	Erosion Rate	**X**	Sediment Transport Study Sedflume Analysis	—
	Concentration of Contaminant in Freshly Deposited Material (mg/g)*	—	—	—
	Time (days to decades)	**X**	Varies	Model periods to include episodic events on the order of days to long-term simulations on the order of decades

Notes:

Definitions: cm = centimeter; g = gram; GIS = geographic information system; mg = milligram; L = liter; O = literature-derived value; TSS = total suspended solids; M = calculated by model; m = meter; Pa = Pascals; s = second; USGS = U.S. Geological Survey.

X = field-derived value; — = not an input to the physical model.

* These lateral inflow and upstream data may come from various sources and may be used in the natural recovery analysis.

** These bed sediment data are interpolated from LDW site data and may be used in the natural recovery analysis.

Table 3-2 Physical Processes Represented by Models

Processes Represented	EFDC Sediment Transport Model	Dilution Factor Natural Recovery Analysis
Resuspension	Yes	No
Scour	Yes	No
Deposition	Yes	No
Changes in Bedded Sediment Particle Type*	Yes	No
Changes in Surface Sediment Concentration	No	Yes

Notes: EFDC = Environmental Fluid Dynamics Code

* Type can mean changes in the composition of existing sediment with new sediments (upstream, bed, or lateral load) as well as in the composition of sediment for three different grain size classes (medium to coarse sand, fine sand, silty/clay fraction).

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Table 3-3 Sources of Existing LDW Model Input Data

Model Input Parameter	Data Source*
Upstream flow rate	Historical gauge data at Auburn
Tidal stage	Historical gauge data in Elliott Bay
Upstream sediment load (TSS)	Harper-Owes (1983) sediment rating curve for the Green River and King County TSS data: USGS Duwamish River data from 1965, 1996-98 (to be allocated over three sediment classes for model)
Lateral inflow rates (TSS)	Total modeled runoff from the LDW drainage basin. For modeling purposes, storm drain inflows will be uniformly distributed along the LDW and CSO inflows will be applied at specific locations.
Lateral sediment load (TSS)	King County CSO TSS data and other TSS data as available • 5 stations from March 1996 to May 1997, varied sampling events
Sediment layer density	Site-specific geotechnical field data
Solids settling velocity	Literature values
Erosion rate	Computed from Sedflume analysis
Grain size	Site-specific grain size distribution data
Model Calibration Data	**Data Source**
Bed elevation changes over time	Historical bathymetric data from Corp of Engineers, LDWG (2003) and others
Sedimentation rates	Harper-Owes (1983) net sedimentation rates from 1960 to 1980 Settling particulate matter data from sediment traps (limited stations; 1995 Harbor Island Supplemental RI - three month duration)
Model Validation Data	**Data Source**
Net sedimentation rates in bench areas	Sedimentation rates derived from geochronology cores and from geologic interpretation of subsurface core logs
Water column TSS concentrations	King County water column TSS data • 21 stations from October 1996 to June 1997, sampled weekly, 4 storm events • 4 stations from August 2005 to July 2006, sampled monthly

Notes: CSO = combined sewer overflow; RI = remedial investigation; TSS = total suspended solids; USGS = U.S. Geological Survey

* Values derived from site-specific data and literature values may be modified during model calibration.

Table 3-4 Identification of Sediment Management Areas

FS Questions		Existing Lines of Evidence		Remaining Uncertainties	Resolution of Uncertainties
		Empirical Data	**Application of Data**		
Spatial Extent of AOPCs					
1	Are the boundaries of the existing EAAs and PPAs well delineated?	Yes for EAAs completed or under way. Removal action has been completed in two EAAs. Numerous surface sediment samples exist for these areas.	Map and identify those point-based SMAs based on the criteria defined in Section 2.3.	Low for completed or underway EAAs. Low to moderate for other potential AOPCs.	Collect Round 3 surface sediment data for SMS chemistry to identify and bound AOPCs. No additional data needed for EAAs completed or under way.
2	Is there sufficient surface sediment information/data to identify and bound those areas that exceed the PRGs (i.e., SMS-defined SMAs)?	Numerous (>1000 outside of EAAs) surface sediment samples validated for use in the Phase 2 RI and risk assessments.	Generate GIS-based isopleths for PCBs, and map additional COCs. Map and identify those point-based or SWAC-based SMAs based on the criteria defined in Sections 2.5, 2.7, and 2.8.	Several stations have COCs exceeding the CSL, but are not horizontally bound. Some potential AOPCs only designated by one station. Also need to check co-occurence of COPCs with PCB interpolation maps (PCBs are the most ubiquitous chemical of potential concern.); there are few areas detected above SQS without PCBs.	Collect Round 3 surface sediment data for SMS chemistry to identify and bound SMS exceedences. No other additional data needed. Areas with bioaccumulative chemicals that are not co-located with PCBs will be included in the SMA delineations.
3	What is the vertical extent of contaminated sediment requiring management?	Subsurface chemistry cores	Depth of contaminated sediments in the SMAs defined by either direct measurements from cores, or extrapolated based on depth to lower (native) alluvium.	Low uncertainty. Able to extraploate results.	No additional data needed. Combine lines of evidence in CSM using physical and chemical characteristics and re-evaluate once subsurface data have been interpreted.
Physical CSM / Sediment Stability / MNR Potential					
1	Is sediment stability sufficient that at-depth chemical exceedances will not become exposed at the surface?	Bathymetry, lithology of historical and Phase 2 sediment cores.	Bathymetry revealed areas where scour has occurred. Lithology of subsurface cores reveals depths of stratigrapic units.	Where does scour occur? To what depth? How far is scoured material carried downstream?	Sediment transport model to assess sediment stability.
2	Is newly deposited sediment "clean" enough to allow natural recovery to occur?	Post-remedy cap data on two EAAs. One sediment trap from south end of Harbor Island.	Chemical concentrations on caps represent condition of newly deposited material.	Cap data exist in limited spatial extents. Cap data can represent recontamination by adjacent sources.	Sediment transport model and natural recovery analysis.
Land Use					
1	What ecologically important areas require remediation to protect wildlife and to restrict bioaccumulation to human receptors?	Shoreline surveys, habitat.	Surveys reveal locations of valuable wildlife habitat.	Specific risks to biota are not quantified. Bioaccumulation is not quantified.	Ecological risk assessment,Phase 2 RI.
2	Where does human exposure to sediments occur through recreational land use?	Shoreline surveys.	Surveys reveal locations of potential human exposue to sediments.	Low.	Human health risk assessment.
3	Where are berthing and navigation areas that will require maintenance dredging? Will anticipated dredging impact cap materials? Will dredging expose buried contaminated sediment?	Mapping of over-water structures and berthing areas. Historical dredge records and chemical data.	Mapping reveals area of high human land use and navigation traffic. Dredge records reveal areas subject to maintenance activities.	Low.	Use existing shoreline and LDW surveys and maps. Historical dredge records and USACE 404 permits coupled with chemistry data track the nature of removed material and condition of newly deposited sediments following dredge events.

Table 3-5 Chemical, Physical, and Geotechnical Data Evaluation

Data Typically Needed	Recommended Calculations, Tests, or Measurements	Feasibility Study (FS) Component and Use	Status of Data*
Site Conditions			
Land Use – staging areas	Site reconnaissance along and near shoreline areas	All. These data will identify potential staging areas for dewatering, cap material stockpiling, dredging preparations, and access to the LDW. Data will also provide context for comparison of remedial alternatives.	No additional FS data needed. Staging area for mechanical dredging or cap stockpiling will occur on site. Staging area for CAD or CDF construction may require identification of upland owner and access.
Land Use – use by local Tribes and public	Site reconnaissance along and near shoreline areas	All. Areas designated for public and Tribal use could affect the evaluation of potential remedial alternatives, including extent, cleanup levels, duration, and expectations.	No additional FS data needed. Shoreline inventory completed. No new data needed.
Physical – bottom conditions	Bathymetry/side-scan sonar/ sub-bottom profiling	Capping and dredging. These measurements define the lateral extent of soft sediment for delineation/ characterization. They also identify debris and obstructions that a dredging contractor must address. Sediment Management Areas (SMAs). Scour areas, bathymetry, and bottom conditions will be considered in defining the SMAs.	A 2003 site-wide bathymetry survey has been completed and reported in a Phase 2 data report (Windward and David Evans Associates 2004). No additional FS data needed. Physical subsurface surveys are often conducted during design to identify buried debris and wood, but FS costs will be determined without additional data. Make assumptions based on Early Action Areas.
Physical – structures survey	Site reconnaissance along shoreline areas	All. This activity identifies the presence, condition, and accessibility of under-pier areas. Piling structures can influence fate and transport properties, dredging feasibility, and access to contaminated sediments.	Existing aerial photographs show many over-water structures. Shoreline conditions (bulkheads, riprap, easy access areas) will be inventoried in the Phase 2 RI. No additional FS data needed.

Table 3-5 Chemical, Physical, and Geotechnical Data Evaluation

Data Typically Needed	Recommended Calculations, Tests, or Measurements	Feasibility Study (FS) Component and Use	Status of Data*
Sediment Properties and Remedial Technologies			
Biological – valuable habitat areas	Site reconnaissance	All. Identification of valuable habitat areas will influence the spatial extent of active remedies as they relate to net environmental benefit.	Shoreline surveys to assess habitat value are complete. No additional FS data needed.
Chemical characteristics – in-river sediment	Solids: SMS chemicals, dioxins/furans, total organic carbon	Dredging. Data needed to construct GIS-based contaminant distribution profiles to evaluate remedial action levels and volume estimates. Capping. Sediment concentrations are used as input into advective and diffusive flux modeling needed to account for flux in cap design.	Sufficient surface and subsurface data have been collected during the Phase 2 RI. Sediment properties and chemical concentrations are well defined. No additional FS data needed.
Geotechnical properties – in-river sediment	Grain size (ASTM D422) Bulk unit weight (ASTM D2937) Percent solids (ASTM D2216) Specific gravity (ASTM D854) Atterberg limits (ASTM D4318)	Dredging. The test results will be used collectively to assess dredged material properties, dredgeability, and handling characteristics. Dewatering. The amount of dry solids generated per unit of time also determines sizing. Disposal. The quantity of solids ultimately determines the volume of dewatered material, and hence the volume of sediment transport to a landfill. In addition, needed to estimate volume requirements for disposal in a CDF. Capping. Properties like the Atterberg limits and consolidation characteristics of the sediments are used in the evaluation of cap designs.	Grain size, bulk density, percent solids, Atterberg limits, and specific gravity data were collected as part of the 2006 subsurface core analysis. Grain size surface sediment data currently available. No additional FS data needed.

Table 3-5 Chemical, Physical, and Geotechnical Data Evaluation

Data Typically Needed	Recommended Calculations, Tests, or Measurements	Feasibility Study (FS) Component and Use	Status of Data*
Sediment Properties and Remedial Technologies (continued)			
Geotechnical – *in situ* materials	Shear strength; ASTM D2573 (field vane shear test); ASTM D2850; consolidation testing (ASTM)	Capping. This testing is conducted for final design of the cap, in particular the ability of the in-place material to support the weight of the overlying cover materials.	Design-level consideration beyond the scope of the FS. Typical consolidation and shear strength properties can be applied to capping, CAD, and CDF locations and conceptual designs in the FS. No additional FS data needed.
Treatability – solids dewatering	Column settling tests (U.S. Army Corps of Engineers Engineering Manual 1110-2-5027); filter press and belt press testing (no single method; use conventional engineering practice and vendor proprietary methods, as appropriate)	Paint Filter Test. This test may be required if dredged sediments are disposed of in certain landfills without the paint filter exclusion . Dewatering. The results may be used in design to determine the settling properties of the dredge slurry if design includes hydraulic dredging.	No additional FS data needed. Data from nearby sediment removal projects are available. Use existing and literature data and assumptions for the FS.
Contaminant Mobility testing	Dredging Elutriate Test (DRET; DiGiano 1995)	Dredging. Estimation of contaminant release to water column during dredging.	DRET data and review of water quality from nearby sediment removals are available to help assess FS issues. No additional FS data needed.

Notes:

ASTM = American Society for Testing and Materials; CAD = contained aquatic disposal; CDF = confined disposal facility; DRET = dredging elutriate test; GIS = geographic information system; SMS = Sediment Management Standards

* Additional data typically collected during the design phase.

Table 3-6 Summary of EAAs Under Way and Completed LDW Remedies

Early Action Area Site	River Mile Location	Approx-imate Acres	Activities			
			Investigative Sampling (Total PCB Concentrations in Surface Sediment)	**Remedy Status**	**Post-Remedy Monitoring (Total PCBs in Surface Sediment; µg/kg dw)**	**Status of Upland Source Control**
Duwamish/ Diagonal	0.5 East	11	King County 1994 and 1996, EPA 1998 (Non-detect to 84,000 µg/kg dw; n = 89)	Remedy completed: 68,250 cy dredged to a minimum 3-foot depth, 3-layer cap placed in 2004; adjacent thin-layer (6-inch) sand cap over 4 acres in 2005.	6 cap stations sampled annually from June 2004 to 2014; baseline June 2004 results ranged from non-detect to 120.3; Year-1 results ranged from 11.7 to 294. Recent results show that chemicals are accumulating in the cap, indicating potential recontamination.	Sewer separation, sediment removal from sewers, upland business inspections.
Slip 4	2.8 East	3.6	Numerous sampling events, historical to 2005.	Draft Engineering Evaluation / Cost Analysis completed in 2006. Design is under way.	—	Inspections of businesses in the Slip 4 drainage basin; source tracing and identification using storm drain sediment traps and collection of in-line and catch basin sediment samples; and an investigation of the Georgetown flume.
Boeing Plant 2	3.4 East	14.9	Ongoing in-water and upland environmental investigations since 1994.	To be determined.	—	Numerous interim measure remedies, including a few dozen soil excavations; three groundwater sheetpile containments; one soil vapor extraction and groundwater stripping system; one floating product extraction system; an ongoing stormwater system management initiative involving monitoring, containment, and replacement of stormwater drainages; and over 5 years of quarterly monitoring at 29 shoreline wells.

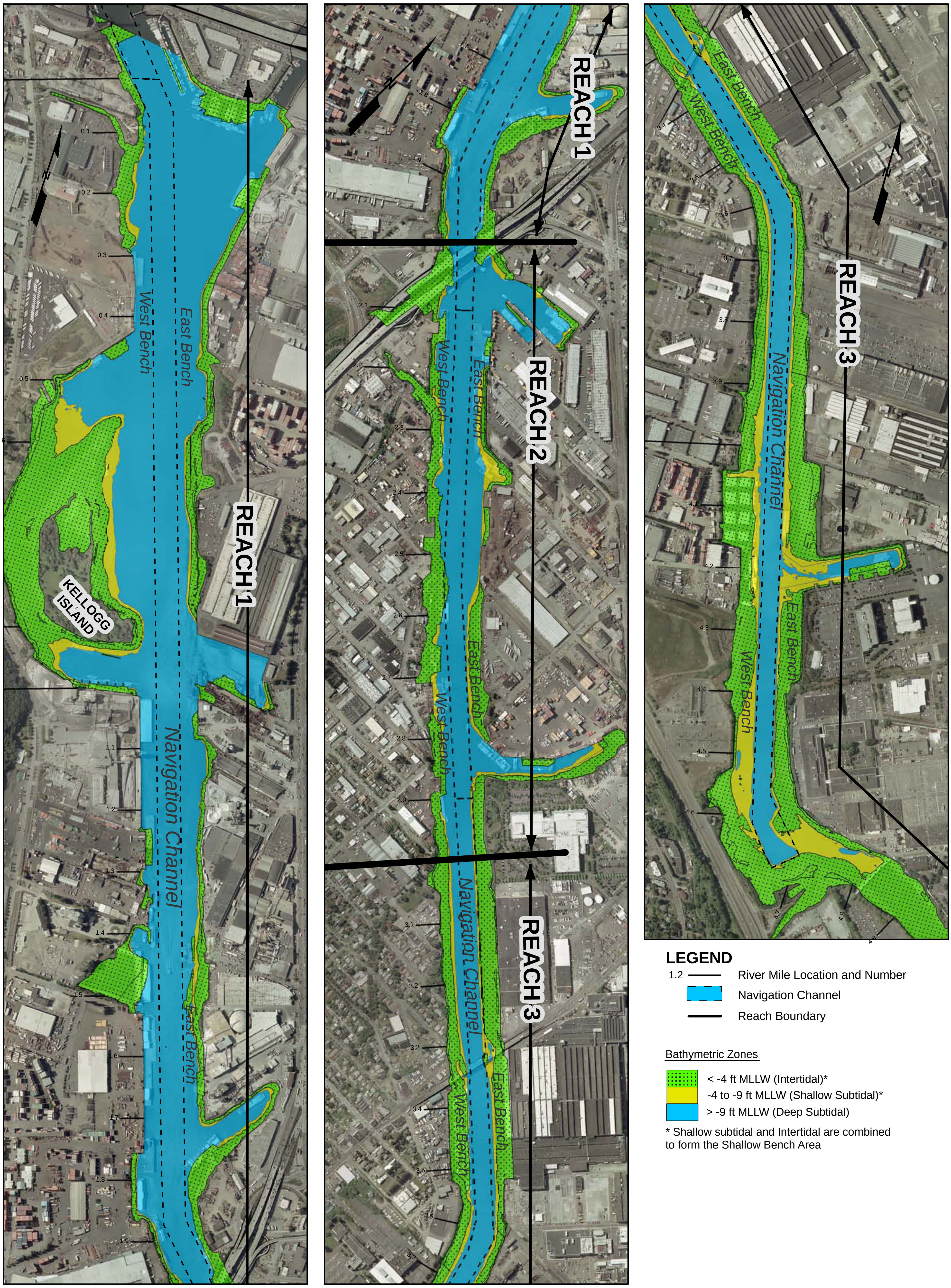
Table 3-6 Summary of EAAs Under Way and Completed LDW Remedies

Early Action Area Site	River Mile Location	Approx-imate Acres	Activities			
			Investigative Sampling (Total PCB Concentrations in Surface Sediment)	**Remedy Status**	**Post-Remedy Monitoring (Total PCBs in Surface Sediment; µg/kg dw)**	**Status of Upland Source Control**
Terminal 117	3.6 West	2.2	Numerous sampling events, historical to 2005.	Draft Engineering Evaluation / Cost Analysis completed in 2005. New EE/CA to be drafted in 2007. Combined upland and in-water remedy with habitat enhancement planned for 2007.	—	Time-critical removal action completed in November 2006 for three upland areas and the riverbank. An interim asphalt cap was constructed on each area over clean fill and filter fabric. Approximately 2,000 cy of soil impacted with PCBs were removed (RETEC 2007).
Norfolk Area: Norfolk CSO 1999[1]	4.9 East	0.74[1]	Three rounds in 1994 and 1995. (Cleanup study report, non-detect to 478,000 µg/kg dw; n = 46)	Remedy completed; dredge to maximum depth of 9 feet, 6,700 cy clean sand backfill in 1999.	4 stations sampled annually from 1999 to 2004; Year-5 results ranged from non-detect to 470.	1998 Henderson diversion structure.
Norfolk Area: Boeing Development Center South Storm Drain 2003	4.9 East	0.04	2002 and 2003 Ecology and Boeing (non-detect to 15,000 µg/kg dw)	Remedy completed; dredge 60 cy by hand at low tide, cap, stabilize drainage channel, plant native vegetation in 2003.	3 grabs composited, samples collected annually for 3 years; adjacent storm drain monitoring.	Cleanout of storm drain system, installation of oil-water separator.

Notes:

— = action has not occurred to date; CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act; cy = cubic yards; dw = dry weight; PCB = polychlorinated biphenyl; µg/kg = micrograms per kilogram

[1] The Norfolk Area: Norfolk CSO sediment remediation was completed in 1999, and thus the post-remedy sampling is used in the baseline dataset. This area is not an EAA; however, this remedy is tracked in the FS from an engineering and a chemical recovery/cap recontamination standpoint.



LEGEND

1.2 —— River Mile Location and Number

🟦 Navigation Channel

▬ Reach Boundary

Bathymetric Zones

🟩 < -4 ft MLLW (Intertidal)*

🟨 -4 to -9 ft MLLW (Shallow Subtidal)*

🟦 > -9 ft MLLW (Deep Subtidal)

* Shallow subtidal and Intertidal are combined to form the Shallow Bench Area

1. Bathymetry data provided by Windward Environmental, LLC based on waterway-wide October 2003 survey.
2. USGS 2002 photograph provided by Windward Environmental, LLC.
3. Conceptual site model (CSM) represents 9 CSM segments comprised of 3 reaches with 3 different bathymetric zones.
4. Reach 1 is from river mile (RM) 0.0 to 2.0. Reach 2 is from RM 2.0 to 3.0. Reach 3 is from RM 3.0 to 5.0.

0 400 800
Feet

FILE: T:/LDWG_Duwamish/Projects/FSworkplan_Oct06/RivSections_Aerial.MXD

RETEC

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

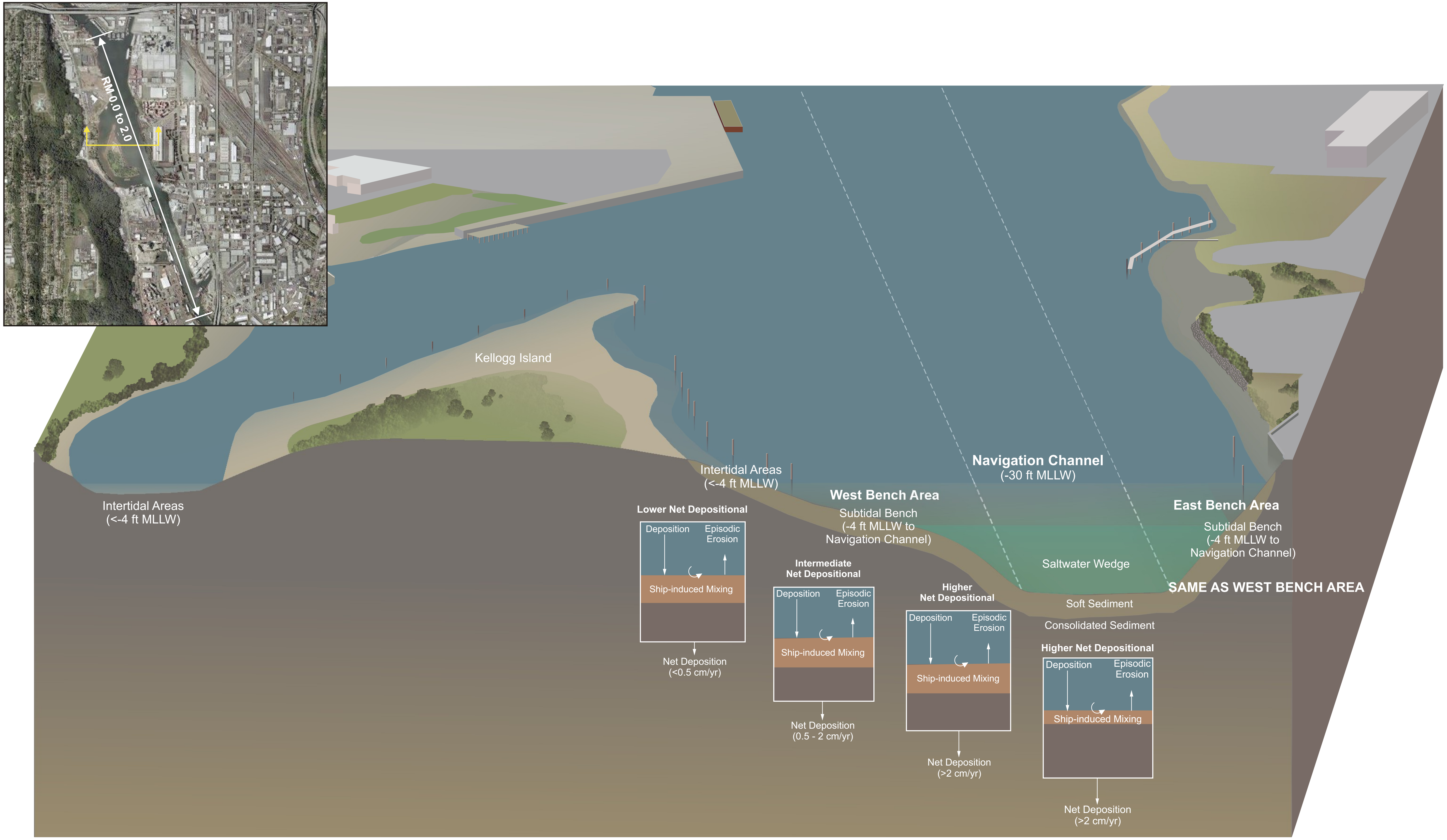
LDW
DRAFT FEASIBILITY STUDY WORK PLAN
(PORS5-18220-623)

CONCEPTUAL SITE MODEL OF LDW REACHES

DATE: 10/12/06 | DWN. BY: KBL/ftc

FIGURE 3-1

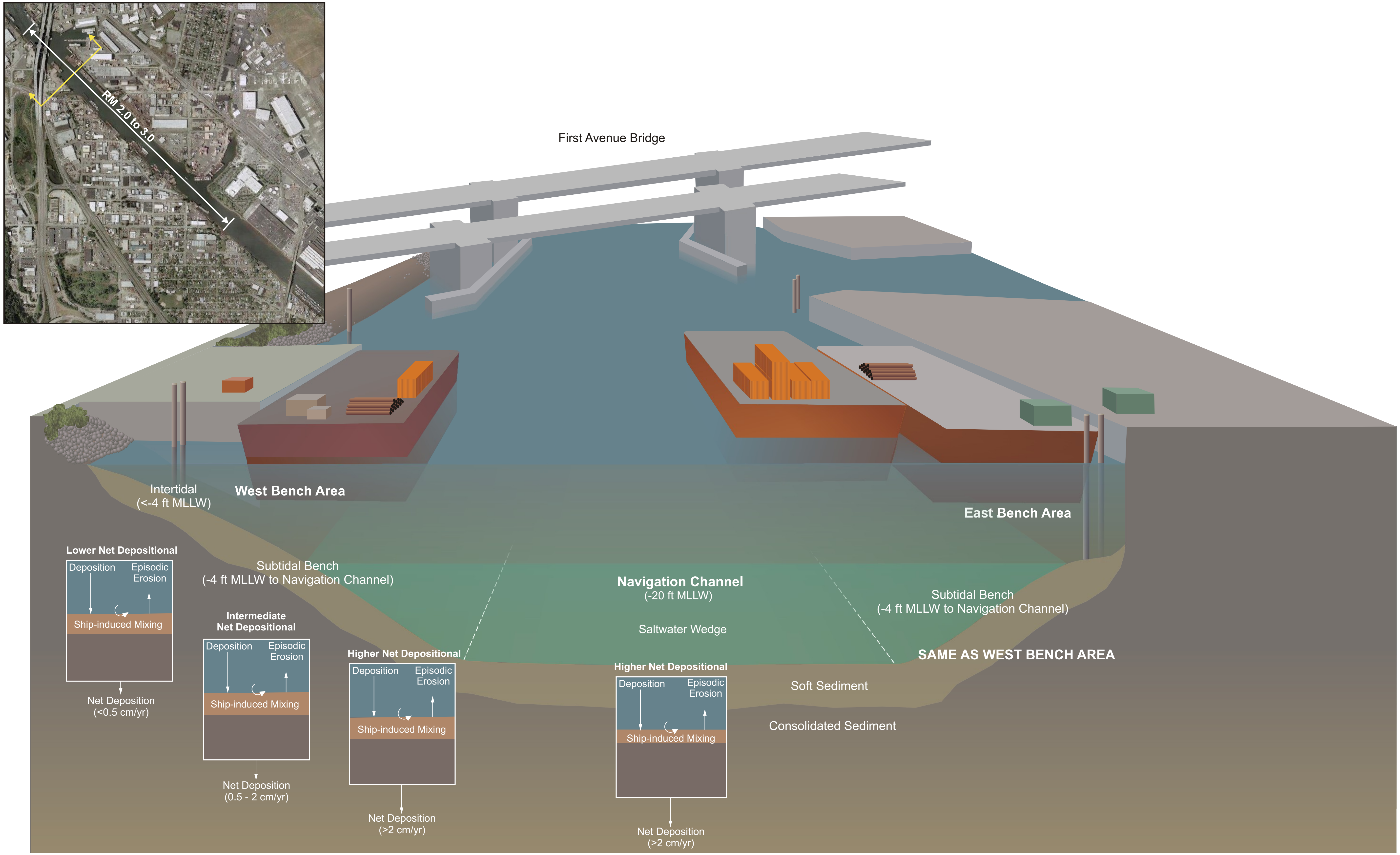
Figure 3-2. LDW Conceptual Site Model for Reach 1 (RM 0.0 - 2.0)



Notes: 1. Approximate net depositional rates from Sediment Transport Analysis Report, Windward and QEA 2006.
2. Inserts are qualitative illustrations and are not to scale.

Figure last updated on April 4, 2007

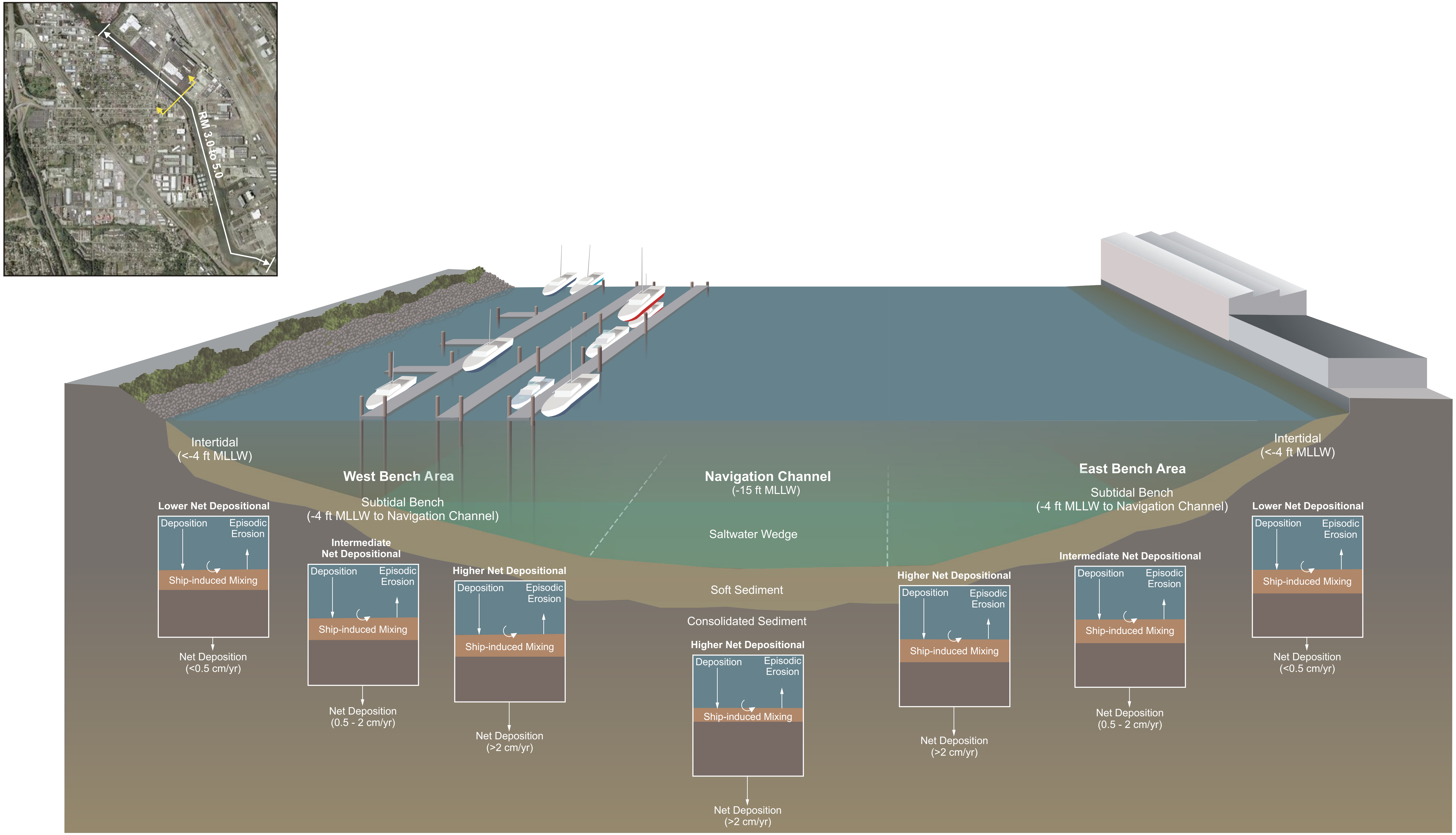
Figure 3-3. LDW Conceptual Site Model for Reach 2 (RM 2.0 - 3.0)



Notes: 1. Approximate net depositional rates from Sediment Transport Analysis Report, Windward and QEA 2006.
2. Inserts are qualitative illustrations and are not to scale.

Figure last updated on April 4, 2007

Figure 3-4. LDW Conceptual Site Model for Reach 3 (RM 3.0 - 5.0)



Notes: 1. Approximate net depositional rates from Sediment Transport Analysis Report, Windward and QEA 2006.
2. Inserts are qualitative illustrations and are not to scale.

Figure last updated on April 4, 2007

4 Project Management

This section describes the overall organizational structure for the project and the general responsibilities of each entity involved in the RI/FS.

LDWG has primary responsibility for managing the work completed for the RI/FS. The primary contacts for LDWG are:

- Doug Hotchkiss (Port of Seattle)
- Jeff Stern (King County)
- Jennie Goldberg (City of Seattle)
- Skip Fox (The Boeing Company).

Windward Environmental, LLC (Windward) is the primary consultant for the Phase 2 RI and risk assessment portions of the RI/FS, while The RETEC Group, Inc. (RETEC) is the primary consultant for the FS. John Ryan (Program Manager) will manage RETEC's role on the project. Anne Fitzpatrick (Project Manager) will complete the daily management of the FS. Other key staff members include Timothy Thompson, Mike Riley of S.S. Papadopoulos and Associates, Inc. (SSPA), and Kirk Ziegler of Quantitative Environmental Analysis LLC (QEA), who will be responsible for specific technical tasks of the FS. Figure 4-1 illustrates the project roles.

RETEC is responsible for performing the FS work under the direction of LDWG. These responsibilities include preparing necessary deliverables (as outlined below) for submittal to EPA and Ecology and other involved parties, as well as attending meetings and overseeing subcontractors (e.g., modeling work) as necessary to complete the FS in accordance with the AOC and scope of work.

Table 4-1 identifies the key personnel assigned to this project and provides their contact information. Additional RETEC staff will be assigned to the project as necessary to meet the intent of the AOC and the schedule identified in the statement of work.

4.1 Communication

Drafts of each deliverable will undergo review by LDWG, EPA, and Ecology. LDWG and RETEC will also meet with EPA and Ecology to discuss the intent and content of each deliverable. EPA and Ecology will receive draft and final versions of each deliverable unless otherwise specified. Comments from the agencies and stakeholders and discussion of the drafts will be addressed in the final FS report.

All drafts will be submitted electronically in portable document format (known as PDF) as well as in other software formats (i.e., in Microsoft Word and as Microsoft Excel spreadsheets), as appropriate. Electronic files will be loaded to the project website (http://www.ldwg.org). The need for hard-copy submittals of draft documents will be determined on a case-by-case basis in consultation with EPA and Ecology. The final version of each document will be delivered to EPA and Ecology in both electronic and hard-copy formats. LDWG will send a notification e-mail to the agencies specifying the location of posted electronic deliverables, including documents, GIS layers, and appropriate metadata.

EPA and Ecology are responsible for managing public outreach and document distribution to stakeholders. Communication with the stakeholders and the public will be managed by EPA and Ecology.

4.2 File Management

Project files, including GIS files, database files, reports, and referenced documents, will be maintained on the RETEC server throughout the duration of the project. Windward manages the project website, where all official versions of the deliverables are posted. RETEC is responsible for providing the Windward webmaster with an electronic copy of each deliverable for posting to the website.

4.3 Deliverables

This FSWP specifies and describes agreed-upon tasks to be accomplished for completion of the FS. Unforeseen changes to the scope and objectives of this FSWP resulting from the collection and analysis of new data, modeling results, and results of the data gap analysis will be discussed with EPA and Ecology. To date, the FS deliverables include those discussed below.

This FSWP is a key document in a series of deliverables addressing remedial alternatives for the LDW, in that it lays out the scope of work for assessing the feasibility of various alternatives. This document builds upon the investigation work conducted by LDWG in the Phase 2 RI and risk assessments. The key pre-FSWP and remaining deliverables are highlighted in the project schedule (Section 5) and listed below.

4.3.1 Completed FS Deliverables

FS deliverables already completed include:

- *Remedial Investigation/Feasibility Study Integration Memorandum for the Lower Duwamish Waterway Superfund Site* (RETEC 2005a)

- *Identification of Candidate Cleanup Technologies Memorandum for the Lower Duwamish Waterway Superfund Site* (CTM) (RETEC 2005b)

- The draft *Preliminary Screening of Remedial Alternatives Memorandum, Lower Duwamish Waterway Superfund Site* (RETEC 2006b).

4.3.2 Upcoming FS Deliverables

This FSWP also defines a series of forthcoming memoranda or sections of the FS that will be written as information from the Phase 2 RI and risk assessments becomes available and as FS analyses progress. These include:

- The draft RAO memorandum, which will be finalized in the FS
- The draft Sediment Transport Modeling Report, which will also be finalized in the FS
- The draft and final FS report.

In addition, relevant tables and figures will be provided to EPA and Ecology in advance of milestone meetings to facilitate productive discussions during those meetings.

4.3.3 Requirements for Electronic Deliverables

The requirements for electronic deliverables associated with the FS are described below. Database requirements specific to the Phase 2 RI are not included in the FS deliverables.

Document deliverables will include posting to the project website or delivery on disk of GIS files associated with mapping, interpolations, models, and data analysis presented in maps, figures, and charts and/or referred to in the text. Specifically, the deliverables will include:

- Summary of the GIS layers, either in the notification e-mail or with the document deliverable, with associated figure/model/analysis sources clearly referenced
- Basemap, shapefiles, or geodatabases or other spatial data files
- Shapefiles of points, boundaries, interpolation barriers, and clip files, as appropriate; grids and grid calculations created as a model or interpolation of the data
- For GIS (ESRI) files, the layer file (extension.lyr) containing symbology or mxd with the layer symbolized
- Metadata describing the source and/or process used to create the files and explicit projection and datum information

For models, interpolations, and calculations performed for the final FS, LDWG will provide details (in an appendix or equivalent) describing:

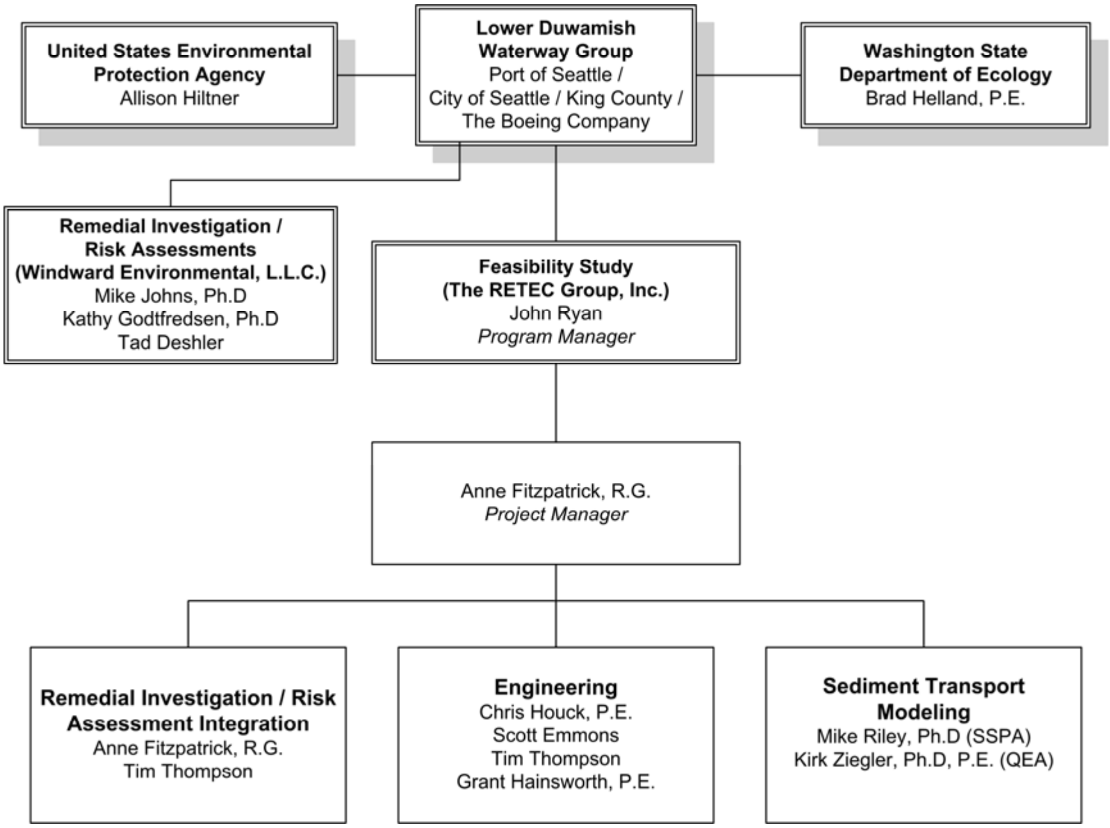
- The purpose, intended use, and limitations of the model or interpolation
- Input parameters to the model and the parameter selection process
- Input data, including date, version, and calculations or summaries applied to the data.

The model code and output for the sediment transport model, as revised and used by LDWG, will be made available to the agencies upon request.

Table 4-1 List of Contacts

Organization	Name	Address	Phone	Email
Lower Duwamish Waterway Group				
Port of Seattle	Doug Hotchkiss	PO Box 1209, 2711 Alaskan Way, Pier 69 Seattle, WA 98111-1209	206-728-3192	Hotchkiss.D@portseattle.org
King County	Jeff Stern	King Street Center, 201 S. Jackson Street, Room 512, Mail Stop: KSC-NR-0512, Seattle, WA 98104	206-263-6447	jeff.stern@metrokc.gov
City of Seattle-City Light	Jennie Goldberg	PO Box 34023, Seattle, WA 98124-4023	206-684-3167	jennie.goldberg@seattle.gov
The Boeing Company	Skip Fox	PO Box 3707, MC: 1 W-12 Seattle, WA 98124-2205	206-851-5991	skip.fox@boeing.com
Feasibility Study				
The RETEC Group, Inc.	John Ryan	1011 SW Klickitat Way, Suite 207, Seattle, WA 98134	206-624-9349	jryan@retec.com
	Anne Fitzpatrick			afitzpatrick@retec.com
	Tim Thompson			tthompson@retec.com
SSPA, Inc.	Mike Riley, Ph. D.	101 N. Capitol Way, Suite 107 Olympia, WA 98501	360-709-9540	mriley@sspa.com
QEA, LLC	Kirk Ziegler, Ph.D., P.E.	305 West Grand Ave, Montvale, NJ 07645	201-930-9890	kziegler@qeallc.com
Remedial Investigation/Risk Assessment				
Windward Environmental, LLC	Mike Johns, Ph.D.	200 West Mercer Street, Suite 401, Seattle, WA 98119	206-378-1364	mikej@windwardenv.com
	Kathy Godtfredsen, Ph.D.			kathyg@windwardenv.com
	Tad Deshler			tad@windwardenv.com
	Zachariah Cassady (webmaster)			zackc@windwardenv.com
Regulatory Oversight				
EPA Region 10	Allison Hiltner	1200 Sixth Avenue, Seattle, WA 98101	206-553-2140	hiltner.allison@epa.gov
Washington State Department of Ecology	Brad Helland, P.E.	3190 160th Avenue SE, Bellevue, WA 98008-5452	425-469-7138	bhel461@ecy.wa.gov

Figure 4-1 Project Participants and FS Organizational Chart



5 Schedule of Activities

Figure 5-1 presents the schedule of activities for the entire FS process and the key Phase 2 RI and risk assessment inputs. Table 5-1 summarizes the key dates for submitting deliverables, including the RAO memorandum, the draft Sediment Transport Modeling Report, and the draft and final FS report, to the agencies. The draft FS report is scheduled to be submitted in September 2008.

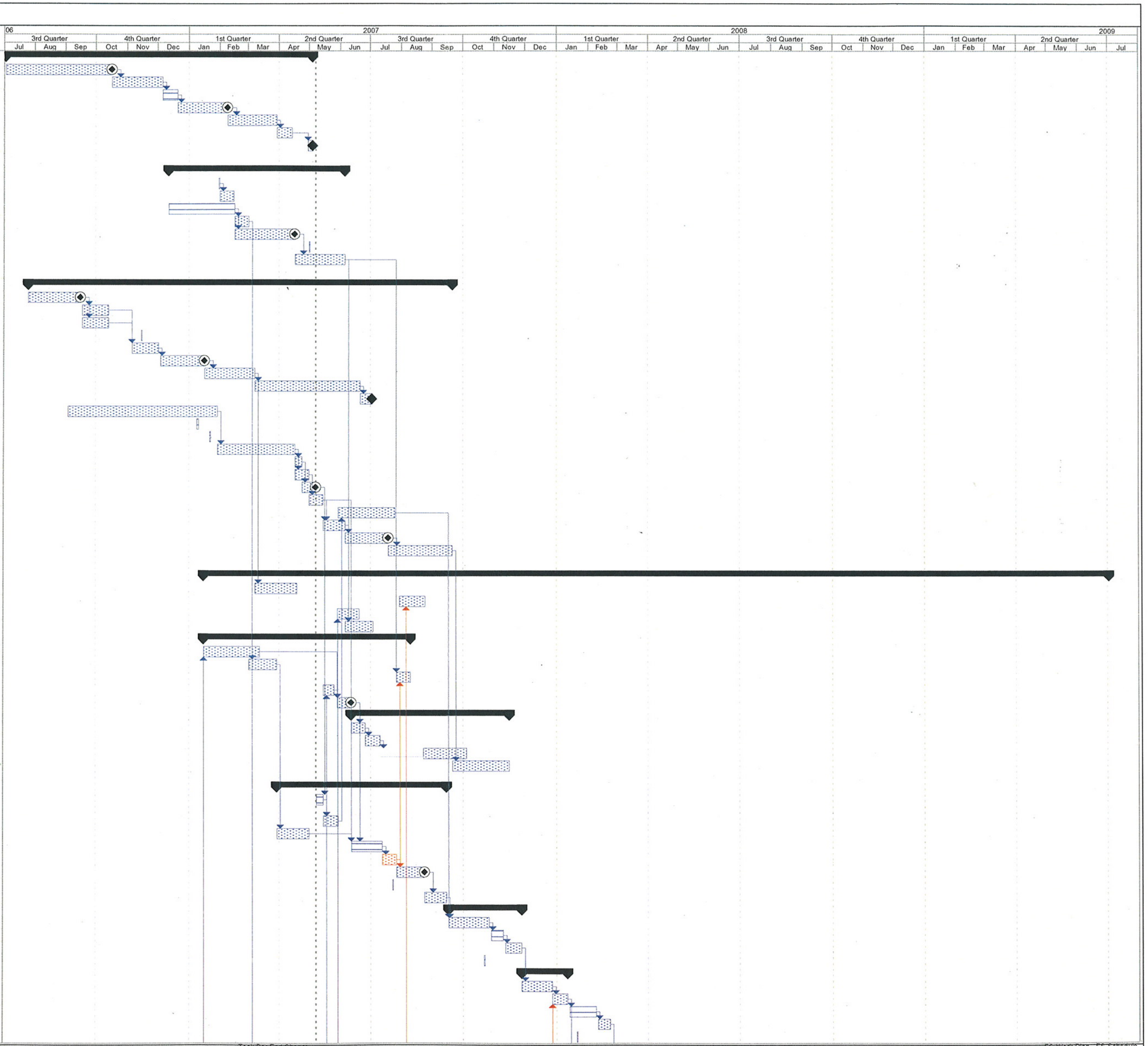
Each key deliverable will build on the outcome of the preceding deliverables. In addition, results of the Phase 2 RI and risk assessments will be used in the FS deliverables. If consensus cannot be reached in a timely manner, then the proposed FS schedule may require modification.

Table 5-1 Key Submittal Dates for the FS Deliverables

FS Deliverable	Draft to Agencies	Revised Draft to Agencies	Final to Agencies
QEA Technical Memorandum: Scope of Work for sediment transport modeling	08/18/06	10/16/06	2/08/07 (presented in Appendix B of the FSWP)
Sediment Transport Analysis Report	04/18/06	01/16/07	6/20/07 (presented in an appendix to the draft Sediment Transport Modeling Report)
Draft RAO Memorandum	4/16/07	Content revised in milestone meetings	Content finalized in FS
Draft Sediment Transport Modeling Report	7/18/07	To be determined (est. late 2007)	Finalized in FS
Feasibility Study Report	09/24/08	03/11/09	07/02/09

Figure 5-1 Schedule of Activities for the FS Process

ID	RI/FS TASK NAME	Duration (working days)	Start Date	Finish Date	Task Predecessor
1	**FS Work Plan**	**43.8 wks**	**Mon 7/3/06**	**Fri 5/4/07**	
2	FS WP draft to agencies	76 days	Mon 7/3/06	Mon 10/16/06	
3	FS WP agency comments	36 days	Tue 10/17/06	Tue 12/5/06	2
4	Agency meeting to review comments/schedule (FSWP)	11 days	Wed 12/6/06	Wed 12/20/06	3
5	FS WP draft final to agencies	35 days	Thu 12/21/06	Thu 2/8/07	4
6	FS WP DF agency comments	35 days	Fri 2/9/07	Thu 3/29/07	5
7	FS WP Final back to agencies	11 days	Fri 3/30/07	Fri 4/13/07	6
8	FS WP approved final	5 days	Mon 4/30/07	Fri 5/4/07	7
9					
10	**RAO Memorandum**	**24.8 wks**	**Tue 12/12/06**	**Tue 6/5/07**	
11	Tech Meeting to review risk results	1 day	Wed 1/31/07	Wed 1/31/07	
12	Draft COCs and RBTCs from risk assessments	10 days	Thu 2/1/07	Wed 2/14/07	11
13	Milestone Meeting #1: RAOs, RBTCs, COCs, and background approach	47 days	Tue 12/12/06	Thu 2/15/07	
14	Follow up to Milestone Meeting #1	10 days	Fri 2/16/07	Thu 3/1/07	13
15	RAO Memo draft to agencies	42 days	Fri 2/16/07	Mon 4/16/07	13
16	Quarterly Stakeholder Meeting - RAOs (Q2 2007)	1 day	Tue 5/1/07	Tue 5/1/07	
17	RAO Memo draft agency comments	35 days	Tue 4/17/07	Tue 6/5/07	15
18					
19	**Sediment Transport Modeling**	**59.6 wks**	**Wed 7/26/06**	**Thu 9/20/07**	
20	Model scoping memo to Agencies	38 days	Wed 7/26/06	Fri 9/15/06	
21	Sed flume analysis	20 days	Mon 9/18/06	Fri 10/13/06	20
22	Ship scour analysis	20 days	Mon 9/18/06	Fri 10/13/06	20
23	Modeling Group Meeting #1 & #2 Parameterization	1 day	Wed 11/15/06	Wed 11/15/06	
24	Update physical CSM and Revise STAR	20 days	Mon 11/6/06	Fri 12/1/06	21,22
25	STAR Draft final to Agencies	31 days	Mon 12/4/06	Tue 1/16/07	24
26	Agency comments on STAR DF	36 days	Wed 1/17/07	Wed 3/7/07	25
27	Final STAR back to agencies	74 days	Thu 3/8/07	Wed 6/20/07	26
28	Finalize Approved STAR	8 days	Thu 6/21/07	Mon 7/2/07	27
29	Sed transport model calibration	105 days	Mon 9/4/06	Mon 1/29/07	
30	Modeling Group Meeting #3 Calibration, design sensitivity	2 days	Tue 1/9/07	Wed 1/10/07	
31	Quarterly Agency/Stakeholder Meeting (Q1 2007)	1 day	Mon 1/22/07	Mon 1/22/07	
32	STM Model application / validation	55 days	Tue 1/30/07	Mon 4/16/07	29
33	Flood event model runs (21 yr simulation) and sed rates	5 days	Tue 4/17/07	Mon 4/23/07	32
34	Long-term model runs for composition (30 year) (2 wks run time)	10 days	Tue 4/17/07	Mon 4/30/07	32
35	Preliminary sediment transport results and example outputs	10 days	Tue 4/24/07	Mon 5/7/07	33
36	Preliminary dilution calculation example outputs	10 days	Tue 5/1/07	Mon 5/14/07	34
37	Scenario model runs	40 days	Wed 5/30/07	Wed 7/25/07	60
38	Draft STM (w/o scenario model runs)	15 days	Tue 5/15/07	Tue 6/5/07	35,36
39	Draft STM to Agency (w/o scenario runs)	30 days	Wed 6/6/07	Wed 7/18/07	38
40	Agency comments on draft STM	45 days	Thu 7/19/07	Thu 9/20/07	39
41					
42	**Draft and Final Feasibility Study**	**125.2 wks**	**Tue 1/16/07**	**Thu 7/2/09**	
43	Revise physical CSM from STAR1 (FS)	30 days	Thu 3/8/07	Wed 4/18/07	26
44	Summarize RI (FS)	20 days	Mon 7/30/07	Fri 8/24/07	122
45	Revise COCs and RBTCs based on agency comments on RAOs (FS)	16 days	Tue 5/29/07	Tue 6/19/07	114
46	Revise RAOs and ARARs based on agency comments	20 days	Wed 6/6/07	Tue 7/3/07	17
47	**AOPCs/PRGs**	**29.2 wks**	**Tue 1/16/07**	**Thu 8/9/07**	
48	Map / interpolate surface sediment COCs with Rd 3 data (AOPCs)	40 days	Tue 1/16/07	Mon 3/12/07	136FS+8 wks
49	Select background values for AOPCs/PRGs	20 days	Fri 3/2/07	Thu 3/29/07	14
50	Revise PRGs from agency comments (FS)	10 days	Fri 7/27/07	Thu 8/9/07	63,17
51	Overlay of scour areas & subsurface data (AOPCs)	9 days	Tue 5/15/07	Fri 5/25/07	59
52	Map areas and volumes for AOPCs	10 days	Tue 5/29/07	Mon 6/11/07	51,48
53	**Preliminary Screening of Alternatives**	**22.2 wks**	**Tue 6/12/07**	**Thu 11/15/07**	
54	Calculate SWAC for Range of RBTCs @ time 0	10 days	Tue 6/12/07	Mon 6/25/07	52
55	Select Range of RALs for MNR analysis	10 days	Tue 6/26/07	Tue 7/10/07	54
56	Rescreen Alternatives / Technologies (PSA)	30 days	Wed 7/11/07	Thu 10/4/07	55
57	Revise CSM based on STM comments, revise technologies as needed	40 days	Fri 9/21/07	Thu 11/15/07	40
58	**MNR Analysis**	**23.6 wks**	**Fri 3/30/07**	**Fri 9/14/07**	
59	Agency Tech Meeting to discuss STM flood/scour/deposition results & lateral loading (TSS)	5 days	Tue 5/8/07	Mon 5/14/07	35
60	Summary Notes of Tech Meeting (STM results)	10 days	Tue 5/15/07	Tue 5/29/07	59
61	Select replacement values for equilibrium and model scenarios (MNR)	22 days	Fri 3/30/07	Mon 4/30/07	49
62	Milestone Meeting #2: PRGs, AOPCs, MNR scenarios, backgrnd, revised	22 days	Tue 6/12/07	Thu 7/12/07	61,52,36
63	Follow up to Milestone Meeting #2	10 days	Fri 7/13/07	Thu 7/26/07	62
64	MNR Analysis & Model Runs	20 days	Fri 7/27/07	Thu 8/23/07	63
65	Quarterly Agency/Stakeholder Meeting (Q3 2007)	1 day	Mon 7/23/07	Mon 7/23/07	
66	Evaluate results of SWAC @ t=10 and 30 for range of RALs*	15 days	Fri 8/24/07	Fri 9/14/07	64
67	**Refine AOPCs, Develop SMAs/RALs, Revise PRGs**	**10 wks**	**Mon 9/17/07**	**Tue 11/27/07**	
68	Modify AOPCs & Select RALs, PRGs & SMAs	30 days	Mon 9/17/07	Fri 10/26/07	66,37
69	Milestone Meeting #3 to discuss SMAs & MNR results	10 days	Mon 10/29/07	Fri 11/9/07	68
70	Follow up to Milestone Meeting #3	10 days	Mon 11/12/07	Tue 11/27/07	69
71	Quarterly Stakeholder Meeting (Q4 2007)	1 day	Mon 10/22/07	Mon 10/22/07	
72	**Assemble Alternatives**	**6 wks**	**Wed 11/28/07**	**Fri 1/11/08**	
73	Modify alternatives from PSA to include RALs and SMAs	20 days	Wed 11/28/07	Thu 12/27/07	70
74	Consider Sources, Outfalls, and Land Use (for alternatives)	10 days	Fri 12/28/07	Fri 1/11/08	123,73
75	Agency Tech Meeting to discuss Alternatives	20 days	Mon 1/14/08	Fri 2/8/08	74
76	Follow up on Tech Meeting (Alternatives)	10 days	Mon 2/11/08	Fri 2/22/08	75
77	Quartery Stakeholder Meeting (Q1 2008)	1 day	Mon 1/21/08	Mon 1/21/08	



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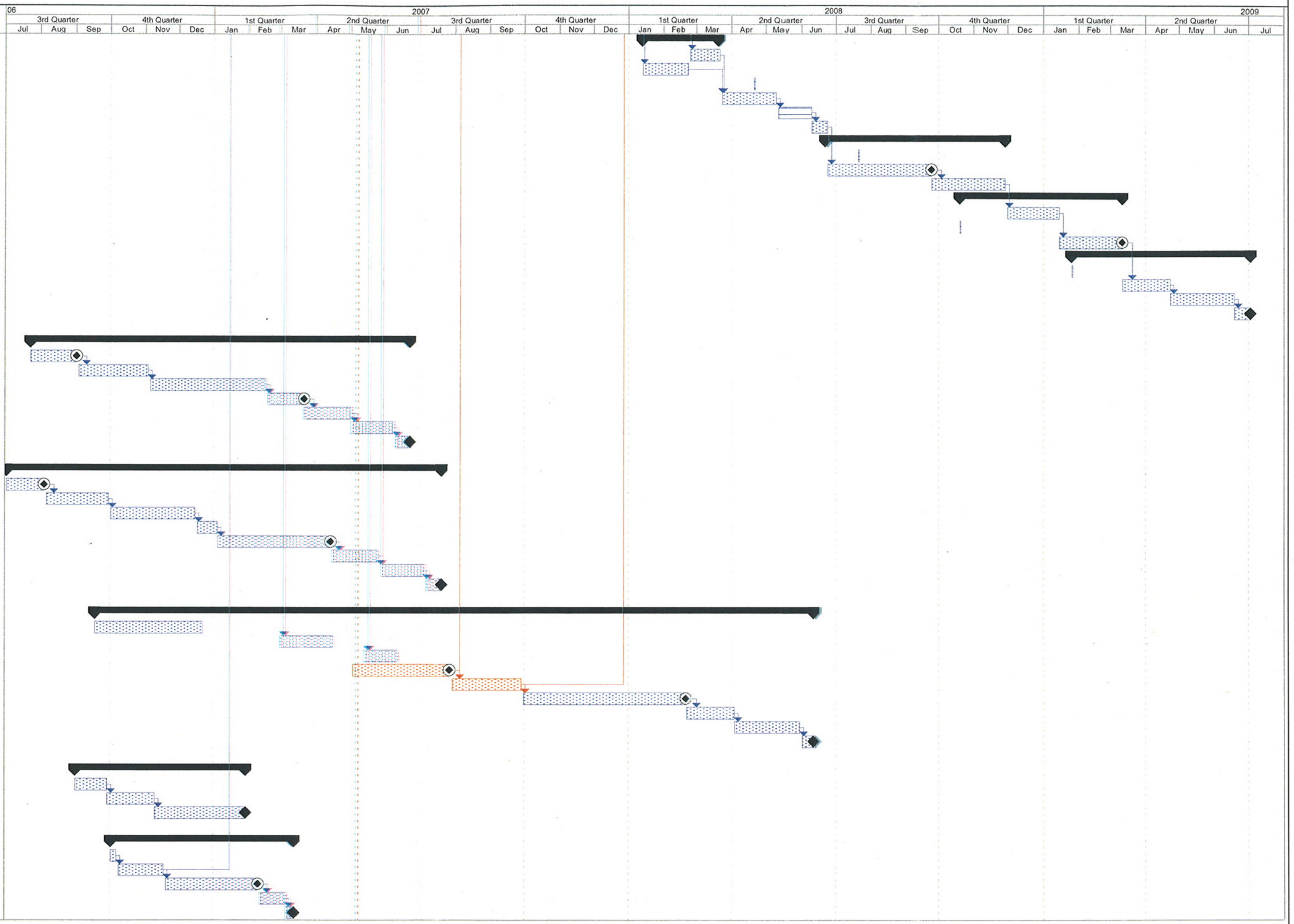
Milestone meeting duration includes handout submittal to agencies prior to meeting.

Task Bar End Shape:
◆ = final deliverable
◈ = draft or key milestone deliverable

Figure 5-1 Schedule of Activities for the FS Process

ID	RI/FS TASK NAME	Duration (working days)	Start Date	Finish Date	Task Predecessor
78	**Detailed and Comparative Analysis**	**10 wks**	**Mon 1/14/08**	**Fri 3/21/08**	
79	Evaluate SWAC at t=10 and t=30 for alternatives	20 days	Mon 2/25/08	Fri 3/21/08	76
80	Detailed analysis of Alternatives (add source control status)	30 days	Mon 1/14/08	Fri 2/22/08	74
81	Quarterly Stakeholder Meeting (Q2 2008)	1 day	Mon 4/21/08	Mon 4/21/08	
82	Comparative Analysis of Alternatives	35 days	Mon 3/24/08	Fri 5/9/08	79,80
83	Milestone Meeting #4 to discuss comparative analysis	20 days	Mon 5/12/08	Mon 6/9/08	82
84	Follow up to Milestone Meeting #4	10 days	Tue 6/10/08	Mon 6/23/08	83
85	**Assembly of Draft FS**	**22 wks**	**Tue 6/24/08**	**Fri 11/28/08**	
86	Quarterly Agency/Stakeholder Meeting (Q3 2008)	1 day	Mon 7/21/08	Mon 7/21/08	
87	Final edits/Draft FS to Agency	65 days	Tue 6/24/08	Wed 9/24/08	84
88	Draft FS agency comments	45 days	Thu 9/25/08	Fri 11/28/08	87
89	**Revisions to FS**	**19.6 wks**	**Mon 10/20/08**	**Wed 3/11/09**	
90	Draft FS revisions	30 days	Mon 12/1/08	Wed 1/14/09	88
91	Quarterly Agency/Stakeholder Meeting (Q4 2008)	1 day	Mon 10/20/08	Mon 10/20/08	
92	Draft Final FS to Agencies	40 days	Thu 1/15/09	Wed 3/11/09	90
93	**Agency Review of Draft Final FS**	**22.6 wks**	**Mon 1/26/09**	**Thu 7/2/09**	
94	Quarterly Agency/Stakeholder Meeting (Q1 2009)	1 day	Mon 1/26/09	Mon 1/26/09	
95	Agency comments on DF FS	30 days	Thu 3/12/09	Wed 4/22/09	92
96	Final FS back to agencies	40 days	Thu 4/23/09	Thu 6/18/09	95
97	***FS Approved Final***	10 days	Fri 6/19/09	Thu 7/2/09	96
98					
99	**ERA report**	**47.6 wks**	**Mon 7/24/06**	**Fri 6/22/07**	
100	ERA draft to agencies	30 days	Mon 7/24/06	Fri 9/1/06	
101	ERA agency comments	45 days	Mon 9/4/06	Fri 11/3/06	100
102	Submit selected ERA text for EPA/Ecology review	74 days	Mon 11/6/06	Fri 2/16/07	101
103	ERA draft final to agencies	23 days	Mon 2/19/07	Wed 3/21/07	102
104	ERA DF agency comments	30 days	Thu 3/22/07	Wed 5/2/07	103
105	ERA Final back to agencies	26 days	Thu 5/3/07	Fri 6/8/07	104
106	ERA approved final	10 days	Mon 6/11/07	Fri 6/22/07	105
107					
108	**HHRA report**	**54.4 wks**	**Mon 7/3/06**	**Fri 7/20/07**	
109	HHRA draft to agencies	25 days	Mon 7/3/06	Fri 8/4/06	
110	HHRA agency comments	40 days	Mon 8/7/06	Fri 9/29/06	109
111	HHRA Memo to Agencies on scenarios	55 days	Mon 10/2/06	Fri 12/15/06	110
112	Agency review of HHRA memo	13 days	Mon 12/18/06	Thu 1/4/07	111
113	HHRA draft final to agencies	71 days	Fri 1/5/07	Fri 4/13/07	112
114	HHRA DF agency comments	30 days	Mon 4/16/07	Fri 5/25/07	113
115	HHRA Final back to agencies	28 days	Tue 5/29/07	Fri 7/6/07	114
116	HHRA approved final	10 days	Mon 7/9/07	Fri 7/20/07	115
117					
118	**Phase 2 RI report**	**89 wks**	**Mon 9/18/06**	**Fri 6/13/08**	
119	Preliminary RBTCs from Food Web Model (RI)	70 days	Mon 9/18/06	Fri 12/22/06	
120	Area background for PCBs & arsenic (RI)	32 days	Fri 3/2/07	Mon 4/16/07	14
121	Summary of outfall data & equilibrium values (RI)	20 days	Tue 5/15/07	Tue 6/12/07	59
122	RI report draft to agencies	60 days	Thu 5/3/07	Fri 7/27/07	
123	RI report agency comments	44 days	Mon 7/30/07	Fri 9/28/07	122
124	RI report draft final to agencies	99 days	Mon 10/1/07	Thu 2/21/08	123
125	RI report DF agency comments	30 days	Fri 2/22/08	Thu 4/3/08	124
126	RI Final back to agencies	40 days	Fri 4/4/08	Fri 5/30/08	125
127	RI report approved final	10 days	Mon 6/2/08	Fri 6/13/08	126
128					
129	**Subsurface Sediment Data Report**	**21.2 wks**	**Fri 9/1/06**	**Mon 1/29/07**	
130	Subsurface DR chemistry & sediment profile and database	20 days	Fri 9/1/06	Thu 9/28/06	
131	Subsurface DR Draft to Agencies	30 days	Fri 9/29/06	Thu 11/9/06	130
132	Subsurface DR approved final	56 days	Fri 11/10/06	Mon 1/29/07	131
133					
134	**Rd 3 Surface Sediment Data Report**	**23 wks**	**Mon 10/2/06**	**Mon 3/12/07**	
135	Rd 3 sediment sampling	5 days	Mon 10/2/06	Fri 10/6/06	
136	Rd 3 analysis & data validation	30 days	Mon 10/9/06	Fri 11/17/06	135
137	Rd 3 DR Draft to Agencies	59 days	Mon 11/20/06	Fri 2/9/07	136
138	Rd 3 DR Agency comments	17 days	Mon 2/12/07	Tue 3/6/07	137
139	Rd 3 DR Data report approved final	4 days	Wed 3/7/07	Mon 3/12/07	138



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Appendix A

Overview of CERCLA and MTCA Criteria for Selection of Remedial Alternatives

Overview of CERCLA and MTCA Criteria for Selection of Remedial Alternatives

This appendix analyzes the requirements for selection of a remedial action under the federal Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and corresponding requirements under the Washington State's Model Toxics Control Act (MTCA). Although many of the requirements of CERCLA have MTCA counterparts, there are some important differences. Table A-1 outlines the major criteria used under CERCLA to evaluate remedial alternatives in a feasibility study (FS) and compares them to the corresponding MTCA requirements. Tables A-2 and A-3 also compare the requirements of the two programs while Table A-4 compares the terminology used in the development of cleanup levels in the two programs. The FS may use separate discussions or checklists to help describe how the combined requirements of both MTCA and CERCLA are being met.

A.1 Threshold Criteria

Both MTCA and CERCLA prescribe threshold criteria that must be met by a remedial or cleanup action. CERCLA's two threshold criteria—overall protection of human health and the environment and compliance with applicable or relevant and appropriate requirements (ARARs)—have direct counterparts in MTCA, which also requires a threshold determination that a cleanup action protects human health and the environment and that it complies with cleanup standards and applicable state and federal laws. Tables A-2 and A-3 compare 40 Code of Federal Regulations (CFR) § 300.430(e)(9)(iii)(A)-(B) with Washington Administrative Code (WAC) 173-340-360(2)(a)(i)-(iii) threshold criteria.

A.1.1 Protection of Human Health and the Environment

Under CERCLA, the criteria used to determine whether a remedial alternative is protective of human health and the environment include consideration of how the alternative addresses unacceptable risks to human health and the environment in the short and long term by reducing or controlling exposure to levels set during the development of remediation goals. This determination necessarily draws on the other evaluation criteria (discussed below), particularly long-term effectiveness and permanence, but also short-term effectiveness and compliance with ARARs (40 CFR § 300.430(e)(9)(iii)(A)).

MTCA takes a different approach to ensuring protectiveness of human health and the environment. Such protectiveness, while a threshold criterion in the cleanup action selection process, is determined during the development and establishment of cleanup levels and cleanup standards, which are required to be protective of human health and the environment (WAC 173-340-700(2)). Therefore, in conducting the FS for the Lower Duwamish Waterway under combined federal and state authorities, it will be necessary to provide an analysis that meets both CERCLA and MTCA requirements.

A.1.2 Compliance with ARARs, Cleanup Standards, and State and Federal Laws

The requirements of compliance with ARARs under CERCLA and compliance with cleanup standards and state and federal laws under MTCA are interrelated. As a result, the discussion and evaluation of these criteria relative to the remedial alternatives developed in the FS could be combined, with an introductory note that the discussion is designed to fulfill the relevant threshold requirements under both CERCLA and MTCA. While state and federal laws are typically ARARs under CERCLA, since the LDW is a joint-led site, compliance with cleanup standards under MTCA and SMS are regulatory requirements.

A.1.3 Compliance Monitoring Required Under MTCA

MTCA imposes the additional threshold criterion of providing compliance monitoring (WAC 173-340-360(2)(a)(iv)), which is not specifically a selection criterion under CERCLA. Compliance monitoring includes protection monitoring (ensuring that human health and the environment are protected during construction and operation and maintenance); performance monitoring (confirming that the cleanup action has attained cleanup standards, remediation levels, and performance standards, or demonstrating compliance with the substantive requirements of other laws); and confirmation monitoring (ensuring long-term effectiveness of the cleanup action once cleanup standards are met) (WAC 173-340-410(1)). While compliance monitoring is required for remedial actions under CERCLA whenever hazardous substances remain on site at levels that do not allow unrestricted use or unrestricted exposure, MTCA's implementing regulations require a specific discussion of the nature of that monitoring in the FS and when making a cleanup decision.

Under CERCLA, evaluation of the sufficiency of compliance monitoring occurs as part of the evaluation of long-term effectiveness and permanence, short-term effectiveness, implementability, and cost. In addition, the sampling requirements associated with operation and maintenance of the remedy, the prescribed measurements associated with verifying attainment of remediation goals, and the measurements related to treatment technologies and engineered controls that are required to be considered in a Record of Decision under CERCLA may all be considered analogous to MTCA's requirement to provide for compliance monitoring. Therefore, the required actions to comply with MTCA are present in a CERCLA remedial action, and this section of the FS—like that which discusses compliance with ARARs, cleanup standards, and state and federal laws—may be a compilation and reiteration of the various actions prescribed by CERCLA that also meet MTCA's compliance monitoring requirements.

A.2 CERCLA's Primary Balancing and Modifying Criteria and MTCA's Other Requirements

Both CERCLA and MTCA prescribe criteria in addition to the threshold criteria described above. CERCLA prescribes five *balancing criteria* and two additional *modifying criteria*, while MTCA prescribes three additional minimum requirements (40 CFR 300.430(f)(i); WAC 173-340-360(2)(b)). All of CERCLA's primary balancing criteria are addressed by MTCA's disproportionate cost analysis, which is the procedure for determining whether a cleanup action is permanent to the maximum extent practicable. Tables A-2 and A-3 compare 40 CFR 300.430(e)(9)(iii)(C)-(G) with WAC 173-340-360(3)(e) requirements. Therefore, in drafting the FS, the discussion of CERCLA's primary balancing criteria (long-term effectiveness and permanence; reduction of toxicity, mobility, or volume through treatment; short-term effectiveness; implementability; and cost) may be combined with the disproportionate cost analysis under MTCA to determine whether a remedy is permanent to the maximum extent practicable.

A.2.1 MTCA Requires a Reasonable Restoration Time Frame, Which Is Not Explicitly Addressed by CERCLA

In addition, MTCA contains a requirement that a cleanup action provide for a reasonable restoration time frame. Under CERCLA, this consideration is evaluated under the short-term effectiveness criterion, specifically as the estimated time to achieve remedial action objectives. In structuring the FS, this topic will need to be a stand-alone subsection in the evaluation of cleanup/remedial alternatives, although the discussion may be able to draw upon other information required for the FS under both CERCLA and MTCA. The factors used to determine whether a restoration time frame is reasonable include risks posed by the site to human health and the environment; the practicability of achieving a shorter restoration time frame; current and potential future uses of the site, surrounding areas, and associated resources; the availability of alternative water supplies; the effectiveness and reliability of institutional controls; the ability to control and monitor migration of hazardous substances from the site; the toxicity of those substances; and natural processes that have been documented to reduce concentrations at the site or under similar site conditions (WAC 173-340-360(4)(b)). Other elements of determining whether or not a cleanup action provides for a reasonable restoration time frame include the consideration of the potential for recontamination when area background concentrations exceed cleanup levels (WAC 173-340-360(4)(d)-(e)) and consideration of technical limitations to meeting cleanup levels (WAC 173- 340-360(4)(e)). In both of these latter cases, MTCA considers the remedial action an interim action until cleanup levels are attained.

Many of these factors are already addressed by both CERCLA and MTCA, so complying with this requirement in the FS may involve reiterating information contained in other sections of the FS. For instance, risks posed by the site to human health and the environment for a particular remedial alternative will be discussed under both CERCLA and MTCA in evaluating overall protection of human health and the environment, as well as in the evaluation of short- and long-term effectiveness under CERCLA's balancing criteria and MTCA's disproportionate cost analysis. In addition, because each individual remedial alternative will be evaluated with regard to its practicability as part of the permanence determination under MTCA, the practicability of achieving shorter restoration time frames should be evaluated by comparing the time frames associated with the different remedial alternatives.

A.2.2 CERCLA's Modifying Criterion of Community Acceptance

The final component of the analysis of remedial alternatives under CERCLA involves consideration of state, tribal, and community acceptance. State acceptance will be satisfied by the approval of cleanup actions and interim actions by the Washington State Department of Ecology. MTCA requires a similar consideration of public concerns solicited during the remedy selection process, so the FS can discuss these concerns from the standpoint of both MTCA and CERCLA in the same section.

A.3 Conclusion

The threshold requirements of protecting human health and the environment and complying with cleanup standards and ARARs are similar under CERCLA and MTCA. The major differences between CERCLA and MTCA requirements for a feasibility study are: (1) MTCA's requirement that a cleanup action provide for compliance monitoring, and (2) MTCA's requirement that a proposed cleanup action provide for a reasonable restoration time frame. The other requirements of MTCA and CERCLA largely overlap, with CERCLA's modifying criteria being components of the MTCA disproportionate cost analysis used to determine if a cleanup action is permanent to the maximum extent practicable.

Table A-1 Comparison of CERCLA and MTCA Remedial Alternative Screening Criteria

	CERCLA[1]		MTCA	
	Detailed Screening		MTCA Detailed Screening Considerations[2]	SMS Detailed Screening Considerations[3]
Minimum Requirements or Threshold Criteria	Overall protection of human health and the environment 40 CFR 300.430(e)(9)(iii)(A)	How alternative provides human health and environmental protection	Overall protectiveness of human health and the environment, including degree to which existing risks are reduced, time required to reduce risk and attain cleanup standards, risks resulting from implementing the alternative, and improvement of overall environmental quality.	Overall protection of human health and the environment by eliminating, reducing, or otherwise controlling risks posed through each exposure pathway and migration route.
	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 guidances	Comply with cleanup standards; comply with applicable state and federal laws; and provide for compliance monitoring. Provide for a reasonable restoration time frame.	Compliance with cleanup standards and applicable laws, including time required to attain cleanup standards.
			Compliance Monitoring	
Other Requirements or Balancing Criteria	Long-term effectiveness and permanence 40 CFR 300.430(e)(9)(C)	● Magnitude of residual risk ● Adequacy and reliability of controls	Degree of certainty that the alternative will be successful in maintaining compliance with cleanup standards over the long-term performance of the remedy, magnitude of remaining risk with alternative in place, and effectiveness of controls to manage remaining wastes.	Short-term effectiveness, including degree of certainty that the alternative will be successful, long-term reliability, magnitude of residual human health and biological risks, effectiveness of controls for ongoing discharges, management of treatment residues, and disposal site risks. Reasonable restoration time frame.
	Reduction in toxicity, mobility, or volume 40 CFR 300.430(e)(9)(D)	● Treatment process used and materials treated ● Amount of hazardous materials destroyed or treated ● Degree of expected reductions in toxicity, mobility, and volume ● Degree to which treatment is irreversible ● Type and quantity of residuals remaining after treatment	Degree to which alternative permanently reduces toxicity, mobility, or volume of hazardous substances, including reduction or elimination of releases and sources of releases and characteristics and quantity of treatment residuals generated.	
	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	Risk to human health and the environment during construction and implementation, and the effectiveness of measures to manage risk (CERCLA considers effectiveness of protective measures implemented during construction for workers.)	
	Implementability 40 CFR 300.430(3)(9)(F)(1)-(3) (technical feasibility, administrative feasibility, availability of services and materials)	● 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 other agencies (for off-site actions) ● Coordination with other agencies ● Availability of offsite treatment, storage, and disposal services and capacity ● Availability of necessary equipment and specialists ● Availability of prospective technologies	Overall measurement expressing relative difficulty and uncertainty of implementing the project. Includes technical factors such as availability of experienced contractors and administrative factors associated with permitting, funding, etc.	Ability to be implemented, including the potential for land owner cooperation, technical feasibility, availability of disposal facilities, services and materials required, administrative and regulatory requirements, schedule, monitoring requirements, access needs, operation and maintenance, and integration with existing facility operations and other current or potential cleanup actions.
	Cost 40 CFR 300.430(e)(9)(G)(1)-(2)	● Capital costs, direct and indirect ● Operating and maintenance costs ● Net present value of capital and O&M cost	All costs associated with the alternative, including design, construction, long-term monitoring, institutional controls, net present value, and agency oversight costs. Costs are evaluated against remedy benefits to assess whether cleanup actions use permanent solutions to the maximum extent practicable (WAC 173-340-360(3) and (2)(b)(i)).	Cost, including consideration of present and future direct and indirect capital, operation and maintenance cost, and other foreseeable costs.
CERCLA *Modifying Criteria*	Community acceptance 40 CFR 300.430(e)(9)(I)		Outreach process identifies public concerns. Disporportionate cost analysis includes evaluation of how the alternative addresses community concerns.	The degree to which community concerns are addressed.
	State acceptance 40 CFR 300.430(e)(9)(H)			

Notes: CERCLA - Comprehensive Environmental Response, Compensation, and Liability Act
MTCA - Model Toxics Control Act
Sources:
1. EPA 1988. Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA. Interim Final. EPA/540/G-89/004. October 1988.
2. MTCA: Ecology 2001. Model Toxics Control Act Cleanup Regulation, Chapter 173-340 WAC, Section 360, Selection of cleanup actions. Amended February 12, 2001.
3. SMS: Ecology 1991. Sediment Cleanup Standards User Manual. First Edition. December, 1991.

Table A-2 CERCLA Threshold, Balancing, and Modifying Criteria Compared to MTCA Threshold Criteria and Other Requirements

CERCLA *Threshold Criteria*	**MTCA *Threshold Criteria***
1. Overall Protection of Human Health and the Environment (threshold). 40 CFR 300.430(e)(9)(iii)(A).	The first threshold criterion 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).
2. Compliance with ARARs. 40 CFR 400.430(e)(9)(iii)(B).	MTCA's second threshold criterion is compliance with cleanup standards (ARARs under CERCLA) and the third criterion is compliance with state and federal laws. WAC 173-340-360(2)(a)(ii)-(iii).
	Compliance monitoring
CERCLA *Balancing Criteria*	**MTCA *Other Requirements***
1. Long-term effectiveness and permanence. 40 CFR 300.430(e)(9)(C).	**NOTE:** MTCA requires use of permanent solutions to the maximum extent practicable. WAC 173-340-260(2)(b)(i). Practicability is determined using a disproportionate cost analysis. WAC 173-360-340(3)(e). Part of the disproportionate cost analysis is evaluating "effectiveness over the long term," which includes the same criteria used under CERCLA for evaluating long-term effectiveness and permanence. WAC 173-340-360(3)(f)(iv).
2. Reduction of toxicity, mobility or volume through treatment. 40 CFR 300.430(e)(9)(D).	The corresponding criterion under MTCA is the evaluation of the permanence of a remedial alternative conducted as part of the disproportionate cost analysis. WAC 173-40-360(3)(f)(ii). MTCA's individual criteria in evaluating permanence correspond to CERCLA's criteria on evaluating the reduction of toxicity mobility or volume. Following CERCLA's requirements should cover MTCA's requirements.
3. Short-term effectiveness. 40 CFR 300.430(e)(9)(E)(1)-(3).	Provide for a reasonable restoration time frame WAC 173-340-360(2)(b)(iii). Short-term risks are also 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)(ii)).
4. Implementability. 40 CFR 300.430(3)(9)(F)(1)-(3) (technical feasibility, administrative feasibility, availability of services and materials).	Technical feasibility and administrative feasibility are part of the disproportionate cost analysis and include a very similar assessment of administrative issues and availability of services and materials. WAC 173-340-360(3)(f)(vi).

Table A-2 CERCLA Threshold, Balancing, and Modifying Criteria Compared to MTCA Threshold Criteria and Other Requirements

CERCLA Balancing Criteria	***MTCA Other Requirements***
5. Cost. 40 CFR 300.430(e)(9)(G)(1)-(2). CERCLA considers three types of costs: (1) capital costs, including both direct and indirect costs; (2) annual operation and maintenance (O&M) costs; and (3) net present value of capital and O&M costs.	MTCA includes similar cost considerations in the disproportionate cost analysis. However, MTCA provides a bit more detail in its requirements, including breaking out the pretreatment, analytical, labor, and waste management costs associated with treatment technologies and taking into account the design life of a cleanup action, including the costs to replace or repair major elements. WAC 173-340-360(3)(f)(iii).
CERCLA *Modifying Criteria*	
1. State and Tribal Acceptance. 40 CFR 300.430(e)(9)(H).	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).
2. Community Acceptance. 40 CFR 300.430(e)(9)(I).	

Table A-3 MTCA Threshold and Other Requirements Compared to CERCLA Threshold, Balancing, and Modifying Criteria

MTCA Minimum Requirements for Cleanup Actions: Threshold Requirement WAC 173-340-360(a)	***CERCLA Threshold Criteria***
i Protect human health and the environment	Overall Protection of Human Health and the Environment (threshold). 40 CFR 300.430(e)(9)(iii)(A).
ii. Comply with cleanup standards	Compliance with ARARs. 40 CFR 400.430(e)(9)(iii)(B).
iii. Comply with applicable state and federal laws.	Compliance with ARARs. 40 CFR 400.430(e)(9)(iii)(B).
iv. Provide for compliance monitoring	
Other Minimum MTCA Requirements WAC 173-340-360 (b)	***CERCLA Balancing and Modifying Criteria***
i. Use permanent solutions to the maximum extent practicable	Balancing criterion of Long-term Effectiveness and Permanence. 40 CFR 300.430(e)(9)(C).
ii Provide for a reasonable restoration time frame	Balancing criterion of Short-term Effectiveness. 40 CFR 300.430(e)(9)(E)(1)-(3).
iii Consider public concerns	Modifying criteria of State, Tribal, and Community Acceptance. 40 CFR 300.430(e)(9)(H)and 40 CFR 300.430(e)(9)(I).
Other MTCA Requirements for Cleanup Actions	
Prevent or minimize present and future releases and migration of hazardous substances in the environment. WAC 173-340-360(f).	Balancing criteria of Short- and Long-term Effectiveness and Permanence. 40 CFR 300.430(e)(9)(C).
"Shall not rely primarily on dilution and dispersion unless the incremental costs of any active remedial measures 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).	Balancing criteria of Reduction of Toxicity, Mobility or Volume Through Treatment. 40 CFR 300.430(e)(9)(D). CERCLA considers three types of costs: (1) capital costs, including both direct and indirect costs; (2) annual operation and maintenance (O&M) costs; and (3) net present value of capital and O&M costs. 40 CFR 300.430(e)(9)(G)(1)-(2).
Remediation levels can be used if a determination that a more permanent cleanup action is not practicable, based on disproportionate cost analysis. WAC 173-340-360 (h).	Balancing criterion of Implementability. 40 CFR 300.430(3)(9)(F)(1)-(3) (technical feasibility, administrative feasibility, availability of services and materials).

Table A-4 MTCA/CERCLA Terminology Comparison

Term	CERCLA Definition	MTCA Definition
Natural Background	Naturally occurring substances are those present in the environment in forms that have not been influenced by human activity	Natural background means the concentration of hazardous substance consistently present in the environment that has not been influenced by localized human activities. Treatment of PCBs: [L]ow concentrations of some particularly persistent organic compounds such as polychlorinated biphenyls (PCBs) can be found in surficial soils and sediment throughout much of the state due to global distribution of these hazardous substances**.** *These low concentrations would be considered natural background.* WAC 173-340-200 (emphasis added).
Area (MTCA) or Anthropogenic (CERCLA) Background	Anthropogenic substances *are* natural and human-made substances present in the environment as a result of human activities (not specifically related to the CERCLA release in question). EPA 2002b	Area background means the concentrations of hazardous substances that are consistently present in the environment in the vicinity of a site which are the result of human activities unrelated to releases from that site. WAC 173-340-200.
Application of Background to cleanup levels	Generally, under CERCLA, cleanup levels are not set at concentrations below natural or anthropogenic background concentrations. EPA 2002b, 2005	Under MTCA, cleanup levels have a "floor" of natural background. "Area" background can be used to assess and respond to potential for recontamination and an interim action can be used to address contamination not due to area background: When area background concentrations would result in recontamination of the site to levels that exceed cleanup levels, that portion of the cleanup action which addresses cleanup below area background concentrations may be delayed until the off-site sources of hazardous substances are controlled. In these cases the remedial action shall be considered an interim action until cleanup levels are attained. WAC 173-340-360.

Table A-4 MTCA/CERCLA Terminology Comparison

Term	CERCLA Definition	MTCA Definition
Remedial Action Objectives	Remedial Action Objectives (RAOs**)** describe what the proposed sediment cleanup 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. Narrative RAOs form the basis for establishing preliminary remediation goals. (EPA 1991a).	There is no comparable term under MTCA, although the specified exposure conditions used to define RAOs may also be applied to develop a "modified Method B cleanup level" under MTCA if they meet the criteria specified in WAC 173-340-708 Human Health Risk Assessment Procedures
Preliminary Remediation Goals	Preliminary remediation goals (PRGs) are specific statements of the 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 preliminary site information. EPA 1991a, 1997b	There is no comparable term under MTCA, although the specified exposure conditions used to define PRGs may also be applied to develop a "modified Method B cleanup level" under MTCA if they meet the criteria specified in WAC 173-340-708 (Human Health Risk Assessment Procedures.)
Cleanup Levels	Under CERCLA, the cleanup level means the concentration of a COC in the environment that is determined to be protective of human health and the environment under specific exposure conditions. EPA 1999, 2005	The MTCA definition of cleanup level is the same as that under CERCLA. MTCA's Sediment Management Standards use the term Minimum Cleanup Level, defined as the "maximum allowable 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)
Remediation Action Levels (CERCLA) and Remediation Levels (MTCA)	Remediation action levels (RALs) are defined under CERCLA as the "not-to-exceed" level (EPA 2000) or the concentration above which remedial action would be necessary to reduce concentrations in sediment sufficiently to reach a target risk level within a specified period of time.	Remediation level (REL) means 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. A cleanup action selected in accordance with WAC 173-340-350 through 173-340-390 that includes remediation levels constitutes a cleanup action that is protective of human health and the environment. WAC 173-340-200. Under MTCA, this level may include passive remedial actions.

Appendix B

Sediment Transport Modeling Scope of Work

Quantitative Environmental Analysis, LLC
∂c/∂t

TECHNICAL MEMORANDUM

TO:	Allison Hiltner, U.S. Environmental Protection Agency, Region 10	**DATE:**	January 3, 2007
FROM:	Lower Duwamish Waterway Group C. Kirk Ziegler, QEA	**RE:**	LDW Sediment Transport Model Modeling and STAR Revision
CC:		**JOB#:**	WINldw:132

The objectives of this technical memorandum are to present: 1) a discussion of revisions to the Sediment Transport Analysis Report (STAR; Windward and QEA 2006); and 2) an approach for the development, calibration, and application of a sediment transport model for the Lower Duwamish Waterway (LDW). Other investigations concerning sediment transport in the LDW have been conducted, including the analyses presented in the STAR. A draft version of the STAR has been submitted and reviewed by the U. S. Environmental Protection Agency (USEPA). Based on comments received from USEPA (Allison Hiltner, personal communication, June 22, 2006), a revised version of the STAR is currently being prepared and a discussion of those revisions is presented below.

The evaluation of various remedial alternatives in the LDW, including Monitored Natural Recovery (MNR), during the Feasibility Study (FS) requires an understanding of sediment transport within the study area. The draft STAR provides a significant amount of information on LDW sediment transport. However, a limitation of those analyses is the inability to predict erosion, deposition, and net sedimentation throughout the LDW during high-flow events and over multi-year periods. It was recognized by the Lower Duwamish Waterway Group (LDWG) and USEPA that development of a sediment transport model may enhance the efficacy of various analyses during the FS process. Discussions and meetings between LDWG and USEPA, during July and August, 2006, concerning a sediment transport model have resulted in the formation of a sediment transport modeling (STM) group that will work collaboratively and provide advice on the development, calibration, and application of the model. The members of this group include: Joe Gailani (USACE), Earl Hayter (USEPA), Karl Eriksen (USACE), Kirk Ziegler (QEA), Mike Riley (S.S. Papadopulos & Associates), Shane Cherry (Shaw Group), and Bruce Nairn (King County). The contents of this memorandum are the result of discussions and meetings that the STM group held during August 2006.

STAR REVISIONS

Five primary revisions to the STAR are planned. First, a re-analysis of the Sedflume data will be conducted. A description of the re-analysis is provided below (see the section entitled *Erosion and Deposition*). Second, additional lines-of-evidence regarding the depositional environment in the bench areas will be provided. These lines-of-evidence are being compiled by RETEC personnel and will be included as an appendix to the STAR. Third, additional information on LDW ship traffic will be compiled and incorporated into the ship scour analysis. This task will include obtaining information, based on U.S. Army Corps of Engineers (USACE) investigations at other sites, on tug propeller angles while pushing or pulling barges. Fourth, results of the normalized gross erosion analysis will be removed from the STAR. That analysis is unnecessary because a sediment transport model is being proposed. Fifth, the conceptual site model (CSM) for sediment transport will be modified based on the report revisions.

QEA will prepare a written response to USEPA comments (June 2006) on the draft of the STAR (April 2006). The comment responses will be contained in the cover letter that will accompany the revised STAR when it is submitted to USEPA.

SEDIMENT TRANSPORT MODEL DEVELOPMENT AND APPLICATION

This technical memorandum presents an overview of the approach that will be used to develop, calibrate/validate, and apply a sediment transport model of the LDW. This approach may be modified during the course of model development and calibration/validation through discussions between members of the STM group and during the Milestone meetings, which are discussed below.

Goals and Products of the Modeling Analysis

The overall goal of the modeling analysis is to develop a quantitative tool that can be used to evaluate sediment transport processes in the LDW. Several issues concerning the potential effects of sediment transport on chemical fate & transport will be addressed through application of the sediment transport model. First, multi-year simulations will be conducted to predict long-term changes in bed elevation (i.e., net sedimentation rate). These results will be used to develop insights concerning the rate of natural recovery in the LDW (e.g., spatial variability in the rates of net sedimentation and natural recovery). Second, the effects of high-flow events on bed scour, and the potential for re-exposing elevated chemical concentrations buried at depth in the bed, will be evaluated with the model.

Specific questions that may be addressed using the sediment transport model for long-term, multi-year periods include:

- What areas in the LDW are net depositional, net erosional, or in dynamic equilibrium?
- How much dilution of the surface-layer sediment occurs due to external sediment loads (e.g., Green River loads)?
- In areas that are net depositional or in dynamic equilibrium, what is the approximate rate of natural recovery attributable to dilution from external sediment loads?
- What is the effect of high-flow events on episodic scour in net depositional areas?
- In areas that are net depositional, what is the potential depth of scour during high-flow events?

For high-flow events, questions of interest include:

- What areas in the LDW are depositional and what areas experience erosion during a high-flow event?
- In the areas that experience erosion, what is the potential depth of scour?
- What is the potential for re-exposing relatively high chemical concentrations that are presently buried at depth in the bed?

The following model output will be used to achieve the goals of this study and address various questions related to the FS:

- Areas of net deposition and net erosion, areas that experience erosion during a high-flow event, and areas that are in dynamic equilibrium
- Spatial and temporal changes in bed elevation and composition
- Water column concentrations of suspended sediment (temporally and spatially variable)
- Dilution of surface-layer sediment as a result of external sediment loads
- Resuspension and fate of sediment from the bed

Description of Modeling Framework

The computer model that will be used during this study is the Environmental Fluid Dynamics Code (EFDC), which was developed by John Hamrick. The version of EFDC used in this study was modified by QEA as follows: 1) conversion of code to Fortran 90/95; 2) inclusion of SEDZL and SEDZLJ sediment transport algorithms; 3) streamlining of model inputs and outputs; and 4) added capability to use ‘external’ hydrodynamics for transport simulations. This model was used to conduct the hydrodynamic simulations of the LDW for the STAR.

Development of Model Inputs and Parameters

Numerical Grid Modification

The numerical grid used to represent the geometry of the LDW and Elliott Bay for the STAR hydrodynamic modeling analysis was developed by Arega and Hayter (2004). This grid has 10 layers in the vertical and about 2,000 grid cells in the horizontal plane. Based on experience with the modeling conducted for the STAR, this numerical grid results in simulation times that are excessively long, which would make using it to conduct long-term, multi-year simulations impractical. In addition, use of the 2,000-cell grid will limit the number of multi-year simulations that could be conducted during the model-application phase of the study. Thus, it will be necessary to modify the numerical grid so that practical simulation times are achieved.

The goal of the grid modification is to reduce simulation times by decreasing the number of horizontal grid cells to about 1,000, such that the predictive capabilities of the model are not affected within the LDW. It is anticipated that the numerical grid in the region upstream of the LDW (i.e., in the river upstream of RM 5.7) will be the focus of the grid modification. That portion of the grid has relatively high resolution, with three lateral grid cells and a large number of longitudinal grid cells, resulting in a total of about 700 grid cells. This level of grid resolution in that region is not necessary for achieving the goals of this study. It is anticipated that the grid resolution in this region will be reduced so that there is one lateral grid cell and about 20 longitudinal grid cells. The grid modification upstream of RM 5.7 will focus on representing the gross geometry of this reach (i.e., volume and length), rather than the detailed geometry of the river. The 10-layer vertical grid structure will be used throughout the model domain.

Additional modifications to the numerical grid may include moving the open boundary, which is presently located near the outer edge of Elliott Bay, closer to the mouth of the LDW. The effects of the grid modifications on hydrodynamic model performance will be evaluated through comparisons of predicted tidal elevation, current velocity, and salinity for the original and modified grids. The grid modifications will be done such that minimal effect on the predictive capability of the hydrodynamic model occurs (i.e., model results for the modified grid are similar to those for the original grid).

In addition to the grid modifications discussed above, which focus on reducing simulation time, the grid will be modified so as to include the various slips that are located along the eastern shore of the LDW. While these slips have minimal effect on the hydrodynamics of the LDW, the effect of the slips on sediment transport in the study area is unclear at the present time. It is anticipated that their inclusion in the model will produce an improved evaluation of sediment transport in the LDW.

Analysis of Bed Property Data

Two bed properties need to be evaluated for the sediment transport model: grain size distribution and dry density. Preliminary analyses of both quantities were conducted during the STAR study. Those analyses will be refined for development of the sediment transport model.

Grain size distribution data are available from two sources: 1) Sedflume cores; and 2) the baseline surface sediment data set assembled for the LDW remedial investigation (1989-2005). These data sets will be combined and used to determine the following input parameters for the sediment transport model: 1) D_{90} (90th percentile particle diameter); 2) D_{50} (median particle diameter); and 3) bed composition (e.g., fractions of clay/silt, sand, and gravel). The data will be analyzed and used to evaluate the spatial variability, both horizontal and vertical, of D_{90}, D_{50} and bed composition.

Dry density data were obtained from the cores collected during the Sedflume study. If additional data are available from other studies, then those data sets will be combined with the dry density data from the Sedflume cores. Similar to the grain size distribution data analysis, the horizontal and vertical variability in dry density will be investigated. Grain size data may be used, if possible, to support the evaluation of spatial variability of dry density within the LDW.

External Sediment Loads

The primary source of external sediment loading to the LDW is the Green River (Harper-Owes 1983). Thus, determination of sediment loading from this source is of critical importance, for both model calibration and use of the model to evaluate sediment transport in the LDW. A previous study (Harper-Owes 1983) developed a sediment rating curve for the Green River:

$$C = 20.4\,(Q/1000)^{1.48} \tag{1}$$

where C is total suspended solids (TSS) concentration (mg/L) and Q is river flow rate (cfs). This rating curve will be the starting point for developing an approach for estimating the sediment load from the river to the LDW.

Available historical TSS concentration data will be combined with river flow rate data to develop a refined sediment rating curve for the river. The effects of log-linear regression bias, which occurs when developing a rating curve and can cause an underestimation of sediment load, will be accounted for in the analysis through use of a correction factor, e.g., see Ferguson (1987). It is anticipated that refinement of the sediment rating curve will be accomplished without the collection of additional data.

The rating curve will provide an estimate of the magnitude of the suspended sediment load from the river. As a result of the Howard Hanson Dam upstream on the Green River, bed load is probably a minor component of the total sediment load. In addition, nearly all of the bed load (i.e., coarse sand and gravel) moving from the Green River into the LDW will be trapped in the upper turning basin and not transported to downstream portions of the LDW. Thus, neglecting bed load from the river is reasonable because this assumption will have minimal effect on model predictions.

In addition to the magnitude of the incoming suspended load, the composition of the incoming sediment load needs to be specified for model input. It is likely that minimal, or no, suspended sediment composition data exist for the Green River. Thus, it will be necessary to estimate the composition of the incoming sediment load based on the composition of the LDW sediment bed. For example, if the average composition of the sediment bed is 75% clay/silt and 25% sand, then a reasonable upper-bound estimate of the sand content in the sediment load from the river is 25%.

Other external sources of sediment to the LDW (e.g., CSOs, storm drains) are relatively minor when compared to the load from the river (Harper-Owes 1983). However, these sources will be included in the sediment transport model; while having a minor effect on sediment transport, inflows from CSOs and storm drains are a concern to regulatory agencies and stakeholders. Available data (e.g., King County CSO data) will be used to estimate sediment loads from these other sources.

Erosion and Deposition Processes

Sediment transport in the LDW will be simulated using three sediment size classes. Class 1 represents flocculating cohesive sediment (i.e., clay and silt). Class 2 corresponds to fine sand, with particle diameters ranging from 62 to 250 μm. Class 3 represents medium and coarse sand, with particle diameters ranging from 250 to 2,000 μm. The effective diameter for classes 2 and 3 will be estimated using the results of the grain size distribution analysis described above.

The Sedflume data analysis in the STAR considered two algorithms for calculating erosion rate (E). Algorithm 1 assumes that E is dependent only on shear stress (τ):

$$E = A_1 \tau^{n1} \tag{2}$$

Algorithm 2 incorporates the effects of sediment bulk density (ρ) and shear stress:

$$E = A_2 \rho^{m2} \tau^{n2} \tag{3}$$

The erosion parameters A, m, and n in Algorithms 1 and 2 are determined through an analysis of the Sedflume data (i.e., measured erosion rate as a function of shear stress and depth in the bed).

Previous analyses of the Sedflume data focused on the application of Algorithm 1 to data collected at all depths in a core, with that analysis examining each Sedflume core individually. Algorithm 2 was investigated for each core individually, but only the data collected in the first shear stress series (i.e., approximately 0-5 cm layer) were considered in the analysis. Additional analysis of the Sedflume cores will be conducted such that Algorithm 2 will be applied to data obtained at all depths in the core. A Matlab program developed by USACE personnel at the Engineer Research and Development Center (ERDC) specifically for analyzing Sedflume core data will be used to conduct these analyses (Joe Gailani, personal communication, August 3, 2006). The results of this work will be used to determine which algorithm will provide the best representation of LDW erosion properties for use in the modeling effort.

In addition to conducting the above analyses on individual cores, spatial variability, both horizontally and vertically, in the Sedflume data and erosion parameters (i.e., A, m, and n) will be evaluated. Vertical variations in the data and erosion parameters will be examined, with the focus being on differences between various bed layers (e.g., 0-5 cm and 5-10 cm layers); generally, erosion rates tend to decrease with increasing depth in the bed, primarily due to consolidation effects.

Horizontal variability in LDW erosion properties will be evaluated in a systematic manner. The first step will be to examine the vertical profiles of erosion rate data for all of the cores and attempt to separate the cores into groups with similar characteristics. The grouping of cores will be accomplished using both qualitative (e.g., visual inspection) and quantitative (e.g., calculation of vertical gradients in erosion rate) methods. The next step will be to apply either Algorithm 1 or 2, depending on which approach is used to develop model input parameters, to each group of cores, with the goal being to determine representative erosion parameters for each group. For example, if the cores are separated into three groups, the analysis will produce three sets of erosion parameters (i.e., A, m, and n) for use in the model. The groups of cores will represent different regions of the LDW, with these regions corresponding to relatively large spatial scales (e.g., navigation channel between RM 2.0 and 4.0, bench areas downstream of RM 3.0). Horizontal variation in erosion parameters will not be specified on small spatial scales (i.e., grid-cell scales).

As mentioned above, the SEDZLJ algorithm will be used to predict erosion rates and corresponding resuspension fluxes. The sediment bed model will separate the bed into distinct layers with the erosion properties of each layer being determined using the results of the bed property and Sedflume data analyses. The structure of the bed model (e.g., number and thickness of layers) will be determined after the bed property and Sedflume data analyses are completed. At the surface of the bed, an ‘active’ layer will be used to simulate the effects of bed armoring on erosion rate. Various approaches are available for calculating the thickness of the active layer (T_a), including the method used by Jones (2000):

$$T_a = 2\, D_m\, (\tau / \tau_{cr}) \qquad (4)$$

where D_m is the mean particle diameter of the bed sediment and τ_{cr} is a critical shear stress. The active layer is the surface portion of the top layer in the bed model.

Erosion rate is dependent on the bed shear stress, which is calculated using the near-bed current velocity predicted by the hydrodynamic model. The bed shear stress calculated within the hydrodynamic model, and used in the shear stress analyses discussed in the STAR, is the total bed shear stress, which represents the total drag on the water column by the sediment bed. The total bed shear stress (τ_{tot}) is the sum of shear stresses due to skin friction (τ_{sf}) and form drag (τ_{fd}):

$$\tau_{tot} = \tau_{sf} + \tau_{fd} \tag{5}$$

Skin friction represents the shear stress generated by sediment particles (i.e., small-scale physical features), whereas form drag corresponds to the drag generated by bedforms (e.g., ripples, dunes) and other large-scale physical features. When simulating the erosion of a cohesive bed, as in the LDW, skin friction is the appropriate component of the bed shear stress for use in Equations 2 and 3 (i.e., Algorithms 1 and 2). This approach is consistent with accepted sediment transport theory (Parker 2004).

Skin friction shear stress is calculated using the quadratic stress law:

$$\tau_{sf} = \rho_w \, C_f \, u^2 \tag{6}$$

where ρ_w is the density of water, C_f is the bottom friction coefficient, and u is the near-bed current velocity (i.e., predicted velocity in the bottom layer of the numerical grid). The bottom friction coefficient is determined using (Parker 2004):

$$C_f = \kappa^2 \ln^{-2}(11 \, z_{ref} / k_s) \tag{7}$$

where z_{ref} is a reference height above the sediment bed (e.g., thickness of bottom layer of numerical grid), k_s is the effective bed roughness, and κ is von Karman’s constant (0.4). The effective bed roughness is assumed to be proportional to the D_{90} of the surface sediment layer:

$$k_s = \alpha \, D_{90} \tag{8}$$

where the proportionality constant (α) typically ranges between 2 and 3 (Parker 2004, Wright and Parker 2004). Grain size distribution data will be used to specify D_{90} values for the surface layer of LDW sediments. As discussed above, the spatial variability of D_{90} in the LDW will be evaluated; accounting for potential spatial variation of D_{90} in the model will produce qualitatively correct results (i.e., effective bed roughness and skin friction will increase as the bed becomes rougher). This approach provides an objective method for estimating the effective bed roughness, which will decrease the uncertainty in calculation of the skin friction shear stress and, ultimately, bed erosion rates.

The depositional flux of suspended sediment, for class k sediment, (D_k) is calculated as follows:

$$D_k = P_k \, W_{s,k} \, C_k \tag{9}$$

where P_k is probability of deposition, $W_{s.k}$ is settling speed, and C_k is near-bed suspended sediment concentration. The near-bed concentration (C_k) for each sediment size-class is calculated by the sediment transport model.

The settling speeds of flocculating cohesive sediment have been studied by numerous researchers. The laboratory studies of Burban et al. (1990) showed that: 1) floc settling speed depends on the concentration and water-column shear stress at which the flocs are formed; 2) settling speed tends to increase with increasing concentration and shear stress; and 3) flocs formed in seawater have higher settling speeds than flocs formed in freshwater (for the same concentration and shear stress). The typical range of floc settling speeds is about 1 to 20 m/day. Ziegler has used the Burban et al. (1990) data to develop settling speed relationships (i.e., $W_s = A\ (C\tau)^n$) for flocs in freshwater (Ziegler et al. 2000) and seawater (HydroQual 1998). These relationships, which have been used in a wide range of modeling studies, will be used to calculate the settling speed of cohesive (Class 1) sediment in the LDW model.

Modeling suspended cohesive sediments as a single class, with an effective settling speed of $W_{s,1}$, makes it necessary to use a probability of deposition (P_1) to parameterize the effects of near-bed turbulence and particle/floc size heterogeneity on the deposition rate. The complex interactions occurring in the vicinity of the sediment-water interface cause only a certain fraction of the settling cohesive sediments to become incorporated into the bed (Krone 1962, Partheniades 1992). An experimentally-based formulation that represents the effects of variable floc size on probability of deposition was developed by Partheniades (1992), see Ziegler et al. (2000). The probability of deposition is dependent on the bed shear stress (τ), with $P_1 = 1$ for $\tau < \tau_{b,min}$, where $\tau_{b,min}$ has a typical value of 0.01 Pa. As shear stress increases above $\tau_{b,min}$, P_1 decreases and approaches zero for shear stresses greater than approximately 0.2 Pa.

Settling speeds of non-cohesive sediment (i.e., sand) have been investigated for approximately the last 50 years and a large body of literature exists on this topic. Cheng (1997) used laboratory data to develop a relationship between the settling speed of sand particles and particle diameter. Settling speeds of suspended sand (i.e., particle diameter between 62 and 500 μm) range from about 200 to 5,000 m/day.

Similar to the probability of deposition for cohesive sediment, the effects of near-bed turbulence and particle size variations on sand deposition are incorporated into Equation (9) for Classes 2 and 3 through use of a formulation developed by Gessler (1967). The Gessler approach uses a Gaussian distribution to specify the dependence between $P_{2,3}$ and near-bed shear stress and particle diameter (Ziegler et al. 2000).

Additional Data Needs

No field studies to collect additional data have been identified at this time. The STM group discussed the possibility of collecting site-specific data related to the settling speed of cohesive (flocculating clay and silt) sediment with the LDW. However, it was determined that sufficient data could not be collected, given project schedule constraints, to significantly reduce uncertainties in the model related to using laboratory-based settling speeds (e.g., the relationships for $W_{s,1}$ developed by Ziegler, as discussed above). Specifically, it is unlikely that data could be collected during high-flow conditions when relatively high deposition occurs, not only because of increased sediment loading to the LDW, but also because of increased settling speeds due to cohesive flocculation processes. It is anticipated that the uncertainty in the cohesive settling speed function, and potential effects on model predictions, will be addressed during the sensitivity analysis (see below). In addition to in-house data at QEA, an effort will be made to compile available data, from various sources, that may be useful for development and calibration of the sediment transport model.

Model Calibration and Validation Process

Initial Model Testing

Initial testing of the model will begin as soon as the modifications to the numerical grid are completed. The primary objective of these tests is to evaluate the computational requirements for conducting long-term, multi-year simulations, which are needed for model calibration and application. For practical purposes, it will be necessary to complete a multi-year simulation in approximately 2 to 3 days of total computation time. Various hydrodynamic and sediment transport simulations will be conducted to benchmark the model using the modified numerical grid and determine the computational requirements for multi-year simulations. After the benchmarking is completed, the maximum simulation period (e.g., 10, 20, or 30 years) that is practical will be determined. This information will be used to guide the model calibration process, as discussed below.

A secondary objective of the initial testing is to conduct preliminary sediment transport simulations in preparation for model calibration. These preliminary simulations will be used to perform quality control checks and ensure that various parameters (e.g., external sediment loads, bed properties) are correctly specified in the model input files.

Re-Calibration of Hydrodynamic Model

Due to modification of the numerical grid, it will be necessary to re-calibrate the hydrodynamic model. The calibration process described in the STAR will be repeated, with model calibration being achieved through adjustment of the effective bottom roughness (Z_o) and the tidal harmonic components at the open boundary in Elliott Bay. Similar to the previous calibration effort, model-data comparisons will focus on water surface elevation (tidal height), current velocity, and salinity.

The original calibration results indicated a discrepancy between observed and predicted values of near-bed current velocity. Discussions between QEA personnel and Earl Hayter (personal communication, August 3, 2006) about this discrepancy have led to the conclusion that it is probably due to difficulties with the model-data comparison process. Properly matching measured current velocities, which were obtained using an acoustic-doppler-current-profiler (ADCP), to predicted values within the water column is a complicated process, primarily due to time-variable water depth caused by tidal action. The procedure used by QEA involved comparing predicted and measured current velocities at specific absolute heights above the bed (e.g., 2, 5 and 9 m). Spatial interpolation of current velocity data was used to estimate the values at the absolute heights above the bed, which introduces uncertainty into the analysis. The process used by Earl Hayter relied on model-data comparisons at relative heights above the bed (e.g., 20, 50 and 80 % of the water depth). The relative height method appears to be a more reliable approach (i.e., less uncertainty in proper matching of predicted and observed values) than using the absolute height method. Thus, the relative height method will be applied to the model-data comparisons during the re-calibration of the hydrodynamic model.

Sediment Transport Model Calibration and Validation

The primary calibration target for the sediment transport model will be sedimentation rates in the LDW navigation channel. A data set exists for sedimentation rates in the navigation channel, which range from about 50 cm/yr near the upper turning basin to about 2-5 cm year in the downstream portions of the LDW. The objective of the calibration process will be to determine the ability of the model to simulate the spatial gradient in the navigation channel (i.e., approximate factor-of-10 decrease along the length of the channel) and the magnitude of sedimentation. Using net sedimentation data for calibration is a good test of the model's capabilities to simulate deposition and erosion over a multi-year period. Predicted net sedimentation is the result of a combination of deposition and erosion fluxes; net sedimentation is not an adjustable parameter in the model. Calibration of the model does not entail the adjustment of deposition and erosion fluxes to achieve agreement between observed and predicted net sedimentation rates. Mechanistic formulations are used in the model to simulate deposition and erosion processes. Generally, parameters in those formulations are constrained using site-specific and literature data. Thus, if the model is able to adequately predict net sedimentation rates in the LDW, then the reliability of the model to simulate deposition and erosion processes is increased.

The observed sedimentation rates are representative of the 20-year period from 1960 to 1980 (Harper-Owes 1983). A multi-year portion of this 20-year period will be selected for model calibration. The length of this multi-year calibration period will depend on the initial model testing, as discussed above. Ideally, the entire 20-year period will be simulated, but it is possible that a shorter simulation will be needed due to computational restrictions; the length of the calibration simulation will be maximized. If the multi-year calibration period is shorter than 20 years, then the inflow hydrograph for the Green River during the 1960-80 period will be examined and a representative period, corresponding to the length of the calibration simulation, will be selected.

Four 'forcing functions' need to be specified for the calibration period. First, freshwater inflow from the Green River will be determined using flow rate data collected at the USGS gauging station located near Auburn. Second, tidal forcing at the open boundary in Elliott Bay will be specified using six harmonic components (i.e., M2, S2, N2, K1, O1, P1), which realistically predicts semi-diurnal variations and the spring-neap tidal cycle. Third, sediment loading from the Green River will be estimated using the sediment rating curve developed during the loading analysis; suspended sediment concentration will vary as freshwater inflow changes. Fourth, sediment loads from CSOs and storm drains will be estimated and applied as model inputs.

It is anticipated that model calibration will be achieved through adjustment of two primary input parameters: 1) composition of the incoming sediment load from the Green River; and 2) thickness of the active layer (T_a), see Equation 4. The composition of the incoming sediment load (i.e., fractions of Class 1, 2 and 3 sediment) is uncertain due to data limitations. An initial estimate of the load composition will be made based on an analysis of the LDW grain size distribution data. However, this estimate will have uncertainty associated with it. Thus, the load composition, and how it varies with flow rate, will be treated as an adjustable calibration parameter. Generally, the active layer thickness is assumed to be proportional to grain size distribution (typically represented as D_m or D_{50}) and to increase with increasing bed shear stress. However, the relationship between T_a and these quantities is not well understood and is difficult to determine from experimental data. Therefore, adjustments to Equation 4, or a similar relationship for T_a, will be made during model calibration. In addition to these two primary parameters, it is possible that the effective particle diameters of Class 2 and 3 sediment (i.e., fine sand, medium-coarse sand) will also be adjusted during calibration. Initial estimates of the effective particle diameters will be based on the results of the grain size distribution analysis, but those values may be adjusted, within realistic bounds, to improve the predictive capabilities of the model.

Validation of the sediment model will be accomplished through additional analysis of the multi-year calibration simulation. This analysis will occur after model calibration is completed; no adjustment of input parameters will be made based on the validation analysis. The primary focus of model validation will be an evaluation of the ability of the model to predict sedimentation in the bench areas of the LDW. The data sets that will be used to conduct this evaluation are: 1) geochronology core date and sedimentation rates based on those cores; and 2) sedimentation information derived from various analyses of the sub-surface core data. Other data and information that may be considered for model validation include the results of various analyses of historical dredging records. Finally, TSS concentration data collected in the LDW during the multi-year calibration simulation will be compared to predicted suspended sediment concentrations.

Application of Calibrated Model

As discussed above, the primary goal of the modeling analysis is to develop a quantitative tool that can be used to evaluate sediment transport processes in the LDW. This goal will be achieved by conducting: 1) multi-year simulations to predict long-term changes in bed elevation and evaluate surface-layer dilution that can be expected as a result of external sediment loads; and 2) simulations of high-flow events to predict bed scour and evaluate the potential for re-exposing elevated chemical concentrations buried at depth in the bed.

Long-Term, Multi-Year Simulation

The multi-year simulation used to calibrate the model will be repeated, with the inclusion of a bed dilution calculation. As an initial effort to investigate the rate of natural recovery in the LDW, the effects of incoming sediment from the Green River on the ‘dilution’ of bedded sediments in the LDW will be simulated. The dilution simulation will be accomplished as follows: 1) assign a ‘tracer’ concentration to sediment particles (i.e., similar to assuming that a chemical is permanently bound to a particle); 2) set the initial tracer concentration of sediment in the LDW bed equal to one; 3) set the tracer concentration of sediment in the incoming load from the Green River equal to zero; and 4) calculate changes in tracer concentration in the surface layer of the sediment bed during the multi-year simulation. The effects of deposition and erosion processes (e.g., bed scour during episodic high-flow events) on the dilution of initial tracer concentrations in the bed will be incorporated into the simulation results. The predicted tracer concentrations in the surface layer of the bed at the end of the multi-year simulation can be used to develop insights about net sedimentation and natural recovery rates; final bed tracer concentrations will be less than one, with bed dilution increasing as tracer concentration decreases below a value of one.

In addition to the dilution calculation, the model will be used to predict: 1) bed elevation changes (i.e., net sedimentation rates, bed scour depths); 2) suspended sediment concentration in the water column; and 3) mass balances over various time periods. Sediment mass balances are useful for developing an understanding of the amount of sediment entering the LDW from different sources and how much of that incoming sediment is deposited (i.e., trapped) in the LDW.

As noted in the discussion of model calibration, uncertainty exists in some of the model inputs, primarily due to data limitations. This situation is not unique and occurs in all modeling studies. It is useful to evaluate the effects of input parameter uncertainty on model predictions through a sensitivity analysis. This task will be accomplished by varying critical model parameters (e.g., magnitude and composition of incoming sediment loads) within a range of realistic values. It is anticipated that input parameters to be included in the sensitivity analysis will be determined after the model calibration process is complete; an understanding of the behavior of the model with respect to input parameters will be developed during model calibration. The sensitivity analysis will be conducted using one-year simulations, selected from the multi-year simulation period, and varying the model parameters included in the analysis between realistic upper- and lower-bound values. The results of the sensitivity simulations will be quantitatively compared to the base case results.

Effects of High-Flow Events

The high-flow event analysis conducted in the STAR used a 100-year flood combined with spring tide conditions as the ‘worst case’ scenario. This event is actually rarer than a 100-year event, which is defined as having a 1% chance of occurring in any particular year. In fact, when the combined probabilities of a 100-year flood and spring tide conditions occurring at the same time are considered, the return period for this event is greater than 100 years. Thus, this rare event will not be considered in this analysis.

Defining a 100-year event for the LDW is not as easy as defining a 100-year event on a river because of the interactions between the river inflow and tidal conditions. One possible approach is to select the high-flow event from the hydrograph of the multi-year simulation. The flood with the maximum peak flow rate during the multi-year simulation period will be selected for use in the high-flow event analysis. This flood provides the best representation of a ‘real’ event and the interactions between freshwater inflow and tidal conditions. For the selected flood, the magnitude of the peak flow rate and the timing of the flood hydrograph with respect to the tides will be evaluated. The results of this analysis will provide an estimate of the return period for the selected flood, which depends on a combination of the probabilities of occurrence of the inflow and tidal conditions. If the return period is less than a 100-year event, then the magnitude of the peak flow rate will be adjusted until a 100-year event is achieved.

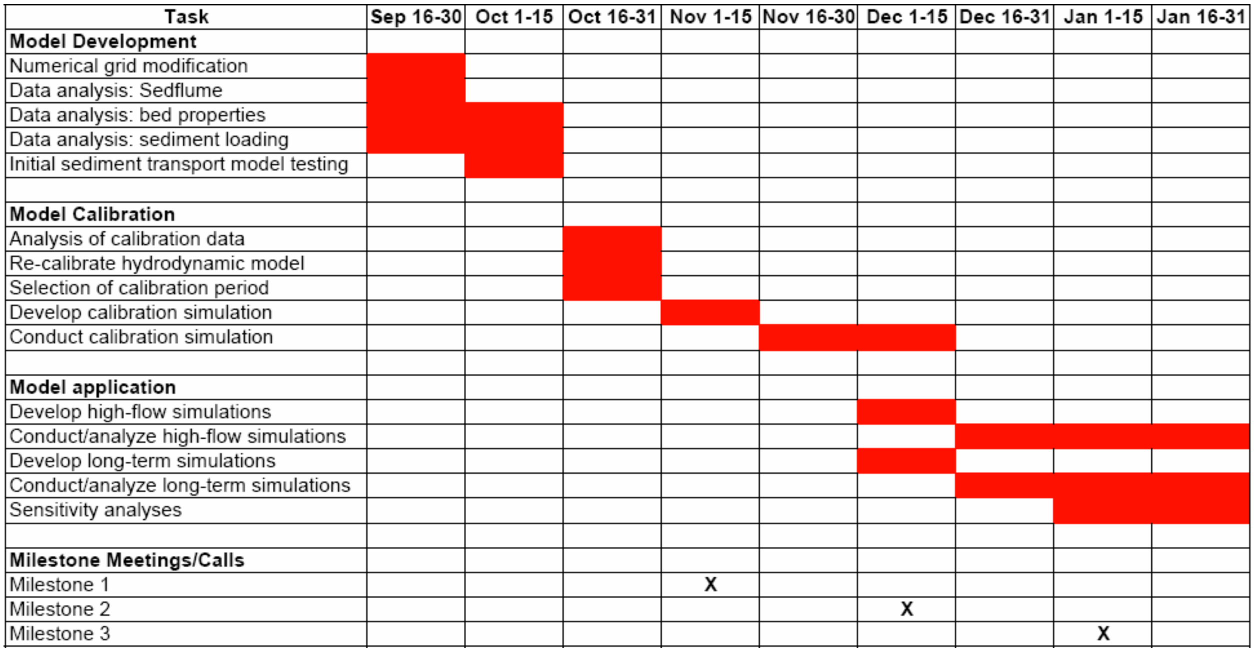
Another possible approach is to use a multi-variant scenario tool, where the effects of various combinations of freshwater inflow and tidal conditions are used to define a 100-year event. This approach could result in an array of simulations that would produce a distribution of predicted effects of a high-flow event. The distribution of model predictions could be statistically analyzed (e.g., establish 95% confidence intervals).

Both of these approaches have strengths and weaknesses. At the present time, it is not clear which approach will produce the most reliable results. Thus, the approach for defining and evaluating the 100-year event will be discussed by the STM group during the Milestone 3 meeting.

Whichever approach is chosen for evaluating high-flow events in the LDW, a sensitivity analysis will be conducted to investigate the effects of model inputs and parameters on model predictions. Similar to the multi-year sensitivity analysis, the high-flow sensitivity analysis will be designed after model calibration is completed.

Schedule and Milestones

The tasks described above will be completed by February 2007 (see Figure 1 for details). It is anticipated that the study will begin during mid-September 2006. Model development will be completed by mid-October. Model calibration and validation are planned to be completed by mid-December. Application of the model to study multi-year simulations and the effects of high-flow events will begin once the model calibration process is completed.



Task	Sep 16-30	Oct 1-15	Oct 16-31	Nov 1-15	Nov 16-30	Dec 1-15	Dec 16-31	Jan 1-15	Jan 16-31
Model Development									
Numerical grid modification	🟥								
Data analysis: Sedflume	🟥								
Data analysis: bed properties	🟥	🟥							
Data analysis: sediment loading	🟥	🟥							
Initial sediment transport model testing		🟥							
Model Calibration									
Analysis of calibration data			🟥						
Re-calibrate hydrodynamic model			🟥						
Selection of calibration period			🟥						
Develop calibration simulation				🟥					
Conduct calibration simulation					🟥	🟥			
Model application									
Develop high-flow simulations						🟥			
Conduct/analyze high-flow simulations							🟥	🟥	🟥
Develop long-term simulations						🟥			
Conduct/analyze long-term simulations							🟥	🟥	🟥
Sensitivity analyses								🟥	🟥
Milestone Meetings/Calls									
Milestone 1				X					
Milestone 2						X			
Milestone 3								X	

Figure 1. Schedule for sediment transport model development and application.

It is envisioned that the model development, calibration, and application process will be a collaborative effort among the members of the STM group (i.e., Joe Gailani, Earl Hayter, Karl Eriksen, Kirk Ziegler, Mike Riley, Shane Cherry, Bruce Nairn). The collaboration will take two forms. First, informal communication between various members of the STM group to discuss technical details of various analyses and modeling issues. Second, formal meetings of the STM group, in the form of face-to-face meetings or conference calls, at critical points, or milestones, during the project to discuss results and make decisions about the path forward (e.g., reach agreement on model input parameters). A technical lead from LDWG will also participate in the milestone meetings. Three milestone meetings have been proposed (see Table 1). During the milestone meetings, the group will discuss the results of specific topics related to model development and application, with the goal of reaching consensus on the topic and determining the next step in the modeling study. After each meeting, a memorandum will be prepared that summarizes the meeting discussions and presents decisions made by the STM group on the path forward. This memorandum will be distributed to LDWG and USEPA. It is anticipated that this method will produce a model that the various stakeholders can accept as a reliable tool for studying LDW sediment transport.

Table 1. Milestones for sediment transport model development and application.

Milestone	Tentative Date of Meeting/Call	Topics to Discuss and Achieve Consensus
1	November 14, 2006	1) Numerical grid modification; 2) data analyses: a) erosion rate parameters (Sedflume), b) bed properties, c) sediment loading; 3) review hydrodynamic model re-calibration; 4) determine calibration period for sediment transport model; 5) calibration data and strategy for sediment transport model
2	December 14, 2006	1) Review sediment transport model calibration; 2) specification of long-term simulations; 3) specification of high-flow events
3	January 11, 2007	Design of sensitivity analysis

Deliverables

The revised STAR report will be delivered to USEPA on January 15, 2006. A draft version of the Sediment Transport Modeling (STM) report, which will document the modeling analysis proposed in this memorandum, will be delivered to USEPA on May 1, 2007.

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