# East Waterway Operable Unit
# Supplemental Remedial Investigation/ Feasibility Study
# Final Sediment Transport Evaluation Approach Memorandum

**For submittal to**

**The U.S. Environmental Protection Agency**
Region 10
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**Prepared by**


ANCHOR ENVIRONMENTAL, L.L.C.
1423 3rd Avenue ♦ Suite 300
Seattle, Washington ♦ 98101

Battelle
Seattle Research Center
1100 Dexter Avenue N. ♦ Suite 400
Seattle, WA ♦ 98109

**KPFF Consulting Engineers** | **Coast and Harbor Engineering**

## EXECUTIVE SUMMARY

The Sediment Transport Evaluation Approach Memorandum (STEAM) outlines various modeling approaches and selects a preferred approach to evaluate and characterize sediment transport physical processes within the East Waterway (EW). The focus of the STEAM is to present an approach to evaluate hydrodynamics and sediment transport physical processes in relation to solids transport and to identify the data needs necessary to evaluate sediment transport processes in the EW.

The STEAM identifies the preferred Sediment Transport Evaluation (STE) approach to address sediment transport physical processes within the EW. There are two main components to evaluating sediment transport within the EW: 1) sediment transport due to natural processes, including lateral solids loads (solids entering the EW from combined sewer overflows [CSOs] and storm drains), and 2) sediment transport due to vessel-induced hydrodynamic effects.

Several modeling approaches were considered for evaluating sediment transport from natural processes. These approaches included using mass balance calculations, using a screening-level model, and using a physics-based modeling approach that included three variations of model grid resolution (coarse, moderate, and fine). The physics-based modeling approach was based on the existing Lower Duwamish Waterway (LDW) Environmental Fluid Dynamics Code (EFDC) model (QEA 2007). Following discussions between the East Waterway Group (EWG) and U.S. Environmental Protection Agency (EPA), a preferred approach was selected. The preferred approach combines using physics-based modeling with moderate grid resolution to evaluate hydrodynamics and erosion potential, using measured sediment transport characteristics to inform sediment transport rates, and localized modeling to assess recontamination potential.

Existing hydrodynamic and sediment transport information that was compiled in the Existing Information Summary Report (EISR; Anchor and Windward 2008a) was evaluated to assess its applicability for use in the preferred approach for natural processes. Data needs included bathymetry, salinity and temperature profiles, velocity profiles, and net sedimentation data. An important component of the natural processes preferred approach will be to incorporate lateral solids loads from EW CSOs and storm drains. Additional data will be collected to support hydrodynamic and sediment data gaps for CSOs and storm drains. These data will be identified in the Initial Source Screening and Data Gaps Memorandum, to be completed as part of the Source Control Evaluation process.

The second main component of the STE is evaluating vessel-induced hydrodynamic effects. The modeling approach included addressing propeller wash (propwash), pressure fields from passing vessels, and vessel-generated wake impacts. Pressure fields and vessel wakes are not expected to be a significant factor in EW sediment transport processes; however, propwash is expected to have a significant effect, and will be important to consider during the Feasibility Study (FS) review of various remedial alternatives, including monitored natural recovery (MNR) and cap stability evaluations.

The information presented in the STEAM is closely linked to and relies in part on the Physical Processes Conceptual Site Model (CSM) presented in the CSM and Data Gaps Analysis Report (Anchor, Windward and Battelle 2008). In that report, the Physical Processes CSM description synthesizes what is currently known about important hydrodynamic and physical processes within the EW, focusing specifically on the processes that govern sediment transport within the waterway. The Physical Processes CSM will serve to inform subsequent steps in the Supplemental Remedial Investigation and Feasibility Study (SRI/FS), including investigation of the nature and extent of contamination, recontamination potential, and feasibility of remedial alternatives.

The STE results will be summarized in the Sediment Transport Evaluation Report and the results will be used to help refine the Physical Processes CSM. As part of the FS Report, the sediment transport processes will be integrated with Source Control Evaluation work in order to assess sediment recontamination potential. Following EPA review and approval of the STEAM, the evaluation steps listed below are anticipated:

- Establish STE workgroup and develop detailed STE modeling methodology with workgroup input
- Develop field sampling program (i.e., Quality Assurance Project Plans [QAPPs]) to fill the data needs
- Conduct field-sampling investigations after review and approval of the STE QAPPs by EPA
- Develop and run the STE models based on the approved STE modeling methodology plan
- Prepare Sediment Transport Evaluation Report
- Refine Physical Processes CSM in the SRI Report
- Integrate STE results with Source Control Evaluation results to assess recontamination potential in the FS Report

## List of Tables



## List of Figures

| | |
|---|---|
| 1-D | one-dimensional |
| 2-D | two-dimensional |
| 3-D | three-dimensional |
| ADP | Acoustic Doppler Profiler |
| Anchor | Anchor Environmental, L.L.C. |
| ASAOC | Administrative Settlement Agreement and Order on Consent |
| CERCLA | Comprehensive Environmental Response, Compensation and Liability Act |
| City | City of Seattle |
| County | King County |
| Cs-137 | Cesium-137 |
| CSM | Conceptual Site Model |
| CSO | combined sewer overflow |
| CSTR | Continually Stirred Tank Reactor |
| DWEB | Duwamish Waterway-Elliott Bay |
| EFDC | Environmental Fluid Dynamics Code |
| EISR | Existing Information Summary Report |
| EPA | U.S. Environmental Protection Agency |
| ERA | Ecological Risk Assessment |
| EW | East Waterway |
| EWG | East Waterway Group (Port of Seattle, City of Seattle, and King County) |
| FS | Feasibility Study |
| HHRA | Human Health Risk Assessment |
| HISWG | Harbor Island Sediment Work Group |
| LDW | Lower Duwamish Waterway |
| LDWG | Lower Duwamish Waterway Group |
| MHW | mean high water |
| MHHW | mean higher high water |
| MLW | mean low water |
| MLLW | mean lower low water |
| MNR | monitored natural recovery |
| MTL | mean tide level |
| NAVD | North American Vertical Datum |
| NOAA | National Oceanic and Atmospheric Administration |

| | |
|---|---|
| OU | Operable Unit |
| Pb-210 | Lead-210 |
| PCB | polychlorinated biphenyl |
| Port | Port of Seattle |
| QAPP | Quality Assurance Project Plan |
| RI | remedial investigation |
| RM | River Mile |
| ROD | Record of Decision |
| SCEAM | Source Control Evaluation Approach Memorandum |
| SOW | Statement of Work |
| SRI/FS | Supplemental Remedial Investigation/Feasibility Study |
| STA | Sediment Transport Analysis approach |
| STE | Sediment Transport Evaluation |
| STEAM | Sediment Transport Evaluation Approach Memorandum |
| TOC | total organic carbon |
| TSS | total suspended solids |
| U&A | Usual and Accustomed |
| USCG | U.S. Coast Guard |
| USGS | U.S. Geological Survey |
| WASP | Water Quality Analysis Simulation Program |
| WQA | King County Water Quality Assessment (King County 1999) |
| WW | West Waterway |

# 1 INTRODUCTION

## 1.1 Overview

The U.S. Environmental Protection Agency (EPA) has ordered the Port of Seattle (Port) to conduct a Supplemental Remedial Investigation/Feasibility Study (SRI/FS) for the East Waterway (EW) Operable Unit (OU) of the Harbor Island Superfund Site per the process defined by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), or Superfund. The SRI/FS will ultimately lead to an EPA Record of Decision (ROD) outlining cleanup actions to address threats to human health and the environment in the EW.

The Sediment Transport Evaluation Approach Memorandum (STEAM) is a required deliverable set forth in the SRI/FS Workplan (Workplan; Anchor and Windward 2007), prepared in response to the Administrative Settlement Agreement and Order on Consent (ASAOC) and Statement of Work (SOW) (EPA 2006).

The objective of the STEAM is to outline a plan to evaluate and characterize sediment transport dynamics within the EW. The STEAM includes a description of objectives, an analysis of existing information, a proposed strategy and modeling approach for the Sediment Transport Evaluation (STE), and a discussion of the STEAM's relationship to the overall SRI/FS process for the EW.

## 1.2 Purpose of the Sediment Transport Evaluation

The primary purpose of the STEAM is to describe how the sediment transport dynamics within the EW will be characterized for the SRI/FS, and how this work will be coordinated with other SRI/FS activities described in the Workplan (Anchor and Windward 2007).

The Workplan (Anchor and Windward 2007) provides the guidelines and objectives for conducting the STE. Because the EW receives flows from the Lower Duwamish Waterway (LDW), and the southern boundary of the EW OU is identical to the northern boundary of the LDW Superfund Site at the EW, the STE will be largely based on the approach used to evaluate sediment transport in the LDW for the analysis conducted as part of the LDW RI/FS evaluation (Windward and QEA 2008; QEA 2007). The hydrodynamic model used for the LDW sediment transport analysis includes the EW as part of its model grid.

As stated in the Workplan, the objectives of the STE are as follows:

1. Identify and evaluate the primary sources of sediment to EW
2. Identify temporal and spatial patterns of sediment erosion and deposition (if applicable)
3. Identify the physical processes driving sediment transport
4. Identify likely routes or pathways for sediment movement
5. Assess how sediment transport pathways may affect the feasibility of remedial alternatives, including monitored natural recovery (MNR), enhanced natural recovery, dredging, and isolation capping
6. Assess potential for physical processes to contribute to recontamination

The STE will be conducted using information described in the Existing Information Summary Report (EISR; Anchor and Windward 2008a) and new information obtained through the STE preferred approach discussed in this document. The STE will be summarized in a Sediment Transport Evaluation Report, as described in the Workplan (Anchor and Windward 2007), and will be used to refine the Physical Processes Conceptual Site Model (CSM) presented in the CSM and Data Gaps Analysis Report (Anchor, Windward and Battelle 2008). The Physical Processes CSM will be refined in the SRI Report, and the SRI will also merge the STE and Source Control Evaluation. The FS will assess recontamination potential. The STEAM and the Sediment Transport Evaluation Report will focus only on the physical processes associated with transport of sediment. Source control issues will be evaluated in a separate evaluation as described in the Source Control Evaluation Approach Memorandum (SCEAM) (Anchor and Windward 2008b).

As described in the SCEAM, information on lateral solids inputs from combined sewer overflows (CSOs) and storm drains will be developed as part of the Source Control Evaluation. The STE will incorporate lateral solids inputs in development of the hydrodynamic and sediment transport model. The SRI Report will integrate the results of the STE and Source Control Evaluation work, along with the results of the risk assessments and other SRI activities. The FS Report will evaluate the risk of recontamination by integrating the findings of the Source Control Evaluation and other SRI activities.

The focus of the STEAM is to present an approach to evaluate hydrodynamics and sediment transport dynamics in relation to solids transport and to identify data needs necessary to evaluate sediment transport processes in the EW. The STEAM discusses the selection of the modeling approach to be used in the STE. The information presented in the STEAM is closely linked to and relies in part on the Physical Processes CSM presented in the CSM and Data Gaps Analysis Report (Anchor, Windward and Battelle 2008). In that report, the Physical Processes CSM description synthesizes what is currently known about important hydrodynamic and physical processes within the EW, focusing specifically on the processes that govern sediment transport within the waterway. Data and information presented in the EISR (Anchor and Windward 2008a) was used to develop the Physical Processes CSM and will be used to develop the Ecological Risk Assessment (ERA) and Human Health Risk Assessment (HHRA) CSMs. The Physical Processes CSM will also inform subsequent steps in the SRI/FS and design process, including investigation of the nature and extent of contamination, recontamination potential, and feasibility of remedial alternatives.

As discussed in the Workplan (Anchor and Windward 2007), the STEAM identifies data needs necessary to evaluate sediment transport processes, primarily through a modeling approach, and to also help refine the Physical Processes CSM. As part of the data gaps evaluation identification in the STEAM, specific data needed to carry out the preferred STE modeling approach are identified. The preferred approach is designed to improve the understanding of the sediment transport dynamics necessary to support the refinement of the Physical Processes CSM, determine the potential mechanisms that redistribute sediments, map areas that may be prone to accumulation or loss of sediment, and identify potential pathways of sediment movement away from potential contaminant sources.

This STEAM is being completed as a stand-alone submittal to expedite completing the data gaps analysis and initiate Quality Assurance Project Plans (QAPPs) to collect needed data. Detailed study designs to fill these data gaps will be presented in separate QAPPs, as outlined in the Workplan (Anchor and Windward 2007).

Additional data needs will also be identified in the Initial Source Screening and Data Gaps Memorandum as part of the Source Control Evaluation process. The SCEAM (Anchor and Windward 2008b) describes an approach for evaluating potential contaminant sources to the

EW, including the objectives and approach of source control integration into the SRI/FS. Potential sources of contamination to EW sediment are identified in Section 5 of the EISR (Anchor and Windward 2008a) and may include CSO discharges, stormwater discharges, overwater uses and spills, industrial wastewater discharges, nearshore cleanup sites, and atmospheric deposition.

### 1.3 Sediment Transport Evaluation Process

The East Waterway Group (EWG) anticipates that the STE will be an iterative process between EWG and EPA. This Memorandum presents a preferred evaluation approach, and EWG recognizes that the evaluation approach may need to be refined as EWG works with EPA to approve model selection and methodology, key modeling parameters, evaluation assumptions, and subsequent evaluation steps. It is important to note that the preferred approach does have risks associated with meeting the original Workplan schedule (Anchor and Windward 2007), primarily due to potential for changes to the analysis based on Agency input. However, EWG considers the preferred approach to be the approach that most closely meets the selection criteria (Section 3.4). Following EPA review and approval of the STEAM, the evaluation steps listed below are anticipated:

- **Establish STE workgroup.** This workgroup will consist of EWG members and EPA representatives, and will provide technical input to the modeling approach and other sediment transport evaluation approaches during the STE. The workgroup will also coordinate with the ongoing work for LDW sediment transport evaluation. Workgroup recommendations (e.g., recommendations for key modeling parameters and assumptions) will be documented and provided to EPA.
- **Develop field sampling program to fill the data needs.** The STEAM identifies key data needs to complete the STE. QAPPs will be prepared to address STE data needs and will include details of how the sediment transport data needs will be filled.
- **Conduct field-sampling investigations after review and approval of the STE QAPPs by EPA.**
- **Develop and run the STE models based on the approved STE modeling methodology plan.** Conduct additional sediment transport evaluations as needed to support refining the Physical Processes CSM.

- **Prepare Sediment Transport Evaluation Report.** This report will provide the results of the sediment transport modeling efforts and any additional evaluations of sediment transport processes.
- **Refine Physical Processes CSM in the SRI Report.** The Physical Processes CSM will be refined in the SRI Report based on additional sediment transport and hydrodynamic data collected during field sampling. The results of the STE modeling efforts will also be used to refine the Physical Processes CSM.
- **Integrate STE results with Source Control Evaluation results to assess recontamination potential.** This integration includes sources of contamination from upstream sources, as well as from lateral solids loads. The evaluation of recontamination potential will be included in the FS Report.

The results of all SRI tasks, including sediment transport and source control evaluation, will be combined and synthesized in the SRI Report. The FS Report will incorporate results of the STE that contribute to evaluating the feasibility of remedial alternatives, including MNR, enhanced natural recovery, dredging, and isolation capping.

## 1.4 Physical Setting of the East Waterway

This section presents an overview of the physical site characteristics pertinent to the development of the STE. Additional detailed information on the environmental setting of the EW is presented in Section 2 of the EISR (Anchor and Windward 2008a), including habitat and biological conditions (EISR Section 2.3) and human use characteristics (EISR Section 2.4). Section 1 of the EISR also presents a detailed site history of the EW and surrounding areas.

The EW is located approximately 1 mile southwest of downtown Seattle, in King County, Washington. It is part of the greater Duwamish River estuary, which includes the freshwater/salt water interface extending as far as 10 miles upstream. The Duwamish River drains approximately 362,000 acres, flowing northward to its terminus in Puget Sound at Elliott Bay. Near the mouth of the Duwamish River at River Mile (RM) 0, the northward flowing river splits into the EW and the West Waterway (WW), surrounding Harbor Island. The EW and WW extend from the southern end of Harbor Island to the island's north end at Elliott Bay (Figure 1-1). The EW runs along the eastern shore of Harbor Island. The EW OU is immediately downstream from the LDW Superfund Site. Proposed northern and southern study area boundaries for the EW OU are shown on Figure 1-1. The extent of the LDW model is from the mouth of Elliott Bay (approximately the line between Alki Point and Magnolia Bluff) to the Tukwila Gauge on the Green River. It is expected that the hydrodynamic model for the EW will also need to encompass this same domain so that hydrodynamic conditions in the interior of the model can be properly represented. The east and west boundaries of the EW OU are defined by mean higher high water (MHHW), as shown in Figure 1-2.

The former Duwamish River channel and surrounding floodplains were filled and graded to form the present day topography. Dredging in 1903 to 1905 created the EW and WW, and dredged material from the river was used to create Harbor Island (Weston 1993).

The EW is approximately 7,100 feet long and 750 feet wide (for most of its length). It is channelized and has a south-to-north orientation. The southern 1,700-foot section of the EW varies in width from 250 feet north of the Spokane Street corridor and beneath the bridges to approximately 150 feet south of the bridges (see Figure 1-2). The mudline elevation of the EW varies from approximately -40 to -60 feet mean lower low water (MLLW) in the 750-foot-wide portion of the waterway (Figures 1-3A and 1-3B). Mudline elevations increase to between -13 and -6 feet MLLW in the vicinity of Spokane Street and the West Seattle Bridge. However, besides water depth soundings in the EW south of the Spokane Street corridor conducted for Nautical Chart #18450 (NOAA 2004), no detailed bathymetry exists in the vicinity of the Spokane Street corridor and south of the Spokane Street corridor (DEA 2003). The shallow water depths associated with this “sill” along the Spokane Street corridor form a physical constriction that causes the Duwamish River to primarily flow through the WW. The presence of the bridges along the Spokane Street corridor also prohibits any type of boat passage, except at low tide by small, shallow-draft boats (e.g., kayaks and skiffs).

The highly developed shoreline within the EW is primarily composed of piers, riprap, constructed seawalls, and bulkheads for industrial and commercial use (Anchor and Windward 2008a). In addition, three CSOs and 39 storm drains are present along the EW that contribute freshwater and solids to the waterway (Figure 1-2).

The EW, north of the Spokane Street corridor, experiences regular vessel traffic of various sizes and types. Container ships call at Terminals 18 (T-18), 25 (T-25), and 30 (T-30). Cruise ships currently call at T-30, however, cruise ships are planned to be moved to Pier 91 in 2009 (previously identified as 2008 in the EISR). U.S. Coast Guard (USCG) vessels are based at Pier 36. The EW also has significant tug and barge traffic. The EW is part of the Tribal Usual and Accustomed (U&A) fishing areas for the Muckleshoot and Suquamish Tribes and is extensively utilized for gill net fishing for salmon. There is recreational use of the EW at the public park adjacent to Slip 36. The public fishing pier at the head of the EW at the Spokane Street Bridge was identified as a popular harvest area within Elliott Bay in a King County 1999 creel survey (King County 1999). South of the Spokane Street corridor, the Harbor Island Marina is located on the southern tip of Harbor Island and is used by recreational and commercial boats from the LDW. Also present south of the Spokane Street corridor, a 750-foot dock along Harbor Island is used for commercial moorage.

# 2 DISCUSSION OF EXISTING INFORMATION

The EISR (Anchor and Windward 2008a) identified the available data that pertains to the EW. For the sediment transport aspects of the EISR, these data included measurements of river flow, tidal elevations, current velocity, sedimentation rates, bathymetry, and studies of sediment transport in the LDW and Elliott Bay. These data are discussed in greater detail in the following subsections, followed by an evaluation of the suitability of the data for use in the STE. This section also includes a brief discussion of the current understanding of the sediment transport dynamics in the EW, which is summarized in greater detail in the Physical Processes CSM (Anchor, Windward and Battelle 2008).

## 2.1 Green River Flow and Elliott Bay Tidal Data

The EW receives freshwater flows from the Green/Duwamish River watershed. The Green River flow is recorded at the U.S. Geological Survey (USGS) gauge (Station 1213000) at Auburn at RM 32. The Green River basin has 399 square miles (640 acres) of drainage area. The river flow has been regulated by the Howard Hanson Dam that was constructed at RM 64.5 in 1961 (USACE 2005). After dam regulation, the daily peak flow rate was reduced below 12,000 cubic feet per second (cfs).

The river flow time-series corresponding to the available velocity measurement period (see Section 2.2) is plotted in Figure 2-1. The general characteristic of flow showed high peak flow during the wet season (winter through spring) and low flow during the dry season (summer). The minimum river flow for 1996 was 248 cfs, whereas the winter of 1997 had a daily peak flow of 11,600 cfs. The peak flow (measured to date) from Howard Hanson Dam is 12,000 cfs (see Figure 2-1). For the erosion potential analyses in the LDW, the peak flow was assumed to occur for a 1-week period. At the Tukwila gauge (USGS Station 12113350) on the Green River, (downstream of the Auburn gauge), the annual flow is only slightly higher than at the Auburn gauge. The seasonal flow variation is expected to affect the hydrodynamic characteristics of the entire river system to its mouth, including the LDW and the EW.

Both the EW and the LDW are tidally influenced. This influence extends as far as 10 miles upstream. Tidal data are available from the nearby National Oceanic and Atmospheric Administration (NOAA) Seattle station (9447130), located approximately 0.65 miles north of the northern end of the EW (shown in Figure 2-2). Tidal statistics referenced to feet MLLW for this station are summarized below.

- MHHW: 11.34
- Mean high water (MHW): 10.48
- Mean tide level (MTL): 6.66
- Mean low water (MLW): 2.83
- North American Vertical Datum 88 (NAVD88): 2.51
- MLLW: 0.00

The time-series plots of tide elevation at Seattle in 2007 are presented in Figure 2-3, including periods from 1995 and 1997, which correspond to velocity measurement periods. As is characteristic of Puget Sound, tides are semi-diurnal. Mean tidal range, measured from MHW to MLW, and diurnal range, measured from MHHW to MLLW are 7.66 feet (2.33 meters) and 11.36 feet (3.46 meters), respectively. The maximum and minimum water levels recorded are +14.52 feet (4.43 meters) and -5.00 feet (-1.52 meters) MLLW, respectively.

## 2.2 Velocity Data

Two sets of velocity data from the EW are available, as identified in the EISR (Anchor and Windward 2008a). These included Acoustic Doppler Profilers (ADP) data (King County 1999) and S4 current meter data collected for the Harbor Island RI (HISWG 1996). These data are discussed in the following sections.

### *2.2.1 King County Water Quality Analysis Study*

ADP measurements were made at several stations along the Duwamish River and Elliott Bay during 1996 to 1997, as a component of the Water Quality Analysis (WQA) study for the Duwamish Waterway-Elliott Bay (DWEB) (King County 1999). The data collection activities consisted of two separate, continuous measurements during 1996 and 1997. However, some data were missing due to instrument failure and other reasons. During the WQA study, velocities were measured at several locations but included only one EW station (EWW), located south of the Spokane Street Bridge (Figures 2-2 and 2-4). Besides the EWW station, the SBW station (located upstream in the LDW) and ARC station (located in the WW) are included because the conditions there contribute to the understanding of the Duwamish River system and boundary conditions for the alternative modeling approaches. The measurement periods at the stations in the Duwamish, range of Green River flow from Auburn gauge (USGS station 12113000), and velocity measurements are summarized in Table 2-1.

**Table 2-1**
**ADP Velocity Profile Measurement Station and Period**

| Station | Measurement Period | Range of Green River Flow (USGS station 12113000) | Velocity Measurements | |
|---|---|---|---|---|
| | | | Surface (1 meter below surface) | Bottom (1 meter above sediment) |
| SBW | 8/21/96 to 11/8/96 | 248 to 2,540 cfs | -82 to +103 cm/sec | -96 to +78 cm/sec |
| EWW | 3/19/97 to 5/28/97, 6/5/97 to 6/13/97, 8/8/97 to 9/7/97 | 308 to 8,970 cfs | -50 to +124 cm/sec | -57 to +51 cm/sec |
| ARC2 | 3/12/97 to 4/17/97, 4/30/97 to 5/8/97, 5/29/97 to 7/9/97, 7/17/97 to 10/30/97 | 308 to 8,970 cfs | -62 to +127 cm/sec | -55 to +82 cm/sec |

Source: King County 1999
Note that positive velocities are downstream (northward) and minus velocities are upstream (southward).
cfs – cubic feet per second
cm/sec – centimeters per second

Bottom-mounted 1,500 kilohertz (kHz) Sontek ADPs were deployed at the stations to measure the velocity profile at every 0.5 meter in vertical resolution (King County 1999). The ADP sampling data were ensemble-averaged every 15 minutes. Water surface elevations were determined from acoustical signal strength and tidal elevation data from NOAA. Figures detailing the velocity profiles, seasonal variations, and direction are presented in the CSM and Data Gaps Analysis Report (Figure 1), as well as further discussion on the hydrodynamics of the EW (Anchor, Windward and Battelle 2008). The velocity data indicate typical estuarine circulation patterns, including two-layer circulation, diurnal variation, and seasonal variation at all three stations in the Duwamish. The velocities were generally in the range of -50 centimeters per second (cm/sec) to +120 cm/sec, with minus velocity directed upstream (southward) and positive velocity directed downstream (northward). In general, during flood tide, flow structure has two distinct layers with freshwater river flowing downstream (+) toward Elliott Bay in the surface layer and saline seawater from Elliott Bay flowing upstream (-) in the bottom layer. During ebb tides, the water in the whole water column flowed seaward toward Elliott Bay at the shallowest station (EWW station), but tended to retain two-layer flow at the other stations (King County 1999).

Seasonal variations were also observed. During the wet season (high river flow), the channel flow velocities, particularly in the surface layer, are significantly increased proportional to river discharge. These are seaward flows maintained in the surface layer over the tidal cycle. During the dry season (low river flow), seaward channel velocities are significantly decreased due to the reduced river flow, and may only flow seaward during ebb tides.

### 2.2.2 Harbor Island RI Study

The Harbor Island RI Report described velocity data from stations HI-03 and HI-04 (Figure 2-4) that were collected from the main body of the EW (north of the Spokane Street corridor) during 1996 (HISWG 1996). A summary of these data were presented in Harbor Island Sediment Work Group (HISWG; 1996), but locating the raw data from which the summaries were generated has so far been unsuccessful. These data are summarized below, but additional analysis of these data may not be possible unless the raw data are located.

The HISWG summarized that at the two stations within the EW (Figure 2-4), velocities were measured approximately 1 meter above the sediment bed during the period March 27 through May 17, 1995[1]. The velocities averaged 2 to 2.5 cm/sec, with more than 99 percent of the velocities measuring less than 10 cm/sec and less than 0.01 percent of the velocities measuring greater than 25 cm/sec (HISWG 1996). The velocities measuring greater than 25 cm/sec were attributed to propwash (HISWG 1996) due to the relatively short (burst) duration of the velocities measured in that range and the presence of ships in the vicinity during the bursts. The net direction of flow at the measurement locations was to the south, in alignment with the EW channel and indicating a net inflow near the bottom. The highest measured velocities (maximums of 85 and 129 cm/sec at the two stations) were attributed to ship passage.

[1] During this period, the average daily flow for the Green River was 1,010 cfs, the peak tidal elevation was 11.76 feet MLLW, and the minimum tidal elevation was -3.07 feet MLLW.

## 2.3 Sedimentation Rate Data

Samples for sedimentation rate analyses were collected from the EW stations HI-03 and HI-04 shown in Figure 2-4. Sedimentation rate data for the EW includes net sedimentation measured from high-resolution sediment cores and gross sedimentation measured from sediment traps in the water column (HISWG 1996). Both sedimentation rates are expressed in terms of the thickness of sediment accumulated per unit time and in terms of the mass accumulation (sediment mass per unit area per unit time). This section discusses the net and gross sedimentation rate measurements. Net sedimentation rate is the accumulation rate of sediment in the bed following deposition of sediment from the water column and erosion of sediment from the bed. Gross sedimentation rate is the rate of deposition from the water column due to the settling of sediment particles.

Net sedimentation rates in the EW were estimated from the radioisotope and chemical profile data. Cesium-137 (Cs-137), lead-210 (Pb-210), mercury, and polychlorinated biphenyls (PCBs) were measured in all the high-resolution sediment cores. Cs-137 and PCB profiles from the study are presented in Figure 2-5. According to HISWG (1996), mercury data were influenced by numerous sources and were not used in the estimation of sedimentation rates. The Pb-210 data were found to be uninterpretable and were not analyzed further (HISWG 1996). Dating using the Cs-137 core data was based on both the first appearance of Cs-127 in 1950 and the peak level in 1965. Because the source of Cs-137 was from atmospheric nuclear weapons testing, it is not continuously generated and provided a suitable marker for estimating sedimentation rates. The PCBs in the sediment cores were thought to originate from a single spill at Slip 1 in September 1974 (HISWG 1996). This large spill was also thought to provide a suitable marker for estimating sedimentation rates. Note that the Lower Duwamish Waterway Group (LDWG) assigned the year 1960 (the year of peak use) as the peak in PCB deposition for the determination of net sedimentation rates at core collection locations away from Slip 1. However, for cores near Slip 1, the year of the spill (1974) was assigned by LDWG as the peak date for PCB deposition (Appendix F in Windward and QEA 2008).

The net sedimentation rates expressed in terms of depth and mass are given in Table 2-2 for each of the markers and dates. The rates were estimated from the sediment depth where the marker occurred in the sediment and the year at which the marker was placed. The year during which each marker was placed is also indicated in Figure 2-5.

**Table 2-2**
**Net Sedimentation Rates at the East Waterway Stations from the Harbor Island RI (HISWG 1996)**

| Marker | Station HI-03 | Station HI-04 |
|---|---|---|
| | **Sedimentation Rate (cm/yr)** | |
| PCB | 2.46 | 1.26 |
| Cs-137 (peak, 1965) | 2.44 | 1.65 |
| Cs-137 (first appearance, 1950) | n/a | 1.56 |
| | Average ± SD | |
| | 2.45 ± 0.012 | 1.49 ± 0.20 |
| | **Mass Sedimentation Rate ($g/cm^2/yr$)** | |
| PCB | 1.52 | 0.91 |
| Cs-137 (peak, 1965) | 1.42 | 1.14 |
| Cs-137 (first appearance, 1950) | n/a | 0.99 |
| | Average ± SD | |
| | 1.47 ± 0.067 | 1.01 ± 0.118 |

cm/yr – centimeters per year
Cs-137 – Cesium-137
$g/cm^2/yr$ – grams per square centimeter per year
n/a – no data are available
PCB – polychlorinated biphenyl
SD – standard deviation

The estimated net sedimentation rates for each station were computed as the average of the measured net sedimentation rates for each marker. For station HI-03, in the middle of the EW, the sedimentation rate was 2.45 centimeters per year (cm/yr), while at station HI-04, just north of the Spokane Street corridor, the sedimentation rate was 1.49 cm/yr. These data indicate a lower rate of net sedimentation at the south end of the EW (north of the sill) than at the middle of the EW.

The gross sedimentation rates were measured using sediment traps that were deployed 1 meter above the bottom at the same locations where the high-resolution sediment cores were collected. The sediment traps were deployed over 31 to 96 days in 1995 during two rounds of sampling (Table 2-3), which is much shorter than the period over which net sedimentation occurred. The physical data (wet and dry weight) measured in the sediment traps, other than percent solids and size fractions, were not reported in HISWG (1996).

**Table 2-3**
**Gross Sedimentation Rates at the East Waterway Stations from the Harbor Island RI (HISWG 1996)**

| Station | Deployment Dates | Length of Deployment (days) | Percent Solids | Gross Sedimentation Rate (cm/yr) | Gross Mass Sedimentation Rate ($g/cm^2/yr$) |
|---|---|---|---|---|---|
| | **Round 1** | | | | |
| HI-ST-03 | March 27 to May 16, 1995 | 50 | 51.2 | 3.2 | 2.3 |
| HI-ST-04 | April 13 to May 17, 1995 | 31 | 49.4 | 7.8 | 5.3 |
| | **Round 2** | | | | |
| HI-ST-03 | n/a | n/a | n/a | n/a | n/a |
| HI-ST-04 | May 17 to August 21, 1995 | 96 | 49.4 | 6.6 | 4.5 |

cm/yr – centimeters per year
$g/cm^2/yr$ – grams per square centimeter per year
n/a – deployed but no useable samples collected

During the Round 1 sampling, the gross sedimentation rate at station HI-ST-04 was 7.8 cm/yr, while the gross sedimentation rate at station HI-ST-03 was 3.2 cm/yr (Table 2-3). The gross mass sedimentation rate at HI-ST-04 was 5.3 grams per square centimeter per year ($g/cm^2/yr$), and the rate at HI-ST-03 was 2.3 $g/cm^2/yr$. The Round 2 rates at HI-ST-04 were slightly lower than in Round 1. The Round 1 data indicate a higher rate of gross sedimentation at the south end of the EW (north of the Spokane Street corridor) than at the middle of the EW.

Also computed in the Harbor Island RI (HISWG 1996) were the mass resuspension rates, which were computed as the difference between the gross and net sedimentation rates. From the Round 1 gross sedimentation rate data, the calculated mass resuspension rates were as follows:

- HI-03: 0.83 $g/cm^2/yr$
- HI-04: 4.29 $g/cm^2/yr$

These data indicate a higher rate of resuspension at the south end of the EW, north of the sill, than at the middle of the EW. It is unknown what effect propwash and/or other vessel-induced hydrodynamic effects may have had on resuspension.

### 2.4 Sediment Transport Data

A study of net sediment transport was conducted by McLaren and Ren (1994) in the Elliott Bay-Duwamish Waterway estuary system. The study collected samples from the top 10 to 15 cm of sediment from a gridded network of stations across Elliott Bay, the EW, the WW, and the LDW. Statistical analyses of sediment size distribution in lines of cores samples were conducted as an indicator of sediment transported from one grid point to another (Note that sediment composition data are available from previous studies in the EW). This study was presented in the EISR (Anchor and Windward 2008a) as part of the available information concerning sediment dynamics and transport.

McLaren and Ren (1994) hypothesized that a circulation pattern generated during storm periods produced currents capable of transporting sediment from Elliott Bay into the EW, which was not consistent with some of the net circulation studies to date. Note that the study estimates direction of sediment movement, but cannot determine the mass of sediment movement.

### 2.5 Bathymetric Data

Bathymetric data is important for understanding and predicting sediment transport dynamics. Existing bathymetry in the EW is presented in Figures 1-3A and 1-3B. The geometry of the system strongly influences the hydrodynamics by guiding the currents that transport suspended sediments and influencing the current speed and sedimentation rates. Relatively recent bathymetric surveys have been conducted in 2003 and 2005 in the EW north of the Spokane Street corridor. There are limited bathymetric survey data under the bridges or between the bridges and the junction with the LDW.

The mudline profile along the centerline of the EW north of the Spokane Street corridor is shown in Figure 2-6. However, no recent data are available south of the Spokane Street corridor in the EW. The general elevation south of the Spokane Street corridor is shown on NOAA chart #18450 as being approximately -20 feet MLLW (NOAA 2004).

Based on the elevation information and aerial photographs, the EW's configuration goes from an approximately 150-foot-wide shallow section (sill) south of the Spokane Street corridor, widens to an approximate 400-foot-wide narrow section (junction) under the bridges, and to a much wider and deeper section north of the bridges (forming the main body of the EW approximately 750 feet in width).

## 2.6 Hydrodynamic and Sediment Transport Modeling

The hydrodynamic and sediment transport modeling studies for the LDW are currently in draft form and in progress. The studies recently published in July 2007 for that modeling program (Appendix G in Windward and QEA 2008; QEA 2007) report the sediment load exiting from the LDW and entering the combined WW and EW for the 2-year, 10-year, and 100-year return period flow events (Windward and QEA 2008) and over a 30-year analysis period (QEA 2007). The reported sediment load exiting the LDW was not split between the EW and WW, although the LDW hydrodynamic model extended into these waterways and Elliott Bay with a coarser grid.

The EWG has requested the model from the LDWG and anticipates that the model will be available for use in more detailed analyses of sediment dynamics and transport in the EW. A brief overview of sedimentation results from the model is described below.

For the LDW over the 30-year simulation period, the estimated influx of sediment from the Green River (RM 4.8) was 6,220,000 metric tons. The model-estimated transport downstream from the LDW was 3,213,700 metric tons, which gives an overall trapping efficiency of 49 percent for the LDW. Lateral solids loads accounted for 36,200 metric tons of the sediment influx to the LDW, with 17,100 metric tons of the lateral solids load transported downstream from the LDW. Of the sediment transported downstream from the LDW over the 30-year period, 99 percent of the mass was derived from the Green River. For the analysis of the high-flow event (100-year return period), 97 percent of the sediment from the Green River was computed to be transported downstream of the LDW past RM 0.0; the remainder was from bed and lateral sources. For the purposes of the STE, the time-series of flows and sediment loads from the LDW model entering the EW are needed.

## 2.7 Estimation of Lateral Solids Loadings within the East Waterway

The SCEAM (Anchor and Windward 2008b) describes how potential sources of sediment recontamination are to be evaluated. As described in that memorandum, current and anticipated future solids loadings from storm drain and CSO discharges will be estimated, which are potentially relevant to the evaluation of sediment transport within the EW. This information will be summarized in an Initial Source Screening and Data Gaps Memorandum (per the SCEAM) that will be available for use in STE work. Information to be developed that is potentially relevant to the STE includes the following:

- Estimated solids loadings from storm drains based on storm drainage basin sizes, land use, particle size distribution and total suspended solids (TSS) data from regional studies, and local rainfall data
- Locations of storm drain and CSO discharges, based on surveys, drawings, or inspections of outfall locations
- Representative discharges from storm drains and CSOs within the EW, based on recent discharge patterns
- Information on typical solids loadings from storm drain and CSO discharges from previous sampling of conveyance systems typical of those discharging to the EW
- Locations and characteristics of other potential discharges of solids and/or pollutants to the EW

## 2.8 Propwash, Hydrodynamic Pressure Fields, and Vessel Wakes

There are no specific studies for the EW concerning sediment resuspension due to propwash, hydrodynamic pressure fields ("drawdown" or Bernoulli effects), or vessel wakes. Analysis and modeling specific to the physical layout and sediment characteristics of the EW, vessel types, and vessel operations will be required.

## 2.9 Suitability of Data for Use in East Waterway Sediment Transport Evaluation

The data presented in Section 2 consist of hydrodynamic, sediment transport, bathymetry, and model-generated data. The first three data types consist of measurements from different studies in the LDW, EW, and Elliott Bay. Model data were from the LDW study reports (Windward and QEA 2008; QEA 2007).

The velocity data that are directly pertinent to the EW include measurements from the WQA study (King County 1999). These velocity data are suitable for use in the STE. The WQA velocity data provide information about the nature of flow interactions with the LDW. They could also be used for model validation.

Dredging records have been collected and summarized in the EISR (Anchor and Windward 2008a). Since most dredging activities in the EW have been undertaken to deepen navigable depths, rather than to perform maintenance dredging, it is difficult to quantify sedimentation from these records. The effect of dredging on sediment mass balance is not being incorporated into the STE and dredging activities are also not being included in any modeling analyses.

The sediment transport data consist of the sedimentation rate data and the study of sediment transport. The data used to calculate sedimentation rates are suitable for use in the STE. They give the historical sedimentation patterns in the EW. It is possible that the sites from which the high-resolution core samples were collected may have been dredged, but the data can still be used for estimating sediment deposition rates, conducting historical sedimentation analyses, and for model validation.

The sediment transport study by McLaren and Ren (1994) is problematic in that while it suggests direction of movement of the sediment bed, it cannot be used to determine amounts of that movement or sources of the material that comprised the bed. Therefore, it provides only one line of evidence for a net measurement.

### 2.10 Current Understanding of Sediment Transport in the East Waterway

The current understanding of sediment transport in the EW is described in the CSM and Data Gaps Analysis Report (Anchor, Windward and Battelle 2008). The existing information was reviewed and used as the basis for conceptualizing the processes that influence sediment transport in the EW. The following section summarizes the sediment transport processes due to natural and anthropogenic processes described in the CSM and Data Gaps Analysis Report. In the Physical Processes CSM, three reaches of the EW were identified: the Junction Reach (south of the Spokane Street corridor to the southern boundary of the EW), the Sill Reach (the shallow area in the Spokane Street corridor), and the Main Body Reach (north of the Spokane Street corridor). Sediment transport and hydrodynamic processes are different in each of these reaches.

### 2.10.1 Natural Sediment Transport Processes

#### 2.10.1.1 Hydrodynamics

Hydrodynamics in the EW are influenced by tidally-induced fluctuations of the water surface in Elliott Bay and inflows from the LDW. The influence of the tide on inflows to the EW from Elliott Bay depends on the flows in the Green River. Specific hydrodynamic data for three reaches in the EW (Junction, Sill, and Main Body) are not currently available; however, a general discussion of anticipated flow is provided.

Stratified flow conditions develop throughout the EW with freshwater flows from the LDW flowing northward over the higher salinity bottom waters of the EW from Elliott Bay.

During periods of high flow in the Green River and during tidal ebb, the velocity profile throughout the water column is directed to the north into the Main Body Reach from the Junction and Sill Reaches. Also during periods of high river flow, but with flood tides, the surface of the water column velocity is directed to the north, but there is also flow in the bottom layer directed to the south, which is presumably composed of marine waters. This bottom-layer flow would depend on the Green River flow and height and strength of the flood tide. From evaluation of velocity data in the Junction Reach of the EW and assumptions based on hydrodynamic principles, it is concluded that velocities within the water column will be highest in the Junction and Sill Reaches, and lowest in the Main Body Reach due to the increase in cross-sectional area.

During periods of low flow in the Green River, the velocity profile in the water column is dominated by tidal variations. During ebb tide the velocity profile is directed to the north, and during flood tide the velocity profile is directed to the south.

#### 2.10.1.2 Sediment Transport

Suspended solids concentrations during low river flow periods will likely be relatively small in comparison to high river flow periods. It is during the high flow periods that the greatest sediment loads likely will be transported into the EW, because of the large water flows and the likely higher concentrations of suspended sediment. The highest deposition is expected in the Main Body Reach, where the fluid velocities decrease in comparison with the Junction and Sill Reaches. Deposition in the Main Body Reach is likely highest at the south end, near the Sill Reach, and decreases as sediment is transported northward toward Elliott Bay.

#### 2.10.1.3 Sediment Deposition and Resuspension

Sedimentation is influenced by the deposition of sediment from the water column (gross sedimentation) and by resuspension of the sediment bed due to current-induced shear stress applied to the sediment bed. The difference between the gross sedimentation and resuspension is the net sedimentation. The fluid shear stress from natural currents will vary depending upon the direction and velocity of flow and on the depth of water due to estuarine dynamics. Historically, the depth of the southern end of the Main Body Reach was shallow, so that resuspension from natural currents was likely larger than in deeper regions of the Main Body Reach. Consequently, provided sediment type and cross-sectional area are uniform, net sedimentation at the south end is likely lower under those conditions than in the deeper sections further north.

### 2.10.2 Vessel-induced Hydrodynamic Effects

Most vessel traffic in the EW consists of container ships that are assisted by tugboats moving into and out of the EW. Each container ship requires at least one tugboat to maneuver the ship during berthing. Cruise ships have called on T-30 for the past several years. However, the Port of Seattle plans to move cruise ship operations from T-30 to Terminal 91 (T-91) in Elliott Bay in 2009 (previously identified as 2008 in the EISR) and restore T-30 to a container facility. Cruise ships typically maneuver under their own power. Vessels from NOAA (which are much smaller) will temporarily dock at T-30 from November through March of 2008, prior to its conversion to a container facility.

In addition to the above ship traffic, tugboats, barges, and small craft also use the EW. USCG moors numerous vessels in Slip 36, including USCG icebreakers, cutters (greater than 65 feet in length), and gunboats. Other miscellaneous vessel moorage is present in

Slip 27. South of the Spokane Street corridor, recreational and commercial boats move in and out of the Harbor Island Marina (T-102) from the LDW. Along the T-102 shoreline within the EW, the Port leases out moorages at a 750-foot-long dock for commercial use. Detailed information on vessel arrivals and departures is included in Section 2.4.2 in the EISR (Anchor and Windward 2008a).

***Propwash*** from deep-draft vessels, tugboats, and pleasure craft can generate strong currents, resulting in shear stresses on adjacent bottom and sideslopes of the EW. Propwash velocities can often exceed velocities from tidal currents or river flow velocities.

A preliminary review of vessels operating in the EW suggests that propwash may be the primary cause of sediment resuspension from the bottom and sideslopes along the EW. The random nature of vessel-induced sediment resuspension is a complicating factor in the analysis of sediment transport physical processes. The location, time of passage, and maneuvering of a specific vessel can occur with any tidal height and flow condition.

In addition to propwash, ship-induced pressure field effects (also known as drawdown or Bernoulli effects) and vessel wake are other vessel-produced hydrodynamic phenomena typically considered when evaluating the potential for resuspension of bottom and bank sediment.

***Pressure fields*** are long period waves from moving deep-draft vessels in restricted waterways, such as the EW, that cause high water velocities in the nearshore shallow areas and potential resuspension of fine sediment.

Formation of any significant pressure field effects in the EW likely would occur only if a large deep-draft vessel exceeded a certain speed criteria and/or traveled along a sailing line offset from the channel centerline. These conditions are not typical and are not expected to occur within the EW. It is anticipated that pressure field effects are not a significant factor for sediment resuspension in the EW due to the slow velocities of deep-draft vessels while docking and undocking within the EW. An analysis of operational conditions of deep-draft vessels in the EW will be conducted to confirm this expectation. If the analysis confirms that operational conditions of deep-draft vessels minimize or exclude pressure field effects, these effects will be removed from the analysis of sediment resuspension and sediment transport.

***Vessel wakes*** are generated by shallow-draft vessels transiting the EW. Docking and undocking deep-draft vessels do not reach speeds that produce discernible wakes, which will be verified in the modeling. When vessel wakes transform on shallow bottom and slopes, they can generate flow or orbital velocities that may resuspend available sediment.

Previous experience with vessel wakes in Puget Sound and other regions suggests that hydrodynamic effects on sediment resuspension may extend only to an effective depth of approximately 10 to 15 feet below the water surface. If the sediment of concern is located at a water depth deeper than 15 feet, it is unlikely that vessel wakes will cause significant resuspension effects on the sediment. A description of the EW shoreline is included in the EISR (Anchor and Windward 2008a). It is important to note that nearly all of the EW shorelines are protected with riprap armor from the top of slopes down to the toe of slopes, which is typically located deeper than 15 feet below the water surface.

Vessel speed is a critical factor for the development of significant hydrodynamic forces and vessel wake effects on sediment resuspension. Vessels maneuvering within the EW typically operate at slow speeds due to the relatively narrow widths and presence of structures and other vessels.

# 3 SEDIMENT TRANSPORT EVALUATION MODELING APPROACH SELECTION AND DATA NEEDS DETERMINATION

As discussed in Section 1, the Sediment Transport Evaluation Report will summarize the STE and will be used to refine the Physical Processes CSM presented in the CSM and Data Gaps Analysis Report (Anchor, Windward and Battelle 2008). The STE will be conducted using existing information obtained from the EISR (Anchor and Windward 2008a) and new information obtained to support the STE preferred approach discussed in this STEAM.

Potential modeling approaches to inform the STE are examined in this section and are evaluated on the ability to meet the objectives outlined in Section 1. How well the modeling approaches are able to incorporate the relevant physical processes, scales, and the level of effort involved (e.g., model setup and run time) are used to select which approach will adequately address the objectives of the STE. The preferred approach must also be able to examine the potential for recontamination during future SRI/FS activities. In addition, another important factor that should influence the selection of a preferred approach is whether a modeling approach can effectively achieve the STE objectives while meeting the Workplan (Anchor and Windward 2007) schedule.

Section 3.1 provides an overview of relevant physical processes that influence sediment transport in the EW. Potential modeling approaches to inform the STE have been discussed with EWG and EPA. These approaches are examined in Sections 3.2 and 3.3. Section 3.2 identifies several modeling approaches to assess sediment transport from natural processes, and Section 3.3 reviews their data requirements. Following preparation of the Draft STEAM, several meetings were held between EWG and EPA to develop a consensus STE approach. An overview of the consensus modeling approach has been developed that includes hydrodynamic modeling, localized transport modeling, and empirical data analyses. This preferred approach is discussed in Section 3.4. Section 3.5 identifies data needs for the preferred approach.

Section 3.6 presents the modeling approach for evaluating vessel-induced hydrodynamic effects. The STEAM provides much more detail in the selection of the modeling approach for evaluating sediment transport from natural processes than is provided for vessel-induced hydrodynamic effects since there are limited modeling alternatives available to assess these effects.

## 3.1 Relevant Sediment Transport Processes in the East Waterway

Sections 3.1.1 through 3.1.4 describe the relevant sediment transport processes in the EW. These physical processes form the basis to develop potential STE approaches and are incorporated into the Physical Processes CSM for the EW (Anchor, Windward and Battelle 2008). The discussion is separated between the processes of sediment transport through the water column and the interactions between the sediment bed and the water column.

### *3.1.1 Hydrodynamics*

The hydrodynamics of the EW have a major effect on the transport of sediment. The tidal conditions and marine waters (with high salinity) in Elliott Bay and the freshwater flow in the Green River (with low salinity) govern the velocity field and the density stratification of the EW. Freshwater inflows from the LDW into the EW will produce stratified flow conditions. Freshwater lateral solids loads from CSOs and storm drains have intermittent and random discharges to the EW. The discharge of freshwater into high salinity marine waters will produce buoyancy effects that influence mixing and entrainment of the discharge into the receiving water. The elevation of the discharge pipe with respect to the range of tidal elevations determines if the discharge behaves as a surface or subsurface discharge. Discharges from lateral solids loads are not expected to affect the overall circulation patterns produced by the tidal exchange and inflows from the LDW.

The interaction of the fluid flow with solid boundaries and fluid layers produces turbulence in the EW that promotes mixing and dispersion processes. These processes, in turn, influence the loading of sediment into the EW from the LDW and lateral solids loads and the pathways of transport within the EW.

Additionally, localized vessel-induced hydrodynamic effects (e.g., propwash, pressure field effects, and ship wakes) influence sediment transport in the localized region where the vessel-induced effects occur. Vessel-induced effects can have significant localized impacts on sediment stability and transport, and cumulatively may result in mixing of surface sediments over larger spatial scales.

#### *3.1.2 Sediment Transport and Sedimentation*

As sediment is brought into and transported through the EW by advective fluid flow, suspended sediment particles will tend to settle through the water column. No salt wedge is expected to develop in the EW and, therefore, it is not expected to have a significant influence on settling dynamics. This settling process can be counteracted by turbulent processes that lift sediment particles back up into the water column. The turbulence-induced motion promotes mixing of sediment particles through the water column. The time needed for settling depends on the particle size (settling velocity), the depth of water through which the particle settles, and the residence time of the system. If the residence time of the sediment particle is long enough, the particle will eventually settle to the sediment bed. Large particles, such as gravel and sand, will settle faster than smaller particles (silts and clays). In the process of settling, smaller sediment particles may form flocs along with other sediment particles by differential settling. Differential settling allows particles to aggregate and form flocs, resulting in increased settling rates. Floc formation is also increased when sediments suspended in freshwater come into contact with saline waters. This reduces the electrostatic repulsion of the smaller particles and allows them to aggregate and flocculate. Turbulence and velocity shear in the water column just above the bed can break apart flocs (de-flocculation) that are settling to the bed, resulting in a reduced rate of sediment deposition.

#### *3.1.3 Bed Sediment*

After sediment is deposited to the sediment bed, sediment particles will either undergo sedimentation (burial) or resuspension. A fluff layer forms on the sediment surface composed of the recently deposited sediment particles. If sediment particles continue to be deposited on the bed surface, particles will be buried deeper in the sediment column.

As sediment particles are buried, the interstitial porewater will be squeezed out due to the increasing weight of sediment. This results in sediment consolidation and increasing shear strength with depth. The vertical variation in shear strength in the sediment bed can also be affected by episodic deposition of less cohesive sediment, bioturbation (sediment mixing from benthic infauna), and anthropogenic disturbances.

Periodically, the fluid velocity above the sediment bed may be so large as to produce large shear stresses on the bed that cause entrainment of sediment particles into the water column (resuspension). The re-entrained sediment can be removed from the surface of the sediment bed, or if there is a shear strength weakness within the bed, mass erosion of the sediment bed can occur.

#### *3.1.4 Time and Spatial Scales of Sediment Transport Processes*

Sediment transport dynamics occur over a spectrum of time scales. River floods carrying large sediment loads occur over a period of hours to days. Tidal influences on sediment transport occur over a period of hours. Sedimentation occurs over a period of years, with shorter-term processes influencing the rate on the order of hours to days.

There is also a range of spatial scales over which sediment transport dynamics occur. Factors that affect spatial scales include the diameter of a discharge pipe, the width of a sediment plume or sediment footprint, the distance it takes for an advected sediment particle to settle, the scale and distribution of propwash effects, and the size of the whole waterbody being analyzed.

## 3.2 Sediment Transport Modeling Approaches For Natural Processes

There are several modeling approaches that have been discussed between EWG and EPA to inform the STE for natural processes. They range from simple mass balance calculations to physics-based models with fine-resolution grids used with multi-year simulations. The following subsections describe and document the range of approaches considered and discuss the advantages and limitations of each approach presented. For the physics-based model approaches, it should be recognized that a spectrum of possible approaches could be presented with variations of grid resolution, period of analysis, and model domain size.

The evaluation of modeling approaches for natural processes presented in the STEAM is based on the ability of the approach to meet STE objectives. The STE objectives identified in the Workplan (Anchor and Windward 2007) are as follows:

1. Identify and evaluate the primary sources of sediment to EW
2. Identify temporal and spatial patterns of sediment erosion and deposition (if applicable)

3. Identify the physical processes driving sediment transport
4. Identify likely routes or pathways for sediment movement
5. Assess how sediment transport pathways may affect the feasibility of remedial alternatives, including MNR, enhanced natural recovery, dredging, and isolation capping
6. Assess potential for physical processes to contribute to recontamination

The evaluation of each modeling approach also considers the anticipated likelihood of whether the modeling approach can meet the Workplan schedule (Anchor and Windward 2007). Table 3-1 provides details of each modeling approach, as well as the advantages and limitations of each approach.

Five modeling approaches for natural processes are presented in Table 3-1 and summarized in this section, as follows:

1. Single-box mass balance calculation approach
2. Two-layer screening-level modeling approach
3. Physics-based modeling approach – existing/coarse grid resolution in the EW
4. Physics-based modeling approach – moderate grid resolution in the EW
5. Physics-based modeling approach – fine grid resolution in the EW

**Table 3-1**
**Advantages and Limitations of the Modeling Approaches for Natural Processes**

| Approach | Description | Outputs | Advantages | Limitations |
|---|---|---|---|---|
| Single-box Mass Balance Calculations | • Spreadsheet calculations<br>• EW considered as a box<br>• Uses annual time scales (sedimentation rates are annual)<br>• Inflow and sediment loads to the EW are derived from the existing LDW model<br>• Lateral source inflows and sediment loads come from Source Control Evaluation<br>• Net sedimentation rates used to calculate net loss of sediment from the water column | • Estimates of sediment mass depositing in the EW as a whole over multi-year period<br>• Percentage change in sediment mass between inflow from the LDW and outflow to Elliott Bay | • Relatively simple<br>• Uses only existing information<br>• Uses annual data from existing model<br>• Provides annual time-scale analysis<br>• Relatively short duration to complete analysis | • Does not provide spatial distribution of sediment deposition<br>• Does not provide seasonal or storm event analyses<br>• Does not include many of the relevant physical processes: momentum, shear stress, buoyancy, stratified flow |
| Two-layer Screening-Level Model | • Uses WASP model (as typical screening-level model)<br>• EW considered as a box<br>• Two-layer flow is assumed<br>• Time scale depends on the averaging period<br>• Net inflows and sediment loads are derived from the LDW model for the EW<br>• Flow balance provides vertical exchange<br>• Lateral source inflows and sediment loads come from Source Control Evaluation<br>• Settling velocity of median particle specified<br>• Model validation of settling velocity and resuspension flux to net sediment accumulation from radioisotope profiles over the period 1964 to present | • Estimates of sediment mass depositing in the EW as a whole over multi-year period<br>• Percentage change in sediment mass between inflow from the LDW and outflow to Elliott Bay | • Relatively simple<br>• Model widely accepted<br>• Uses only existing information<br>• Uses data from existing model<br>• Can provide long-term simulations with low computational cost<br>• Relatively short duration to complete analysis | • Does not provide spatial distribution of sediment deposition<br>• Does not include many of the relevant physical processes: momentum, shear stress, buoyancy, stratified flow<br>• Inflow data has to be obtained from the existing LDW model and averaged<br>• Model validation required |
| Physics-Based Modeling Approach – Existing Grid in EW | • Uses existing model of the LDW that includes coarse grid of the EW<br>• Includes updated bathymetry in the EW<br>• Analysis time scales based on storm events (or seasonal) durations<br>• Lateral sources are added to the model<br>• Lateral source inflows and sediment loads come from Source Control Evaluation<br>• Model setup is consistent with the LDW model: number of sediment classes, sediment transport parameters, LDW grid, Green River inflows, LDW lateral solids load inflows, and LDW sediment bed composition<br>• Initial sediment bed composition in the EW defined from measurements<br>• Model validation to available hydrodynamic data (velocity and salinity profiles)<br>• Model validation to net sediment accumulation (weeks to months) - (net sedimentation rate * period) | • Estimates the spatial distribution of sediment mass depositing in the EW<br>• Percentage change in sediment mass between inflow from the LDW and outflow to Elliott Bay<br>• Coarse spatial distribution of sediment deposition from lateral sources<br>• Percent contribution of sources to bed composition<br>• Relative importance of various sediment transport processes<br>• Results under various conditions could be combined for longer-term analyses | • Existing model of the LDW available that includes the EW represented with coarse grid resolution<br>• Includes the relevant physical processes: momentum, shear stress, buoyancy, stratified flow, flocculation<br>• Limiting analyses to storm events (or seasonal periods) is expected to provide adequate distribution of sediment deposition patterns<br>• Anticipated to be moderate duration to complete analysis | • Model more complex than simple single-box mass balance calculations or two-layer screen-level model<br>• Long-term (multi-year) simulations are problematic<br>• Coarse grid resolution dilutes sediment plumes from lateral sources changing the physics of deposition<br>• Model validation required<br>• Sideslope bathymetry is not represented |
| Physics-Based Modeling Approach – Moderate Grid Resolution in the EW | • Uses existing model of the LDW<br>• EW grid resolution is doubled or tripled over existing grid<br>• Includes updated bathymetry in the EW<br>• Adds in Slip 27 and Slip 36 to model grid<br>• Analysis time scales based on storm events (or seasonal) durations<br>• Lateral sources are added to the model<br>• Lateral source inflows and sediment loads come from Source Control Evaluation<br>• Model setup is consistent with the LDW model: number of sediment classes, sediment transport parameters, LDW grid, Green River inflows, LDW lateral solids load inflows, and LDW sediment bed composition<br>• Initial sediment bed composition in the EW defined from measurements<br>• Model validation to available hydrodynamic data (velocity and salinity profiles)<br>• Model validation to net sediment accumulation (weeks to months) - (net sedimentation rate * period) | • Estimates the spatial distribution of sediment mass depositing in the EW<br>• Percentage change in sediment mass between inflow from the LDW and outflow to Elliott Bay<br>• Moderate level of resolution of the spatial distribution of sediment deposition from lateral sources<br>• Percent contribution of sources to bed composition<br>• Relative importance of various sediment transport processes<br>• Results under various conditions could be combined for longer-term analyses | • Existing model of the LDW available that includes the EW<br>• Includes the relevant physical processes: momentum, shear stress, buoyancy, stratified flow, flocculation<br>• Limiting analyses to storm events (or seasonal periods) is expected to provide adequate distribution of sediment deposition patterns<br>• Higher resolution grid provides better estimates of plume dilution than existing EW grid from the LDW | • Model more complex than simple single-box mass balance calculations or two-layer screen-level model<br>• Long-term (multi-year) simulations are problematic<br>• Sideslope bathymetry may not be represented |
| Physics-Based Modeling Approach – Fine Grid Resolution in the EW and Multi-Year Simulations | • Uses existing model of the LDW<br>• EW grid resolution is increased locally to represent lateral source configurations<br>• Includes updated bathymetry in the EW<br>• Adds in Slip 27 and Slip 36 to model grid<br>• Analysis time scales based on need to validate net sedimentation data, requiring multi-year simulations<br>• Lateral sources are added to the model<br>• Lateral source inflows and sediment loads come from Source Control Evaluation. Flows and loads provided for multi-year simulations<br>• Model setup is consistent with the LDW model: number of sediment classes, sediment transport parameters, LDW grid, Green River inflows, LDW lateral solids load inflows, and LDW sediment bed composition<br>• Initial sediment bed composition generated from the final sediment characteristics of a multi-year model simulation<br>• Model validation to available hydrodynamic data (velocity and salinity profiles)<br>• Model validation to net sediment accumulation from radioisotope profiles over the period 1964 to present | • Estimates the spatial distribution of sediment mass depositing in the EW over multi-year period<br>• Percentage change in sediment mass between inflow from the LDW and outflow to Elliott Bay over multi-year period<br>• High level of resolution of the spatial distribution of sediment deposition from lateral sources<br>• Percent contribution of sources to bed composition<br>• Relative importance of various sediment transport processes | • Existing model of the LDW available that includes the EW<br>• Includes the relevant physical processes: momentum, shear stress, buoyancy, stratified flow, flocculation<br>• Multi-year simulation covers a wide range of tidal and flow conditions<br>• Fine grid resolution provides relatively accurate representation of initial dilution processes of lateral source plumes and resulting sediment deposition<br>• Fine grid provides high-resolution distribution of sediment deposition patterns | • Model more complex than simple single-box mass balance calculations or two-layer screen-level model<br>• Long-term (multi-year) simulations are problematic<br>• Significant calibration effort<br>• Significant increase to model grid complexity<br>• SRI/FS Workplan schedule will likely not be met due to extensive model calibration and validation needs and longer model runtimes<br>• Decreased potential to perform sensitivity analysis<br>• Apparent increase in model resolution may not reflect actual long-term sediment distribution due to sediment mixing from propwash<br>• Increased model grid resolution may not be needed in order to meet the STE objectives |

EW – East Waterway
LDW – Lower Duwamish Waterway
SRI/FS – Supplemental Remedial Investigation/Feasibility Study
STE – Sediment Transport Evaluation
WASP – Water Quality Analysis Simulation Program

### 3.2.1 Single-Box Mass Balance Calculation Approach

This simplest modeling approach considers the EW as a whole, and examines sediment transport on annual periods. The approach models the EW as a single box, or Continually Stirred Tank Reactor (CSTR), and calculates a sedimentation rate from a settling speed, the suspended sediment concentration within the box, and the average geometry. The model would use the output from the existing LDW model (QEA 2007) to provide annual inputs of flow and sediment load to the EW. Flow and solids loads from lateral sources would be refined as described in the Initial Source Screening and Data Gaps Memorandum (per the SCEAM process). A flow balance would compute the net flow at the Elliott Bay boundary. This net flow is anticipated to be outward, meaning sediment concentrations at this boundary would not be a required input. The suspended solids concentration would be calculated from the net sediment fluxes, and the net sedimentation rate would be computed as the product of this concentration, the settling speed, and the effective area. The net sedimentation rate would be compared with the measured net sedimentation rates. Discrepancies would be reconciled based on the current understanding of the physical processes in the EW and the level of confidence of the boundary values.

While this approach is relatively simple, it does not provide spatial distributions of sediment bed contributions from sediment sources. It also does not include the important physical processes of hydrodynamics and sediment transport. It can provide an estimate of sediment deposition with time, at least on an annual time scale or longer.

### 3.2.2 Two-Layer Screening-Level Modeling Approach

The two-layer screening-level modeling approach assumes the use of the Water Quality Analysis Simulation Program (WASP) model (Wool et al. 2001) with a simplified two-layer flow model. The EW is represented as two vertical boxes with no horizontal segmentation.

This modeling approach assumes a simplified two-layer flow model with the surface layer representing freshwater flows from the LDW and the bottom layer representing saline inflows from Elliott Bay. The existing LDW model output (Windward and QEA 2008) would be averaged to provide the net inflows and outflows of the surface and bottom layers from the LDW and Elliott Bay. These inflow data are used to derive a flow balance within the EW to estimate vertical exchange between the bottom and surface layers. The averaging period would be of a reasonable length to quicken computation and remove tidal exchanges, such as a monthly or seasonal interval. Suspended sediment concentrations would come from the existing LDW model (QEA 2007) at the LDW boundary and from existing Elliott Bay monitoring data for the Elliott Bay boundary. Model validation would involve adjusting boundary concentrations, settling rates, and resuspension fluxes to match the predicted sedimentation rate to observed net sedimentation rates.

As with the single-box mass balance approach, this modeling approach does not provide spatial distributions of sediment bed contributions from lateral solids loads, but it can provide a slightly higher temporal resolution, at least on the time scale of net inflow calculations. It only includes a subset of the physical processes important for hydrodynamic and sediment transport analyses. In the case of the EW, using the existing (coarse-grid) physics-based model would be faster and more cost-effective than developing a two-layer screening-level model.

### 3.2.3 Physics-Based Modeling Approach – Existing/Coarse Grid Resolution in the EW

The existing model used for the LDW analyses includes the EW in the model domain (QEA 2007). The use of the existing model provides an advantage in time savings in that the model is already set up. The existing model for the LDW includes Environmental Fluid Dynamics Code (EFDC) for the hydrodynamic processes and SEDZLJ for the sediment transport processes. It is a physics-based model, in that it includes the important physical processes and state-of-the-art algorithms to describe the hydrodynamic and sediment transport processes. The model domain extends from the Duwamish River at the south to a boundary between Puget Sound and Elliott Bay that is located between Alki and West Points. The scale of the existing grid is generally consistent with the scale of longitudinal bathymetric features in the EW in that the resolution of the model grid captures longitudinal changes in bathymetry. The grid resolution is relatively coarse and transverse bathymetric features, such as steep shorelines, are not accurately represented by this grid. Another limitation of the existing grid is that it does not depict Slip 27 and Slip 36.

This physics-based modeling approach for natural processes includes a coarse grid resolution in the EW, but the model would be updated with the latest bathymetry data for the EW. The initial sediment bed composition is not currently configured for the EW, but will be derived from existing sediment composition data. Boundary conditions would be provided by USGS gauge data, sediment rating curves (TSS) at the Green River boundary, and tidal elevations and average sediment concentrations (TSS) at the Elliott Bay-Puget Sound boundary. The model resolution is coarse in the EW, with two cells across the width and 13 cells along the length. This includes one row (two cells wide) in the Junction Reach and two rows (two cells wide) in the Sill Reach. The model has a very fine temporal resolution, on the scale of minutes. Model calibration would come extensively from the LDW modeling work (QEA 2007).

Lateral solids loads would be input as point sources into the existing model grid. Lateral solids loads in the EW include three CSOs and an estimated 39 storm drains. Flows and sediment concentrations in CSOs and storm drain discharges to the EW will be developed as part of the Source Control Evaluation process. The key output of the modeling analysis of lateral discharges will be the fraction of sediment from CSOs and storm drains deposited in the EW. Due to the coarse grid, the existing model would provide only a general distribution of lateral solids loads but would be sufficient to provide a general picture of how lateral solids loads impact EW sediment transport processes. However, the deposition resolution can be no greater than the grid resolution, as all model calculations are defined by the grid resolution.

The existing/coarse-grid approach is an improvement over the single-box mass balance calculations and two-layer screening-level modeling as it provides results of the spatial distribution of sediment deposition. The time scales of analysis will be adequate to accurately characterize the variations of flow and sediment load over storm events and seasonal hydrologic cycles. The approach includes all of the physical processes important for hydrodynamic and sediment transport analyses (presented in Section 3.1). Since this approach utilizes an existing model, relatively minor configuration changes are required to simulate the EW, thus reducing the effort required as compared to the two-layer screening-level approach. Though current bathymetry would be applied to the existing grid, because of the coarse resolution of the grid cells in the Junction and Sill Reaches, the shallow depths and narrowing associated with the Sill Reach may not adequately capture the two-layer hydrodynamic flows in the Sill Reach.

#### 3.2.4 Physics-Based Modeling Approach – Moderate Grid Resolution in the EW

The second variant of the physics-based model approach is similar to the previous coarse-grid approach. Its difference is that the grid resolution in the EW would be doubled or tripled compared to the existing grid to provide a moderate grid resolution. The moderate grid would also depict Slip 27 and Slip 36. Increasing the grid resolution would be done to provide more accurate representation of dilution processes for solids from lateral sources. This approach also provides higher spatial resolution of sediment deposition patterns from lateral sources and the LDW than would result from using the existing/coarse grid. More accurate results from the moderate grid model would provide more confidence in evaluating the feasibility of MNR as a remedial alternative and for evaluating recontamination potential. With the potential for slightly greater resolution, lateral solids loads would be modeled similar to the approach using the existing/coarse grid resolution. This approach also increases the potential to capture the complexities of the impact of the Sill and Junction Reach restrictions on the two-layer hydrodynamic flow.

As is the case for the coarse grid, using a physics-based modeling approach at moderate grid resolution is an improvement over the single-box mass balance calculations and two-layer screening-level modeling because it provides results of the spatial distribution of sediment deposition. Since this approach utilizes an existing model, relatively minor configuration changes are required to simulate the EW, thus reducing the effort required. However, additional effort (above that needed for the existing/coarse grid) to refine the grid and to validate and potentially re-calibrate the LDW model is required for this approach. This approach provides adequate time scale resolution over the duration of analyses. It also includes the physical processes important for hydrodynamic and sediment transport analyses (presented in Section 3.1).

#### 3.2.5 Physics-Based Modeling Approach – Fine Grid Resolution in the EW

The third variant of the physics-based model approach has some significant differences from the previous two approaches. It calls for significant improvements to the existing model grid resolution in the EW. Fine grid resolution would be better able to resolve the localized nature of plumes of solids from lateral solids loads (i.e., storm drains and CSOs), which would require that the smallest grid dimension would be about the size of a typical discharge pipe in the vicinity of the lateral sources. Other areas within the EW could utilize a larger grid resolution. The effects of lateral solids loads could then be represented as accurately as possible in the vicinity of the discharge. A fine grid model also improves the resolution of possible contaminant footprint from lateral solids loads in the sediment bed, which may help to better evaluate recontamination potential. As is the case for the coarse and moderate grid resolution approaches, the model setup for the fine grid would be consistent with the LDW model.

Using a physics-based modeling approach at fine grid resolution is an improvement over the other natural process modeling approaches discussed as it provides greater precision of results of the spatial distribution of sediment deposition. This approach provides adequate time scale resolution. It also includes the physical processes important for hydrodynamic and sediment transport analyses (presented in Section 3.1). However, there are significant difficulties in this modeling approach. Significant additional calibration of the model is expected. Another critical factor is that refining the existing LDW model to address lateral solids loads to a detailed degree would significantly increase the overall complexity of the model grid and likely would result in the need to conduct extensive model validation and calibration. Increasing the model resolution to a fine grid would also significantly increase model run times to a degree that long-term simulations may not be feasible.

### 3.3 Data Requirements of the Natural Processes Modeling Approaches

The data required to conduct each modeling approach are listed in Table 3-2. The data required for the single-box mass balance calculations and two-layer screening-level model have several differences from the data requirements of the physics-based models. The mass balance calculations use data at annual time scales, primarily due to the annual rates determined for net sedimentation. Net sedimentation rate data are used for comparison purposes to mass balance calculation results. The two-layer screening-level model uses net inflows computed over averaging periods corresponding to tidal cycles (i.e., daily, biweekly, or monthly). These longer time scales are used for inputs of flows and sediment loads to the EW. The data for the single-box mass balance and two-layer screening-level modeling approaches would be obtained from the LDW existing model output (Windward and QEA 2008).

The physics-based models use time intervals on the order of the frequency of the data: 15 minutes for tide and hourly for river flows. These data are taken from measurements at gauge stations in the case of flows and tides. A rating curve is used to estimate sediment concentrations from the flow measurements. Additional data requirements for physics-based models are listed below:

- Measurements of velocity and salinity profiles in each of the reaches.
- Flows and sediment concentrations from lateral sources.
- Settling velocity data for several size classes are needed for both the two-layer screening-level and physics-based models. For consistency, the settling velocity data would be the same data for four primary sediment size classes as used for the LDW analyses (QEA 2007). It is likely that the variability of measured settling velocity will be greater than the estimation from physical principles. A very large sample set would be needed to reduce the variation. This has been accomplished already in many studies of sediment settling rates of various sizes and particle types. Therefore, literature values will be used.
- Sediment physical characteristics from existing data can be used for all of the physics-based model approaches. Critical sheer strees and erosion rates would be used as calibration parameters with the coarse-grid resolution approach, whereas in the medium- and fine-grid approach, they are measured from intact sediment cores using Sedflume (McNeil et al. 1996) methods and specified as inputs.
- Net sedimentation rate data are used for model validation in physics-based modeling approaches.

**Table 3-2**
**Summary of Data Required for the Various Sediment Transport Evaluation Modeling Approaches**

| Local-domain Model Approach Data Needs | Single-box Mass Balance Calculations | Two-layer Screening-Level Model | Physics-based Model – Existing/Coarse Grid Resolution | Physics-based Model – Moderate Grid Resolution | Physics-based Model – Fine Grid Resolution |
|---|---|---|---|---|---|
| **Hydrodynamics** | | | | | |
| EW – Bathymetry and Cross-sections | -- | X | X | X | X |
| EW Lateral Load – Annual/Averaging Period Flow | X | X | -- | -- | -- |
| LDW Inflow to EW – Annual/Averaging Period Flow | X | X | -- | -- | -- |
| Elliott Bay – Time-series Tide Elevation | -- | -- | X | X | X |
| EW Lateral Load – Time-series of Flow | -- | -- | X | X | X |
| Green River – Time-series Freshwater Inflow | -- | -- | X | X | X |
| DWEB – Meteorological Data (wind speed and direction) | -- | -- | X | X | X |
| EW, WW, LDW, Elliott Bay – Profiles and Time-series Salinity and Temperature | -- | -- | X | X | X |
| EW, WW, LDW – Profiles and Time-series Velocity | -- | -- | X | X | X |
| EW, WW, LDW – Time-series Tide Elevation | -- | -- | X | X | X |
| **Sediment Transport** | | | | | |
| DWEB – Suspended Sediment Settling Velocities | -- | X | X | X | X |
| EW Lateral Solids Load – Annual/Averaging Period Loads and Particle Size Distribution | X | X | -- | -- | -- |
| LDW Inflow to EW – Annual/Averaging Period Sediment Loads and Particle Size Distribution | X | X | -- | -- | -- |
| LDW Inflow to EW – Time-series of Event Loads and Particle Size Distribution | -- | -- | X | X | X |
| EW Lateral Solids Load – Time-series and Grab Sample Suspended Solids Concentrations and Particle Size Distribution | -- | -- | X | X | X |
| Green River – Time-series and Grab Sample Suspended Sediment Concentrations and Particle Size Distribution | -- | -- | X | X | X |
| **Sediment Bed** | | | | | |
| Sediment Bulk and Dry-densities (sediment void fraction) | -- | X | X | X | X |
| Sediment Grain Size Distribution and TOC | -- | X | X | X | X |
| Sediment Shear Strength, Critical Shear Stress, and Erosion Rate Profiles from Sedflume measurements | -- | -- | X | X | X |
| Net Sediment Accumulation | -- | -- | X | X | -- |
| Net Sediment Accumulation from radioisotope profiles over the period 1964 to present | -- | X | -- | -- | X |

DWEB – Duwamish Waterway-Elliott Bay
EW – East Waterway
LDW – Lower Duwamish Waterway
TOC – total organic carbon
WW – West Waterway

### 3.4 Preferred Approach

In order to select the preferred approach, each approach is evaluated based on the following criteria:

- Does the approach address the STE objectives and address the analytical needs for the SRI/FS?
- Does the approach present the most practical, technically defensible, and cost-effective approach?
- Can the Workplan schedule be met with the anticipated field data collection, level of modeling design effort, and analysis times needed to conduct the approach?

The STE objectives identified in the Workplan (Anchor and Windward 2007) are as follows:

1. Identify and evaluate the primary sources of sediment to the EW
2. Identify temporal and spatial patterns of sediment erosion and deposition (if applicable)
3. Identify the physical processes driving sediment transport
4. Identify likely routes or pathways for sediment movement
5. Assess how sediment transport pathways may affect the feasibility of remedial alternatives including MNR, enhanced natural recovery, dredging, and isolation capping
6. Assess potential for physical processes to contribute to recontamination

Objectives 1 and 2 require an approach that can provide spatial distribution and handle sediment transport dynamics. Objective 2 also requires an approach that can accommodate the range of spatial and temporal scales found in a system like the EW. Objective 3 requires an approach based on physical principles that affect sediment transport dynamics.

Objective 4 links to the Source Control Evaluation (as do Objectives 5 and 6) and the need to temporally and spatially evaluate the distribution of sediments (and contaminants) from sources within the EW as well as from outside the EW. The approach must include the capability to evaluate recontamination potential as given in Objective 6.

As stated in the introduction to Section 3, various approaches (presented in Sections 3.2 of 3.3 of this document) were discussed with EWG (Port of Seattle, City of Seattle, and King County) and EPA following submittal of the Draft STEAM on March 7, 2008. The discussions occurred during meetings between EWG and EPA on May 15, 2008, and July 22, 2008, and focused on the level of complexity of the analyses, the needs for the SRI/FS, and the impact of the approach on the schedule. Through these discussions, a consensus was reached that the initial preferred approach outlined in the Draft STEAM (March 2008) could not meet all of the objectives of the Workplan (Anchor and Windward 2007) and a new tiered approach was developed. This approach combines use of the EFDC model developed for the LDW at moderate grid resolution to evaluate hydrodynamics and erosion potential in the EW, use of measured sediment transport characteristics to inform sediment transport rates, and localized plume and/or particle tracking modeling to assess recontamination potential from lateral sources[2].

The proposed sediment transport evaluation approach for the EW includes updating and utilizing the existing LDW hydrodynamic model. The hydrodynamic model updates will be focused on the EW and will include bathymetry, geometry, and calibration in the EW. In particular, there is a need to update the bathymetry in the vicinity of the shallow water Sill Reach and the Junction Reach of the EW with the LDW, and include the slips. The updated model will be used to evaluate the hydrodynamics and erosion potential (by determining shear stresses) within the EW to help validate the EW CSM. Also, the split of LDW flow and suspended sediment between the EW and WW will be estimated using the updated hydrodynamic model.

The updated hydrodynamic model will be run in a consistent method with the Sediment Transport Analyses (STA) of the LDW model, in that high-flow events (such as 2- and 100-year events in the Green River and LDW) will be examined for the EW. The hydrodynamic model data will be used to analyze the erosion potential in the EW for these events. Based on existing information for the EW, we anticipated that the erosion potential in the EW will be low, such that simplified methods for sediment transport analysis can be used[3].

[2] The approach initially assumes that hydrodynamic modeling analyses of erosion potential will not indicate that significant resuspension will occur under the most extreme tidal exchange or flooding conditions in the Green River and Duwamish Waterway.

[3] If the erosion potential is significant, then more detailed methods of sediment transport analysis may be needed. This will be evaluated following the hydrodynamic analyses.

The updated hydrodynamic model will also be used to confirm the natural physical processes CSM directly for hydrodynamics and indirectly for sediment transport. The direct confirmation of hydrodynamics will be based on velocity, salinity, and depth output from the model. The indirect confirmation for sediment transport will be based on erosion potential of the EW sediment bed and other indirect indicators of sediment transport processes.

Evaluation of sediment transport from the LDW will primarily rely on empirical calculations. The LDW sediment transport model will be utilized only to provide boundary conditions to the EW (i.e., TSS concentrations in the LDW upstream of the Junction Reach) for the empirical calculations, and will not be employed directly to predict sediment transport within the EW[4]. Sediment transport from lateral sources will be evaluated using localized stand-alone models (e.g., CORMIX or PTM) and empirical calculations. Final determination of the sediment transport evaluation approach is subject to EPA approval. It is currently assumed that the LDW will be used to provide boundary conditions. This approach will be evaluated pending recalibration of the model.

Following refinement and validation of the CSM for the EW, an empirical sediment transport evaluation will be conducted to assess MNR potential and sediment recontamination potential. This evaluation will incorporate sediment loadings from the LDW model, results from the updated hydrodynamic model, and geochronological cores to estimate net sedimentation from undisturbed areas in the main body of the EW. This information will be used to estimate residence time and trapping efficiency of the EW and the contribution to the EW from lateral loading sources. A preliminary outline of the STA approach steps is summarized below:

1. Collect bathymetry for the EW within the existing LDW hydrodynamic model in the vicinity of the sill
2. Calibrate the updated LDW hydrodynamic model with site-specific velocity and salinity profile data (to be collected in the fall of 2008). Specific attention will be paid to calibration of bottom velocities.
3. Collect and analyze geochronological cores (fall of 2008)

[4] The existing sediment transport model of the LDW uses a hard bottom in the EW. Detailed calibration would be needed if sediment transport modeling analyses are to be conducted.

4. Run the updated hydrodynamic model consistently with the STA approach used in the LDW
5. Use results from the EW hydrodynamic model to:
   a. Determine erosion potential (i.e., shear stresses) within the EW
   b. Determine need for Sedflume cores
   c. Validate, and refine as necessary, the CSM for the EW
   d. Estimate inflows (including the flow split) from LDW and the residence time of EW
   e. Compare results of the EW hydrodynamic model with the existing LDW model to ensure that they do not differ fundamentally from each other.
6. Utilize data provided from erosion potential and from geochronological cores to determine potential depositional areas and net deposition rates within the EW (where propwash is not a significant factor). Erosion areas will also be identified using these data. The recalibrated hydrodynamic model will be used to confirm/refine the CSM. Based on that initial analysis, the methodology for determining loads from the LDW will be determined.
7. Apply results from the existing LDW sediment transport model to provide estimates of sediment loading input to the EW from the LDW
8. Use a "box model" approach to evaluate:
   a. Mass balance of sediment load from LDW and lateral loads to the EW; sediment loading from LDW to the EW comes from
      - LDW sediment load upstream of the Junction Reach
      - Newly estimated flow split to the Junction Reach from the updated hydrodynamic model
   b. Trapping efficiency of the EW
9. Use a Lagrangian particle tracking model (such as PTM) or a localized plume model (such as CORMIX) to estimate the contribution to and distribution of lateral sediment loads to the EW

The final selected approach will include coordination with EPA throughout the process. Key milestones requiring EPA input include recalibration of the hydrodynamic model, determination of need for Sedflume cores, and selection of particle tracking or localized plume models.

Data needs for this evaluation include bathymetry, short-term synoptic velocity, salinity, and water level measurements, and geochronological cores within the EW.

## 3.5 Data Gaps Evaluation for Preferred Approach

The preferred approach for evaluating sediment transport natural processes must be supported by information describing the physical processes in the EW. The existing information has been identified in the EISR (Anchor and Windward 2008a) and briefly discussed in Section 2 of this Memorandum.

As identified in the Physical Processes CSM (Anchor, Windward and Battelle 2008), there are three reaches of the EW: the Junction Reach, the Sill Reach, and the Main Body Reach. Each of these is subject to different hydrodynamic conditions under the varying tidal and flow regimes of Elliott Bay and the Green River, respectively. Additional information on the hydrodynamic and sediment transport processes in each reach will help to refine the Physical Processes CSM for the EW. The following subsections review the adequacy of the existing information for the preferred approach and identify data needs that should be filled with additional field investigations in the EW. In general, the data is needed to support the calibration of the hydrodynamic model of the EW and the estimation of erosion potential of the sediment bed. In addition, lateral flows and sediment loads are needed to evaluate recontamination potential from those sources.

### *3.5.1 Review of Existing Information for Natural Processes Preferred Approach*

The data presented in the EISR (Anchor and Windward 2008a) and reviewed in Section 2 of this Memorandum are summarized in Table 3-3. The data are useful for hydrodynamic and sediment transport analysis and will be incorporated into the preferred approach, as appropriate.

The hydrodynamic data include a velocity profile at one location in the Junction Reach and a point velocity time series at two locations within the Main Body Reach. The point velocity data have been identified in the EISR (Anchor and Windward 2008a), and summaries of these data have been reviewed. However, the raw data have not been located and may not be available for further analysis. The existing hydrodynamic data also include tidal data from the Seattle waterfront and flow data from the Green River. The existing sediment transport data include gross and net sedimentation rates estimated from sediment traps and radioisotope measurements from high-resolution sediment cores in the Main Body Reach of the EW.

**Table 3-3**
**Available Data for Natural Processes Preferred Approach**

| Data | Source | Location | Description | Period | Data Available? | Useable for STE Development? |
|---|---|---|---|---|---|---|
| **Hydrodynamics** | | | | | | |
| Velocity Profiles | King County WQA Analysis (King County 1999) | Junction Reach of the EW | High-frequency ADP measurements | March through August 1997 | Yes | Yes |
| Point Velocity | Harbor Island RI (HISWG 1996) | Near North and South Ends of the Main Body Reach of the EW | High-frequency S4 velocity measurements 1 meter off the bottom | March through May 1995 | Not yet located * | Yes, but not reviewed * |
| Tidal Elevations | NOAA (Station ID 9447130) | Seattle Waterfront | High-frequency water surface elevation measurements | Continuous | Yes | Yes |
| River Flows | USGS (Station 1213000) | Green River at Auburn | 15-minute to daily interval flow measurements | Continuous | Yes | Yes |
| **Sediment Transport** | | | | | | |
| Sediment Trap | Harbor Island RI (HISWG 1996) | Near North and South Ends of the Main Body Reach of the EW | Used for gross sedimentation rate estimation 1 meter off the bottom | Round 1: March through May 1995 Round 2: May through August 1995 | Yes | Yes |
| Radioisotope Analyses from High-resolution Sediment Cores | Harbor Island RI (HISWG 1996) | Near North and South Ends of the Main Body Reach of the EW | Used for net sedimentation rate estimation | Accumulation from 1950 | Yes | Yes |

* – Raw data have not been located. Summary data have been reviewed.
ADP – Acoustic Doppler Profilers with Sontek current meters
EW – East Waterway
NOAA – National Oceanic and Atmospheric Administration
RI – Remedial Investigation
STE – Sediment Transport Evaluation
USGS – U.S. Geological Survey
WQA – Water Quality Assessment

It is expected that the hydrodynamics and sediment transport characteristics will differ between the three distinct EW reaches (i.e., the Junction Reach, the Sill Reach, and the Main Body Reach). The existing information does not include full coverage of each of the reaches. Also, for the hydrodynamic characterization, it is important to note that no salinity profiles are available within the EW. While the existing information from the EISR (Anchor and Windward 2008a) was used to develop the Physical Processes CSM in the CSM and Data Gaps Analysis Report (Anchor, Windward and Battelle 2008), additional data are needed to support the implementation of the preferred approach.

### 3.5.2 Data Needs Identification

#### 3.5.2.1 Hydrodynamic Characterization

Table 3-4 presents the data needs for the hydrodynamic characterization and model calibration of the EW for the preferred approach for natural processes. Data needs include detailed bathymetry, velocity, and salinity profiles from each reach. Because bathymetry data from the Sill and Junction Reaches are limited, detailed bathymetric data in those reaches is a required component to accurately estimate flows into and through the EW.

A velocity profile in the Junction Reach was measured in 1997, but it is not accompanied by salinity profile data to confirm the estuarine conditions. Hydrodynamic data in the other reaches are not available. Additional velocity profiles should be measured synoptically in each reach to evaluate how hydrodynamic characteristics change from reach to reach under the same tidal and Green River flow forcing.

**Table 3-4**
**Summary of Data Needs for Natural Processes Preferred Approach**

| Data Type | Purpose | Data Need Explanation | Additional Sampling Required and General Description |
|---|---|---|---|
| **Hydrodynamics** | | | |
| EW Bathymetry | Bathymetry influences the flow split from the LDW between the EW and WW. | Bathymetry data are available for the Main Body Reach (Anchor and Windward 2008a) but not for the Sill and Junction Reaches. The data are critical to correctly computing the flow from the LDW. | Yes, at the Sill and Junction Reaches of the EW and at Slip 36. |
| EW Lateral Load – Time-series of Flow | Discharge flows from the CSOs and storm drains are needed for estimating contribution from lateral solids loads. | No flow data or very limited flow data from CSOs and storm drains. | Flows are to be estimated as part of the Initial Source Screening and Data Gaps Memorandum. |
| Salinity Profiles | The data will be used for model validation in the EW. The estuarine conditions are expected to produce stratified flow under varying tides and river flows. | Salinity profile data for the EW are not available. | Yes, at two stations in the Main Body Reach, one station in the Sill Reach, and one station in the Junction Reach. Sampling will attempt to fit existing schedule. |
| Velocity Profiles | The data will be used for model validation in the EW. The estuarine conditions are expected to produce stratified flow under varying tides and river flows. The net southerly velocity in the bottom layers needs to be verified and the net velocity in middle and upper layers needs to be determined. | Velocity profile data for the Main Body and Junction Reaches of the EW are not available. Data from the WQA (King County 1999) are available, but they are for 1996-1997 with only one station in the Junction Reach. Bottom velocity data in the Main Body Reach from the Harbor Island RI (HISWG 1996) have not yet been located. | Yes, at two stations in the Main Body Reach and one station each in the Sill Reach, Junction Reach, and WW. Will be deployed for 1 month. |
| **Sediment Transport** | | | |
| EW Lateral Solids Load – Solids Concentration Time-series | Solids loads from the CSOs and storm drains are needed for estimating contribution from lateral solids loads. | No flow data or very limited flow data from CSOs and storm drains. | Solids loads are to be estimated as part of the Initial Source Screening and Data Gaps Memorandum. |
| Net Sedimentation Rate (e.g., radioisotope profiles) | Used to estimate the accumulation of sediment in the bed. Note that sediment cores must be collected in areas that have not been disturbed by dredging. | Gross sediment rates have been estimated at two stations in the Main Body Reach of the EW at the same locations where net sedimentation rates have been estimated. Results indicate that gross sediment rates are higher in the southern end of the Main Body Reach. This may need to be confirmed. Also, additional stations are needed for the Sill and Junction Reaches. | Additional profiles from the EW, including the Sill, Junction, and Main Body Reaches, depending on the ability to collect undisturbed sediment cores. |
| Sedflume Erosion Rates and Shear Strength Profiles | Used to specify the characteristics of the sediment bed pertaining to sediment resuspension. The Sedflume method measures erosion rates and shear strengths throughout the sediment profile and these are used as inputs to a sediment transport model. In combination with the net sedimentation rate data and fluid stresses generated by the hydrodynamic model, the resuspension rate can be estimated. The sum of the net sedimentation rate and resuspension rate is the gross sedimentation rate. | No characterization of sediment shear strength or erosion rates has been done within the EW. These will be needed for estimation of the erosion potential. | The need and extent of Sedflume data will be determined through discussions with EPA. |

CSO – combined sewer overflow
EPA – U.S. Environmental Protection Agency
EW – East Waterway
LDW – Lower Duwamish Waterway
RI – Remedial Investigation
WQA – Water Quality Assessment
WW – West Waterway

#### 3.5.2.2 Sediment Transport Characterization

Table 3-4 also presents the data needs for sediment transport evaluation. For the preferred approach, net sedimentation rate and estimates of bottom shear stress and sediment shear strength are needed in each reach. The analysis of erosion potential needs an estimate of the sediment shear strength for comparison to estimated bed shear stress from hydrodynamic action. This is typically accomplished by the use of Sedflume measurements of sediment cores. The Sedflume data include measurements of erosion rate and shear strength in the sediment profile. Sedflume data has been collected for the LDW and may be utilized for the EW depending upon results of the hydrodynamic analysis, evaluation of the geochronological cores, and additional sediment characteristics for the EW. Sedflume data may be collected specifically for the EW following discussions with EPA. The net sedimentation rate data are used in combination with the sediment loading data and the defined erosion/deposition potential areas to estimate the sediment trapping efficiency of the EW.

High-resolution sediment cores have also been collected in the Main Body Reach of the EW in 1997 for estimation of net sedimentation rates using radioisotope analyses. Collection and radioisotope analyses of additional sediment cores within all three reaches of the EW (Junction, Sill, and Main Body) are included in the preferred STE approach. The core locations will focus on areas that have not been dredged recently (from approximately 1964 through the present). Existing and available dredging records and existing sediment core data will be utilized to assist with determination of proposed core locations. However, because of the high degree of dredging in the Main Body Reach, it may be difficult to find undisturbed locations within the reach.

As shown in Table 3-4, analysis of flows and solids concentrations in lateral solids loads (e.g., storm drains and CSOs) are being proposed as part of the Initial Source Screening and Data Gaps Memorandum (per the SCEAM process). When those data are available, they will be incorporated into the STE.

## 3.6 Sediment Transport from Vessel-induced Hydrodynamic Effects Modeling Approach

Vessel-induced hydrodynamic effects (i.e., propwash, pressure fields, and vessel wakes) are the second main component of the STE for the EW. Understanding these effects through physics-based modeling and analysis is important to meet several of the objectives of the STE, as listed below:

- Identify temporal and spatial patterns of sediment erosion and deposition (if applicable)
- Identify the physical processes driving sediment transport
- Assess how sediment transport pathways may affect the feasibility of remedial alternatives
- Assess potential for physical processes to contribute to recontamination

The propwash, pressure field, and vessel wake modeling and analysis will be used to inform the STE and also to support initial screening of remedial alternatives for the EW as part of the FS. Evaluating vessel-induced hydrodynamic effects requires using specialized methods since there are limited previously tested and accepted methods to conduct these types of sediment transport evaluations. Each main hydrodynamic effect is discussed in more detail below, with a description of the proposed modeling approach for each to inform the STE.

### *3.6.1 Propwash Modeling*

Evaluating potential propwash effects on sediment stability and resuspension from berthing and navigation of a vessel is a complex exercise because vessel operations can occur at any location within the EW and at any tidal elevation and river flow condition. Therefore, a two-step tiered process (i.e., deterministic and probabilistic analysis) would be used to determine vessel-induced sediment resuspension and bottom scour.

The deterministic analysis is the first tier and will define the specific limiting factors, such as vessel type, maneuvering operations, and water depth that could induce sediment resuspension and scour. The need for probabilistic analysis is dependent on the evaluation of FS remedial alternatives and an assessment of the results of the deterministic analysis. If the EWG and EPA determine there is a need to conduct probabilistic analysis, it will be based on Monte Carlo simulations that incorporate statistical parameters for such items as vessel location-based berthing schedules at each terminal in the EW, duration of vessel operations, tide elevations, and other key parameters. The results of the modeling and analysis will provide spatial displays of the EW showing probability of sediment resuspension, scour locations, and scour depth.

The standard approach to modeling potential propwash impacts consists of using 1-dimensional (1-D) or 2-dimensional (2-D) steady-state physics-based models developed by Albertson et al. (1948) and further modified by Blaauw and van de Kaa (1978), Verhey (1983), Fuerher et al. (1987), Maynord (2000), Shepsis et al. (2000), and others. These models are based on semi-empirical formation of the velocity field generated by jets discharging as it expands into a volume of water. However, the fluid structure simulated with 1- or 2-D models does not describe the complexity and spatial variability of propwash flow and interaction of the flow field with the sediment bed. In order to better simulate the propwash complexity, EWG proposes to use both 2-D and 3-dimensional (3-D) models to assess potential propwash impacts.

Hydrodynamic modeling for propwash is proposed to be conducted using the numerical models JETWASH and VH-PU. JETWASH is a 2-D steady-state numerical model that simulates propeller-generated velocity at 0.8 feet above the bottom surface elevation. The model is applicable to both flat and sloped bottom topography. The methodology used in the JETWASH model has been accepted by EPA Region 5, including the methods used to determine granular sediment mobility based on propeller-induced currents, regardless of duration of the current (Shaw and Anchor 2007).

The model selected will be based on the specific types of vessels, operational scenarios, and ambient environmental conditions. It is pointed out that the proposed propwash models have features not found with the model in Maynord (2000). For example, JETWASH and VH-PU can model propwash velocities over sloped bottoms, whereas the model in Maynord (2000) is limited to flat bottoms. Unlike the Maynord model, JETWASH and VH-PU can also model cycloidal propellers and propwash from nonhorizontal propeller shafts. The two proposed models allow flexibility for modeling any type of vessel and bottom topography.

The model VH-PU is a 3-D unsteady-state numerical model that simulates velocities generated by ship propellers (including turbulence intensity and length scale in a given domain of arbitrary bottom and coastal topography). The JETWASH and VH-PU numerical models have been validated with data from numerous field studies and have been successfully used for various projects in Puget Sound, other regions of the U.S., and overseas. Table 3-5 shows the data required for each existing and future vessel used for propwash analysis.

**Table 3-5**
**Vessel and Propulsion Data Requirements for Main Propulsion and Thrusters**

| Key Model Parameters |
|---|
| Vessel Name |
| Length Overall |
| Beam |
| Draft (loaded) |
| Number of Propellers |
| Distance from Waterline to Center of Propeller |
| Propeller Diameter |
| Distance Between Propellers (if twin screw vessel) |
| Ducted or Open Propeller? |
| Variable Pitch or Fixed Propeller? |
| Propeller Revolutions per minute for:<br>1. Maneuvering in East Waterway<br>2. Docking<br>3. Undocking |
| Propeller Engine Power (horsepower or kilowatts) Delivered to Propeller for:<br>1. Maneuvering in East Waterway<br>2. Docking<br>3. Undocking |
| Thrust per Propeller for:<br>1. Maneuvering in East Waterway<br>2. Docking<br>3. Undocking |
| Depth Below Propeller Centerline at Design Tide Level |
| Propeller Shaft Angle Relative to Horizontal Plane |

Propwash modeling will include simulation of current velocities generated by the propellers of representative ships and tugboats, and estimates of these velocities along the bottom and slopes of the EW. The results of propwash modeling will be used as input parameters for sediment stability modeling to determine potential sediment depth of scour, resuspension, and transport. The sediment stability model is based on a standard approach using equations of fluid dynamics that considers two criteria for initiation of sediment movement: flow velocity threshold and flow duration. The sediment stability model has been developed specifically for the analysis of stability of capping material for contaminated sediment and has been accepted by EPA Region 5, the U.S. Army Corps of Engineers (USACE), and local and state agencies (Shaw and Anchor 2007).

Input parameters for the modeling would consist of two dataset types: deterministic and random. The deterministic dataset includes, but is not limited to, waterway bathymetry, dimensions, and technical characteristics of propulsion systems for all vessels (hereinafter referred to as "impact vessels") considered in propwash, bottom sediment, and tide elevation. (Please note that for propwash modeling, tide elevation is considered a deterministic input factor. In other types of modeling, tide elevation would be considered as a random input parameter). The random dataset would only be used if the deterministic analysis indicated the need to conduct further probabilistic analysis (per discussion with EWG and EPA) and includes, but is not limit to, occurrence of a specific impact vessel, vessel position in the EW, vessel speed, and operating characteristics of the propulsion system relative to the rated characteristics (for example, applied shaft power relative to the rated power). Random input parameters would be statistically estimated and assigned with certain statistical distributions to be used further in the probabilistic Monte Carlo simulations.

Data needs for propwash modeling will include the input parameters identified in Table 3-5. All of the data needs from Table 3-5 are typically obtainable from vessel manufacturers, interviews with pilots, and marine facility operations managers. For the needs of the SRI/FS, site- and vessel-specific calibration field data are not anticipated to be necessary in order for this modeling approach to meet the STE objectives.

### 3.6.2 Pressure Field Modeling

Because of the typically slow operating speeds of vessels within the EW, the EWG anticipates that pressure field impacts to sediment transport processes will be negligible.

To verify this expectation, pressure field analysis will be conducted in two tiers. The first tier involves analyzing deep-draft vessel operational conditions in the EW. The first tier of analysis will assess the potential for vessels using the EW to generate significant pressure field effects in the EW. It is possible (and likely) that vessel speeds are insufficient to create pressure fields that induce hydrodynamic effects sufficient to resuspend and transport sediment. However, if the first tier review results in determining that there is indeed potential for significant impacts, the second tier of the study (detailed hydrodynamic modeling and analysis of pressure field effects) will be initiated.

If necessary, second-tier modeling involves conducting hydrodynamic modeling of pressure field effects using the 3-D model VH-LU. The VH-LU model simulates water surface elevations and velocities in the modeling domain during passage of a vessel through a channel. Results of pressure field modeling, wave parameters, and bore velocities may then be used as input parameters for sediment stability analysis.

Input parameters for the modeling include, but are not limited to, waterway bathymetry, tonnage of vessels, vessel speed, vessel relative position, bottom sediment characteristics, and tidal elevation. Data needs for pressure field analysis are typically obtainable from vessel manufacturers, interviews with pilots, waterway speed restrictions, and marine facility operations managers. For the needs of the SRI/FS, site- and vessel-specific calibration field data are not anticipated to be necessary in order for this modeling approach to meet the STE objectives.

### 3.6.3 Vessel Wake Modeling

Because of the typically slow operating speeds of vessels within the EW, the EWG anticipates that vessel wake impacts to sediment resuspension and transport processes will be negligible. To verify this expectation, a vessel wake sediment resuspension analysis will be conducted using the 2-D model SHIPWAVE. This modeling approach can provide a simple analysis to assess the potential for resuspension of sediment from vessel-generated wakes within the EW. The SHIPWAVE model simulates propagation of near-field wakes generated by the vessel hull to the nearshore areas, and computes velocities and shear stresses on the bottom and slopes. The SHIPWAVE model has been successfully used for a number of projects in Puget Sound, San Francisco Bay, and other regions of the U.S. The results of the SHIPWAVE modeling will be reviewed to assess a vessel's potential to generate sufficient velocities (from waves) to resuspend sediment within the EW.

Major input parameters for the SHIPWAVE modeling include waterway bathymetry and near-field wake train parameters. Near-field wake train parameters represent water motion at the location of vessel wake formation in close proximity to the moving hull. Near-field wake train parameters may be obtained from existing databases (previous measurements or Computational Fluid Dynamics computations) or may be computed analytically using appropriate empirical/analytical procedures. For analytical computations, the following parameters may be required: tonnage of vessel, vessel speed, vessel relative position, bottom sediment characteristics, and tidal elevation. Data needs for vessel wake modeling are typically obtainable from vessel manufacturers, interviews with pilots, waterway speed restrictions, and marine facility operations managers. For the needs of the EW SRI/FS, site- and vessel-specific calibration field data are not anticipated to be necessary in order for this modeling approach to meet the STE objectives.

### 3.6.4 Monte Carlo Simulations

If evaluation of FS remedial alternatives and the magnitude and extent of propwash effects indicates a need to conduct additional probabilistic analysis (i.e., tier 2), then the Monte Carlo approach will be utilized. Input parameters and results from the propwash analysis will be used for Monte Carlo simulation to evaluate potential for scour throughout the EW. The EW would be divided into sectors based on waterway use and physical characteristics. These sectors may or may not be the same as the three reaches identified in this Memorandum (i.e., the Junction, Sill, and Main Body Reaches). Simulation would then be conducted for each sector of the waterway. The output of the Monte Carlo modeling would include probability of occurrences of resuspension (and/or scour) of bottom sediment at each of the EW sectors due to propwash. The probability of occurrence of scour depth will be determined. Also, the Monte Carlo simulation would help to assess the potential risk of using various remedial alternatives, including stability of potential capping at the channel bottom or sideslopes. An example of a

Monte Carlo simulation is shown in Figure 3-1. The figure shows the probability of stability of different sizes of capping material relative to propwash scour, based on simulations of 10,000 cases of input parameters.

# 4 NEXT STEPS AND FUTURE DELIVERABLES

This STEAM focuses on outlining various STE approaches and selecting a preferred approach to evaluate sediment transport physical processes within the EW, including sediment transport due to natural processes and vessel-induced hydrodynamic effects. The EWG has discussed the STE with EPA (and its technical experts from USACE) and EWG, and a consensus approach is presented in Section 3.4.

The EWG recognizes that the preferred approach presented in this Memorandum may need to be refined as we work with EPA to approve model selection and methodology, key modeling parameters, evaluation assumptions, and subsequent evaluation steps. It is important to note that the preferred approach does have risks associated with meeting the original Workplan schedule (Anchor and Windward 2007), primarily due to the potential need to re-calibrate the hydrodynamic model. However, EWG considers the preferred approach to be the approach that most closely meets the selection criteria (Section 3.4).

The STE results will be summarized in the Sediment Transport Evaluation Report, and the results will be used to help refine the Physical Processes CSM. Eventually, as part of the SRI Report, the sediment transport processes will be integrated with Source Control Evaluation work. The FS will assess sediment recontamination potential. Following EPA review and approval of the STEAM, the steps listed below are anticipated, as previously discussed in Section 1.3:

- Establish STE workgroup and develop detailed STE modeling methodology with workgroup input
- Develop field sampling program (i.e., QAPPs) to fill the data needs
- Conduct field sampling investigations after review and approval of the STE QAPPs by EPA
- Develop and run the STE models based on the approved STE modeling methodology
- Prepare Sediment Transport Evaluation Report
- Refine Physical Processes CSM in the SRI Report
- Integrate STE results with Source Control Evaluation results to assess recontamination potential in the FS Report

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# FIGURES

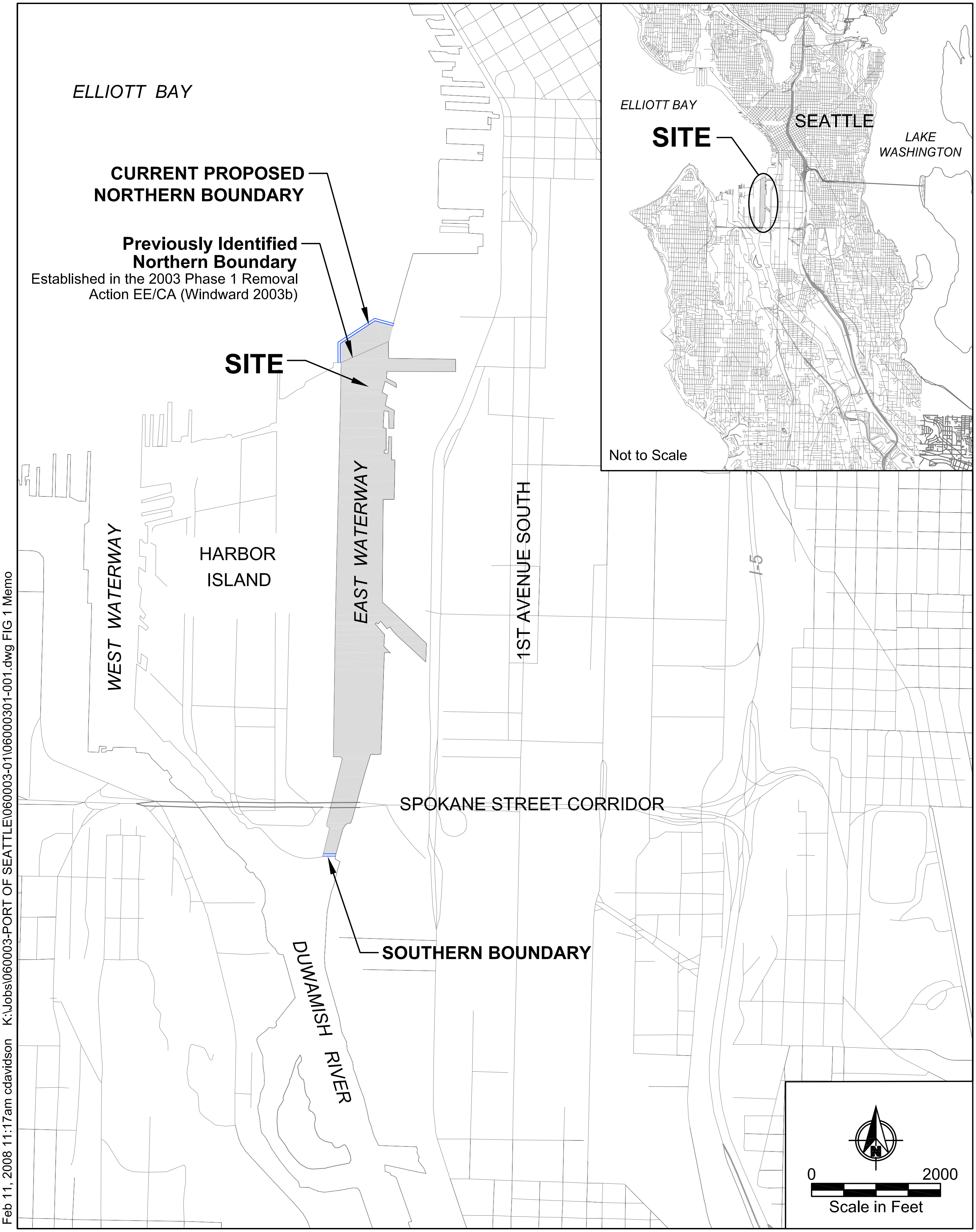


**Figure 1-1**
Vicinity Map and Proposed East Waterway SRI/FS Boundary
Sediment Transport Evaluation Approach Memorandum
East Waterway Operable Unit

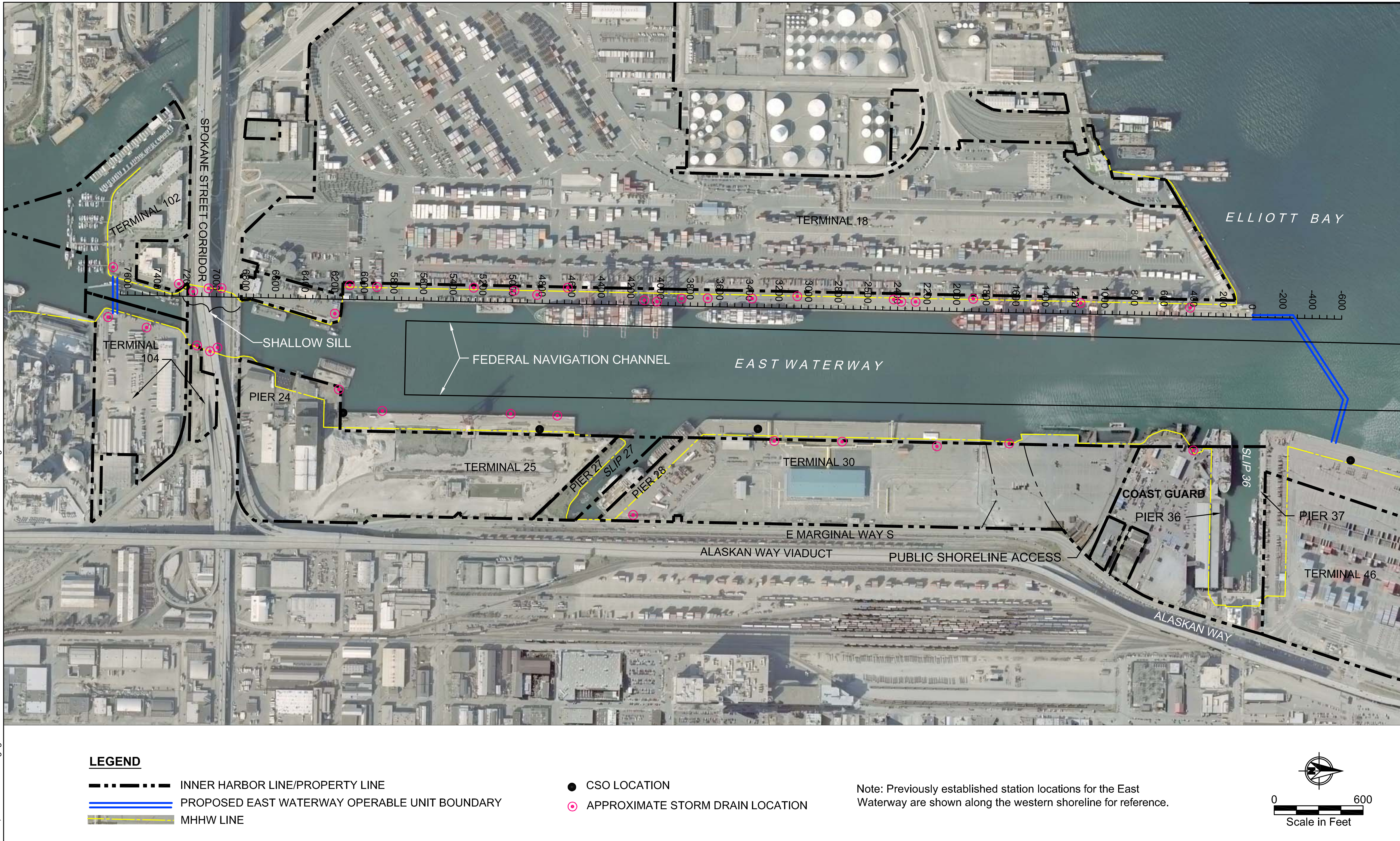


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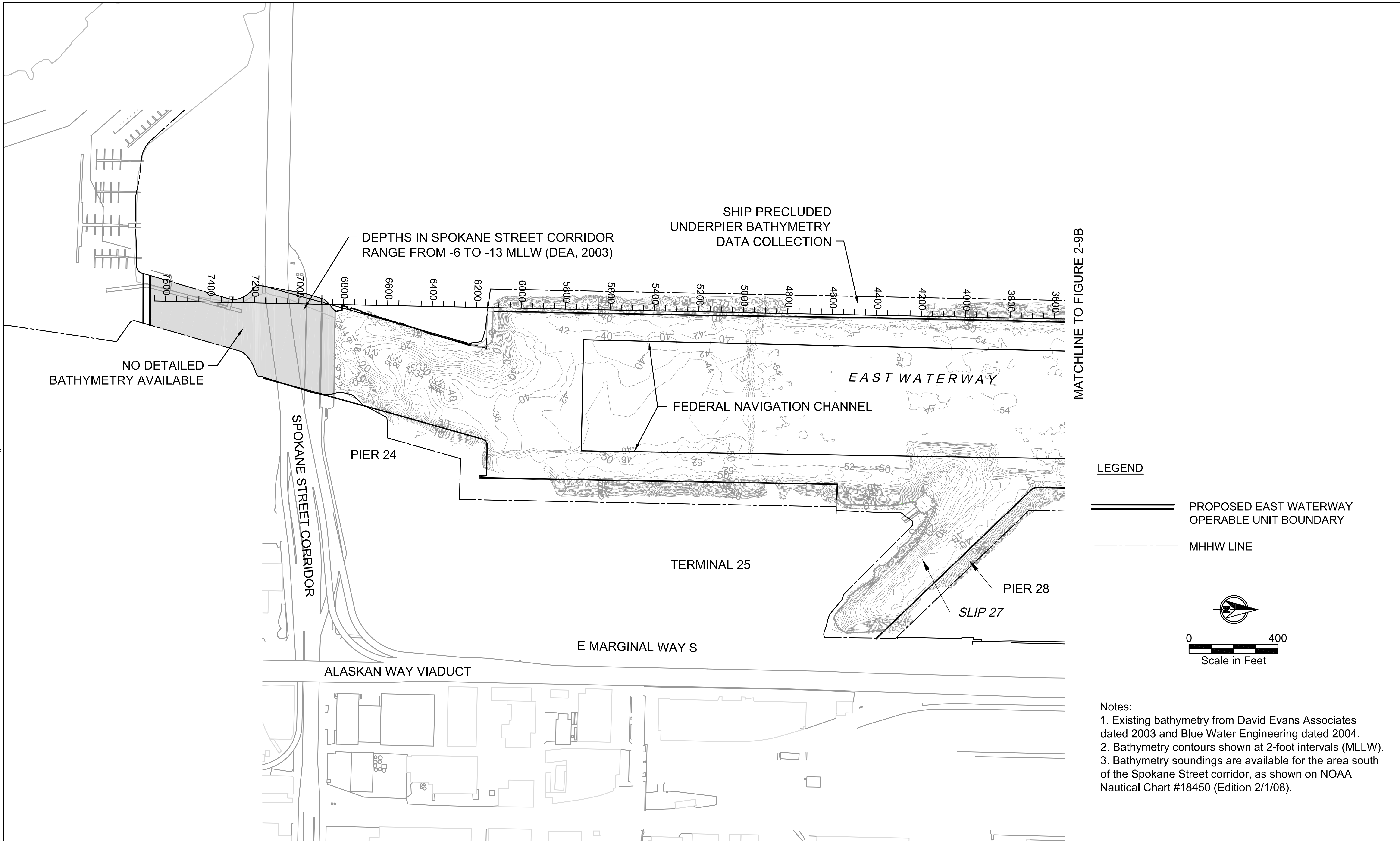
**Figure 1-2**

Major East Waterway Features

Sediment Transport Evaluation Approach Memorandum

East Waterway Operable Unit




Notes:
1. Existing bathymetry from David Evans Associates dated 2003 and Blue Water Engineering dated 2004.
2. Bathymetry contours shown at 2-foot intervals (MLLW).
3. Bathymetry soundings are available for the area south of the Spokane Street corridor, as shown on NOAA Nautical Chart #18450 (Edition 2/1/08).

Feb 26, 2008 12:23pm cdavidson K:\Jobs\060003-PORT OF SEATTLE\060003-01\06000301-018.dwg FIG1-3A Memo

**Figure 1-3A**
Existing Bathymetry
Sediment Transport Evaluation Approach Memorandum
East Waterway Operable Unit

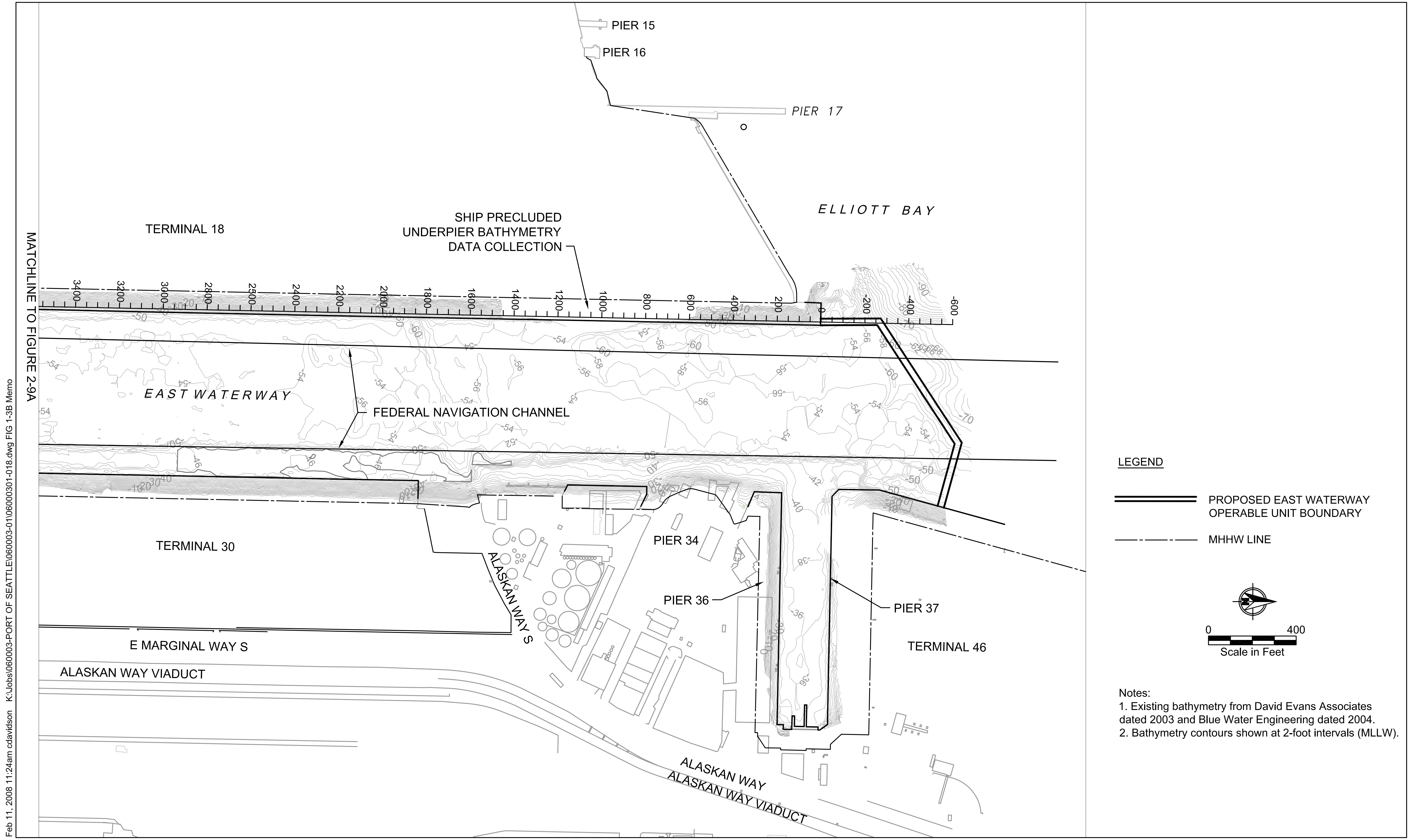



**Figure 1-3B**
Existing Bathymetry
Sediment Transport Evaluation Approach Memorandum
East Waterway Operable Unit

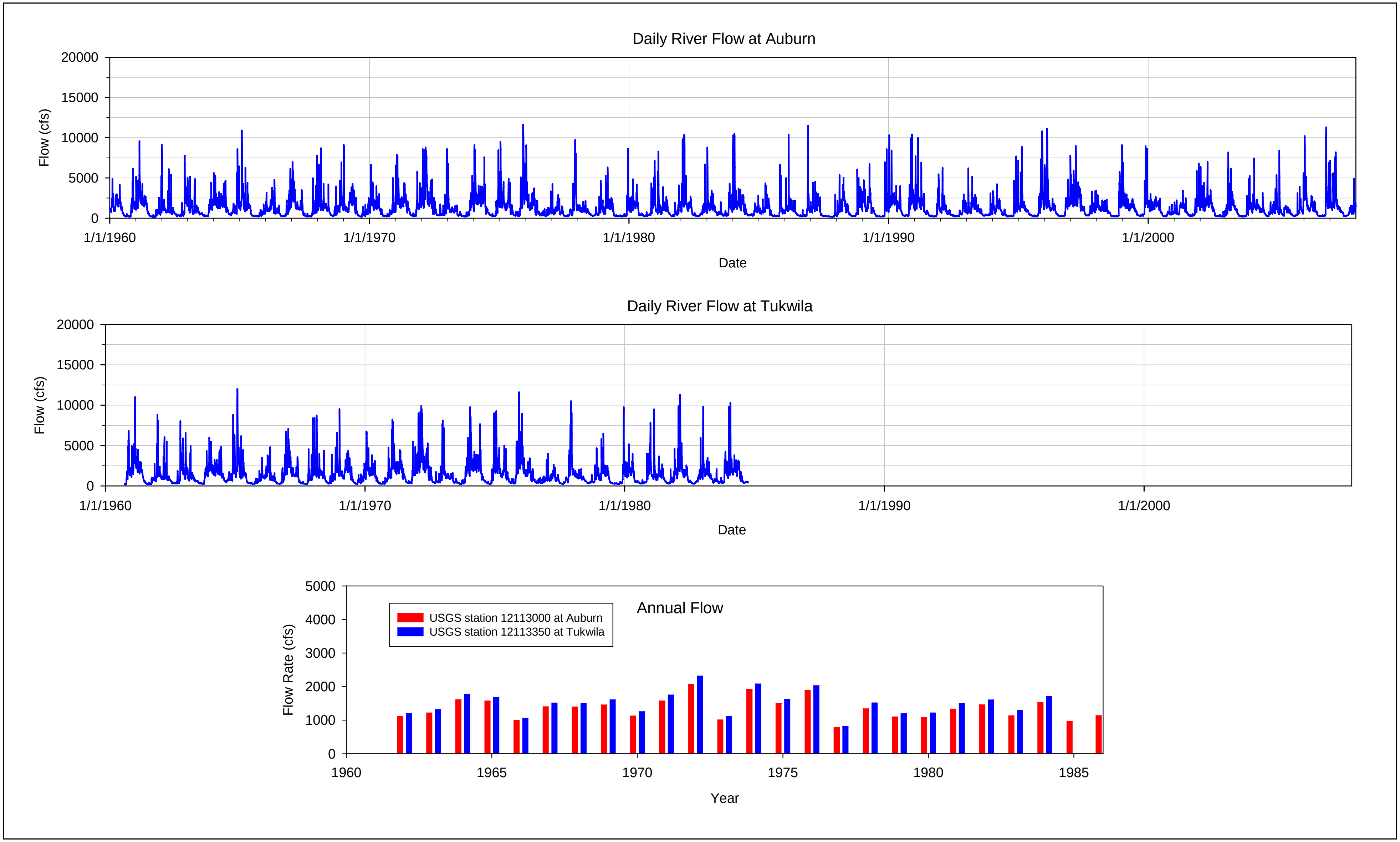



**Figure 2-1**
River Flow at USGS Auburn and Tukwila Gauge Stations
Sediment Transport Evaluation Approach Memorandum
East Waterway Operable Unit

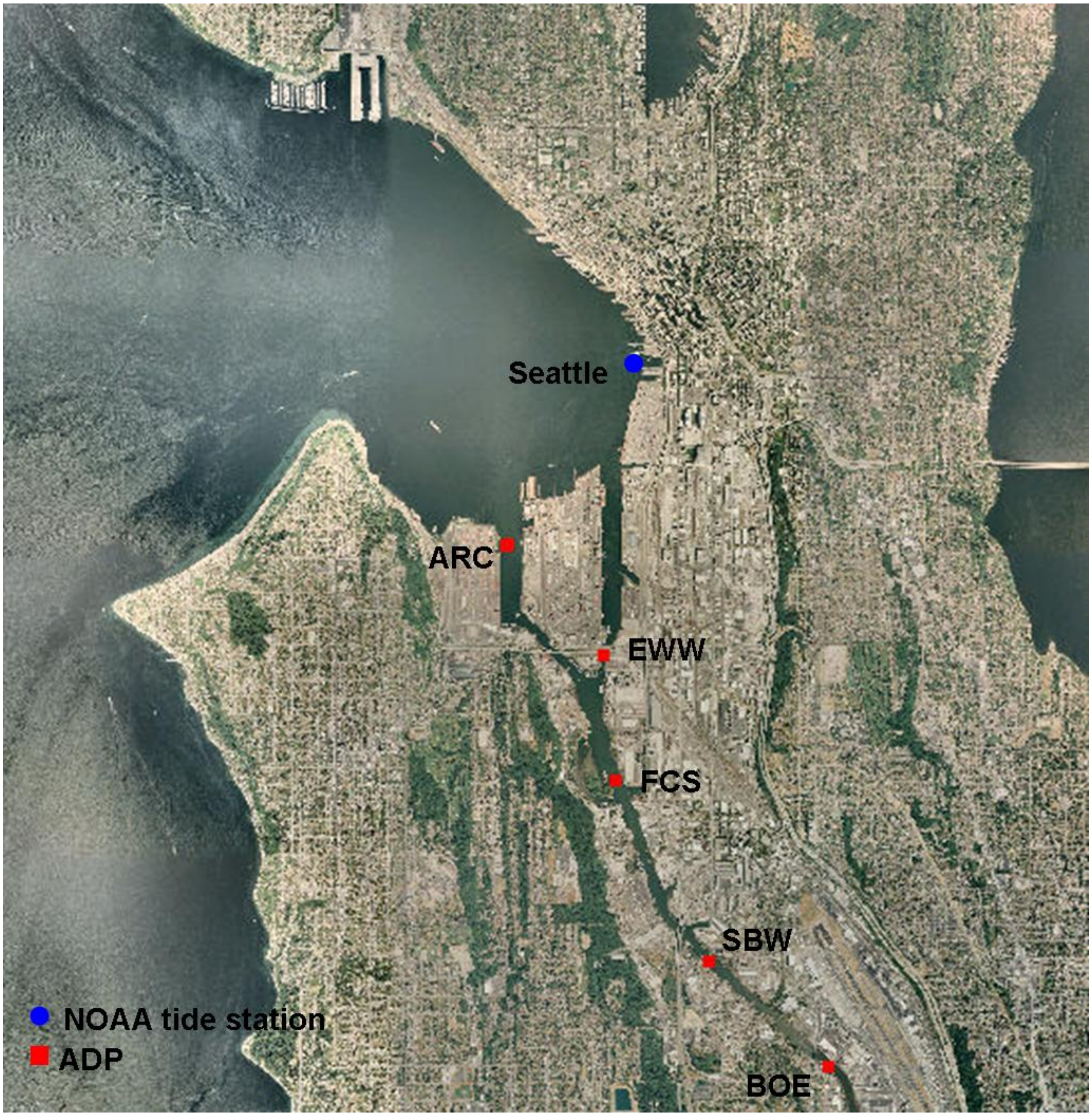



**Figure 2-2**
Velocity and NOAA Tide Measurement Stations
Sediment Transport Evaluation Approach Memorandum
East Waterway Operable Unit

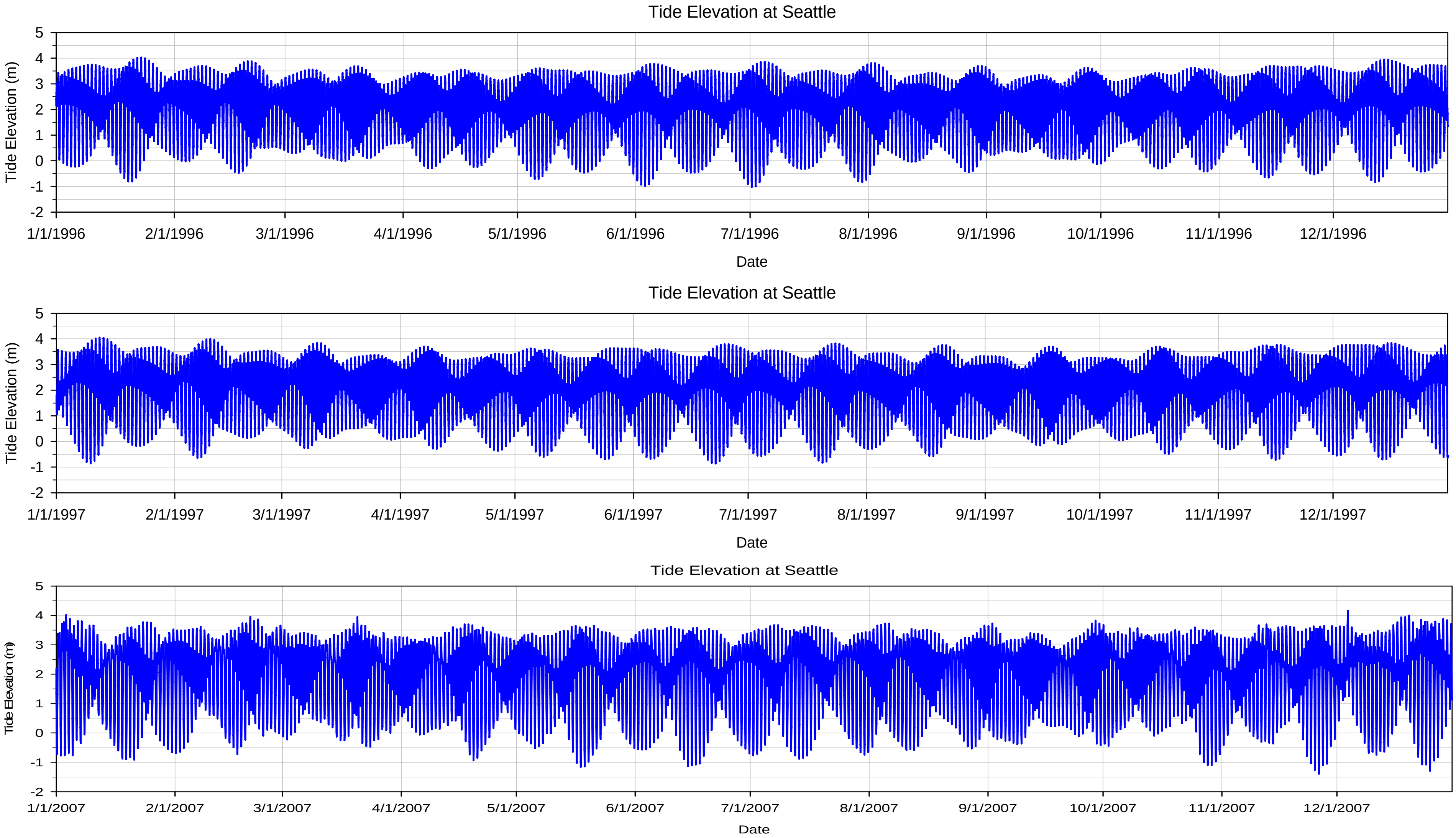
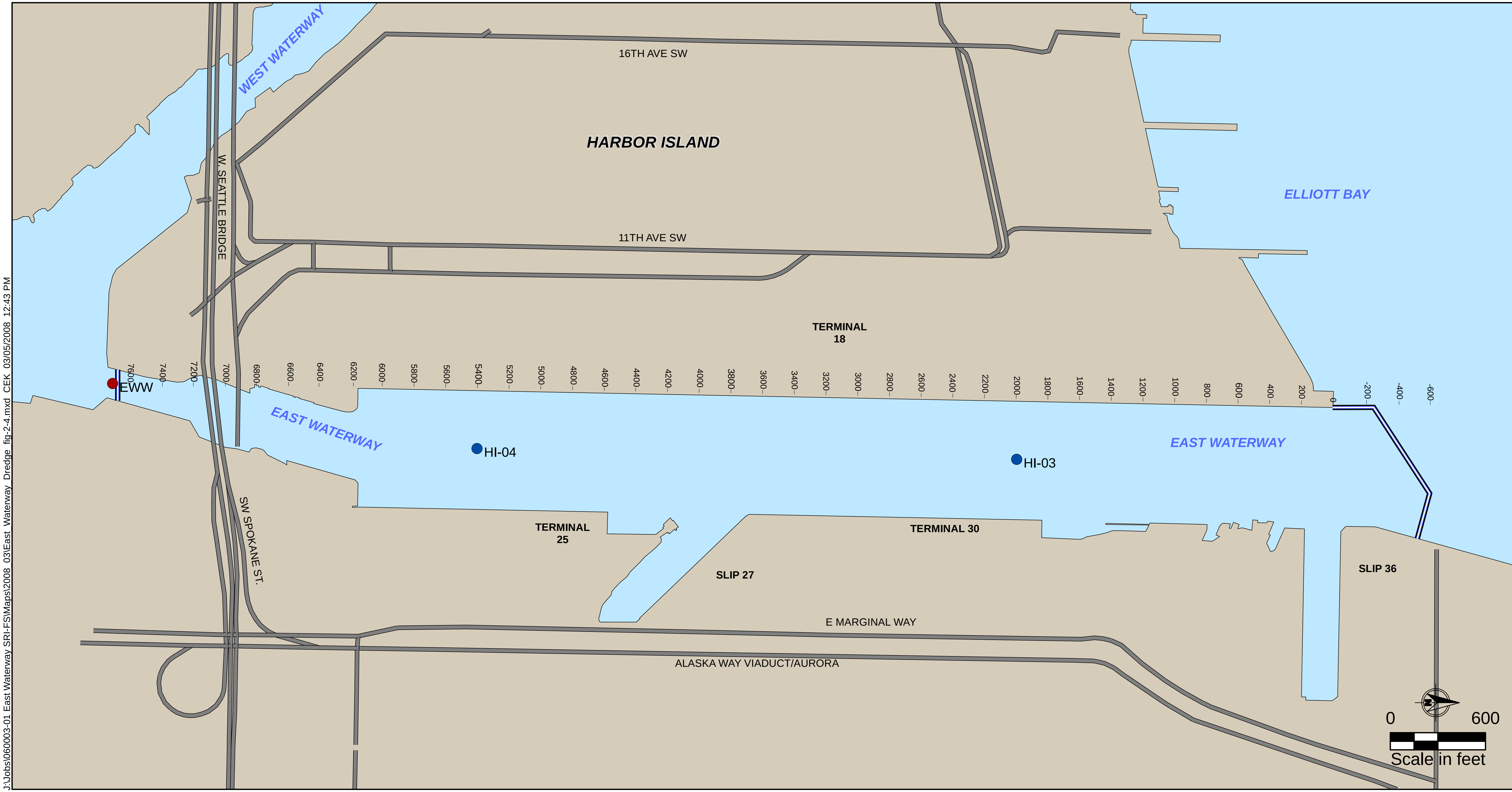



**Figure 2-3**
Tide Elevation During ADP Measurement Periods
Sediment Transport Evaluation Approach Memorandum
East Waterway Operable Unit

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- King County WQA velocity sampling location
- Sediment trap and near-bottom velocity sampling locations

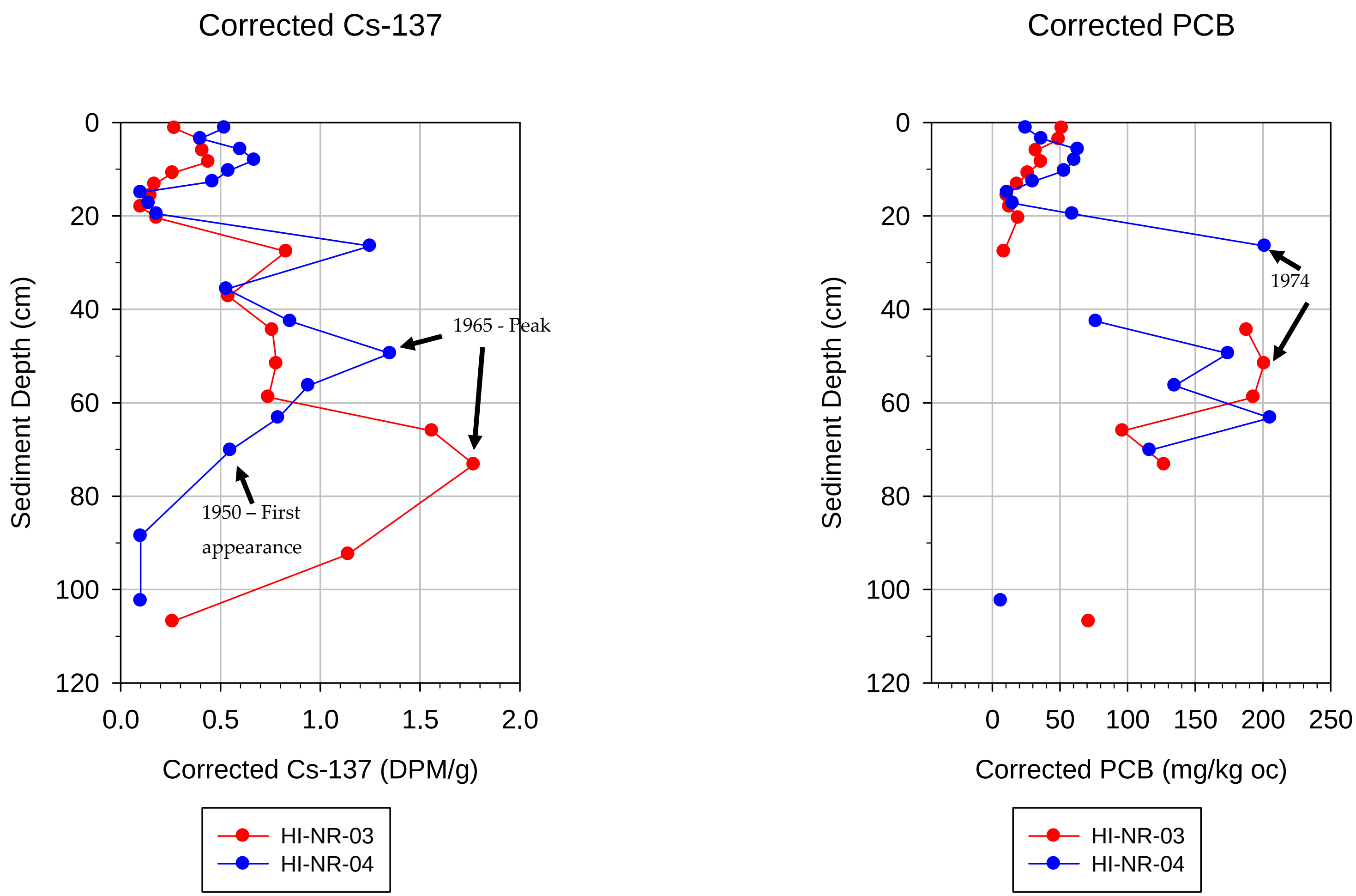
**Notes**

**1.** Previously established station locations for the East Waterway are shown along the western shoreline for reference.

**2.** Current meters and sediment trap deployed during Spring 1995.

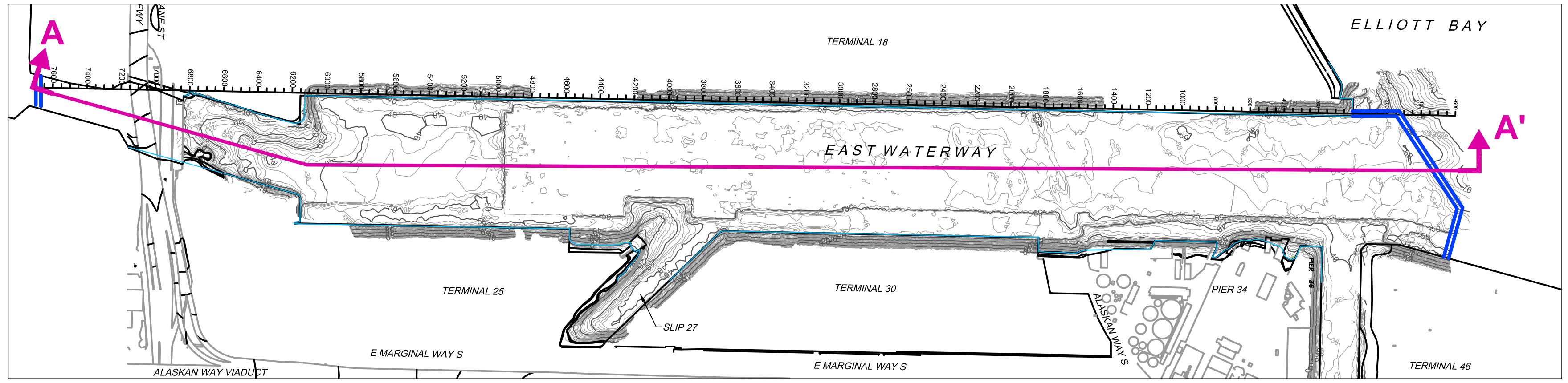
**3.** King county WQA velocity sampling conducted in 1996.

**Figure 2-4**
Near-Bottom Velocity and Sediment Trap Sampling Locations
Sediment Transport Evaluation Approach Memorandum
East Waterway Operable Unit




Note: The data are from HISWG (1996). Note that the dating of the Cesium-137 (Cs-137) profiles differs based on whether the first appearance of Cs-137 is used (1950) or the peak levels of Cs-137 are used (1965). The estimated sedimentation rates in HISWG (1996) were based on the averages of the estimates.

**Figure 2-5**
Cesium-137 and PCB Profiles from the East Waterway used for Dating and Estimation of Sedimentation Rates
Sediment Transport Evaluation Approach Memorandum
East Waterway Operable Unit



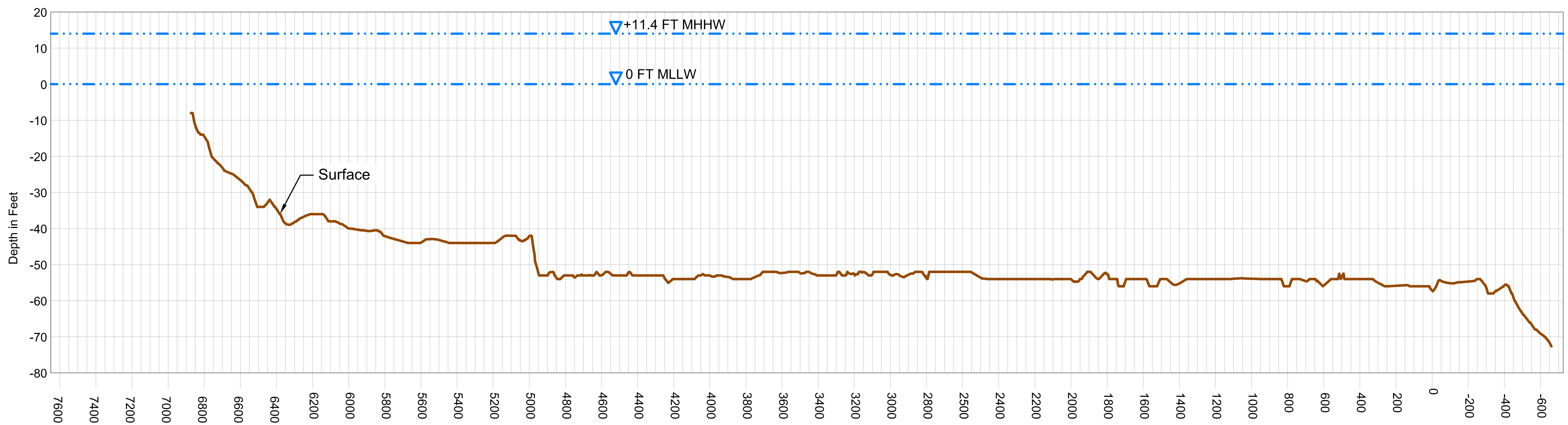

Legend

Proposed East Waterway Operable Unit Boundary

AA' Cross Section Location And Designation

0 1000
Scale in Feet

Notes:
1. Existing bathymetry from David Evans Associates dated 2003 and Blue Water Engineering dated 2004.
2. Contours shown at 2-foot intervals.

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ANCHOR ENVIRONMENTAL, L.L.C.

**Figure 2-6**
Mudline Elevation Profile along the Centerline of the East Waterway
Sediment Transport Evaluation Approach Memorandum
East Waterway Operable Unit

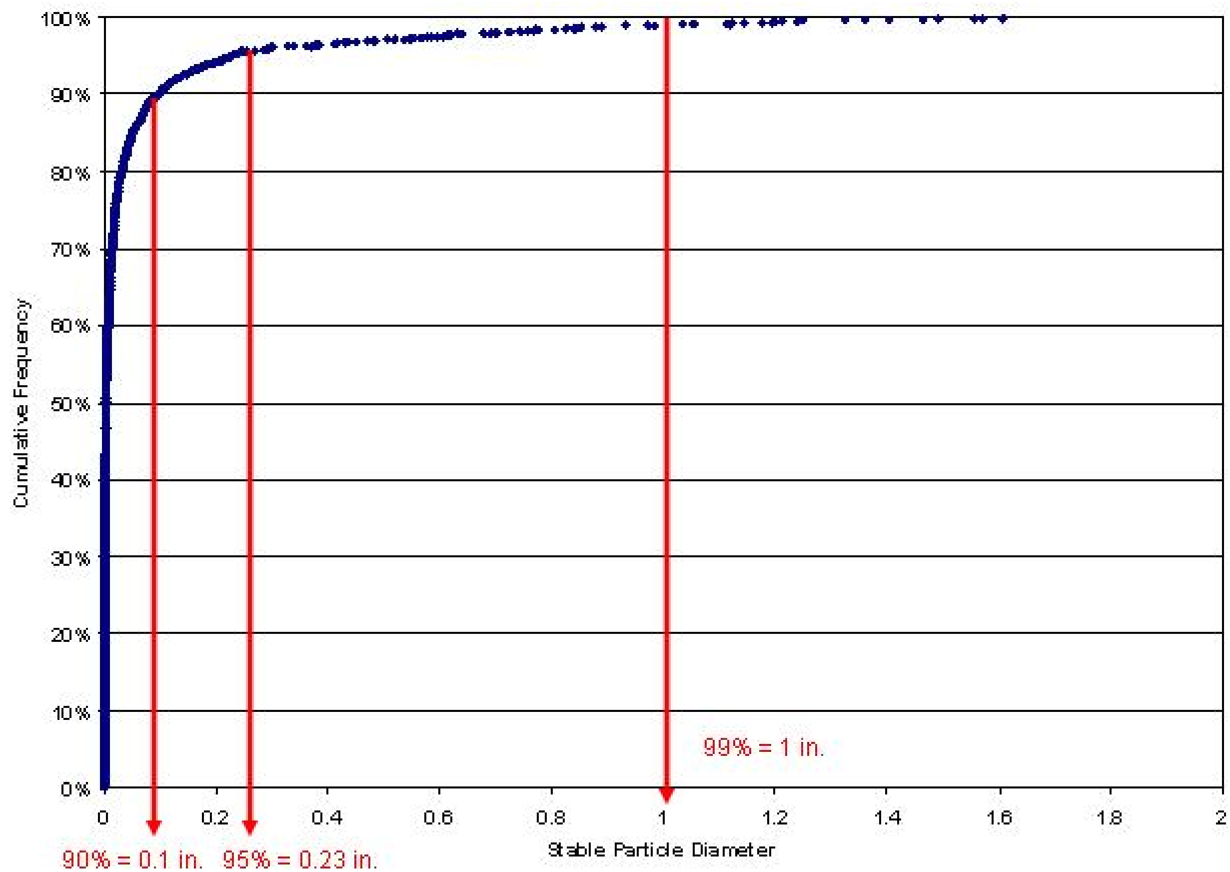


**Figure 3-1**
Probability of Stability of Capping Material Based on Monte Carlo Simulations
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