EAST WATERWAY OPERABLE UNIT

SUPPLEMENTAL REMEDIAL INVESTIGATION/ FEASIBILITY STUDY

FINAL SEDIMENT TRANSPORT EVALUATION REPORT

For submittal to

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Region 10
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LIST OF ACRONYMS AND ABBREVIATIONS

1-D	one-dimensional
2-D	two-dimensional
3-D	three-dimensional
ADCP	Acoustic Doppler Current Profiler
Anchor QEA	Anchor QEA, LLC
ASAOC	Administrative Settlement Agreement and Order on Consent
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
cfs	cubic feet per second
City	City of Seattle
cm	centimeter
cm/s	centimeters per second
cm/yr	centimeters per year
County	King County
Cs-137	cesium-137
CSM	Conceptual Site Model
CSO	combined sewer outfall
CTD	conductivity/temperature/depth
DWT	deadweight tonnage
EFDC	Environmental Fluid Dynamics Code
EHI	Evans Hamilton, Inc.
EISR	Existing Information Summary Report (Anchor and Windward 2008a)
ENR	enhanced natural recovery
EPA	U.S. Environmental Protection Agency
EW	East Waterway
EWG	East Waterway Group (Port of Seattle, City of Seattle, and King County)
FS	Feasibility Study
ft/s	feet per second
kg/s	kilograms per second
lb/ft^2	pounds per square foot
LDW	Lower Duwamish Waterway

m	meters
MHHW	mean higher high water
MLLW	mean lower low water
MNR	monitored natural recovery
MSL	mean sea level
NAD83	North American Datum of 1983
NAVD88	North American Vertical Datum of 1988
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
OU	Operable Unit
Pa	Pascals
Pb-210	lead-210
Port	Port of Seattle
psu	practical salinity unit
PTM	particle tracking model
QAPP	Quality Assurance Project Plan
RI	remedial investigation
RM	River Mile
RMS	root mean square
Rn-222	radon-222
ROD	Record of Decision
SCE	Source Control Evaluation
SCEAM	Source Control Evaluation Approach Memorandum (Anchor and Windward 2008b)
Sea Engineering	Sea Engineering, Inc.
SEDGM	Initial Source Evaluation and Data Gaps Memorandum (Anchor and Windward 2009)
SOW	Statement of Work
SPU	Seattle Public Utilities
SRI/FS	Supplemental Remedial Investigation/Feasibility Study
STAR	Sediment Transport Analysis Report (Windward and QEA 2008)
STE	Sediment Transport Evaluation
STER	Sediment Transport Evaluation Report

STEAM	Sediment Transport Evaluation Approach Memorandum (Anchor and Battelle 2008a)
STM Report	Lower Duwamish Waterway Sediment Transport Modeling Report (QEA 2008)
TEU	twenty-foot equivalent units
TSS	total suspended solids
U-238	uranium-238
U&A	Usual and Accustomed
USACE	U.S. Army Corps of Engineers
USCG	U.S. Coast Guard
USGS	U.S. Geological Survey
Workplan	SRI/FS Workplan (Anchor and Windward 2007)
WW	West Waterway

1 INTRODUCTION

The Sediment Transport Evaluation Report (STER) presents the data and modeling outcomes that will be used to characterize sediment transport dynamics within the East Waterway (EW). The EW is one of seven operable units (OU) of the Harbor Island Superfund site, which was added to the US Environmental Protection Agency's (EPA's) National Priorities List (NPL) in September 1983 under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as Superfund. As described in EPA's Superfund regulations (1988), EPA requires that a remedial investigation and feasibility study be conducted for each site listed on the NPL, and thus EPA has ordered the Port of Seattle (Port) to conduct a Supplemental Remedial Investigation/Feasibility Study (SRI/FS) for the EW OU. Under the oversight of EPA, the EW SRI/FS is being conducted by the East Waterway Group (EWG), which consists of the Port, the City of Seattle (City), and King County (County). The Port signed the Administrative Settlement Agreement and Order on Consent (ASAOC) with EPA in October 2006, and subsequently signed a Memorandum of Agreement with the City and County to conduct the SRI/FS. 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 STER is a required deliverable set forth in the SRI/FS Workplan (Workplan; Anchor and Windward 2007), prepared in response to the ASAOC and Statement of Work (SOW; EPA 2006).

1.1 Report Organization

This report is organized into eight main sections, as follows:

- Introduction and study objectives (Section 1)
- Description of data collection efforts (Section 2)
- Evaluation of net sedimentation rate in the EW (Section 3)
- Development, calibration, and results from the hydrodynamic model (Section 4)
- Propwash modeling and description of vessel operations in the EW (Section 5)
- Evaluation of erosion potential due to natural processes and vessel operations within the EW (Section 6)

- Evaluation of mass contribution from lateral sources in the EW, and Particle Tracking Model (PTM) (Section 7)
- Preliminary reassessment of Physical Processes Conceptual Site Model (CSM) (Section 8)

The main body of the report is supported by the following appendices:

- Appendix A – Bathymetry Data
- Appendix B – Velocity and Salinity Data
- Appendix C – Geochronological Core Data
- Appendix D – Sedflume Core Data
- Appendix E – Hydrodynamic Model Calibration
- Appendix F – Lateral Flow and Solids Data, PTM Model Input Data
- Appendix G – PTM Model Sensitivity Analysis

1.2 Sediment Transport Evaluation Objectives

The primary purpose of the Sediment Transport Evaluation (STE) is to develop datasets and complete modeling and analytical evaluations that will be used to characterize sediment transport dynamics and assess sediment stability within the EW. The information provided in the STER will be used to refine the preliminary Physical Processes CSM within the SRI Report; the preliminary Physical Processes CSM was presented in the CSM and Data Gaps Analysis Report (Anchor, Windward and Battelle 2008).

The Workplan (Anchor and Windward 2007) provides the guidelines and objectives for conducting the STE. As stated in the Workplan, the objectives of the STE are to address the following topics:

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 monitored natural recovery (MNR), enhanced natural recovery (ENR), dredging, and isolation capping
6. Assess potential for physical processes to contribute to recontamination

The STER will address STE objectives 1 through 4, while objectives 5 and 6 will be addressed in the SRI Report. Much of the information required to address objectives 5 and 6 is provided in the STER; however, interpretation of the data will occur in the SRI Report. The specific topics addressed in the STER include an outline of the methodology for the STE, descriptions of data collected as part of the STE, and results of proposed evaluations. The STER only describes the physical measurements and processes associated with transport of sediment and stability of the sediment bed. A preliminary verification of the Physical Processes CSM based on the information developed through the STE process is provided in Section 8 of this report. Updates to the preliminary Physical Processes CSM will be completed as part of the SRI.

The sediment transport evaluation was developed using information described in the Existing Information Summary Report (EISR; Anchor and Windward 2008a) and methodology outlined in the Sediment Transport Evaluation Approach Memorandum (STEAM; Anchor and Battelle 2008a) and the STE Workshop Summary Memorandum (Anchor and Battelle 2008b). The information presented in the STEAM is closely linked to, and relies in part on, the preliminary Physical Processes CSM presented in the CSM and Data Gaps Analysis Report (Anchor, Windward and Battelle 2008). In that report, the preliminary Physical Processes CSM description synthesized the EWG's understanding 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 preliminary Physical Processes CSM. Data and information developed as part of the STE process will be used to update the preliminary Physical Processes CSM in the SRI/FS process, including investigation of the nature and extent of contamination, recontamination potential, and feasibility of remedial alternatives.

1.3 Review of Sediment Transport Evaluation Process

The development of the STER was an iterative process between the EWG and EPA. This process consisted of several evaluation and coordination steps, which are listed below:

- **Establish STE Workgroup.** This Workgroup consisted of sediment transport and modeling experts from the EWG and EPA, and provided technical input to the modeling approach and other STE methodologies. The Workgroup met at regular intervals during development of the STER to discuss key milestones and solicit input on technical issues and inform the Workgroup on results of preliminary evaluations. Workgroup recommendations (e.g., recommendations for key modeling parameters and assumptions) were documented and provided to EPA.
- **Develop field sampling program to fill the data needs.** The STEAM (Anchor and Battelle 2008a) identified key data needs to complete the STE. A Quality Assurance Project Plan (QAPP) was prepared to address STE data needs with input from the STE Workgroup and included details of how the sediment transport data needs were to be filled (Anchor QEA 2009).
- **Conduct field-sampling investigations.** Data collection included bathymetry within the EW, vertical current profiles, salinity and temperature profiles, geochronological cores (lead-210 [Pb-210] and cesium-137 [Cs-137]), and Sedflume cores.
- **Develop and run the STE models based on an approach developed with the STE Workgroup.** The approved STE modeling methodology was documented in the STEAM (Anchor and Battelle 2008a) and meeting minutes from the STE Workshop (Anchor and Battelle 2008b).
- **Prepare STER.** This report provides the results of related data collection efforts, the sediment transport modeling efforts and an assessment of sediment stability.

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). 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/saltwater interface extending as far as 10 miles upstream from the mouth at Elliott Bay. 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) 1.5, 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 Lower Duwamish Waterway (LDW) Superfund Site. The northern and southern study area boundaries for the EW OU are shown in Figure 1-1. The east and west boundaries of the EW OU are defined by mean higher high water (MHHW), as shown in Figure 1-2.

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 (DEA 2010). The shallow water depths associated with this "sill" along the Spokane Street corridor form a physical constriction that generally causes a larger fraction of the total riverine flow to pass 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 combined sewer outfalls (CSOs) and 39 storm drains are present along the EW that contribute freshwater and solids to the waterway (Figures 1-4A and 1-4B).

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). 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. South of the Spokane Street corridor, a 750-foot dock along Harbor Island is used for commercial moorage.

1.5 Preliminary Physical Processes Conceptual Site Model of 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). Information available prior to completion of the STE was reviewed and used as the basis for conceptualizing the processes that influence sediment transport in the EW. Section 2 in the CSM and Data Gaps Analysis Report (Anchor, Windward and Battelle 2008) summarizes sediment transport processes due to natural and anthropogenic processes within the EW study area. The results of the STE (as provided in this report) will be used to update the preliminary Physical Processes CSM in the SRI Report.

In the preliminary 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) (Figure 1-5). These three reaches are characterized by different sediment transport and hydrodynamic processes, and are used to refer to particular areas within the EW throughout the STER.

1.6 Overview of Sediment Transport Evaluation Technical Approach

The STE Workgroup revised and developed a preferred approach during a series of meeting from March to July 2008. This approach and rationale is described in the STEAM (Anchor and Battelle 2008a).

The STE for the EW utilized the Environmental Fluid Dynamics Code (EFDC) model previously developed for the LDW sediment transport study (Windward and QEA 2008). The first phase of the LDW modeling study began during 2004. That phase of the study involved the development, calibration, and application of the LDW hydrodynamic model. The model was used to evaluate bed stability during high-flow events. The modeling work was documented in the Sediment Transport Analysis Report (STAR; Windward and QEA 2008), which was approved by EPA and finalized in January 2008. The second phase of the modeling study began during 2006, and focused on the development, calibration, and application of the LDW sediment transport model. The sediment transport model was documented in the Sediment Transport Modeling (STM) Report, which was approved by EPA and finalized in October 2008 (QEA 2008).

The EW STE approach used a modified LDW hydrodynamics model (with increased resolution and updated bathymetry in the EW), together with empirical measurements of net sedimentation rates (geochronological cores) and critical shear stresses (Sedflume cores), to evaluate hydrodynamics and erosion potential in the EW. The LDW hydrodynamic model was then combined with a localized PTM to assess recontamination potential from lateral sources (Anchor and Battelle 2008a).

An outline of the STE approach steps is summarized below:

1. Collect bathymetry within the EW, including under-bridge and under-pier areas. Update the existing hydrodynamic model developed for the LDW (Windward and QEA 2008) for the EW study area using the new bathymetry data.
2. Calibrate the updated hydrodynamic model with site-specific velocity and salinity profile data collected as part of the STE. Specific attention will be paid to calibration of bottom velocities.
3. Collect and analyze geochronological cores collected as part of the STE.
4. Collect and analyze Sedflume cores collected as part of the STE.
5. Run the updated hydrodynamic model consistently with hydrodynamic forcing utilized in the LDW (Windward and QEA 2008); spring tide with mean annual, 2-year, 10-year, and 100-year upstream flow.

6. Use a Lagrangian PTM (developed by the U.S. Army Corps of Engineers [USACE; McDonald et al. 2006]) to estimate the contribution and distribution of lateral sediment loads to the EW.
7. Use results from the EW hydrodynamic model to:
   a. Determine erosion potential (i.e., bottom shear stresses) within the EW
   b. Estimate inflows (including the flow split) from LDW and the residence time of EW
   c. Provide input to the PTM model
8. Utilize data provided from erosion potential and 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 hydrodynamic model will be used to confirm/refine the preliminary Physical Processes CSM in the SRI Report. Sediment load from the LDW will be estimated from geochronological cores located in the southern portion of the EW.
9. Sedimentation within the EW due to upstream sources will be estimated from geochronological core data located south of Slip 27 and the results of the PTM model. These estimates will be compared to existing estimates of incoming sediment load (Windward and QEA 2008). Use a "box model approach" to evaluate the mass balance of sediment load from lateral sources (PTM model) and upstream sources (Steps 6 and 7 above).
10. Use the results of all above analyses to validate, and refine as necessary, the preliminary Physical Processes CSM for the EW.

Steps 1 through 6 represent data collection and modeling tasks, which have been completed and are summarized in this report. Steps 7 through 11 involve interpretation of the data and modeling efforts. These analyses will be completed as part of the SRI process, and the results will be provided in the SRI Report.

2 OVERVIEW OF DATA COLLECTION

Data gaps associated with the STE approach were identified in Table 3-4 of the STEAM (Anchor and Battelle 2008a). These data gaps included bathymetry within the Sill and Junction Reaches of the EW, updated bathymetry within the Main Body Reach of the EW, synoptic vertical current and salinity profiles within the EW, and site specific empirical surface and subsurface sediment data to inform an evaluation of net sedimentation rate (geochronological cores) and critical shear stress at the bed (Sedflume cores). These data were collected as part of the STE. Details regarding field collection and laboratory methods are provided in the Sediment Transport Characterization QAPP (Anchor QEA 2009).

An overview of the data collected is provided in Sections 2.1 through 2.4. Sampling locations and durations, field data collection methods, laboratory methods (where applicable), and field deviations from the Sediment Transport Characterization QAPP (Anchor QEA 2009) are described in detail in Appendices A through D of this report. Discharge flows and total suspended solids (TSS) values from lateral sources (CSOs and storm drains) were also identified as data gaps for the STE approach as required input for the PTM. These data are being developed through the Source Control Evaluation (SCE), and will be discussed in detail the SRI Report. A summary of these data are provided in Section 7.2 of this report, and additional detail regarding development of these data is provided in Appendix F.

2.1 Bathymetry

Bathymetry data were collected as part of the EW STE on January 13 through January 15, 2010. David Evans and Associates collected multi-beam bathymetry data within the EW, including under-pier areas (DEA 2010). Lead-line depth information was collected under the Spokane Street Bridge, where depths were too shallow and overhead freeboard was too limited to use conventional multi-beam equipment (DEA 2010). The datasets were merged together to form a contiguous surface of bathymetric elevations with the EW. The horizontal datum for the survey was Washington State Plane North Zone, North American Datum of 1983 (NAD83), and the vertical survey datum was North American Vertical Datum of 1988 (NAVD88). Tidal datum information for the EW was used to convert NAVD88 to MLLW and mean sea level (MSL) for use in the hydrodynamic model. The tidal benchmark used to convert between NAVD88 and various tidal datums was Seattle National Oceanic and

Atmospheric Administration (NOAA) Station #9447130. Tidal datum information is provided in Table 2-1.

Table 2-1
Tidal Datums for the East Waterway

Tidal Datum	Relative to MLLW (feet)	Relative to NAVD88 (feet)
MHHW	11.4	9.1
MHW	10.5	8.2
MSL	6.6	4.3
MLW	3.7	1.4
NAVD88	2.3	0
MLLW	0	-2.3

The updated bathymetric surface developed for the EW is shown in Figures 1-3A and 1-3B. Appendix A provides a more detailed description of the bathymetry data collection.

2.2 Current and Salinity Data

Site-specific empirical measurements of velocity and salinity profiles and water levels within the EW were identified as a data gap (Table 3-4; Anchor and Battelle 2008a) and are discussed in detail in the STE Workshop Summary Memorandum (Anchor and Battelle 2008b). Velocity and salinity profile data and velocity transects were collected by Evans Hamilton, Inc. (EHI), within the EW study area. In addition, a tide gage was also installed by EHI south of the bridges in the Junction Reach of the EW and surveyed into NAVD88. Figure 2-1 shows the locations of the moored Acoustic Doppler Current Profilers (ADCPs), tide gage, and the current transects. These data facilitated calibration of the existing LDW hydrodynamic model for the EW. The original LDW hydrodynamic model calibration did not include any data collected in the EW (Windward and QEA 2008). The data collection efforts for velocity and salinity were targeted to allow examination of the proposed hydrodynamic characteristics of the EW study area and calibration of the hydrodynamic model within the study area.

Velocity data collected consisted of four moored (bottom-mounted) upward-looking ADCPs, which collected velocity profile data from May 7 through August 18, 2009. Each ADCP provided velocity measurements at discrete vertical intervals. Sites 3 and 4 (shown in Figure 2-1) provide velocity measurements every 0.5 meter (m) in the vertical; Sites 1 and 2 (shown in Figure 2-1) were recorded at a 1.0-m vertical interval (due to deeper water depths at these sites). Measured velocities ranged from near-bed to near-surface based on the height of the instrument off the bed, the blanking distance above each current meter, and the distance below the water surface where viable backscatter measurements can be taken. The blanking distance is a function of the frequency of the instrument, as well as other factors. Taking into account these issues, velocity measurements are available from approximately 1 m above the bed and 1.5 m below the water surface for Sites 3 and 4. For Sites 1 and 2, velocity measurements are available from approximately 2 m above the bed to 2 m below the water surface. In addition, velocity measurements may not be available at particular locations or times if the velocity in the water column was very small (due to limitations of the ADCPs to measure and record small current velocities).

In addition, 16 velocity transects were collected over a complete tidal cycle from May 13 to 14, 2009. Salinity profiles were taken using conductivity/temperature/depth (CTD) casts at the same time that the velocity transects were being completed. Sixteen salinity profiles were measured at Site 3, Site 2, and Site 1 (shown in Figure 2-1), and coincided temporally with the velocity transects. Data reports provided by EHI (EHI 2009a, 2009b, and 2009c), as well as digital copies of the raw velocity and salinity data, are provided in Appendix B.

2.3 Geochronological Cores

Geochronological cores were collected as part of the EW STE to provide empirical site-specific estimates of net sedimentation rate within the EW. Geochronological cores were collected and processed between January 25 and February 1, 2010. Twenty-two sediment cores were proposed for collection. Of the 22 proposed cores, 18 were collected. Four cores were not collected due to the presence of dense substrate near the surface in those proposed locations, which prevented penetration and sampling. The locations of the 18 collected geochronological cores, as well as locations of the four cores that were not collected, are shown in Figure 2-2.

The cores were collected to a maximum length of 90 centimeters (cm) (or to refusal) and sliced into 2-cm sections. The top 2-cm sample from each 6-cm increment was tested and all others were archived. Samples were tested for radiochemistry (Cs-137 and Pb-210), as well as grain size distribution, bulk density, percent solids, and total organic carbon (TOC). Additional information regarding the geochronological core data collection is provided in Appendix C.

2.4 Sedflume Cores

Sedflume cores were collected as part of the EW STE to provide empirical site-specific estimates of critical shear stress within the EW. Sedflume cores were collected and analyzed on site by Sea Engineering, Inc. (Sea Engineering) between April 19 and April 21, 2010. A total of eight cores were collected throughout the EW, as shown in Figure 2-3. Critical shear stress, grain size distribution, and bulk density were evaluated at various vertical intervals in the core down to approximately 20 cm below mudline. Additional information regarding the Sedflume data collection, including data reports provided by Sea Engineering, are provided in Appendix D.

3 EVALUATION OF NET SEDIMENTATION RATE IN THE EAST WATERWAY

The purpose of collecting geochronology cores was to evaluate net sedimentation rates within various portions of the EW and the occurrence of significant mixing of deposited sediment by physical processes. These data provide a key line of evidence in the evaluation of net sedimentation rates throughout the study area. Variation observed among the different cores provides information on the potential variability of net sedimentation rates and potential mixing within the EW.

3.1 Geochronology Core Sampling and Analysis

Geochronology core sampling included field collection of subsurface sediment cores from 18 locations located throughout the EW, and testing for Cs-137 (Figure 3-1) and Pb-210 (Figure 3-2). The geochronology core collection effort originally included 22 core locations; however, four cores had no recovery due to surface sediment conditions (i.e., gravel) at those locations (GC-4, GC-17, GC-21, and GC-22), and one core (GC-20) had low recovery. The locations of the cores included the Main Body, Junction, and Sill Reaches of the EW (Figure 1-5). This spatial coverage was intended to encompass a wide range of depositional conditions within the EW. Sampling locations did not include known dredge areas since using geochronology analysis to estimate net sedimentation rates may be problematic due to the disturbance of the sediment profile. Details of the sampling methodology and deviations from the approved Sediment Transport Characterization QAPP (Anchor QEA 2009) are presented in Appendix C.

Selection of cores for geochronology (age-dating) analysis followed a tiered approach. This approach determined the order in which core samples underwent radioisotope analysis in the laboratory and subsequent results made available. Tier 1 samples included all cores located in areas within the EW where influence from propwash was expected to be low (generally south of Slip 27), and a selection of cores in areas where propwash was expected to have some impact on evaluation of core data.

Radiochemistry results from the Tier 1 samples showed that cores located north of Slip 27 all appeared to be influenced by vessel operations in that area and were not viable for evaluation

of net sedimentation rates. Therefore, archived samples from the remaining cores in the Main Body Reach north of Slip 27 (Cores GC-06, -07, -03, and-01) were not analyzed.

Detailed information regarding the collection and processing methodology, tier rationale, field logs, archiving procedures, and summaries of results and observations for the geochronology cores is in Appendix C. Table C-1 presents a summary of the subsurface sediment collection including recovery percentage, major lithologic units, and general sampling scheme.

3.2 Sediment Dating

The geochronology analysis was conducted by evaluating the vertical profiles of Cs-137 and Pb-210 activities, which are used to age-date sediments and estimate net sedimentation rates in estuarine and freshwater systems (Olsen et al. 1978; Orson et al. 1990). Additional information regarding specific core intervals and sampling methods is provided in Section 2.3 and Appendix C.

3.2.1 Cs-137 Data Evaluation

The ages and sedimentation characteristics of the sediment cores were analyzed using Cs-137 activity data consistent with the method described in Jeter (2000). The first occurrence of detectable Cs-137 in sediments generally marks the year 1954 (i.e., start of atmospheric testing of nuclear bombs), while peak activities correspond to 1963 (Simpson et al. 1976). Based on these dates, the best estimate of the long-term average net sedimentation rate for a particular core is computed by dividing the depth of sediment between the sediment surface and the buried Cs-137 peak by the number of years between 1963 and the time of core collection (e.g., 47 years for a core collected in 2010). Significant compaction of the sediments was not observed during the geochronology study; therefore, recovered and sediment horizon depths were not altered from field measurements. This approach was successfully used to date sediment cores in the LDW (Windward and QEA 2008).

Uncertainty in the exact location of the true Cs-137 peak exists for the following reasons: 1) the laboratory reports 95% confidence intervals around the best estimate of the Cs-137 activity for each sample (to reflect measurement uncertainty); and 2) the true Cs-137 peak

could exist within un-analyzed sediment segments located immediately above and below the observed Cs-137 peak. Therefore, to account for this uncertainty, a range of net sedimentation rates was computed for each core. A lower-bound net sedimentation rate was computed by dividing the depth (in cm) between the sediment surface and the lower edge of the analyzed segment immediately above the observed Cs-137 peak by 47 years. An upper-bound net sedimentation rate was computed by dividing the depth (in cm) between the sediment surface and the upper edge of the analyzed segment immediately below the observed Cs-137 peak by 47 years. Net sedimentation rates for each core, as estimated using these two approaches, are presented in Table 3-1 and Figure 3-1.

Table 3-1
Estimated Net Sedimentation Rates based on Cs-137 Data

Sediment Core ID	Depth of Cs-137 Peak (cm)	Estimated Net Sedimentation Rate (cm/yr)	
		Via Cs-137 Peak	Estimated Range
GC-02	--	--[a]	--[a]
GC-05	--	--[a]	--[a]
GC-08	--	--[a]	--[a]
GC-09	--	--[a]	--[a]
GC-10	62	1.3	1.2 - 1.4
GC-11	80	Greater or equal to 1.7 [b]	1.6 - 1.8
GC-12	90	Greater or equal to 1.9 [b]	1.8 - 2.0
GC-13	--	--[a]	--[a]
GC-14	56	1.2	1.1 - 1.3
GC-15	62	1.3	1.2 - 1.4
GC-16	74	1.6	1.5 - 1.7
GC-18	90	Greater or equal to 1.9 [b]	1.8 - 2.0
GC-19A	56	1.2	1.1 - 1.3
GC-20	--	--[c]	--[c]

Notes:
GC-01, -03, -06, and -07 were archived.
a. No peak observed.

b. Cs-137 peak was at the bottom of the core; therefore, the actual peak may be below the recovered depth of the core.
c. Low recovery.

Eight of the 15 sediment cores analyzed contained distinct Cs-137 activity that allowed the calculation of an estimated net sedimentation range. For cores GC-11, GC-12, and GC-18, it is expected that the maximum Cs-137 peak is below the recovered depth of the core. This expectation was based on the increasing trend in Cs-137 activity at the bottom of the core and comparison of Cs-137 profiles at nearby cores (GC-14, GC-15, and GC-19A) that exhibit similar trends. Deep vertical mixing is not expected to produce the results seen at core locations GC-11, GC-12, and GC-18 due to review of vessel operations in these areas and comparison of cesium profiles in areas where deep vertical mixing is expected (GC-05 and GC-08) that show different trends over the vertical. Therefore, a minimum net sedimentation rate for these cores was assigned based on the deepest sampled interval in the core. As shown in Figures 3-3A and 3-3B and in Table 3-1, the depth of the Cs-137 activity peak varied between 56 and 90 cm in these eight cores, which corresponds to a net sedimentation rate range of 1.2 to 1.9 centimeters per year (cm/yr). These net sedimentation rates are similar in magnitude to previous geochronological cores collected in the EW, which ranged between 1.0 and 1.5 cm/yr (Table 4-2 of the EISR; Anchor and Windward 2008a). Due to a lack of recovery in the Junction Reach (south of the bridges) and lack of discernable Cs-137 peaks in cores located in the northern portion of the EW, net sedimentation rates cannot be compared throughout the waterway. Within the Main Body Reach, there was no consistent variation in estimated net sedimentation rates between analyzed cores.

3.2.2 Pb-210 Data Evaluation

Pb-210, which is a decay product of volatilized atmospheric radon-222 (Rn-222), is present in sediments primarily as a result of atmospheric deposition. Rn-222 is a volatile, short-lived, intermediate daughter of uranium-238 (U-238), a naturally occurring radioisotope found in the earth's crust. The Pb-210 activity in a sediment sample represents the total Pb-210 activity, which is measured indirectly by analysis of its radioactive decay products bismuth-210 or polonium-210. Total Pb-210 activity consists of two components: 1) unsupported Pb-210, which represents Pb-210 that is deposited on the earth's surface at an approximately constant rate via atmospheric deposition; and 2) supported Pb-210, which is the background Pb-210 activity in the sediment. In aquatic environments, the approximately constant

atmospheric flux of Pb-210 and its decay half-life of 22.3 years results in relatively homogeneous Pb-210 activities within the biologically-active surface layer of the sediments and activities that decay exponentially below this depth (see Figure 3-4). For this reason, Pb-210 serves as a useful tracer for estimating net sedimentation rates in aquatic systems.

Estimation of net sedimentation rates using Pb-210 data relies on determination of the unsupported fraction of the total Pb-210 activity, also referred to as excess Pb-210. The unsupported fraction (Pb_u-210) is estimated as follows:

$$Pb_u\text{-}210 = Pb_T\text{-}210 - Pb_S\text{-}210 \qquad (3\text{-}1)$$

Where:

Pb_T-210 = total Pb-210 activity reported by the laboratory in the sediment samples

Pb_S-210 = supported Pb-210 activity derived from natural decay in sediments

Unsupported Pb_u-210 activities are computed by subtracting the average supported Pb_S-210 activity from the total Pb_T-210 activities throughout the core, as per Equation 3-1. Based on the affinity of Pb-210 for silts and clays, the unsupported Pb_u-210 values were fines normalized (Ab Razak et al. 1996). The natural log of the unsupported Pb_u-210 (i.e., ln [Pb_u-210]) was plotted as a function of core depth, and a linear regression was performed. The slope of this line (m) was used to estimate the average net sedimentation rate (Pb_R with units of cm/yr):

$$Pb_R = -\ 0.0311/m \qquad (3\text{-}2)$$

The supported (Pb_S-210) activity in the sediments was estimated for this study. Therefore, to account for this uncertainty in values of the supported Pb-210 activity, an analysis was performed to determine the best estimate of the net sedimentation rate for each core based on varying assumptions regarding unsupported Pb-210 activities in the EW sediments. This analysis was performed independently for each of the cores with interpretable Pb-210 profiles.

This approach yields best estimates of the average net sedimentation rates for each core in consideration of the uncertainty associated with the actual supported Pb_S-210 activities in the sediments. However, these best estimates are subject to other sources of uncertainty (see Section 3.4). Therefore, in addition to the best estimate, a range of average net sedimentation rates was determined for each core to account for these additional sources of uncertainty. The lower-bound ($Pb_{R\ lcl}$) and upper-bound ($Pb_{R\ ucl}$) estimates were computed for each core using the confidence limits around the slope of the best-fit lines and Equations 3-3 and 3-4, respectively:

$$Pb_{R\ lcl} = -\ 0.0311/(m-m_{cl}) \quad (3\text{-}3)$$

$$Pb_{R\ ucl} = -\ 0.0311/(m+m_{cl}) \quad (3\text{-}4)$$

Where:

m_{cl} = 95% confidence interval around the mean slope of the best-fit line

The best estimate and range of average net sedimentation rates for each of the cores with interpretable Pb-210 profiles are presented in Table 3-2 and shown in Figures 3-5A and 3-5B.

Table 3-2
Estimated Net Sedimentation Rates based on Pb-210 Data

Sediment Core ID	R^2 value for Best-fit Line	Estimated Net Sedimentation Rates (cm/yr)	
		Estimate Based on Best-fit Line	Range
GC-02	0.17	--[a]	--[a]
GC-05	0.78	0.67	0.26 - 0.67
GC-08	0.92	0.28	0.20 - 0.48
GC-09	0.78	0.56	0.35 - 1.4
GC-10	0.63	0.61	0.30 - 0.61
GC-11	0.70	0.47	0.27 - 1.8
GC-12	0.71	0.46	0.27 - 1.8
GC-13	0.63	0.69	0.34 - 0.69
GC-14	0.003	--[a]	--[a]
GC-15	0.45	--[a]	--[a]

Sediment Core ID	R^2 value for Best-fit Line	Estimated Net Sedimentation Rates (cm/yr)	
		Estimate Based on Best-fit Line	Range
GC-16	0.91	0.18	0.09 - 4.2
GC-18	0.48	--[a]	--[a]
GC-19A	--[b]	--[b]	--[b]
GC-20	--	--[c]	--[c]

Notes:
GC-01, -03, -06, and -07 were archived.
a. Net sedimentation rate not estimated due to low correlation ($R^2 < 0.50$).
b. Core contains un-interpretable Pb-210 profile.
c. Low recovery.

The correlation coefficient (R^2) values for the best-fit lines determined during the Pb-210 analysis range from 0.003 to 0.92. Eight of 13 cores produced correlations in the Pb-210 profile with R^2 values greater than 0.50; net sedimentation rates for cores with R^2 values less than 0.50 are considered to be unreliable estimates and, therefore, were not calculated. Cores with R^2 values less than 0.50 are GC-02, GC-14, GC-15, and GC-18. GC-15 and GC-18 had R^2 values that were close to 0.50 (0.45 and 0.48, respectively) and exhibited reasonable Cs-137 peaks. Therefore, the slightly lower than threshold (0.50) R^2 values for these cores are likely due to uncertainties/variability in the evaluation (see Section 3.4). Cores GC-02 and GC-14 had significantly lower R^2 values (0.17 and 0.003, respectively). The lower correlation values for these cores are due to variability in the Pb-210 values primarily at one depth interval; approximately 14 cm below mudline for both cores (see Figures 3-5A and 3-5B). This variability could be due to the presence of a sand layer at that depth interval for Core GC-02 (see Figures 3-3A and 3-3B), or could be due to mixing of the surface sediments in either core.

Some of the uncertainties discussed in this section and Section 3.4 with respect to the Pb-210 analysis may also contribute to the low R^2 values computed for some cores. However, consistent relationships between R^2 values and core characteristics (e.g., core recovery) were not observed. Best-estimate net sedimentation rates for the eight cores with R^2 values greater than 0.50 ranged from 0.18 to 0.69 cm/yr as provided in Table 3-2 and shown graphically in Figure 3-2.

3.3 Summary of Results – Net Sedimentation Rates in the East Waterway

Net sedimentation rates were calculated for each of the eight cores with interpretable Cs-137 activity profiles and eight cores with high correlation Pb-210 activity profiles. The estimated rates are shown in Table 3-3.

Table 3-3
Comparison of Net Sedimentation Rates

Sediment Core ID	Estimated Net Sedimentation Rates from Cs-137 Analysis (cm/yr)		Estimated Net Sedimentation Rate from Pb-210 Analysis (cm/yr)	
	Via Cs-137 Peak	Peak Range	Estimate Based on Best-fit Line	Range
GC-02	--[a]	--[a]	--[b]	--[b]
GC-05	--[a]	--[a]	0.67	0.26 - 0.67
GC-08	--[a]	--[a]	0.28	0.20 - 0.48
GC-09	--[a]	--[a]	0.56	0.35 - 1.4
GC-10	1.3	1.2 - 1.4	0.61	0.30 - 0.61
GC-11	>1.7	1.6 - 1.8	0.47	0.27 - 1.8
GC-12	>1.9	1.8 - 2.0	0.46	0.27 - 1.8
GC-13	--[a]	--[a]	0.69	0.34 - 0.69
GC-14	1.2	1.1 - 1.3	--[b]	--[b]
GC-15	1.3	1.2 - 1.4	--[b]	--[b]
GC-16	1.6	1.5 - 1.7	0.18	0.09 - 4.2
GC-18	>1.9	1.8 - 2.0	--[b]	--[b]
GC-19A	1.2	1.1 - 1.3	--[c]	--[c]
GC-20	--[d]	--[d]	--[d]	--[d]

Notes:
GC-01, -03, -06, and -07 were archived.
a. No Cs-137 peak observed.
b. Net sedimentation rate not estimated due to low correlation ($R^2 < 0.50$).
c. Core contains un-interpretable Pb-210 profile.
d. Low recovery.

Direct comparisons of the two methodologies are possible for four cores: GC-10, GC-11, GC-12, and GC-16. At two of the four locations (GC-11 and GC-16), the net sedimentation rate based on the Cs-137 profile analysis fell within the range of the net sedimentation rate based on the Pb-210 profile analysis. In the other two cores (GC-10 and GC-12), net sedimentation

rates determined from the Pb-210 profile analysis were lower than those estimated using the Cs-137 profile analysis.

Analyses of Cs-137 and Pb-210 profiles in the cores for which net sedimentation rates can be reliably estimated indicated that net sedimentation rates range from 0.2 to greater than 2.0 cm/yr. These net sedimentation rates are consistent with the results of earlier studies in the EW and WW for Cs-137 (1.0 to 2.4 cm/yr) and Pb-210 (0.5 to 0.8 cm/yr) (EVS and Hart Crowser 1995).

The majority of cores analyzed for radioisotopes during this investigation exhibited relatively uniform, interpretable profiles with depth, suggesting that, overall, these areas are net depositional. However, vertical profiles of physical and chemical properties in the sediments also provide a means of identifying evidence of episodic disturbances. For some of the EW cores, the absence of discernable peaks of Cs-137 and variations in the vertical distributions of Cs-137 activity, Pb-210 activity, TOC, grain size distribution, and total solids content indicate that episodic disturbances may be occurring on a local scale. These episodic erosion/deposition events may be the result of several phenomena (e.g., dredging activities, slumping of nearby sediments, high-flow events, or ship-induced bed scour), although the exact nature of these events is not known.

3.4 Uncertainty Discussion

Several physical, chemical, and biological factors introduce uncertainty into net sedimentation rates estimated from the radioisotope profiles. Some of these factors include:

1. Temporal variability of the net sedimentation rate
2. Natural variability in radioisotope measurements
3. Variations in sediment characteristics
4. Spatial variability of depths to which benthic invertebrates burrow into the EW sediments (e.g., mixing or bioturbation depth)
5. Spatial variability of physical disturbances of the sediments in the EW (e.g., erosion, dredging, or ship-induced vertical mixing)
6. Compaction and/or mixing of sediments during core collection/extrusion
7. Poor sediment recovery rates in core samples

Some of these sources of uncertainty are documented by NOAA and Battelle in a Pb-210 study that was conducted in Puget Sound (Lavelle et al. 1985). The first five factors are likely the greatest contributors to uncertainty in net sedimentation rates estimated during this study, primarily due to the variability in the extent and magnitude that these processes occur in the EW.

The final two factors were mitigated through careful sample collection methodology. Core collection and processing are not believed to be significant contributors to uncertainty in estimated net sedimentation rates. Core compaction and/or mixing of sediments during core collection/extrusion can result in the smearing of Cs-137 and Pb-210 activity gradients throughout the sediment column. However, significant compaction and/or mixing of the sediments was not observed during the geochronology study; therefore, cores were not corrected for compaction and sediment was not sampled from the core side walls where smearing occurs. Sediment recovery rates ranged from 73% to 96%. If core compaction did occur to any significant extent, then actual net sedimentation rates would be greater than those presented in this report.

4 HYDRODYNAMIC MODEL

4.1 Overview of Technical Approach

The hydrodynamic model utilized in the STE was developed through modification of an existing model used to evaluate hydrodynamics in the LDW (Windward and QEA 2008). The model utilizes the three-dimensional (3-D) EFDC computer code to represent hydrodynamic processes. It is a physics-based model in that it includes the important physical processes and algorithms to describe the hydrodynamic processes in the system. 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 Point and West Point.

The LDW hydrodynamic model was updated to increase the grid resolution within the EW. Data collected as part of the STE were used to update the bathymetry within the EW and calibrate the model within the EW (current and salinity data). In particular, there was a need to update bathymetry in the vicinity of the shallow water Sill Reach, the Junction Reach of the EW with the LDW, and under-pier areas. In addition, Slips 27 and 36 were included in the model domain.

The updated hydrodynamic model was used to evaluate hydrodynamics (current velocities, salinity distribution, water surface elevations) within the EW due to tidal forcing and various upstream inflow conditions in the Green River and LDW (annual average, mean wet season, 2-year, 10-year, and 100-year flow events). The updated model was also used to evaluate erosion potential (by determining bottom shear stresses) within the EW for these events. These model results will be used to help refine and validate the preliminary EW Physical Processes CSM during the SRI process.

4.2 Development of Numerical Grid

Modifications to the original numerical grid included updated bathymetry based on data collected for the STE and increased grid resolution within the EW. The modified numerical grid included approximately 375 horizontal cells within the EW study area, with ten layers in the vertical direction. Specific changes to model resolution within the EW included the following (see Figure 4-1):

- In the Main Body Reach of the EW (see Figure 1-5), eleven grid cells were used across the EW (east to west), which resulted in an average grid cell width of approximately 75 feet.
- Along the channel of the EW, grid cells are approximately 200 feet long (north to south), which produced approximately 250 horizontal grid cells within the Main Body Reach of the EW (approximately 27 cells along the channel and 9 cells perpendicular to the channel).
- In the Sill Reach (see Figure 1-5), three grid cells were used across the EW, expanding to four and five grid cells in the area north of the bridges.
- In Slip 27, six grid cells (approximately 400 feet by 200 feet) were used; three cells along the slip and two cells across the slip.
- In Slip 36, 12 grid cells (approximately 300 feet by 200 feet) were used; six cells along the slip and two cells across the slip.
- Additional increases to grid resolution at the confluence of the EW and LDW were required to blend the upstream grid cells from the original LDW model into the higher resolution grid cells in the EW. This change was required to ensure model stability.
- Additional increases to grid resolution within Elliott Bay were required to better represent the confluence of Elliott Bay and the EW and to ensure model stability.

Bathymetry values were assigned to each grid cell as the average elevation within the extent of a specific grid cell. The input bathymetry was converted from feet, NAVD88, to MSL based on the tidal datums provided in Table 2-1. Figure 4 shows the updated numerical grid within the EW.

4.3 Boundary Conditions

In all calibration and production simulations, the model was driven by two boundary conditions: 1) inflow rate at the upstream boundary in the Green River; and 2) spatially-uniform water surface elevation at the Elliott Bay open boundary. The upstream boundary condition was specified using measured daily-average flow rates obtained at the U.S. Geological Survey (USGS) gage near Auburn, Washington. The tidal boundary condition was established using verified, 6-minute water level data collected at the NOAA tidal gage

station in Elliott Bay (#9447130). The tidal elevation data were referenced to the MSL datum, consistent with the input bathymetry datum. In addition, upstream and downstream boundary conditions for salinity were also included in the model. The upstream inflow at the Green River was set to a constant salinity of 0 practical salinity unit (psu) (freshwater) and the downstream boundary at Elliott Bay was set to a constant salinity of 31 psu. Each model simulation included 45 days of simulation time before the time period of interest in order to fully develop the salinity distribution within the model domain. The boundary conditions for the model calibration simulations were designed to temporally coincide with current velocity and water level data collected between March 1 and August 31, 2009. Temporal variations in tidal elevation at the open boundary and upstream inflow rate during this time period are shown in Figures 4-2 and 4-3.

The production simulations focused on a 2-month time period (June 1 to July 31, 2009) in order to facilitate integration with the PTM discussed in subsequent sections of this report. There were five different production simulations, each with the same tidal boundary condition (Figure 4-4) and time-independent upstream inflow representing the mean annual, wet mean annual, 2-year, 10-year, and 100-year flows. The second two weeks of June 2009 exhibited tidal fluctuations consistent with a typical spring tide event in the area, with a maximum range of 16 feet between consecutive high and low water levels.

Five upstream inflow boundary conditions were used for the production simulations, based on extreme return period flow events developed previously for the LDW: 1) mean annual discharge; 2) mean 'wet season' discharge (defined here as November through May); 3) 2-year high-flow event; 4) 10-year high-flow event; and 5) 100-year high-flow event. Figure 4-5 illustrates variations in the monthly-average flow rate; it is evident that the period of November through May experiences significantly higher flow rates than June through September. The 2-, 10-, and 100-year high-flow events were taken from the LDW Sediment Transport Modeling Report (Windward and QEA 2008). Mean annual flow rate was estimated as the average monthly flow rate over all 12 months of the year and mean 'wet season' flow rate was taken as the average monthly flow rate for the months of November through May (see Figure 4-5). Table 4-1 lists the flow rates corresponding to the five production simulations.

Table 4-1
Upstream Flow Rates for Production Simulations

Flow Condition	Flow Rate (cfs)
Mean annual	1,330
Mean 'wet season'	1,875
2-year high-flow event	8,400
10-year high-flow event	10,800
100-year high-flow event	12,000

Notes:
cfs = cubic feet per second

4.4 Calibration Strategy

The hydrodynamic model calibration effort optimized the agreement between measured and predicted current velocities, water surface elevations, and salinity in the EW using data collected during the 4-month period of May 2009 through August 2009. Calibration metrics included the root mean square (RMS) error between the measured and predicted time series of water surface elevation and depth-averaged salinity and current velocity, along with qualitative assessments of the vertical profiles of predicted and observed salinity and current velocity. The primary parameters/inputs adjusted during model calibration were: 1) bottom roughness height in the EW, particularly in the vicinity of the West Seattle Bridge; and 2) bathymetry of the WW. The numerical grid in the WW was not modified from the original LDW model and the resolution of the numerical grid within the WW was relatively coarse (two grid cells across the WW). Therefore, representation of WW geometry within the model was assumed to be uncertain (compared to the updated model geometry within the EW) and the bathymetry within the WW was treated as a calibration parameter during the calibration process for the hydrodynamic model.

Model predictions of vertical distribution of salinity showed good agreement with measurements prior to the calibration effort. Figures E-1 through E-48 show comparisons of measured and predicted values of salinity for each of the 16 salinity profiles measured at locations 1, 2, and 3 (see Figure 2-1 for locations). Measurements of water surface elevation were also well predicted by the model prior to model calibration; RMS errors ranged between 6 and 10 cm. Figure 4-6 shows a comparison of predicted and measured water

surface elevation at the tide gage installed by EHI just south of the bridges in the Junction Reach (see Figure 2-1 for location). As illustrated in Figure 4-6, the model is able to accurately predict tidal elevations over a wide range of tidal forcing and freshwater inflow conditions.

The calibration effort focused on the comparison of measured near-bed current velocities (1 to 2 m above the bed) and measured vertical distribution of current velocities at Sites 1, 3, and 4, (as shown in Figure 2-1) with corresponding model predictions. Current measurements at Site 2 were very small, and together with the high signal-to-noise ratio, could not be quantified accurately by the instrument. Therefore, current velocities at this location were not used in the calibration effort (see Section 2.2). During calibration, the bottom roughness height in the section of the EW adjacent to the West Seattle Bridge was increased to 50 cm, tapering to 5 cm away from the narrowest section to account for interaction of the flow with the bridge pilings and shallower water in those areas. The bottom roughness for the remainder of the numerical grid was left at the original value assigned for the majority of the areas in the LDW model: 0.2 cm. In addition, the depth in the WW was increased by 25% (relative to the bathymetry in the WW in the original LDW model), and the transitions into Elliott Bay and the LDW were smoothed to ensure numerical stability in those areas. These changes in bottom roughness and WW bathymetry made the modeled vertical current profiles align more closely with the measured data.

After the above adjustments, the predicted water surface elevations and salinity and current velocity profiles matched reasonably well with measurements. Table 4-2 provides a comparison of RMS error for the initial model simulations and the final calibrated model for depth-averaged current velocity and salinity.

Table 4-2
Summary of RMS Error for Model Calibration

Calibration Simulation	Calibration Parameter		RMS Error in Depth Averaged Current (cm/s) 1-month Simulation Time - May 2009			
	West Waterway Bathymetry	Bottom Roughness in Junction Reach (m)	Site 1	Site 2	Site 3	Site 4
1	no changes	0.05	1.7	1.7	3.3	8.0
2	no changes	varies from 0.05 to 0.1	1.7	1.7	3.1	8.0

Calibration Simulation	Calibration Parameter		RMS Error in Depth Averaged Current (cm/s) 1-month Simulation Time - May 2009			
	West Waterway Bathymetry	Bottom Roughness in Junction Reach (m)	Site 1	Site 2	Site 3	Site 4
3	no changes	varies from 0.05 to 0.25	1.7	1.7	2.9	7.8
4	no changes	varies from 0.05 to 0.5	1.7	1.7	2.8	7.8
5	25% deeper and blended upstream into LDW	0.002	1.7	1.7	3.2	8.2
6 (final calibrated model)	25% deeper and blended upstream into LDW	varies from 0.05 to 0.5	1.7	1.7	2.5	7.9
7	50% deeper and blended upstream into LDW	varies from 0.05 to 0.5	1.7	1.7	2.5	8.5

Notes:
cm/s = centimeters per second
m = meters
LDW = Lower Duwamish Waterway

Comparisons of predicted and measured current velocity profiles for the calibrated model are provided in Appendix E. These comparisons are provided in Adobe PDF format for locations 1, 3, and 4 (see Figure 2-1 for site locations). Each PDF file contains current velocity profiles plotted in 15-minute intervals from May 7 to May 31, 2009.

Figures 4-7, 4-8, and 4-9 show typical examples of agreement between predicted and measured current velocity profiles at Sites 4, 3, and 1, respectively (see Figure 2-1 for site locations). Overall, model predictions of the vertical current velocity distribution were in close agreement with measurements over a majority of the tidal cycle for Sites 3 and 4, which were located in the southern portion of the EW where the width is constricted and the water depth is shallow compared to the EW basin. The vertical current velocity profiles at Site 1 (as well as Site 2) were not as accurately predicted by the model because the magnitudes of the current velocities were relatively small and the vertical profile had minimal structure. The current velocity magnitudes predicted by the model at Sites 1 and 2 were within acceptable errors compared to measurements.

An additional evaluation of model performance was conducted by analyzing the distribution of flow rate between the EW and WW as a function of upstream inflow. This analysis was done to ensure that deepening the WW (in order to calibrate the model to current velocities measured within the EW) did not unrealistically affect the split in flow rate during high-flow events. The modeled relationship between flow rate through the EW and total upstream flow rate indicates that:

- For low to moderate flow conditions, there is approximately a 50% - 50% split between flow in the EW and WW
- As the LDW flow rates increases and shifts to high-flow conditions (i.e., 2-year flood), the East:West flow split is about 30% to 70%, and this ratio is approximately constant as flow rate increases above the 2-year flood
- The reduction in the percentage of flow within the EW (compared to the WW) can be explained by the relatively constricted entrance to the EW. Therefore, changes to the WW bathymetry during calibration do not appear to have a significant effect on the split in flow between the EW and WW in the calibrated hydrodynamic model.

Model predictions of flow rate within the EW (just north of the bridges) were compared to flow rates estimated from three cross-channel ADCP transects taken as part of the data collection effort (see Figure 2-1 for locations). Figure 4-10 illustrates this comparison. Variability in flow rates estimated from ADCP transects shown in Figure 4-10 is due to overall low current velocities, higher signal-to-noise ratios (and thus higher error in the measurements), and lack of distinct flow patterns within the transect data. The flow rate in the EW predicted by the model appears to be the slightly higher than measured values on ebb tide and slightly lower than measured values on flood tide. However, flow rates estimated from the ADCP transect data did not include flow in the surface (top 2 m) and near bottom (variable, but generally equal to or less than 0.5 m above the bottom) due to limitations of the instrument (blanking distance). Based on ADCP transect data (see Appendix B), approximately 20% of the total flow cross-sectional area was excluded from the ADCP measurements due to blanking distances for the instrument. This may account for some of the differences noted between predicted and measured flow rates in the EW. Within the variability of the data, measured and predicted flow rates within the EW appear to be within the same order of magnitude and follow similar temporal patterns.

Overall, calibration of the hydrodynamic model was successful based on agreement between measurements and model predictions of salinity, current velocity, and water surface elevation. The results of the calibration effort indicate that the model is sufficiently accurate and reliable to meet the stated STE objectives in Section 1.

4.5 Hydrodynamics Model Results

Results of the hydrodynamic model runs are described in Sections 4.5.1 through 4.5.3, and are broken down by EW Reach. The hydrodynamic model results are used in this report to describe hydrodynamics within the EW and to estimate bottom shear stress throughout the EW under various flow conditions. The evaluation of bottom shear stress is discussed in Section 6.

The hydrodynamics within the EW were evaluated overall and within each defined reach (i.e., Sill, Junction, and Main Body Reaches) (see Figure 1-5). General discussion of the hydrodynamics within the EW is included in this section of the report. Discussion of hydrodynamics specific to each reach is provided in Sections 4.5.1 through 4.5.3.

Histograms of modeled velocity magnitudes within the entire EW at the surface, mid-depth, and near-bottom layers are provided in Figures 4-11 through 4-13 for mean annual flow, Figures 4-14 through 4-16 for the 2-year flood, and Figures 4-17 through 4-19 for the 100-year flood. These figures show that higher current velocities with greater spread in the velocity magnitude are present in the surface layer, compared to mid-depth and near-bottom layers. Current velocities in all layers increase with increasing river flow rate. Velocity magnitudes in the surface layer range from 0 to 70 centimeters per second (cm/s), with a mean near 10 cm/s for mean annual inflow. These current velocities increase in range from 0 to 100 cm/s, with a mean near 30 cm/s for the 100-year high-flow event. Velocity magnitudes in the near-bottom layer range from 0 to 20 cm/s, with a mean near 5 cm/s for mean annual inflow. These velocities increase slightly under 100-year flood conditions, with maximum values of about 30 cm/s, but the mean remains near 5 cm/s.

Maximum ebb (downstream) and flood (upstream) current velocities within the EW are plotted as a function of upstream flow rate in Figure 4-20. Maximum ebb velocities in the

surface layer are greater than at mid-depth, which are greater than at near-bottom. These current velocities all increase as upstream flow increases. This pattern is expected, as increased flow rate in the river should increase downstream velocities within the EW. Maximum flood velocities, on the other hand, decrease in the surface and mid-depth layers with increases in upstream flow rate. This pattern is also expected, as increased flows in the river reduce the influence of the incoming tide in the upper water column. Near-bottom flood velocities show a slight increase in magnitude with increased river flow rate.

Vertical salinity distribution and 3-D current structure was examined for each model simulation. Figures 4-21 through 4-23 show vertical distributions of salinity and along-channel velocities within the EW (RMs in the EW shown on Figure 1-5) for all three reaches for typical flood tide conditions for the mean annual, 2-year, and 100-year high-flow events, respectively. Figures 4-24 through 4-26 show the same information for typical ebb tide conditions for the mean annual, 2-year, and 100-year high-flow events, respectively. These figures illustrate typical extremes of current velocities and salinities within the EW over the tidal cycle with increased river flow rates. Figures 4-27 through 4-29 show residual (tidally averaged) current velocities and average salinities over several tidal cycles for the mean annual, 2-year, and 100-year high-flow events, respectively. These figures illustrate the net current magnitude and direction and average salinities within the EW. In all events, there is a net outflow of lower salinity (fresher) water in the upper layers of the EW, and a net inflow of high-salinity water in the bottom layers. Higher outgoing (downstream) current velocities are located in the surface layer in the Junction and Sill Reaches, and higher incoming (upstream) current velocity is found in the bottom layers near the mouth of the EW. The magnitude of the surface current velocity decreases moving downstream from the Junction Reach into the Main Body Reach, while the magnitude of the bottom current velocity increases from the mouth of the EW upstream toward the Sill and Junction Reaches. Salinity is highest in the bottom layers near the mouth of the EW and lowest in the surface layers in the Junction Reach.

As the upstream inflow rate increases, so does the magnitude of the net current velocities. During the 2-year and 100-year high-flow events, there is no net incoming (upstream) flow in the Sill and Junction Reaches; all vertical layers have a net outgoing flow. At any given location, average salinity decreases as upstream inflow increases.

4.5.1 Main Body Reach

The Main Body Reach is characterized by relatively low current velocities and a distinct distribution of top to bottom salinity. Velocity magnitudes at the surface range from approximately 0 to 40 (cm/s), with higher current velocities occurring during ebb tide during higher upstream flow events. Surface current velocities tended to be higher in the southern portion of the Reach and were lower toward the mouth of the EW. Surface water flows towards the LDW during flood tide during low upstream flows; however, these current velocities are very low. Maximum near bottom velocities within this reach ranged from approximately 0 to 18 cm/s, with current velocity increasing as upstream flow increases. Near bottom current velocities were higher near the mouth of the EW and were lower to the south. The increase in near bottom velocity at the mouth of the EW, and subsequent reduction in current velocities moving upstream (and with increasing upstream flow), is due to the two-layer density-driven circulation within the EW. During incoming tide, higher salinity water flows from Elliott Bay into the relatively constricted opening of the EW at depth, which produces relatively high near bottom velocities at the mouth of the EW. As this flow moves upstream, density-driven circulation and vertical mixing of the incoming tidal waters with the lower salinity surface waters (from upstream flows) causes a reduction in near bottom velocities between the mouth and the Sill Reach in the EW (see Figures 4-27 through 4-29).

A layer of fresher water ranging in depth from about 5 to 20 feet (depending on tide and upstream flow conditions) is found at the top of the water column, with a nearly constant vertical distribution of high salinity water found from the bottom of the fresher water layer to the sediment bed. Over the tidal cycle, surface salinities range from 22 to 26 psu for mean annual flow and 14 to 18 psu for 100-year high-flow event. Bottom salinities range from 30 to 31 psu for mean annual and 100-year high-flow event (see Figures 4-21 through 4-29).

4.5.2 The Junction Reach

The Junction Reach is characterized by high surface current velocities (compared to the Main Body Reach) with a distinct top to bottom salinity stratification during most flow conditions. Current velocity magnitudes at the surface range from approximately 0 to 90

cm/s, with higher velocities occurring during ebb tide at higher upstream flows. Surface water does flow upstream into the LDW during low flow conditions at flood tide; however, these current velocities are quite low. Maximum near bottom velocities range from 0 to 10 cm/s and are generally consistent throughout the reach. Near bottom velocities are highest during ebb tide, increase with increasing upstream flow rate, and are affected by the pervasive two-layer flow that exists in this reach, as well as the majority of the EW (see Figures 4-27 to 4-29). Upstream flow of higher salinity water in the bottom layers (compared to surface layer salinities) confine high downstream current velocities (due to upstream freshwater input) to the surface layers. This results in lower near bottom current velocities in the Junction Reach than would be expected if the system had single-layer flow (no flow reversal at depth) (see Section 4.5).

A layer of fresher water is found at the top of the water column with a nearly constant vertical distribution of higher salinity water found at the bottom of the water column. The thickness of the freshwater layer, and top to bottom salinity differences, vary with upstream flow conditions. During periods of high flow, lower salinity water can encompass most of the water column. Top to bottom salinity ranges from 0 to 22 psu for mean annual flow and 0 to 14 psu for 100-year high-flow events (see Figures 4-21 through 4-29).

4.5.3 The Sill Reach

The Sill Reach is similar to the Junction Reach in both current velocity structure and salinity distribution. The Sill Reach is characterized by shallow water (approximately 6 feet MSL at its most shallow) with no defined deeper channel, which is present in the Junction Reach. Surface current velocities have similar magnitudes to the Junction Reach and react similarly to increases in upstream flow and tidal conditions. Maximum near bottom velocities within the Sill Reach are slightly lower than in the Junction Reach and range from 0 cm/s to approximately 7 cm/s. This difference between the two reaches is caused by the increased width of the Sill Reach. Salinity distribution within the Sill Reach is also similar to the Junction Reach; however, bottom salinities remain slightly higher than in the Junction Reach for all flow conditions. Top to bottom salinity ranges from 0 to 22 psu for mean annual flow and 0 to 18 psu for 100-year high-flow event (see Figures 4-21 through 4-29). Near bottom current velocities within the Sill Reach are similar to the Junction Reach, in

that they are also affected by the pervasive two-layer flow that is characteristic of the EW (see Figures 4-27 to 4-29). Therefore, near bottom current velocities in this reach are lower than would be expected if the system were riverine (as opposed to estuarine).

5 PROPWASH MODELING AND VESSEL OPERATIONS IN THE EAST WATERWAY

Major vessel hydrodynamic characteristics that can have an impact on the mobility of bottom and slope sediment include propwash, vessel wakes, and pressure fields. Impact analysis from vessel hydrodynamics on bottom sediment was limited herein to propwash and pressure fields only. Due to low vessel speeds, impacts from ship wakes are expected to be minimal except along armored side slopes in the Main Body Reach of the EW and in the Sill and Junction Reaches where water depths are shallow. Estimates of ship wakes are provided in this section of the report; however, an analysis of their effect on sediment mobility will be completed as part of the FS.

5.1 Propwash Modeling

5.1.1 Overview of Technical Approach

The first step in estimating the magnitude and location of bottom scour due to ship propulsion (e.g., ship propellers) is to simulate the current velocity pattern created by the propulsion source installed on the ship, incorporating the channel depth at separate locations in the waterway. The second step is to apply the maximum near-bed velocity in each location to determine the bed shear stress and sediment size at threshold of motion.

The modeling tool applied to determine near-bed velocities is the two-dimensional (2-D) model JETWASH (CHE 2003). The JETWASH model simulates the velocity field created by propulsion systems and accounts for the interaction of the velocity jet with the sediment bed. The model and data requirements were briefly summarized in the STEAM (Anchor and Battelle 2008a). The JETWASH model is based on a well-established and empirically verified theory of flow produced by a momentum jet. The JETWASH model has been implemented by EPA Region 8 and USACE for the analysis of sediment stability under impact from propwash of vessels ranging in size from small recreational boats to large ships (CHE 2007). JETWASH has also been successfully applied to studies of ships equipped with thrusters.

The velocity distribution through the water column (due to propwash) in JETWASH is modeled by a Gaussian distribution, as described by Albertson et al. (1948), which is used in most other propwash models, including that developed by the USACE (Maynord 2000). The vertical distribution of velocity is calculated from the water surface to a height of 26 cm off

the seabed (CHE 2003). The logarithmic distribution assumption is then applied in JETWASH to extrapolate velocities below 26 cm (USACE 2002). The height above bottom of 26 cm for the model output was selected because at this distance (26 cm), JETWASH was calibrated in a number of field experiments and proved to be a reliable predictor for propwash velocity (CHE 2003).

The JETWASH model assumes a fully developed boundary layer (steady-state conditions) for prediction of bed velocities, and does not explicitly account for velocities produced within a developing boundary layer. This assumption may reduce the computed shear stresses at the bottom layer, depending on local site conditions. However, it should be noted that at present, no methods exist for assessing boundary layer development for conditions such as propeller wash impinging on the sediment bed. Analytical (computational) tests conducted previously with JETWASH concluded that the conservative assumptions built into the model compensate for the deficiency of not accounting for a developing boundary layer. The test was conducted assuming that shear stress at the bottom is proportional to bottom flow velocity at a small distance above the bed. The test consisted of computing velocities with JETWASH for cases with a near bottom boundary and with no bottom boundary (bottom was lowered to indefinite depth). The computational test description and results are provided in Appendix H, Attachment 1.

Shear stresses developed in the near-bed propwash velocity field were calculated using the assumptions of rough, turbulent flow and logarithmic velocity profile. Sediment stability (or threshold of initiation of motion) is assumed to be related to sediment critical shear stress (threshold) through the Shields parameter (Vanoni 2006). The bottom roughness was estimated as described in Section 6.2.1.1 and shown in Equation 6-9, and is thus consistent with bottom roughness values used to estimate bed shear stress due to tidal and riverine currents. More detailed discussion on shear stress computation procedure, including input parameters, is presented in a technical memorandum produced by Coast and Harbor Engineering (July 14, 2011; provided in Appendix H, Attachment 2).

5.1.2 Development of Propwash Operational Areas (Segmentation)

Typical and extreme vessel operations within the EW were developed through interviews and personal conversations with various organizations, agencies, and companies that operate vessels within the EW. Table 5-1 provides a list of these information sources and dates of communication.

Table 5-1
Information Sources used to Develop Vessel Operation Areas

Type of Information	Organizational Source	Individual Source	Communication Date(s)
Ship and Tug Operations	Puget Sound Pilots Association	Captain Jonathan Ward and Captain Eric VonBrandenfels	January 2011/February 2011
USCG Operations	USCG	Bobbie Battaglia (Environmental Branch Chief) and Randy Sommerville, (Port Services Division Officer)	February 2011
Barge and Tug Operations	Harley Marine (formerly Olympic Tug and Barge)	Don Meberg	February 7, 2011
General Vessel Operations and Future Vessel Operations	Port of Seattle	Eric Hanson and Doug Hotchkiss	January 2011 through March 2011
Vessel Operations in Junction Reach	Harbor Island Marina	Kathy Goodman	February 2011

Information on vessel types and typical and extreme vessel operations during berthing and navigation with the EW were compiled from the various sources shown in Table 5-1. This information was used to develop operational areas within the EW where vessel operations were similar. Figure 5-1 provides a map of the operational areas developed for the EW through this process.

Within each of these operational areas, anticipated extreme vessel operation scenarios (with respect to potential for erosion due to propwash) were chosen as representative of that operational area. These vessel operations do not represent typical fair weather operating procedures; instead they represent berthing and navigation operations in high winds, high currents, or other atypical environmental conditions within the EW. These propwash

scenarios are adequate to meet the purpose of the STER, which is to evaluate the overall feasibility of the project. They do not represent "worst case" or emergency operations that could result in deep vertical mixing of bed sediments, such as vessel maneuvers required to avoid collision, vessel grounding, or similar. Additional evaluation will be conducted during the remedial design phase of the project to address impacts on bed sediments of these types of extreme events on design.

This process resulted in a list of extreme vessel operations by operational area (shown in Figure 5-1), which were used to develop site-specific propwash modeling scenarios for the purpose of evaluating erosion potential due to vessel operations in the EW. This list is provided in Table 5-2, and includes type of vessel, vessel characteristics, vessel maneuvers, representative water depths, and anticipated operational power during maneuvers.

Table 5-2
Vessel Operations within each Operational Area in the East Waterway

Propwash Area	Terminals	EW Station		Bathy Range (feet MLLW)[a]		Type of Ship(s)[b]	Types of Tugs[c]	Tug Operations		Ship Operations	
		Start	End	low end	high end			Description	Max. Power (operational)	Description	Max. Power (operational)
1A (berthing)	18, 30	0	4800	-54	-50	Large and small container vessels	4,000 to 5,500 HP	Ships are brought in bow first along Terminal 18. Two tugs use lines fore and aft of the ship. Ships are turned in Elliott Bay (outside of the EW) and brought in stern first for Terminal 30. Two tugs use lines fore and aft of the ship. Bow thrusters of ship are used as "rudder" to help steer ship as it is brought in.	50% or more	Bow thrusters are used 15-35% of time coming into the waterway, and 50% of time leaving the waterway for "short bursts" of power. During "pinning," bow thrusters are sometimes used; hard to quantify frequency and power. Main props are used 60-80% of the time while in waterway at "dead slow" (10% power)	100% (bow thrusters) 10% (main prop)
1B (in channel operation)	18, 30	0	4800	-54	-50	Large and small container vessels	4,000 to 5,500 HP	Ships are brought in bow first along Terminal 18. Two tugs use lines fore and aft of the ship. Ships are turned in Elliott Bay (outside of the EW) and brought in stern first for Terminal 30. Two tugs use lines fore and aft of the ship.	30-50%	(none)	(none)
1C (no berthing)	n/a	0	1500	-54	-50	No berthing in this area	No berthing in this area	Potential for some overlap with in-waterway maneuvers in Area 1B and from berthing operations in Area 1A	Potential for some overlap with in-waterway maneuvers in Area 1B and from berthing operations in Area 1A	Potential for some overlap with in-waterway maneuvers in Area 1B and from berthing operations in Area 1A	Potential for some overlap with in-waterway maneuvers in Area 1B and from berthing operations in Area 1A
2 (berthing)	Slip 36	0E	200E	-40	-40	USGC 378-foot High Performance Cutter and *Polar* Class Icebreaker (~400 feet). Other smaller vessels down to ~87 feet in length. Berthing may be tug–assisted.	Similar types used in other areas of the EW— 11 different tugs (1,350 to 4,400 HP).	Some vessels use one tug; others use two tugs.	Used similar operating criteria as Area 6. Within the waterway, 30%; while docking, 50% (based on conversations with USCG).	Based on discussions with USGC, come in at very slow speed under their own power (or tug-assisted). Can be placed anywhere in the slip depending on availability.	Used upper limit as 25% for both the High Performance Cutter and *Polar* Class Icebreaker (based on conversations with USCG).

Propwash Area	Terminals	EW Station		Bathy Range (feet MLLW)[a]		Type of Ship(s)[b]	Types of Tugs[c]	Tug Operations		Ship Operations	
		Start	End	low end	high end			Description	Max. Power (operational)	Description	Max. Power (operational)
3 (berthing)	Slip 27	3600	4200	-40	-30	North edge: Tugs and empty barges; may be used for vessel storage in the future South edge: Barge for Boeing plane parts (travels to Everett)	(Estimate operational criteria from Area 4)	(Estimate berthing operational criteria from Area 6)	(Estimate berthing operational criteria from Area 6)	(Estimate berthing operational criteria from Area 6)	(Estimate berthing operational criteria from Area 6)
4A (berthing) - current operations	25 (now called south T30)	3600	5700	-40	-40	Far south end of Area used to be Olympic Tug and Barge (now Harley Marine Services) Tugs and barges	11 different tugs (1,350 to 4,400 HP)	Typically use two tugs to move barges down the waterway.	Within the waterway, 30%; while making up lines, briefly 50%	n/a	n/a
4A (berthing) - future operations)	25 (now called south T30)	3600	5700	-46	-46	Small Container vessels	4,000 to 5,500 HP	Ships are brought in bow first along Terminal 18. Two tugs use lines fore and aft of the ship. Ships are turned in Elliott Bay (outside of the EW) and brought in stern first for Terminal 30. Two tugs use lines fore and aft of the ship. Bow thrusters of ship are used as "rudder" to help steer ship as it is brought in.	While operating within the waterway, 30-50% power; while docking, 50% or more	Bow thrusters are used 15-35% of time coming into the waterway, and 50% of time leaving the waterway for "short bursts" of power. During "pinning," bow thrusters are sometimes used; hard to quantify frequency and power. Main props are used 60-80% of the time while in waterway at "dead slow" (10% power)	30-50% (bow thrusters) 10% (main prop)
4B (in channel operation)	25 (now called south T30)	3600	5700	-40	-40	In channel operations from vessels that berth in Areas 4A, 5, and 6 Tugs and barges	In channel operations from vessels that berth in Areas 4A, 5, and 6 Tugs and barges	In channel operations from vessels that berth in Areas 4A, 5, and 6 Tugs and barges	In channel operations from vessels that berth in Areas 4A, 5, and 6 Tugs and barges	In channel operations from vessels that berth in Areas 4A, 5, and 6 Tugs and barges	In channel operations from vessels that berth in Areas 4A, 5, and 6 Tugs and barges
5 (berthing)	n/a	4900 (west)	5800 (west)	-40	-40	~600-foot ships (bulk carriers) docking under tug power only; turn around within the EW. Four times per year - molasses bulk.	4,000 to 5,500 HP	Two tugs are used; ships are turned within the EW.	Within the waterway, 30-50% power; while docking, 50% or more	~600-foot ships - bulk carrier	30-50% (bow thrusters) 10% (main prop)
6 (berthing)	n/a	6150 (west)	7050 (west)	-40	-20	Leased by Olympic Tug and Barge (now Harley Marine Services) Tugs and barges	11 different tugs (1,350 to 4,400 HP)	Typically use two tugs to move barges down the waterway.	Within the waterway, 30%; while making up lines, briefly 50%	n/a	n/a

Propwash Area	Terminals	EW Station		Bathy Range (feet MLLW)[a]		Type of Ship(s)[b]	Types of Tugs[c]	Tug Operations		Ship Operations	
		Start	End	low end	high end			Description	Max. Power (operational)	Description	Max. Power (operational)
7 (no berthing)	n/a	6150 (east)	7050 (east)	-40	-30	No berthing in this area	No berthing in this area	Potential for some overlap from operations in Area 6	Potential for some overlap from operations in Area 6	Potential for some overlap from operations in Area 6	Potential for some overlap from operations in Area 6
8 (berthing)	Harbor Island Marina - Lateral dock in EW	7200 (west)	7600 (west)	-30	-15	Tugs, barges, and towboats 94 to 110 feet (complete list available)	Prudhoe Bay tug	Moorage	Minimal (assumed to be less than 25%)	n/a	n/a

Notes:
a. Excluding underdock areas because slopes are all armored. Representative of most of the propwash area.
b. Ship inventory available
c. Tug inventory available

5.1.3 Test Matrix and List of Scenarios

Fifteen scenarios were developed for analyzing propwash effects based on the list of vessel operations provided in Table 5-2. The scenarios consist of maneuvers for: 1) docking, undocking, and navigating the waterway; 2) using a ship's main power and thrusters; and 3) using various types of tugs. Additional specifics regarding vessel characteristics (e.g., length, depth, and draft) and propulsion were collected from public information obtained from the shipping line, tug companies, and Coast and Harbor Engineering archives.

All simulations assumed a tidal elevation of MLLW. This will result in conservatively high estimates of near-bed velocity and bed shear stress due to propwash because it represents the case where the ship's propulsion system is closest to the bed. Simulations of all vessels, including tugs, in the docking and undocking maneuvers assumed that the source of propwash was stationary. Tugs transiting the waterway were assumed to have a speed of 4 knots, which represents safe operating speeds within the EW based on interviews with tug pilots. The 15 simulation scenarios and pertinent model input parameters are listed in Table 5-3.

Table 5-3
Propwash Modeling Scenarios for East Waterway

Scenario Number	Propwash Area/Terminal	Depth at MLLW (feet)	Vessel Type/Name	Maneuver	Propulsion Type	Available Power (%)
1	Area 1A Berths 1 and 2 Terminal 18	50	Container *Xin Mei Zhou*	Docking	Ship's main power	10
2	Area 1A Berths 1 and 2 Terminal 18	50	Container *Xin Mei Zhou*	Undocking	Bow thruster	100
3	Areas 1A and 1B All Berths Terminal 18	50	Tractor Tug *Garth Foss*	Docking a container ship	Voith-Schneider	75
4	Area 1A Berths 3 and 4 Terminal 30	50	Container *Margrit Rickmers*	Docking	Ship's main power	10

Scenario Number	Propwash Area/Terminal	Depth at MLLW (feet)	Vessel Type/Name	Maneuver	Propulsion Type	Available Power (%)
5	Area 1A Berths 3 and 4 Terminal 30	50	Container *Margrit Rickmers*	Undocking	Bow thruster	100
6	Area 2 Slip 36	40	USCG Icebreaker *Polar Star*	Docking	3 controllable pitch props	50
7	Area 2 Slip 36	40	USCG Cutter *Hamilton* Class	Docking	2 controllable pitch props	50
8	Area 3 Slip 27	30	Tug *Hunter D*	Docking a barge	2 standard props	50
9	Areas 4, 4A, 4B, and 5 South Terminal 30	40	Tug *Eagle*	Docking a barge	Twin ducted props	75
10	Area 6	20	Tug *Eagle*	Docking a barge	Twin ducted props	50
11	Area 7	30	Tug *Eagle*	Maneuverin g with Barge	Twin ducted props	50
12	Area 8	20	Tug *Alaska Mariner*	Docking	Twin props	50
13	Areas 1B and 1C Terminals 18 and 30	50	Tractor Tug *Garth Foss*	Navigation through EW	Voith-Schneider	50
14	Area 4A (future condition)	46	Container *Margrit Rickmers*	Docking	Ship's main power	10
15	Area 4A (future condition)	46	Container *Margrit Rickmers*	Undocking	Bow thruster	100

5.1.4 Results

Near-bed propwash velocity and associated shear stresses were evaluated for each scenario listed in Table 5-3. These results are summarized in the following sections. Velocities and shear stresses estimated for each scenario were applied to the entire operational area in which that scenario occurs.

The JETWASH model was used to estimate near-bed velocity, and bottom roughness values provided in Table 6-4 were used to evaluate bed shear stress associated with predicted near-bed velocities. A detailed description of this methodology is provided in Section 6.2.1.1 and a technical memorandum produced by Coast and Harbor Engineering (July 14, 2011; provided in Appendix H).

5.1.4.1 Scenario 1 – Area 1A, Terminal 18 Berths 1 and 2 (Main Ship Propulsion)

The largest container ships that utilize the EW call at Terminal 18, Berths 1 and 2, and were represented by the *Xin Mei Zhou*, a 102,500 deadweight tonnage (DWT) vessel with a capacity of 8,530 twenty-foot equivalent units (TEU). Propwash generated by the ship's main propulsion was simulated for Scenario 1. The area of propwash modeling was Berths 1 and 2 of Terminal 18, as shown in Figure 5-2. In simulating propwash, the *Xin Mei Zhou* was assumed to be drafted to 46 feet, corresponding to a minimum under-keel clearance of 4 feet. Predicted propwash velocity generated by the ship's main propulsion during docking is shown in Figure 5-2, which shows the horizontal plane of the pattern of near-bed velocity. The maximum near-bed velocity predicted by the model is 9.3 feet per second (ft/s). The bed shear stress corresponding to this velocity is 0.32 pounds per square foot (lb/ft^2) (15 Pa).

5.1.4.2 Scenario 2 – Area 1A, Terminal 18 Berths 1 and 2 (Bow Thruster)

For this scenario, the *Xin Mei Zhou* was assumed to undock using the bow thruster at full power. All container ships operating in the waterway were assumed to be fitted with a bow thruster, and the *Xin Mei Zhou* represents the most powerful thruster located closest to the sediment bed. For conservatively examining near-bed velocity, the vessel draft upon departing was assumed to be 46 feet. A diagram illustrating the size and location of a bow thruster on a container ship is shown in Figure 5-3. Thruster wash generated by the bow thruster was simulated in Scenario 2. Predicted velocity generated by the ship's thruster during undocking is shown in Figure 5-4, which shows the horizontal plane of the pattern of near-bed velocity toward the berth. The maximum near-bed velocity is 11.4 ft/s. The bed shear stress corresponding to this velocity is 0.48 lb/ft^2 (23 Pa).

5.1.4.3 Scenario 3 – Areas 1A and 1B, Terminal 18 Berths 1 and 2 (Tug Operations)

Tugs assisting container ships during docking, undocking, and navigating in the waterway are represented by the *Garth Foss*. This tug is powered by Voith-Schneider propulsors and can output 5,000 horsepower. Propwash generated by the two propulsors is simulated in Scenario 3. Predicted near-bed velocity generated by the tug during application of 50% power is shown in Figure 5-5, which shows the horizontal plane of the pattern of near-bed velocity. The maximum near-bed velocity is 3.6 ft/s. The bed shear stress corresponding to this velocity is 0.05 lb/ft^2 (2 Pa).

5.1.4.4 Scenario 4 – Area 1A, Terminal 18 Berths 3 and 4; Terminal 30 (Main Ship Propulsion)

A container ship representing vessels calling at Terminal 18, Berths 3 and 4, and at Terminal 30 is the *Margrit Rickmers*, a 67,600 DWT vessel. This ship has a capacity of 5,080 TEU. The maximum draft is 39 feet. Propwash generated by this ship's main propulsion was simulated for Scenario 4. The area of propwash modeling was Terminal 18, Berths 3 and 4, and Terminal 30 in Area 1, as shown in Figure 5-6. Predicted propwash velocity generated by the ship's main propulsion during docking is shown in Figure 5-6, which shows the horizontal plane of the pattern of near-bed velocity. The maximum near-bed velocity is 6.3 ft/s. The bed shear stress corresponding to this velocity is 0.15 lb/ft^2 (7 Pa).

5.1.4.5 Scenario 5 – Area 1A, Terminal 18 Berths 3 and 4; Terminal 30 (Bow Thruster)

The vessel *Margrit Rickmers* is assumed to undock using the bow thruster at full power. The position and dimensions of the bow thruster are shown in Figure 5-3. Thruster wash generated by the bow thruster was simulated in Scenario 5. For conservatively examining propwash-generated near-bed velocity, the vessel draft upon departing was assumed to be the same as when arriving (39 feet). The area of propwash modeling was Berths 3 and 4 of Terminal 18 and all of Terminal 30 in Area 1, as shown in Figure 5-7. Predicted velocity generated by the ship's thruster during undocking is shown in Figure 5-7, which shows the horizontal plane of the pattern of near-bed velocity toward the berth. The maximum near-

bed velocity is 7.1 ft/s. The bed shear stress corresponding to this velocity is 0.19 lb/ft^2 (9 Pa).

*5.1.4.6 Scenario 6 – Area 2, Slip 36 (*Polar *Class Icebreaker)*

USCG vessels identified as sources of propwash that may have the potential for initiating bed sediment movement in Area 2 are the *Polar* class icebreakers and the *Hamilton* class high-endurance cutters. The icebreakers have a loaded draft of 32 feet, and have three controllable pitch propellers. The area of propwash modeling is Slip 36, as shown in Figure 5-8. Predicted propwash velocity generated by the main propulsion of the *Polar* class icebreaker during docking is shown in Figure 5-8, which shows the horizontal plane of the pattern of near-bed velocity. The maximum near-bed velocity is 6.5 ft/s. The bed shear stress corresponding to this velocity is 0.16 lb/ft^2 (8 Pa).

*5.1.4.7 Scenario 7 – Area 2, Slip 36 (*Hamilton *Class USCG Cutter)*

The *Hamilton* class USCG cutter has a draft of 20 feet and has twin controllable pitch propellers, which was simulated to determine the potential for initiating bed sediment movement in Area 2. These cutters are fitted with retractable thrusters that are capable of outputting 350 horsepower, which were not simulated because the power is small relative to the main propulsion. The area of propwash modeling is Slip 36, as shown in Figure 5-9. Predicted propwash velocity generated by the main propulsion of the *Hamilton* class cutter during docking is shown in Figure 5-9, which shows the horizontal plane of the pattern of near-bed velocity. The maximum near-bed velocity is 4.5 ft/s. The bed shear stress corresponding to this velocity is 0.08 lb/ft^2 (4 Pa).

5.1.4.8 Scenario 8 – Area 3, Slip 27 (Tug Operations)

Vessel activity at Area 3 consists of tugs, represented by the *Hunter D,* moving barges to and from the slip. This tug has a draft of 14 feet and is powered by two engines that can develop 3,420 horsepower each. The area of propwash modeling is Slip 27, as shown in Figure 5-10. Predicted propwash velocity generated by the *Hunter D* during maneuvering is shown in Figure 5-10, which shows the horizontal plane of the pattern of near-bed velocity. The maximum near-bed velocity is 3.0 ft/s. The bed shear stress corresponding to this velocity is 0.03 lb/ft^2 (2 Pa).

5.1.4.9 Scenario 9 – Areas 4, 4A, 4B, and 5 (Tug Operations)

The *Eagle* represents tugs that maneuver barges at South Terminal 30 (Area 4), and that assist bulk carriers that call at the south end of Terminal 18 (Area 5). The *Eagle* has a draft of 17 feet and is powered by two engines that can develop 3,000 horsepower each. The tug is assumed to apply 75% of available power in these two areas. Areas 4 and 5 for propwash modeling are shown in Figure 5-11. Sediment bed elevation in both areas is -40 feet MLLW. Predicted propwash velocity generated by the *Eagle* during maneuvering is shown in Figure 5-11, which shows the horizontal plane of the pattern of near-bed velocity. The maximum near-bed velocity is 3.0 ft/s. The bed shear stress corresponding to this velocity is 0.03 lb/ft^2 (2 Pa).

5.1.4.10 Scenario 10 – Area 6 (Tug Operations)

The *Eagle* represents tugs that maneuver at the west side of the EW north of the West Seattle Bridge (Area 6). The *Eagle* is assumed to apply 50% of available power in this area. Sediment bed elevation in this area is -20 feet MLLW. Predicted propwash velocity generated by the *Eagle* during maneuvering is shown in Figure 5-12, which shows the horizontal plane of the pattern of near-bed velocity. The maximum near-bed velocity is 11 ft/s. The bed shear stress corresponding to this velocity is 0.45 lb/ft^2 (22 Pa).

5.1.4.11 Scenario 11 – Area 7 (Tug Operations)

The *Eagle* represents tugs that transit the eastern part of the EW north of the bridges (Area 7). The *Eagle* is assumed to apply 50% of available power in this area. Bed elevation in this area is -30 feet MLLW. Area 7 for propwash modeling is shown in Figure 5-13. Predicted propwash velocity generated by the *Eagle* during maneuvering is shown in Figure 5-13, which shows the horizontal plane of the pattern of near-bed velocity. The maximum near-bed velocity is 4.7 ft/s. The bed shear stress corresponding to this velocity is 0.08 lb/ft^2 (4 Pa).

5.1.4.12 Scenario 12 – Area 8 (Tug Operations)

The tug *Alaska Mariner* represents the largest of the Western Towboat fleet that moors in Area 8. This tug has a draft of 14 feet and is powered by twin engines, each producing 2,260 horsepower. The area of propwash modeling is shown in Figure 5-14. Sediment bed elevation in this area is -20 feet MLLW. Predicted propwash velocity generated by the *Alaska Mariner* during maneuvering in Area 8 is shown in Figure 5-14, which shows the horizontal plane of the pattern of near-bed velocity. The maximum near-bed velocity is 4.2 ft/s. The bed shear stress corresponding to this velocity is 0.07 lb/ft^2 (3 Pa).

5.1.4.13 Scenario 13 – Areas 1B and 1C, Navigating in East Waterway (Tug Operations)

Container ships mooring at Terminal 18 and 30 are moved into the EW bow-first by at least two tugs. Tugs are at the bow and stern, and the ship's thruster aids in steering the ship in the waterway. Container ships mooring at Terminal 30 enter the EW stern-first, under the assistance of at least two tugs. The *Garth Foss* represents tugs that assist ships in the EW. Tug speed is assumed to be 4 knots, and the maximum power applied while moving a ship into or out of the EW is assumed to be 50% of available power. Predicted propwash velocity generated by the *Garth Foss* during assisting in Area 1 (bed elevation in this area is -50 feet MLLW) is shown in Figure 5-15, which shows the horizontal plane of the pattern of near-bed velocity. The maximum near-bed velocity is 3.0 ft/s. The bed shear stress corresponding to this velocity is 0.03 lb/ft^2 (2 Pa).

5.1.4.14 Scenario 14 – Area 4A, Future Condition of Small Container Ship (Main Propulsion)

Scenario 14 was developed to represent future conditions at South Terminal 30. It is assumed that the berthing area at the terminal would have a minimum depth of 46 feet (at MLLW) to accommodate a container ship such as the *Margrit Rickmers*, a 67,550 DWT and 5,080 TEU capacity vessel. The maximum draft of the ship for this scenario is assumed to be 39 feet.

Predicted propwash velocity generated by the ship's main propulsion during docking is shown in Figure 5-16. The figure shows the horizontal plane of the pattern of near-bed

velocity. The maximum near-bed velocity is 7.0 ft/s. The bed shear stress corresponding to this velocity is 0.18 lb/ft^2 (9 Pa).

5.1.4.15 Scenario 15 – Future Condition of Small Container Ship in Area 4A (Bow Thruster)

Scenario 15, similar to Scenario 14, was also developed to represent future conditions at South Terminal 30 with a representative depth of 46 feet. The container vessel *Margrit Rickmers* is assumed to undock using the bow thruster at full power. For conservatively examining propwash-generated bed velocity, the vessel draft upon departing was assumed to be the same as when arriving.

Predicted velocity generated by the ship's thruster during undocking is shown in Figure 5-17. The figure shows the horizontal plane of the pattern of near-bed velocity toward the berth. The maximum near-bed velocity is 9.0 ft/s. The bed shear stress corresponding to this velocity is 0.30 lb/ft^2 (14 Pa).

5.2 Summary of Results

Maximum near-bed velocities and bed shear stresses within each of the operating areas shown in Figure 5-1 were evaluated by choosing the maximum values from the 15 different scenarios described in Section 5.1. Table 5-4 provides a summary of these values for each operating area. It is important to note that the boundary between operational Area 1B (navigational area) and the berthing areas adjacent to Terminals 18 and 30 (Area 1A) is an approximation based on our current understanding of vessel operations within the EW. The estimated shear stress value of 2 Pa in Area 1B (navigation area) is representative of typical transiting maneuvers in the navigation channel; however, the navigation channel is expected to experience a range of shear stresses due to adjacent berthing maneuvers. Therefore, it is possible that portions of the navigation channel (Area 1B) along this boundary may experience higher bed shear stress than estimated in Table 5-4 (2 Pa).

Area 4 has values associated with current operations (Scenario 9) and future planned operations (Scenario 15). Figure 5-18 provides maximum near-bed velocities based on current and future operating conditions (Area 4). Figure 5-19 provides maximum bed shear

stresses for the same conditions. Evaluation of erosion potential due to propwash is discussed in Section 6.3.

Table 5-4
Summary of Maximum Near-Bed Velocities and Bed Shear Stresses Due to Propwash

Operating Area (see Figure 5-1)	Scenario in Area Resulting in Maximum Near-Bed Velocity (see Table 5-3)	Maximum Near-Bed Velocity ft/s	Maximum Bed Shear Stress lb/ft^2(Pa)
Terminal 18, Berths 1 and 2 Area 1A	Scenario 2	11.4	0.48 (23 Pa)
Terminal 18, Berths 3 and 4 Area 1A	Scenario 5	7.1	0.19 (9 Pa)
Area 1B	Scenario 13	3.0	0.03 (2.0 Pa)
Area 1C	Scenario 13	3.0	0.03 (2.0 Pa)
Slip 36 Area 2	Scenario 6	6.5	0.16 (8.0 Pa)
Slip 27 Area 3	Scenario 8	3.0	0.03 (2.0 Pa)
South Terminal 30 Area 4A [a]	Scenario 9 (Future Conditions - Scenario 15)	3.0 (Future Conditions - 9.0)	0.03 (2.0 Pa) (Future conditions - 0.30 [14 Pa])
South Terminal 30 Area 4	Scenario 9	3.0	0.03 (2.0 Pa)
Area 4B	Scenario 9	3.0	0.03 (2.0 Pa)
Area 5	Scenario 9	3.0	0.03 (2.0 Pa)
Area 6	Scenario 10	10.6	0.45 (22 Pa)
Area 7	Scenario 11	4.7	0.08 (4 Pa)
Area 8	Scenario 12	4.2	0.07 (3 Pa)

Note:
a Operational Conditions in Area 4A may change in the future. These future conditions are described in Scenario 15.

5.3 Pressure Field Evaluation

As a vessel moves through a waterway it produces a depression in the water surface and generates return currents around the vessel. Near-bed currents generated beneath a moving vessel can be an agent for mobilizing sediment on the sediment bed if the velocity is of sufficient magnitude. Within the EW, these velocities are expected to be small compared to velocities produced by propwash, as described in Section 5.1. In addition, velocities generated by the pressure fields are directed along the direction of ship movement, which is opposite the direction of bed velocities due to propwash. (In addition, velocities due to pressure fields are spatially separate from those produced by propwash.) In order to validate this assumption, near-bed velocities generated by a ship being assisted by a tug are discussed in this section.

5.3.1 Overview of Technical Approach

Hydrodynamic forces generated by the pressure field of a vessel were calculated using the Vessel Hydrodynamics Longwave Unsteady (VH-LU) model (Shepsis et al. 2001). The VH-LU model predicts water level and velocity fluctuations surrounding a moving ship and the resulting velocity beneath the hull. The main factors that determine the magnitude of the pressure wave generated by the moving vessel are the ship's length, beam, draft, shape, and speed at which it moves relative to the water.

A container ship representative of those calling at Berths 3 and 4 of Terminal 18 and the assisting tug were the vessels selected for pressure field analysis. Results of the analysis include near-bed velocity as the vessel passes above. Channel depth and dimensions are nearly uniform along the length of the EW. Therefore, the vessel-induced near-bed velocity at one location along the sailing line is similar to that at other locations, and a single snapshot of velocity pattern is sufficient to characterize conditions in the waterway. Figures 1-3A and 1-3B show the bathymetry within the navigation channel alongside Terminal 18. Vessel speed while moving in the EW is assumed to be 4 knots or less.

5.3.2 Evaluation and Results

Figure 5-20 shows the predicted velocity from the pressure-field modeling at a single location for a container ship moving inbound along the channel centerline at 4 knots. For this container ship simulation, the maximum near-bed velocity relative to the stationary bed was 1.3 ft/s, averaged in the 13-foot vertical distance between the hull and the bottom. Bed shear stress associated with this velocity is 0.30 Pa (0.0063 lb/ft^2). This value falls within the range of estimated critical shear stress values for bed sediments in the EW (0.20 to 0.37 Pa); therefore, velocities due to pressure fields are not expected to cause significant movement of surface sediments in the EW. In addition, bed shear stress due to pressure fields are 85% lower than the lowest estimated value of bed shear stress due to propwash (2 Pa).

Figure 5-21 shows the predicted water velocity induced by tug movement that would assist the ship in the EW. The assumed tug characteristics are those listed in Tables 5-3 for Area 1. For this simulation, the maximum near-bed velocity relative to the stationary bed was less than 1.3 ft/s, averaged in the 36-foot vertical distance between the tug hull and the sediment bed.

For all cases, the near-bed velocity due to pressure fields (1.3 ft/s) was less than the near-bed velocities predicted due to propwash throughout the EW (3.0 ft/s and greater). While these are significant velocities compared to riverine and tidal current velocities (see Section 4), they are smaller than velocities produced by propwash activities. Therefore, pressure fields due to ship movement are of secondary importance for sediment mobility in the EW when compared to propwash activities.

5.4 Vessel Wake Evaluation

Impacts to the sediment bed due to ship wakes are expected to be minimal in the navigation areas within the EW. However, at lower tidal elevations, wakes from faster-moving tugs may impact sediments overlying armored side slopes and non-armored slopes in the Main Body Reach and the sediment bed within shallow areas of the Sill and Junction Reaches. Wake heights over a range of tug operating conditions were evaluated and are provided in this section of the report. Impacts to sediment mobility in areas of concern for wakes will be completed as part of the FS.

5.4.1 Overview of Technical Approach

Wave height and steepness were estimated for wakes produced by the tug *Garth Foss* (see Table 5-3, Area 1, for tug characteristics). The *Garth Foss* has a length of 94 feet, a beam of 36 feet, a draft of 17 feet, and a gross tonnage of 194 tons. This information was input into a ship wave prediction model based on methodology developed by Weggel and Sorensen (1986).

5.4.2 Evaluation and Results

Since operating conditions of tugs within the EW are variable (especially when not assisting other larger ships) wakes were estimated using a range of reasonable expected vessel speeds and locations within the navigation channel. There is no documented speed limit within the EW; therefore, ranges of tug speed were chosen based on discussion with pilots and tug operators within the EW. Sail distances (distance from the moving tug to the shoreline of the EW) between 100 and 365 feet represent the tug operating in the wider (north) section of the EW. Sail distances of 50 to 75 feet represent operation in the narrower section (south). Wakes are affected by water depths; therefore, a range of water depths over the tidal cycle were used to evaluate wake heights. Table 5-5 lists predicted wave heights for the different scenarios.

Table 5-5
Wake Heights Estimated in the East Waterway

Water Depth (feet)	Speed (knots)	Distance to Sail Line (feet)	Wave Height (feet)
54	6.0	365	1.2
54	6.0	100	2.4
54	5.5	365	0.9
54	5.5	100	2.0
54	5.0	365	0.7
54	5.0	100	1.6
50	6.0	365	1.1
50	6.0	100	2.1
50	5.5	365	0.8

Water Depth (feet)	Speed (knots)	Distance to Sail Line (feet)	Wave Height (feet)
50	5.5	100	1.7
50	5.0	365	0.6
50	5.0	100	1.3
40	6.0	365	0.8
40	6.0	50	2.2
40	5.5	365	0.6
40	5.5	50	1.7
40	5.0	365	0.4
40	5.0	50	1.3
30	6.0	75	1.4
30	6.0	50	1.7
30	5.5	75	1.0
30	5.5	50	1.3
30	5.0	75	0.7
30	5.0	50	0.9
15	6.0	75	1.1
15	6.0	50	1.3
15	5.5	75	0.7
15	5.5	50	0.9
15	5.0	75	0.4
15	5.0	50	0.6

5.4.3 Uncertainty Discussion

Vessel operations information has been collected through conversations with various individuals that work within the EW including pilots, operations managers, USCG officials, Port planners, and others (Table 5-1). Therefore, uncertainty in the evaluation of erosion potential due to propwash is primarily dependent on the reliability of this information. In the case of USCG operations, conservative assumptions were made regarding power of main propulsion and bow thrusters used during berthing based on past project experience. Modeling scenarios developed for the analysis took this uncertainty into account by using conservative operational criteria for the propwash simulations based on an understanding of vessel operations. However, there is still some uncertainty in the definitions of specific vessel operation parameters for each scenario (e.g., percent power used for bow thrusters and

actual tug operations). Extreme handling situations due to emergencies and unforeseen circumstances (such as berthing of larger vessels than anticipated in locations within the EW due to an emergency, maneuvers required to avoid collision, ship grounding, or other situations) are difficult to define and quantify. Therefore, modeled scenarios have been chosen to represent extreme conditions, as defined in Section 5.1.2. These scenarios are anticipated to drive sediment mobilization in the EW (due to propwash) to a larger extent than a single emergency maneuver or event. However, additional evaluation will be conducted during the remedial design phase of the project to address impacts on bed sediments due to emergency situations, which were not included in this analysis.

Additional uncertainties include defining transitions between operational areas, understanding the duration of each operation (e.g., how long the vessel uses its bow thruster at 100% power), and choice of representative water depths for the simulations. As with uncertainties in operational information, conservative assumptions were used when developing the simulations to offset these additional uncertainties as much as possible. Simulations assumed steady state conditions for vessels transiting the EW (i.e., infinite duration of operations in one location), and water depths chosen for the simulations in each of the operational areas were conservatively low (i.e., shallower depths at MLLW within each operational area).

The JETWASH model assumes steady state conditions (i.e., fully developed boundary) that may not be a conservative assumption for berthing vessels. Boundary layer development may influence bottom shear stress and stability of bed material. The logarithmic profile of velocity, assumed by JETWASH, is appropriate for a developed boundary layer and may differ from that of the profile for a developing boundary layer. However, estimates of velocities within developing boundary layers due to propwash are still an active area of research and a subject for future fundamental studies. To account for the potential effect of a developing boundary layer, the JETWASH model uses several conservative parameters to develop velocity predictions, which are discussed in detail in Appendix H.

6 EVALUATION OF EROSION POTENTIAL WITHIN THE EAST WATERWAY

Mechanisms for erosion of bed sediments within the EW include currents due to tidal fluctuations and upstream freshwater flows and vessel operations, including propwash, pressured fields, and wakes. The potential for erosion within the EW from these various sources was estimated through a combination of hydrodynamic modeling, propwash and pressure field modeling, and evaluation of Sedflume core data collected within the EW.

Sedflume cores were collected within the EW (Section 2.4) to evaluate in situ critical shear stress of bed sediments. This evaluation is discussed in Section 6.1. Near bottom current velocities provided by the hydrodynamic model (Section 4) were used to estimate bed shear stresses within the EW due to tidal and riverine currents as described in Section 6.2. Near bottom velocities due to vessel operations (Section 5) were utilized to estimate bed shear stresses due to propwash and pressure fields as described in Section 6.3. Estimates of bed shear stresses due to tidal/riverine currents and vessel operations were compared to critical shear stresses from Sedflume cores to evaluate erosion potential within the EW.

6.1 Analysis of Sedflume Erosion Rate Data

6.1.1 Overview of Sedflume Testing

Eight Sedflume cores were collected within the EW to provide empirical estimates of critical shear stress. The discrete values of critical shear stress from the Sedflume core data were used to estimate a representative range.

Locations of the Sedflume cores are shown in Figure 2-3. Table 6-1 lists the EW station, approximate bed elevation, and water depth at each Sedflume core location. A summary of the core data collection (including any deviations from the QAPP), reports produced by Sea Engineering, and laboratory forms are provided in Appendix D. Detailed summaries outlining collection, observations, and testing of each Sedflume core are provided in the Executive Summary of the Sea Engineering report provided in Appendix D, Attachment 2.

Table 6-1
East Waterway Station and Bed Elevation at Sedflume Core Locations

Core ID	EW Station	Approximate Bed Elevation (feet MLLW)	Approximate Water Depth (feet)
SF_1	6000	-38	45
SF_2	5300	-44	47
SF_3	6500	-30	32
SF_4	7100	-6	7
SF_5	6800	-10	17
SF_6	3800	-52	52
SF_7	550	-56	57
SF_8	2000	-54	59

6.1.2 Results of Sedflume Testing (Critical Shear Stress)

Sedflume cores were tested in a mobile laboratory facility set up near the EW to measure erosion rates as a function of shear stress and depth in the core. Sedflume erosion rate data were analyzed to estimate the critical shear stress for initiation of erosion. This analysis was conducted using three different regression methods: 1) power law; 2) linear; and 3) log-linear. The power law and linear regression analyses were completed by Sea Engineering and described in their report in Appendix D), and a log-linear regression was completed by Anchor QEA and described in detail below.

The critical shear stress is defined as the shear stress needed to produce an erosion rate of 0.0001 cm/s. For each interpolation method, an equation is developed that relates erosion rate to shear stress. The value of critical shear stress can then be computed from the developed relationship by inserting an erosion rate of 0.0001 cm/s into the equation.

The log-linear regression analysis was conducted as follows. Erosion rate data obtained from Sedflume testing were analyzed to develop a relationship between erosion rate and shear stress (Jones 2000):

$$E = A\tau^n \quad \text{for } \tau > \tau_{cr} \qquad (6\text{-}1)$$
$$= 0 \qquad \text{for } \tau \leq \tau_{cr}$$

Where:

E	=	erosion rate (cm/s)
τ	=	shear stress (Pascals [Pa])
τ_{cr}	=	critical shear stress (Pa)

The parameters, A and n, are site-specific and may be spatially variable, both horizontally and vertically. The site-specific parameters, A and n, were determined using the erosion rate data collected during the Sedflume study as follows:

- Each core was divided into 5-cm-thick layers (in the vertical)
- Erosion data within each 5-cm layer of a core were analyzed using a log-linear regression analysis between erosion rate and shear stress.
- The regression analysis produced values of A and n for each 5-cm layer in a core.

Critical shear stress for each 5-cm layer was calculated using:

$$\tau_{cr} = (E_{cr} / A)^{1/n} \tag{6-2}$$

Where:

E_{cr}	=	0.0001 cm/s

Figures 6-1 through 6-8 show the results of the log-linear regression analyses for each 5-cm layer within all of the Sedflume cores. The site-specific parameters (A and n) developed from the log-linear analyses were used to estimate critical shear stress based on Equation 6-2 and are provided in Figures 6-1 through 6-8. The critical shear stress results for each core interval are listed in Table 6-2 and graphically shown in Figure 6-9.

Table 6-2
Critical Shear Stress Based on Log-Linear Regression Analysis

Vertical Interval (cm)	Critical Shear Stress (Pa)							
	Core SF_1	Core SF_2	Core SF_3	Core SF_4	Core SF_5	Core SF_6	Core SF_7	Core SF_8
0-5	0.33	0.35	0.41	0.08	0.27	0.42	0.04	0.35
5-10	0.64	0.73	0.38	0.22	0.39	0.32	0.23	0.31
10-15	0.36	0.82	0.44	NA	0.60	0.61	0.35	1.15
15-20	0.36	1.23	0.49	NA	NA	2.17	NA	NA
20-25	0.32	0.56	0.26	NA	NA	1.52	NA	NA

Note:
NA = not available due to shallow core recovery

6.1.3 Surface Critical Shear Stress Estimates for the East Waterway

In order to evaluate erosion potential within the EW, an average critical shear stress for surface sediments in the EW was developed through comparison of three estimates of critical shear stress of surface sediments developed from the results of the Sedflume evaluation as defined below:

- τ_{cr1} = Estimates of critical shear stress from power law, linear, and log-linear regression analysis using 0.0001 cm/s criteria (the erosion rate that corresponds to critical shear stress). (These values are shown in columns 2 through 4 of Table 6-3.)
- τ_{cr2} = The lowest shear stress applied during the Sedflume test for the surface interval (0 to 5 cm). (This value is shown in column 5 of Table 6-3.)
- τ_{cr3} = The lowest shear stress for which erosion occurred in the surface interval (0 to 5 cm). (This value is shown in column 6 of Table 6-3.)

Critical shear stress for surface sediments for each Sedflume core (τ_{cr}) were adjusted using the following comparison criteria (values shown in column 7 of Table 6-3):

$$\text{If } \tau_{cr2} < \tau_{cr1} < \tau_{cr3} \rightarrow \text{ Then } \tau_{cr} = \tau_{ct1} \quad (6\text{-}3)$$

$$\text{If } \tau_{cr1} < \tau_{cr2} \rightarrow \text{ Then } \tau_{cr} = \tau_{ct2} \quad (6\text{-}4)$$

$$\text{If } \tau_{cr1} > \tau_{cr3} \rightarrow \text{ Then } \tau_{cr} = \tau_{ct3} \quad (6\text{-}5)$$

These comparisons also help define uncertainty in estimates of critical shear stress due to differences in the regression analyses.

Surface critical shear stresses for each core estimated using the three regression methods and the comparison criteria described above are summarized in Table 6-3. To develop an average representative value and 95% confidence interval for critical shear stress of surface sediments within the EW, estimates of critical shear stress were averaged within each method and the standard deviation and 95% confidence interval were calculated, as shown in Table 6-3. The range of critical shear stress within the EW is 0.20 to 0.37 Pa.

Table 6-3

Comparisons of Surface Critical Shear Stress Estimated by Multiple Methods

Core	Critical Shear Stress in Surface Sediments (Pa)			Lowest Applied Shear Stress (Pa)[c]	Lowest Shear Stress Resulting in Erosion[d] (0 to 5 cm layer) (Pa)	Adjusted Critical Shear Stress in Surface Sediments (Pa)[e]
	Power Law Regression	Linear Regression	Log-Linear Regression			
SF_01	0.38	0.32	0.33	0.10	0.40	**0.33**
SF_02	0.42	0.26	0.35	0.10	0.40	**0.35**
SF_03	0.45	0.32	0.41	0.10	0.40	**0.40**
SF_04	n/a[a]	0.24[b]	0.08	0.10	0.20	**0.10**
SF_05	0.43	0.26	0.27	0.10	0.40	**0.27**
SF_06	0.49	0.32	0.42	0.10	0.40	**0.40**
SF_07	0.34	0.24	0.04	0.10	0.40	**0.10**
SF_08	0.34	0.24	0.35	0.10	0.40	**0.35**
Average	0.41	0.27	0.28	n/a	n/a	**0.29**
Standard Deviation	0.049	0.072	0.14	n/a	n/a	**0.12**
95% Confidence Interval	0.37 to 0.45	0.22 to 0.32	0.19 to 0.37	n/a	n/a	**0.20 to 0.37**

Notes:
a. Shell hash and organic material in surface layer of core. Erosion occurred in clumps in surface layer. Power law was not a good fit to the data.
b. Due to uneven erosion in the core, the average critical shear stress over the depth of the core was used (see Note a).
c. This value is the lowest shear stress applied during the Sedflume test (see Appendix D).
d. This value is the lowest shear stress applied to the 0 to 5 cm layer during the Sedflume test (see Appendix D) that resulted in sediment erosion.
e. This value is the adjusted critical shear stress determined by Equations 6-3 through 6-5.

Particle size (median diameter) and wet bulk density were also estimated within each vertical interval in the core as described in Sea Engineering's report in Appendix D. Figures 6-10 and 6-11 show the vertical distribution of both median diameter and wet bulk density for all eight Sedflume cores (laboratory forms are provided in Appendix D, Attachment 3). Observations and general trends from estimates of critical shear stress and vertical distribution of median grain size diameter and wet bulk density are summarized below:

- Based on the range of critical shear stresses estimated by the three regression methods, reasonable lower- and upper-bound values for critical shear stress of surface sediments in the EW are 0.20 and 0.37 Pa.
- The adjusted critical shear stress in the 0 to 5 cm layer ranges from 0.10 to 0.40 Pa (based on log-linear regression) for six of the eight cores. Cores SF_4 and SF_7 have relatively low critical shear stress values in the 0 to 5 cm layer (approximately 0.1 Pa). Both of these cores were difficult to extract due to consolidated sediments just under the surface, which resulted in a retrieved core that was relatively shallow due to less penetration. The surface sediments (0 to 5 cm interval) of these two cores were characterized by fine silty sands, which were easier to erode than the 5 to 10 cm interval in these same cores (see Appendix D for more information).
- Generally, critical shear stress increases, or is approximately constant, with depth. Core SF_2 exhibited uneven erosion during Sedflume testing, which may have contributed to some of the variability in the vertical distribution of critical shear stress for that core. Core SF_6 exhibited a consolidated layer around 15 cm below mudline that was difficult to erode (Appendix D, Attachment 1).
- Mean particle diameter (Figure 6-10) ranges from 20 to 40 microns for six of eight cores. Cores SF_06 and SF_07 exhibit larger mean diameters in the upper portions of the core (from 0 to approximately 10 cm) with sizes ranging between approximately 50 to 106 microns. Below 10 cm, mean particle diameters return to the range of 20 to 40 microns found in the other six cores. For core SF_06, this is evidence of the sand cap that was placed in this area. In the case of core SF_07, there is no known anthropogenic explanation for the variation in surface sediments in this area compared to other cores. Trends in the vertical distribution of wet bulk density (Figure 6-11) generally follow the trends in critical shear stress, with the exception of Cores SF_05 and SF_06. Comparison of trends in wet bulk density and mean particle diameter exhibit variability from core to core.

6.2 Erosion Potential Due to Tidal and Riverine Currents

Results from the hydrodynamic model simulations described in Section 4 were used to evaluate bed shear stress within the EW. These estimates of bed shear stress were compared to critical shear stress estimates of in situ sediments obtained from Sedflume cores (Section 6.1) to evaluate erosion potential within the EW due to tidal and riverine currents.

6.2.1 Bed Shear Stress due to Tidal and Riverine Currents

6.2.1.1 Estimates of Bed Shear Stress

Bed shear stresses were estimated from the results of five hydrodynamic model simulations (see Section 4), which included mean annual, mean wet-season, 2-year, 10-year, and 100-year flood inflow rates with spring tide conditions. Bed shear stresses were calculated using near-bed velocity (velocity in the lowest sigma layer of the model) for each hydrodynamic model grid cell within the EW (see Figures 4-1A and 4-1B) and for each time step in the simulation (42 days).

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

$$\tau_{tot} = \tau_{sf} + \tau_{fd} \tag{6-6}$$

Skin friction represents the shear stress generated by sediment particles (i.e., small-scale physical features), whereas form drag corresponds to the drag generated by bedforms (e.g., ripples, dunes) and other large-scale physical features. When simulating the erosion of a cohesive bed, as is present in the EW, skin friction is considered the dominant component of the bed shear stress for most applications. The natural (e.g., tidal and riverine current velocities) hydrodynamic and sediment bed conditions in the EW are likely not favorable for developing physical features (e.g., wavy beds) that induce form drag. This assumption was

corroborated through collection and evaluation of bathymetry data within the EW (Figures 1-3A and 1-3B and Section 2.1). Bed features may exist in the areas where propwash is significant. However, in those areas, bed shear stress due to propwash will dominate and it is calculated using a different methodology (see Section 5). Thus, for estimates of bed shear stress due to tidal and riverine currents, it is a reasonable approximation and a standard approach to use the skin friction component and neglect form drag for calculating bed shear stress for a cohesive bed. This approach is consistent with accepted sediment transport theory (Parker 2004). Skin friction shear stress is calculated using the quadratic stress law:

$$\tau_{sf} = \rho_w C_f u^2 \tag{6-7}$$

Where:

ρ_w = density of water

C_f = bottom friction coefficient

u = near-bed current velocity (i.e., predicted velocity in the bottom layer of the numerical grid)

Use of the near-bed current velocity is standard practice for calculating bed shear stress in a 3-D model. The bottom friction coefficient is determined using (Parker 2004):

$$C_f = \kappa^2 \ln^{-2}(11\, z_{ref} / k_s) \tag{6-8}$$

Where:

z_{ref} = a reference height above the sediment bed

k_s = effective bed roughness

κ = von Karman's constant (0.4)

The reference height (z_{ref}) is spatially and temporally variable because it is equal to half of the thickness of the bottom layer of the numerical grid. Because a stretched (sigma-layer) grid with ten layers is used in the vertical direction, the thickness of the bottom layer of the vertical grid is equal to 10% of the local water depth, which varies due to changes in tidal elevation and river flow rate. Thus, the reference height properly incorporates temporal and

spatial variations in water depth into the calculation of the bottom friction coefficient. The effective bed roughness is assumed to be proportional to the D_{90} (diameter where 90% of the particles by weight in the sediment sample are smaller) of the surface sediment layer (Parker 2004; Wright and Parker 2004):

$$k_s = 2D_{90} \tag{6-9}$$

Grain size distribution data from the geochronology cores were used to specify the value of D_{90} for the surface layer of EW sediments (0 to 2 cm below mudline). Based on these D_{90} values, three representative areas within the EW were designated and assigned a representative upper-bound value for D_{90} (Table 6-4). No viable geochronology cores are available for the Junction and Sill Reaches (see Section 3). Therefore, the D_{90} value for these two reaches was assumed to be equivalent to Area 3 as shown in Table 6-4 (3,000 microns). These upper-bound D_{90} values were used to determine the effective bed roughness throughout the EW. Since bed shear stress increases with increasing effective bed roughness, using upper-bound D_{90} values produces conservatively high estimates of bed shear stress throughout the EW.

Grain size information for surface sediment samples collected in the Junction and Sill Reaches, as well as Slip 27 within the EW (Figure 4-1 of the Final Surface Sediment Data Report; Windward 2010) were compared to the upper-bound values for D_{90} obtained from the geochronology core data. Values of D_{90} based on these cores were consistent with values shown in Table 6-4. In the Junction Reach and Area 3, surface sediment cores SS-003 and SS-005 have values of D_{90} greater than 2,000 microns. In the interior of Slip 27, cores SS-104 and SS-106 also have D_{90} values greater than 2,000 microns.

Table 6-4
Area-Specific Upper-Bound D_{90} Values

Area	Upper-Bound D_{90} (microns)
Area 1: Main Body Reach between EW Stations 0 and 6200	370
Area 2: Interior of Slip 27	8,000
Area 3: Main Body Reach between EW Stations 6200 and 6800	3,000

6.2.1.2 Comparison of Bed Shear Stress to Critical Shear Stress

The maximum bed shear stress within each hydrodynamic model grid cell during each of the five 42-day simulations was determined using the methodology outlined in Section 6.2.1.1. Spatial distributions of maximum bed shear stresses for the mean annual, mean wet-season, 2-year, 10-year, and 100-year flood simulations are shown in Figures 6-12 through 6-16.

As discussed in Section 6.1, Sedflume data indicate that the representative range in critical shear stress for surface sediments (0 to 5cm) within the EW (95% confidence interval about the average) is 0.20 to 0.37 Pa (2.0 to 3.7 dyne/cm^2). Maximum bed shear stress predicted by the model ranges from 0.05 Pa during mean annual flow to 0.12 Pa during the 100-year high-flow event. As shown in Table 6-2, shear stress at each Sedflume core location generally increases with depth below the surface (below 5 cm).

Figures 6-17 through 6-21 show the spatial distributions of maximum bed shear stresses normalized by the lower bound of critical shear stress estimated for the EW (0.20 Pa) for the mean annual, mean wet-season, 2-year, 10-year, and 100-year flood simulations. Figures 6-22 through 6-26 show the cumulative probability distribution of maximum bed shear stress within the EW for the mean annual, mean wet-season, 2-year, 10-year, and 100-year flood simulations, as summarized in Table 6-5. These figures show that even with 100-year flows, the maximum predicted bed shear stress due to tidal/riverine currents (0.12 Pa) is approximately 35% less than the critical shear stress for EW bed sediments. In addition, the 99th percentile bed shear stress (on average) is 54% less and the 50th percentile bed shear stress (on average) is 94% less than the estimated lower bound of critical shear stress for EW bed sediments (0.20 Pa).

Table 6-5
Cumulative Probability Distribution of Maximum Predicted Bed Shear Stresses in the East Waterway

Upstream Flow	Maximum Value of Bed Shear Stress (Pa)	50th Percentile (Pa)	99th Percentile (Pa)
Mean Annual	0.046	0.007	0.045
Mean Wet Season	0.053	0.007	0.051
2-year	0.097	0.011	0.095

Upstream Flow	Maximum Value of Bed Shear Stress (Pa)	50th Percentile (Pa)	99th Percentile (Pa)
10-year	0.113	0.013	0.106
100-year	0.120	0.013	0.114

Because the maximum bed shear stress predicted by the model for all flow events is at least 35% below the lower confidence bound value for critical shear stress (0.20 Pa) as estimated from the Sedflume core data, it is anticipated that significant bed scour or erosion of in situ bed sediments within the EW will not occur as a result of tidal or riverine currents.

6.2.1.3 Discussion of Spatial Distribution of Bed Shear Stress in the East Waterway

The spatial distribution of bed shear stress within the EW is characterized by the highest bed shear stresses at the mouth of the EW, becoming lower in value moving upstream (to the south). Higher near bottom current velocities (and corresponding higher bed shear stress) at the mouth are due to the two-layer flow structure within the EW. During incoming tide, higher salinity water flows from Elliott Bay into the relatively constricted opening of the EW at depth producing relatively high near bottom velocities at the mouth. As this flow moves upstream, density-driven circulation and vertical mixing of the incoming tidal waters with the lower salinity surface waters (from upstream flows) causes a reduction in near bottom current velocities between the mouth and the Sill Reach in the EW (see Section 4.5).

Maximum bed shear stresses within the Sill Reach are affected by pervasive two-layer flow that exists in this reach (as well as the majority of the EW). Upstream flow of higher salinity water in the bottom layers (compared to surface layer salinities) confine downstream current velocities (due to upstream freshwater input) to the surface layers. This circulation pattern results in lower bed shear stress in the Sill Reach than would be expected if the system had single-layer flow (i.e., no flow reversal at depth) (see Section 4.5).

Relatively high bed shear stresses (associated with relatively high current velocities) are predicted along the southern half (shallower) of Slip 27. The higher current velocities may be due to the geometry and resolution of the numerical grid in that location. However, bed

shear stresses predicted throughout Slip 27 are still at least 20% lower than critical shear stress values for surface sediments in the EW.

Grain size information for surface sediment samples collected in Slip 27 (Figure 4-1 of the Final Surface Sediment Data Report; Windward 2010) were reviewed to provide an additional line of evidence for comparison with these results. Surface sediments along the southern (shallow) portions of Slip 27 (cores SS-104 and SS-106) have a median diameter of approximately 200 microns and a D_{90} of greater than 2,000 microns. Surface sediments along the northern (deeper) portions of Slip 27 (cores SS-109 and SS-112) have a median diameter of 15 microns and a D_{90} of 250 microns. This information implies that southern (shallower) portions of Slip 27 may be impacted by higher near bottom current velocities than northern (deeper) portions of Slip 27. This observation is consistent with the results of the hydrodynamic model evaluation.

6.2.2 Uncertainty Discussion

The purpose of this analysis is to evaluate the effect of uncertainty in estimates of critical shear stress (from Sedflume core data) and estimates of bed shear stress (from hydrodynamic model results) on the evaluation of erosion potential due to tidal and riverine flows. Uncertainties in estimates of critical shear stress, as evaluated from Sedflume data, include collection effects on sediment properties, experimental error during testing, methodology used to estimate critical shear stress, and spatial variability in erosion properties. Collection effects and experimental errors are difficult to quantify. However, it is important to note that while Sedflume testing is a standard accepted methodology, there is uncertainty associated with the laboratory measurements. Variability due to differences in the method for calculating critical shear stress was discussed in Section 6.1. While spatial variability in critical shear stress does exist, the representative range in critical shear stress for surface sediments was estimated to be about 0.20 to 0.37 Pa.

6.3 Erosion Potential Due to Vessel Operations

Near-bed velocities in the EW due to vessel operations, including propwash and pressure field velocities, were calculated and this analysis was discussed in Section 5. Near-bed velocities were estimated assuming extreme vessel operations (e.g., vessels operating under

extreme weather versus emergency vessel operations as defined in Section 5.1.2) as opposed to operations during typical fair weather conditions. Maximum near-bed velocities and bed shear stresses are discussed in Section 5.2. Table 5-4 provides a summary of these values for each operating area. The maximum near-bed velocity and bed shear stress in each operational area (shown in Figure 5-1) were taken as the maximum result due to all vessel operations considered within each area. Maximum bed shear stresses due to propwash were estimated for all operational areas and range from 2 to 23 Pa within the EW (based on estimates of extreme vessel operations, as defined in Section 5.1.2, while navigating and berthing). Figures 5-18 and 5-19 show the spatial variation of maximum near-bed velocities and bed shear stress due to propwash throughout the EW.

The 95th percentile confidence interval of critical bed shear stress for surface sediments in the EW ranges between 0.20 and 0.37 Pa (Section 6.1). Based on this analysis, surface sediments within the waterway have the potential to be eroded due to extreme vessel operations (as defined in Section 5.1.2) throughout the EW.

Geochronology cores collected as part of the STE and surface sediment samples collected for sediment characterization were used to provide additional lines of evidence for comparison with propwash results. In general, results of the geochronology evaluation coincide with the results of the propwash evaluation. Cs-137 results from the geochronology core analysis (Figure 3-1) suggest that areas within Slip 27 and south of Slip 27 (between EW Stations 4000 and 5200) are net depositional and have not been impacted by mixing events below the surface sediments (since Cs-137 peaks were documented for most of those cores). This area coincides with propwash operational Areas 3, 4A, 4B, 4C, and 5 where maximum bed shear stress due to propwash (for existing conditions at extreme vessel operations) is estimated at 2 Pa. Bed shear stress values of 2 Pa may be large enough to disturb surface sediments, but are less likely to disturb sediments below the surface. The area north of Slip 27 (where Cs-137 peaks were not found in tested cores) appears to be impacted by vertical mixing of both surface and subsurface sediments. This area coincides with propwash operational areas 1A and 1B, where maximum bed shear stress due to propwash is estimated at 9 to 23 Pa.

Grain size information for surface sediment samples collected along the front of Terminal 25 (South Terminal 30) and Terminal 18 (Figure 4-1 of the Final Surface Sediment Data Report;

Windward 2010) was reviewed to see if surface grain size (median diameter and D_{90}) is related to bed shear stress due to propwash. Areas impacted by higher bed shear stress are expected to have higher surface sediment grain sizes. Surface sediments along the face of Terminal 25 (South Terminal 30) (cores SS-040, SS-031, SS-034, SS-038, and SS-103) and south Terminal 18 (cores SS-028 and SS-035) have a median diameter of approximately 15 microns and a D_{90} of 125 microns. These areas coincide with propwash operational areas 4A, and 5 where maximum bed shear stress due to propwash (for existing conditions) is estimated at 2 Pa. Surface sediments along Terminal 18, Berths 1, 2, and 3 (cores SS-122, SS-126, SS-205, SS-207, and SS-112) have a median diameter of 125 microns and a D_{90} of 500 to greater than 2,000 microns. This area coincides with propwash operational area 1A where maximum bed shear stress due to propwash (for existing conditions) is estimated to be between 9 and 23 Pa. This information suggests that areas predicted to have high bed shear stress due to propwash have larger grain sizes in the surface sediments (on average) compared to areas predicted to have lower bed shear stress due to propwash.

6.3.1 Uncertainty Discussion

The evaluation of erosion potential with the EW due to vessel operations involves comparison of estimates of bed critical shear stress (from Sedflume data) with estimates of bed shear stress due to vessel operations (propwash and pressure field modeling). Therefore, uncertainties in this evaluation are dependent on the uncertainty in the estimates of those parameters, as described in Sections 5.4.3 (bed shear stress due to vessel operations) and Section 6.2.2 (critical bed shear stress from Sedflume data).

7 SPATIAL DISTRIBUTION OF SEDIMENTS ORIGINATING FROM LATERAL SOURCES

The spatial distribution of sediments deposited within the EW from lateral sources was estimated using the PTM developed by USACE. The purpose of the PTM modeling effort was to provide information that can be used to evaluate the potential for recontamination due to sediment loads from identified lateral sources, as well as estimate the relative contribution of solids loads from lateral sources to sedimentation in the EW. Net sedimentation for the EW as a whole was estimated through evaluation of geochronological cores described in Section 3.

7.1 Overview of Technical Approach

The PTM model uses a Lagrangian method to simulate the transport of discrete particles within the modeling domain (McDonald et. al 2006). The PTM model uses the hydrodynamic model results (e.g., current velocities) to simulate the transport of suspended particles within the EW. The hydrodynamic model (see Section 4) is run independently of the PTM model. The PTM model tracks the path particles may travel in the water column from the time of particle release at the source location until the particle is deposited on the sediment bed. Particles are released into the flow field at their discharge location with no incoming plume velocity; therefore, the initial velocity of the particle within the model is solely dictated by the hydrodynamic model results at the discharge location. Results of the PTM model will be combined with empirical estimates of net sedimentation rate developed from the evaluation of geochronological cores (which includes contribution from all sediment sources to the EW as described in Section 3) to evaluate the relative contribution of solids loads from lateral sources to sedimentation in the EW.

The PTM model is best suited for simulating relatively short-term sediment transport events such as resuspension due to dredging or other activities. Conducting a long-term, multi-year PTM simulation can be impractical due to exceedingly long runtimes as increasing numbers of particles are created within the model. Thus, a base-case PTM simulation, with an acceptable simulation time, was developed that is assumed to be representative of long-term average conditions. Results from the base-case simulation are used to estimate long-term sedimentation rates from lateral sources based on extrapolation from a shorter simulation

period. The inputs and boundary conditions for the base-case simulation are discussed in Section 7.3. Bounding simulations (based on results of the sensitivity analysis discussed in Section 7.3.4) were conducted to define reasonable upper- and lower-bound estimates of sedimentation rates due to lateral sources.

7.2 Lateral Sources of Sediment Within the East Waterway

Sediment loads to the EW are from three types of sources: 1) upstream solids from the Green/Duwamish River; 2) solids from Elliott Bay; and 3) solids from lateral sources (Anchor and Windward 2009). Lateral sources include both stormwater discharges and CSOs. Data from lateral sources are used as inputs to the PTM; specifically, discharge volumes, TSS, and particles size distributions associated with those discharges.

Lateral sources of sediment to the EW were identified through the SCE and are presented in the Final Initial Source Evaluation and Data Gaps Memorandum (SEDGM; Anchor and Windward 2009). Sediment loading from these sources was developed using existing information (i.e., overflow volumes and TSS measurements for CSOs and modeling and literature values for TSS for the storm drains).

Currently, 39 outfalls (36 storm drains, one CSO, and two CSO/SDs) to the EW have been identified. Two of the outfalls (at S Hinds Street and S Lander Street) are shared by the separated storm drain and combined sewer service systems. These outfalls are referred to as CSO/SD outfalls. Loading for the stormwater component of these discharges is discussed in Section 7.2.1.1. Loading for the CSO component is discussed in Section 7.2.1.2. Locations and ownership information for each of these storm drains and CSOs, and associated drainage basins, is shown in Figures 1-4A and 1-4B. Drainage basins are identified with a number that matches the City's National Pollutant Discharge Elimination System (NPDES) number for the outfall that the basin discharges through into the EW. Bridges and port aprons are identified with a number that corresponds to the closest storm drain. Additional information regarding the routing of stormwater discharges is provided in Appendix F.

7.2.1 Sediment Mass Loading from Lateral Sources

7.2.1.1 Stormwater Discharge

Stormwater discharges to the EW are described in detail in Section 4 of the SEDGM (Anchor and Windward 2009). Drainage basin boundaries and stormwater discharge volumes have been revised since publication of the SEDGM. Because of these changes, estimates of annual stormwater discharges and solids loading for drainage basins, bridges, and port aprons that discharge to the EW have also been updated. These updates are described in a report produced by Seattle Public Utilities (SPU) dated June 2011 provided in Appendix F, Attachment 1.

Sediment loads from stormwater discharges were developed based on the estimated runoff for an average water year (1986). Runoff estimates were developed using a simplified Hydrologic Simulation Program-Fortran (HSPF) model that calculated runoff volumes per unit area for individual land use, soil type, and slope based on regional Puget Sound input parameters and local rainfall data. Sediment loads were calculated by multiplying the annual stormwater volume by a representative TSS concentration. Representative TSS values were estimated based on land use using stormwater data compiled from studies conducted in western Washington and Oregon. TSS values from parking lots and other paved areas were used to characterize runoff quality for the largely paved Port terminal areas. For all other areas, TSS values were based on available stormwater data for the various land use categories within each drainage basin (e.g., industrial, commercial, single-family residential, multi-family residential, roadway/right-of-way). Table 7-1 provides 25th percentile, 50th percentile (median), and 75th percentile TSS values, which were used to develop stormwater solids loading for the STE.

Table 7-1
TSS Values for Stormwater

Land Use	Low (25th percentile)	Base-Case (10% trimmed mean)	High (75th percentile)
Single-family residential	24	48	70
Multi-family residential	39	68	101
Commercial	31	58	84
Industrial[a]	34	74	117

Land Use	Low (25th percentile)	Base-Case (10% trimmed mean)	High (75th percentile)
Industrial (Port terminals)[b]	20	43	60
Open/Vacant/Park	8	13	18
Right-of-way	34	71	86

Notes

a. Used for industrial land use in all Seattle Public Utilities (SPU) drainage basins except B-21, plus Port of Seattle (Port) basin B-34, and all private basins.
b. Used for all Port terminals that are mostly paved except B-34 plus SPU basin B-21.

Tables 7, 8, and 9 in Appendix F, Attachment 1, provide summary information on basin size, stormwater discharge, and sediment loading for all stormwater basins shown in Figures 1-4A and 1-4B for the 25th percentile, 50th percentile, and 75th percentile TSS values, respectively.

Sediment load was partitioned into four sediment size fractions consistent with the sediment transport evaluation completed for the LDW (Windward and QEA 2008). The particle size distribution of the four sediment classes for stormwater discharge was developed through evaluation of site-specific data, as described in Appendix F, Attachment 1. The particle size distribution used to develop sediment load for the PTM model was taken from EW sediment trap samples rather than available stormwater samples that were used in the LDW study (see Appendix F, Figure F-1). Compared to the LDW, particle size distribution used for stormwater discharges in the EW contained a larger percentage of sands, compared to clay and silt fractions. This will provide a conservative estimate of sedimentation at lateral source discharge locations; as sands will settle out quickly compared to silts and clays, which could be dispersed more broadly throughout the EW. This will not necessarily provide a conservative estimate of sedimentation for locations in the EW that are farther away from the discharge location. A sensitivity run was completed using the particle size distribution for stormwater used in the LDW study (Windward and QEA 2008) to validate this assumption. Characteristic diameters used for stormwater inputs in the PTM model were defined in the LDW Sediment Transport Modeling Report (Windward and QEA 2008) and are provided in Table 7-2; see Section 7.3.3 for their usage in the PTM model runs.

Table 7-2
Characteristic Diameter and Particle Size Distribution for Stormwater

Sediment Size Class	Effective Diameter (microns)	Effective Diameter (mm)	Percent of Each Sediment Class in Stormwater	
			From Site-specific Sediment Trap Data	Assumptions Used in LDW Study[a]
1A: clay and fine silt	5	0.005	15%	55%
1B: medium/coarse silt	20	0.02	23%	18%
2: fine sand	130	0.13	26%	23%
3: medium/coarse sand	540	0.54	35%	4%

Notes:
a Windward and QEA (2008)
LDW = Lower Duwamish Waterway

Annual solids load for stormwater drainage basins for the average water year (1986) and for CSO discharges (10-year average) for each basin (Tables F-1 through F-3 in Appendix F) were converted to a mass flux (kilograms per second [kg/s]) and partitioned by grain size (based on values provided in Table 7-2) for input into the PTM model. Tables 7-3, 7-4, and 7-5 provide mass flux used as input to the PTM model for base-case (50th percentile), 25th percentile, and 75th percentile TSS values, respectively.

Table 7-3

Solids Input to PTM Model by Outfall for Base-Case (50th Percentile TSS Values)

Seattle Public Utilities-owned Outfalls/Basins (and Bridges BR-39, 34, 4, 5, and 6)

Outfall	Annual Average Sediment Load in lbs[a]	Annual Average Sediment Load in kg	Annual Avg. Mass Flux Total Solids in kg/s	Mass Flux (kg/s) - By Size Class[b]			
				1A (0.005 mm)	1B (0.02 mm)	2 (0.13 mm)	3 (0.54 mm)
Hinds[d]	1.525E+04	6.920E+03	2.19E-04	0.00003377	0.00005066	0.00005723	0.00007763
Lander[d,e]	7.041E+04	3.194E+04	1.01E-03	0.00015587	0.00023380	0.00026417	0.00035830
21	3105	1408	4.46E-05	0.00000687	0.00001031	0.00001165	0.00001580
25	1449	657	2.08E-05	0.00000321	0.00000481	0.00000544	0.00000737
36	2340	1061	3.36E-05	0.00000518	0.00000777	0.00000878	0.00001191
4	3236	1468	4.65E-05	0.00000716	0.00001074	0.00001214	0.00001647
5	1417	643	2.04E-05	0.00000314	0.00000470	0.00000532	0.00000721
39	515	234	7.40E-06	0.00000114	0.00000171	0.00000193	0.00000262

Port of Seattle-owned Basins (and Bridges BR-2 and BR-27)

Outfall	Annual Average Sediment Load in lbs[a]	Annual Average Sediment Load in kg	Annual Avg. Mass Flux Total Solids in kg/s	Mass Flux (kg/s) - By Size Class[b]			
				1A (0.005 mm)	1B (0.02 mm)	2 (0.13 mm)	3 (0.54 mm)
1	378	171	5.43E-06	0.00000084	0.00000126	0.00000142	0.00000192
7	3598	1632	5.17E-05	0.00000796	0.00001195	0.00001350	0.00001831
10	2276	1032	3.27E-05	0.00000504	0.00000756	0.00000854	0.00001158
11	11514	5223	1.65E-04	0.00002549	0.00003823	0.00004320	0.00005859
12	2034	923	2.92E-05	0.00000450	0.00000675	0.00000763	0.00001035
13	1599	725	2.30E-05	0.00000354	0.00000531	0.00000600	0.00000814
14	609	276	8.75E-06	0.00000135	0.00000202	0.00000228	0.00000310
16	1212	550	1.74E-05	0.00000268	0.00000402	0.00000455	0.00000617
17	674	306	9.69E-06	0.00000149	0.00000224	0.00000253	0.00000343
18	2058	933	2.96E-05	0.00000456	0.00000683	0.00000772	0.00001047
19	1657	752	2.38E-05	0.00000367	0.00000550	0.00000622	0.00000843
22	3348	1519	4.81E-05	0.00000741	0.00001112	0.00001256	0.00001704
23	3108	1410	4.47E-05	0.00000688	0.00001032	0.00001166	0.00001581
24	2665	1209	3.83E-05	0.00000590	0.00000885	0.00001000	0.00001356
26	3349	1519	4.81E-05	0.00000741	0.00001112	0.00001256	0.00001704
27	2162	981	3.11E-05	0.00000479	0.00000718	0.00000811	0.00001100
28	1218	552	1.75E-05	0.00000270	0.00000404	0.00000457	0.00000620
29	2365	1073	3.40E-05	0.00000524	0.00000785	0.00000887	0.00001203
30	1910	866	2.75E-05	0.00000423	0.00000634	0.00000717	0.00000972

31	2529	1147	3.64E-05	0.00000560	0.00000840	0.00000949	0.00001287
32	1083	491	1.56E-05	0.00000240	0.00000360	0.00000406	0.00000551
33	3415	1549	4.91E-05	0.00000756	0.00001134	0.00001281	0.00001738
34	5416	2457	7.78E-05	0.00001199	0.00001798	0.00002032	0.00002756
37	1519	689	2.18E-05	0.00000336	0.00000504	0.00000570	0.00000773
39	496	225	7.13E-06	0.00000110	0.00000165	0.00000186	0.00000252
2	63	29	9.06E-07	0.00000014	0.00000021	0.00000024	0.00000032

Privately-owned Basins

Outfall	Annual Average Sediment Load in lbs[a]	Annual Average Sediment Load in kg	Annual Avg. Mass Flux Total Solids in kg/s	Mass Flux (kg/s) - By Size Class[b]			
				1A (0.005 mm)	1B (0.02 mm)	2 (0.13 mm)	3 (0.54 mm)
6	1300	590	1.87E-05	0.00000288	0.00000432	0.00000488	0.00000661
40	989	449	1.42E-05	0.00000219	0.00000328	0.00000371	0.00000503
41	1890	857	2.72E-05	0.00000418	0.00000628	0.00000709	0.00000962
42	190	86	2.73E-06	0.00000042	0.00000063	0.00000071	0.00000097
43	2362	1071	3.40E-05	0.00000523	0.00000784	0.00000886	0.00001202

Seattle Public Utilities CSOs

Outfall	Average TSS in kg/L[c]	Average Flow in million gal/yr[c]	Average Flow in liters/yr	Average Solids in kg per year	Mass Flux - Total Solids TSS in kg/s	Mass Flux (kg/s) - By Size Class[b]			
						1A (0.005 mm)	1B (0.02 mm)	2 (0.13 mm)	3 (0.54 mm)
Hinds	0.000086	1	3.785E+06	3.255E+02	1.03E-05	0.00000433	0.00000423	0.00000175	0.00000000

King County CSOs

Outfall	Average TSS in kg/L[c]	Average Flow in million gal/yr[c]	Average Flow in liters/yr	Average Solids in kg per year	Mass Flux - Total Solids TSS in kg/s	Mass Flux (kg/s) - By Size Class[b]			
						1A (0.005 mm)	1B (0.02 mm)	2 (0.13 mm)	3 (0.54 mm)
Lander	0.000086	39.8	1.507E+08	1.296E+04	4.11E-04	0.00017244	0.00016834	0.00006980	0.00000000
Hanford	0.000086	74.3	2.813E+08	2.419E+04	7.66E-04	0.00032193	0.00031426	0.00013030	0.00000000

Notes:
a. Sediment load taken from runoff modeling completed by Seattle Public Utilities as described in Appendix F, Attachment 1.
b. Characteristic particle sizes and particle size distributions provided in Table 7-2.
c. TSS and flow rates for Lander and Hanford CSOs developed by King County; Hinds developed by SPU. Described in Appendix F, Attachment 2.
d. Lander drainage basin discharges to the Lander Street outfall, which is shared with the Lander CSO. Hinds drainage basin discharges to the Hinds outfall, which is shared with the Hinds CSO.
e. Low runoff assumption.
N/A - Not applicable

Table 7-4
Solids Input to PTM Model by Outfall for 25th Percentile TSS Values

Seattle Public Utilities-owned Outfalls/Basins (and Bridges BR-39, 34, 4, 5, and 6)

Outfall	Annual Average Sediment Load in lbs[a]	Annual Average Sediment Load in kg	Annual Avg. Mass Flux Total Solids in kg/s	Mass Flux (kg/s) - By Size Class[b]			
				1A (0.005 mm)	1B (0.02 mm)	2 (0.13 mm)	3 (0.54 mm)
Hinds[d]	7.087E+03	3.215E+03	1.02E-04	0.00001569	0.00002353	0.00002659	0.00003607
Lander[d,e]	3.322E+04	1.507E+04	4.77E-04	0.00007353	0.00011029	0.00012462	0.00016902
21	1444	655	2.08E-05	0.00000320	0.00000479	0.00000542	0.00000735
25	723	328	1.04E-05	0.00000160	0.00000240	0.00000271	0.00000368
36	1106	502	1.59E-05	0.00000245	0.00000367	0.00000415	0.00000563
4	1518	689	2.18E-05	0.00000336	0.00000504	0.00000569	0.00000772
5	672	305	9.66E-06	0.00000149	0.00000223	0.00000252	0.00000342
39	236	107	3.39E-06	0.00000052	0.00000078	0.00000089	0.00000120

Port of Seattle-owned Basins (and Bridges BR-2 and BR-27)

Outfall	Annual Average Sediment Load in lbs[a]	Annual Average Sediment Load in kg	Annual Avg. Mass Flux Total Solids in kg/s	Mass Flux (kg/s) - By Size Class[b]			
				1A (0.005 mm)	1B (0.02 mm)	2 (0.13 mm)	3 (0.54 mm)
1	175	79	2.52E-06	0.00000039	0.00000058	0.00000066	0.00000089
7	1677	761	2.41E-05	0.00000371	0.00000557	0.00000629	0.00000853
10	1058	480	1.52E-05	0.00000234	0.00000351	0.00000397	0.00000538
11	5355	2429	7.70E-05	0.00001185	0.00001778	0.00002009	0.00002725
12	946	429	1.36E-05	0.00000209	0.00000314	0.00000355	0.00000481
13	744	337	1.07E-05	0.00000165	0.00000247	0.00000279	0.00000379
14	283	128	4.07E-06	0.00000063	0.00000094	0.00000106	0.00000144
16	563	255	8.09E-06	0.00000125	0.00000187	0.00000211	0.00000286
17	314	142	4.51E-06	0.00000070	0.00000104	0.00000118	0.00000160
18	957	434	1.38E-05	0.00000212	0.00000318	0.00000359	0.00000487
19	770	349	1.11E-05	0.00000170	0.00000256	0.00000289	0.00000392
22	1556	706	2.24E-05	0.00000344	0.00000517	0.00000584	0.00000792
23	1444	655	2.08E-05	0.00000320	0.00000479	0.00000542	0.00000735
24	1239	562	1.78E-05	0.00000274	0.00000411	0.00000465	0.00000630
26	1557	706	2.24E-05	0.00000345	0.00000517	0.00000584	0.00000792
27	1005	456	1.44E-05	0.00000222	0.00000334	0.00000377	0.00000511
28	566	257	8.14E-06	0.00000125	0.00000188	0.00000212	0.00000288
29	1099	498	1.58E-05	0.00000243	0.00000365	0.00000412	0.00000559
30	889	403	1.28E-05	0.00000197	0.00000295	0.00000334	0.00000452

31	1175	533	1.69E-05	0.00000260	0.00000390	0.00000441	0.00000598
32	503	228	7.23E-06	0.00000111	0.00000167	0.00000189	0.00000256
33	1588	720	2.28E-05	0.00000352	0.00000527	0.00000596	0.00000808
34	2488	1129	3.58E-05	0.00000551	0.00000826	0.00000933	0.00001266
37	706	320	1.01E-05	0.00000156	0.00000234	0.00000265	0.00000359
39	231	105	3.32E-06	0.00000051	0.00000077	0.00000087	0.00000118
2	29	13	4.17E-07	0.00000006	0.00000010	0.00000011	0.00000015

Privately-owned Basins

Outfall	Annual Average Sediment Load in lbs[a]	Annual Average Sediment Load in kg	Annual Avg. Mass Flux Total Solids in kg/s	Mass Flux (kg/s) - By Size Class[b]			
				1A (0.005 mm)	1B (0.02 mm)	2 (0.13 mm)	3 (0.54 mm)
6	597	271	8.58E-06	0.00000132	0.00000198	0.00000224	0.00000304
40	528	239	7.59E-06	0.00000117	0.00000175	0.00000198	0.00000269
41	869	394	1.25E-05	0.00000192	0.00000289	0.00000326	0.00000442
42	87	39	1.25E-06	0.00000019	0.00000029	0.00000033	0.00000044
43	1085	492	1.56E-05	0.00000240	0.00000360	0.00000407	0.00000552

Seattle Public Utilities CSOs

Outfall	Average TSS in kg/L[c]	Average Flow in million gal/yr[c]	Average Flow in liters/yr	Average Solids in kg per year	Mass Flux - Total Solids TSS in kg/s	Mass Flux (kg/s) - By Size Class[b]			
						1A (0.005 mm)	1B (0.02 mm)	2 (0.13 mm)	3 (0.54 mm)
Hinds	0.0000653	1	3.785E+06	2.472E+02	7.83E-06	0.00000329	0.00000321	0.00000133	0.00000000

King County CSOs

Outfall	Average TSS in kg/L[c]	Average Flow in million gal/yr[c]	Average Flow in liters/yr	Average Solids in kg per year	Mass Flux - Total Solids TSS in kg/s	Mass Flux (kg/s) - By Size Class[b]			
						1A (0.005 mm)	1B (0.02 mm)	2 (0.13 mm)	3 (0.54 mm)
Lander	0.0000653	39.8	1.507E+08	9.838E+03	3.12E-04	0.00013094	0.00012782	0.00005300	0.00000000
Hanford	0.0000653	74.3	2.813E+08	1.837E+04	5.82E-04	0.00024444	0.00023862	0.00009894	0.00000000

Notes:
a. Sediment load taken from runoff modeling completed by Seattle Public Utilities as described in Appendix F, Attachment 1.
b. Characteristic particle sizes and particle size distributions provided in Table 7-2.
c. TSS and flow rates for Lander and Hanford CSOs developed by King County; Hinds developed by SPU. Described in Appendix F, Attachment 2.
d. Lander drainage basin discharges to the Lander Street outfall, which is shared with the Lander CSO. Hinds drainage basin discharges to the Hinds outfall, which is shared with the Hinds CSO.
e. Low runoff assumption.
N/A - Not applicable

Table 7-5

Solids Input to PTM Model by Outfall for 75th Percentile TSS Values

Seattle Public Utilities-owned Outfalls/Basins (and Bridges BR-39, 34, 4, 5, and 6)

Outfall	Annual Average Sediment Load in lbs[a]	Annual Average Sediment Load in kg	Annual Avg. Mass Flux Total Solids in kg/s	Mass Flux (kg/s) - By Size Class[b]			
				1A (0.005 mm)	1B (0.02 mm)	2 (0.13 mm)	3 (0.54 mm)
Hinds[d]	2.255E+04	1.023E+04	3.24E-04	0.00004993	0.00007489	0.00008462	0.00011477
Lander[d,e]	9.321E+04	4.228E+04	1.34E-03	0.00020632	0.00030949	0.00034968	0.00047428
21	4332	1965	6.23E-05	0.00000959	0.00001438	0.00001625	0.00002204
25	2176	987	3.13E-05	0.00000482	0.00000723	0.00000816	0.00001107
36	3084	1399	4.43E-05	0.00000683	0.00001024	0.00001157	0.00001569
4	4584	2079	6.59E-05	0.00001015	0.00001522	0.00001720	0.00002332
5	1834	832	2.64E-05	0.00000406	0.00000609	0.00000688	0.00000933
39	813	369	1.17E-05	0.00000180	0.00000270	0.00000305	0.00000414

Port of Seattle-owned Basins (and Bridges BR-2 and BR-27)

Outfall	Annual Average Sediment Load in lbs[a]	Annual Average Sediment Load in kg	Annual Avg. Mass Flux Total Solids in kg/s	Mass Flux (kg/s) - By Size Class[b]			
				1A (0.005 mm)	1B (0.02 mm)	2 (0.13 mm)	3 (0.54 mm)
1	527	239	7.57E-06	0.00000117	0.00000175	0.00000198	0.00000268
7	5035	2284	7.24E-05	0.00001115	0.00001672	0.00001889	0.00002562
10	3175	1440	4.56E-05	0.00000703	0.00001054	0.00001191	0.00001616
11	16066	7287	2.31E-04	0.00003556	0.00005334	0.00006027	0.00008175
12	2839	1288	4.08E-05	0.00000628	0.00000943	0.00001065	0.00001445
13	2232	1012	3.21E-05	0.00000494	0.00000741	0.00000837	0.00001136
14	851	386	1.22E-05	0.00000188	0.00000283	0.00000319	0.00000433
16	1691	767	2.43E-05	0.00000374	0.00000561	0.00000634	0.00000860
17	942	427	1.35E-05	0.00000209	0.00000313	0.00000353	0.00000479
18	2873	1303	4.13E-05	0.00000636	0.00000954	0.00001078	0.00001462
19	2312	1049	3.32E-05	0.00000512	0.00000768	0.00000867	0.00001176
22	4671	2119	6.71E-05	0.00001034	0.00001551	0.00001752	0.00002377
23	4336	1967	6.23E-05	0.00000960	0.00001440	0.00001627	0.00002206
24	3719	1687	5.35E-05	0.00000823	0.00001235	0.00001395	0.00001892
26	4673	2120	6.72E-05	0.00001034	0.00001552	0.00001753	0.00002378
27	3017	1368	4.34E-05	0.00000668	0.00001002	0.00001132	0.00001535
28	1700	771	2.44E-05	0.00000376	0.00000564	0.00000638	0.00000865
29	3300	1497	4.74E-05	0.00000730	0.00001096	0.00001238	0.00001679
30	2667	1210	3.83E-05	0.00000590	0.00000886	0.00001001	0.00001357

31	3529	1601	5.07E-05	0.00000781	0.00001172	0.00001324	0.00001796
32	1511	685	2.17E-05	0.00000334	0.00000502	0.00000567	0.00000769
33	4766	2162	6.85E-05	0.00001055	0.00001582	0.00001788	0.00002425
34	8563	3884	1.23E-04	0.00001895	0.00002843	0.00003212	0.00004357
37	2120	962	3.05E-05	0.00000469	0.00000704	0.00000795	0.00001079
39	693	314	9.96E-06	0.00000153	0.00000230	0.00000260	0.00000353
2	89	40	1.28E-06	0.00000020	0.00000030	0.00000033	0.00000045

Privately-owned Basins

Outfall	Annual Average Sediment Load in lbs[a]	Annual Average Sediment Load in kg	Annual Avg. Mass Flux Total Solids in kg/s	Mass Flux (kg/s) - By Size Class[b]			
				1A (0.005 mm)	1B (0.02 mm)	2 (0.13 mm)	3 (0.54 mm)
6	2055	932	2.95E-05	0.00000455	0.00000682	0.00000771	0.00001046
40	1434	650	2.06E-05	0.00000317	0.00000476	0.00000538	0.00000730
41	2984	1354	4.29E-05	0.00000661	0.00000991	0.00001119	0.00001518
42	300	136	4.31E-06	0.00000066	0.00000100	0.00000113	0.00000153
43	3735	1694	5.37E-05	0.00000827	0.00001240	0.00001401	0.00001900

Seattle Public Utilities CSOs

Outfall	Average TSS in kg/L[c]	Average Flow in million gal/yr[c]	Average Flow in liters/yr	Average Solids in kg per year	Mass Flux - Total Solids TSS in kg/s	Mass Flux (kg/s) - By Size Class[b]			
						1A (0.005 mm)	1B (0.02 mm)	2 (0.13 mm)	3 (0.54 mm)
Hinds	0.000106	1	3.785E+06	4.013E+02	1.27E-05	0.00000534	0.00000521	0.00000216	0.00000000

King County CSOs

Outfall	Average TSS in kg/L[c]	Average Flow in million gal/yr[c]	Average Flow in liters/yr	Average Solids in kg per year	Mass Flux - Total Solids TSS in kg/s	Mass Flux (kg/s) - By Size Class[b]			
						1A (0.005 mm)	1B (0.02 mm)	2 (0.13 mm)	3 (0.54 mm)
Lander	0.000106	39.8	1.507E+08	1.597E+04	5.06E-04	0.00021255	0.00020749	0.00008603	0.00000000
Hanford	0.000106	74.3	2.813E+08	2.981E+04	9.45E-04	0.00039679	0.00038734	0.00016061	0.00000000

Notes:
a. Sediment load taken from runoff modeling completed by Seattle Public Utilities as described in Appendix F, Attachment 1.
b. Characteristic particle sizes and particle size distributions provided in Table 7-2.
c. TSS and flow rates for Lander and Hanford CSOs developed by King County; Hinds developed by SPU. Described in Appendix F, Attachment 2.
d. Lander drainage basin discharges to the Lander Street outfall, which is shared with the Lander CSO. Hinds drainage basin discharges to the Hinds outfall, which is shared with the Hinds CSO.
e. Low runoff assumption.
N/A - Not applicable

7.2.1.2 CSOs

Three CSOs discharge into the EW, as shown in Figures 1-4A and 1-4B. Detailed information regarding these CSOs is provided in Section 5 of the SEDGM (Anchor and Windward 2009). The County and City routinely monitor CSO discharges as part of their CSO control programs. The County collected CSO TSS data as part of ongoing source control activities. CSO volume and discharge frequencies are recorded by the County and SPU as part of their permit reporting requirements for CSOs. Flow information for Lander and Hanford #2 CSOs and TSS information for these two CSOs are summarized in a memorandum produced by the County dated May 13, 2011, provided in Appendix F, Attachment 2. Flow data for the Hinds CSO is summarized in a report produced by SPU dated June 2011, provided in Appendix F, Attachment 1. CSO discharge volumes and frequencies were based on annual averages from the 2000-2009 reporting period. TSS values, based on samples collected between 1995 and 2009 (with the majority collected between 2007 and 2009), were developed for all CSOs and are provided below:

- 25th Percentile = 65.3 milligrams per liter (mg/L)
- 50th Percentile (average) = 86 mg/L
- 75th Percentile = 106 mg/L

Table 7-6 provides CSO flow and particle size distribution used to develop CSO solids loads for the PTM model. The particle size distribution of the four sediment classes for CSOs was developed through evaluation of data from four King County CSOs, as described in Section 5.1.3.2 of the SEDGM (Anchor and Windward 2009). Effective diameters of the four size classes for CSOs are the same as used for stormwater provided in Table 7-2.

Table 7-6
Flow and Particle Size Distribution for CSOs

CSO	Average Annual Flow (million gallons per year)	Percent of each Sediment Size Class in CSO Flow[a]			
		1A	1B	2	3
Hanford #2	74.3	42%	41%	17%	0%
Lander	39.8	42%	41%	17%	0%
Hinds	1.0	42%	41%	17%	0%

Note:
a Characteristic diameters for each size class shown in Table 7-2.

The mean annual solids load for each CSO is based on the average TSS values and the average annual flows for each CSO. These annual mass loads were then converted to a mass flux (kg/s) and partitioned by grain size (based on values provided in Table 7-6) for input into the PTM model. This information is provided in Tables 7-3 through 7-5.

7.3 Particle Tracking Model

7.3.1 Input From the Hydrodynamic Model

Section 4.3 describes boundary conditions for the five hydrodynamic model simulations that provided input to the PTM model. Each hydrodynamic model simulation was 42 days in duration (4 weeks of particle input plus 2 weeks of spindown/settling). Tidal elevations at the open boundary in Elliott Bay were specified using measured water surface elevations during June and July 2009. The incoming flow rate at the upstream boundary (i.e., Green River inflow) was temporally constant during each hydrodynamic simulation, as described in Section 4. While this results in high flow events that last much longer than in reality, it serves to estimate the potential range of particle dispersion within the EW and beyond due to tidal and river flow. Incoming flow rates for the five hydrodynamic simulations were as follows:

- Annual average (1,300 cubic feet per second [cfs])
- 'Wet-season' (November through May) average (1,875 cfs)
- 2-year high-flow event (8,400 cfs)
- 10-year high-flow event (10,800 cfs)
- 100-year high-flow event (12,000 cfs)

Once the hydrodynamic simulations were completed using EFDC, the output files were converted to 3-D ADCIRC format (Luettich and Westerink 2004) using a command-line utility program developed by USACE personnel. This utility program converted the hydrodynamic model output at each rectangular grid cell (with ten layers in the vertical) into two triangular grid cells (also with ten layers in the vertical). This conversion process did not change the resolution of the hydrodynamic model output. A comparison of EFDC and ADCIRC grid cells within the EW is shown in Figure 7-1.

7.3.2 Model Output Post-Processing

The PTM directly uses ADCIRC-format output files; there is no need to create a separate numerical grid for the PTM. The output of the PTM consists of location coordinates, source information, and path of travel data for each particle released into the model at each recorded time step of the simulation. The location coordinates provided by the PTM output are not directly linked to a particular hydrodynamic grid cell. Therefore, the particle location information output by the PTM can be post-processed in numerous ways. For the purposes of the STE, positions of particles deposited within the EW during the simulation period were extracted from the PTM output file and imported into ArcGIS. The points were then post-processed to create a raster representation of mass accumulation in the EW with a 50-foot by 50-foot resolution. Mass accumulation within each 50-foot by 50-foot cell in the raster was calculated by adding up all of the particles that had been deposited within that area. This cell size was chosen to provide an appropriate level of resolution for predicting sediment deposition patterns within the EW and to inform recontamination potential within the EW as part of the SRI process.

The effect of raster cell size on the representation of mass accumulation was evaluated by varying the resolution of the raster cells for the base-case simulation (simulation 1) and simulation 5 (75% TSS sediment loading), and comparing mass accumulation in kilograms deposited per square foot of area between the different resolution raster maps. Resolutions of 50- and 100-feet square were used. The resulting figures are provided as Figures G-1 through G-4 in Appendix G. From this evaluation, it was concluded that the resolution of the raster does not have a significant impact on the representation of deposition patterns within the EW. However, in portions of the EW where deposition is very high (large numbers of points deposited in a small area), increasing the size of the raster tends to smooth out the peak in mass accumulation.

7.3.3 Lateral Source Inputs

The lateral source sediment loading information (described in Section 7.2) was used to develop a total of ten sediment source files to be used as input for the PTM simulations. These ten variations in sediment loading were used as input to the base run, bounding runs and a variety of sensitivity runs to test model sensitivity to changes in sediment load and

model parameters. These input files are used to specify the following for each sediment input:

- Parcel mass (the mass of each 'parcel' representing individual sediment particles)
- Mass loading rate
- Representative particle diameter
- Standard deviation of particle diameter (assuming Gaussian distribution)

Resuspension processes in the PTM were not included in the simulations, as the objective of the PTM model was to evaluate initial sediment deposition patterns from lateral sources (since resuspension of deposited material is expected to be dominated by propwash). This was accomplished by setting the critical shear stress for initiation of motion to a very high value (100 Pa), which resulted in no resuspension of particles due to currents. Table 7-7 outlines the characteristics of the ten lateral source sediment input files. These sediment source files are used in conjunction with the hydrodynamic model input to develop PTM model scenarios. Source S1 was used for the base-case, while sources S4 and S5 were used for bounding runs and sensitivity runs. All others were used for sensitivity analysis only. The PTM model tracks the movement of parcels of sediment with a set mass, as opposed to individual particles. The parcel size was set to 0.5 kg for all simulations (except for Simulation 3, where it was changed as a sensitivity parameter) and standard deviation of the particle size distribution was set to 0.8 φ. These values are commonly accepted values for this application (McDonald et. al 2006). Increasing the standard deviation of the particle size distribution within the PTM model does not change the median diameter of each sediment size class, but results in a larger percentage of particles both smaller and larger than the median diameter to be input into the model.

Table 7-7
Lateral Source Load Characteristics for PTM Simulations

Source File No.	Parcel Mass (kg)	Standard Deviation of Particle Diameter	Characteristic Particle Diameter, by Size Class (microns)				Particle Size Distribution in Storm Drain Flows (%)				TSS Loading Rate (percentile)
			1A	1B	2	3	1A	1B	2	3	
S1	0.5	0.8	5	20	130	540	15	23	26	35	50th
S2	0.25	0.8	5	20	130	540	15	23	26	35	50th
S3	0.5	1.0	5	20	130	540	15	23	26	35	50th

Source File No.	Parcel Mass (kg)	Standard Deviation of Particle Diameter	Characteristic Particle Diameter, by Size Class (microns)				Particle Size Distribution in Storm Drain Flows (%)				TSS Loading Rate (percentile)
			1A	1B	2	3	1A	1B	2	3	
S4	0.5	0.8	3.5	14	130	540	15	23	26	35	50th
S5	0.5	0.8	7	28	130	540	15	23	26	35	50th
S6	0.5	0.8	5	20	130	540	15	23	26	35	75th
S7	0.5	0.8	5	20	130	540	15	23	26	35	25th
S8	0.5	0.0	5	20	130	540	15	23	26	35	50th
S9	0.5	0.8	5	20	130	540	15	23	26	35	50th, higher Lander[a]
S10	0.5	0.8	5	20	130	540	55	18	23	4	50th

Note:
a Higher estimate of flow in the Lander separated storm basin based on its operation

7.3.4 Base-Case Simulation

The PTM simulations were conducted using the hydrodynamic input described in Section 7.3.1. Sediment loads from the lateral sources were active during the first 28 days of a simulation (June 3 through June 30, 2009 of the tidal boundary condition), with the lateral source loads set to zero for the last 14 days of a simulation. The result is an estimate of average lateral sediment loads and initial sediment deposition within the EW over a 4-week period.

The base-case simulation, which was considered to be representative of average long-term conditions within the EW, was specified as follows:

- Hydrodynamic boundary conditions
  - Annual average flow in the Green River (1,300 cfs)
  - 28-day tidal cycle (includes spring and neap tides)
- Lateral source load input (sediment source file S1, Table 7-7)
  - Annual average stormwater runoff and CSO flows
  - Median (50%) TSS concentration developed for stormwater and CSO discharges
  - Particle size distribution of CSO flows (see Table 7-6)
  - Particle size distribution of stormwater flows based on sediment trap data (see Table 7-2)

- PTM input parameters
  - Standard deviation set to 0.8 (default model parameter)
  - Parcel size set to 0.5 kg (considered an appropriate parcel size for this application)
  - Critical bed shear stress set to 100 Pa

The predicted spatial distribution of sediment mass accumulation for the base-case simulation is presented in Figure 7-2.

7.3.5 Sensitivity Simulations

The effects of hydrodynamic boundary conditions and various model inputs on PTM predictions were evaluated during a sensitivity analysis. A total of 13 sensitivity simulations were conducted and compared to the base-case simulation. Table 7-8 outlines the characteristics of the sensitivity simulations. These sensitivity simulations were developed in cooperation with EPA prior to completing the evaluation.

The sensitivity evaluations were divided into two tiers for consideration of model performance:

- Tier 1 included simulations that evaluated the response to the model to changes in sediment loads and particles size distributions, which have recognized uncertainties based on evaluation of existing datasets (see Section 7.2). The results of these simulations were ultimately used as representative bounding runs for the base-case simulation. Tier 1 simulations included 4, 5, 7, and 8, as described in Table 7-8. Results of these simulations are provided in Figures 7-3 through 7-6.
- Tier 2 included simulations that were evaluated to better understand the behavior of the model in response to either internal model parameters or hydrodynamic input. The results of these simulations were used to evaluate model sensitivity only, and were not used directly to evaluate deposition patterns from lateral sources within the EW. Tier 2 simulations included 2, 3, 6, and 9 through 14, as shown in Table 7-8. Results of these simulations are provided in Appendix G.

The PTM sensitivity simulations utilized the same tidal boundary condition and run duration as the base-case simulation. Sediment loads from the lateral sources were active during the

first 28 days of a simulation (June 3 through June 30, 2009), with the lateral source loads set to zero for the last 14 days of a simulation. The result is an estimate of lateral sediment loads and spatial distribution of initial sediment deposition within the EW over a 4-week period.

Table 7-8
PTM Sensitivity Simulations

Simulation	Type of Simulation	Description of Simulation	Inflow Condition	Sediment Source File (from Table 7-7)
1	Base-case	Base-case	Mean annual	S1
2	Tier 2 Sensitivity	Repeat base-case	Mean annual	S1
3	Tier 2 Sensitivity	Base-case with 0.25-kg parcel size for Class 1A/1B particles	Mean annual	S2
4	Tier 1 Sensitivity (bounding run)	Base-case with 25% TSS values	Mean annual	S7
5	Tier 1 Sensitivity (bounding run)	Base-case with 75% TSS values	Mean annual	S6
6	Tier 2 Sensitivity	Base-case with Standard Deviation set to 1	Mean annual	S3
7	Tier 1 Sensitivity (bounding run)	Base-case with smaller Class 1A/1B particle diameters	Mean annual	S4
8	Tier 1 Sensitivity (bounding run)	Base-case with larger Class 1A/1B particle diameters	Mean annual	S5
9	Tier 2 Sensitivity	Simulation 5 with 2-year flow	2-year	S6
10	Tier 2 Sensitivity	Simulation 5 with 10-year flow	10-year	S6
11	Tier 2 Sensitivity	Simulation 5 with 100-year flow	100-year	S6
12	Tier 2 Sensitivity	Base-case with Standard Deviation set to 0	Mean annual	S8
13	Tier 2 Sensitivity	Base-case with higher median flow at Lander SD	Mean annual	S9
14	Tier 2 Sensitivity	Base-case with different particle size distribution in stormwater	Mean annual	S10

In order to assist in the comparison of the results of the PTM base-case and sensitivity simulations, sediment mass accumulations within discrete areas of the EW were tallied for each simulation and then compared using the following procedure:

- Define five discrete areas within the EW that were used to compare sediment mass accumulation from the different runs. These areas each represent an area that is two

hydrodynamic model grid cells wide by two hydrodynamic model grid cells long (see Figure 7-7). Each of these areas represents a different location in the EW both hydrodynamically and by the magnitude of sedimentation expected.

- Calculate total mass deposited within each of the defined areas for each PTM simulation. This was done by calculating the sum of all mass parcels that were deposited in the area at the end of the simulation.
- Normalize the mass deposited in each area for Tier 1 sensitivity simulations (4, 5, 7, and 8) by the mass deposited in the base-case simulation. Comparison of these normalized values and the mass deposited in each area for the base-case simulation are shown in Figure 7-8.
- Normalize the mass deposited in each area for Tier 1 and Tier 2 sensitivity simulations that used annual average upstream flow conditions (2 to 8 and 12 to 14) by the mass deposited in the base-case simulation. Comparison of these normalized values and the mass deposited in each area for the base-case simulation are shown in Figure 7-9.
- Normalize the mass deposited in each area for Tier 2 sensitivity simulations that used extreme upstream flow conditions and 75% TSS loading (9, 10, and 11) by the mass deposited in sensitivity simulation 5 (which used annual average flow and 75% TSS loading). This comparison provides an evaluation of the model response to increases in riverine flow (see Figure 7-10).

Based on the comparisons illustrated in Figures 7-8 and 7-10, the following observations regarding sensitivity of the PTM to model inputs and parameters are developed:

- Decreasing (increasing) the TSS concentration for lateral sources causes deposition decreases (increases) in deposition that are proportional to changes in sediment loading.
- Based on comparisons of deposition patterns and amounts between simulations 1 and 2, PTM predictions are repeatable (i.e., stochastic component of the model does not have significant effect on predictions) in areas where deposition is significant. Caution must be taken when comparing results between model runs in areas of low deposition, as a small change in the number of deposited packets will make the differences between the runs appear exaggerated.

- Based on comparisons of deposition patterns and amounts between simulations 1 and 3, increasing the number of particles (reducing the parcel size) released during a simulation does not have a significant effect on results.
- Increasing the standard deviation of the particle size distribution (which introduces increased numbers of larger, faster settling particles into the model) has similar effects as increasing Class 1A and 1B particle sizes (i.e., increased deposition). This is because an increase in the standard deviation for the larger particles causes a wider range of particle sizes to be input into the model; as a result, there is a greater number of 'larger' particles introduced into the model as standard deviation increases, and these larger particles settle out faster than smaller particles.
- Decreasing Class 1A and 1B particle sizes produces less deposition.
- No significant change in deposition occurs during the 2-year high-flow event, when compared to average-flow conditions.
- Generally, less deposition occurs during 10- and 100-year high-flow events, when compared to average-flow conditions, due to higher current velocities in the EW, which tend to transport suspended particles in the surface layer out of the EW prior to deposition. These model runs were performed to verify expected particle transport behavior and were not used for a detailed analysis of deposition in the EW.
- Simulation 13, which increased the sediment load for Lander (storm only) showed increased deposition just outside the Lander outfall (Area 4), but little change in other high-deposition areas.
- Simulation 14, which increased the percentage of fines in stormwater flow, reduced deposition at outfall locations and increased deposition in areas farther away from outfalls.

7.3.6 Deposition Patterns Due to Lateral Source Sediment Loads

The results of the sensitivity analysis were used to evaluate reasonable lower- and upper-bound simulations for the PTM. The base-case simulation represents the best estimate of model inputs and parameters. However, uncertainty exists in the model inputs and parameters. These uncertainties were taken into account through bounding run simulations, which both increase and decrease the sediment load from lateral sources and the particle size diameter for clay and silt fraction based on evaluation of lateral load data (Section 7.2).

These bounding runs are represented by the Tier 1 sensitivity simulations (Table 7-8). These reasonable lower- and upper-bound simulations correspond to the realistic range of model predictions, with the base-case results corresponding to the best estimate within that range.

The results of the base-case and bounding PTM simulations were used to provide a reasonable range of values for initial sediment mass accumulation in the EW from lateral sources (excluding resuspension due to vessel operations). The results of the base-case simulation (Figure 7-2) define a representative average mass accumulation. Minimum and maximum values of mass accumulation were estimated through the sensitivity analysis (Tier 1 sensitivity simulations) discussed in Section 7.3.4 (Table 7-8), as shown in Figure 7-8. Based on review of Figures 7-8 and 7-9, simulations 4 and 5 produce consistent low and high predictions of sediment mass accumulation and encompass the range of variation seen in other sensitivity runs. One exception is Area 4, which exhibited the highest deposition during Run 8, where particle sizes for smaller size fraction particles were increased. This resulted in higher deposition adjacent to the outfall location in Area 4. However, particle size distributions used for the base-case and Tier 1 sensitivity runs already assume a high percentage of coarser particles; which results in a conservative estimate of deposition adjacent to outfall locations. Therefore, for the purpose of evaluating the contribution of lateral sources to sedimentation in the EW, sensitivity simulations 4 and 5 were selected to represent reasonable lower- and upper-bound inputs and parameters for the PTM, respectively.

7.3.7 Uncertainty Discussion

Uncertainty in the PTM model results arises from several sources. Some inherent randomness exists within the model related to the standard deviation of the characteristic particle size and “random walk” in the particle paths. This randomness is evident in the differences between the results of simulations 1 and 2, which have identical input files but exhibit differences in final particle positions predicted by the PTM. These uncertainties are not significant in areas where there is relatively high deposition; the total amount deposited in these areas is nearly identical between simulations 1 and 2. Since the purpose of the STE is to identify areas where mass contribution from lateral sources is significant enough (relative to other potential sources) to present recontamination potential, the uncertainty in

estimates within low deposition areas is not a serious concern for this application. The model does not account for the initial momentum of particles as they enter the system; this could have an influence on their final deposition location, the effect being similar to spreading the PTM discharge location along the plume trajectory. However, the scale of the hydrodynamic model (which drives the PTM model simulation) is not appropriate for resolving flow fields from individual outfalls. In addition, resuspension and redeposition of sediments by ship operations is not included in the PTM model simulations.

Additional uncertainties exist within the lateral source input data developed for the PTM including particle size distributions, stormwater and CSO flows, and TSS concentrations. These uncertainties have been integrated (to the extent practical) into the STE through the development of lower- and upper-bound simulations, which provide a range of model results based on variations in the input data. Uncertainties may also arise from the hydrodynamic model due to limitations in grid resolution (both horizontally and vertically).

As discussed, shorter-term simulations were performed to provide data that can be used to evaluate long-term conditions. This involved using a representative tidal condition and temporally-constant mean annual average riverine inflow and sediment source input rates. This information, while not representative of any particular storm event, provides average deposition rates and patterns that can be utilized to evaluate recontamination potential from lateral sources over the long term.

8 PRELIMINARY REASSESSMENT OF PHYSICAL PROCESSES CONCEPTUAL SITE MODEL

The preliminary Physical Processes CSM for the EW, which was developed prior to completion of the STE, was presented in the CSM and Data Gaps Analysis Report (Anchor, Windward and Battelle 2008). This CSM will be updated in the SRI Report based on results of the STE, as provided in this report. However, a brief summary of the STE results and a screening-level comparison of those results to the preliminary Physical Processes CSM is provided in this section. In general, the results of the STE support and validate the preliminary Physical Processes CSM for the EW.

8.1 East Waterway Hydrodynamics

Hydrodynamic modeling results confirmed the validity of the preliminary Physical Processes CSM. Modeled current velocities within the EW due to tidal and riverine currents are confirmed to be relatively low during periods of low upstream inflow. As upstream inflow increases, surface velocities within the EW increase. Surface velocities are highest in the Junction and Sill Reaches (maximum 90 cm/s), and are lower in the Main Body Reach (maximum 40 cm/s). Near-bed velocities are highest in the Main Body Reach near the mouth of the EW (maximum 18 cm/s) and lowest in the area south of Slip 27 (maximum 2 cm/s). The presence of distinct two-layer flow (inflow of higher density saline water at depth with outflow of fresher water at the surface) becomes more prevalent as upstream inflow increases. During low flow events, vertical gradients in salinity are consistent throughout the EW. During high flow events, vertical gradients in salinity are more pronounced in the Main Body Reach, where a layer of freshwater overlies high salinity water. During high flow events in the Sill and Junction Reaches, freshwater may be present throughout the water column.

Freshwater input to the EW and WW from upstream sources is split equally during periods of lower flow (i.e., less than 2-year flood). During flood events greater than the 2-year flow, the EW:WW flow split is consistently about 30% to 70% (from 2- to 100-year flood flows).

8.2 Erosion Potential

The 95th percentile confidence interval of critical bed shear stress for surface sediments in the EW ranges between 0.20 and 0.37 Pa. The maximum predicted bed shear stress for a 100-year high-flow event (0.12 Pa) is below the lower confidence bound value for critical shear stress (0.20 Pa) as estimated from the Sedflume data. Therefore, it is not anticipated that significant bed scour or erosion of in situ bed sediments will occur as a result of tidal or riverine currents.

Near-bed velocities generated by episodes of propwash are confirmed to be significantly higher than those due to tidal and riverine currents in areas of the EW that are subjected to large vessel operations (generally north of Slip 27). Consequently, bed shear stress due to vessel operations is significantly greater than bed shear stress due to natural forces for all areas experiencing vessel operations. Erosion potential due to propwash is anticipated to be more significant north of Slip 27 (compared to areas south of Slip 27) due to concentrated large container ship activity in those areas. This assumption is consistent with geochronological core data (see Section 3). Estimates of bed shear stress due to propwash range from 2 to 23 Pa within the EW based on estimates of vessel operations while navigating and berthing. Based on the propwash evaluation, surface sediments within the waterway have the potential to be eroded due to extreme vessel operations (as defined in Section 5.1.2) throughout the EW. This observation is not necessarily consistent with the results of geochronological core data (Section 3); which imply that areas south of Slip 27 (between EW Stations 4000 and 5200) are not subject to significant mixing at depth below the mudline. However, it is possible for this area to be net depositional over time (as shown by the geochronological core data) but subject to occasional suspension of surface sediments due to propwash/vessel activity in those areas. Since the propwash evaluation focused on extreme standard vessel operations, and there is vessel activity south of Slip 27, it is likely that potential erosional events are not as frequent in that area compared to areas north of Slip 27 possibly associated with smaller vessel size.

8.3 Net Sedimentation in the East Waterway

An evaluation of 17 geochronology cores suggests that portions of the EW south of Slip 27 and portions of the EW north of Station 6200 are net depositional with minimal mixing of

sediments in these areas. An evaluation of the one geochronology core collected within the interior of Slip 27 suggests that portions of the slip may also be net depositional. Areas north of Slip 27 (including at the mouth of Slip 36) appear to be heavily influenced by episodic erosion events, as radiochemistry results for cores located in those areas indicate the presence of a well-mixed sediment bed. No geochronology cores were collected within the interior of Slip 36.

Although areas in the Main Body Reach south of Station 6200 and north of Station 6800 (north of the bridges), as well as the southern portion (shallower areas) within the interior of Slip 27, appear to be net depositional, grain size distribution data for those cores shows that surface sediments in those areas are significantly coarser than in the deeper areas of the Main Body Reach. This may imply that finer sediments tend to settle in the deeper areas within the EW north of Station 6800 (where the EW becomes both wider and deeper and current velocities are relatively low). In addition, bed sediments in the western side of the Main Body Reach between Station 6200 to 6800 (propwash operation Area 6) are likely impacted by propwash due to tug and barge operations in that area.

Geochronology cores were not retrieved in the Sill and Junction Reaches due to consolidated gravel surface sediments in those areas. This suggests that these areas are likely not net depositional due to relatively high tidal and riverine currents in this portion of the EW.

8.4 Contribution of Solids from Lateral Sources

Preliminary PTM model results, which predict initial sediment mass accumulation within the EW from lateral sources, imply that the solids mass contribution to the EW from lateral sources is greatest close to the outfall locations. The mass accumulation predicted by the PTM model does not account for resuspension and transport of material due to vessel operations.

The contribution of solids from lateral sources declines quickly with increasing distance from the outfall location with relatively little deposition occurring in much of the deeper areas of the Main Body Reach. Coarser sediment size fractions (sands) tend to settle quite close to outfall locations, whereas silts and clays tend to settle farther away from their source, as would be expected.

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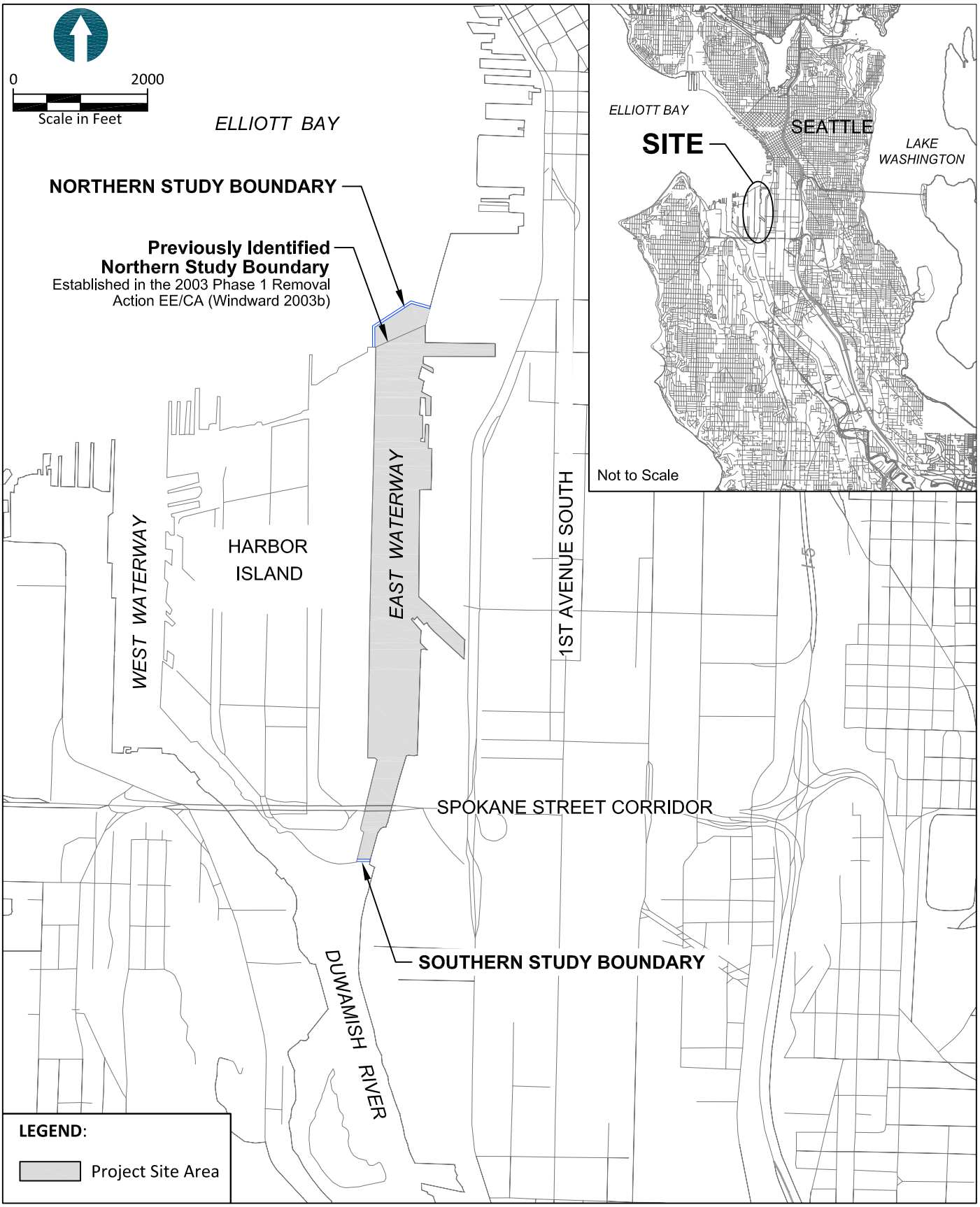
FIGURES



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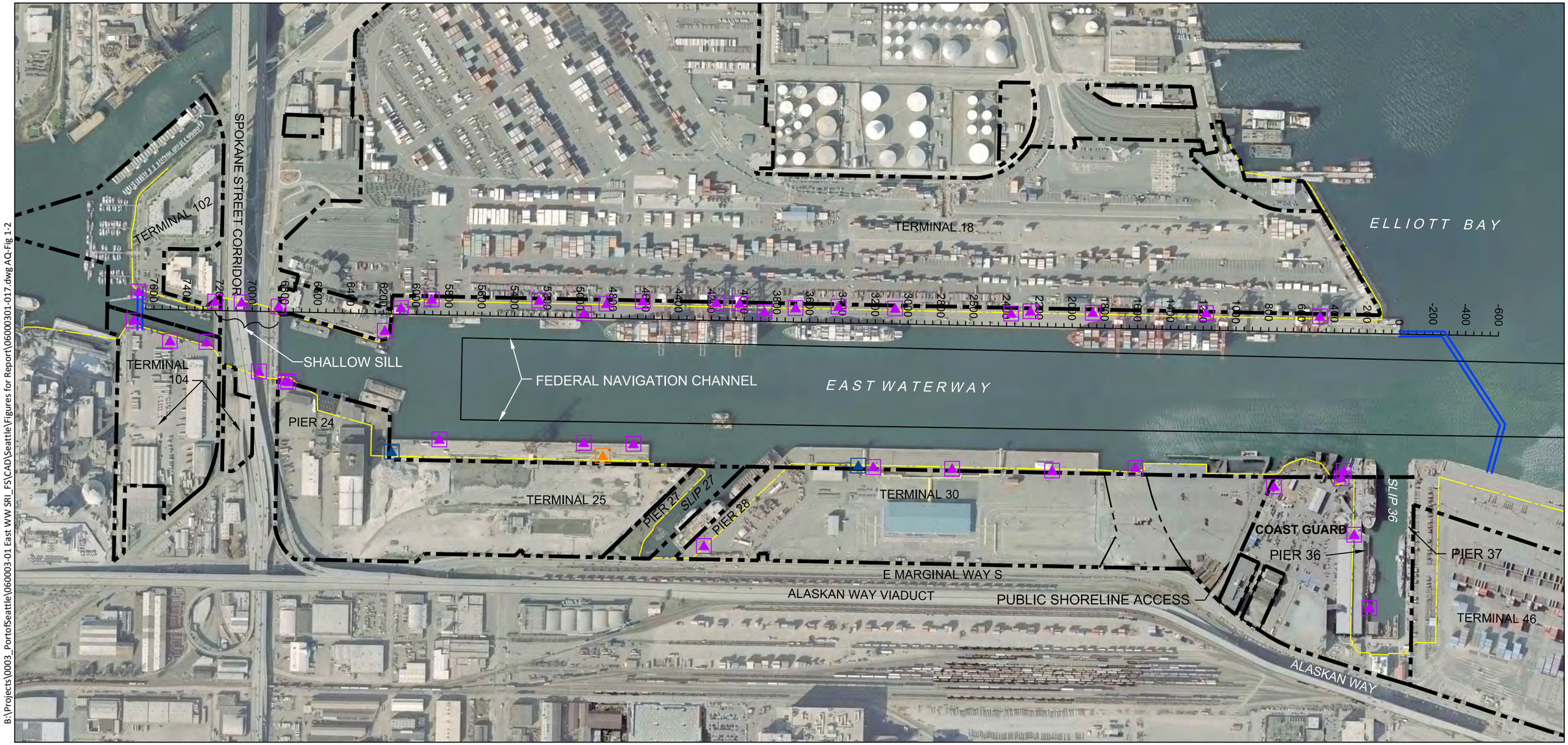
Nov 22, 2011 7:46am epipkin

Figure 1-1
Vicinity Map and East Waterway SRI/FS Boundary
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA



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LEGEND

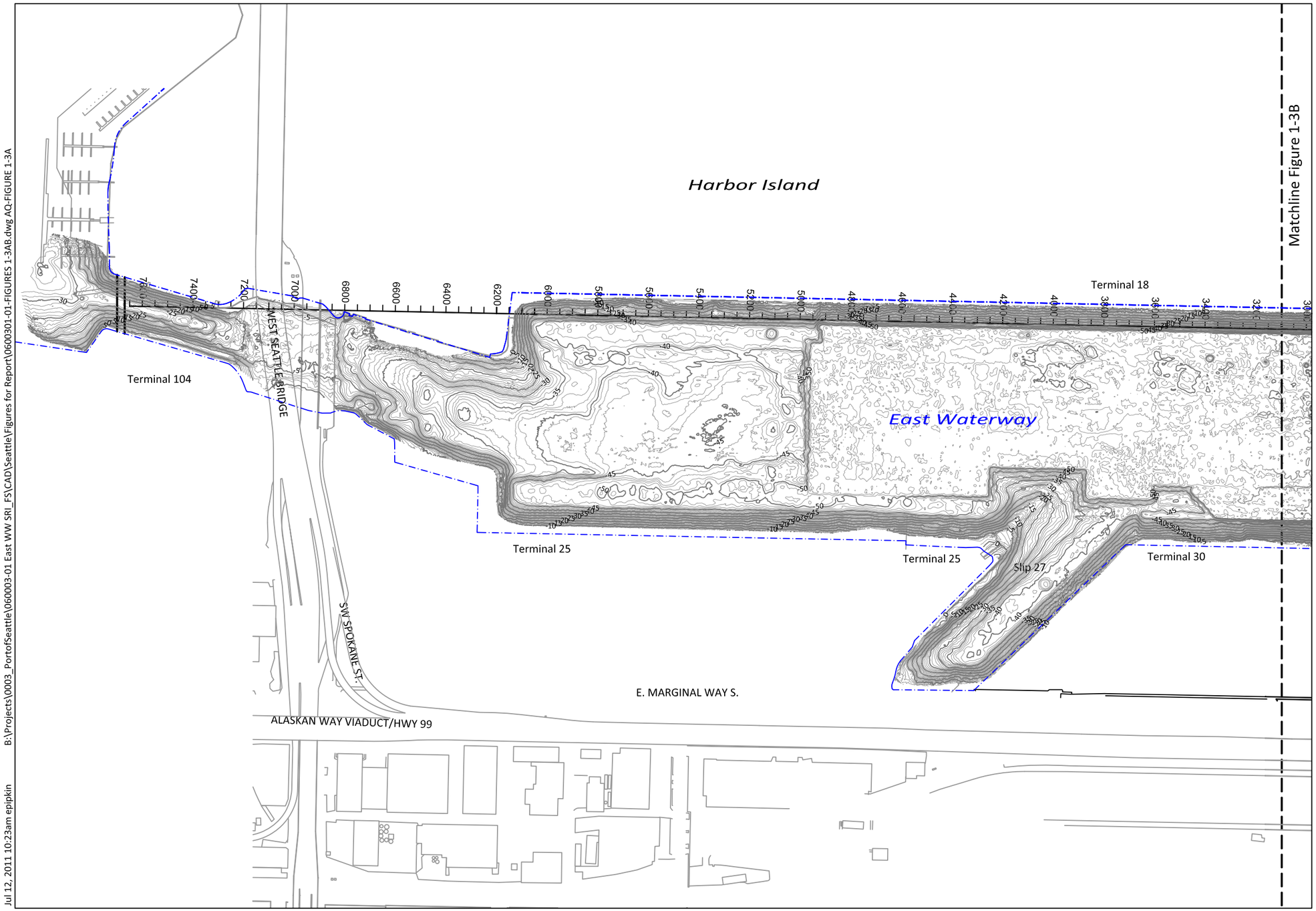
- Inner Harbor Line / Property Line
- East Waterway Operable Unit Study Boundary
- MHHW Line
- CSO
- Storm Drain
- CSO/Storm Drain Location

Note: Previously established station locations for the East Waterway are shown along the western shoreline for reference.

0 600
Scale in Feet

ANCHOR QEA

Figure 1-2
Major East Waterway Features
Sediment Transport Evaluation Report
East Waterway Operable Unit



LEGEND:

- East Waterway Operable Unit Boundary
- MHHW Line
- Bathymetric Contour-Major
- Bathymetric Contour-Minor

0 400
Scale in Feet

SOURCE: Existing bathymetry survey provided by David Evans and Associates.
HORIZONTAL DATUM: Washington State Plane North, NAD83.
VERTICAL DATUM: Mean Lower Low Water (MLLW).

NOTES:
1. Contour interval is 1-foot.

Jul 12, 2011 10:23am epipkin B:\Projects\0003_PortofSeattle\060003-01 East WW SRI_FS\CAD\Seattle\Figures for Report\0600301-01-FIGURES 1-3AB.dwg AQ-FIGURE 1-3A

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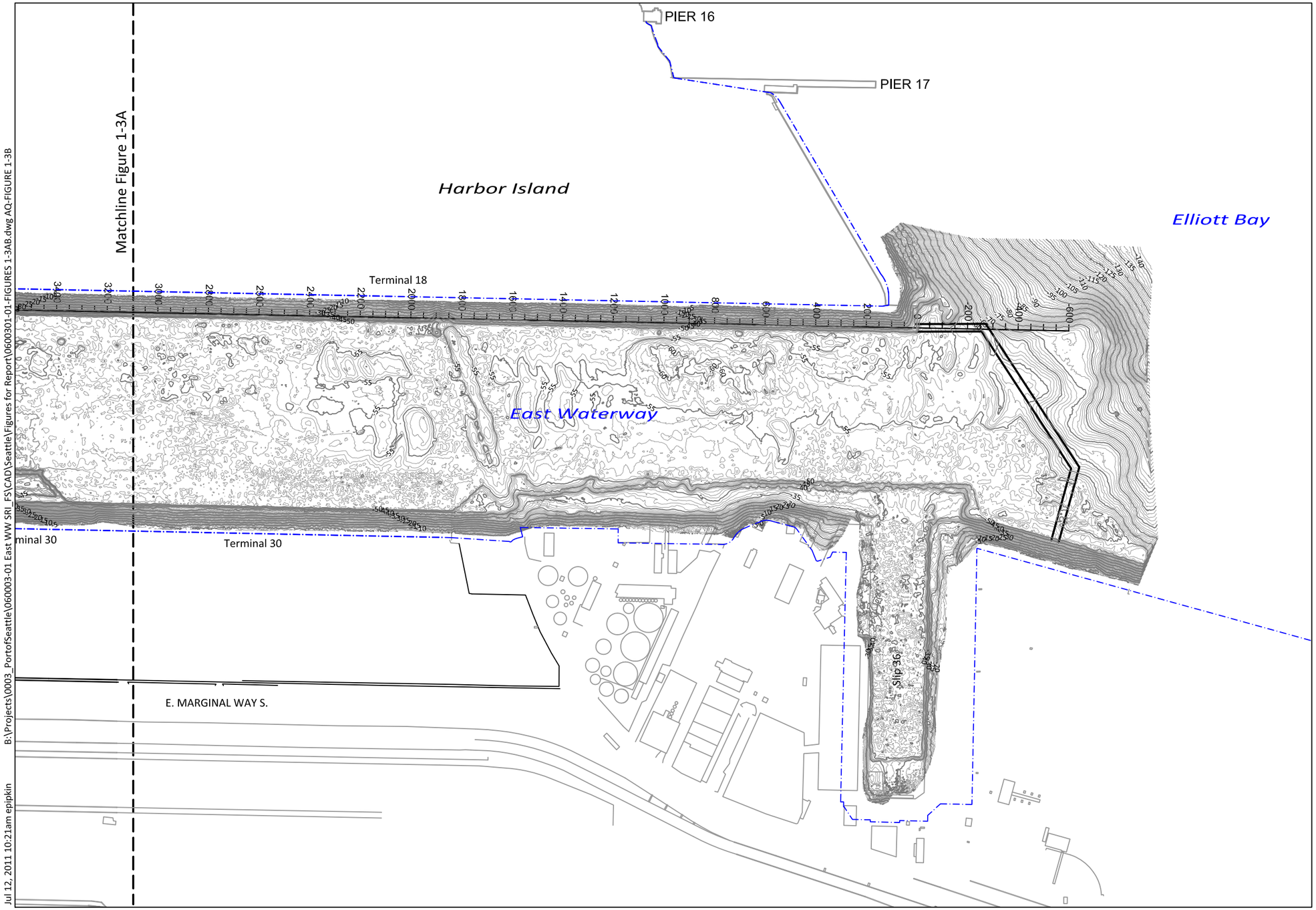
Figure 1-3A
Existing Bathymetry
Sediment Transport Evaluation Report
East Waterway Operable Unit



LEGEND:

- East Waterway Operable Unit Boundary
- MHHW Line
- -15 Bathymetric Contour-Major
- Bathymetric Contour-Minor

0 400
Scale in Feet

SOURCE: Existing bathymetry survey provided by David Evans and Associates.
HORIZONTAL DATUM: Washington State Plane North, NAD83.
VERTICAL DATUM: Mean Lower Low Water (MLLW).

NOTES:
1. Contour interval is 1-foot.

B:\Projects\0003_PortofSeattle\060003-01 East WW SRI_FS\CAD\Seattle\Figures for Report\0600301-01-FIGURES 1-3AB.dwg AQ-FIGURE 1-3B
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Figure 1-3B
Existing Bathymetry
Sediment Transport Evaluation Report
East Waterway Operable Unit

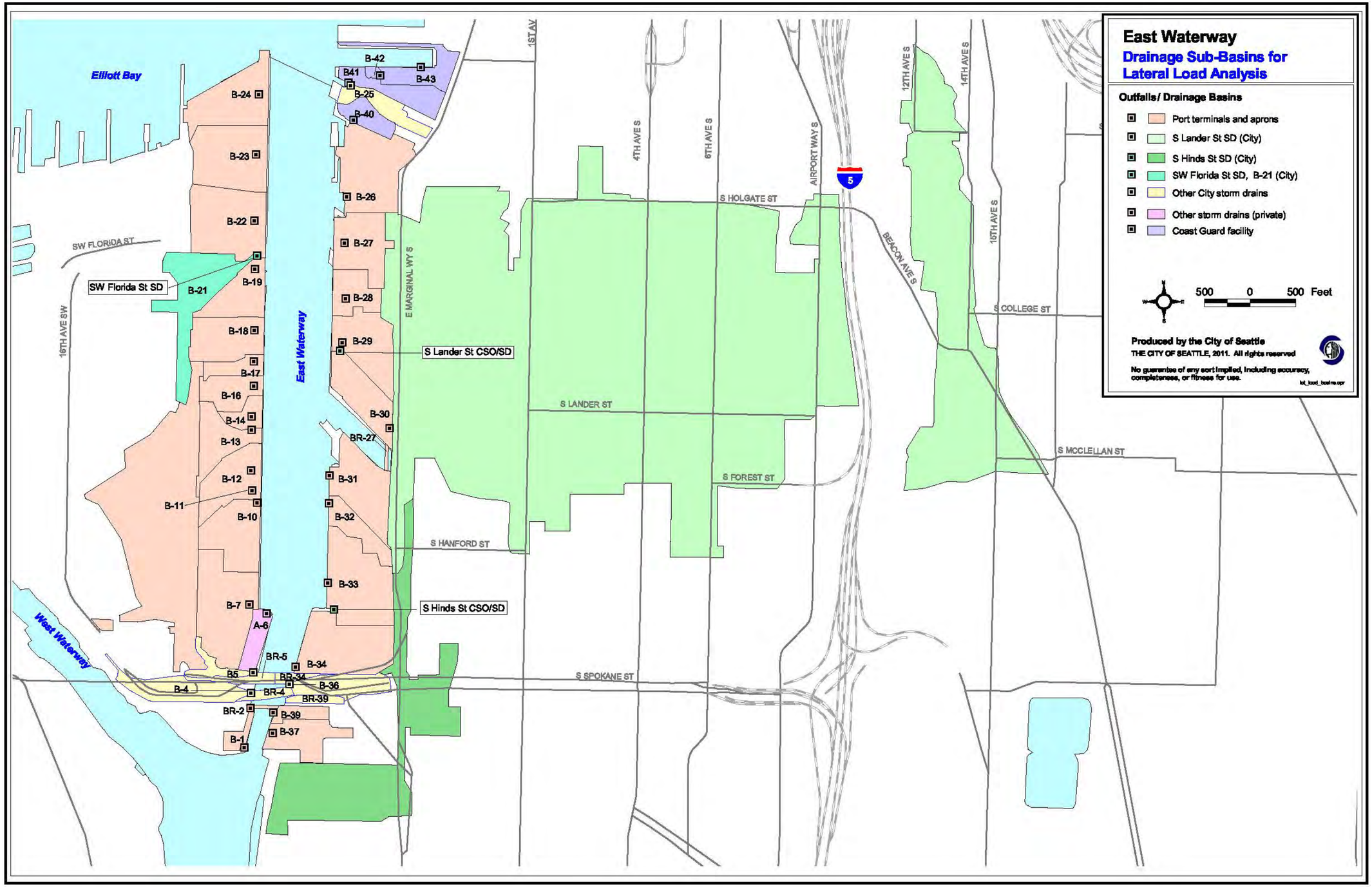

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Figure 1-4A
Drainage Basins and Outfall Locations
Sediment Transport Evaluation Report
East Waterway Operable Unit

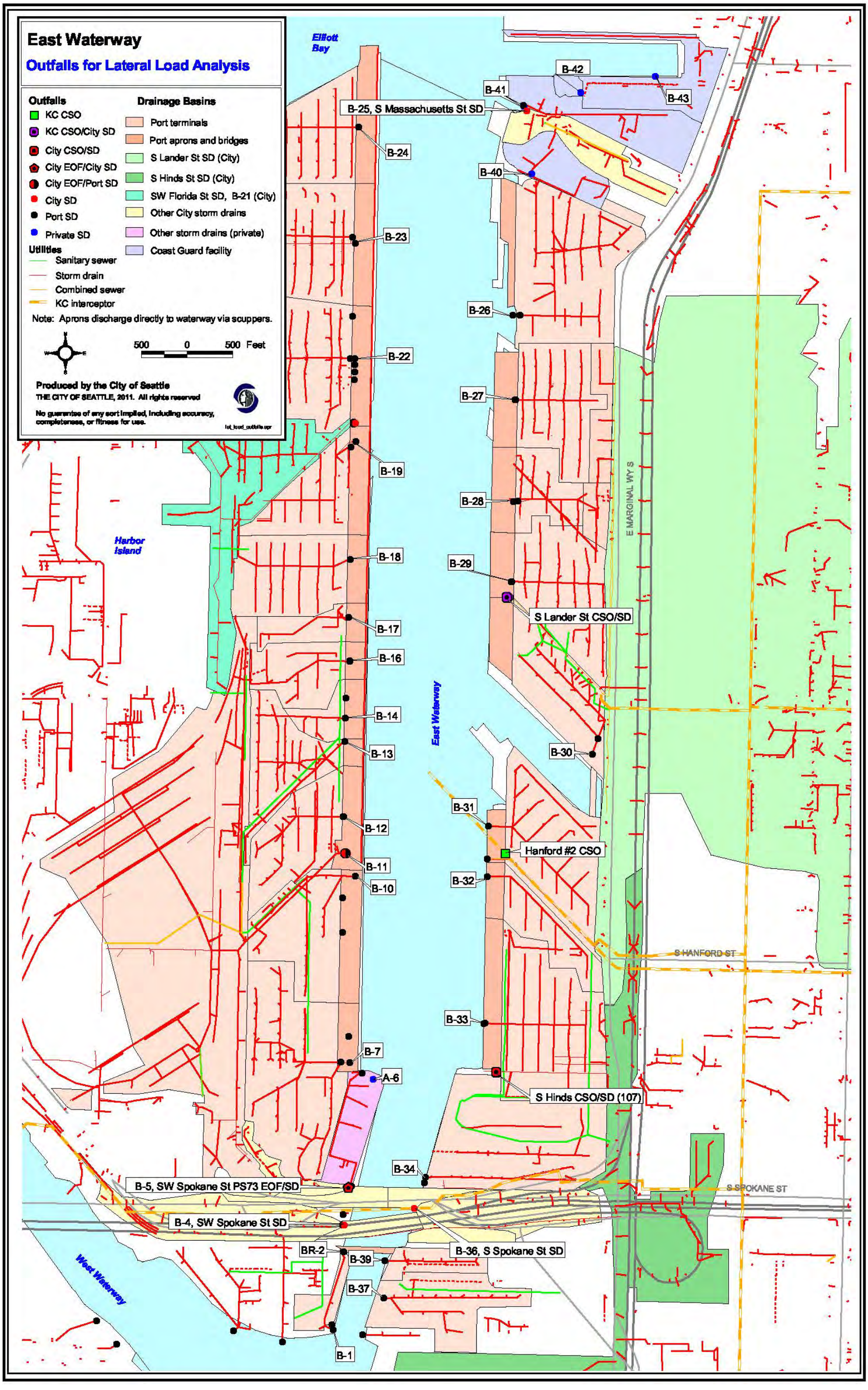

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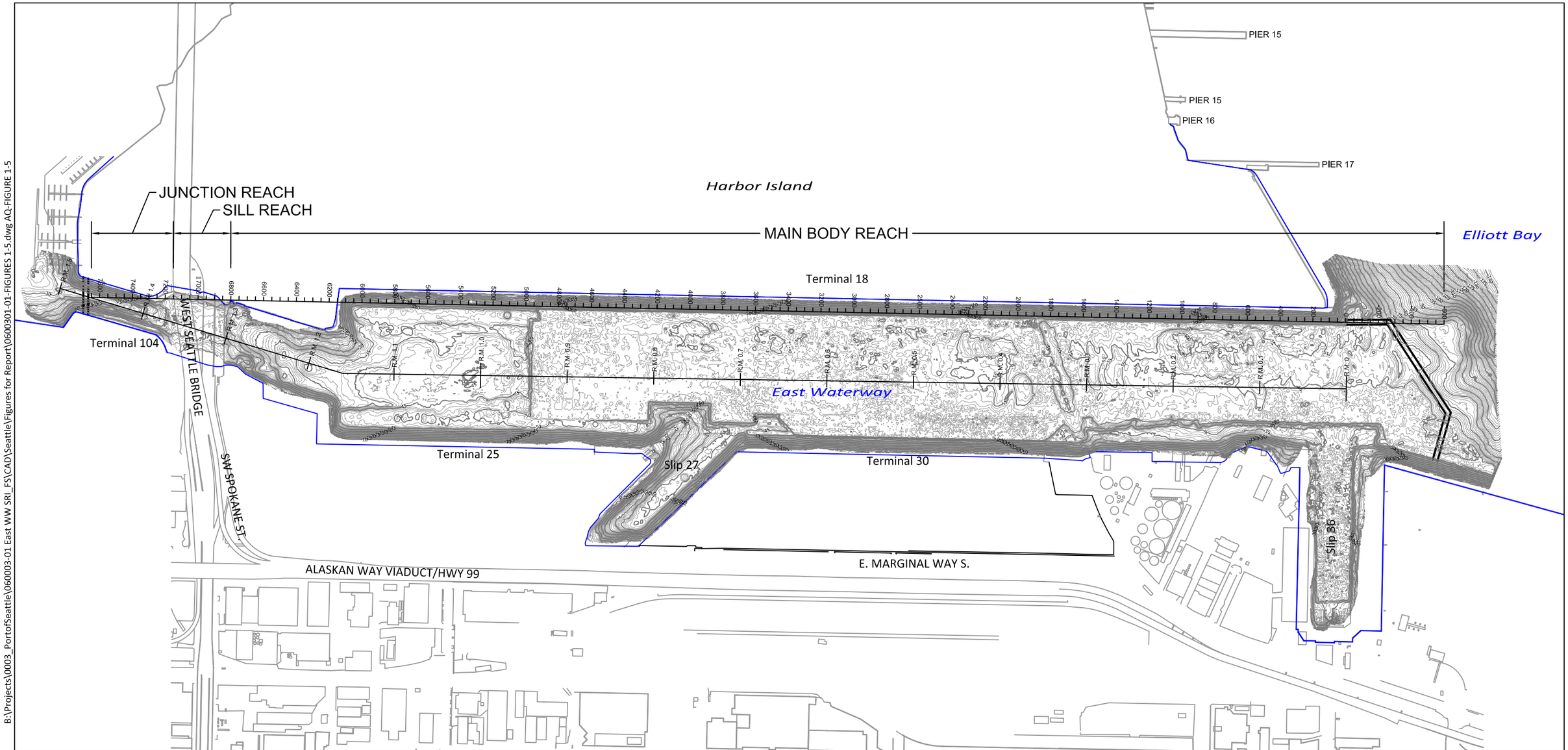
Figure 1-4B
Drainage Basins and Outfall Locations
Sediment Transport Evaluation Report
East Waterway Operable Unit



LEGEND:

- East Waterway Operable Unit Boundary
- MHHW Line
- -15 Bathymetric Contour-Major
- Bathymetric Contour-Minor

0 600
Scale in Feet

SOURCE: Existing bathymetry survey provided by David Evans and Associates.
HORIZONTAL DATUM: Washington State Plane North, NAD83.
VERTICAL DATUM: Mean Lower Low Water (MLLW).

NOTES:
1. Contour interval is 1-foot.

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Figure 1-5
East Waterway Reaches and River Miles
Sediment Transport Evaluation Report
East Waterway Operable Unit

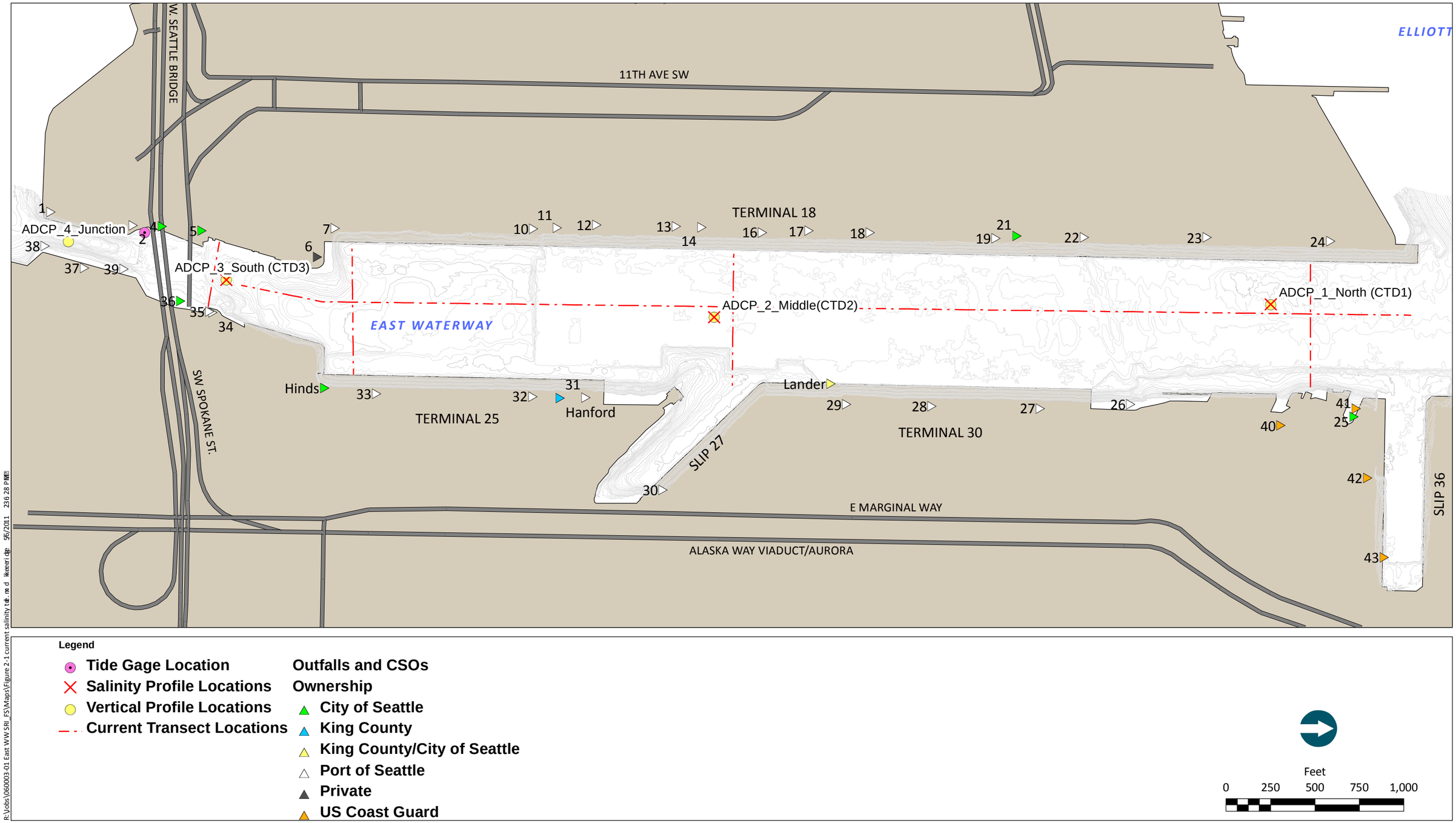

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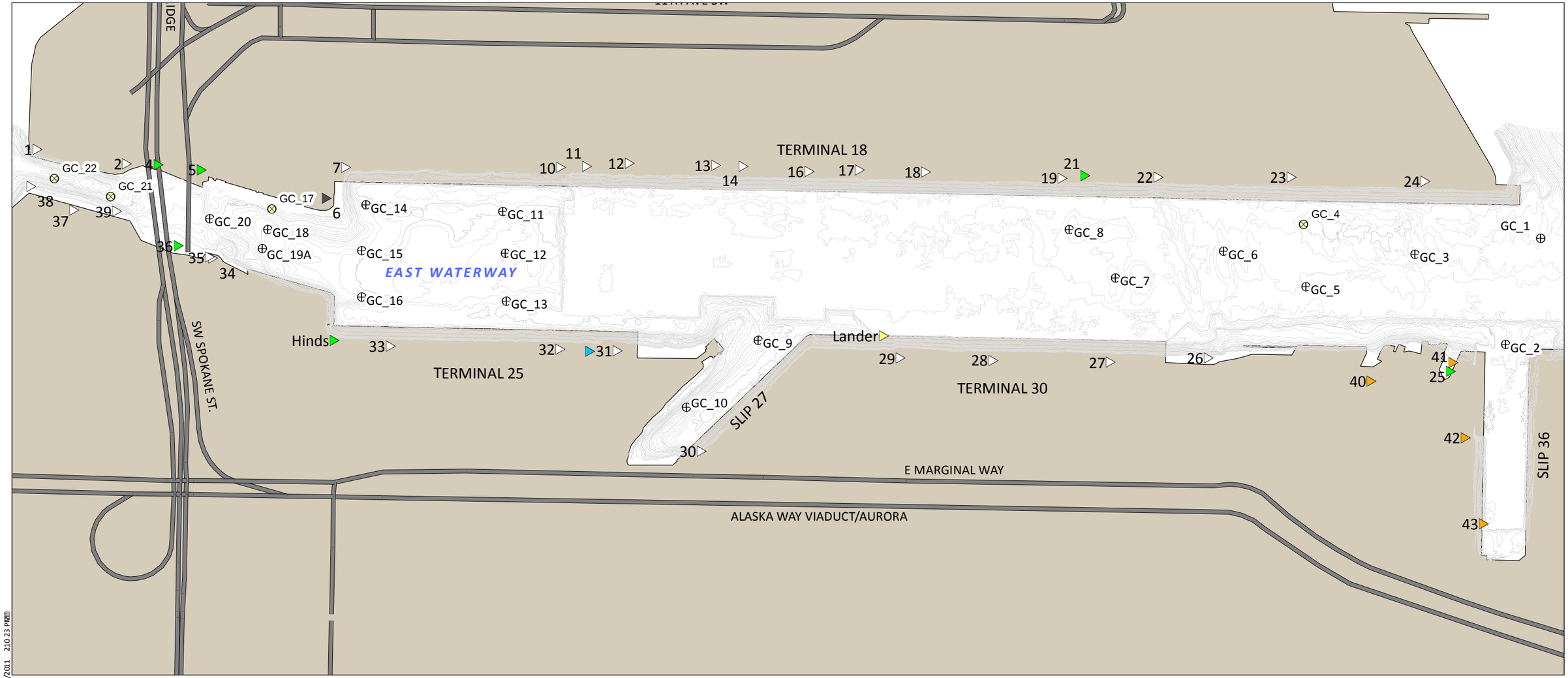
Figure 2-1
Current and Salinity Data Collection and Tide Gage Locations
Sediment Transport Evaluation Report
East Waterway Operable Unit



Legend

- ⊗ Geochron Cores - No Recovery
- ⊕ Geochron Cores - Collected

Outfalls and CSOs

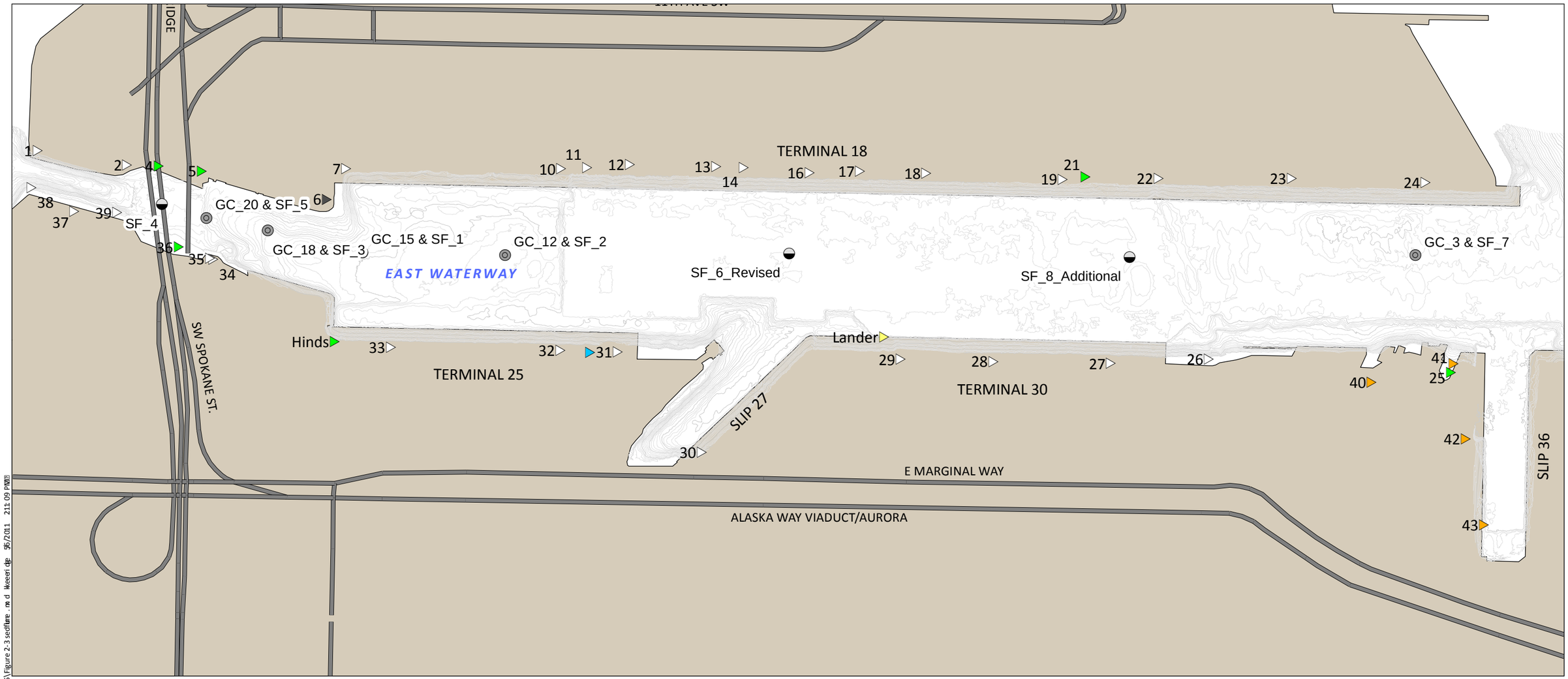
Ownership

- ▲ **City of Seattle**
- ▲ **King County**
- △ **King County/City of Seattle**
- △ **Port of Seattle**
- ▲ **Private**
- ▲ **US Coast Guard**

Feet
0 250 500 750 1,000

C:\Users\kketeridge\Figure 2 2 geochron. mxd kkeeri dge 5/6/2011 2:10:23 PM

Figure 2-2
Geochronological Core Locations
Sediment Transport Evaluation Report
East Waterway Operable Unit



Legend

- **Sedflume Core Locations - Co-located with Geochron Cores**
- **Sedflume Core Locations**

Outfalls and CSOs

Ownership

- **City of Seattle**
- **King County**
- **King County/City of Seattle**
- **Port of Seattle**
- **Private**
- **US Coast Guard**

Feet

0 250 500 750 1,000

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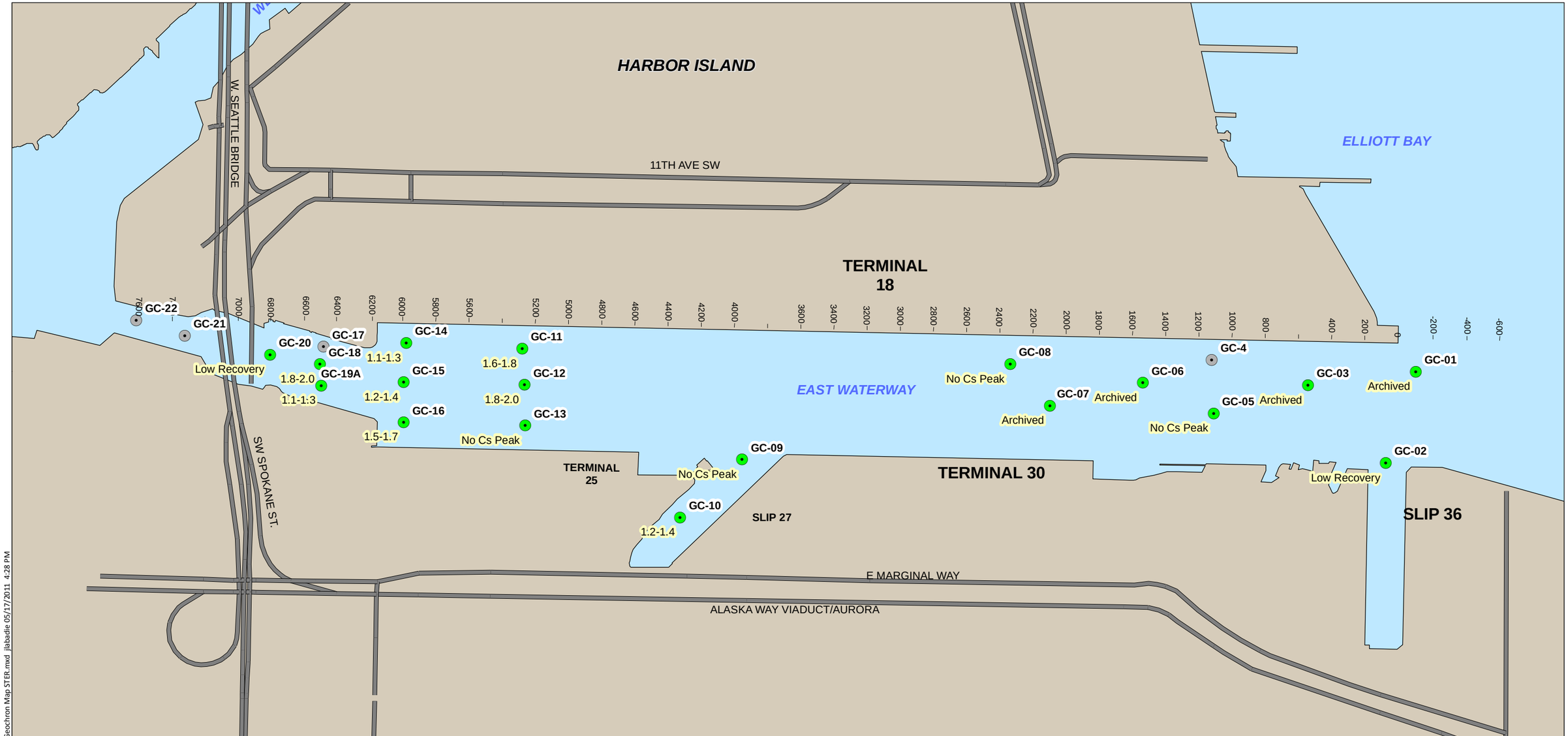
Figure 2-3
Sedflume Core Locations
Sediment Transport Evaluation Report
East Waterway Operable Unit



NOTES:
1. Horizontal Datum: NAD 83 WA North US ft
2. Rates are in cm/yr
3. Presented locations represent accepted at or final attempt.

Geochronological Cores, Cesium-137 Results

Geochronological Cores - No Recovery

0 500 1,000

Scale in feet

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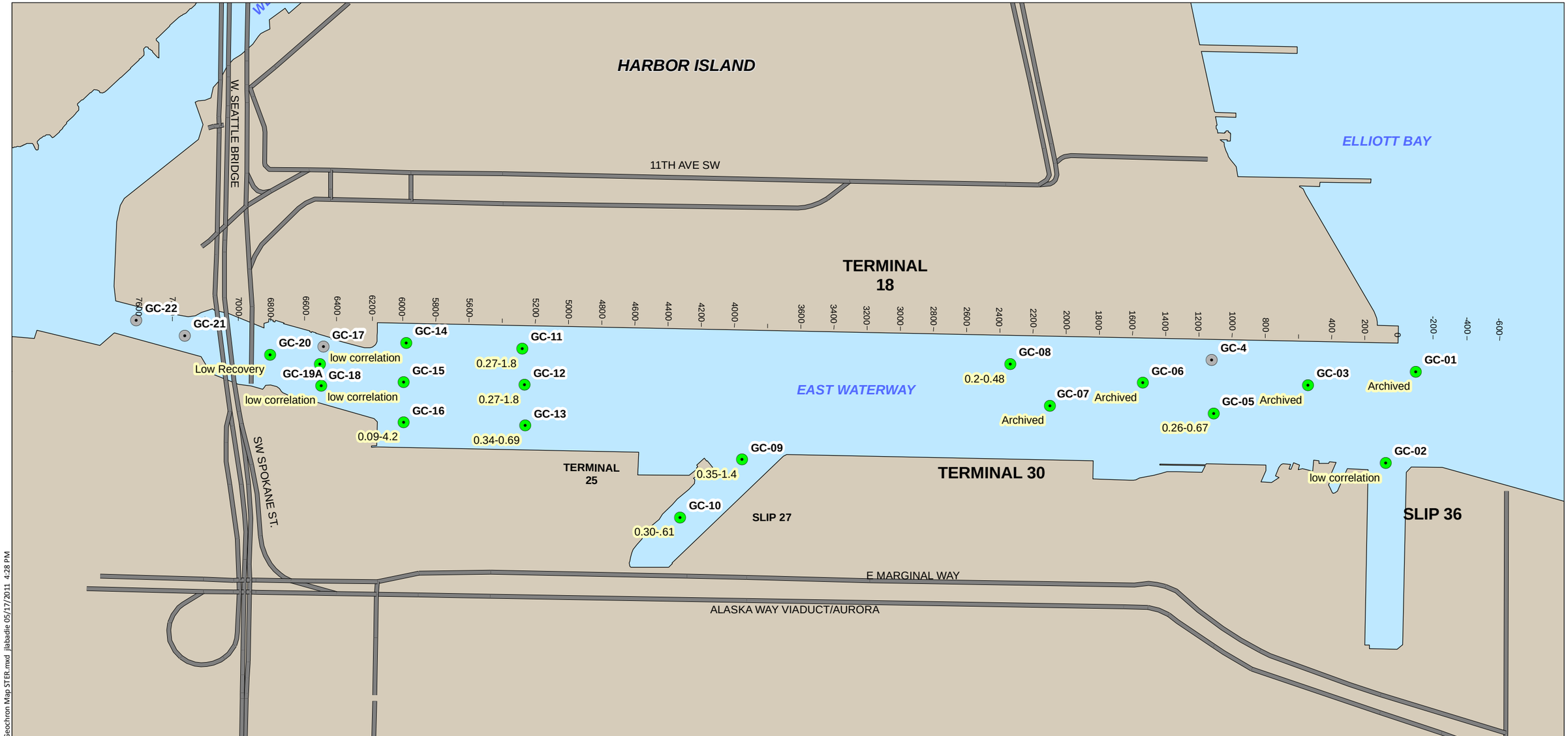
Figure 3-1
Geochronology Core Location Map and Cesium-137 Sedimentation Rates (cm/year)
Sediment Transport Evaluation Report
East Waterway Operable Unit SRI/FS



NOTES:
1. Horizontal Datum: NAD 83 WA North US ft
2. Rates are in cm/yr
3. Presented locations represent accepted at or final attempt.

Geochronological Cores, Lead-210 Results
Geochronological Cores - No Recovery

0 500 1,000
Scale in feet

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ANCHOR QEA

Figure 3-2
Geochronology Core Location Map and Lead-210 Sedimentation Rates (cm/year)
Sediment Transport Evaluation Report
East Waterway Operable Unit SRI/FS

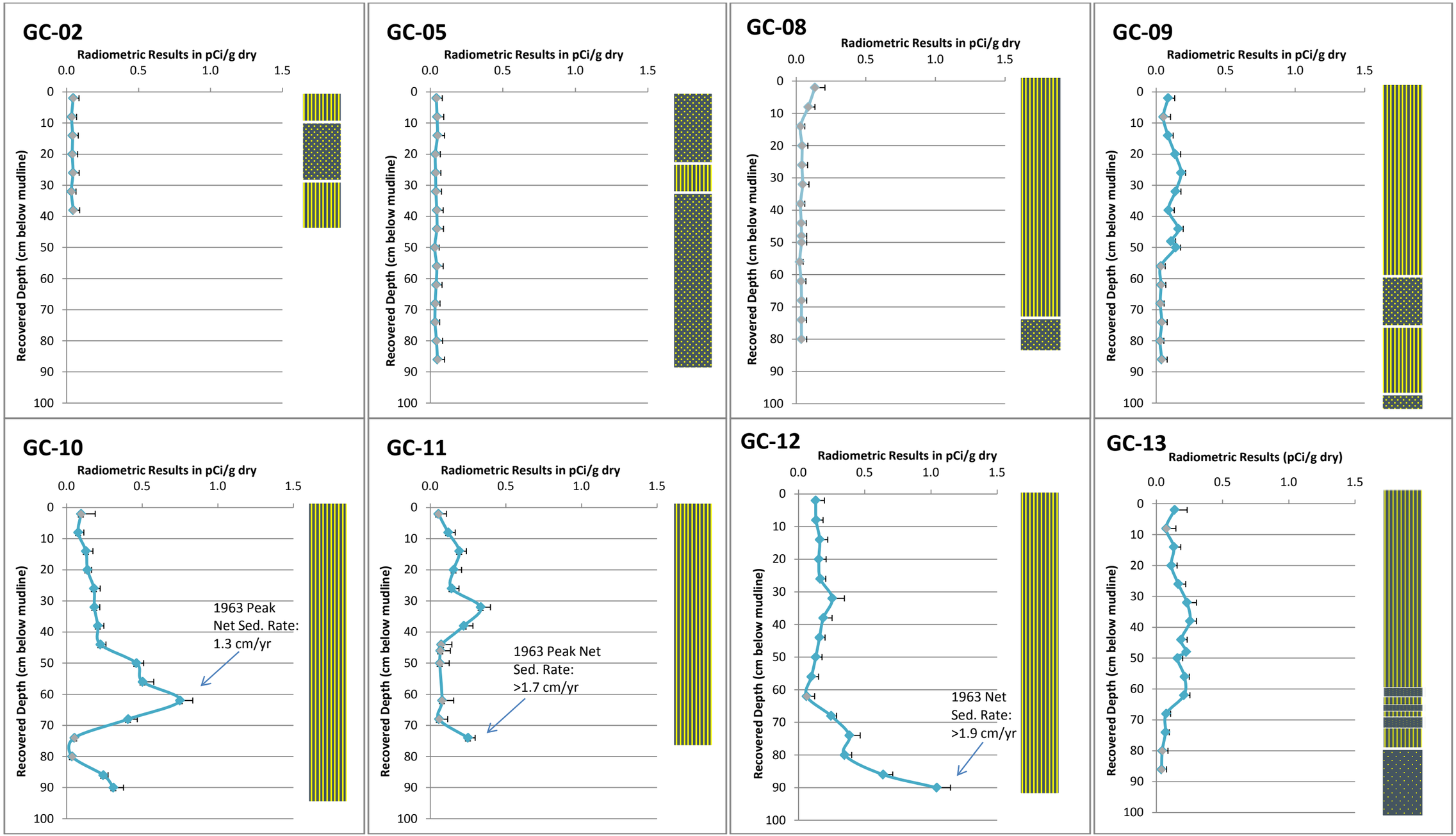

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Figure 3-3A
Summary of Cesium-137 Core Profiles
Sediment Transport Evaluation Report
East Waterway Operable Unit

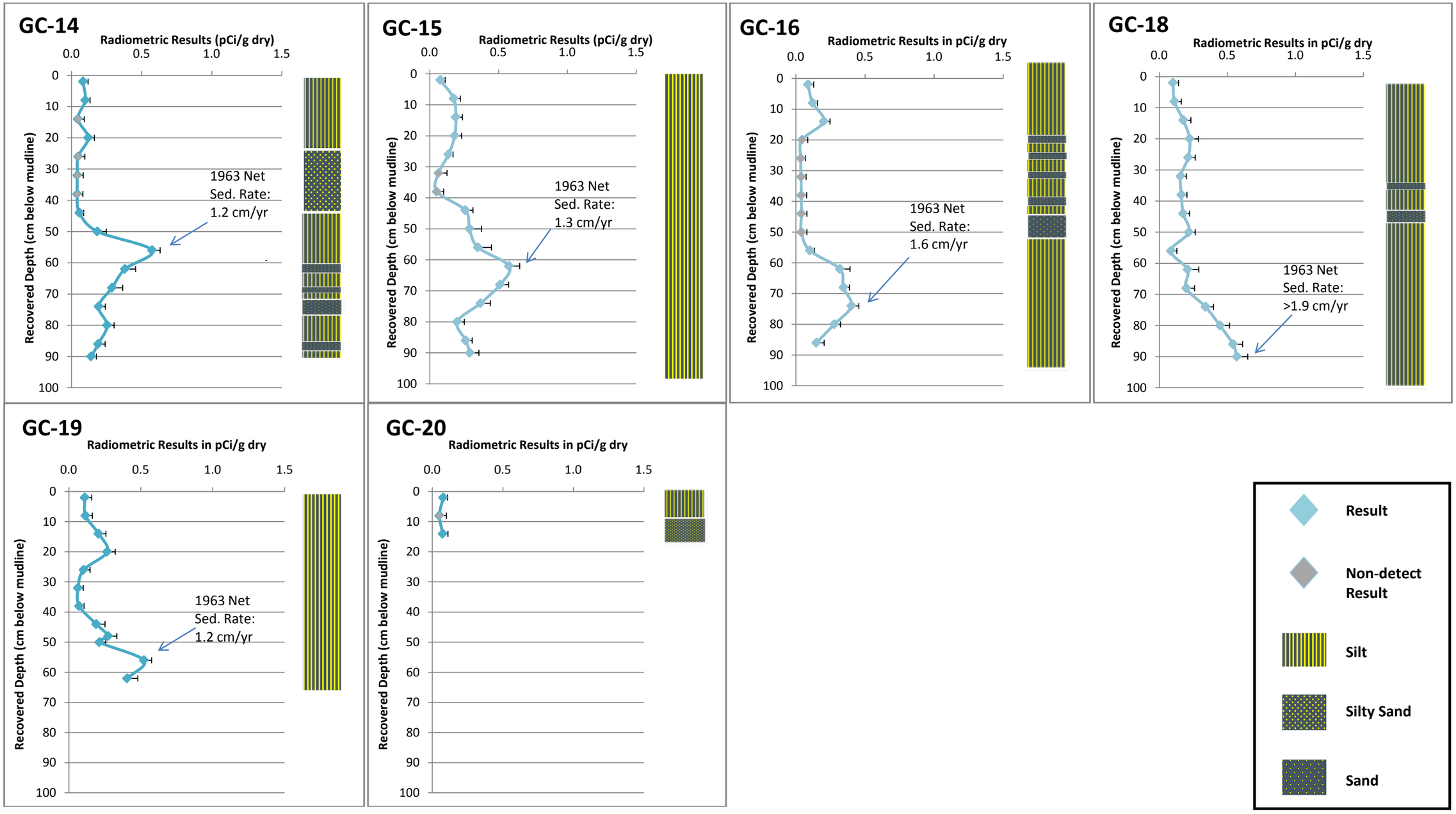

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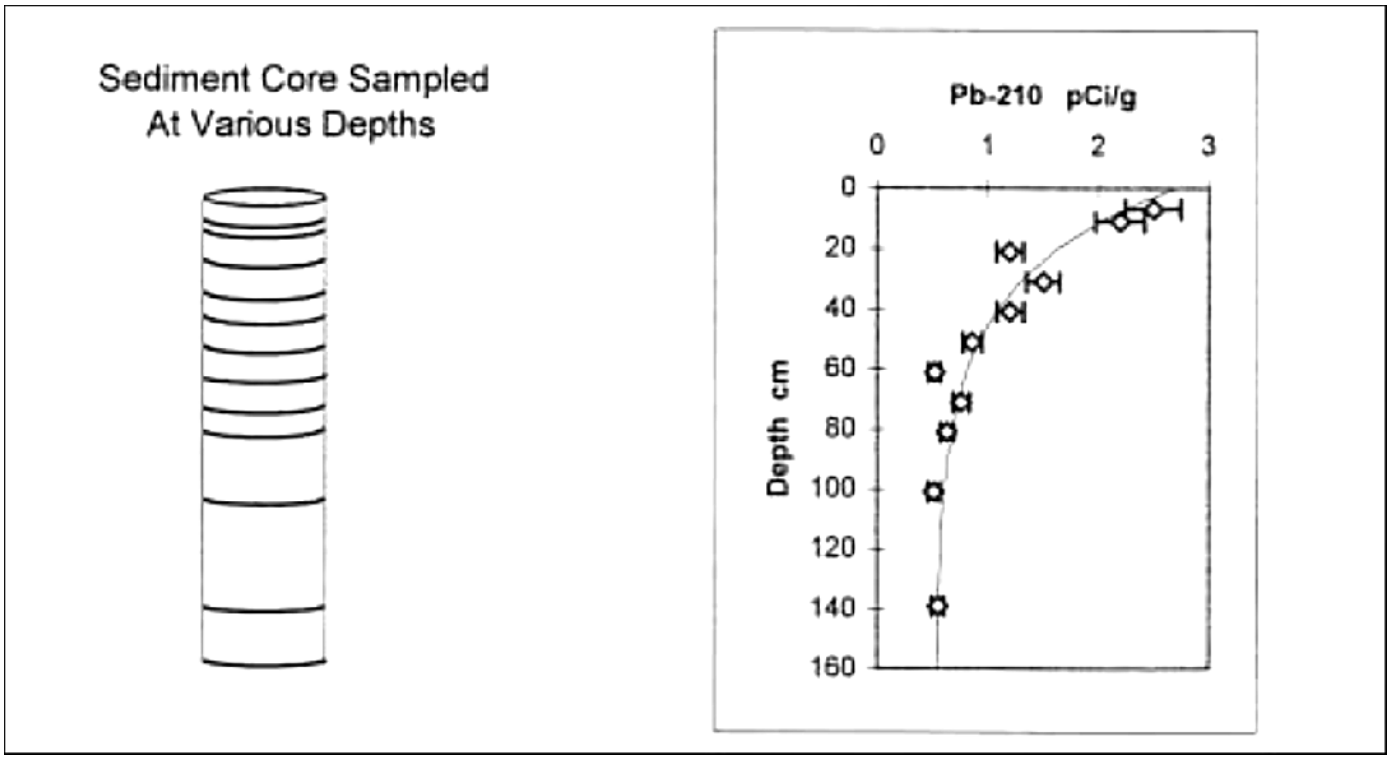
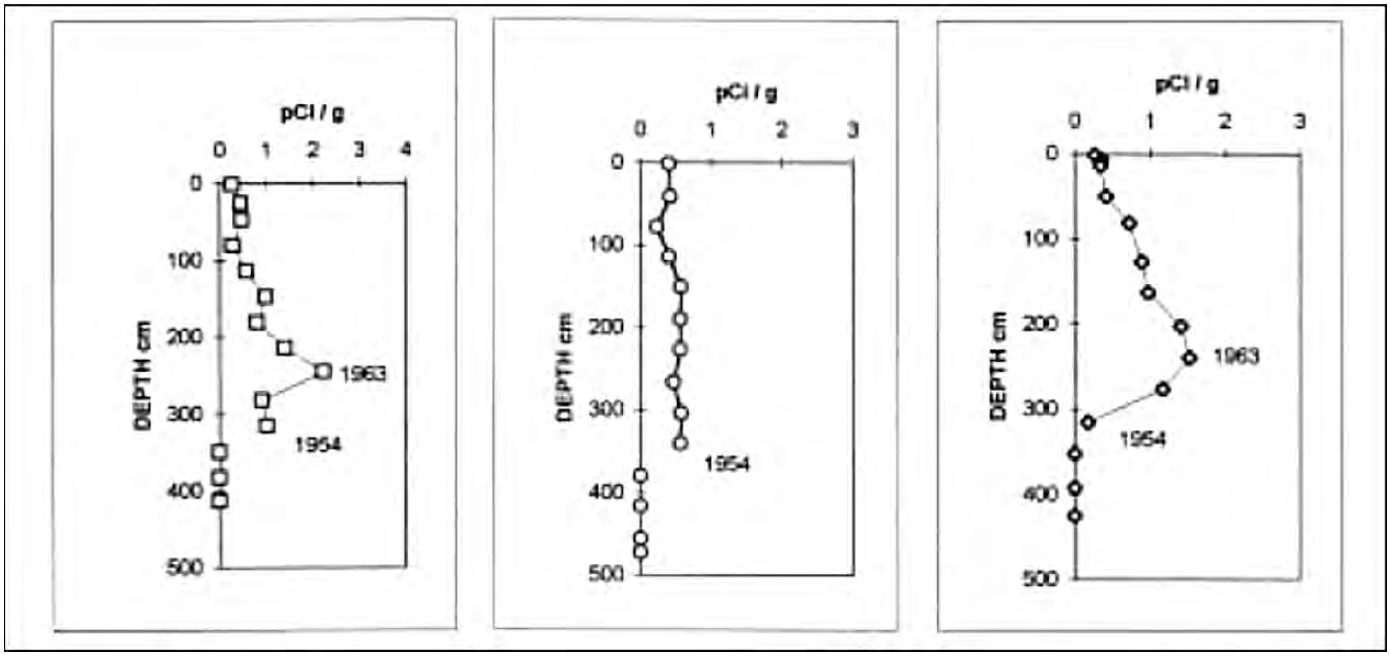
Figure 3-3B
Summary of Cesium-137 Core Profiles
Sediment Transport Evaluation Report
East Waterway Operable Unit



Source: (Jeter 2000)[a]



Source: (Jeter 2000)[b]

Notes:

a. Concentration profiles typically show an exponential decrease in Pb-210 with depth, caused by radioactive decay.
b. The shapes of Cs-137 profiles may vary significantly based on overall concentration levels and mixing of surface sediments.

Figure 3-4
Reference Lead-210 and Cesium-137 Profiles
Sediment Transport Evaluation Report
East Waterway Operable Unit

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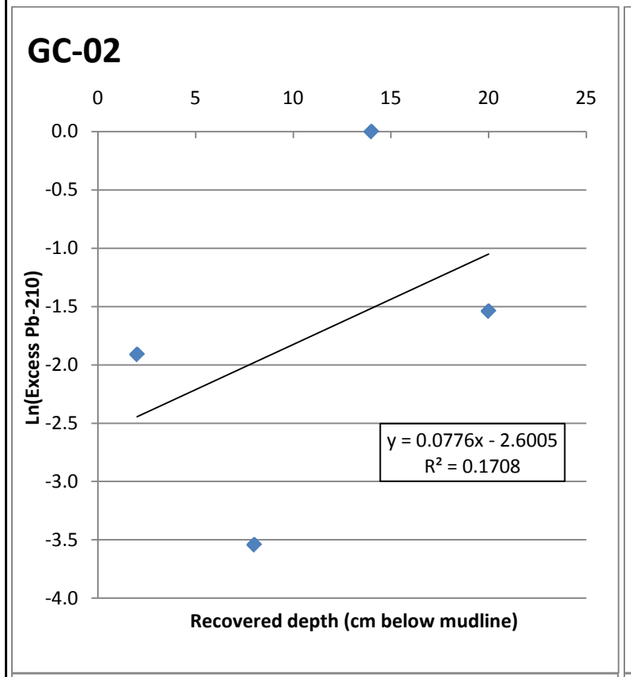
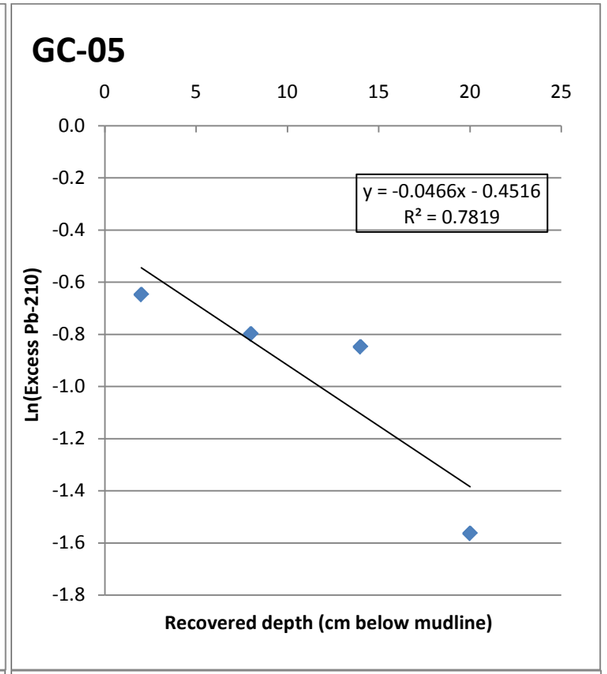
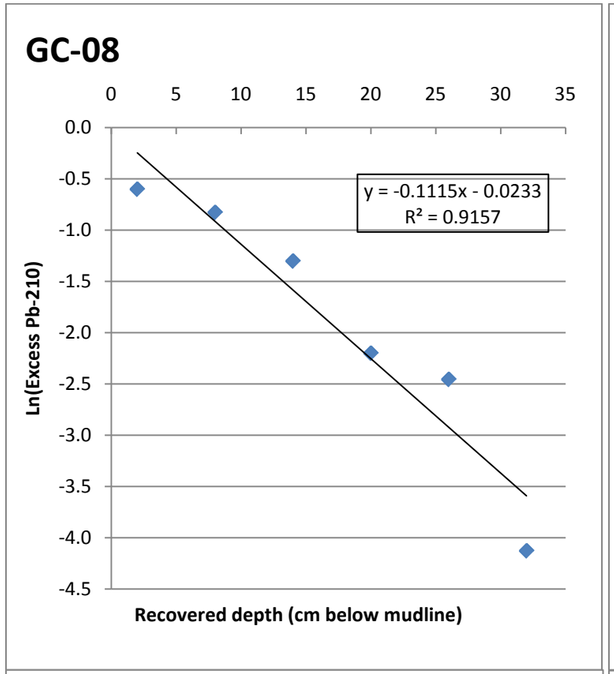
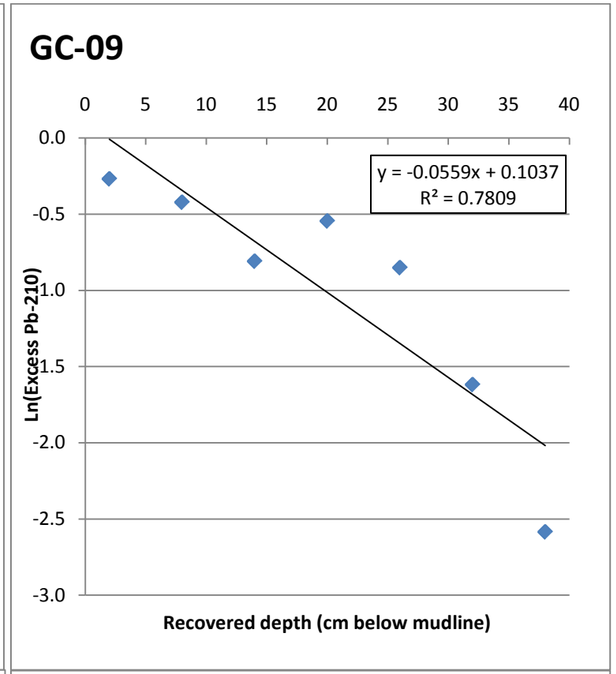
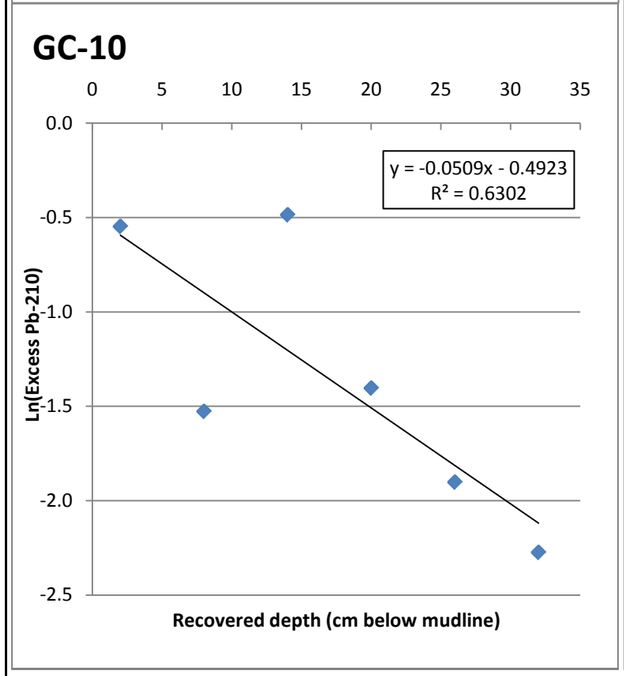
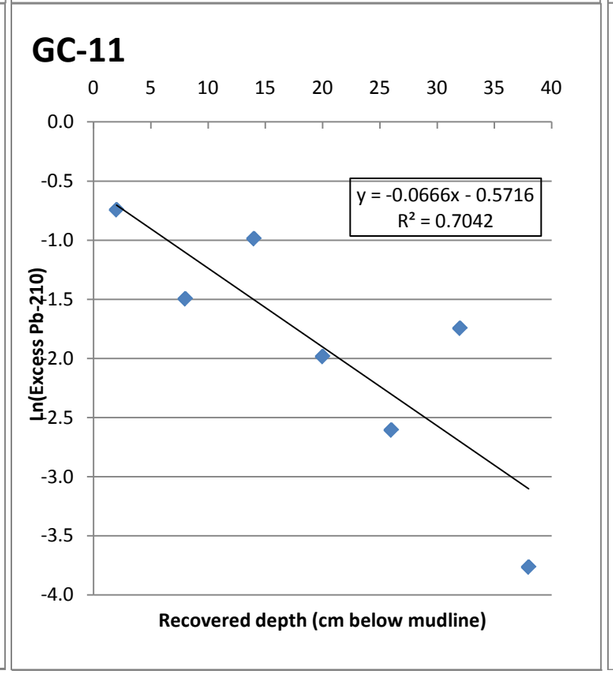


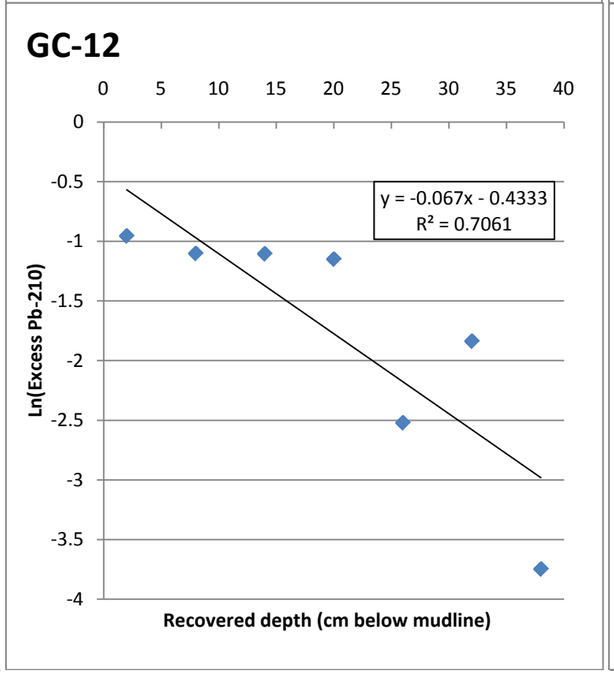


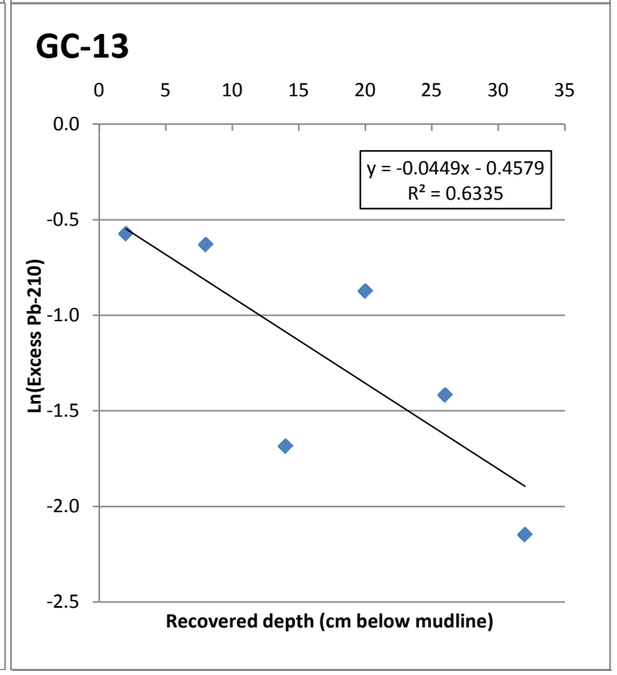






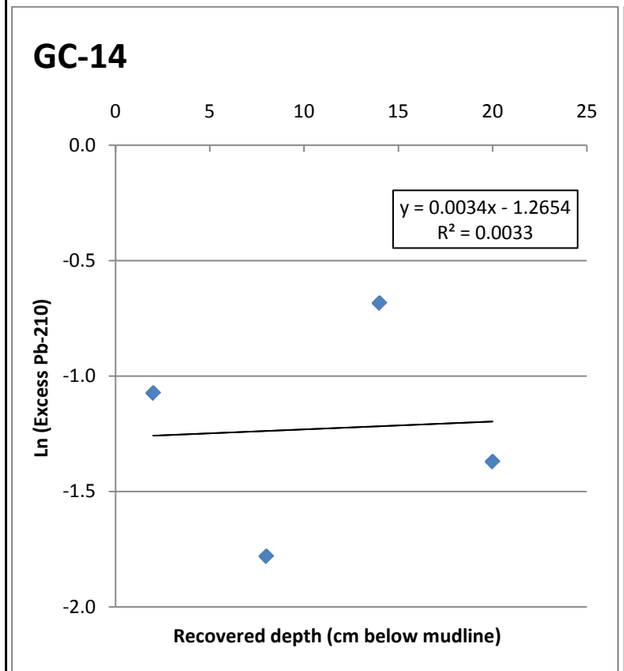


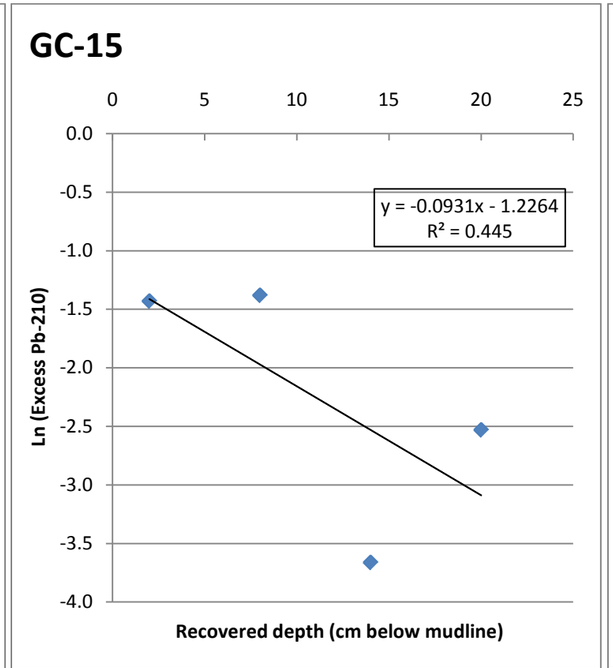


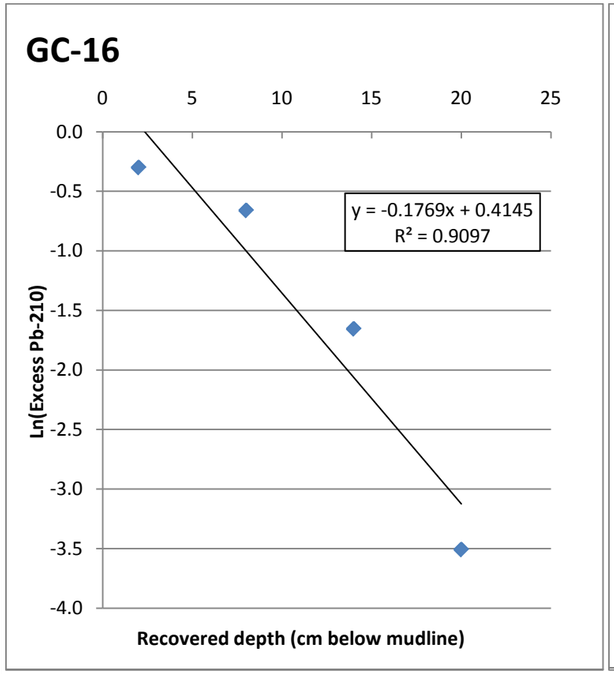


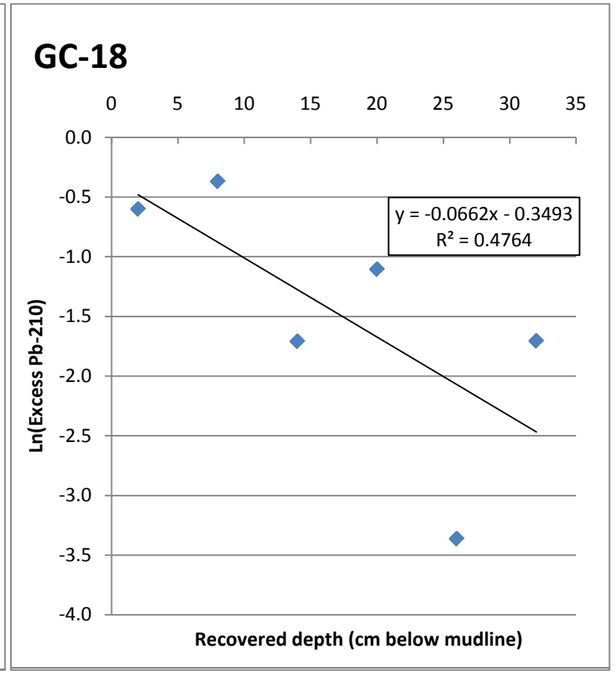
ANCHOR QEA

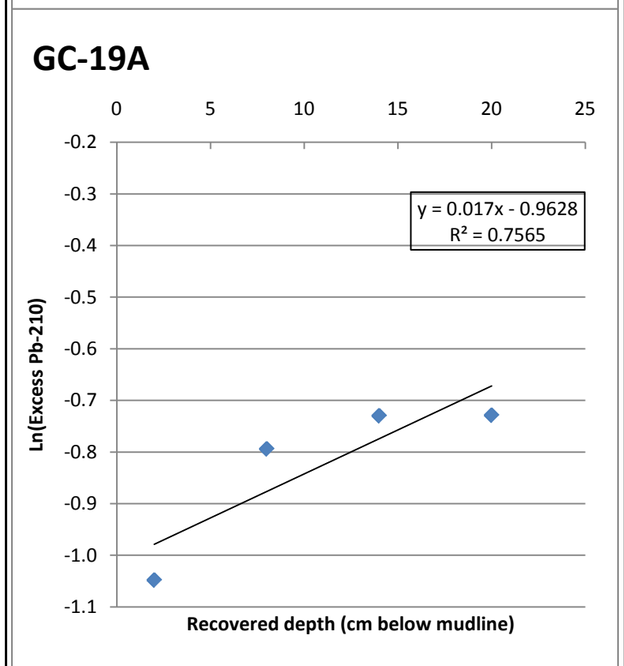
Figure 3-5A
Summary of Lead-210 Core Profiles
Sediment Transport Evaluation Report
East Waterway Operable Unit

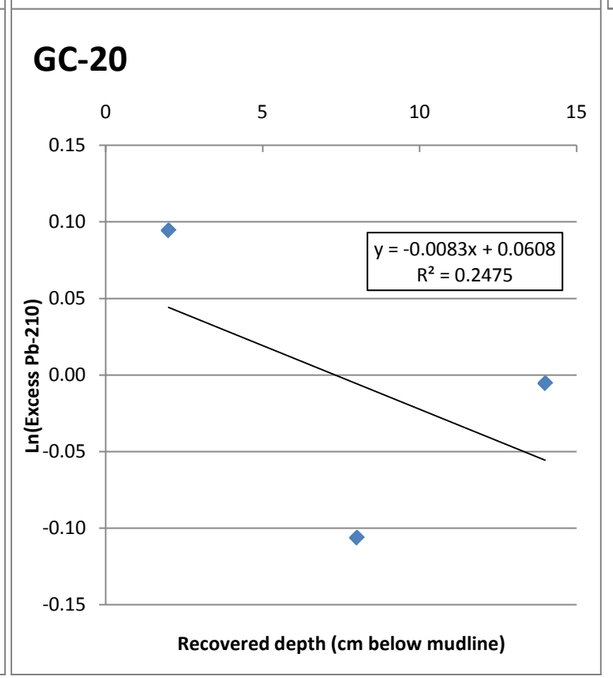












ANCHOR QEA

Figure 3-5B
Summary of Lead-210 Core Profiles
Sediment Transport Evaluation Report
East Waterway Operable Unit SRI/FS

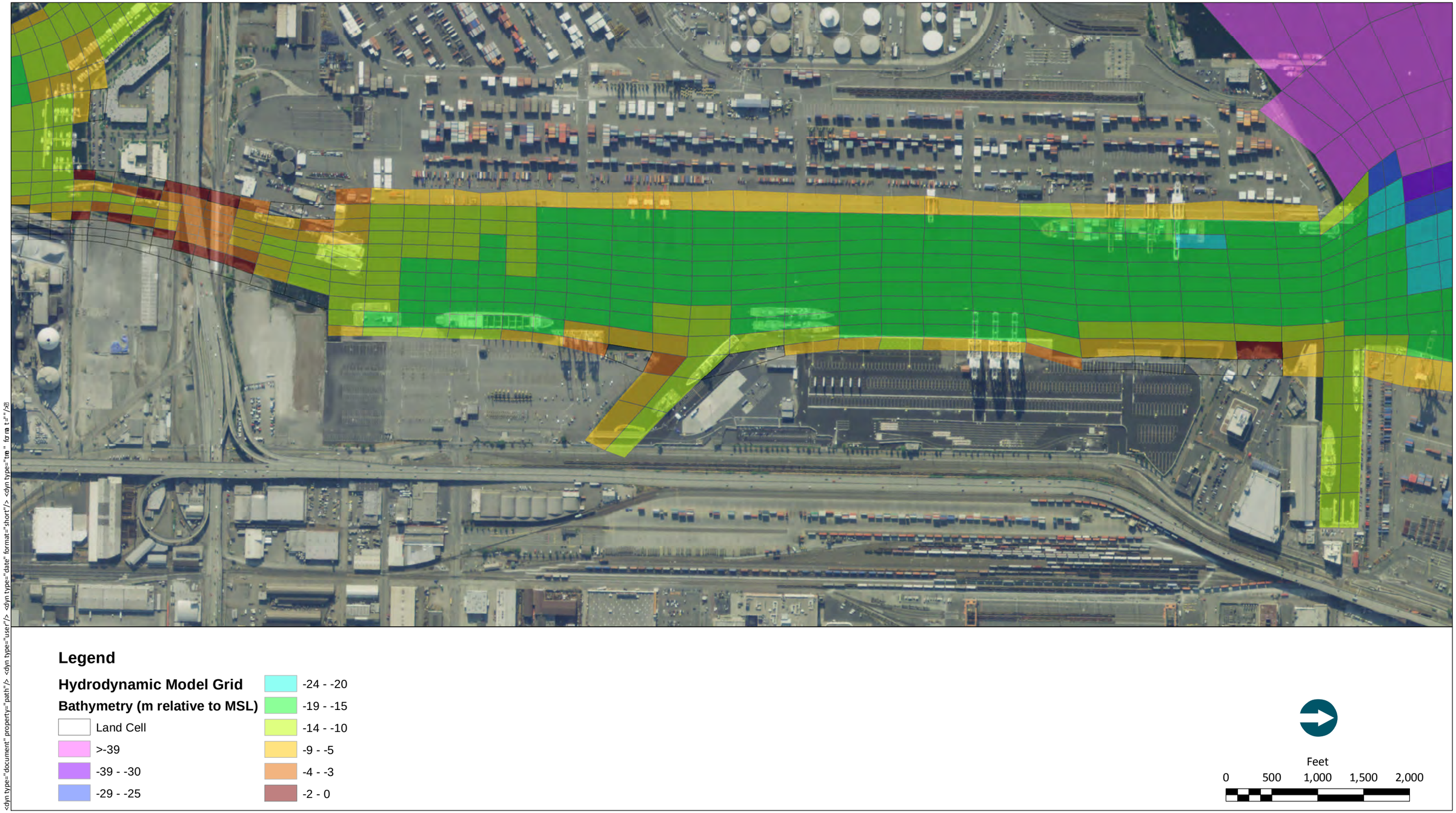


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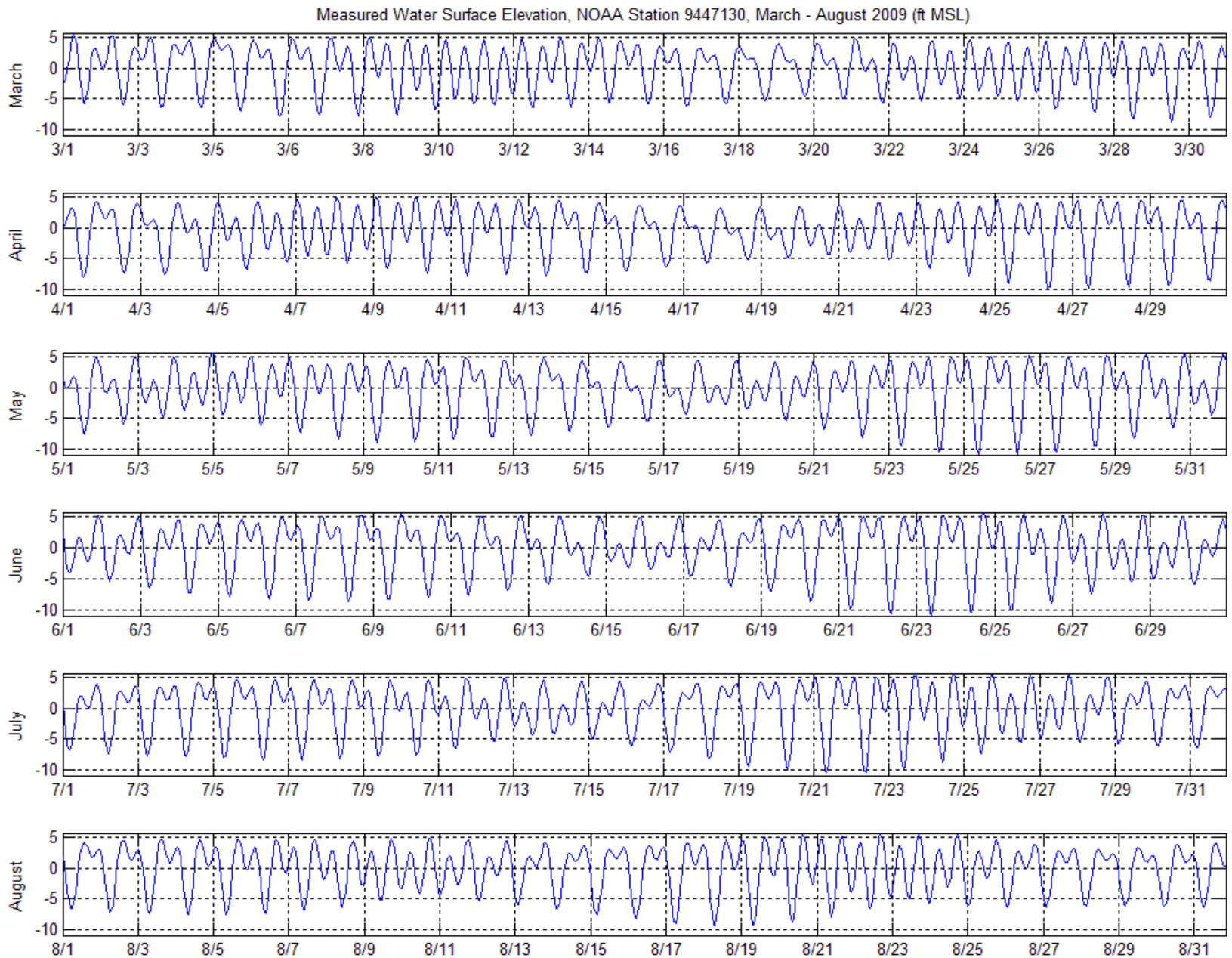
Figure 4-1
Hydrodynamic Model Grid within the EW
Sediment Transport Evaluation Report
East Waterway Operable Unit



ANCHOR QEA

Figure 4-2
Tidal Elevations at Seattle, March 1 through August 31, 2009
Sediment Transport Evaluation Report
East Waterway Operable Unit

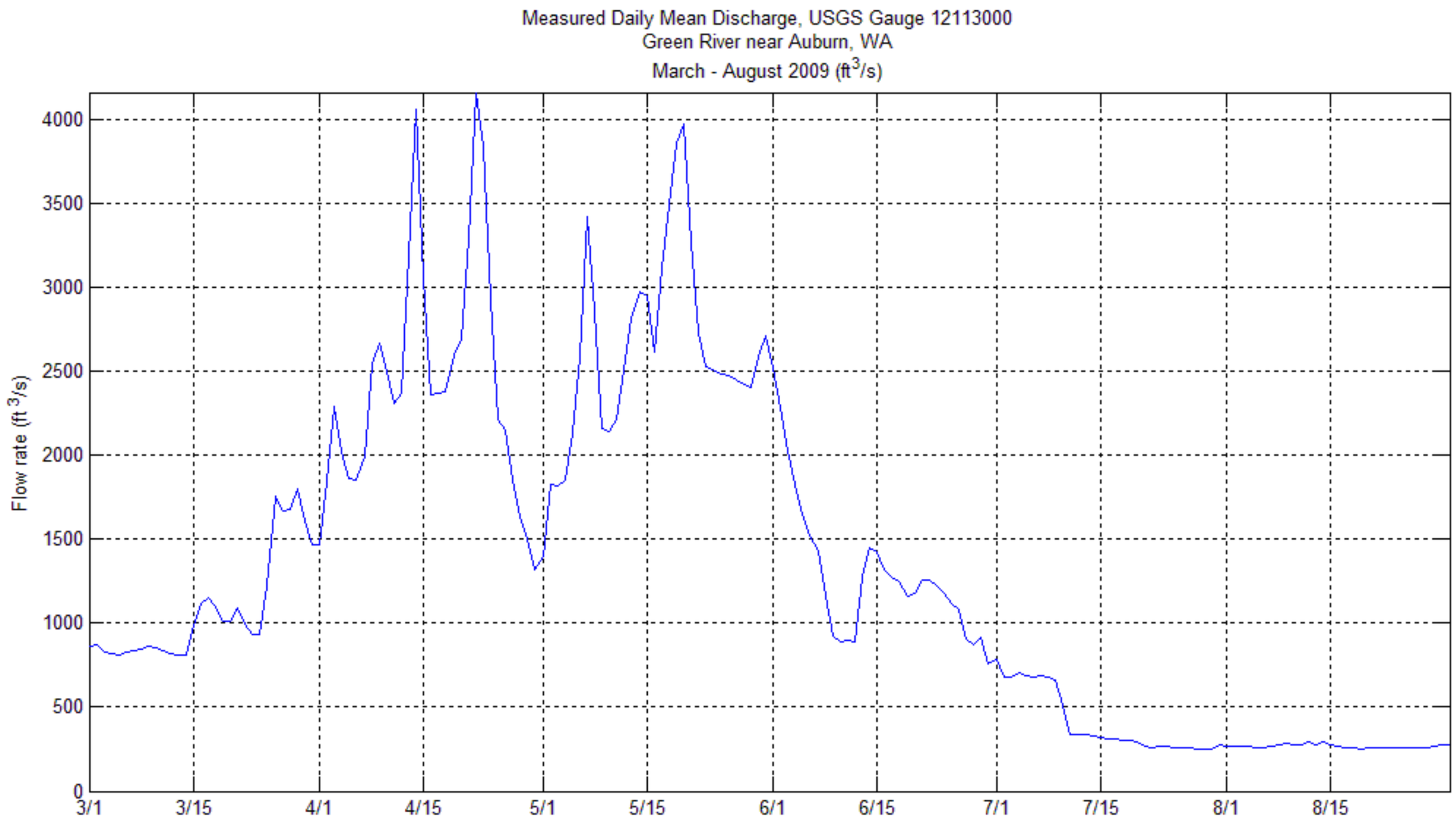


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Figure 4-3
Flow in Green River at Auburn, March 1 through August 31, 2009
Sediment Transport Evaluation Report
East Waterway Operable Unit

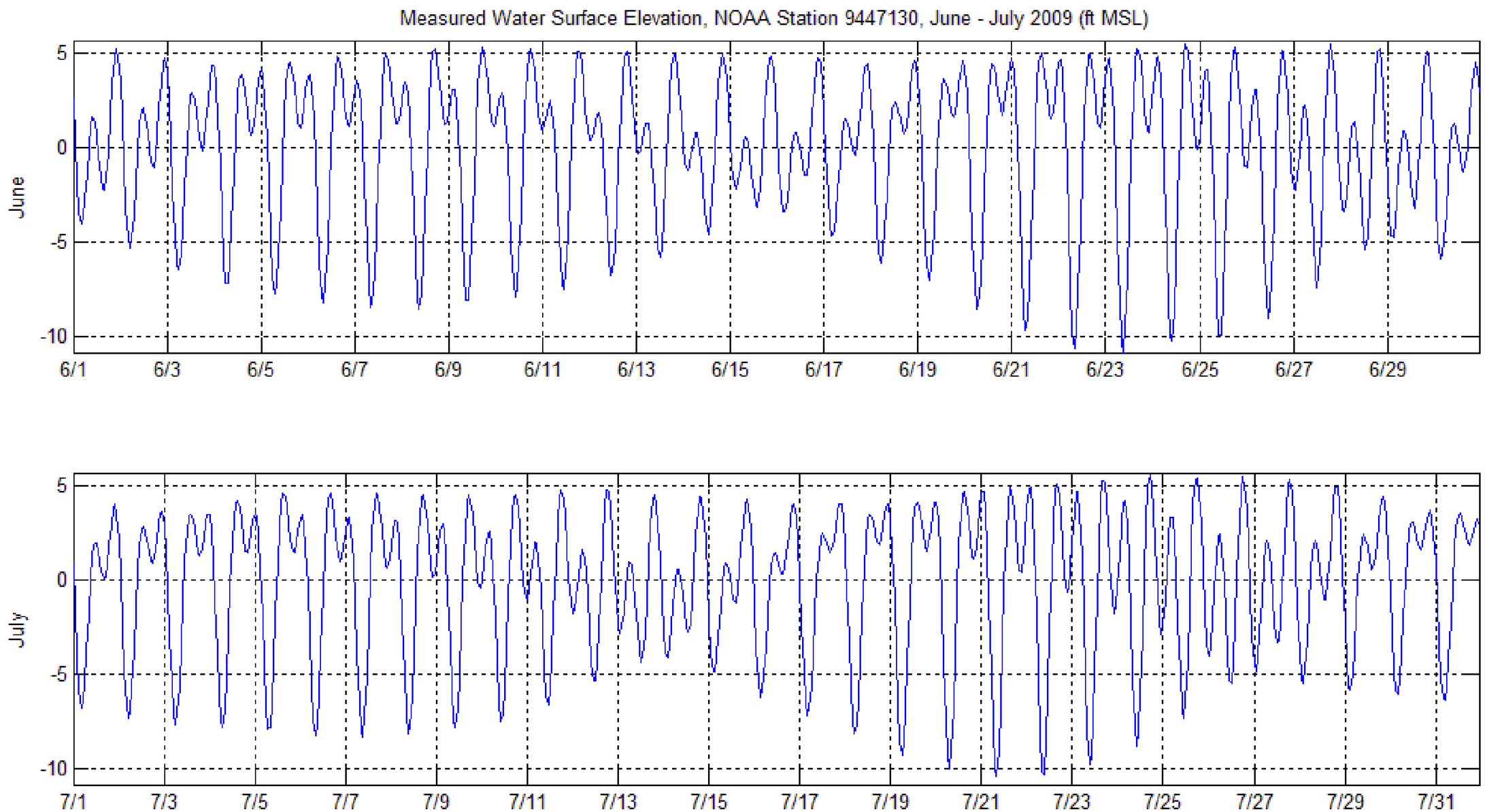

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Figure 4-4
Tidal Elevations at Seattle, June 1 to July 31, 2009
Sediment Transport Evaluation Report
East Waterway Operable Unit

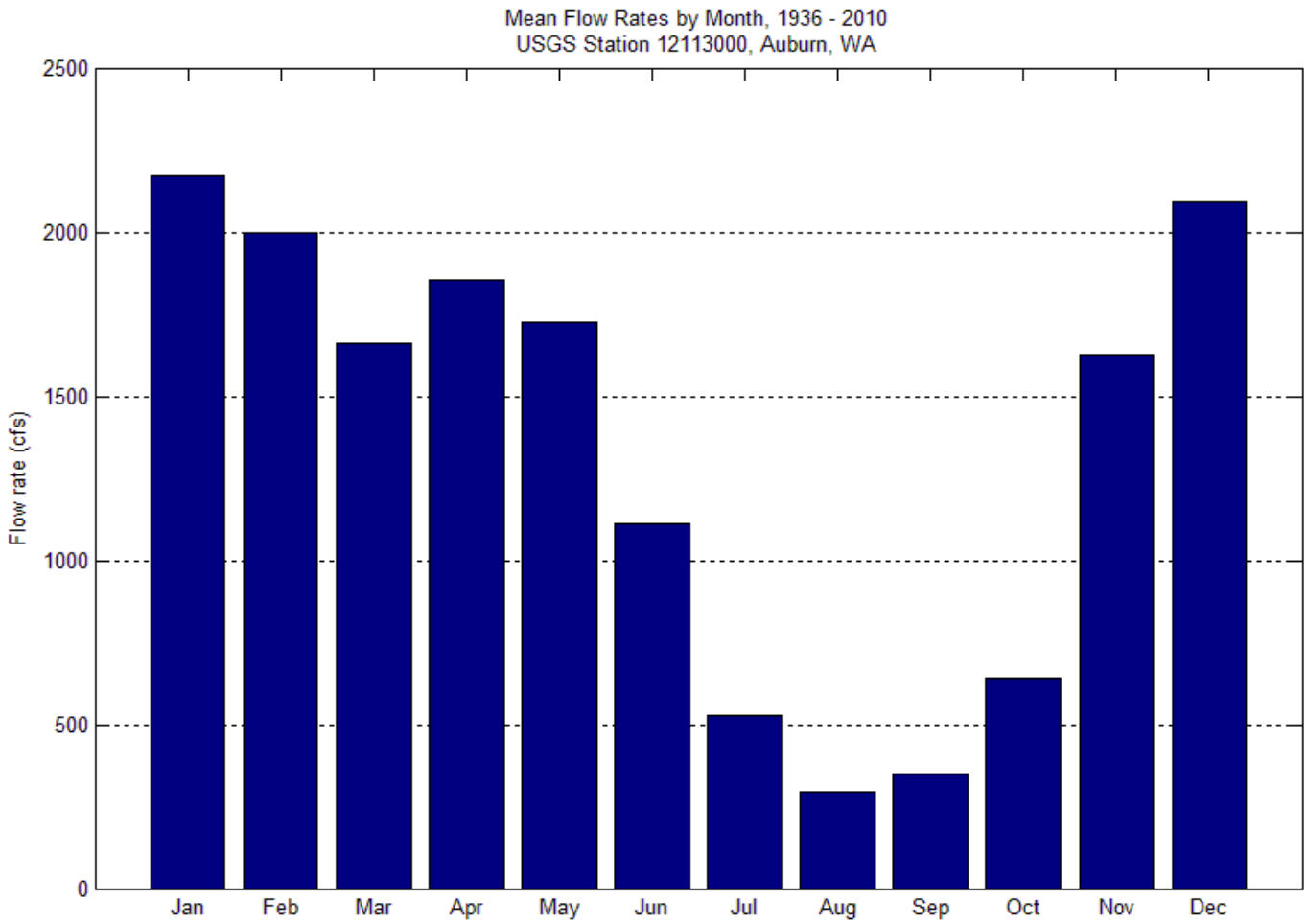

Figure 4-5
Average Monthly Flows in the Green River at Auburn
Sediment Transport Evaluation Report
East Waterway Operable Unit

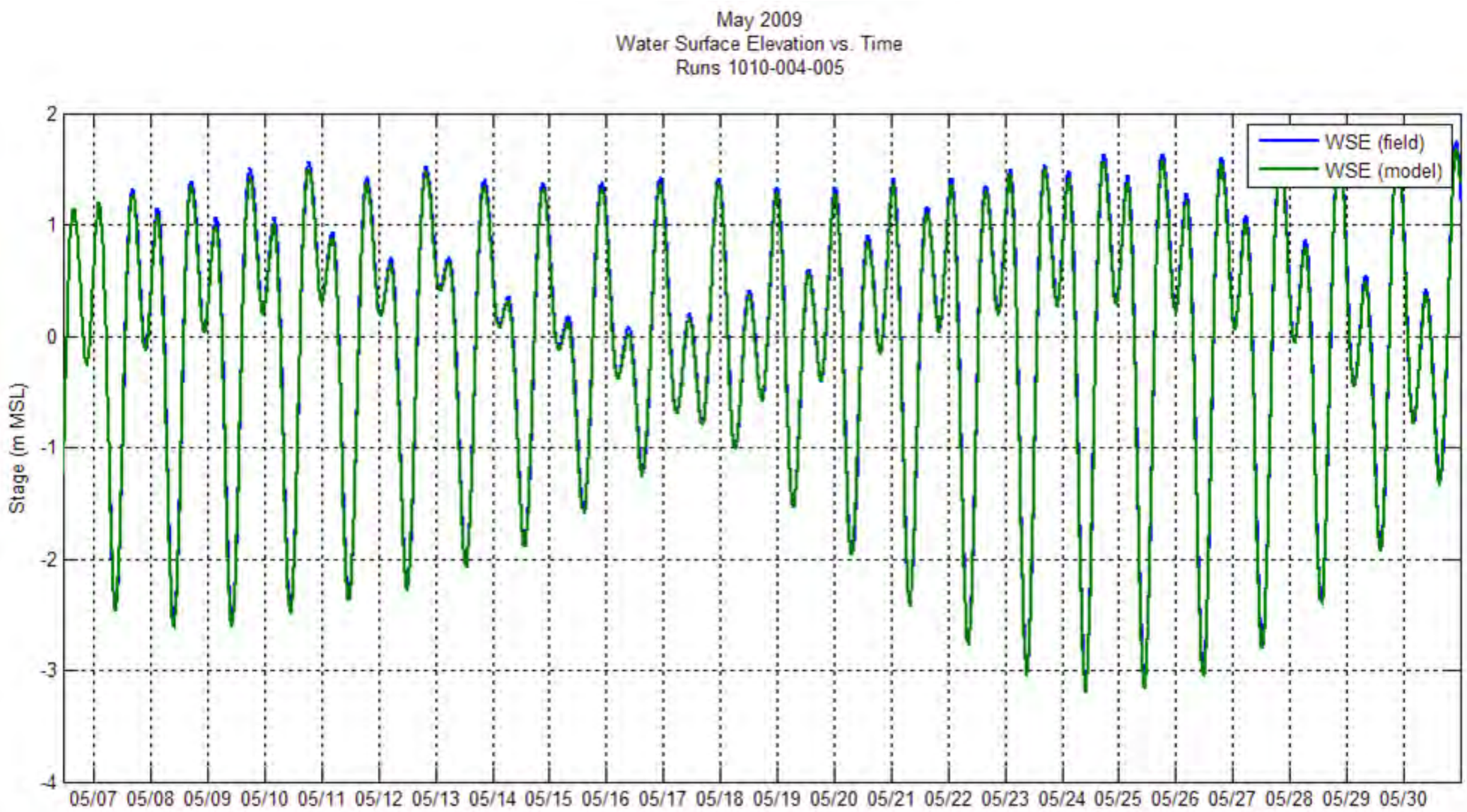

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Figure 4-6
Comparison of Water Surface Elevations between Tide Gage Data (installed in the EW) and Model Predictions
Sediment Transport Evaluation Report
East Waterway Operable Unit

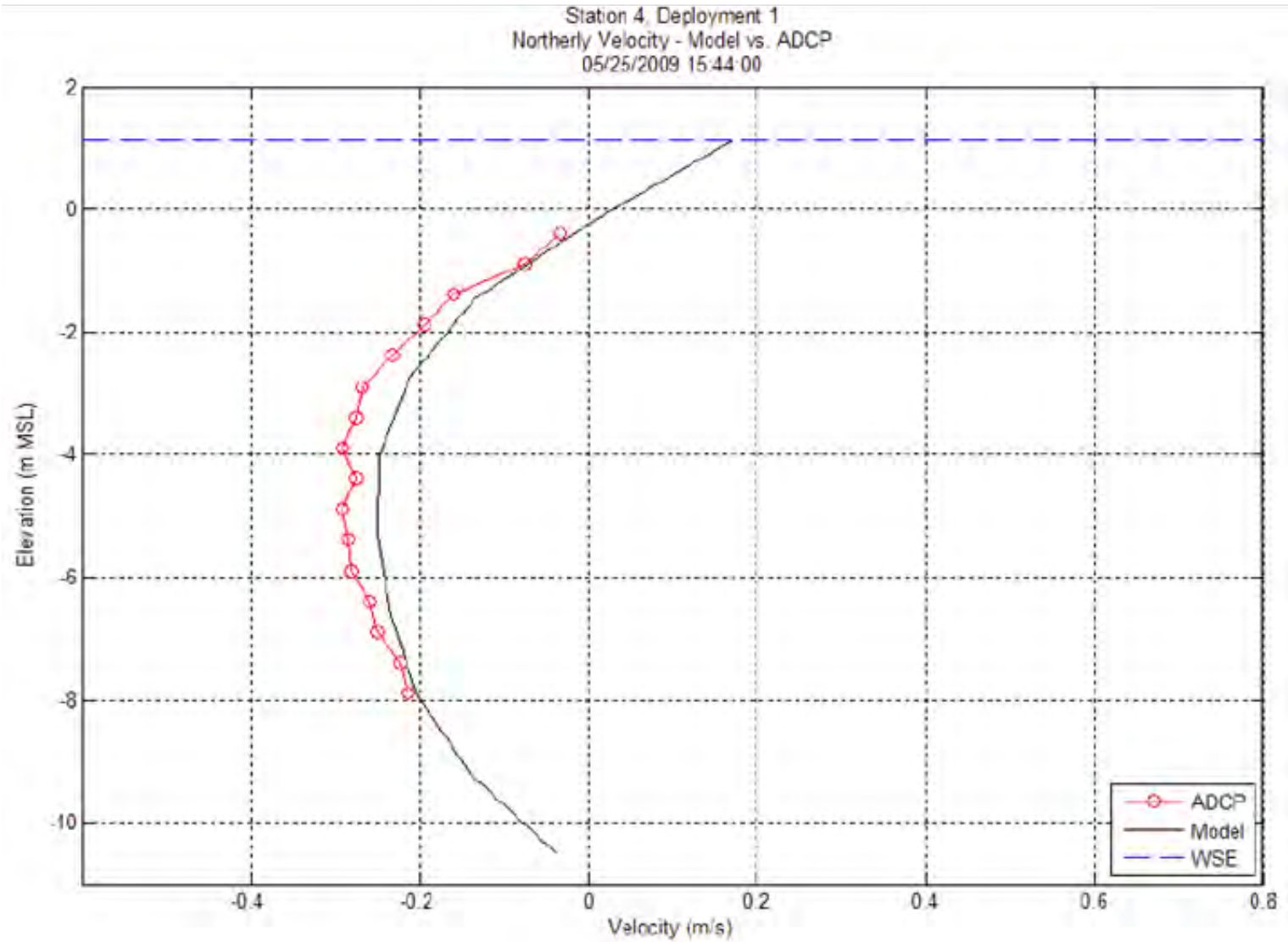

Figure 4-7
Comparison of Vertical Velocity Profile at Site 4
Sediment Transport Evaluation Report
East Waterway Operable Unit

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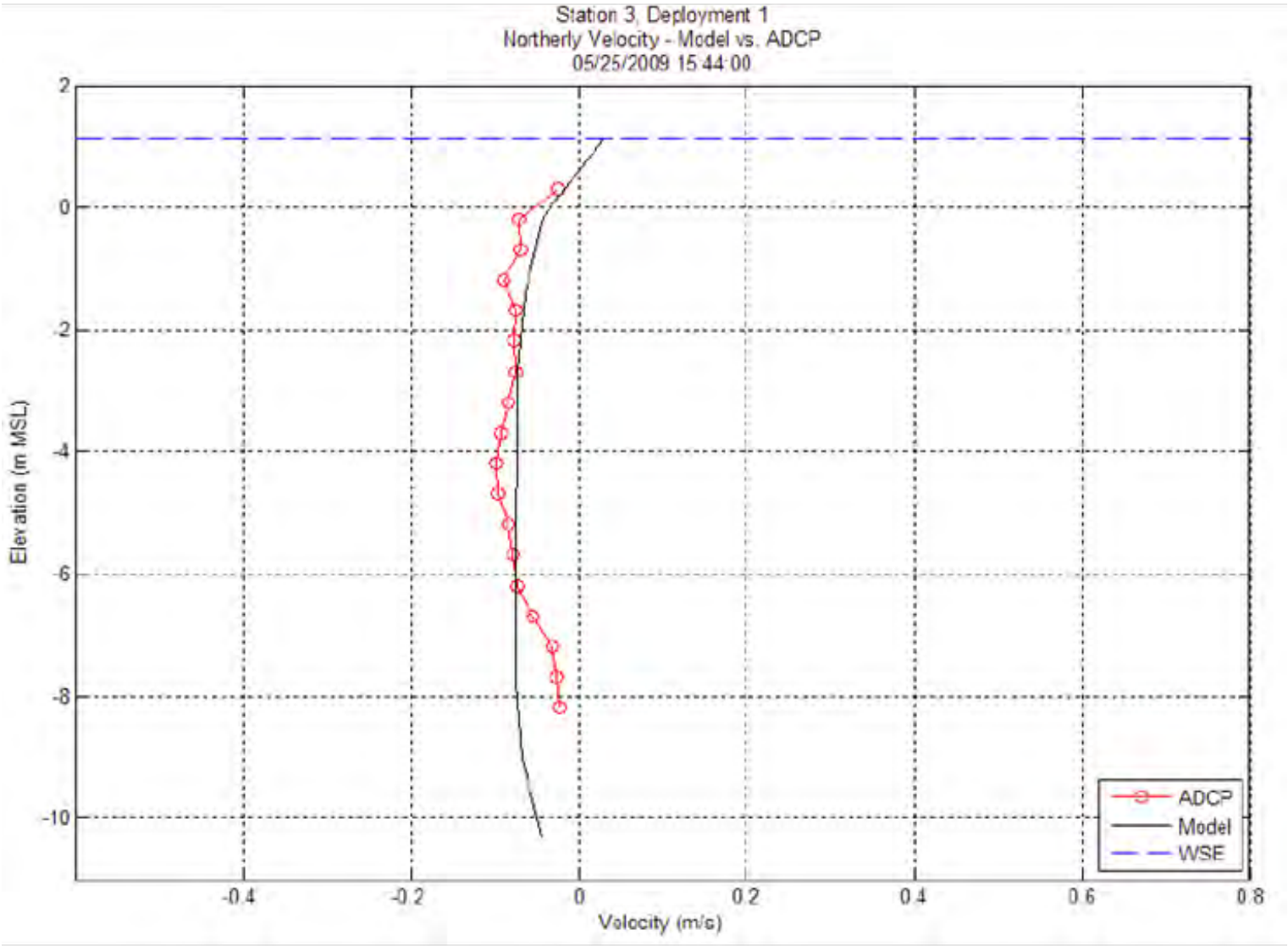

Figure 4-8
Comparison of Vertical Velocity Profile at Site 3
Sediment Transport Evaluation Report
East Waterway Operable Unit

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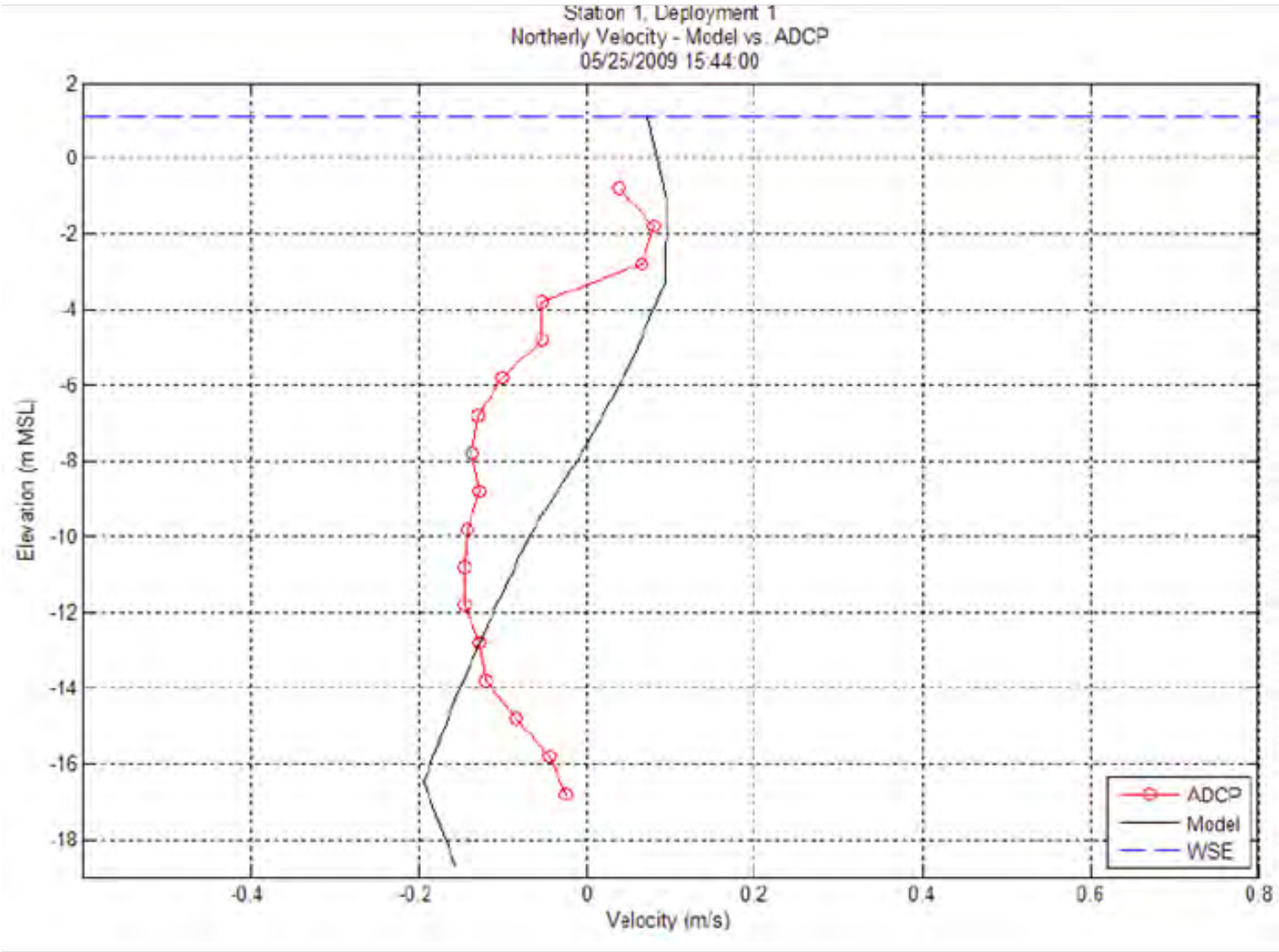

Figure 4-9
Comparison of Vertical Velocity Profile at Site 1
Sediment Transport Evaluation Report
East Waterway Operable Unit

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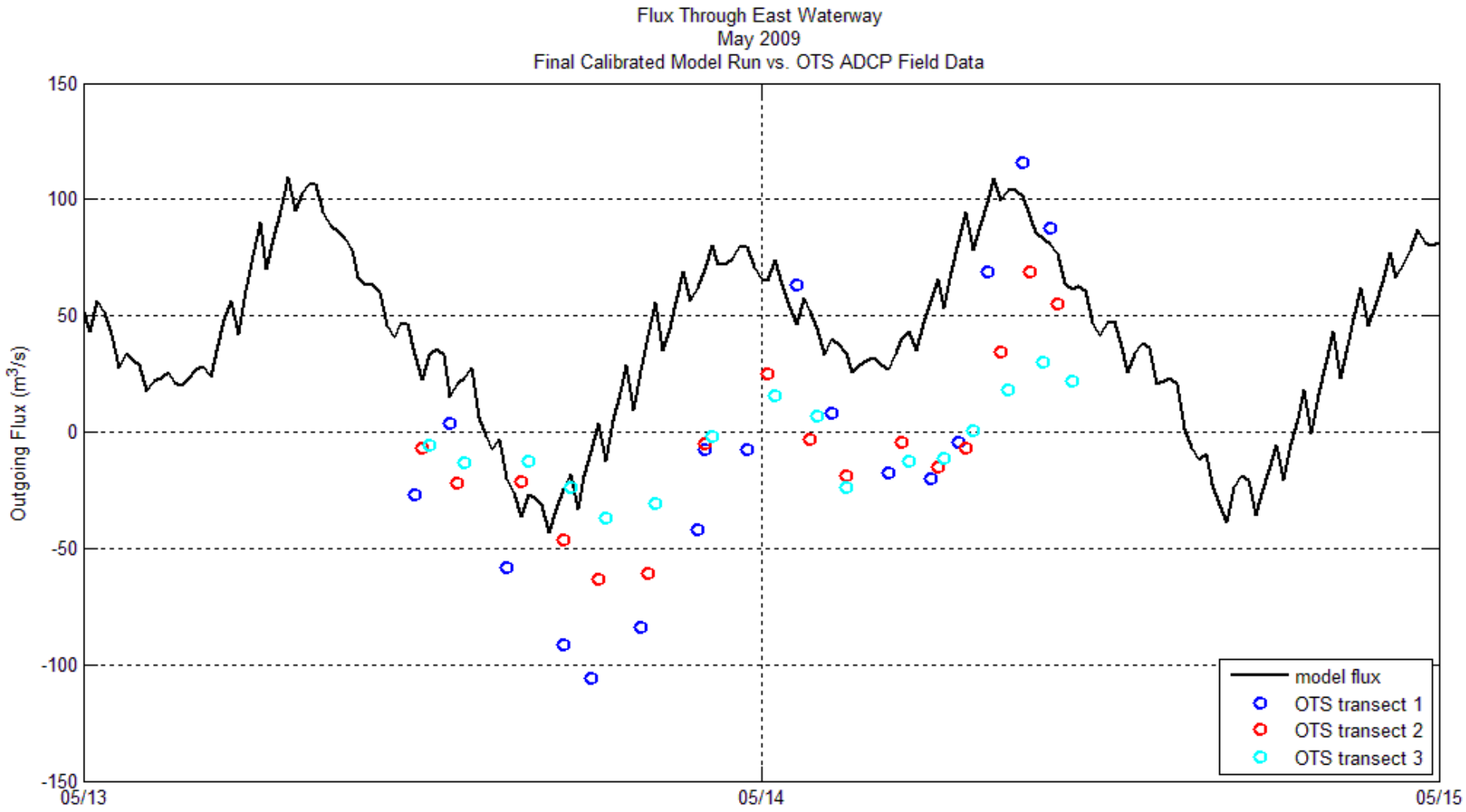

Figure 4-10
Comparison of Measured and Predicted Flow Rate in the East Waterway
Sediment Transport Evaluation Report
East Waterway Operable Unit

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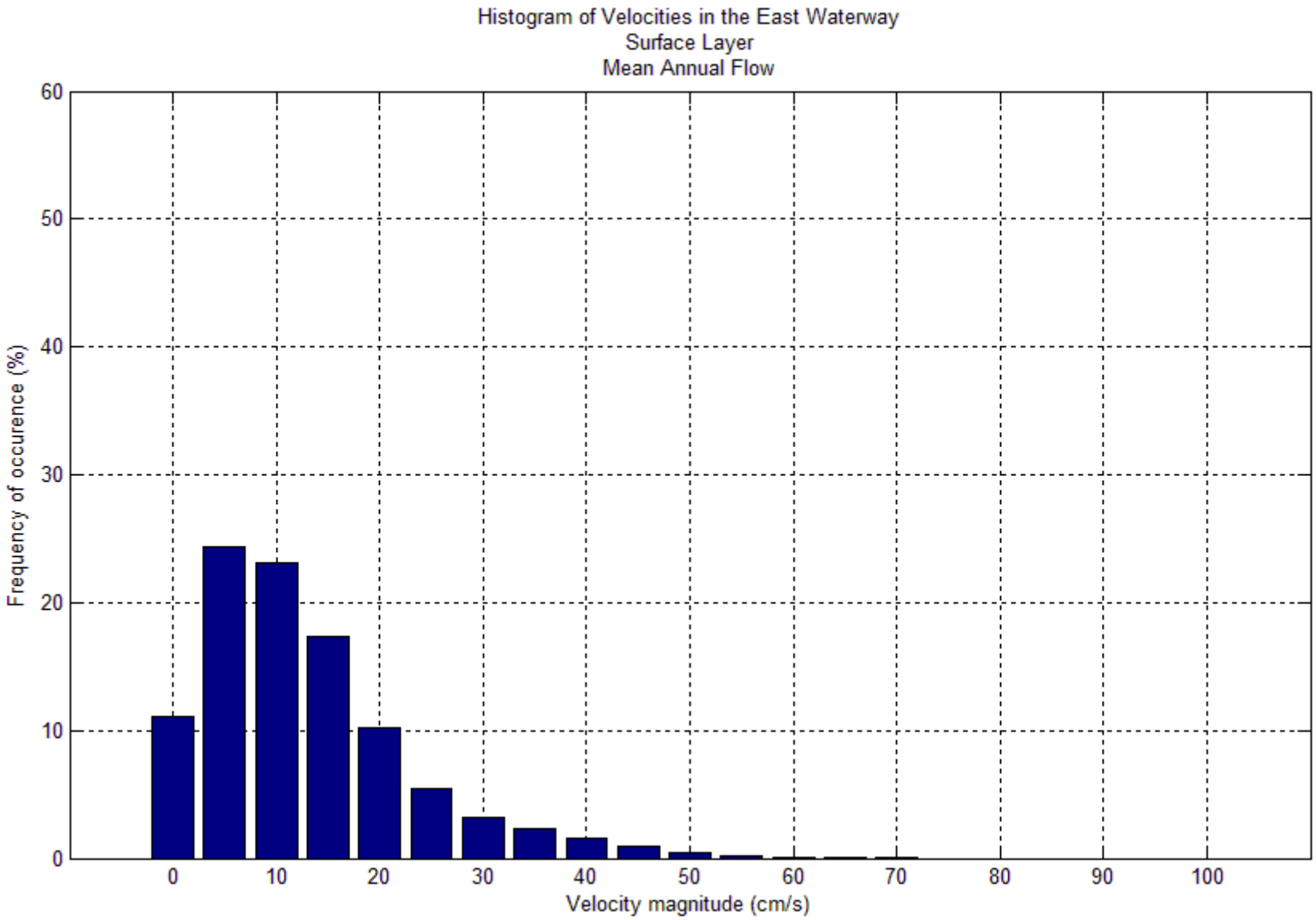

Figure 4-11
Velocity Histogram During Mean Annual Flow at Surface

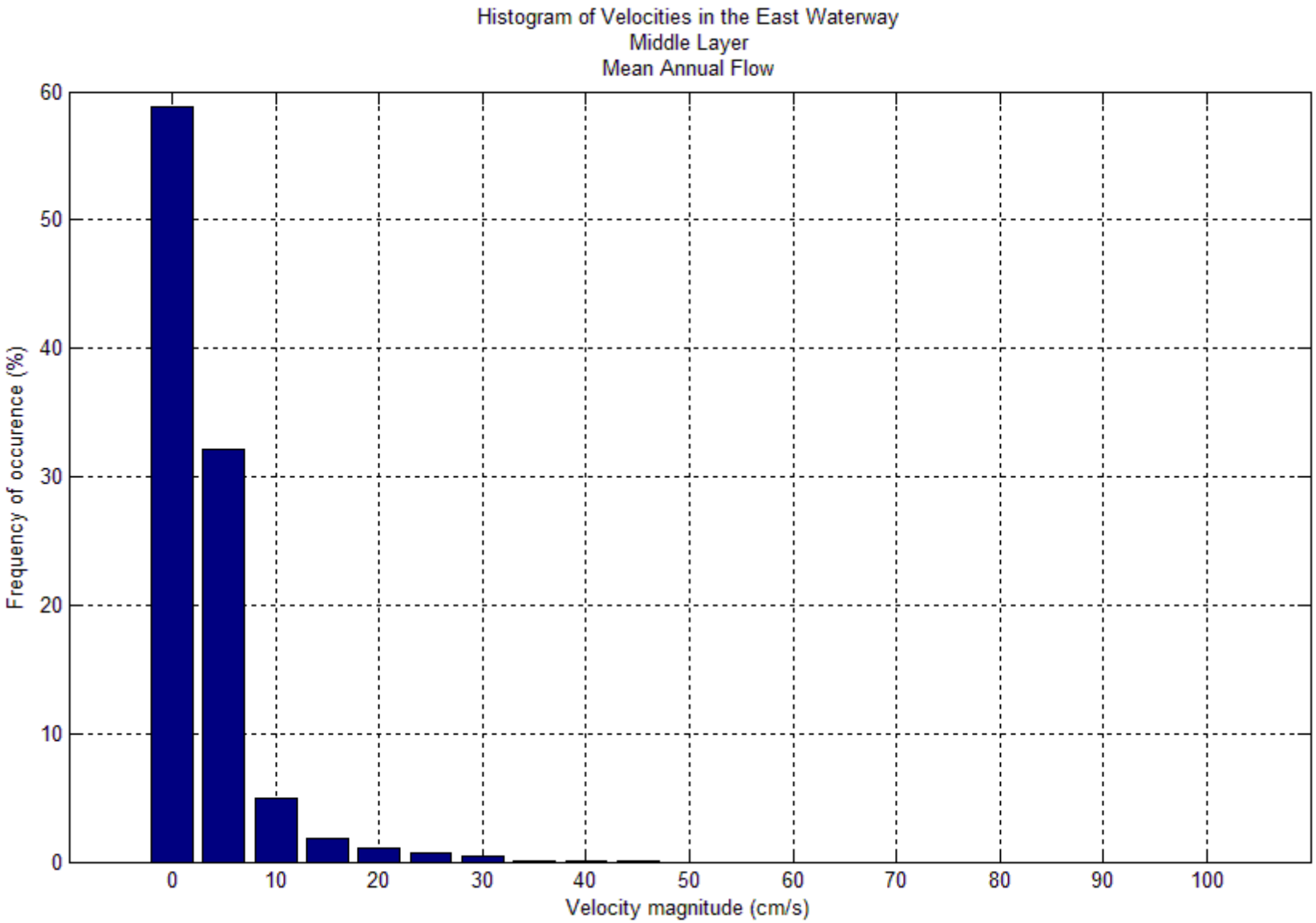

Figure 4-12
Velocity Histogram During Mean Annual Flow at Mid-Depth
Sediment Transport Evaluation Report
East Waterway Operable Unit

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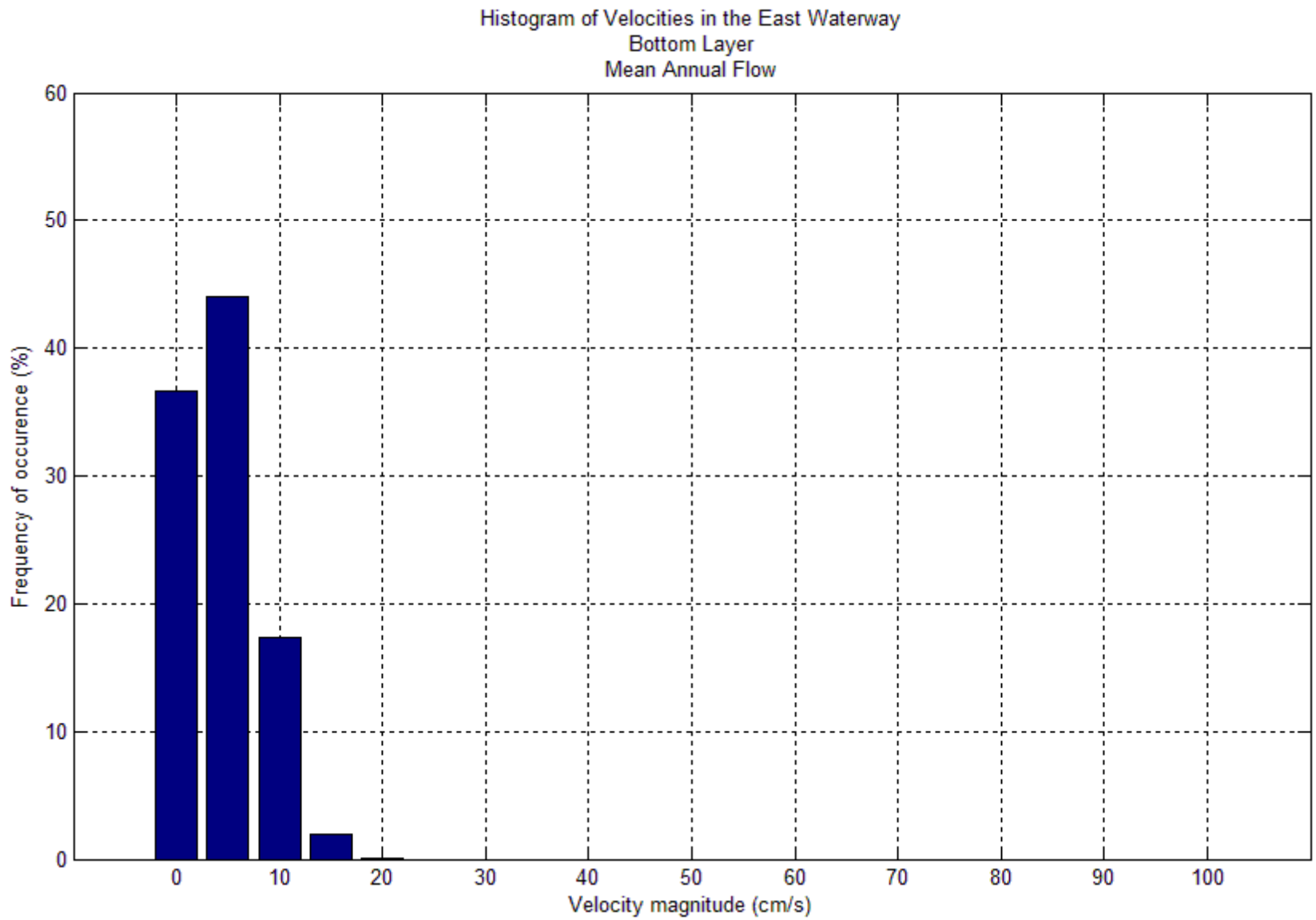

Figure 4-13
Velocity Histogram During Mean Annual Flow Near Bottom
Sediment Transport Evaluation Report
East Waterway Operable Unit

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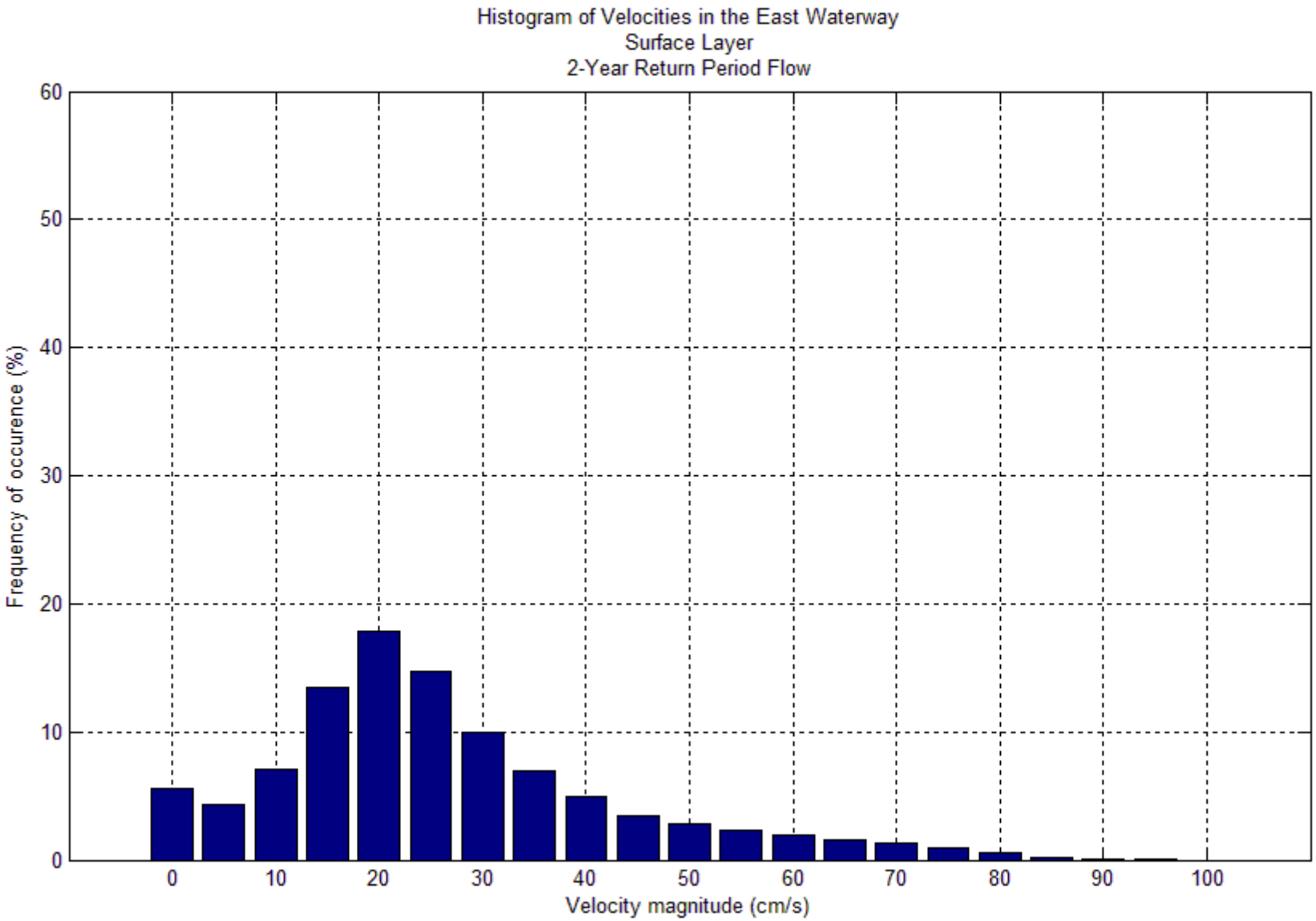

Figure 4-14
Velocity Histogram During 2-Year Return Period Flow at Surface
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA

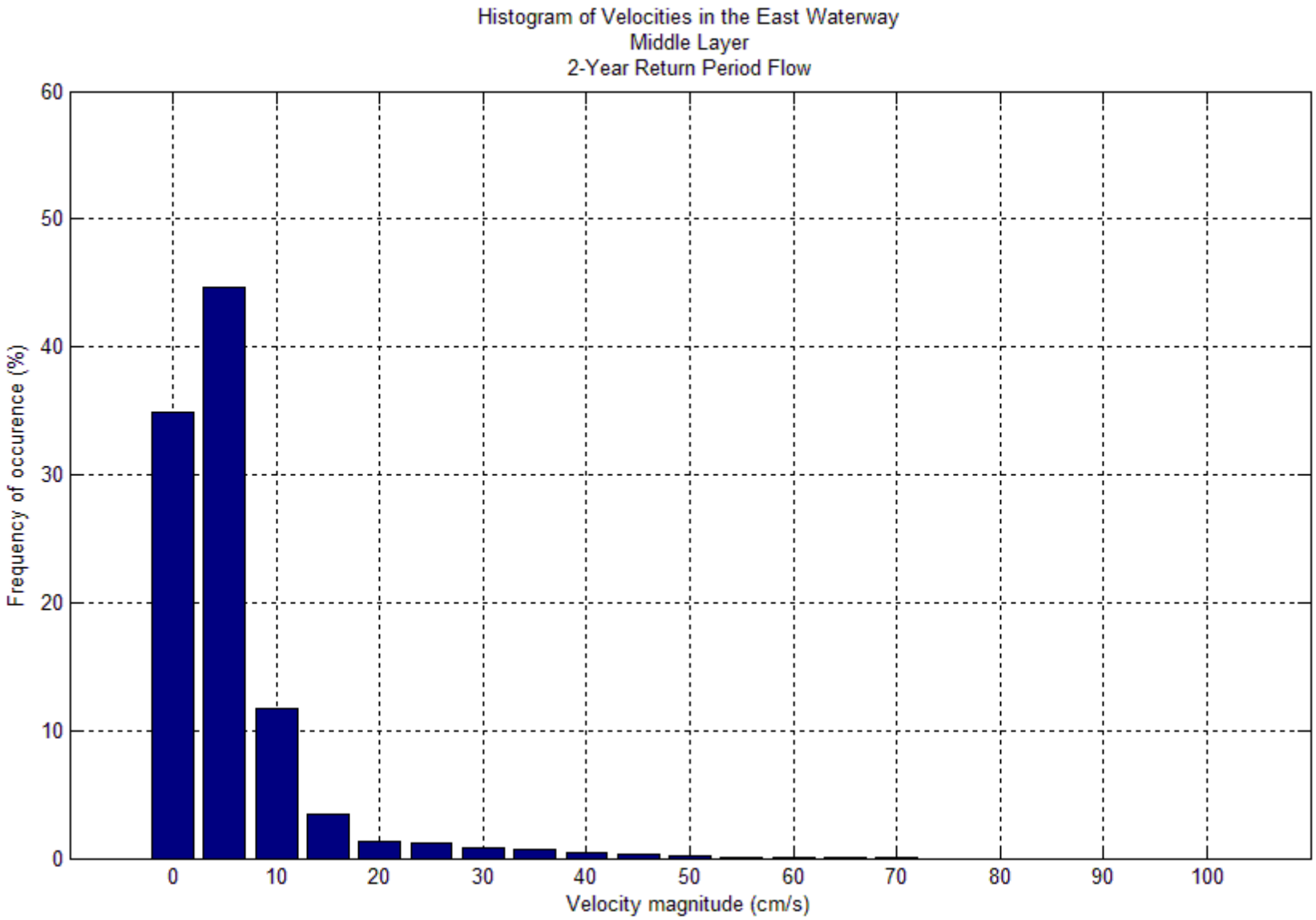

Figure 4-15
Velocity Histogram During 2-Year Return Period Flow at Mid-Depth
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA

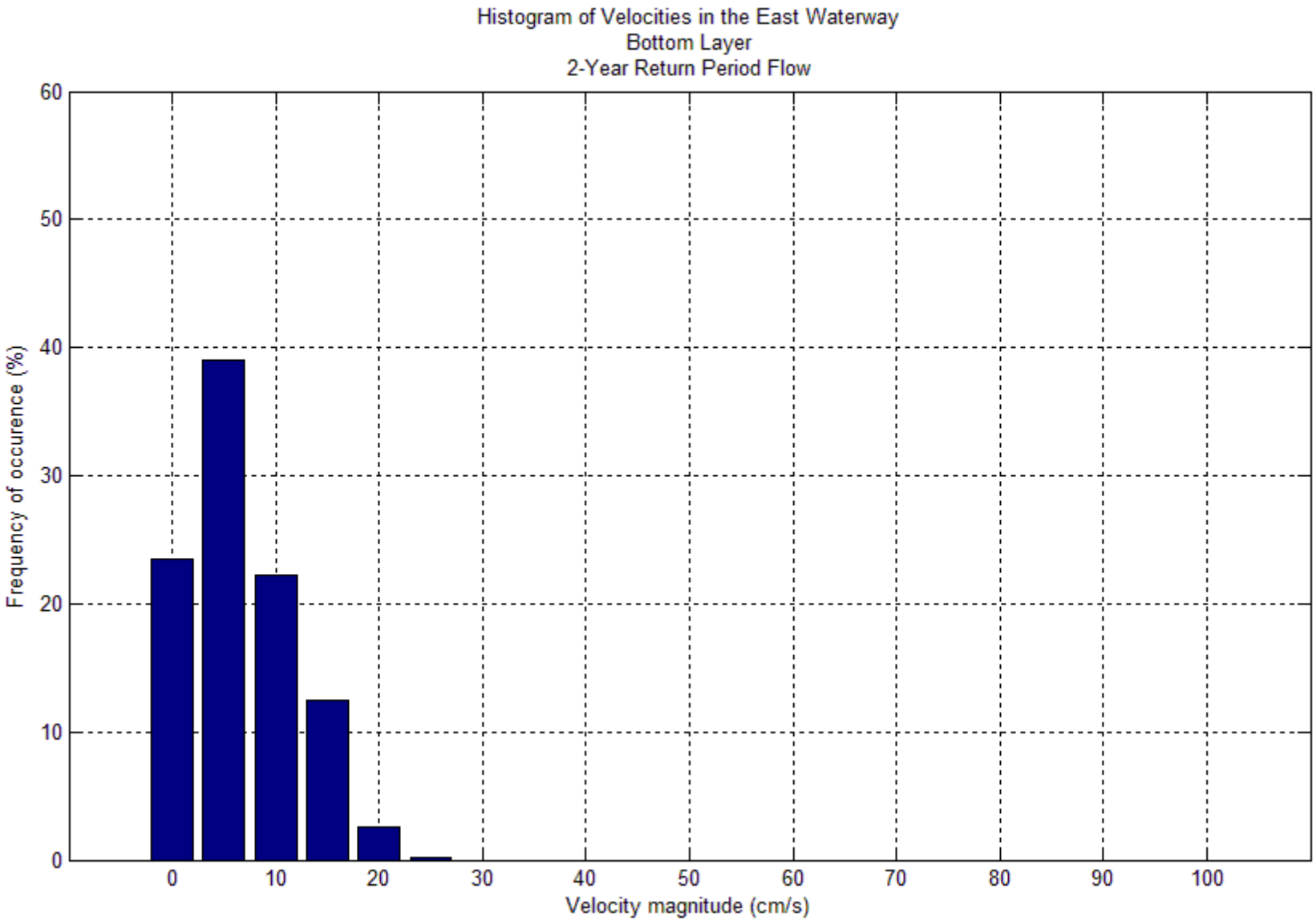

Figure 4-16
Velocity Histogram During 2-Year Return Period Flow Near Bottom
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA

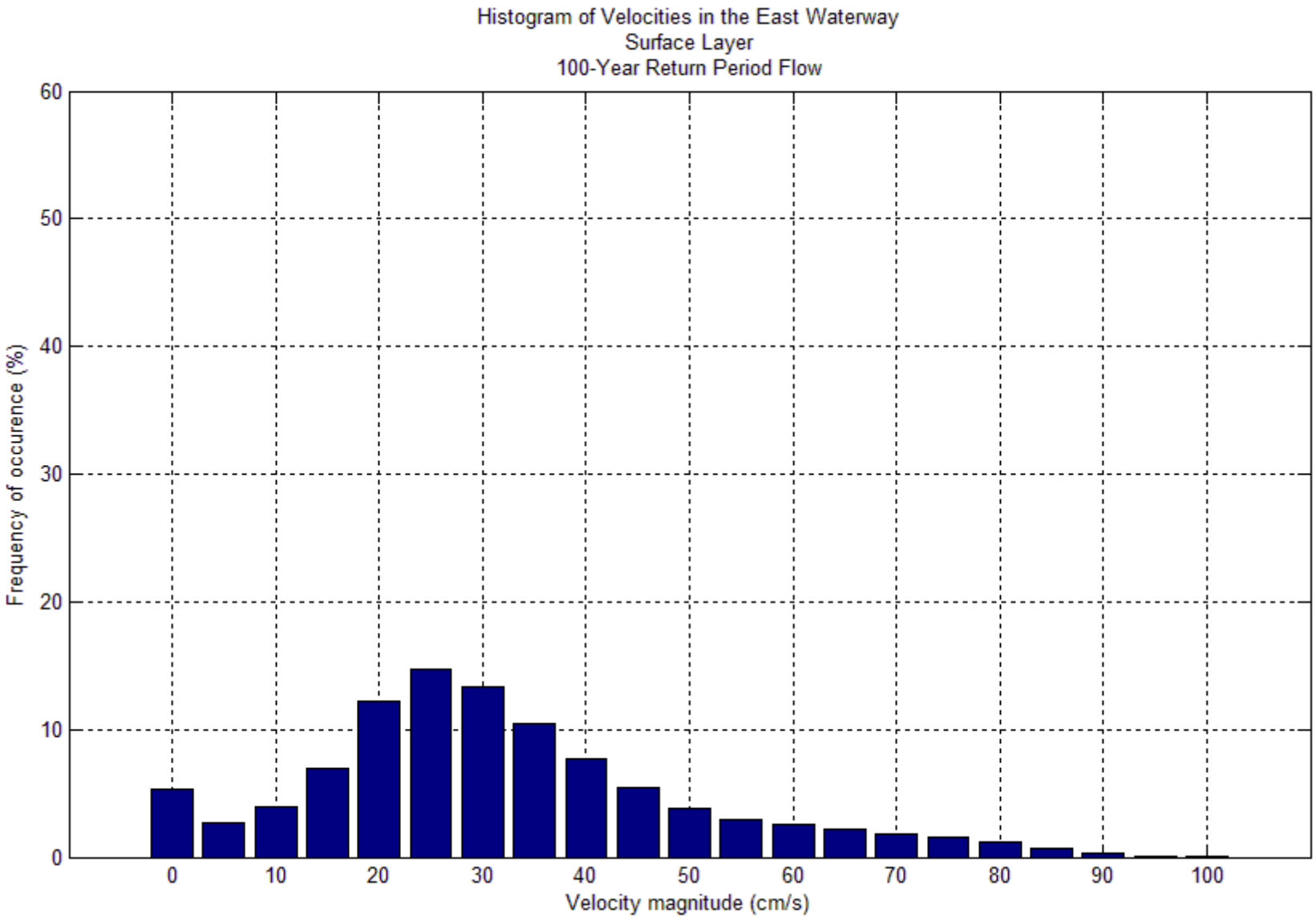

Figure 4-17
Velocity Histogram During 100-Year Return Period Flow at Surface
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA

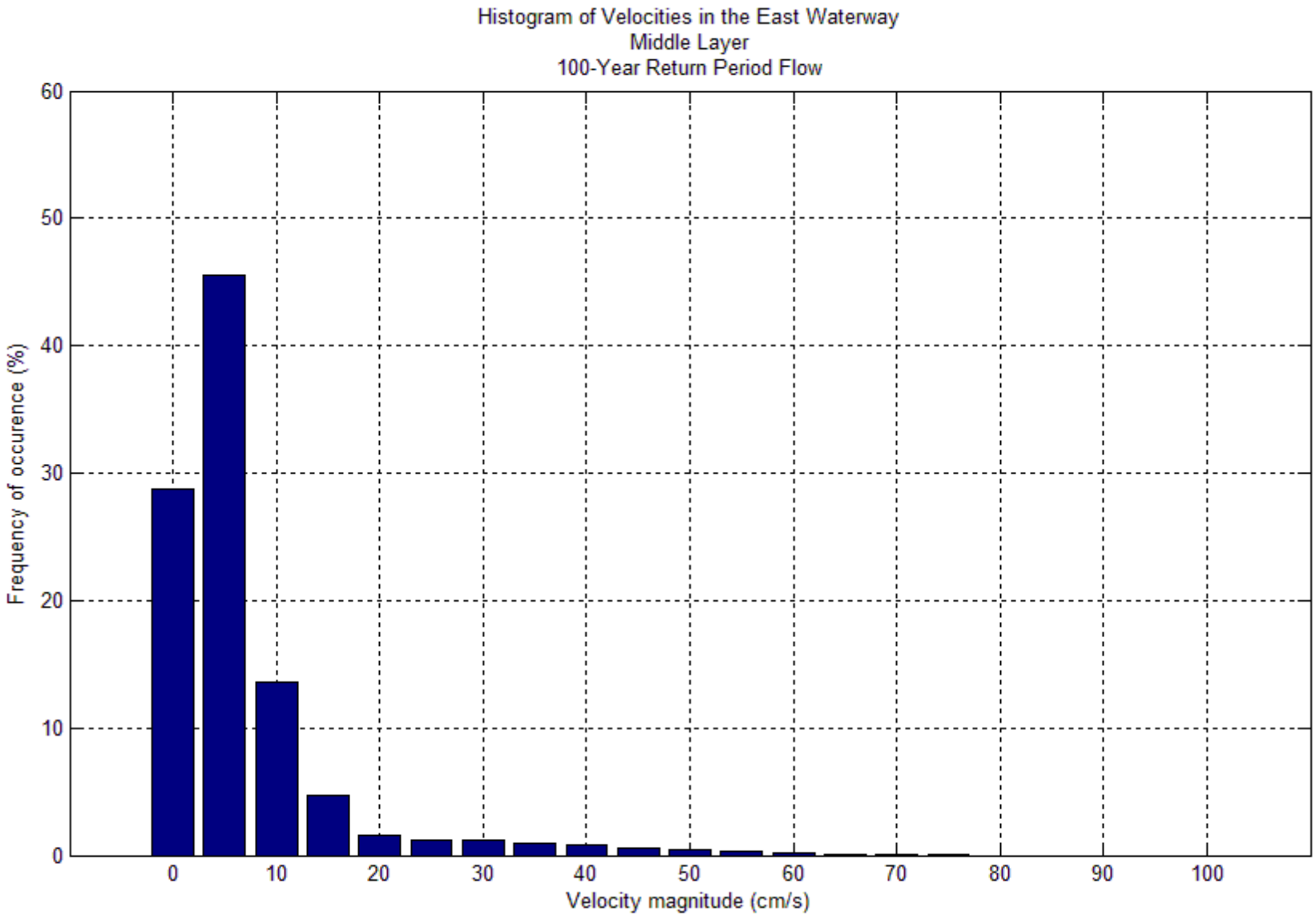

Figure 4-18
Velocity Histogram During 100-Year Return Period Flow at Mid-Depth
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA

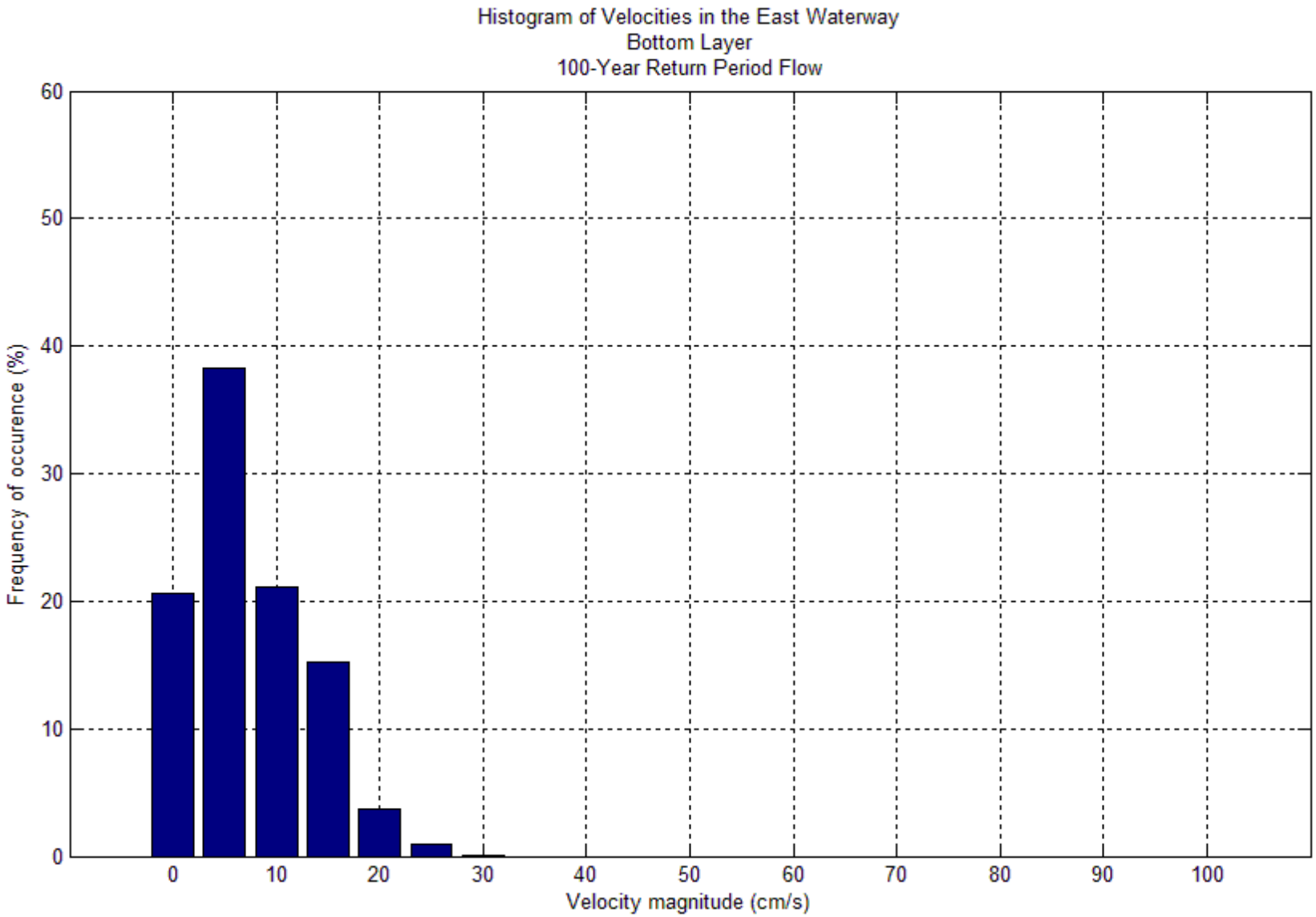

Figure 4-19
Velocity Histogram During 100-Year Return Period Flow Near Bottom
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA

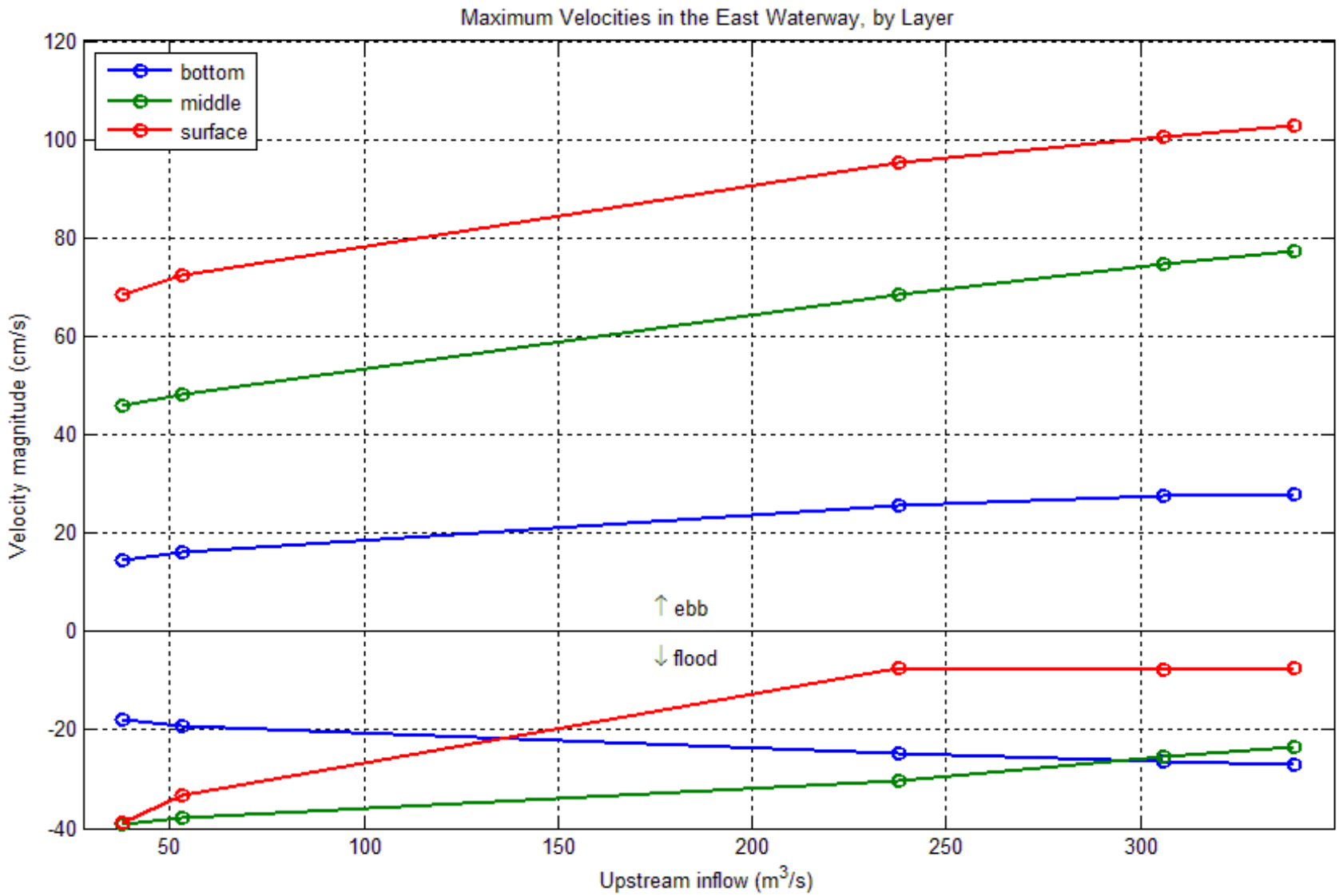

Figure 4-20
Maximum Ebb and Flood Velocities in the East Waterway
Sediment Transport Evaluation Report
East Waterway Operable Unit

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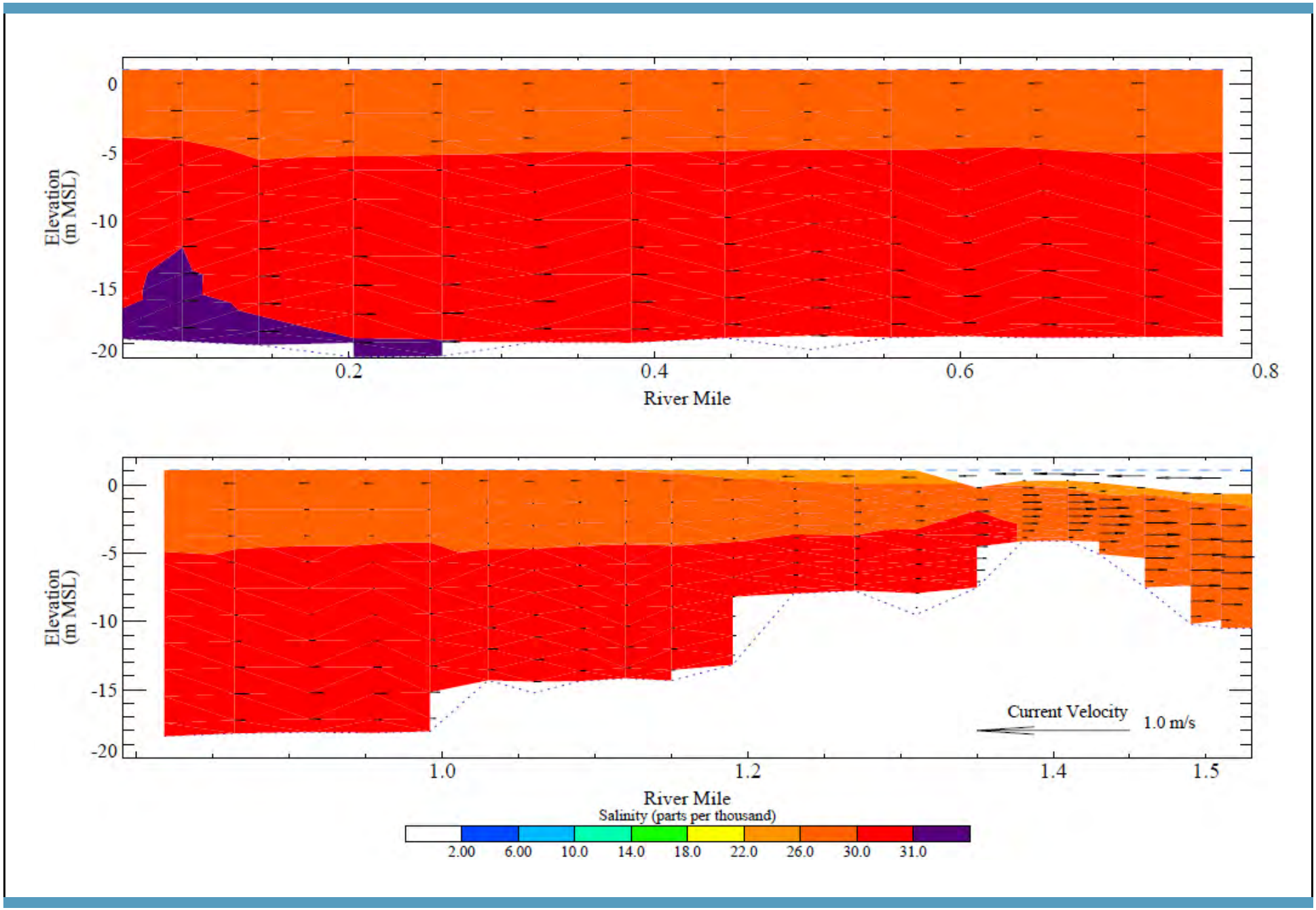

Figure 4-21

Hydrodynamic Model Results: Transect of Salinity and Velocity at Flood Tide with Mean Annual Upstream Flow

Sediment Transport Evaluation Report

East Waterway Operable Unit

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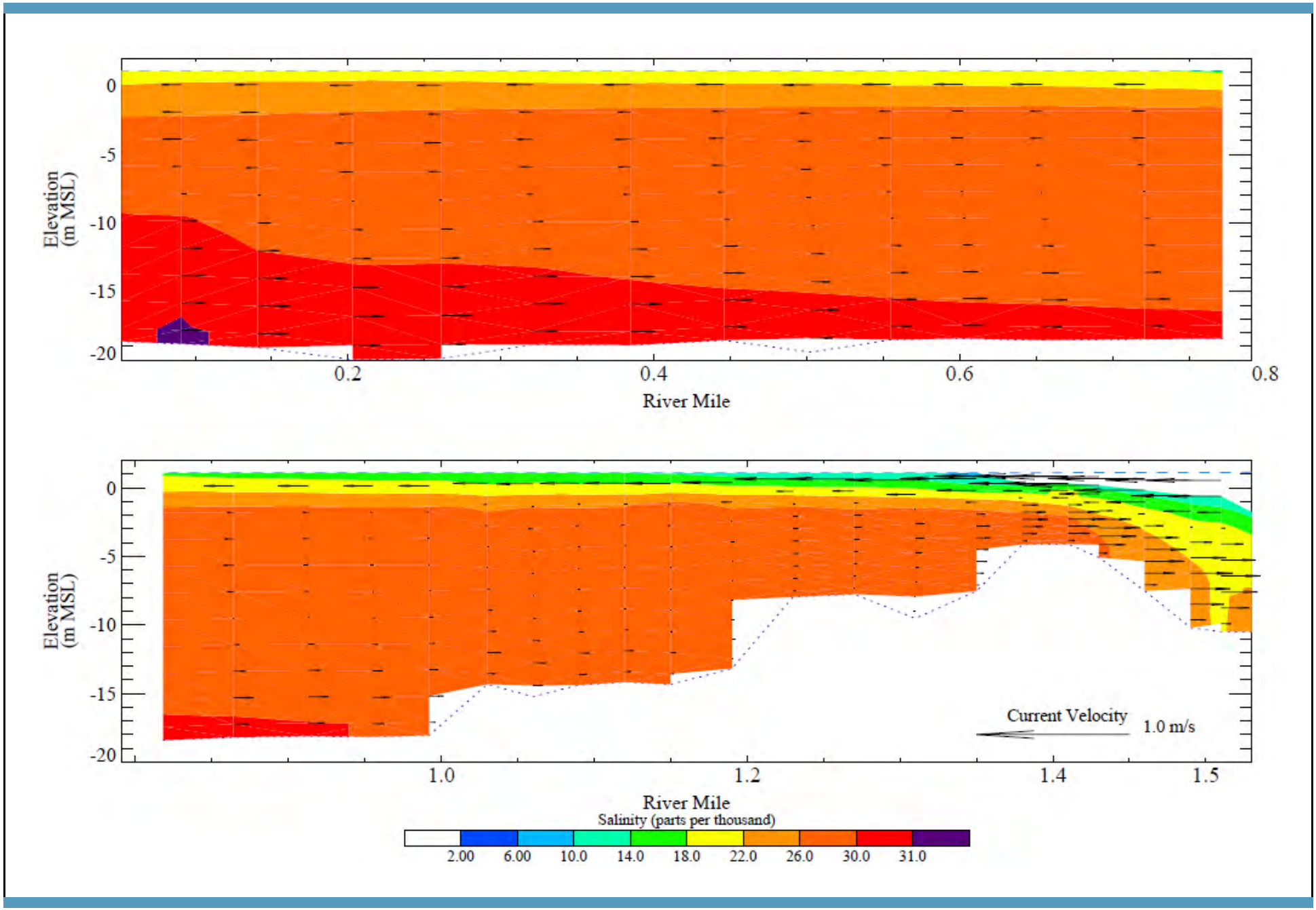

Figure 4-22

Hydrodynamic Model Results: Transect of Salinity and Velocity at Flood Tide with 2-Year Upstream Flow

Sediment Transport Evaluation Report

East Waterway Operable Unit

ANCHOR QEA

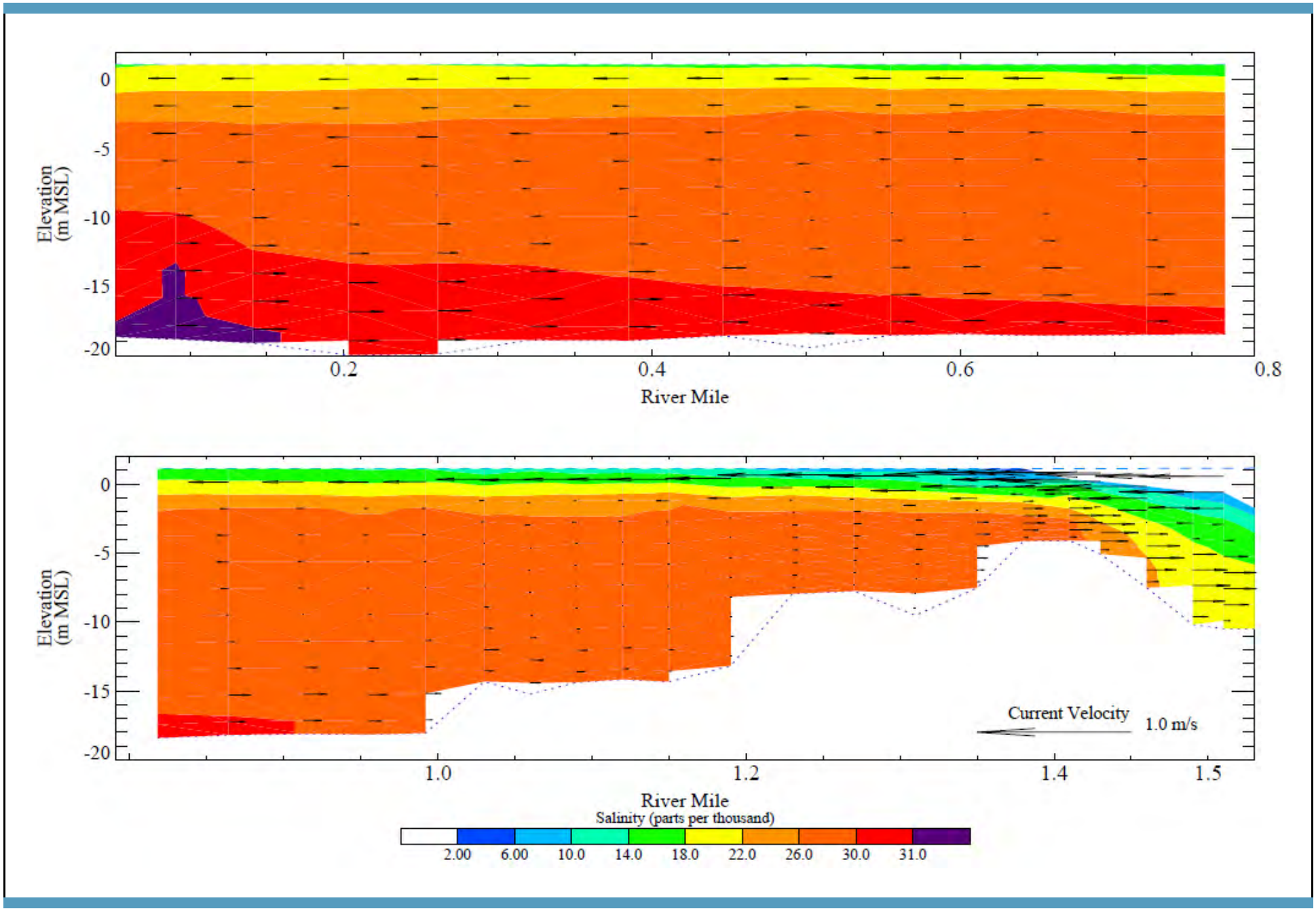

Figure 4-23

Hydrodynamic Model Results: Transect of Salinity and Velocity at Flood Tide with 100-Year Upstream Flow

Sediment Transport Evaluation Report

East Waterway Operable Unit

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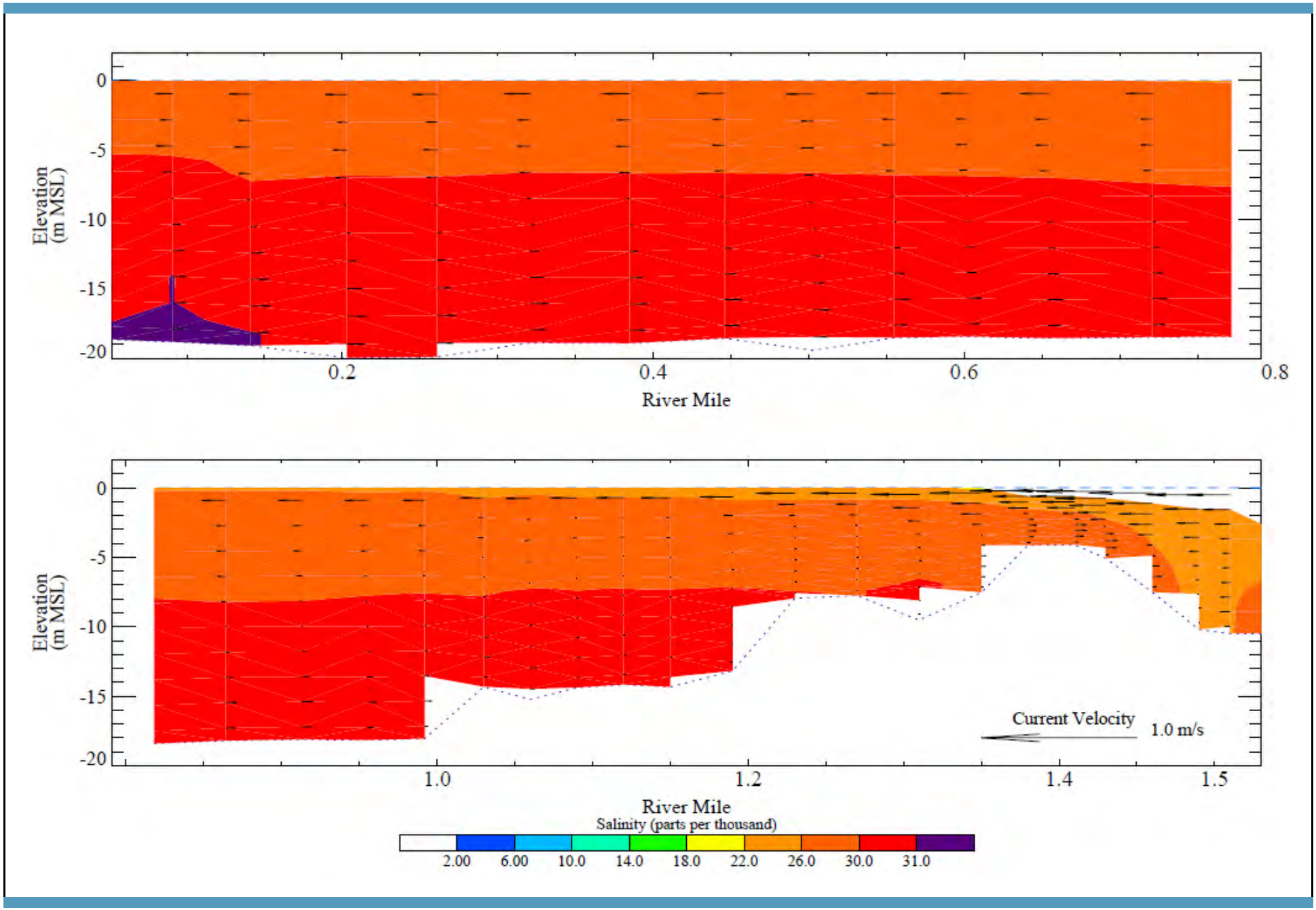

Figure 4-24

Hydrodynamic Model Results: Transect of Salinity and Velocity at Ebb Tide with Mean Annual Upstream Flow

Sediment Transport Evaluation Report

East Waterway Operable Unit

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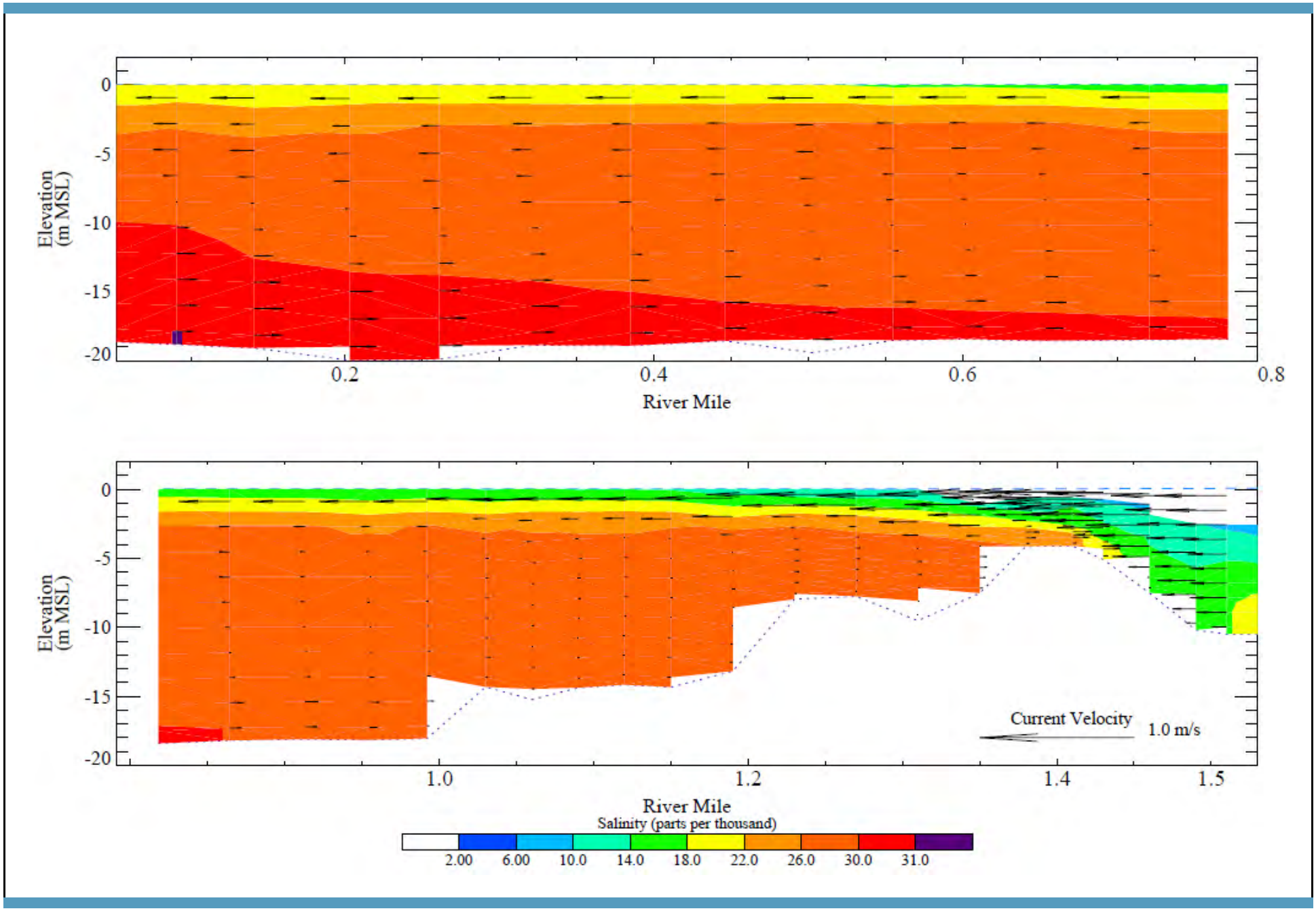

Figure 4-25

Hydrodynamic Model Results: Transect of Salinity and Velocity at Ebb Tide with 2-Year Upstream Flow

Sediment Transport Evaluation Report

East Waterway Operable Unit

ANCHOR QEA

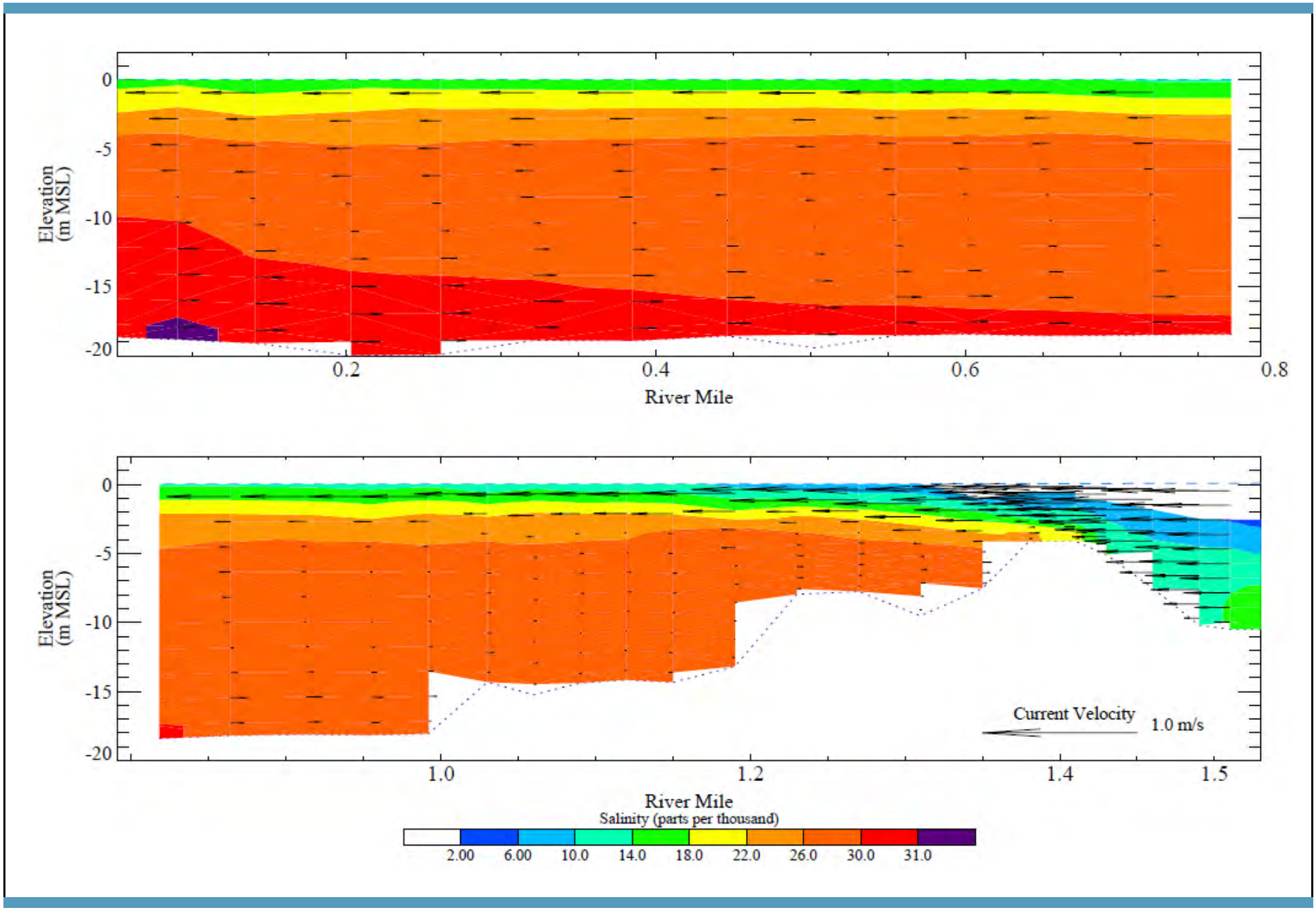

Figure 4-26

Hydrodynamic Model Results: Transect of Salinity and Velocity at Ebb Tide with 100-Year Upstream Flow

Sediment Transport Evaluation Report

East Waterway Operable Unit

ANCHOR QEA

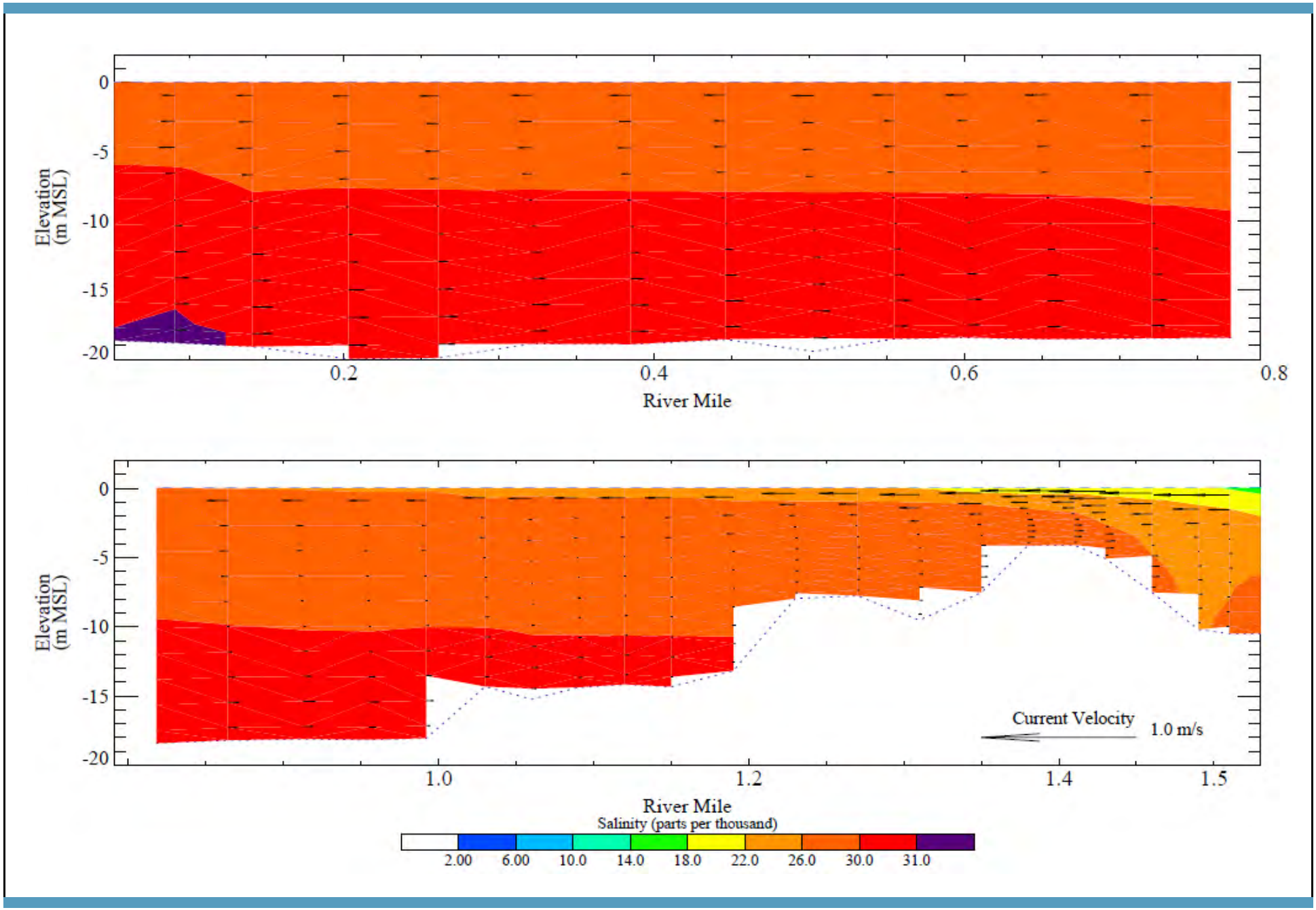

Figure 4-27

Hydrodynamic Model Results: Transect of Average Salinity and Velocity with Mean Annual Upstream Flow

Sediment Transport Evaluation Report

East Waterway Operable Unit

ANCHOR QEA

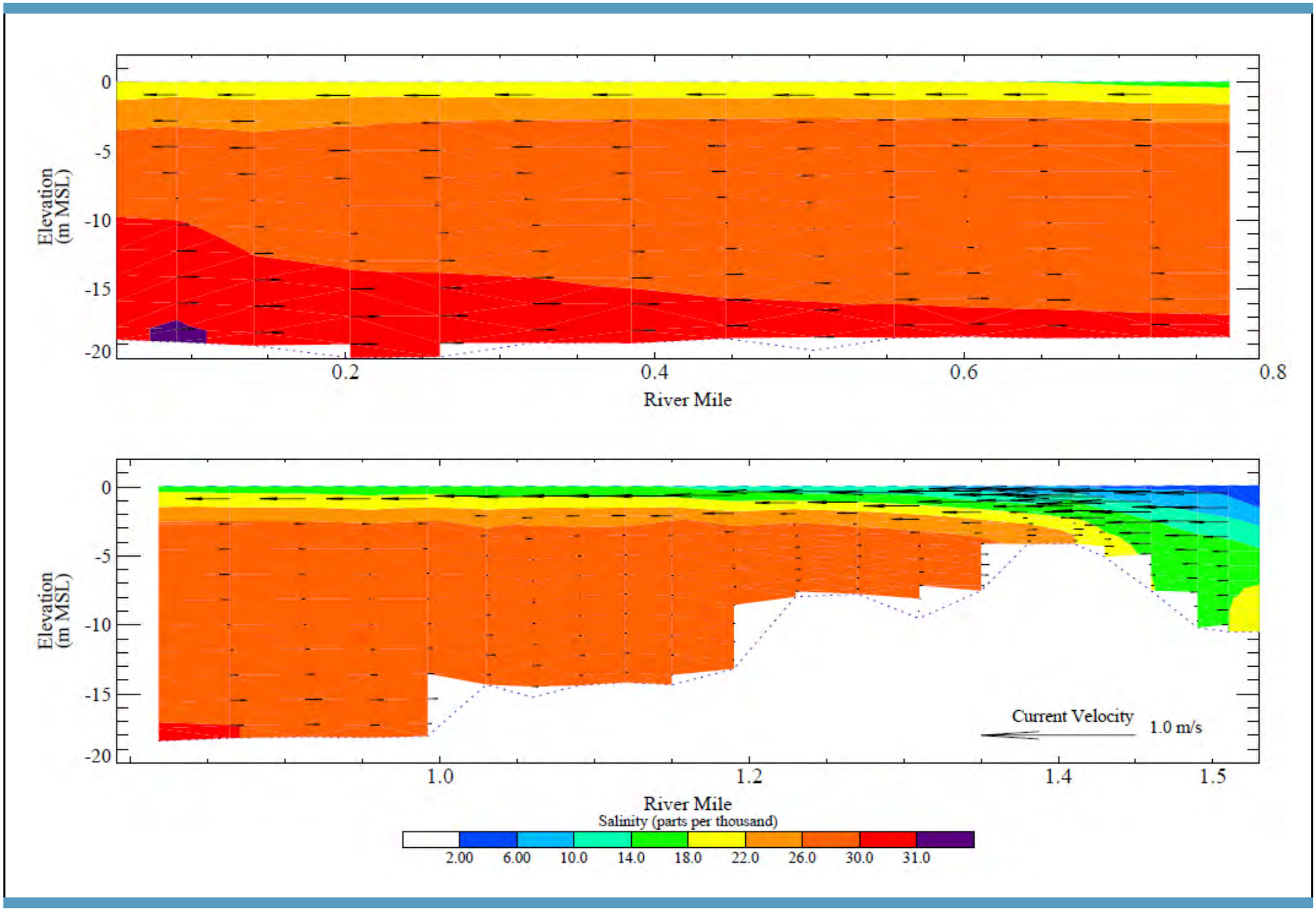

Figure 4-28

Hydrodynamic Model Results: Transect of Average Salinity and Velocity with 2-Year Upstream Flow

Sediment Transport Evaluation Report

East Waterway Operable Unit

ANCHOR QEA

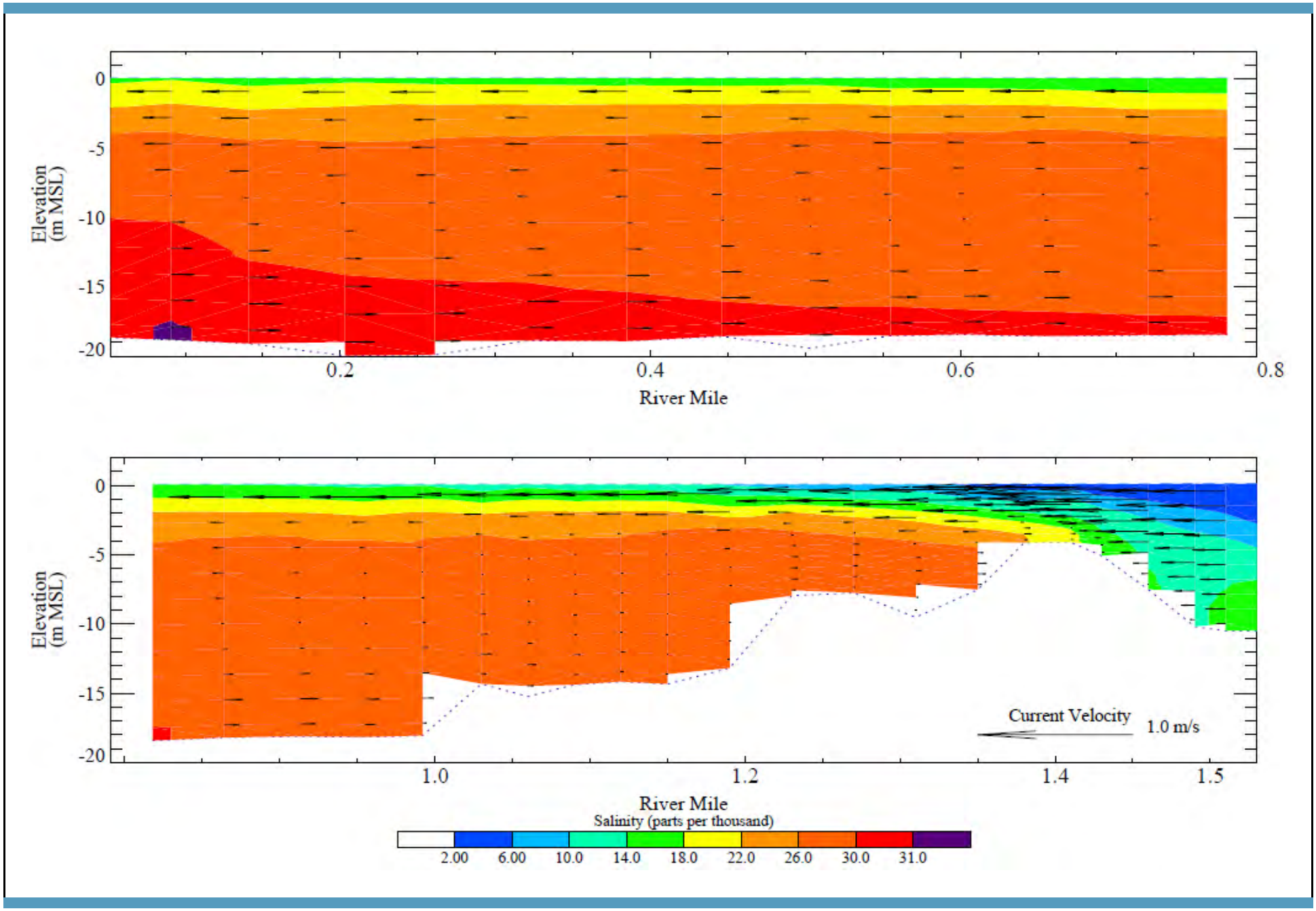

Figure 4-29

Hydrodynamic Model Results: Transect of Average Salinity and Velocity with 100-Year Upstream Flow

Sediment Transport Evaluation Report

East Waterway Operable Unit

ANCHOR QEA

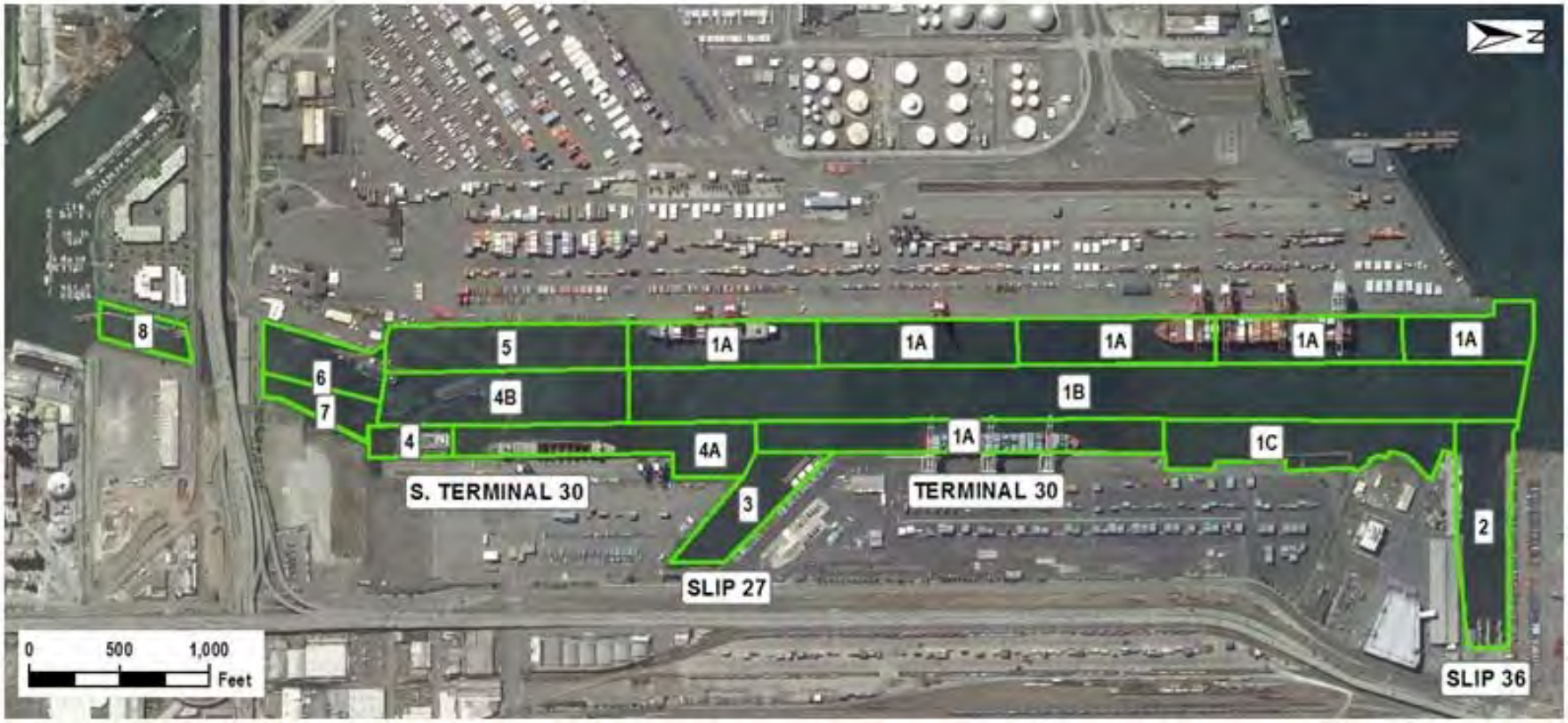

Figure 5-1
Operational Propwash Areas
Sediment Transport Evaluation Report
East Waterway Operable Unit

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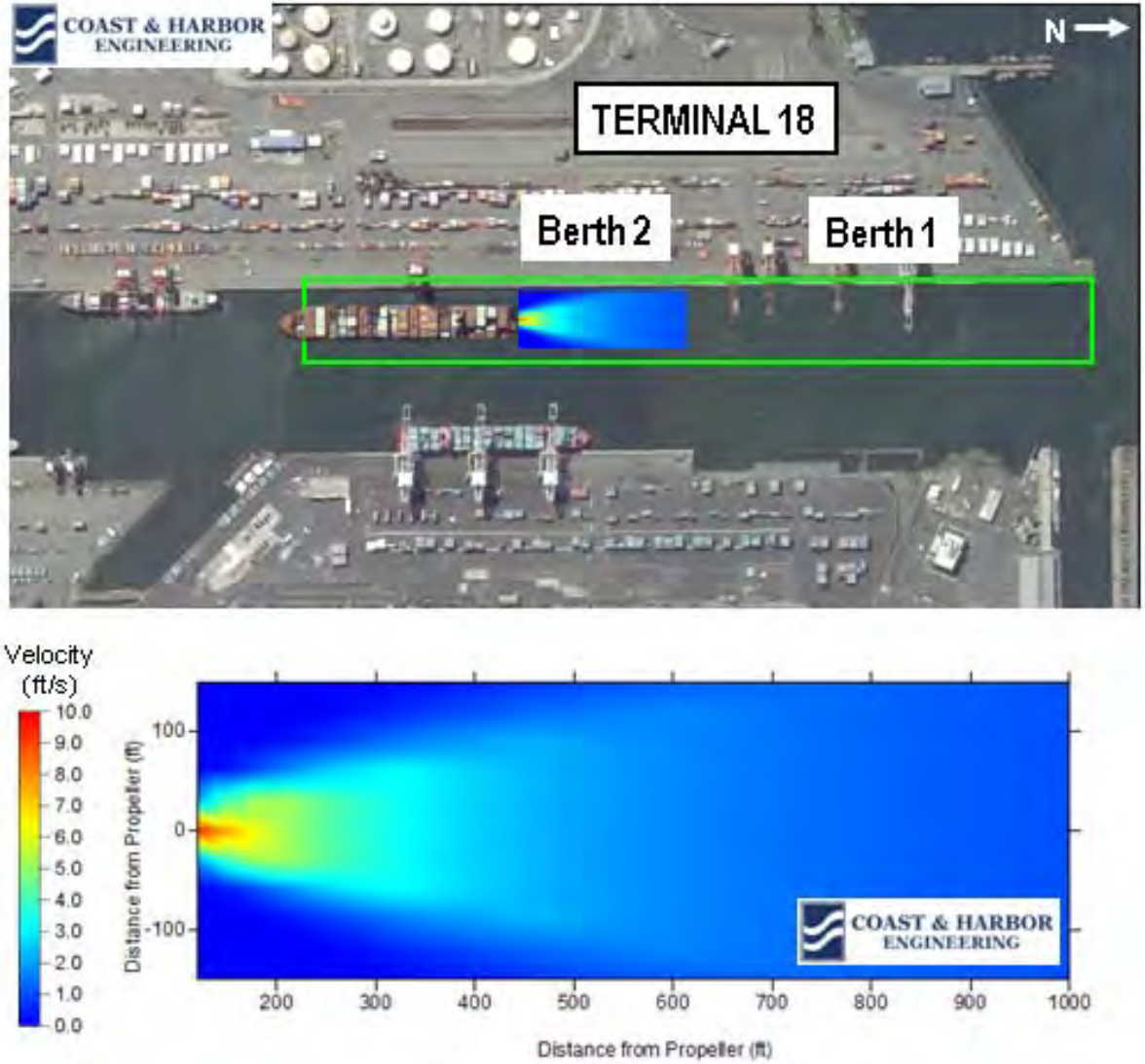

Figure 5-2
Scenario 1: Container Ship Main Propulsion in Area 1
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA

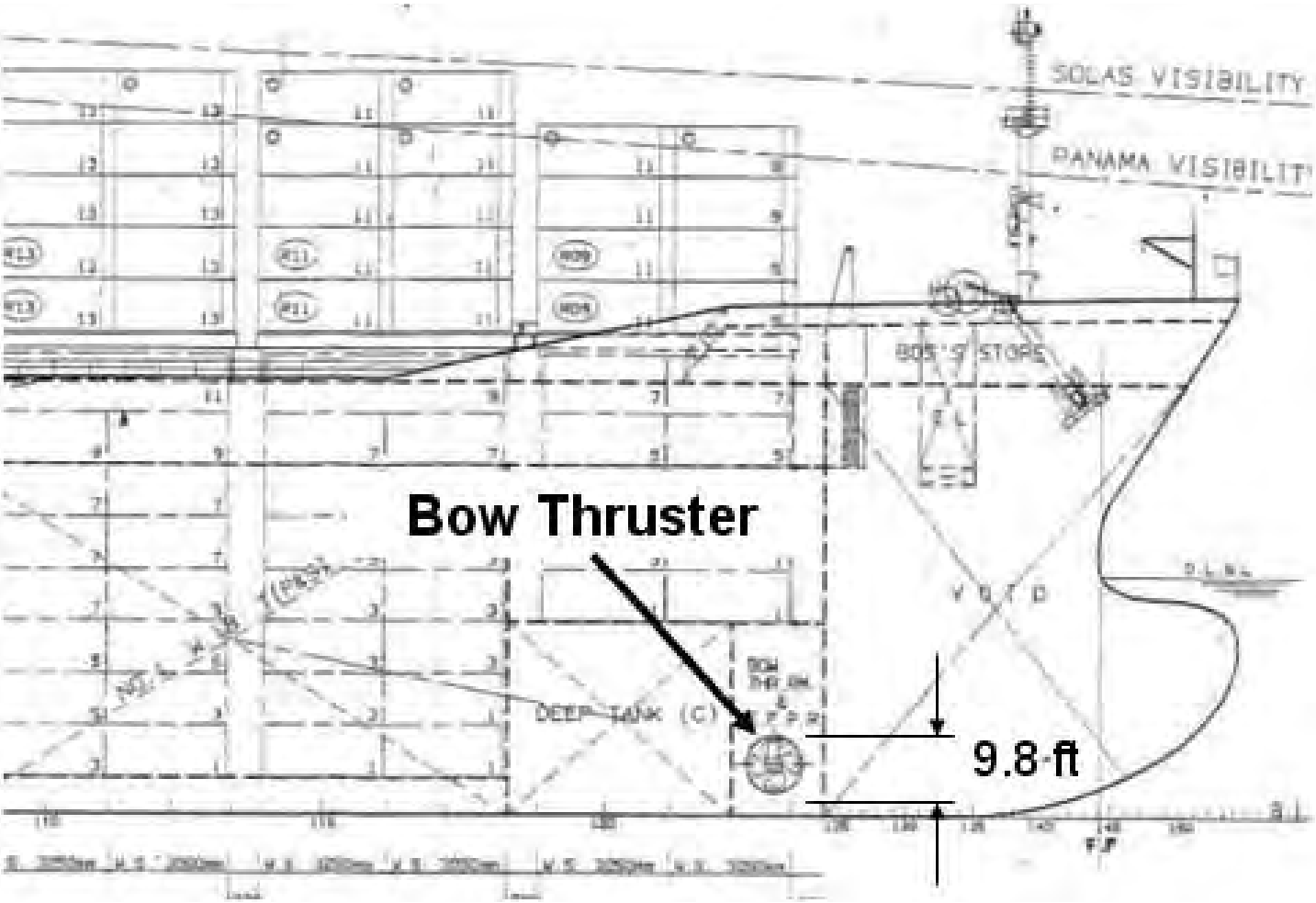

Figure 5-3
Bow Thruster Configuration on Container Ship Hull
Sediment Transport Evaluation Report
East Waterway Operable Unit

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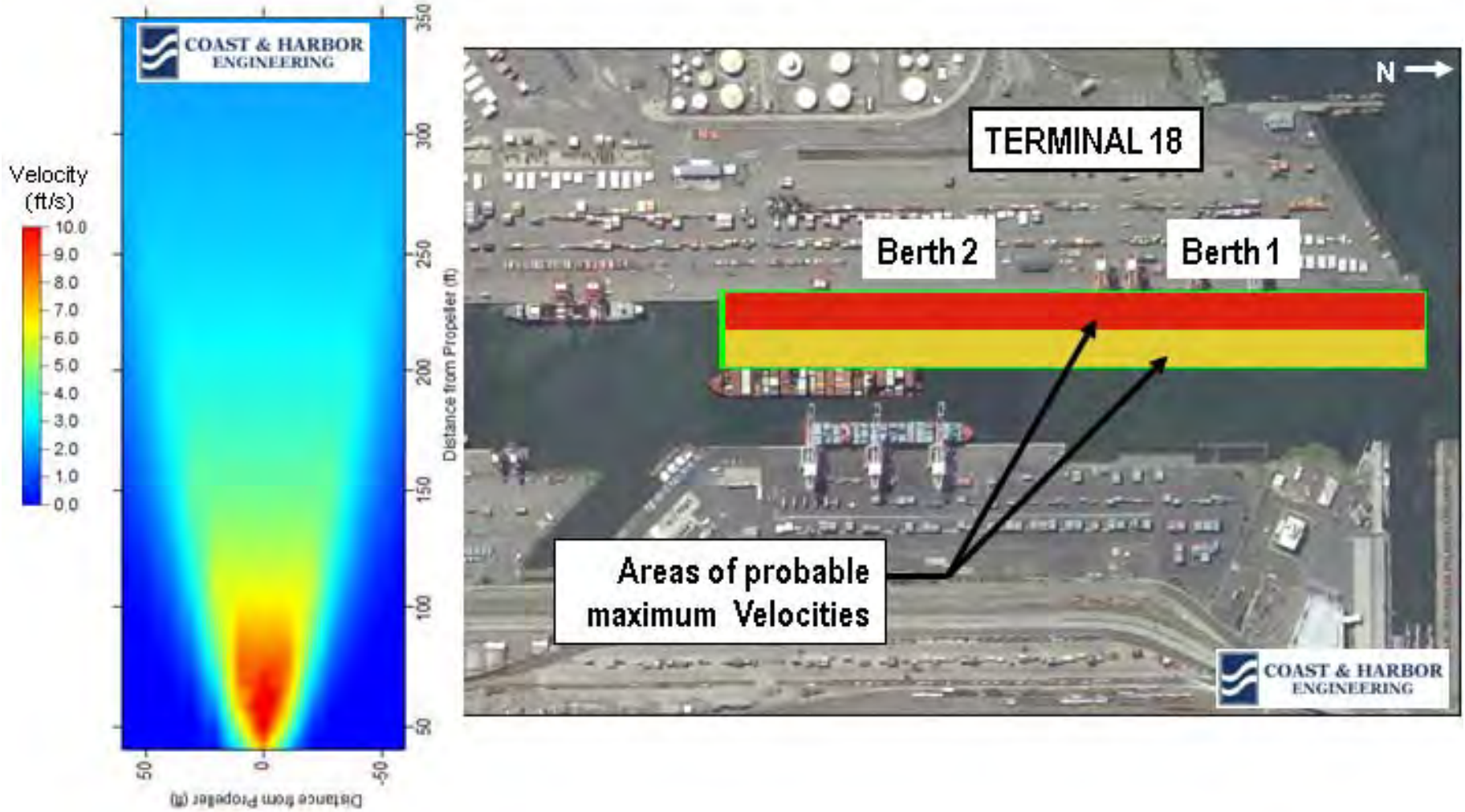

Figure 5-4
Scenario 2: Bow Thruster in Area 1
Sediment Transport Evaluation Report
East Waterway Operable Unit

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Figure 5-5
Scenario 3: Tug Operation within Area 1
Sediment Transport Evaluation Report
East Waterway Operable Unit

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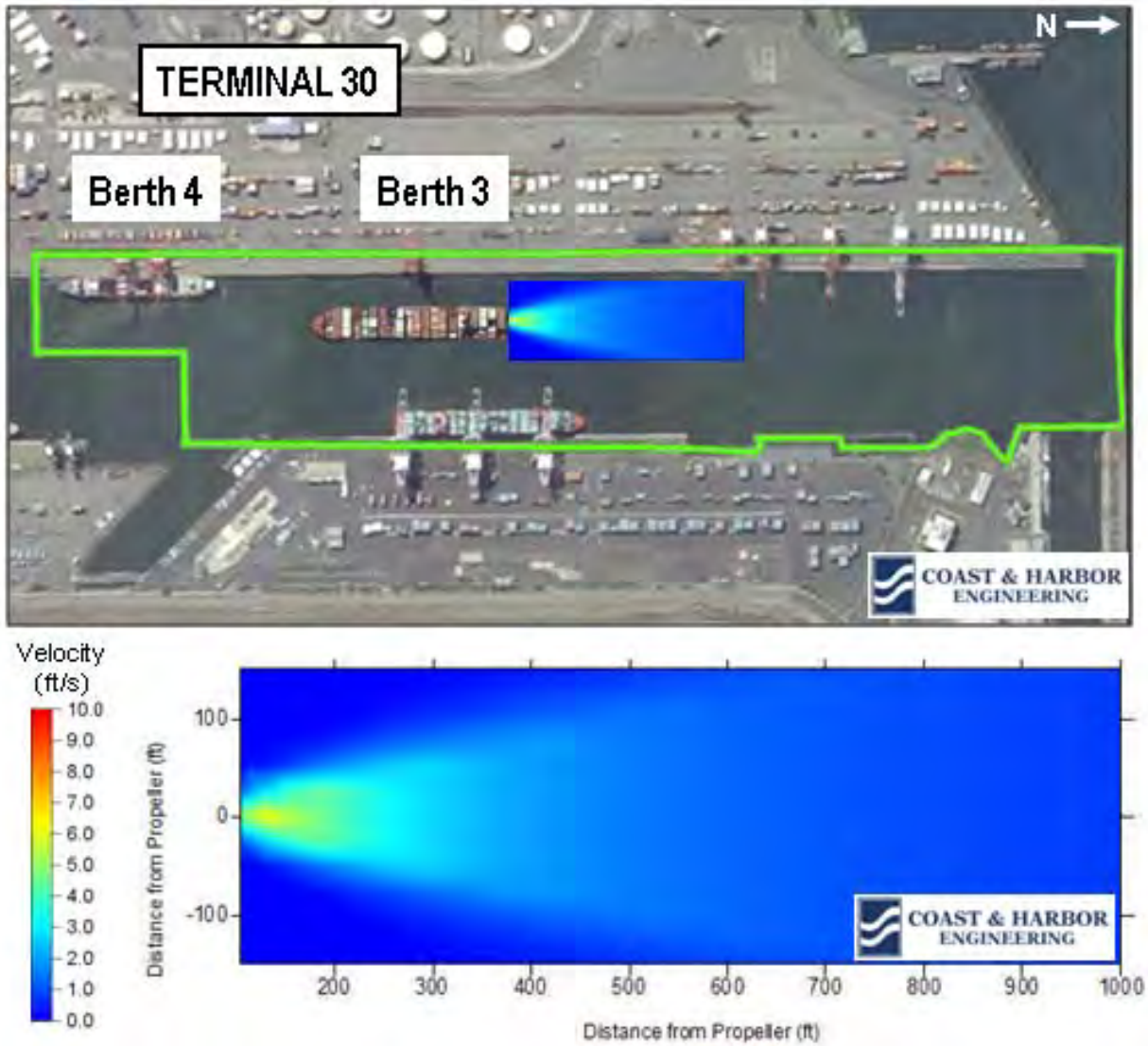

Figure 5-6
Scenario 4: Small Container Ship Main Propulsion in Area 1
Sediment Transport Evaluation Report
East Waterway Operable Unit

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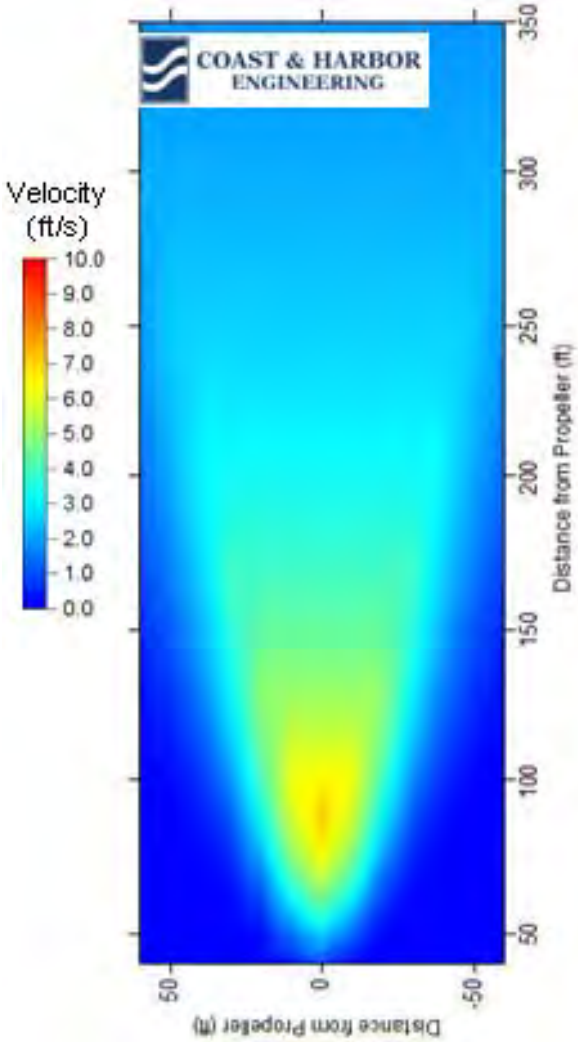

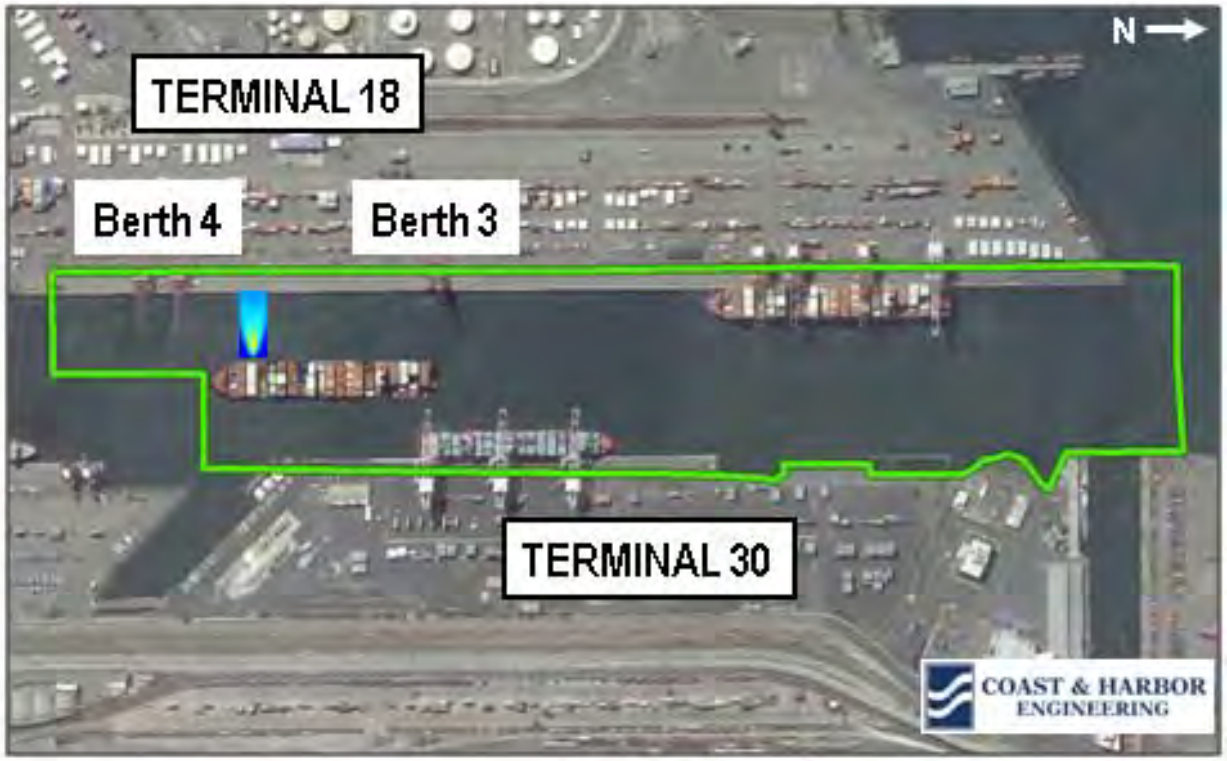

Figure 5-7
Scenario 5: Small Container Ship Bow Thruster in Area 1
Sediment Transport Evaluation Report
East Waterway Operable Unit

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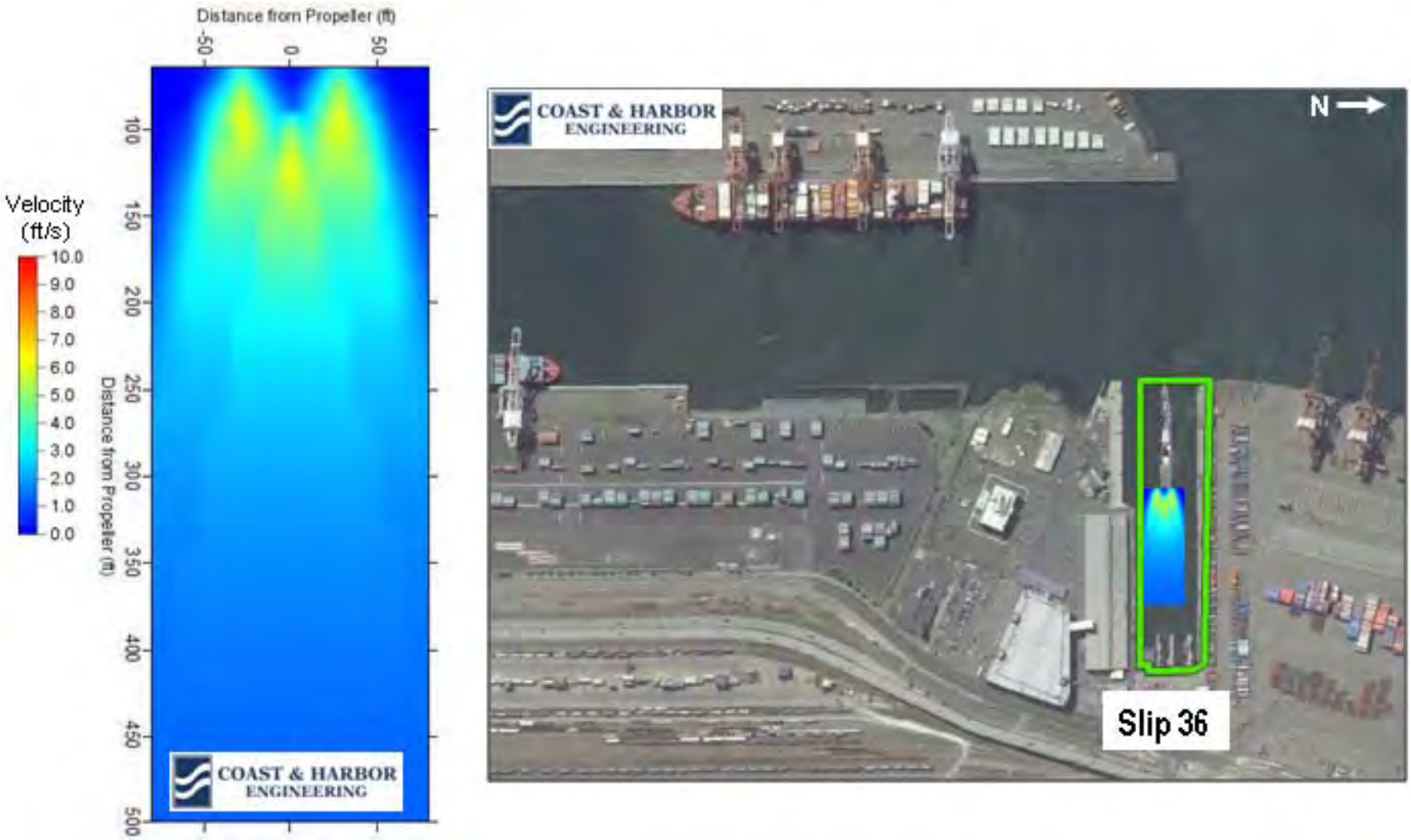

Figure 5-8
Scenario 6: *Polar* Class Icebreaker Propwash in Area 2
Sediment Transport Evaluation Report
East Waterway Operable Unit

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Figure 5-9
Scenario 7: *Hamilton* Class Cutter Propulsion in Area 2
Sediment Transport Evaluation Report
East Waterway Operable Unit

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Figure 5-10
Scenario 8: Tug Operating in Area 3
Sediment Transport Evaluation Report
East Waterway Operable Unit

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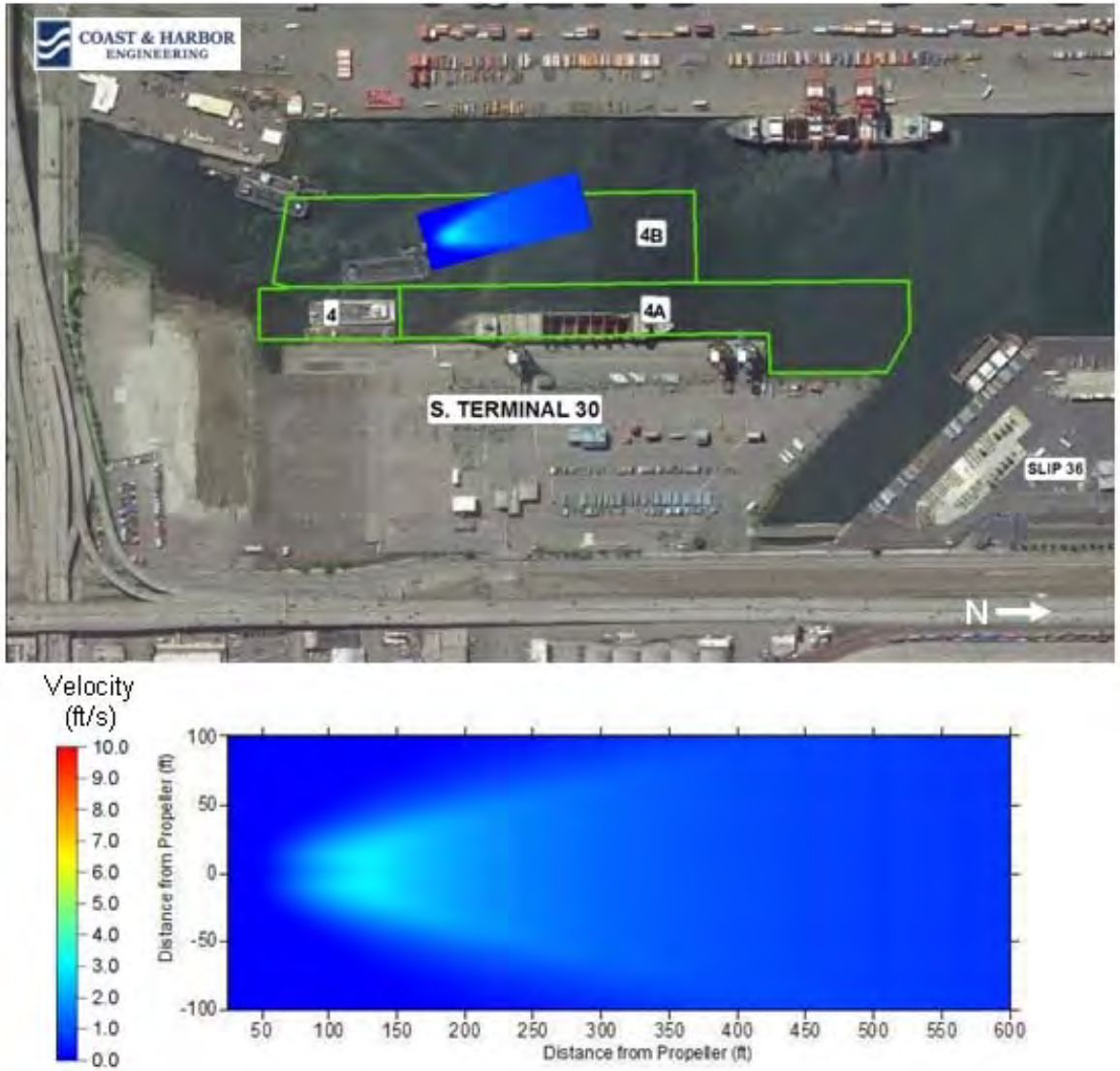

Figure 5-11
Scenario 9: Tug Operating in Areas 4 and 5
Sediment Transport Evaluation Report
East Waterway Operable Unit

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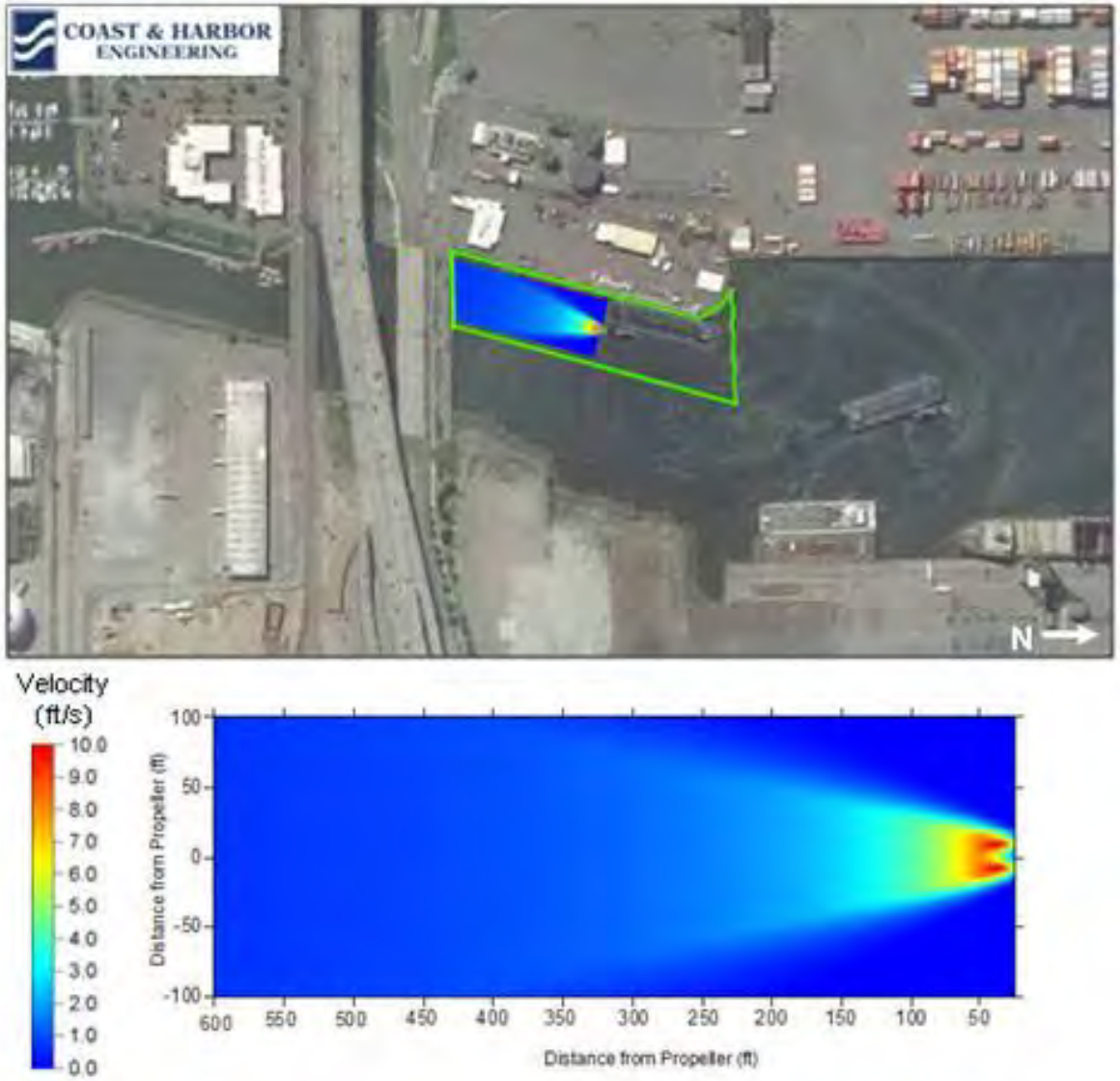

Figure 5-12
Scenario 10: Tug Operating in Area 6
Sediment Transport Evaluation Report
East Waterway Operable Unit

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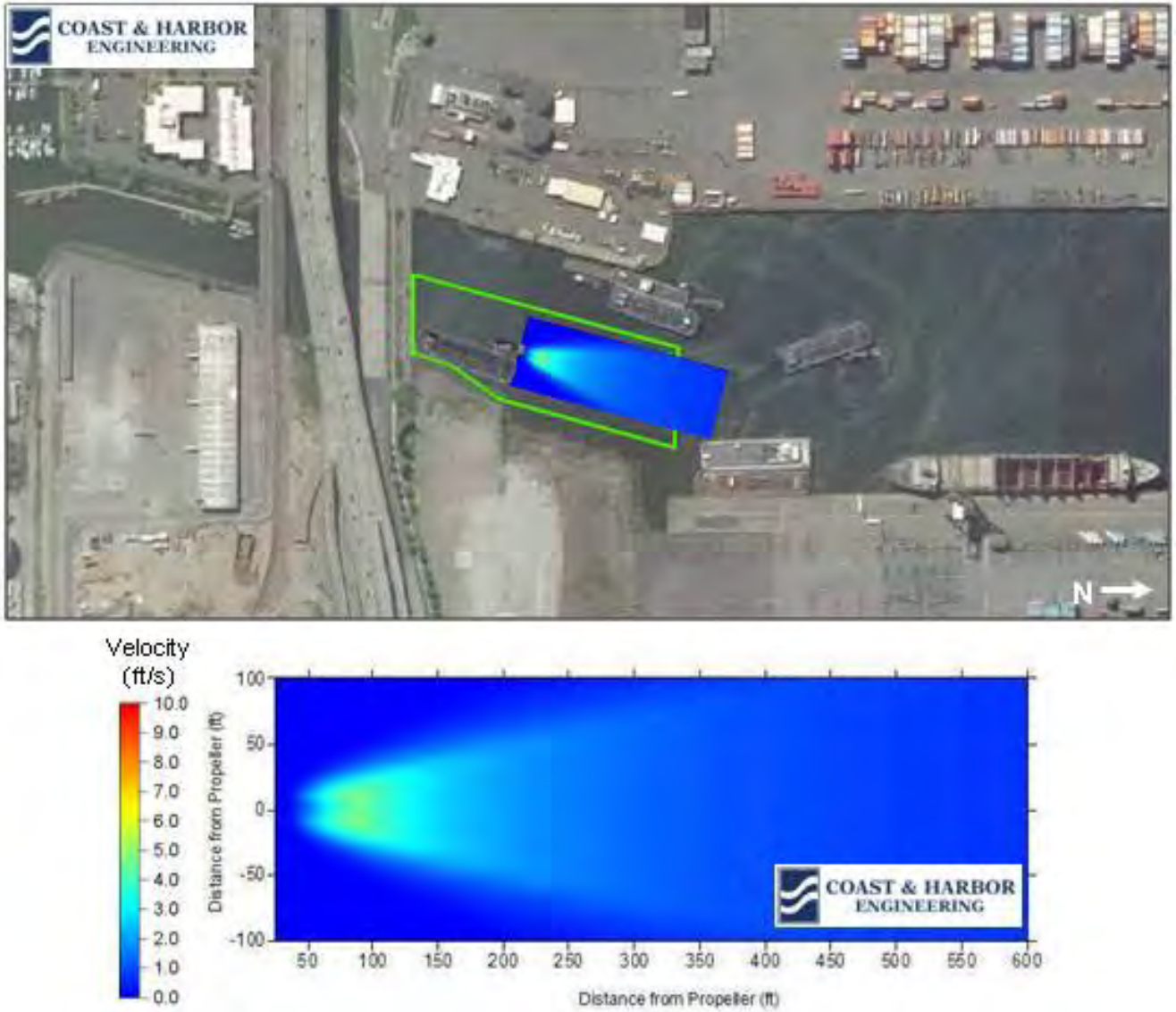

Figure 5-13
Scenario 11: Tug Operating in Area 7
Sediment Transport Evaluation Report
East Waterway Operable Unit

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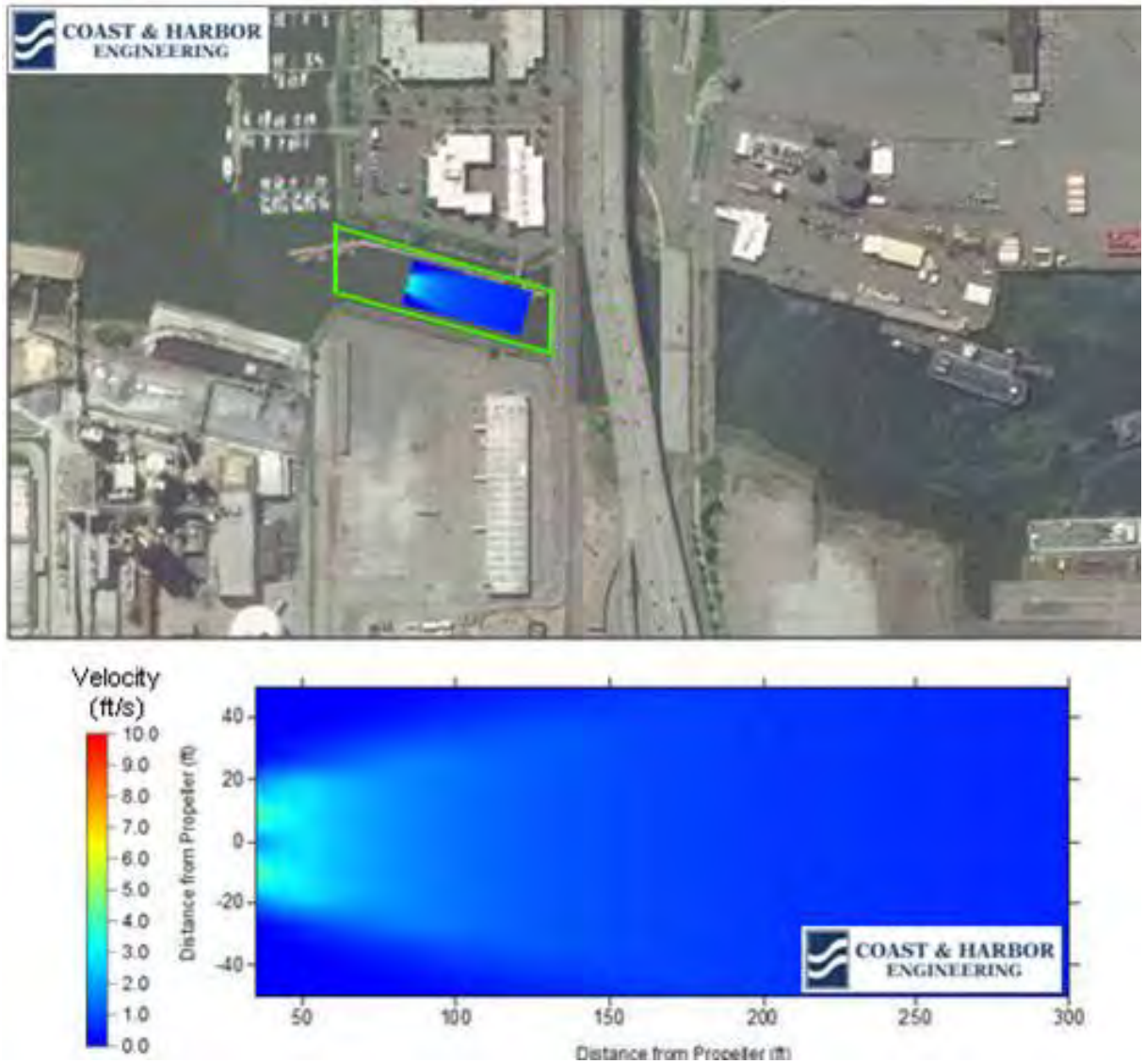

Figure 5-14
Scenario 12: Tug Operating in Area 8
Sediment Transport Evaluation Report
East Waterway Operable Unit

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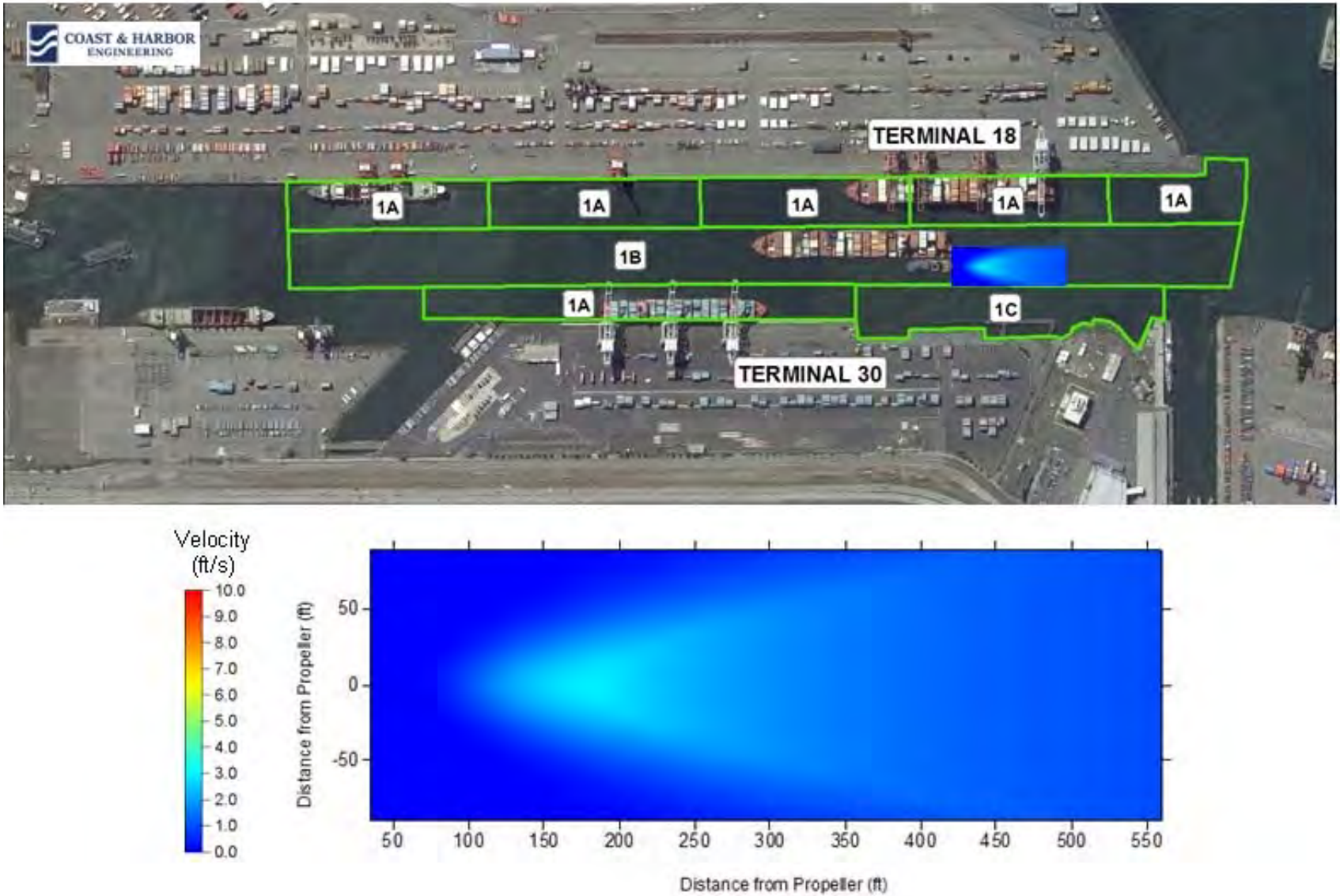

Figure 5-15
Scenario 13: Tug Assisting a Ship in Area 1
Sediment Transport Evaluation Report
East Waterway Operable Unit

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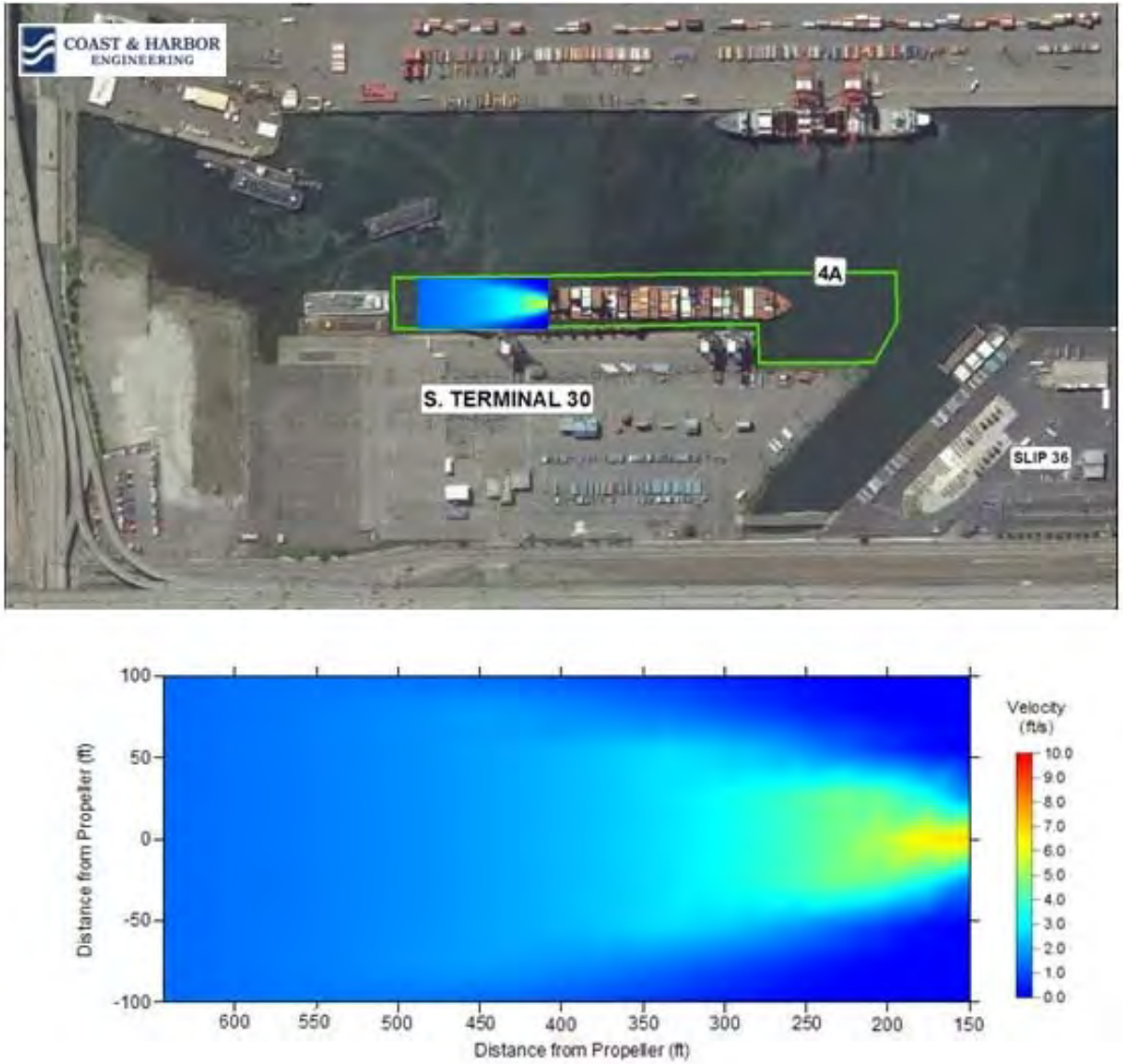

Figure 5-16
Scenario 14: Small Container Ship Main Propulsion in Area 4 (future condition)
Sediment Transport Evaluation Report
East Waterway Operable Unit

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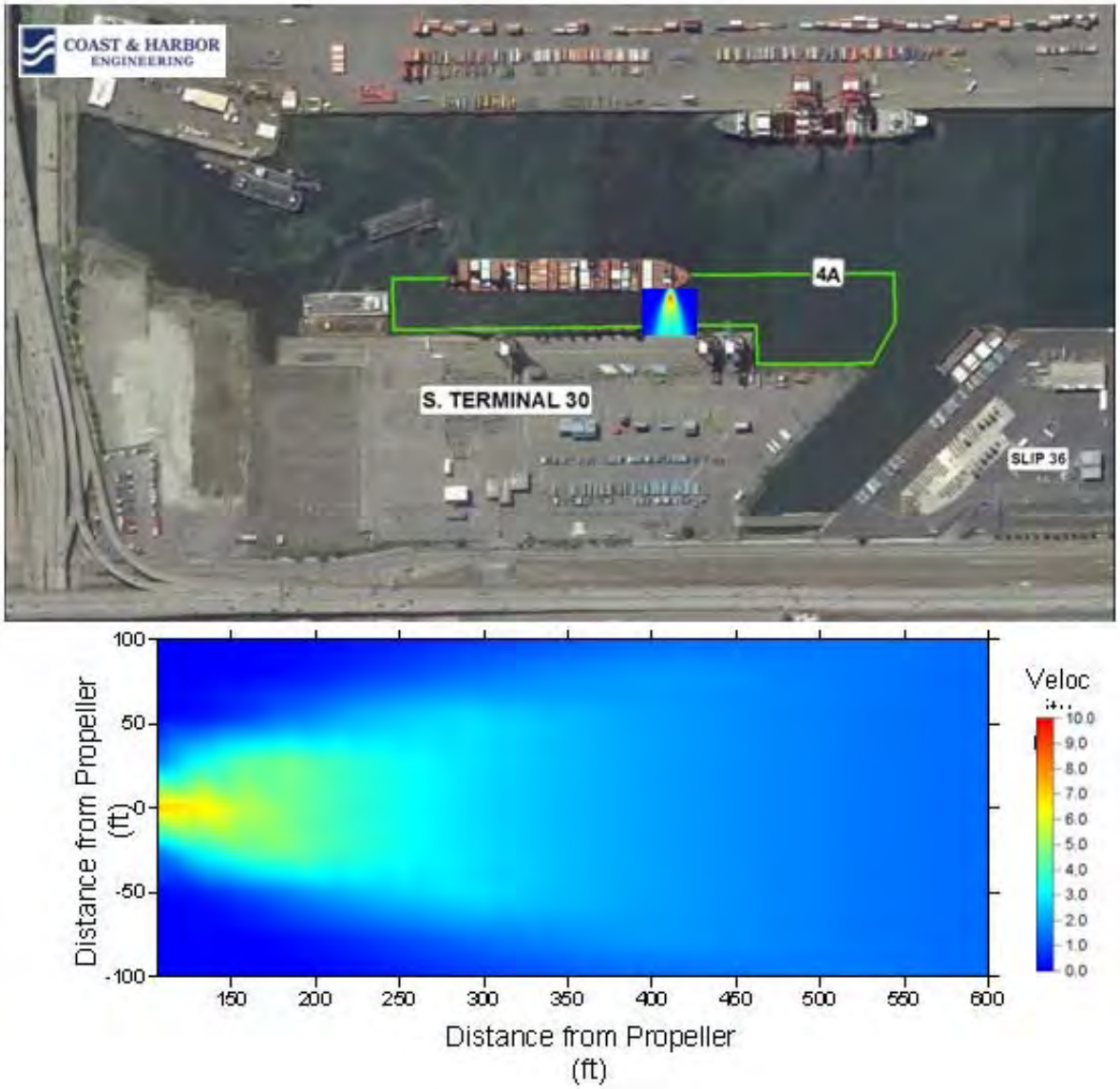
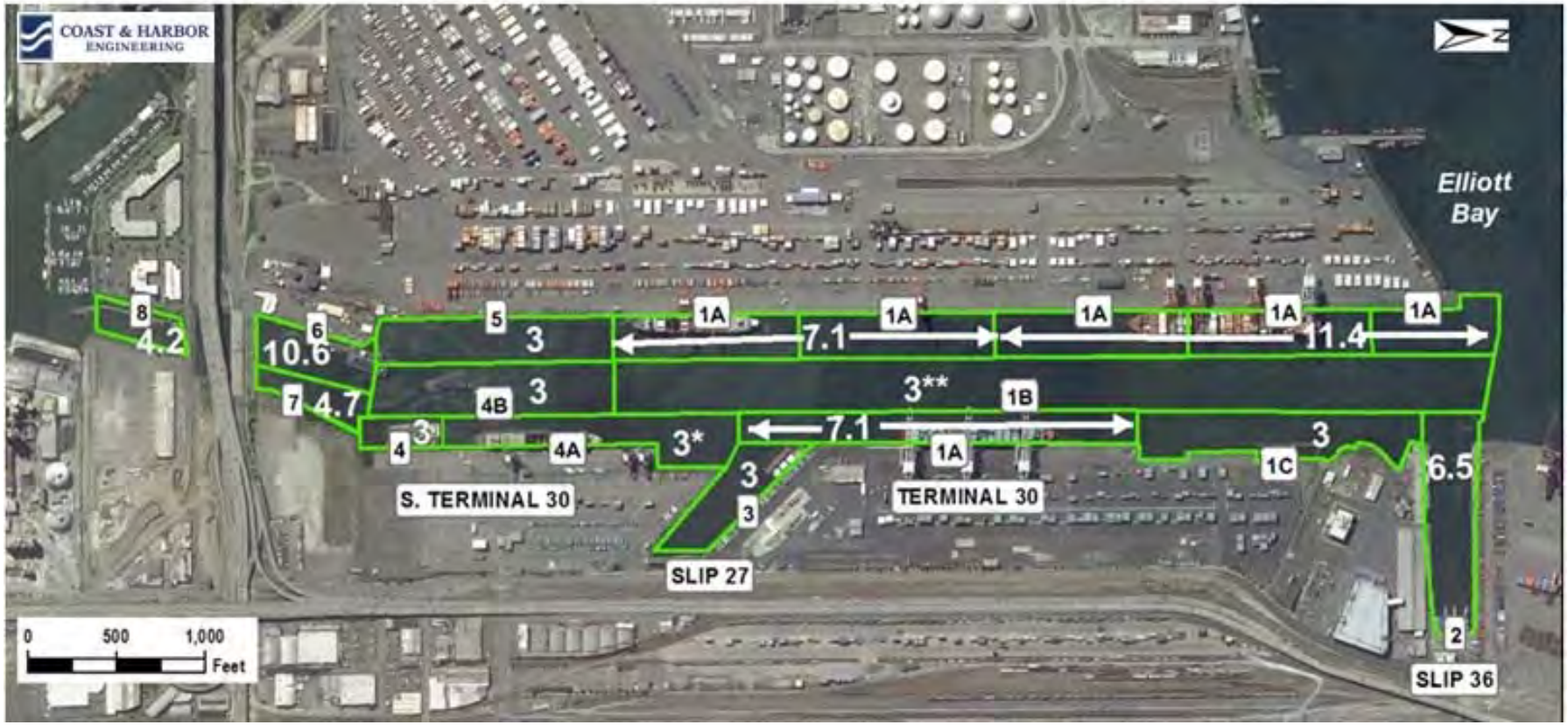


Figure 5-17
Scenario 15: Small Container Ship Bow Thruster in Area 4 (future condition)
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA



Notes:

* Maximum velocity due to Future Conditions Area 4A is 9 ft/s

** Assumes steady state condition for transit through the East Waterway

Figure 5-18

Propwash Modeling Results – Maximum Near-Bed Velocities (ft/s)

Sediment Transport Evaluation Report

East Waterway Operable Unit

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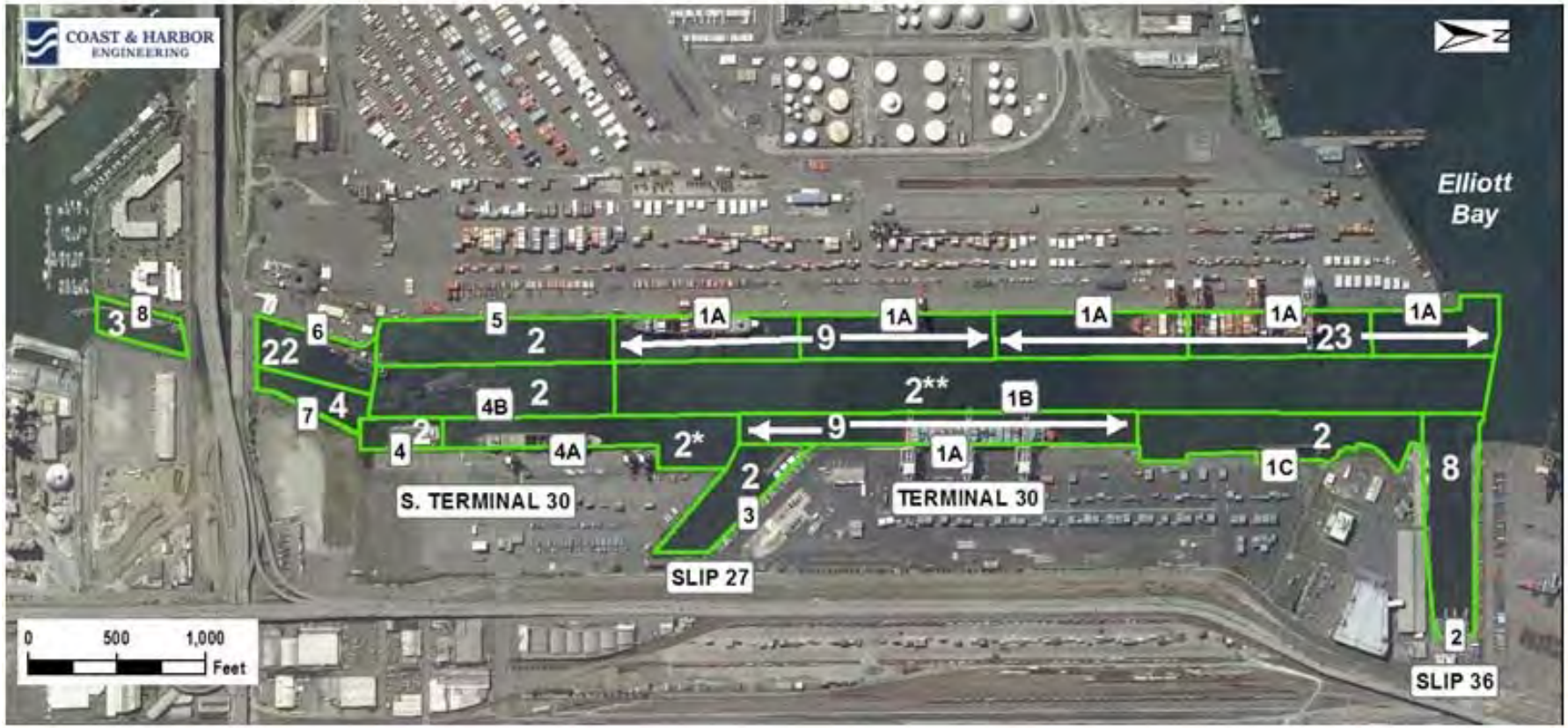

Notes:

* Maximum velocity due to Future Conditions Area 4A is 9 ft/s

** Assumes steady state condition for transit through the East Waterway

Figure 5-19

Propwash Modeling Results – Maximum Near-Bed Shear Stress (Pa)

Sediment Transport Evaluation Report

East Waterway Operable Unit

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Figure 5-20
Bottom Velocity due to Pressure Fields Generated by a Tug at 4-knot Speed
Sediment Transport Evaluation Report
East Waterway Operable Unit

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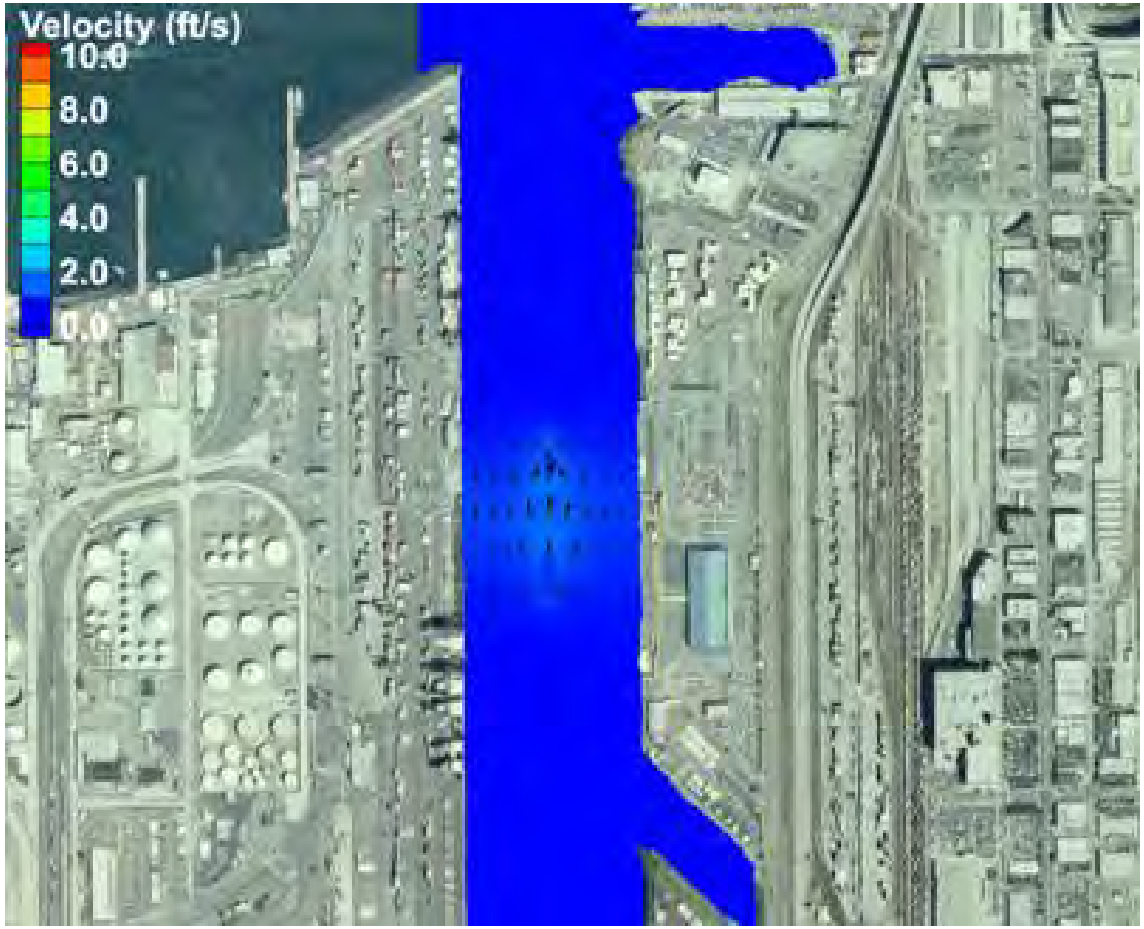


Figure 5-21
Bottom Velocity due to Pressure Fields Generated by a Small Container Ship at 4-knot Speed
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA

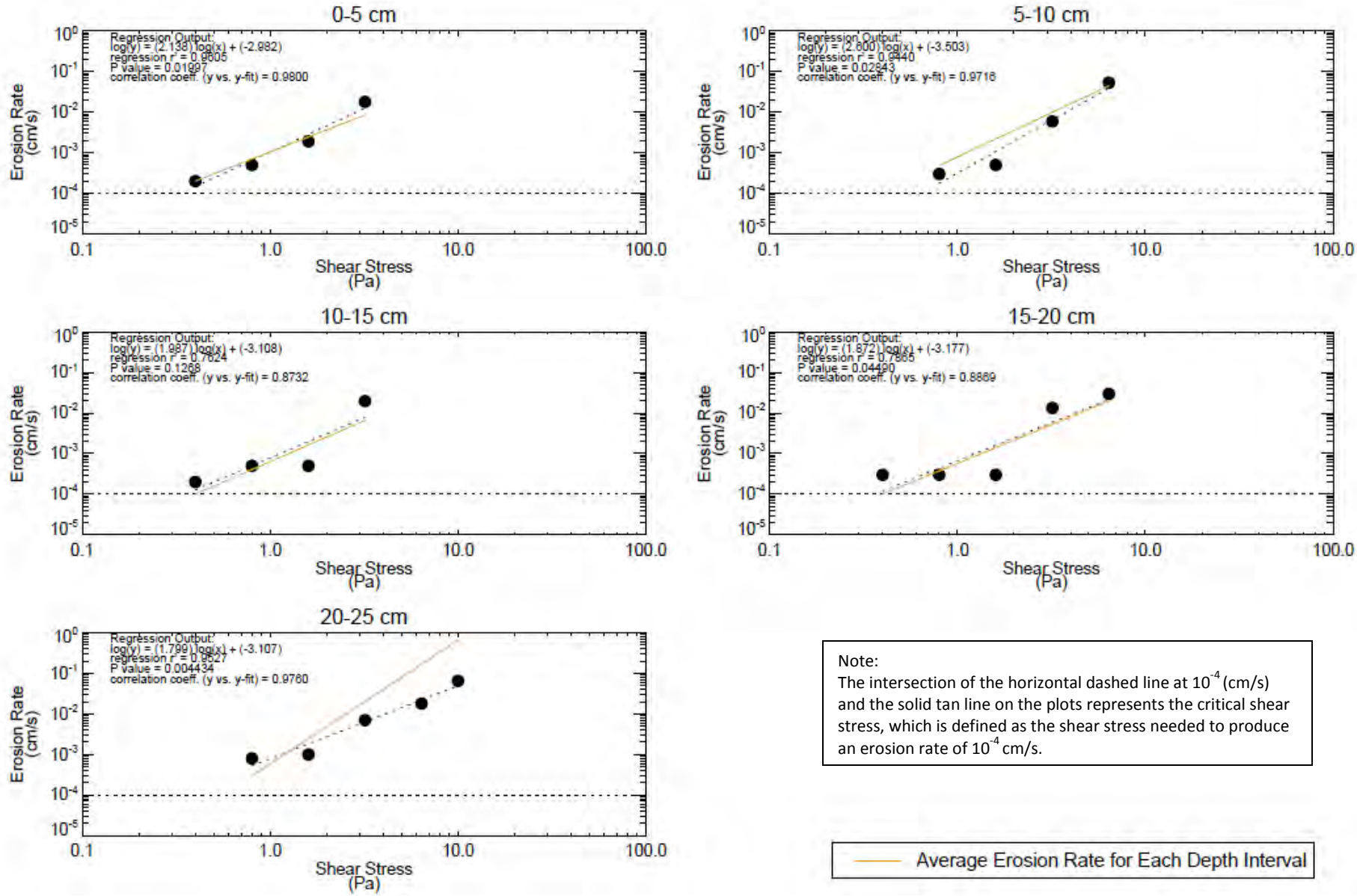


Figure 6-1

Comparison of Data (symbols) to Results of Log-linear Regression (dashed line) for Core SF_1

Sediment Transport Evaluation Report

East Waterway Operable Unit

ANCHOR QEA

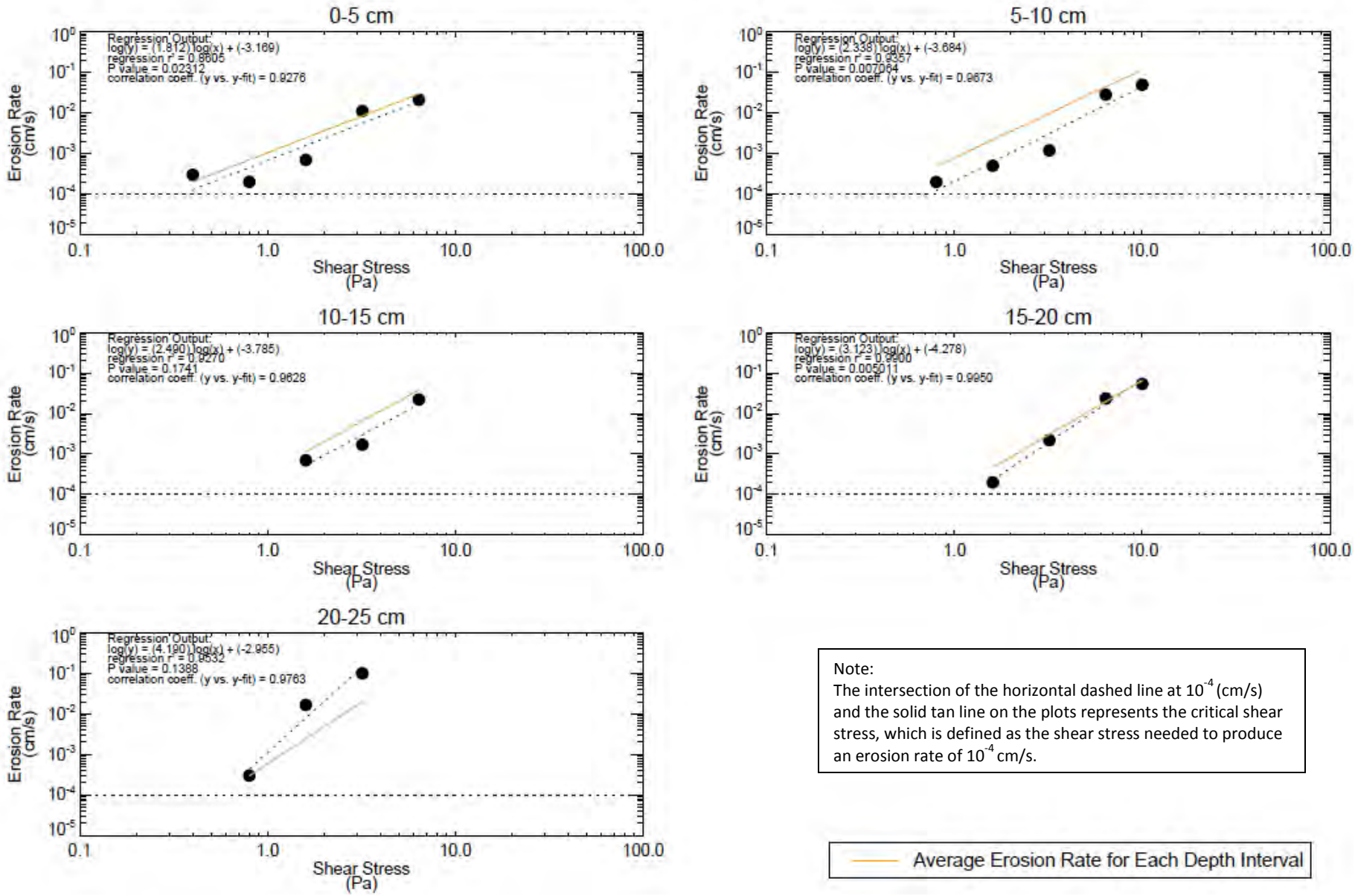


Figure 6-2

Comparison of Data (symbols) to Results of Log-linear Regression (dashed line) for Core SF_2

Sediment Transport Evaluation Report

East Waterway Operable Unit

ANCHOR QEA

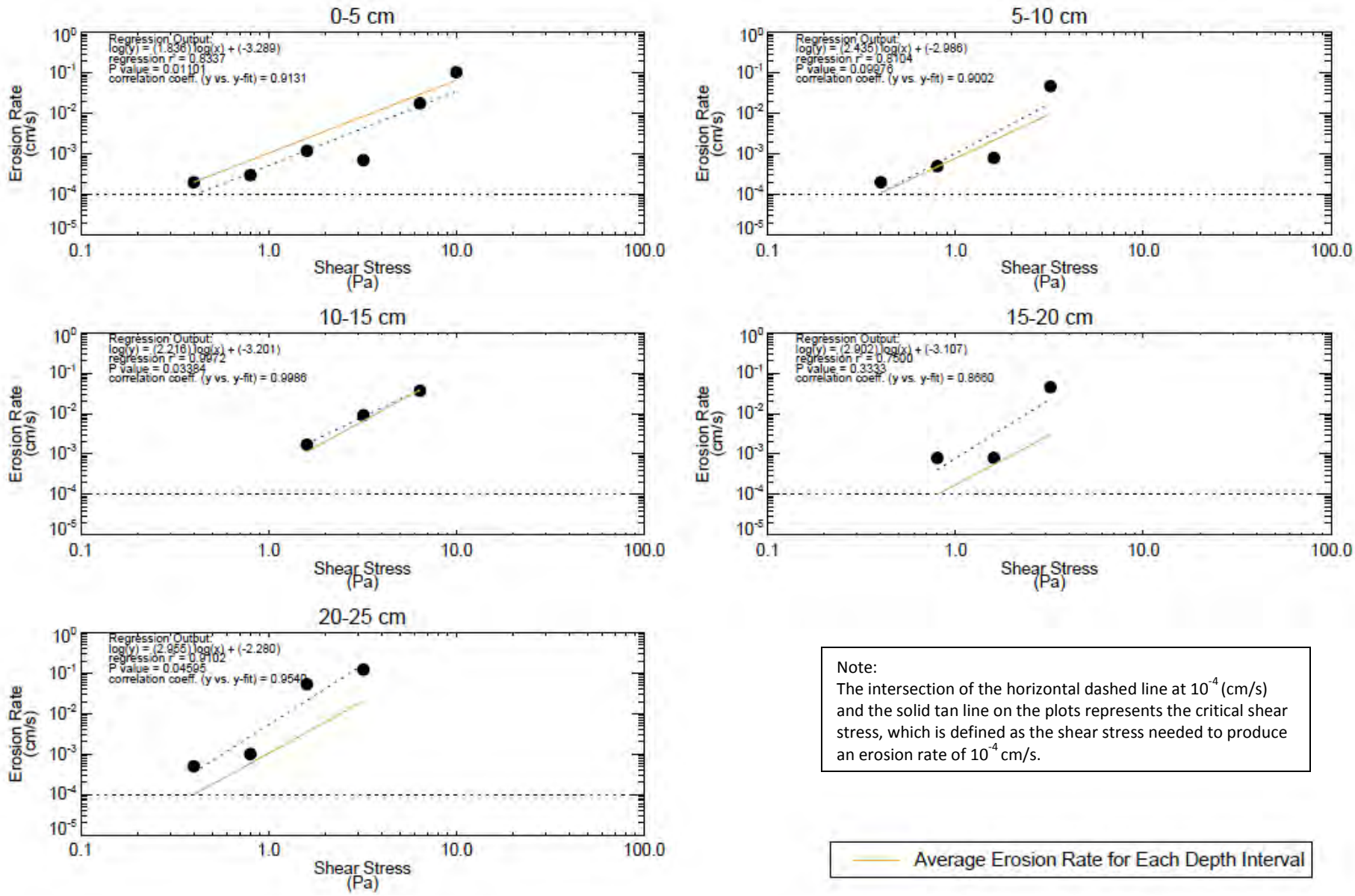


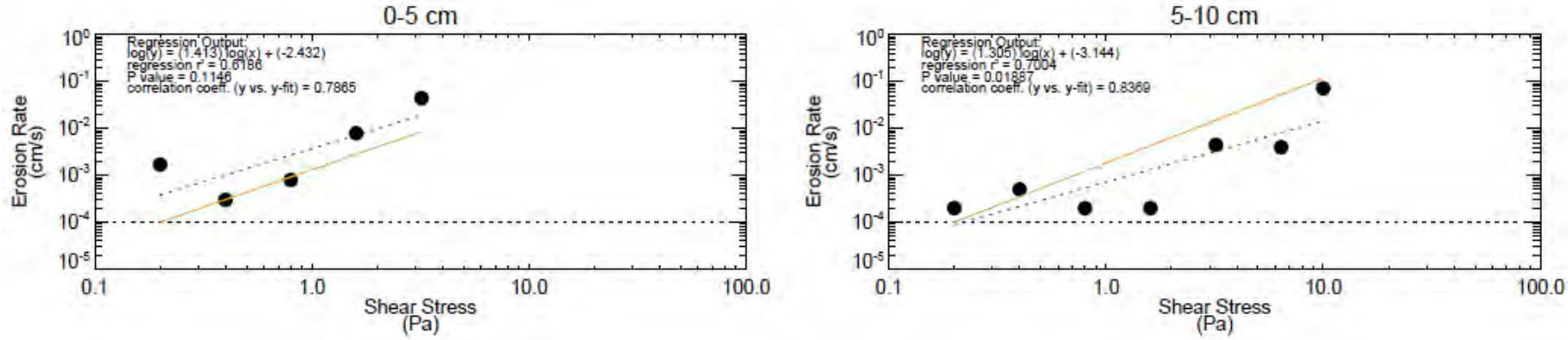
Figure 6-3

Comparison of Data (symbols) to Results of Log-linear Regression (dashed line) for Core SF_3

Sediment Transport Evaluation Report

East Waterway Operable Unit

ANCHOR QEA

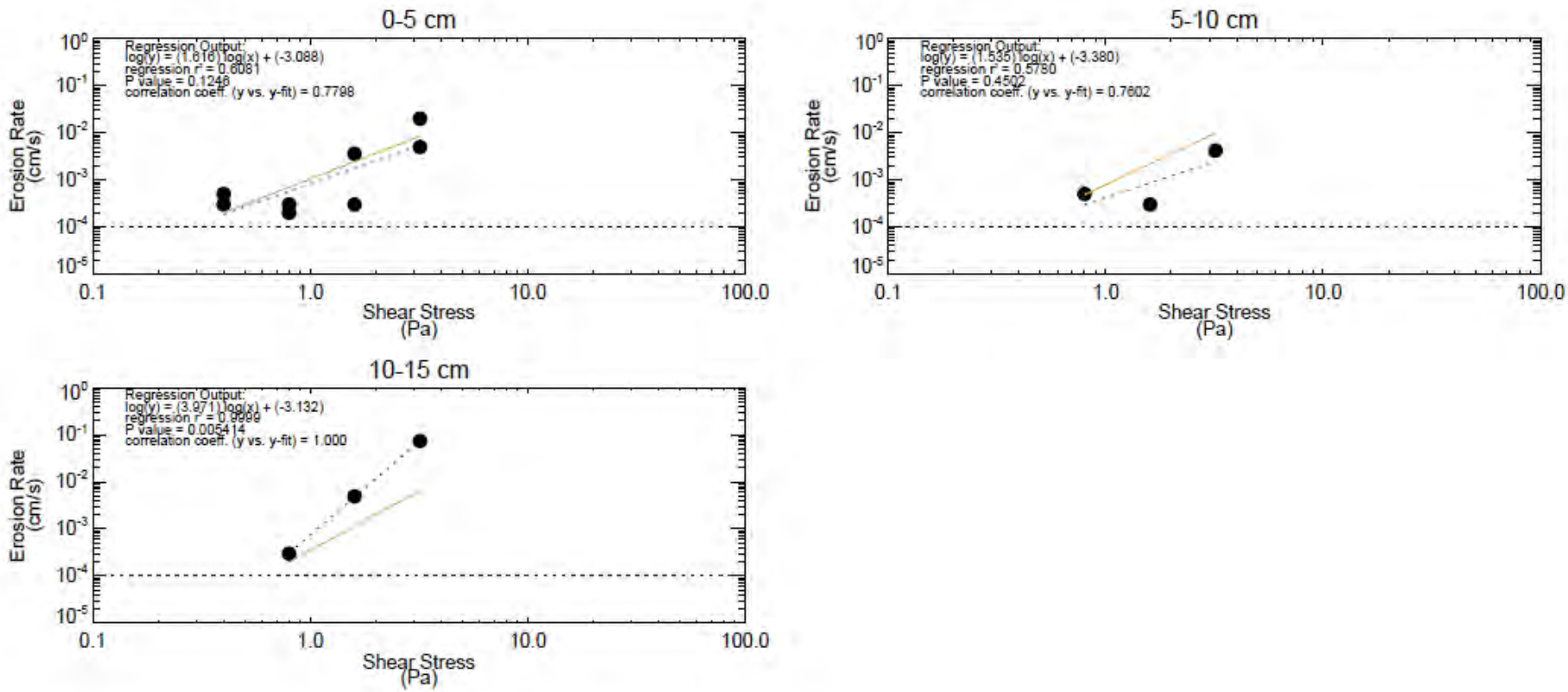


Note:
The intersection of the horizontal dashed line at 10^{-4} (cm/s) and the solid tan line on the plots represents the critical shear stress, which is defined as the shear stress needed to produce an erosion rate of 10^{-4} cm/s.

Average Erosion Rate for Each Depth Interval

Figure 6-4
Comparison of Data (symbols) to Results of Log-linear Regression (dashed line) for Core SF_4
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA



Note:
The intersection of the horizontal dashed line at 10^{-4} (cm/s) and the solid tan line on the plots represents the critical shear stress, which is defined as the shear stress needed to produce an erosion rate of 10^{-4} cm/s.

Average Erosion Rate for Each Depth Interval

Figure 6-5
Comparison of Data (symbols) to Results of Log-linear Regression (dashed line) for Core SF_5
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA

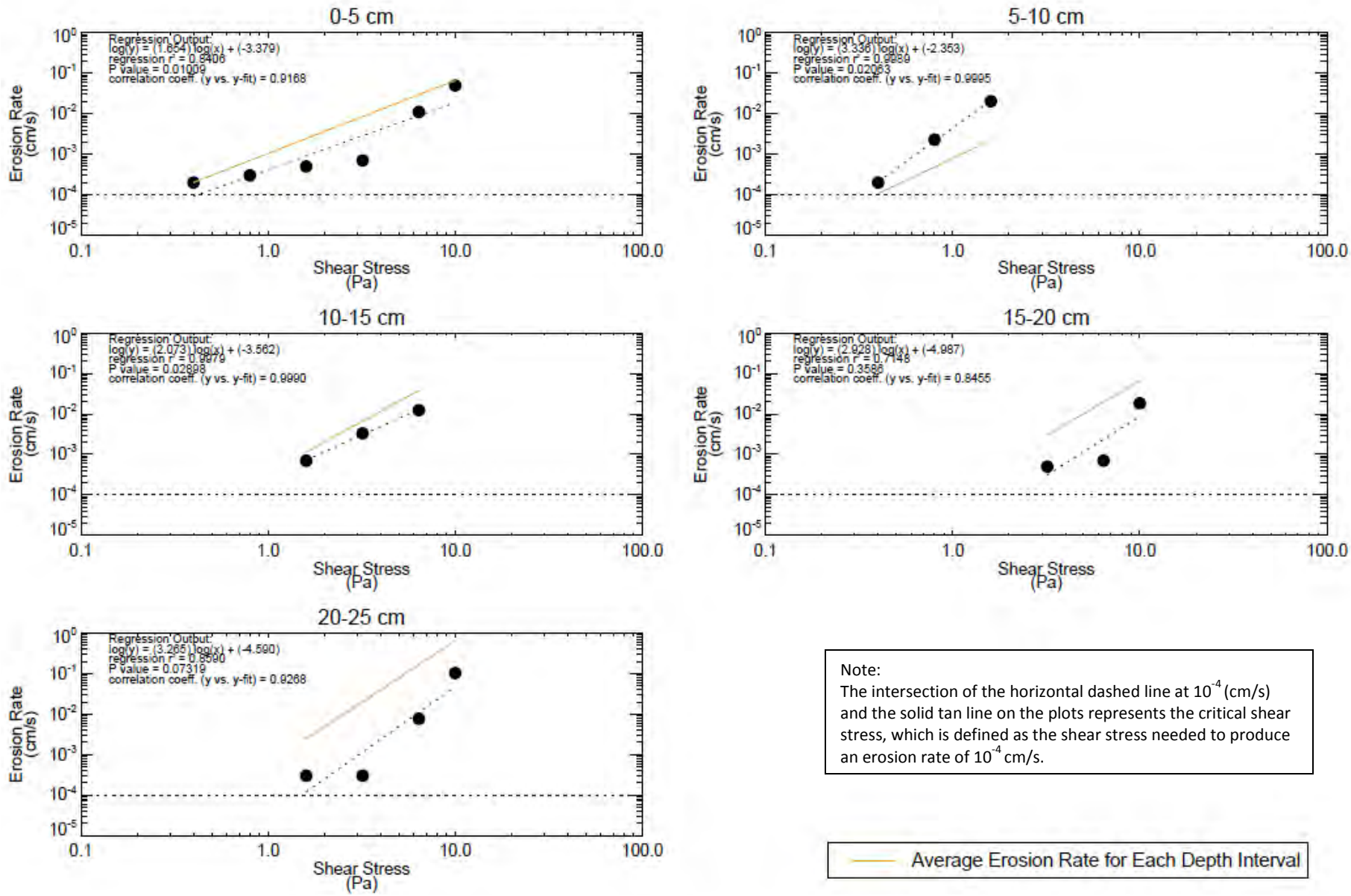


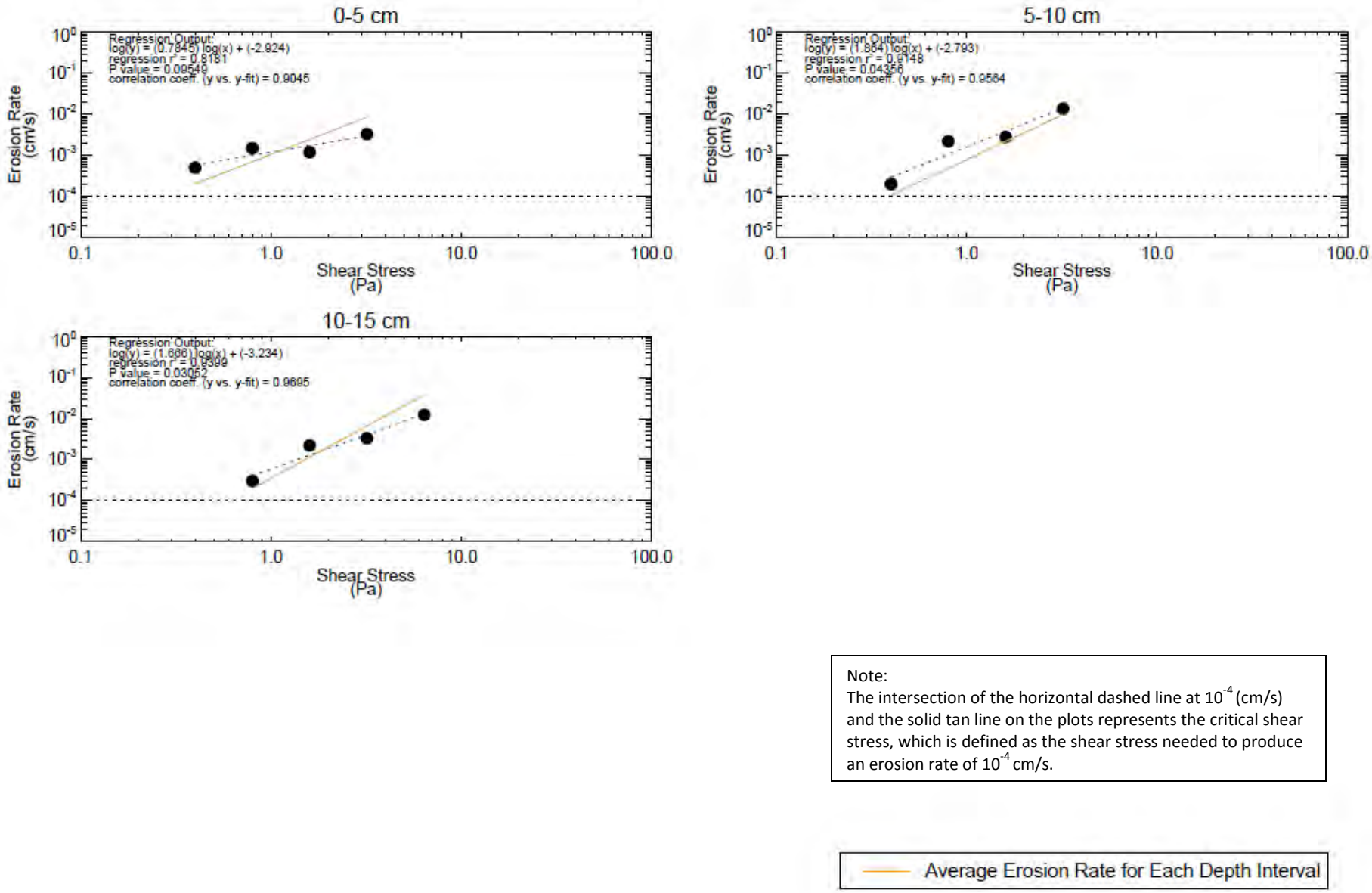
Figure 6-6

Comparison of Data (symbols) to Results of Log-linear Regression (dashed line) for Core SF_6

Sediment Transport Evaluation Report

East Waterway Operable Unit

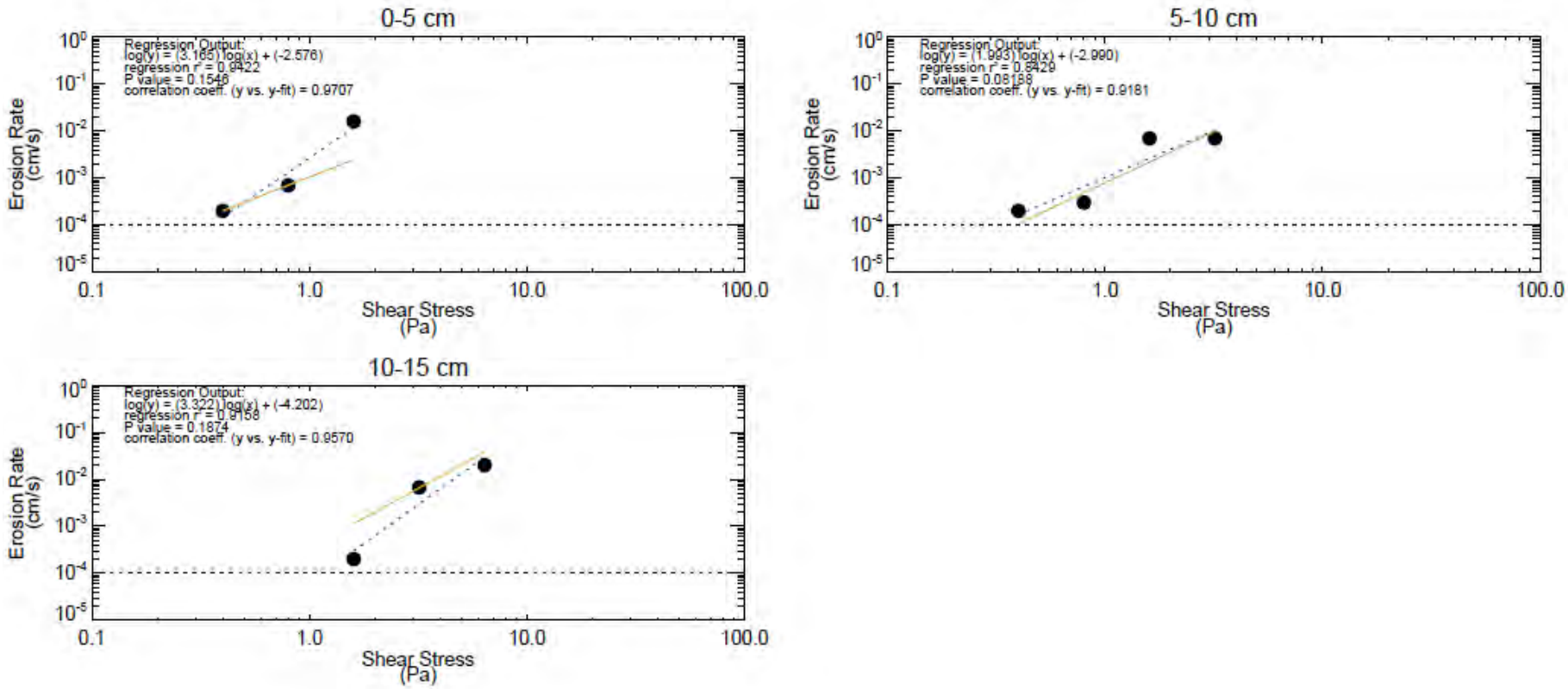
ANCHOR QEA



Note:
The intersection of the horizontal dashed line at 10^{-4} (cm/s) and the solid tan line on the plots represents the critical shear stress, which is defined as the shear stress needed to produce an erosion rate of 10^{-4} cm/s.

Figure 6-7
Comparison of Data (symbols) to Results of Log-linear Regression (dashed line) for Core SF_7
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA



Note:
The intersection of the horizontal dashed line at 10^{-4} (cm/s) and the solid tan line on the plots represents the critical shear stress, which is defined as the shear stress needed to produce an erosion rate of 10^{-4} cm/s.

Average Erosion Rate for Each Depth Interval

Figure 6-8
Comparison of Data (symbols) to Results of Log-linear Regression (dashed line) for Core SF_8
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA

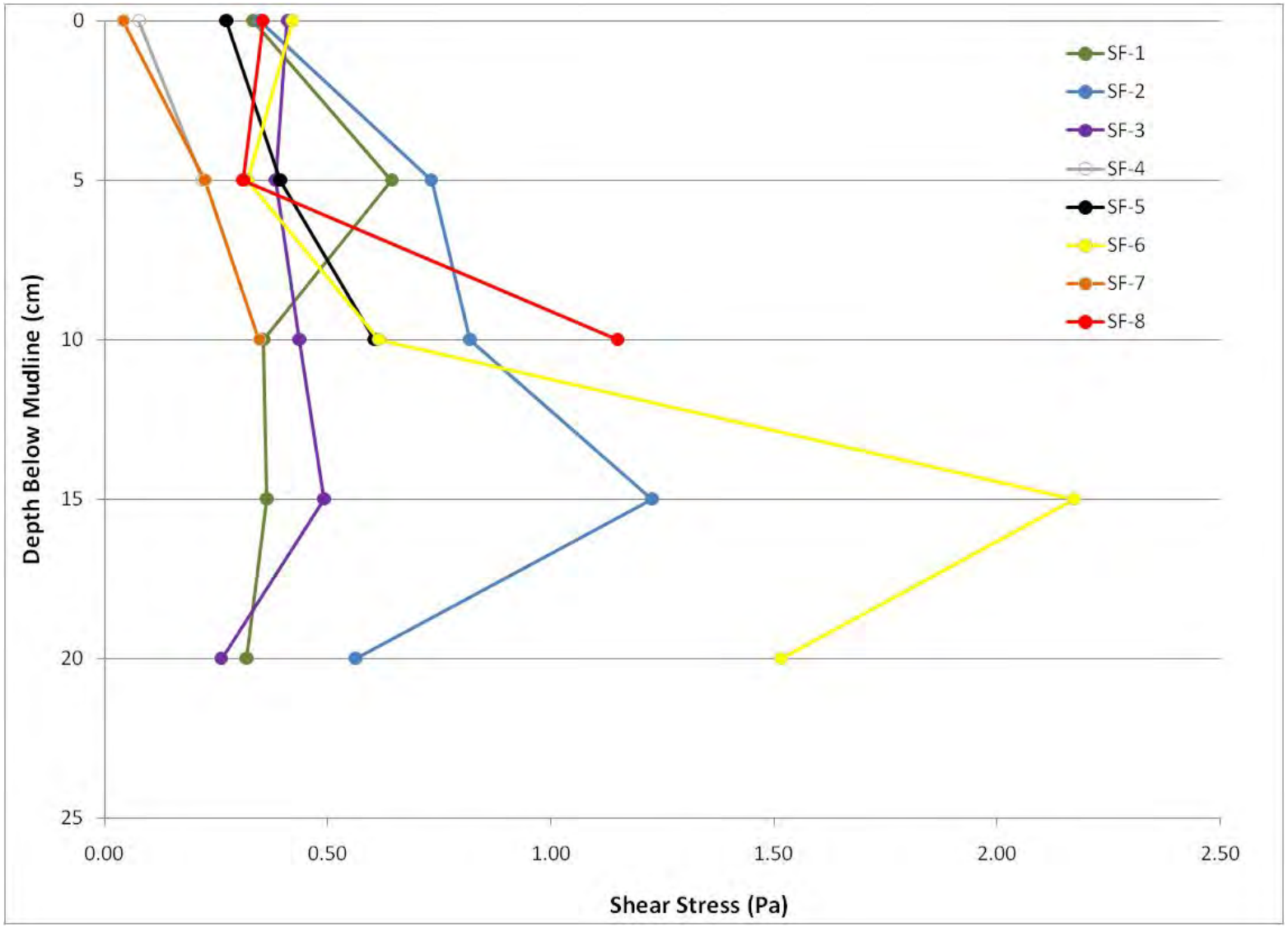


Figure 6-9
Critical Shear Stress (from Sedflume Cores) as a Function of Depth Below Mudline
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA

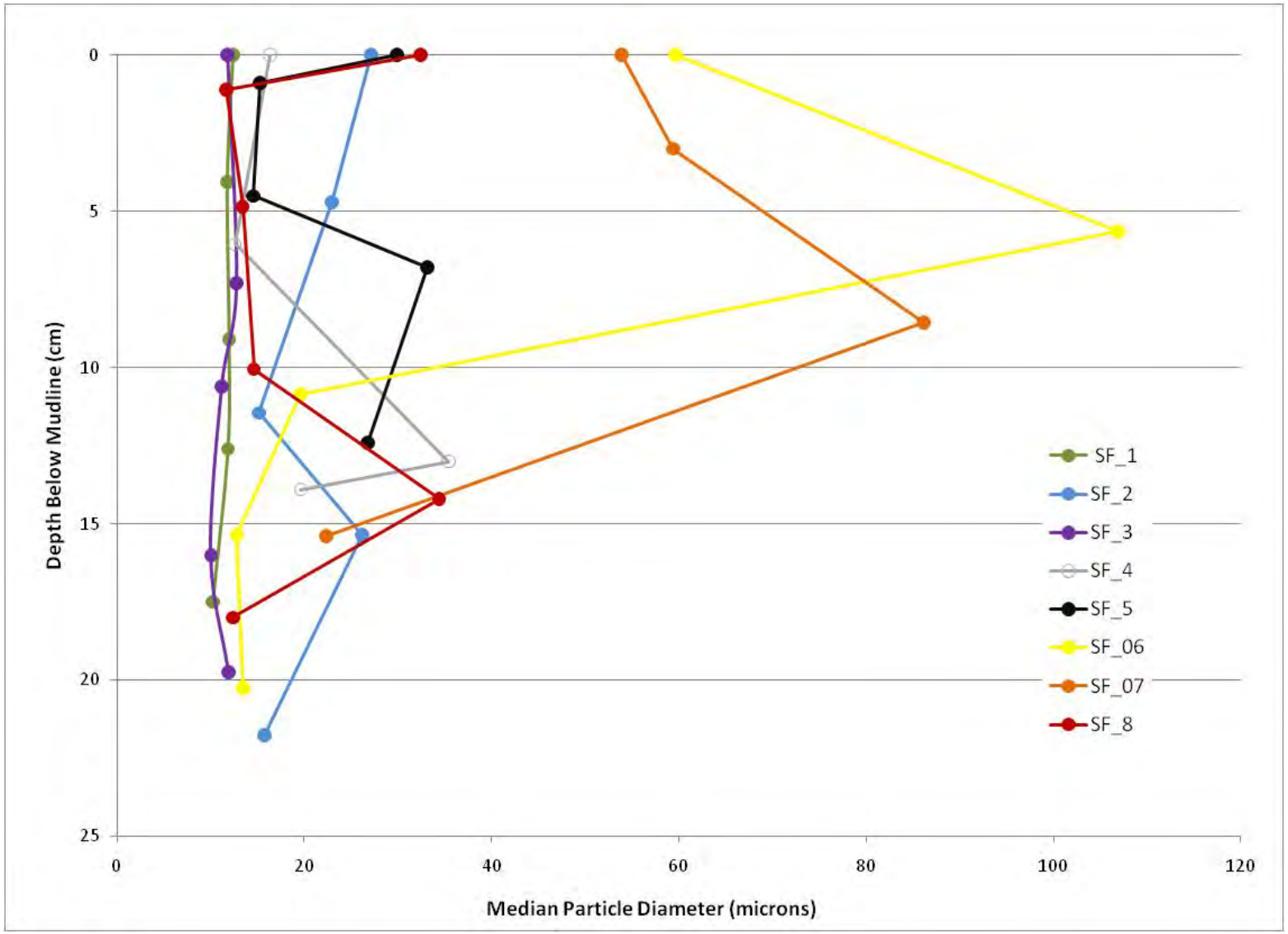


Figure 6-10
Median Particle Diameter (from Sedflume Cores) as a Function of Depth Below Mudline
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA

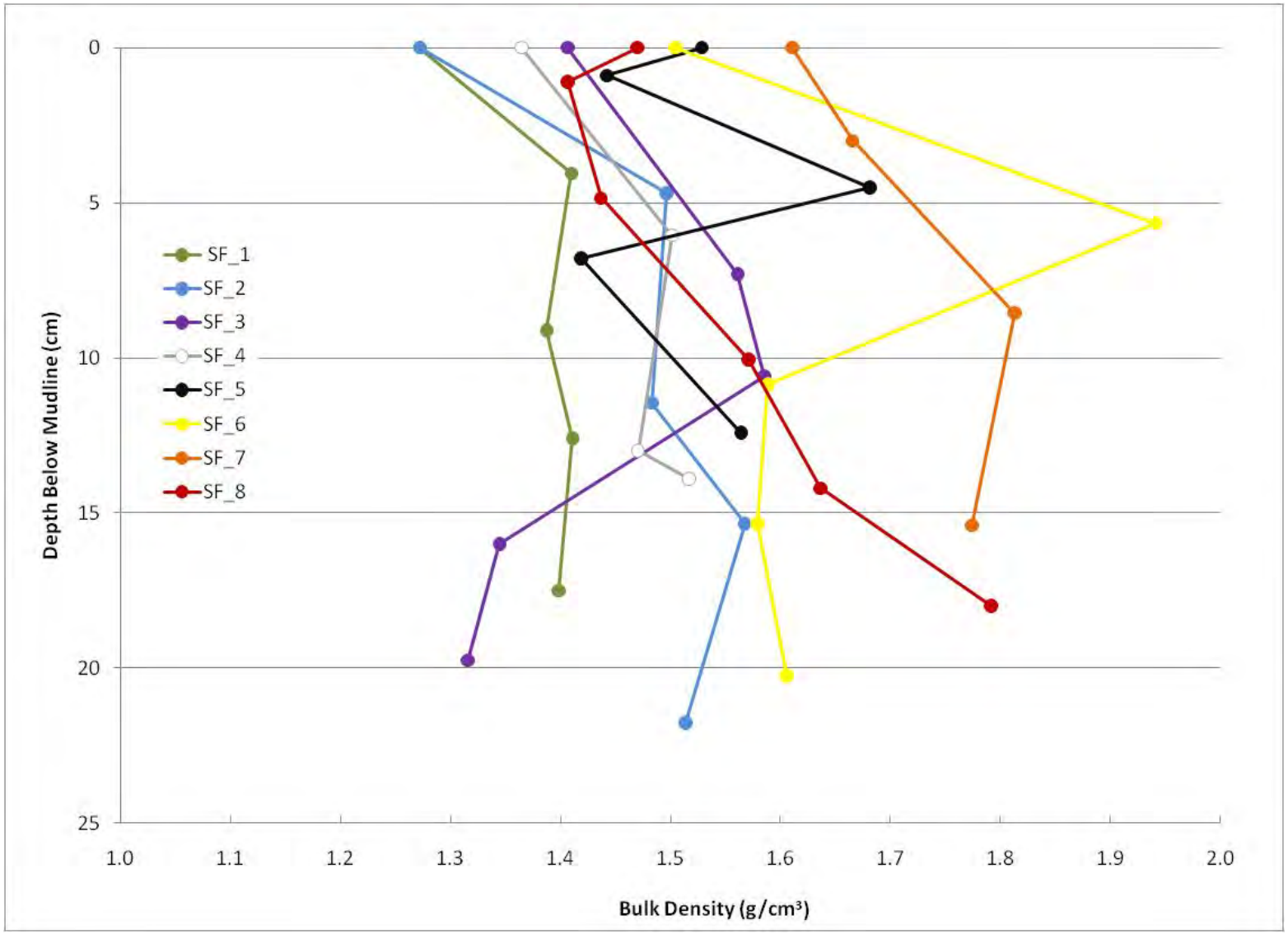
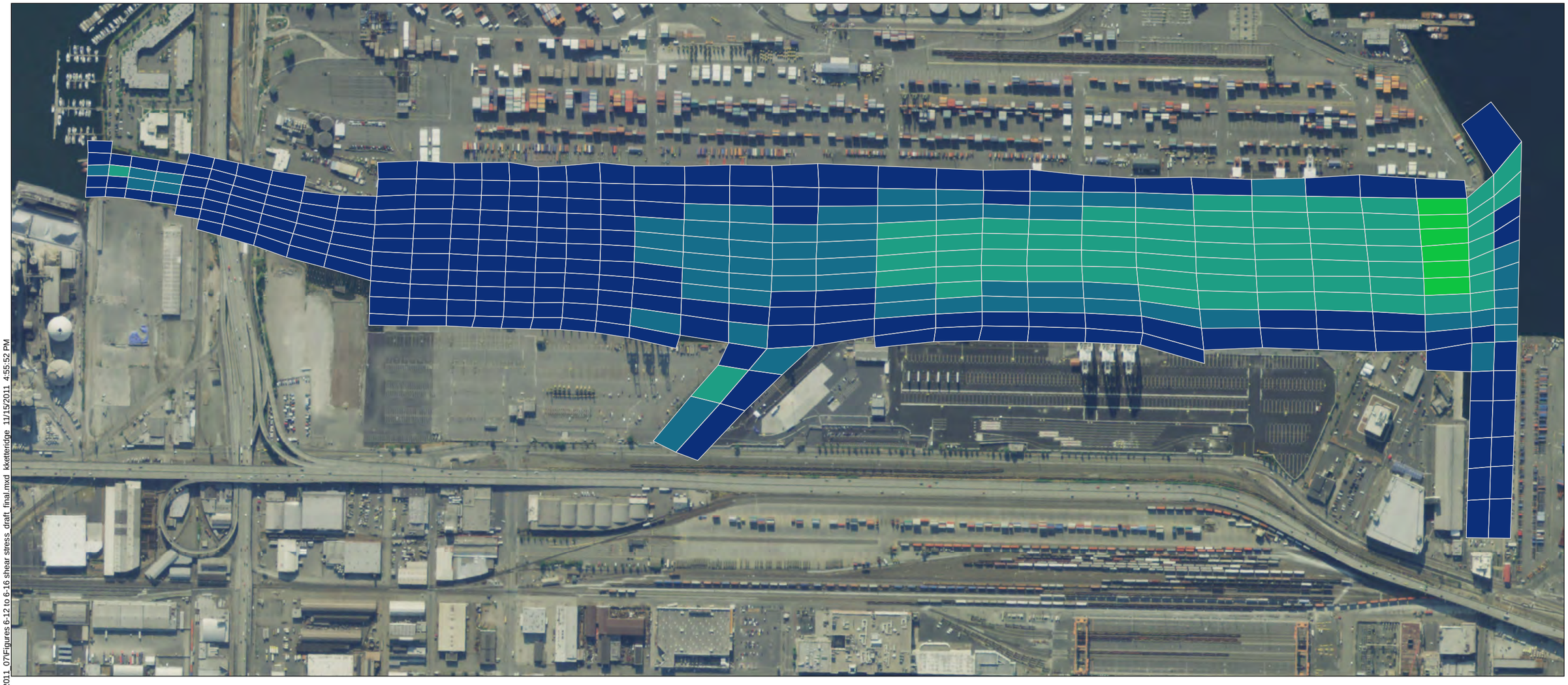


Figure 6-11
Bulk Density (from Sedflume Cores) as a Function of Depth Below Mudline
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA



NOTES:
1. Maximum shear stresses estimated from maximum bottom velocities over the entire 42 day hydrodynamic model simulation.
2. Bottom shear stresses calculated as described in Section 6.2 in the EW STER.
3. Critical shear stresses of surface sediments within the EW (evaluated from Sedflume Cores) are estimated to range between 0.20 and 37 Pa (see Section 6.1 in the EW STER).

Legend

EW Hydrodynamic Grid

Maximum Bottom Shear Stress (Pa)

0.00 - 0.01
0.01 - 0.02
0.02 - 0.04
0.04 - 0.06
0.06 - 0.08
0.08 0.09
0.90 - 0.10
0.10 - 0.11
0.11 - 0.12
0.12 - 0.13

Feet
0 250 500 750 1,000

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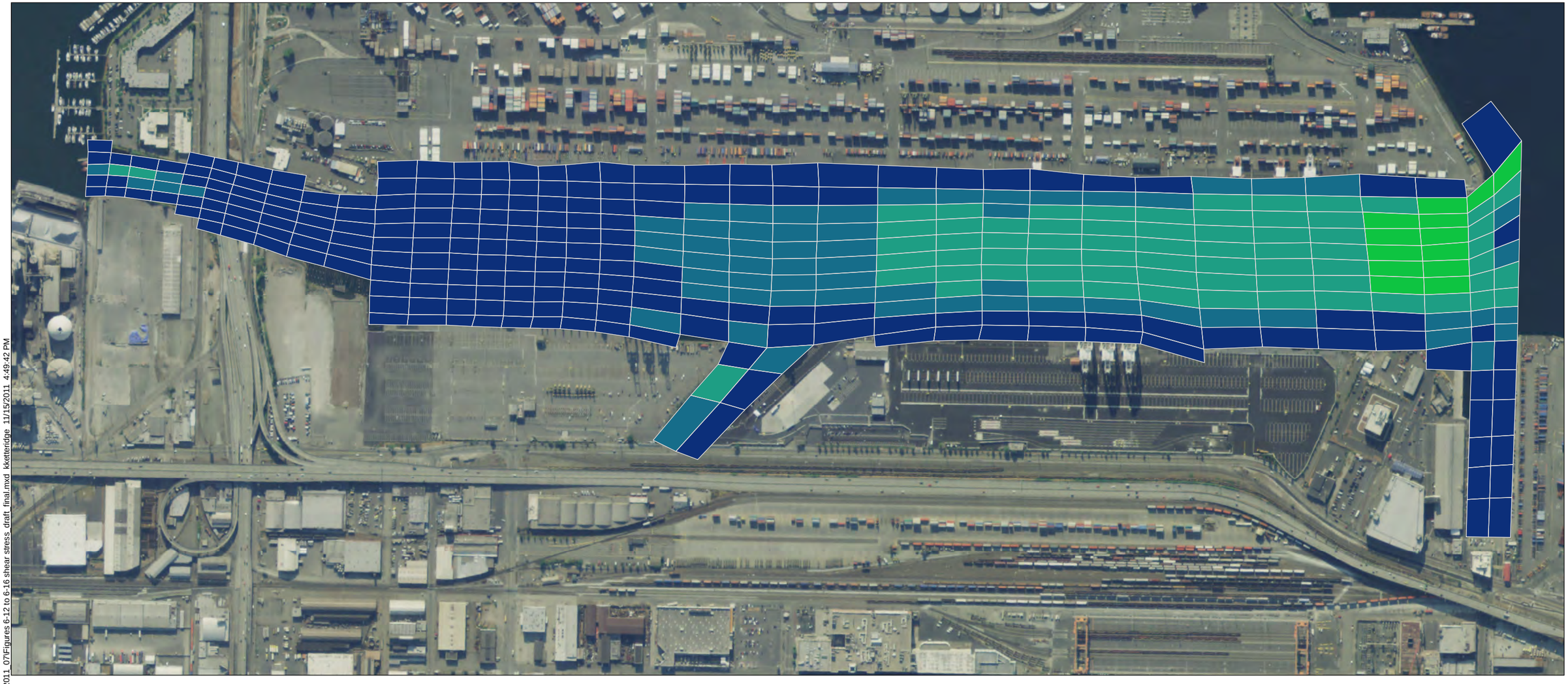
ANCHOR QEA

Figure 6-12
Maximum Bottom Shear Stress Estimated from Hydrodynamic Model Results - Mean Annual Year Flow
Sediment Transport Evaluation Report
East Waterway Opererable Unit



NOTES:
1. Maximum shear stresses estimated from maximum bottom velocities over the entire 42 day hydrodynamic model simulation.
2. Bottom shear stresses calculated as described in Section 6.2 in the EW STER.
3. Critical shear stresses of surface sediments within the EW (evaluated from Sedflume Cores) are estimated to range between 0.20 and 37 Pa (see Section 6.1 in the EW STER).

Legend

EW Hydrodynamic Grid

Maximum Bottom Shear Stress (Pa)

0.00 - 0.01
0.01 - 0.02
0.02 - 0.04
0.04 - 0.06
0.06 - 0.08
0.08 - 0.09
0.09 - 0.10
0.10 - 0.11
0.11 - 0.12
0.12 - 0.13

Feet
0 250 500 750 1,000

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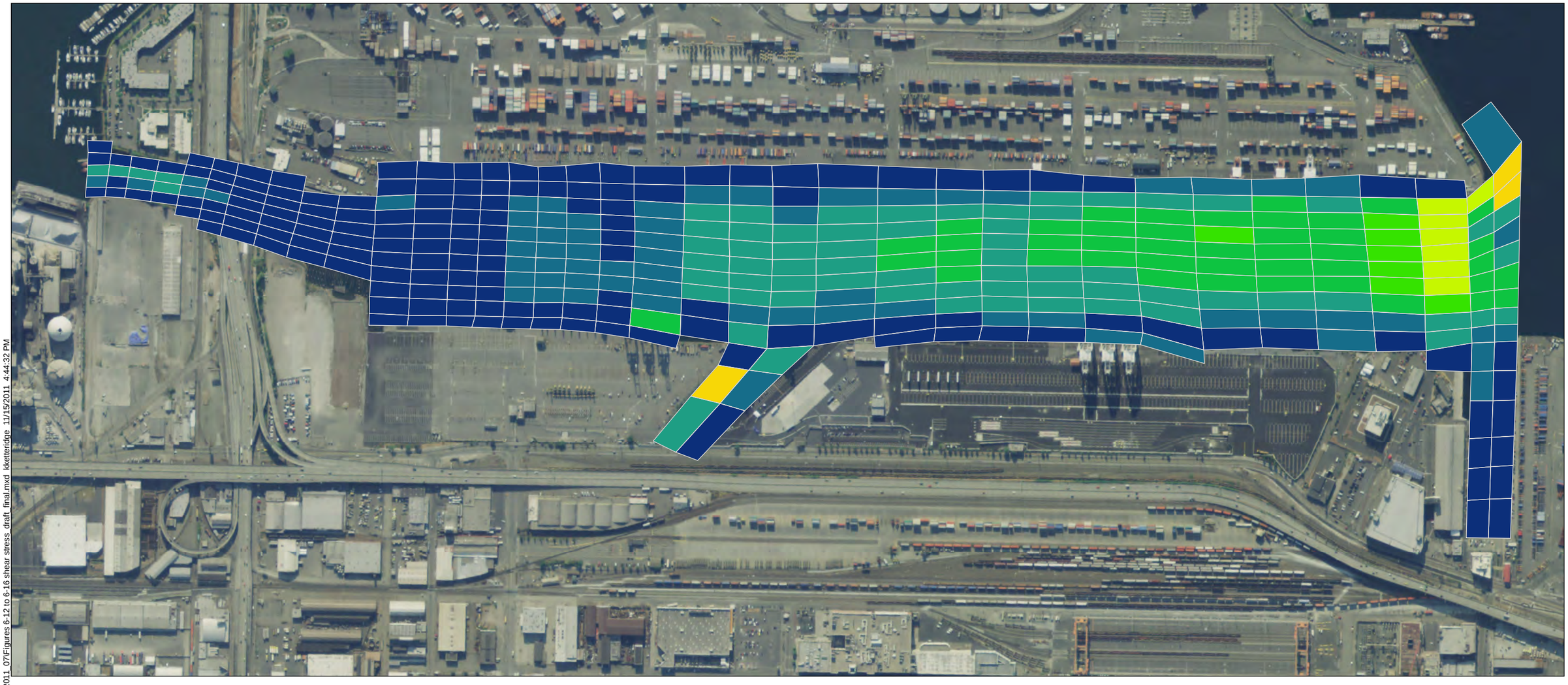
ANCHOR QEA

Figure 6-13
Maximum Bottom Shear Stress Estimated from Hydrodynamic Model Results - Mean Wet Annual Year Flow
Sediment Transport Evaluation Report
East Waterway Opererable Unit



NOTES:
1. Maximum shear stresses estimated from maximum bottom velocities over the entire 42 day hydrodynamic model simulation.
2. Bottom shear stresses calculated as described in Section 6.2 in the EW STER.
3. Critical shear stresses of surface sediments within the EW (evaluated from Sedflume Cores) are estimated to range between 0.20 and 0.37 Pa (see Section 6.1 in the EW STER).

Legend

EW Hydrodynamic Grid

Maximum Bottom Shear Stress (Pa)

0.00 - 0.01
0.01 - 0.02
0.02 - 0.04
0.04 - 0.06
0.06 - 0.08
0.08 - 0.09
0.09 - 0.10
0.10 - 0.11
0.11 - 0.12
0.12 - 0.13

Feet
0 250 500 750 1,000

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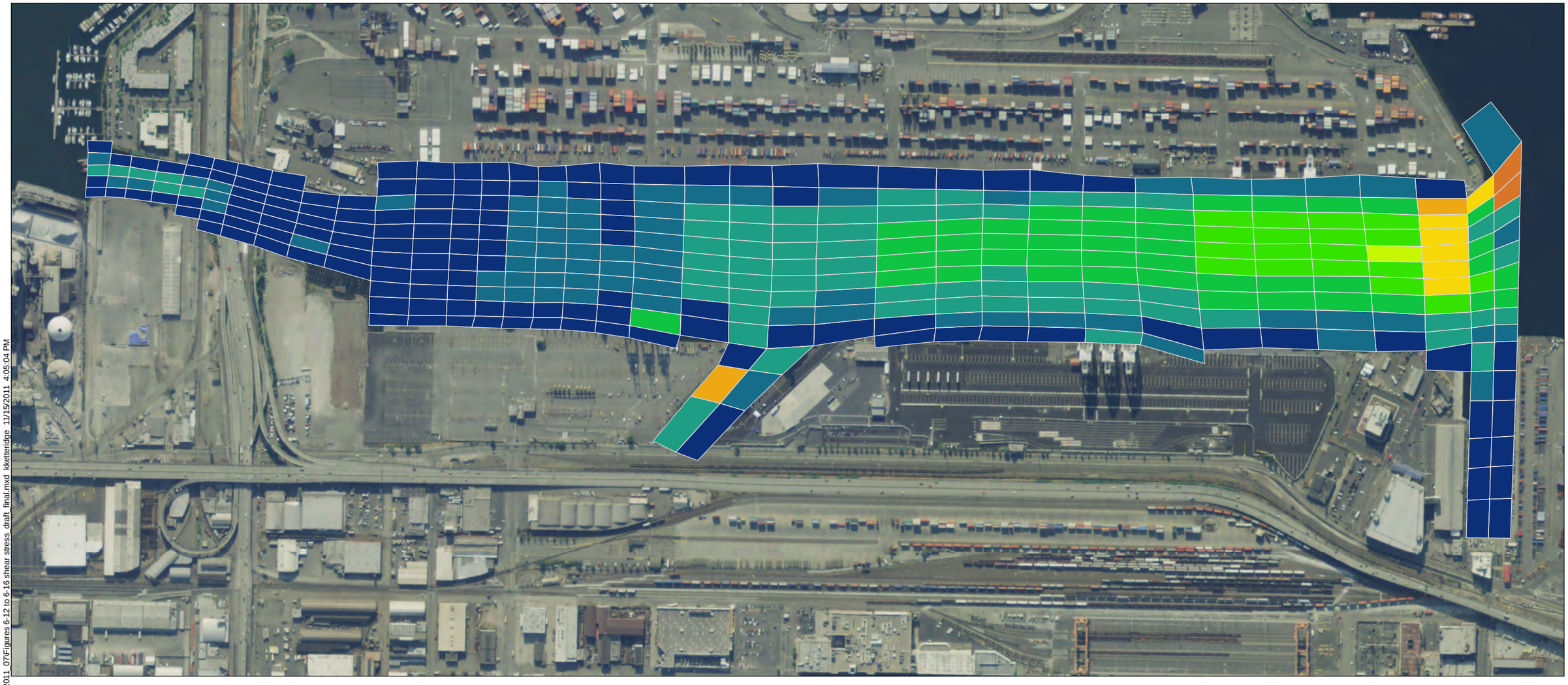
ANCHOR QEA

Figure 6-14
Maximum Bottom Shear Stress Estimated from Hydrodynamic Model Results - 2 Year Flow
Sediment Transport Evaluation Report
East Waterway Opererable Unit



NOTES:

1. Maximum shear stresses estimated from maximum bottom velocities over the entire 42 day hydrodynamic model simulation.
2. Bottom shear stresses calculated as described in Section 6.2 in the EW STER.
3. Critical shear stresses of surface sediments within the EW (evaluated from Sedflume Cores) are estimated to range between 0.20 and 0.37 Pa (see Section 6.1 in the EW STER).

Legend

EW Hydrodynamic Grid

Maximum Bottom Shear Stress (Pa)

0 - 0.01
0.01 - 0.02
0.02 - 0.04
0.04 - 0.06
0.06 - 0.08
0.08 - 0.90
0.90 - 0.10
0.10 -0.11
0.11 - 0.12
0.12 - 0.13

Feet
0 250 500 750 1,000

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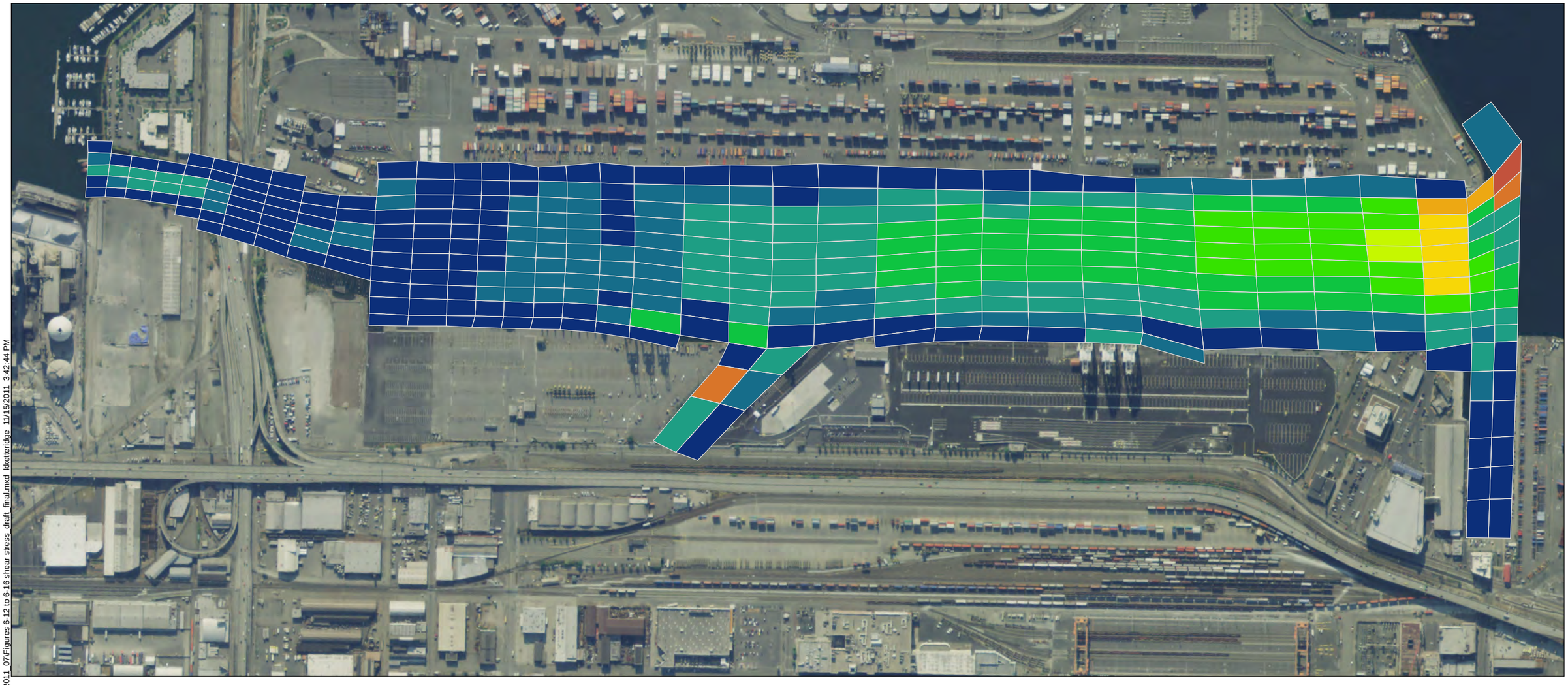
ANCHOR QEA

Figure 6-15
Maximum Bottom Shear Stress Estimated from Hydrodynamic Model Results - 10 Year Flow
Sediment Transport Evaluation Report
East Waterway Opererable Unit



NOTES:

1. Maximum shear stresses estimated from maximum bottom velocities over the entire 42 day hydrodynamic model simulation.
2. Bottom shear stresses calculated as described in Section 6.2 in the EW STER.
3. Critical shear stresses of surface sediments within the EW (evaluated from Sedflume Cores) are estimated to range between 0.20 and 37 Pa (see Section 6.1 in the EW STER).

Legend

EW Hydrodynamic Grid

Maximum Bottom Shear Stress (Pa)

0.00 - 0.01
0.01 - 0.02
0.02 - 0.04
0.04 - 0.06
0.06 - 0.08
0.08 - 0.09
0.09 - 0.10
0.10 - 0.11
0.11 - 0.12
0.12 - 0.13

Feet
0 250 500 750 1,000

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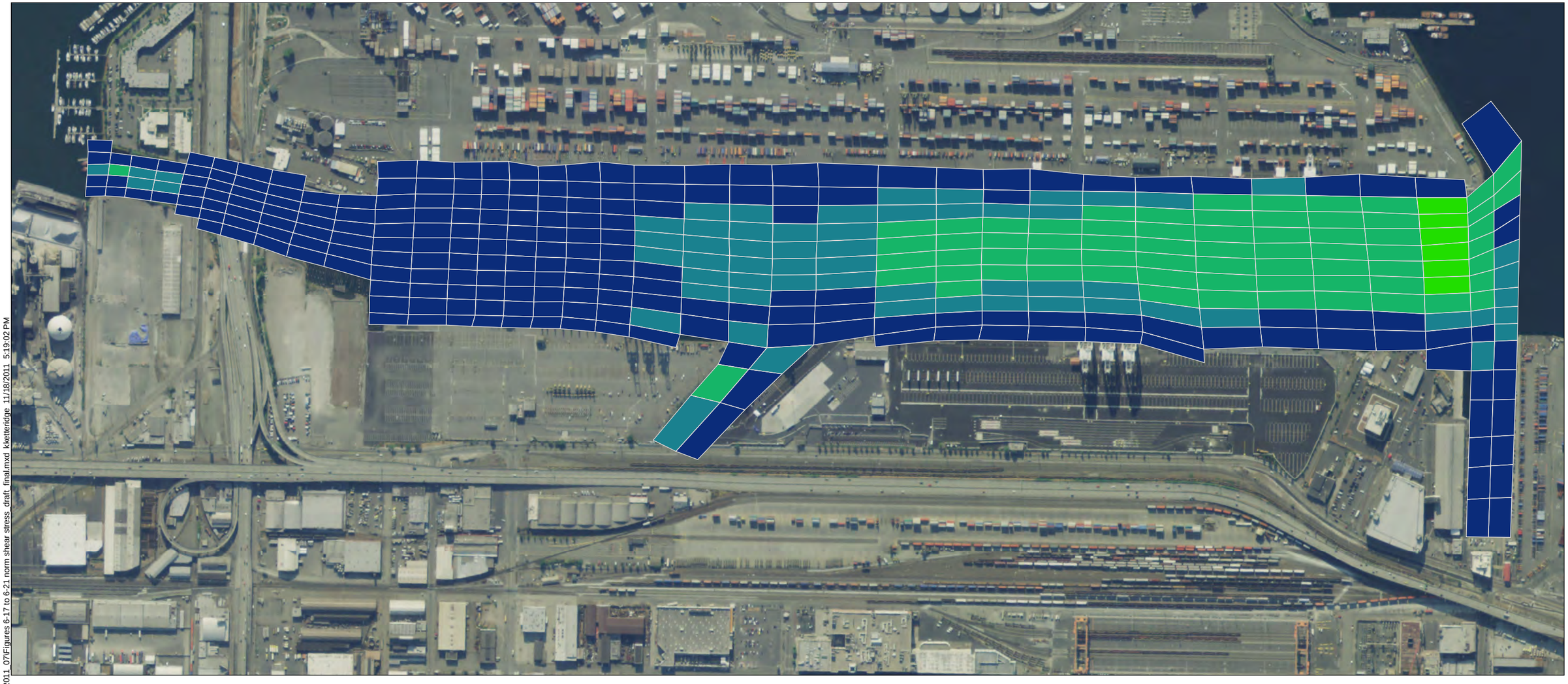
ANCHOR QEA

Figure 6-16
Maximum Bottom Shear Stress Estimated from Hydrodynamic Model Results - 100 Year Flow
Sediment Transport Evaluation Report
East Waterway Opererable Unit



NOTES:

1. Maximum shear stresses estimated from maximum bottom velocities over the entire 42 day hydrodynamic model simulation.
2. Bottom shear stresses calculated as described in Section 6.2 in the EW STER.
3. Critical shear stresses of surface sediments within the EW (evaluated from Sedflume Cores) are estimated to range between 0.20 and 0.37 Pa (see Section 6.1 in the EW STER).
4. Maximum shear stress normalized by lower bound of critical shear stress range (0.20 Pa).

Legend

EW Hydrodynamic Grid

Normalized Maximum Bottom Shear Stress

0.00 - 0.05
0.05 - 0.10
0.11 - 0.20
0.21 - 0.30
0.31 - 0.40
0.41 - 0.50
0.51 - 0.60
0.61 - 0.70

Feet
0 250 500 750 1,000

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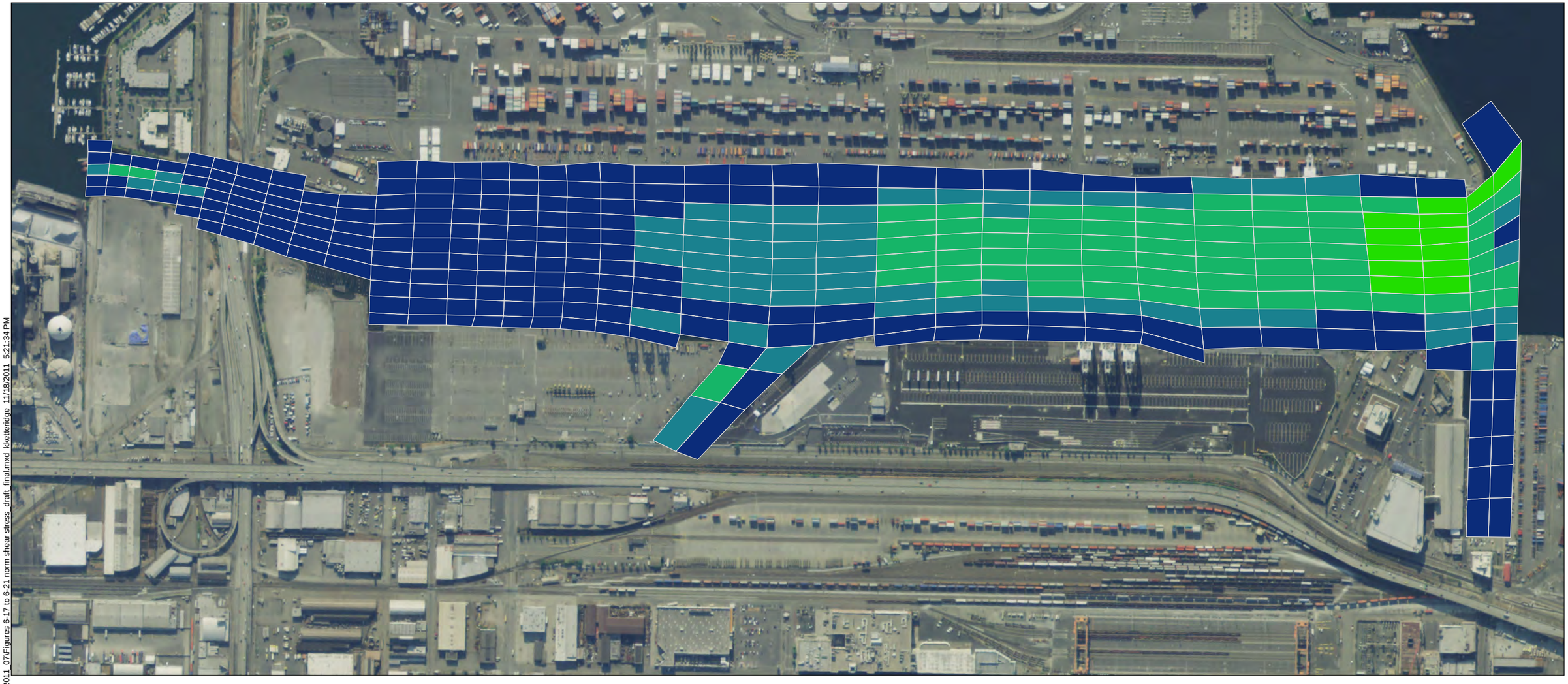
ANCHOR QEA

Figure 6-17

Normalized (by critical shear stress of bed sediments) Maximum Bottom Shear Stress Estimated from Hydrodynamic Model Results - Annual Mean Flow
Sediment Transport Evaluation Report
East Waterway Opererable Unit



NOTES:

1. Maximum shear stresses estimated from maximum bottom velocities over the entire 42 day hydrodynamic model simulation.
2. Bottom shear stresses calculated as described in Section 6.2 in the EW STER.
3. Critical shear stresses of surface sediments within the EW (evaluated from Sedflume Cores) are estimated to range between 0.20 and 37 Pa (see Section 6.1 in the EW STER).
4. Maximum shear stress normalized by lower bound of critical shear stress range (0.20 Pa).

Legend

EW Hydrodynamic Grid

Normalized Maximum Bottom Shear Stress

0.00 - 0.05
0.05 - 0.10
0.11 - 0.20
0.21 - 0.30
0.31 - 0.40
0.41 - 0.50
0.51 - 0.60
0.61 - 0.70

Feet
0 250 500 750 1,000

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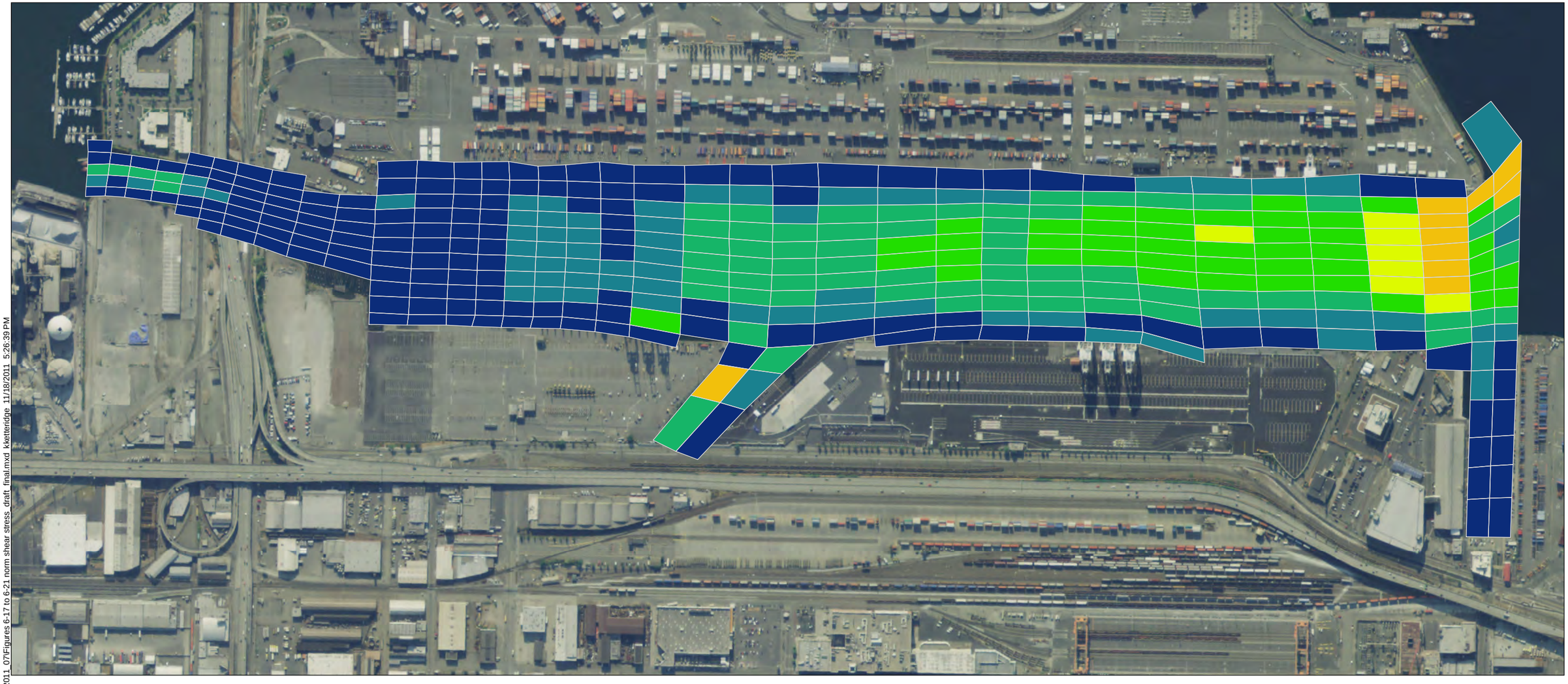
ANCHOR QEA

Figure 6-18

Normalized (by critical shear stress of bed sediments) Maximum Bottom Shear Stress Estimated from Hydrodynamic Model Results - Annual Wet Mean Flow
Sediment Transport Evaluation Report
East Waterway Opererable Unit



NOTES:

1. Maximum shear stresses estimated from maximum bottom velocities over the entire 42 day hydrodynamic model simulation.
2. Bottom shear stresses calculated as described in Section 6.2 in the EW STER.
3. Critical shear stresses of surface sediments within the EW (evaluated from Sedflume Cores) are estimated to range between 0.20 and 0.37 Pa (see Section 6.1 in the EW STER).
4. Maximum shear stress normalized by lower bound of critical shear stress range (0.20 Pa).

Legend

EW Hydrodynamic Grid

Normalized Maximum Bottom Shear Stress

0.00 - 0.05
0.05 - 0.10
0.11 - 0.20
0.21 - 0.30
0.31 - 0.40
0.41 - 0.50
0.51 - 0.60
0.61 - 0.71

Feet
0 250 500 750 1,000

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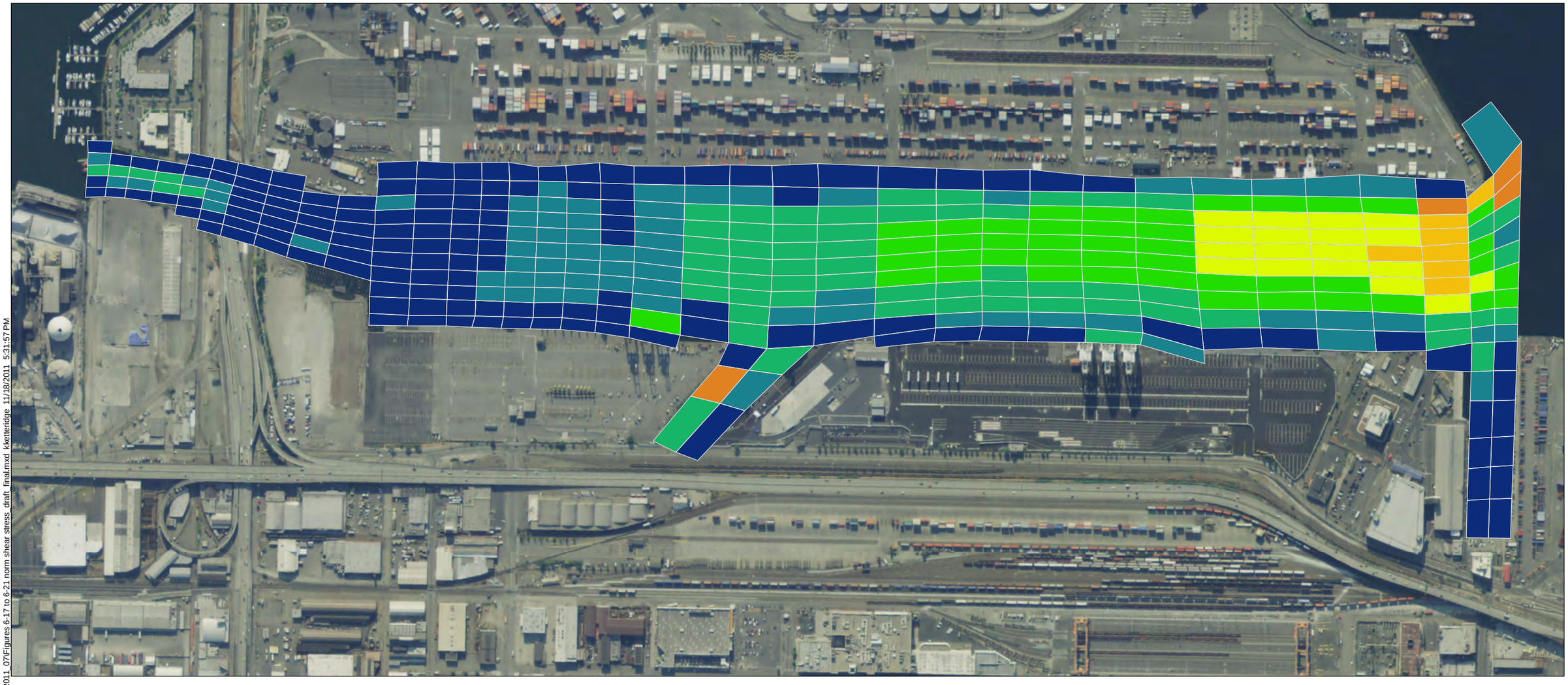
ANCHOR QEA

Figure 6-19

Normalized (by critical shear stress of bed sediments) Maximum Bottom Shear Stress Estimated from Hydrodynamic Model Results - 2-Year Flow
Sediment Transport Evaluation Report
East Waterway Opererable Unit



NOTES:

1. Maximum shear stresses estimated from maximum bottom velocities over the entire 42 day hydrodynamic model simulation.
2. Bottom shear stresses calculated as described in Section 6.2 in the EW STER.
3. Critical shear stresses of surface sediments within the EW (evaluated from Sedflume Cores) are estimated to range between 0.20 and 0.37 Pa (see Section 6.1 in the EW STER).
4. Maximum shear stress normalized by lower bound of critical shear stress range (0.20 Pa).

Legend

EW Hydrodynamic Grid

Normalized Maximum Bottom Shear Stress

0.00 - 0.05
0.05 - 0.10
0.11 - 0.20
0.21 - 0.30
0.31 - 0.40
0.41 - 0.50
0.51 - 0.60
0.61 - 0.70

Feet
0 250 500 750 1,000

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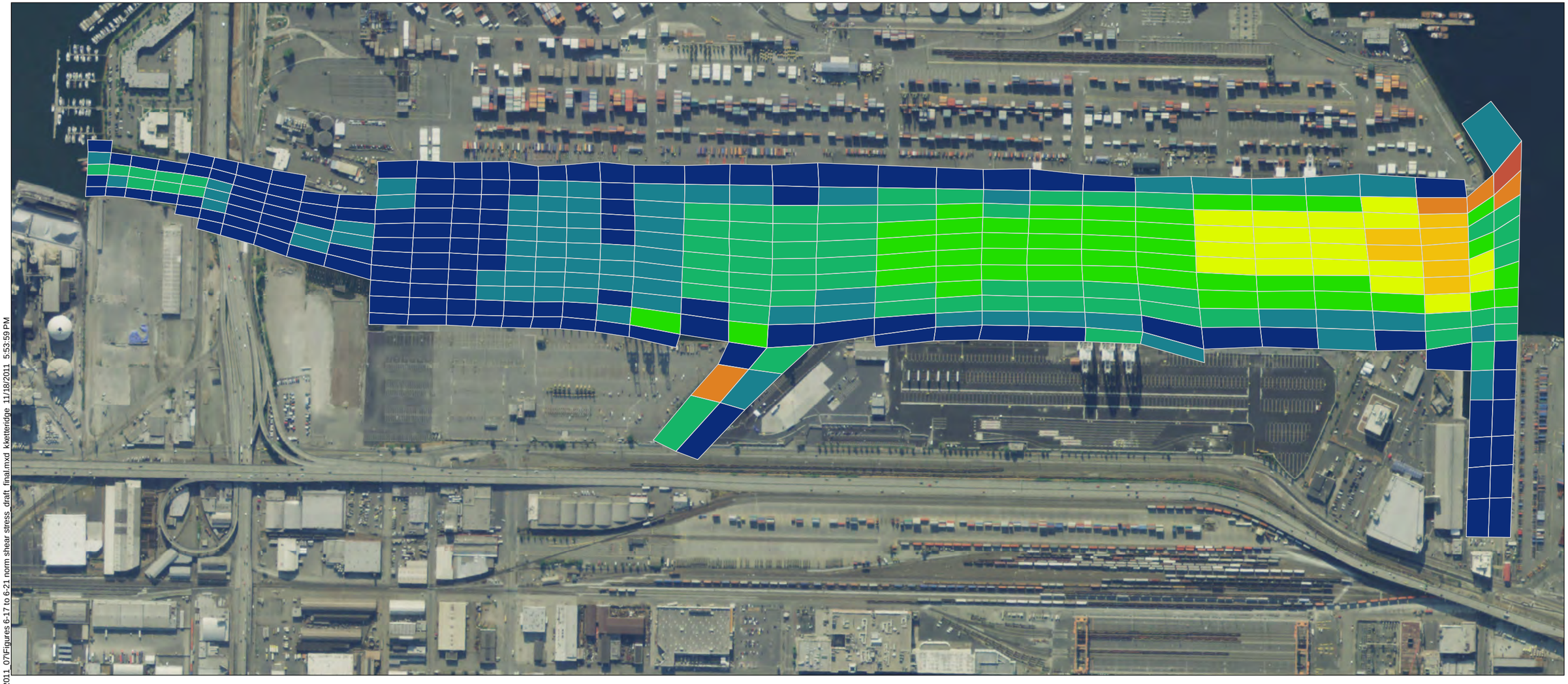
ANCHOR QEA

Figure 6-20

Normalized (by critical shear stress of bed sediments) Maximum Bottom Shear Stress Estimated from Hydrodynamic Model Results - 10-Year Flow

Sediment Transport Evaluation Report

East Waterway Opererable Unit



NOTES:

1. Maximum shear stresses estimated from maximum bottom velocities over the entire 42 day hydrodynamic model simulation.
2. Bottom shear stresses calculated as described in Section 6.2 in the EW STER.
3. Critical shear stresses of surface sediments within the EW (evaluated from Sedflume Cores) are estimated to range between 0.20 and 0.37 Pa (see Section 6.1 in the EW STER).
4. Maximum shear stress normalized by lower bound of critical shear stress range (0.20 Pa).

Legend

EW Hydrodynamic Grid

Normalized Maximum Bottom Shear Stress

0.00 - 0.05
0.05 - 0.10
0.11 - 0.20
0.21 - 0.30
0.31 - 0.40
0.41 - 0.50
0.51 - 0.60
0.61 - 0.70

Feet
0 250 500 750 1,000

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ANCHOR QEA

Figure 6-21

Normalized (by critical shear stress of bed sediments) Maximum Bottom Shear Stress Estimated from Hydrodynamic Model Results - 100-Year Flow
Sediment Transport Evaluation Report
East Waterway Opererable Unit

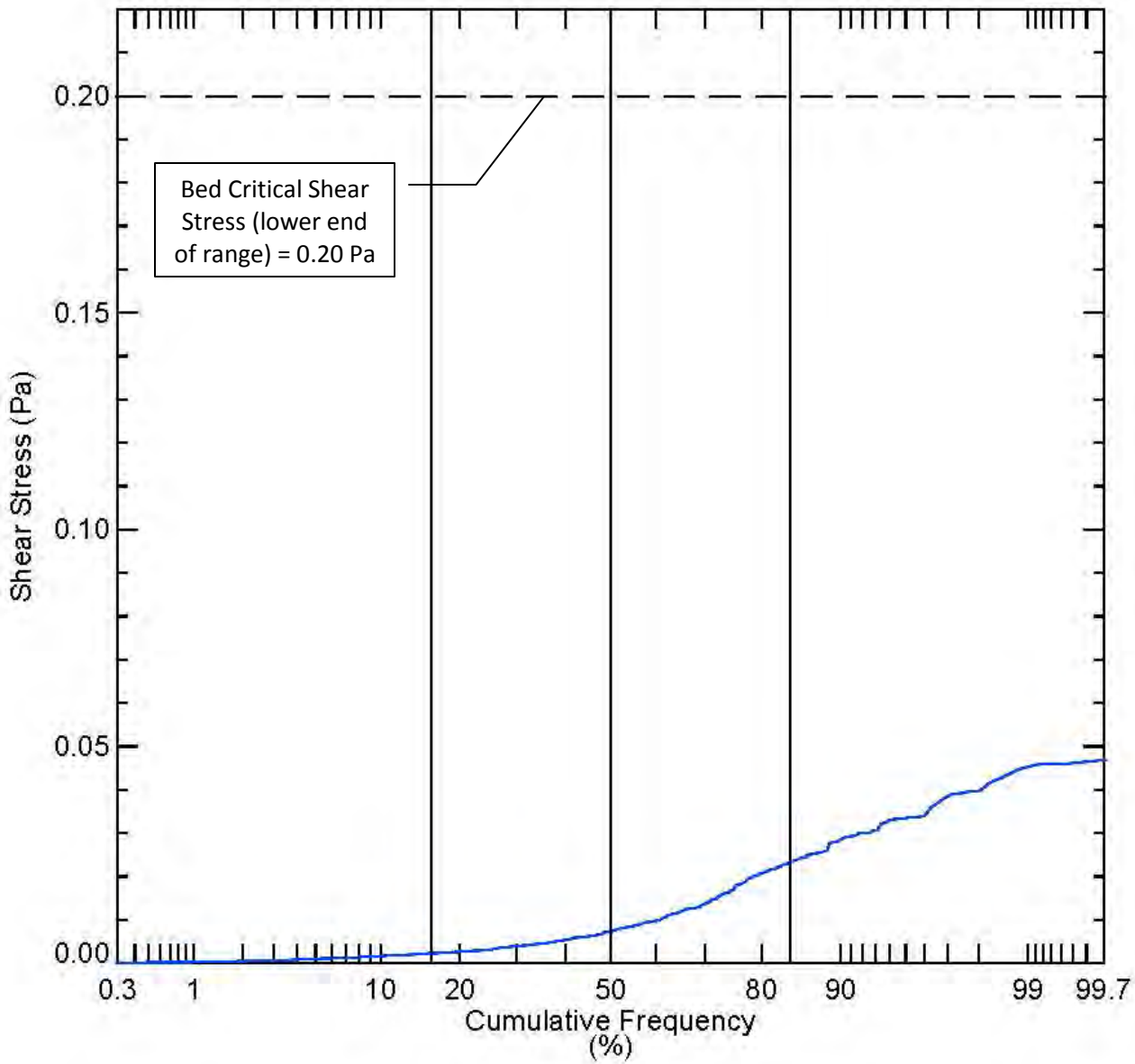


Figure 6-22

Cumulative Frequency Distribution of Maximum Bed Shear Stress from Hydro. Model Results - Mean Annual Flow

Sediment Transport Evaluation Report

East Waterway Operable Unit

ANCHOR QEA

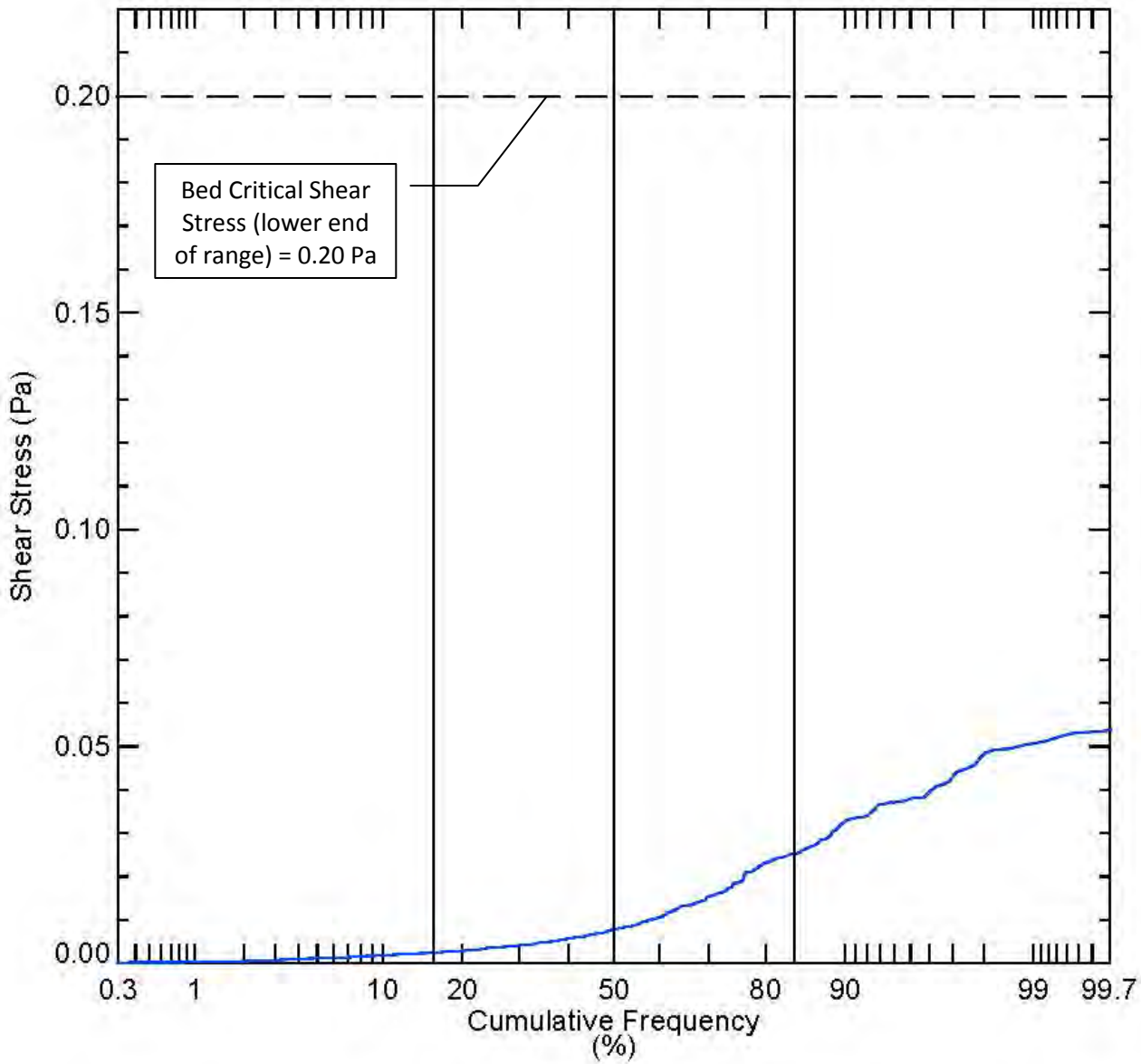


Figure 6-23

Cumulative Frequency Distribution of Maximum Bed Shear Stress from Hydro. Model Results - Mean Wet Annual Flow

Sediment Transport Evaluation Report

East Waterway Operable Unit

ANCHOR QEA

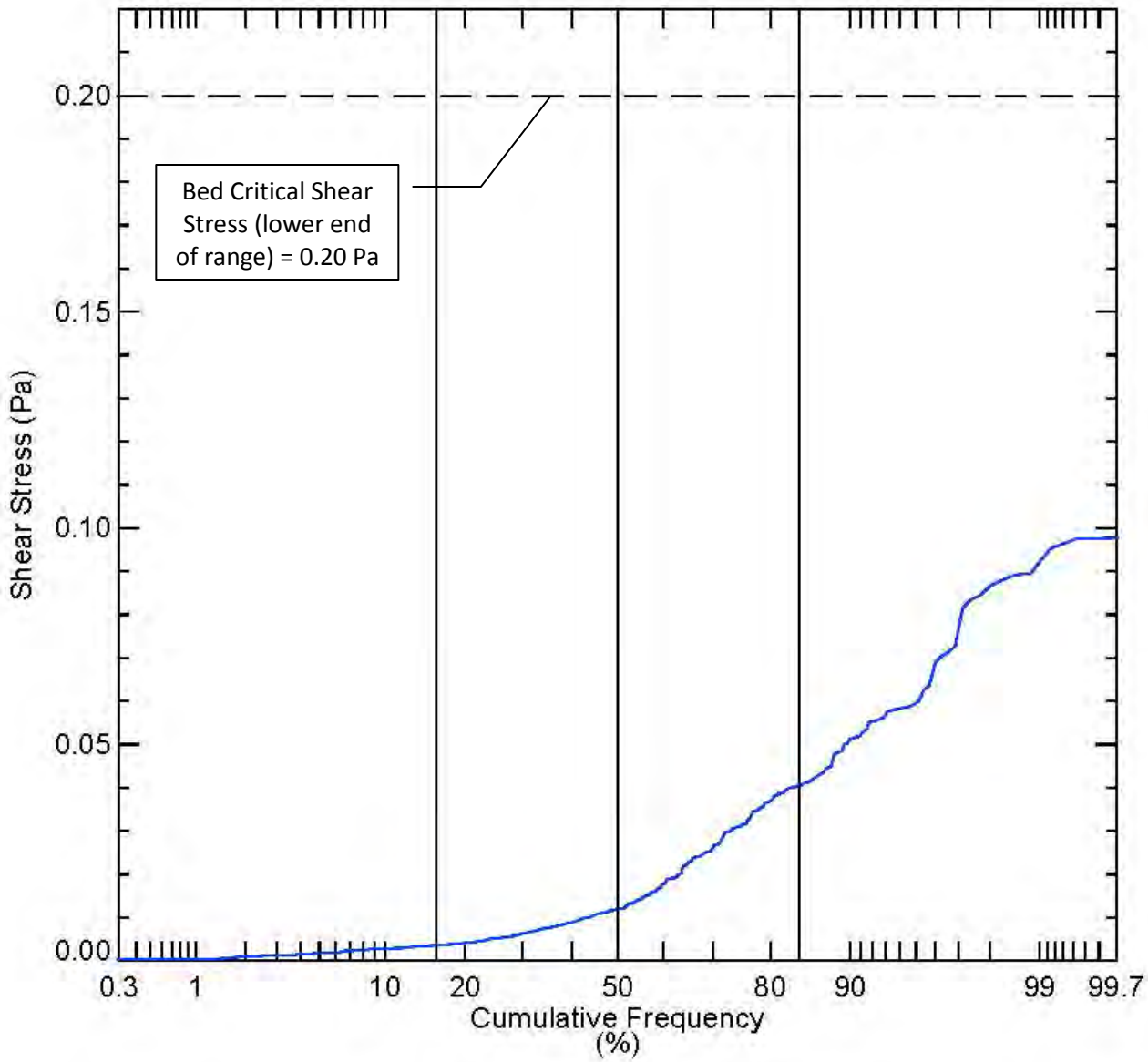


Figure 6-24

Cumulative Frequency Distribution of Maximum Bed Shear Stress from Hydro. Model Results - 2-Year Flow

Sediment Transport Evaluation Report

East Waterway Operable Unit

ANCHOR QEA

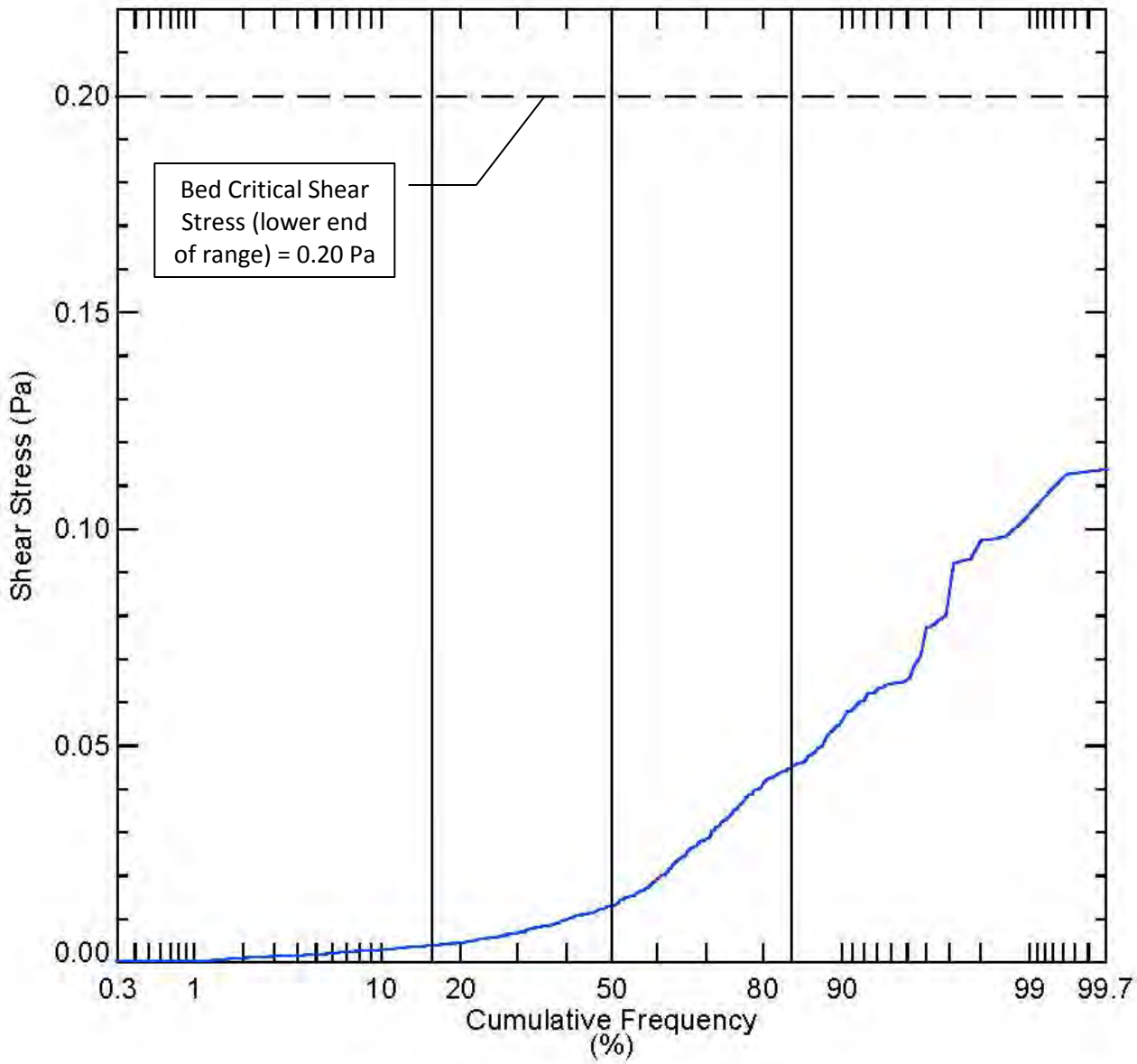


Figure 6-25

Cumulative Frequency Distribution of Maximum Bed Shear Stress from Hydro. Model Results - 10-Year Flow

Sediment Transport Evaluation Report

East Waterway Operable Unit

ANCHOR QEA

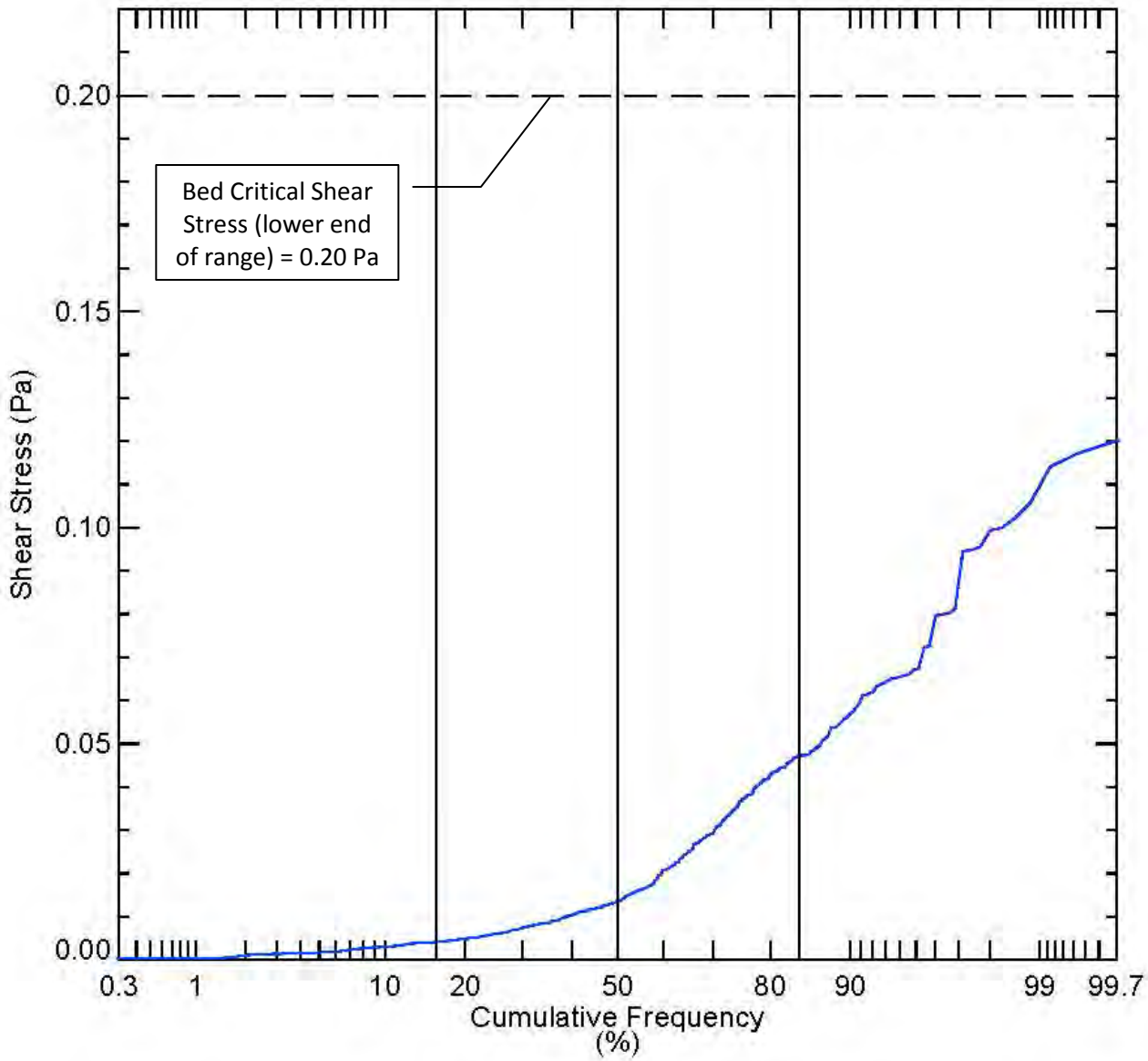


Figure 6-26

Cumulative Frequency Distribution of Maximum Bed Shear Stress from Hydro. Model Results - 100-Year Flow

Sediment Transport Evaluation Report

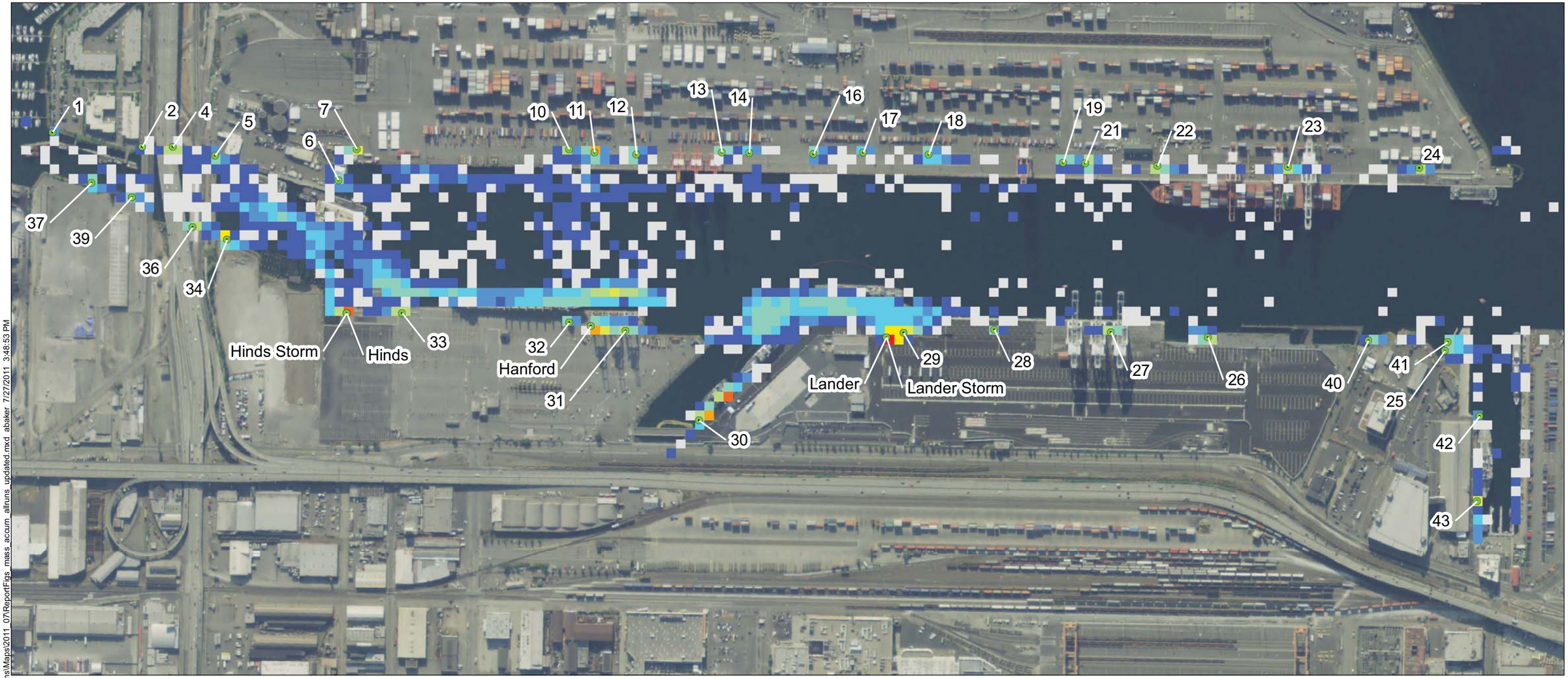
East Waterway Operable Unit

ANCHOR QEA

R:\Jobs\060003-01_East_Waterway_SedTrans\Maps\2011_05\Figure 7-1 EFDC vs ADCIRC grid.mxd kketerridge 6/8/2011 4:07:07 PM

ANCHOR QEA

Figure 7-1
Comparison of EFDC and ADCIRC Grids within the EW
Sediment Transport Evaluation Report
East Waterway Operable Unit



LEGEND

- PTM Outfall Locations

Mass Accumulation (kg)

0.5 | 0.6 - 2.5 | 2.6 - 5 | 5.1 - 10 | 10.1 - 25 | 25.1 - 50 | 50.1 - 75 | 75.1 - 100 | 100.1 - 250 | 250.1 - 500 | 1,293.4

Feet

0 250 500 750 1,000

NOTES:

1. Deposition data (points) output from PTM model simulation has been represented by a 50 ft x 50 ft resolution raster map of mass accumulation (kg)
2. Mass accumulation represents deposition over the simulation time (1 month with sources included, 2 weeks with sources turned off, for a total of 42 days).
3. Lander, Hanford, and Hines are CSOs.
4. Outfall numbers (names) coorespond to drainage basins.

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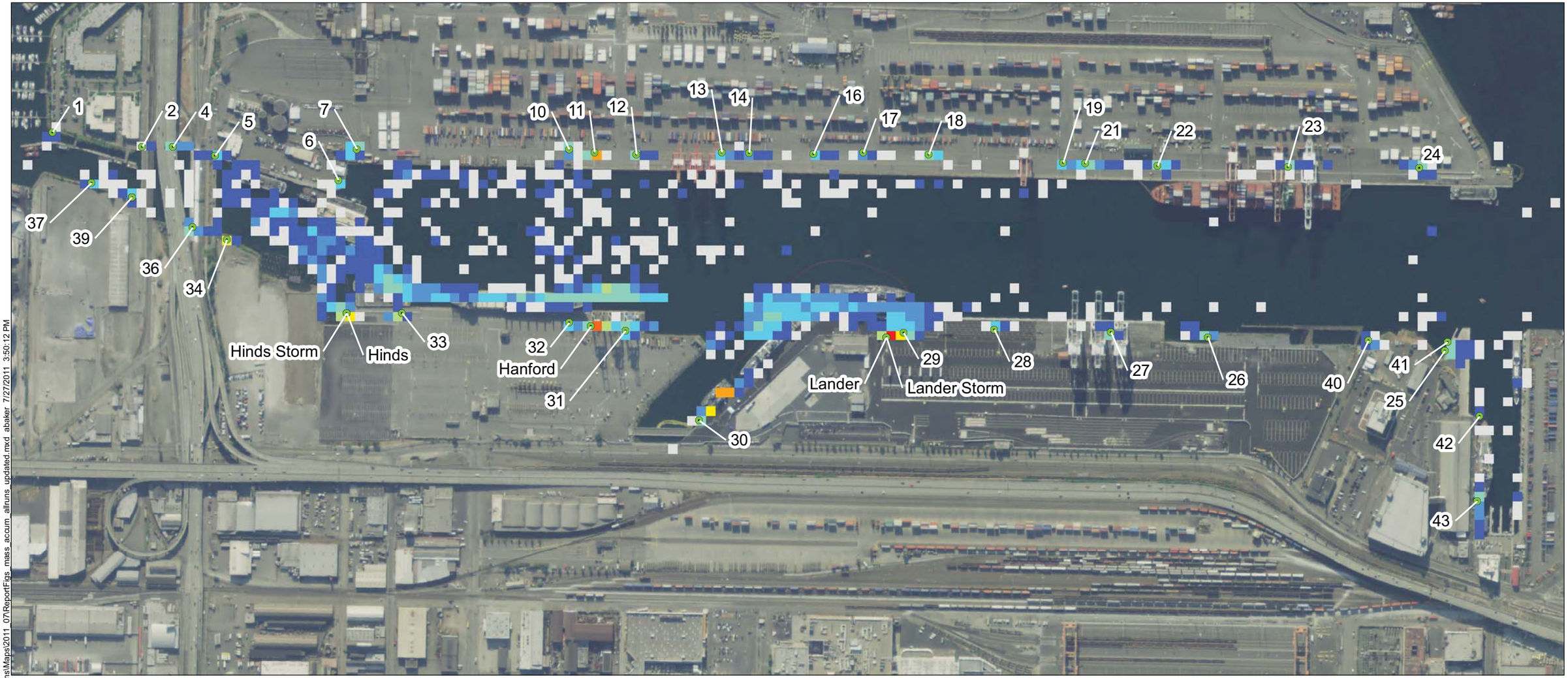
ANCHOR QEA

Figure 7-2
PTM Model Simulation 1 (Base Case) - Mass Accumulation during Simulation Period (kg)
Sediment Transport Evaluation Report
East Waterway Operable Unit



LEGEND

- PTM Outfall Locations

Mass Accumulation (kg)

0.5 | 0.6 - 2.5 | 2.6 - 5 | 5.1 - 10 | 10.1 - 25 | 25.1 - 43.8 | 43.9 - 74.4 | 74.5 - 97.4 | 97.5 - 186.6 | 186.7 - 500 | 650.7

Feet

0 250 500 750 1,000

NOTES:

1. Deposition data (points) output from PTM model simulation has been represented by a 50 ft x 50 ft resolution raster map of mass accumulation (kg)
2. Mass accumulation represents deposition over the simulation time (1 month with sources included, 2 weeks with sources turned off, for a total of 42 days).
3. Lander, Hanford, and Hines are CSOs.
4. Outfall numbers (names) coorespond to drainage basins.

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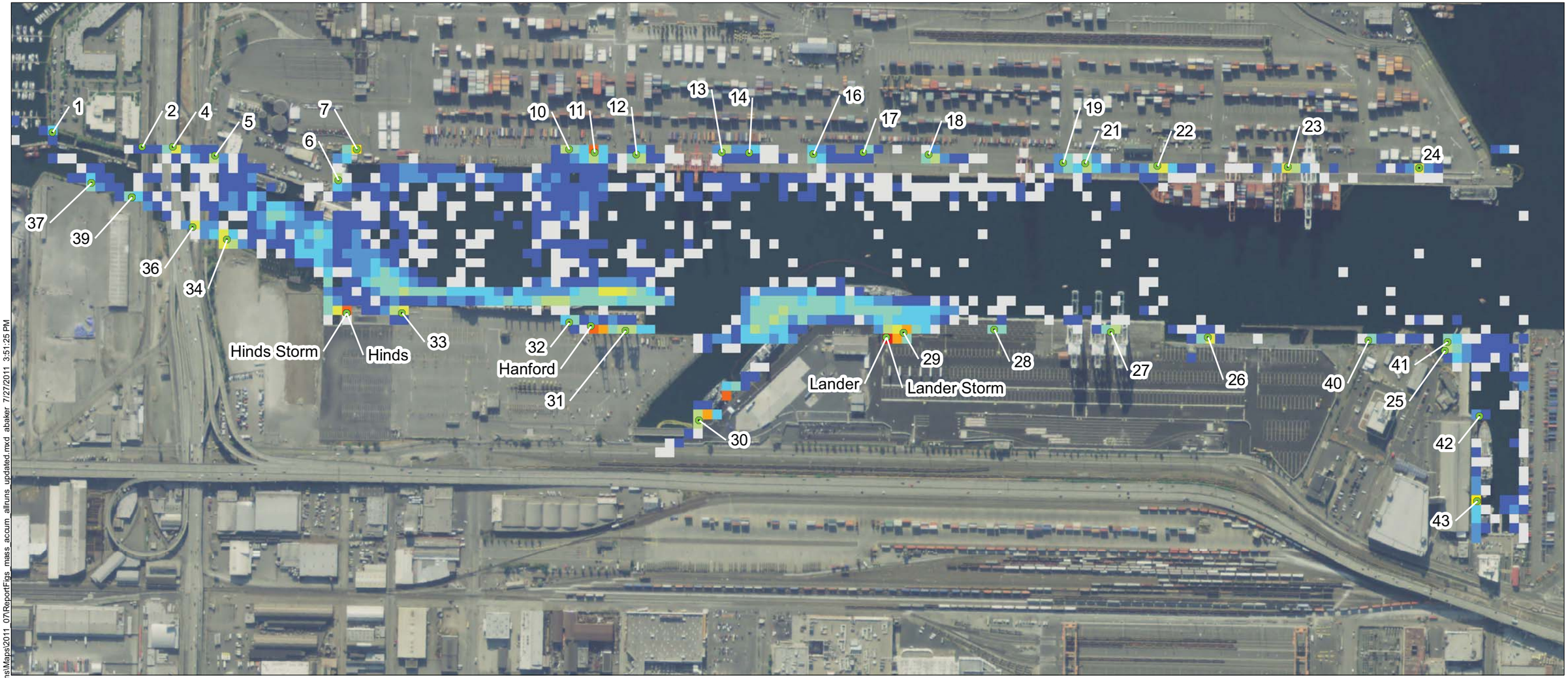
Figure 7-3
PTM Model Simulation 4 (25% TSS Values) - Mass Accumulation during Simulation Period (kg)
Sediment Transport Evaluation Report
East Waterway Operable Unit



LEGEND

- PTM Outfall Locations

Mass Accumulation (kg)

0.5 | 0.6 - 2.5 | 2.6 - 5 | 5.1 - 10 | 10.1 - 25 | 25.1 - 50 | 50.1 - 75 | 75.1 - 100 | 100.1 - 250 | 250.1 - 500 | 1,678

Feet
0 250 500 750 1,000

NOTES:
1. Deposition data (points) output from PTM model simulation has been represented by a 50 ft x 50 ft resolution raster map of mass accumulation (kg)
2. Mass accumulation represents deposition over the simulation time (1 month with sources included, 2 weeks with sources turned off, for a total of 42 days).
3. Lander, Hanford, and Hines are CSOs.
4. Outfall numbers (names) coorespond to drainage basins.

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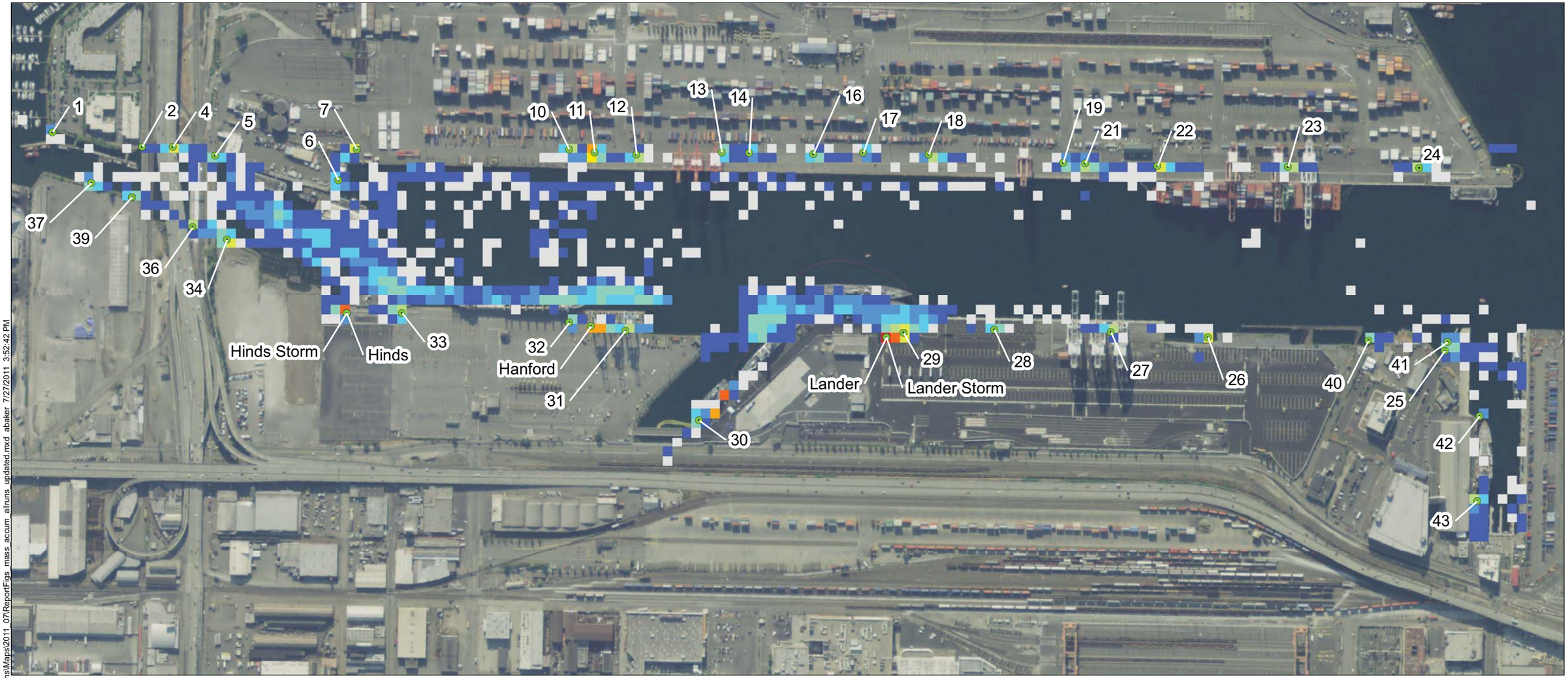
Figure 7-4
PTM Model Simulation 5 (75% TSS Values) - Mass Accumulation during Simulation Period (kg)
Sediment Transport Evaluation Report
East Waterway Operable Unit



LEGEND

- PTM Outfall Locations

Mass Accumulation (kg)

0.5 | 0.6 - 2.5 | 2.6 - 5 | 5.1 - 10 | 10.1 - 25 | 25.1 - 50 | 50.1 - 75 | 75.1 - 100 | 100.1 - 250 | 250.1 - 500 | 1,293.4

Feet
0 250 500 750 1,000

NOTES:
1. Deposition data (points) output from PTM model simulation has been represented by a 50 ft x 50 ft resolution raster map of mass accumulation (kg)
2. Mass accumulation represents deposition over the simulation time (1 month with sources included, 2 weeks with sources turned off, for a total of 42 days).
3. Lander, Hanford, and Hines are CSOs.
4. Outfall numbers (names) coorespond to drainage basins.

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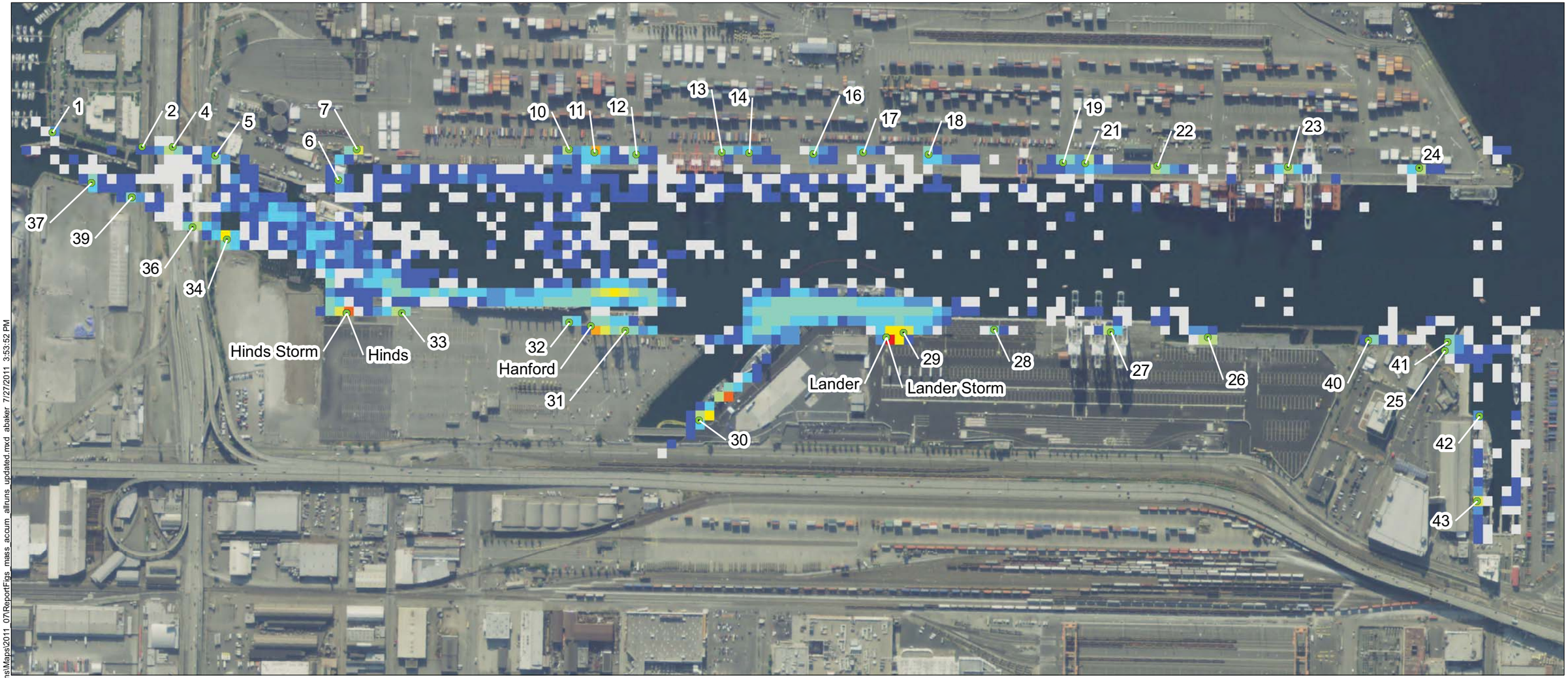
Figure 7-5
PTM Model Simulation 7 (Smaller median diameters of silt and clay fractions) - Mass Accumulation during Simulation Period (kg)
Sediment Transport Evaluation Report
East Waterway Operable Unit



LEGEND

- PTM Outfall Locations

Mass Accumulation (kg)

0.5 | 0.6 - 2.5 | 2.6 - 5 | 5.1 - 10 | 10.1 - 25 | 25.1 - 50 | 50.1 - 75 | 75.1 - 100 | 100.1 - 250 | 250.1 - 500 | 1,293.4

Feet
0 250 500 750 1,000

NOTES:
1. Deposition data (points) output from PTM model simulation has been represented by a 50 ft x 50 ft resolution raster map of mass accumulation (kg)
2. Mass accumulation represents deposition over the simulation time (1 month with sources included, 2 weeks with sources turned off, for a total of 42 days).
3. Lander, Hanford, and Hines are CSOs.
4. Outfall numbers (names) coorespond to drainage basins.

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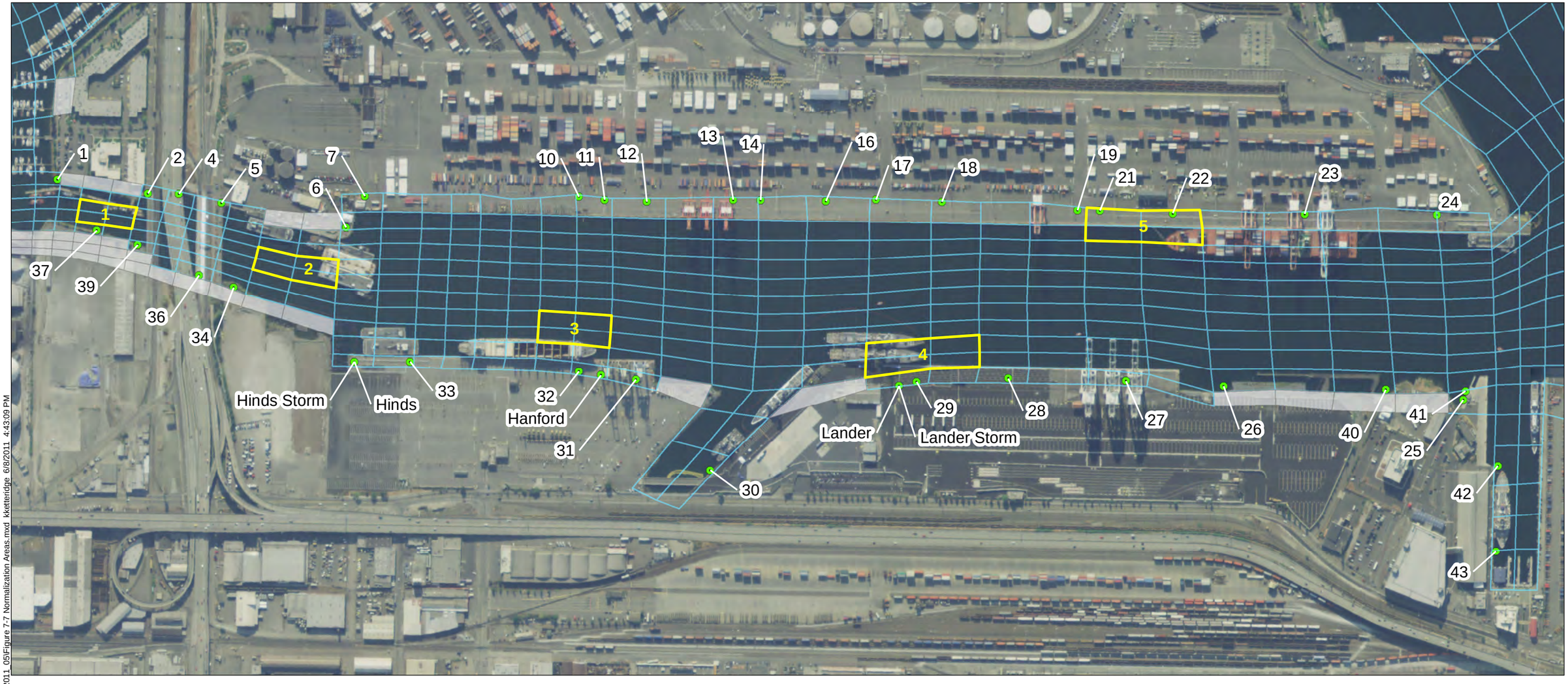
Figure 7-6
PTM Model Simulation 8 (Larger median diameters of silt and clay fractions) - Mass Accumulation during Simulation Period (kg)
Sediment Transport Evaluation Report
East Waterway Operable Unit



LEGEND

Areas Utilized for Sensitivity Analysis

PTM Outfall Locations

EFDC Hydrodynamic Model Grid

Type of Cell

Land

Ocean

Feet

0 250 500 750 1,000

NOTES:

1. Hinds, Lander, and Hanford are CSO outfalls
2. Outfall numbers (names) coorespond to drainage basins

R:\Jobs\060003-01_East_Waterway_SedTrans\Maps\2011_05\Figure 7-7 Normalization Areas.mxd kketteridge 6/8/2011 4:43:09 PM

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Figure 7-7
Areas Utilized for Sensitivity Analysis
Sediment Transport Evaluation Report
East Waterway Operable Unit

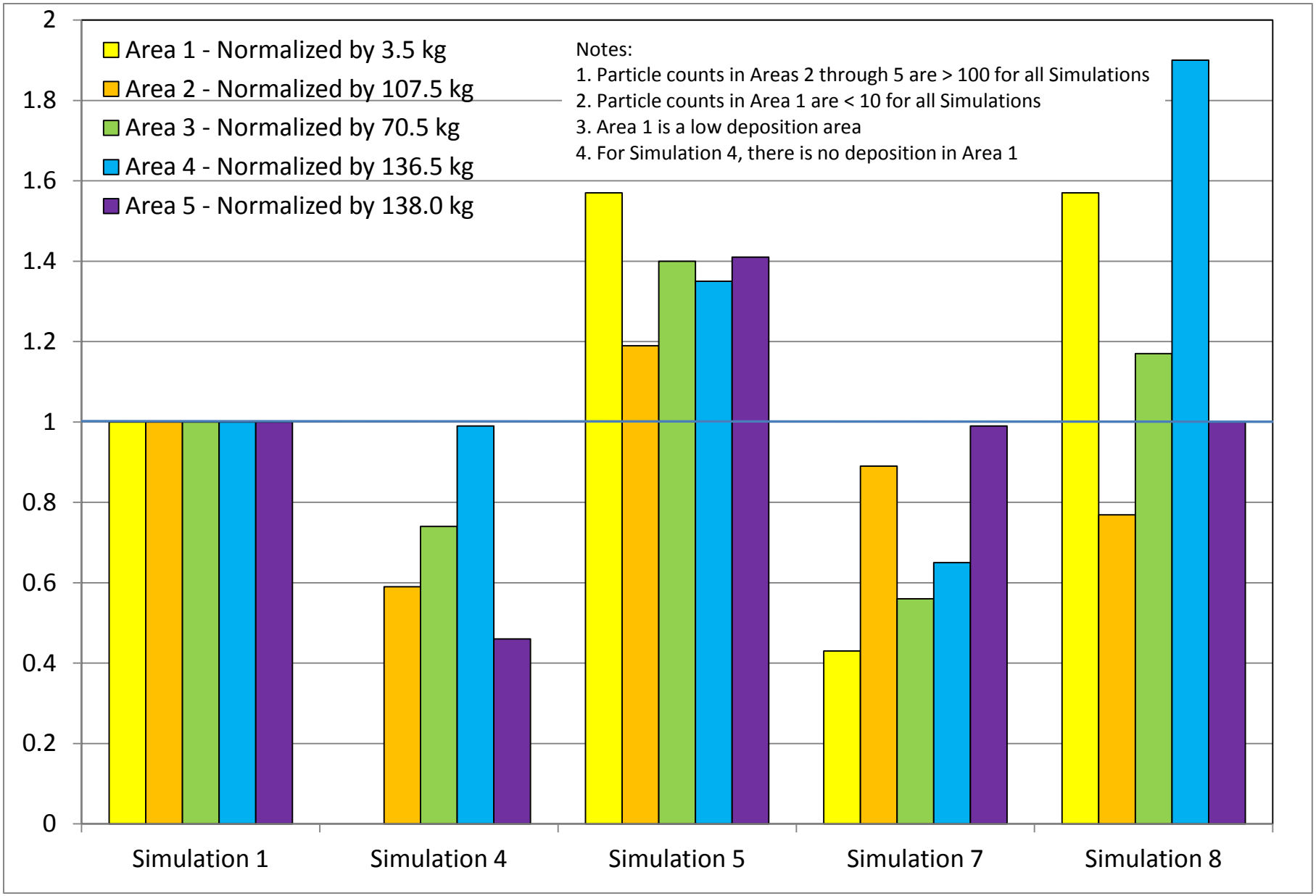

Figure 7-8

Comparison of PTM Model Simulations for Base Case and Tier 1 Sensitivity Simulations (Normalized by Base Case Simulation)

Sediment Transport Evaluation Report

East Waterway Operable Unit

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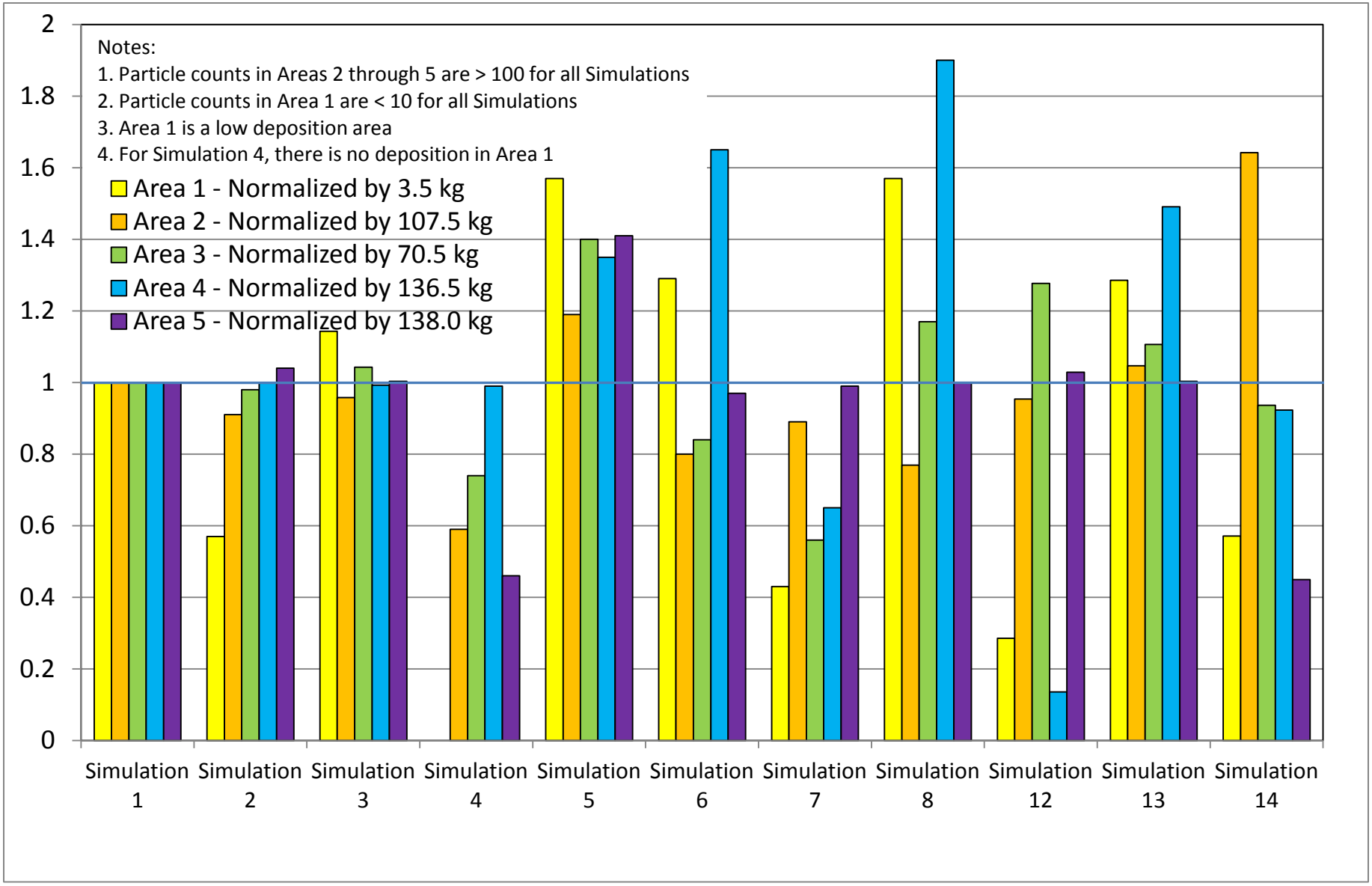

Figure 7-9

Comparison of Mass Accumulation between PTM Model Simulations using Annual Average Upstream Flow (Normalized by Simulation 1)

Sediment Transport Evaluation Report
East Waterway Operable Unit

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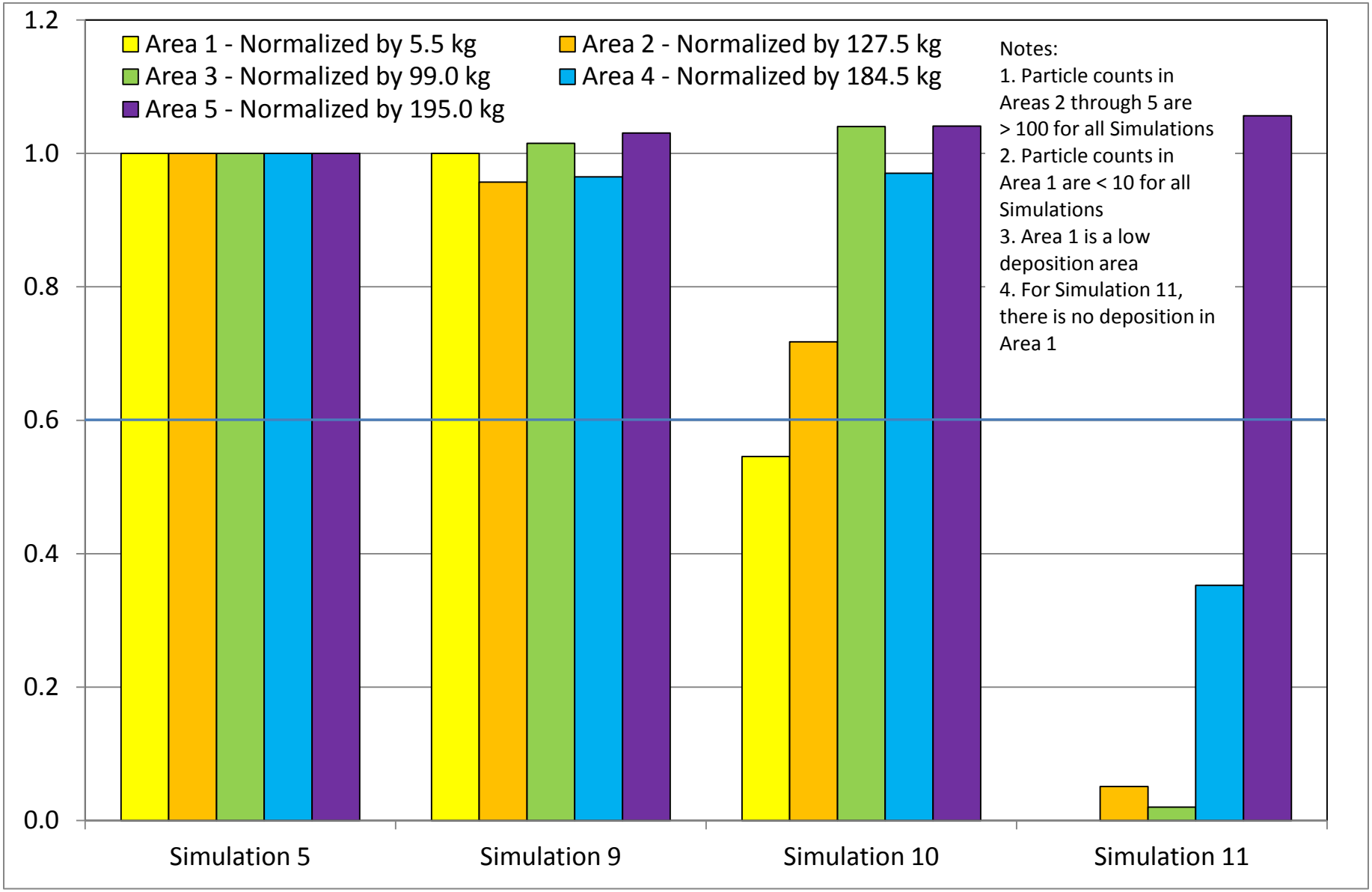

Figure 7-10

Comparison of PTM Model Simulations with increasing Riverine Flows and 75% TSS Values (Normalized by Simulation 5)

Sediment Transport Evaluation Report

East Waterway Operable Unit

ANCHOR QEA

APPENDIX A
BATHYMETRY DATA

DAVID EVANS AND ASSOCIATES INC.

MEMORANDUM

Date: June 15, 2010
Client: Anchor Environmental
Subject: East Waterway Supplemental Remedial Investigation & Feasibility Study, Port of Seattle Multibeam Bathymetry

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Project Parameters
Horizontal Datum: *NAD 83/91*
Vertical Datum: *MLLW (1983 -2001 epoch)*
Coordinate System: *Washington State Plane – North Zone*
Units: *US Survey Feet*

Primary Survey Dates (multibeam and jetski)
January 13, 14 & 15, 2010

Supplemental Survey Dates (under bridge tag-line)
April 16, 2010

Survey Crew
Ben Hocker – Lead Hydrographer
Josh Sampey – Hydrographer ll
Travis Brennan – Hydrographer III
Nicholas Lesnikowski – Lead Hydrographer, Project Manager, ACSM* Hydrographer

Supplemental Survey Crew
Gabe Swartz – Land survey technician
Matt Pybas – Land survey technician
Josh Sampey – Hydrographer ll
Nicholas Lesnikowski – Lead Hydrographer, Project Manager, ACSM* Hydrographer

Equipment
Vessels – DEA's 33-foot *John B Preston,* Hydrographic survey jetski, 11' Livingston
Multibeam – Reson 8101 240 kHz, 101 beam, 150° swath with 15° roll bias to starboard.
Singlebeam – Odom CV100 on jetski with 200kHz narrow beam transducer, Odom MkIII with 200 kHz narrowbeam transducer for tag-line survey.
Motion Sensor – Applanix POS-MV
Heading Sensor – Applanix POS-MV
Positioning – Trimble MS750 RTK GPS rover on vessel with a base station setup on temporary site at north end of Olympic Tug & Barge facility. Jetski positioning under West Seattle overpass was accomplished with a Trimble automated total station (range-azimuth system). Tag line survey positioning based on DEA land survey reference points and taped distances.
Navigation and data logging – HypackMax - Hysweep Ver. 2009a & Trito ISIS
Sound Speed - AML-SV Plus, Sound Velocity Profiler

Field Procedures

Position Check

Each day after base station setup, a confidence check was made on a secondary control point DEA #2000 (S end of Harbor Island) by decoupling the RTK antenna from the vessel, placing it on a fixed length staff and occupying the control point. Comparisons for the RTK system, utilized for the multibeam aspects of this survey, are displayed in the following table.

	Easting (X) US Feet	**Northing (Y) US Feet**	**Elevation (Z) FT**
Actual DEA 2000	*1266932.88*	*211485.40*	*17.11*
Obs. 01/14/10	1266932.95	211485.41	17.16
Obs. 01/15/10	1266932.96	211485.35	17.26

Position checks for the range-azimuth system used to position the jet ski under the ramp to the West Seattle Bridge, consisted of back-sighting the EHI control point (provided by Anchor Environmental) and checking both the opposite side range-azimuth station location, as well as, a secondary point established close to the waters edge. The hydrographer on the jet ski decoupled the tracking prism and held it on the check point while logging the data with the vessel's onboard Hypack navigation system. This procedure was used on both sides of the waterway.

Patch Test

Prior to the start of multibeam survey operations, data was collected along a series of controlled transects to be used for checking the alignment and system latency of the survey equipment. After analysis during data processing the following correction values were determined and applied during data processing.

Roll	Pitch	Yaw	Latency
0.52°	1.037°	0.55°	0.00 sec

Sound Velocity Casts

Detailed measurements of the sound velocity profile through the water column are crucial in multibeam surveys. Changes in the velocity profile will not only affect acoustic distance measurements, but can also cause refraction or bending of the sonar path as it passes through layers in the water column with different velocities. An AML SV-Plus was used to measure the speed of sound of the water column. A total of nine sound speed casts were made during survey operations. The casts showed a freshwater lens in the upper 5-6 feet of the water column, especially toward the head of the waterway; consisting of a slower velocity of approximately 4773 ft/sec. Deeper depths within the waterway were very consistent showing speeds of approximately 4855 ft/sec to the maximum depth of all the casts (62 feet).

Bar Check and Draft Readings
A flat bar target was held below the single-beam transducer installed on the jetski to verify the system draft. On the multi-beam, vessel draft readings were made off draft markings established on the multibeam mount.

Data Acquisition (primary survey)
In the open portions of the survey area, soundings were acquired with a Reson SeaBat 8101 multibeam bathymetric sonar using a frequency of 240 kiloHertz (kHz). The system records 101 soundings in a single sonar ping. Additionally, DEA's 8101 includes options such as a stick projector for enhanced shallow water performance and the ability to output side scan sonar imagery. The stick projector option on the Reson SeaBat 8101 improves the system performance in shallow water (depths less than
150 ft).

Multibeam data was conducted by running lines both parallel and perpendicular with the waterway for the length of the project. For this survey, the sonar head was mounted with 15° starboard angle to allow for maximum coverage of side slope areas. This enabled coverage over a range of 90° from nadir (straight down) to starboard and 60° from nadir to port with a recorded depth every 1.5°. Sonar swaths were recorded at a rate of 14 Hz as the vessel transited along the survey track lines. Multibeam data were clipped at 45° (90° total swath width) during processing to improve data quality for the main waterway, the accepted angles were opened up along the slopes (50° port/90° stbd) and to reach under obstructions. The total swath width of full coverage mapping in a single pass varied with the water depth.

The most vital measurements in a multibeam survey are heading and roll angles. To account for vessel heading, heave (vertical movement), pitch and roll, an Applanix POS/MV motion reference sensor was utilized. By utilizing vessel speed over ground and heading data provided by GPS, the POS/MV can isolate horizontal accelerations from vessel turns and provide highly accurate motion data. The POS/MV system was also used to record vessel heading (yaw) from which the sonar beam orientation was derived. The POS/MV provides a higher degree of accuracy for heading measurements than a conventional gyrocompass.

The navigation and survey control system was a personal computer running Hypack MAX software. Hypack Hysweep software and Triton ISIS were used for multibeam and sensor data acquisition. Hypack MAX software allowed the swath bathymetric data to be displayed as a painted color image in a "matrix" on the navigation screen. The matrix cell size on was set to 3-ft during operations and nearly all cells were filled with sounding data. This real-time display gave the hydrographers immediate indications of data quality and coverage.

Under the West Seattle freeway, where no GPS signals could be obtained and the larger survey vessel could not enter, soundings were acquired with a customized personal watercraft (i.e. jetski) which was tracked with a range-azimuth system setup on the banks on local control established for this survey. The jetski ran transects within the small basin between the railraoad bridge to the south and the Spokane street bridge to the North. The large bridge supports for the freeway partially blocked the tracking of the vessel which required a second setup of the range azimuth system on the opposite bank of the basin. The jetski was equipped with an ODOM CV-

100 singlebeam system with a 200 kHz narrow beam transducer and the data was logged to an onboard computer running Hypack acquisition software.

Data Acquisition (tag-line survey)
Additional survey data was needed in the area under the Spokane Street bridge which could not be accessed during the January field effort due to high tides limiting clearance. In April, DEA brought a small boat and single beam system and ran transects between accessible pile bents under the Spokane Street roadway. Due to difficult logistics the vessel could only be positioned relative to stretched out lines which were pre-marked in 5-foot intervals (tag-lines). A DEA land crew was also on site to provide reference points for the tag line setups and to shoot the survey vessel when possible. In addition, the land survey team was able to take wading "topo" shots for cross checking the hydro data, as well as, in-filling some hard to reach areas.

Processing Procedures

Tides
The elevation data obtained from the RTK GPS system during multi-beam acquisition was stripped out and averaged at a 30-second sliding window. In addition, tide data from the NOAA gauge in Seattle (9447130) was downloaded for the survey period for comparison, as well as, readings from a tape set on DEA BM #1 which had been established at the south end of Harbor Island during the 2003 Lower Duwamish Working Group survey. The readings at BM #1 were useful in establishing any phase differences that may occur between the south end of the survey area and the NOAA site in Elliott Bay. No significant phase difference was noticed; with the tape, RTK and NOAA values generally agreeing to with 0.1 to 0.2 ft. The RTK-30 sec tide was used for processing the multibeam data and the single beam data was corrected using NOAA observations.

The tagline data was corrected for tide based on observations from the NOAA gauge in Elliott Bay.

Data Editing
Post-processing of multibeam data was conducted utilizing Caris HIPS multibeam analysis and processing software version 6.1/SP2/HF 7. Patch test data was analyzed and alignment corrections were applied. Water-level data was applied to adjust all depth measurements to project datum from the RTK GPS processed data. Velocity profiles were used to correct slant range measurements and compensate for any ray path bending.

Applanix POSPAC-MMS software was used to refine and improve the final vessel navigation and attitude solution. This software post-processes the raw GNSS (Global Navigation Satellite System) and IMU (Inertial Motion Unit) data to produce a "smoothed best estimate of trajectory" (SBET) using advanced forward and backward filtering algorithms. These navigation solutions are considered more accurate than stand-alone RTK (real-time kinematic) positions.

Processing began with review of each survey line using Caris swath editor. Verified water surface correctors were applied to the data set at this time. Position and sensor data was reviewed and accepted. Sounding data was reviewed and edited for data flyers. Sounding data, including sonar beams reflecting from sediment in the water column or noise in the water

column, were carefully reviewed before flagged as rejected. In each case, data was not eliminated and can be re-accepted in the future if required. Also during editing, real features not associated with bottom elevations but of possible interest, pilings and bridge footings, etc., were designated as examined. This designation allows these features to be included in the hillshade images which add references points to aid in interpretation. The “examined” soundings were not included in the final data exported for difference modeling or contouring.

After swath editing, all data was reviewed through the Caris HIPS subset editing program to ensure no flyers remained in the data set, or to re-accept data previously flagged in the swath editor. In the Caris subset editor, a set of lines was reviewed together for line-to-line comparison to ensure agreement to one another in a Caris session.

Single-beam bathymetric data acquired near the Spokane Street bridge, was processed using CARIS-HIPS software. Navigation data was reviewed for flyers, latency adjustments applied and NOAA tide corrections made, on a line-by-line basis. Exported data was thinned using Hypack’s sort routine to a 3-foot density and imported into Terramodel for final contouring.

For the tag-line survey the processing involved creating a file of XY points based on the idealized tagline positions for each line. These 5-foot interval points were brought into an excel spreadsheet where the digitized raw sounding values, stamped on the hardcopy record, were entered for each point. The raw soundings were adjusted to MLLW by applying the NOAA tided value associated with the time of each line. The corrected files were then exported in XYZ format and brought in to Terramodel where the points were compared to any land shots acquired to help adjust the idealized tag-line positions closer to the actual track of the vessel. The final adjusted points were exported from Terramodel in XYZ format and merged in with the survey data previously acquired.

Data Export

To take advantage of the level of detail the multibeam bathymetric survey provided for the waterway, a 3.28 foot (1.0-meter) grid of the survey area was created by the HIPS processing software and exported to an ASCII XYZ file. This process created a 1.0-meter grid over the survey coverage area and then assigned values to each grid node with an inverse distance weighted algorithm. The ASCII XYZ points file uses the North American Datum of 1983 (NAD83), State Plane Coordinate System (SPCS), Washington North Zone with units in US Survey feet.

Data Images

The 1.0-meter database was rendered in CARIS to produce a hillshade image of the bottom bathymetry. The hillshade image is a colored rendering of the surface with shadows created by a artificial sun to help draw out features and make the image more interpretable. For the East Waterway a 3x3 interpolation was applied to the 1.0-meter surface to reduce the distracting effects of empty pixels. The interpolation was only applied to the hillshade image and not to any other products. The parameters used for creating the hillshade image were:

Sun Azimuth	Sun Elevation	Vertical Exaggeration
345°	45°	2X

Various multibeam datasets from the East Waterway, conducted by DEA in ’02, ’03 and ‘05, were imported into Trimble TerraModel for comparison. The surveys agreed well (i.e. better than +/- 0.25 ft in most areas). In addition, the junction with the LDWG data at the south end of Harbor Island also agreed well, however apparent changes in the bottom have occurred over the more than six years which has transpired between the surveys.

Data Contours

A set of 2-foot contours were produced and delivered as .pdf files. In addition, ASCII XYZ data at a 3.28 foot (1-meter) grid was exported for use in digital models. The data is in NAD83/91 WA-N, US feet and corrected to the ‘83-‘01 MLLW tidal epoch.

Data Files

Copies of the contour drawings and exported ASCII xyz data files were delivered along with this memorandum.

APPENDIX B
VELOCITY AND SALINITY DATA

B.1 DATA COLLECTION SUMMARY

B.1.1 Moored Current Meters (Velocity Profiles)

Four upward-looking Acoustic Doppler Current Profilers (ADCPs) were installed within the East Waterway (EW); one in the Sill Reach south of the bridges, and three in the Main Body Reach (see Figure 2-3). The current meters were installed in four deployments between May 7 and August 18, 2009, with temporary retrievals on May 20, June 24, and July 28, 2009, during which data were downloaded and diagnostic checks were performed to confirm proper operation. All times and dates are referenced to Universal Coordinated Time (UTC). Table B-1 outlines the instrumentation, sampling rate, and vertical resolution for the four current meters. Table B-2 lists the locations and approximate water depths at deployment for each of the current meters for each deployment. Figure 1-6 in the main body of the report shows the location of the moored current meters.

Table B-1
ADCP Instrumentation and Setup Details

Station	Instrumentation	Sampling Rate (min)	Averaging Period(s)	Vertical Resolution (m)	Number of Vertical Bins
1 (North)	Nortek 600 kHz AWAC	10	180	1.0	50
2 (Middle)	Sontek 500 kHz ADCP	10	120	1.0	24
3 (South)	RDI 1200 kHz ADCP	10	600	0.5	23
4 (Junction)	RDI 1200 kHz ADCP	10	600	0.5	23

Table B-2
ADCP Deployment Times and Locations

Station	Deployment	Latitude (DMS)	Longitude (DMS)	Water Depth at Deployment (m)
1 (North)	1	47° 35’ 14.0520”	122° 20’ 41.7780”	16.7 (54 ft)
	2	47° 35’ 13.9242”	122° 20’ 39.1424”	17.9 (58 (ft)
	3	47° 35’ 13.8852”	122° 20’ 39.1111”	18.5 (60 ft)
	4	47° 35’ 14.0053”	122° 20’ 39.5096”	15.0 (49 ft)
2 (Middle)	1	47° 34’ 45.3420”	122° 20’ 40.6860”	16.7 (54 ft)
	2	47° 34’ 45.6416”	122° 20’ 38.5395”	18.0 (59 ft)
	3	47° 34’ 45.4986”	122° 20’ 38.5722”	15.2 (49.8 ft)
	4	47° 34’ 45.3177”	122° 20’ 38.8685”	15.2 (49.8 ft)

Station	Deployment	Latitude (DMS)	Longitude (DMS)	Water Depth at Deployment (m)
3 (South)	1	47° 34′ 20.7900″	122° 20′ 41.3340″	7.6 (24 ft)
	2	47° 34′ 20.8573″	122° 20′ 41.4859″	10.3 (33 ft)
	3	47° 34′ 20.8032″	122° 20′ 41.6560″	7.6 (24 ft)
	4	47° 34′ 20.3944″	122° 20′ 41.6036″	7.0 (23 ft)
4 (Junction)	1	47° 34′ 10.3080″	122° 20′ 45.8520″	7.6 (24 ft)
	2	47° 34′ 10.4970″	122° 20′ 45.6173″	8.0 (26 ft)
	3	47° 34′ 10.8940″	122° 20′ 45.1922″	7.6 (24 ft)
	4	47° 34′ 10.8940″	122° 20′ 45.1922″	7.1 (23 ft)

B.1.2 Velocity Transects

Velocity transects were obtained over a 24-hour period between May 13 and May 14, 2009, using a pole-mounted, downward-facing Teledyne RDI 600 kHz ADCP mounted on the starboard side of the sampling vessel. The instrument was submerged approximately 1.0 meter (m) below the water surface to move the sensors away from the wake created by the sampling vessel while underway. One set of transects (three perpendicular to the EW channel and one along the EW channel) was completed within 1 hour to obtain synoptic velocity measurements representative of a single phase of the tide. A total of 16 sets of transects (64 total profiles) were completed during the 24-hour sampling period. Table B-3 outlines the sample times and approximate tidal stage for the velocity transect data. Figure 1-6 in the main body of the report shows the locations of the transects.

Table B-3
Sampling Times and Tide Stages for Velocity Transect Measurements

Transect Round #	Date (UTC)	Time (UTC)	Tidal Stage
1	5/13/2009	18:57 to 20:04	Ebb to low slack
2	5/13/2009	20:16 to 21:19	Low slack
3	5/13/2009	22:13 to 23:30	Low slack to flood
4	5/14/2009	00:03 to 01:03	Flood
5	5/14/2009	01:12 to 02:15	Flood
6	5/14/2009	02:56 to 03:59	Flood to high slack
7	5/14/2009	04:55 to 06:05	High slack
8	5/14/2009	06:49 to 08:14	High slack to ebb
9	5/14/2009	08:32 to 09:43	Ebb to low slack

Currents and Salinity Data Collection

Transect Round #	Date (UTC)	Time (UTC)	Tidal Stage
10	5/14/2009	09:47 to 10:47	Low slack
11	5/14/2009	11:51 to 12:59	Flood
12	5/14/2009	13:03 to 14:16	Flood to high slack
13	5/14/2009	14:20 to 15:16	High slack
14	5/14/2009	15:20 to 16:23	High slack to ebb
15	5/14/2009	16:28 to 17:26	Ebb
16	5/14/2009	17:31 to 18:37	Ebb

B.1.3 Salinity Profiles

Salinity profiles were obtained using a Hydrolab DS5 conductivity temperature depth (CTD) meter during the velocity transect data collection. The locations of the salinity profiles were co-located with three of the four moored ACDPs: Stations 1, 2, and 3 north of the Junction Reach. Sixteen CTD casts at each of the three identified locations were completed in the 24-hour sampling period. Table B-4 provides the sampling times and approximate tidal stage for each of the CTD casts. Figure 1-6 in the main body of the report shows the location of the salinity profiles.

Table B-4
Sampling Times and Tide Stages for CTD Measurements

Cast Round #	Date (UTC)	Time (UTC)	Tidal Stage
1	5/13/2009	19:05 to 19:39	Ebb
2	5/13/2009	20:21 to 20:55	Low slack
3	5/13/2009	22:21 to 23:05	Low slack to flood
4	5/14/2009	00:09 to 00:40	Flood
5	5/14/2009	01:17 to 01:48	Flood
6	5/14/2009	03:03 to 03:34	Flood to high slack
7	5/14/2009	05:04 to 05:40	High slack
8	5/14/2009	07:03 to 07:51	Ebb
9	5/14/2009	08:43 to 09:17	Ebb
10	5/14/2009	09:52 to 10:21	Low slack
11	5/14/2009	11:57 to 12:29	Low slack to flood
12	5/14/2009	13:09 to 13:43	Flood
13	5/14/2009	14:26 to 14:53	High slack

Currents and Salinity Data Collection

Cast Round #	Date (UTC)	Time (UTC)	Tidal Stage
14	5/14/2009	15:26 to 16:01	High slack to ebb
15	5/14/2009	16:34 to 17:06	Ebb
16	5/14/2009	17:37 to 18:14	Ebb

B.1.4 Tide Gauge

A Paros Digi-quartz pressure sensor was installed in the Junction Reach near ADCP Station 4, mounted onto a stable wood piling on the northernmost dock south of the Spokane Street Bridge on the west side of the EW, in order to measure water levels during the instrument deployment. The tide gauge was deployed between May 8 and August 18, 2009, with intermediate data retrievals occurring on May 21, June 21, and July 27, 2009. The gauge was located at coordinates 47° 34' 13.5000" N, 122° 20' 45.4500" W, with an elevation of -2.324 m North American Vertical Datum of 1988 (NAVD88) determined by a 2.5-hour static differential global positioning system (DGPS) observation. It collected samples at a rate of 10 minutes using a 120-second averaging period. Figure 1-6 in the main body of the report shows the location of the tide gauge.

B.2 DATA SUMMARY

Reports detailing the instrument deployments and presentation of the collected data were produced by Evans Hamilton, Inc. (EHI 2009a, 2009b, and 2009c) and are included in this appendix as Attachments 1 (deployments 1 and 2), Attachment 2 (deployment 3), and Attachment 3 (deployment 4).

B.3 DEVIATIONS FROM THE SEDIMENT TRANSPORT CHARACTERIZATION QAPP

The Sediment Transport Characterization Quality Assurance Project Plan (QAPP; Anchor QEA 2009, Section 3.1.3) outlines the required data collection procedures and locations for velocity and salinity data. There were no significant deviations from the QAPP that altered the quality of data collected. On the contrary, additional data were collected within the EW that were beyond the requirements laid out in the QAPP. An additional moored ADCP was placed in the Junction Reach, near the confluence of the EW with the Lower Duwamish Waterway (LDW). This ADCP was included to provide additional spatial resolution in the velocity profile data, and to obtain velocity information as close as possible to the upstream

mouth of the EW. A tide gauge was placed in the EW to obtain precise measurements of water levels during the data collection period; this was not a requirement in the QAPP.

Table 3-3 in the QAPP provides proposed locations and water depths for the three moored current meters (not including the location in the Junction Reach) and salinity profiles (these were co-located). Actual water depths and locations for the current meters varied slightly, but not significantly, from those proposed due to updated bathymetry data (collected as part of the Sediment Transport Evaluation), variations in the bed elevation, and navigation concerns. In particular, Locations 1 and 2 (in the Main Body Reach north of Slip 27) were moved slightly between deployments 1 and 2 due to concerns that the current meters would be hit by passing ships at lower tides. Table B-2 provides updated locations and water depths for each instrument and deployment.

REFERENCES

Anchor QEA, 2009. East Waterway Operable Unit, Supplemental Remedial Investigation/Feasibility Study, Final Sediment Transport Characterization Quality Assurance Project Plan. Prepared for Port of Seattle. March.

EHI, 2009a. Evans Hamilton, Inc. East Waterway, Oceanographic Data Collection, Deployment 1 & 2 Data Report. Prepared for Anchor QEA, LLC. July 2009.

EHI, 2009b. Evans Hamilton, Inc. East Waterway, Oceanographic Data Collection, Deployment 3 Data Report. Prepared for Anchor QEA, LLC. September 2009.

EHI, 2009c. Evans Hamilton, Inc. East Waterway, Oceanographic Data Collection, Deployment 4 Data Report. Prepared for Anchor QEA, LLC. October 2009.

EVANS-HAMILTON, INC.

DUWAMISH RIVER – EAST WATERWAY

OCEANOGRAPHIC DATA COLLECTION

DEPLOYMENT 1 DATA REPORT

JULY 2009

PREPARED FOR

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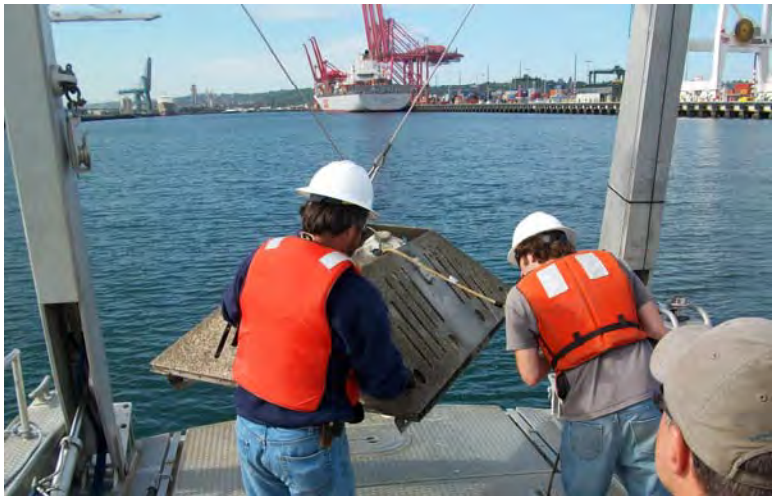

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APPENDIX C
GEOCHRONOLOGICAL CORE DATA

Table C-1
Subsurface Sediment Collection Summary

Core	Core Priority	Core Collection				Core Processing				
							Lithology			
		Attempt	Drive Length (in)	Recovered Length (in)	Percent Recovery	Total Length Processed (cm)	Upper Depth	Lower Depth	USCS	Notes
GC-01	Tier 3	1 of 1	51	46	90%	86.5	0	86.5	ML	
GC-02	Tier 2	1 of 1	35.5	26	73%	44	0	9	ML	Trace black, gritty, anthropogenic debris (coarse gravel sized)
							9	26	SM	
							36	44	ML	
GC-03	Tier 3	1 of 1	36	20	56%	30	0	24	ML	
							24	30	SM	
GC-04	Not Collected	--	--	--	--	--	--	--	--	
GC-05	Tier 1	1 of 1	53	51	96%	88	0	22	SM	
							22	32	ML	
							32	88	SM	
GC-06	Tier 3	1 of 1	54	43	79%	76	0	76	ML	
GC-07	Tier 3	1 of 1	61	55	90%	115	0	115	ML	
GC-08	Tier 2	2 of 2	49	40	82%	83	0	75	ML	
							75	88	SM	
GC-09	Tier 1	1 of 1	58	53.5	92%	105	0	60	ML	Trace fine to coarse gravel (subrounded, up to 20-cm diameter)
							60	75	SM	
							75	95	ML	
							95	105	SM	
GC-10	Tier 2	1 of 1	52.5	45	86%	92	0	92	ML	Trace to occasional coarse gravel (angular, 20-cm diameter), trace anthropogenic debris
GC-11	Tier 1	1 of 1	52	39	75%	77	0	77	ML	Trace fine gravel (subrounded, up to 20-cm diameter)
GC-12	Tier 1	1 of 1	50.5	45	89%	91	0	91	ML	Occasional anthropogenic debris
GC-13	Tier 1	1 of 1	57	55	96%	107	0	79	ML	
							79	107	SP	
GC-14	Tier 1	1 of 1	54	47	87%	91	0	23	ML	
							23	45	SM	
							45	91	ML	
GC-15	Tier 1	1 of 1	55	48	87%	99	0	99	ML	
GC-16	Tier 1	1 of 1	60.5	53.5	88%	104	0	104	ML	Trace fine gravel (subrounded)
GC-17	Not Collected	--	--	--	--	--	--	--	--	
GC-18	Tier 1	1 of 1	60	48	80%	100	0	100	ML	
GC-19A	Tier 1	1 of 2	--	33	--		0	65	ML	Trace anthropogenic debris and fine gravel (subangular)
GC-19B	Tier 1	2 of 2	60	48	80%	100	0	100	ML	Trace anthropogenic debris
GC-20	Tier 1	3 of 3	21	16	76%	17	0	10	ML	
							10	17	SM	
GC-21	Not Collected	--	--	--	--	--	--	--	--	
GC-22	Not Collected	--	--	--	--	--	--	--	--	

Note:
USCS = Unified Soil Classification System

Table C-2
Geochronology Sediment Sampling Results

Location ID	GC-01	GC-01	GC-01	GC-01	GC-01	GC-01	GC-01	GC-01	GC-01
Sample ID	GC-01-20100203-S0002	GC-01-20100203-S0608	GC-01-20100203-S1214	GC-01-20100203-S1820	GC-01-20100203-S2426	GC-01-20100203-S3032	GC-01-20100203-S3638	GC-01-20100203-S4244	GC-01-20100203-S4448
Sample Date	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010
Depth	0 - 2 cm	6 - 8 cm	12 - 14 cm	18 - 20 cm	24 - 26 cm	30 - 32 cm	36 - 38 cm	42 - 44 cm	44 - 48 cm
Conventional Parameters (pct)									
Total organic carbon	**0.722**	**1.31**	**0.896**	**0.798**	**0.613**	**0.707**	**0.695**	**0.789**	**0.763**
Total solids	**72.7**	**74.9**	**76.7**	**77.9**	**76.2**	**75.1**	**74.9**	**72.9**	**74.6**
Grain Size (pct)									
Gravel	**0.1**	**0.5**	0.1 U	0.1 U	**0.4**	0.1 U	**0.2**	**0.1**	0.1 U
Sand, Coarse	**0.4**	**1**	**0.7**	**0.9**	**0.8**	**0.8**	**0.5**	**0.4**	**0.5**
Sand, Very Coarse	**0.1**	**0.5**	**0.2**	**0.2**	**0.3**	**0.3**	**0.1**	**0.2**	**0.1**
Sand, Medium	**8.3**	**15.4**	**12.2**	**18.2**	**12.5**	**11.3**	**6.6**	**2.4**	**7.2**
Sand, Fine	**28.3**	**28.3**	**24.8**	**30.6**	**24.7**	**21.9**	**15.1**	**8.2**	**18.3**
Sand, Very Fine	**22.7**	**16.3**	**17**	**15.4**	**17.6**	**15.3**	**20.2**	**17.2**	**18.7**
Silt, Coarse	**13.5**	**9**	**13.9**	**10.7**	**13.9**	**15.2**	**20.9**	**25.4**	**17.3**
Silt, Medium	**6.6**	**5.6**	**7.3**	**5.8**	**7.6**	**8.5**	**10.2**	**13.3**	**10**
Silt, Fine	**5.3**	**5.4**	**5.9**	**4.8**	**5.9**	**6.9**	**7.3**	**9.5**	**7.2**
Silt, Very Fine	**4.9**	**5.6**	**5.7**	**4.4**	**5.3**	**6.2**	**6**	**7.4**	**6.2**
Clay, Coarse	**3.5**	**4.4**	**4.3**	**3.2**	**4**	**4.7**	**4.4**	**5.4**	**4.8**
Clay, Medium	**2.6**	**3.4**	**3.4**	**2.4**	**3.1**	**3.7**	**3.5**	**4.3**	**3.9**
Clay, Fine	**3.6**	**4.4**	**4.6**	**3.3**	**4.1**	**5**	**5.1**	**6.1**	**5.7**
Radioisotopes (pci/g)									
Cesium-137	--	--	--	--	--	--	--	--	--
Lead-210	--	--	--	--	--	--	--	--	--

Notes:
Bold = Detected result
U = Compound analyzed, but not detected above detection limit

Table C-2
Geochronology Sediment Sampling Results

Location ID	GC-01	GC-01	GC-01	GC-01	GC-01	GC-01	GC-01	GC-02	GC-02
Sample ID	GC-01-20100203-S4850	GC-01-20100203-S5456	GC-01-20100203-S6062	GC-01-20100203-S6668	GC-01-20100203-S7274	GC-01-20100203-S7880	GC-01-20100203-S8486	GC-02-20100203-S0002	GC-02-20100203-S0608
Sample Date	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010
Depth	48 - 50 cm	54 - 56 cm	60 - 62 cm	66 - 68 cm	72 - 74 cm	78 - 80 cm	84 - 86 cm	0 - 2 cm	6 - 8 cm
Conventional Parameters (pct)									
Total organic carbon	**0.663**	**0.764**	**0.21**	**0.838**	**0.783**	**0.485**	**0.532**	**0.705**	**0.456**
Total solids	**74.7**	**75.7**	**78.8**	**75.4**	**75.1**	**79.2**	**79.2**	**62.6**	**75.6**
Grain Size (pct)									
Gravel	--	--	--	--	--	--	--	**0.2**	**0.2**
Sand, Coarse	--	--	--	--	--	--	--	**0.7**	**0.5**
Sand, Very Coarse	--	--	--	--	--	--	--	**0.7**	**0.1**
Sand, Medium	--	--	--	--	--	--	--	**5.2**	**5.9**
Sand, Fine	--	--	--	--	--	--	--	**25.9**	**32.1**
Sand, Very Fine	--	--	--	--	--	--	--	**26.8**	**26.7**
Silt, Coarse	--	--	--	--	--	--	--	**13.7**	**12.4**
Silt, Medium	--	--	--	--	--	--	--	**5.5**	**5.1**
Silt, Fine	--	--	--	--	--	--	--	**5.2**	**4.5**
Silt, Very Fine	--	--	--	--	--	--	--	**5.4**	**4.3**
Clay, Coarse	--	--	--	--	--	--	--	**4**	**3**
Clay, Medium	--	--	--	--	--	--	--	**2.9**	**2.1**
Clay, Fine	--	--	--	--	--	--	--	**3.7**	**3**
Radioisotopes (pci/g)									
Cesium-137	--	--	--	--	--	--	--	0.045 U	0.035 U
Lead-210	--	--	--	--	--	--	--	**0.25**	**0.2**

Notes:
Bold = Detected result
U = Compound analyzed, but not detected above detection limit

Table C-2
Geochronology Sediment Sampling Results

Location ID	GC-02	GC-02	GC-02	GC-02	GC-02	GC-03	GC-03	GC-03	GC-03
Sample ID	GC-02-20100203-S1214	GC-02-20100203-S1820	GC-02-20100203-S2426	GC-02-20100203-S3032	GC-02-20100203-S3638	GC-03-20100203-S0002	GC-03-20100203-S0608	GC-03-20100203-S1214	GC-03-20100203-S1820
Sample Date	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010
Depth	12 - 14 cm	18 - 20 cm	24 - 26 cm	30 - 32 cm	36 - 38 cm	0 - 2 cm	6 - 8 cm	12 - 14 cm	18 - 20 cm
Conventional Parameters (pct)									
Total organic carbon	**0.916**	**1.14**	**1.44**	**1.02**	**1.14**	**1.31**	**1.98**	**1.53**	**1**
Total solids	**72.1**	**70.1**	**71.9**	**72**	**71.7**	**62.6**	**60.1**	**63.8**	**74.4**
Grain Size (pct)									
Gravel	**0.1**	**0.1**	**0.7**	**2**	0.1 U	0.1 U	**0.6**	0.1 U	0.1 U
Sand, Coarse	**0.4**	**0.5**	**0.7**	**0.7**	**0.7**	**0.3**	**1**	**0.8**	**0.3**
Sand, Very Coarse	**0.2**	**0.5**	**0.3**	**0.2**	**0.3**	0.1 U	**1.1**	**0.3**	0.1 U
Sand, Medium	**4.7**	**5.9**	**7**	**5.5**	**5.7**	**2.2**	**1.1**	**1.1**	**3.5**
Sand, Fine	**23.9**	**18.6**	**17.2**	**17.5**	**19**	**2.9**	**3.2**	**1.4**	**21.6**
Sand, Very Fine	**24.6**	**18.6**	**16.2**	**16.5**	**18.4**	**4.9**	**11.5**	**6.3**	**19.5**
Silt, Coarse	**15.7**	**14.8**	**15.8**	**16.6**	**14.7**	**17.1**	**15.8**	**21.2**	**15.1**
Silt, Medium	**7.5**	**8.5**	**9.6**	**9.5**	**9**	**14.8**	**13.4**	**14.6**	**8.8**
Silt, Fine	**6**	**7.5**	**7.7**	**7.6**	**7.3**	**13.2**	**12**	**12.5**	**7.3**
Silt, Very Fine	**5.8**	**7.9**	**7.5**	**7.5**	**7.5**	**13.3**	**12.1**	**12.7**	**7.2**
Clay, Coarse	**4.1**	**6.2**	**6.1**	**5.8**	**6**	**10.8**	**10**	**10.3**	**5.9**
Clay, Medium	**3**	**4.8**	**4.9**	**4.6**	**4.8**	**8.7**	**7.9**	**8.2**	**4.7**
Clay, Fine	**4**	**6.1**	**6.2**	**5.9**	**6.6**	**11.7**	**10.2**	**10.7**	**6.1**
Radioisotopes (pci/g)									
Cesium-137	0.041 U	0.039 U	0.044 U	0.033 U	0.046 U	--	--	--	--
Lead-210	**0.16**	**0.31**	**0.17**	**0.21**	**0.19**	--	--	--	--

Notes:
Bold = Detected result
U = Compound analyzed, but not detected above detection limit

Table C-2
Geochronology Sediment Sampling Results

Location ID	GC-03	GC-05	GC-05	GC-05	GC-05	GC-05	GC-05	GC-05	GC-05
Sample ID	GC-03-20100203-S2426	GC-05-20100203-S0002	GC-05-20100203-S0608	GC-05-20100203-S1214	GC-05-20100203-S1820	GC-05-20100203-S2426	GC-05-20100203-S3032	GC-05-20100203-S3638	GC-05-20100203-S4244
Sample Date	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010
Depth	24 - 26 cm	0 - 2 cm	6 - 8 cm	12 - 14 cm	18 - 20 cm	24 - 26 cm	30 - 32 cm	36 - 38 cm	42 - 44 cm
Conventional Parameters (pct)									
Total organic carbon	**0.896**	**1.34**	**0.973**	**1.26**	**0.7**	**0.627**	**0.384**	**0.281**	**0.35**
Total solids	**74.3**	**71.1**	**69.6**	**69.9**	**77.1**	**75.1**	**76.6**	**76.3**	**77.6**
Grain Size (pct)									
Gravel	**0.1**	0.1 U	**0.1**	**0.2**	**0.3**	0.1 U	0.1 U	0.1 U	0.1 U
Sand, Coarse	**0.3**	**1.5**	**0.4**	**0.8**	**0.3**	**0.3**	**0.3**	**0.2**	**0.3**
Sand, Very Coarse	**0.1**	**0.4**	**0.1**	**0.1**	**0.2**	**0.1**	0.1 U	**0.1**	**0.1**
Sand, Medium	**3.5**	**9.7**	**5.3**	**6.9**	**6**	**2.7**	**1.9**	**2**	**5.7**
Sand, Fine	**18.4**	**25.6**	**22.9**	**19.8**	**28.2**	**16.9**	**24.2**	**26.2**	**36.1**
Sand, Very Fine	**20.6**	**15.4**	**16.2**	**14.3**	**23.2**	**24.9**	**33.7**	**36.2**	**23.2**
Silt, Coarse	**16.1**	**11**	**10.1**	**10**	**10**	**16.4**	**14.8**	**7.4**	**7**
Silt, Medium	**8.7**	**7.1**	**8**	**8.5**	**7.1**	**9.6**	**6.4**	**7.2**	**7.4**
Silt, Fine	**7.2**	**7.7**	**8.4**	**8.4**	**6.3**	**7.6**	**5.1**	**6**	**6.3**
Silt, Very Fine	**7.4**	**7.6**	**9.1**	**9.2**	**6**	**6.9**	**4.5**	**5.2**	**5.3**
Clay, Coarse	**6.1**	**5.3**	**7.1**	**7.7**	**4.4**	**5.1**	**3.2**	**3.5**	**3.5**
Clay, Medium	**5**	**3.8**	**5.5**	**6.2**	**3.4**	**4.1**	**2.4**	**2.6**	**2.6**
Clay, Fine	**6.6**	**4.8**	**6.9**	**7.8**	**4.5**	**5.7**	**3.5**	**3.5**	**2.7**
Radioisotopes (pci/g)									
Cesium-137	--	0.042 U	0.047 U	0.05 U	0.035 U	0.037 U	0.039 U	0.045 U	0.046 U
Lead-210	--	**0.35**	**0.35**	**0.35**	**0.19**	**0.09**	0.09 U	**0.1**	**0.13**

Notes:
Bold = Detected result
U = Compound analyzed, but not detected above detection limit

Table C-2
Geochronology Sediment Sampling Results

Location ID	GC-05	GC-05	GC-05	GC-05	GC-05	GC-05	GC-05	GC-06	GC-06
Sample ID	GC-05-20100203-S4850	GC-05-20100203-S5456	GC-05-20100203-S6062	GC-05-20100203-S6668	GC-05-20100203-S7274	GC-05-20100203-S7880	GC-05-20100203-S8486	GC-06-20100203-S0002	GC-06-20100203-S0608
Sample Date	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010
Depth	48 - 50 cm	54 - 56 cm	60 - 62 cm	66 - 68 cm	72 - 74 cm	78 - 80 cm	84 - 86 cm	0 - 2 cm	6 - 8 cm
Conventional Parameters (pct)									
Total organic carbon	**0.341**	**0.617**	**1.87**	**0.415**	**0.443**	**0.429**	**0.131**	**1.65**	**1.55**
Total solids	**77.6**	**45.6**	**49**	**73.7**	**76.6**	**73.6**	**75.6**	**67.8**	**64**
Grain Size (pct)									
Gravel	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	**0.3**	**0.3**
Sand, Coarse	**0.2**	**0.2**	**0.3**	**0.2**	**0.2**	**0.4**	**0.1**	**1.6**	**1.4**
Sand, Very Coarse	**0.1**	0.1 U	0.1 U	0.1 U	**0.1**	0.1 U	0.1 U	**0.5**	**0.4**
Sand, Medium	**6.8**	**0.7**	**1.9**	**0.9**	**4.9**	**1.1**	**0.9**	**18.5**	**11.5**
Sand, Fine	**41.2**	**15.6**	**24.8**	**13.1**	**56.4**	**21.7**	**38.5**	**33.7**	**21.3**
Sand, Very Fine	**23.6**	**37.7**	**28.6**	**27.5**	**19.3**	**33.6**	**40.3**	**11.7**	**11.1**
Silt, Coarse	**8.5**	**19.1**	**17.2**	**22.1**	**5.7**	**17.2**	**7.8**	**5.9**	**8.2**
Silt, Medium	**4.9**	**7.7**	**7.5**	**10.1**	**3.5**	**6.8**	**3**	**4.9**	**8.3**
Silt, Fine	**3.9**	**6.3**	**5.8**	**7.4**	**2.9**	**5.5**	**2.7**	**5.4**	**8.7**
Silt, Very Fine	**3.5**	**4.6**	**4.8**	**6.2**	**2.5**	**4.6**	**2.3**	**5.9**	**9.2**
Clay, Coarse	**2.6**	**2.9**	**3.2**	**4.3**	**1.6**	**3.1**	**1.5**	**4.3**	**7.2**
Clay, Medium	**2**	**2.1**	**2.5**	**3.3**	**1.2**	**2.4**	**1.1**	**3.1**	**5.4**
Clay, Fine	**2.7**	**3.2**	**3.5**	**4.9**	**1.7**	**3.5**	**1.8**	**4**	**7**
Radioisotopes (pci/g)									
Cesium-137	0.031 U	0.045 U	0.041 U	0.034 U	0.033 U	0.043 U	0.05 U	--	--
Lead-210	**0.11**	**0.16**	**0.08**	**0.16**	0.09 U	0.1 U	0.1 U	--	--

Notes:
Bold = Detected result
U = Compound analyzed, but not detected above detection limit

Table C-2
Geochronology Sediment Sampling Results

Location ID	GC-06	GC-06	GC-06	GC-06	GC-06	GC-06	GC-06	GC-06	GC-06
Sample ID	GC-06-20100203-S1214	GC-06-20100203-S1820	GC-06-20100203-S2426	GC-06-20100203-S3032	GC-06-20100203-S3638	GC-06-20100203-S4244	GC-06-20100203-S4448	GC-06-20100203-S4850	GC-06-20100203-S5456
Sample Date	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010
Depth	12 - 14 cm	18 - 20 cm	24 - 26 cm	30 - 32 cm	36 - 38 cm	42 - 44 cm	44 - 48 cm	48 - 50 cm	54 - 56 cm
Conventional Parameters (pct)									
Total organic carbon	**1.97**	**2.17**	**2.22**	**2.08**	**1.91**	**1.97**	**1.77**	**1.25**	**0.417**
Total solids	**65.3**	**65.8**	**64.2**	**62.8**	**61.7**	**65.2**	**61.6**	**64.1**	**74**
Grain Size (pct)									
Gravel	**0.1**	0.1 U	0.1 U	0.1 U	0.1 U	**1.7**	0.1 U	--	--
Sand, Coarse	**1**	**0.9**	**0.9**	**0.5**	**0.5**	**0.6**	**0.3**	--	--
Sand, Very Coarse	**0.5**	**0.5**	**0.7**	**0.4**	**0.1**	**1.2**	**0.1**	--	--
Sand, Medium	**7.1**	**8.3**	**4.7**	**1.9**	**3**	**3.7**	**0.8**	--	--
Sand, Fine	**14.9**	**18.1**	**8.7**	**2.8**	**6.2**	**8.1**	**2**	--	--
Sand, Very Fine	**9.6**	**10.1**	**7.5**	**8.5**	**13.4**	**6.6**	**4.7**	--	--
Silt, Coarse	**11.3**	**10.5**	**12.9**	**16.8**	**12.9**	**14.9**	**16.1**	--	--
Silt, Medium	**9.6**	**9.9**	**11.9**	**15.4**	**12.8**	**14.4**	**15.8**	--	--
Silt, Fine	**9.9**	**9.9**	**11.9**	**12.3**	**12.6**	**11.9**	**14.3**	--	--
Silt, Very Fine	**10.8**	**10.2**	**12.5**	**11.5**	**12.4**	**11.2**	**14.1**	--	--
Clay, Coarse	**8.8**	**7.8**	**10**	**9.3**	**9.4**	**8.9**	**11.2**	--	--
Clay, Medium	**7.1**	**6**	**7.9**	**7.9**	**7.2**	**7.2**	**9**	--	--
Clay, Fine	**9.2**	**7.9**	**10.4**	**12.8**	**9.3**	**9.5**	**11.6**	--	--
Radioisotopes (pci/g)									
Cesium-137	--	--	--	--	--	--	--	--	--
Lead-210	--	--	--	--	--	--	--	--	--

Notes:
Bold = Detected result
U = Compound analyzed, but not detected above detection limit

Table C-2
Geochronology Sediment Sampling Results

Location ID	GC-06	GC-06	GC-06	GC-07	GC-07	GC-07	GC-07	GC-07	GC-07
Sample ID	GC-06-20100203-S6062	GC-06-20100203-S6668	GC-06-20100203-S7274	GC-07-20100203-S0002	GC-07-20100203-S0608	GC-07-20100203-S1214	GC-07-20100203-S1820	GC-07-20100203-S2426	GC-07-20100203-S3032
Sample Date	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010
Depth	60 - 62 cm	66 - 68 cm	72 - 74 cm	0 - 2 cm	6 - 8 cm	12 - 14 cm	18 - 20 cm	24 - 26 cm	30 - 32 cm
Conventional Parameters (pct)									
Total organic carbon	**0.74**	**0.527**	**0.662**	**1.27**	**1.72**	**1.67**	**1.58**	**2.54**	**3.36**
Total solids	**69.1**	**72.7**	**74.3**	**56.6**	**63.1**	**65**	**56.1**	**57.4**	**57.2**
Grain Size (pct)									
Gravel	--	--	--	**0.1**	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U
Sand, Coarse	--	--	--	**1.3**	**1.1**	**0.8**	**0.2**	**0.4**	**0.5**
Sand, Very Coarse	--	--	--	**0.4**	**0.3**	**0.2**	**0.2**	**0.1**	**0.1**
Sand, Medium	--	--	--	**10.5**	**8.6**	**3.2**	**1.8**	**2.3**	**3.5**
Sand, Fine	--	--	--	**24.4**	**24.1**	**18.2**	**7.2**	**7.3**	**7.3**
Sand, Very Fine	--	--	--	**14.8**	**16.2**	**18.7**	**9.9**	**9.3**	**7.7**
Silt, Coarse	--	--	--	**6.1**	**6.9**	**11**	**9.8**	**11.8**	**11.6**
Silt, Medium	--	--	--	**6.9**	**7.3**	**10.1**	**11**	**12.2**	**12**
Silt, Fine	--	--	--	**8.4**	**8.2**	**9.9**	**12.3**	**12.8**	**12.7**
Silt, Very Fine	--	--	--	**9.4**	**9.2**	**9.8**	**14.4**	**13.7**	**14**
Clay, Coarse	--	--	--	**6.8**	**6.9**	**6.8**	**11.7**	**10.9**	**10.9**
Clay, Medium	--	--	--	**4.9**	**5**	**4.9**	**9.3**	**8.5**	**8.4**
Clay, Fine	--	--	--	**6.1**	**6.3**	**6.6**	**12.2**	**10.9**	**11.2**
Radioisotopes (pci/g)									
Cesium-137	--	--	--	--	--	--	--	--	--
Lead-210	--	--	--	--	--	--	--	--	--

Notes:
Bold = Detected result
U = Compound analyzed, but not detected above detection limit

Table C-2
Geochronology Sediment Sampling Results

Location ID	GC-07	GC-07	GC-07	GC-07	GC-07	GC-07	GC-07	GC-07	GC-07
Sample ID	GC-07-20100203-S3638	GC-07-20100203-S4244	GC-07-20100203-S4850	GC-07-20100203-S5456	GC-07-20100203-S6062	GC-07-20100203-S6668	GC-07-20100203-S7274	GC-07-20100203-S7880	GC-07-20100203-S8486
Sample Date	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010
Depth	36 - 38 cm	42 - 44 cm	48 - 50 cm	54 - 56 cm	60 - 62 cm	66 - 68 cm	72 - 74 cm	78 - 80 cm	84 - 86 cm
Conventional Parameters (pct)									
Total organic carbon	**2.95**	**1.78**	**2.15**	**1.8**	**3.75**	**4.8**	**2.48**	**2.37**	**2.07**
Total solids	**57**	**56.4**	**49.7**	**51.6**	**49.6**	**46.1**	**46.6**	**57**	**56.5**
Grain Size (pct)									
Gravel	0.1 U	0.1 U	--	--	--	--	--	--	--
Sand, Coarse	**0.6**	**0.2**	--	--	--	--	--	--	--
Sand, Very Coarse	**0.1**	**0.1**	--	--	--	--	--	--	--
Sand, Medium	**3.5**	**1.8**	--	--	--	--	--	--	--
Sand, Fine	**6.9**	**4.4**	--	--	--	--	--	--	--
Sand, Very Fine	**6.9**	**5.8**	--	--	--	--	--	--	--
Silt, Coarse	**12**	**11.5**	--	--	--	--	--	--	--
Silt, Medium	**12.8**	**13.7**	--	--	--	--	--	--	--
Silt, Fine	**13.2**	**14.9**	--	--	--	--	--	--	--
Silt, Very Fine	**14**	**15.2**	--	--	--	--	--	--	--
Clay, Coarse	**10.9**	**11.7**	--	--	--	--	--	--	--
Clay, Medium	**8.4**	**9.1**	--	--	--	--	--	--	--
Clay, Fine	**10.6**	**11.6**	--	--	--	--	--	--	--
Radioisotopes (pci/g)									
Cesium-137	--	--	--	--	--	--	--	--	--
Lead-210	--	--	--	--	--	--	--	--	--

Notes:
Bold = Detected result
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Table C-2
Geochronology Sediment Sampling Results

Location ID	GC-08	GC-08	GC-08	GC-08	GC-08	GC-08	GC-08	GC-08	GC-08
Sample ID	GC-08-20100202-S0002	GC-08-20100202-S0608	GC-08-20100202-S1214	GC-08-20100202-S1820	GC-08-20100202-S2426	GC-08-20100202-S3032	GC-08-20100202-S3638	GC-08-20100202-S4244	GC-08-20100202-S4448
Sample Date	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010
Depth	0 - 2 cm	6 - 8 cm	12 - 14 cm	18 - 20 cm	24 - 26 cm	30 - 32 cm	36 - 38 cm	42 - 44 cm	44 - 48 cm
Conventional Parameters (pct)									
Total organic carbon	**1.75**	**1.77**	**1.35**	**1.3**	**1.41**	**0.109**	**0.723**	**0.468**	**0.738**
Total solids	**50.2**	**53.1**	**60.7**	**64.1**	**60.5**	**68.8**	**72.4**	**74.8**	**75**
Grain Size (pct)									
Gravel	**0.2**	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U
Sand, Coarse	**1.6**	**1**	**0.8**	**0.6**	**0.8**	**0.7**	**0.4**	**0.2**	**0.2**
Sand, Very Coarse	**0.9**	**0.4**	**0.1**	**0.1**	**0.3**	**0.3**	**0.1**	0.1 U	**0.1**
Sand, Medium	**5.7**	**4.7**	**3.9**	**1.3**	**2.1**	**1.5**	**1.2**	**0.9**	**1.6**
Sand, Fine	**11.8**	**10.9**	**7.9**	**6.9**	**9.1**	**9.9**	**9.6**	**16.2**	**17.3**
Sand, Very Fine	**10.6**	**12.3**	**13.8**	**18.9**	**17.7**	**25.6**	**26.7**	**32**	**32.7**
Silt, Coarse	**10.1**	**11.5**	**15.6**	**18.4**	**15.7**	**17.3**	**19.2**	**17.4**	**14.3**
Silt, Medium	**11**	**11.1**	**11.7**	**12**	**11.8**	**10.1**	**9.5**	**7.4**	**7.2**
Silt, Fine	**11.8**	**11.7**	**10.7**	**10.2**	**11**	**8.1**	**7.6**	**5.9**	**5.7**
Silt, Very Fine	**12.4**	**12.3**	**10.9**	**9.9**	**10.4**	**7.9**	**7.4**	**5.8**	**5.8**
Clay, Coarse	**8.9**	**9**	**8.4**	**7.5**	**7.6**	**6.4**	**6.2**	**4.8**	**5**
Clay, Medium	**6.5**	**6.6**	**6.7**	**5.9**	**5.8**	**5.2**	**5.2**	**3.9**	**4.2**
Clay, Fine	**8.6**	**8.7**	**9.4**	**8.3**	**7.7**	**7**	**7**	**5.4**	**5.9**
Radioisotopes (pci/g)									
Cesium-137	**0.134**	**0.087**	-- U	-- U	-- U	-- U	-- U	-- U	-- U
Lead-210	**0.5**	**0.43**	**0.32**	**0.2**	**0.18**	**0.13**	**0.15**	**0.11**	**0.13**

Notes:
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Table C-2
Geochronology Sediment Sampling Results

Location ID	GC-08	GC-08	GC-08	GC-08	GC-08	GC-08	GC-09	GC-09	GC-09
Sample ID	GC-08-20100202-S4850	GC-08-20100202-S5456	GC-08-20100202-S6062	GC-08-20100202-S6668	GC-08-20100202-S7274	GC-08-20100202-S7880	GC-09-20100202-S0002	GC-09-20100202-S0608	GC-09-20100202-S1214
Sample Date	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010
Depth	48 - 50 cm	54 - 56 cm	60 - 62 cm	66 - 68 cm	72 - 74 cm	78 - 80 cm	0 - 2 cm	6 - 8 cm	12 - 14 cm
Conventional Parameters (pct)									
Total organic carbon	**0.574**	**0.717**	**0.846**	**0.438**	**0.253**	**0.556**	**1.71**	**1.98**	**2.37**
Total solids	**74.6**	**74.7**	**71**	**75.2**	**77.4**	**74.9**	**64.4**	**60.5**	**56.7**
Grain Size (pct)									
Gravel	--	--	--	--	--	--	**4.5**	**0.3**	0.1 U
Sand, Coarse	--	--	--	--	--	--	**1.8**	**1.7**	**0.8**
Sand, Very Coarse	--	--	--	--	--	--	**1.2**	**0.6**	**0.3**
Sand, Medium	--	--	--	--	--	--	**6.1**	**7.7**	**3.4**
Sand, Fine	--	--	--	--	--	--	**15.4**	**15.5**	**7.5**
Sand, Very Fine	--	--	--	--	--	--	**16.1**	**16.3**	**11.6**
Silt, Coarse	--	--	--	--	--	--	**10.9**	**10.3**	**14.4**
Silt, Medium	--	--	--	--	--	--	**7.5**	**8.6**	**12.4**
Silt, Fine	--	--	--	--	--	--	**8**	**9.1**	**12.5**
Silt, Very Fine	--	--	--	--	--	--	**9**	**10**	**12.6**
Clay, Coarse	--	--	--	--	--	--	**6.8**	**7.5**	**9.2**
Clay, Medium	--	--	--	--	--	--	**5.2**	**5.5**	**6.6**
Clay, Fine	--	--	--	--	--	--	**7.4**	**6.9**	**8.6**
Radioisotopes (pci/g)									
Cesium-137	-- U	-- U	-- U	-- U	-- U	-- U	**0.086**	0.052 U	**0.085**
Lead-210	-- U	**0.16**	**0.09**	**0.14**	**0.1**	**0.12**	**0.57**	**0.53**	**0.49**

Notes:
Bold = Detected result
U = Compound analyzed, but not detected above detection limit

Table C-2
Geochronology Sediment Sampling Results

Location ID	GC-09	GC-09	GC-09	GC-09	GC-09	GC-09	GC-09	GC-09	GC-09
Sample ID	GC-09-20100202-S1820	GC-09-20100202-S2426	GC-09-20100202-S3032	GC-09-20100202-S3638	GC-09-20100202-S4244	GC-09-20100202-S4448	GC-09-20100202-S4850	GC-09-20100202-S5456	GC-09-20100202-S6062
Sample Date	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010
Depth	18 - 20 cm	24 - 26 cm	30 - 32 cm	36 - 38 cm	42 - 44 cm	44 - 48 cm	48 - 50 cm	54 - 56 cm	60 - 62 cm
Conventional Parameters (pct)									
Total organic carbon	**2.4**	**2.68**	**2.36**	**2.3**	**3.36**	**3.27**	**3.38**	**1.26**	**1.48**
Total solids	**54**	**53.2**	**59.3**	**63.8**	**57.6**	**61.9**	**66.2**	**75.9**	**75.8**
Grain Size (pct)									
Gravel	0.1 U	0.1 U	**0.8**	**0.1**	0.1 U	0.1 U	**0.7**	**0.3**	0.1 U
Sand, Coarse	**0.8**	**0.6**	**5.4**	**4.9**	**1.3**	**4.2**	**8.7**	**4.5**	**0.2**
Sand, Very Coarse	**0.4**	**0.2**	**1.1**	**0.9**	**0.1**	**0.6**	**1**	**0.3**	0.1 U
Sand, Medium	**3.8**	**3.2**	**19.8**	**20.9**	**4.6**	**15.8**	**27.8**	**25.8**	**0.7**
Sand, Fine	**5.7**	**3.9**	**9**	**13.1**	**5.5**	**10.7**	**13.8**	**21.6**	**15.6**
Sand, Very Fine	**8.3**	**5.5**	**3.5**	**7.2**	**7.6**	**7.6**	**6.9**	**10.3**	**37.7**
Silt, Coarse	**12.3**	**11.1**	**5.9**	**8.3**	**9.7**	**9.3**	**6.2**	**6.5**	**8.5**
Silt, Medium	**11.9**	**13.8**	**8.3**	**7.8**	**11.6**	**9.6**	**6.5**	**5.1**	**7**
Silt, Fine	**13**	**14.6**	**9.9**	**8.2**	**12.1**	**9.2**	**7**	**5.3**	**6.4**
Silt, Very Fine	**14.3**	**15.8**	**11.3**	**9.1**	**14**	**10**	**7.5**	**6.1**	**7.1**
Clay, Coarse	**11**	**12.2**	**9.2**	**7.2**	**11.9**	**8.3**	**5.5**	**5.2**	**6.1**
Clay, Medium	**8.3**	**8.7**	**7.1**	**5.4**	**9.5**	**6.6**	**3.8**	**4.1**	**4.9**
Clay, Fine	**10.3**	**10.3**	**8.7**	**6.9**	**12**	**7.9**	**4.6**	**4.9**	**5.9**
Radioisotopes (pci/g)									
Cesium-137	**0.136**	**0.179**	**0.139**	**0.089**	**0.159**	**0.107**	**0.142**	0.033 U	0.035 U
Lead-210	**0.62**	**0.52**	**0.27**	**0.19**	**0.36**	**0.26**	**0.16**	0.11 U	**0.12**

Notes:
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Table C-2
Geochronology Sediment Sampling Results

Location ID	GC-09	GC-09	GC-09	GC-09	GC-10	GC-10	GC-10	GC-10	GC-10
Sample ID	GC-09-20100202-S6668	GC-09-20100202-S7274	GC-09-20100202-S7880	GC-09-20100202-S8486	GC-10-20100202-S0002	GC-10-20100202-S0608	GC-10-20100202-S1214	GC-10-20100202-S1820	GC-10-20100202-S2426
Sample Date	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010
Depth	66 - 68 cm	72 - 74 cm	78 - 80 cm	84 - 86 cm	0 - 2 cm	6 - 8 cm	12 - 14 cm	18 - 20 cm	24 - 26 cm
Conventional Parameters (pct)									
Total organic carbon	**0.986**	**1.49**	**2.22**	**3.04**	**3.1**	**2.72**	**2.7**	**2.81**	**2.88**
Total solids	**80.1**	**73.6**	**75.1**	**70.9**	**45.8**	**49.3**	**50.2**	**46.2**	**46.1**
Grain Size (pct)									
Gravel	**0.5**	**0.4**	**5.1**	**0.4**	**43.2**	**2.4**	**28.1**	**0.6**	**4.6**
Sand, Coarse	**9.5**	**6.5**	**8.1**	**5.2**	**1.9**	**1.2**	**1.6**	**0.8**	**0.9**
Sand, Very Coarse	**0.9**	**0.6**	**0.6**	**0.3**	**4.1**	**1.1**	**3.8**	**0.3**	**0.8**
Sand, Medium	**38.6**	**29.2**	**31.4**	**22.1**	**2.6**	**3.2**	**5.1**	**2.4**	**3.4**
Sand, Fine	**19.3**	**12**	**12.1**	**10.5**	**2.5**	**3**	**4.1**	**4.9**	**5.2**
Sand, Very Fine	**8.1**	**5**	**6.1**	**4.6**	**9.5**	**6.3**	**5.2**	**5.5**	**4.8**
Silt, Coarse	**4.7**	**3**	**4.9**	**5.3**	**5.9**	**15.7**	**9.1**	**11.5**	**13.7**
Silt, Medium	**3.6**	**6**	**5.7**	**7.6**	**6.3**	**13.5**	**8.1**	**11.7**	**12.3**
Silt, Fine	**3.4**	**7.1**	**6**	**8.5**	**6.8**	**14**	**8.7**	**13.6**	**13.2**
Silt, Very Fine	**3.7**	**8.8**	**6.6**	**10.7**	**6.4**	**14**	**9**	**15.8**	**14**
Clay, Coarse	**2.9**	**7.7**	**5.2**	**9.3**	**4.1**	**9.7**	**6.4**	**12.2**	**10.2**
Clay, Medium	**2.2**	**6.4**	**3.9**	**7.2**	**2.8**	**6.9**	**4.5**	**9**	**7.4**
Clay, Fine	**2.6**	**7.4**	**4.4**	**8.2**	**3.9**	**9.1**	**6.2**	**11.8**	**9.7**
Radioisotopes (pci/g)									
Cesium-137	0.029 U	0.04 U	0.028 U	0.04 U	-- U	**0.077**	**0.128**	**0.138**	**0.181**
Lead-210	0.09 U	**0.19**	**0.13**	**0.16**	**0.62**	**0.59**	**0.73**	**0.62**	**0.53**

Notes:
Bold = Detected result
U = Compound analyzed, but not detected above detection limit

Table C-2
Geochronology Sediment Sampling Results

Location ID	GC-10	GC-10	GC-10	GC-10	GC-10	GC-10	GC-10	GC-10	GC-10
Sample ID	GC-10-20100202-S3032	GC-10-20100202-S3638	GC-10-20100202-S4244	GC-10-20100202-S4850	GC-10-20100202-S5456	GC-10-20100202-S6062	GC-10-20100202-S6668	GC-10-20100202-S7274	GC-10-20100202-S7880
Sample Date	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010
Depth	30 - 32 cm	36 - 38 cm	42 - 44 cm	48 - 50 cm	54 - 56 cm	60 - 62 cm	66 - 68 cm	72 - 74 cm	78 - 80 cm
Conventional Parameters (pct)									
Total organic carbon	**3.36**	**3.58**	**3.71**	**11**	**6.59**	**5.63**	**4.94**	**2.68**	**2.32**
Total solids	**46**	**53.1**	**54.7**	**43.5**	**37.5**	**47.2**	**48.3**	**49.9**	**60.9**
Grain Size (pct)									
Gravel	**0.4**	**2.2**	**1.1**	**4.2**	**0.1**	**0.1**	0.1 U	**0.8**	0.1 U
Sand, Coarse	**1.2**	**2**	**1.4**	**2**	**1.2**	**1.3**	**1.5**	**0.6**	**0.8**
Sand, Very Coarse	**0.8**	**1.2**	**0.9**	**2**	**0.8**	**0.6**	**0.4**	**0.6**	**0.2**
Sand, Medium	**2.5**	**9**	**5**	**7**	**2.6**	**5.1**	**6.3**	**1.4**	**1.9**
Sand, Fine	**3.8**	**8.2**	**14.4**	**6.3**	**2.8**	**8.6**	**7.1**	**2.2**	**12.3**
Sand, Very Fine	**3.8**	**5.9**	**12.2**	**2.7**	**2**	**4.9**	**3.8**	**4.3**	**13.7**
Silt, Coarse	**12**	**11.2**	**10**	**11.3**	**14.5**	**11.7**	**11.6**	**13.2**	**14.6**
Silt, Medium	**12**	**11.8**	**10.1**	**12.8**	**14.9**	**11.9**	**11.4**	**13.8**	**11.9**
Silt, Fine	**13.8**	**12.2**	**10.4**	**13.1**	**15**	**12.6**	**12.6**	**14.5**	**10.9**
Silt, Very Fine	**16**	**12.6**	**11.3**	**13.9**	**16.2**	**14.3**	**14.7**	**15.5**	**10.9**
Clay, Coarse	**12.7**	**9.3**	**8.8**	**10.1**	**12.1**	**11.2**	**11.8**	**11.9**	**8.4**
Clay, Medium	**9.6**	**6.6**	**6.4**	**6.9**	**8.4**	**8.1**	**8.6**	**9.1**	**6.4**
Clay, Fine	**11.4**	**7.8**	**8**	**7.7**	**9.6**	**9.4**	**10.3**	**12**	**8.1**
Radioisotopes (pci/g)									
Cesium-137	**0.184**	**0.207**	**0.224**	**0.462**	**0.503**	**0.75**	**0.407**	0.051 U	0.036 U
Lead-210	**0.5**	**0.35**	**0.36**	**0.55**	**0.67**	**0.39**	**0.45**	**0.28**	**0.2**

Notes:
Bold = Detected result
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Table C-2
Geochronology Sediment Sampling Results

Location ID	GC-10	GC-10	GC-11	GC-11	GC-11	GC-11	GC-11	GC-11	GC-11
Sample ID	GC-10-20100202-S8486	GC-10-20100202-S8690	GC-11-20100202-S0002	GC-11-20100202-S0608	GC-11-20100202-S1214	GC-11-20100202-S1820	GC-11-20100202-S2426	GC-11-20100202-S3032	GC-11-20100202-S3638
Sample Date	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010
Depth	84 - 86 cm	86 - 90 cm	0 - 2 cm	6 - 8 cm	12 - 14 cm	18 - 20 cm	24 - 26 cm	30 - 32 cm	36 - 38 cm
Conventional Parameters (pct)									
Total organic carbon	**4.48**	**5.63**	**1.55**	**1.98**	**2.27**	**2.47**	**1.88**	**4.16**	**4.31**
Total solids	**52.1**	**49.8**	**46.4**	**55.4**	**50.8**	**55.1**	**57**	**53.8**	**49.8**
Grain Size (pct)									
Gravel	0.1 U	**1.1**	**0.2**	0.1 U	0.1 U	**1.8**	**0.2**	0.1 U	0.1 U
Sand, Coarse	**0.6**	**1.9**	**1**	**0.7**	**0.3**	**1.1**	**1.4**	**1**	**1.2**
Sand, Very Coarse	**0.2**	**1.2**	**0.3**	**0.2**	0.1 U	**0.4**	**0.2**	**0.4**	**0.3**
Sand, Medium	**0.6**	**2.2**	**2.8**	**3.5**	**2**	**7.4**	**12.2**	**6.6**	**3.5**
Sand, Fine	**1.8**	**3.4**	**5.9**	**6.8**	**4.5**	**10.7**	**13.4**	**10.8**	**4.8**
Sand, Very Fine	**3.8**	**3.8**	**9.9**	**8.5**	**4.6**	**5.9**	**4.9**	**6.8**	**3.9**
Silt, Coarse	**10.3**	**12**	**15.3**	**13.7**	**12.4**	**8.8**	**9.1**	**8.9**	**9.4**
Silt, Medium	**13.5**	**12.8**	**12.8**	**13.1**	**13.6**	**11.3**	**10.4**	**9.6**	**12.3**
Silt, Fine	**14.9**	**13.5**	**13.5**	**13.2**	**15.2**	**12.3**	**11.4**	**11.1**	**14.1**
Silt, Very Fine	**17.2**	**15.4**	**13.3**	**13.5**	**15.7**	**13.4**	**12**	**13.8**	**16.4**
Clay, Coarse	**14**	**12.3**	**9.3**	**9.9**	**11.8**	**10.2**	**9.3**	**11.2**	**12.8**
Clay, Medium	**10.7**	**9.1**	**6.8**	**7.4**	**8.7**	**7.7**	**7**	**8.6**	**9.5**
Clay, Fine	**12.4**	**11.2**	**8.9**	**9.6**	**11**	**9**	**8.6**	**11.2**	**11.7**
Radioisotopes (pci/g)									
Cesium-137	**0.243**	**0.31**	0.054 U	**0.119**	**0.192**	**0.155**	**0.142**	**0.334**	**0.222**
Lead-210	**0.41**	**0.43**	**0.69**	**0.49**	**0.64**	**0.41**	**0.36**	**0.44**	**0.33**

Notes:
Bold = Detected result
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Table C-2
Geochronology Sediment Sampling Results

Location ID	GC-11	GC-11	GC-11	GC-11	GC-11	GC-11	GC-12	GC-12	GC-12
Sample ID	GC-11-20100202-S4244	GC-11-20100202-S4850	GC-11-20100202-S5456	GC-11-20100202-S6062	GC-11-20100202-S6668	GC-11-20100202-S7274	GC-12-20100201-S0002	GC-12-20100201-S0608	GC-12-20100201-S1214
Sample Date	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/1/2010	2/1/2010	2/1/2010
Depth	42 - 44 cm	48 - 50 cm	54 - 56 cm	60 - 62 cm	66 - 68 cm	72 - 74 cm	0 - 2 cm	6 - 8 cm	12 - 14 cm
Conventional Parameters (pct)									
Total organic carbon	**3.93**	**3.68**	**4.63**	**5.6**	**3.46**	**3**	**1.81**	**2.14**	**1.87**
Total solids	**50.7**	**49.9**	**54.4**	**54.3**	**55.9**	**60.4**	**47.6**	**52.2**	**50.5**
Grain Size (pct)									
Gravel	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	**0.9**	**0.2**	0.1 U	0.1 U
Sand, Coarse	**0.9**	**1.3**	**1.1**	**0.6**	**0.9**	**1.9**	**1.1**	**0.5**	**0.3**
Sand, Very Coarse	**0.2**	**1.1**	**0.6**	**0.4**	**0.6**	**1.2**	**0.2**	**0.1**	**0.1**
Sand, Medium	**4.7**	**1.2**	**0.9**	**0.6**	**0.8**	**5.5**	**2.1**	**0.9**	**0.7**
Sand, Fine	**6.3**	**1.3**	**0.8**	**0.7**	**0.9**	**9.5**	**4.7**	**2.4**	**1.8**
Sand, Very Fine	**3.2**	**1.9**	**1.4**	**1.4**	**1.9**	**7.8**	**11**	**5.8**	**3.5**
Silt, Coarse	**10**	**8.5**	**9.6**	**9.8**	**9.6**	**9.1**	**15.7**	**18.6**	**11.1**
Silt, Medium	**12.1**	**11.8**	**13.6**	**13.5**	**13.3**	**10.7**	**14.2**	**16.1**	**15.4**
Silt, Fine	**14.4**	**14.2**	**16.5**	**16.3**	**16**	**11.9**	**13.9**	**14.5**	**16.5**
Silt, Very Fine	**16.1**	**15.7**	**18**	**18.2**	**17.9**	**13.3**	**13.2**	**14**	**17**
Clay, Coarse	**12.4**	**13.3**	**14.1**	**14.2**	**14.1**	**10.5**	**8.8**	**9.8**	**12.5**
Clay, Medium	**9.1**	**11.5**	**10.6**	**10.9**	**10.7**	**8.1**	**6.3**	**7.3**	**9.3**
Clay, Fine	**10.8**	**18.1**	**12.8**	**13.5**	**13.3**	**9.7**	**8.5**	**9.9**	**11.8**
Radioisotopes (pci/g)									
Cesium-137	0.072 U	0.063 U	0.067 U	0.078 U	0.058 U	**0.25**	**0.129**	**0.132**	**0.16**
Lead-210	**0.37**	**0.31**	**0.32**	**0.26**	**0.38**	**0.31**	**0.72**	**0.71**	**0.72**

Notes:
Bold = Detected result
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Table C-2
Geochronology Sediment Sampling Results

Location ID	GC-12	GC-12	GC-12	GC-12	GC-12	GC-12	GC-12	GC-12	GC-12
Sample ID	GC-12-20100201-S1820	GC-12-20100201-S2426	GC-12-20100201-S3032	GC-12-20100201-S3638	GC-12-20100201-S4244	GC-12-20100201-S4850	GC-12-20100201-S5456	GC-12-20100201-S6062	GC-12-20100201-S6668
Sample Date	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010
Depth	18 - 20 cm	24 - 26 cm	30 - 32 cm	36 - 38 cm	42 - 44 cm	48 - 50 cm	54 - 56 cm	60 - 62 cm	66 - 68 cm
Conventional Parameters (pct)									
Total organic carbon	**2.24**	**1.79**	**1.9**	**2.32**	**2.7**	**2.03**	**1.47**	**0.508**	**2.8**
Total solids	**49.9**	**49.1**	**52.5**	**51.1**	**55.9**	**56.9**	**58**	**53.8**	**52.2**
Grain Size (pct)									
Gravel	0.1 U	0.1 U	0.1 U	**0.1**	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U
Sand, Coarse	**0.2**	**0.5**	**0.6**	**0.6**	**0.7**	**0.7**	**0.5**	**1.3**	**1**
Sand, Very Coarse	**0.1**	**0.2**	**0.3**	**0.2**	**0.2**	**0.3**	**0.1**	**0.9**	**0.2**
Sand, Medium	**0.6**	**1.9**	**2.2**	**1.7**	**1.5**	**3.4**	**5.6**	**3.3**	**2**
Sand, Fine	**1.8**	**4.8**	**4.3**	**5.2**	**4.2**	**9.5**	**15.5**	**12.3**	**3.3**
Sand, Very Fine	**2.7**	**5.6**	**4.6**	**7.5**	**6.5**	**7.9**	**10**	**12**	**3.6**
Silt, Coarse	**7.6**	**11.4**	**9.9**	**9.8**	**14.2**	**11.3**	**10.6**	**4.2**	**15.2**
Silt, Medium	**15.2**	**13.6**	**13.7**	**12.5**	**14.9**	**12.9**	**11.5**	**10.7**	**14.4**
Silt, Fine	**17.3**	**15.2**	**15.3**	**14.6**	**14.9**	**12.5**	**11.9**	**11.4**	**15.2**
Silt, Very Fine	**18.5**	**16.1**	**16.3**	**15.9**	**14.9**	**13.5**	**11.5**	**12.9**	**15.4**
Clay, Coarse	**13.8**	**11.7**	**12.3**	**12.3**	**10.8**	**10.4**	**8.5**	**10.7**	**11.2**
Clay, Medium	**10.2**	**8.5**	**9.2**	**9.2**	**7.6**	**8.1**	**6.3**	**9**	**8.1**
Clay, Fine	**12**	**10.5**	**11.2**	**10.5**	**9.6**	**9.6**	**8**	**11.3**	**10.4**
Radioisotopes (pci/g)									
Cesium-137	**0.153**	**0.164**	**0.255**	**0.187**	**0.158**	**0.13**	**0.097**	0.061 U	**0.246**
Lead-210	**0.71**	**0.48**	**0.55**	**0.43**	**0.34**	**0.32**	**0.27**	**0.32**	**0.49**

Notes:
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Table C-2
Geochronology Sediment Sampling Results

Location ID	GC-12	GC-12	GC-12	GC-12	GC-13	GC-13	GC-13	GC-13	GC-13
Sample ID	GC-12-20100201-S7274	GC-12-20100201-S7880	GC-12-20100201-S8486	GC-12-20100201-S8690	GC-13-20100202-S0002	GC-13-20100202-S0608	GC-13-20100202-S1214	GC-13-20100202-S1820	GC-13-20100202-S2426
Sample Date	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010
Depth	72 - 74 cm	78 - 80 cm	84 - 86 cm	86 - 90 cm	0 - 2 cm	6 - 8 cm	12 - 14 cm	18 - 20 cm	24 - 26 cm
Conventional Parameters (pct)									
Total organic carbon	**4.57**	**3.29**	**3.57**	**3.74**	**2.12**	**2.42**	**2.49**	**2.41**	**1.46**
Total solids	**48.3**	**51.1**	**48.2**	**49.9**	**35.1**	**47.1**	**51.7**	**47.2**	**48.9**
Grain Size (pct)									
Gravel	0.1 U	**2.4**	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U
Sand, Coarse	**0.5**	**1.6**	**0.7**	**1.1**	**0.5**	**0.6**	**0.4**	**0.7**	**0.3**
Sand, Very Coarse	**0.3**	**1.9**	**0.5**	**0.4**	**0.2**	**0.1**	**0.3**	**0.2**	**0.1**
Sand, Medium	**1.3**	**1.5**	**1.3**	**1.9**	**1.3**	**2.1**	**1.2**	**1.7**	**1.6**
Sand, Fine	**3.6**	**2.5**	**2.1**	**3.1**	**2**	**4.6**	**1.6**	**2.2**	**1.4**
Sand, Very Fine	**3.5**	**4.2**	**3.2**	**4.1**	**3.8**	**8**	**4.8**	**4.2**	**1.7**
Silt, Coarse	**8.5**	**10.7**	**6.9**	**11.1**	**12.6**	**15.1**	**16.8**	**13.4**	**9.3**
Silt, Medium	**14**	**12.9**	**14.3**	**13.9**	**15.5**	**15.2**	**16.4**	**15.4**	**12.8**
Silt, Fine	**16**	**14.3**	**15.3**	**15.3**	**18.3**	**15.5**	**16.2**	**16.7**	**15.9**
Silt, Very Fine	**17.6**	**15.5**	**17.1**	**16.2**	**17.4**	**14.3**	**15.1**	**16.3**	**18**
Clay, Coarse	**13.4**	**11.9**	**13.8**	**12.4**	**11**	**9.4**	**10.3**	**11.2**	**14.2**
Clay, Medium	**9.9**	**8.9**	**10.3**	**9.2**	**7.5**	**6.5**	**7.3**	**7.8**	**10.9**
Clay, Fine	**11.4**	**11.7**	**14.6**	**11.3**	**9.9**	**8.7**	**9.6**	**10.2**	**13.7**
Radioisotopes (pci/g)									
Cesium-137	**0.384**	**0.348**	**0.639**	**1.044**	**0.138**	0.074 U	**0.132**	**0.113**	**0.166**
Lead-210	**0.51**	**0.39**	**0.44**	**0.45**	**0.93**	**0.86**	**0.58**	**0.79**	**0.64**

Notes:
Bold = Detected result
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Table C-2
Geochronology Sediment Sampling Results

Location ID	GC-13	GC-13	GC-13	GC-13	GC-13	GC-13	GC-13	GC-13	GC-13
Sample ID	GC-13-20100202-S3032	GC-13-20100202-S3638	GC-13-20100202-S4244	GC-13-20100202-S4448	GC-13-20100202-S4850	GC-13-20100202-S5456	GC-13-20100202-S6062	GC-13-20100202-S6668	GC-13-20100202-S7274
Sample Date	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010	2/2/2010
Depth	30 - 32 cm	36 - 38 cm	42 - 44 cm	44 - 48 cm	48 - 50 cm	54 - 56 cm	60 - 62 cm	66 - 68 cm	72 - 74 cm
Conventional Parameters (pct)									
Total organic carbon	**2.68**	**2.49**	**2.19**	**2.72**	**2.34**	**1.73**	**3.3**	**2.23**	**2.06**
Total solids	**50**	**51.1**	**55.3**	**55.1**	**59**	**50.8**	**56**	**68.5**	**67.2**
Grain Size (pct)									
Gravel	0.1 U	0.1 U	0.1 U	**3**	**1.9**	0.1 U	0.1 U	0.1 U	**0.6**
Sand, Coarse	**0.2**	**0.5**	**0.8**	**1.7**	**3.1**	**0.4**	**1**	**4.5**	**6.2**
Sand, Very Coarse	**0.1**	**0.1**	**0.2**	**0.7**	**1**	**0.1**	**0.2**	**0.5**	**1.3**
Sand, Medium	**0.9**	**1.9**	**3.5**	**5**	**10.7**	**2.9**	**3.8**	**15.6**	**22.1**
Sand, Fine	**1.9**	**3.3**	**5.7**	**5.4**	**9.9**	**3.1**	**4.5**	**9.9**	**15.9**
Sand, Very Fine	**2.8**	**4.4**	**5**	**3.5**	**5.1**	**1.6**	**4**	**6.5**	**6.3**
Silt, Coarse	**10.9**	**12.3**	**9.9**	**10.5**	**7.7**	**2.6**	**9.8**	**10.1**	**7.2**
Silt, Medium	**13.5**	**13.5**	**12.4**	**11.3**	**9.6**	**7.1**	**12.5**	**10.4**	**7.7**
Silt, Fine	**16.1**	**15.3**	**14.6**	**13.3**	**11.7**	**12.4**	**15**	**10.8**	**8.2**
Silt, Very Fine	**17.8**	**16.3**	**15.7**	**14.4**	**12.8**	**18.9**	**16**	**10.6**	**8.2**
Clay, Coarse	**13.5**	**12.1**	**11.9**	**11.3**	**10**	**17.5**	**12.1**	**7.7**	**6**
Clay, Medium	**10**	**8.9**	**9**	**8.8**	**7.5**	**14.8**	**9.3**	**5.8**	**4.5**
Clay, Fine	**12.5**	**11.2**	**11.3**	**11.2**	**8.9**	**18.7**	**11.8**	**7.7**	**5.8**
Radioisotopes (pci/g)									
Cesium-137	**0.231**	**0.254**	**0.187**	**0.226**	**0.159**	**0.213**	**0.209**	**0.074**	**0.069**
Lead-210	**0.52**	**0.61**	**0.52**	**0.52**	**0.41**	**0.43**	**0.51**	**0.39**	**0.29**

Notes:
Bold = Detected result
U = Compound analyzed, but not detected above detection limit

Table C-2
Geochronology Sediment Sampling Results

Location ID	GC-13	GC-13	GC-14	GC-14	GC-14	GC-14	GC-14	GC-14	GC-14
Sample ID	GC-13-20100202-S7880	GC-13-20100202-S8486	GC-14-20100201-S0002	GC-14-20100201-S0608	GC-14-20100201-S1214	GC-14-20100201-S1820	GC-14-20100201-S2426	GC-14-20100201-S3032	GC-14-20100201-S3638
Sample Date	2/2/2010	2/2/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010
Depth	78 - 80 cm	84 - 86 cm	0 - 2 cm	6 - 8 cm	12 - 14 cm	18 - 20 cm	24 - 26 cm	30 - 32 cm	36 - 38 cm
Conventional Parameters (pct)									
Total organic carbon	**0.505**	**0.677**	**2.15**	**2.18**	**2.19**	**2.25**	**0.842**	**0.998**	**1.31**
Total solids	**72.7**	**79.8**	**54.7**	**59.9**	**60.4**	**61.5**	**80.1**	**77**	**75**
Grain Size (pct)									
Gravel	**0.3**	**0.3**	**0.3**	0.1 U	0.1 U	**0.2**	**24.4**	**1.3**	**0.3**
Sand, Coarse	**3.5**	**11**	**1.7**	**2.6**	**2.2**	**3.3**	**4.4**	**3.4**	**4.1**
Sand, Very Coarse	**0.8**	**2.1**	**0.3**	**0.3**	**0.1**	**0.7**	**2.2**	**0.7**	**0.8**
Sand, Medium	**30.5**	**37.4**	**13.4**	**16.6**	**18.2**	**17.8**	**21.8**	**28.3**	**29.5**
Sand, Fine	**24.5**	**23.9**	**13.1**	**10.8**	**14**	**13.4**	**26.2**	**35.8**	**33.9**
Sand, Very Fine	**7.5**	**6.1**	**6.8**	**4.4**	**5.9**	**5.5**	**8.8**	**11.1**	**10**
Silt, Coarse	**4.2**	**3.3**	**12.5**	**10.4**	**8.9**	**8.1**	**1.6**	**4.5**	**5.7**
Silt, Medium	**4.7**	**2.8**	**11.4**	**10.6**	**9.9**	**9.2**	**2**	**3.2**	**3.4**
Silt, Fine	**5.2**	**2.9**	**11.3**	**11.3**	**10.2**	**10.2**	**2.1**	**3.1**	**3.3**
Silt, Very Fine	**5.6**	**3.1**	**10.5**	**11.2**	**10.3**	**10.5**	**2.2**	**3**	**3.2**
Clay, Coarse	**4.6**	**2.5**	**7**	**8**	**7.6**	**7.9**	**1.7**	**2.2**	**2.3**
Clay, Medium	**3.8**	**2**	**5**	**5.9**	**5.5**	**5.8**	**1.2**	**1.5**	**1.5**
Clay, Fine	**4.7**	**2.7**	**6.7**	**7.9**	**7**	**7.5**	**1.5**	**1.9**	**2**
Radioisotopes (pci/g)									
Cesium-137	0.044 U	0.039 U	**0.082**	**0.098**	0.046 U	**0.119**	0.048 U	0.042 U	0.041 U
Lead-210	**0.16**	**0.12**	**0.55**	**0.44**	**0.63**	**0.48**	**0.13**	0.11 U	**0.15**

Notes:
Bold = Detected result
U = Compound analyzed, but not detected above detection limit

Table C-2
Geochronology Sediment Sampling Results

Location ID	GC-14	GC-14	GC-14	GC-14	GC-14	GC-14	GC-14	GC-14	GC-14
Sample ID	GC-14-20100201-S4244	GC-14-20100201-S4850	GC-14-20100201-S5456	GC-14-20100201-S6062	GC-14-20100201-S6668	GC-14-20100201-S7274	GC-14-20100201-S7880	GC-14-20100201-S8486	GC-14-20100201-S8690
Sample Date	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010
Depth	42 - 44 cm	48 - 50 cm	54 - 56 cm	60 - 62 cm	66 - 68 cm	72 - 74 cm	78 - 80 cm	84 - 86 cm	86 - 90 cm
Conventional Parameters (pct)									
Total organic carbon	**1.31**	**1.16**	**2.53**	**2.45**	**2.88**	**4.2**	**2.14**	**6.79**	**4.06**
Total solids	**73.5**	**67.9**	**62.1**	**51.2**	**51.2**	**46.8**	**58.2**	**41.7**	**53.8**
Grain Size (pct)									
Gravel	**0.7**	**0.5**	**0.1**	**0.1**	**1.9**	0.1 U	0.1 U	**0.3**	**0.5**
Sand, Coarse	**3.7**	**1.8**	**0.7**	**0.2**	**2.1**	**0.6**	**2.7**	**1.3**	**1.5**
Sand, Very Coarse	**1.2**	**0.4**	**0.2**	**0.1**	**1.8**	**0.2**	**0.4**	**0.6**	**0.5**
Sand, Medium	**30.3**	**13.6**	**6.6**	**0.8**	**4.5**	**7.4**	**20.1**	**7**	**12.1**
Sand, Fine	**36.5**	**18.3**	**13.1**	**2.4**	**7.8**	**9**	**13.1**	**5.7**	**9.2**
Sand, Very Fine	**7.8**	**9.4**	**9.7**	**3.1**	**8.8**	**3.3**	**2**	**2.5**	**2.5**
Silt, Coarse	**2.7**	**13.8**	**12.6**	**9**	**12.2**	**9.4**	**0.8**	**7.6**	**5.4**
Silt, Medium	**3.2**	**9.4**	**12.4**	**13.6**	**13.1**	**11.4**	**7.5**	**12.2**	**10.2**
Silt, Fine	**3.3**	**8**	**11.7**	**16.6**	**13.7**	**13.6**	**10.5**	**14.5**	**12.9**
Silt, Very Fine	**3.4**	**7.6**	**11.8**	**18.2**	**13.4**	**15.6**	**13.2**	**17**	**15.1**
Clay, Coarse	**2.7**	**6.1**	**8.2**	**13.9**	**9**	**12**	**11.5**	**12.8**	**12**
Clay, Medium	**2**	**4.8**	**5.7**	**10**	**5.5**	**8.3**	**9**	**8.8**	**8.6**
Clay, Fine	**2.6**	**6.4**	**7.3**	**12**	**6.3**	**9.2**	**9.2**	**9.6**	**9.5**
Radioisotopes (pci/g)									
Cesium-137	**0.056**	**0.184**	**0.575**	**0.381**	**0.289**	**0.193**	**0.254**	**0.19**	**0.14**
Lead-210	0.11 U	**0.26**	**0.49**	**0.42**	**0.25**	**0.38**	**0.38**	**0.35**	**0.35**

Notes:
Bold = Detected result
U = Compound analyzed, but not detected above detection limit

Table C-2
Geochronology Sediment Sampling Results

Location ID	GC-15	GC-15	GC-15	GC-15	GC-15	GC-15	GC-15	GC-15	GC-15
Sample ID	GC-15-20100201-S0002	GC-15-20100201-S0608	GC-15-20100201-S1214	GC-15-20100201-S1820	GC-15-20100201-S2426	GC-15-20100201-S3032	GC-15-20100201-S3638	GC-15-20100201-S4244	GC-15-20100201-S4850
Sample Date	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010
Depth	0 - 2 cm	6 - 8 cm	12 - 14 cm	18 - 20 cm	24 - 26 cm	30 - 32 cm	36 - 38 cm	42 - 44 cm	48 - 50 cm
Conventional Parameters (pct)									
Total organic carbon	**2.31**	**2.68**	**1.87**	**2.24**	**1.74**	**0.594**	**0.578**	**3.04**	**4.05**
Total solids	**55.1**	**48.4**	**52.3**	**52.8**	**53.6**	**48**	**55.1**	**52.5**	**41.6**
Grain Size (pct)									
Gravel	**0.2**	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	**0.6**
Sand, Coarse	**3.2**	**0.5**	**1**	**1.1**	**0.1**	**0.1**	**0.1**	**0.5**	**0.7**
Sand, Very Coarse	**0.4**	**0.1**	**0.2**	**0.1**	**0.1**	**0.1**	0.1 U	**0.4**	**0.1**
Sand, Medium	**14**	**2.7**	**8**	**6.8**	**1.8**	**1.3**	**4.5**	**2.3**	**2.9**
Sand, Fine	**9.6**	**2.6**	**7.6**	**10**	**6.3**	**7.4**	**18.8**	**3.8**	**4.2**
Sand, Very Fine	**5.7**	**2.7**	**5.4**	**6.7**	**8.7**	**11.1**	**13.5**	**4.6**	**3.5**
Silt, Coarse	**6.8**	**10.2**	**6.3**	**4.3**	**9.4**	**9.7**	**8.5**	**12.4**	**10.7**
Silt, Medium	**10.9**	**14.1**	**11.3**	**10.5**	**12.4**	**12.7**	**9.6**	**13.3**	**14.2**
Silt, Fine	**12.3**	**16**	**14.4**	**12.9**	**13.9**	**13.3**	**9.9**	**14.2**	**16.1**
Silt, Very Fine	**12.6**	**16.7**	**15.3**	**15.3**	**15.1**	**13.4**	**10.5**	**16.1**	**17.4**
Clay, Coarse	**9.1**	**12.5**	**11.6**	**12.1**	**11.8**	**10.9**	**8.5**	**12.4**	**12.4**
Clay, Medium	**6.7**	**9.4**	**8.6**	**9.4**	**9.1**	**9**	**7**	**9**	**8.2**
Clay, Fine	**8.4**	**12.5**	**10.4**	**10.8**	**11.4**	**11.1**	**9.2**	**11**	**9**
Radioisotopes (pci/g)									
Cesium-137	**0.077**	**0.174**	**0.189**	**0.181**	**0.136**	0.063 U	0.051 U	**0.258**	**0.289**
Lead-210	**0.6**	**0.67**	**0.46**	**0.5**	**0.3**	**0.35**	**0.25**	**0.35**	**0.52**

Notes:
Bold = Detected result
U = Compound analyzed, but not detected above detection limit

Table C-2
Geochronology Sediment Sampling Results

Location ID	GC-15	GC-15	GC-15	GC-15	GC-15	GC-15	GC-15	GC-16	GC-16
Sample ID	GC-15-20100201-S5456	GC-15-20100201-S6062	GC-15-20100201-S6668	GC-15-20100201-S7274	GC-15-20100201-S7880	GC-15-20100201-S8486	GC-15-20100201-S8690	GC-16-20100201-S0002	GC-16-20100201-S0608
Sample Date	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010
Depth	54 - 56 cm	60 - 62 cm	66 - 68 cm	72 - 74 cm	78 - 80 cm	84 - 86 cm	86 - 90 cm	0 - 2 cm	6 - 8 cm
Conventional Parameters (pct)									
Total organic carbon	**3.63**	**1.79**	**3.76**	**4.28**	**3.74**	**4.39**	**5.35**	**3.18**	**2.8**
Total solids	**46.6**	**45.2**	**45.1**	**43.1**	**47.8**	**46.2**	**47.7**	**48.5**	**51.5**
Grain Size (pct)									
Gravel	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	**0.7**	0.1 U
Sand, Coarse	**0.7**	**0.3**	**0.5**	**0.5**	**0.6**	**0.5**	**0.4**	**0.9**	**0.7**
Sand, Very Coarse	**0.2**	**0.1**	**0.1**	**0.2**	**0.2**	**0.2**	**0.2**	**0.1**	**0.2**
Sand, Medium	**1.4**	**1.2**	**1.4**	**1.2**	**2.4**	**0.8**	**0.7**	**3.3**	**2.6**
Sand, Fine	**2.5**	**2.2**	**1.9**	**2**	**2.5**	**0.9**	**1.1**	**3.7**	**4.3**
Sand, Very Fine	**3.6**	**3.2**	**2.6**	**2.1**	**1.7**	**1.2**	**1.5**	**4.9**	**4.9**
Silt, Coarse	**12.1**	**11.7**	**9.5**	**10.1**	**8.4**	**8.8**	**9**	**14.4**	**14.1**
Silt, Medium	**14.4**	**14.4**	**13.8**	**13.3**	**12.9**	**11.4**	**14.6**	**14**	**14.8**
Silt, Fine	**15.4**	**16.6**	**16**	**15.7**	**15.4**	**14.3**	**16.4**	**15.1**	**15.3**
Silt, Very Fine	**16.9**	**17.9**	**18.4**	**18.7**	**18.2**	**17.9**	**18.1**	**14.8**	**14.8**
Clay, Coarse	**12.8**	**12.8**	**13.8**	**14.3**	**14.4**	**14.9**	**14.4**	**10.3**	**10.3**
Clay, Medium	**9.1**	**8.9**	**10**	**10.2**	**10.6**	**12.1**	**10.9**	**7.4**	**7.5**
Clay, Fine	**10.9**	**10.7**	**11.9**	**11.8**	**12.6**	**16.9**	**12.7**	**10.5**	**10.4**
Radioisotopes (pci/g)									
Cesium-137	**0.35**	**0.576**	**0.511**	**0.369**	**0.199**	**0.261**	**0.292**	**0.087**	**0.121**
Lead-210	**0.35**	**0.55**	**0.45**	**0.42**	**0.46**	**0.53**	**0.35**	**0.91**	**0.72**

Notes:
Bold = Detected result
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Table C-2
Geochronology Sediment Sampling Results

Location ID	GC-16	GC-16	GC-16	GC-16	GC-16	GC-16	GC-16	GC-16	GC-16
Sample ID	GC-16-20100201-S1214	GC-16-20100201-S1820	GC-16-20100201-S2426	GC-16-20100201-S3032	GC-16-20100201-S3638	GC-16-20100201-S4244	GC-16-20100201-S4850	GC-16-20100201-S5456	GC-16-20100201-S6062
Sample Date	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010
Depth	12 - 14 cm	18 - 20 cm	24 - 26 cm	30 - 32 cm	36 - 38 cm	42 - 44 cm	48 - 50 cm	54 - 56 cm	60 - 62 cm
Conventional Parameters (pct)									
Total organic carbon	**2.55**	**0.388**	**0.341**	**0.268**	**0.331**	**0.711**	**0.083**	**0.845**	**3.59**
Total solids	**53.1**	**74.1**	**69.5**	**73**	**69.1**	**74.4**	**81.7**	**61.2**	**52.5**
Grain Size (pct)									
Gravel	0.1 U	0.1 U	**3**	0.1 U	**0.2**	**0.2**	0.1 U	0.1 U	0.1 U
Sand, Coarse	**0.9**	**0.3**	**3.7**	**1.9**	**0.5**	**6**	**7.4**	**0.7**	**1.3**
Sand, Very Coarse	**0.2**	0.1 U	**3.1**	**0.3**	**0.2**	**1.4**	**0.7**	**0.1**	**0.1**
Sand, Medium	**4**	**6.3**	**11.6**	**25.7**	**10.4**	**30.1**	**39.3**	**8.7**	**6.1**
Sand, Fine	**6.4**	**34.8**	**22.1**	**37.6**	**37.2**	**25.7**	**30.2**	**20.3**	**7.2**
Sand, Very Fine	**4.7**	**25.1**	**15.4**	**11.1**	**18.8**	**8.5**	**6**	**11.8**	**4.5**
Silt, Coarse	**7.4**	**5.5**	**3.8**	**1.7**	**5.9**	**2.1**	**2.7**	**4.7**	**10.3**
Silt, Medium	**10.5**	**5.4**	**4.9**	**2.6**	**4.3**	**4**	**2.2**	**6.9**	**12.4**
Silt, Fine	**13.1**	**3.6**	**5**	**2.7**	**4.2**	**4.2**	**2.5**	**7.6**	**13.5**
Silt, Very Fine	**15.4**	**4**	**6.3**	**3.5**	**4.5**	**4.8**	**2.7**	**9.3**	**15.2**
Clay, Coarse	**12.6**	**3.9**	**5.9**	**3.3**	**3.9**	**3.9**	**2.2**	**8.3**	**11.3**
Clay, Medium	**10.1**	**3.8**	**5.5**	**3.2**	**3.5**	**3.4**	**1.7**	**7.8**	**7.9**
Clay, Fine	**14.8**	**7.1**	**9.6**	**6.4**	**6.5**	**5.7**	**2.3**	**13.8**	**10.1**
Radioisotopes (pci/g)									
Cesium-137	**0.202**	0.043 U	0.035 U	0.037 U	0.039 U	0.04 U	0.04 U	**0.101**	**0.318**
Lead-210	**0.43**	**0.28**	**0.24**	**0.15**	**0.16**	**0.13**	0.09 U	**0.25**	**0.48**

Notes:
Bold = Detected result
U = Compound analyzed, but not detected above detection limit

Table C-2
Geochronology Sediment Sampling Results

Location ID	GC-16	GC-16	GC-16	GC-16	GC-18	GC-18	GC-18	GC-18	GC-18
Sample ID	GC-16-20100201-S6668	GC-16-20100201-S7274	GC-16-20100201-S7880	GC-16-20100201-S8486	GC-18-20100201-S0002	GC-18-20100201-S0608	GC-18-20100201-S1214	GC-18-20100201-S1820	GC-18-20100201-S2426
Sample Date	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010
Depth	66 - 68 cm	72 - 74 cm	78 - 80 cm	84 - 86 cm	0 - 2 cm	6 - 8 cm	12 - 14 cm	18 - 20 cm	24 - 26 cm
Conventional Parameters (pct)									
Total organic carbon	**3.87**	**2.68**	**3.02**	**4.72**	**2.9**	**2.46**	**2.78**	**2.79**	**1.98**
Total solids	**57**	**54.6**	**50**	**50.6**	**50.1**	**52.6**	**51**	**51.9**	**53.5**
Grain Size (pct)									
Gravel	0.1 U	0.1 U	0.1 U	**0.3**	0.1 U	**32.1**	0.1 U	0.1 U	**4.2**
Sand, Coarse	**1.2**	**1**	**0.5**	**2**	**4.4**	**4.2**	**1.4**	**0.9**	**0.7**
Sand, Very Coarse	**0.3**	**0.1**	**0.1**	**0.6**	**1.6**	**0.7**	**0.8**	**0.3**	**0.7**
Sand, Medium	**5**	**3.5**	**1.2**	**4.1**	**10.5**	**10.5**	**6.8**	**5**	**1.8**
Sand, Fine	**8**	**3.9**	**1.2**	**3.4**	**5.9**	**5.3**	**5.4**	**5.6**	**2.7**
Sand, Very Fine	**5.2**	**4.2**	**1.1**	**2.6**	**2.8**	**2.4**	**2.8**	**3.6**	**3.4**
Silt, Coarse	**8**	**6.4**	**4.2**	**10.7**	**9.4**	**6.7**	**13.1**	**10.4**	**10.7**
Silt, Medium	**10.8**	**11.5**	**10.1**	**14.3**	**12.4**	**7.6**	**14**	**12.5**	**13.3**
Silt, Fine	**12.8**	**14.3**	**13.5**	**14.9**	**14**	**8.3**	**15.5**	**14.8**	**15.6**
Silt, Very Fine	**15.3**	**16.7**	**18.4**	**15.5**	**14**	**7.9**	**14.5**	**16.2**	**16.2**
Clay, Coarse	**12.4**	**13.5**	**16.9**	**11.6**	**9.7**	**5.4**	**9.9**	**11.8**	**11.8**
Clay, Medium	**9.3**	**10.5**	**14.7**	**8.2**	**6.8**	**3.8**	**7.2**	**8.5**	**8.5**
Clay, Fine	**11.7**	**14.2**	**18.2**	**12**	**8.6**	**5**	**8.7**	**10.3**	**10.5**
Radioisotopes (pci/g)									
Cesium-137	**0.344**	**0.402**	**0.278**	**0.148**	**0.1**	**0.111**	**0.176**	**0.223**	**0.212**
Lead-210	**0.39**	**0.26**	**0.4**	**0.29**	**0.85**	**0.75**	**0.59**	**0.72**	**0.47**

Notes:
Bold = Detected result
U = Compound analyzed, but not detected above detection limit

Table C-2
Geochronology Sediment Sampling Results

Location ID	GC-18	GC-18	GC-18	GC-18	GC-18	GC-18	GC-18	GC-18	GC-18
Sample ID	GC-18-20100201-S3032	GC-18-20100201-S3638	GC-18-20100201-S4244	GC-18-20100201-S4850	GC-18-20100201-S5456	GC-18-20100201-S6062	GC-18-20100201-S6668	GC-18-20100201-S7274	GC-18-20100201-S7880
Sample Date	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010	2/1/2010
Depth	30 - 32 cm	36 - 38 cm	42 - 44 cm	48 - 50 cm	54 - 56 cm	60 - 62 cm	66 - 68 cm	72 - 74 cm	78 - 80 cm
Conventional Parameters (pct)									
Total organic carbon	**2.32**	**3.03**	**3.24**	**4.11**	**2.23**	**5.8**	**3.33**	**3.15**	**5.11**
Total solids	**51.6**	**54.2**	**52.3**	**48.6**	**51.7**	**39.5**	**36.6**	**44.6**	**44.4**
Grain Size (pct)									
Gravel	**10.3**	0.1 U	0.1 U	0.1 U	**3.1**	0.1 U	0.1 U	0.1 U	**0.1**
Sand, Coarse	**1.5**	**0.7**	0.1 U	**0.1**	**3.3**	**0.7**	**0.4**	**0.4**	**0.7**
Sand, Very Coarse	**0.6**	**0.1**	0.1 U	0.1 U	**2.1**	**0.1**	0.1 U	**0.1**	**0.2**
Sand, Medium	**4.2**	**6**	**0.3**	**0.5**	**2.5**	**3.1**	**2.1**	**1**	**2.7**
Sand, Fine	**3.4**	**7.3**	**1.1**	**1.5**	**2.4**	**4.7**	**4.3**	**1.6**	**3.9**
Sand, Very Fine	**3**	**4.7**	**3.3**	**5.6**	**4.8**	**4.5**	**5.3**	**2**	**2.8**
Silt, Coarse	**6.8**	**11.1**	**14.2**	**16.5**	**13.1**	**12.8**	**17**	**10.6**	**12.4**
Silt, Medium	**9.2**	**13.1**	**15.2**	**16.5**	**15.2**	**15.8**	**19.5**	**14.4**	**14.2**
Silt, Fine	**12.2**	**14**	**16.4**	**16**	**14.9**	**16.6**	**17.4**	**16.7**	**15.6**
Silt, Very Fine	**14.9**	**14.4**	**16.2**	**15.5**	**13.9**	**16.4**	**14.1**	**18.8**	**17.4**
Clay, Coarse	**12.1**	**10.7**	**12.1**	**11.2**	**9.8**	**11.1**	**8.6**	**14.1**	**12.5**
Clay, Medium	**9.7**	**7.9**	**9.2**	**7.7**	**6.8**	**6.8**	**5**	**9.6**	**8.3**
Clay, Fine	**12**	**9.8**	**11.9**	**8.9**	**8.2**	**7.4**	**6.5**	**10.6**	**9.2**
Radioisotopes (pci/g)									
Cesium-137	**0.156**	**0.162**	**0.175**	**0.217**	**0.085**	**0.208**	**0.198**	**0.34**	**0.446**
Lead-210	**0.58**	**0.43**	**0.45**	**0.47**	**0.53**	**0.41**	**0.31**	**0.44**	**0.39**

Notes:
Bold = Detected result
U = Compound analyzed, but not detected above detection limit

Table C-2
Geochronology Sediment Sampling Results

Location ID	GC-18	GC-18	GC-19A	GC-19A	GC-19A	GC-19A	GC-19A	GC-19A
Sample ID	GC-18-20100201-S8486	GC-18-20100201-S8690	GC-19A-20100203-S0002	GC-19A-20100203-S0608	GC-19A-20100203-S1214	GC-19A-20100203-S1820	GC-19A-20100203-S2426	GC-19A-20100203-S3032
Sample Date	2/1/2010	2/1/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010
Depth	84 - 86 cm	86 - 90 cm	0 - 2 cm	6 - 8 cm	12 - 14 cm	18 - 20 cm	24 - 26 cm	30 - 32 cm
Conventional Parameters (pct)								
Total organic carbon	**4.27**	**5.4**	**2.78**	**3.19**	**3.36**	**3.07**	**1.85**	**7.32**
Total solids	**47.3**	**45.1**	**54.1**	**46.8**	**50.4**	**52.9**	**55.1**	**47**
Grain Size (pct)								
Gravel	**0.2**	**0.1**	**15.9**	0.1 U	0.1 U	**22.4**	**1.1**	**6.3**
Sand, Coarse	**0.6**	**0.6**	**5.7**	**1.5**	**0.9**	**1.4**	**3.5**	**4.1**
Sand, Very Coarse	**0.2**	**0.2**	**2.9**	**1**	**0.5**	**0.7**	**1.2**	**2.9**
Sand, Medium	**1.2**	**1.3**	**8.9**	**3**	**2.3**	**4**	**10.1**	**10.8**
Sand, Fine	**1.6**	**2.9**	**4**	**2.5**	**2.4**	**4.2**	**6.2**	**8.3**
Sand, Very Fine	**1.8**	**3.2**	**2.9**	**3.6**	**3.1**	**4.3**	**6.3**	**5.8**
Silt, Coarse	**10.9**	**13.5**	**7.7**	**13.9**	**9.7**	**9.6**	**11.4**	**11.9**
Silt, Medium	**14.2**	**17.4**	**9**	**14.1**	**13.2**	**9.5**	**11.1**	**10.9**
Silt, Fine	**16.4**	**16.4**	**10.4**	**14.8**	**15.4**	**10.6**	**12**	**10.4**
Silt, Very Fine	**18.4**	**14.3**	**10.9**	**15.4**	**16.8**	**11.1**	**12.1**	**10**
Clay, Coarse	**13.6**	**12.5**	**8.2**	**11.6**	**13.2**	**8.5**	**9.3**	**7.2**
Clay, Medium	**9.4**	**8.9**	**6.1**	**8.4**	**10.2**	**6.4**	**7.2**	**5.2**
Clay, Fine	**11.5**	**8.5**	**7.3**	**10.2**	**12.3**	**7.5**	**8.7**	**6.3**
Radioisotopes (pci/g)								
Cesium-137	**0.542**	**0.57**	**0.111**	**0.116**	**0.207**	**0.267**	**0.103**	**0.064**
Lead-210	**0.57**	**0.58**	**0.57**	**0.77**	**0.81**	**0.67**	**0.26**	**0.22**

Notes:
Bold = Detected result
U = Compound analyzed, but not detected above detection limit

Table C-2
Geochronology Sediment Sampling Results

Location ID	GC-19A	GC-19A	GC-19A	GC-19A	GC-19A	GC-19A	GC-20	GC-20	GC-20
Sample ID	GC-19A-20100203-S3638	GC-19A-20100203-S4244	GC-19A-20100203-S4448	GC-19A-20100203-S4850	GC-19A-20100203-S5456	GC-19A-20100203-S6062	GC-20-20100202-S0002	GC-20-20100202-S0608	GC-20-20100202-S1214
Sample Date	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/3/2010	2/2/2010	2/2/2010	2/2/2010
Depth	36 - 38 cm	42 - 44 cm	44 - 48 cm	48 - 50 cm	54 - 56 cm	60 - 62 cm	0 - 2 cm	6 - 8 cm	12 - 14 cm
Conventional Parameters (pct)									
Total organic carbon	**5.15**	**2.14**	**4.61**	**3.56**	**5.29**	**3.87**	**3.19**	**2.39**	**4.91**
Total solids	**57.6**	**55.1**	**46.8**	**44.6**	**44.6**	**45.8**	**56.5**	**64.1**	**54.7**
Grain Size (pct)									
Gravel	**6.5**	**0.1**	0.1 U	**0.1**	0.1 U	**0.2**	**1.6**	**3.6**	**8.3**
Sand, Coarse	**6.3**	**1.7**	**2.9**	**2.4**	**2**	**1.3**	**9.6**	**9.6**	**12.4**
Sand, Very Coarse	**2.4**	**0.5**	**0.9**	**0.9**	**0.6**	**0.9**	**3.2**	**3.3**	**4**
Sand, Medium	**17.5**	**4.1**	**5.1**	**4.1**	**5.3**	**2**	**19.5**	**21.5**	**21.3**
Sand, Fine	**12.4**	**3.5**	**5.4**	**4.6**	**4.2**	**2.1**	**10.1**	**14.3**	**11**
Sand, Very Fine	**8.3**	**7.2**	**5.7**	**5.6**	**3.6**	**2.2**	**2.9**	**3.1**	**2.7**
Silt, Coarse	**9.6**	**18.6**	**10.9**	**11.4**	**10.6**	**9.8**	**6.3**	**3.4**	**6.9**
Silt, Medium	**8.3**	**13.2**	**13.4**	**13.7**	**13.2**	**12.3**	**7**	**4.9**	**7.5**
Silt, Fine	**7.6**	**12.6**	**14.7**	**15**	**14.9**	**15.4**	**8.6**	**6.8**	**7.7**
Silt, Very Fine	**7.5**	**12.9**	**15.3**	**15.4**	**16.3**	**18.2**	**10.4**	**9**	**7.1**
Clay, Coarse	**5.4**	**9.8**	**10.8**	**11**	**11.9**	**14.1**	**8.1**	**7.4**	**4.6**
Clay, Medium	**3.8**	**7.2**	**7.1**	**7.3**	**8**	**10**	**5.7**	**5.7**	**2.9**
Clay, Fine	**4.5**	**8.7**	**7.8**	**8.5**	**9.6**	**11.8**	**7**	**7.5**	**3.7**
Radioisotopes (pci/g)									
Cesium-137	**0.072**	**0.191**	**0.274**	**0.213**	**0.522**	**0.406**	**0.077**	0.05 U	**0.074**
Lead-210	**0.24**	**0.36**	**0.43**	**0.34**	**0.45**	**0.5**	**0.92**	**0.61**	**0.66**

Notes:
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U = Compound analyzed, but not detected above detection limit

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MEMORANDUM

To:	Ravi Sanga, EPA	**Date:**	March 3, 2010
From:	Tom Wang and Dan Berlin, Anchor QEA	**Project:**	060003-01
Re:	East Waterway Sediment Transport Characterization – Core Collection and Processing Summary		

This memorandum summarizes the core collection and processing activities that occurred as part of the East Waterway Sediment Transport Characterization for the Supplemental Remedial Investigation/Feasibility Study (SRI/FS). Descriptions of sampling deviations, core collection and processing activities, and sampling scheme are provided below.

SUMMARY OF SAMPLING DEVIATIONS

All collection, processing, and sampling activities were performed in accordance with the Quality Assurance Project Plan (Anchor QEA 2009), with the exception of the deviations approved by EPA on January 22, 2010. These deviations will be summarized in the forthcoming Data Report and included the following:

- Change in processing technique from hydraulic extruder jack to longitudinal cutting in order to better preserve the sediment profile and increase sample interval accuracy.
- Clarification regarding compaction correction such that field sampling would be conducted using recovered depths (ex situ) and compaction corrections would be applied later during the data analysis stage.

SUMMARY OF CORE COLLECTION AND PROCESSING

Eighteen sediment cores were collected by divers using manually operated slide-hammer methodology in order to minimize disturbance to the sediment. Cores were collected from January 25 to February 1, 2010. Cores were processed, logged, and sampled from February 1 to February 3, 2010. The collected cores included GC-01, GC-02, GC-03, GC-05, GC-06, GC-07, GC-08, GC-09, GC-10, GC-11, GC-12, GC-13, GC-14, GC-15, GC-16, GC-18, GC-19, and GC-20. An additional four cores were proposed (GC-04, GC-17, GC-21, and GC-22), but were unable to be collected due to difficulties penetrating into the substrate. Figure 1 depicts the location of each collected core, as well as the location of the four cores that were unable

to be collected (shown in gray). Table 1 summarizes the recovered sediment length and sampled length for the 18 cores that were collected, as well as a summary of the number of attempts and observations made regarding the subsurface texture for each of the four cores that were unable to be collected. For each of the four cores not collected, the diver attempted multiple times to retrieve an acceptable core; however, dense substrate near the surface at each of these locations prevented penetration. The diver also searched in the vicinity of the target core location for suitable substrate to core, but was unable to find suitable coring locations in the vicinity of GC-04, GC-17, GC-21, and GC-22.

It should be noted that the absence of soft substrate in the vicinity of each of these four core locations suggests the absence of recent sediment deposition, making it unlikely that radioisotope analysis of sediment in these areas would provide any useful sediment accumulation rates. These cores were identified as low-priority cores based on the low likelihood that they would provide useful sediment accumulation rate information.

Table 1
Summary of East Waterway Sediment Characterization Cores

Station ID	Collection Attempts[2]	Core Collection Notes	Core Quality[1]	Length Processed (cm)	Bottom Sample Depth (cm)
GC-01	1	Successful collection, dense substrate prevented full penetration	good	86.5	86
GC-02	1	Short core, dense substrate prevented full penetration	good	44	42
GC-03	3	Short core, equipment malfunction prevented full penetration on first attempt; core tube broke on second attempt; third attempt yielded <1 foot of disturbed sediment. Restricted access from Coast Guard prevented recollection. The core from the first attempt was processed and sampled.	good	30	30
GC-04	1	Dense substrate prevented collection (e.g., sand substrate), no recent sediment deposition	not collected	0	0
GC-05	1	Successful collection	good	88	88
GC-06	1	Successful collection, dense substrate prevented full penetration	good	76	76
GC-07	1	Successful collection	good	115	90

Station ID	Collection Attempts[2]	Core Collection Notes	Core Quality[1]	Length Processed (cm)	Bottom Sample Depth (cm)
GC-08	2	First attempt core was stuck in sediment after retrieval coupling broke; core extracted during second attempt	fair	83	82
GC-09	1	Successful collection	good	105	90
GC-10	1	Successful collection	good	92	90
GC-11	1	Successful collection, dense substrate prevented full penetration (sand and wood)	good	77	76
GC-12	1	Successful collection	good	91	90
GC-13	1	Successful collection	good	107	90
GC-14	1	Successful collection	good	91	90
GC-15	1	Successful collection	good	99	90
GC-16	1	Successful collection	good	104	90
GC-17	1	Short core (<30 cm) due to dense substrate, but core lost when core barrel failed on extraction, diver observed vessel scour (sand substrate); no recent sediment deposition	not collected	0	0
GC-18	1	Successful collection	good	100	90
GC-19	2	Two cores were collected (A and B). Core A may have experienced pile driving due to presence of wood below 33 inches, but upper interval is likely intact. A second collection (Core B) was partially transported horizontally, which may have compromised the sediment structure. During processing it was noted that Core A was intact and did not show any signs of pile driving; Core B was slightly disturbed. Based on processing observations, Core A was submitted for sampling.	good (A), disturbed (B)	65 (A) 89 (B)	64 (A) 88 (B)
GC-20	3	Successful collection, during processing it was noted that the sidewalls were encased with broken shells in the top two units; the sidewalls were not sampled	poor	17	16
GC-21	1	Diver noted impenetrable armoring with rock, shell, and debris; no recent sediment deposition	not collected	0	0
GC-22	1	Diver noted impenetrable armoring with rock and shells below approx. 1 foot of silty sand; no recent sediment deposition	not collected	0	0

Notes:

1. Core quality was assessed during processing after settling.
2. Number of times diver descended and surfaced. For cores unable to be collected, diver tried several times to acquire a core before surfacing.

SUMMARY OF SAMPLING APPROACH

A recommended tiered sampling approach is presented in Figure 1 based on field observations, presence of thick layers of undisturbed recent sediment deposition, and spatial location of collected cores. This sampling scheme prioritizes samples to be analyzed based on a three-tiered approach. Field samples were triggered for analysis as follows:

Tier #1 Samples (analyzed immediately):

- Cores include: GC-05, GC-09, GC-11, GC-12, GC-13, GC-14, GC-15, GC-16, GC-18, GC-19(A), and GC-20
- Sample intervals: triggered every 6 cm to a depth of 90 cm below mudline (or to refusal)
- Tier #1 Rationale:
    1. Core located outside of areas where propwash would be a significant factor in mixing
    2. Core located in an area where a high percent of fines is observed (potential deposition area)
    3. Core located within the sill area because no data are currently available in this location

Tier #2 Samples (analyzed second depending on Tier #1 results, prioritized vertically):

- Cores include: GC-02, GC-08, and GC-10
- Sample intervals: triggered every 6 cm to a depth of 48 cm below mudline (or to refusal); depending on results, these could be triggered from 48 to 90 cm below mudline (or to refusal)
- Tier #2 Rationale:
    1. Core located in slip area where propwash is anticipated to be less of a disturbance
    2. Core located in an area where a high percent of fines is observed (potential deposition area)

Tier #3 Samples (analyzed last if needed, prioritized vertically):

- Cores include: GC-01, GC-03, GC-06, and GC-07
- Sample intervals: triggered every 6 cm to a depth of 48 cm below mudline (or to refusal); depending on results, these could be triggered from 48 to 90 cm below mudline (or to refusal)
- Tier #3 Rationale:
    1. Core located in areas where propwash is expected to be a significant factor in subsurface mixing
    2. Core located in an area where a low percent of fines is observed

Analytical results from the geochronology testing laboratory will be received over the next several months. The East Waterway Group will summarize and provide the analytical results to EPA as data become available. Conference calls will be scheduled to discuss the analytical results, and to discuss the merits of conducting additional analysis of archived samples. Please contact us if you have any questions regarding this information.

Geochronology Core Profiles

C.1 SUMMARY

Cesium-137 (Cs-137) and Lead-210 (Pb-210) profiles were analyzed to better understand net sedimentation rates within the East Waterway (EW). The results of this evaluation are presented in the subsections below, organized by core location. Several physical, chemical, and biological factors affect these radioisotope profiles to various extents and, thus, introduce uncertainty into the net sedimentation rates estimated from these data. Potential factors affecting the estimated net sedimentation rates are discussed in Section 3.4 in the main body of the report. To account for these uncertainties, best estimates (where possible) and ranges of estimated net sedimentation rates are reported. Stations were grouped into areas based on location along the EW.

C.1.1 Core GC-01

This core was collected at the mouth of the EW in the vicinity of Harbor Island. Core GC-01 contained intact strata of very sandy silt, which is not the preferred substrate for radioisotope analysis. Core GC-01 was not analyzed based on the low data quality of adjacent core locations. Samples were archived as part of Tier 3.

C.1.2 Core GC-02

This core was collected from the mouth of the EW near the mouth of Slip 36. Core GC-02 had low recovery (73%) as a result of slow coring to refusal at 36 inches below mudline. This core contained primarily fine sandy silt and silty fine sand with gravel-sized asphalt pieces at depth. Core GC-02 was analyzed for Pb-210, Cs-137, total solids (TS), total organic carbon (TOC), and grain size as part of the Tier 2 testing group.

Evaluation of the Cs-137 and Pb-210 data was inconclusive due to low recovery. No Cs-137 peak signifying 1963 was detected, and the Pb-210 regression analysis resulted in a low correlation R^2 value of 0.21. The TOC and TS measurements are relatively uniform throughout the core, suggesting that these sediments have not experienced significant disturbance.

C.1.3 Core GC-03

This core was collected near the mouth of the EW in the middle of the waterway. Core GC-03 was not selected for radioisotope analysis based on poor recovery (56%) after three attempts and its proximity to core locations with poor data quality. This core contained primarily silt that grades to silty fine sand. Samples were archived as part of Tier 3.

C.1.4 Core GC-04

This core was attempted once near the mouth of the EW in the vicinity of Harbor Island. The core was not able to penetrate the dense fine sand at the mudline and encountered refusal. This location was not re-attempted based on the density of the substrate and available collection methods.

C.1.5 Core GC-05

This core was collected on the north end of the EW in the middle of the waterway. Core GC-05 had high recovery (96%), contained alternating beds of silty sand and sandy silt, and was analyzed for Pb-210, Cs-137, TS, TOC, and grain size as part of the Tier 1 testing group.

Evaluation of the Cs-137 data was inconclusive, with no 1963 peak identified and all activities below detection limits. The absence of a Cs-137 peak suggests that either it resides within a sample interval that was not analyzed, below the depth of the core, or that this area has experienced disturbance. Pb-210 regression analysis resulted in an R^2 value of 0.78 and a sedimentation range of 0.26 to 0.67 centimeters per year (cm/yr). The TOC measurements are relatively uniform throughout the core. TS measurements vary at 54 to 62 cm, suggesting a slight disturbance. Sediment grain sizes throughout this core vary in small layers, signifying short-term episodic disturbances of sand deposition above the lower alluvium.

C.1.6 Core GC-06

This core was collected on the north end of the EW in the middle of the waterway. Core GC-06 was not selected for radioisotope analysis based on an assumption that this core would likely exhibit the low data quality characteristic of adjacent core locations. This core contained homogenous sandy silt and was archived as part of Tier 3.

C.1.7 Core GC-07

This core was collected on the north end of the EW in the middle of the waterway. Core GC-07 was not selected for radioisotope analysis based on the assumption that this core would likely exhibit the low data quality characteristic of adjacent core locations. This core contained silt with trace sand and was archived as part of Tier 3.

C.1.8 Core GC-08

This core was collected on the north end of the EW in the vicinity of Harbor Island. Core GC-08 was attempted twice; the initial core was lost due to barrel failure. The accepted core had an adequate recovery (82%) and consisted of silt with increasing sand content at depth. Core GC-08 was analyzed for Pb-210, Cs-137, TS, TOC, and grain size as part of the Tier 2 testing group.

Evaluation of the Cs-137 data was inconclusive, with no 1963 peak identified and relatively low activities ranging from 0.03 U to 0.1 picocuries per gram dry weight (pCi/g dw). The absence of a Cs-137 peak suggests that either it resides within a sample interval that was not analyzed, below the depth of the core, or that this area has experienced disturbance. Pb-210 regression analysis resulted in an R^2 value of 0.92 and a sedimentation range of 0.20 to 0.48 cm/yr. The TOC measurements vary down the length of the core with intervals above 30 cm greater than 1.0% and lower intervals ranging from 0.1% to 0.86%, corresponding to a lower percentage of fines. TS measurements are relatively uniform throughout the core. Sediment grain sizes throughout the core grade from silts and clays at the surface to fine sand at depth.

C.1.9 Core GC-09

This core was collected in the central portion of the EW in the vicinity of Slip 27. Core GC-09 had a high recovery (92%) and consisted of alternating layers of sandy silt and silty sand. This core was analyzed for Pb-210, Cs-137, TS, TOC, and grain size as part of the Tier 1 testing group.

Evaluation of the Cs-137 data was inconclusive, with no 1963 peak identified and relatively low activities ranging from 0.03 U to 0.18 pCi/g dw. The absence of a Cs-137 peak suggests that either it resides within a sample interval that was not analyzed, below the depth of the core, or that this area has experienced disturbance. Pb-210 regression analysis resulted in an

R^2 value of 0.78 and a sedimentation range of 0.35 to 1.4 cm/yr. The TOC and TS measurements are relatively uniform throughout the core. Sediment grain sizes vary in thin layers throughout the core, indicating episodic sand deposition above the lower alluvium.

C.1.10 Core GC-10

This core was collected in the central portion of the EW, within Slip 27. Core GC-10 had an adequate recovery (86%) and consisted primarily of homogenous, slightly clayey silt with trace sand and trace anthropogenic debris below 53 cm in depth. This core was analyzed for Pb-210, Cs-137, TS, TOC, and grain size as part of the Tier 2 testing group.

Evaluation of the Cs-137 data indicated an average net sedimentation rate of 1.3 cm/yr with the 1963 peak identified at 60 to 62 cm below sediment surface. These rates are higher than those determined in the Pb-210 regression analysis (0.30 to 0.61 cm/yr, 0.63 R^2). The TOC and TS measurements are relatively uniform throughout the core. Sediment grain sizes are homogenous throughout the core, primarily consisting of clayey silt with occasional gravel. The presence of gravel and anthropogenic materials suggest the deposition in this area has been affected by input sources other than natural episodic deposition.

C.1.11 Core GC-11

This core was collected on the southern end of the EW in the vicinity of Harbor Island. Core GC-11 had moderate recovery (75%), consisted of homogenous silt with trace anthropogenic debris, and was analyzed for Pb-210, Cs-137, TS, TOC, and grain size as part of the Tier 1 testing group.

Evaluation of the Cs-137 data indicated an average net sedimentation rate of greater than 1.7 cm/yr with the 1963 peak estimated at 80 cm below sediment surface based on the activity trendline. The alternating pattern of high and low Cs-137 activity suggests that this core was subjected to disturbance as a result of an episodic event. The disturbance appears to be limited to a single event and coincides with the presence of a 4-cm layer of trace fine gravel from 26 to 30 cm below mudline. This rate corresponds to those determined in the Pb-210 regression analysis (0.27 to 1.8 cm/yr, 0.71 R^2). The TOC and TS measurements are relatively uniform throughout the core. Sediment grain sizes are homogenous throughout the core, primarily consisting of clayey silt with occasional gravel. The presence of gravel and

anthropogenic materials suggest the deposition in this area has been affected by input sources other than natural episodic deposition.

C.1.12 Core GC-12

This core was collected on the southern end of the EW in the middle of the channel. Core GC-12 had an adequate recovery (89%) and consisted primarily of homogenous sandy silt, with anthropogenic debris below 64 cm depth. This core was analyzed for Pb-210, Cs-137, TS, TOC, and grain size as part of the Tier 1 testing group.

Evaluation of the Cs-137 data indicated an average net sedimentation rate of greater than 1.9 cm/yr with the 1963 peak estimated at 90 cm below sediment surface based on the activity trendline. This rate corresponds to those determined in the Pb-210 regression analysis (0.27 to 1.8 cm/yr, 0.71 R^2). The TOC and TS measurements are relatively uniform throughout the core and vary according to the lithology. Sediment grain sizes are homogenous throughout the core, primarily consisting of clayey silt with occasional gravel. The presence of anthropogenic materials suggests the deposition in this area has been affected by input sources other than natural episodic deposition.

C.1.13 Core GC-13

This core was collected on the southern end of the EW in the vicinity of Terminal 25. Core GC-13 had high recovery (96%) and consisted of alternating layers of silt and sand, with dense, medium sand present at the base of the core. This core was analyzed for Pb-210, Cs-137, TS, TOC, and grain size as part of the Tier 1 testing group.

Evaluation of the Cs-137 data was inconclusive, with no 1963 peak identified. The absence of a Cs-137 peak suggests that either it resides within a sample interval that was not analyzed, below the depth of the core, or that this area has experienced disturbance. The depths below sediment surface with variations in activities correspond closely to observations of hydrocarbon-like odor. Pb-210 regression analysis resulted in an R^2 value of 0.63 and a sedimentation range of 0.34 to 0.69 cm/yr. The TOC and TS measurements are relatively uniform throughout the core and vary according to the lithology. Sediment grain sizes vary in thin layers throughout the core, primarily consisting of clayey silt with sand at depth, suggesting recent episodic deposition above the lower alluvium.

C.1.14 Core GC-14

This core was collected on the southern end of the EW in the vicinity of Harbor Island. Core GC-14 had an adequate recovery (87%) and consisted of alternating beds of sandy silt and silty sand with trace gravel. This core was analyzed for Pb-210, Cs-137, TS, TOC, and grain size as part of the Tier 1 testing group.

Evaluation of the Cs-137 data indicated an average net sedimentation rate of 1.2 cm/yr with the 1963 peak at 54 to 56 cm below sediment surface. Pb-210 regression analysis resulted in a low correlation R^2 value of 0.003 making the profile un-interpretable. The TOC and TS measurements are relatively uniform throughout the core and vary according to lithology and organic matter. Sediment grain sizes vary in large and thin layers throughout the core primarily consisting of silt with sand beds and trace gravel. The presence of gravel suggests the deposition in this area has been affected by input sources other than natural episodic deposition.

C.1.15 Core GC-15

This core was collected on the southern end of the EW in the middle of the channel. Core GC-15 had an adequate recovery (87%), consisted of homogenous silt, and was analyzed for Pb-210, Cs-137, TS, TOC, and grain size as part of the Tier 1 testing group.

Evaluation of the Cs-137 data indicated an average net sedimentation rate of 1.3 cm/yr with the 1963 peak at 60 to 62 cm below sediment surface. Pb-210 regression analysis resulted in a low correlation R^2 value of 0.45 making the profile un-interpretable. There is some variation in TOC and TS values with depth; however, the profiles do not provide any clear indications of episodic erosion or deposition events. Sediment grain sizes are homogenous throughout the core, primarily consisting of clayey silt.

C.1.16 Core GC-16

This core was collected on the southern end of the EW in the vicinity of Terminal 25. Core GC-16 had an adequate recovery (88%) and consisted primarily of silt with thin seams of fine

sand with trace gravel. This core was analyzed for Pb-210, Cs-137, TS, TOC, and grain size as part of the Tier 1 testing group.

Evaluation of the Cs-137 data indicated an average net sedimentation rate of 1.6 cm/yr with the 1963 peak at 72 to 74 cm below sediment surface. This rate corresponds to those determined in the Pb-210 regression analysis (0.09 to 4.2 cm/yr, 0.91 R^2). The TOC and TS measurements are relatively uniform throughout the core and vary according to the lithology. Sediment grain sizes vary in thin layers throughout the core, primarily consisting of silt with sand and gravel layers, suggesting episodic sand deposition.

C.1.17 Core GC-17

This core was attempted once on the southern end of the EW, in the vicinity of Harbor Island and the West Seattle Bridge. The core penetrated approximately 18 inches of dense fine sand at the mudline and encountered refusal. This location was not re-attempted based on the density of the substrate and observations of vessel scour at the sample location by the diver.

C.1.18 Core GC-18

This core was collected in the middle of the channel in the southern portion of the EW near the West Seattle Bridge. Core GC-18 had an adequate recovery (80%) and consisted of slightly clayey silt with thin seams of sand. This core was analyzed for Pb-210, Cs-137, TS, TOC, and grain size as part of the Tier 1 testing group.

Evaluation of the Cs-137 data indicated an average net sedimentation rate of greater than 1.9 cm/yr with the 1963 peak estimated at 90 cm below sediment surface based on the activity trendline. Pb-210 regression analysis resulted in a low correlation R^2 value of 0.48 making the profile un-interpretable. There is some variation in TOC and TS values with depth; however, the profiles do not provide any clear indications of episodic erosion or deposition events. Sediment grain sizes vary in thin layers throughout the core, indicating episodic sand deposition.

C.1.19 Core GC-19A

This core was collected in the southern portion of the EW in the vicinity of the West Seattle Bridge. Two attempts were made at this location (19A and 19B); however, Core GC-19B was disturbed during transport making it unusable for radioisotope analysis. Core GC-19A had an estimated recovery of 80% (penetration estimated) and consisted primarily of silt with trace sand, gravel, and anthropogenic material. This core was analyzed for Pb-210, Cs-137, TS, TOC, and grain size as part of the Tier 1 testing group.

Evaluation of the Cs-137 data indicated an average net sedimentation rate of 1.2 cm/yr with the 1963 peak at 54 to 56 cm below sediment surface. Pb-210 regression analysis resulted in a positive slope making the profile un-interpretable. The TOC and TS measurements are relatively uniform throughout the core and vary according to the lithology and organic matter. Sediment grain sizes are homogenous throughout the core, primarily consisting of silt with trace gravel. The presence of gravel and anthropogenic materials suggest the deposition in this area has been affected by input sources other than natural episodic deposition.

C.1.20 Core GC-20

This core was collected in the southern portion of the EW near the West Seattle Bridge. Three attempts were made in the vicinity of this location, the accepted core had moderate recovery (76%) and low penetration through the dense sand beneath the surface. Core GC-20 consisted of beds silt and sand with trace cobbles and was analyzed for Pb-210, Cs-137, TS, TOC, and grain size as part of the Tier 1 testing group.

Evaluation of the Cs-137 and Pb-210 data was inconclusive due to low recovery (14 cm). No Cs-137 peak signifying 1963 was detected, and the Pb-210 regression analysis resulted in a low correlation R^2 value of 0.25. The TOC and TS measurements are relatively uniform throughout the core and vary with the lithology and organic matter.

C.1.21 Core GC-21

No core was attempted for GC-21. Just north of the confluence of the EW and the West Waterway (WW), in the vicinity of the West Seattle Bridge, the dive report indicated that

the core location and surrounding area is armored, has abundant shell and debris, and resembles a rock bottom.

C.1.22 Core GC-22

No core was attempted for GC-22. Just north of the confluence of the EW and WW, in the vicinity of the West Seattle Bridge, the dive report indicated that the core location and surrounding area is in a narrow channel with significant riprap from adjacent banks, which would inhibit coring beyond 1 to 2 feet.

Sediment Core Log

GC-01

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **51**
Project #: **060003-01**	SW Elevation (ft MLLW): **7.45**	Recovery Length (in): **46**
Client: **Port of Seattle**	Water Depth - LL (ft): **64.5**	Core Quality: **Good**
Collection Date: **2/1/2010**	Mudline Elevation (ft MLLW): **-57.1**	Percent Recovery: **90%**
Contractor: **RSS**	Northing: **219169** Easting: **1267342**	Process Date: **2/3/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	**Sediment Description** Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
0–1	GC-01-S0002	TS, TOC, GS	ML: Moist, medium stiff, black, slightly clayey, very f-sandy SILT. Trace scattered shells, wood fragments, and biota (worm) in upper 18 cm.	
1–3	GC-01-S0204	Archive		
3–5	GC-01-S0406	Archive		
5–7	GC-01-S0608	TS, TOC, GS		
7–9	GC-01-S0810	Archive		
9–11	GC-01-S1012	Archive		
11–13	GC-01-S1214	TS, TOC, GS	@12 cm: Horizontal seam of clay (2-cm wide) running down core	
13–15	GC-01-S1416	Archive	@15 cm: Wood fragment (3 cm-long)	
15–17	GC-01-S1618	Archive		
17–19	GC-01-S1820	TS, TOC, GS	@18 cm: 1 worm (sipuncula)	
19–21	GC-01-S2022	Archive		
21–23	GC-01-S2224	Archive		
23–25	GC-01-S2426	TS, TOC, GS		
25–27	GC-01-S2628	Archive		
27–29	GC-01-S2830	Archive		
29–31	GC-01-S3032	TS, TOC, GS		
31–33	GC-01-S3234	Archive		
33–35	GC-01-S3436	Archive		
35–37	GC-01-S3638	TS, TOC, GS		
37–39	GC-01-S3840	Archive		
39–41	GC-01-S4042	Archive		
41–43	GC-01-S4244	TS, TOC, GS		
43–46	GC-01-S4448	TS, TOC, GS		
46–49	GC-01-S4850	TS, TOC		

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Drive Notes (1): Attempt 1 of 1. Slow, steady coring.

Notes (2): GC-01 was not analyzed for geochronology.

Calculated Recovery
Sample Length/Penetration Length:
46/51 in = 90%

Sediment Core Log

GC-01

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **51**
Project #: **060003-01**	SW Elevation (ft MLLW): **7.45**	Recovery Length (in): **46**
Client: **Port of Seattle**	Water Depth - LL (ft): **64.5**	Core Quality: **Good**
Collection Date: **2/1/2010**	Mudline Elevation (ft MLLW): **-57.1**	Percent Recovery: **90%**
Contractor: **RSS**	Northing: **219169** Easting: **1267342**	Process Date: **2/3/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	**Sediment Description** Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
50–100	GC-01-S5052	Archive	ML: Moist, medium stiff, black, slightly clayey, very f-sandy SILT.	
	GC-01-S5254	Archive		
	GC-01-S5456	TS, TOC		
	GC-01-S5658	Archive		
	GC-01-S5860	Archive		
	GC-01-S6062	TS, TOC		
	GC-01-S6264	Archive		
	GC-01-S6466	Archive		
	GC-01-S6668	TS, TOC		
	GC-01-S6870	Archive		
	GC-01-S7072	Archive		
	GC-01-S7274	TS, TOC		
	GC-01-S7476	Archive		
	GC-01-S7678	Archive		
	GC-01-S7880	TS, TOC		
	GC-01-S8082	Archive	ML: Moist, stiff, black, slightly sandy, SILT. Slight H2S-like odor.	
	GC-01-S8284	Archive		
	GC-01-S8486	TS, TOC		
			End of core @ 86.5 cm	

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Drive Notes (1): Attempt 1 of 1. Slow, steady coring.

Notes (2): GC-01 was not analyzed for geochronology.

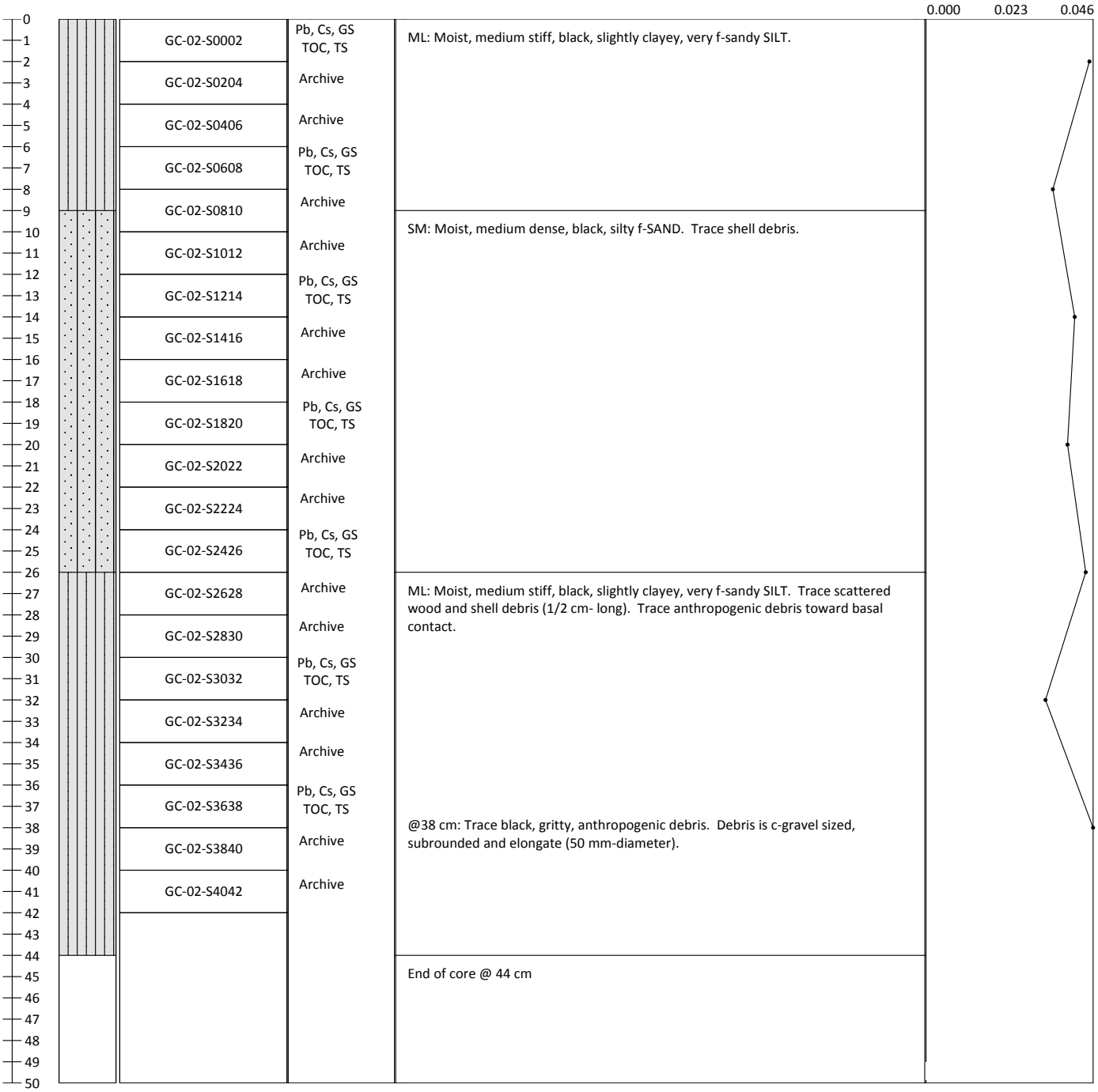
Calculated Recovery
Sample Length/Penetration Length:
46/51 in = 90%

Sediment Core Log

GC-02

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **35.5**
Project #: **060003-01**	SW Elevation (ft MLLW): **4.21**	Recovery Length (in): **26**
Client: **Port of Seattle**	Water Depth - LL (ft): **44.8**	Core Quality: **Good**
Collection Date: **2/1/2010**	Mudline Elevation (ft MLLW): **-40.6**	Percent Recovery: **73%**
Contractor: **RSS**	Northing: **1267893** Easting: **218988**	Process Date: **2/3/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	**Sediment Description** Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
	GC-02-S0002	Pb, Cs, GS TOC, TS	ML: Moist, medium stiff, black, slightly clayey, very f-sandy SILT.	
	GC-02-S0204	Archive		
	GC-02-S0406	Archive		
	GC-02-S0608	Pb, Cs, GS TOC, TS		
	GC-02-S0810	Archive		
	GC-02-S1012	Archive	SM: Moist, medium dense, black, silty f-SAND. Trace shell debris.	
	GC-02-S1214	Pb, Cs, GS TOC, TS		
	GC-02-S1416	Archive		
	GC-02-S1618	Archive		
	GC-02-S1820	Pb, Cs, GS TOC, TS		
	GC-02-S2022	Archive		
	GC-02-S2224	Archive		
	GC-02-S2426	Pb, Cs, GS TOC, TS		
	GC-02-S2628	Archive	ML: Moist, medium stiff, black, slightly clayey, very f-sandy SILT. Trace scattered wood and shell debris (1/2 cm- long). Trace anthropogenic debris toward basal contact.	
	GC-02-S2830	Archive		
	GC-02-S3032	Pb, Cs, GS TOC, TS		
	GC-02-S3234	Archive		
	GC-02-S3436	Archive		
	GC-02-S3638	Pb, Cs, GS TOC, TS	@38 cm: Trace black, gritty, anthropogenic debris. Debris is c-gravel sized, subrounded and elongate (50 mm-diameter).	
	GC-02-S3840	Archive		
	GC-02-S4042	Archive		
			End of core @ 44 cm	



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Drive Notes (1): Attempt 1 of 1. Hard bottom, slow drive, core tube compressed and cracked on sides (~2" long).

Notes (2): No Cs-137 peak observed.

Calculated Recovery
Sample Length/Penetration Length:
26/35.5 in = 73%

Sediment Core Log

GC-03

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **36**
Project #: **060003-01**	SW Elevation (ft MLLW): **10.28**	Recovery Length (in): **20**
Client: **Port of Seattle**	Water Depth - LL (ft): **67.7**	Core Quality: **Good**
Collection Date: **1/26/2010**	Mudline Elevation (ft MLLW): **-57.4**	Percent Recovery: **56%**
Contractor: **RSS**	Northing: **1267424** Easting: **218519**	Process Date: **2/3/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	**Sediment Description** Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
0–23 cm	GC-03-S0002	¢{Ï¢h/Ï D{	ML: Moist, soft, black, SILT. SILT is smooth and homogenous. Trace shell and wood debris, trace septic odor with 1 cm brown staining to 12 cm. Competency increases toward basal contact.	
	GC-03-S0204	Archive		
	GC-03-S0406	Archive		
	GC-03-S0608	¢{Ï¢h/Ï D{		
	GC-03-S0810	Archive		
	GC-03-S1012	Archive		
	GC-03-S1214	¢{Ï¢h/Ï D{	@13 cm: Broken razor clam shell (3 cm-long). Strong decomposing odor.	
	GC-03-S1416	Archive	@16-18 cm: Fresh wood debris	
	GC-03-S1618	Archive		
	GC-03-S1820	¢{Ï¢h/Ï D{		
	GC-03-S2022	Archive		
	GC-03-S2224	Archive		
24–29 cm	GC-03-S2426	¢{Ï¢h/Ï D{	SM: Moist, medium dense, black, silty f-SAND. Trace wood fragments (up to 5 cm-long).	
	GC-03-S2628	Archive		
	GC-03-S2830			
30			End of core @ 30 cm	

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Drive Notes (1): Attempt 1 of 3. Moderately easy drive on top, stiffer below. Diver reported a problem with piston which limited recovery.

Notes (2): GC-03 was not analyzed for geochronology.

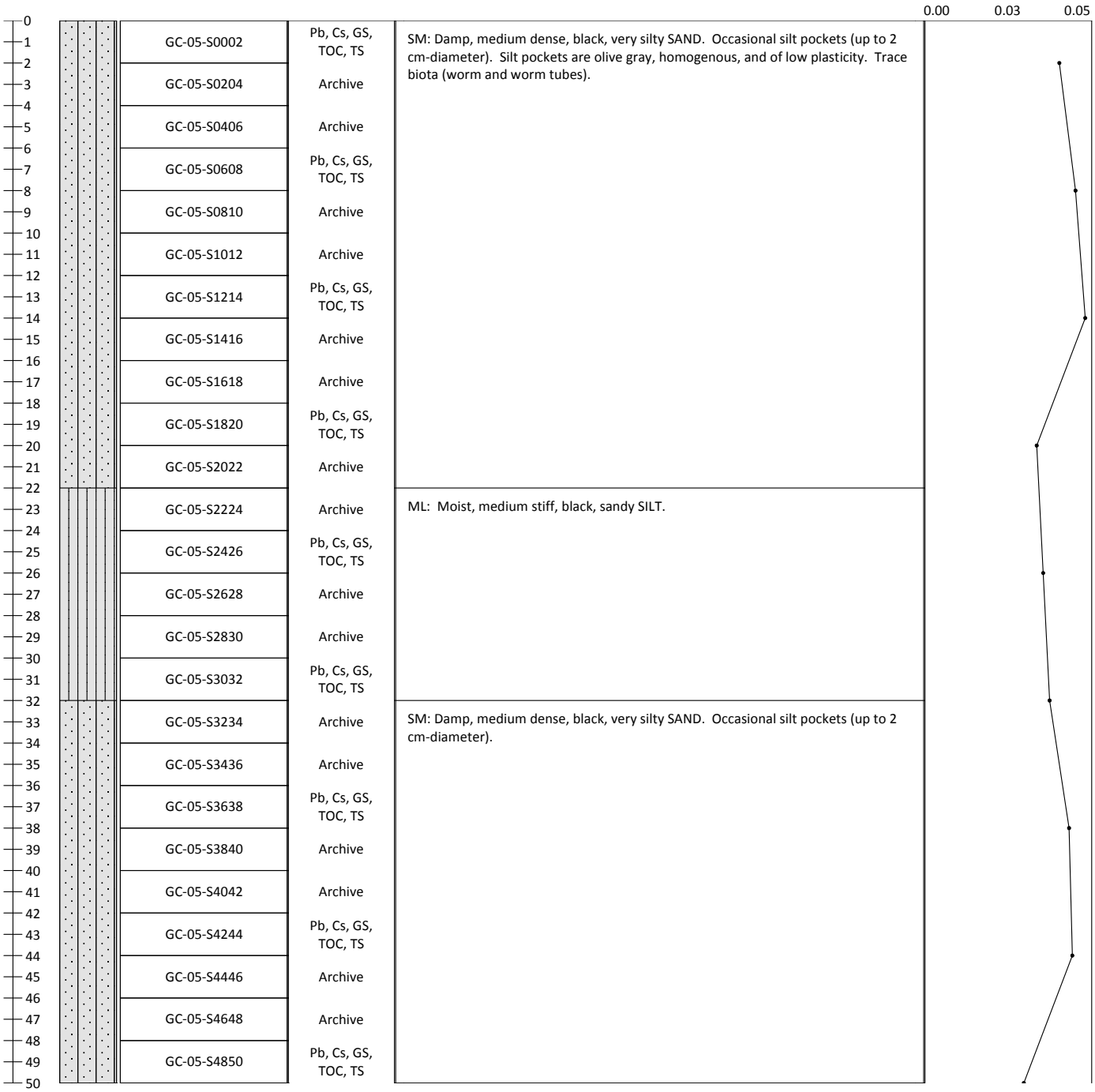
Calculated Recovery
Sample Length/Penetration Length:
20/36 in = 56%

Sediment Core Log

GC-05

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **53**
Project #: **060003-01**	SW Elevation (ft MLLW): **7.98**	Recovery Length (in): **51**
Client: **Port of Seattle**	Water Depth - LL (ft): **61.8**	Core Quality: **Good**
Collection Date: **1/29/2010**	Mudline Elevation (ft MLLW): **-53.8**	Percent Recovery: **96%**
Contractor: **RSS**	Northing: **1267593** Easting: **217952**	Process Date: **2/3/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	Sediment Description Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
0–22	GC-05-S0002	Pb, Cs, GS, TOC, TS	SM: Damp, medium dense, black, very silty SAND. Occasional silt pockets (up to 2 cm-diameter). Silt pockets are olive gray, homogenous, and of low plasticity. Trace biota (worm and worm tubes).	
	GC-05-S0204	Archive		
	GC-05-S0406	Archive		
	GC-05-S0608	Pb, Cs, GS, TOC, TS		
	GC-05-S0810	Archive		
	GC-05-S1012	Archive		
	GC-05-S1214	Pb, Cs, GS, TOC, TS		
	GC-05-S1416	Archive		
	GC-05-S1618	Archive		
	GC-05-S1820	Pb, Cs, GS, TOC, TS		
	GC-05-S2022	Archive		
22–32	GC-05-S2224	Archive	ML: Moist, medium stiff, black, sandy SILT.	
	GC-05-S2426	Pb, Cs, GS, TOC, TS		
	GC-05-S2628	Archive		
	GC-05-S2830	Archive		
	GC-05-S3032	Pb, Cs, GS, TOC, TS		
32–50	GC-05-S3234	Archive	SM: Damp, medium dense, black, very silty SAND. Occasional silt pockets (up to 2 cm-diameter).	
	GC-05-S3436	Archive		
	GC-05-S3638	Pb, Cs, GS, TOC, TS		
	GC-05-S3840	Archive		
	GC-05-S4042	Archive		
	GC-05-S4244	Pb, Cs, GS, TOC, TS		
	GC-05-S4446	Archive		
	GC-05-S4648	Archive		
	GC-05-S4850	Pb, Cs, GS, TOC, TS		



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Drive Notes (1): Attempt 1 of 1. Steady coring.

Notes (2): No Cs-137 peak observed.

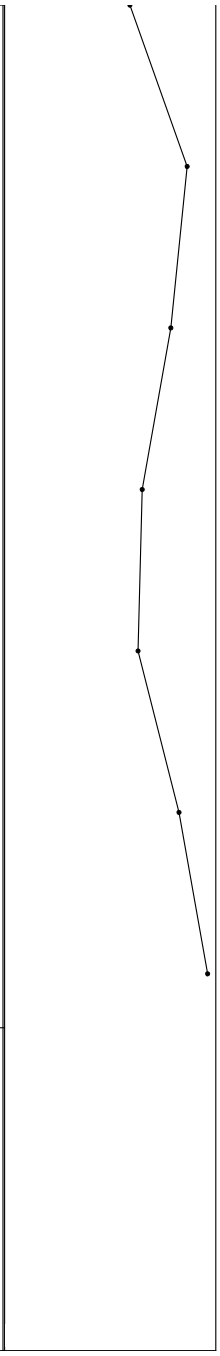
Calculated Recovery
Sample Length/Penetration Length:
51/53 in = 96%

Sediment Core Log

GC-05

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **53**
Project #: **060003-01**	SW Elevation (ft MLLW): **7.98**	Recovery Length (in): **51**
Client: **Port of Seattle**	Water Depth - LL (ft): **61.8**	Core Quality: **Good**
Collection Date: **1/29/2010**	Mudline Elevation (ft MLLW): **-53.8**	Percent Recovery: **96%**
Contractor: **RSS**	Northing: **1267593** Easting: **217952**	Process Date: **2/3/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	**Sediment Description** Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
50–100	GC-05-S5052	Archive	SM: Damp, medium dense, black, very silty SAND. Occasional silt pockets (up to 2 cm-diameter).	
	GC-05-S5254	Archive		
	GC-05-S5456	Pb, Cs, GS, TOC, TS		
	GC-05-S5658	Archive		
	GC-05-S5860	Archive		
	GC-05-S6062	Pb, Cs, GS, TOC, TS		
	GC-05-S6264	Archive		
	GC-05-S6466	Archive		
	GC-05-S6668	Pb, Cs, GS, TOC, TS		
	GC-05-S6870	Archive		
	GC-05-S7072	Archive		
	GC-05-S7274	Pb, Cs, GS, TOC, TS	SM: Damp, medium dense, black, slightly silty f-SAND.	
	GC-05-S7476	Archive		
	GC-05-S7678	Archive		
	GC-05-S7880	Pb, Cs, GS, TOC, TS		
	GC-05-S8082	Archive		
	GC-05-S8284	Archive		
	GC-05-S8486	Pb, Cs, GS, TOC, TS		
	GC-05-S8688	Archive		
			End of core @ 88 cm	



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Drive Notes (1): Attempt 1 of 1. Steady coring.

Notes (2): No Cs-137 peak observed.

Calculated Recovery
Sample Length/Penetration Length:
51/53 in = 96%

Sediment Core Log

GC-06

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **54**
Project #: **060003-01**	SW Elevation (ft MLLW): **9.06**	Recovery Length (in): **43**
Client: **Port of Seattle**	Water Depth - LL (ft): **66**	Core Quality: **Good**
Collection Date: **1/27/2010**	Mudline Elevation (ft MLLW): **-56.9**	Percent Recovery: **79%**
Contractor: **RSS**	Northing: **1267409** Easting: **217524**	Process Date: **2/3/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	**Sediment Description** Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
0–1	GC-06-S0002	TS, TOC, GS	ML: Moist, medium stiff, black, f-sandy SILT. Sand grains are black and white. No odor.	
2–3	GC-06-S0204	Archive		
4–5	GC-06-S0406	Archive	@5 cm: Slight H2S-like odor.	
6–7	GC-06-S0608	TS, TOC, GS		
8–9	GC-06-S0810	Archive		
10–11	GC-06-S1012	Archive	ML: Moist, soft, black, slightly vf-sandy SILT. Silt is smooth. Trace silt pockets. Trace wood fragments (twigs). Slight HC-like odor.	
12–13	GC-06-S1214	TS, TOC, GS		
14–15	GC-06-S1416	Archive		
16–17	GC-06-S1618	Archive		
18–19	GC-06-S1820	TS, TOC, GS		
20–21	GC-06-S2022	Archive		
22–23	GC-06-S2224	Archive		
24–25	GC-06-S2426	TS, TOC, GS		
26–27	GC-06-S2628	Archive	@26-28 cm: Silt pocket @28 cm: Competency increases, very homogenous	
28–29	GC-06-S2830	Archive		
30–31	GC-06-S3032	TS, TOC, GS		
32–33	GC-06-S3234	Archive		
34–35	GC-06-S3436	Archive		
36–37	GC-06-S3638	TS, TOC, GS		
38–39	GC-06-S3840	Archive		
40–41	GC-06-S4042	Archive	@40 cm: Twig (4 cm-long)	
42–43	GC-06-S4244	TS, TOC, GS		
44–46	GC-06-S4448	TS, TOC, GS QC		
47–49	GC-06-S4850	TS, TOC		
50				

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Drive Notes (1): Attempt 1 of 1. Rapid coring to 42", slower coring to 54".

Notes (2): GC-06 was not analyzed for geochronology.

Calculated Recovery
Sample Length/Penetration Length:
43/54 in = 79%

Sediment Core Log

GC-06

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **54**
Project #: **060003-01**	SW Elevation (ft MLLW): **9.06**	Recovery Length (in): **43**
Client: **Port of Seattle**	Water Depth - LL (ft): **66**	Core Quality: **Good**
Collection Date: **1/27/2010**	Mudline Elevation (ft MLLW): **-56.9**	Percent Recovery: **79%**
Contractor: **RSS**	Northing: **1267409** Easting: **217524**	Process Date: **2/3/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	**Sediment Description** Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
50–76	GC-06-S5052	Archive	ML: Moist, soft, black, slightly vf-sandy SILT. Silt is smooth. Trace silt pockets. Trace wood fragments (twigs). Slight HC-like odor.	
	GC-06-S5254	Archive		
	GC-06-S5456	TS, TOC		
	GC-06-S5658	Archive		
	GC-06-S5860	Archive	@58 cm: Scattered broken shells on sidewalls @60 cm: Competency increases to medium stiff	
	GC-06-S6062	TS, TOC		
	GC-06-S6264	Archive		
	GC-06-S6466	Archive		
	GC-06-S6668	TS, TOC		
	GC-06-S6870	Archive		
	GC-06-S7072	Archive		
	GC-06-S7274	TS, TOC	ML: Moist, soft, light gray, SILT. SILT is smooth and homogenous. Slight H2S-like odor.	
	GC-06-S7476	Archive	ML: Moist, soft, black, slightly vf-sandy SILT. Slight H2S-like odor.	
			End of core @ 76 cm	

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Drive Notes (1): Attempt 1 of 1. Rapid coring to 42", slower coring to 54".

Notes (2): GC-06 was not analyzed for geochronology.

Calculated Recovery
Sample Length/Penetration Length:
43/54 in = 79%

Sediment Core Log

GC-07

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **61**
Project #: **060003-01**	SW Elevation (ft MLLW): **9.38**	Recovery Length (in): **55**
Client: **Port of Seattle**	Water Depth - LL (ft): **66.2**	Core Quality: **Good**
Collection Date: **1/29/2010**	Mudline Elevation (ft MLLW): **-57.61**	Percent Recovery: **90%**
Contractor: **RSS**	Northing: **1267547** Easting: **216964**	Process Date: **2/3/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	**Sediment Description** Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
0–50	GC-06-S0002	TS, TOC, GS	ML: Moist, soft, black with olive gray mottling, slightly vf-f-sandy SILT.	
	GC-06-S0204	Archive		
	GC-06-S0406	Archive		
	GC-06-S0608	TS, TOC, GS		
	GC-06-S0810	Archive		
	GC-06-S1012	Archive	@10 cm: Increase in sand content	
	GC-06-S1214	TS, TOC, GS		
	GC-06-S1416	Archive	ML: Moist, medium stiff, black, slightly vf-f sandy SILT. SILT is homogenous and smooth. Moderate H2S-like odor.	
	GC-06-S1618	Archive		
	GC-06-S1820	TS, TOC, GS		
	GC-06-S2022	Archive		
	GC-06-S2224	Archive		
	GC-06-S2426	TS, TOC, GS		
	GC-06-S2628	Archive		
	GC-06-S2830	Archive		
	GC-06-S3032	TS, TOC, GS		
	GC-06-S3234	Archive		
	GC-06-S3436	Archive		
	GC-06-S3638	TS, TOC, GS		
	GC-06-S3840	Archive		
	GC-06-S4042	Archive		
	GC-06-S4244	TS, TOC, GS		
	GC-06-S4448	Archive Archive		
	GC-06-S4850	TS, TOC		

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Drive Notes (1): Attempt 1 of 1. Steady coring.

Notes (2): GC-07 was not analyzed for geochronology.

Calculated Recovery
Sample Length/Penetration Length:
55/61 in = 90%

Sediment Core Log

GC-07

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **61**
Project #: **060003-01**	SW Elevation (ft MLLW): **9.38**	Recovery Length (in): **55**
Client: **Port of Seattle**	Water Depth - LL (ft): **66.2**	Core Quality: **Good**
Collection Date: **1/29/2010**	Mudline Elevation (ft MLLW): **-57.61**	Percent Recovery: **90%**
Contractor: **RSS**	Northing: **1267547** Easting: **216964**	Process Date: **2/3/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	Sediment Description Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
50–70	GC-06-S5052	Archive	ML: Moist, medium stiff, black, slightly vf-f sandy SILT. SILT is homogenous and smooth. Moderate H2S-like odor.	
	GC-06-S5254	Archive		
	GC-06-S5456	TS, TOC		
	GC-06-S5658	Archive		
	GC-06-S5860	Archive		
	GC-06-S6062	TS, TOC	@60 cm: Strong H2S-like odor.	
	GC-06-S6264	Archive		
	GC-06-S6466	Archive		
	GC-06-S6668	TS, TOC		
	GC-06-S6870	Archive		
70–100	GC-06-S7072	Archive	ML: Moist, medium stiff, black with olive gray mottling, slightly vf-f sandy SILT. Trace wood fragments (twigs up to 8 cm). Moderate H2S-like odor.	
	GC-06-S7274	TS, TOC		
	GC-06-S7476	Archive		
	GC-07-S7678	Archive		
	GC-07-S7880	TS, TOC		
	GC-07-S8082	Archive		
	GC-07-S8284	Archive		
	GC-07-S8486	TS, TOC		
	GC-07-S8688	Archive		
	GC-07-S8890	Archive		

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Drive Notes (1): Attempt 1 of 1. Steady coring.

Notes (2): GC-07 was not analyzed for geochronology.

Calculated Recovery
Sample Length/Penetration Length:
55/61 in = 90%

Sediment Core Log

GC-07

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **61**
Project #: **060003-01**	SW Elevation (ft MLLW): **9.38**	Recovery Length (in): **55**
Client: **Port of Seattle**	Water Depth - LL (ft): **66.2**	Core Quality: **Good**
Collection Date: **1/29/2010**	Mudline Elevation (ft MLLW): **-57.61**	Percent Recovery: **90%**
Contractor: **RSS**	Northing: **1267547** Easting: **216964**	Process Date: **2/3/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	**Sediment Description** Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
100–115			ML: Moist, medium stiff, black with olive gray mottling, slightly vf-f sandy SILT. Trace wood fragments (twigs up to 8 cm). Moderate H2S-like odor. @100 cm: Black seam with strong HC-like odor (1/2 cm-thick)	
115–150			End of core @ 115 cm	

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Drive Notes (1): Attempt 1 of 1. Steady coring.

Notes (2): GC-07 was not analyzed for geochronology.

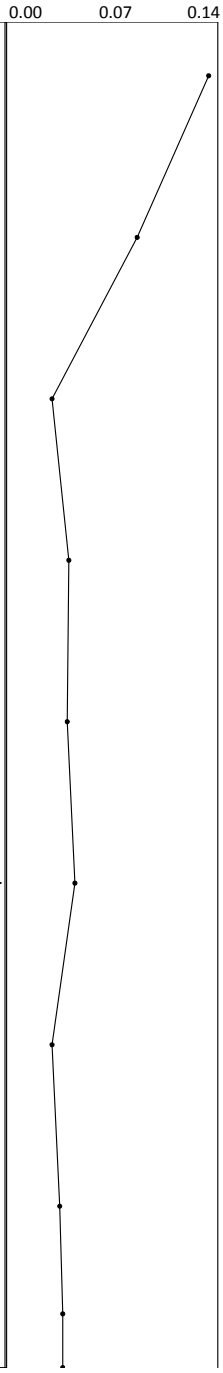
Calculated Recovery
Sample Length/Penetration Length:
55/61 in = 90%

Sediment Core Log

GC-08

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **49**
Project #: **060003-01**	SW Elevation (ft MLLW): **5.74**	Recovery Length (in): **40**
Client: **Port of Seattle**	Water Depth - LL (ft): **62.7**	Core Quality: **Fair**
Collection Date: **2/1/2010**	Mudline Elevation (ft MLLW): **-57**	Percent Recovery: **81.6%**
Contractor: **RSS**	Northing: **1267297** Easting: **216725**	Process Date: **2/2/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	Sediment Description Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
0–50	GC-08-S0002	Pb, Cs, GS TOC, TS	ML: Moist, soft, black, SILT, trace f-sand. Silt is smooth and homogenous. Trace rootlets and biota (worms).	
	GC-08-S0204	Archive		
	GC-08-S0406	Archive		
	GC-08-S0608	Pb, Cs, GS TOC, TS		
	GC-08-S0810	Archive		
	GC-08-S1012	Archive		
	GC-08-S1214	Pb, Cs, GS TOC, TS		
	GC-08-S1416	Archive		
	GC-08-S1618	Archive		
	GC-08-S1820	Pb, Cs, GS TOC, TS		
	GC-08-S2022	Archive		
	GC-08-S2224	Archive		
	GC-08-S2426	Pb, Cs, GS TOC, TS	@24-26 cm: Interbed of slightly sandy SILT	
	GC-08-S2628	Archive		
	GC-08-S2830	Archive		
	GC-08-S3032	Pb, Cs, GS TOC, TS		
	GC-08-S3234	Archive	ML: Grades to moist, medium stiff, black, vf-f-sandy SILT. Sand is homogenous.	
	GC-08-S3436	Archive		
	GC-08-S3638	Pb, Cs, GS TOC, TS		
	GC-08-S3840	Archive		
	GC-08-S4042	Archive		
	GC-08-S4244	Pb, Cs, GS TOC, TS		
	GC-08-S4448	Pb, Cs, GS TOC, TS		
	GC-08-S4850	Pb, Cs, GS TOC, TS		



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Drive Notes (1): Attempt 2 of 2. Core stuck from previous drive (extracted).

Notes (2): No Cs-137 peak observed.

Calculated Recovery
Sample Length/Penetration Length:
40/49 in = 81.6%

Sediment Core Log

GC-08

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **49**
Project #: **060003-01**	SW Elevation (ft MLLW): **5.74**	Recovery Length (in): **40**
Client: **Port of Seattle**	Water Depth - LL (ft): **62.7**	Core Quality: **Fair**
Collection Date: **2/1/2010**	Mudline Elevation (ft MLLW): **-57**	Percent Recovery: **81.6%**
Contractor: **RSS**	Northing: **1267297** Easting: **216725**	Process Date: **2/2/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	Sediment Description Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
50–59	GC-08-S5052	Archive	ML: Moist, medium stiff, black, vf-f-sandy SILT. Sand is homogenous.	0.00 0.07 0.14
	GC-08-S5254	Archive		
	GC-08-S5456	Pb, Cs, TOC, TS		
	GC-08-S5658	Archive		
	GC-08-S5860	Archive		
59–75	GC-08-S6062	Pb, Cs, TOC, TS	ML: Moist, medium stiff, black, very sandy SILT. Trace wood fragments (up to 1 mm-long).	
	GC-08-S6264	Archive		
	GC-08-S6466	Archive		
	GC-08-S6668	Pb, Cs, TOC, TS		
	GC-08-S6870	Archive		
	GC-08-S7072	Archive		
	GC-08-S7274	Pb, Cs, TOC, TS		
	GC-08-S7476	Archive		
75–83	GC-08-S7678	Archive	SM: Moist, medium dense, black, slightly silty, vf-SAND. Trace silt pockets. Slight HC-like odor.	
	GC-08-S7880	Pb, Cs, TOC, TS		
	GC-08-S8082	Archive		
83–100			End of core @ 83 cm	

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Drive Notes (1): Attempt 2 of 2. Core stuck from previous drive (extracted).

Notes (2): No Cs-137 peak observed.

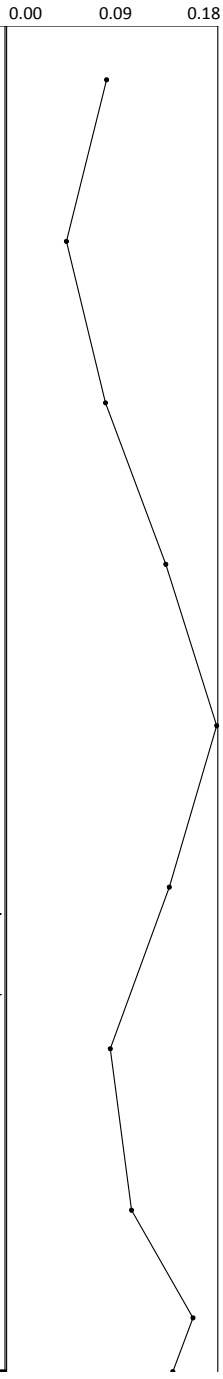
Calculated Recovery
Sample Length/Penetration Length:
40/49 in = 81.6%

Sediment Core Log

GC-09

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **58**
Project #: **060003-01**	SW Elevation (ft MLLW): **8.74**	Recovery Length (in): **53.5**
Client: **Port of Seattle**	Water Depth - LL (ft): **40.7**	Core Quality: **Good**
Collection Date: **1/28/2010**	Mudline Elevation (ft MLLW): **-32.0**	Percent Recovery: **92%**
Contractor: **RSS**	Northing: **1267872** Easting: **215110**	Process Date: **2/2/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	**Sediment Description** Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
0–50	GC-09-S0002	Pb, Cs, GS, TOC, TS	ML: Moist, soft to medium stiff, black with olive gray mottling, slightly f-sandy SILT. Trace biota (worms).	
	GC-09-S0204	Archive		
	GC-09-S0406	Archive		
	GC-09-S0608	Pb, Cs, GS, TOC, TS		
	GC-09-S0810	Archive		
	GC-09-S1012	Archive		
	GC-09-S1214	Pb, Cs, GS, TOC, TS		
	GC-09-S1416	Archive		
	GC-09-S1618	Archive		
	GC-09-S1820	Pb, Cs, GS, TOC, TS		
	GC-09-S2022	Archive		
	GC-09-S2224	Archive		
	GC-09-S2426	Pb, Cs, GS, TOC, TS		
	GC-09-S2628	Archive		
	GC-09-S2830	Archive		
	GC-09-S3032	Pb, Cs, GS, TOC, TS		
	GC-09-S3234	Archive		
	GC-09-S3436	Archive	SM: Interbed of slightly silty, m-SAND, trace f-gravel (subrounded, up to 10 cm-diameter).	
	GC-09-S3638	Pb, Cs, GS, TOC, TS	ML: Moist, soft to medium stiff, black with olive gray mottling, slightly f-sandy SILT.	
	GC-09-S3840	Archive		
	GC-09-S4042	Archive		
	GC-09-S4244	Pb, Cs, GS, TOC, TS		
	GC-09-S4448	Pb, Cs, GS, TOC, TS, QC		
	GC-09-S4850	Pb, Cs, GS, TOC, TS		



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Drive Notes (1): Attempt 1 of 1. Steady coring.

Notes (2): No Cs-137 peak observed.

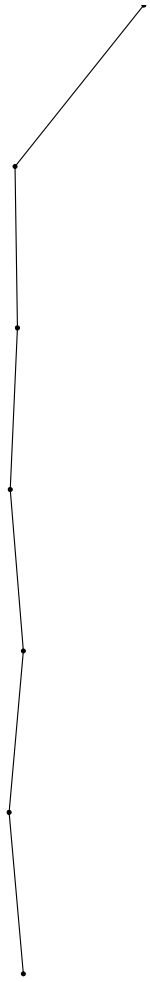
Calculated Recovery
Sample Length/Penetration Length:
53.5/58 in = 92%

Sediment Core Log

GC-09

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **58**
Project #: **060003-01**	SW Elevation (ft MLLW): **8.74**	Recovery Length (in): **53.5**
Client: **Port of Seattle**	Water Depth - LL (ft): **40.7**	Core Quality: **Good**
Collection Date: **1/28/2010**	Mudline Elevation (ft MLLW): **-32.0**	Percent Recovery: **92%**
Contractor: **RSS**	Northing: **1267872** Easting: **215110**	Process Date: **2/2/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	**Sediment Description** Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
50–51	GC-09-S5052	Archive	SM: Interbed of slightly silty, m-SAND.	
51–52	GC-09-S5254	Archive		
52–54	GC-09-S5456	Pb, Cs, GS, TOC, TS	ML: Moist, medium stiff, black with olive gray mottling, very sandy SILT, trace f-gravel (subangular to subrounded, 20 cm-diameter).	
54–56	GC-09-S5658	Archive		
56–58	GC-09-S5860	Archive		
58–60	GC-09-S6062	Pb, Cs, GS, TOC, TS	SM: Moist, medium dense, black, silty SAND. Trace wood fragments (fresh cedar, up to 4 cm-long).	
60–62	GC-09-S6264	Archive		
62–64	GC-09-S6466	Archive		
64–66	GC-09-S6668	Pb, Cs, GS, TOC, TS		
66–68	GC-09-S6870	Archive		
68–70	GC-09-S7072	Archive		
70–72	GC-09-S7274	Pb, Cs, GS, TOC, TS		
72–74	GC-09-S7476	Archive		
74–76	GC-09-S7678	Archive	ML: Moist, medium stiff, black, sandy SILT. Occasional interbeds of silty SAND. Trace 1 cm-long wood fragments (fresh, cedar).	
76–78	GC-09-S7880	Pb, Cs, GS, TOC, TS		
78–80	GC-09-S8082	Archive		
80–82	GC-09-S8284	Archive	@83-85 cm: Interbed of silty SAND with silt pockets	
82–84	GC-09-S8486	Pb, Cs, GS, TOC, TS		
84–86	GC-09-S8688	Archive		
86–88	GC-09-S8890	Archive		
88–95			@90-92 cm: Interbed of silty SAND with silt pockets. Strong H2S-like odor.	
95–100			SM: Moist, medium dense, black, slightly silty SAND with silt pockets.	



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Drive Notes (1): Attempt 1 of 1. Steady coring.

Notes (2): No Cs-137 peak observed.

Calculated Recovery
Sample Length/Penetration Length:
53.5/58 in = 92%

Sediment Core Log

GC-09

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **58**
Project #: **060003-01**	SW Elevation (ft MLLW): **8.74**	Recovery Length (in): **53.5**
Client: **Port of Seattle**	Water Depth - LL (ft): **40.7**	Core Quality: **Good**
Collection Date: **1/28/2010**	Mudline Elevation (ft MLLW): **-32.0**	Percent Recovery: **92%**
Contractor: **RSS**	Northing: **1267872** Easting: **215110**	Process Date: **2/2/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	**Sediment Description** Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
100–105			SM: Moist, medium dense, black, slightly silty SAND with silt pockets.	
105			End of core at 105 cm.	

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Drive Notes (1): Attempt 1 of 1. Steady coring.

Notes (2): No Cs-137 peak observed.

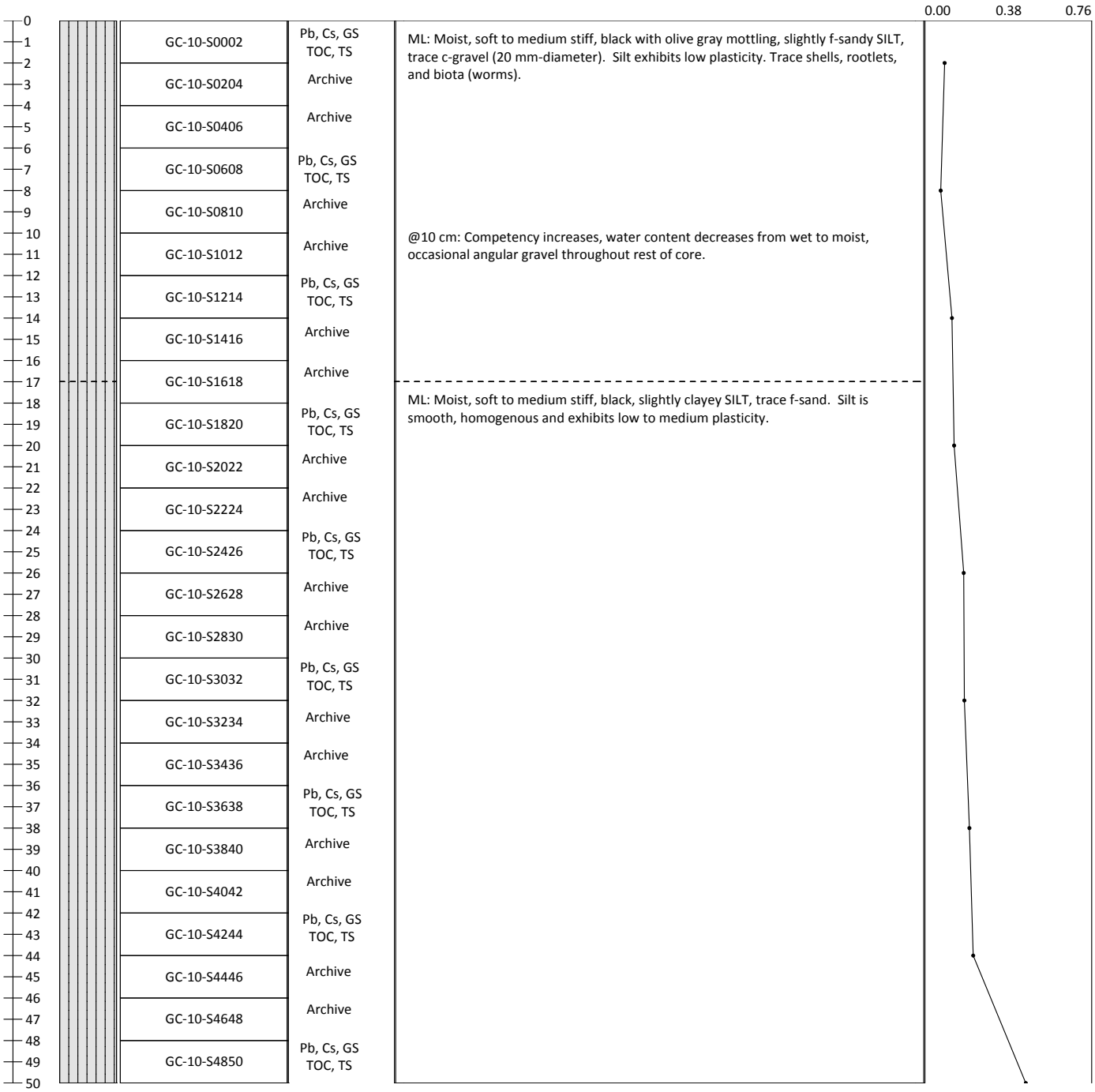
Calculated Recovery
Sample Length/Penetration Length:
53.5/58 in = 92%

Sediment Core Log

GC-10

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **52.5**
Project #: **060003-01**	SW Elevation (ft MLLW): **10.83**	Recovery Length (in): **45**
Client: **Port of Seattle**	Water Depth - LL (ft): **39.8**	Core Quality: **Good**
Collection Date: **1/26/2010**	Mudline Elevation (ft MLLW): **-29.0**	Percent Recovery: **86%**
Contractor: **RSS**	Northing: **1268220** Easting: **214736**	Process Date: **2/2/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	Sediment Description Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
0–17	GC-10-S0002	Pb, Cs, GS TOC, TS	ML: Moist, soft to medium stiff, black with olive gray mottling, slightly f-sandy SILT, trace c-gravel (20 mm-diameter). Silt exhibits low plasticity. Trace shells, rootlets, and biota (worms).	
	GC-10-S0204	Archive		
	GC-10-S0406	Archive		
	GC-10-S0608	Pb, Cs, GS TOC, TS		
	GC-10-S0810	Archive		
	GC-10-S1012	Archive	@10 cm: Competency increases, water content decreases from wet to moist, occasional angular gravel throughout rest of core.	
	GC-10-S1214	Pb, Cs, GS TOC, TS		
	GC-10-S1416	Archive		
	GC-10-S1618	Archive		
17–50	GC-10-S1820	Pb, Cs, GS TOC, TS	ML: Moist, soft to medium stiff, black, slightly clayey SILT, trace f-sand. Silt is smooth, homogenous and exhibits low to medium plasticity.	
	GC-10-S2022	Archive		
	GC-10-S2224	Archive		
	GC-10-S2426	Pb, Cs, GS TOC, TS		
	GC-10-S2628	Archive		
	GC-10-S2830	Archive		
	GC-10-S3032	Pb, Cs, GS TOC, TS		
	GC-10-S3234	Archive		
	GC-10-S3436	Archive		
	GC-10-S3638	Pb, Cs, GS TOC, TS		
	GC-10-S3840	Archive		
	GC-10-S4042	Archive		
	GC-10-S4244	Pb, Cs, GS TOC, TS		
	GC-10-S4446	Archive		
	GC-10-S4648	Archive		
	GC-10-S4850	Pb, Cs, GS TOC, TS		



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Drive Notes (1): Attempt 1 of 1. Smooth coring.

Notes (2): A Cs-137 peak of 0.75 pCi/g (dry) is observed at 62 cm below mudline.

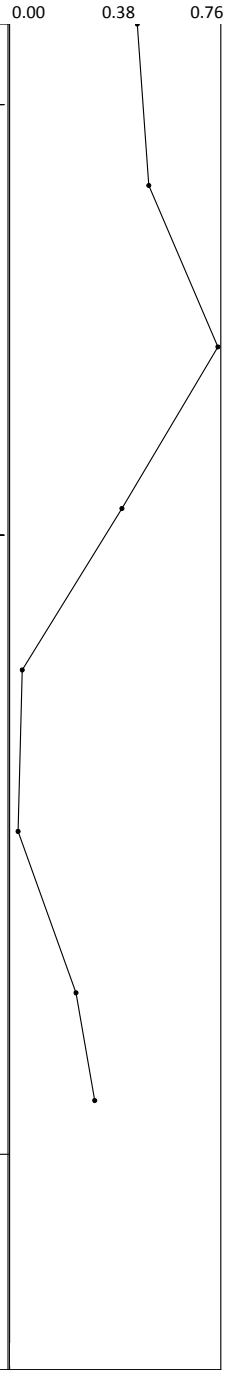
Calculated Recovery
Sample Length/Penetration Length:
45/52.5 in = 86%

Sediment Core Log

GC-10

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **52.5**
Project #: **060003-01**	SW Elevation (ft MLLW): **10.83**	Recovery Length (in): **45**
Client: **Port of Seattle**	Water Depth - LL (ft): **39.8**	Core Quality: **Good**
Collection Date: **1/26/2010**	Mudline Elevation (ft MLLW): **-29.0**	Percent Recovery: **86%**
Contractor: **RSS**	Northing: **1268220** Easting: **214736**	Process Date: **2/2/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	Sediment Description Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
50–92	GC-10-S5052	Archive	ML: Moist, soft to medium stiff, black, slightly clayey SILT, trace f-sand. Silt is smooth, homogenous and exhibits low to medium plasticity.	
	GC-10-S5254	Archive		
	GC-10-S5456	Pb, Cs, GS TOC, TS	ML: Moist, medium stiff, black SILT. Blocky texture. Occasional rootlets. Slight H2S and HC-like odors. @54-56 cm: Trace anthropogenic debris (1 cm-long piece of plastic)	
	GC-10-S5658	Archive		
	GC-10-S5860	Archive		
	GC-10-S6062	Pb, Cs, GS TOC, TS		
	GC-10-S6264	Archive		
	GC-10-S6466	Archive		
	GC-10-S6668	Pb, Cs, GS TOC, TS		
	GC-10-S6870	Archive		
	GC-10-S7072	Archive	ML: Moist, medium stiff, black with olive gray mottling, slightly clayey SILT. Silt is smooth, homogenous, and exhibits low to medium plasticity. Slight H2S and HC-like odors.	
	GC-10-S7274	Pb, Cs, GS TOC, TS		
	GC-10-S7476	Archive		
	GC-10-S7678	Archive		
	GC-10-S7880	Pb, Cs, GS TOC, TS		
	GC-10-S8082	Archive		
	GC-10-S8284	Archive		
	GC-10-S8486	Pb, Cs, GS TOC, TS		
	GC-10-S8690	Pb, Cs, GS TOC, TS		
92–100			End of core @ 92 cm	



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Drive Notes (1): Attempt 1 of 1. Smooth coring.

Notes (2): A Cs-137 peak of 0.75 pCi/g (dry) is observed at 62 cm below mudline.

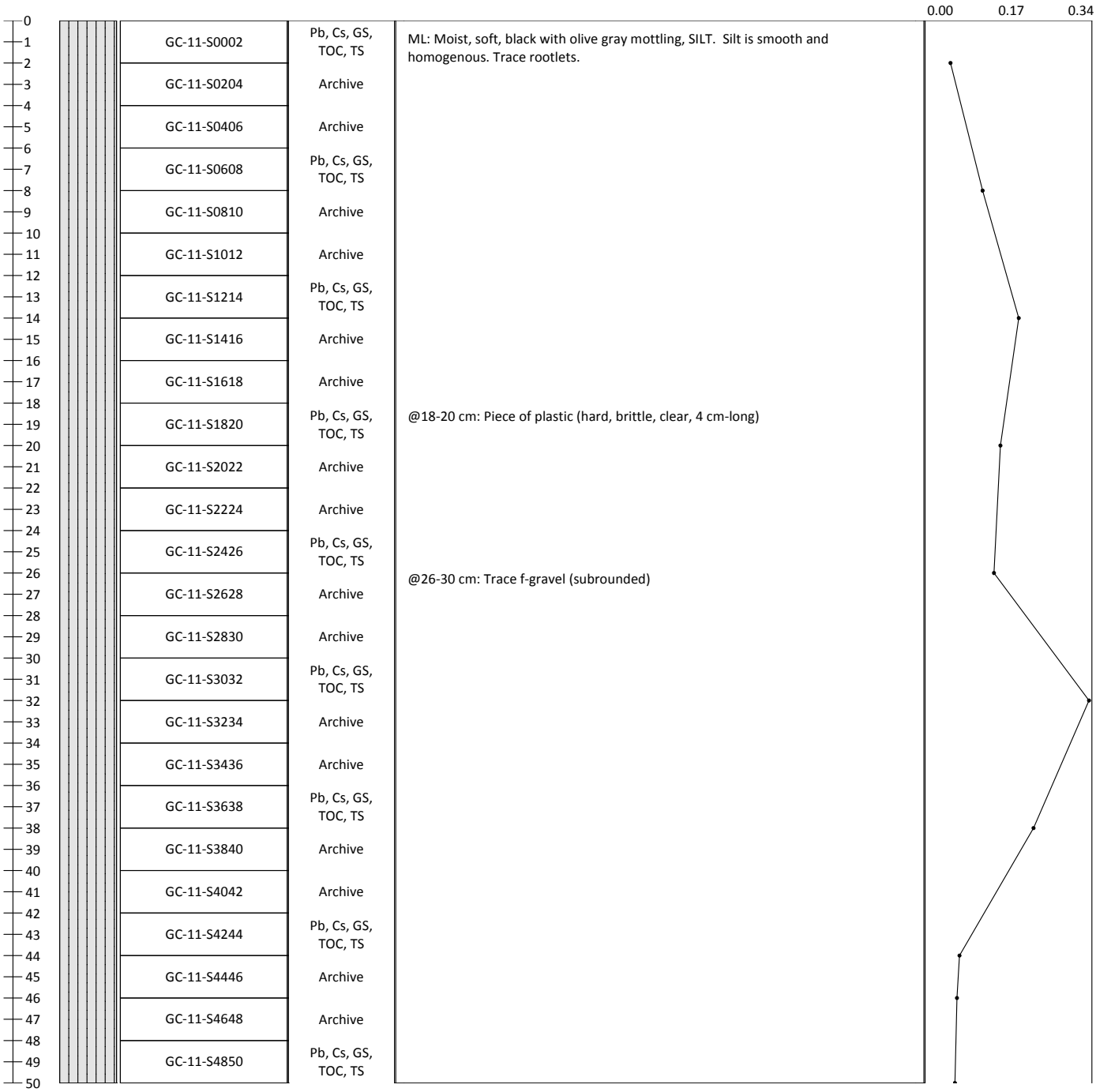
Calculated Recovery
Sample Length/Penetration Length:
45/52.5 in = 86%

Sediment Core Log

GC-11

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **52**
Project #: **060003-01**	SW Elevation (ft MLLW): **10.25**	Recovery Length (in): **39**
Client: **Port of Seattle**	Water Depth - LL (ft): **49.9**	Core Quality: **Good**
Collection Date: **1/28/2010**	Mudline Elevation (ft MLLW): **-39.7**	Percent Recovery: **75%**
Contractor: **RSS**	Northing: **1267203** Easting: **213784**	Process Date: **2/2/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	**Sediment Description** Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
	GC-11-S0002	Pb, Cs, GS, TOC, TS	ML: Moist, soft, black with olive gray mottling, SILT. Silt is smooth and homogenous. Trace rootlets.	
	GC-11-S0204	Archive		
	GC-11-S0406	Archive		
	GC-11-S0608	Pb, Cs, GS, TOC, TS		
	GC-11-S0810	Archive		
	GC-11-S1012	Archive		
	GC-11-S1214	Pb, Cs, GS, TOC, TS		
	GC-11-S1416	Archive		
	GC-11-S1618	Archive		
	GC-11-S1820	Pb, Cs, GS, TOC, TS	@18-20 cm: Piece of plastic (hard, brittle, clear, 4 cm-long)	
	GC-11-S2022	Archive		
	GC-11-S2224	Archive		
	GC-11-S2426	Pb, Cs, GS, TOC, TS		
	GC-11-S2628	Archive	@26-30 cm: Trace f-gravel (subrounded)	
	GC-11-S2830	Archive		
	GC-11-S3032	Pb, Cs, GS, TOC, TS		
	GC-11-S3234	Archive		
	GC-11-S3436	Archive		
	GC-11-S3638	Pb, Cs, GS, TOC, TS		
	GC-11-S3840	Archive		
	GC-11-S4042	Archive		
	GC-11-S4244	Pb, Cs, GS, TOC, TS		
	GC-11-S4446	Archive		
	GC-11-S4648	Archive		
	GC-11-S4850	Pb, Cs, GS, TOC, TS		



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Drive Notes (1): Attempt 1 of 1. Moderately easy coring.

Notes (2): A Cs-137 peak is estimated at greater than 80 cm below mudline.

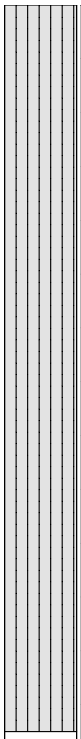
Calculated Recovery
Sample Length/Penetration Length:
39/52 in = 75%

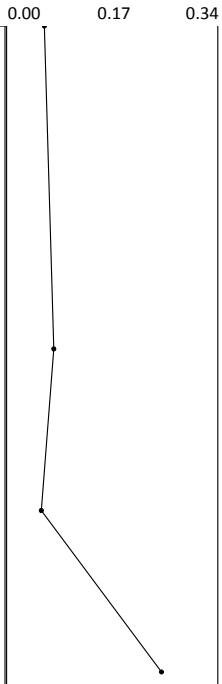
Sediment Core Log

GC-11

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **52**
Project #: **060003-01**	SW Elevation (ft MLLW): **10.25**	Recovery Length (in): **39**
Client: **Port of Seattle**	Water Depth - LL (ft): **49.9**	Core Quality: **Good**
Collection Date: **1/28/2010**	Mudline Elevation (ft MLLW): **-39.7**	Percent Recovery: **75%**
Contractor: **RSS**	Northing: **1267203** Easting: **213784**	Process Date: **2/2/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	**Sediment Description** Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
50–77	GC-11-S5052	Archive	ML: Moist, soft, black with olive gray mottling, SILT. Silt is smooth and homogenous. Trace rootlets. @50-65 cm: Moderate H2S-like odor.	0.00 0.17 0.34
	GC-11-S5254	Archive		
	GC-11-S5456	Pb, Cs, GS, TOC, TS		
	GC-11-S5658	Archive		
	GC-11-S5860	Archive		
	GC-11-S6062	Pb, Cs, GS, TOC, TS		
	GC-11-S6264	Archive		
	GC-11-S6466	Archive		
	GC-11-S6668	Pb, Cs, GS, TOC, TS		
	GC-11-S6870	Archive		
	GC-11-S7072	Archive		
	GC-11-S7274	Pb, Cs, GS, TOC, TS		
	GC-11-S7476	Archive	@74 cm: Moderate HC-like odor to bottom of core	
77–100			End of core @77 cm	





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Drive Notes (1): Attempt 1 of 1. Moderately easy coring.

Notes (2): A Cs-137 peak is estimated at greater than 80 cm below mudline.

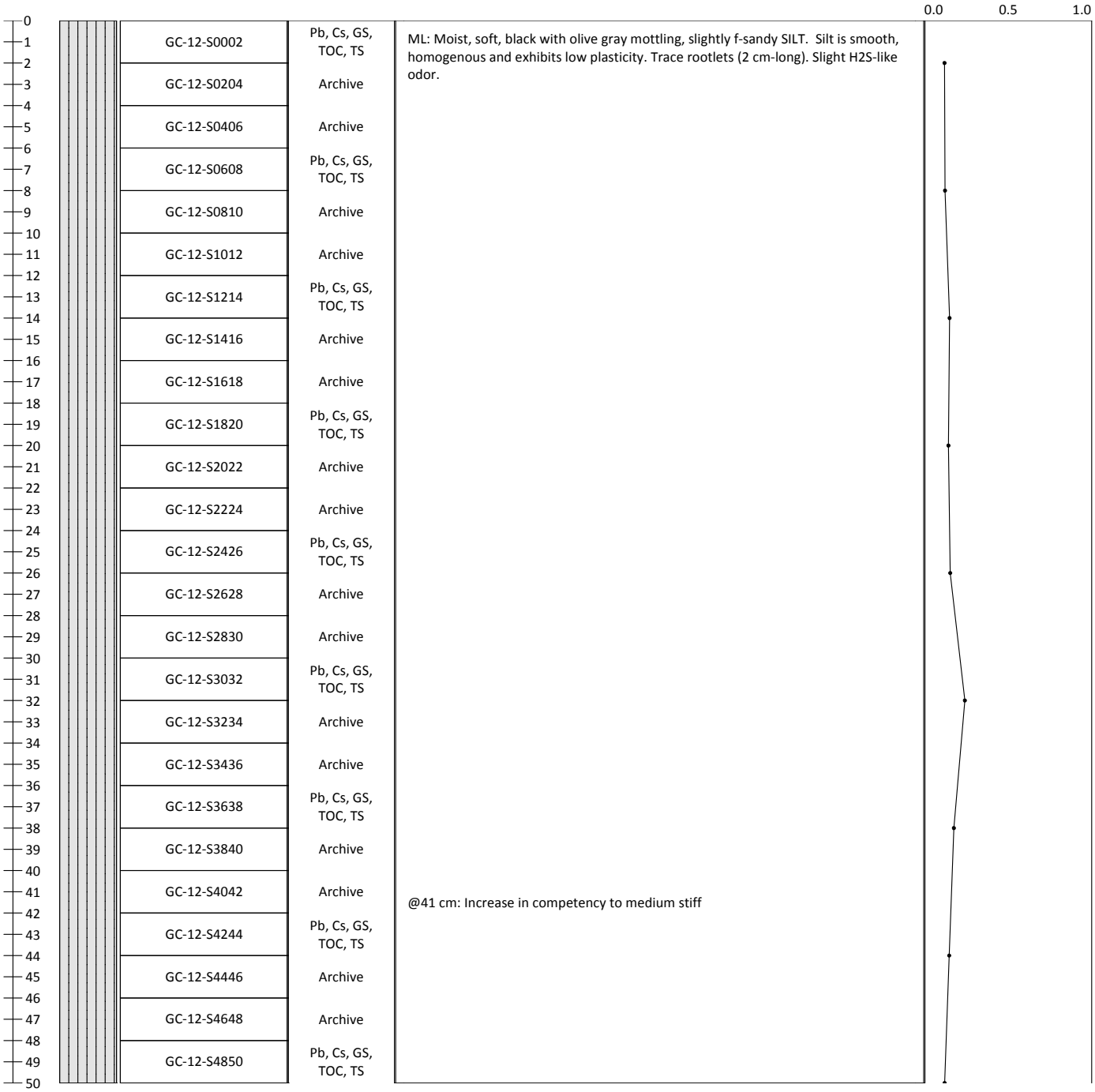
Calculated Recovery
Sample Length/Penetration Length:
39/52 in = 75%

Sediment Core Log

GC-12

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **50.5**
Project #: **060003-01**	SW Elevation (ft MLLW): **11.14**	Recovery Length (in): **45**
Client: **Port of Seattle**	Water Depth - LL (ft): **56.2**	Core Quality: **Good**
Collection Date: **1/26/2010**	Mudline Elevation (ft MLLW): **-45.1**	Percent Recovery: **89%**
Contractor: **RSS**	Northing: **1267421** Easting: **213798**	Process Date: **2/1/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	**Sediment Description** Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
	GC-12-S0002	Pb, Cs, GS, TOC, TS	ML: Moist, soft, black with olive gray mottling, slightly f-sandy SILT. Silt is smooth, homogenous and exhibits low plasticity. Trace rootlets (2 cm-long). Slight H2S-like odor.	
	GC-12-S0204	Archive		
	GC-12-S0406	Archive		
	GC-12-S0608	Pb, Cs, GS, TOC, TS		
	GC-12-S0810	Archive		
	GC-12-S1012	Archive		
	GC-12-S1214	Pb, Cs, GS, TOC, TS		
	GC-12-S1416	Archive		
	GC-12-S1618	Archive		
	GC-12-S1820	Pb, Cs, GS, TOC, TS		
	GC-12-S2022	Archive		
	GC-12-S2224	Archive		
	GC-12-S2426	Pb, Cs, GS, TOC, TS		
	GC-12-S2628	Archive		
	GC-12-S2830	Archive		
	GC-12-S3032	Pb, Cs, GS, TOC, TS		
	GC-12-S3234	Archive		
	GC-12-S3436	Archive		
	GC-12-S3638	Pb, Cs, GS, TOC, TS		
	GC-12-S3840	Archive		
	GC-12-S4042	Archive	@41 cm: Increase in competency to medium stiff	
	GC-12-S4244	Pb, Cs, GS, TOC, TS		
	GC-12-S4446	Archive		
	GC-12-S4648	Archive		
	GC-12-S4850	Pb, Cs, GS, TOC, TS		



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Drive Notes (1): Attempt 1 of 1. Moderately steady coring.

Notes (2): A Cs-137 peak is estimated at greater than 90 cm below mudline.

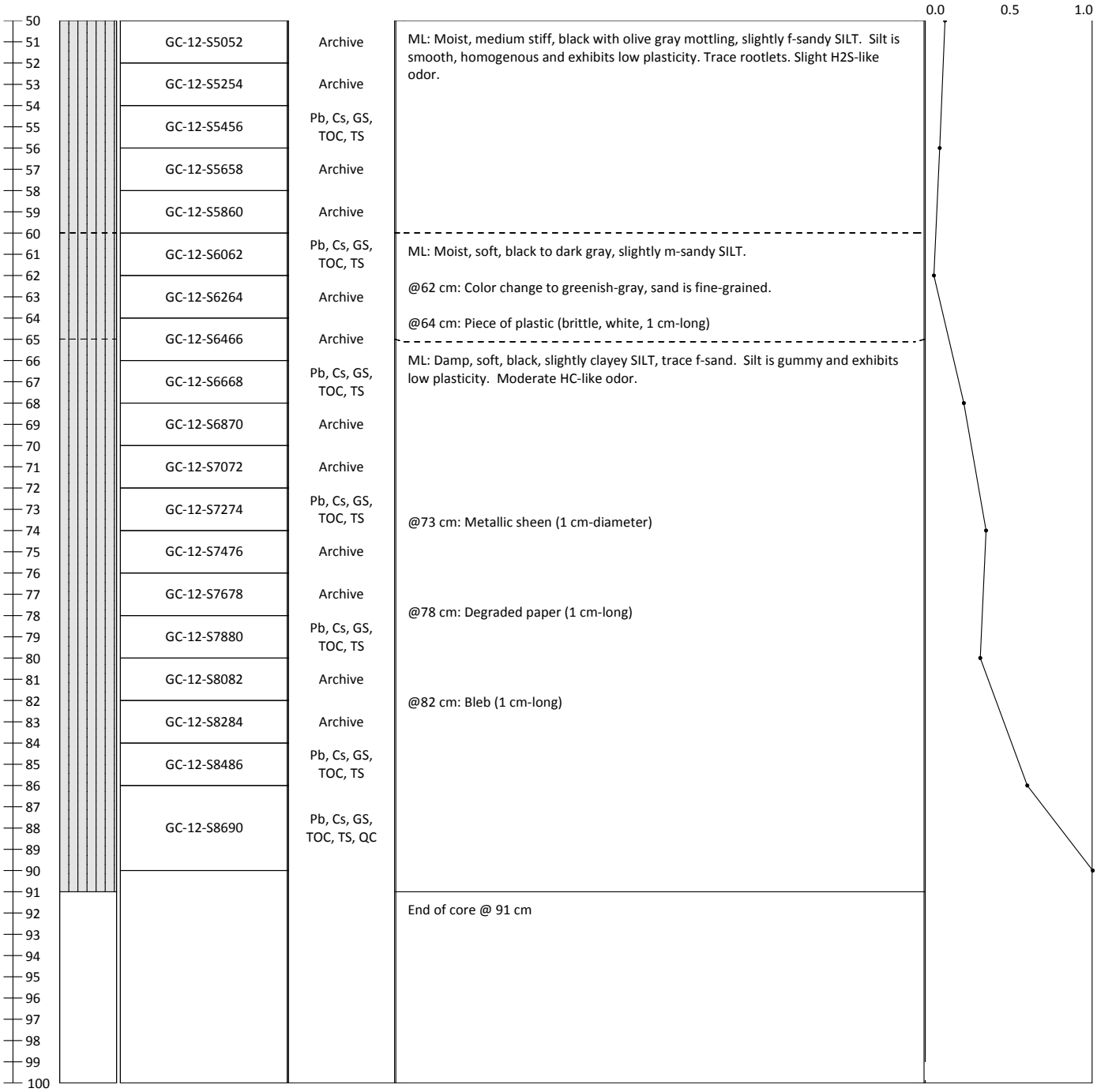
Calculated Recovery
Sample Length/Penetration Length:
45/50.5 in = 89%

Sediment Core Log

GC-12

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **50.5**
Project #: **060003-01**	SW Elevation (ft MLLW): **11.14**	Recovery Length (in): **45**
Client: **Port of Seattle**	Water Depth - LL (ft): **56.2**	Core Quality: **Good**
Collection Date: **1/26/2010**	Mudline Elevation (ft MLLW): **-45.1**	Percent Recovery: **89%**
Contractor: **RSS**	Northing: **1267421** Easting: **213798**	Process Date: **2/1/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	Sediment Description Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
50–91	GC-12-S5052	Archive	ML: Moist, medium stiff, black with olive gray mottling, slightly f-sandy SILT. Silt is smooth, homogenous and exhibits low plasticity. Trace rootlets. Slight H2S-like odor.	
	GC-12-S5254	Archive		
	GC-12-S5456	Pb, Cs, GS, TOC, TS		
	GC-12-S5658	Archive		
	GC-12-S5860	Archive		
60–65	GC-12-S6062	Pb, Cs, GS, TOC, TS	ML: Moist, soft, black to dark gray, slightly m-sandy SILT. @62 cm: Color change to greenish-gray, sand is fine-grained. @64 cm: Piece of plastic (brittle, white, 1 cm-long)	
	GC-12-S6264	Archive		
	GC-12-S6466	Archive		
65–91	GC-12-S6668	Pb, Cs, GS, TOC, TS	ML: Damp, soft, black, slightly clayey SILT, trace f-sand. Silt is gummy and exhibits low plasticity. Moderate HC-like odor.	
	GC-12-S6870	Archive		
	GC-12-S7072	Archive		
	GC-12-S7274	Pb, Cs, GS, TOC, TS	@73 cm: Metallic sheen (1 cm-diameter)	
	GC-12-S7476	Archive		
	GC-12-S7678	Archive		
	GC-12-S7880	Pb, Cs, GS, TOC, TS	@78 cm: Degraded paper (1 cm-long)	
	GC-12-S8082	Archive		
	GC-12-S8284	Archive	@82 cm: Bleb (1 cm-long)	
	GC-12-S8486	Pb, Cs, GS, TOC, TS		
	GC-12-S8690	Pb, Cs, GS, TOC, TS, QC		
91–100			End of core @ 91 cm	



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Drive Notes (1): Attempt 1 of 1. Moderately steady coring.

Notes (2): A Cs-137 peak is estimated at greater than 90 cm below mudline.

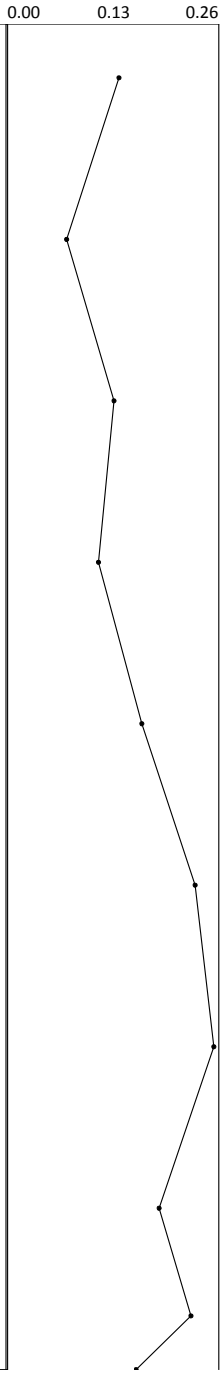
Calculated Recovery
Sample Length/Penetration Length:
45/50.5 in = 89%

Sediment Core Log

GC-13

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **57**
Project #: **060003-01**	SW Elevation (ft MLLW): **11.45**	Recovery Length (in): **55**
Client: **Port of Seattle**	Water Depth - LL (ft): **59.8**	Core Quality: **Good**
Collection Date: **1/28/2010**	Mudline Elevation (ft MLLW): **-48.4**	Percent Recovery: **96%**
Contractor: **RSS**	Northing: **1267667** Easting: **213803**	Process Date: **2/2/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	Sediment Description Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
0–50	GC-13-S0002	Pb, Cs, GS, TOC, TS	ML: Wet to moist, soft, black with olive gray mottling, SILT, trace f-sand. Silt is smooth and homogenous.	
	GC-13-S0204	Archive		
	GC-13-S0406	Archive		
	GC-13-S0608	Pb, Cs, GS, TOC, TS		
	GC-13-S0810	Archive		
	GC-13-S1012	Archive		
	GC-13-S1214	Pb, Cs, GS, TOC, TS		
	GC-13-S1416	Archive	@15 cm: Competency increases, sand content decreases, clay content increases	
	GC-13-S1618	Archive		
	GC-13-S1820	Pb, Cs, GS, TOC, TS		
	GC-13-S2022	Archive		
	GC-13-S2224	Archive		
	GC-13-S2426	Pb, Cs, GS, TOC, TS		
	GC-13-S2628	Archive		
	GC-13-S2830	Archive		
	GC-13-S3032	Pb, Cs, GS, TOC, TS		
	GC-13-S3234	Archive	@34 cm: Slight HC-like odor	
	GC-13-S3436	Archive		
	GC-13-S3638	Pb, Cs, GS, TOC, TS		
	GC-13-S3840	Archive		
	GC-13-S4042	Archive		
	GC-13-S4244	Pb, Cs, GS, TOC, TS		
	GC-13-S4448	Pb, Cs, GS, TOC, TS, QC		
	GC-13-S4850	Pb, Cs, GS, TOC, TS		



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360-733-4311

Drive Notes (1): Attempt 1 of 1. Steady coring.

Notes (2): No Cs-137 peak observed.

Calculated Recovery
Sample Length/Penetration Length:
55/57 in = 96%

Sediment Core Log

GC-13

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **57**
Project #: **060003-01**	SW Elevation (ft MLLW): **11.45**	Recovery Length (in): **55**
Client: **Port of Seattle**	Water Depth - LL (ft): **59.8**	Core Quality: **Good**
Collection Date: **1/28/2010**	Mudline Elevation (ft MLLW): **-48.4**	Percent Recovery: **96%**
Contractor: **RSS**	Northing: **1267667** Easting: **213803**	Process Date: **2/2/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	Sediment Description Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
50–100	GC-13-S5052	Archive	ML: Wet to moist, medium stiff, black with olive gray mottling, slightly clayey, SILT, trace f-sand. Silt is smooth and homogenous. Slight HC-like odor.	0.00 0.13 0.26
	GC-13-S5254	Archive		
	GC-13-S5456	Pb, Cs, GS, TOC, TS		
	GC-13-S5658	Archive		
	GC-13-S5860	Archive		
	GC-13-S6062	Pb, Cs, GS, TOC, TS	ML: Grades to moist, soft, black, SILT with moderate stratified beds of black, medium dense, SAND, trace silt (SP). Slight HC-like odor.	
	GC-13-S6264	Archive		
	GC-13-S6466	Archive		
	GC-13-S6668	Pb, Cs, GS, TOC, TS		
	GC-13-S6870	Archive		
	GC-13-S7072	Archive	@71 cm: No odor.	
	GC-13-S7274	Pb, Cs, GS, TOC, TS		
	GC-13-S7476	Archive		
	GC-13-S7678	Archive		
	GC-13-S7880	Pb, Cs, GS, TOC, TS	SP: Moist, medium dense to dense, m-SAND. Sand grains are black, white, gray, green, beige. No odor.	
	GC-13-S8082	Archive		
	GC-13-S8284	Archive	@82-84 cm: Trace silt pockets	
	GC-13-S8486	Pb, Cs, GS, TOC, TS		
	GC-13-S8688	Archive		
	GC-13-S8890	Archive		

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Drive Notes (1): Attempt 1 of 1. Steady coring.

Notes (2): No Cs-137 peak observed.

Calculated Recovery
Sample Length/Penetration Length:
55/57 in = 96%

Sediment Core Log

GC-13

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **57**
Project #: **060003-01**	SW Elevation (ft MLLW): **11.45**	Recovery Length (in): **55**
Client: **Port of Seattle**	Water Depth - LL (ft): **59.8**	Core Quality: **Good**
Collection Date: **1/28/2010**	Mudline Elevation (ft MLLW): **-48.4**	Percent Recovery: **96%**
Contractor: **RSS**	Northing: **1267667** Easting: **213803**	Process Date: **2/2/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	**Sediment Description** Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
100–107			SP: Moist, medium dense to dense, m-SAND. Sand grains are black, white, gray, green, beige. No odor.	
107–150			End of core @ 107 cm	

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Drive Notes (1): Attempt 1 of 1. Steady coring.

Notes (2): No Cs-137 peak observed.

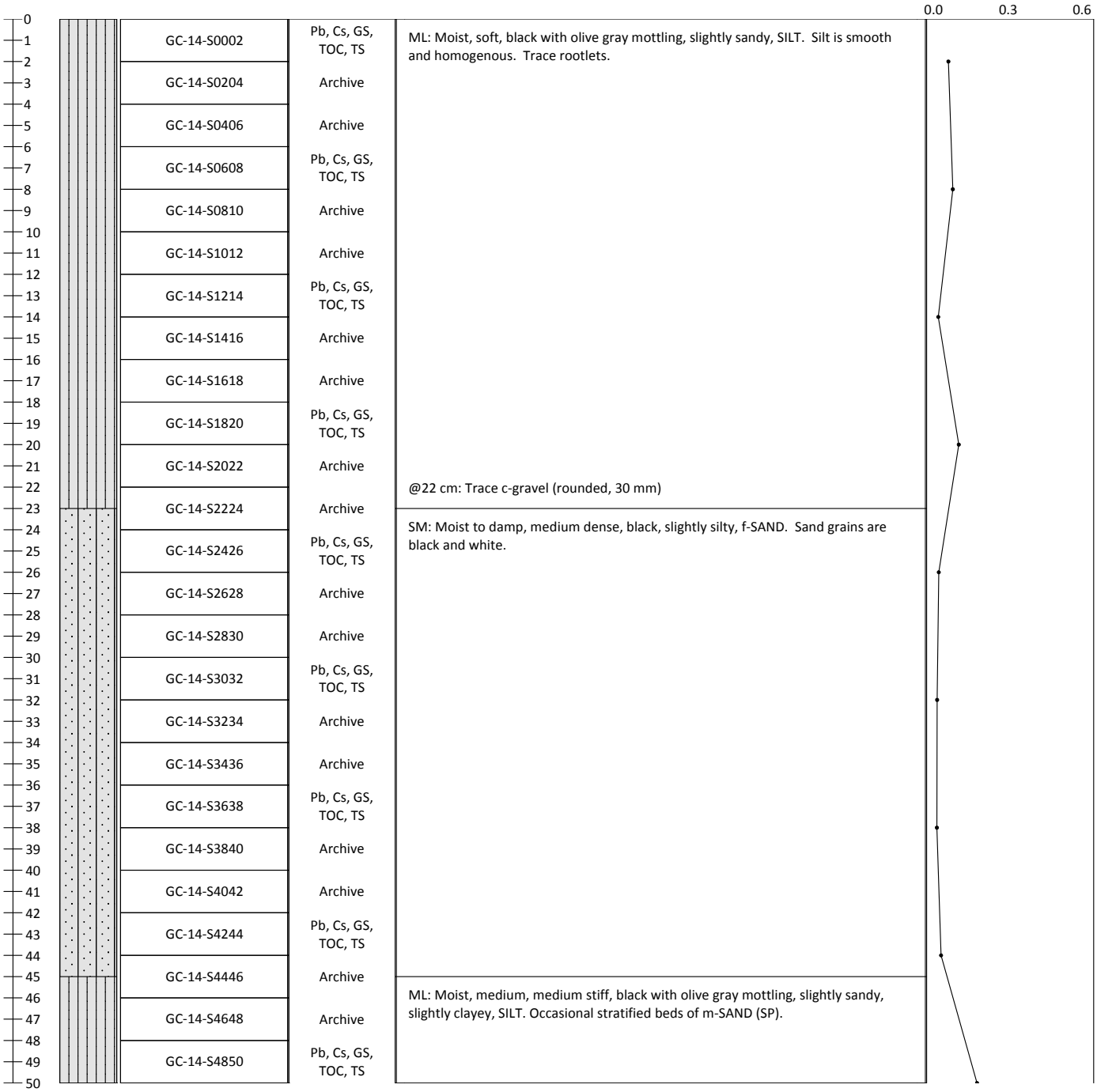
Calculated Recovery
Sample Length/Penetration Length:
55/57 in = 96%

Sediment Core Log

GC-14

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **54**
Project #: **060003-01**	SW Elevation (ft MLLW): **10.78**	Recovery Length (in): **47**
Client: **Port of Seattle**	Water Depth - LL (ft): **47.5**	Core Quality: **Good**
Collection Date: **1/27/2010**	Mudline Elevation (ft MLLW): **-36.7**	Percent Recovery: **87%**
Contractor: **RSS**	Northing: **1267170** Easting: **213075**	Process Date: **2/1/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	**Sediment Description** Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
0–22	GC-14-S0002	Pb, Cs, GS, TOC, TS	ML: Moist, soft, black with olive gray mottling, slightly sandy, SILT. Silt is smooth and homogenous. Trace rootlets.	
	GC-14-S0204	Archive		
	GC-14-S0406	Archive		
	GC-14-S0608	Pb, Cs, GS, TOC, TS		
	GC-14-S0810	Archive		
	GC-14-S1012	Archive		
	GC-14-S1214	Pb, Cs, GS, TOC, TS		
	GC-14-S1416	Archive		
	GC-14-S1618	Archive		
	GC-14-S1820	Pb, Cs, GS, TOC, TS		
	GC-14-S2022	Archive		
22–45	GC-14-S2224	Archive	@22 cm: Trace c-gravel (rounded, 30 mm)	
	GC-14-S2426	Pb, Cs, GS, TOC, TS	SM: Moist to damp, medium dense, black, slightly silty, f-SAND. Sand grains are black and white.	
	GC-14-S2628	Archive		
	GC-14-S2830	Archive		
	GC-14-S3032	Pb, Cs, GS, TOC, TS		
	GC-14-S3234	Archive		
	GC-14-S3436	Archive		
	GC-14-S3638	Pb, Cs, GS, TOC, TS		
	GC-14-S3840	Archive		
	GC-14-S4042	Archive		
	GC-14-S4244	Pb, Cs, GS, TOC, TS		
	GC-14-S4446	Archive		
45–50	GC-14-S4648	Archive	ML: Moist, medium, medium stiff, black with olive gray mottling, slightly sandy, slightly clayey, SILT. Occasional stratified beds of m-SAND (SP).	
	GC-14-S4850	Pb, Cs, GS, TOC, TS		



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Drive Notes (1): Attempt 1 of 1. Steady coring.

Notes (2): A Cs-137 peak of 0.575 pCi/g (dry) is observed at 56 cm below mudline.

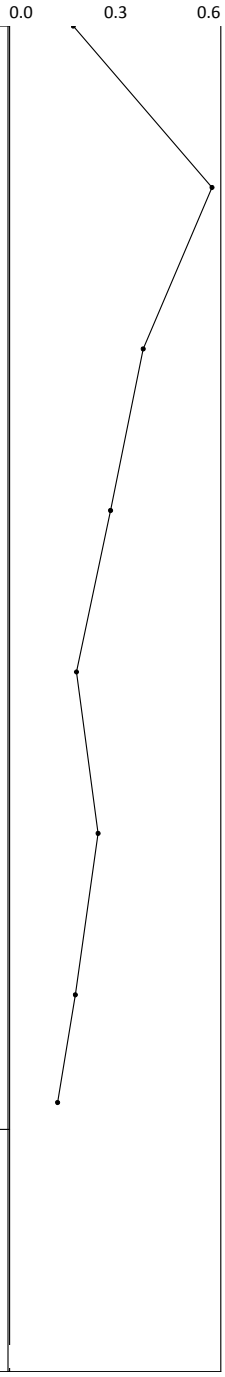
Calculated Recovery
Sample Length/Penetration Length:
47/54 in = 87%

Sediment Core Log

GC-14

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **54**
Project #: **060003-01**	SW Elevation (ft MLLW): **10.78**	Recovery Length (in): **47**
Client: **Port of Seattle**	Water Depth - LL (ft): **47.5**	Core Quality: **Good**
Collection Date: **1/27/2010**	Mudline Elevation (ft MLLW): **-36.7**	Percent Recovery: **87%**
Contractor: **RSS**	Northing: **1267170** Easting: **213075**	Process Date: **2/1/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	**Sediment Description** Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
50–91	GC-14-S5052	Archive	ML: Moist, medium, medium stiff, black with olive gray mottling, slightly sandy, slightly clayey, SILT. Occasional stratified beds of m-SAND (SP).	
	GC-14-S5254	Archive		
	GC-14-S5456	Pb, Cs, GS, TOC, TS	@54 cm: Color changes to homogenous black	
	GC-14-S5658	Archive		
	GC-14-S5860	Archive		
	GC-14-S6062	Pb, Cs, GS, TOC, TS	@60 cm: Stratified bed of m-SAND. Moderate H2S and slight HC-like odors.	
	GC-14-S6264	Archive		
	GC-14-S6466	Archive		
	GC-14-S6668	Pb, Cs, GS, TOC, TS	@67 cm: Stratified bed of m-SAND. Moderate H2S and slight HC-like odors.	
	GC-14-S6870	Archive		
	GC-14-S7072	Archive		
	GC-14-S7274	Pb, Cs, GS, TOC, TS		
	GC-14-S7476	Archive	@74-77 cm: Stratified bed of m-SAND. Trace decomposed wood (2 cm-long). Moderate H2S and slight HC-like odors.	
	GC-14-S7678	Archive		
	GC-14-S7880	Pb, Cs, GS, TOC, TS		
	GC-14-S8082	Archive		
	GC-14-S8284	Archive		
	GC-14-S8486	Pb, Cs, GS, TOC, TS		
	GC-14-S8690	Pb, Cs, GS, TOC, TS, QC	@88 cm: Seam of decomposed wood (1 cm-long) @89 cm: Stratified bed of m-SAND. Moderate H2S and slight HC-like odors.	
91–100			End of core @ 91 cm	



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Drive Notes (1): Attempt 1 of 1. Steady coring.

Notes (2): A Cs-137 peak of 0.575 pCi/g (dry) is observed at 56 cm below mudline.

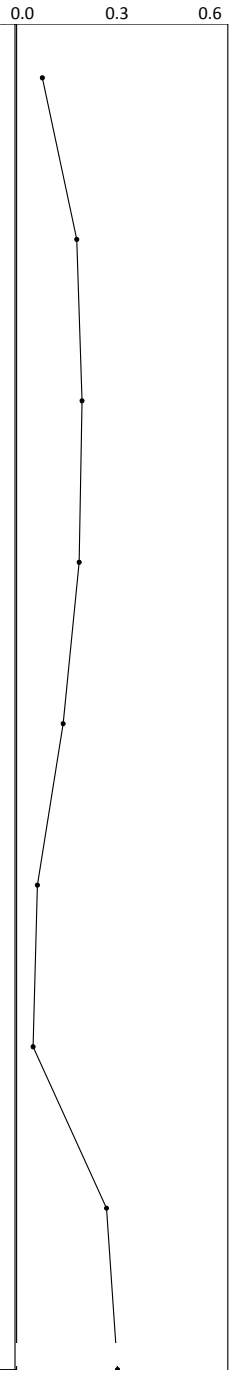
Calculated Recovery
Sample Length/Penetration Length:
47/54 in = 87%

Sediment Core Log

GC-15

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **55**
Project #: **060003-01**	SW Elevation (ft MLLW): **10.96**	Recovery Length (in): **48**
Client: **Port of Seattle**	Water Depth - LL (ft): **48**	Core Quality: **Good**
Collection Date: **1/27/2010**	Mudline Elevation (ft MLLW): **-37**	Percent Recovery: **87%**
Contractor: **RSS**	Northing: **1267406** Easting: **213053**	Process Date: **2/1/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	**Sediment Description** Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
0–50	GC-15-S0002	Pb, Cs, GS, TOC, TS	ML: Moist, soft, black with olive gray mottling, SILT, trace f-m-sand. Silt is smooth, homogenous, and exhibits low plasticity. Trace biota (worms) in top 5 cm. Slight H2S-like odor.	
	GC-15-S0204	Archive		
	GC-15-S0406	Archive		
	GC-15-S0608	Pb, Cs, GS, TOC, TS		
	GC-15-S0810	Archive		
	GC-15-S1012	Archive	@11 cm: Color change to black, competency increases to medium stiff (clayey)	
	GC-15-S1214	Pb, Cs, GS, TOC, TS		
	GC-15-S1416	Archive		
	GC-15-S1618	Archive		
	GC-15-S1820	Pb, Cs, GS, TOC, TS		
	GC-15-S2022	Archive		
	GC-15-S2224	Archive		
	GC-15-S2426	Pb, Cs, GS, TOC, TS		
	GC-15-S2628	Archive		
	GC-15-S2830	Archive		
	GC-15-S3032	Pb, Cs, GS, TOC, TS	@30-36 cm: Decreases in competency to soft. Odor increases to moderate H2S-like.	
	GC-15-S3234	Archive		
	GC-15-S3436	Archive		
	GC-15-S3638	Pb, Cs, GS, TOC, TS		
	GC-15-S3840	Archive		
	GC-15-S4042	Archive		
	GC-15-S4244	Pb, Cs, GS, TOC, TS		
	GC-15-S4446	Archive		
	GC-15-S4648	Archive		
	GC-15-S4850	Pb, Cs, GS, TOC, TS		



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Drive Notes (1): Attempt 1 of 1. Steady, easy coring; slight brown material on surface of core.

Notes (2): A Cs-137 peak of 0.576 pCi/g (dry) is observed at 62 cm below mudline.

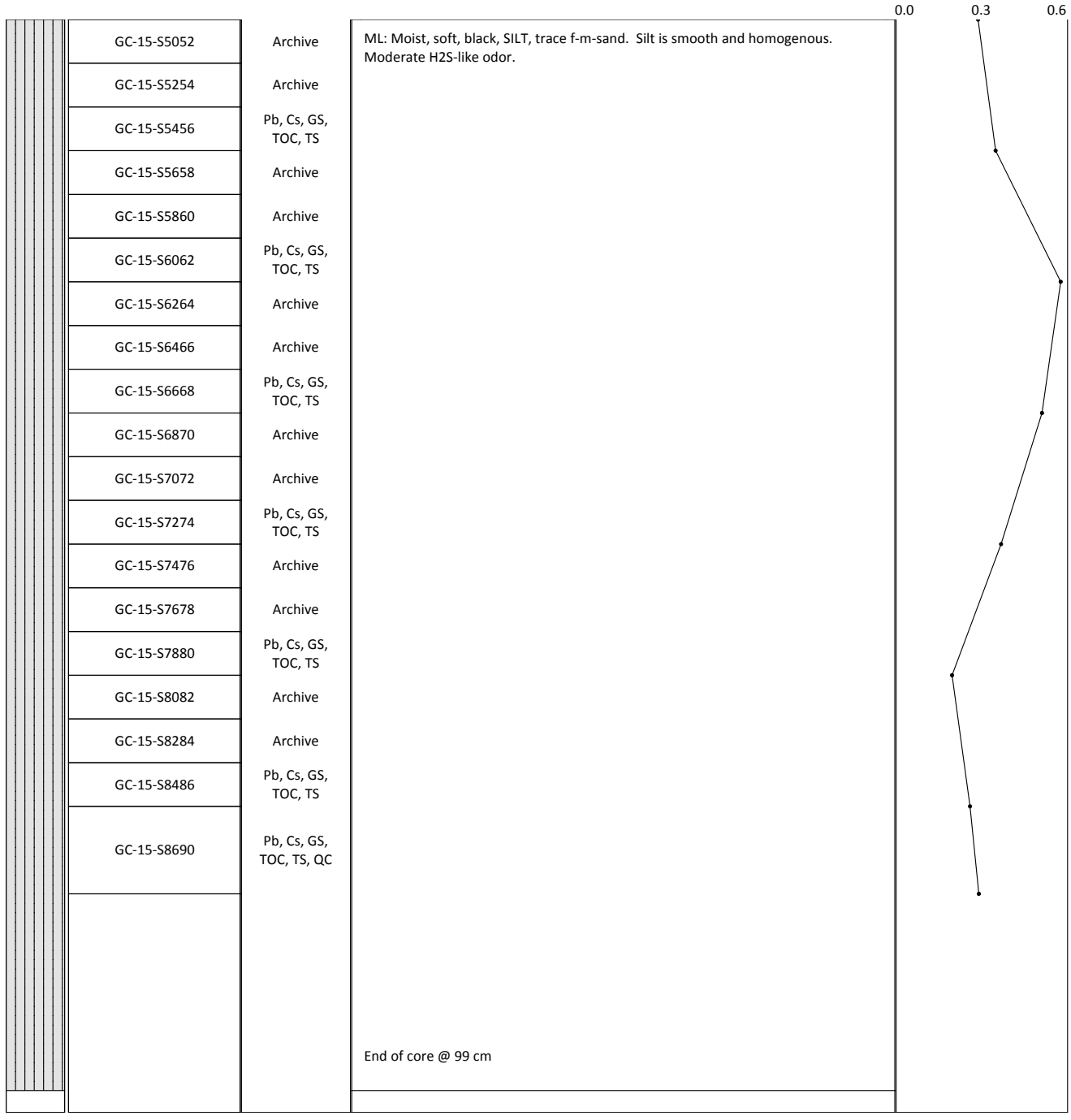
Calculated Recovery
Sample Length/Penetration Length:
48/55 in = 87%

Sediment Core Log

GC-15

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **55**
Project #: **060003-01**	SW Elevation (ft MLLW): **10.96**	Recovery Length (in): **48**
Client: **Port of Seattle**	Water Depth - LL (ft): **48**	Core Quality: **Good**
Collection Date: **1/27/2010**	Mudline Elevation (ft MLLW): **-37**	Percent Recovery: **87%**
Contractor: **RSS**	Northing: **1267406** Easting: **213053**	Process Date: **2/1/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	**Sediment Description** Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
50–100	GC-15-S5052	Archive	ML: Moist, soft, black, SILT, trace f-m-sand. Silt is smooth and homogenous. Moderate H2S-like odor.	0.0 0.3 0.6
	GC-15-S5254	Archive		
	GC-15-S5456	Pb, Cs, GS, TOC, TS		
	GC-15-S5658	Archive		
	GC-15-S5860	Archive		
	GC-15-S6062	Pb, Cs, GS, TOC, TS		
	GC-15-S6264	Archive		
	GC-15-S6466	Archive		
	GC-15-S6668	Pb, Cs, GS, TOC, TS		
	GC-15-S6870	Archive		
	GC-15-S7072	Archive		
	GC-15-S7274	Pb, Cs, GS, TOC, TS		
	GC-15-S7476	Archive		
	GC-15-S7678	Archive		
	GC-15-S7880	Pb, Cs, GS, TOC, TS		
	GC-15-S8082	Archive		
	GC-15-S8284	Archive		
	GC-15-S8486	Pb, Cs, GS, TOC, TS		
	GC-15-S8690	Pb, Cs, GS, TOC, TS, QC	End of core @ 99 cm	



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Drive Notes (1): Attempt 1 of 1. Steady, easy coring; slight brown material on surface of core.

Notes (2): A Cs-137 peak of 0.576 pCi/g (dry) is observed at 62 cm below mudline.

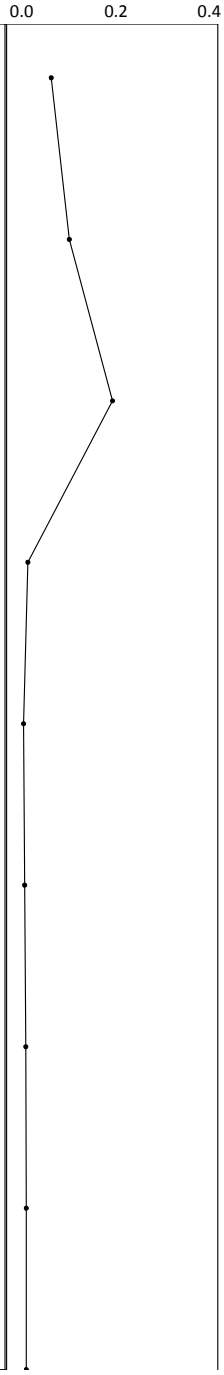
Calculated Recovery
Sample Length/Penetration Length:
48/55 in = 87%

Sediment Core Log

GC-16

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **60.5**
Project #: **060003-01**	SW Elevation (ft MLLW): **8.08**	Recovery Length (in): **53.5**
Client: **Port of Seattle**	Water Depth - LL (ft): **46.5**	Core Quality: **Good**
Collection Date: **1/26/2010**	Mudline Elevation (ft MLLW): **-38.4**	Percent Recovery: **88%**
Contractor: **RSS**	Northing: **1267647** Easting: **213052**	Process Date: **2/1/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	**Sediment Description** Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
0–50	GC-16-S0002	Pb, Cs, GS, TOC, TS	ML: Moist, soft, black with olive gray mottling, SILT, trace f-sand with occasional interbeds of slightly silty f-SAND, trace subrounded f-gravel (SM). Trace biota in top 16 cm (worms).	0.0 0.2 0.4
	GC-16-S0204	Archive		
	GC-16-S0406	Archive		
	GC-16-S0608	Pb, Cs, GS, TOC, TS		
	GC-16-S0810	Archive		
	GC-16-S1012	Archive		
	GC-16-S1214	Pb, Cs, GS, TOC, TS		
	GC-16-S1416	Archive	@15 cm: 1 cm seam of f-m SAND @16cm: Increase in sand content to "slightly" (ML)	
	GC-16-S1618	Archive		
	GC-16-S1820	Pb, Cs, GS, TOC, TS		
	GC-16-S2022	Archive		
	GC-16-S2224	Archive	@22 cm: Seam of f-m sand with subrounded gravel (1.5 cm-diameter)	
	GC-16-S2426	Pb, Cs, GS, TOC, TS		
	GC-16-S2628	Archive		
	GC-16-S2830	Archive		
	GC-16-S3032	Pb, Cs, GS, TOC, TS		
	GC-16-S3234	Archive	@32 cm: 3 cm seam of slightly sitly, f-SAND (SM)	
	GC-16-S3436	Archive		
	GC-16-S3638	Pb, Cs, GS, TOC, TS		
	GC-16-S3840	Archive		
	GC-16-S4042	Archive	@40-42 cm: Seam of slightly silty f-SAND (SM)	
	GC-16-S4244	Pb, Cs, GS, TOC, TS		
	GC-16-S4446	Archive	@45 cm: Subrounded, fine gravel (10 cm-diameter) @46-53 cm: Interbed of slightly silty f-SAND (SM)	
	GC-16-S4648	Archive		
	GC-16-S4850	Pb, Cs, GS, TOC, TS		



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Drive Notes (1): Attempt 1 of 1. Smooth coring.

Notes (2): A Cs-137 peak of 0.402 pCi/g (dry) is observed at 74 cm below mudline.

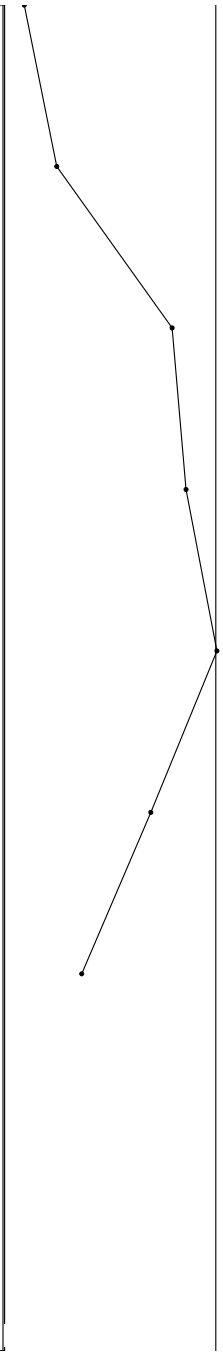
Calculated Recovery
Sample Length/Penetration Length:
53.5/60.5 in = 88%

Sediment Core Log

GC-16

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **60.5**
Project #: **060003-01**	SW Elevation (ft MLLW): **8.08**	Recovery Length (in): **53.5**
Client: **Port of Seattle**	Water Depth - LL (ft): **46.5**	Core Quality: **Good**
Collection Date: **1/26/2010**	Mudline Elevation (ft MLLW): **-38.4**	Percent Recovery: **88%**
Contractor: **RSS**	Northing: **1267647** Easting: **213052**	Process Date: **2/1/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	Sediment Description Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
50–100	C-16-S505 2	Archive	ML: Moist, soft, black with olive gray mottling, SILT, trace f-sand with occasional interbeds of slightly silty f-SAND, trace subrounded f-gravel (SM).	
	GC-16-S5254	Archive	ML: Moist, soft to medium stiff, black, slightly sandy, SILT. Silt is smooth and homogenous. Trace H2S-like odor.	
	GC-16-S5456	Pb, Cs, GS, TOC, TS		
	GC-16-S5658	Archive		
	GC-16-S5860	Archive		
	GC-16-S6062	Pb, Cs, GS, TOC, TS		
	GC-16-S6264	Archive		
	GC-16-S6466	Archive		
	GC-16-S6668	Pb, Cs, GS, TOC, TS		
	GC-16-S6870	Archive		
	GC-16-S7072	Archive		
	GC-16-S7274	Pb, Cs, GS, TOC, TS		
	GC-16-S7476	Archive		
	GC-16-S7678	Archive		
	GC-16-S7880	Pb, Cs, GS, TOC, TS		
	GC-16-S8082	Archive	ML: Moist, medium stiff, black with olive brown mottling, slightly clayey SILT, trace f-sand. Trace wood fragments (decomposed, 3 cm-long).	
	GC-16-S8284	Archive		
	GC-16-S8486	Pb, Cs, GS, TOC, TS		
	GC-16-S8688	Archive		
	GC-16-S8890	Archive		



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Drive Notes (1): Attempt 1 of 1. Smooth coring.

Notes (2): A Cs-137 peak of 0.402 pCi/g (dry) is observed at 74 cm below mudline.

Calculated Recovery
Sample Length/Penetration Length:
53.5/60.5 in = 88%

Sediment Core Log

GC-16

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **60.5**
Project #: **060003-01**	SW Elevation (ft MLLW): **8.08**	Recovery Length (in): **53.5**
Client: **Port of Seattle**	Water Depth - LL (ft): **46.5**	Core Quality: **Good**
Collection Date: **1/26/2010**	Mudline Elevation (ft MLLW): **-38.4**	Percent Recovery: **88%**
Contractor: **RSS**	Northing: **1267647** Easting: **213052**	Process Date: **2/1/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	**Sediment Description** Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
100–104			ML: Moist, medium stiff, black with olive brown mottling, slightly clayey SILT, trace f-sand. Trace wood fragments (decomposed, 3 cm-long).	0.0 0.2 0.4
104–150			End of core @ 104 cm	

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Drive Notes (1): Attempt 1 of 1. Smooth coring.

Notes (2): A Cs-137 peak of 0.402 pCi/g (dry) is observed at 74 cm below mudline.

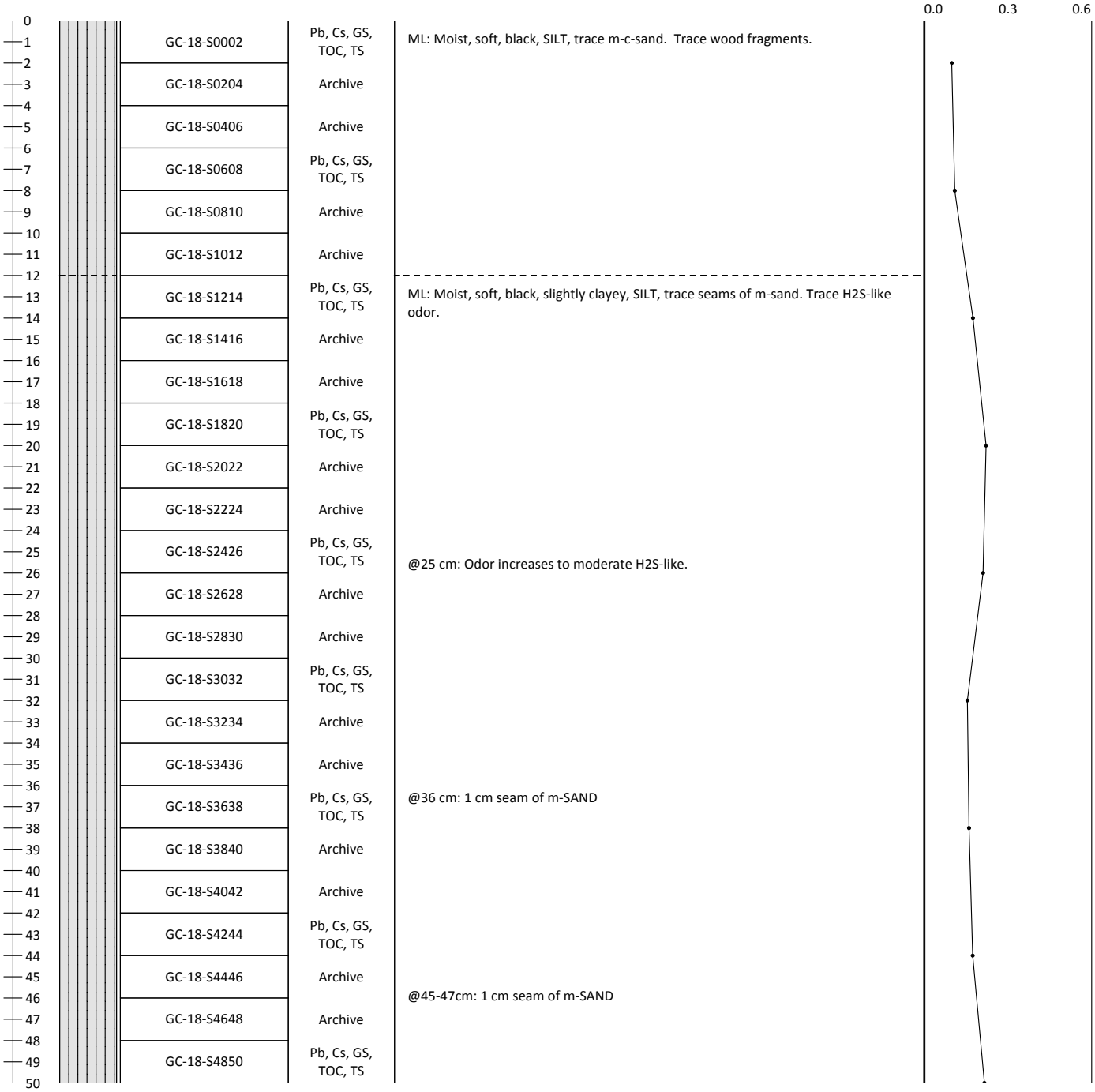
Calculated Recovery
Sample Length/Penetration Length:
53.5/60.5 in = 88%

Sediment Core Log

GC-18

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **60**
Project #: **060003-01**	SW Elevation (ft MLLW): **9.11**	Recovery Length (in): **48**
Client: **Port of Seattle**	Water Depth - LL (ft): **40.5**	Core Quality: **Good**
Collection Date: **1/28/2010**	Mudline Elevation (ft MLLW): **-31.4**	Percent Recovery: **80%**
Contractor: **RSS**	Northing: **1267296** Easting: **212565**	Process Date: **2/1/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	**Sediment Description** Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
	GC-18-S0002	Pb, Cs, GS, TOC, TS	ML: Moist, soft, black, SILT, trace m-c-sand. Trace wood fragments.	
	GC-18-S0204	Archive		
	GC-18-S0406	Archive		
	GC-18-S0608	Pb, Cs, GS, TOC, TS		
	GC-18-S0810	Archive		
	GC-18-S1012	Archive		
	GC-18-S1214	Pb, Cs, GS, TOC, TS	ML: Moist, soft, black, slightly clayey, SILT, trace seams of m-sand. Trace H2S-like odor.	
	GC-18-S1416	Archive		
	GC-18-S1618	Archive		
	GC-18-S1820	Pb, Cs, GS, TOC, TS		
	GC-18-S2022	Archive		
	GC-18-S2224	Archive		
	GC-18-S2426	Pb, Cs, GS, TOC, TS	@25 cm: Odor increases to moderate H2S-like.	
	GC-18-S2628	Archive		
	GC-18-S2830	Archive		
	GC-18-S3032	Pb, Cs, GS, TOC, TS		
	GC-18-S3234	Archive		
	GC-18-S3436	Archive		
	GC-18-S3638	Pb, Cs, GS, TOC, TS	@36 cm: 1 cm seam of m-SAND	
	GC-18-S3840	Archive		
	GC-18-S4042	Archive		
	GC-18-S4244	Pb, Cs, GS, TOC, TS		
	GC-18-S4446	Archive	@45-47cm: 1 cm seam of m-SAND	
	GC-18-S4648	Archive		
	GC-18-S4850	Pb, Cs, GS, TOC, TS		



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360-733-4311

Drive Notes (1): Attempt 1 of 1. Easy coring.

Notes (2): A Cs-137 peak of 0.57 pCi/g (dry) is observed at 90 cm below mudline.

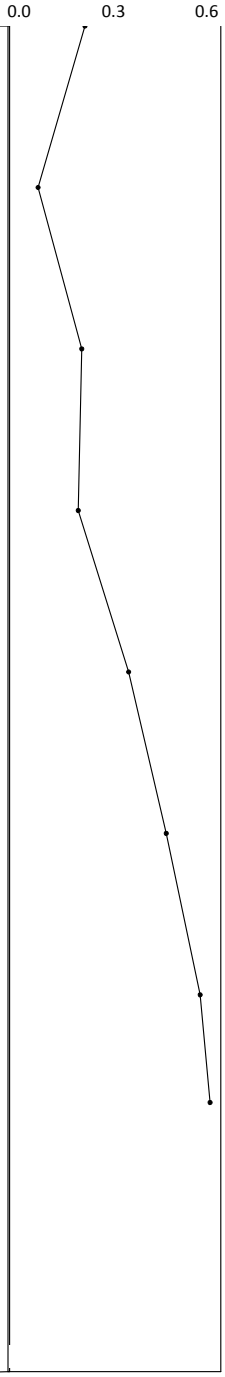
Calculated Recovery
Sample Length/Penetration Length:
48/60 in = 80%

Sediment Core Log

GC-18

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **60**
Project #: **060003-01**	SW Elevation (ft MLLW): **9.11**	Recovery Length (in): **48**
Client: **Port of Seattle**	Water Depth - LL (ft): **40.5**	Core Quality: **Good**
Collection Date: **1/28/2010**	Mudline Elevation (ft MLLW): **-31.4**	Percent Recovery: **80%**
Contractor: **RSS**	Northing: **1267296** Easting: **212565**	Process Date: **2/1/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	**Sediment Description** Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
50–100	GC-18-S5052	Archive	ML: Moist, soft, black, slightly clayey, SILT, trace seams of m-sand. Moderate H2S-like odor.	
	GC-18-S5254	Archive		
	GC-18-S5456	Pb, Cs, GS, TOC, TS		
	GC-18-S5658	Archive		
	GC-18-S5860	Archive		
	GC-18-S6062	Pb, Cs, GS, TOC, TS		
	GC-18-S6264	Archive		
	GC-18-S6466	Archive		
	GC-18-S6668	Pb, Cs, GS, TOC, TS		
	GC-18-S6870	Archive		
	GC-18-S7072	Archive		
	GC-18-S7274	Pb, Cs, GS, TOC, TS		
	GC-18-S7476	Archive		
	GC-18-S7678	Archive		
	GC-18-S7880	Pb, Cs, GS, TOC, TS		
	GC-18-S8082	Archive		
	GC-18-S8284	Archive		
	GC-18-S8486	Pb, Cs, GS, TOC, TS		
	GC-18-S8690	Pb, Cs, GS, TOC, TS, QC		
			@91-92 cm: Layer of red wood (Cedar)	
			@100 cm: Layer of red wood (Cedar) End of core @ 100 cm	



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Drive Notes (1): Attempt 1 of 1. Easy coring.

Notes (2): A Cs-137 peak of 0.57 pCi/g (dry) is observed at 90 cm below mudline.

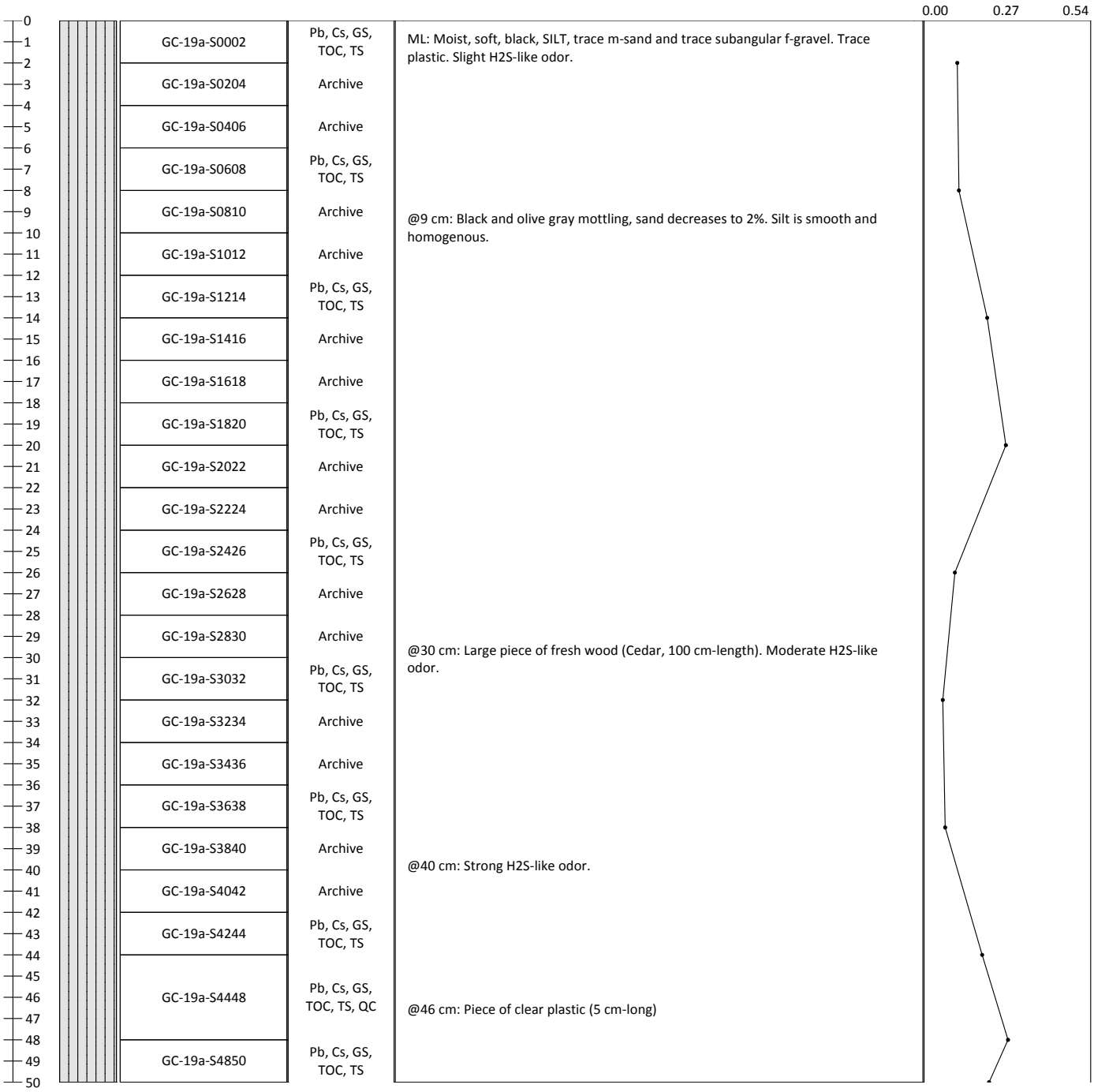
Calculated Recovery
Sample Length/Penetration Length:
48/60 in = 80%

Sediment Core Log

GC-19A

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **-**
Project #: **060003-01**	SW Elevation (ft MLLW): **11.16**	Recovery Length (in): **33**
Client: **Port of Seattle**	Water Depth - LL (ft): **40.9**	Core Quality: **Good**
Collection Date: **1/28/2010**	Mudline Elevation (ft MLLW): **-29.7**	Percent Recovery: **-**
Contractor: **RSS**	Northing: **1267396** Easting: **212535**	Process Date: **2/3/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	Sediment Description Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
	GC-19a-S0002	Pb, Cs, GS, TOC, TS	ML: Moist, soft, black, SILT, trace m-sand and trace subangular f-gravel. Trace plastic. Slight H2S-like odor.	
	GC-19a-S0204	Archive		
	GC-19a-S0406	Archive		
	GC-19a-S0608	Pb, Cs, GS, TOC, TS		
	GC-19a-S0810	Archive	@9 cm: Black and olive gray mottling, sand decreases to 2%. Silt is smooth and homogenous.	
	GC-19a-S1012	Archive		
	GC-19a-S1214	Pb, Cs, GS, TOC, TS		
	GC-19a-S1416	Archive		
	GC-19a-S1618	Archive		
	GC-19a-S1820	Pb, Cs, GS, TOC, TS		
	GC-19a-S2022	Archive		
	GC-19a-S2224	Archive		
	GC-19a-S2426	Pb, Cs, GS, TOC, TS		
	GC-19a-S2628	Archive		
	GC-19a-S2830	Archive		
	GC-19a-S3032	Pb, Cs, GS, TOC, TS	@30 cm: Large piece of fresh wood (Cedar, 100 cm-length). Moderate H2S-like odor.	
	GC-19a-S3234	Archive		
	GC-19a-S3436	Archive		
	GC-19a-S3638	Pb, Cs, GS, TOC, TS		
	GC-19a-S3840	Archive	@40 cm: Strong H2S-like odor.	
	GC-19a-S4042	Archive		
	GC-19a-S4244	Pb, Cs, GS, TOC, TS		
	GC-19a-S4448	Pb, Cs, GS, TOC, TS, QC	@46 cm: Piece of clear plastic (5 cm-long)	
	GC-19a-S4850	Pb, Cs, GS, TOC, TS		



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Drive Notes (1): Attempt 1 of 2. Soft material driven to 3", diver reports that core is pushing soft sediment aside- penetration difficult to determine.

Notes (2): A Cs-137 peak of 0.522 pCi/g (dry) is observed at 56 cm below mudline.

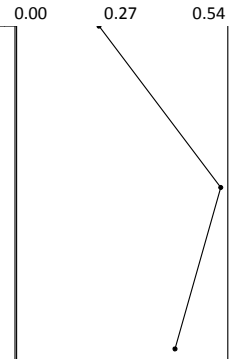
Calculated Recovery
Sample Length/Penetration Length:
Estimated at 80%

Sediment Core Log

GC-19A

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **-**
Project #: **060003-01**	SW Elevation (ft MLLW): **11.16**	Recovery Length (in): **33**
Client: **Port of Seattle**	Water Depth - LL (ft): **40.9**	Core Quality: **Good**
Collection Date: **1/28/2010**	Mudline Elevation (ft MLLW): **-29.7**	Percent Recovery: **-**
Contractor: **RSS**	Northing: **1267396** Easting: **212535**	Process Date: **2/3/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	Sediment Description Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
50–65	GC-19a-S5052	Archive	ML: Moist, soft, black with olive gray mottling, SILT, trace m-sand and trace subangular f-gravel. Moderate H2S-like odor.	0.00 0.27 0.54
	GC-19a-S5254	Archive		
	GC-19a-S5456	Pb, CS, GS, TOC, TS		
	GC-19a-S5658	Archive		
	GC-19a-S5860	Archive	@59 cm: Wood fragment (5 cm-long)	
	GC-19a-S6062	Pb, Cs, GS, TOC, TS		
	GC-19a-S6264	Archive		
66–100			End of core @ 65 cm	



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Drive Notes (1): Attempt 1 of 2. Soft material driven to 3", diver reports that core is pushing soft sediment aside- penetration difficult to determine.

Notes (2): A Cs-137 peak of 0.522 pCi/g (dry) is observed at 56 cm below mudline.

Calculated Recovery
Sample Length/Penetration Length:
Estimated at 80%

Sediment Core Log

GC-19B

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **51.5**
Project #: **060003-01**	SW Elevation (ft MLLW): **4.07**	Recovery Length (in): **47**
Client: **Port of Seattle**	Water Depth - LL (ft): **36**	Core Quality: **Disturbed**
Collection Date: **2/2/2010**	Mudline Elevation (ft MLLW): **-31.9**	Percent Recovery: **91.3%**
Contractor: **RSS**	Northing: **1267389** Easting: **212541**	Process Date: **2/3/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	**Sediment Description** Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
0–30	GC-19b-S0002	Archive	ML: moist, soft, black, SILT, trace m-sand and trace subangular f-gravel. From 0-4 cm the core was slightly disturbed due to handling.	
	GC-19b-S0204	Archive		
	GC-19b-S0406	Archive		
	GC-19b-S0608	Archive		
	GC-19b-S0810	Archive		
	GC-19b-S1012	Archive		
	GC-19b-S1214	Archive		
	GC-19b-S1416	Archive		
	GC-19b-S1618	Archive		
	GC-19b-S1820	Archive		
	GC-19b-S2022	Archive		
	GC-19b-S2224	Archive		
	GC-19b-S2426	Archive		
	GC-19b-S2628	Archive		
	GC-19b-S2830	Archive		
30–50	GC-19b-S3032	Archive	ML: Moist, medium stiff, black, SILT, trace vf-sand. Trace wood fragments.	
	GC-19b-S3234	Archive		
	GC-19b-S3436	Archive		
	GC-19b-S3638	Archive	@37 cm: Piece of wood (3 cm-long, cedar).	
	GC-19b-S3840	Archive		
	GC-19b-S4042	Archive		
	GC-19b-S4244	Archive		
	GC-19b-S4448	Archive, QC		
	GC-19b-S4850	Archive		

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Drive Notes (1): Attempt 2 of 2. Steady, even coring. Stopped coring early because core tube began to compress.

Notes (2): GC-19B was not analyzed for geochronology.

Calculated Recovery
Sample Length/Penetration Length:
47/51.5 in = 91.3%

Sediment Core Log

GC-19B

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **51.5**
Project #: **060003-01**	SW Elevation (ft MLLW): **4.07**	Recovery Length (in): **47**
Client: **Port of Seattle**	Water Depth - LL (ft): **36**	Core Quality: **Disturbed**
Collection Date: **2/2/2010**	Mudline Elevation (ft MLLW): **-31.9**	Percent Recovery: **91.3%**
Contractor: **RSS**	Northing: **1267389** Easting: **212541**	Process Date: **2/3/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	**Sediment Description** Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
50–89	GC-19b-S5052	Archive	ML: Moist, medium stiff, black, SILT, trace vf-sand. Trace wood fragments.	
	GC-19b-S5254	Archive		
	GC-19b-S5456	Archive		
	GC-19b-S5658	Archive		
	GC-19b-S5860	Archive		
	GC-19b-S6062	Archive		
	GC-19b-S6264	Archive		
	GC-19b-S6466	Archive		
	GC-19b-S6668	Archive		
	GC-19b-S6870	Archive		
	GC-19b-S7072	Archive		
	GC-19b-S7274	Archive		
	GC-19b-S7476	Archive		
	GC-19b-S7678	Archive		
	GC-19b-S7880	Archive		
	GC-19b-S8082	Archive		
	GC-19b-S8284	Archive		
	GC-19b-S8486	Archive		
	GC-19b-S8688	Archive		
89–100			End of core @ 89 cm	

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Drive Notes (1): Attempt 2 of 2. Steady, even coring. Stopped coring early because core tube began to compress.

Notes (2): GC-19B was not analyzed for geochronology.

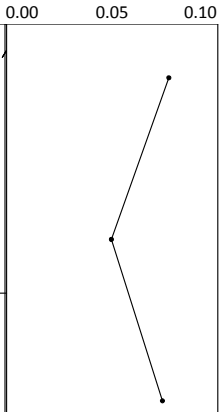
Calculated Recovery
Sample Length/Penetration Length:
47/51.5 in = 91.3%

Sediment Core Log

GC-20

Project: **East Waterway - STE**	Area: **East Waterway**	Drive Length (in): **21**
Project #: **060003-01**	SW Elevation (ft MLLW): **8.38**	Recovery Length (in): **16**
Client: **Port of Seattle**	Water Depth - LL (ft): **22.5**	Core Quality: **Poor**
Collection Date: **1/27/2010**	Mudline Elevation (ft MLLW): **-14.1**	Percent Recovery: **76%**
Contractor: **RSS**	Northing: **1267239** Easting: **212264**	Process Date: **2/2/2010**
Vessel: **Caroline Dow**	Horiz. Datum: **NAD 83 WA N US Ft** Vert. Datum: **MLLW**	Process Method: **Cut-Tube**
Operator: **Parker**	Method/Tube ID: **Diver Core/ 4" Polycarbonate Tube**	Logged By: **LM/DP/AO**

Recovered Depth (cm) and Graphic Log	Sample Interval	Analysis	Sediment Description Contacts are Recovered Depths. Classification Scheme: USCS	Cs-137 Profile (pCi/g dry)
0–17	GC-20-S0002	Pb, Cs, GS, TOC, TS	ML: Moist to damp, soft, olive gray, clayey, SILT. Abundant biota (worms).	
	GC-20-S0204	Archive	ML: Moist, medium stiff, black with olive gray mottling, slightly m-sandy SILT. Broken shell debris encase the silt along the sidewalls (encasement not sampled).	
	GC-20-S0406	Archive		
	GC-20-S0608	Pb, Cs, GS, TOC, TS		
	GC-20-S0810	Archive		
	GC-20-S1012	Archive	SM: Moist, medium dense, black, slightly silty, m-c-SAND. Occasional shells and wood fragments (up to 1.5 cm-long). Trace subrounded cobble (100 mm-diameter) and decomposed wood piece (6 cm-long x 5 cm-wide) in bottom of core.	
	GC-20-S1214	Pb, Cs, GS, TOC, TS		
	GC-20-S1416	Archive		
			End of core @ 17 cm	



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Drive Notes (1): Attempt 1 of 1. Very stiff coring.

Notes (2): No Cs-137 peak observed.

Calculated Recovery
Sample Length/Penetration Length:
16/21 in = 76%

APPENDIX D
SEDFLUME CORE DATA

ATTACHMENT 1

Sedflume Data Collection

D.1 DATA COLLECTION OVERVIEW

Eight Sedflume cores were collected as part of the East Waterway (EW) Sediment Transport Evaluation (STE) to provide in situ sediment properties and empirical site-specific estimates of critical shear stress within the EW. Sedflume cores were collected on April 19, 2010, and analyzed on site April 20 through April 21, 2010, by Sea Engineering, Inc. (SEI; 2010). The cores were collected using a deep-water coring system that does not require the use of divers. The system includes a pneumatic piston mounted on an aluminum frame with weighted horizontal legs for stability. Sedflume core barrels are inserted into the frame beneath the piston and the corer system is lowered to the sea bed from an A-frame on the bow of the research vessel. The piston forces the core barrel into the sediment and then reverses direction to extract the core from the sediment bed. A spring-loaded door closes after core extraction to ensure that no sediment is lost as the core is brought to the surface. Detailed descriptions of core collection and Sedflume analysis procedures are provided on pages 5 and 6 of the SEI report (included in this appendix as Attachment 2). Table D-1 provides the locations and approximate water depths at the time of retrieval for each Sedflume core. Figure 2-3 in the main body of the report shows the locations of collected cores.

Table D-1
Sampling Locations of Sedflume Cores

Core Location	Latitude (ºN)	Longitude (ºW)	Coring Date	Time (PDT)	Depth ft (m)[a]
SF_1	47.57415	122.3445	4/19/2010	12:20	46.0 (14.0)
SF_2	47.57628	122.3446	4/19/2010	10:40	48.0 (14.6)
SF_3	47.57265	122.345	4/19/2010	12:55	32.0 (9.8)
SF_4	47.57125	122.3455	4/19/2010	13:40	7.5 (2.3)
SF_5	47.57187	122.3452	4/19/2010	14:20	17.0 (5.2)
SF_6	47.5801	122.3447	4/19/2010	15:05	52.0 (15.8)
SF_7	47.58915	122.3447	4/19/2010	17:00	57.0 (17.4)
SF_8	47.58492	122.3449	4/19/2010	18:30	59.0 (18.0)

Notes:
a. Depths are measured at time of deployment from the water surface and are not corrected to any datum.

D.2 DATA OVERVIEW

For each of the eight Sedflume cores collected, erosion rate, grain size distribution, and bulk density were evaluated at various vertical intervals in the core down to approximately 20 centimeters (cm) below mudline. Data summary tables and associated laboratory reports (provided by SEI) are included in this appendix as Attachment 3. A summary of observations and results of data analyses for each core are provided in the Executive Summary of the SEI report (Attachment 2 in this appendix). Additional data evaluation, which included estimates of critical shear stress based on measured erosion rates, was also completed by SEI using regression techniques. This information is also provided in detail in the attached SEI report. Anchor QEA, LLC, completed an additional evaluation (also using regression techniques) to evaluate critical shear stress from erosion rates provided by the Sedflume analysis. This information is provided in Section 6.1 in the main body of the report.

D.3 DEVIATIONS FROM THE SEDIMENT TRANSPORT CHARACTERIZATION QAPP

Procedures for Sedflume core collection and laboratory testing are outlined in the Sediment Transport Characterization Quality Assurance Project Plan (QAPP; Anchor QEA 2009). Sections 3.1.2 and 3.2.4 in the QAPP outline the required data collection locations and procedures, respectively, for Sedflume data collection. There were no significant deviations from the QAPP that altered the quality of data collected. However, there were several deviations from the QAPP that should be noted.

The QAPP required collection of seven Sedflume cores (Table 3-2 in the QAPP), including one proposed for the Junction Reach (SF_6). During collection of the geochronological cores, it became apparent that bottom sediments in the Junction Reach were primarily consolidated gravels and sands, which would make collection of a Sedflume core in that location prohibitively difficult. Through discussions with the U.S. Environmental Protection Agency (EPA), it was decided that core SF_6 would be moved out into the Main Body Reach, where there was a higher expectation of successful retrieval. In addition, another core location was added (SF_8) to a deeper area within the EW to increase spatial resolution of the dataset. Water depths and locations proposed in the QAPP (Table 3-2) for the Sedflume cores varied slightly from actual values due to updated bathymetry (collected as part of the STE), variability in bed elevation, and navigation concerns during core collection. None of

these changes are significantly different than proposed. Table D-1 provides the actual locations and water depths for each Sedflume core.

The QAPP required the use of piston coring, which would be employed by divers for collection of the Sedflume cores. Deep water depths at some locations (approximately 60 feet) and navigation concerns within the EW, produced concerns regarding the efficiency and safety of using divers to extract the Sedflume cores. Therefore, through discussions with SEI and EPA, the coring method was changed to a remote coring system that employed piston coring methods as required by the QAPP, but was set up to extract and retrieve cores at depth without the use of divers. The collection procedure is outlined in detail in the SEI report (Attachment 2), and has been used successfully at other sites for Sedflume core collection.

REFERENCES

Anchor QEA, 2009. East Waterway Operable Unit, Supplemental Remedial Investigation/Feasibility Study, Final Sediment Transport Characterization Quality Assurance Project Plan. Prepared for Port of Seattle. March.

SEI, 2010. Sea Engineering Inc. East Waterway Sedflume Analysis. Prepared for Anchor QEA, LLC. June 2010.

ATTACHMENT 2

DRAFT

East Waterway Sedflume Analysis, Washington

June 2010

Prepared for:

Anchor QEA, LLC.

Prepared by:
Sea Engineering, Inc.
200 Washington Street, Suite 210
Santa Cruz, CA 95060
Tel: (831) 421-0871
Fax: (831) 421-0875

Executive Summary

Sea Engineering, Inc. (SEI) conducted a Sedflume analysis for Anchor QEA on eight (8) sediment cores obtained from the East Waterway in the Port of Seattle, Washington. These cores were collected in areas where depths ranged to 18 m of water depth. The primary goal of this work was to characterize the erosion properties of the sediments within the East Waterway. The Sedflume analysis determines sediment erosion rates, critical shear stress, particle size and wet bulk density at depth intervals down-core. The following is a brief physical description of the cores. The report below contains the data from the comprehensive Sedflume analysis:

- Core SF-1 was collected in approximately 14.0 m water depth. The material consisted of silts and sandy silts. Stringy, organic material became exposed when the surrounding finer sediments were scoured away. Several (4-6) larger worms existed to the 4 cm depth. Erosion was uneven and clumpy. A few worms were visible near a depth of 10 cm. Deeper than 15 cm of depth, the material was very difficult to erode. The erosion rate data shows evidence of typical consolidated core material: the material, in general, becomes stiffer with increasing depth. The mean d_{50} in the core is 11.65 μm, fine silt. The mean bulk density in the core is 1.38 g/cm^3.

- Core SF-2 was collected in approximately 14.6 m water depth. The material consisted of silts and sandy silts. A very stiff layer of sediment was encountered at the bottom of the core, preventing any deeper push coring. A large amount of stringy organic material was encountered beneath the surface as fine particulates were scoured away. The organic material persisted until approximately 5 cm, where an easier to erode layer was encountered. Erosion was uneven and clumpy. The erosion rates remain relatively constant down-core, but increase by two orders of magnitude deeper than 20 cm into the core. The mean d_{50} in the core is 21.4 μm, fine silt. The bulk densities averaged 1.47 g/cm^3 in the core.

- Core SF-3 was collected in approximately 9.8 m water depth. Upon extraction, the core consisted of an undisturbed sediment surface comprising small surface debris (e.g. small twigs) and approximately 1 cm of light brown and orange colored fine sediment. Small pebbles (~1 cm diameter) were observed within the top 5 cm. Some worms and stringy organic material became visible in this layer as well, as the finer particulates were eroded. At depths greater than 16 cm, a large amount of woody debris and organic detritus was encountered. Erosion occurred in clumps. The erosion rate data shows evidence of easier-to-erode sediment with increasing depth, which is not typical of consolidated core material. The erosion rates remain relatively constant down-core until a depth of approximately 10 cm, where the increasing erosion rate trend begins. The mean particle size in the core is 11.5 μm. The mean bulk density in the core is 1.44 g/cm^3.

- Core SF-4 was collected in approximately 2.3 m water depth. The core was collected from a very shallow area beneath the bridges connecting Seattle to Harbor Island and West Seattle (West Seattle Bridge). It was difficult to collect a large amount of sediment in the core at this location because of the material composition. The core was driven to refusal several times. Upon extraction, the core consisted of an undisturbed sediment surface comprising 5 cm of fine, lighter-colored sediments. Below the surface layer, shell hash and coarser sands were visible mixed with silts. At the bottom of the core, a visible fine to medium sand layer (2-4 cm thick) was observed. During the analysis, some red-colored grass was visible within the surface layer. Small benthic organisms and worms

were visible. Erosion was clumpy near the top of the core due to the organic material that added strength to the sediment. Near the bottom, erosion was very uneven, eroding the center of the core faster than the sides. The erosion rate data shows evidence of typical consolidated core material: the material, though variable down-core, generally becomes stiffer with increasing depth. The mean d_{50} in the core was 21.0 μm. The mean bulk density in the core is 1.46 g/cm^3.

- Core SF-5 was collected in approximately 5.2 m water depth. The core was collected from a relatively shallow region immediately north of the Harbor Island and West Seattle bridges. It was difficult to collect a large amount of sediment in the core at this location because the material composition was, again, very prohibitive. The core was driven to refusal twice with the subsequent extracted depth similar to the first. The core consisted of an undisturbed sediment surface comprising 1-2 cm of fine, lighter-colored sediments. Below the surface layer, fine to medium sands were visible mixed with silts. At the bottom of the core, a darker colored material was observed, likely the material which prevented a deeper core from being extracted. Many (20-30) 1 cm to 2 cm long, small diameter worms were observed on the surface. The top 1 cm of sediment was difficult to erode because the organic material and benthic organisms added strength to the sediment. Down-core erosion was clumpy and uneven. The erosion rate data shows evidence of wide variation in erosion rates down-core. The core mean value of d_{50} is 23.9 μm. The mean bulk density in the core is 1.53 g/cm^3.

- Core SF-6 was collected in approximately 15.8 m water depth. The core was collected from a central channel location, approximately midway between the West Seattle Bridge to the south and the East Waterway mouth to the north. Upon extraction, the core consisted of an undisturbed, uneven sediment surface comprising benthic organisms and worms over 5 cm of silt and fine sand. Beneath the surface layer a 5-6 cm layer of fine to medium sand and shell hash was clearly visible. Below the sand lens, the sediments comprised darker-colored silty material. Some organic detritus and fine stringy organic material was observed when the fine particulates were scoured away. The erosion rate data shows variation in erosion rates down-core as a result of different material consistencies. The erosion rates increased when the fine to medium sand layer was encountered and at the very bottom of the core, when clumpy erosion caused larger amounts of sediment to be removed. At layers in between the sandy layer and the bottom of the core, the material is stiffer and more difficult-to-erode, resulting in relatively lower erosion rates. The mean d_{50} in the core is 42.5 μm. The mean bulk density in the core is 1.64 g/cm^3.

- Core SF-7 was collected in approximately 17.4 m water depth. The core was collected near the mouth of the East Waterway. This core required 5 attempts to extract a sufficient core. The material consisted of an uneven, undisturbed, 2-3 cm sandy silt layer with some shell hash and organic detritus. Below this layer was a darker-colored stiff clayey silt material. Several worms and worm tubes were observed on the surface layer and throughout the core. An easier-to-erode surface layer gave way to veins of a stiffer layer below, which resulted in uneven erosion. The sediment consistency beneath the surface was stiff, clayey-silt, which tended to erode in clumps. The erosion rate data shows a general increase in erosion rate near a depth of 5 cm before becoming more difficult to erode deeper than 8 cm. The mean d_{50} in the core is 55.5 μm (sandy silt). The mean bulk density in the core is 1.72 g/cm^3.

- Core SF-8 was collected in approximately 18.0 m water depth. The core was collected from a central channel location, between the coring locations of SF-6 and SF-7. This core also required several attempts to collect a sufficient amount of material. Upon extraction, the core consisted of an uneven, but undisturbed, 1 cm light-colored layer of fine sediment over seemingly stiffer, darker-colored silts and sandy silts. Larger, unconsolidated clumps of sediment were distinct within the core. Some benthic organisms were visible on the surface. Some 1-2 cm long worms and tubes were also observed while sediments were eroding. Erosion was clumpy and required manual leveling of the sediment surface during the analysis. The material was stiff clayey-silt near the bottom of the core. The erosion rate data shows variation in erosion rates down-core as a result of different material consistencies. The erosion rates were low on the surface but increased beneath the surface layer before decreasing again down-core. The mean core d_{50} value was 19.8 μm. The mean bulk density in the core is 1.55 g/cm^3.

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Introduction

Sea Engineering, Inc. (SEI) conducted a Sedflume analysis for Anchor QEA on eight (8) sediment cores obtained from the East Waterway in the Port of Seattle, Washington. These cores were collected in areas where depths ranged to 18 m of water depth. The primary goal of this work was to characterize the stability of the sediments within the East Waterway. The cores were eroded using Sedflume to determine erosion rates as a function of shear stress and depth. In addition, each core was sub-sampled periodically to determine sediment wet bulk density and particle size distribution at specific depths within the core. Critical shear stresses were determined through two interpolation techniques for each vertical interval sampled. The following report outlines the procedures used in the Sedflume analysis, presents the Sedflume data, and provides a description of the results.

Experimental Procedures

A detailed description of Sedflume and its application are given in McNeil et al (1996) and Roberts et al (1998). The following section provides a general description of the Sedflume analysis conducted for this study.

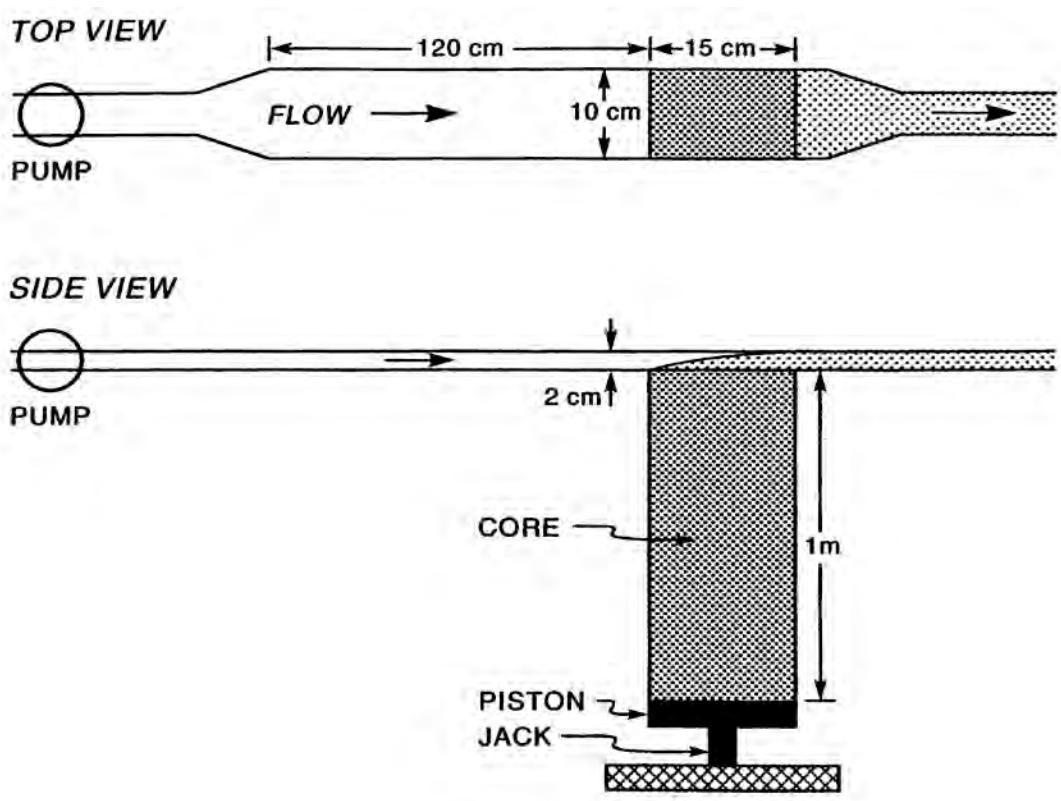

Figure 1. Sedflume Diagram

Description of Sedflume

Sedflume is shown in Figure 1 and is essentially a straight flume that has a test section with an open bottom through which a rectangular cross-section core containing sediment can be inserted. The main components of the flume are the core; the test section; an inlet section for uniform, fully-developed, turbulent flow; a flow exit section; a water storage tank; and a pump to force

water through the system. The coring tube, test section, inlet section, and exit section are made of clear acrylic so that the sediment-water interactions can be observed. The coring barrel has a rectangular cross-section, 10 cm by 15 cm, and can be up to 1 m in length.

Water is pumped through the system from a 300 gallon storage tank, through a 5 cm diameter pipe, and then through a flow converter into the rectangular duct shown. This duct is 2 cm in height, 10 cm in width, and 120 cm in length; it connects to the test section, which has the same cross-sectional area and is 15 cm long. The flow converter changes the shape of the cross-section from circular to the rectangular duct shape while maintaining a constant cross-sectional area. A ball valve regulates the flow so that the flow into the duct can be carefully controlled. Also, there is a small valve in the duct immediately downstream from the test section that is opened at higher flow rates to keep the pressure in the duct and over the test section at atmospheric conditions.

At the start of each test, a core containing sediments collected from the site is prepared. The core and the sediment it contains are then inserted into the bottom of the test section. An operator moves the sediment upward using a piston that is inside the core and is connected to a hydraulic jack with a 1 m drive stroke. The jack is driven by the release of pressure that is regulated with a switch and valve system. By this means, the sediments can be raised and made level with the bottom of the test section. The speed of the hydraulic jack movement can be controlled at a variable rate in measurable increments as small as 0.5 mm.

Water is forced through the duct and the test section over the surface of the sediments. The shear produced by this flow causes the sediments to erode. As the sediments in the core erode, they are continually moved upward by the operator so that the sediment-water interface remains level with the bottom of the test and inlet sections. The erosion rate is recorded as the upward movement of the sediments in the coring tube over time.

Sedflume Core Collection

The sediment cores were collected from the East Waterway in Washington by SEI personnel. At each coring location, a GPS system was used to position the vessel at a fixed sampling station. An innovative deep-water coring system was implemented to collect all cores. The deep-water corer consisted of a pneumatic piston mounted on an aluminum frame which had lead-weighted horizontal legs at its base for roll stability. Sedflume core barrels were inserted in the frame beneath the piston. The corer was lowered to the sea bed from an A-frame on the bow of the vessel. The pneumatic piston forced the core barrel into the sediment bed and reversed to extract the sediment core. A valve on top provided the necessary suction to extract the sediment from the bed. After extraction a spring-loaded door closed beneath the sediment to prevent sediment loss as the system was raised to the water surface. The process was repeated as necessary until a sufficient amount of sediment was extracted in a core (typically at least 30 cm, but less than 100 cm). At times, the bottom sediments were difficult to penetrate to sufficient depths. Shorter were accepted if, after several attempts, at least 30 cm of sediment could not be extracted.

After cores reached the water surface, they were immediately inspected visually for length and quality. Undisturbed surface sediments were present in the cores. The cores were capped and photographed and secured to the vessel to minimize disturbance. Cores were transferred from the vessel to a padded shipping container for transport to SEI's mobile Sedflume laboratory. All cores were collected in one day and were processed within 5 days of collection. All cores arrived at the mobile laboratory intact with sediment structure and surface preserved.

Measurements of Sediment Erosion Rates

The sediment core was inserted into the Sedflume test section using the hydraulic jack until the sediment surface was even with the bottom of the Sedflume channel. A measurement was made of the core length. The flume was then run at a specific flow rate corresponding to a particular shear stress (McNeil et al., 1996). Erosion rates are obtained by measuring the core length at different time intervals, taking the difference between each successive measurement, and dividing by the time interval as shown in Equation 1:

$$E = \frac{\Delta z}{T} \qquad (1)$$

E = Erosion rate
Δz = Amount of sediment eroded
T = Time

In order to measure erosion rates at several different shear stresses using only one core, the following procedure was used. Starting at a low shear stress, the flume was run sequentially at higher shear stresses with each succeeding shear stress being twice the previous one. Generally, a flow rate was applied until 10 minutes had expired or 2 cm of sediment had eroded. The shear stress cycle was halted if the next increase in shear stress would erode more than 2 cm in 20 seconds (for this analysis, measurements less than 20 seconds in duration are not considered to hold a high degree of accuracy). The time interval was recorded for each run with a stopwatch.

This cycle was repeated until all of the sediment had eroded from the core. If after three cycles a particular shear stress showed a rate of erosion less than 10^{-4} cm/s, it was dropped from the cycle; if after many cycles the erosion rates decreased significantly, a higher shear stress was included in the cycle. If the composition of the material changes at a sediment interface resulting in an observable change of erosion properties, the present cycle was stopped and a new cycle started at the lowest shear stress.

Determination of Critical Shear Stress

The critical shear stress of a sediment bed, τ_{cr}, is defined quantitatively as the shear stress at which a very small, but accurately measurable, rate of erosion occurs. For Sedflume studies, this rate of erosion has been practically defined as 10^{-4} cm/s. This represents 1 mm of erosion in approximately 15 minutes. Since it is difficult to measure τ_{cr} exactly at 10^{-4} cm/s, erosion rates were determined above and below 10^{-4} cm/s. The τ_{cr} was then determined by two interpolation techniques, linear and power law regression.

Measurement of Sediment Bulk Properties

In addition to erosion rate measurements, samples were collected at periodic intervals to determine the water content, bulk density, and particle size distribution of the sediments. Sub-samples were collected from the undisturbed sediment surface as well as the sediment surface at the end of each shear stress cycle. This allowed 4-5 samples to be collected approximately every 5 cm for analysis.

Bulk density was determined in the SEI mobile Sedflume laboratory by water content analysis using methods outlined in Hakanson and Jansson (2002). This consisted of determining the wet and dry weight of the collected sample to determine the water content, W, from Equation 2.

$$W = \frac{M_w - M_d}{M_w} \tag{2}$$

W = water content
M_w = wet weight of sample
M_d = dry weight of sample

Once the water content was calculated, the bulk density, ρ_b, was determined from Equation 3.

$$\rho_b = \frac{\rho_w \rho_s}{\rho_w + (\rho_s - \rho_w)W} \tag{3}$$

ρ_w = density of water (1 g/cm^3)
ρ_s = density of sediment particle (2.65 g/cm^3)

Particle size distributions were determined using laser diffraction analysis in the SEI Santa Cruz, CA laboratory. Samples collected from the Sedflume core were prepared and inserted into a Beckman Coulter LS 13 320. Each sample was analyzed in three 1-minute intervals and the results of the three analyses were averaged. This method is valid for particle sizes between 0.04 and 2000 μm. Any fraction over 2000 μm was weighed and compared to total sample weight to determine the weight percentage greater than 2000 μm. Table 1 summarizes all measurements conducted during the Sedflume analysis.

Table 1. Parameters measured and computed for the Olympia, WA, Site.

Measurement	Definition	Units	Detection Limit
Bulk Density, ρ_b (wet/dry weight)	$\rho_b = \frac{\rho_w \rho_s}{\rho_w + (\rho_s - \rho_w)W}$	g/cm^3	Same as water content
Water Content	$W = \frac{M_w - M_d}{M_w}$	unit less	0.1g in sample weight ranging from 10 to 50 g
Particle Size Distribution	Distribution of particle sizes by volume percentage using laser diffraction	μm	0.04 μm – 2000 μm
Erosion Rate	E = Δz/T	cm/s	Δz > 0.5mm T > 15s
Critical Shear Stress τ_{cr}	Shear stress when erosion rate equals 10^{-4} cm/s	N/m^2	0 to 10.0 N/m^2 This value is interpolated as described in the text.

W = water content
M_w = wet weight of sample
M_d = dry weight of sample
Δz = amount of sediment eroded
T = time
ρ_w = density of water (1 g/cm^3)
ρ_s = density of sediment (2.65 g/cm^3)

Erosion Rate Comparisons

A useful method of analyzing sediment characteristics at a specific site is to compare the inter-core and intra-core Sedflume erosion rates. This method provides a means to quantify the erosion susceptibility within each core as well as the general erosion susceptibility of the coring site. In this analysis, each core has been sub-sampled into approximately five separate depth intervals (shear cycles). Following the methods of Roberts et al (1998), the erosion rate for each interval can be approximated by

$$E = A\tau^n \rho^m \tag{4}$$

where E is the erosion rate (cm/s), τ is the shear stress (N/m^2) and ρ is the sediment bulk density (g/cm^3). A, n and m are constants that depend on the sediment characteristics. The equation used in this analysis is an abbreviated variation of Equation 4:

$$E = A\tau^n \tag{5}$$

where the sediment bulk density parameter is a function of the constant A. The variation of erosion rate with density cannot be typically determined in the field due to natural variation in other sediment properties (e.g. mineralogy and particle size). Therefore, the density term for a particular interval of approximately constant density is lumped into the constant A. For each depth interval, the measured Sedflume erosion rates (E) and applied shear stresses (τ) were used to determine the A and n constants that provide a best fit power law curve to the data for that interval. With good fits (i.e $r^2 > 0.8$), these parameters can be used to predict erosion rates for the core interval of interest. A correlation of 0.8 was used as a criteria threshold for acceptance.

From this process an average erosion rate for a particular core can also be determined, and the erosion rate at each depth interval can be directly compared to this average. The result is an erosion rate ratio which provides an estimation of the erosion susceptibility of each depth interval relative to the core average. This procedure highlights the depths of the core that will erode more rapidly, and those that will tend to resist erosion, relative to the other intervals in the core. Intervals for which the r^2 is less than 0.8 or containing less than three data points are omitted from this comparison and will show up as blank intervals in the following bar plots.

In addition, a site-wide erosion rate average can be estimated that incorporates the interval data from all sampled cores. The erosion rate for each depth interval within a core is compared to the site-wide average and a graph of the erosion rate ratios for all of the cores is created. Again, the procedure highlights the cores and depth intervals at which the most rapid erosion would be expected (relative to the other core locations), and a spatial assessment of erosion probability can be generated.

In this analysis, two interpolation techniques were used to determine values of critical shear stress: a power law interpolation and a linear interpolation. For the former, a power law curve was created (in the form of Equation 5) by solving for the variables A and n by maximizing the correlation (r^2) to the measured data points. A solution for the critical shear stress can then be computed from Equation 5 by inserting an erosion rate of 10^{-4} cm/s. For the latter, a simple linear interpolation solves for the critical shear stress at an erosion rate of 10^{-4} cm/s based on the measured Sedflume data.

Results and Discussion

Figure 2 shows a map of the coring site with the coring locations. Table 2 provides the core location, coordinates, coring date and the depth of water for the East Waterway cores.

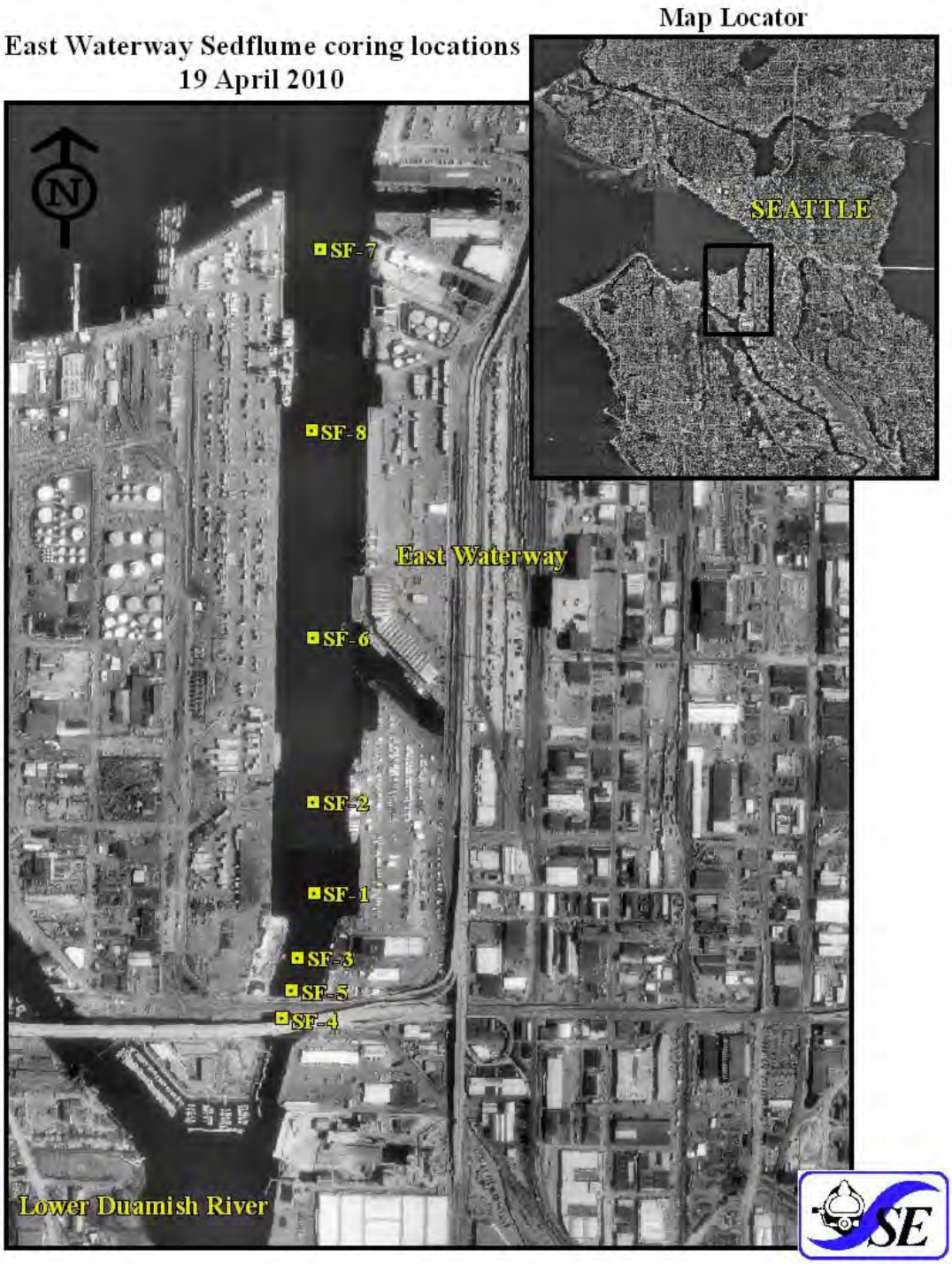

Figure 2. Map of core locations (aerial photo from seamless.usgs.gov).

Table 2. Core collection information.

Core Location	Lat (ºN)	Long (ºW)	Coring Date	Time (PDT)	Depth ft (m)*
SF-1	47.57415	122.3445	4/19/2010	12:20	46.0 (14.0)
SF-2	47.57628	122.3446	4/19/2010	10:40	48.0 (14.6)
SF-3	47.57265	122.345	4/19/2010	12:55	32.0 (9.8)
SF-4	47.57125	122.3455	4/19/2010	13:40	7.5 (2.3)
SF-5	47.57187	122.3452	4/19/2010	14:20	17.0 (5.2)
SF-6	47.5801	122.3447	4/19/2010	15:05	52.0 (15.8)
SF-7	47.58915	122.3447	4/19/2010	17:00	57.0 (17.4)
SF-8	47.58492	122.3449	4/19/2010	18:30	59.0 (18.0)

* Depths are measured from the water surface and are not corrected to any datum.

Core SF-1

Core SF-1 was collected in approximately 14.0 m water depth. Upon extraction, the core consisted of light brown colored, fine sediment in the top 5 cm of the core. The lighter sediment color likely indicates greater oxidation of the sediments near the surface. Some small worm tubes and organic debris were visible on the core surface upon coring implying a relatively undisturbed surface. Beneath the surface layer, dark and lighter colored silts and sandy silts were visible down-core.

During the analysis, benthic activity was observed on the surface and within the first 4 centimeters. Stringy, organic material became exposed when the surrounding finer sediments were scoured away. Several (4-6) larger worms existed to the 4 cm depth. At deeper depths, the material consisted of darker colored, silt and clayey silt, of a thicker consistency. Erosion was uneven and clumpy. A few worms were visible near a depth of 10 cm. Deeper than 15 cm of depth, the material was very difficult to erode: The highest shear stresses were applied and erosion continued to be uneven. Some organic material was observed in the material at these depths (e.g. sticks).

Figure 3 shows a photo of core SF-1 prior to the analysis aligned vertically with the measured erosion rate data. The plot shows each shear stress applied to the core, ranging from 0.1 to 10.0 Pa, as a function of depth. In order to visualize the data on a log-scale, erosion rates of zero are plotted as 1 x 10^{-5} cm/s on the graph. The sediment surface (depth = 0) is plotted at the top of the graph with depth into the sediments increasing down the Y-axis. Variations in erosion rate for each applied shear stress are shown. Figure 4 shows the bulk density and D_{50} (median particle size) as a function of depth.

The erosion rate data shows evidence of typical consolidated core material: the material, in general, becomes stiffer with increasing depth. At depths of approximately 10 cm and 13 cm, small lenses of easier-to-erode sediment are encountered. The median particle sizes remain relatively constant with depth, varying between 10.2 µm and 12.4 µm. The mean d50 in the core is 11.65 µm, fine silt. The bulk densities also remain relatively constant with depth, after increasing from the surface value. They ranged from 1.27

g/cm^3 to 1.41 g/cm^3, with a core average of 1.38 g/cm^3. The interpolated critical shear stresses varied down-core for both manners of computing critical shear. The lowest value computed was 0.26 Pa and the highest value computed was 0.66 Pa. The core average critical shear stresses were 0.53 Pa and 0.37 Pa for the power law and linear interpolation critical shear estimates, respectively.

Figure 5 displays the erosion susceptibility for the depth intervals in core SF-1. The bars represent the starting depth of the different intervals (shear stress cycles) within each core. The vertical dashed line denotes an average erosion rate ratio of 1 (the core average erosion rate). Ratios above this line denote intervals that are more susceptible to rapid erosion than ratios below this line. Missing bars denote data that failed to meet quality threshold criteria (i.e. power law fits that had a correlation (r^2) less than 0.80 with data were omitted). The plot shows that the first and third depth intervals are more susceptible to rapid erosion than the second and fourth intervals. This information agrees with the measured erosion rates, which showed increases in erosion rates corresponding to the same depth intervals more susceptible to rapid erosion. There is also correlation between decreasing erosion rates and depth intervals less susceptible to erosion.

Table 3 summarizes the variables resulting from the power law fit to the data in each shear stress cycle. A and n values for which the correlation was less than 0.80 are omitted. Table 4 summarizes the bulk density, D_{50}, and interpolated critical shear stresses, τ_{cr}, for specific core depths.

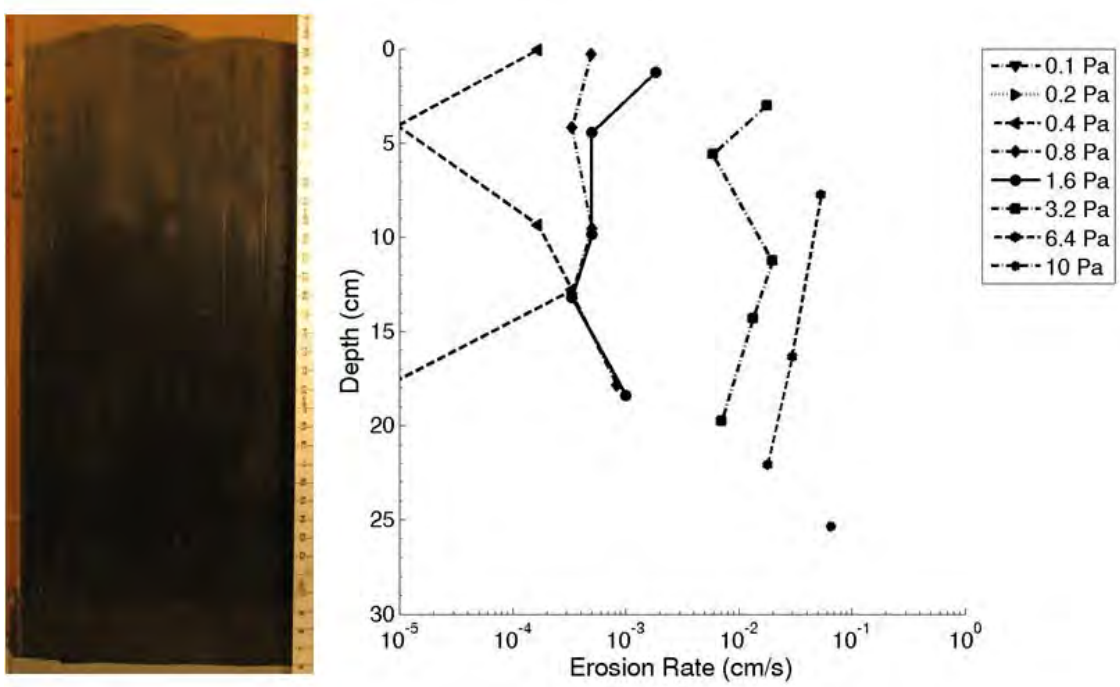

Figure 3. Picture of core SF-1 aligned with Sedflume erosion rate data.

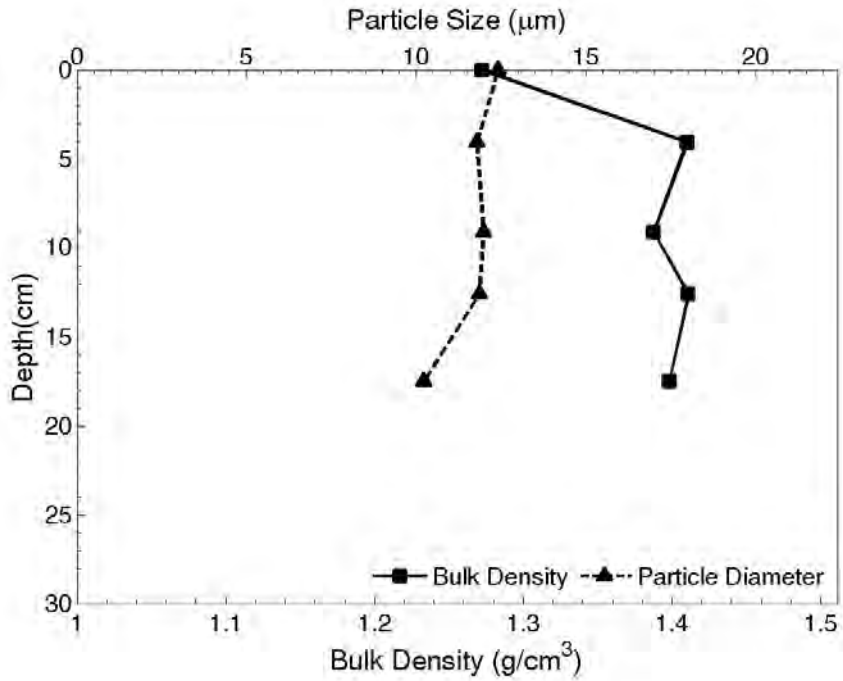

Figure 4. Bulk density and median particle size (d_{50}) with depth for core SF-1.

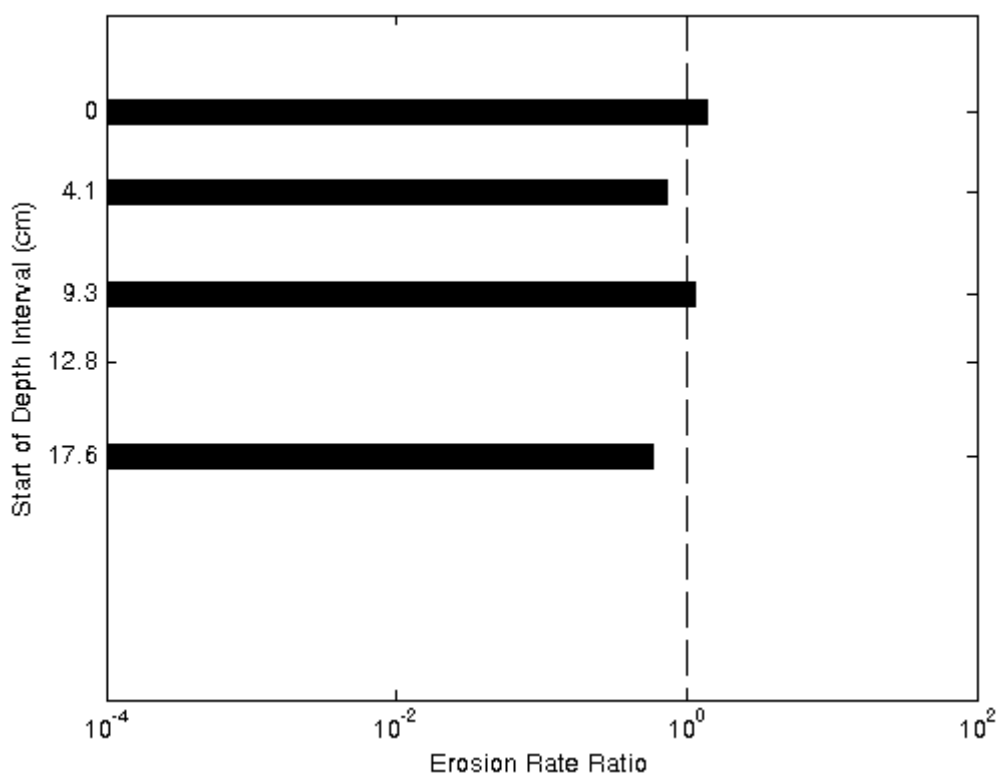

Figure 5. Intra-core erosion rate ratios for core SF-1. Dashed line is core average erosion rate.

Table 3. Power law best-fit variables for specified depth intervals in core SF-1.

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0.00	3.00	0.0009	2.25	0.96
2	4.10	7.75	0.0003	2.59	0.95
3	9.30	11.25	0.0006	2.36	0.89
4	12.80	16.35	-	-	0.79
5	17.60	25.35	0.0003	2.41	0.91

Table 4. Bulk density, $D_{50,}$ critical shear stress with depth for SF-1.

Depth (cm)	D_{50} (µm)	ρ_b (g/cm^3)	Power Law τ_{cr} (Pa)	Linear Interpolation τ_{cr} (Pa)
0.00	12.40	1.27	0.38	0.32
4.05	11.78	1.41	0.66	0.52
9.10	11.98	1.39	0.46	0.32
12.60	11.85	1.41	-	0.26
17.50	10.22	1.40	0.63	0.45
Mean	**11.65**	**1.38**	**0.53**	**0.37**

Core SF-2

Core SF-2 was collected in approximately 14.6 m water depth. Upon extraction, the core consisted of an uneven sediment surface comprising fine sediment, some small shell hash and one large worm tube (1/2 cm diameter, approximately). Down-core the color of the sediment varied between light and dark brown colored silt and sandy silt. A very stiff layer of sediment was encountered at the bottom of the core, preventing any deeper push coring.

During the analysis, a large amount of stringy organic material was encountered beneath the surface as fine particulates were scoured away. The organic material persisted until approximately 5 cm, where an easier to erode layer was encountered. Beneath this layer, fine silt and sandy silt material was observed, and a few small worms were visible to a depth of 10 cm. The material began to erode unevenly in clumps, at times pulling 2-3 cm diameter clumps of sediment upwards into the flume. Near the bottom of the core a large layer (~3cm) of sediment was dislodged upwards and plugged the flume, eliminating the undisturbed characteristics of the sediment, so the analysis was halted at this depth. The material comprised dark gray-colored clayey silt that eroded easier than layers above.

Figure 6 shows a photo of core SF-2 prior to the analysis aligned vertically with the measured erosion rate data. Figure 7 shows the bulk density and D_{50} (median particle size) as a function of depth.

The erosion rate data shows evidence of relatively consistent sediment strength characteristics with increasing depth. The erosion rates remain relatively constant down-core, but increase by two orders of magnitude deeper than 20 cm. The reason for this

sharp increase in erosion rate is uncertain as the bulk densities and median particle sizes remain relatively constant down-core. The mean d50 in the core is 21.4 µm, fine silt, and ranges between 15.1 µm and 27.2 µm. The bulk densities ranged from a surface value of 1.27 g/cm^3 to 1.57 g/cm^3, with a core average of 1.47 g/cm^3.

The interpolated critical shear stresses increased, in general, down to the final depth interval, where the critical shear stresses decreased when the sediment became easier to erode. The surface critical shear stresses were 0.42 Pa and 0.26 Pa for the power law interpolation and linear interpolation, respectively. The highest critical shear stresses were 1.21 Pa and 1.28 Pa for each, at a depth of approximately 15 cm. The mean values of the critical shear stresses in the core were similar, 0.81 Pa and 0.72 Pa, for the power law and linear interpolations, respectively.

Figure 8 displays the erosion susceptibility for the depth intervals in core SF-2. The plot shows that, relative to the core average erosion rate, the deepest depth interval is more susceptible to rapid erosion than the shallower four intervals. These results correspond to the erosion rate plot in which the down-core erosion rates were relatively constant until the deepest interval, which showed a 2 order of magnitude increase in erosion rates.

Table 5 summarizes the variables resulting from the power law fit to the data in each shear stress cycle. Shear stress cycles for which only two applied shear stresses existed (i.e. $r^2 = 1.00$) are omitted from the table. Table 6 summarizes the bulk density, D_{50}, and interpolated critical shear stresses, τ_{cr}, for specific core depths.

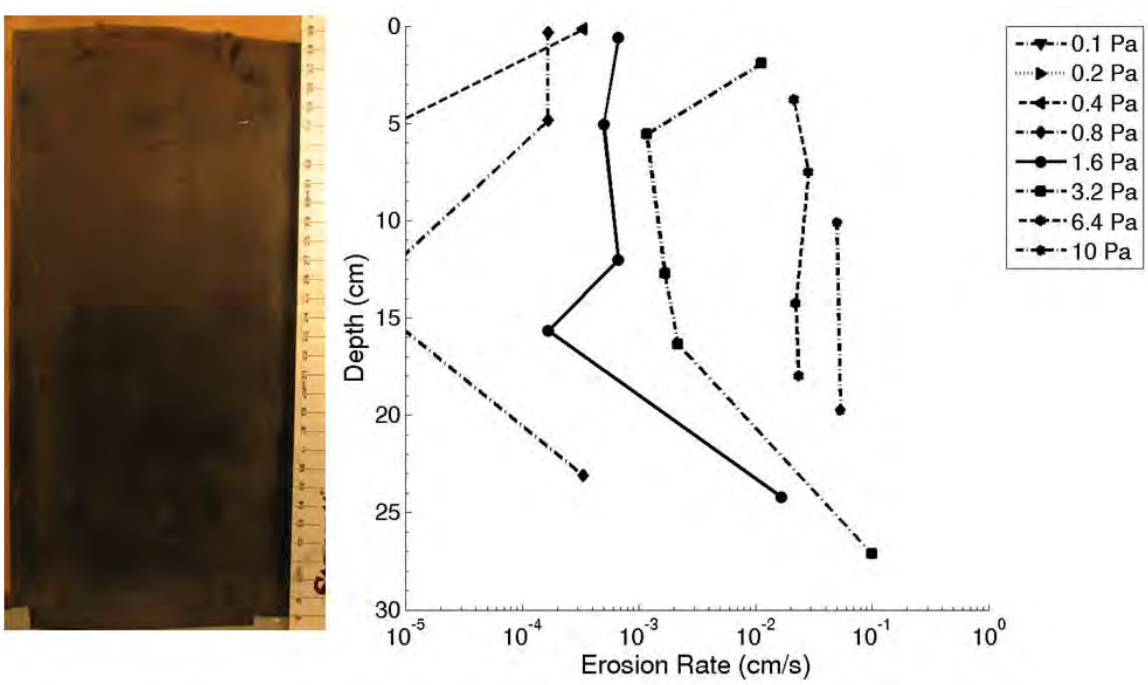

Figure 6. Picture of core SF-2 aligned with Sedflume erosion rate data.

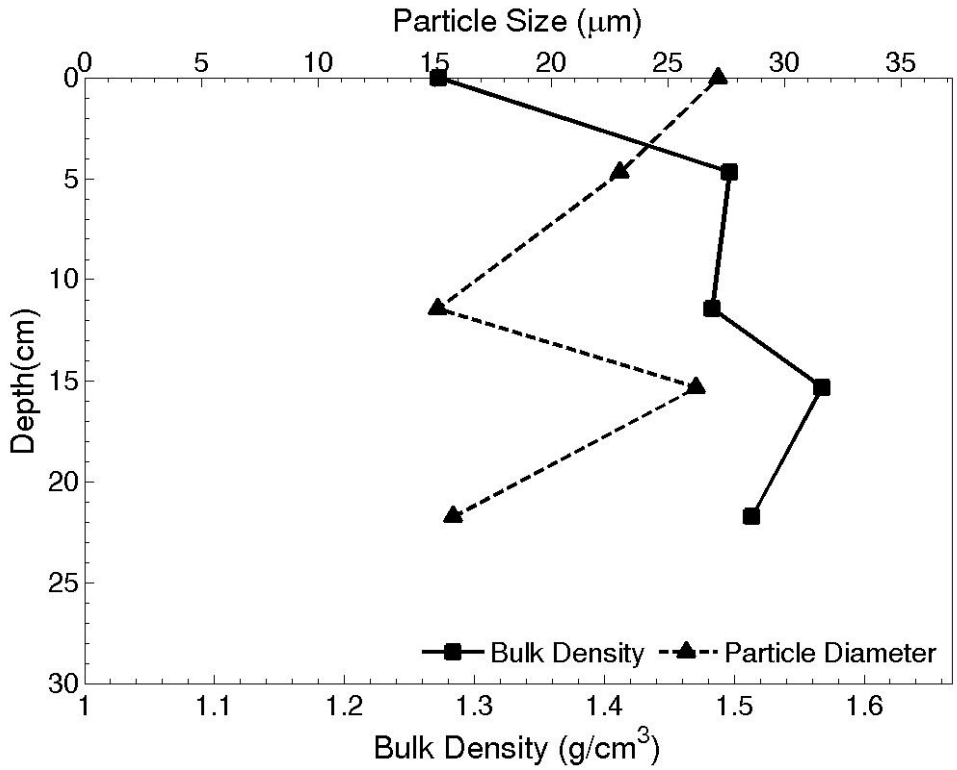

Figure 7. Bulk density and D_{50} with depth for core SF-2.

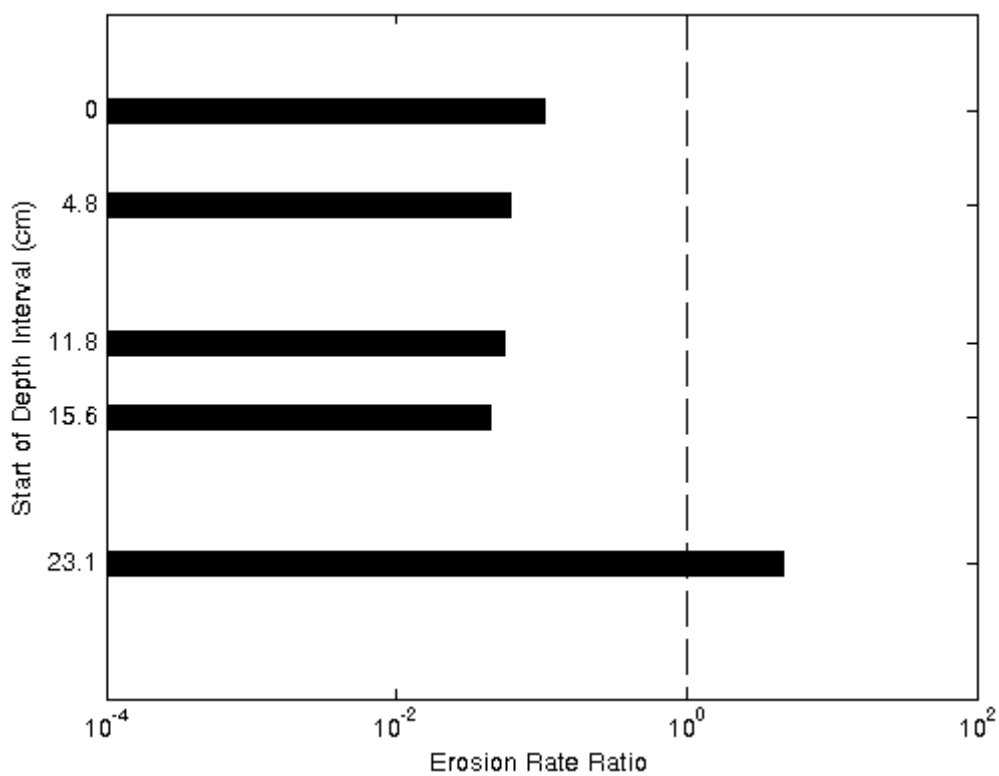

Figure 8. Intra-core erosion rate ratios for core SF-2.

Table 5. Power law best-fit variables for specified depth intervals in core SF-2.

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0.00	3.80	0.0006	1.96	0.92
2	4.80	10.10	0.0002	2.34	0.96
3	11.80	14.25	0.0001	2.98	0.93
4	15.60	19.75	0.0001	3.01	0.96
5	23.10	27.10	0.0012	4.11	0.96

Table 6. Bulk density, $D_{50,}$ critical shear stress with depth for SF-2.

Depth (cm)	D_{50} (µm)	ρ_b (g/cm^3)	Power Law τ_{cr} (Pa)	Linear Interpolation τ_{cr} (Pa)
0.00	27.17	1.27	0.42	0.26
4.70	22.93	1.50	0.75	0.64
11.45	15.12	1.48	1.11	0.92
15.35	26.21	1.57	1.21	1.28
21.75	15.78	1.51	0.55	0.52
Mean	**21.44**	**1.47**	**0.81**	**0.72**

Core SF-3

Core SF-3 was collected in approximately 9.8 m water depth. Upon extraction, the core consisted of an undisturbed sediment surface comprising small surface debris (e.g. small twigs) and approximately 1 cm of light brown and orange colored fine sediment. Beneath the surface layer, light and dark-colored brown silt and sandy silt were observed down-core. Near the bottom of the core, some woody debris was visible in the material.

During the analysis, small pebbles (~1 cm diameter) were observed within the top 5 cm. Some worms and stringy organic material became visible in this layer as well, as the finer particulates were eroded. Beneath this layer, fine silt material was mixed with coarser sandy material and a few larger pebble sized sediment. Two to 3 pebbles were removed from the flume manually as they were too large to be eroded by the flow, and were causing uneven scouring of the finer material around their perimeters. Near depths greater than 16 cm, a large amount of woody debris and organic detritus was encountered. The surrounding dark clayey-silt eroded in clumps, and became easier to erode as depths increased further.

Figure 9 shows a photo of core SF-3 prior to the analysis aligned vertically with the measured erosion rate data. Figure 10 shows the bulk density and D_{50} (median particle size) as a function of depth.

The erosion rate data shows evidence of easier-to-erode sediment with increasing depth, which is not typical of consolidated core material. The erosion rates remain relatively constant down-core until a depth of approximately 10 cm, where the increasing erosion rate trend begins. The median particle size down-core does not fluctuate greatly, varying between 10.0 µm and 12.8 µm. The mean particle size in the core is 11.5 µm. The bulk

densities varied down-core, increasing from a surface value of 1.41 g/cm^3 to 1.59 g/cm^3 before decreasing to 1.32 g/cm^3. The mean bulk density in the core is 1.44 g/cm^3.

The interpolated critical shear stresses increase from the surface value to a maximum at a depth of 10 cm; then they decrease to the bottom of the core. The surface values are 0.44 Pa and 0.32 Pa for the power law and linear interpolation, respectively. The maximum values are 0.97 Pa and 0.85 Pa. At the deepest depths, the values are approximately 0.25 Pa for each. The core average values are 0.55 Pa and 0.44 Pa, for the power law and linear interpolations, respectively.

Figure 11 displays the erosion susceptibility for the depth intervals in core SF-3. The plot shows that, relative to the core average erosion rate, the deepest depth interval is more susceptible to rapid erosion than the shallower four intervals. These results correspond to the erosion rate plot in which the down-core erosion rates showed a general down-core trend of increasing erosion rates. The deepest interval is also the location at which the lowest critical shear stresses were computed, implying more susceptibility to rapid erosion.

Table 7 summarizes the variables resulting from the power law fit to the data in each shear stress cycle. Shear stress cycles for which only two applied shear stresses existed (i.e. $r^2 = 1.00$) are omitted from the table. Table 8 summarizes the bulk density, D_{50}, and interpolated critical shear stresses, τ_{cr}, for specific core depths.

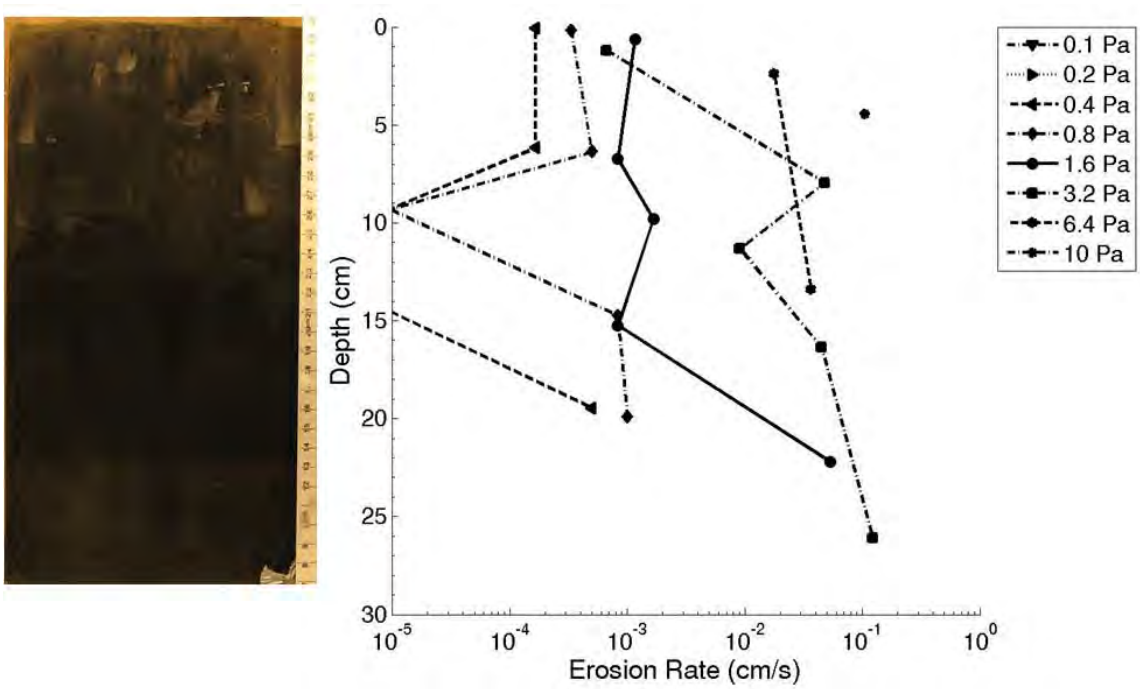

Figure 9. Picture of core SF-3 aligned with Sedflume erosion rate data.

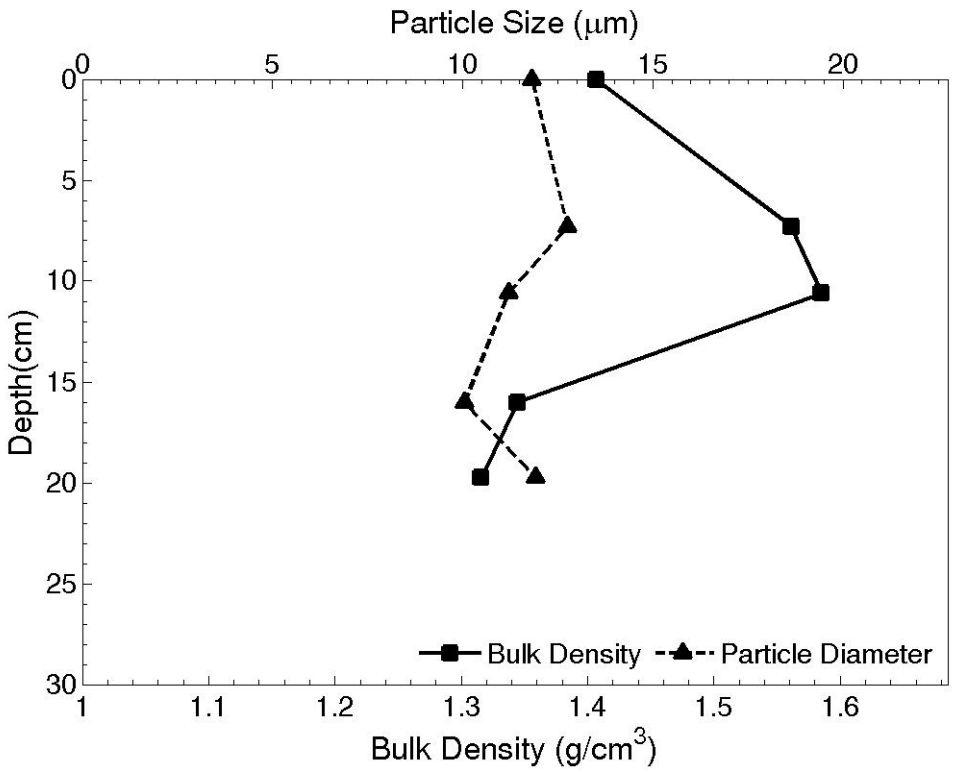

Figure 10. Bulk density and D_{50} with depth for core SF-3.

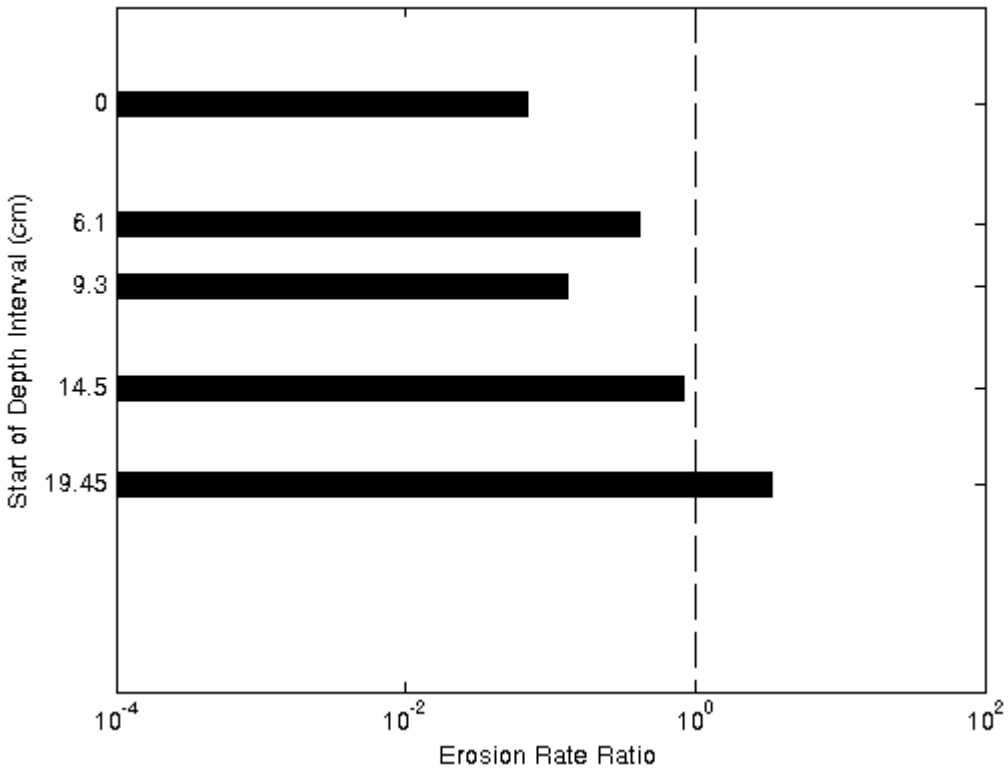

Figure 11. Intra-core erosion rate ratios for core SF-3.

Table 7. Power law best-fit variables for specified depth intervals in core SF-3.

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0.00	4.45	0.0005	1.90	0.92
2	6.10	7.95	0.0009	2.69	0.92
3	9.30	13.40	0.0001	3.37	0.92
4	14.50	16.35	0.0005	3.66	0.90
5	19.45	26.10	0.0053	2.95	0.91

Table 8. Bulk density, $D_{50,}$ critical shear stress with depth for SF-3.

Depth (cm)	D_{50} (µm)	ρ_b (g/cm^3)	Power Law τ_{cr} (Pa)	Linear Interpolation τ_{cr} (Pa)
0.00	11.82	1.41	0.45	0.32
7.30	12.75	1.56	0.44	0.32
10.60	11.20	1.59	0.97	0.85
16.00	10.04	1.34	0.66	0.45
19.75	11.91	1.32	0.26	0.24
Mean	**11.54**	**1.44**	**0.55**	**0.44**

Core SF-4

Core SF-4 was collected in approximately 2.3 m water depth. The core was collected from a very shallow area beneath the bridges connecting Seattle to Harbor Island and West Seattle (West Seattle Bridge). It was difficult to collect a large amount of sediment in the core at this location because the material composition was very prohibitive. The core was driven to refusal several times, to the extent of causing the coring apparatus to lift itself off the bed. Upon extraction, the core consisted of an undisturbed sediment surface comprising 5 cm of fine, lighter-colored sediments. Below the surface layer, shell hash and coarser sands were visible mixed in with silts. At the bottom of the core, a visible fine to medium sand layer (2-4 cm thick) was observed, likely the material which prevented a deeper core from being extracted.

During the analysis, some red-colored grass was visible within the surface layer, which acted to withstand erosion and hold particles together. Small benthic organisms and small worms were visible. Below the top 1 cm, 6-8 ½-cm diameter worm tubes were observed, approximately 2 cm in length. Within the top 5 cm of sediment, shell pieces and hash were observed eroding as well as a large amount of organic detritus. Erosion was clumpy near the top of the core due to the organic material that added strength to the sediment. Deeper than 5 cm, the organic debris persisted, several large sticks were observed (3-5 cm in length) along with several large worms (3-5 cm in length) mixed in with sandy and silty material. A seemingly more difficult-to-erode layer was encountered near depths of 7-13 cm, with erosion rates increasing deeper than this. At depths deeper than 13 cm, the material contained silt and sand as well as a large amount of wood pieces that required manual removal. Large worms were still observed in the sediment at these depths as well as the red-colored grass and shell pieces. The material at this depth contained striations of

stiff material and easier-to-erode sands. The erosion was very uneven, eroding the center of the core faster than the sides.

Figure 12 shows a photo of core SF-4 prior to the analysis aligned vertically with the measured erosion rate data. Figure 13 shows the bulk density and D_{50} (median particle size) as a function of depth.

The erosion rate data shows evidence of typical consolidated core material: the material, though variable down-core, generally becomes stiffer with increasing depth. A more difficult-to-erode layer was encountered near depths of 7-13 cm, resulting in the application of higher shear stresses. Deeper than this, however, the material becomes slightly easier to erode due to the rapid erosive characteristics of sand versus clayey silt. The median particle size down-core varies between 12.5 μm and 35.5 μm, with a core mean value of 21.0 μm. The bulk densities generally increased with depth from 1.36 g/cm^3 to 1.52 g/cm^3. The mean bulk density in the core is 1.46 g/cm^3.

The interpolated critical shear stresses were lowest on the surface (0.11 Pa) and increased with depth to the maximum value of 0.46 Pa. This corresponds well to the general decrease of erosion rate with depth. This core exhibits typical signs of consolidated core material at deeper depths. The mean critical shear stress value for the core was 0.24 Pa. The only valid manner used to compute critical shear stress for core SF-4 was linear interpolation because a power law fit of good correlation was not possible for any of the depth intervals. All r^2 values were less than the quality threshold criteria of 0.80. Therefore, there is no erosion susceptibility plot for core SF-4.

Table 9 summarizes the variables resulting from the power law fit to the data in each shear stress cycle. Shear stress cycles for which only two applied shear stresses existed (i.e. $r^2 = 1.00$) are omitted from the table. Table 10 summarizes the bulk density, D_{50}, and interpolated critical shear stresses, τ_{cr}, for specific core depths.

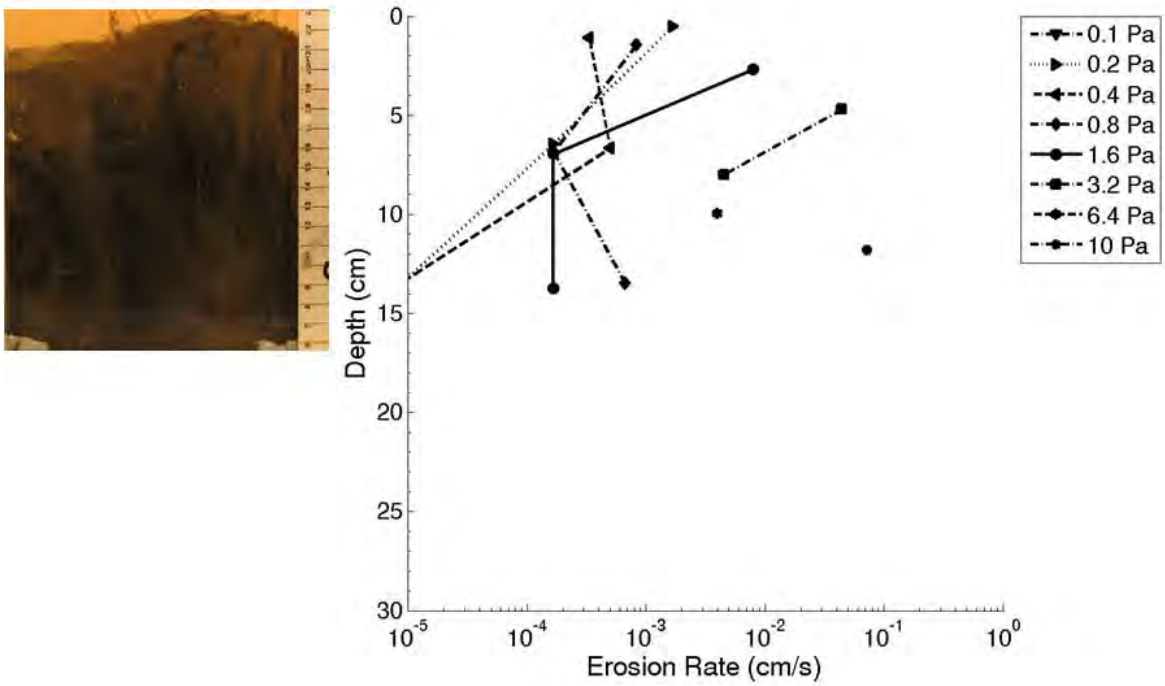

Figure 12. Picture of core SF-4 aligned with Sedflume erosion rate data.

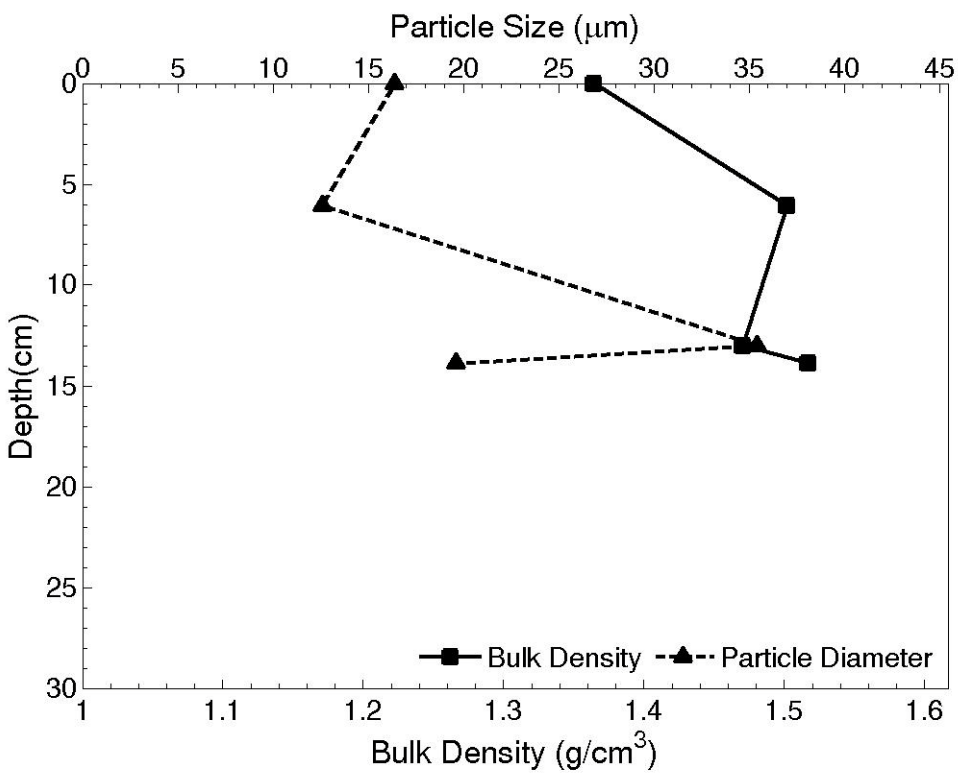

Figure 13. Bulk density and D_{50} with depth for core SF-4.

Table 9. Power law best-fit variables for specified depth intervals in core SF-4.

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0	4.7	-	-	0.78
2	6.45	11.8	-	-	0.69
3	13.3	13.75	-	-	0.61

Table 10. Bulk density, $D_{50,}$ critical shear stress with depth for SF-4.

Depth (cm)	D_{50} (µm)	ρ_b (g/cm^3)	Power Law τ_{cr} (Pa)	Linear Interpolation τ_{cr} (Pa)
0	16.38	1.36	-	0.11
6.05	12.58	1.50	-	0.16
13	35.45	1.47	-	0.46
13.9	19.64	1.52	-	-
Mean	**21.01**	**1.46**	**-**	**0.24**

Core SF-5

Core SF-5 was collected in approximately 5.2 m water depth. The core was collected from a relatively shallow region immediately north of the Harbor Island and West Seattle bridges. It was difficult to collect a large amount of sediment in the core at this location because the material composition was, again, very prohibitive. The core was driven to refusal twice with the subsequent extracted depth similar to the first. Upon extraction, the core consisted of an undisturbed sediment surface comprising 1-2 cm of fine, lighter-colored sediments. Below the surface layer, fine to medium sands were visible mixed with silts. At the bottom of the core, a darker colored material was observed, likely the material which prevented a deeper core from being extracted.

During the analysis, many (20-30) 1 cm to 2 cm long, small diameter worms were observed on the surface. There was one clump of organic material that was removed from the surface before the analysis began. The clump was approximately 3 cm in diameter and was loosely resting on the surface. It was removed so it would not negatively impact the measured erosion rates of the surrounding fine sediments. The top 1 cm of sediment was difficult to erode because the organic material and benthic organisms added strength to the sediment. Deeper than 1 cm, organic detritus was observed with several long worms. The erosion became uneven as organic material eroded from certain locations, but not others. Deeper than 4 cm, the material is comprised of silts, sandy silts and organic material. The erosion was clumpy and uneven. Deeper than 7 cm, the material was a stiff, dark-colored silt, clayey silt and sandy silt, with highly variable erosion. A large erosion hole formed in the core due to the existence of an easier-to-erode layer of sandy-silt. The hole caused erosion down to the bottom of the core material. The test was halted when this occurred and a new layer composition (sandier silt) was encountered.

Figure 14 shows a photo of core SF-5 prior to the analysis aligned vertically with the measured erosion rate data. Figure 15 shows the bulk density and D_{50} (median particle size) as a function of depth.

The erosion rate data shows evidence of wide variation in erosion rates down-core. Beneath the surface, the erosion rates fluctuate between easier- and more difficult-to-erode with each new layer encountered. The median particle size down-core varies between 14.5 µm and 33.1 µm, with a core mean value of 23.9 µm. The bulk densities vary with depth from 1.42 g/cm^3 to 1.68 g/cm^3. The mean bulk density in the core is 1.53 g/cm^3. The interpolated critical shear stresses show a general increase with depth into the core. The surface values are 0.43 Pa and 0.26 Pa for the power law and linear interpolations, respectively. The maximum values were near the deepest part of the core and were 0.68 Pa and 0.52 Pa. The mean core values are 0.54 Pa and 0.38 Pa for the power law and linear interpolations, respectively.

Figure 16 displays the erosion susceptibility for the depth intervals in core SF-5. Table 11 summarizes the variables resulting from the power law fit to the data in each shear stress cycle. Shear stress cycles for which only two applied shear stresses existed (i.e. $r^2 = 1.00$) are omitted from the table. Table 12 summarizes the bulk density, D_{50}, and interpolated critical shear stresses, τ_{cr}, for specific core depths.

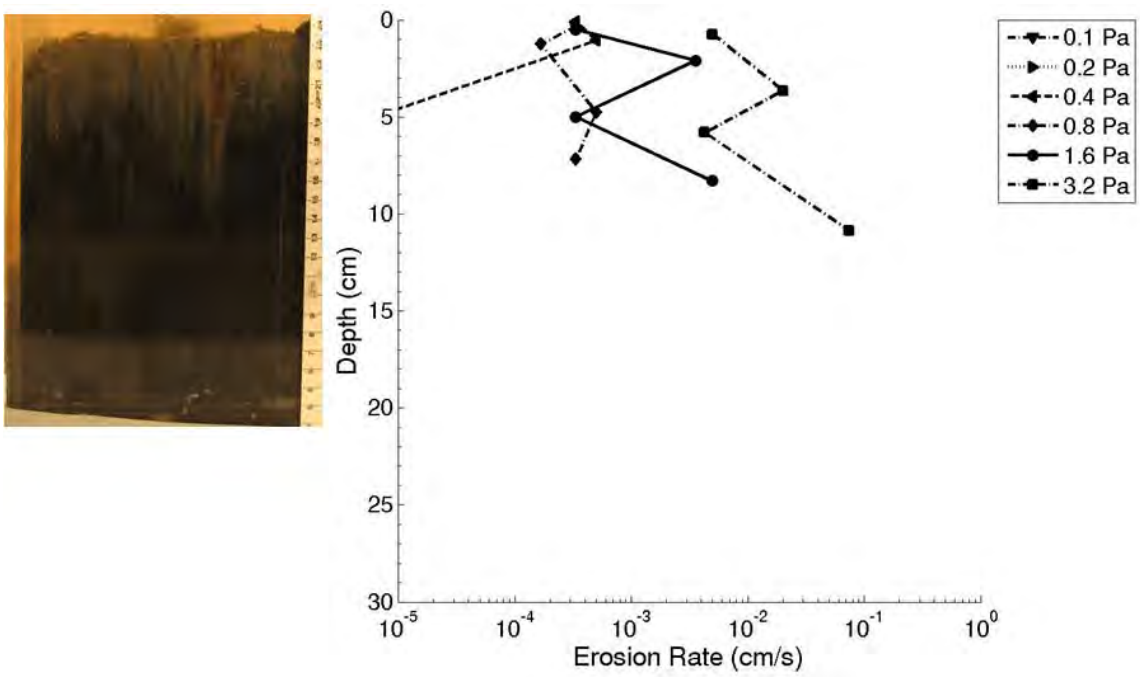

Figure 14. Picture of core SF-5 aligned with Sedflume erosion rate data.

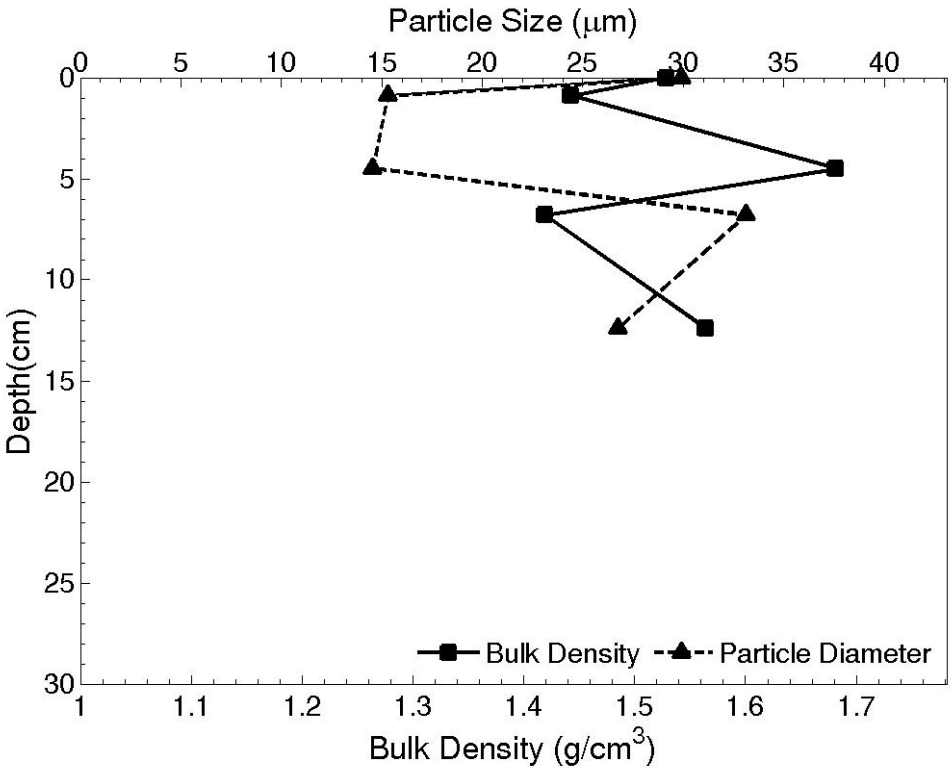

Figure 15. Bulk density and D_{50} with depth for core SF-5.

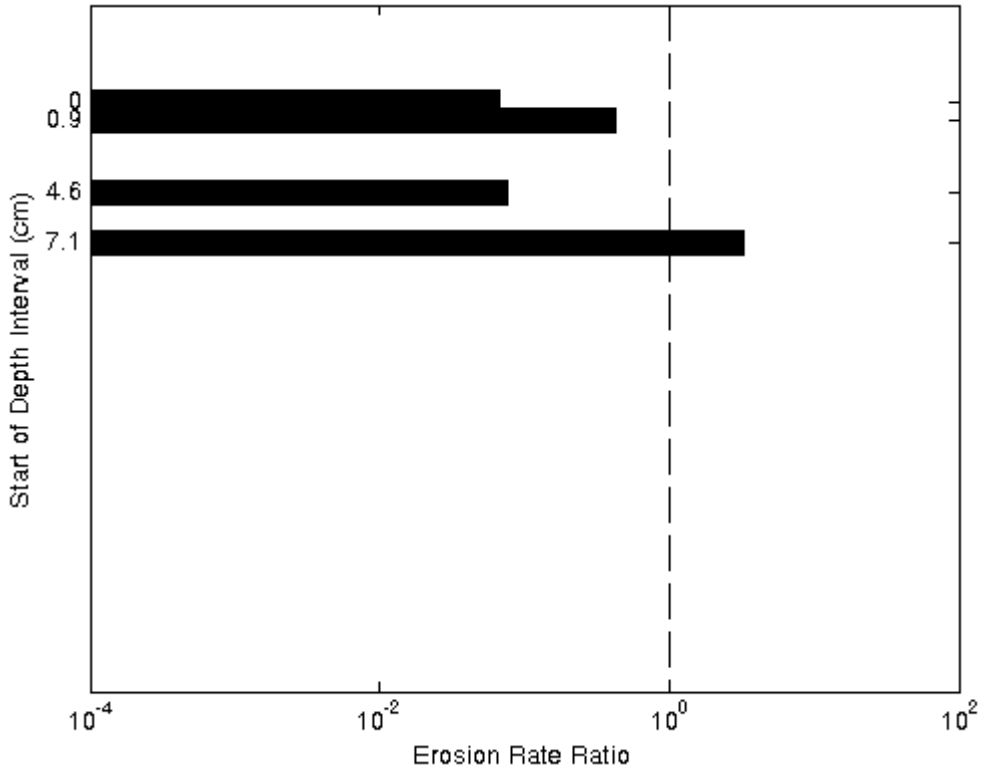

Figure 16. Intra-core erosion rate ratios for core SF-5.

Table 11. Power law best-fit variables for specified depth intervals in core SF-5.

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0.00	0.75	0.0004	1.73	0.86
2	0.90	3.65	0.0010	2.49	0.87
3	4.60	5.80	0.0002	2.27	0.87
4	7.10	10.85	0.0006	4.27	0.99

Table 12. Bulk density, $D_{50,}$ critical shear stress with depth for SF-5.

Depth (cm)	D_{50} (µm)	ρ_b (g/cm^3)	Power Law τ_{cr} (Pa)	Linear Interpolation τ_{cr} (Pa)
0.00	29.93	1.53	0.43	0.26
0.90	15.30	1.44	0.40	0.24
4.50	14.54	1.68	0.68	0.48
6.80	33.11	1.42	0.65	0.52
12.40	26.76	1.56	-	-
Mean	**23.93**	**1.53**	**0.54**	**0.38**

Core SF-6

Core SF-6 was collected in approximately 15.8 m water depth. The core was collected from a central waterway location, approximately midway between the West Seattle Bridge to the south and the waterway mouth to the north. Upon extraction, the core consisted of an undisturbed, uneven sediment surface comprising benthic organisms and worms over 5 cm of silt and fine sand. Beneath the surface layer a 5-6 cm layer of fine to medium sand and shell hash was clearly visible. Below the sand lens, the sediments comprised darker-colored silty material.

During the analysis, some organic detritus and fine stringy organic material was observed when the fine particulates were scoured away. The material eroded in particulates and small clumps down to a depth of 7 cm. At this depth, the fine to medium sand was encountered and persisted to a depth of 15 cm, when a more difficult-to-erode clayey-silt and sandy silt layer was encountered. Deeper than 15 cm, the material was a more difficult-to-erode composition.

Figure 17 shows a photo of core SF-6 prior to the analysis aligned vertically with the measured erosion rate data. Figure 18 shows the bulk density and D_{50} (median particle size) as a function of depth.

The erosion rate data shows variation in erosion rates down-core as a result of different material consistencies. The erosion rates increased when the fine to medium sand layer was encountered and at the very bottom of the core, when clumpy erosion caused larger amounts of sediment to be removed. The sediments collected from the sandy layer were

required to be passed through a 2000 sieve before processing with the particle laser diffractor. The sediment sample contained approximately 4% by weight of sediment larger than 2000 um. The material sieved out at this size was mostly shell fragments and shell hash. The remaining samples in the core contained sediments that were smaller than 2000 um.

At layers in between the sandy layer and the bottom of the core, the material is stiffer and more difficult-to-erode, resulting in relatively lower erosion rates. The median particle size in the core varied from sandy silt (59.6 μm) at the surface to fine sand immediately below (106.90 μm) down to fine silt near the bottom (12.8 μm). The mean d_{50} in the core is 42.5 μm. The bulk densities varied between 1.50 g/cm^3 and 1.94 g/cm^3. The mean bulk density in the core is 1.64 g/cm^3. The interpolated critical shear stresses were lowest on the surface and in the first layer below the surface, where the sediment type was a coarser material (sand) than other layers. The minimum critical shear stresses in these tope two layers was 0.36 Pa and 0.32 Pa for the power law and linear interpolations, respectively. The highest shear stresses were 1.93 Pa and 1.92 Pa, respectively, near depths of 15 cm. Deeper than 20 cm, the critical shear stresses were slightly lower (1.29 Pa and 1.04 Pa, respectively). The mean values of the critical shear stresses in the core are 1.03 Pa and 0.90 Pa, for the power law and linear interpolations, respectively.

Figure 19 displays the erosion susceptibility for the depth intervals in core SF-6. The plot shows a high susceptibility to rapid erosion at a depth of 7 cm, which is where the coarse sandy material was observed and measured. This is easily understood since the coarser material is less cohesive and requires less shear stress to initiate motion. If the sandier layer is not considered, then the remaining depth intervals are relatively similar in erosion susceptibility. The fourth depth interval is least susceptible. This is the location of the highest critical shear stresses and corresponds to a decrease in measured erosion rate.

Table 13 summarizes the variables resulting from the power law fit to the data in each shear stress cycle. Shear stress cycles for which only two applied shear stresses existed (i.e. $r^2 = 1.00$) are omitted from the table. Table 14 summarizes the bulk density, D_{50}, and interpolated critical shear stresses, τ_{cr}, for specific core depths.

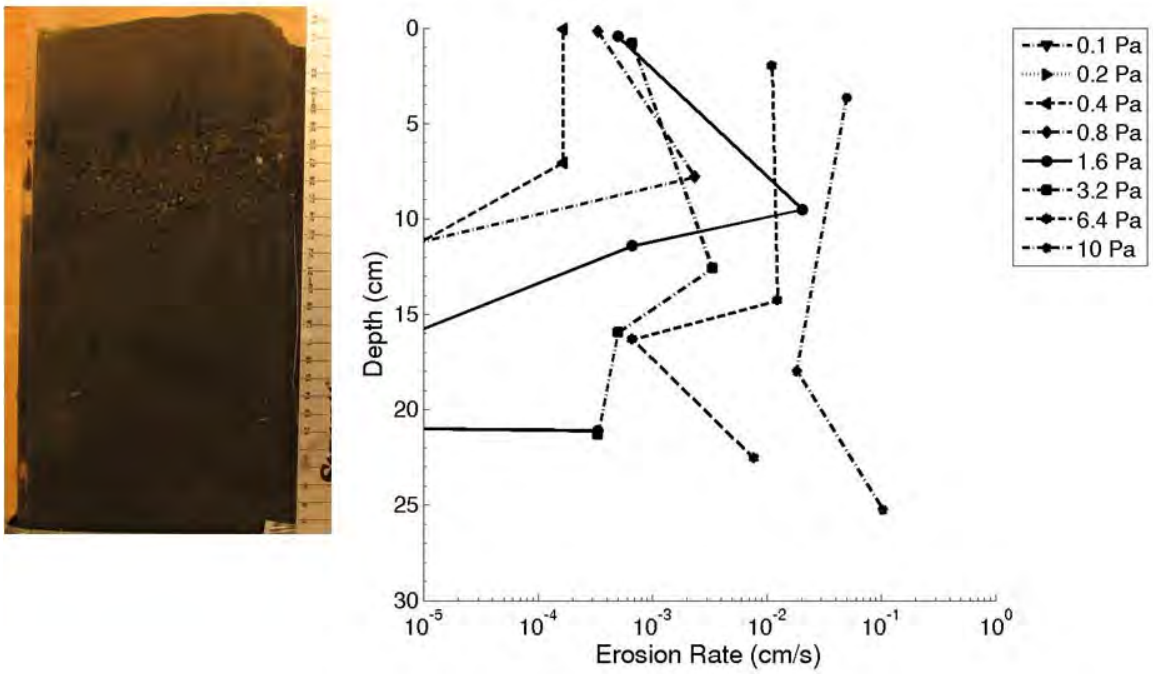

Figure 17. Picture of core SF-6 aligned with Sedflume erosion rate data.

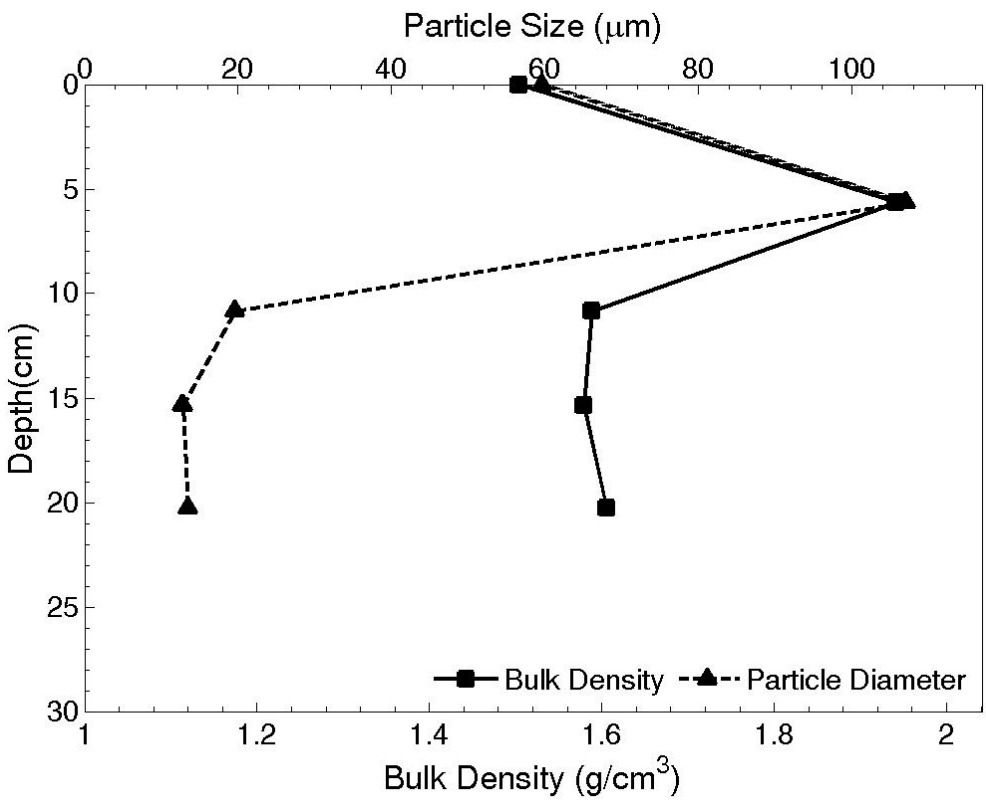

Figure 18. Bulk density and D_{50} with depth for core SF-6.

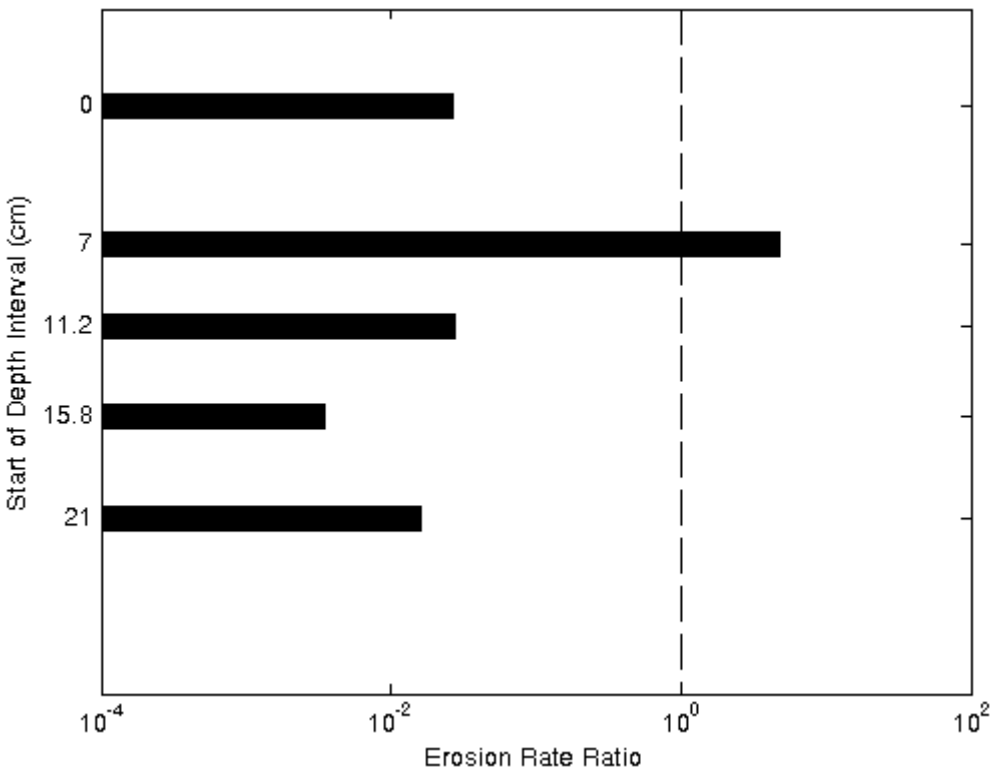

Figure 19. Intra-core erosion rate ratios for core SF-6.

Table 13. Power law best-fit variables for specified depth intervals in core SF-6.

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0.00	3.65	0.0004	1.76	0.93
2	7.00	9.50	0.0043	3.70	1.00
3	11.20	14.25	0.0001	2.92	0.93
4	15.80	18.00	0.0000	2.33	0.83
5	21.00	25.25	0.0000	2.86	0.92

Table 14. Bulk density, D_{50}, critical shear stress with depth for SF-6.

Depth (cm)	D_{50} (µm)	ρ_b (g/cm^3)	Power Law τ_{cr} (Pa)	Linear Interpolation τ_{cr} (Pa)
0.00	59.60	1.50	0.49	0.32
5.65	106.90	1.94	0.36	0.32
10.85	19.57	1.59	1.10	0.92
15.35	12.81	1.58	1.93	1.92
20.25	13.48	1.61	1.29	1.04
Mean	**42.47**	**1.64**	**1.03**	**0.90**

Core SF-7

Core SF-7 was collected in approximately 17.4 m water depth. The core was collected near the mouth of the East Waterway. This core required 5 attempts to extract a sufficient core. The first two attempts resulted in insufficient material recovery. The third attempt resulted in a cracked core due to the stiffness of the bottom material. The fourth attempt returned a cobble-sized piece of cinder block material in the core. Upon extracting the final core, it consisted of an uneven, undisturbed, 2-3 cm sandy silt layer with some shell hash and organic detritus. Below this layer was a darker-colored stiff appearing, silty material. The core material extracted was less than preferred for this analysis; however, this recovery was the best of five attempts and was limited by the stiff bottom sediment characteristics.

During the analysis, several worms and worm tubes were observed on the surface layer. One large vertical worm was removed from the material manually prior to the analysis so that it did not have any negative impacts on the measured erosion rates of the sediments. In addition, a 3-4 cm piece of gravel was removed prior to the analysis. An easier-to-erode surface layer gave way to veins of a stiffer layer below, which resulted in uneven erosion. The sediment consistency beneath the surface was stiff, clayey-silt, which tended to erode in clumps. Worms were observed throughout the core material.

Figure 20 shows a photo of core SF-7 prior to the analysis aligned vertically with the measured erosion rate data.Figure 21 shows the bulk density and D_{50} (median particle size) as a function of depth.

The erosion rate data shows a general increase in erosion rate near a depth of 5 cm before becoming more difficult to erode at depths deeper than approximately 8 cm. The median particle size in the core was in the range of sandy silt (53.9 μm) to fine sand (86.1 μm) until a depth of 15 cm, where the material d_{50} was fine silt (22.4 μm). The mean d_{50} in the core is 55.5 μm (sandy silt). The bulk densities increased, in general, with depth from 1.61 g/cm^3 to 1.81 g/cm^3. The mean bulk density in the core is 1.72 g/cm^3. The interpolated critical shear stresses were lowest on the surface and increased with depth, typical of consolidated core material. The surface critical shear stresses were 0.34 Pa and 0.24 Pa for the power law and linear interpolations, respectively. The maximum critical shear stresses near the bottom of the cored material were 0.68 Pa and 0.52 Pa. The mean values of the critical shear stresses in the core are 0.47 N/m^2 and 0.36 N/m^2, for the power law and linear interpolations, respectively.

Figure 22 displays the erosion susceptibility for the depth intervals in core SF-7. The plot shows that the 5 cm depth interval is more susceptible to rapid erosion than the surface and deeper interval, which agrees with the measured erosion rate data.

Table 15 summarizes the variables resulting from the power law fit to the data in each shear stress cycle. Shear stress cycles for which only two applied shear stresses existed (i.e. $r^2 = 1.00$) are omitted from the table. Table 16 summarizes the bulk density, D_{50}, and interpolated critical shear stresses, τ_{cr}, for specific core depths.

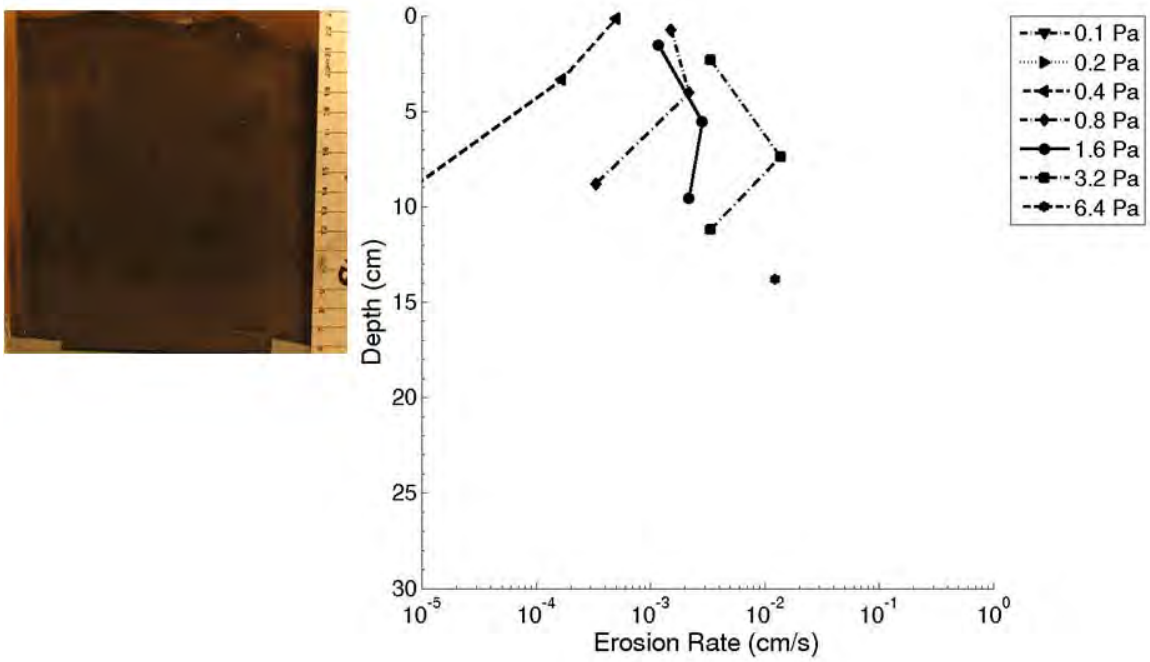

Figure 20. Picture of core SF-7 aligned with Sedflume erosion rate data.

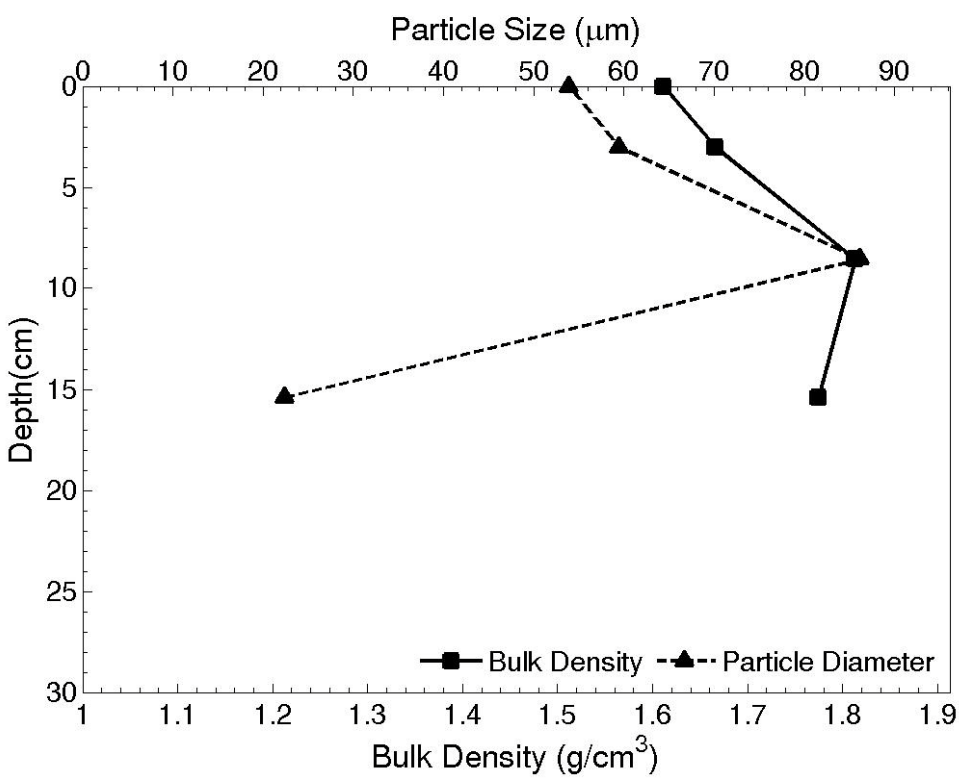

Figure 21. Bulk density and D_{50} with depth for core SF-7.

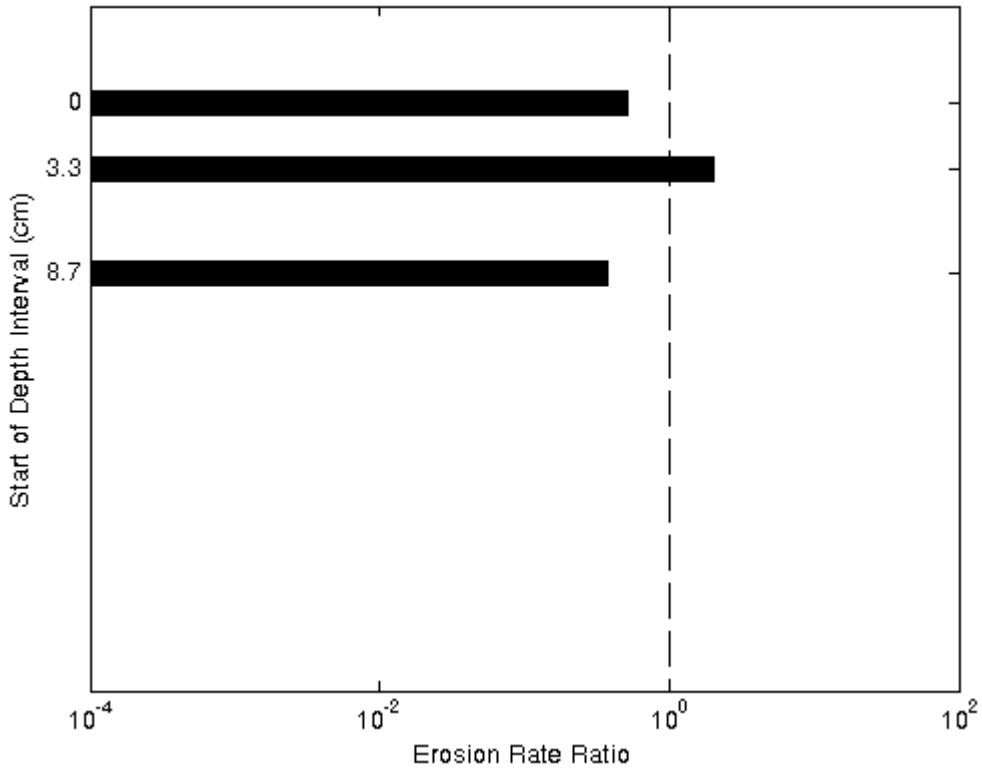

Figure 22. Intra-core erosion rate ratios for core SF-7.

Table 15. Power law best-fit variables for specified depth intervals in core SF-7.

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0.00	2.30	0.0007	1.85	0.84
2	3.30	7.40	0.0012	2.51	0.93
3	8.70	13.80	0.0003	2.40	0.89

Table 16. Bulk density, $D_{50,}$ critical shear stress with depth for SF-7.

Depth (cm)	D_{50} (µm)	ρ_b (g/cm^3)	Power Law τ_{cr} (Pa)	Linear Interpolation τ_{cr} (Pa)
0.00	53.87	1.61	0.34	0.24
3.00	59.43	1.67	0.38	0.32
8.55	86.12	1.81	0.68	0.52
15.40	22.37	1.77	-	-
Mean	**55.45**	**1.72**	**0.47**	**0.36**

Core SF-8

Core SF-8 was collected in approximately 18.0 m water depth. The core was collected from a central channel location, between the coring locations of SF-6 and SF-7. This core also required several attempts to collect a sufficient amount of material. Upon extraction, the core consisted of an uneven, but undisturbed, 1 cm light-colored layer of fine sediment over seemingly stiffer, darker-colored silts and sandy silts. Larger, unconsolidated clumps of sediment were distinct within the core, possibly from suspension and re-settlement (i.e. dredging operations).

During the analysis, some benthic organisms were visible on the surface. Some 1-2 cm long worms and tubes were also observed while sediments were eroding. Down-core the material comprised silty material with some fine sand and fine organic material. Erosion was clumpy and caused manual leveling of the sediment surface during the analysis. The material was stiff clayey-silt near the bottom of the core. A large clump of material eroded into the flume at the bottom of the core, plugging the flume. This caused disturbance of the sediment consolidation characteristics and a manual clean out of the flume. Since it was the bottom of the core, the analysis was halted at that point.

Figure 23 shows a photo of core SF-8 prior to the analysis aligned vertically with the measured erosion rate data. Figure 24 shows the bulk density and D_{50} (median particle size) as a function of depth.

The erosion rate data shows variation in erosion rates down-core as a result of different material consistencies. The erosion rates were low on the surface but increased beneath the surface layer before decreasing again down-core. The sediments collected from the surface layer were required to be passed through a 2000 sieve before processing with the particle laser diffractor. Approximately 20% by weight of the sediments sampled at this layer were larger than 2000 um. The remaining samples contained sediments that were smaller than 2000 um.

The median particle size in the core varied down-core, but remained within the silt range (11.7 μm to 34.4 μm) with a mean core value of 19.8 μm. The bulk densities decreased beneath the surface layer before increasing with depth. The range was between 1.41 g/cm^3 and 1.64 g/cm^3. The mean bulk density in the core is 1.55 g/cm^3. The surface of the core was more difficult to erode than the layer beneath. The calculated linear interpolated critical shear stress was 0.94 Pa. The power law interpolation did not yield a critical shear stress due to a poor correlation between the data and regression line. The critical shear stresses were lower beneath the surface, down to a depth of approximately 10 cm (0.32Pa to 0.42 Pa for both manners of interpolation). At a depth of 10 cm, the critical shear stresses were 0.94 Pa and 1.28 Pa for the power law and linear interpolation, respectively. The mean values of the critical shear stresses in the core are 0.58 N/m^2 and 0.66 N/m^2, for the power law and linear interpolations, respectively.

Figure 25 displays the erosion susceptibility for the depth intervals in core SF-8. Only three of the five depth intervals met the criteria for computing an erosion rate (depths of 2.0 cm, 5.4 cm and 10.4 cm). Based on these results, the layer at a depth of 2 cm is more

susceptible to erosion than the layers below. This depth correlates with the lowest critical shear stress as well as a high erosion rate. At a depth of 5.4 cm, one would expect the erosion susceptibility to be high as well; however, this isn't the case and is unexplainable at the present time.

Table 17 summarizes the variables resulting from the power law fit to the data in each shear stress cycle. Shear stress cycles for which only two applied shear stresses existed (i.e. $r^2 = 1.00$) are omitted from the table. Table 18 summarizes the bulk density, D_{50}, and interpolated critical shear stresses, τ_{cr}, for specific core depths.

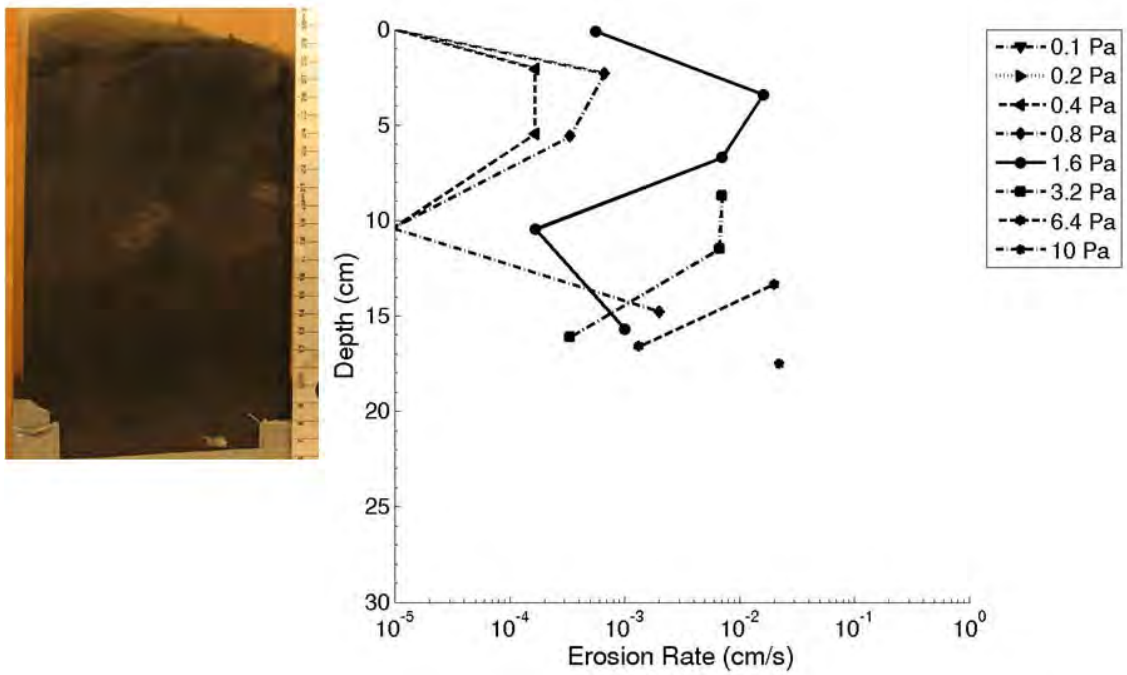

Figure 23. Picture of core SF-8 aligned with Sedflume erosion rate data.

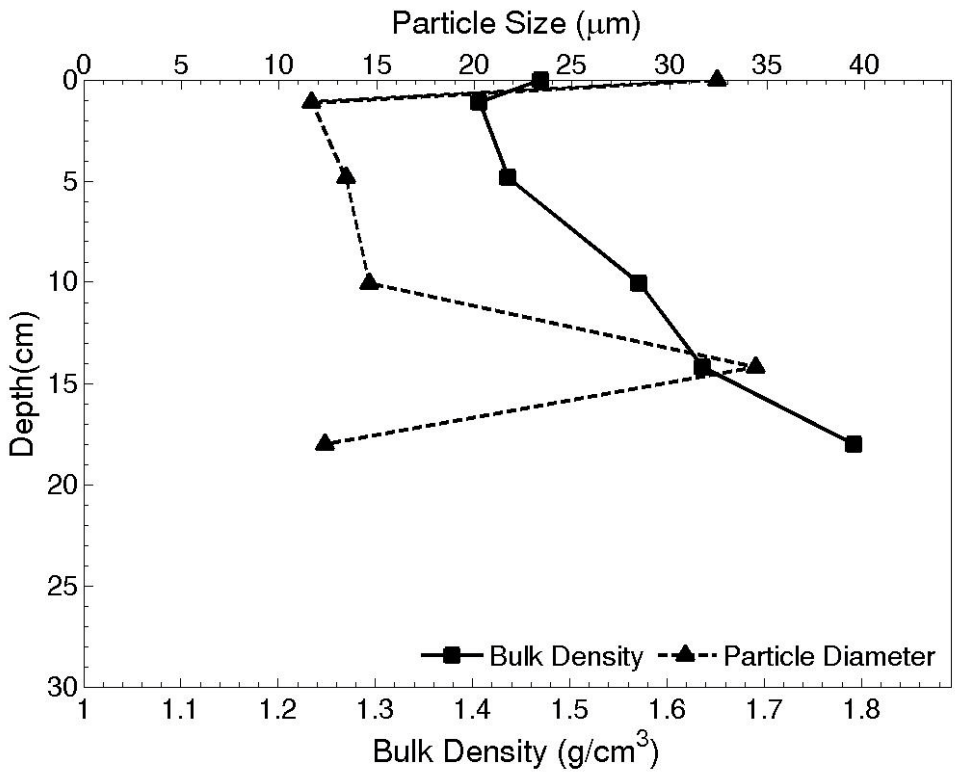

Figure 24. Bulk density and D_{50} with depth for core SF-8.

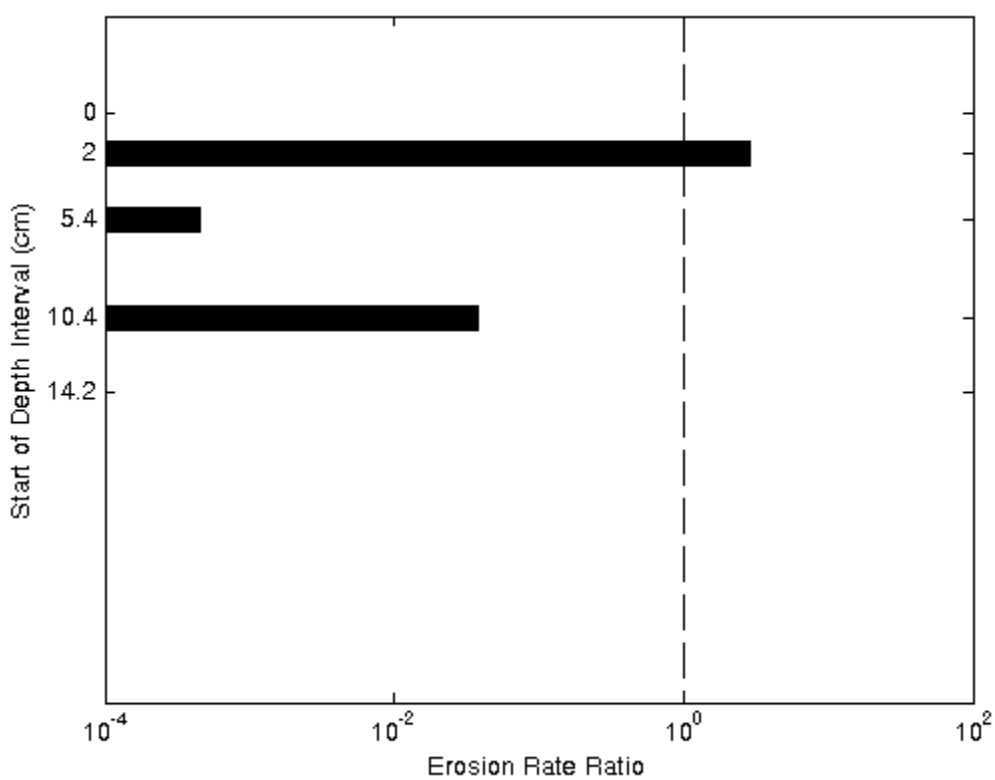

Figure 25. Intra-core erosion rate ratios for core SF-8.

Table 17. Power law best-fit variables for specified depth intervals in core SF-8.

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0.00	0.10	-	-	0.50
2	2.00	3.40	0.0025	3.42	0.98
3	5.40	8.70	0.0008	2.45	0.93
4	10.40	13.35	0.0001	2.51	0.86
5	14.20	17.50	-	-	0.56

Table 18. Bulk density, $D_{50,}$ critical shear stress with depth for SF-8.

Depth (cm)	D_{50} (µm)	ρ_b (g/cm^3)	Power Law τ_{cr} (Pa)	Linear Interpolation τ_{cr} (Pa)
0.00	32.45	1.47	-	0.94
1.10	11.67	1.41	0.39	0.32
4.85	13.42	1.44	0.42	0.32
10.05	14.62	1.57	0.93	1.28
14.20	34.40	1.64	-	0.42
18.00	12.37	1.79	-	-
Mean	**19.82**	**1.55**	**0.58**	**0.66**

Summary

Sea Engineering, Inc. (SEI) conducted a Sedflume analysis for Anchor QEA on eight (8) sediment cores obtained from the East Waterway in the Port of Seattle, Washington. These cores were collected in areas where depths ranged to approximately 18 m of water depth. Sediment compositions were mostly silts, clayey-silts and sandy silts. Many of the cores harbored a great deal of benthic organisms and organic material, which often hindered the erosion of sediments. The primary goal of this work was to characterize the stability of the sediments in the East Waterway. The cores are described in detail in the report.

References

Hakanson, L., and M. Jansson, 2002, Principles of Lake Sedimentology. Blackburn Press, Caldwell, New Jersey, USA.

Jepsen, R., J. Roberts, and W. Lick, 1997, Effects of bulk density on sediment erosion rates, Water, Air and Soil Pollution, 99:21-31.

McNeil, J., C. Taylor, and W. Lick, 1996, Measurements of erosion of undisturbed bottom sediments with depth, J. Hydr. Engr., 122(6):316-324.

Roberts, J., R. Jepsen, D. Gotthard, and W. Lick, 1998, Effects of particle size and bulk density on erosion of quartz particles, J. Hydr. Engrg., 124(12):1261 1267.

Appendix A – Particle Size Distributions

ATTACHMENT 3

Project Location:	**Seattle East Waterway**
Core ID:	**SF1**
Sample Date:	**4/19/2010**
Sample Time:	**12:20**
Analysis Date:	**4/21/2010**
Analysis Time:	**13:00**
Reference:	**J. Magalen**
Core Height (cm):	**39.00**
Reference Height (cm):	**0.00**

Sedflume Data

Cycle Number	Shear Stress (dynes/cm^2)	Starting Height (mm)	Ending Height (mm)	Time (min)	Time (sec)	Core Depth (cm)	Shear Stress (N/m^2)	Erosion Rate (cm/s)
1	1	0.0	0.0	10	30	**0.00**	**0.1**	**0.0000**
2	2	0.0	0.0	10	0	**0.00**	**0.2**	**0.0000**
3	4	0.0	1.0	10	0	**0.05**	**0.4**	**0.0002**
4	8	1.0	5.0	13	30	**0.30**	**0.8**	**0.0005**
5	16	5.0	20.0	13	30	**1.25**	**1.6**	**0.0019**
6	32	20.0	40.0	1	52	**3.00**	**3.2**	**0.0179**
7	2	41.0	41.0	10	0	**4.10**	**0.2**	**0.0000**
8	4	41.0	41.0	10	0	**4.10**	**0.4**	**0.0000**
9	8	41.0	43.0	10	0	**4.20**	**0.8**	**0.0003**
10	16	43.0	46.0	10	0	**4.45**	**1.6**	**0.0005**
11	32	46.0	66.0	5	40	**5.60**	**3.2**	**0.0059**
12	64	66.0	89.0	0	43	**7.75**	**6.4**	**0.0535**
13	2	93.0	93.0	10	0	**9.30**	**0.2**	**0.0000**
14	4	93.0	94.0	10	0	**9.35**	**0.4**	**0.0002**
15	8	94.0	97.0	10	0	**9.55**	**0.8**	**0.0005**
16	16	97.0	100.0	10	0	**9.85**	**1.6**	**0.0005**
17	32	100.0	125.0	2	7	**11.25**	**3.2**	**0.0197**
18	4	127.0	129.0	10	0	**12.80**	**0.4**	**0.0003**
19	8	129.0	131.0	10	0	**13.00**	**0.8**	**0.0003**
20	16	131.0	133.0	10	0	**13.20**	**1.6**	**0.0003**
21	32	133.0	153.0	2	30	**14.30**	**3.2**	**0.0133**
22	64	153.0	174.0	1	11	**16.35**	**6.4**	**0.0296**
23	4	176.0	176.0	10	0	**17.60**	**0.4**	**0.0000**
24	8	176.0	181.0	10	0	**17.85**	**0.8**	**0.0008**
25	16	181.0	187.0	10	0	**18.40**	**1.6**	**0.0010**
26	32	187.0	208.0	5	0	**19.75**	**3.2**	**0.0070**
27	64	208.0	234.0	2	25	**22.10**	**6.4**	**0.0179**
28	100	234.0	273.0	1	0	**25.35**	**10.0**	**0.0650**

New shear cycle begins. Sediment samples taken for particle size and bulk density measurements.

Project Location:	**Seattle East Waterway**
Core ID:	**SF1**
Sample Date:	**4/19/2010**
Sample Time:	**12:20**
Analysis Date:	**4/21/2010**
Analysis Time:	**13:00**
Reference:	**J. Magalen**
$\rho_{sediment\ (g/cm^3)}$	**2.65**
$\rho_{water\ (g/cm^3)}$	**1.00**

Particle Size and Bulk Density Data

Sample Number	Tray Wt. (g)	Wet Wt. (g)	Dry Wt. (g)	Water Content	Depth (cm)	Particle Size (µm)	Bulk Density (g/cm^3)
1	1.282	7.089	3.277	0.66	0.00	12.4000	1.27
2	1.289	12.690	6.614	0.53	4.05	11.7800	1.41
3	1.291	15.440	7.637	0.55	9.10	11.9800	1.39
4	1.292	14.725	7.576	0.53	12.60	11.8500	1.41
5	1.288	16.995	8.471	0.54	17.50	10.2200	1.40

Project Location:	**Seattle East Waterway**
Core ID:	**SF2**
Sample Date:	**4/19/2010**
Sample Time:	**10:40**
Analysis Date:	**4/22/2010**
Analysis Time:	**8:00**
Reference:	**J. Magalen**
Core Height (cm):	**36.00**
Reference Height (cm):	**0.00**

Sedflume Data

Cycle Number	Shear Stress (dynes/cm^2)	Starting Height (mm)	Ending Height (mm)	Time (min)	Time (sec)	Core Depth (cm)	Shear Stress (N/m^2)	Erosion Rate (cm/s)
1	1	0.0	0.0	10	0	**0.00**	**0.1**	**0.0000**
2	2	0.0	0.0	10	0	**0.00**	**0.2**	**0.0000**
3	4	0.0	3.0	15	0	**0.15**	**0.4**	**0.0003**
4	8	3.0	4.0	10	0	**0.35**	**0.8**	**0.0002**
5	16	4.0	8.0	10	0	**0.60**	**1.6**	**0.0007**
6	32	8.0	30.0	3	15	**1.90**	**3.2**	**0.0113**
7	64	30.0	46.0	1	15	**3.80**	**6.4**	**0.0213**
8	2	48.0	48.0	10	0	**4.80**	**0.2**	**0.0000**
9	4	48.0	48.0	10	0	**4.80**	**0.4**	**0.0000**
10	8	48.0	49.0	10	0	**4.85**	**0.8**	**0.0002**
11	16	49.0	52.0	10	0	**5.05**	**1.6**	**0.0005**
12	32	52.0	59.0	10	0	**5.55**	**3.2**	**0.0012**
13	64	59.0	91.0	1	52	**7.50**	**6.4**	**0.0286**
14	100	91.0	111.0	0	40	**10.10**	**10.0**	**0.0500**
15	4	118.0	118.0	10	0	**11.80**	**0.4**	**0.0000**
16	8	118.0	118.0	10	0	**11.80**	**0.8**	**0.0000**
17	16	118.0	122.0	10	0	**12.00**	**1.6**	**0.0007**
18	32	122.0	132.0	10	0	**12.70**	**3.2**	**0.0017**
19	64	132.0	153.0	1	35	**14.25**	**6.4**	**0.0221**
20	4	156.0	156.0	10	0	**15.60**	**0.4**	**0.0000**
21	8	156.0	156.0	10	0	**15.60**	**0.8**	**0.0000**
22	16	156.0	157.0	10	0	**15.65**	**1.6**	**0.0002**
23	32	157.0	170.0	10	0	**16.35**	**3.2**	**0.0022**
24	64	170.0	190.0	1	25	**18.00**	**6.4**	**0.0235**
25	100	190.0	205.0	0	28	**19.75**	**10.0**	**0.0536**
26	8	230.0	232.0	10	0	**23.10**	**0.8**	**0.0003**
27	16	232.0	252.0	2	0	**24.20**	**1.6**	**0.0167**
28	32	252.0	290.0	0	38	**27.10**	**3.2**	**0.1000**

New shear cycle begins. Sediment samples taken for particle size and bulk density measurements.

Project Location:	**Seattle East Waterway**
Core ID:	**SF2**
Sample Date:	**4/19/2010**
Sample Time:	**10:40**
Analysis Date:	**4/22/2010**
Analysis Time:	**8:00**
Reference:	**J. Magalen**
$\rho_{sediment\ (g/cm^3)}$	**2.65**
$\rho_{water\ (g/cm^3)}$	**1.00**

Particle Size and Bulk Density Data

Sample Number	Tray Wt. (g)	Wet Wt. (g)	Dry Wt. (g)	Water Content	Depth (cm)	Particle Size (µm)	Bulk Density (g/cm^3)
1	1.299	8.609	3.812	0.66	0.00	27.1700	1.27
2	1.295	10.373	6.131	0.47	4.70	22.9300	1.50
3	1.285	15.474	8.706	0.48	11.45	15.1200	1.48
4	1.289	10.215	6.479	0.42	15.35	26.2100	1.57
5	1.285	16.089	9.352	0.46	21.75	15.7800	1.51

Project Location:	**Seattle East Waterway**
Core ID:	**SF3**
Sample Date:	**4/19/2010**
Sample Time:	**12:55**
Analysis Date:	**4/22/2010**
Analysis Time:	**15:00**
Reference:	**J. Magalen**
Core Height (cm):	**37.00**
Reference Height (cm):	**1.50**

Sedflume Data

Cycle Number	Shear Stress (dynes/cm^2)	Starting Height (mm)	Ending Height (mm)	Time (min)	Time (sec)	Core Depth (cm)	Shear Stress (N/m^2)	Erosion Rate (cm/s)
1	1	15.0	15.0	10	0	**0.00**	**0.1**	**0.0000**
2	2	15.0	15.0	10	0	**0.00**	**0.2**	**0.0000**
3	4	15.0	16.0	10	0	**0.05**	**0.4**	**0.0002**
4	8	16.0	18.0	10	0	**0.20**	**0.8**	**0.0003**
5	16	18.0	25.0	10	0	**0.65**	**1.6**	**0.0012**
6	32	25.0	29.0	10	0	**1.20**	**3.2**	**0.0007**
7	64	29.0	49.0	1	52	**2.40**	**6.4**	**0.0179**
8	100	49.0	70.0	0	20	**4.45**	**10.0**	**0.1050**
9	2	76.0	76.0	10	0	**6.10**	**0.2**	**0.0000**
10	4	76.0	77.0	10	0	**6.15**	**0.4**	**0.0002**
11	8	77.0	80.0	10	0	**6.35**	**0.8**	**0.0005**
12	16	80.0	85.0	10	0	**6.75**	**1.6**	**0.0008**
13	32	85.0	104.0	0	40	**7.95**	**3.2**	**0.0475**
14	4	108.0	108.0	10	0	**9.30**	**0.4**	**0.0000**
15	8	108.0	108.0	10	0	**9.30**	**0.8**	**0.0000**
16	16	108.0	118.0	10	0	**9.80**	**1.6**	**0.0017**
17	32	118.0	138.0	3	40	**11.30**	**3.2**	**0.0091**
18	64	138.0	160.0	1	0	**13.40**	**6.4**	**0.0367**
19	4	160.0	160.0	10	0	**14.50**	**0.4**	**0.0000**
20	8	160.0	165.0	10	0	**14.75**	**0.8**	**0.0008**
21	16	165.0	170.0	10	0	**15.25**	**1.6**	**0.0008**
22	32	170.0	187.0	0	38	**16.35**	**3.2**	**0.0447**
23	4	208.0	211.0	10	0	**19.45**	**0.4**	**0.0005**
24	8	211.0	217.0	10	0	**19.90**	**0.8**	**0.0010**
25	16	217.0	257.0	1	15	**22.20**	**1.6**	**0.0533**
26	32	257.0	295.0	0	31	**26.10**	**3.2**	**0.1226**

New shear cycle begins. Sediment samples taken for particle size and bulk density measurements.

Project Location:	**Seattle East Waterway**
Core ID:	**SF3**
Sample Date:	**4/19/2010**
Sample Time:	**12:55**
Analysis Date:	**4/22/2010**
Analysis Time:	**15:00**
Reference:	**J. Magalen**
$\rho_{sediment\ (g/cm^3)}$	**2.65**
$\rho_{water\ (g/cm^3)}$	**1.00**

Particle Size and Bulk Density Data

Sample Number	Tray Wt. (g)	Wet Wt. (g)	Dry Wt. (g)	Water Content	Depth (cm)	Particle Size (µm)	Bulk Density (g/cm^3)
1	1.295	7.045	3.964	0.54	0.00	11.8200	1.41
2	1.288	19.122	11.583	0.42	7.30	12.7500	1.56
3	1.284	7.927	5.222	0.41	10.60	11.2000	1.59
4	1.292	12.488	5.900	0.59	16.00	10.0400	1.34
5	1.272	9.949	4.615	0.61	19.75	11.9100	1.32

Project Location:	**Seattle East Waterway**
Core ID:	**SF4**
Sample Date:	**4/19/2010**
Sample Time:	**13:40**
Analysis Date:	**4/20/2010**
Analysis Time:	**16:00**
Reference:	**J. Magalen**
Core Height (cm):	**17.00**
Reference Height (cm):	**16.40**

Sedflume Data

Cycle Number	Shear Stress (dynes/cm^2)	Starting Height (mm)	Ending Height (mm)	Time (min)	Time (sec)	Core Depth (cm)	Shear Stress (N/m^2)	Erosion Rate (cm/s)
1	1	164.0	164.0	10	0	**0.00**	**0.1**	**0.0000**
2	2	164.0	174.0	10	0	**0.50**	**0.2**	**0.0017**
3	4	174.0	176.0	10	0	**1.10**	**0.4**	**0.0003**
4	8	176.0	181.0	10	0	**1.45**	**0.8**	**0.0008**
5	16	181.0	201.0	4	12	**2.70**	**1.6**	**0.0079**
6	32	201.0	221.0	0	45	**4.70**	**3.2**	**0.0444**
7	2	228.0	229.0	10	0	**6.45**	**0.2**	**0.0002**
8	4	229.0	232.0	10	0	**6.65**	**0.4**	**0.0005**
9	8	232.0	233.0	10	0	**6.85**	**0.8**	**0.0002**
10	16	233.0	234.0	10	0	**6.95**	**1.6**	**0.0002**
11	32	234.0	254.0	7	25	**8.00**	**3.2**	**0.0045**
12	64	254.0	273.0	8	0	**9.95**	**6.4**	**0.0040**
13	100	273.0	291.0	0	25	**11.80**	**10.0**	**0.0720**
14	2	297.0	297.0	10	0	**13.30**	**0.2**	**0.0000**
15	4	297.0	297.0	10	0	**13.30**	**0.4**	**0.0000**
16	8	297.0	301.0	10	0	**13.50**	**0.8**	**0.0007**
17	16	301.0	302.0	10	0	**13.75**	**1.6**	**0.0002**
18*	32	302.0	303.0	5	30	**13.85**	**3.2**	**0.0003**

New shear cycle begins. Sediment samples taken for particle size and bulk density measurements.

*** Additional sediment sample taken after shear cycle for particle size and bulk density measurements.**

Project Location:	**Seattle East Waterway**
Core ID:	**SF4**
Sample Date:	**4/19/2010**
Sample Time:	**13:40**
Analysis Date:	**4/20/2010**
Analysis Time:	**16:00**
Reference:	**J. Magalen**
$\rho_{sediment\ (g/cm^3)}$	**2.65**
$\rho_{water\ (g/cm^3)}$	**1.00**

Particle Size and Bulk Density Data

Sample Number	Tray Wt. (g)	Wet Wt. (g)	Dry Wt. (g)	Water Content	Depth (cm)	Particle Size (µm)	Bulk Density (g/cm^3)
1	1.286	7.336	3.881	0.57	0.00	16.3800	1.36
2	1.286	13.812	8.005	0.46	6.05	12.5800	1.50
3	1.287	15.625	8.654	0.49	13.00	35.4500	1.47
4	1.288	10.630	6.398	0.45	13.90	19.6400	1.52

Project Location:	**Seattle East Waterway**
Core ID:	**SF5**
Sample Date:	**4/19/2010**
Sample Time:	**14:20**
Analysis Date:	**4/21/2010**
Analysis Time:	**8:30**
Reference:	**J. Magalen**
Core Height (cm):	**21.00**
Reference Height (cm):	**15.10**

Sedflume Data

Cycle Number	Shear Stress (dynes/cm^2)	Starting Height (mm)	Ending Height (mm)	Time (min)	Time (sec)	Core Depth (cm)	Shear Stress (N/m^2)	Erosion Rate (cm/s)
1	1	151.0	151.0	10	0	**0.00**	**0.1**	**0.0000**
2	2	151.0	151.0	10	0	**0.00**	**0.2**	**0.0000**
3	4	151.0	153.0	10	0	**0.10**	**0.4**	**0.0003**
4	8	153.0	155.0	10	0	**0.30**	**0.8**	**0.0003**
5	16	155.0	157.0	10	0	**0.50**	**1.6**	**0.0003**
6	32	157.0	160.0	1	0	**0.75**	**3.2**	**0.0050**
7	2	160.0	160.0	10	0	**0.90**	**0.2**	**0.0000**
8	4	160.0	163.0	10	0	**1.05**	**0.4**	**0.0005**
9	8	163.0	164.0	10	0	**1.25**	**0.8**	**0.0002**
10	16	164.0	180.0	7	30	**2.10**	**1.6**	**0.0036**
11	32	180.0	195.0	1	15	**3.65**	**3.2**	**0.0200**
13	2	197.0	197.0	10	0	**4.60**	**0.2**	**0.0000**
14	4	197.0	197.0	10	0	**4.60**	**0.4**	**0.0000**
15	8	197.0	200.0	10	0	**4.75**	**0.8**	**0.0005**
16	16	200.0	202.0	10	0	**5.00**	**1.6**	**0.0003**
17	32	202.0	216.0	5	30	**5.80**	**3.2**	**0.0042**
18	4	222.0	222.0	10	0	**7.10**	**0.4**	**0.0000**
19	8	222.0	224.0	10	0	**7.20**	**0.8**	**0.0003**
20	16	224.0	244.0	6	45	**8.30**	**1.6**	**0.0049**
21	32	244.0	275.0	0	42	**10.85**	**3.2**	**0.0738**

New shear cycle begins. Sediment samples taken for particle size and bulk density measurements.

Project Location:	**Seattle East Waterway**
Core ID:	**SF5**
Sample Date:	**4/19/2010**
Sample Time:	**14:20**
Analysis Date:	**4/21/2010**
Analysis Time:	**8:30**
Reference:	**J. Magalen**
$\rho_{sediment\ (g/cm^3)}$	**2.65**
$\rho_{water\ (g/cm^3)}$	**1.00**

Particle Size and Bulk Density Data

Sample Number	Tray Wt. (g)	Wet Wt. (g)	Dry Wt. (g)	Water Content	Depth (cm)	Particle Size (µm)	Bulk Density (g/cm^3)
1	1.294	11.594	7.013	0.44	0.00	29.9300	1.53
2	1.278	8.127	4.651	0.51	0.90	15.3000	1.44
3	1.281	11.316	7.813	0.35	4.50	14.5400	1.68
4	1.293	10.495	5.655	0.53	6.80	33.1100	1.42
5	1.290	25.249	15.169	0.42	12.40	26.7600	1.56

Project Location:	**Seattle East Waterway**
Core ID:	**SF6**
Sample Date:	**4/19/2010**
Sample Time:	**15:05**
Analysis Date:	**4/23/2010**
Analysis Time:	**8:00**
Reference:	**J. Magalen**
Core Height (cm):	**33.00**
Reference Height (cm):	**3.00**

Sedflume Data

Cycle Number	Shear Stress (dynes/cm^2)	Starting Height (mm)	Ending Height (mm)	Time (min)	Time (sec)	Core Depth (cm)	Shear Stress (N/m^2)	Erosion Rate (cm/s)
1	1	30.0	30.0	10	0	**0.00**	**0.1**	**0.0000**
2	2	30.0	30.0	10	0	**0.00**	**0.2**	**0.0000**
3	4	30.0	31.0	10	0	**0.05**	**0.4**	**0.0002**
4	8	31.0	33.0	10	0	**0.20**	**0.8**	**0.0003**
5	16	33.0	36.0	10	0	**0.45**	**1.6**	**0.0005**
6	32	36.0	40.0	10	0	**0.80**	**3.2**	**0.0007**
7	64	40.0	60.0	3	0	**2.00**	**6.4**	**0.0111**
8	100	60.0	73.0	0	26	**3.65**	**10.0**	**0.0500**
9	2	100.0	100.0	10	0	**7.00**	**0.2**	**0.0000**
10	4	100.0	101.0	10	0	**7.05**	**0.4**	**0.0002**
11	8	101.0	115.0	10	0	**7.80**	**0.8**	**0.0023**
12	16	115.0	135.0	1	38	**9.50**	**1.6**	**0.0204**
13	4	142.0	142.0	10	0	**11.20**	**0.4**	**0.0000**
14	8	142.0	142.0	10	0	**11.20**	**0.8**	**0.0000**
15	16	142.0	146.0	10	0	**11.40**	**1.6**	**0.0007**
16	32	146.0	166.0	10	0	**12.60**	**3.2**	**0.0033**
17	64	166.0	179.0	1	45	**14.25**	**6.4**	**0.0124**
18	4	188.0	188.0	10	0	**15.80**	**0.4**	**0.0000**
19	8	188.0	188.0	10	0	**15.80**	**0.8**	**0.0000**
20	16	188.0	188.0	10	0	**15.80**	**1.6**	**0.0000**
21	32	188.0	191.0	10	0	**15.95**	**3.2**	**0.0005**
22	64	191.0	195.0	10	0	**16.30**	**6.4**	**0.0007**
23	100	195.0	225.0	2	44	**18.00**	**10.0**	**0.0183**
24	4	240.0	240.0	10	0	**21.00**	**0.4**	**0.0000**
25	8	240.0	240.0	10	0	**21.00**	**0.8**	**0.0000**
26	16	240.0	242.0	10	0	**21.10**	**1.6**	**0.0003**
27	32	242.0	244.0	10	0	**21.30**	**3.2**	**0.0003**
28	64	244.0	267.0	5	0	**22.55**	**6.4**	**0.0077**
29	100	267.0	298.0	0	30	**25.25**	**10.0**	**0.1033**

New shear cycle begins. Sediment samples taken for particle size and bulk density measurements.

Project Location:	**Seattle East Waterway**
Core ID:	**SF6**
Sample Date:	**4/19/2010**
Sample Time:	**15:05**
Analysis Date:	**4/23/2010**
Analysis Time:	**8:00**
Reference:	**J. Magalen**
$\rho_{sediment\ (g/cm^3)}$	**2.65**
$\rho_{water\ (g/cm^3)}$	**1.00**

Particle Size and Bulk Density Data

Sample Number	Tray Wt. (g)	Wet Wt. (g)	Dry Wt. (g)	Water Content	Depth (cm)	Particle Size (µm)	Bulk Density (g/cm^3)
1	1.299	8.069	4.944	0.46	0.00	59.6000	1.50
2	1.290	15.052	12.006	0.22	5.65	106.9000	1.94
3	1.296	15.378	9.677	0.40	10.85	19.5700	1.59
4	1.291	19.591	12.071	0.41	15.35	12.8100	1.58
5	1.295	19.642	12.406	0.39	20.25	13.4800	1.61

Project Location:	**Seattle East Waterway**
Core ID:	**SF7**
Sample Date:	**4/19/2010**
Sample Time:	**17:10**
Analysis Date:	**4/23/2010**
Analysis Time:	**13:00**
Reference:	**J. Magalen**
Core Height (cm):	**27.00**
Reference Height (cm):	**15.60**

Sedflume Data

Cycle Number	Shear Stress (dynes/cm^2)	Starting Height (mm)	Ending Height (mm)	Time (min)	Time (sec)	Core Depth (cm)	Shear Stress (N/m^2)	Erosion Rate (cm/s)
1	1	156.0	156.0	10	30	**0.00**	**0.1**	**0.0000**
2	2	156.0	156.0	10	0	**0.00**	**0.2**	**0.0000**
3	4	156.0	159.0	10	0	**0.15**	**0.4**	**0.0005**
4	8	159.0	168.0	10	0	**0.75**	**0.8**	**0.0015**
5	16	168.0	175.0	10	0	**1.55**	**1.6**	**0.0012**
6	32	175.0	183.0	4	0	**2.30**	**3.2**	**0.0033**
7	2	189.0	189.0	10	0	**3.30**	**0.2**	**0.0000**
8	4	189.0	190.0	10	0	**3.35**	**0.4**	**0.0002**
9	8	190.0	203.0	10	0	**4.05**	**0.8**	**0.0022**
10	16	203.0	220.0	10	0	**5.55**	**1.6**	**0.0028**
11	32	220.0	240.0	2	26	**7.40**	**3.2**	**0.0137**
12	4	243.0	243.0	10	0	**8.70**	**0.4**	**0.0000**
13	8	243.0	245.0	10	0	**8.80**	**0.8**	**0.0003**
14	16	245.0	258.0	10	0	**9.55**	**1.6**	**0.0022**
15	32	258.0	278.0	10	0	**11.20**	**3.2**	**0.0033**
16	64	278.0	310.0	4	21	**13.80**	**6.4**	**0.0123**

New shear cycle begins. Sediment samples taken for particle size and bulk density measurements.

Project Location:	**Seattle East Waterway**
Core ID:	**SF7**
Sample Date:	**4/19/2010**
Sample Time:	**17:10**
Analysis Date:	**4/23/2010**
Analysis Time:	**13:00**
Reference:	**J. Magalen**
$\rho_{sediment\ (g/cm^3)}$	**2.65**
$\rho_{water\ (g/cm^3)}$	**1.00**

Particle Size and Bulk Density Data

Sample Number	Tray Wt. (g)	Wet Wt. (g)	Dry Wt. (g)	Water Content	Depth (cm)	Particle Size (µm)	Bulk Density (g/cm^3)
1	1.288	7.856	5.289	0.39	0.00	53.8700	1.61
2	1.280	24.715	16.318	0.36	3.00	59.4300	1.67
3	1.288	25.886	19.001	0.28	8.55	86.1200	1.81
4	1.291	27.873	19.917	0.30	15.40	22.3700	1.77

Project Location:	**Seattle East Waterway**
Core ID:	**SF8**
Sample Date:	**4/19/2010**
Sample Time:	**18:30**
Analysis Date:	**4/20/2010**
Analysis Time:	**10:00**
Reference:	**J. Magalen**
Core Height (cm):	**30.00**
Reference Height (cm):	**7.80**

Sedflume Data

Cycle Number	Shear Stress (dynes/cm^2)	Starting Height (mm)	Ending Height (mm)	Time (min)	Time (sec)	Core Depth (cm)	Shear Stress (N/m^2)	Erosion Rate (cm/s)
1	1	78.0	78.0	10	0	**0.00**	**0.1**	**0.0000**
2	2	78.0	78.0	10	0	**0.00**	**0.2**	**0.0000**
3	4	78.0	78.0	10	0	**0.00**	**0.4**	**0.0000**
4	8	78.0	78.0	10	0	**0.00**	**0.8**	**0.0000**
5	16	78.0	80.0	6	0	**0.10**	**1.6**	**0.0006**
6	2	98.0	98.0	10	0	**2.00**	**0.2**	**0.0000**
7	4	98.0	99.0	10	0	**2.05**	**0.4**	**0.0002**
8	8	99.0	103.0	10	0	**2.30**	**0.8**	**0.0007**
9	16	103.0	121.0	1	52	**3.40**	**1.6**	**0.0161**
10	2	132.0	132.0	10	0	**5.40**	**0.2**	**0.0000**
11	4	132.0	133.0	10	0	**5.45**	**0.4**	**0.0002**
12	8	133.0	135.0	10	0	**5.60**	**0.8**	**0.0003**
13	16	135.0	155.0	4	45	**6.70**	**1.6**	**0.0070**
14	32	155.0	175.0	4	45	**8.70**	**3.2**	**0.0070**
16	2	182.0	182.0	10	0	**10.40**	**0.2**	**0.0000**
17	4	182.0	182.0	10	0	**10.40**	**0.4**	**0.0000**
18	8	182.0	182.0	10	0	**10.40**	**0.8**	**0.0000**
19	16	182.0	183.0	10	0	**10.45**	**1.6**	**0.0002**
20	32	183.0	203.0	5	0	**11.50**	**3.2**	**0.0067**
21	64	203.0	220.0	1	25	**13.35**	**6.4**	**0.0200**
22	4	220.0	220.0	10	0	**14.20**	**0.4**	**0.0000**
23	8	220.0	232.0	10	0	**14.80**	**0.8**	**0.0020**
24	16	232.0	238.0	10	0	**15.70**	**1.6**	**0.0010**
25	32	238.0	240.0	10	0	**16.10**	**3.2**	**0.0003**
26	64	240.0	248.0	10	0	**16.60**	**6.4**	**0.0013**
27	100	248.0	258.0	0	45	**17.50**	**10.0**	**0.0222**

New shear cycle begins. Sediment samples taken for particle size and bulk density measurements.

Project Location:	**Seattle East Waterway**
Core ID:	**SF8**
Sample Date:	**4/19/2010**
Sample Time:	**18:30**
Analysis Date:	**4/20/2010**
Analysis Time:	**10:00**
Reference:	**J. Magalen**
$\rho_{sediment\ (g/cm^3)}$	**2.65**
$\rho_{water\ (g/cm^3)}$	**1.00**

Particle Size and Bulk Density Data

Sample Number	Tray Wt. (g)	Wet Wt. (g)	Dry Wt. (g)	Water Content	Depth (cm)	Particle Size (µm)	Bulk Density (g/cm^3)
1	1.295	18.114	9.929	0.49	0.00	32.4500	1.47
2	1.287	17.279	8.714	0.54	1.10	11.6700	1.41
3	1.289	14.384	7.681	0.51	4.85	13.4200	1.44
4	1.287	24.000	14.549	0.42	10.05	14.6200	1.57
5	1.285	25.272	16.270	0.38	14.20	34.4000	1.64
6	1.281	23.237	16.864	0.29	18.00	12.3700	1.79

APPENDIX E
HYDRODYNAMIC MODEL CALIBRATION

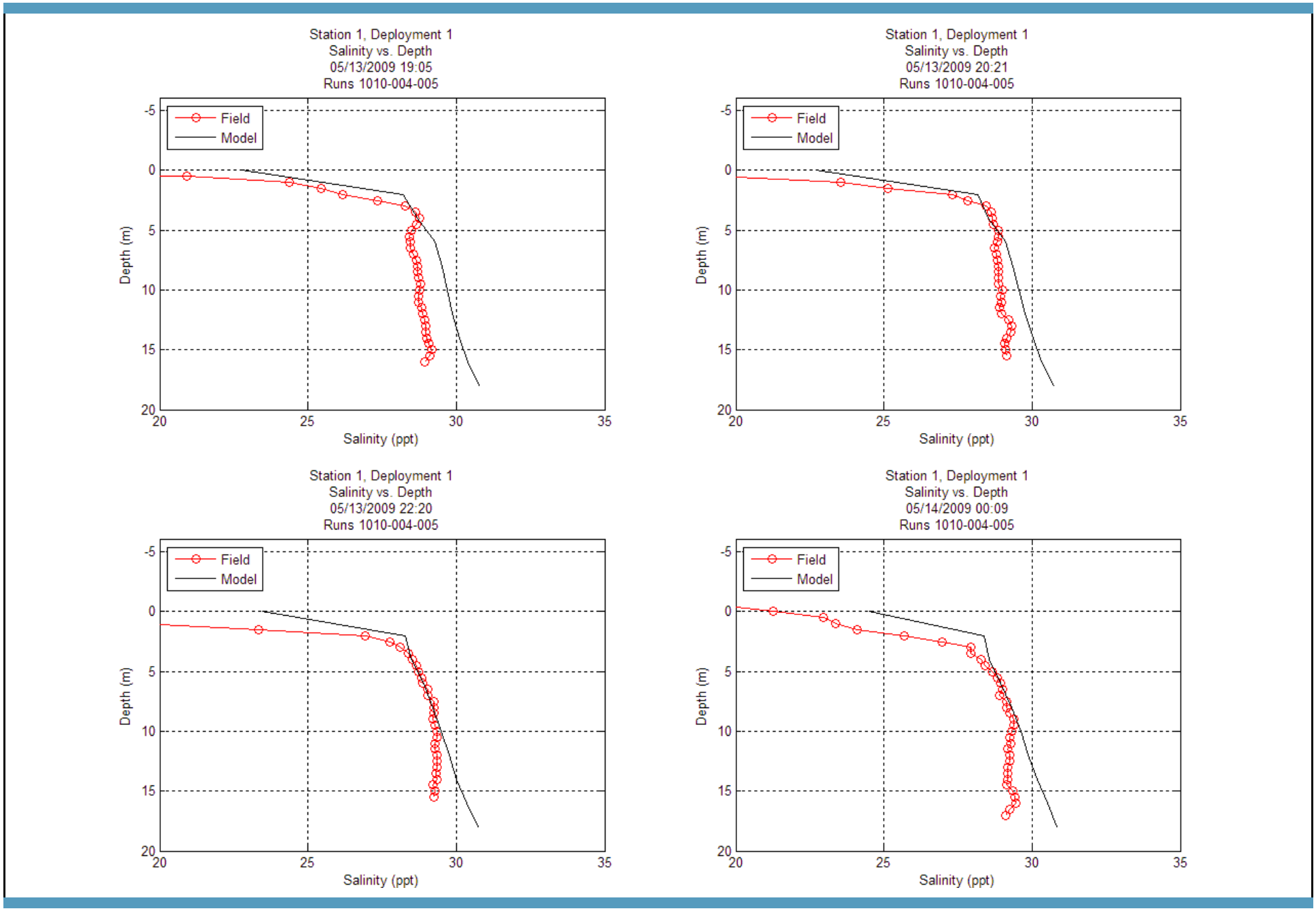

Figure E-1a
Comparison of Predicted and Observed Salinity Profiles, Site 1
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA

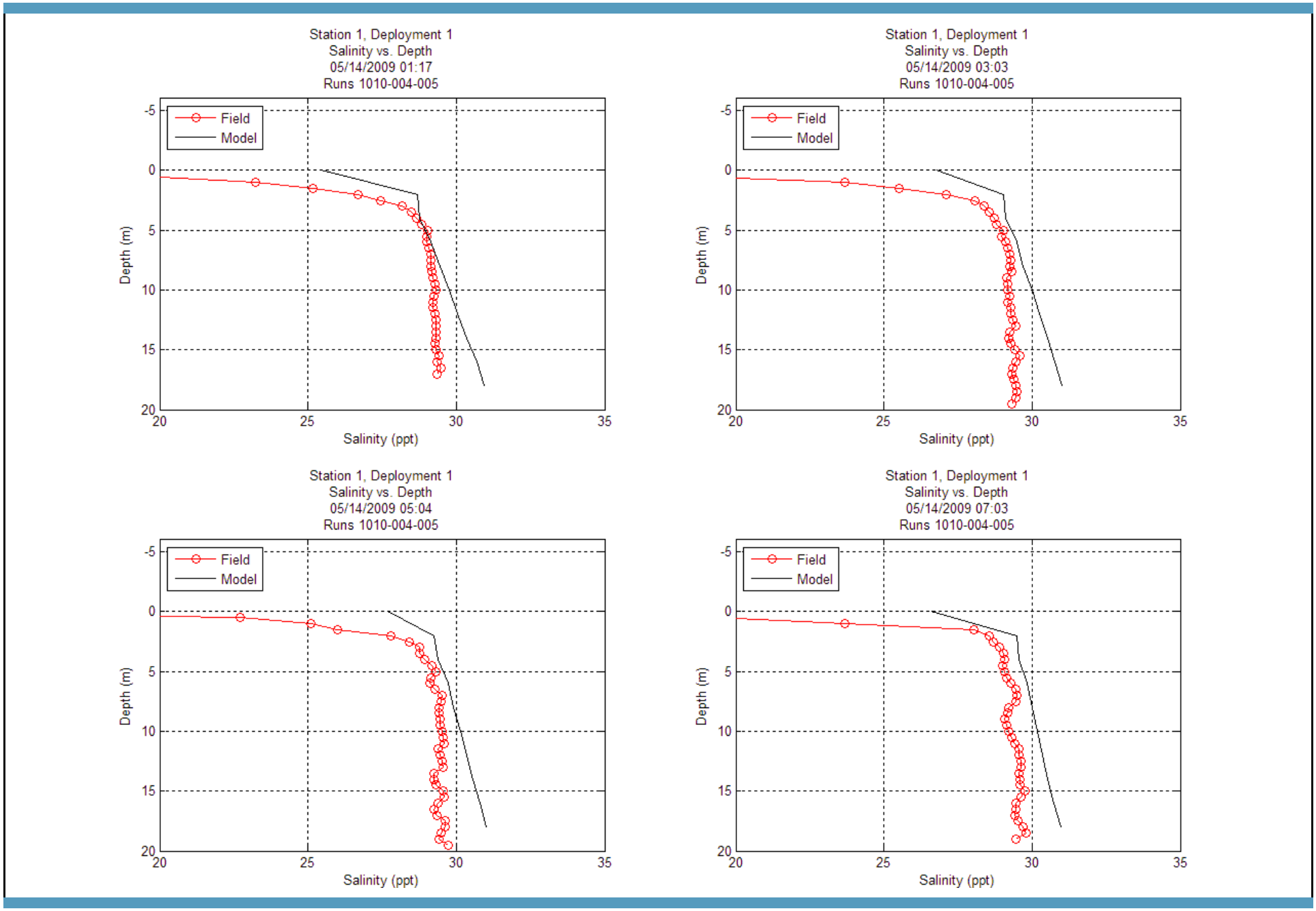

Figure E-1b
Comparison of Predicted and Observed Salinity Profiles, Site 1
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA

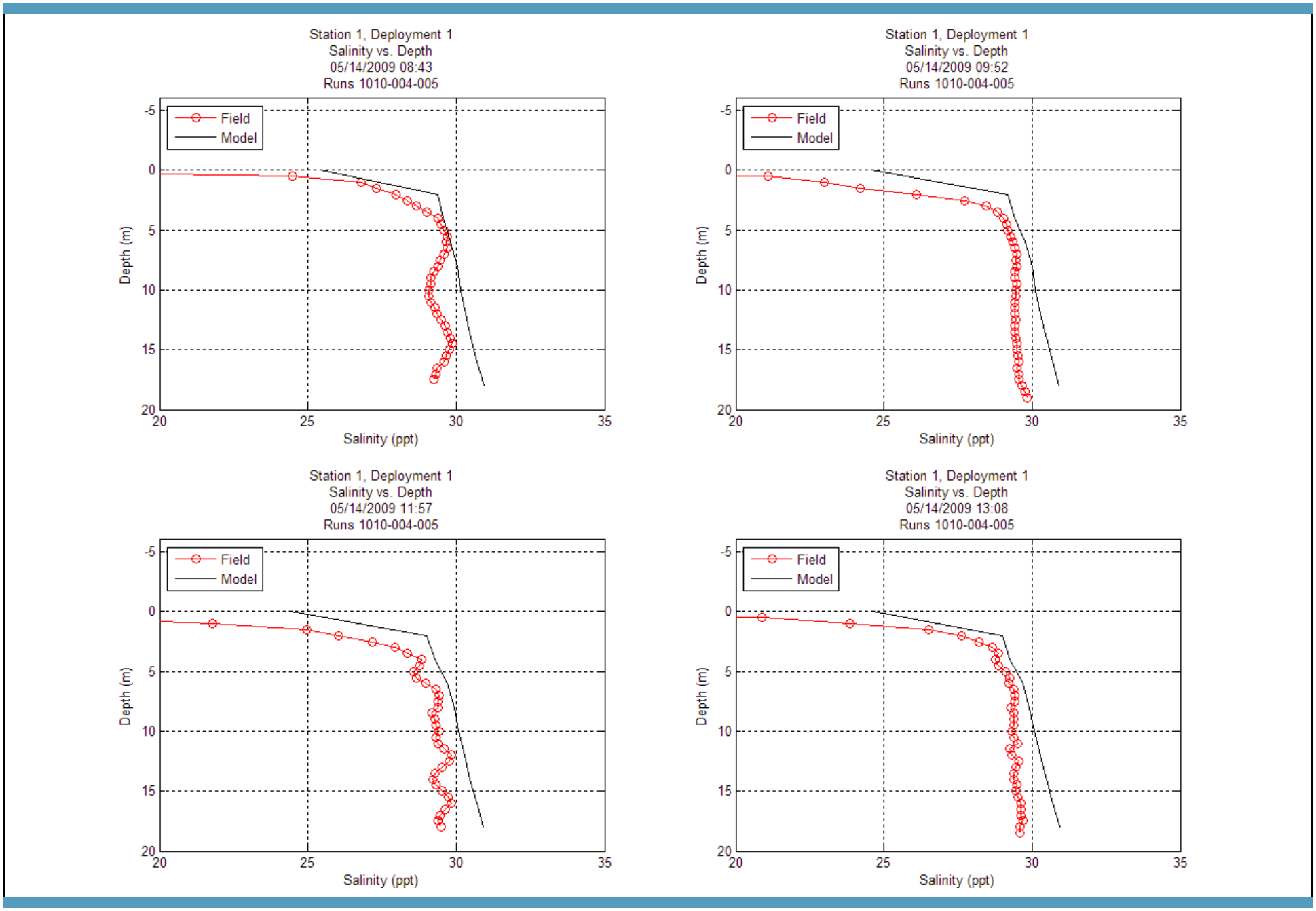

Figure E-1c
Comparison of Predicted and Observed Salinity Profiles, Site 1
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA

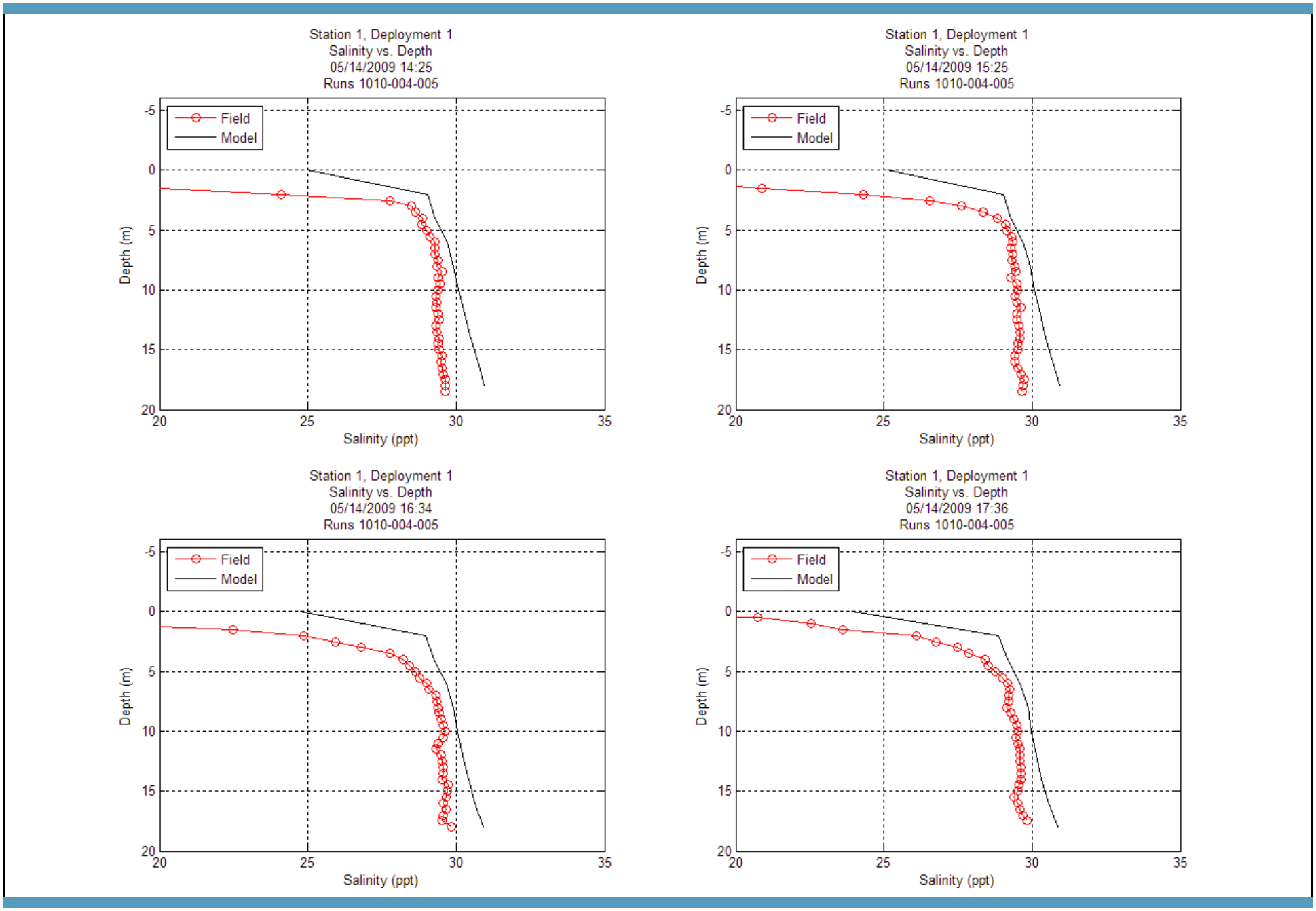

Figure E-1d
Comparison of Predicted and Observed Salinity Profiles, Site 1
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA

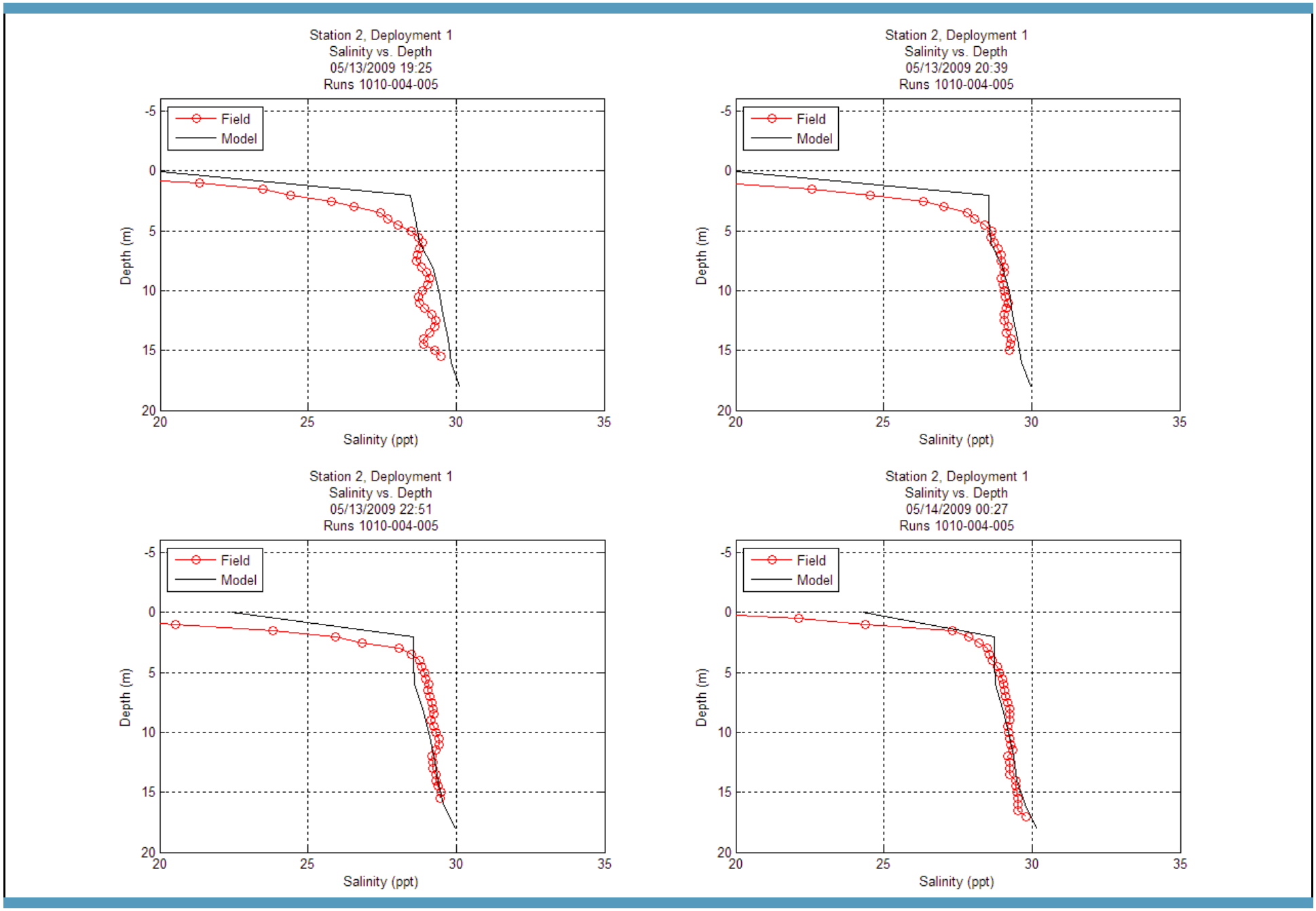

Figure E-2a
Comparison of Predicted and Observed Salinity Profiles, Site 2
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA

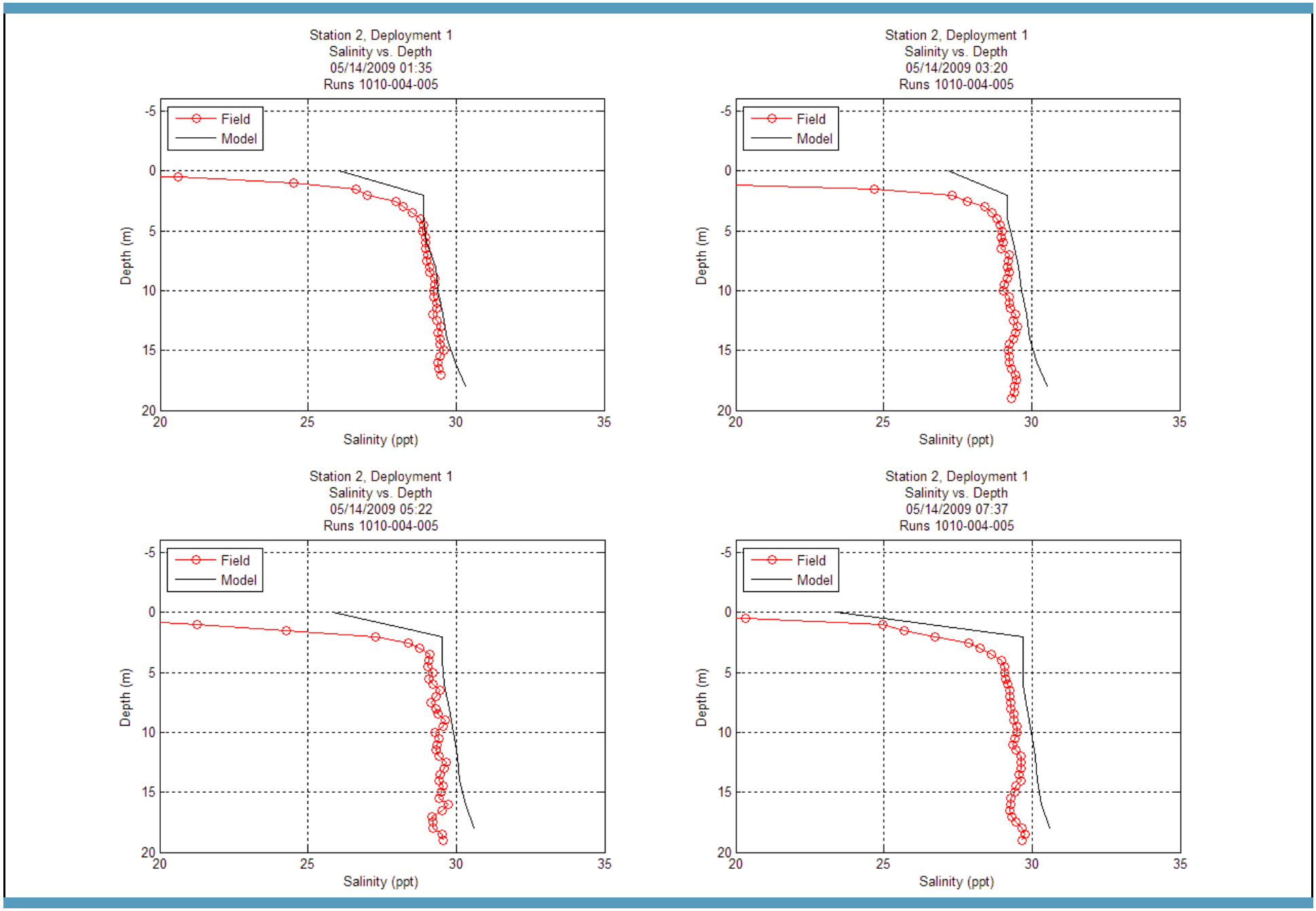

Figure E-2b
Comparison of Predicted and Observed Salinity Profiles, Site 2
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA

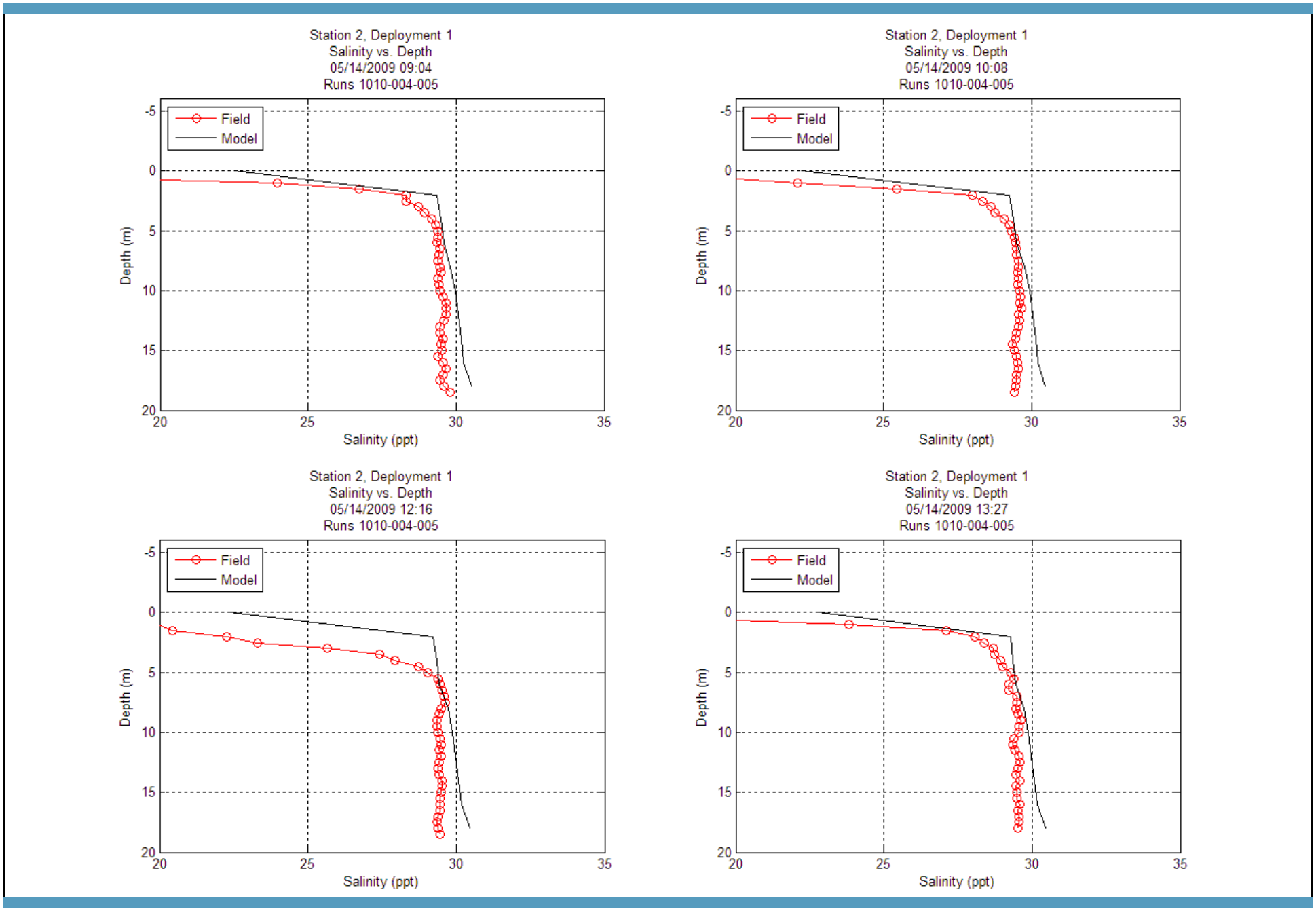

Figure E-2c
Comparison of Predicted and Observed Salinity Profiles, Site 2
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA

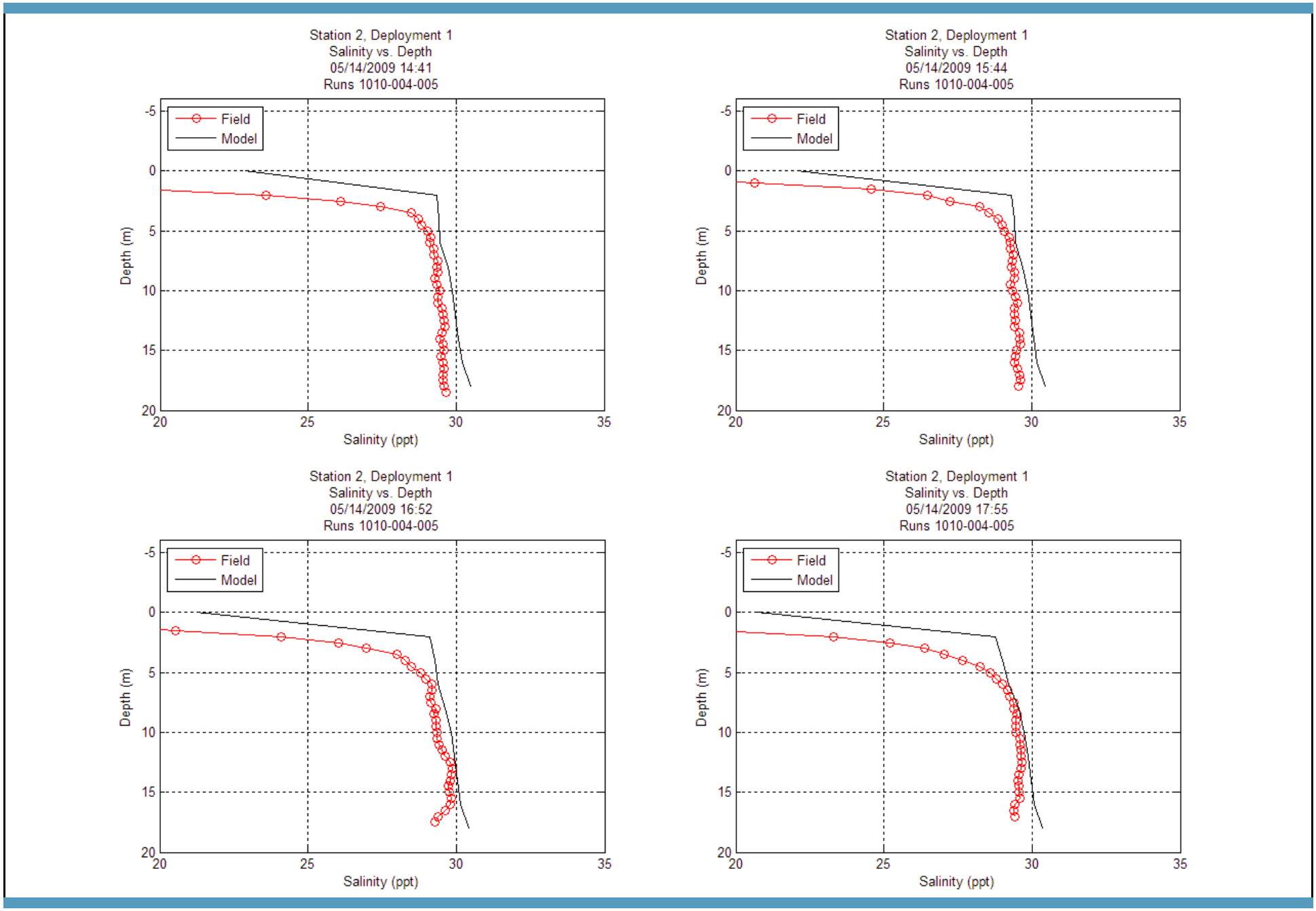

Figure E-2d
Comparison of Predicted and Observed Salinity Profiles, Site 2
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA

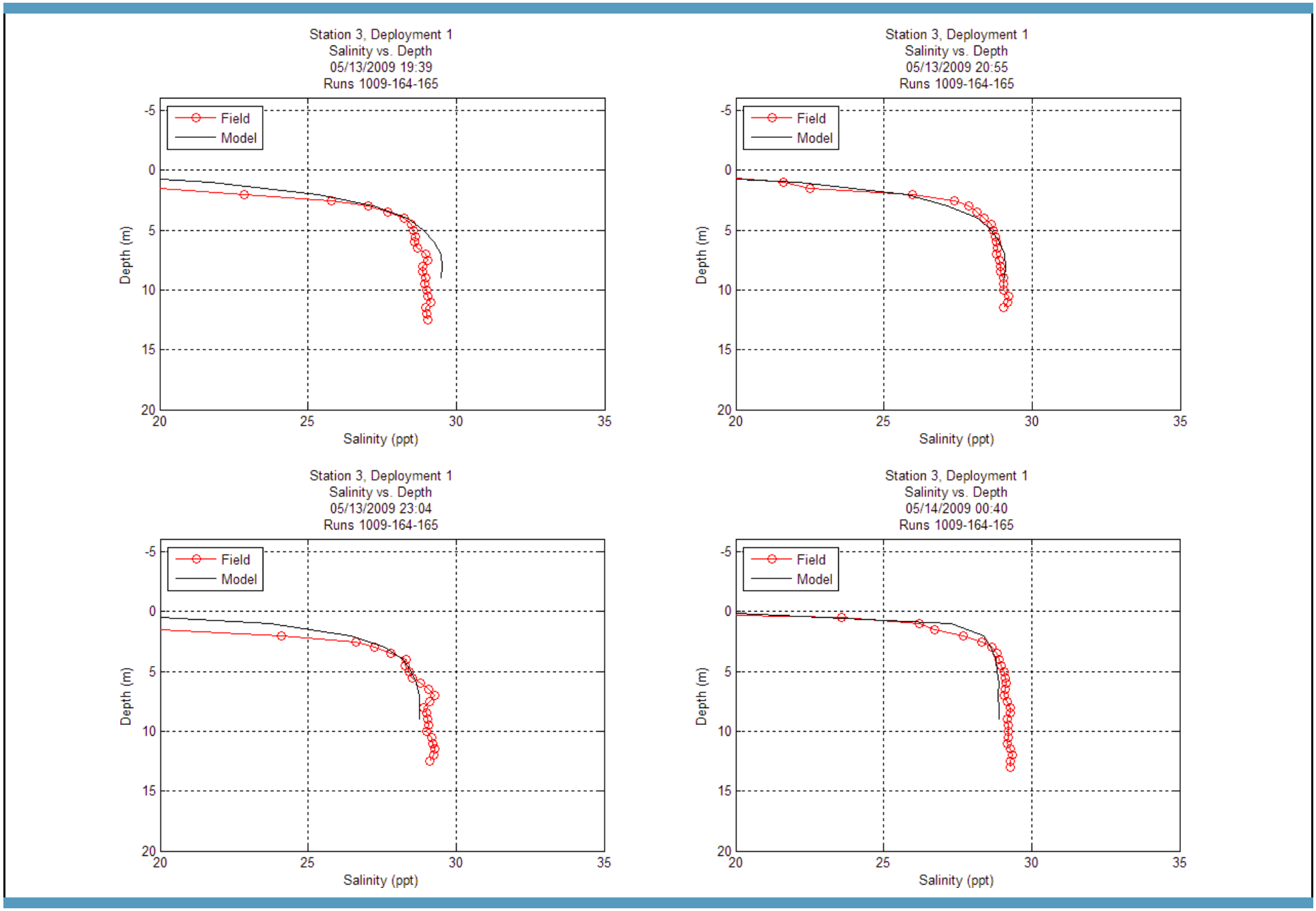

Figure E-3a
Comparison of Predicted and Observed Salinity Profiles, Site 3
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA

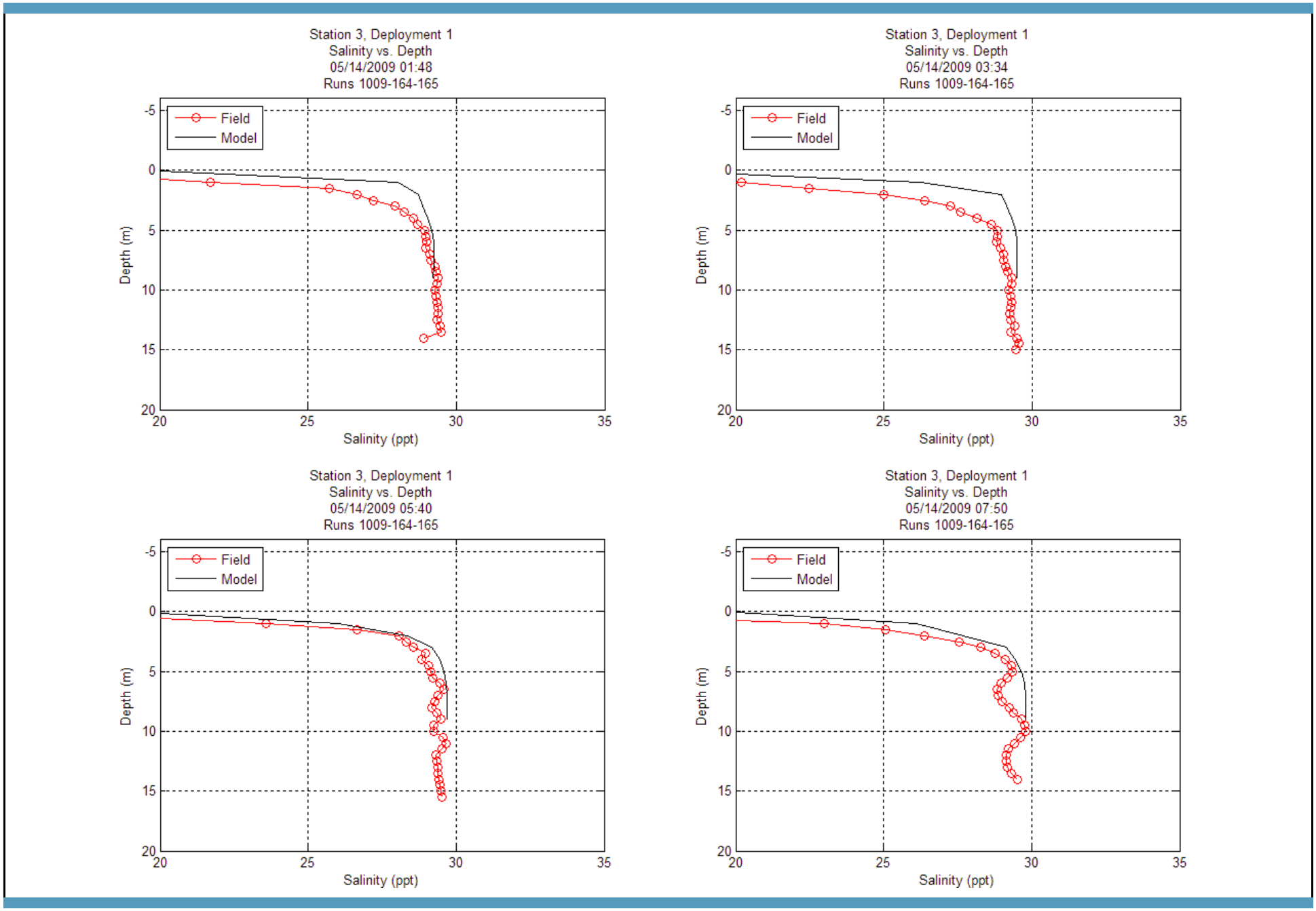

Figure E-3b
Comparison of Predicted and Observed Salinity Profiles, Site 3
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA

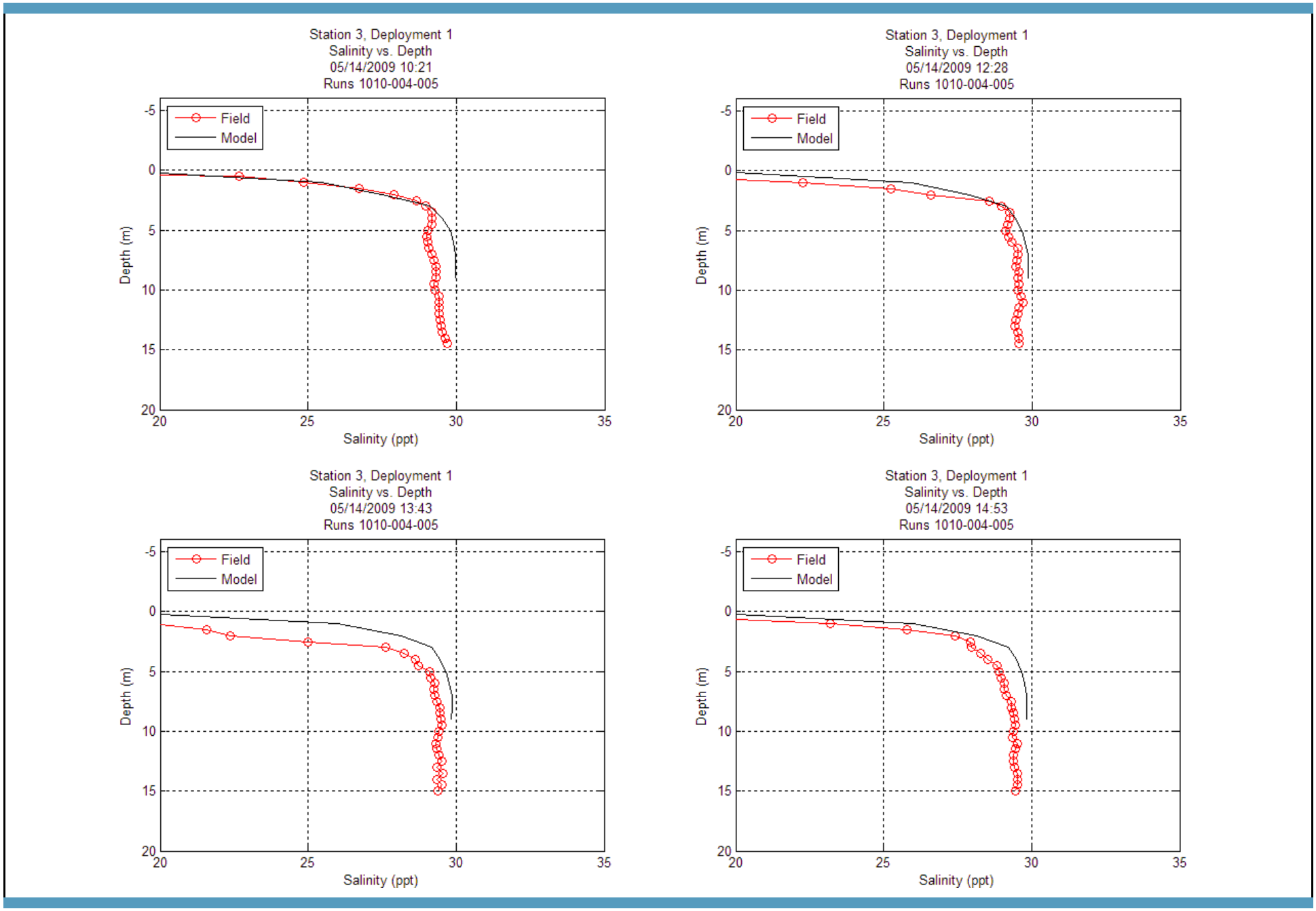

Figure E-3c
Comparison of Predicted and Observed Salinity Profiles, Site 3
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA

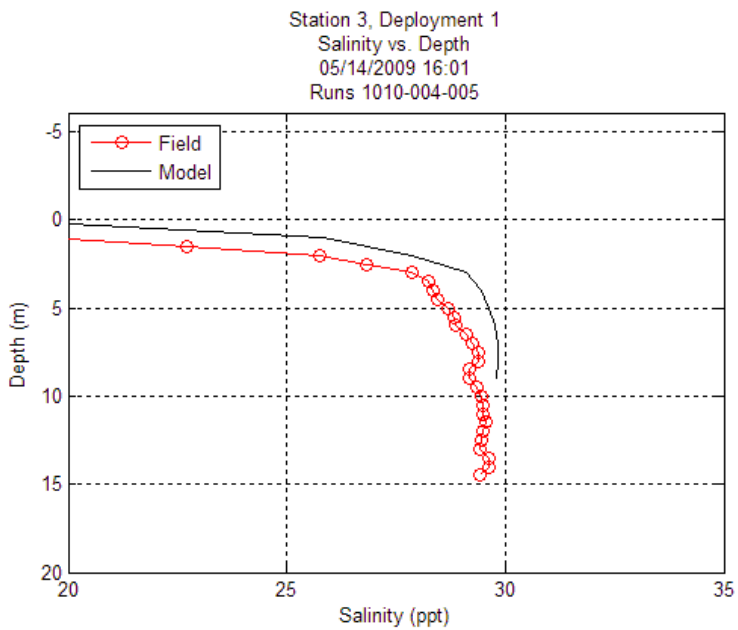

Figure E-3d
Comparison of Predicted and Observed Salinity Profiles, Site 3
Sediment Transport Evaluation Report
East Waterway Operable Unit

ANCHOR QEA

APPENDIX F
LATERAL FLOW AND SOLIDS DATA, PTM MODEL INPUT DATA

ATTACHMENT 1

East Waterway

Storm Drain and Combined Sewer Solids Loading Analysis
August 2011 Update

City of Seattle
Seattle Public Utilities

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Appendix D. S Hinds St CSO/SD CSO records
Appendix E. Particle size distribution data

SUMMARY OF REVISIONS

This report is an update of the September 2008 East Waterway (EW) lateral load report (Northwest Hydraulic Consultants 2008). Changes from the 2008 report are summarized below:

- Drainage basin boundaries for Port-owned storm drains have been revised based on updated information on drainage infrastructure provided by the Port of Seattle (Port). Specific changes include:
  - Basin B-11. Previous mapping from Port did not include areas outside of Port property that are connected to this system. These areas have been added. In addition, the T18 portion of the basin has been modified to reflect changes received from the Port.
  - Basin B-38 has been removed from the study, because Port determined that outfall is located in the Lower Duwamish study area.
  - Basin B-1 delineation has been modified based on Port drainage system mapping.
  - The railroad bridge (BR-6) just south of the West Seattle Bridge and the Port's access road (BR-2) have been added.
  - The bridge at the head of Slip 27 has been added (BR-27).
  - Other bridge and apron basins not included in the 2008 loading analysis have now been incorporated, including: A-7, A-23, A-24, A-26, A-27, A-28, A-29, A-30, A-32, A-33, BR-39, BR-6.

  Changes in drainage basin areas resulting from the revised basin delineations are summarized in Table 1. The updates to the drainage basin boundaries resulted in an overall reduction in basin area of about 6.4 acres (less than one percent change).
- Drainage basin boundaries for the S Lander St CSO/SD and S Hinds St CSO/SD have been revised based on updated information from recent field investigations and drainage maps compiled by Seattle Public Utilities (SPU).
- The S Connecticut St separated storm drain basin has been removed from the study because runoff from this basin enters Elliott Bay just outside of the EW study area boundary and information collected to date indicates that this basin would not contribute significant pollutant loads to the EW.
- Basins B-40, B-41, B-42, B-43 were identified as City-owned storm drain basins in the 2008 report. However, because these areas drain land entirely owned/occupied by the U.S. Coast Guard, these systems are now identified as Coast Guard drains. SPU is currently working to transfer ownership of these storm drain systems to the U.S. Coast Guard.
- Total suspended solids data have been updated to incorporate recent stormwater data from the Portland Harbor project and from SPU NPDES monitoring efforts. In addition, the method used to calculate land use representative TSS concentrations has been modified to improve accuracy.
- EW sediment trap results have been included in the particle size distribution (PSD) analysis, along with the data compiled for stormwater suspended solids samples to provide a range of inputs for the particle transport model.

- CSO volume estimates have been updated to include monitoring data from 2008 and 2009.

The methodology used to calculate annual stormwater volumes and TSS loads is unchanged from the 2008 report. For completeness, this information is repeated in this updated report (Appendix A).

INTRODUCTION

This report summarizes the analyses of stormwater and City combined sewer overflow (CSO) discharges to the East Waterway (EW) completed by SPU for use in the particle transport model for the EW remedial investigation. Annual discharge volume and TSS loads were estimated for all storm drain outfalls and the City CSO at S Hinds St. In addition, available data from SPU source sampling efforts were compiled to estimate the concentrations of chemicals of concern associated with the particulates discharged from these outfalls. Data used in the analyses include:

- King County parcel land use data from the City GIS system.
- Surficial geology data for the Seattle area (Goetz et.al., 2005).
- Rainfall data from Seattle rain gage #15 located at 4401 E Marginal Way S, for years 1978-2007.
- Total suspended solids concentrations in stormwater compiled from studies conducted in western Washington and Oregon (Appendix B).
- Particle size distribution (PSD) data from East Waterway source tracing/characterization samples and data compiled from stormwater samples collected throughout the U.S.

Methods used to calculate suspended solids loads are described in the following sections.

FLOW ESTIMATES

Flow is an important component of the solids load calculations. Neither SPU nor the Port routinely monitor flow from its storm drain outfalls, so a hydrologic model was used to estimate the volume of stormwater discharged to the EW.

In 1999, SPU initiated a flow monitoring program to measure the frequency and volume of overflows from City-owned CSOs. Data from 2000-2009 were used to estimate the volume of overflows from the City-owned CSO in the EW study area (S Hinds St CSO/SD).

Stormwater

The annual volume of stormwater discharged to the EW was estimated from land use, soil type, slope, and rainfall using a simplified Hydrologic Simulation Program-Fortran (HSPF) model (Northwest Hydraulic Consultants 2008). This model calculates runoff volumes per unit area for individual land use, slope, and soil combinations based on regional Puget Sound input parameters and local rainfall data. Runoff volumes have been updated to incorporate changes in basin boundaries. Assumptions and data used in the analysis have not changed from the 2008 analysis. A detailed description of the flow calculations is provided in Appendix A.

Drainage Basin Characteristics

Stormwater runoff from approximately 787 acres of land along the east side of Harbor Island and in the industrial area south of downtown Seattle drains to the EW via a combination of City, Port, and private storm drain systems, as well as direct discharges from apron areas immediately adjacent to the waterway. Drainage basin boundaries for City-owned storm drains were delineated using City GIS utility and topographic data supplemented with site-specific drainage plans where available. Drainage basin boundaries for Port-owned storm drains were provided by the Port.

Basin boundaries have been updated since the Final Initial Source Evaluation and Data Gaps Memorandum was completed (SEDGM; Anchor and Windward 2009). Figure 1 shows original basin delineations from the SEDGM. Updated basin delineations are shown in Figure 2.

Land use in the EW drainage area was determined based on parcel data from King County. Figure 3 shows the distribution of land use in the separated storm drain basin. The area west of I-5 is predominately industrial with a small number of commercial and vacant lots. The portion of the S Lander St drainage basin that lies east of I-5 contains a mixture of residential (single and multi-family) with a small amount of commercial property. Land use characteristics are summarized in Table 2.

Surficial geology maps developed by the University of Washington (Goetz et.al., 2005) were used to characterize soil conditions in the basin. Individual geologic deposits were grouped into the following categories (see Appendix C for details):

- Alluvium
- Till
- Outwash
- Wetland soil.

Using GIS, the soil and parcel information were then overlaid to break down the drainage basin into individual land use and soil types for the runoff analysis. All areas were modeled as moderate slope.

Stormwater Discharge Locations

Locations of the 38 storm drains discharging to the EW are shown in Figure 4. The majority of these outfalls serve nearshore areas along the waterway. The S Lander St system is the largest storm drain in the EW, serving approximately 442 acres. The Seattle municipal storm drain system accounts for approximately 66 percent of the EW drainage, while the POS property drains 32 percent of the basin (Table 3). The remaining outfalls are from small private waterfront storm drain systems.

Stormwater Flow Calculations

Annual stormwater runoff volumes were calculated for each individual outfall as well as for bridges and aprons that drain directly to the waterway. Flow estimates were completed for a typical wet year (2002), dry year (1993), and average year (1986) based on 1978-2007 rainfall records from SPU's rain gage #15 located at 4401 E Marginal Way S (Figure 5). Because the S Lander St CSO/SD system in the EW is partially and not fully separated, the runoff volumes estimated by the HSPF model had to be adjusted to account for areas that continue to drain to the

combined sewer system. For the purposes of this analysis, the S Lander St separated storm drain basin was divided into two subbasins:

- East of I-5 (east Lander)
- West of I-5 (west Lander).

The City of Seattle is served by combined, separated, and partially separated drainage/wastewater systems. In combined areas, stormwater runoff and sanitary sewage are collected and conveyed in a single pipe. In separated areas, stormwater and sanitary sewage are carried in totally separate pipes. However, partially separated areas are served by a combination of separated storm drains and combined sewer systems. In these areas, stormwater runoff can discharge to both systems. Depending on how the separation occurred, in areas that were initially combined and later separated (e.g., Lander system), the roadways are often connected to a new storm drain system, while drainage structures (e.g., inlets, catch basins, and sand boxes) outside the public right-of-way are left connected to the combined sewer system. Without dye testing the individual catch basins, it can be difficult to determine which areas are connected to which system.

Based on discussions with SPU staff familiar with historic separation projects and the City's drainage system, it was assumed that all of the right-of-way and varying percentages of the areas outside of the right-of-way are connected to the storm drain system. Available SPU GIS information was used to estimate the amount of land on private parcels outside of the right-of-way, is connected to the separated storm drain system. The layout of existing drainage systems for all of the private parcels is not available in the SPU GIS system. Therefore, to account for uncertainty, a range of values was developed. In the east Lander sub-basin, it was estimated that between 25 and 75 percent of the areas outside the ROW are connected to the storm drain system. In the west Lander sub-basin, it was estimated that between 15 and 65 percent are connected to the storm drain system.

CSOs

Figure 6 shows the combined sewer service area within the EW study area (approximately 4,840 acres). The City of Seattle operates one CSO in the EW, the S Hinds St CSO/SD outfall (NPDES #107). The S Hinds St combined sewer system serves an area of approximately 45 acres located on Terminals 30 and 104 (Figure 6). Land use in the combined sewer service area is shown in Figure 7 and summarized in Table 4. The combined sewer service area contains a larger proportion of residential development (35 percent) and lower proportion of industrial/commercial property (26 percent) than the separated storm drain basin (4 and 78 percent, respectively).

SPU has monitored overflow frequency and volumes in the S Hinds St CSO since 1998. Annual overflow volumes range from 0 to 34 million gallons (Table 5). The maximum overflow occurred in 2004, with the majority of the overflow occurring during two separate events (January 7 and January 29, 2004) with total rainfall amounts of 1.83 and 1.54 inches, respectively. These large overflow volumes are not consistent with the small service area contributing to the S Hinds St CSO. SPU is working with King County to model the combined sewer system in this area to determine whether the overflows recorded at this location could be caused by overflows from the Elliott Bay Interceptor. For this analysis, the January 2004 overflows were replaced with the average of overflow events occurring during storm events larger than 1 inch during 2007-2010. This three-year time period was used because since 2007,

SPU has conducted more rigorous validation of flow monitoring data. Detailed information on CSOs at the S Hinds St outfall is provided in Appendix D.

SUSPENDED SOLIDS LOADS

Solids loads are calculated by multiplying the annual runoff volumes by representative TSS concentrations based on land use. SPU has not measured TSS in the discharges from storm drains or City CSOs in the EW. To estimate loads, available suspended solids data from other similar sources were compiled and evaluated.

Stormwater

The data set used for the earlier EW (Northwest Hydraulic Consultants 2008) solids loading analysis was expanded to incorporate new data from ongoing SPU NPDES stormwater sampling (SPU 2011) and stormwater characterization data from the Portland Harbor Superfund site (Sanders 2011). Data from over 850 stormwater samples collected from 85 different sites in western Washington and Oregon were compiled and analyzed to determine representative TSS concentrations in urban stormwater. Data used in the analysis are provided in Appendix B. These data include samples analyzed for TSS using Standard Method 2540D and using the suspended solids content (SSC) method recommended by the U.S. Geological Survey (Gray et.al, 2000). Because the TSS and SSC results were comparable, all data were combined for the analysis.

Land use-weighted average TSS concentrations were calculated to account for variations in the quality of stormwater runoff from different types of development in the EW. Most of the regional stormwater samples were collected from mixed use areas and could not be used directly to calculate land-use weighted values. Data from the National Stormwater Quality Database (NSQD version 3) were used to develop a weighting factor that could be applied to the regional data for this purpose (Pitt et. al., 2004). The NSQD data set was queried to extract only those data that represent a single land use (e.g., single family residential, multi-family residential, commercial, industrial, vacant/park, and roadways). A total of 4,291 TSS samples were extracted from the NSQD data base.

A weighting factor was calculated using the median TSS values for each land use category. The single family residential category was selected as the base for the weighting factor. The land use weighting factor was calculated by dividing the median value for each land use type by the median value for single family residential land use:

Single family residential:	1.00
Multi-family residential:	1.27
Commercial:	1.23
Industrial:	1.25
Vacant/Park:	0.30
Roadway:	1.50

This weighting factor was then applied to the mixed use regional data set to develop TSS concentrations for individual land use types. Details are provided in Appendix B.

A range of TSS input values are needed for the PTM model sensitivity analysis. Base case, low, and high values were developed using the land use-weighted TSS concentrations from the regional data set. The high and low ranges are based on the 25th and 75th percentile

concentration. A trimmed mean value was used to estimate a base case TSS concentration (Helsel and Hirsch 2002). A trimmed mean was selected for the base case to account for the fact that the TSS data are skewed. As a result, a relatively few high values greatly affect the mean value. The trimmed mean simply removes a set percentage of the values at the low and high end of the data set to adjust for data extremes. For this analysis, a 10 percent trimmed mean was used.

The Port provided data from NPDES monitoring conducted by tenants in 2005-2009 on Terminals 18, 25, and 30, which indicates that the TSS for industrial land use may not be representative of runoff from terminal areas, which are nearly 100 percent paved (Takasaki 2011). TSS concentrations in 26 samples ranged from 6 to 42 mg/L, with an average of about 19 mg/L. Consequently, the Port recommended that a different data set be used for Port terminal areas. For terminal areas, available data from Portland Harbor stormwater monitoring sites that were mostly paved (greater than 90 percent impervious) and select regional data from parking lots were compiled and evaluated. A total of 141 samples fit the criteria for Port terminal areas. The trimmed mean for these data (43 mg/L) is less than the value used for other industrial areas in the EW study area (74 mg/L).

TSS concentrations used in the solids loading analysis are summarized in Table 6.

The land use weighted TSS concentrations were then multiplied by the annual stormwater volumes calculated for each land use category to determine solids loading at each outfall. The total stormwater solids loading to the EW is estimated to range from about 36 to 180 Mton/year, with a base case of approximately 76-100 Mton/yr. Solids loading results for each outfall are summarized in Tables 7, 8, and 9.

CSOs

The City has not sampled discharges from the S Hinds St CSO in the EW, although data are available for other City CSOs from recent monitoring conducted as part of the City's NPDES CSO permit. In 2008-2010, SPU collected samples from 15 CSOs in the City (Herrera 2010). Up to four samples were collected from each outfall during the monitoring period. TSS concentrations ranged from 7-87 mg/L and averaged about 32 mg/L (Figure 9). As shown in Table 10, land use for most of the City CSOs is primarily residential with only a small proportion of commercial/industrial property (0-14 percent). None of the CSOs monitored by SPU serve a largely industrial area like the S Hinds St CSO.

King County has collected 21 samples from the Hanford #2 CSO (1996-2009) and seven from the Lander CSO (2008-2009) (Williston 2010). The TSS concentrations for the pooled data from these two CSOs range from 36-156 mg/L TSS with an average of about 88 mg/L. As shown in Table 11, the TSS concentrations in City CSOs are significantly lower than the concentrations measured in samples collected from King County CSOs. It is unclear why TSS concentrations in City CSOs are lower than County CSOs. Possible factors include:

- Differences in sampling procedures. City samples were collected during CSO events, when overflows were occurring. King County collected samples when pipes were 60 percent full (King County 2009). As a result, City samples may contain a larger proportion of stormwater than County samples, which could result in lower TSS concentrations.
- Differences in land use in the combined sewer service areas. The City CSOs that were monitored served primarily residential areas. Only two of the CSOs contained more than 10 percent industrial/commercial property (CSO 99 and

CSO 147A). King County's Lander CSO serves a primarily commercial/industrial area. Land use in the Hanford #2 CSO service area is mixed, but industrial and commercial development account for 10 percent and 16 percent of the area, respectively (see Table 4).

For the purpose of the sediment loading analysis, it is recommended that the King County CSO data be used to characterize TSS concentrations in the City's S Hinds St CSO, because land use in the CSOs monitored by King County is more comparable to the conditions in the S Hinds St CSO service area. This will provide a conservative estimate of TSS loading from the City CSO.

With an average annual overflow volume of approximately 900,000 gallons and an average TSS concentration of about 32 mg/L, the annual TSS load from the City CSO at S Hinds St is estimated at approximately 240 lbs/year.

PARTICLE SIZE DISTRIBUTION

Information on particle size distribution (PSD) for stormwater and CSO discharges to the EW is needed for the particle transport model. The model tracks the following four classes of particles (Anchor QEA and Coast & Harbor Engineering 2011).

- Gravel-medium sand: >250 µm
- Fine sand: 62-250 µm
- Coarse-medium silt: 15.6-62 µm
- Fine silt and clay: <15.6 µm

Solids discharged from storm drains and CSOs are typically comprised of two components, the suspended fraction and a heavier fraction often referred to as bedload. Bedload material typically does not become fully entrained in the water column during storm events. Instead, this material moves along the bottom of the pipe as previously deposited sediment is scoured from the pipe during larger storm events.

The PSD of suspended solids in stormwater discharges to the EW are not available, but PSD is routinely analyzed in the source tracing samples collected by SPU (catch basin grabs, inline grabs, and sediment traps). Catch basin sediments are grab samples collected from the sump at the bottom of the structure. These structures are intended to prevent debris from blocking the downstream pipe system. Although catch basins often capture fine sands and silt, they are not expected to be highly effective in trapping fine silt and clay particles. Inline sediment samples are simply grabs collected from relatively quiescent areas within the piped drainage system, such as maintenance holes or other inline structures. Like catch basins, inline samples also contain a relatively low proportion of fine-grained material. Sediment traps passively collect samples of settleable material that passes by the station. Because traps are installed near the bottom of the pipe or maintenance hole, these samples likely contain a mixture of suspended solids and bedload material.

In the previous EW solids loading report (Northwest Hydraulic Consultants 2008) and in the LDW lateral load analysis (SPU 2008), data from stormwater samples collected at 18 sites across the U.S. were compiled to characterize the PSD for the particle/sediment transport models (Appendix E). Suspended solids in stormwater typically contain a large proportion of fine silts and clays that do not readily settle. Therefore, these particles are unlikely to deposit in the nearshore sediment and may be transported beyond the East Waterway. To capture a

representative range in PSD for the particle transport model, it is recommended that both the suspended solids and the bedload characteristics be evaluated.

The PSD data from all EW source tracing samples are compared with the LDW source data, and the national stormwater solids data in Figure 10. PSD in the EW and LDW source samples are similar. The stormwater samples contain the largest proportion of fine silts and clays (44 percent average) and the smallest proportion of coarse grained particles (8.4 percent average) compared to the EW source sediment samples (12.4 percent and 31.8 percent average, respectively). For the particle transport model, it is recommended that PSD for the EW sediment traps be used to bracket the likely range in PSD conditions. Sediment trap PSD will provide a relatively conservative assessment of recontamination potential in the vicinity of the individual storm drain outfalls.

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Tables

Table 1: Summary of changes in basin areas from 2008 report.

Basin/Outfall	Owner	Area (acres)		Change	Explanation
		2008 Report[a]	2011 Update		
B-1	Port	1.1	1.6	1	Basin boundaries revised based on information from Port
B-11	Port	52.1	48.1	-4	Boundaries adjusted to include areas outside of Terminal 18 that drain to this outfall and part of basin determined to drain to the West Waterway
B-25	SPU	5.2	4.2	-1	Some areas previously identified are not connected to this outfall
B-30	Port	7	6.7	-0.3	Areas previously identified as terminal are actually open water and have been removed from basin
B-38	Port	1.3	0	-1.3	Port determined that this area discharges to the Duwamish Waterway rather than the East Waterway
B-40	Coast Guard	3.4	3.3	-0.1	Areas previously identified as terminal are actually open water and have been removed from basin
BR-6	SPU	0	0.3	0.3	Bridge added as new basin
BR-27	Port	0	0.2	0.2	Bridge added as new basin
A-7, A-23, A-24, A-26, A-27, A-28, A-30, A-32, A-33	Port	0	9.5	9.5	Basin not included in 2008 analysis
S Connecticut St SD	SPU	13.6	0	-13.6	Storm drain discharges to Elliott Bay outside of the EW study area and source tracing data indicated pollutant levels relatively low
S Lander St CSO/SD[b]	SPU	447.6	438.4	-9.2	Boundaries modified based on review of information from SPU GIS and business inspections
S Hinds St CSO/SD[b]	SPU	26.4	39.5	13.1	Area previously identified as connected to the combined sewer system found to discharge to the separated storm drain system at S Hinds St.
Total				-6.4	

a. Northwest Hydraulic Consultants (2008)

b. Separated storm drain basin discharging to shared CSO/SD outfall.

Table 2. Land use in East Waterway separated storm drain basins.

Outfall	Commercial	Industrial	Single family residential	Multi-family residential	Right-of-way	Vacant/Park	Total
City							
B-4	0.00	3.69	0.00	0.00	3.41	0.00	7.11
B-5	0.00	0.77	0.00	0.00	1.38	0.00	2.15
B-21	0.00	12.98	0.00	0.00	0.00	0.00	12.98
B-25	2.52	1.58	0.00	0.00	0.10	0.00	4.20
B-36	0.00	1.65	0.00	0.00	3.69	0.00	5.35
BR-4	0.00	0.21	0.00	0.00	1.02	0.00	1.23
BR-5	0.00	0.00	0.00	0.00	1.61	0.00	1.61
BR-34	0.00	0.00	0.00	0.00	0.95	0.00	0.95
S Hinds St CSO/SD	0.00	27.40	0.00	0.00	12.10	0.00	39.50
S Lander St CSO/SD	66.76	222.70	19.45	15.79	110.98	2.65	438.34
City Total	***69.28***	***270.99***	***19.45***	***15.79***	***135.25***	***2.65***	***513.42***
Port							
B-1	0.00	1.58	0.00	0.00	0.00	0.00	1.58
B-7	0.00	13.93	0.00	0.00	0.00	0.00	13.93
B-10	0.00	7.23	0.00	0.00	0.00	0.00	7.23
B-11	0.00	48.14	0.00	0.00	0.00	0.00	48.14
B-12	0.00	6.53	0.00	0.00	0.00	0.00	6.53
B-13	0.00	6.22	0.00	0.00	0.00	0.00	6.22
B-14	0.00	1.52	0.00	0.00	0.00	0.00	1.52
B-16	0.00	4.41	0.00	0.00	0.00	0.00	4.41
B-17	0.00	2.14	0.00	0.00	0.00	0.00	2.14
B-18	0.00	7.41	0.00	0.00	0.00	0.00	7.41
B-19	0.00	5.04	0.00	0.00	0.00	0.00	5.04
B-22	0.00	11.99	0.00	0.00	0.00	0.00	11.99
B-23	0.00	10.95	0.00	0.00	0.00	0.00	10.95
B-24	0.00	8.86	0.00	0.00	0.00	0.00	8.86
B-26	0.00	13.41	0.00	0.00	0.00	0.00	13.41
B-27	0.00	7.35	0.00	0.00	0.00	0.00	7.35
B-28	0.00	3.59	0.00	0.00	0.00	0.00	3.59
B-29	0.00	8.75	0.00	0.00	0.00	0.00	8.75
B-30	0.00	6.69	0.00	0.00	0.00	0.00	6.69
B-31	0.00	9.61	0.00	0.00	0.00	0.00	9.61
B-32	0.00	3.73	0.00	0.00	0.00	0.00	3.73
B-33	0.00	12.11	0.00	0.00	0.00	0.00	12.11
B-34	0.00	13.33	0.00	0.00	0.00	0.00	13.33
B-37	0.00	6.41	0.00	0.00	0.00	0.00	6.41
B-39	0.00	2.08	0.00	0.00	0.00	0.00	2.08
S Lander St CSO/SD	0.00	3.62	0.00	0.00	0.00	0.00	3.62
A-7	0.00	1.16	0.00	0.00	0.00	0.00	1.16
A-10	0.00	2.28	0.00	0.00	0.00	0.00	2.28
A-12	0.00	1.98	0.00	0.00	0.00	0.00	1.98
A-13	0.00	0.47	0.00	0.00	0.00	0.00	0.47
A-14	0.00	1.04	0.00	0.00	0.00	0.00	1.04
A-16	0.00	0.66	0.00	0.00	0.00	0.00	0.66
A-17	0.00	0.68	0.00	0.00	0.00	0.00	0.68
A-18	0.00	1.20	0.00	0.00	0.00	0.00	1.20
A-19	0.00	1.89	0.00	0.00	0.00	0.00	1.89
A-22	0.00	2.01	0.00	0.00	0.00	0.00	2.01
A-23	0.00	2.05	0.00	0.00	0.00	0.00	2.05
A-24	0.00	2.29	0.00	0.00	0.00	0.00	2.29
A-26	0.00	0.60	0.00	0.00	0.00	0.00	0.60
A-27	0.00	1.70	0.00	0.00	0.00	0.00	1.70
A-28	0.00	1.50	0.00	0.00	0.00	0.00	1.50
A-29	0.00	1.15	0.00	0.00	0.00	0.00	1.15
A-30	0.00	1.30	0.00	0.00	0.00	0.00	1.30
A-31	0.00	0.76	0.00	0.00	0.00	0.00	0.76
A-32	0.00	0.80	0.00	0.00	0.00	0.00	0.80
A-33	0.00	2.19	0.00	0.00	0.00	0.00	2.19
BR-2	0.00	0.27	0.00	0.00	0.00	0.00	0.27
BR-39	0.00	1.24	0.00	0.00	0.01	0.00	1.25
Port Total	***0.00***	***255.82***	***0.00***	***0.00***	***0.01***	***0.00***	***255.83***
Private							
A-6	0.00	3.16	0.00	0.00	0.00	0.00	3.16
Coast Guard							
B-40	3.24	0.02	0.00	0.00	0.00	0.00	3.26
B-41	0.02	5.42	0.00	0.00	0.03	0.00	5.46
B-42	0.00	0.46	0.00	0.00	0.00	0.00	0.46
B-43	0.00	5.74	0.00	0.00	0.00	0.00	5.74
Coast Guard Total	***3.25***	***11.64***	***0.00***	***0.00***	***0.03***	***0.00***	***14.93***
EW TOTAL	**72.54**	**541.61**	**19.45**	**15.79**	**135.29**	**2.65**	**787.34**

Table 3. Land use in East Waterway separated storm drain basins (by ownership/jurisdiction).

Land use (%)	City	Port	Private	Coast Guard	EW Total
Commercial	13%	0%	0%	22%	9%
Industrial	53%	100%	100%	78%	69%
Single family residential	4%	0%	0%	0%	2%
Multi-family residential	3%	0%	0%	0%	2%
Right-of-way	26%	0%	0%	0%	17%
Vacant/Park	1%	0%	0%	0%	0%
Total	100%	100%	100%	100%	100%

Table 4: Land use in East Waterway combined sewer service area.

Land use	Area	Percent
Commercial	782	16%
Industrial	483	10%
Multi-family residential	376	8%
Park/open/vacant	378	8%
Right-of-way	1,618	32%
Single family residential	1,359	27%
Total	4,996	100%

Table 5: Annual overflows from S Hinds St CSO (#107).

	Count	Duration (hrs)	Volume (gal)	Rainfall (in)	Storm Duration	Volume (gal)[a]
1998	4	42	192,817	3.84	75	192,817
1999	6	17	110,025	4.07	83	110,025
2000	1	8	45,173	1.31	14	45,173
2001	6	59	604,013	11.79	383	604,013
2002	5	29	107,358	8.47	338	107,358
2003	1	8	20,591	2.13	46	20,591
2004[a]	7	62	33,665,103	8.48	301	1,511,174
2005	1	12	617,204	0.33	31	617,204
2006	0	0	0	0	0	0
2007	1	29	2,008,192	6.34	178	2,008,192
2008	2	13	627,357	2.61	56	627,357
2009	11	67	3,379,938	17.83	591	3,379,938
2010	9	52	2,802,705	14.70	436	2,802,705

a. Modifed large outliers for January 2004 storms. Used average of all storms greater than 1" from 2007 through 2010.

Summary statistics:

Count	10
25th percentile	60,719
Min	42
Max	3,379,938
Median	610,609
75th percentile	1,290,220
Mean	892,100
10th percentile	18,532
90th percentile	2,145,367

Table 6: Stormwater TSS concentrations by land use.

	Low (25th percentile)	Base Case (10% trimmed mean)	High (75th percentile)
Single-family residential	24	48	70
Multi-family residential	39	68	101
Commercial	32	58	84
Industrial[a]	35	74	114
Industrial (Port)[b]	20	43	60
Vacant/park	8	13	18
Right-of-way	33	71	103

Units = mg/L

a. For industrial land use in all SPU drainage basins, except B-21, plus Port Basin B-34 and all private basins.

b. For all Port terminal areas, except B-34, plus SPU basin (B-21)

Table 7: Runoff and solids loading estimates for model base case.

SPU basins

Basin	Area (Acres)	Outfall coordinates [1]		Runoff (million gallons/year)			TSS load (lbs/year) [2]			TSS load (metric tons/year) [3]		
		X coordinate	Y coordinate	Average Year (1986)	Dry Year (1993)	Wet Year (2002)	Average Year (1986)	Dry Year (1993)	Wet Year (2002)	Average Year (1986)	Dry Year (1993)	Wet Year (2002)
B-21	12.98	1,267,025.76	216,799.42	8.7	7.3	11	3,100	2,600	3,800	1.4	1.2	1.7
B-25	4.20	1,268,053.11	218,669.74	2.7	2.3	3.3	1,500	1,200	1,800	0.7	0.5	0.8
B-36	5.35	1,267,380.50	212,096.91	3.3	2.8	4.1	2,000	1,700	2,500	0.9	0.8	1.1
B-4	7.11	1,266,960.50	211,998.11	4.6	3.8	5.6	2,800	2,330	3,400	1.3	1.1	1.5
B-5	2.15	1,266,985.87	212,222.84	1.4	1.2	1.7	830	690	1,000	0.4	0.3	0.5
Lander [4,5] (low)	438.34	1,267,839.97	215,762.30	120	99	150	70,000	58,000	86,000	32	26	39
Lander [4,5] (high)	438.34	1,267,839.97	215,762.30	220	190	270	130,000	109,000	160,000	59	49	73
Hinds	39.50	1,267,870.96	212,912.61	25	21	31	15,000	13,000	19,000	6.8	5.9	8.6
BR-34	0.95	NA [6]	NA [6]	0.6	0.5	0.7	350	290	430	0.2	0.1	0.2
BR-4	1.23	NA [6]	NA [6]	0.8	0.6	1.0	460	390	570	0.2	0.2	0.3
BR-5	1.61	NA [6]	NA [6]	1.0	0.8	1.2	590	500	740	0.3	0.2	0.3
TOTAL (low)	**513**			**170**	**140**	**210**	**97,000**	**81,000**	**119,000**	**44**	**37**	**54**
TOTAL (high)	**513**			**270**	**230**	**330**	**157,000**	**132,000**	**193,000**	**71**	**60**	**88**

Private basins

Basin	Area (Acres)	Outfall coordinates [1]		Runoff (million gallons/year)			TSS load (lbs/year) [2]			TSS load (metric tons/year) [3]		
		X coordinate	Y coordinate	Average Year (1986)	Dry Year (1993)	Wet Year (2002)	Average Year (1986)	Dry Year (1993)	Wet Year (2002)	Average Year (1986)	Dry Year (1993)	Wet Year (2002)
A-6	3.16	1,267,133.00	212,871.00	2.1	1.8	2.6	1,300	1,100	1,600	0.6	0.5	0.7
B-40	3.26	1,268,082.43	218,293.18	2.0	1.7	2.5	990	830	1,200	0.4	0.4	0.5
B-41	5.46	1,268,032.50	218,704.86	3.6	3.1	4.5	1,890	1,900	2,700	0.9	0.9	1.2
B-42	0.46	1,268,376.87	218,781.63	0.3	0.3	0.4	190	160	230	0.1	0.1	0.1
B-43	5.74	1,268,824.23	218,875.21	3.8	3.2	4.7	2,400	2,000	2,900	1.1	0.9	1.3
TOTAL	**18.1**			**12**	**10**	**15**	**6,700**	**6,000**	**8,700**	**3.0**	**2.7**	**3.9**

TSS = total suspended solids

1. North American horizontal datum 1983,1991
2. Calculated using mean value (see Table 6)
3. Metric ton = 2,204.62 lbs
4. Lander basin includes areas east and west sub-basins that drain to the separated storm drain system at S Lander St CSO/SD. Port property located within the S Lander St basin is addressed below under Port basins.
5. Low and high values are provided for partially separated areas to account for the uncertainty in the amount of area that was disconnected from the combined system. In industrial section of the basin (Lander West), the amount of disconnection for parcels outside the public right-of-way was estimated at 25-75 percent. For the primarily residential areas (Lander East), the range was estimated at 15-65 percent, based on SPU GIS data. Public rights-of-way are assumed to be 100 percent disconnected.
6. Runoff from bridges and aprons discharges directly to the waterway via scuppers or deck drains. There is no single outfall.

Table 7: Runoff and solids loading estimates for model base case.

Port basins

Basin	Area (Acres)	Outfall coordinates [1] X coordinate	Y coordinate	Runoff (million gallons/year) Average Year (1986)	Dry Year (1993)	Wet Year (2002)	TSS load (lbs/year) [2] Average Year (1986)	Dry Year (1993)	Wet Year (2002)	TSS load (metric tons/year) [3] Average Year (1986)	Dry Year (1993)	Wet Year (2002)
B-1	1.58	1,266,887.46	211,399.22	1.1	0.9	1.3	380	320	460	0.2	0.1	0.2
B-10	7.23	1,266,968.30	214,087.50	4.8	4.1	5.9	1,700	1,500	2,100	0.8	0.7	1.0
B-11	48.14	1,266,995.91	214,238.77	32	27	39	12,000	10,000	14,000	5.4	4.5	6.4
B-12	6.53	1,266,956.70	214,443.80	4.4	3.7	5.3	1,600	1,300	1,900	0.7	0.6	0.9
B-13	6.22	1,267,027.00	214,961.90	4.1	3.5	5.1	1,500	1,300	1,800	0.7	0.6	0.8
B-14	1.52	1,267,051.30	215,033.60	1.0	0.9	1.2	360	310	440	0.2	0.1	0.2
B-16	4.41	1,266,993.70	215,373.60	2.9	2.5	3.6	1,100	890	1,290	0.5	0.4	0.6
B-17	2.14	1,267,002.40	215,678.30	1.4	1.2	1.7	510	430	630	0.2	0.2	0.3
B-18	7.41	1,266,983.00	215,983.87	4.9	4.2	6.0	1,800	1,500	2,200	0.8	0.7	1.0
B-19	5.04	1,267,000.61	216,655.64	3.4	2.8	4.1	1,200	1,000	1,500	0.5	0.5	0.7
B-22	11.99	1,266,996.20	217,188.40	8.0	6.7	9.8	2,900	2,400	3,500	1.3	1.1	1.6
B-23	10.95	1,267,011.30	217,914.40	7.3	6.1	8.9	2,600	2,200	3,200	1.2	1.0	1.5
B-24	8.86	1,267,046.27	218,573.28	5.9	5.0	7.2	2,100	1,800	2,600	1.0	0.8	1.2
B-26	13.41	1,268,013.00	217,447.20	8.9	7.5	11	3,200	2,700	3,900	1.5	1.2	1.8
B-27	7.35	1,268,014.70	216,941.70	4.9	4.1	6.0	1,800	1,500	2,100	0.8	0.7	1.0
B-28	3.59	1,268,001.70	216,332.40	2.4	2.0	2.9	860	720	1,050	0.4	0.3	0.5
B-29	8.75	1,268,024.30	215,844.00	5.8	4.9	7.1	2,100	1,800	2,600	1.0	0.8	1.2
B-30	6.69	1,268,481.10	214,909.20	4.5	3.8	5.5	1,600	1,300	2,000	0.7	0.6	0.9
B-31/BR-27	9.81	1,267,827.60	214,382.65	6.5	5.5	8.0	2,300	2,000	2,900	1.0	0.9	1.3
B-32	3.73	1,267,816.51	214,084.19	2.5	2.1	3.0	890	750	1,090	0.4	0.3	0.5
B-33	12.11	1,267,802.40	213,205.40	8.1	6.8	9.9	2,900	2,400	3,500	1.3	1.1	1.6
B-34	13.33	1,267,445.56	212,282.86	8.8	7.4	11	5,400	4,600	6,600	2.4	2.1	3.0
B-37	6.41	1,267,196.82	211,561.15	4.2	3.6	5.2	1,500	1,300	1,900	0.7	0.6	0.9
B-39	2.08	1,267,224.50	211,803.70	1.4	1.2	1.7	500	420	610	0.2	0.2	0.3
B-7	13.93	1,266,941.40	212,971.90	9.3	7.8	11	3,300	2,800	4,100	1.5	1.3	1.9
Lander [4]	3.62	1,267,839.97	215,762.30	2.4	2.0	2.9	860	730	1,060	0.4	0.3	0.5
A-7	1.16	NA [6]	NA [6]	0.8	0.6	0.9	280	230	340	0.1	0.1	0.2
A-10	2.28	NA [6]	NA [6]	1.5	1.3	1.9	550	460	670	0.2	0.2	0.3
A-12	1.98	NA [6]	NA [6]	1.3	1.1	1.6	470	400	580	0.2	0.2	0.3
A-13	0.47	NA [6]	NA [6]	0.3	0.3	0.4	110	90	140	0.0	0.0	0.1
A-14	1.04	NA [6]	NA [6]	0.7	0.6	0.8	250	210	300	0.1	0.1	0.1
A-16	0.66	NA [6]	NA [6]	0.4	0.4	0.5	160	130	190	0.1	0.1	0.1
A-17	0.68	NA [6]	NA [6]	0.5	0.4	0.6	160	140	200	0.1	0.1	0.1
A-18	1.20	NA [6]	NA [6]	0.8	0.7	1.0	290	240	350	0.1	0.1	0.2
A-19	1.89	NA [6]	NA [6]	1.3	1.1	1.5	450	380	550	0.2	0.2	0.2
A-22	2.01	NA [6]	NA [6]	1.3	1.1	1.6	480	410	590	0.2	0.2	0.3
A-23	2.05	NA [6]	NA [6]	1.4	1.1	1.7	490	410	600	0.2	0.2	0.3
A-24	2.29	NA [6]	NA [6]	1.5	1.3	1.9	550	460	670	0.2	0.2	0.3
A-26	0.60	NA [6]	NA [6]	0.4	0.3	0.5	140	120	170	0.1	0.1	0.1
A-27	1.70	NA [6]	NA [6]	1.1	1.0	1.4	410	340	500	0.2	0.2	0.2
A-28	1.50	NA [6]	NA [6]	1.0	0.8	1.2	360	300	440	0.2	0.1	0.2
A-29	1.15	NA [6]	NA [6]	0.8	0.6	0.9	270	230	340	0.1	0.1	0.2
A-30	1.30	NA [6]	NA [6]	0.9	0.7	1.1	310	260	380	0.1	0.1	0.2
A-31	0.76	NA [6]	NA [6]	0.5	0.4	0.6	180	150	220	0.1	0.1	0.1
A-32	0.80	NA [6]	NA [6]	0.5	0.5	0.7	190	160	230	0.1	0.1	0.1
A-33	2.19	NA [6]	NA [6]	1.5	1.2	1.8	520	440	640	0.2	0.2	0.3
BR-39	1.25	NA [6]	NA [6]	0.8	0.8	1.0	520	430	630	0.2	0.2	0.3
BR-2	0.27	1,266,955.62	211,835.26	0.2	0.1	0.2	64	54	78	0.0	0.0	0.0
TOTAL PORT	**256**			**170**	**140**	**210**	**64,000**	**54,000**	**78,000**	**29**	**25**	**35**

Table 8: Storm drain solids loading summary (low range).

SPU basins

Basin	Area (acres)	Outfall coordinates [1] X coordinate	Y coordinate	Runoff (million gallons/year) Average Year (1986)	Dry Year (1993)	Wet Year (2002)	TSS load (lbs/year) [2] Average Year (1986)	Dry Year (1993)	Wet Year (2002)	TSS load (metric tons/year) [3] Average Year (1986)	Dry Year (1993)	Wet Year (2002)
B-21	12.98	1,267,025.76	216,799.42	8.7	7.3	11	1,400	1,200	1,800	0.6	0.5	0.8
B-25	4.20	1,268,053.11	218,669.74	2.7	2.3	3.3	720	610	890	0.3	0.3	0.4
B-36	5.35	1,267,380.50	212,096.91	3.3	2.8	4.1	940	790	1,200	0.4	0.4	0.5
B-4	7.11	1,266,960.50	211,998.11	4.6	3.8	5.6	1,300	1,100	1,600	0.6	0.5	0.7
B-5	2.15	1,266,985.87	212,222.84	1.4	1.2	1.7	390	330	480	0.2	0.1	0.2
Lander [4,5] (low)	438.34	1,267,839.97	215,762.30	120	100	150	33,000	28,000	41,000	15	13	19
Lander [4,5] (high)	438.34	1,267,839.97	215,762.30	220	190	270	62,000	52,000	76,000	28	24	34
Hinds	39.50	1,267,870.96	212,912.61	25	21	31	7,100	6,000	8,700	3.2	2.7	3.9
BR-34	0.95	NA[6]	NA[6]	0.6	0.5	0.7	170	140	210	0.08	0.06	0.10
BR-4	1.23	NA[6]	NA[6]	0.8	0.6	1.0	220	180	270	0.10	0.08	0.12
BR-5	1.61	NA[6]	NA[6]	1.0	0.8	1.2	280	240	350	0.13	0.11	0.16
TOTAL (low)	**513**			**170**	**140**	**210**	**46,000**	**39,000**	**56,000**	**21**	**18**	**26**
TOTAL (high)	**513**			**270**	**230**	**330**	**75,000**	**63,000**	**91,000**	**34**	**28**	**42**

Private basins

Basin	Area (acres)	Outfall coordinates [1] X coordinate	Y coordinate	Runoff (million gallons/year) Average Year (1986)	Dry Year (1993)	Wet Year (2002)	TSS load (lbs/year)[2] Average Year (1986)	Dry Year (1993)	Wet Year (2002)	TSS load (metric tons/year)[3] Average Year (1986)	Dry Year (1993)	Wet Year (2002)
A-6	3.16	1,267,133.00	212,871.00	2.1	1.8	2.6	600	500	730	0.3	0.2	0.3
B-40	3.26	1,268,082.43	218,293.18	2.0	1.7	2.5	530	440	650	0.2	0.2	0.3
B-41	5.46	1,268,032.50	218,704.86	3.6	3.1	4.5	870	870	1,260	0.4	0.4	0.6
B-42	0.46	1,268,376.87	218,781.63	0.3	0.3	0.4	87	73	107	0.0	0.0	0.0
B-43	5.74	1,268,824.23	218,875.21	3.8	3.2	4.7	1,100	900	1,300	0.5	0.4	0.6
TOTAL	**18.1**			**12**	**10**	**15**	**3,200**	**2,800**	**4,100**	**1.5**	**1.3**	**1.9**

TSS = total suspended solids

1. North American horizontal datum 1983,1991
2. Calculated using 25th percentile TSS value (see Table 6)
3. Metric ton = 2,204.62 lbs
4. Lander basin includes areas east and west sub-basins that drain to the separated storm drain system at S Lander St CSO/SD. Port property located within the S Lander St basin is addressed under Port basins.
5. Low and high values are provided for partially separated areas to account for the uncertainty in the amount of area that was disconnected from the combined system. In industrial section of the basin (Lander West), the amount of disconnection for parcels outside the public right-of-way was estimated at 25-75 percent. For the primarily residential areas (Lander East), the range was estimated at 15-65 percent, based on SPU GIS data. Public rights-of-way are assumed to be 100 percent disconnected.
6. Runoff from bridges and aprons discharges directly to the waterway via scuppers or deck drains. There is no single outfall.

Table 8: Storm drain solids loading summary (low range).

Port basins

Basin	Area (acres)	Outfall coordinates [1] X coordinate	Y coordinate	Runoff (million gallons/year) Average Year (1986)	Dry Year (1993)	Wet Year (2002)	TSS load (lbs/year)[2] Average Year (1986)	Dry Year (1993)	Wet Year (2002)	TSS load (metric tons/year)[3] Average Year (1986)	Dry Year (1993)	Wet Year (2002)
B-1	1.58	1,266,887.46	211,399.22	1.1	0.9	1.3	180	150	220	0.1	0.1	0.1
B-10	7.23	1,266,968.30	214,087.50	4.8	4.1	5.9	800	680	980	0.4	0.3	0.4
B-11	48.14	1,266,995.91	214,238.77	32	27	39	5,400	4,500	6,500	2.4	2.0	2.9
B-12	6.53	1,266,956.70	214,443.80	4.4	3.7	5.3	730	610	890	0.3	0.3	0.4
B-13	6.22	1,267,027.00	214,961.90	4.1	3.5	5.1	690	580	850	0.3	0.3	0.4
B-14	1.52	1,267,051.30	215,033.60	1.0	0.9	1.2	170	140	210	0.1	0.1	0.1
B-16	4.41	1,266,993.70	215,373.60	2.9	2.5	3.6	490	410	600	0.2	0.2	0.3
B-17	2.14	1,267,002.40	215,678.30	1.4	1.2	1.7	240	200	290	0.1	0.1	0.1
B-18	7.41	1,266,983.00	215,983.87	4.9	4.2	6.0	820	690	1,010	0.4	0.3	0.5
B-19	5.04	1,267,000.61	216,655.64	3.4	2.8	4.1	560	470	690	0.3	0.2	0.3
B-22	11.99	1,266,996.20	217,188.40	8.0	6.7	9.8	1,300	1,100	1,600	0.6	0.5	0.7
B-23	10.95	1,267,011.30	217,914.40	7.3	6.1	8.9	1,200	1,000	1,500	0.5	0.5	0.7
B-24	8.86	1,267,046.27	218,573.28	5.9	5.0	7.2	990	830	1,200	0.4	0.4	0.5
B-26	13.41	1,268,013.00	217,447.20	8.9	7.5	11	1,500	1,300	1,800	0.7	0.6	0.8
B-27	7.35	1,268,014.70	216,941.70	4.9	4.1	6.0	820	690	1,000	0.4	0.3	0.5
B-28	3.59	1,268,001.70	216,332.40	2.4	2.0	2.9	400	340	490	0.2	0.2	0.2
B-29	8.75	1,268,024.30	215,844.00	5.8	4.9	7.1	970	820	1,190	0.4	0.4	0.5
B-30	6.69	1,268,481.10	214,909.20	4.5	3.8	5.5	740	630	910	0.3	0.3	0.4
B-31/BR-27	9.81	1,267,827.60	214,382.65	6.5	5.5	8.0	1,100	900	1,300	0.5	0.4	0.6
B-32	3.73	1,267,816.51	214,084.19	2.5	2.1	3.0	410	350	510	0.2	0.2	0.2
B-33	12.11	1,267,802.40	213,205.40	8.1	6.8	9.9	1,300	1,100	1,600	0.6	0.5	0.7
B-34	13.33	1,267,445.56	212,282.86	8.8	7.4	11	2,500	2,100	3,000	1.1	1.0	1.4
B-37	6.41	1,267,196.82	211,561.15	4.2	3.6	5.2	710	590	860	0.3	0.3	0.4
B-39	2.08	1,267,224.50	211,803.70	1.4	1.2	1.7	230	190	280	0.1	0.1	0.1
B-7	13.93	1,266,941.40	212,971.90	9.3	7.8	11	1,500	1,300	1,900	0.7	0.6	0.9
Lander [4]	3.62	1,267,839.97	215,762.30	2.4	2.0	2.9	400	340	490	0.2	0.2	0.2
A-7	1.16	NA[6]	NA[6]	0.8	0.6	0.9	130	110	160	0.1	0.0	0.1
A-10	2.28	NA[6]	NA[6]	1.5	1.3	1.9	250	210	310	0.1	0.1	0.1
A-12	1.98	NA[6]	NA[6]	1.3	1.1	1.6	220	190	270	0.1	0.1	0.1
A-13	0.47	NA[6]	NA[6]	0.3	0.3	0.4	52	44	64	0.0	0.0	0.0
A-14	1.04	NA[6]	NA[6]	0.7	0.6	0.8	120	100	140	0.1	0.0	0.1
A-16	0.66	NA[6]	NA[6]	0.4	0.4	0.5	73	62	89	0.0	0.0	0.0
A-17	0.68	NA[6]	NA[6]	0.5	0.4	0.6	76	64	93	0.0	0.0	0.0
A-18	1.20	NA[6]	NA[6]	0.8	0.7	1.0	130	110	160	0.1	0.0	0.1
A-19	1.89	NA[6]	NA[6]	1.3	1.1	1.5	210	180	260	0.1	0.1	0.1
A-22	2.01	NA[6]	NA[6]	1.3	1.1	1.6	220	190	270	0.1	0.1	0.1
A-23	2.05	NA[6]	NA[6]	1.4	1.1	1.7	230	190	280	0.1	0.1	0.1
A-24	2.29	NA[6]	NA[6]	1.5	1.3	1.9	250	210	310	0.1	0.1	0.1
A-26	0.60	NA[6]	NA[6]	0.4	0.3	0.5	67	56	81	0.0	0.0	0.0
A-27	1.70	NA[6]	NA[6]	1.1	1.0	1.4	190	160	230	0.1	0.1	0.1
A-28	1.50	NA[6]	NA[6]	1.0	0.8	1.2	170	140	200	0.1	0.1	0.1
A-29	1.15	NA[6]	NA[6]	0.8	0.6	0.9	130	110	160	0.1	0.0	0.1
A-30	1.30	NA[6]	NA[6]	0.9	0.7	1.1	150	120	180	0.1	0.1	0.1
A-31	0.76	NA[6]	NA[6]	0.5	0.4	0.6	85	71	104	0.0	0.0	0.0
A-32	0.80	NA[6]	NA[6]	0.5	0.5	0.7	89	75	109	0.0	0.0	0.0
A-33	2.19	NA[6]	NA[6]	1.5	1.2	1.8	240	200	300	0.1	0.1	0.1
BR-39	1.25	NA[6]	NA[6]	0.8	0.8	1.0	240	200	290	0.1	0.1	0.1
BR-2	0.27	1,266,955.62	211,835.26	0.2	0.1	0.2	30	25	36	0.0	0.0	0.0
TOTAL PORT	**256**			**170**	**140**	**210**	**30,000**	**25,000**	**36,000**	**13**	**11**	**16**

Table 9: Runoff and solids loading estimates (high range).

SPU basins

Basin	Area (acres)	Outfall coordinates [1] X coordinate	Y coordinate	Runoff (million gallons/year) Average Year (1986)	Dry Year (1993)	Wet Year (2002)	TSS load (lbs/year) [2] Average Year (1986)	Dry Year (1993)	Wet Year (2002)	TSS load (metric tons/year) [3] Average Year (1986)	Dry Year (1993)	Wet Year (2002)
B-21	12.98	1,267,025.76	216,799.42	8.7	7.3	11	4,300	3,600	5,300	2.0	1.6	2.4
B-25	4.20	1,268,053.11	218,669.74	2.7	2.3	3.3	2,200	1,800	2,700	1.0	0.8	1.2
B-36	5.35	1,267,380.50	212,096.91	3.3	2.8	4.1	2,700	2,200	3,300	1.2	1.0	1.5
B-4	7.11	1,266,960.50	211,998.11	4.6	3.8	5.6	3,900	3,300	4,800	1.8	1.5	2.2
B-5	2.15	1,266,985.87	212,222.84	1.4	1.2	1.7	1,100	940	1,400	0.5	0.4	0.6
Lander [4,5] (low)	438.34	1,267,839.97	215,762.30	120	100	150	94,000	79,000	116,000	43	36	53
Lander [4,5] (high)	438.34	1,267,839.97	215,762.30	220	190	270	188,000	158,000	231,000	85	72	105
Hinds	39.50	1,267,870.96	212,912.61	25	21	31	23,000	19,000	28,000	10	8.6	13
BR-34	0.95	NA[6]	NA[6]	0.6	0.5	0.7	420	350	520	0.2	0.2	0.2
BR-4	1.23	NA[6]	NA[6]	0.8	0.6	1.0	590	500	730	0.3	0.2	0.3
BR-5	1.61	NA[6]	NA[6]	1.0	0.8	1.2	720	600	890	0.3	0.3	0.4
TOTAL (low)	**513**			**170**	**140**	**210**	**133,000**	**111,000**	**164,000**	**60**	**50**	**74**
TOTAL (high)	**513**			**270**	**230**	**330**	**227,000**	**190,000**	**279,000**	**103**	**86**	**126**

Private basins

Basin	Area (acres)	Outfall coordinates [1] X coordinate	Y coordinate	Runoff (million gallons/year) Average Year (1986)	Dry Year (1993)	Wet Year (2002)	TSS load (lbs/year) [2] Average Year (1986)	Dry Year (1993)	Wet Year (2002)	TSS load (metric tons/year) [3] Average Year (1986)	Dry Year (1993)	Wet Year (2002)
A-6	3.16	1,267,133.00	212,871.00	2.1	1.8	2.6	2,100	1,700	2,500	1.0	0.8	1.1
B-40	3.26	1,268,082.43	218,293.18	2.0	1.7	2.5	1,400	1,200	1,800	0.6	0.5	0.8
B-41	5.46	1,268,032.50	218,704.86	3.6	3.1	4.5	3,000	3,000	4,300	1.4	1.4	2.0
B-42	0.46	1,268,376.87	218,781.63	0.3	0.3	0.4	300	250	370	0.1	0.1	0.2
B-43	5.74	1,268,824.23	218,875.21	3.8	3.2	4.7	3,700	3,100	4,600	1.7	1.4	2.1
TOTAL	**18.1**			**12**	**10**	**15**	**11,000**	**9,300**	**14,000**	**5.0**	**4.2**	**6.4**

TSS = total suspended solids

1. North American horizontal datum 1983,1991
2. Calculated using 75th percentile TSS value (see Table 6)
3. Metric ton = 2,204.62 lbs
4. Lander basin includes areas east and west sub-basins that drain to the separated storm drain system at S Lander St CSO/SD. Port property located within the S Lander St basin is addressed under Port basins.
5. Low and high values are provided for partially separated areas to account for the uncertainty in the amount of area that was disconnected from the combined system. In industrial section of the basin (Lander West), the amount of disconnection for parcels outside the public right-of-way was estimated at 25-75 percent. For the primarily residential areas (Lander East), the range was estimated at 15-65 percent, based on SPU GIS data. Public rights-of-way are assumed to be 100 percent disconnected.
6. Runoff from bridges and aprons discharges directly to the waterway via scuppers or deck drains. There is no single outfall.

Table 9: Runoff and solids loading estimates (high range).

Port basins

Basin	Area (acres)	Outfall coordinates [1] X coordinate	Y coordinate	Runoff (million gallons/year) Average Year (1986)	Dry Year (1993)	Wet Year (2002)	TSS load (lbs/year) [2] Average Year (1986)	Dry Year (1993)	Wet Year (2002)	TSS load (metric tons/year) [3] Average Year (1986)	Dry Year (1993)	Wet Year (2002)
B-1	1.58	1,266,887.46	211,399.22	1.1	0.9	1.3	530	440	650	0.2	0.2	0.3
B-10	7.23	1,266,968.30	214,087.50	4.8	4.1	5.9	2,400	2,000	3,000	1.1	0.9	1.4
B-11	48.14	1,266,995.91	214,238.77	32	27	39	16,000	14,000	20,000	7.3	6.4	9.1
B-12	6.53	1,266,956.70	214,443.80	4.4	3.7	5.3	2,200	1,800	2,700	1.0	0.8	1.2
B-13	6.22	1,267,027.00	214,961.90	4.1	3.5	5.1	2,100	1,700	2,500	1.0	0.8	1.1
B-14	1.52	1,267,051.30	215,033.60	1.0	0.9	1.2	510	430	620	0.2	0.2	0.3
B-16	4.41	1,266,993.70	215,373.60	2.9	2.5	3.6	1,500	1,200	1,800	0.7	0.5	0.8
B-17	2.14	1,267,002.40	215,678.30	1.4	1.2	1.7	710	600	870	0.3	0.3	0.4
B-18	7.41	1,266,983.00	215,983.87	4.9	4.2	6.0	2,500	2,100	3,000	1.1	1.0	1.4
B-19	5.04	1,267,000.61	216,655.64	3.4	2.8	4.1	1,700	1,400	2,100	0.8	0.6	1.0
B-22	11.99	1,266,996.20	217,188.40	8.0	6.7	9.8	4,000	3,400	4,900	1.8	1.5	2.2
B-23	10.95	1,267,011.30	217,914.40	7.3	6.1	8.9	3,700	3,100	4,500	1.7	1.4	2.0
B-24	8.86	1,267,046.27	218,573.28	5.9	5.0	7.2	3,000	2,500	3,600	1.4	1.1	1.6
B-26	13.41	1,268,013.00	217,447.20	8.9	7.5	11	4,500	3,800	5,500	2.0	1.7	2.5
B-27	7.35	1,268,014.70	216,941.70	4.9	4.1	6.0	2,500	2,100	3,000	1.1	1.0	1.4
B-28	3.59	1,268,001.70	216,332.40	2.4	2.0	2.9	1,200	1,000	1,500	0.5	0.5	0.7
B-29	8.75	1,268,024.30	215,844.00	5.8	4.9	7.1	2,900	2,500	3,600	1.3	1.1	1.6
B-30	6.69	1,268,481.10	214,909.20	4.5	3.8	5.5	2,200	1,900	2,700	1.0	0.9	1.2
B-31/BR-27	9.81	1,267,827.60	214,382.65	6.5	5.5	8.0	3,300	2,800	4,000	1.5	1.3	1.8
B-32	3.73	1,267,816.51	214,084.19	2.5	2.1	3.0	1,200	1,000	1,500	0.5	0.5	0.7
B-33	12.11	1,267,802.40	213,205.40	8.1	6.8	9.9	4,000	3,400	4,900	1.8	1.5	2.2
B-34	13.33	1,267,445.56	212,282.86	8.8	7.4	11	8,600	7,200	10,500	3.9	3.3	4.8
B-37	6.41	1,267,196.82	211,561.15	4.2	3.6	5.2	2,100	1,800	2,600	1.0	0.8	1.2
B-39	2.08	1,267,224.50	211,803.70	1.4	1.2	1.7	690	580	850	0.3	0.3	0.4
B-7	13.93	1,266,941.40	212,971.90	9.3	7.8	11	4,600	3,900	5,700	2.1	1.8	2.6
Lander [4]	3.62	1,267,839.97	215,762.30	2.4	2.0	2.9	1,200	1,000	1,500	0.5	0.5	0.7
A-7	1.16	NA[6]	NA[6]	0.8	0.6	0.9	390	330	470	0.2	0.1	0.2
A-10	2.28	NA[6]	NA[6]	1.5	1.3	1.9	760	640	930	0.3	0.3	0.4
A-12	1.98	NA[6]	NA[6]	1.3	1.1	1.6	660	560	810	0.3	0.3	0.4
A-13	0.47	NA[6]	NA[6]	0.3	0.3	0.4	160	130	190	0.1	0.1	0.1
A-14	1.04	NA[6]	NA[6]	0.7	0.6	0.8	350	290	420	0.2	0.1	0.2
A-16	0.66	NA[6]	NA[6]	0.4	0.4	0.5	220	180	270	0.1	0.1	0.1
A-17	0.68	NA[6]	NA[6]	0.5	0.4	0.6	230	190	280	0.1	0.1	0.1
A-18	1.20	NA[6]	NA[6]	0.8	0.7	1.0	400	340	490	0.2	0.2	0.2
A-19	1.89	NA[6]	NA[6]	1.3	1.1	1.5	630	530	770	0.3	0.2	0.3
A-22	2.01	NA[6]	NA[6]	1.3	1.1	1.6	670	570	820	0.3	0.3	0.4
A-23	2.05	NA[6]	NA[6]	1.4	1.1	1.7	680	580	840	0.3	0.3	0.4
A-24	2.29	NA[6]	NA[6]	1.5	1.3	1.9	760	640	930	0.3	0.3	0.4
A-26	0.60	NA[6]	NA[6]	0.4	0.3	0.5	200	170	240	0.1	0.1	0.1
A-27	1.70	NA[6]	NA[6]	1.1	1.0	1.4	570	480	690	0.3	0.2	0.3
A-28	1.50	NA[6]	NA[6]	1.0	0.8	1.2	500	420	610	0.2	0.2	0.3
A-29	1.15	NA[6]	NA[6]	0.8	0.6	0.9	380	320	470	0.2	0.1	0.2
A-30	1.30	NA[6]	NA[6]	0.9	0.7	1.1	440	370	530	0.2	0.2	0.2
A-31	0.76	NA[6]	NA[6]	0.5	0.4	0.6	250	210	310	0.1	0.1	0.1
A-32	0.80	NA[6]	NA[6]	0.5	0.5	0.7	270	230	330	0.1	0.1	0.1
A-33	2.19	NA[6]	NA[6]	1.5	1.2	1.8	730	610	890	0.3	0.3	0.4
BR-39	1.25	NA[6]	NA[6]	0.8	0.8	1.0	810	680	990	0.4	0.3	0.4
BR-2	0.27	1,266,955.62	211,835.26	0.2	0.1	0.2	90	80	110	0.0	0.0	0.0
TOTAL	**256**			**170**	**140**	**210**	**90,000**	**76,000**	**110,000**	**41**	**35**	**50**

Table 10: Land use in CSOs monitored by SPU.

CSO	Area (acres)	Commercial	Industrial	Multi-family	Single-family	School	Undeveloped	ROW
13A	614	2%	2%	1%	57%	3%	4%	32%
18A	925	11%	0%	7%	80%	4%	5%	44%
28	21	0%	0%	0%	2%	0%	0%	1%
31	6	0%	0%	0%	0%	0%	0%	0%
41B	94	0%	0%	0%	9%	0%	0%	6%
43	75	0%	0%	0%	7%	0%	0%	4%
44B	262	0%	0%	0%	18%	0%	18%	6%
47B	950	8%	0%	6%	86%	7%	12%	35%
99	180	2%	3%	2%	6%	0%	7%	8%
147A	196	3%	2%	4%	9%	1%	1%	13%
150/151	394	5%	0%	6%	30%	1%	2%	21%
152	676	3%	0%	9%	60%	1%	1%	36%
169	184	2%	0%	2%	15%	0%	1%	10%
171	179	1%	0%	4%	63%	5%	2%	25%
174	324	2%	1%	10%	18%	1%	1%	20%

Table 11: Comparison of TSS from King County and SPU CSOs.

	King County[1]	SPU[2]
Number of samples	28	42
Min	36	7
Max	156	87
25th percentile	66	16
Median	95	27
75th percentile	108	45
Mean	88	32
Geomean	83	26

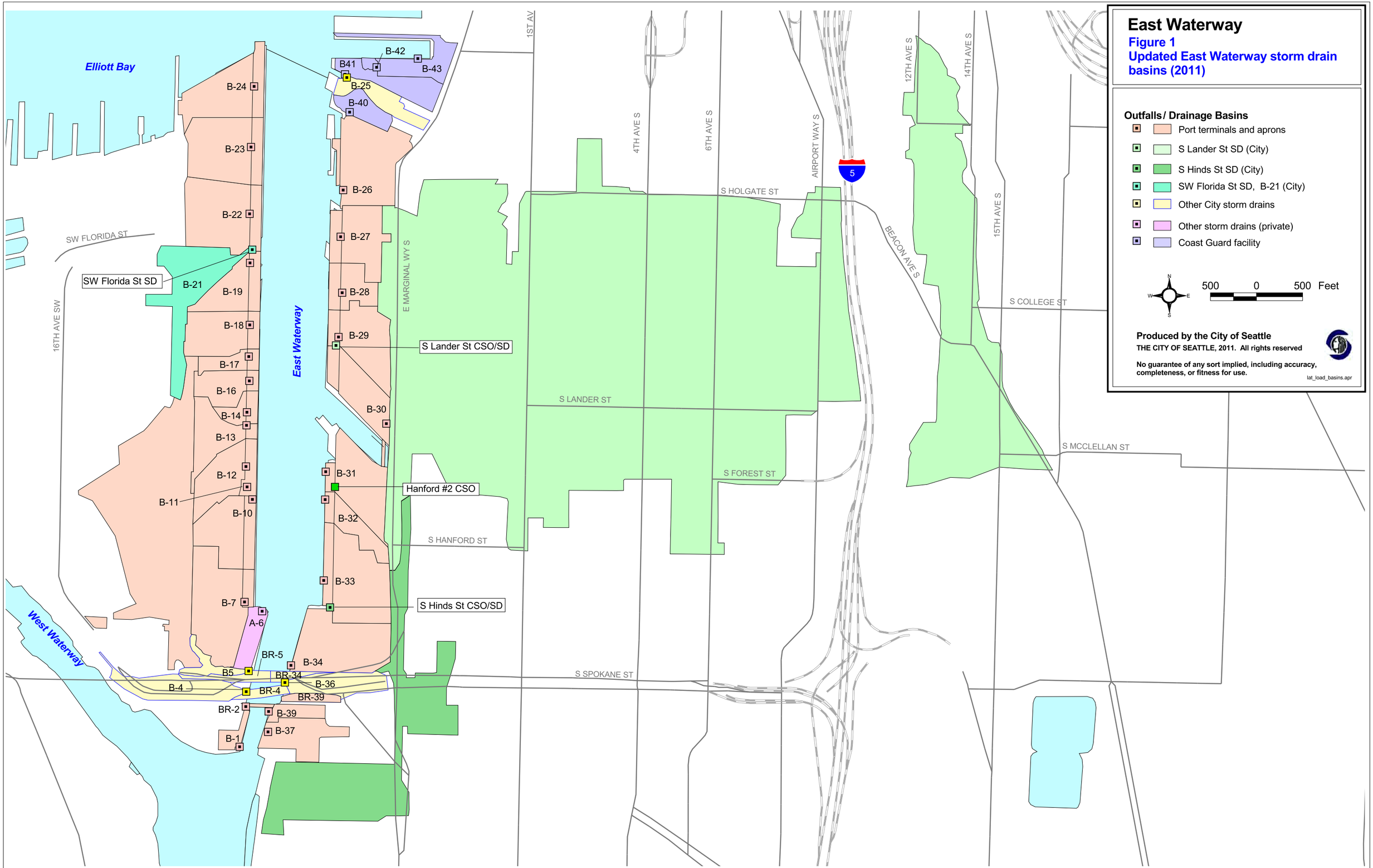
Units: TSS in mg/L.

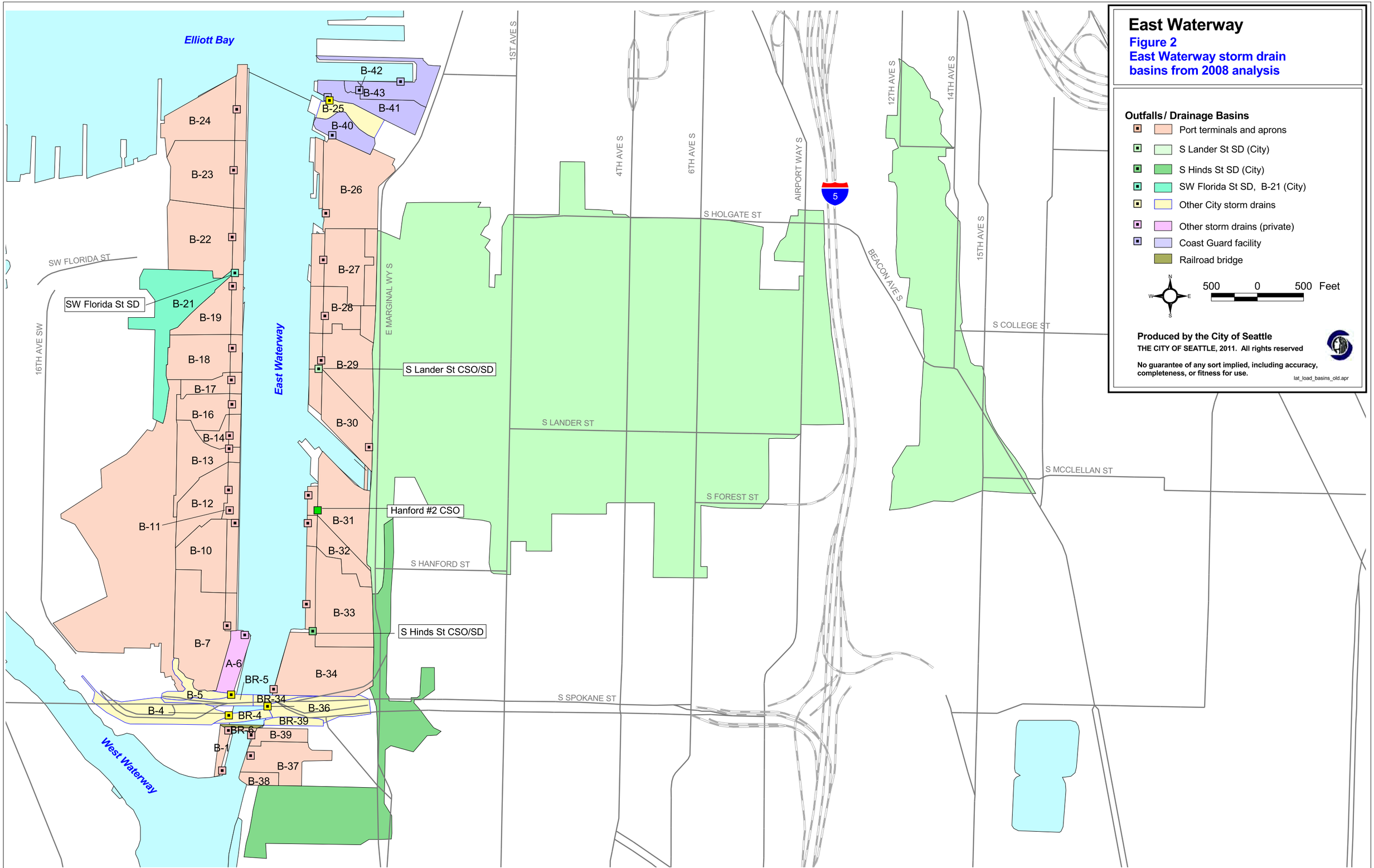
1. 1998-2009 samples from Hanford #2 and Lander CSOs (Williston 2010)
2. 2007-2010 samples from 15 CSOs in City system. None discharge to the EW.

Figures

East Waterway

Figure 1
Updated East Waterway storm drain basins (2011)




East Waterway
Figure 2
East Waterway storm drain basins from 2008 analysis
Outfalls / Drainage Basins
Port terminals and aprons
S Lander St SD (City)
S Hinds St SD (City)
SW Florida St SD, B-21 (City)
Other City storm drains
Other storm drains (private)
Coast Guard facility
Railroad bridge
500 0 500 Feet
Produced by the City of Seattle
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lat_load_basins_old.apr
Elliott Bay
East Waterway
West Waterway
SW FLORIDA ST
16TH AVE SW
1ST AVE S
4TH AVE S
6TH AVE S
AIRPORT WAY S
12TH AVE S
14TH AVE S
15TH AVE S
E MARGINAL WY S
S HOLGATE ST
BEACON AVE S
S COLLEGE ST
S LANDER ST
S MCCLELLAN ST
S FOREST ST
S HANFORD ST
S SPOKANE ST
5
SW Florida St SD
S Lander St CSO/SD
Hanford #2 CSO
S Hinds St CSO/SD
B-42
B-43
B-41
B-25
B-40
B-24
B-23
B-26
B-22
B-27
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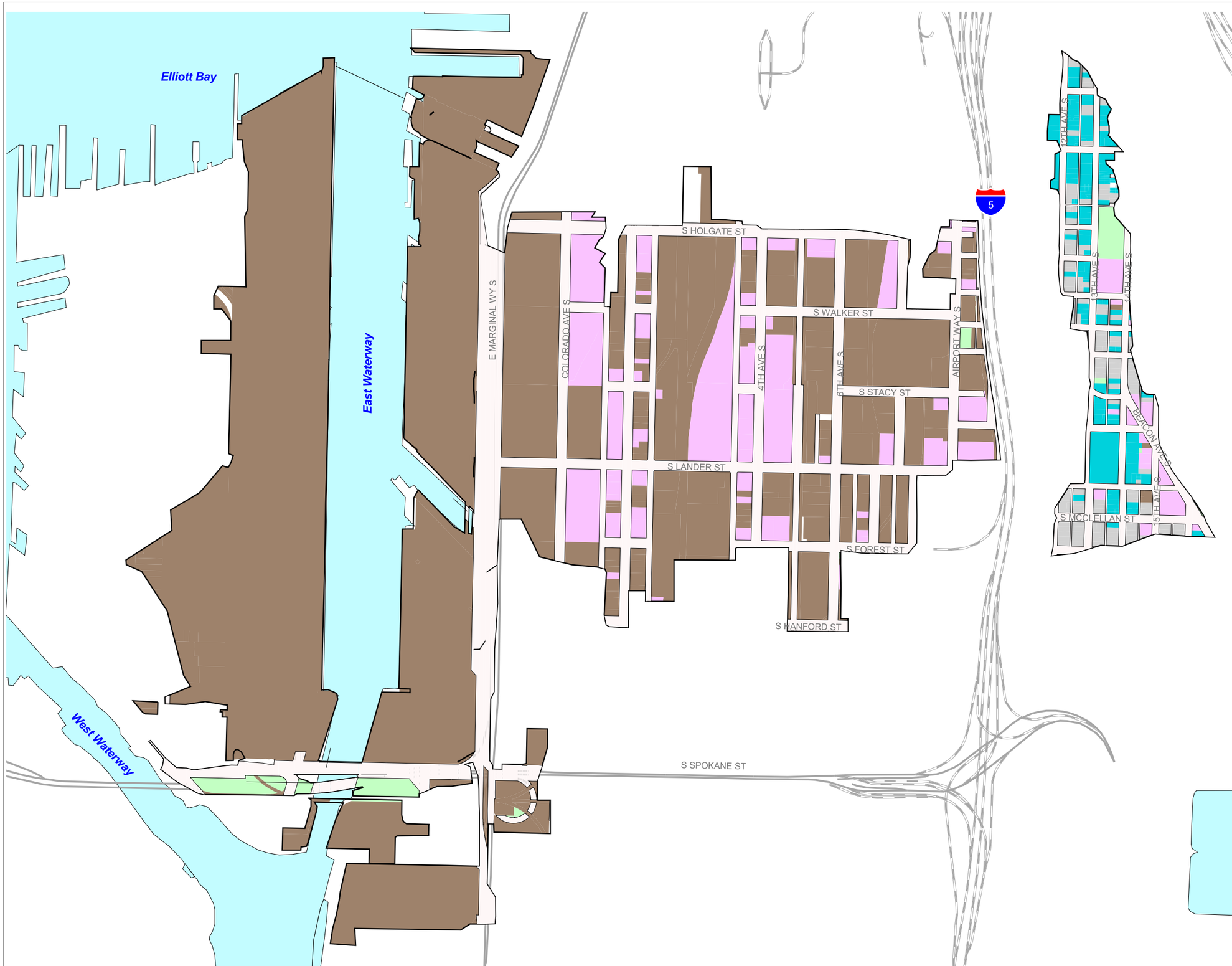
B-11
B-31
B-10
B-32
B-33
B-7
A-6
B-34
BR-5
B-5
BR-34
B-36
B-4
BR-4
BR-39
BR-6
B-39
B-1
B-37
B-38

East Waterway

Figure 3
Land use in the separated storm drain basin



Legend

Land use

- Commercial
- Industrial
- Single family residential
- Multi-family residential
- Open, vacant, parks
- Public right-of-way

N W E S

500 0 500 Feet

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lat_load_basins_landuse.apr

East Waterway

Figure 4
Outfalls for Solids Load Analysis

Outfalls
- KC CSO
- KC CSO/City SD
- City CSO/SD
- City EOF/City SD
- City EOF/Port SD
- City SD
- Port SD
- Private SD

Utilities
- Sanitary sewer
- Storm drain
- Combined sewer
- KC interceptor

Drainage Basins
- Port terminals
- Port aprons and bridges
- S Lander St SD (City)
- S Hinds St SD (City)
- SW Florida St SD, B-21 (City)
- Other City storm drains
- Other storm drains (private)
- Coast Guard facility

Note: Aprons discharge directly to waterway via scuppers.

N W E S

500 0 500 Feet

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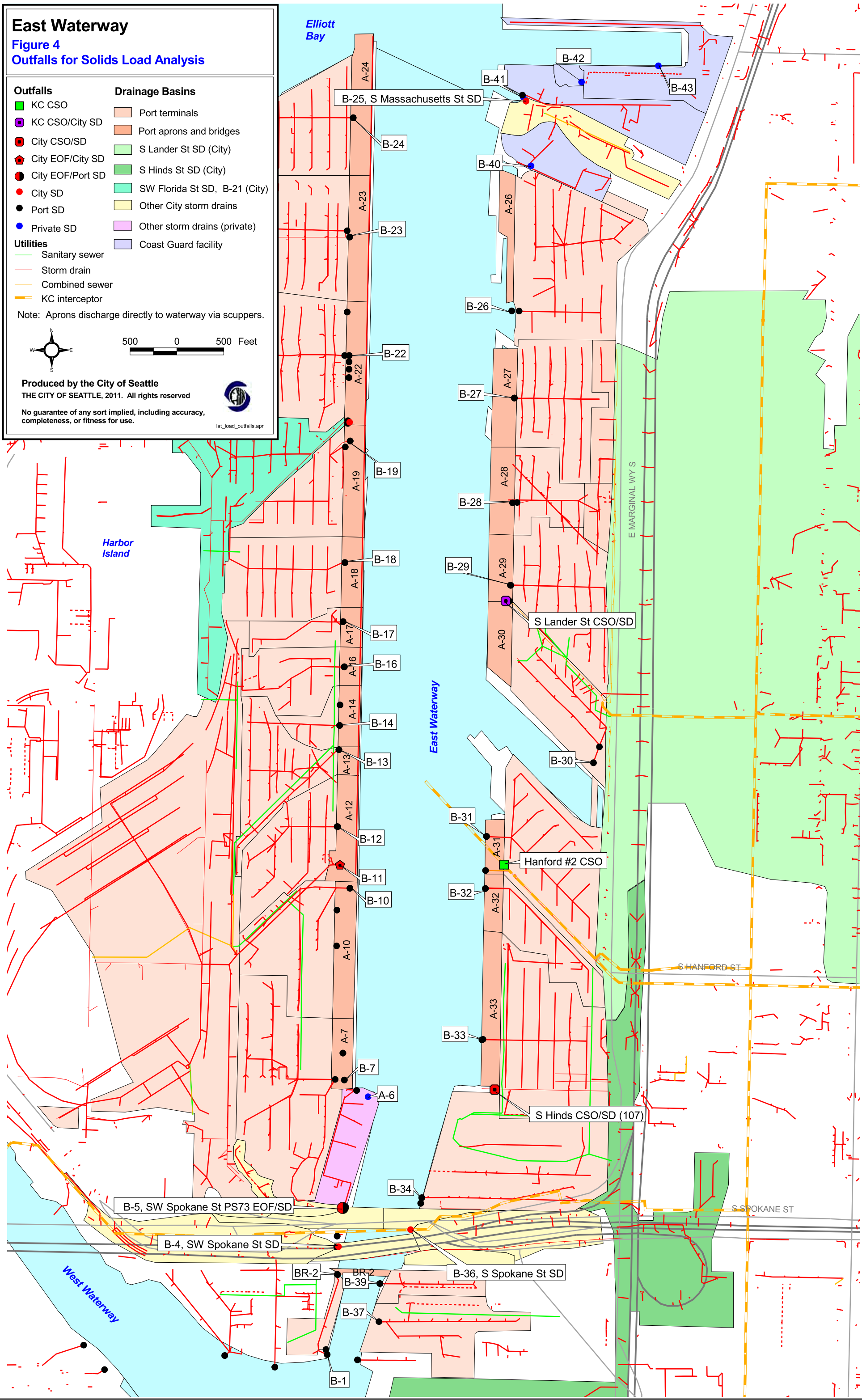
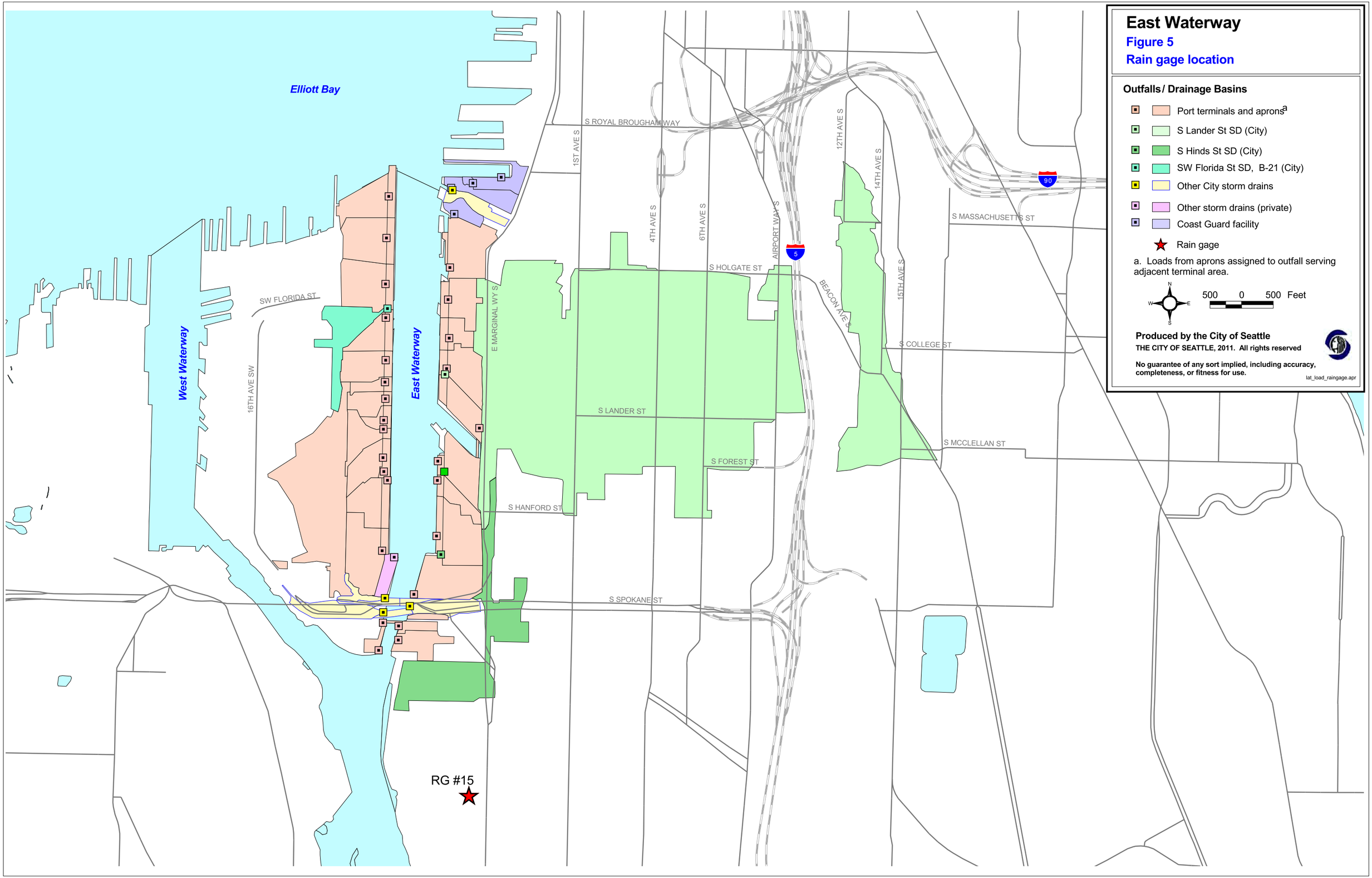
lat_load_outfalls.apr



East Waterway

Figure 5

Rain gage location



Outfalls / Drainage Basins

- Port terminals and aprons[a]
- S Lander St SD (City)
- S Hinds St SD (City)
- SW Florida St SD, B-21 (City)
- Other City storm drains
- Other storm drains (private)
- Coast Guard facility
- Rain gage

a. Loads from aprons assigned to outfall serving adjacent terminal area.

N W E S

500 0 500 Feet

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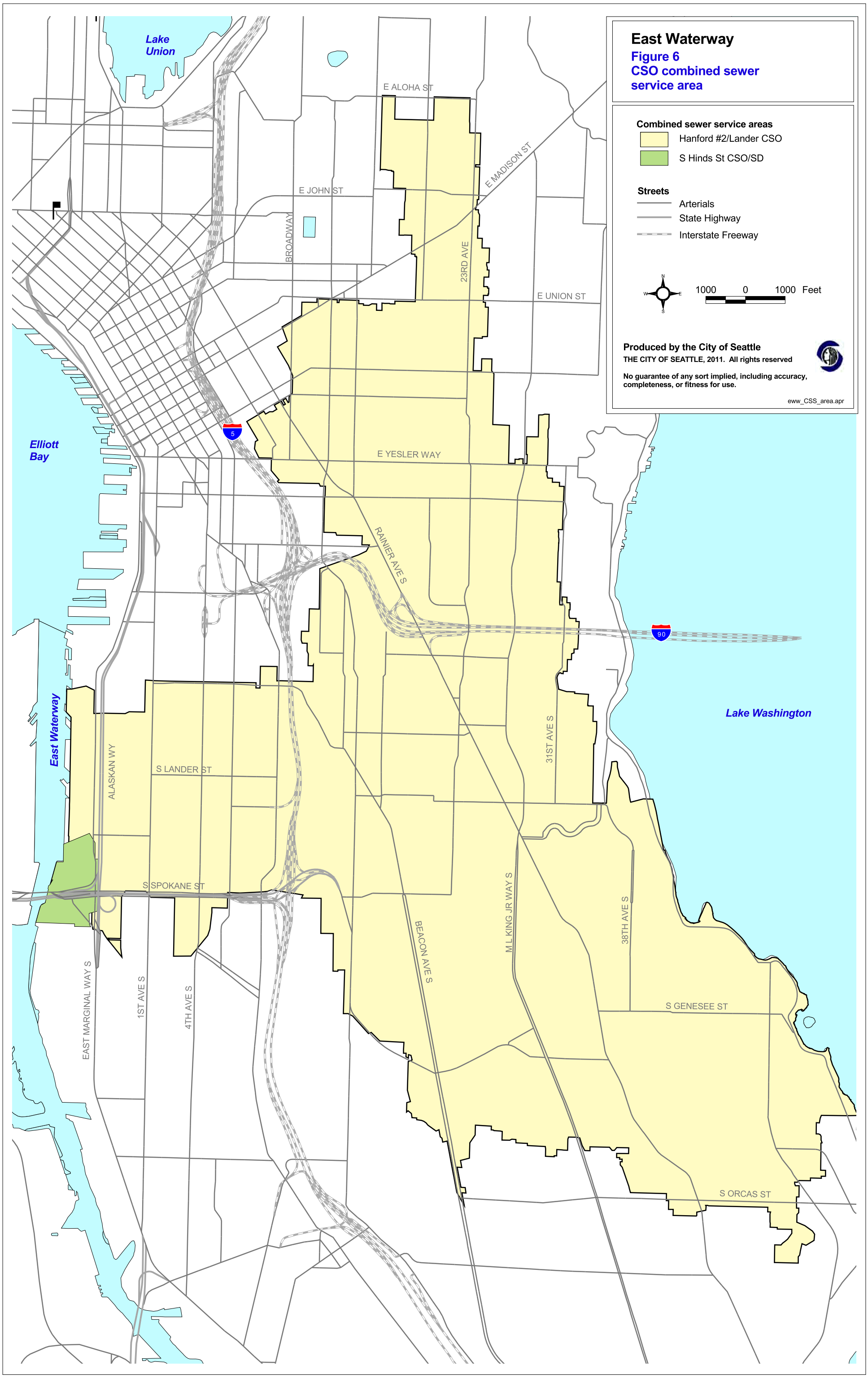
lat_load_raingage.apr


East Waterway
Figure 6
CSO combined sewer service area
Combined sewer service areas
Hanford #2/Lander CSO
S Hinds St CSO/SD
Streets
Arterials
State Highway
Interstate Freeway
1000 0 1000 Feet
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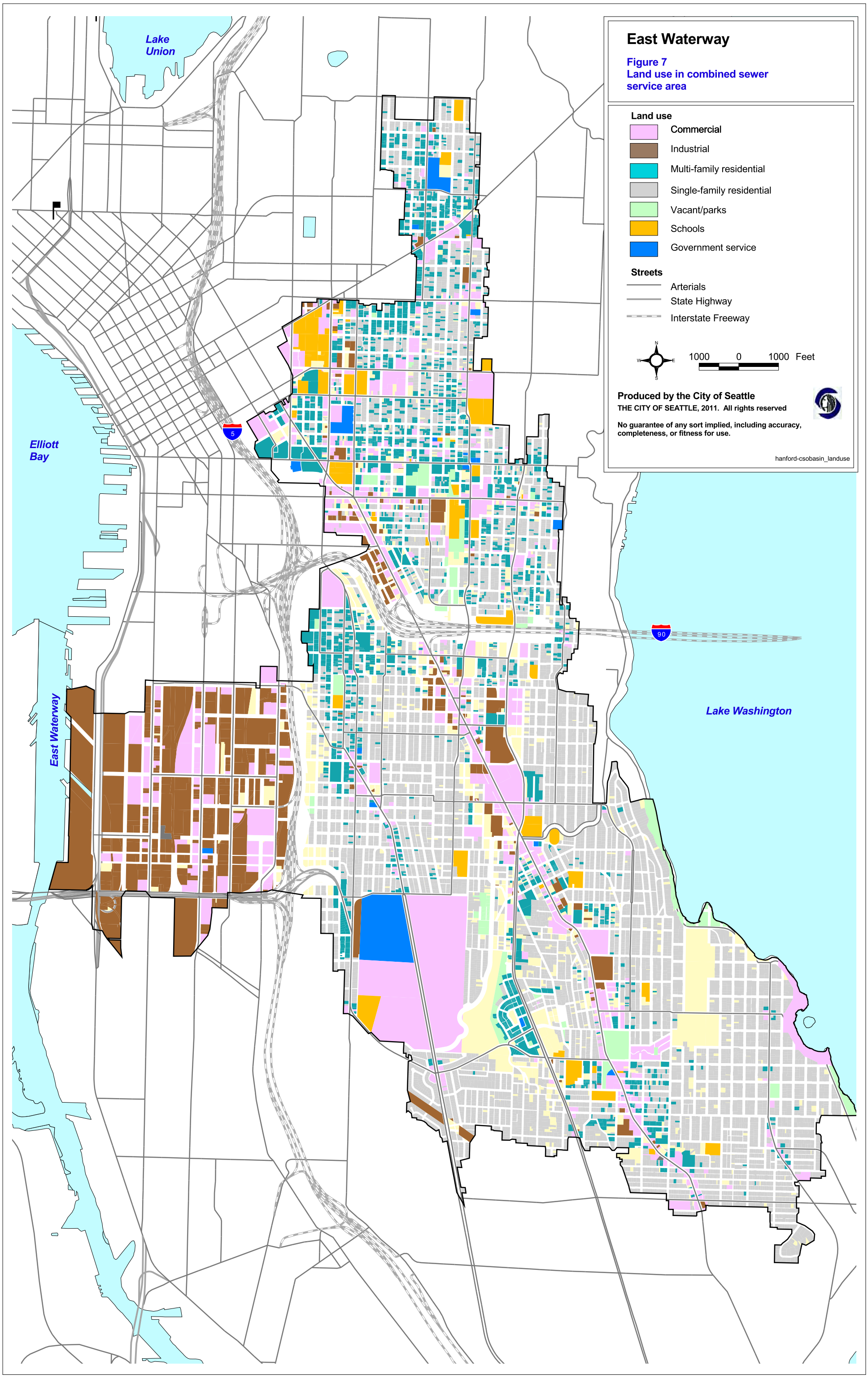
eww_CSS_area.apr
Lake Union
Elliott Bay
East Waterway
Lake Washington
E ALOHA ST
E JOHN ST
E MADISON ST
E UNION ST
E YESLER WAY
S LANDER ST
S SPOKANE ST
S GENESEE ST
S ORCAS ST
BROADWAY
23RD AVE
RAINIER AVE S
ALASKAN WY
EAST MARGINAL WAY S
1ST AVE S
4TH AVE S
BEACON AVE S
M L KING JR WAY S
31ST AVE S
38TH AVE S
5
90


East Waterway
Figure 7
Land use in combined sewer service area
Land use
Commercial
Industrial
Multi-family residential
Single-family residential
Vacant/parks
Schools
Government service
Streets
Arterials
State Highway
Interstate Freeway
N
W
E
S
1000 0 1000 Feet
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No guarantee of any sort implied, including accuracy, completeness, or fitness for use.
hanford-csobasin_landuse
Lake Union
Elliott Bay
East Waterway
Lake Washington
5
90

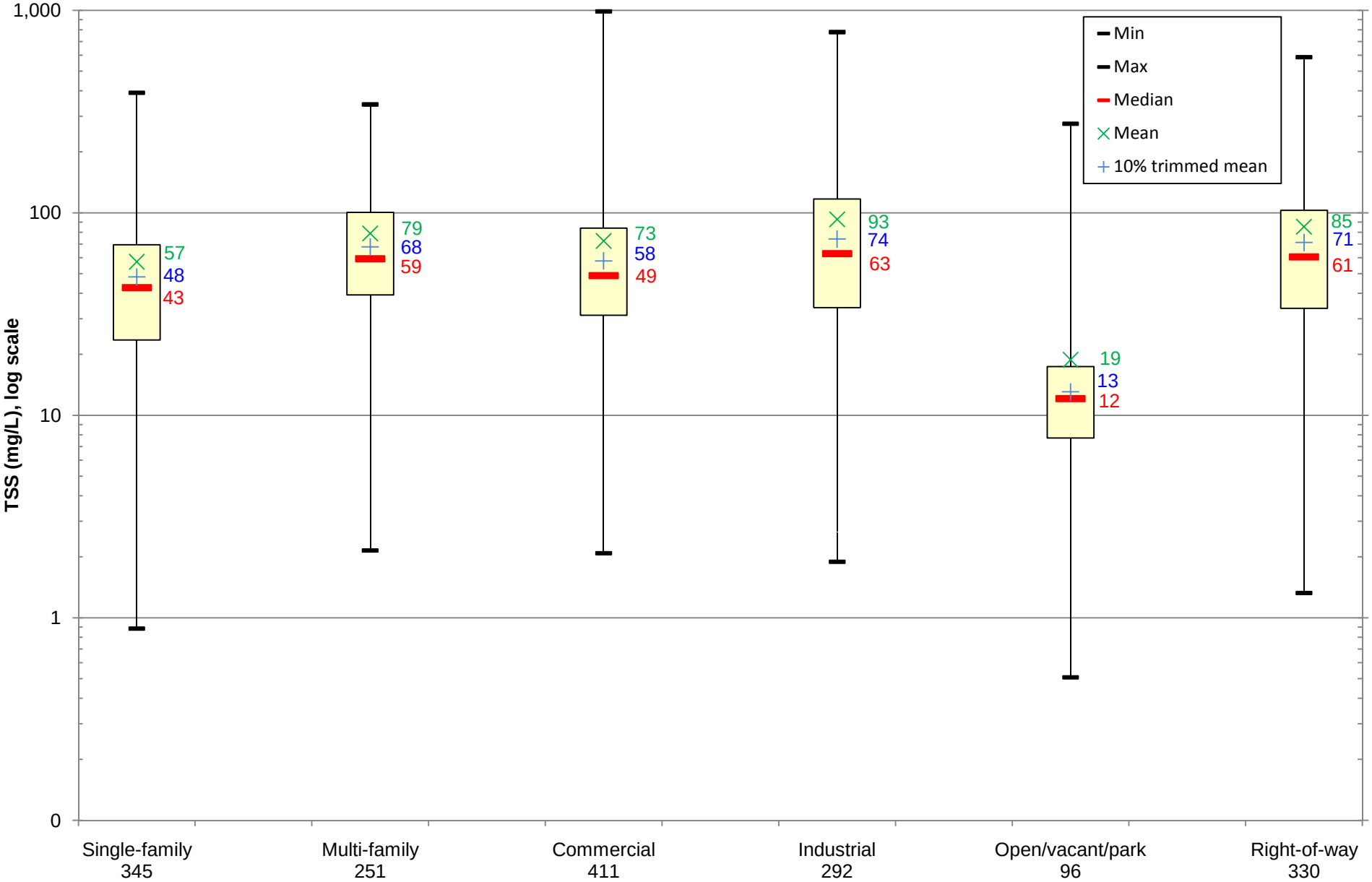


Figure 8: Box plot of TSS concentrations by land use.

Compiled TSS data DSA 040607_SyntheticValues_v1c.xlsx PTM box

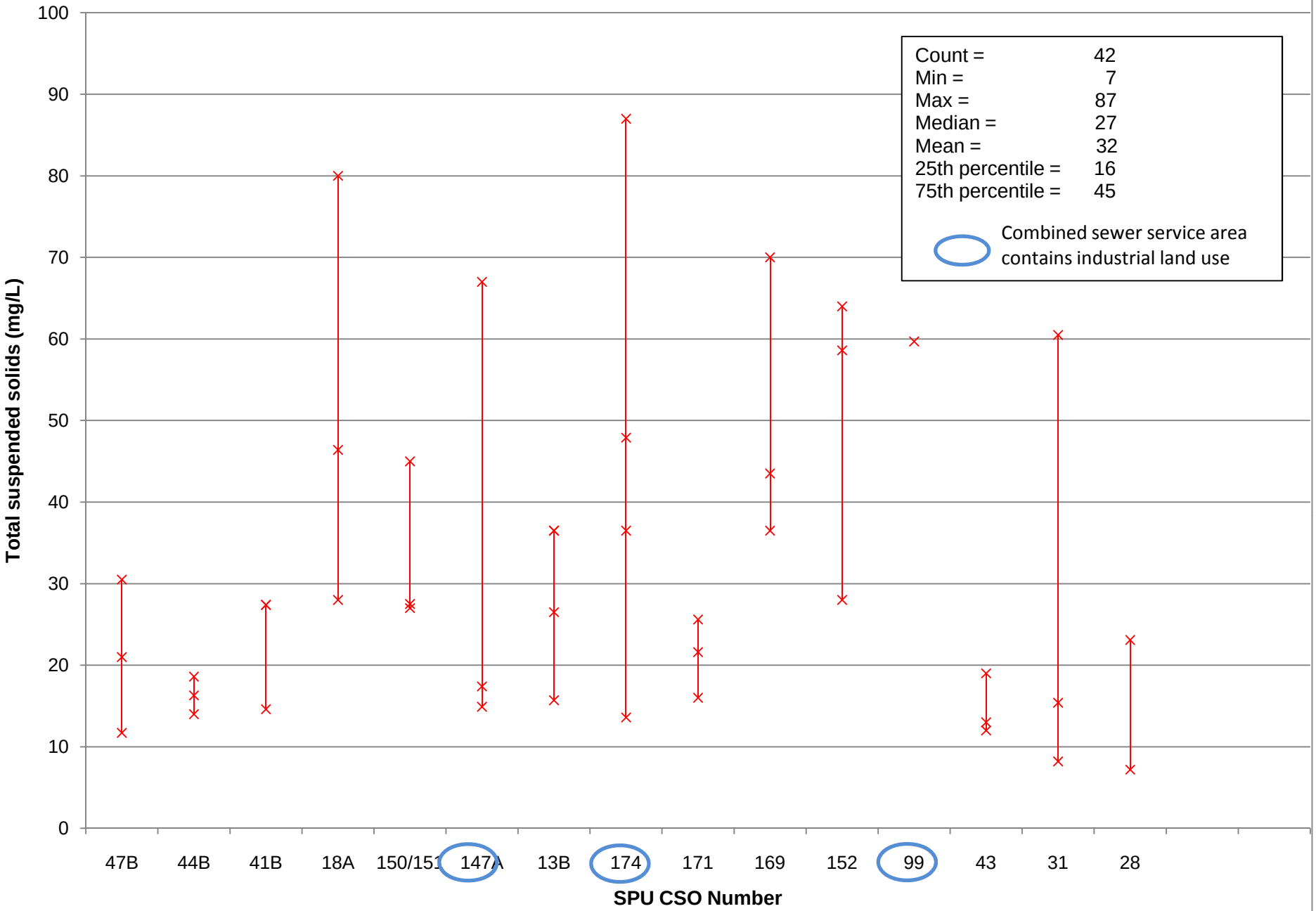
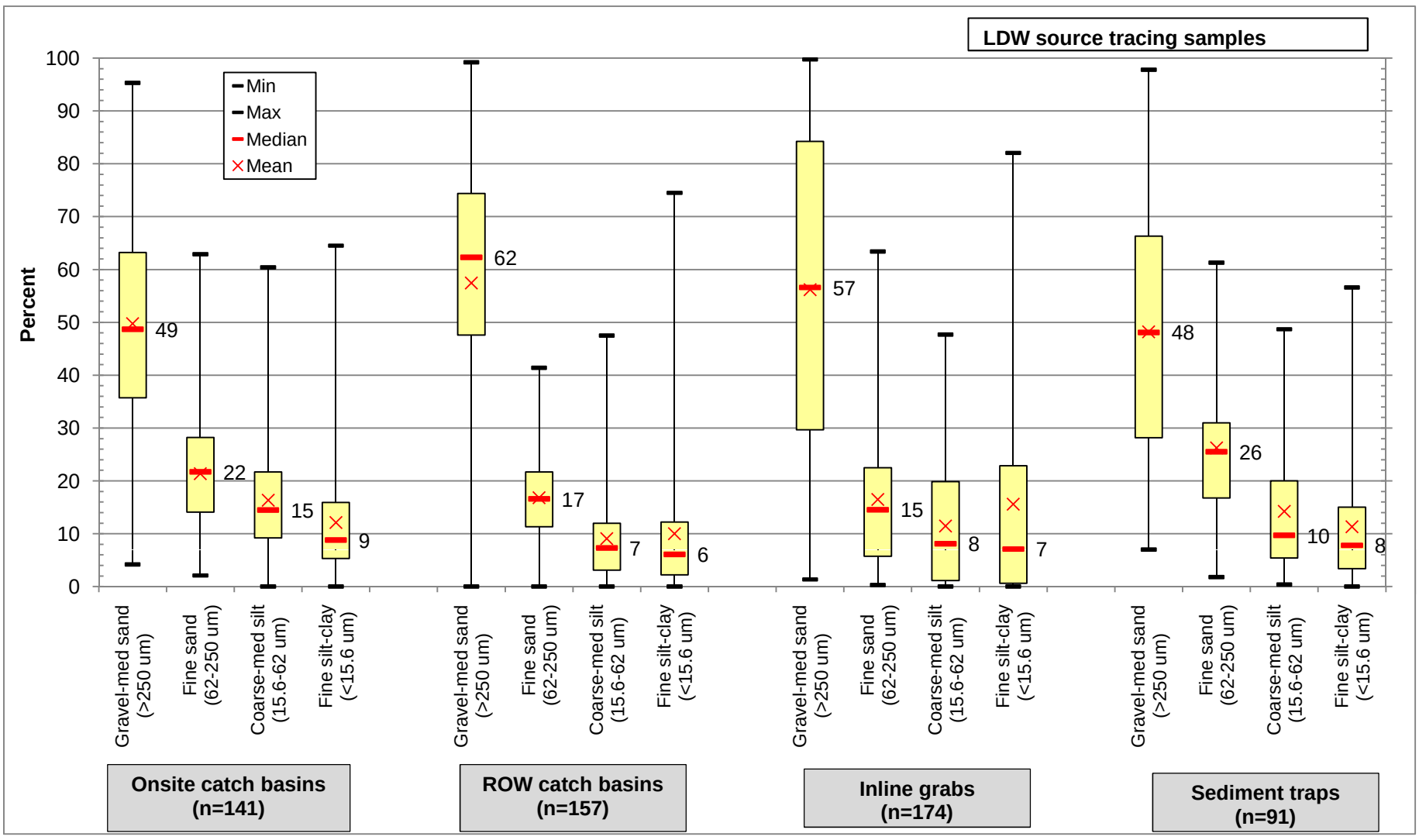
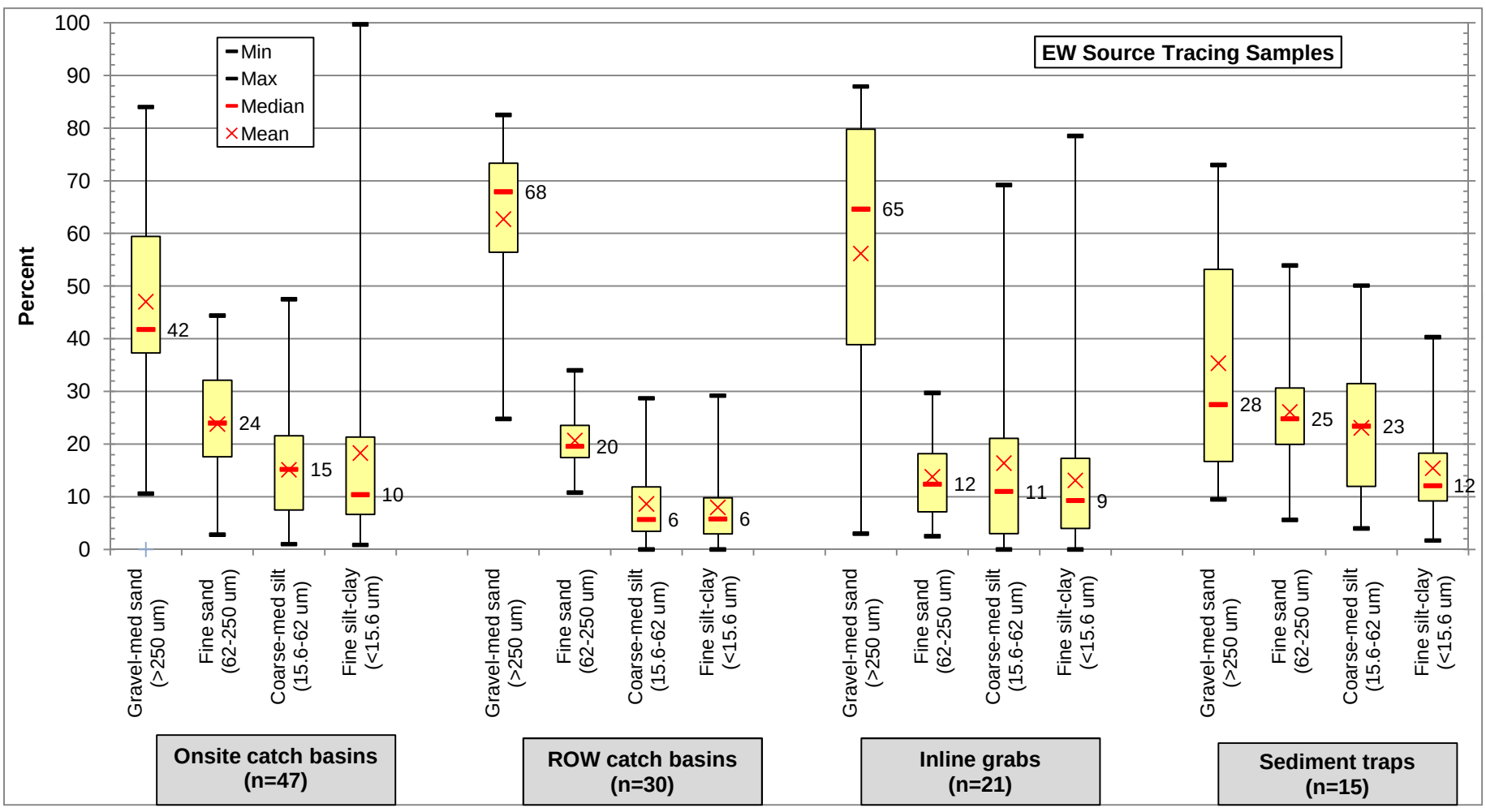


Figure 9: Total suspended solids in Seattle CSOs





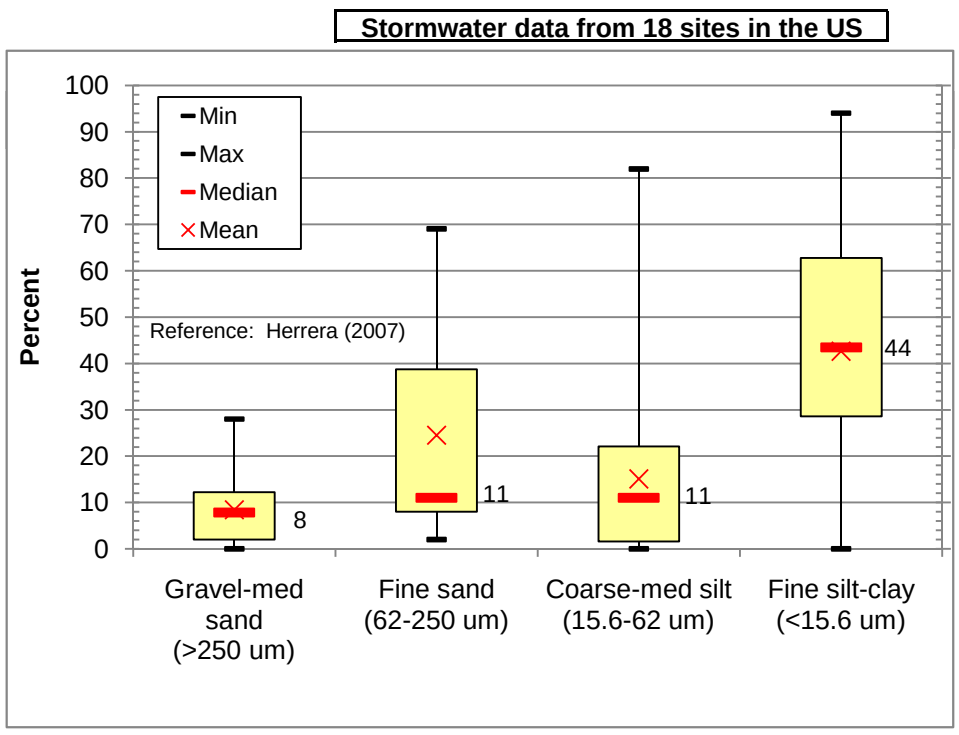


Figure 10: Comparison of PSD in stormwater and East Waterway and Lower Duwamish Waterway source samples.

Appendix A:

Stormwater Volume Calculations
(Northwest Hydraulic Consultants 2008)

MEMORANDUM

northwest hydraulic consultants inc.

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(206) 241-6000
fax no. (206) 439-2420

DATE: September 11, 2008

TO: Beth Schmoyer and Peter Rude, Seattle Public Utilities

FROM: Sam Gould and David Hartley, Northwest Hydraulic Consultants, Inc. (**nhc**)

SUBJECT: East Waterway Runoff and Water Quality

This memorandum summarizes the work performed by Northwest Hydraulic Consultants (**nhc**) for Seattle Public Utilities (SPU) with respect to East Waterway runoff and water quality. **nhc**'s contribution to this project included rainfall analysis, HSPF unit runoff simulation, runoff volume calculations, and total suspended solids (TSS) calculations.

Rainfall Analysis

For the Lower Duwamish Water Way Solids Loading Study **nhc** selected a wet, average and dry year based on annual rainfall depths at rain gauges 15, 16, 17 and SEA-TAC (**nhc** 2007). The water years selected are listed below.

Wet:	2002
Average:	1986
Dry:	1993

For this study the period of record has been extended to include calendar years 2006 – 2007. In order to see if the addition of these years should result in a change to the selected wet, average, and dry years, the annual rainfall depth at rain gauge 15 was calculated for the period of record of water year 1978 through 2007. These values were then ranked and put into five bins as can be seen in Table 1. From this table it can be seen that the 2002, 1986 and 1993 still adequately represent wet, average, and dry years.

HSPF Unit Runoff/Interflow Simulation

For the HSPF rainfall runoff simulations time series data from only one rain gauge is needed. The locations of rain gauge 15, 16, and 17 and the drainage basins are shown in Figure 1. Rain gauge 15 was chosen based on its close proximity to the East Waterway storm water basins. A basic HSPF model was created using pervious land segments (PERLNDs) with runoff characteristics representative of the different regional soil-vegetation-slope combinations. The 5-minute precipitation time series for rain gauge 15 and Puyallup evaporation record between calendar years 1978 and 2007 were applied to the regional parameter PERLNDs. The unit depth of annual and monthly surface runoff and interflow were tabulated for each PERLND type.

Land Use/Land Cover Calculations

SPU provided **nhc** with GIS layers containing land use, soil type, and basin delineations for the study area. The soil type layer was produced by the USGS in 2006 (Goetz 2006).

The basins were separated into SPU, Port of Seattle (POS), and private basins. Basins were merged together that had runoff going to the same outfall and fell into the same ownership category (i.e. an SPU basin would not be merged with a POS or private basin).

As directed by SPU, the land use types were consolidated into six categories: single family housing, multifamily housing, commercial, industrial, vacant/park, and open forest. For the small percentage of parcels that did not have a land use defined in the GIS layer provided, a land use was assigned based on an examination of 2002 USGS and 2006 USDA orthophotos. The soil types were consolidated into four categories (till, outwash, alluvium, and wetland). Areas mapped as "modified" soils were considered to have the same characteristics as till. A GIS overlay analysis was then performed to calculate the areas of different soil-land use complexes in each basin. Areas within the basin that were not covered by the land use layer were considered to be right of way (RoW). A GIS overlay analysis was performed with the RoW and soil type layers to determine the area of RoW with each soil type in each basin. RoW was divided into Residential RoW and Industrial/Commercial RoW based on the percentage of Residential and Commercial/Industrial land use for each soil type in each basin. The basin delineation and soil-land use complexes are shown in Figures 2 and 3. As can be seen in Figure 3 all of the study area is designated as till with the exception of 5.5 acres of outwash in the East Lander basin. Tables 2 through 6 show a break down of land use and soil type for each basin that was modeled.

For hydrologic calculations, land uses were decomposed into characteristic land cover components consisting of effective impervious, grass, and forest areas. The same land use - land cover assumptions as used in the Lower Duwamish Waterway Solids Loading Analysis (**nhc** 2007) were used in this study. The land use - land cover assumptions are summarized in Table 7.

The assumed land use - land cover assumptions were used to calculated the unit runoff and interflow for the different land use types using the HSPF land cover results. Monthly and annual unit runoff from the different land cover types (presented as millions of gallons per acre) can be found in the accompanying Excel spreadsheets.

Runoff Volume Calculations

Total areas of the different land cover types were calculated by **nhc** for each basin. These tabulated areas were used in conjunction with the unit runoff/interflow volumes for the different land use categories to calculate runoff volumes. In partially separated areas, runoff can be discharged to both the storm drain and the combined sewer systems. In most partially separated areas in the city, the roadways are typically plumbed to the storm drain system, while areas outside the public right-of-way can be plumbed to either the storm or the combined systems. Information about onsite drainage systems in the Lander East/West drainage basins from SPU's GIS system was reviewed to identify parcels that are currently connected to the storm drain system and discharge to the East Waterway. Because the SPU GIS coverage for onsite drainage systems is incomplete, this analysis represents the minimum area connected to the separate storm drain system. In addition, as properties redevelop, runoff from onsite areas will likely be plumbed to the storm drain rather than the combined sewer system. To develop a high end value for the runoff estimates, it was assumed that up to 50 percent of the remaining parcels could eventually connect to the storm drain system. Assumptions regarding areas connected to the storm drain system in each basin that were used in the runoff model are summarized in Table 8.

The resulting annual runoff volumes for water years 2000 through 2007 as well as the wet, average and dry years for each basin can be found in Tables 9 through 14. Tabulation of the monthly and annual runoff volumes for each basin broken down by land use and soil type for the entire period of record from 1978 through 2007 can be found in the accompanying Excel spreadsheets. Since only two soil types, till and outwash, were found in the basins only land cover with these soil types are shown in the Excel runoff tables.

Total Suspended Solids Calculations

The TSS calculations were made according to the method used in the 2007 Herrera study *Analysis of Total Solids Loading in the Lower Duwamish Waterway*. The runoff was first calculated for six land use types: right of way, industrial, multifamily residential, commercial, open space, and single family residential. This was done by adding Commercial/Industrial Right of Way runoff with Residential Right of Way runoff to calculate right of way runoff. Then Open Forest runoff and Parks/ Open Space/ Vacant runoff were added together to calculate open space runoff. For all land use types both surface runoff and interflow were included in the runoff calculation. After the runoff for each land use was determined, the TSS for each land use was calculated by multiplying the runoff by the appropriate TSS concentration for each land use shown in Table 15 (Herrera 2007). The resulting annual TSS values for each basin for water years 2000 through 2007 as well as the wet, average and dry years can be found in Tables 9 through 14. Tabulation of the monthly and annual TSS for each basin broken down by land use can be found in the accompanying Excel spreadsheets. A summary of the total runoff and TSS loading for each ownership category for dry, average, and wet years can be found in Table 16.

References

Northwest Hydraulic Consultants, Summary of Rain Gauge Analysis of the Lower Duwamish Waterway Solids Loading Analysis Study, January 2007, prepared for Seattle Public Utilities.

Goetz Troost, K., D.B. Booth, A.P. Wisher, and S.A. Shimel, The geologic map of Seattle, a progress report, USGS Open File Report 2005-1252, 2006, prepared in cooperation with the City of Seattle and the Pacific Northwest Center for Geological Mapping Studies at the Department of Earth and Space Sciences, University of Washington, Seattle, WA.

Herrera Environmental Consultants, Analysis of Total Suspended Solids Loading in the Lower Duwamish Waterway, April 2007, prepared for Seattle Public Utilities.

Table 1 Precipitation Analysis for Seattle Rain Gauge 15

		RG15	
		Annual	
	nth Largest	W. Year	Inches
Very Wet	1	1999	44.6
	2	1983	44.2
	3	1996	44.0
	4	1980	42.6
	5	1997	42.2
	6	1982	41.4
	7	2007	41.4
Wet	8	1984	38.3
	9	**2002**	**37.5**
	10	1991	35.5
	11	1995	35.4
	12	2006	34.3
Average	13	1981	33.0
	14	**1986**	**32.4**
	15	1990	31.8
	16	1987	31.7
	17	2000	30.6
Dry	18	2005	30.5
	19	1998	29.7
	20	1989	29.4
	21	2004	28.9
	22	1985	28.5
	23	1992	27.9
Very Dry	24	**1993**	**27.2**
	25	2003	27.2
	26	1988	26.6
	27	1979	24.8
	28	1994	23.3
	29	2001	23.0

Table 2 SPU Basins Land Use Soil Complexes

		Till (acres)								Outwash (acres)							
Basin 1)	Area (acre)	Single Family	Multi-Family	Commercial	Industrial	Parks/ Open Space/ Vacant	Forested Open Space	RoW Residential	RoW Commercial/ Industrial	Single Family	Multi-Family	Commercial	Industrial	Parks/ Open Space/ Vacant	Forested Open Space	RoW Residential	RoW Commercial/ Industrial
B-21	13.0	0.0	0.0	0.1	7.0	0.4	0.0	0.0	5.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-25	3.0	0.0	0.0	2.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-36	5.3	0.0	0.0	0.5	0.1	1.1	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-4	7.1	0.0	0.0	0.4	0.0	3.3	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-5	2.2	0.0	0.0	0.0	0.8	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-40	3.4	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-41	5.5	0.0	0.0	0.0	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-42	0.5	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-43	5.7	0.0	0.0	0.0	5.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
East Lander	76.3	16.9	15.9	6.1	0.4	3.3	0.0	23.6	4.7	1.1	1.8	0.1	0.0	0.1	0.0	2.1	0.1
Hinds	26.4	0.0	0.0	1.5	14.5	0.2	0.0	0.0	10.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lander West	371.3	0.0	0.0	80.6	168.3	5.7	0.0	0.0	116.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

1) Only till and outwash were present in the Study Area so all other soil types are not reported.

Table 3 SPU Bridges Land Use Soil Complexes

		Till (acres)								Outwash (acres)							
Basin 1)	Area (acre)	Single Family	Multi-Family	Commercial	Industrial	Parks/ Open Space/ Vacant	Forested Open Space	RoW Residential	RoW Commercial/ Industrial	Single Family	Multi-Family	Commercial	Industrial	Parks/ Open Space/ Vacant	Forested Open Space	RoW Residential	RoW Commercial/ Industrial
B-34	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-4	1.2	0.0	0.0	0.0	0.0	0.2	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-5	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

1) Only till and outwash were present in the Study Area so all other soil types are not reported.

Table 4 POS Basins Land Use Soil Complexes

		Till (acres)								Outwash (acres)							
Basin 1)	Area (acre)	Single Family	Multi-Family	Commercial	Industrial	Parks/ Open Space/ Vacant	Forested Open Space	RoW Residential	RoW Commercial/ Industrial	Single Family	Multi-Family	Commercial	Industrial	Parks/ Open Space/ Vacant	Forested Open Space	RoW Residential	RoW Commercial/ Industrial
B-1	1.1	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-10	7.2	0.0	0.0	0.1	6.7	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-11_a	16.5	0.0	0.0	0.0	15.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-11_b	46.3	0.0	0.0	0.0	23.2	4.0	0.0	0.0	19.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-11_c	12.6	0.0	0.0	0.0	8.3	2.1	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-11_d	5.8	0.0	0.0	0.0	3.6	1.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-12	6.5	0.0	0.0	0.0	6.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-13	6.2	0.0	0.0	0.0	6.2	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-14	1.5	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-16	4.4	0.0	0.0	0.0	4.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-17	2.1	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-18	7.4	0.0	0.0	0.0	7.3	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-19	5.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-22	12.0	0.0	0.0	0.0	12.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-23	10.9	0.0	0.0	0.0	10.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-24	8.9	0.0	0.0	0.0	8.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-25	2.2	0.0	0.0	0.4	1.6	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-26	12.7	0.0	0.0	0.0	0.6	7.7	0.0	0.0	4.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-27	7.3	0.0	0.0	0.0	7.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-28	3.6	0.0	0.0	0.0	2.7	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-29	8.7	0.0	0.0	0.0	7.9	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-30	7.0	0.0	0.0	0.0	6.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-31	9.6	0.0	0.0	0.0	9.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-32	3.7	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-33	12.1	0.0	0.0	0.0	11.9	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-34	13.3	0.0	0.0	0.0	13.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-37	6.4	0.0	0.0	0.0	6.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-38	1.3	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-39	2.1	0.0	0.0	0.0	1.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-7	13.9	0.0	0.0	0.0	13.9	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lander	3.6	0.0	0.0	0.0	3.6	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

1) Only till and outwash were present in the Study Area so all other soil types are not reported.

Table 5 POS Aprons Land Use Soil Complexes

		Till (acres)								Outwash (acres)							
Basin 1)	Area (acre)	Single Family	Multi-Family	Commercial	Industrial	Parks/ Open Space/ Vacant	Forested Open Space	RoW Residential	RoW Commercial/ Industrial	Single Family	Multi-Family	Commercial	Industrial	Parks/ Open Space/ Vacant	Forested Open Space	RoW Residential	RoW Commercial/ Industrial
A-10	2.3	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
A-12	2.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
A-13	0.5	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
A-14	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
A-16	0.7	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
A-17	0.7	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
A-18	1.2	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
A-19	1.9	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
A-22	2.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
A-31	0.8	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

1) Only till and outwash were present in the Study Area so all other soil types are not reported.

Table 6 Private Basins Land Use Soil Complexes

		Till (acres)								Outwash (acres)							
Basin 1)	Area (acre)	Single Family	Multi-Family	Commercial	Industrial	Parks/ Open Space/ Vacant	Forested Open Space	RoW Residential	RoW Commercial/ Industrial	Single Family	Multi-Family	Commercial	Industrial	Parks/ Open Space/ Vacant	Forested Open Space	RoW Residential	RoW Commercial/ Industrial
A-6	3.2	0.0	0.0	0.0	3.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

1) Only till and outwash were present in the Study Area so all other soil types are not reported.

Table 7 Land Use - Land Cover Assumptions

Landuse	Total Impervious Area (TIA)	Effective Impervious Area % (EIA)	Adopted Land Cover Assumptions		
			EIA	Forest	Grass
Single Family	48%	80%	39%	0%	61%
Multi-Family	86%	90%	78%	0%	22%
Commercial	82%	100%	82%	0%	18%
Industrial	94%	100%	94%	0%	6%
Parks/Open Space/Vacant	25%	70%	18%	0%	83%
Forested Open Space	0%	0%	0%	100%	0%
RoW Residential	50%	100%	50%	0%	50%
RoW Commercial/Industrial	80%	100%	80%	0%	20%

Table 8 Assumed Percent of Area Connected to Storm Drain System for Partially Separated Basins

	Low	High
Lander West		
ROW	100%	100%
Non-ROW	25%	75%
Lander East		
ROW	100%	100%
Non-ROW	15%	65%

Table 9 Runoff and TSS from SPU Basins For Water Years 1986, 1993 and 2000-2007 (Low Runoff Assumption from Partially Separated Basins)

		Annual Runoff in million gallons										Annual Average TSS in lbs									
Basin	Area (acre)	1986 (Average)	1993 (Dry)	2000	2001	2002 (Wet)	2003	2004	2005	2006	2007	1986 (Average)	1993 (Dry)	2000	2001	2002 (Wet)	2003	2004	2005	2006	2007
B-21	13.0	8.29	6.96	7.67	4.99	10.22	6.92	7.03	7.20	8.83	11.21	5,753	4,830	5,325	3,465	7,094	4,801	4,880	5,003	6,128	7,778
B-25	3.0	1.90	1.60	1.76	1.14	2.35	1.59	1.61	1.65	2.03	2.58	1,257	1,055	1,164	751	1,554	1,049	1,063	1,090	1,340	1,703
B-36	5.3	3.10	2.58	2.87	1.73	3.90	2.59	2.54	2.61	3.31	4.27	2,115	1,766	1,962	1,190	2,659	1,766	1,742	1,790	2,260	2,909
B-4	7.1	3.73	3.09	3.47	1.89	4.81	3.11	2.94	3.03	4.00	5.25	2,445	2,028	2,273	1,265	3,139	2,042	1,943	2,004	2,621	3,426
B-5	2.2	1.37	1.15	1.27	0.82	1.69	1.14	1.16	1.19	1.46	1.85	960	806	889	576	1,185	801	813	834	1,023	1,299
B-40	3.4	2.10	1.76	1.95	1.25	2.60	1.75	1.77	1.82	2.24	2.85	1,376	1,153	1,274	816	1,704	1,148	1,159	1,189	1,467	1,868
B-41	5.5	3.68	3.10	3.41	2.28	4.50	3.07	3.16	3.24	3.92	4.94	2,540	2,138	2,349	1,574	3,105	2,119	2,182	2,235	2,702	3,408
B-42	0.5	0.31	0.26	0.28	0.19	0.38	0.26	0.26	0.27	0.33	0.41	212	179	196	132	260	177	183	187	226	285
B-43	5.7	3.83	3.22	3.54	2.37	4.68	3.19	3.29	3.37	4.07	5.13	2,639	2,221	2,440	1,636	3,226	2,202	2,268	2,322	2,807	3,541
East Lander[1]	76.3	19.64	16.31	18.25	10.33	25.12	16.40	15.72	16.20	21.05	27.44	13,525	11,233	12,565	7,127	17,288	11,295	10,833	11,161	14,490	18,885
Hinds	26.4	17.00	14.28	15.74	10.30	20.93	14.19	14.46	14.82	18.11	22.95	11,797	9,908	10,917	7,145	14,523	9,845	10,032	10,282	12,564	15,926
Lander West[2]	371.3	113.57	95.25	105.15	67.63	140.50	94.79	95.86	98.31	121.05	153.99	79,086	66,332	73,226	47,107	97,839	66,010	66,759	68,466	84,294	107,231
Total	519.7	178.52	149.56	165.35	104.92	221.70	149.01	149.80	153.71	190.39	242.88	123,705	103,649	114,580	72,785	153,578	103,257	103,857	106,562	131,923	168,259

1) East Lander is a partially separated basin. For the low runoff assumption it was assumed that 100% of the runoff from RoW and 15% of the runoff from all non RoW parcels is routed to the East Waterway.
2) Lander West is a partially separated basin. For the low runoff assumption it was assumed that 100% of the runoff from RoW and 25% of the runoff from all non RoW parcels is routed to the East Waterway.

Table 10 Runoff and TSS from SPU Basins For Water Years 1986, 1993 and 2000-2007 (High Runoff Assumption from Partially Separated Basins)

		Annual Runoff in million gallons										Annual Average TSS in lbs									
Basin	Area (acre)	1986 (Average)	1993 (Dry)	2000	2001	2002 (Wet)	2003	2004	2005	2006	2007	1986 (Average)	1993 (Dry)	2000	2001	2002 (Wet)	2003	2004	2005	2006	2007
B-21	13.0	8.29	6.96	7.67	4.99	10.22	6.92	7.03	7.20	8.83	11.21	5,753	4,830	5,325	3,465	7,094	4,801	4,880	5,003	6,128	7,778
B-25	3.0	1.90	1.60	1.76	1.14	2.35	1.59	1.61	1.65	2.03	2.58	1,257	1,055	1,164	751	1,554	1,049	1,063	1,090	1,340	1,703
B-36	5.3	3.10	2.58	2.87	1.73	3.90	2.59	2.54	2.61	3.31	4.27	2,115	1,766	1,962	1,190	2,659	1,766	1,742	1,790	2,260	2,909
B-4	7.1	3.73	3.09	3.47	1.89	4.81	3.11	2.94	3.03	4.00	5.25	2,445	2,028	2,273	1,265	3,139	2,042	1,943	2,004	2,621	3,426
B-5	2.2	1.37	1.15	1.27	0.82	1.69	1.14	1.16	1.19	1.46	1.85	960	806	889	576	1,185	801	813	834	1,023	1,299
B-40	3.4	2.10	1.76	1.95	1.25	2.60	1.75	1.77	1.82	2.24	2.85	1,376	1,153	1,274	816	1,704	1,148	1,159	1,189	1,467	1,868
B-41	5.5	3.68	3.10	3.41	2.28	4.50	3.07	3.16	3.24	3.92	4.94	2,540	2,138	2,349	1,574	3,105	2,119	2,182	2,235	2,702	3,408
B-42	0.5	0.31	0.26	0.28	0.19	0.38	0.26	0.26	0.27	0.33	0.41	212	179	196	132	260	177	183	187	226	285
B-43	5.7	3.83	3.22	3.54	2.37	4.68	3.19	3.29	3.37	4.07	5.13	2,639	2,221	2,440	1,636	3,226	2,202	2,268	2,322	2,807	3,541
East Lander[1]	76.3	31.98	26.57	29.71	16.93	40.83	26.70	25.66	26.43	34.25	44.61	21,027	17,477	19,530	11,190	26,812	17,559	16,911	17,416	22,519	29,295
Hinds	26.4	17.00	14.28	15.74	10.30	20.93	14.19	14.46	14.82	18.11	22.95	11,797	9,908	10,917	7,145	14,523	9,845	10,032	10,282	12,564	15,926
Lander West[2]	371.3	196.06	164.56	181.48	117.78	241.94	163.63	166.13	170.32	208.88	265.24	134,962	113,285	124,928	81,126	166,524	112,642	114,388	117,272	143,789	182,564
Total	519.7	273.34	229.12	253.14	161.66	338.85	228.15	230.01	235.96	291.43	371.30	187,083	156,846	173,246	110,866	231,786	156,153	157,564	161,624	199,447	254,002

1) East Lander is a partially separated basin. For the high runoff assumption it was assumed that 100% of the runoff from RoW and 65% of the runoff from all non RoW parcels is routed to the East Waterway.
2) Lander West is a partially separated basin. For the high runoff assumption it was assumed that 100% of the runoff from RoW and 75% of the runoff from all non RoW parcels is routed to the East Waterway.

Table 11 Runoff and TSS from SPU Bridges For Water Years 1986, 1993 and 2000-2007

		Annual Runoff in million gallons										Annual Average TSS in lbs									
Basin	Area (acre)	1986 (Average)	1993 (Dry)	2000	2001	2002 (Wet)	2003	2004	2005	2006	2007	1986 (Average)	1993 (Dry)	2000	2001	2002 (Wet)	2003	2004	2005	2006	2007
B-34	0.9	0.58	0.49	0.54	0.34	0.72	0.48	0.49	0.50	0.62	0.79	408	342	378	238	508	341	342	351	436	557
B-4	1.2	0.72	0.60	0.67	0.41	0.91	0.60	0.59	0.61	0.77	1.00	499	417	463	282	627	417	412	423	533	686
B-5	1.6	0.99	0.83	0.92	0.58	1.24	0.83	0.83	0.85	1.06	1.35	701	587	650	411	872	585	587	603	748	955
Total	3.8	2.30	1.92	2.13	1.32	2.87	1.92	1.91	1.96	2.45	3.14	1,609	1,346	1,491	931	2,007	1,343	1,341	1,377	1,717	2,198

Table 12 Runoff and TSS from POS Basins For Water Years 1986, 1993 and 2000-2007

		Annual Runoff in million gallons										Annual Average TSS in lbs									
Basin	Area (acre)	1986 (Average)	1993 (Dry)	2000	2001	2002 (Wet)	2003	2004	2005	2006	2007	1986 (Average)	1993 (Dry)	2000	2001	2002 (Wet)	2003	2004	2005	2006	2007
B-1	1.1	0.71	0.59	0.65	0.44	0.86	0.59	0.61	0.62	0.75	0.95	487	410	451	302	596	407	419	429	518	654
B-10	7.2	4.80	4.04	4.44	2.96	5.87	4.00	4.12	4.22	5.10	6.44	3,311	2,786	3,063	2,046	4,052	2,763	2,842	2,910	3,523	4,447
B-11_a	16.5	10.95	9.22	10.13	6.76	13.41	9.14	9.40	9.62	11.66	14.71	7,571	6,370	7,003	4,674	9,269	6,319	6,494	6,651	8,057	10,171
B-11_b	46.3	28.97	24.29	26.83	17.16	35.90	24.18	24.39	25.02	30.88	39.33	19,999	16,771	18,518	11,890	24,754	16,692	16,868	17,300	21,317	27,129
B-11_c	12.6	7.79	6.52	7.22	4.56	9.68	6.50	6.53	6.70	8.31	10.61	5,296	4,438	4,905	3,124	6,570	4,421	4,451	4,567	5,647	7,199
B-11_d	5.8	3.55	2.98	3.29	2.07	4.43	2.97	2.97	3.05	3.79	4.85	2,415	2,023	2,237	1,417	3,000	2,016	2,025	2,078	2,576	3,287
B-12	6.5	4.35	3.66	4.03	2.70	5.32	3.63	3.74	3.83	4.63	5.84	3,002	2,527	2,776	1,861	3,670	2,505	2,580	2,642	3,194	4,028
B-13	6.2	4.14	3.49	3.83	2.57	5.07	3.46	3.56	3.65	4.41	5.56	2,858	2,406	2,643	1,771	3,495	2,385	2,456	2,515	3,041	3,836
B-14	1.5	1.01	0.85	0.93	0.63	1.24	0.84	0.87	0.89	1.08	1.36	697	587	645	432	852	582	599	614	742	935
B-16	4.4	2.94	2.48	2.72	1.82	3.60	2.45	2.53	2.59	3.13	3.95	2,029	1,708	1,876	1,258	2,480	1,693	1,744	1,785	2,158	2,722
B-17	2.1	1.43	1.20	1.32	0.88	1.74	1.19	1.23	1.26	1.52	1.91	984	828	910	610	1,203	821	846	866	1,047	1,320
B-18	7.4	4.93	4.15	4.56	3.06	6.03	4.12	4.24	4.34	5.25	6.62	3,403	2,864	3,147	2,108	4,162	2,840	2,924	2,994	3,621	4,567
B-19	5.0	3.36	2.83	3.10	2.08	4.10	2.80	2.88	2.95	3.57	4.50	2,315	1,949	2,141	1,435	2,831	1,932	1,990	2,038	2,463	3,107
B-22	12.0	7.99	6.72	7.39	4.95	9.77	6.67	6.87	7.03	8.50	10.72	5,511	4,638	5,096	3,417	6,737	4,599	4,736	4,850	5,863	7,394
B-23	10.9	7.30	6.14	6.75	4.52	8.92	6.09	6.27	6.42	7.76	9.79	5,032	4,235	4,654	3,120	6,152	4,199	4,325	4,429	5,354	6,752
B-24	8.9	5.90	4.97	5.46	3.66	7.22	4.93	5.07	5.20	6.28	7.92	4,072	3,428	3,766	2,525	4,979	3,398	3,500	3,584	4,333	5,464
B-25	2.2	1.45	1.22	1.34	0.89	1.78	1.21	1.24	1.27	1.55	1.95	995	837	921	610	1,221	831	851	872	1,060	1,340
B-26	12.7	6.32	5.21	5.89	3.02	8.27	5.28	4.87	5.03	6.80	9.01	4,043	3,340	3,764	1,976	5,262	3,378	3,141	3,245	4,345	5,734
B-27	7.3	4.90	4.12	4.53	3.04	5.99	4.09	4.21	4.31	5.21	6.57	3,378	2,843	3,124	2,094	4,130	2,819	2,903	2,973	3,594	4,533
B-28	3.6	2.35	1.98	2.17	1.44	2.88	1.96	2.01	2.06	2.50	3.16	1,631	1,372	1,509	999	2,002	1,361	1,394	1,428	1,737	2,196
B-29	8.7	5.79	4.87	5.36	3.57	7.09	4.83	4.97	5.09	6.16	7.78	4,004	3,368	3,703	2,470	4,902	3,341	3,433	3,516	4,260	5,379
B-30	7.0	4.68	3.94	4.33	2.90	5.72	3.90	4.02	4.11	4.98	6.28	3,225	2,714	2,983	1,999	3,944	2,692	2,771	2,838	3,431	4,328
B-31	9.6	6.41	5.39	5.93	3.97	7.84	5.35	5.51	5.64	6.82	8.60	4,420	3,720	4,088	2,740	5,404	3,689	3,799	3,890	4,703	5,931
B-32	1.1	0.71	0.59	0.65	0.44	0.86	0.59	0.61	0.62	0.75	0.95	487	410	451	302	596	407	419	429	518	654
B-33	12.1	8.06	6.78	7.45	4.99	9.86	6.73	6.93	7.09	8.58	10.82	5,561	4,680	5,143	3,446	6,801	4,641	4,778	4,893	5,917	7,463
B-34	13.3	8.88	7.47	8.21	5.50	10.85	7.41	7.63	7.81	9.45	11.91	6,124	5,154	5,663	3,797	7,487	5,110	5,263	5,389	6,515	8,217
B-37	6.4	4.27	3.59	3.95	2.65	5.22	3.56	3.67	3.76	4.54	5.73	2,945	2,479	2,723	1,826	3,600	2,458	2,531	2,592	3,133	3,951
B-38	1.3	0.87	0.74	0.81	0.54	1.07	0.73	0.75	0.77	0.93	1.17	603	507	557	374	737	503	518	530	641	809
B-39	2.1	1.33	1.12	1.23	0.80	1.64	1.11	1.13	1.16	1.42	1.80	906	761	838	548	1,115	756	770	789	965	1,223
B-7	13.9	9.28	7.81	8.58	5.75	11.35	7.75	7.98	8.17	9.88	12.46	6,403	5,389	5,922	3,969	7,829	5,344	5,503	5,635	6,812	8,592
Lander	3.6	2.42	2.03	2.23	1.50	2.95	2.02	2.08	2.13	2.57	3.24	1,667	1,403	1,542	1,033	2,039	1,391	1,432	1,467	1,774	2,238
Total	259.8	167.84	141.00	155.32	101.83	206.53	140.08	142.85	146.40	178.74	226.50	115,379	96,945	106,763	70,172	141,870	96,292	98,304	100,738	122,858	155,598

Table 13 Runoff and TSS from POS Aprons For Water Years 1986, 1993 and 2000-2007

		Annual Runoff in million gallons										Annual Average TSS in lbs									
Basin	Area (acre)	1986 (Average)	1993 (Dry)	2000	2001	2002 (Wet)	2003	2004	2005	2006	2007	1986 (Average)	1993 (Dry)	2000	2001	2002 (Wet)	2003	2004	2005	2006	2007
A-10	2.3	1.52	1.28	1.41	0.94	1.86	1.27	1.31	1.34	1.62	2.04	1,050	884	971	651	1,284	877	903	924	1,117	1,409
A-12	2.0	1.32	1.11	1.22	0.82	1.61	1.10	1.13	1.16	1.40	1.77	911	767	842	565	1,113	760	783	802	969	1,222
A-13	0.5	0.31	0.26	0.29	0.19	0.38	0.26	0.27	0.28	0.33	0.42	216	182	200	134	264	180	186	190	230	290
A-14	1.0	0.69	0.58	0.64	0.43	0.84	0.58	0.59	0.61	0.73	0.93	476	401	441	295	582	398	409	419	507	639
A-16	0.7	0.44	0.37	0.41	0.27	0.54	0.37	0.38	0.39	0.47	0.59	302	254	280	187	370	252	260	266	322	406
A-17	0.7	0.46	0.38	0.42	0.28	0.56	0.38	0.39	0.40	0.49	0.61	315	265	291	195	385	263	270	277	335	422
A-18	1.2	0.80	0.68	0.74	0.50	0.98	0.67	0.69	0.71	0.85	1.08	553	466	512	343	677	462	476	487	589	742
A-19	1.9	1.27	1.07	1.17	0.78	1.55	1.06	1.09	1.11	1.35	1.70	873	735	807	541	1,067	728	750	768	929	1,171
A-22	2.0	1.34	1.13	1.24	0.83	1.64	1.12	1.15	1.18	1.43	1.80	925	779	856	574	1,131	772	795	814	984	1,241
A-31	0.8	0.54	0.45	0.50	0.33	0.66	0.45	0.46	0.47	0.57	0.72	370	312	342	230	453	309	318	326	394	497
Total	13.0	8.69	7.31	8.03	5.39	10.62	7.25	7.47	7.65	9.24	11.66	5,992	5,043	5,542	3,715	7,326	5,001	5,150	5,274	6,375	8,040

Table 14 Runoff and TSS from Private Basins For Water Years 1986, 1993 and 2000-2007

		Annual Runoff in million gallons										Annual Average TSS in lbs									
Basin	Area (acre)	1986 (Average)	1993 (Dry)	2000	2001	2002 (Wet)	2003	2004	2005	2006	2007	1986 (Average)	1993 (Dry)	2000	2001	2002 (Wet)	2003	2004	2005	2006	2007
A-6	3.2	2.10	1.77	1.94	1.30	2.57	1.75	1.80	1.85	2.24	2.82	1,450	1,221	1,341	898	1,774	1,210	1,246	1,276	1,543	1,947
Total	3.2	2.10	1.77	1.94	1.30	2.57	1.75	1.80	1.85	2.24	2.82	1,450	1,221	1,341	898	1,774	1,210	1,246	1,276	1,543	1,947

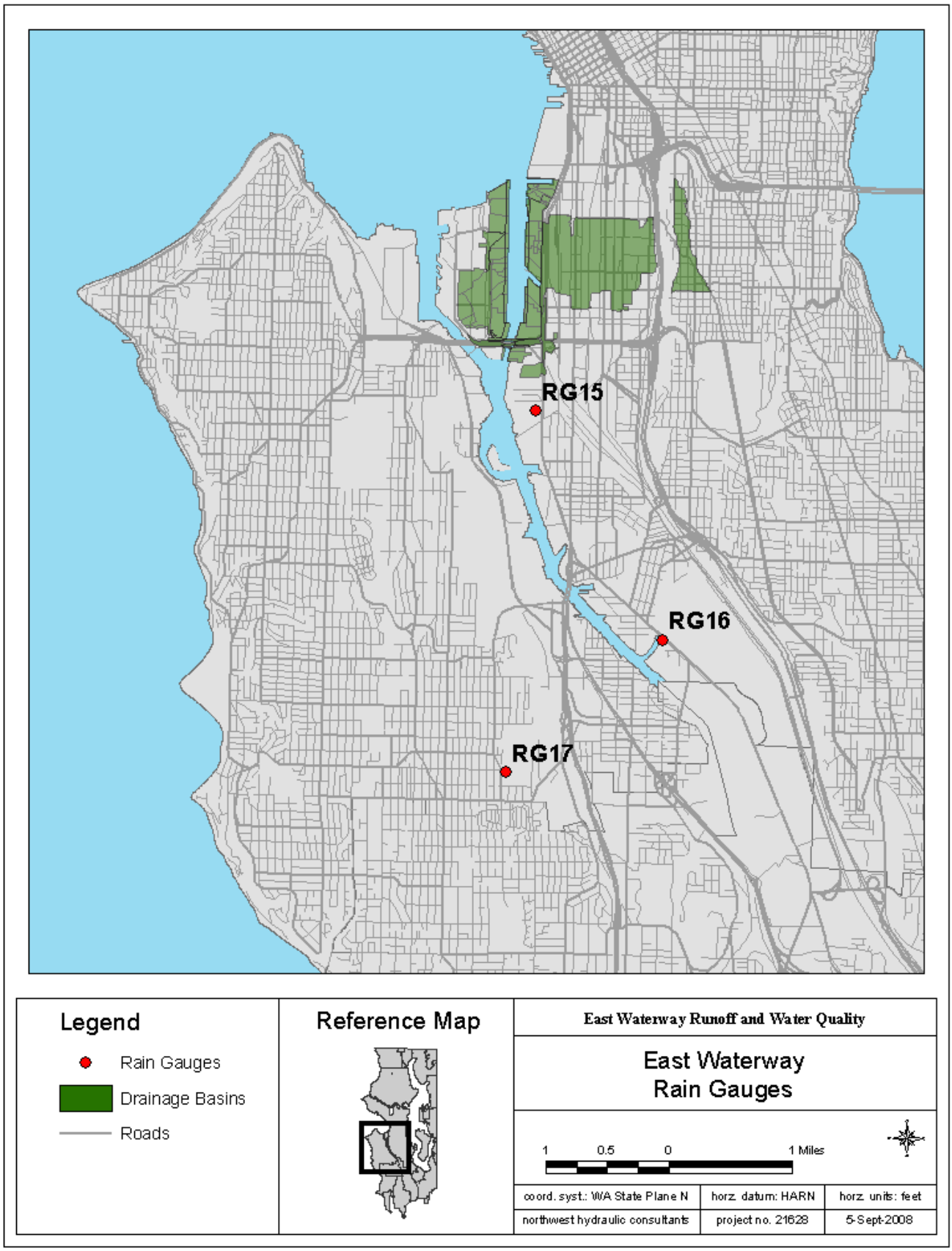
Table 15 TSS Concentrations in mg/L (Herrera 2007)

Land Use	RoW	Industrial	MFR	Commercial	Open	SFR
Concentration (mg/L)	84.9	82.8	79.9	78.6	68.9	62.1

Table 16 Summary of Runoff and TSS Load For Each Ownership Category

			Runoff			TSS Load		
	Area	TSS	Dry WY	Average WY	Wet WY	Dry WY	Average WY	Wet WY
Ownership Category	ac	mg/L	Mgal/yr	Mgal/yr	Mgal/yr	lbs/yr	lbs/yr	lbs/yr
SPU Basins Low Runoff Assumption[1]	519.7	83.2	149.56	178.52	221.70	103,649	123,705	153,578
SPU Bridges And Aprons	3.8	84.1	1.92	2.30	2.87	1,346	1,609	2,007
Total[1]	523.5	83.2	151.48	180.82	224.57	104,995	125,314	155,585
SPU Basins High Runoff Assumption[2]	519.7	82.1	229.12	273.34	338.85	156,846	187,083	231,786
SPU Bridges And Aprons	3.8	84.1	1.92	2.30	2.87	1,346	1,609	2,007
Total[2]	523.5	82.2	231.05	275.64	341.72	158,192	188,692	233,793
POS Basins	259.8	82.5	141.00	167.84	206.53	96,945	115,379	141,870
POS Aprons	13.0	82.8	7.31	8.69	10.62	5,043	5,992	7,326
Total	272.9	82.5	148.31	176.53	217.15	101,988	121,371	149,196
Private Basins	3.2	82.8	1.77	2.10	2.57	1,221	1,450	1,774

1) Low runoff assumption from non ROW land use in partially separated basins (East and West Lander)
2) High runoff assumption from non ROW land use in partially separated basins (East and West Lander)


RG15
RG16
RG17
Legend
Rain Gauges
Drainage Basins
Roads
Reference Map
East Waterway Runoff and Water Quality
East Waterway
Rain Gauges
1
0.5
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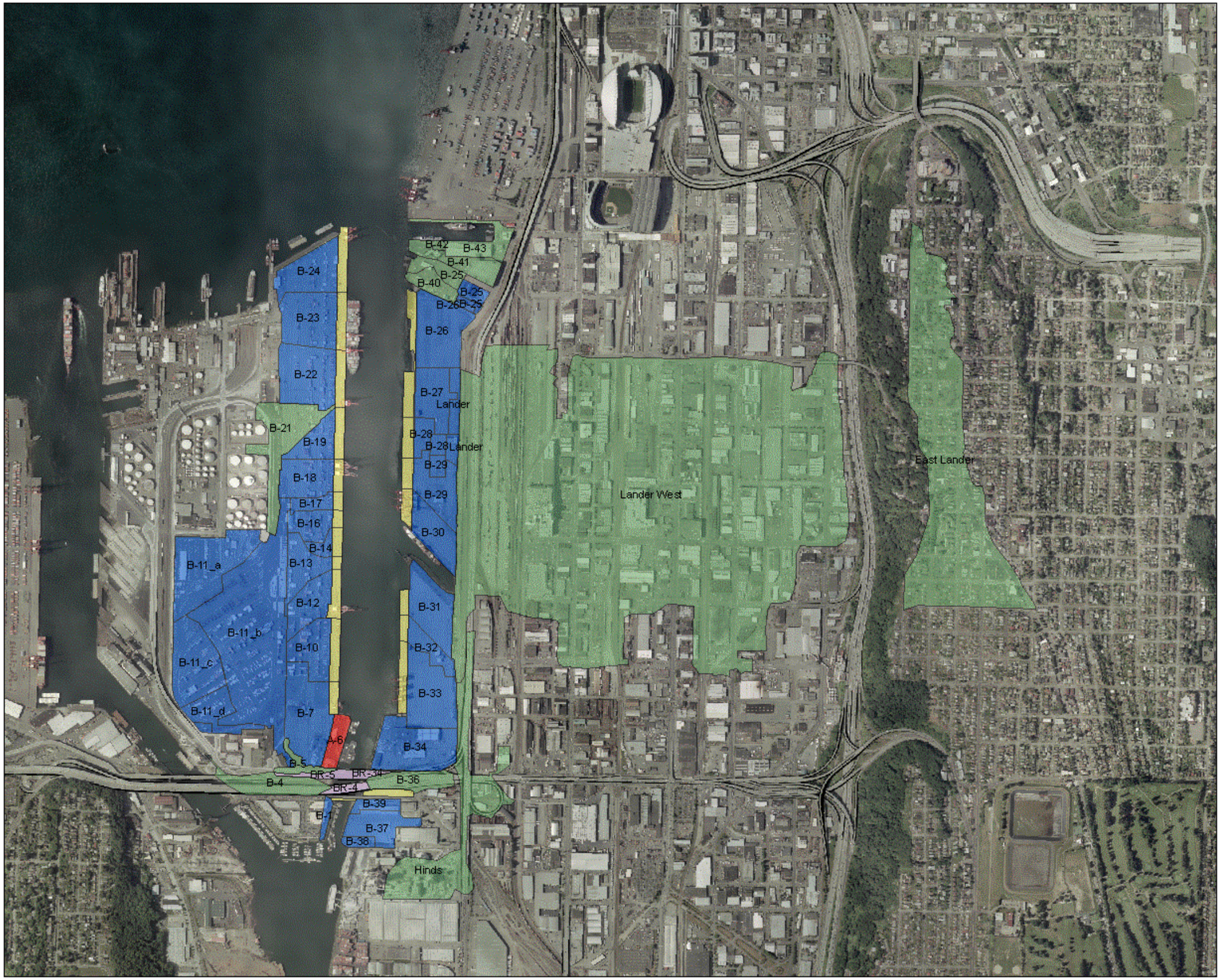
1 Miles
coord. syst.: WA State Plane N
horz. datum: HARN
horz. units: feet
northwest hydraulic consultants
project no. 21628
5-Sept-2008

Figure 1



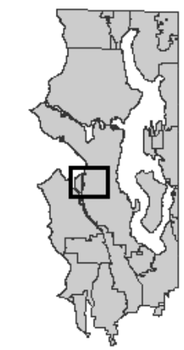
East Waterway Runoff and Water Quality

East Waterway Drainage Basins Deliniation

0.25 0.125 0 0.25 Miles

coord. syst.: WA State Plane N	horz. datum: HARN	horz. units: feet
northwest hydraulic consultants	project no. 21628	5-Sept-2008

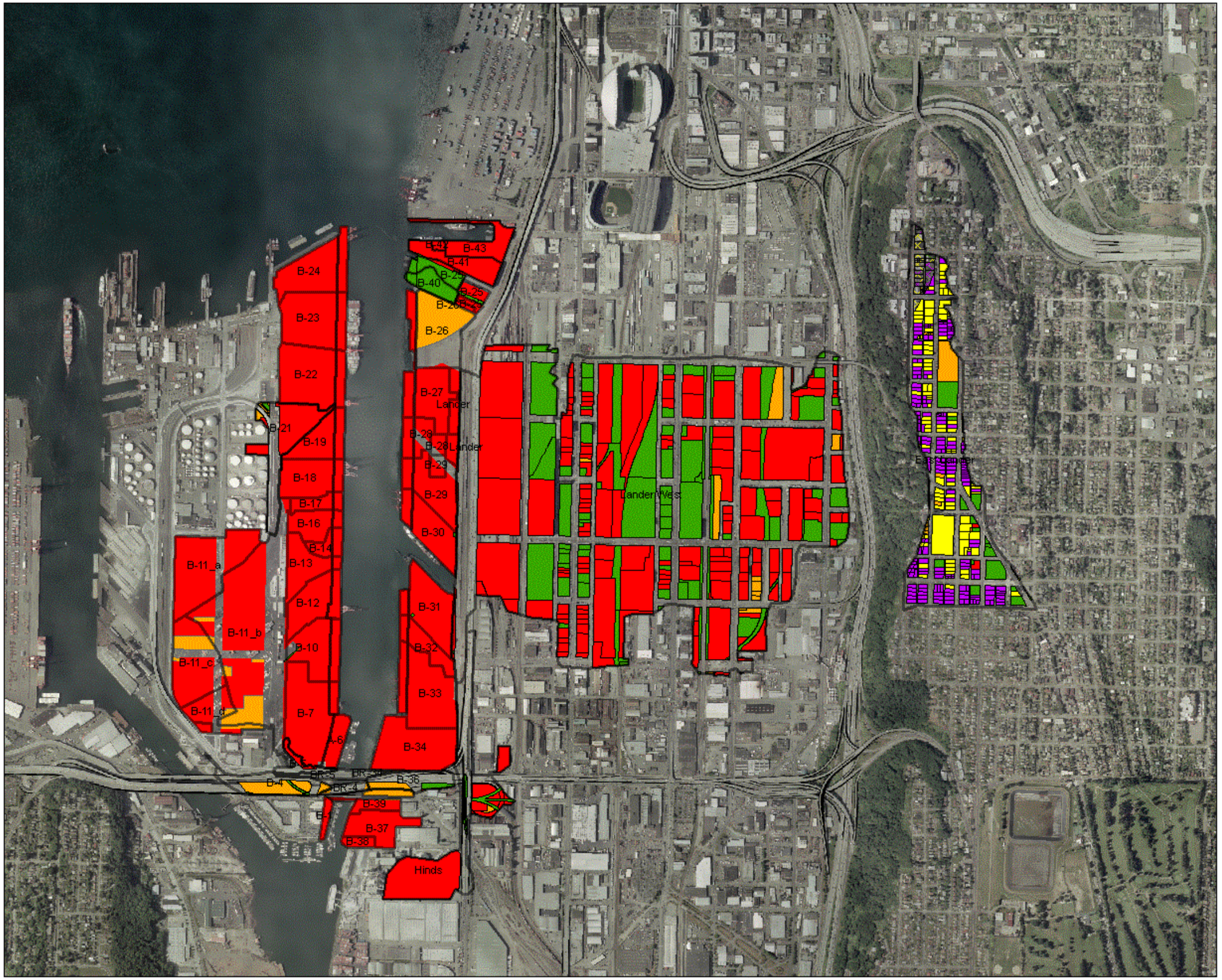
Reference Map



Legend

- SPU_Aprons_Bridges_Rev6_23_08
- Private_Basins_Rev6-23-08
- POS_BASINS_REV7-18-08
- POS_Aprons_Bridges_Rev6-23-08
- EVWV_BASINS_Rev6-23-08

Figure 2



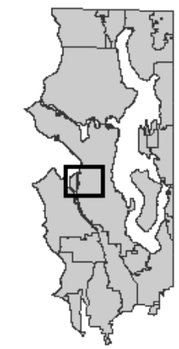
East Waterway Runoff and Water Quality

East Waterway
Land Use Soil Complexes

0.25 0.125 0 0.25 Miles

coord. syst.: WA State Plane N	horz. datum: HARN	horz. units: feet
northwest hydraulic consultants	project no. 21628	5-Sept-2008

Reference Map



Legend

- Commercial, Till
- Industrial, Till
- MFR, Till
- SFR, Till
- Vacant/park, Till
- Commercial, Outwash
- Industrial, Outwash
- MFR, Outwash
- SFR, Outwash
- Vacant/park, Outwash

Figure 3

Appendix B:
Total Suspended Solids Analysis

INTRODUCTION

Total suspended solids (TSS) data for stormwater and combined sewer overflow (CSO) discharges are needed to estimate solids loading to the East Waterway (EW) for the particle transport model that is being used to evaluate recontamination potential. TSS data are available for CSOs from samples collected by King County and Seattle Public Utilities (SPU). These data have been compiled to determine appropriate TSS concentrations for the EW solids loading analysis. There are no site specific TSS data for storm drains discharging to the EW. Therefore, data from other similar sources have been compiled and used to assess solids loads from storm drains.

AVAILABLE TSS DATA

Herrera (2007) compiled TSS data from stormwater samples collected in western Washington for use in the Lower Duwamish lateral loads analysis (SPU 2008). Approximately 500 stormwater samples from 24 studies in western Washington and Oregon were used in the analysis. Sources of TSS information are summarized in Table B-1. This regional data set has been expanded for the EW analysis to incorporate 2007-2008 samples collected for the Portland Harbor Superfund investigation (Sanders 2011) and the SPU NPDES stormwater monitoring program (SPU 2011).

The Portland Harbor data set includes 235 samples from 53 stations in the Portland area. Samples were collected to isolate specific land use types so that representative pollutant concentrations could be identified and used in chemical loading model (Anchor and Integral 2007). Land use and sampling information are provided in Table B-2.

In 2010, SPU initiated a stormwater monitoring program as required under its National Pollutant Discharge Elimination System (NPDES) municipal stormwater permit. Under the permit, Seattle is required to monitor stormwater quality from three land use types (residential, commercial, and industrial) and to evaluate the performance of structural stormwater best management practices (BMP) in Seattle. Stormwater characterization sampling is being conducted at the following locations:

- Norfolk (industrial)
- Venema (residential)
- University (commercial).

Land use conditions and sampling information for each monitoring station are provided in Table B-3.

BMP monitoring is being conducted at two Stormfilter® catch basin installations on California Ave SW in West Seattle. Influent and effluent samples are collected to assess the performance of this system. Only the 22 influent samples have been compiled for use in the EW solids loading analysis.

This new information expands the regional TSS data set to a total of 826 stormwater samples. A box plot of TSS by study is presented in Figure B-1. The various studies have been grouped into the following categories:

- Tacoma: 191 samples from end-of-pipe samples collected at seven storm drains in the Thea Foss Waterway (Tacoma 2008).

- Contech BMP: 103 samples from Stormfilter performance studies at six locations in western Washington and Oregon (influent samples only, Contech 2004, 2006).
- SPU NDS: 62 samples from natural drainage system performance studies in Broadview and Venema neighborhoods (WA).
- SPU BMP: 47 samples from three hydrodynamic separator installations in Seattle (influent samples only).
- SPU NPDES: 67 samples from three stormwater characterization stations and two Stormfilter installations in Seattle (influent samples only).
- Portland Harbor: 235 samples from 53 stations in Portland.
- Highway BMP: 50 samples from 3 stations in Mill Creek and Auburn (WA).
- Bellevue: 65 samples from the Lakemont residential development (WA).

TSS concentrations were highly variable, ranging from <10 mg/L to nearly 1,000 mg/L. However, as shown in Figure B-1, the median and average values for most of the studies was fairly comparable, with median TSS concentrations ranging from about 40 to 60 mg/L and average TSS concentrations ranging from 60-80 mg/L. The highway BMP (median TSS of 88 mg/L and average TSS of 114 mg/L) and the Bellevue study (median TSS of 20 mg/L and average TSS of 36 mg/L) were somewhat different than the other studies.

LAND USE CALCULATIONS

The regional data set covers a wide variety of land use conditions, ranging from relatively undeveloped to highly urbanized conditions. A few of the regional samples were collected form areas that represent a single land use, but most were collected from mixed use areas. To aid in applying the regional data set to the EW drainage basin, data from the National Stormwater Quality Data Base (NSQD version 3) were compiled to evaluate potential land use differences in TSS concentrations (Pitt et. al., 2004). The NSQD data set includes stormwater samples collected from stations across the country. The data set was queried to extract only those samples that represent a single land use (e.g., single family residential, multi-family residential, commercial, industrial, vacant/park, and roadways). Results from the approximately 4,300 samples, presented in Figure B-2, indicate that there is some variability in TSS by land use. Higher median/mean TSS concentrations generally occurred in samples collected from industrial areas, while lower concentrations were observed in samples collected from open space/undeveloped areas. TSS concentrations in runoff from residential, commercial, and roadways was fairly similar.

The NSQD data were used to develop a weighting factor that could be applied to the regional data to develop TSS concentrations for individual land use categories. The weighting factor was calculated using the median TSS values for each land use category from the NSQD data set. The single family residential category was selected as the base for the weighting factor. The land use weighting factor was calculated by dividing the median value for each land use type by the median value for single family residential land use:

Single family residential:	1.00
Multi-family residential:	1.27
Commercial:	1.23
Industrial:	1.25
Open/Vacant/Park:	0.30
Roadway:	1.50

This weighting factor was then applied to the mixed use regional data set to develop TSS concentrations for individual land use types. The regional TSS sample results were deconstructed to separate data into TSS by land use by applying the weighting factor to the relative distribution of land use in the drainage basin represented by each sampling station. First, the total TSS was divided by the sum of the products of the percent land use in each category and the weighting factor to calculate a base TSS value. Then the TSS for other land use categories were calculated by multiplying the base TSS by the appropriate land use weighting factor. An example of the calculations is provided below:

- TSS in sample: 55 mg/L
- Land use: 55% residential, 10 % commercial, 5% open/park, 30 percent right-of-way

$$Base\ TSS = \frac{55}{[(0.55 * 1) + (0.1 * 1.23) + (0.05 * 0.3) + (0.3 * 1.5)]}$$

$$= 48.3 \text{ mg/L}$$

The weighting factors are then applied to calculate the TSS for each land use category:

Land Use	Weighting Factor	TSS (mg/L)
Residential	1.00	48
Commercial	1.23	59
Open/park	0.30	14
Right-of-way	1.50	72

These calculations were performed for each sample in the regional data set. Results are summarized in Figure B-3. Summary statistics are provided in Table B-3.

A range of TSS input values are needed for the PTM model sensitivity analysis. Base case, low, and high values were developed using the land use-weighted TSS concentrations from the regional data set. The high and low ranges are based on the 25th and 75th percentile concentration. A trimmed mean value was used to estimate a base case TSS concentration (Helsel and Hirsch 2002). A trimmed mean was selected for the base case to account for the fact that the TSS data are skewed. As a result, a relatively few high values greatly affect the mean value. The trimmed mean simply removes a set percentage of the values at the low and high end of the data set to adjust for data extremes. For this analysis, a 10 percent trimmed mean was used.

The Port provided data from NPDES monitoring conducted by tenants in 2005-2009 on Terminals 18, 25, and 30, which indicates that the TSS for industrial land use calculated from the regional data set may not be representative of runoff from terminal areas, which are nearly 100 percent paved (Takasaki 2011). TSS concentrations in 26 samples from terminal areas ranged from 6 to 42 mg/L, with an average of about 19 mg/L. Consequently, the Port recommended that a different data set be used for Port terminal areas. For terminal areas, available data from Portland Harbor stormwater monitoring sites that were mostly paved (greater than 90 percent impervious) and select regional data from parking lots were compiled and evaluated. A total of 141 samples fit the criteria for Port terminal areas (Table B-4). The trimmed mean for these data (43 mg/L) is less than the value used for other industrial areas in the EW study area (74 mg/L).

TSS concentrations used in the solids loading analysis are summarized in Table B-5.

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Appendix B: Tables

Table B-1: Land use and sample counts for TSS data used in the 2008 solids loading analysis.

Station ID	Location	Reference	Basin Area (acres)	Percent Impervious	Description	Industrial, total	Commercial	Residential, total	SFR	MFR	Parks/Open Space	Transportation /ROW	No. of samples
Data used in 2008 study													
NW120th St and 4th Ave NW (NS007)	Seattle, WA	Enstrom 2004, Chapman 2006	69.5	44%	Residential	0%	0%	67%	59%	7%	2%	31%	14
NW 110th St and Palatine Ave N (NS001)	Seattle, WA	Chapman 2006	10		Residential	0%	0%	64%	50%	14%	7%	30%	27
NW122nd St and Ridgemont Ave N	Seattle, WA	Engstrom 2004			Residential	0%	0%	65%	53%	12%	4%	31%	14
NW107th St and 4th Ave NW	Seattle, WA	Engstrom 2004	33.6	42%	Residential	0%	0%	66%	58%	8%	2%	32%	7
Downstream Defender BMP	Seattle, WA	Taylor and SPU 2005	208	35%	Highway, commercial, residential	0%	8%	44%	41%	3%	7%	42%	20
Stormceptor BMP	Seattle, WA	Taylor and SPU 2005	0.8	100%	Parking lot	0%	100%	0%	0%	0%	0%	0%	7
Vortechs BMP	Seattle, WA	Taylor and SPU 2005	25		Residential	0%	9%	52%	47%	5%	3%	36%	20
WSDOT Stormfilter	Seattle, WA	Tacoma and Taylor 2008	31.6	72%	Highway, vacant, residential	0%	0%	0%	0%	0%	0%	100%	18
Lakemont sand filter (Station 1 inlet)	Bellevue, WA	Bellevue and Shapiro 1999	252		Residential, commercial	0%	0%	0%	85%	0%	0%	15%	65
Contech Tualatin	Tualatin, OR	Contech 2006			Commercial	0%	100%	0%	0%	0%	0%	0%	12
Contech University Pl (TSS)	University Place, WA	Contech 2006		100%	Parking lot-department store	0%	100%	0%	0%	0%	0%	0%	18
Contech Vancouver (SSC)	Vancouver, WA	Contech 2004	4	100%	Parking lot-shopping mall	0%	100%	0%	0%	0%	0%	0%	21
Contech Portland	Portland, OR	Contech 2006			Parking lot-shopping mall	0%	100%	0%	0%	0%	0%	0%	27
Contech Lake Stevens	Lake Stevens, WA	Contech 2004	0.29	>90%	Road and bridge	0%	0%	0%	0%	0%	0%	100%	13
Contech Olympia	Olympia, WA	Contech 2006		100%	Parking-business	0%	100%	0%	0%	0%	0%	0%	14
Outfall 230	Tacoma, WA	Tacoma 2007	513		Commercial, residential	0%	59%	41%	31%	11%	0%	0%	31
Outfall 235	Tacoma, WA	Tacoma 2007	181		Commercial, residential	0%	70%	30%	24%	6%	0%	0%	33
Outfall 237A	Tacoma, WA	Tacoma 2007	2,794		Commercial, industrial, residential	18%	18%	65%	60%	5%	0%	0%	15
Outfall 237B	Tacoma, WA	Tacoma 2007	1,821		Residential	1%	12%	87%	82%	6%	0%	0%	33
Outfall 243	Tacoma, WA	Tacoma 2007	52.6		Commercial, industrial	100%	0%	0%	0%	0%	0%	0%	24
Outfall 245	Tacoma, WA	Tacoma 2007	36		Industrial	100%	0%	0%	0%	0%	0%	0%	29
Outfall 254	Tacoma, WA	Tacoma 2007	51.3		Industrial	100%	0%	0%	0%	0%	0%	0%	26
Herrera EE, SR167	Auburn, WA	Herrera 2006a	NA		Highway	0%	0%	0%	0%	0%	0%	100%	25
Herrera CAVFS I5, MP184	Mill Creek, WA	WSDOT 2006	0.5		Highway	0%	0%	0%	0%	0%	0%	100%	7
Total													520

Table B-2: Land use and sample counts for the additional TSS data used in the 2011 solids loading analysis.

Station ID	Location	Reference	Basin Area (acres)	Percent Impervious	Description	Industrial, total	Commercial	Residential, total	SFR	MFR	Parks/Open Space	Transportation /ROW	No. of samples
Data added for 2011 analysis													
45_SW1[a]	Portland, OR	Sanders 2011	NA	NA	Heavy industrial	100%	0%	0%	NA	NA	0%	0%	4
46_SW1[a]	Portland, OR	Sanders 2011	NA	NA	Heavy industrial	100%	0%	0%	NA	NA	0%	0%	4
47_SW1[a]	Portland, OR	Sanders 2011	NA	NA	Heavy industrial	100%	0%	0%	NA	NA	0%	0%	4
48_SW1[a]	Portland, OR	Sanders 2011	NA	NA	Residential	0%	0%	100%	NA	NA	0%	0%	4
50_SW1[a]	Portland, OR	Sanders 2011	NA	NA	Light industrial	0%	100%	0%	NA	NA	0%	0%	4
52_SW1[a]	Portland, OR	Sanders 2011	NA	NA	Light industrial	0%	100%	0%	NA	NA	0%	0%	4
52A_SW1[a]	Portland, OR	Sanders 2011	NA	NA	Light industrial	0%	100%	0%	NA	NA	0%	0%	4
53_SW1[a]	Portland, OR	Sanders 2011	NA	NA	Residential	0%	0%	100%	NA	NA	0%	0%	3
53A_SW1[a]	Portland, OR	Sanders 2011	NA	NA	Heavy industrial	100%	0%	0%	NA	NA	0%	0%	3
53A_SW2[a]	Portland, OR	Sanders 2011	NA	NA	Heavy industrial	100%	0%	0%	NA	NA	0%	0%	1
HWY 30A	Portland, OR	Sanders 2011	4.7	92%	Highway	61%	0%	0%	NA	NA	0%	39%	4
HWY 30B	Portland, OR	Sanders 2011	4.8	97%	Highway	3%	0%	0%	NA	NA	0%	97%	5
M1_SW1[a]	Portland, OR	Sanders 2011	NA	NA	Light industrial	0%	100%	0%	NA	NA	0%	0%	4
M2_SW1[a]	Portland, OR	Sanders 2011	NA	NA	Light industrial	0%	100%	0%	NA	NA	0%	0%	4
M3_SW1[a]	Portland, OR	Sanders 2011	NA	NA	Light industrial	0%	100%	0%	NA	NA	0%	0%	4
OF-16	Portland, OR	Sanders 2011	41.8	89%	Mixed industrial/highway	89%	0%	0%	NA	NA	0%	11%	5
OF-18	Portland, OR	Sanders 2011	413	31%	Open space, heavy industrial, highway	33%	0%	0%	NA	NA	3%	1%	5
OF-19	Portland, OR	Sanders 2011	486	22%	Open space, heavy industrial	28%	0%	0%	NA	NA	3%	2%	17
OF-22	Portland, OR	Sanders 2011	94.3	66%	Petroleum storage/undeveloped	72%	0%	0%	NA	NA	1%	2%	4
OF-22B	Portland, OR	Sanders 2011	31.6	38%	Chemical manufacturing	74%	0%	0%	NA	NA	26%	0%	5
OF-22C	Portland, OR	Sanders 2011	715	0%	Open space/forested	0%	0%	0%	NA	NA	16%	0%	7
OF-22D	Portland, OR	Sanders 2011			Parks/open space	0%	0%	0%	NA	NA	100%	0%	4
OF-49	Portland, OR	Sanders 2011	32.7	50%	Residential street	4%	0%	88%	NA	NA	5%	1%	4
OF-52C/Basin T	Portland, OR	Sanders 2011	21.5	95%	Paved parking lot	99%	0%	0%	NA	NA	1%	0%	4
OF-53	Portland, OR	Sanders 2011	21.3	53%	Residential street	4%	0%	95%	NA	NA	1%	0%	3
OF-M1	Portland, OR	Sanders 2011	71.1	74%	Various light industrial	98%	0%	0%	NA	NA	1%	0%	4
OF-M2	Portland, OR	Sanders 2011	91.3	81%	Trucking and distribution	99%	0%	0%	NA	NA	0%	0%	4
S1_SW1[a]	Portland, OR	Sanders 2011	NA	NA	Heavy industrial	100%	0%	0%	NA	NA	0%	0%	4
S2_SW1[a]	Portland, OR	Sanders 2011	NA	NA	Light industrial	0%	100%	0%	NA	NA	0%	0%	4
S5_SW1[a]	Portland, OR	Sanders 2011	NA	NA	Light industrial	0%	100%	0%	NA	NA	0%	0%	4
S6_SW1[a]	Portland, OR	Sanders 2011	NA	NA	Heavy industrial	100%	0%	0%	NA	NA	0%	0%	4
St. Johns Bridge	Portland, OR	Sanders 2011	1.3	62%	Highway	23%	0%	0%	NA	NA	0%	77%	7
WLCGED07MH2	Portland, OR	Sanders 2011	NA	NA	Heavy industrial	100%	0%	0%	NA	NA	0%	0%	3
WLCGED07SV1	Portland, OR	Sanders 2011	NA	NA	Heavy industrial	100%	0%	0%	NA	NA	0%	0%	3
WR-107	Portland, OR	Sanders 2011	8.1	35%	Manufactured gas plant	100%	0%	0%	NA	NA	0%	0%	5
WR-123	Portland, OR	Sanders 2011	75.9	80%	Heavy industrial-metals	100%	0%	0%	NA	NA	0%	0%	6
WR-14	Portland, OR	Sanders 2011	1.5	95%	Bulk fuel	100%	0%	0%	NA	NA	0%	0%	5
WR-142	Portland, OR	Sanders 2011	0.5	100%	Barge and railroad car manufacture	100%	0%	0%	NA	NA	0%	0%	6
WR-145	Portland, OR	Sanders 2011	0.7	100%	Barge and railroad car manufacture	100%	0%	0%	NA	NA	0%	0%	1
WR-147	Portland, OR	Sanders 2011	5.0	63%	Metals handling	100%	0%	0%	NA	NA	0%	0%	5
WR-161	Portland, OR	Sanders 2011	0.8	100%	Ship maintenance and repair	100%	0%	0%	NA	NA	0%	0%	6
WR-169/Basin D	Portland, OR	Sanders 2011	16.9	95%	Paved auto receiving yard	87%	0%	0%	NA	NA	13%	0%	4
WR-177/Basin M	Portland, OR	Sanders 2011	29.8	55%	Cark parking, liquid bulk storage	92%	0%	0%	NA	NA	8%	0%	4
WR-181/Basin Q	Portland, OR	Sanders 2011	18.3	60%	Vacant/former grain storage	100%	0%	0%	NA	NA	0%	0%	3
WR-183/Basin R	Portland, OR	Sanders 2011	15.1	20%	Grain storage/transport	100%	0%	0%	NA	NA	0%	0%	3
WR-20/Basin L	Portland, OR	Sanders 2011	16.6	22%	Bulk storage	98%	0%	0%	NA	NA	2%	0%	4
WR-218	Portland, OR	Sanders 2011	66.7	45%	Railyard	95%	0%	0%	NA	NA	0%	0%	4
WR-22	Portland, OR	Sanders 2011	51.9	48%	Steel manufacturing	100%	0%	0%	NA	NA	0%	0%	5
WR-384	Portland, OR	Sanders 2011	10.3	81%	Heavy industrial	100%	0%	0%	NA	NA	0%	0%	5
WR-4	Portland, OR	Sanders 2011	2.0	100%	Manufacturing	100%	0%	0%	NA	NA	0%	0%	3
WR-67	Portland, OR	Sanders 2011	5.9	97%	Industrial	100%	0%	0%	NA	NA	0%	0%	6
WR-96	Portland, OR	Sanders 2011	1.8	100%	Chemical manufacturing	100%	0%	0%	NA	NA	0%	0%	6
Yeon Mixed Use	Portland, OR	Sanders 2011	17.6	92%	Mixed	100%	0%	0%	NA	NA	0%	0%	3
University/C1	Seattle, WA	SPU 2011	187	NA	Commercial, residential	0%	41%	20%	7%	13%	2%	37%	21
Venema/R1	Seattle, WA	SPU 2011	157	NA	Residential, commercial	0%	3%	66%	61%	6%	0%	30%	12
Norfolk/I1	Seattle, WA	SPU 2011	214	NA	Industrial, commercial, residential	3%	33%	25%	24%	1%	15%	18%	12
CBSF1-IN Stormfilter, Calif Ave SW	Seattle, WA	SPU 2011	<1	100%	Arterial	0%	0%	0%	0%	0%	0%	100%	12
CBSF2-IN Stormfilter, Calif Ave SW	Seattle, WA	SPU 2011	<1	100%	Arterial	0%	0%	0%	0%	0%	0%	100%	10
Subtotal													302

a. Grab sample

Table B-3: Summary statistics for land use TSS calculations.

	Single-family	Multi-family	Commercial	Industrial	Open/park/vacant	Right-of-way
Total count	345	251	411	292	96	330
Trim count	276	195	329	230	75	266
25th percentile	24	39	31	34	8	34
Min	1	2	2	2	1	1
Max	391	343	987	780	275	587
Median	43	59	49	63	12	61
75th percentile	70	101	84	117	17	103
Mean	57	79	73	93	19	85
10th percentile	9	24	16	14	4	13
90th percentile	126	162	149	199	30	194
10% trimmed mean	48	68	58	74	13	71

Table B-4: Summary statistics for land use TSS calculations.

	Single-family	Multi-family	Commercial	Industrial	Open/park/vacant	Right-of-way
Total count	342	251	407	278	95	326
Trim count	276	195	329	230	75	266
25th percentile	24	39	32	35	8	33
Min	1	2	2	2	1	1
Max	391	343	987	780	275	587
Median	43	59	49	63	12	61
75th percentile	70	101	84	114	18	103
Mean	57	79	73	92	19	85
10th percentile	9	24	16	15	4	13
90th percentile	126	162	149	194	31	194
10% trimmed mean	48	68	58	74	13	71

Table B-5: Stormwater TSS concentrations by land use.

	Total Samples	Trimmed Samples	Low (25th percentile)	Base Case (10% trimmed mean)	High (75th percentile)
Single-family residential	342	276	24	48	70
Multi-family residential	251	195	39	68	101
Commercial	407	329	32	58	84
Industrial[a]	230	278	35	74	114
Industrial (Port)[b]	141	113	20	43	60
Vacant/park	95	75	8	13	18
Right-of-way	326	266	33	71	103

Units = mg/L

a. For industrial land use in all SPU drainage basins, except B-21, plus Port Basin B-34 and all private basins.

b. For all Port terminal areas, except B-34, plus SPU basin (B-21)

Appendix B: Figures

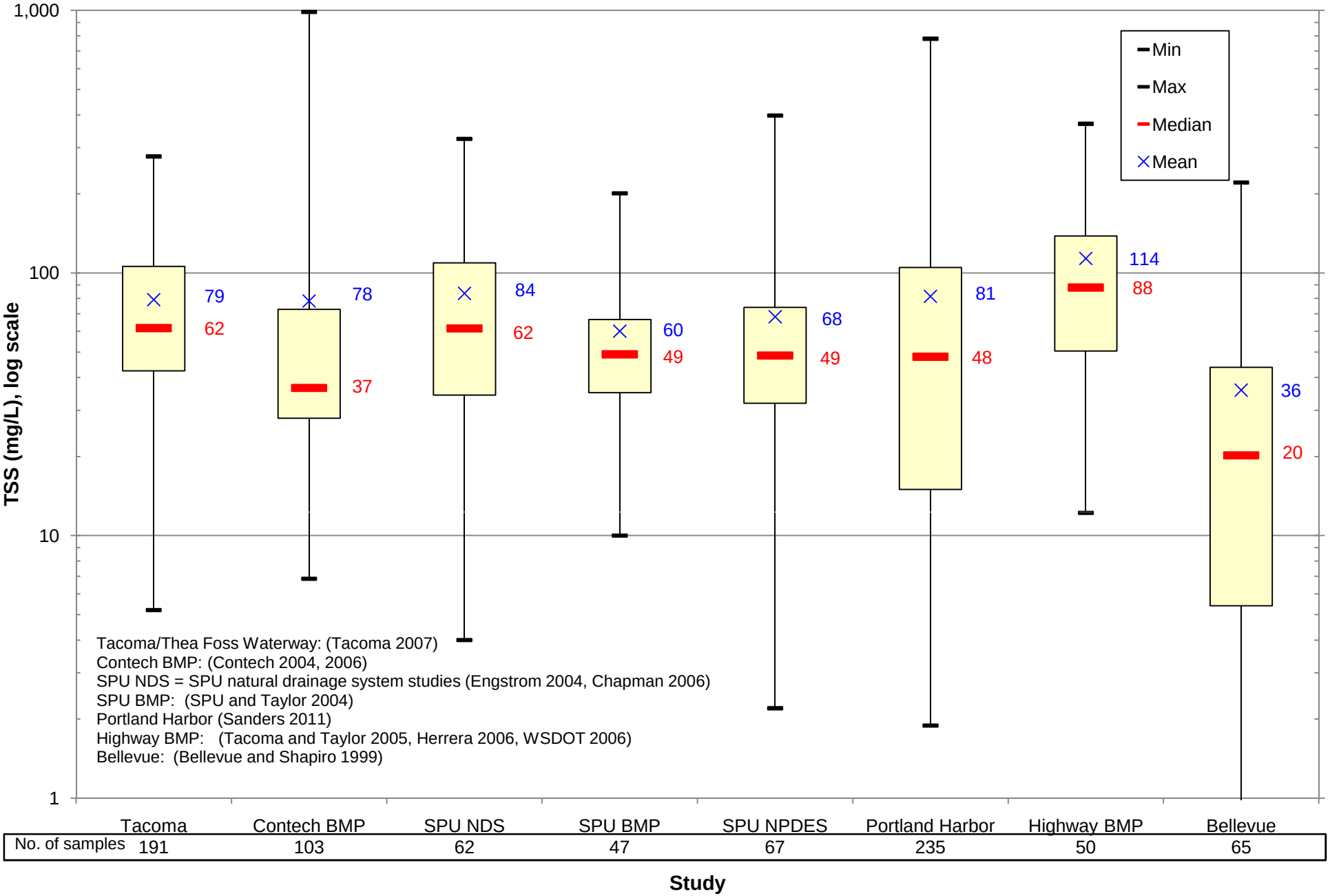


Figure B-1: Box plot of TSS for each study area.

Compiled TSS data DSA 040607_SyntheticValues_v1c.xlsx study box

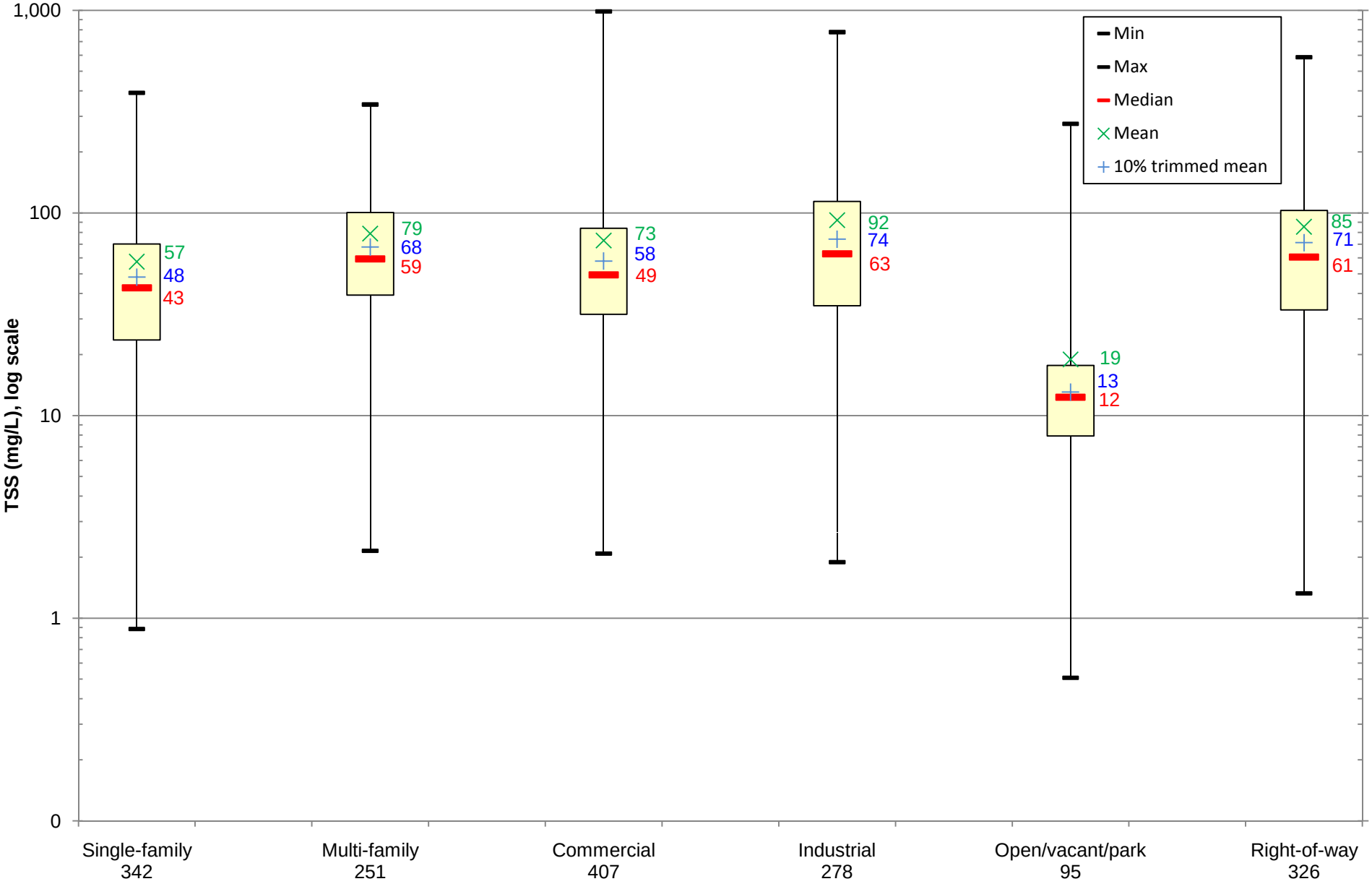
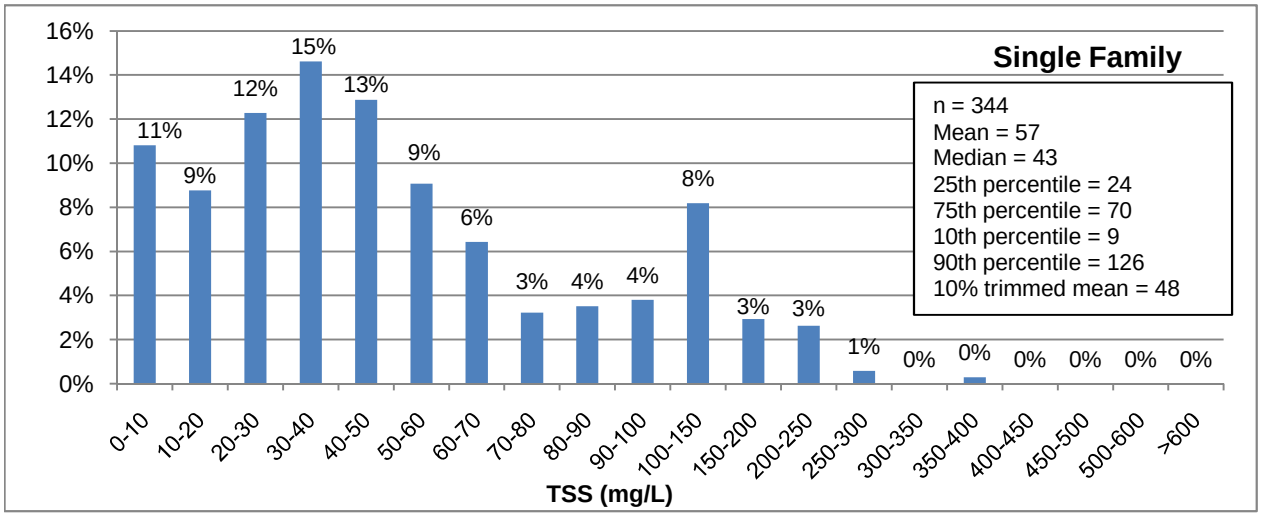
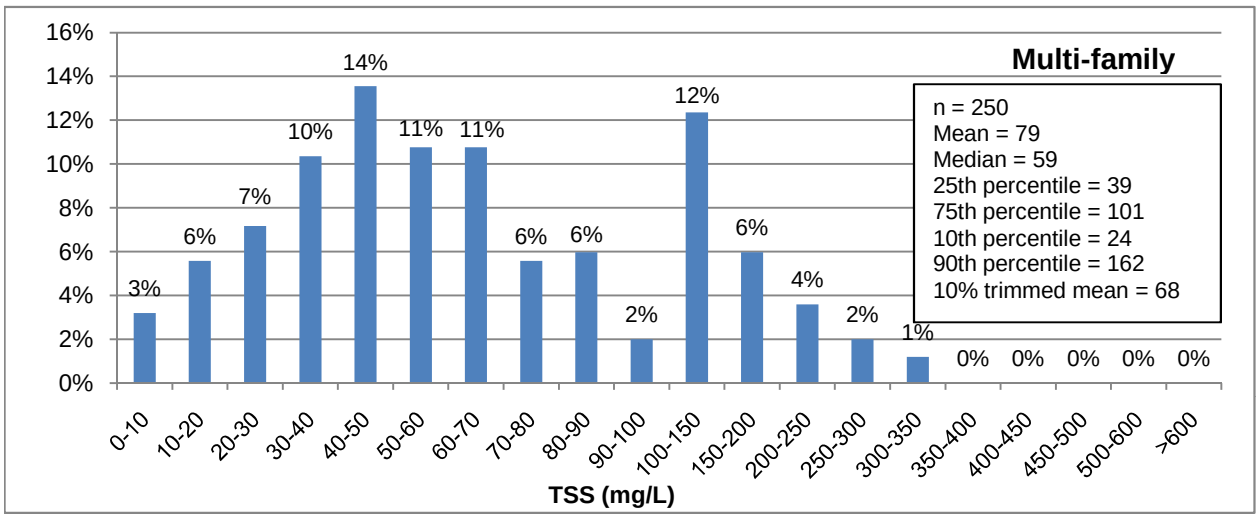


Figure B-2: Box plot of TSS concentrations by land use.

Compiled TSS data DSA 040607_SyntheticValues_v1c.xlsx PTM box

Figure B-3: TSS histograms by land use.





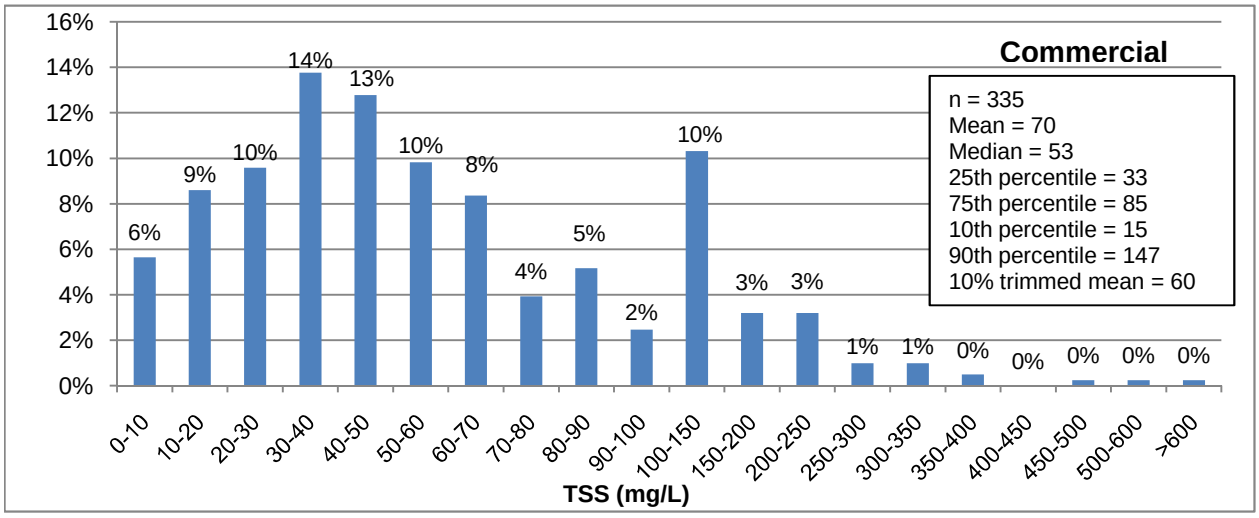
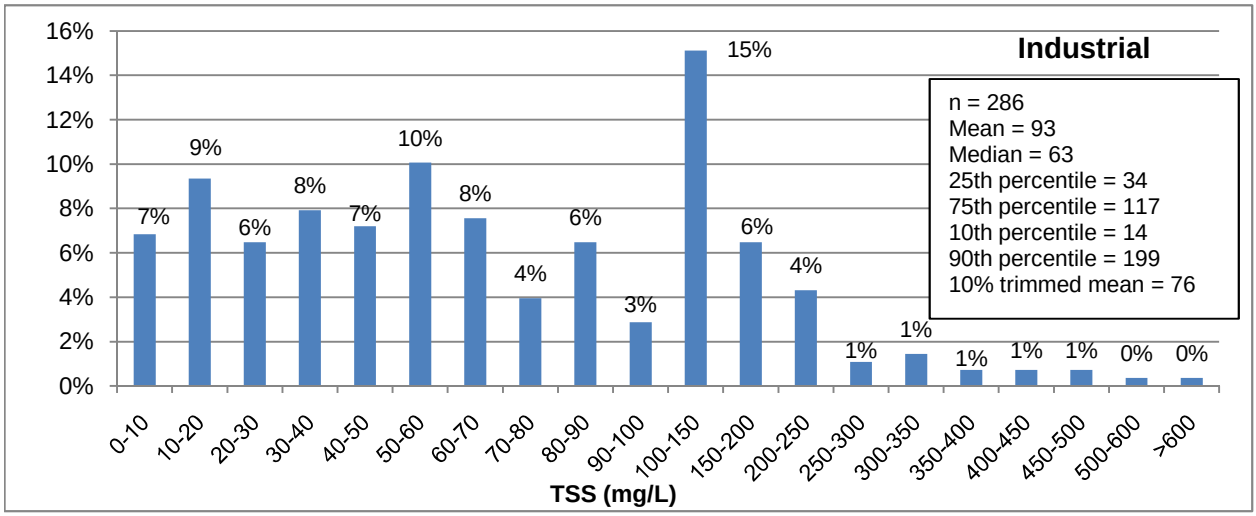
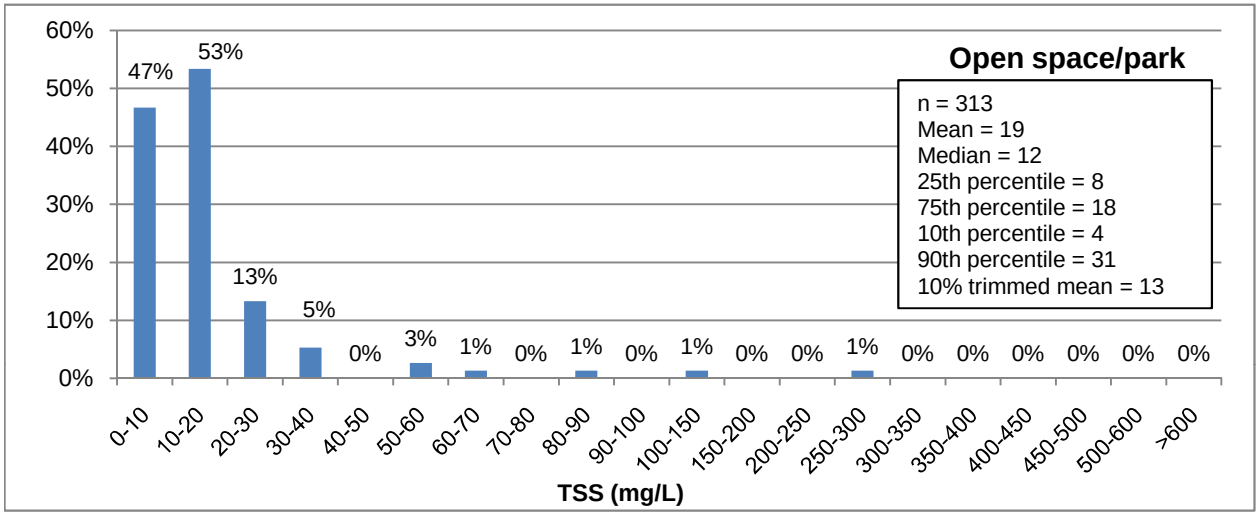


Figure B-3: TSS histograms by land use.





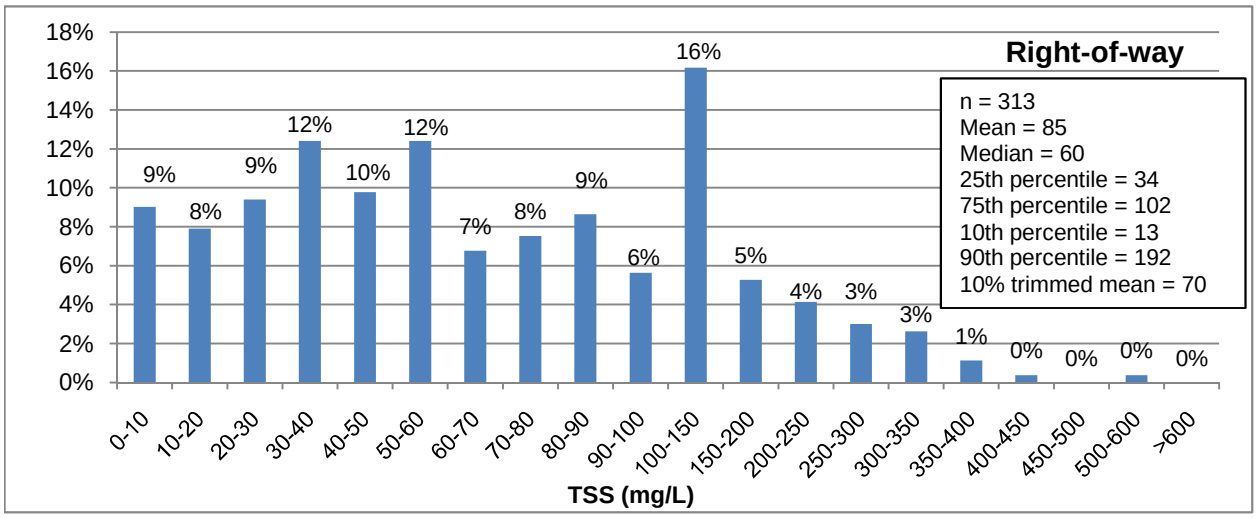
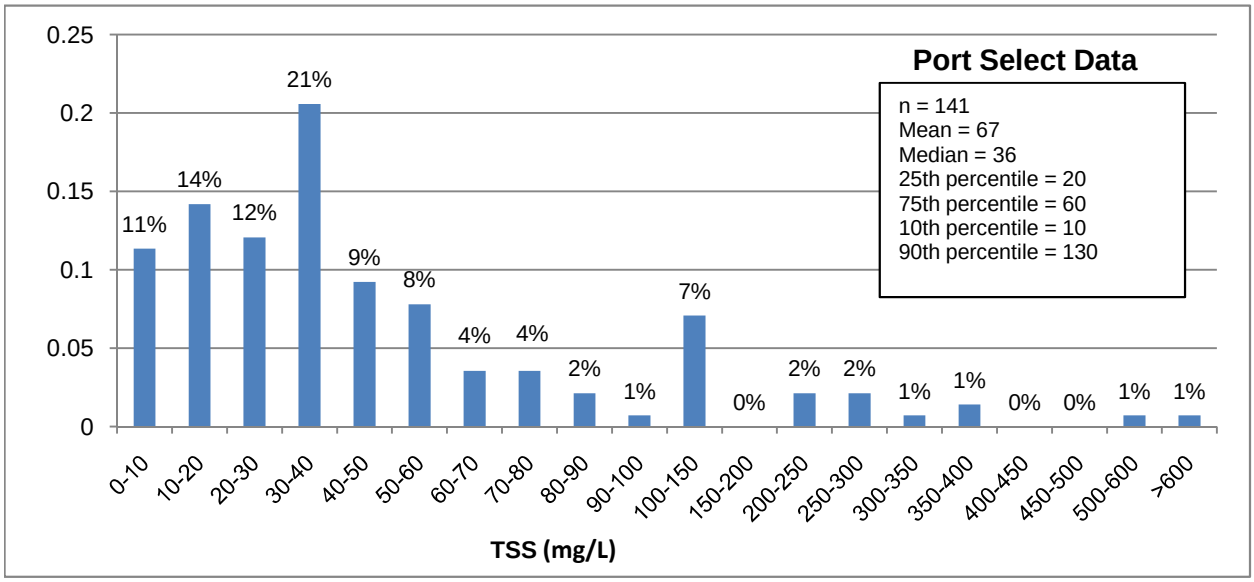
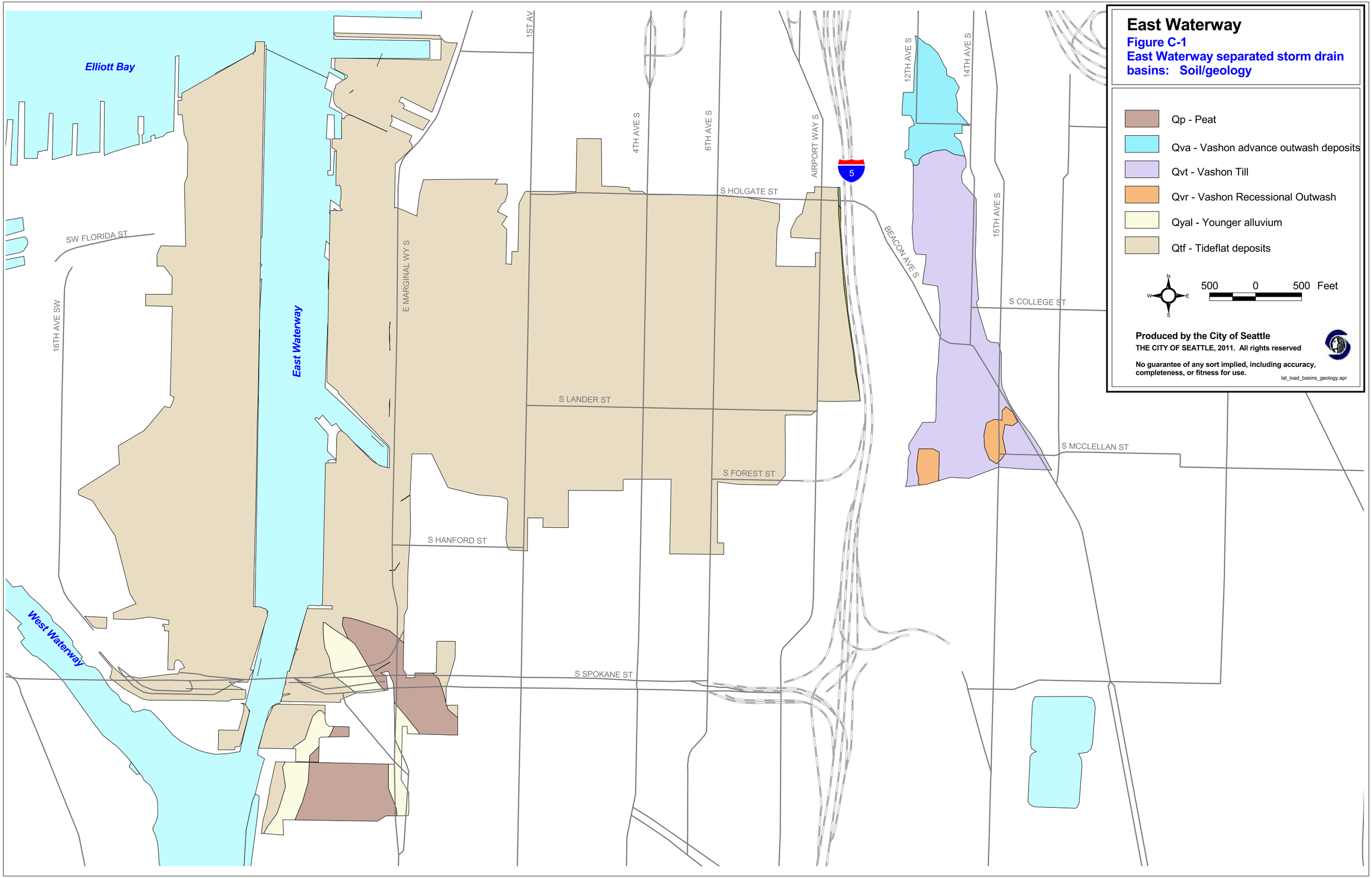


Figure B-3: TSS histograms by land use.



Includes TSS and SSC data for stormwater samples collected in western Washington and Oregon
Land use TSS values estimated using National Stormater Quality Database (Pitt et.al., 2004)
Note: 2 outliers excluded (2,300 mg/L at industrial site--broken pipe and 744 mg/L at highway site--sanding event).

Appendix C:
Surface Geology Data


East Waterway
Figure C-1
East Waterway separated storm drain basins: Soil/geology
Qp - Peat
Qva - Vashon advance outwash deposits
Qvt - Vashon Till
Qvr - Vashon Recessional Outwash
Qyal - Younger alluvium
Qtf - Tideflat deposits
500 0 500 Feet
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lat_load_basins_geology.apr
Elliott Bay
East Waterway
West Waterway
SW FLORIDA ST
16TH AVE SW
E MARGINAL WY S
1ST AV
4TH AVE S
6TH AVE S
AIRPORT WAY S
12TH AVE S
14TH AVE S
15TH AVE S
BEACON AVE S
S HOLGATE ST
S LANDER ST
S FOREST ST
S HANFORD ST
S SPOKANE ST
S COLLEGE ST
S MCCLELLAN ST
5

Table C-1: East Waterway separated storm drain basin, soil/geology classification for HSPF model.

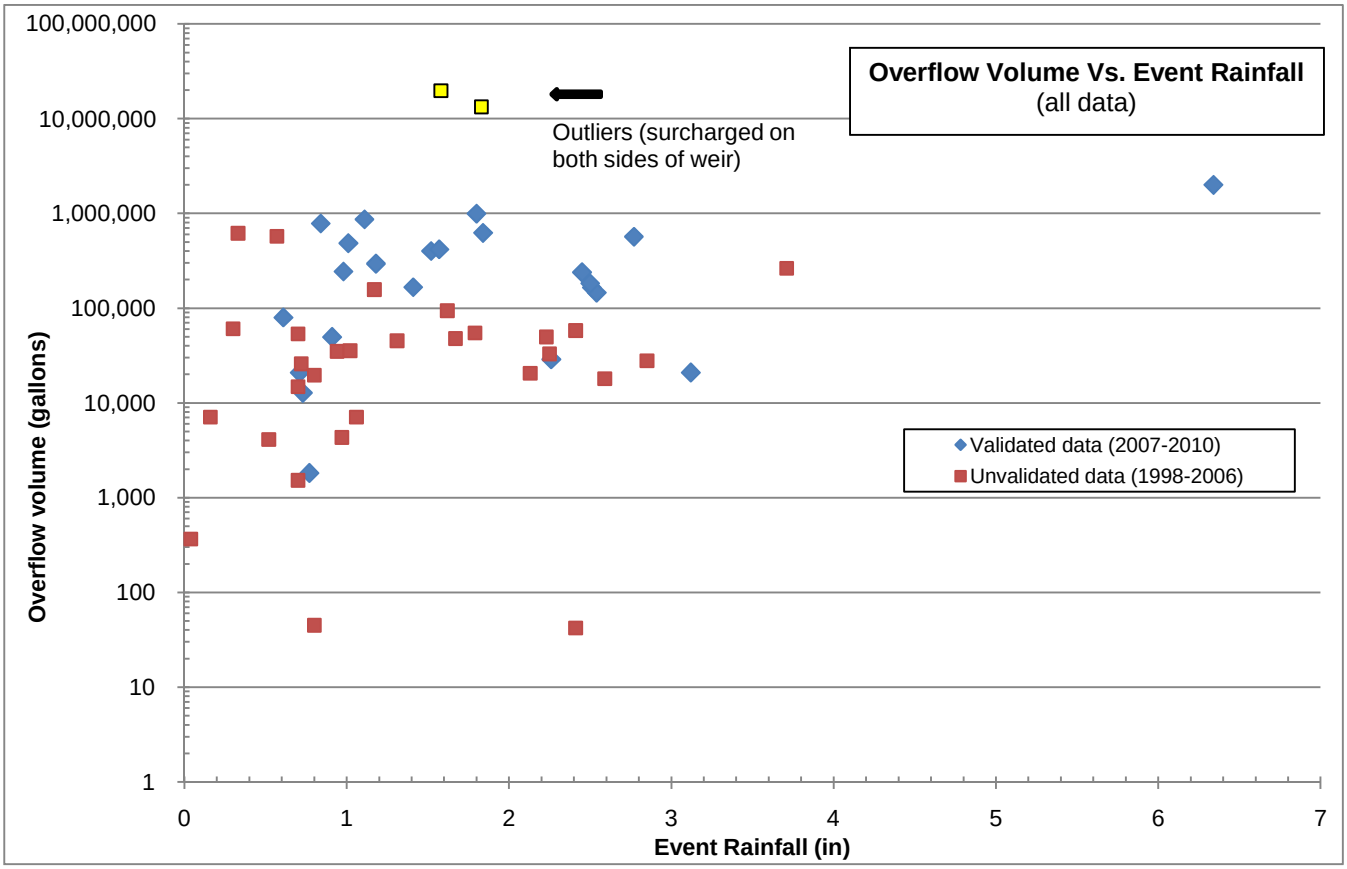
Symbol	Description	More_description	Hydrologic_Class
Qvt	Vashon till	Compact diamict of silt, sand, and subrounded to well-rounded gravel, glacially transported and deposited under ice	Till
Qva	Vashon advance outwash deposits	Well-sorted sand and gravel deposited by streams issuing from advancing ice sheet	Outwash
Qvr	Vashon recessional outwash	Stratified sand and gravel, moderately sorted to well sorted, and less common silty sand and silt.	Outwash
Qyal	Younger alluvium	Sand, silt, gravel, and cobbles deposited by streams and running water	Alluvium
Qp	Peat		Wetland soil
Qtf	Tideflat deposits	Silt, sand, and organic sediment and detritus with some shells, historically exposed in broad coastal benches at low tide and now fill covered.	Till

Appendix D:
S Hinds St CSO/SD combined sewer overflow records

Table D-1: S Hinds St CSO/SD(#107) combined sewer overflow records (1998-2010).

Date	CSO #	Rainfall (inches)	Storm Duration (hours)	Overflow Duration (hrs)	Volume (gallons)	Volume (ft^3)	Volume (Mgal)	Volume Minus Outliers (gallons)
12/02/98	107	0.70	15.4	7.0	53,503	7,153	0.05	53,503
12/13/98	107	1.62	34.9	23.0	93,855	12,547	0.09	93,855
12/25/98	107	0.80	9.8	4.0	19,588	2,619	0.02	19,588
12/27/98	107	0.72	15.4	8.0	25,871	3,459	0.03	25,871
01/17/99	107	0.94	22.8	8.0	35,007	4,680	0.04	35,007
01/18/99	107	0.52	13.1	2.0	4,108	549	0.00	4,108
01/20/99	107	0.04	2.8	1.0	365	49	0.00	365
01/21/99	107	0.16	8.6	2.0	7,076	946	0.01	7,076
02/27/99	107	1.02	16.6	10.0	35,586	4,757	0.04	35,586
11/11/99	107	2.85	55.2	4.0	27,883	3,728	0.03	27,883
02/01/00	107	1.31	14.4	8.0	45,173	6,039	0.05	45,173
06/11/01	107	1.17	44.4	5.0	157,002	20,990	0.16	157,002
08/22/01	107	1.79	63.1	6.0	54,862	7,335	0.05	54,862
11/13/01	107	3.71	108.2	25.0	263,820	35,270	0.26	263,820
11/19/01	107	2.59	89.7	3.0	17,962	2,401	0.02	17,962
12/13/01	107	0.30	40.6	8.0	60,656	8,109	0.06	60,656
12/16/01	107	2.23	37.5	12.0	49,711	6,646	0.05	49,711
01/02/02	107	0.70	46.6	2.0	14,798	1,978	0.01	14,798
01/03/02	107	0.70	46.6	1.0	1,522	203	0.00	1,522
01/05/02	107	2.41	80.3	1.0	42	6	0.00	42
01/06/02	107	2.41	80.3	18.0	58,122	7,770	0.06	58,122
01/25/02	107	2.25	84.3	7.0	32,874	4,395	0.03	32,874
10/20/03	107	2.13	46.0	8.0	20,591	2,753	0.02	20,591
01/07/04	107	**1.83**	85	23.0	**13,322,604**	1,781,099	13.32	439,685
01/29/04	107	**1.58**	67	26.0	**19,710,696**	2,635,123	19.71	439,685
10/08/04	107	0.80	30	1.0	45	6	0.00	45
10/17/04	107	0.57	29	4.0	572,604	76,551	0.57	572,604
12/08/04	107	0.97	34	3.0	4,323	578	0.00	4,323
12/10/04	107	1.67	38	3.0	47,740	6,382	0.05	47,740
12/11/04	107	1.06	18	2.0	7,091	948	0.01	7,091
03/27/05	107	0.33	31.0	12.0	617,204	82,514	0.62	617,204
12/02/07	107	**6.34**	178.0	29.0	2,008,192	268,475	2.01	2,008,192
03/23/08	107	0.77	27.0	1.0	1,820	243	0.00	1,820
11/06/08	107	1.84	29.0	12.0	625,537	83,628	0.63	625,537
01/07/09	107	2.51	79.9	5.8	165,998	22,192	0.17	165,998
04/02/09	107	0.98	59.6	1.8	244,327	32,664	0.24	244,327
05/05/09	107	1.52	67.7	2.5	402,134	53,761	0.40	402,134
10/14/09	107	0.73	28.7	1.0	12,772	1,708	0.01	12,772
10/16/09	107	2.45	96.4	16.0	239,803	32,059	0.24	239,803
10/26/09	107	1.01	22.5	4.9	486,610	65,055	0.49	486,610
11/06/09	107	2.54	49.3	12.6	146,038	19,524	0.15	146,038
11/16/09	107	1.57	50.1	13.0	418,365	55,931	0.42	418,365
11/19/09	107	2.50	105.9	2.1	183,001	24,465	0.18	183,001
11/22/09	107	0.84	13.6	3.1	785,230	104,977	0.79	785,230
11/26/09	107	1.18	17.4	3.8	295,660	39,527	0.30	295,660
01/04/10	107	0.61	14.7	1.3	79,758	10,663	0.08	79,758
01/08/10	107	0.91	23.3	1.6	49,692	6,643	0.05	49,692
01/11/10	107	1.11	19.7	6.1	868,057	116,051	0.87	868,057
01/13/10	107	2.26	71.2	1.0	28,842	3,856	0.03	28,842
01/15/10	107	3.12	112.9	1.7	20,952	2,801	0.02	20,952
04/21/10	107	0.71	27.8	1.1	20,883	2,792	0.02	20,883
09/17/10	107	2.77	85.2	28.7	569,936	76,195	0.57	569,936
10/09/10	107	1.41	27.6	3.0	166,775	22,296	0.17	166,775
11/01/10	107	1.80	53.9	7.9	997,810	133,397	1.00	997,810

No documentation of data quality from contractor. Data quality unknown.



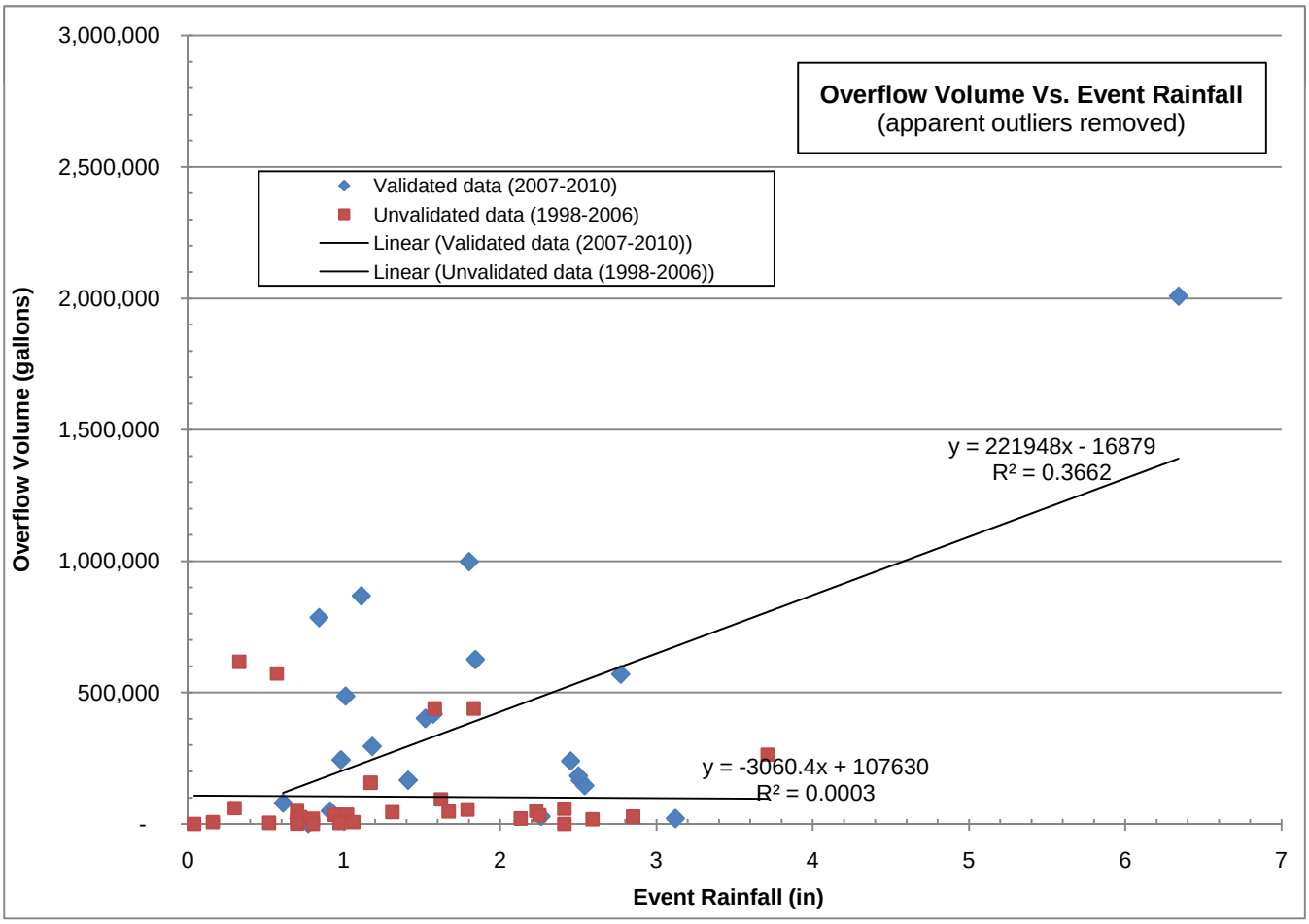


Figure D-1: S Hinds St CSO overflow versus rainfall scatter plots.

Hinds_CSO_statistics-bs.xlsx event scatters

Appendix E:
Particle Size Distribution Data

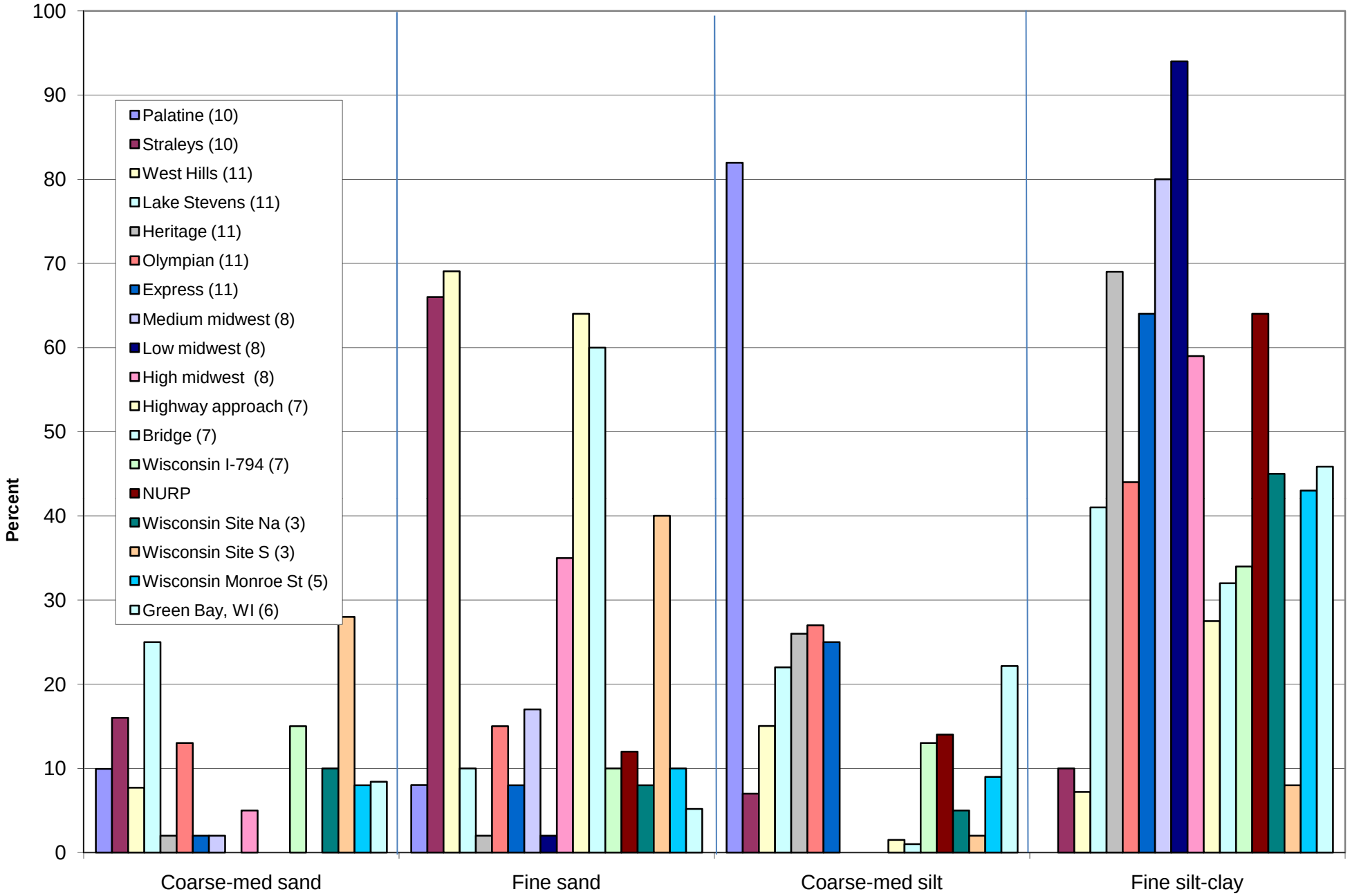


Figure E-1: PSD in urban stormwater samples collected in the U.S.

psd analysis-v2.xls Chart1 (2)

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ATTACHMENT 2

Memorandum

King County

To: Anchor QEA LLC

CC: Jeff Stern, Bruce Nairn, Doug Hotchkiss, Kym Takasaki, Pete Rude

From: Debra Williston, King County DNRP

Date: 12/22/2010

Re: King County East Waterway (EW) Combine Sewer Overflow Total Suspended Solids and Discharge Data for use in EW Supplemental Remedial Investigation and Sediment Transport Modeling Efforts

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This memo outlines the total suspended solids (TSS) data and discharge frequency and volume data from King County Combine Sewer Overflows (CSOs) that discharge into the East Waterway (EW). The two King County CSOs that discharge into EW are Hanford #2 and Lander. These data are being submitted to support the EW Supplemental Remedial Investigation (SRI) and sediment transport modeling efforts.

TSS Data

The TSS data for the two King County CSOs in EW are included as Attachment A to this memo and summary statistics are presented below. All TSS data are based on Standard Method 2540-D (using standard 1 µ filter).

TSS (mg/L) Summary Stats	
86	average
81	geomean
36.4	min
156	max
94.5	median
65.3	25th percentile
106	75th percentile
109.2	90th percentile
27	count

Data from Hanford #2 CSO includes eight sampling events collected between 1996-1997 for the King County Water Quality Assessment of the Duwamish River and Elliott Bay (King County 1999), two sampling events in 2004, and 10 sampling events collected from 2007-2009 as part of the most recent characterization of King County Duwamish River CSOs (King County 2007). There are a total of 14 duplicate samples collected during these events. All duplicate results were first averaged prior to calculating summary statistics shown above.

Data for Lander CSO includes seven sampling events collected from 2008-2009 as part of the most recent characterization of King County Duwamish River CSOs (King County 2007).

King County recommends the same TSS concentrations be applied to both Hanford #2 and Lander CSOs. This is because the two basins are connected, there is a smaller dataset available for Lander to calculate TSS loads, and what data are available do not suggest higher TSS loads than Hanford #2. King County reviewed TSS data for other CSOs within the Duwamish Basin and found some basins have higher than average TSS concentrations than Hanford #2 and Lander, and therefore, we do not feel it would be appropriate to use the TSS dataset from all Duwamish CSO basins combined.

Discharge Frequency and Volume Data

King County event frequency and volume discharge data for the County's two EW CSOs (Hanford #2 and Lander) and for Kingdome CSO, which is just north of the EW are presented in Table 1. Table 1 presents overall average frequency and volumes for each of these CSOs for the period of June 2000-December 2009. Table 2 presents frequency and volume for each CSO by year. Table 3 presents monthly average frequencies and volumes for each CSO. The annual average data was derived from the data presented in Table 3.

If you have any questions regarding these data, please let me know.

King County. 1999. King County Combined Sewer Overflow Water Quality Assessment for the Duwamish River and Elliott Bay; Appendix A: Problem Formulation, Analysis Plan, and Field Sampling Work Plan A3: Field Sampling Work Plan. Prepared by Parametrix, Inc. and King County DNR, Seattle, WA.

King County. 2007. Duwamish River Basin Combined Sewer Overflow Survey Sampling and Analysis Plan. Prepared by King County DNRP, Seattle, WA.

Table 1. Annual Average CSO Frequencies and Volumes for 2000-2009 period for Discharges to the East Waterway and Vicinity.

Station	Annual Average CSO Discharge Frequency (June 2000-Dec2009) (events/year)	Annual Average CSO Discharge Volume (June 2000-Dec2009) (million gallons/year)
Hanford #2	13.6	74.3
Kingdome (a)	6.2	17.4
Lander	6.7	39.8

(a) Value is based on data from Nov. 2004-Dec.2009. Prior to the 1988 separation project, the combined system overflowed at the Connecticut regulator (but discharged to same outfall location). CSO discharge monitoring data from the 1998-2003 monitoring periods are not available. Kingdome discharges reported as not measured from June 2005-Nov. 2006

Table 2. Yearly CSO Volume and Event Frequency Summary for Discharges to the EW and vicinity.

		1981-1983 Baseline		2001 (Jan-Dec)		2002 (Jan-Dec)		2003 (Jan-Dec)		2004 (Jan-Dec)	
Station	**Discharge Number**	**Vol. (mg)**	**Events**	**Vol. (mg)**	**Events**	**Vol. (mg)**	**Events**	**Vol. (mg)**	**Events**	**Vol. (mg)**	**Events**
Connecticut/Kingdome (a)	029	90	23	1.42	3	1.15	1	0.00	0	1.26	2
Hanford #2	031	644	63	91.15	8	77.10	10	57.93	12	78.23	16
Lander	030	143	22	15.49	7	38.97	9	112.60	8	2.04	2

(a) Values shown represent totals listed in annual reports for discharge #029, including "Connecticut" and "Kingdome" discharges.

Highlighted values are different than those printed in the CSO Annual Report because they are only for Hanford #2 and are not a combination of Hanford #1 and Hanford #2.

Table 2. Yearly CSO Volume and Event Frequency Summary for Discharges to the EW and vicinity.

Station	Discharge Number	2005 (Jan-Dec)		2006 (Jan-Dec)		2007 (Jan-Dec)		2008 (Jan-Dec)		2009 (Jan-Dec)	
		Vol. (mg)	Events	Vol. (mg)	Events	Vol. (mg)	Events	Vol. (mg)	Events	Vol. (mg)	Events
Connecticut/Kingdome (a)	029	27.25	5	17.60	4	28.55	5	0.23	1	3.54	8
Hanford #2	031	91.33	15	183.06	26	65.60	12	23.94	8	36.34	17
Lander	030	15.53	2	43.73	13	41.51	4	4.07	3	111.67	16

Table 3. Monthly Average CSO Event Frequency and Volume Summary for Discharges to the EW and Vicinity.

June 2000-May 2009

Station	DSN	Year	June	July	August	September	October	November	December	January	February	March
CSO Discharge Frequency (# events)												
Connecticut	29	1999-2000	0	0	0	0	0	0	0	0	0	0
Connecticut	29	2000-2001	0	0	0	0	0	0	0	0	0	0
Connecticut	29	2001-2002	0	0	0	0	2	0	1	1	0	0
Connecticut	29	2002-2003	0	0	0	0	0	0	0	0	0	0
Kingdome		2003-2004	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
Kingdome		2004-2005	NM	NM	NM	NM	NM	0	2	2	1	1
Kingdome		2005-2006	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
Kingdome		2006-2007	NM	NM	NM	NM	NM	NM	4	3	0	0
Kingdome		2007-2008	0	0	0	0	0	0	1	0	0	0
Kingdome		2008-2009	0	0	0	0	0	1	0	1	0	0
Kingdome		2009	0	0	0	1	2	3	0			
Average			0	0	0	0.333333333	0.666666667	1	1.4	1.5	0.25	0.25
Hanford #2	31	1999-2000	1	0	0	0	0	5	3	2	3	3
Hanford #2	31	2000-2001	1	0	0	0	2	2	1	2	0	0
Hanford #2	31	2001-2002	0	0	0	0	1	3	2	3	2	1
Hanford #2	31	2002-2003	1	0	0	0	0	1	1	8	0	1
Hanford #2	31	2003-2004	0	0	0	0	0	2	1	3	1	1
Hanford #2	31	2004-2005	0	0	3	1	2	1	2	1	1	1
Hanford #2	31	2005-2006	1	0	0	0	1	5	2	6	2	1
Hanford #2	31	2006-2007	2	0	0	0	0	10	4	3	0	0
Hanford #2	31	2007-2008	0	0	0	2	0	3	2	1	0	2
Hanford #2	31	2008-2009	0	0	2	0	0	2	1	1	0	0
Hanford #2	31	2009	0	0	0	1	3	6	1			
Average			0.5	0	0.5	0.4	0.9	3.5	1.7	3.111111111	0.666666667	0.777777778
Lander St. #2	30	1999-2000	0	0	0	0	0	3	2	1	0	0
Lander St. #2	30	2000-2001	0	0	0	0	0	0	0	0	0	0
Lander St. #2	30	2001-2002	0	0	1	0	0	4	2	3	2	1
Lander St. #2	30	2002-2003	1	0	0	0	0	0	1	3	0	1
Lander St. #2	30	2003-2004	0	0	0	0	2	2	0	1	0	0
Lander St. #2	30	2004-2005	0	0	0	0	0	0	1	1	0	0
Lander St. #2	30	2005-2006	0	0	0	0	0	0	1	3	1	0
Lander St. #2	30	2006-2007	0	0	0	0	0	5	4	2	0	0
Lander St. #2	30	2007-2008	0	0	0	0	0	0	1	0	0	1
Lander St. #2	30	2008-2009	0	0	0	0	0	2	0	2	0	0
Lander St. #2	30	2009	0	0	0	1	3	5	1			
Average			0.1	0	0.1	0.1	0.5	1.8	1.1	1.666666667	0.333333333	0.333333333

Table 3. Monthly Average CSO Event Frequency and Volume Summary for Discharges to the EW and Vicinity.

June 2000-May 2009

Station	DSN	Year	April	May	Total	Baseline (1981-1983)
CSO Discharge Frequency (# events)						
Connecticut	29	1999-2000	0	0	0	34
Connecticut	29	2000-2001	0	0	0	
Connecticut	29	2001-2002	0	0	4	29
Connecticut	29	2002-2003	0	0	0	23
Kingdome		2003-2004	NM	NM	NM	
Kingdome		2004-2005	0	1	7	
Kingdome		2005-2006	NM	NM	0	
Kingdome		2006-2007	0	1	8	
Kingdome		2007-2008	0	0	1	
Kingdome		2008-2009	0	1	3	
Kingdome		2009			6	
Average			0	0.75	6.15	
Hanford #2	31	1999-2000	0	0	17	40
Hanford #2	31	2000-2001	0	0	8	
Hanford #2	31	2001-2002	1	0	13	
Hanford #2	31	2002-2003	0	0	12	
Hanford #2	31	2003-2004	0	2	10	
Hanford #2	31	2004-2005	2	1	15	28
Hanford #2	31	2005-2006	1	0	19	28
Hanford #2	31	2006-2007	0	2	21	
Hanford #2	31	2007-2008	0	0	10	
Hanford #2	31	2008-2009	2	3	11	
Hanford #2	31	2009			11	
Average			0.666666667	0.888888889	13.61	
Lander St. #2	30	1999-2000	0	0	6	29
Lander St. #2	30	2000-2001	0	0	0	
Lander St. #2	30	2001-2002	1	0	14	26
Lander St. #2	30	2002-2003	0	0	6	22
Lander St. #2	30	2003-2004	0	0	5	22
Lander St. #2	30	2004-2005	0	0	2	26
Lander St. #2	30	2005-2006	0	0	5	26
Lander St. #2	30	2006-2007	0	1	12	
Lander St. #2	30	2007-2008	0	0	2	
Lander St. #2	30	2008-2009	2	2	8	
Lander St. #2	30	2009			10	
Average			0.333333333	0.333333333	6.7	

Table 3. Monthly Average CSO Event Frequency and Volume Summary for Discharges to the EW and Vicinity.

June 2000-May 2009

Station	DSN	Year	June	July	August	September	October	November	December	January	February	March
CSO Discharge Volume (million gallons)												
Station	**DSN**	**Year**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**January**	**February**	**March**
Connecticut	29	1999-2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Connecticut	29	2000-2001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Connecticut	29	2001-2002	<0.01	<0.01	<0.01	<0.01	1.34	<0.01	0.08	1.15	<0.01	<0.01
Connecticut	29	2002-2003	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Kingdome		2003-2004	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
Kingdome		2004-2005	NM	NM	NM	NM	NM	0.00	1.26	18.45	2.74	5.91
Kingdome		2005-2006	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
Kingdome		2006-2007	NM	NM	NM	NM	NM	NM	17.60	0.84	0.00	0.00
Kingdome		2007-2008	0.00	0.00	0.00	0.00	0.00	0.00	27.62	0.00	0.00	0.00
Kingdome		2008-2009	0.00	0.00	0.00	0.00	0.00	0.23	0.00	0.27	0.00	0.00
Kingdome		2009	0.00	0.00	0.00	0.13	1.55	0.21	0.00			
Average			0.00	0.00	0.00	0.04	0.52	0.11	9.30	4.89	0.69	1.48
Hanford #2	31	1999-2000	9.34	0.00	0.00	0.00	0.00	17.70	5.61	0.41	11.21	2.21
Hanford #2	31	2000-2001	0.65	0.00	0.00	0.00	1.96	1.43	0.83	3.30	0.00	0.00
Hanford #2	31	2001-2002	0.00	0.00	0.00	0.00	0.66	49.11	38.08	28.79	22.79	5.48
Hanford #2	31	2002-2003	0.01	0.00	0.00	0.00	0.00	1.08	14.16	34.12	0.00	7.01
Hanford #2	31	2003-2004	0.00	0.00	0.00	0.00	0.00	16.03	0.77	38.04	3.19	1.31
Hanford #2	31	2004-2005	0.00	0.00	6.85	0.84	2.34	5.66	18.27	23.46	2.65	11.55
Hanford #2	31	2005-2006	0.46	0.00	0.00	0.00	1.82	13.64	30.58	67.50	3.69	0.01
Hanford #2	31	2006-2007	0.91	0.00	0.00	0.00	0.00	64.49	45.85	21.61	0.00	0.00
Hanford #2	31	2007-2008	0.00	0.00	0.00	3.58	0.00	2.80	35.64	0.73	0.00	1.79
Hanford #2	31	2008-2009	0.00	0.00	1.62	0.00	0.00	17.52	2.28	0.67	0.00	0.00
Hanford #2	31	2009	0.00	0.00	0.00	0.35	3.52	27.61	0.46			
Average			0.20	0.00	0.85	0.48	1.03	19.94	18.69	24.25	3.59	3.02
Lander St. #2	30	1999-2000	0.00	0.00	0.00	0.00	0.00	0.62	0.53	0.04	0.00	0.00
Lander St. #2	30	2000-2001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lander St. #2	30	2001-2002	0.00	0.00	0.93	0.00	0.00	13.38	1.17	30.22	4.65	1.85
Lander St. #2	30	2002-2003	0.88	0.00	0.00	0.00	0.00	0.00	0.43	16.93	0.00	6.11
Lander St. #2	30	2003-2004	0.00	0.00	0.00	0.00	79.58	9.98	0.00	1.97	0.00	0.00
Lander St. #2	30	2004-2005	0.00	0.00	0.00	0.00	0.00	0.00	0.07	4.25	0.00	0.00
Lander St. #2	30	2005-2006	0.00	0.00	0.00	0.00	0.00	0.00	11.29	12.45	2.70	0.00
Lander St. #2	30	2006-2007	0.00	0.00	0.00	0.00	0.00	12.92	15.67	10.65	0.00	0.00
Lander St. #2	30	2007-2008	0.00	0.00	0.00	0.00	0.00	0.00	30.16	0.00	0.00	2.40
Lander St. #2	30	2008-2009	0	0	0	0	0	1.67	0	2.11	0	0
Lander St. #2	30	2009	0	0	0	0.01	5.52	84.38	6.38			
Average			0.09	0.00	0.09	0.00	8.51	12.23	6.52	8.73	0.82	1.15

DSN - Discharge Serial Number
CSO - Combined Sewer Overflow
NM - not measured

Table 3. Monthly Average CSO Event Frequency and Volume Summary for Discharges to the EW and Vicinity.

June 2000-May 2009

Station	DSN	Year	April	May	Total	Baseline (1981-1983)
CSO Discharge Volume (million gallons)						
Station	**DSN**	**Year**	**April**	**May**	**Total**	**Baseline (1981-1983)**
Connecticut	29	1999-2000	0.00	0.00	0.00	90
Connecticut	29	2000-2001	0.00	0.00	0.00	
Connecticut	29	2001-2002	<0.01	<0.01	2.57	90
Connecticut	29	2002-2003	<0.01	<0.01	0.00	90
Kingdome		2003-2004	NM	NM	0.00	
Kingdome		2004-2005	0.00	0.16	28.51	
Kingdome		2005-2006	NM	NM	0.00	
Kingdome		2006-2007	0.00	0.10	18.54	
Kingdome		2007-2008	0.00	0.00	27.62	
Kingdome		2008-2009	0.00	1.38	1.89	
Kingdome		2009			1.89	
Average			0.00	0.41	17.43	
Hanford #2	31	1999-2000	0.00	0.00	46.48	644
Hanford #2	31	2000-2001	0.00	0.00	8.17	
Hanford #2	31	2001-2002	4.79	0.00	149.70	
Hanford #2	31	2002-2003	0.00	0.00	56.38	
Hanford #2	31	2003-2004	0.00	1.73	61.07	
Hanford #2	31	2004-2005	5.33	1.84	78.78	
Hanford #2	31	2005-2006	0.61	0.00	118.33	
Hanford #2	31	2006-2007	0.00	1.97	134.83	
Hanford #2	31	2007-2008	0.00	0.00	44.55	
Hanford #2	31	2008-2009	1.31	2.42	25.82	
Hanford #2	31	2009			31.94	
Average			1.34	0.88	74.26	
Lander St. #2	30	1999-2000	0.00	0.00	1.19	143
Lander St. #2	30	2000-2001	0.00	0.00	0.00	
Lander St. #2	30	2001-2002	0.94	0.00	53.15	143
Lander St. #2	30	2002-2003	0.00	0.00	24.35	143
Lander St. #2	30	2003-2004	0.00	0.00	91.53	143
Lander St. #2	30	2004-2005	0.00	0.00	4.32	143
Lander St. #2	30	2005-2006	0.00	0.00	26.44	143
Lander St. #2	30	2006-2007	0.00	0.71	39.94	
Lander St. #2	30	2007-2008	0.00	0.00	32.56	
Lander St. #2	30	2008-2009	3.78	9.49	17.04	
Lander St. #2	30	2009			96.29	
Average			0.52	1.13	39.80	

DSN - Discharge Serial Number
CSO - Combined Sewer Overflow
NM - not measured

Attachment A: King County TSS Data (all 1.0 µ method) for Hanford #2 and Lander CSOs

SITE	LOCATOR	COLLECTDATE	TIMESPAN	SAMPLE NUM	PARMNAME	NUMVALUE	UNITS	MDL	RDL	Value with Dups averaged
Hanford #2	CS030	12/2/2007 11:24	2	L44133-3	Total Suspended Solids	79	mg/L	5	10	67.85
Hanford #2	CS030	12/2/2007 11:24	2	L44133-4	Total Suspended Solids	56.7	mg/L	3.3	6.7	
Hanford #2	CS030	8/20/2008 1:35	1	L45811-3	Total Suspended Solids	53	mg/L	5	10	53
Hanford #2	CS030	11/4/2008 5:34	2	L46418-3	Total Suspended Solids	62.5	mg/L	2.5	5	62.5
Hanford #2	CS030	11/6/2008 16:05	2	L46918-3	Total Suspended Solids	156	mg/L	5	10	156
Hanford #2	CS030	4/2/2009 19:28	0.5	L47597-3	Total Suspended Solids	109	mg/L	7.1	14	94.5
Hanford #2	CS030	4/2/2009 19:28	0.5	L47597-4	Total Suspended Solids	80	mg/L	6.3	13	
Hanford #2	CS030	4/12/2009 17:13	2	L47834-1	Total Suspended Solids	34	mg/L	3.3	6.7	36.35
Hanford #2	CS030	4/12/2009 17:13	2	L47834-2	Total Suspended Solids	38.7	mg/L	3.3	6.7	
Hanford #2	CS030	5/5/2009 5:02	1	L48009-2	Total Suspended Solids	106	mg/L	5	10	108
Hanford #2	CS030	5/5/2009 5:02	1	L48009-3	Total Suspended Solids	110	mg/L	5	10	
Hanford #2	CS030	9/6/2009 12:02	1.75	L49003-1	Total Suspended Solids	108	mg/L	4.2	8.3	108
Hanford #2	CS030	11/6/2009 3:38	2	L49556-3	Total Suspended Solids	94.7	mg/L	3.3	6.7	94.7
Hanford #2	CS030	12/21/2009 9:04	1.5	L49832-1	Total Suspended Solids	46	mg/L	2.5	5	46
Lander	LANDER II REGI	6/3/2008 9:09	2	L44912-6	Total Suspended Solids	109	mg/L	5	10	109
Lander	LANDER II REGI	8/20/2008 1:01	2	L45811-6	Total Suspended Solids	38	mg/L	5	10	38
Lander	LANDER II REGI	11/4/2008 4:14	2	L46418-6	Total Suspended Solids	51.5	mg/L	2.5	5	51.5
Lander	LANDER II REGI	11/6/2008 15:42	2	L46918-6	Total Suspended Solids	84.2	mg/L	4.2	8.3	84.2
Lander	LANDER II REGI	4/12/2009 16:42	2	L47834-3	Total Suspended Solids	72.7	mg/L	3.3	6.7	72.7
Lander	LANDER II REGI	5/2/2009 22:12	1.5	L47992-2	Total Suspended Solids	80.8	mg/L	4.2	8.3	80.8
Lander	LANDER II REGI	5/4/2009 21:09	2	L48009-5	Total Suspended Solids	65	mg/L	5	10	65

Attachment A: King County TSS Data (all 1.0 µ method) for Hanford #2 and Lander CSOs

SITE	LOCATOR	COLLECTDATE	TIMESPAN	SAMPLE NUM	PARMNAME	NUMVALUE	UNITS	MDL	RDL	Value with Dups averaged
Hanford #2	CS030	1/29/2004 8:08	2.5	L30881-2	Total Suspended Solids	122	mg/L	5	10	118
Hanford #2	CS030	1/29/2004 8:08	2.5	L30881-3	Total Suspended Solids	114	mg/L	5	10	
Hanford #2	CS030	5/26/2004 10:21	1.75	L31912-2	Total Suspended Solids	106	mg/L	5	10	104
Hanford #2	CS030	5/26/2004 10:21	1.75	L31912-3	Total Suspended Solids	102	mg/L	5	10	
Hanford #2	CS030	10/28/1996 12:00	2.5	L9820-1	Total Suspended Solids	84.7	mg/L	0.5	1	89.25
Hanford #2	CS030	10/28/1996 12:00	2.5	L9820-2	Total Suspended Solids	93.8	mg/L	0.5	1	
Hanford #2	CS030	12/4/1996 14:04	3	L10025-7	Total Suspended Solids	97	mg/L	0.5	1	99.5
Hanford #2	CS030	12/4/1996 14:04	3	L10025-8	Total Suspended Solids	102	mg/L	0.5	1	
Hanford #2	CS030	1/27/1997 20:55	1	L10292-3	Total Suspended Solids	97.3	mg/L	0.5	1	98.15
Hanford #2	CS030	1/27/1997 20:55	1	L10292-4	Total Suspended Solids	99	mg/L	0.5	1	
Hanford #2	CS030	1/30/1997 3:45	2.5	L10322-3	Total Suspended Solids	93.3	mg/L	0.5	1	95.35
Hanford #2	CS030	1/30/1997 3:45	2.5	L10322-4	Total Suspended Solids	97.4	mg/L	0.5	1	
Hanford #2	CS030	3/1/1997 10:24	3.5	L10524-3	Total Suspended Solids	128	mg/L	0.5	1	107.95
Hanford #2	CS030	3/1/1997 10:24	3.5	L10524-4	Total Suspended Solids	87.9	mg/L	0.5	1	
Hanford #2	CS030	3/7/1997 1:50	2	L10588-3	Total Suspended Solids	65.6	mg/L	0.5	1	65.6
Hanford #2	CS030	3/15/1997 10:59	3	L10645-3	Total Suspended Solids	114	mg/L	0.5	1	109.5
Hanford #2	CS030	3/15/1997 10:59	3	L10645-4	Total Suspended Solids	105	mg/L	0.5	1	
Hanford #2	CS030	4/19/1997 19:18	3	L10939-7	Total Suspended Solids	90.6	mg/L	0.5	1	95.8
Hanford #2	CS030	4/19/1997 19:18	3	L10939-8	Total Suspended Solids	101	mg/L	0.5	1	
Hanford #2	CS030	5/31/1997 7:40	3	L11233-7	Total Suspended Solids	143	mg/L	0.5	1	148
Hanford #2	CS030	5/31/1997 7:40	3	L11233-8	Total Suspended Solids	153	mg/L	0.5	1	

Attachment A: King County TSS Data (all 1.0 µ method) for Hanford #2 and Lander CSOs

Collect Date	All EW Data	TSS (mg/L) Summary Stats	
12/2/2007	67.8	86	average
8/20/2008	53	81	geomean
11/4/2008	62.5	36.4	min
11/6/2008	156	156	max
4/2/2009	94.5	94.5	median
4/12/2009	36.4	65.3	25th percentile
5/5/2009	108	106	75th percentile
9/6/2009	108	109.2	90th percentile
11/6/2009	94.7	27	count
12/21/2009	46		
6/3/2008	109		
8/20/2008	38		
11/4/2008	51.5		
11/6/2008	84.2		
4/12/2009	72.7		
5/2/2009	80.8		
5/4/2009	65		
1/29/2004	118		
5/26/2004	104		
10/28/1996	89.2		
12/4/1996	99.5		
1/27/1995	98.2		
1/30/1997	95.4		
3/1/1997	108		
3/7/1997	65.6		
3/15/1997	109.5		
4/19/1997	95.8		

TABLES F-1 TO F-3

Stormwater runoff and solids loading estimates for EWW storm drain basins (25th percentile estimate; TSS values updated 2/7/2011)

Runoff and TSS from SPU Basins (Low Runoff Assumption for Partially Separated Basins)[1]

		Outfall Coordinates[3]		Annual Runoff in Million gallons			Annual Average TSS in lbs			Annual Average TSS in metric tons[2]		
Basin	Area (Acres)	X coordinate	Y coordinate	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)
B-21	12.98	1,267,025.76	216,799.42	8.65	7.28	10.58	1,444.23	1,215.55	1,765.61	0.66	0.55	0.80
B-25	4.20	1,268,053.11	218,669.74	2.69	2.26	3.32	723.95	607.93	892.05	0.33	0.28	0.40
B-36	5.35	1,267,380.50	212,096.91	3.32	2.77	4.09	940.79	787.21	1,160.18	0.43	0.36	0.53
B-4	7.11	1,266,960.50	211,998.11	4.58	3.85	5.64	1,299.08	1,091.13	1,599.51	0.59	0.49	0.73
B-5	2.15	1,266,985.87	212,222.84	1.37	1.15	1.69	389.12	326.59	480.30	0.18	0.15	0.22
Lander[4] (SPU)	438.34	1,267,839.97	215,762.30	118.25	99.23	146.06	33,218.79	27,877.84	41,019.14	15.07	12.65	18.61
Hinds	39.50	1,267,870.96	212,912.61	24.99	20.99	30.57	7,090.27	5,956.38	8,674.67	3.22	2.70	3.93
total	509.62			163.84	137.53	201.95	45,106.24	37,862.64	55,591.47	20.46	17.17	25.22

1. Low and high values are provided to account for the uncertainty in how much area outside the right-of-way has been disconnected from the combined sewer and plumbed to the drainage system in partially separated areas. Low corresponds to 25 percent for Lander West and 15 percent for Lander East, and high corresponds to 75 percent for Lander West and 65 percent for Lander East.
2. Metric Ton = 2,204.62 lbs
3. Horizontal North American Datum of 1983,1991 adjustment
4. Lander drainage basin includes east and west sub-basins that discharge to the Lander St outfall; the Port Lander sub-basin is addressed in the POS Basins table below.

Runoff and TSS from SPU Basins (High Runoff Assumption for Partially Separated Basins)[1]

		Outfall Coordinates[3]		Annual Runoff in Million gallons			Annual Average TSS in lbs			Annual Average TSS in metric tons[2]		
Basin	Area (Acres)	X coordinate[3]	Y coordinate[3]	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)
B-21	12.98	1,267,025.76	216,799.42	8.65	7.28	10.58	1,444.23	1,215.55	1,765.61	0.66	0.55	0.80
B-25	4.20	1,268,053.11	218,669.74	2.69	2.26	3.32	723.95	607.93	892.05	0.33	0.28	0.40
B-36	5.35	1,267,380.50	212,096.91	3.32	2.77	4.09	940.79	787.21	1,160.18	0.43	0.36	0.53
B-4	7.11	1,266,960.50	211,998.11	4.58	3.85	5.64	1,299.08	1,091.13	1,599.51	0.59	0.49	0.73
B-5	2.15	1,266,985.87	212,222.84	1.37	1.15	1.69	389.12	326.59	480.30	0.18	0.15	0.22
Lander[4] (SPU)	438.34	1,267,839.97	215,762.30	222.70	186.98	274.59	62,056.74	52,113.65	76,455.34	28.15	23.64	34.68
Hinds	39.50	1,267,870.96	212,912.61	24.99	20.99	30.57	7,090.27	5,956.38	8,674.67	3.22	2.70	3.93
total	509.62			268.30	225.28	330.47	73,944.19	62,098.45	91,027.66	33.54	28.17	41.29

1. Low and high values are provided to account for the uncertainty in how much area outside the right-of-way has been disconnected from the combined sewer and plumbed to the drainage system in partially separated areas. Low corresponds to 25 percent for Lander West and 15 percent for Lander East, and high corresponds to 75 percent for Lander West and 65 percent for Lander East.
2. Metric Ton = 2,204.62 lbs
3. Horizontal North American Datum of 1983,1991 adjustment
4. Lander drainage basin includes east and west sub-basins that discharge to the Lander St outfall; the Port Lander sub-basin is addressed in the POS Basins table below.

Runoff and TSS from SPU Bridges

		Outfall Coordinates[1]		Annual Runoff in Million gallons			Annual Average TSS in lbs			Annual Average TSS in metric tons[2]		
Basin	Area (Acres)	X coordinate	Y coordinate	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)
BR-34	0.95			0.59	0.49	0.73	166.74	139.71	207.00	0.08	0.06	0.09
BR-4	1.23			0.77	0.65	0.96	219.84	184.36	272.16	0.10	0.08	0.12
BR-5	1.61			1.00	0.84	1.24	283.81	237.80	352.33	0.13	0.11	0.16
total	3.80			2.36	1.98	2.93	670.40	561.88	831.49	0.30	0.25	0.38

1. Horizontal North American Datum of 1983,1991 adjustment; basins with no X, Y coordinates do not drain to an outfall
2. Metric Ton = 2,204.62 lbs

Stormwater runoff and solids loading estimates for EWW storm drain basins (25th percentile estimate; TSS values updated 2/7/2011)

Runoff and TSS from POS Basins

		Outfall Coordinates[1]		Annual Runoff in Million gallons			Annual Average TSS in lbs			Annual Average TSS in metric tons[2]		
Basin	Area (Acres)	X coordinate	Y coordinate	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)
B-1	1.58	1,266,887.46	211,399.22	1.05	0.89	1.29	175.96	148.10	215.11	0.08	0.07	0.10
B-10	7.23	1,266,968.30	214,087.50	4.82	4.06	5.89	804.65	677.24	983.71	0.36	0.31	0.45
B-11	48.14	1,266,995.91	214,238.77	32.08	27.00	39.22	5,355.44	4,507.46	6,547.18	2.43	2.04	2.97
B-12	6.53	1,266,956.70	214,443.80	4.35	3.66	5.32	726.47	611.44	888.12	0.33	0.28	0.40
B-13	6.22	1,267,027.00	214,961.90	4.15	3.49	5.07	692.01	582.44	846.00	0.31	0.26	0.38
B-14	1.52	1,267,051.30	215,033.60	1.01	0.85	1.24	168.70	141.99	206.25	0.08	0.06	0.09
B-16	4.41	1,266,993.70	215,373.60	2.94	2.48	3.60	490.97	413.23	600.22	0.22	0.19	0.27
B-17	2.14	1,267,002.40	215,678.30	1.43	1.20	1.74	238.08	200.38	291.06	0.11	0.09	0.13
B-18	7.41	1,266,983.00	215,983.87	4.94	4.16	6.04	824.18	693.68	1,007.58	0.37	0.31	0.46
B-19	5.04	1,267,000.61	216,655.64	3.36	2.83	4.11	560.58	471.82	685.33	0.25	0.21	0.31
B-22	11.99	1,266,996.20	217,188.40	7.99	6.72	9.77	1,333.63	1,122.47	1,630.40	0.60	0.51	0.74
B-23	10.95	1,267,011.30	217,914.40	7.30	6.14	8.92	1,217.71	1,024.90	1,488.68	0.55	0.46	0.68
B-24	8.86	1,267,046.27	218,573.28	5.90	4.97	7.22	985.46	829.42	1,204.75	0.45	0.38	0.55
B-26	13.41	1,268,013.00	217,447.20	8.94	7.52	10.92	1,491.49	1,255.33	1,823.39	0.68	0.57	0.83
B-27	7.35	1,268,014.70	216,941.70	4.90	4.12	5.99	817.26	687.86	999.13	0.37	0.31	0.45
B-28	3.59	1,268,001.70	216,332.40	2.40	2.02	2.93	399.88	336.56	488.86	0.18	0.15	0.22
B-29	8.75	1,268,024.30	215,844.00	5.83	4.91	7.13	972.93	818.88	1,189.44	0.44	0.37	0.54
B-30	6.69	1,268,481.10	214,909.20	4.46	3.75	5.45	744.15	626.32	909.74	0.34	0.28	0.41
B-31[3]	9.81	1,267,827.60	214,382.65	6.54	5.51	8.00	1,091.90	919.01	1,334.88	0.50	0.42	0.61
B-32	3.73	1,267,816.51	214,084.19	2.48	2.09	3.04	414.63	348.98	506.90	0.19	0.16	0.23
B-33	12.11	1,267,802.40	213,205.40	8.06	6.79	9.86	1,345.93	1,132.83	1,645.31	0.61	0.51	0.75
B-34	13.33	1,267,445.56	212,282.86	8.77	7.38	10.71	2,488.66	2,093.33	3,038.01	1.13	0.95	1.38
B-37	6.41	1,267,196.82	211,561.15	4.23	3.56	5.17	706.74	594.29	863.35	0.32	0.27	0.39
B-39	2.08	1,267,224.50	211,803.70	1.38	1.16	1.69	231.01	194.38	282.40	0.10	0.09	0.13
B-7	13.93	1,266,941.40	212,971.90	9.29	7.81	11.35	1,549.86	1,304.46	1,894.75	0.70	0.59	0.86
Lander (POS)[4]	3.62	1,267,839.97	215,762.30	2.41	2.03	2.95	402.29	338.59	491.81	0.18	0.15	0.22
total	226.80			151.01	127.09	184.59	26,230.58	22,075.38	32,062.35	11.90	10.01	14.54

1. Horizontal North American Datum of 1983,1991 adjustment
2. Metric Ton = 2,204.62 lbs
3. Basin B-31 includes basin BR-27
4. Lander (POS) sub-basin discharges to the Lander St outfall. Lander East and West (SPU) also discharge to this outfall, and are addressed in the SPU Basins table above

Runoff and TSS from POS Aprons

		Outfall Coordinates[1]		Annual Runoff in Million gallons			Annual Average TSS in lbs			Annual Average TSS in metric tons[2]		
Basin	Area (Acres)	X coordinate	Y coordinate	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)
A-7	1.16			0.77	0.65	0.94	128.72	108.34	157.36	0.06	0.05	0.07
A-10	2.28			1.52	1.28	1.86	254.18	213.93	310.74	0.12	0.10	0.14
A-12	1.98			1.32	1.11	1.61	220.29	185.41	269.32	0.10	0.08	0.12
A-13	0.47			0.31	0.26	0.38	52.33	44.04	63.98	0.02	0.02	0.03
A-14	1.04			0.69	0.58	0.84	115.27	97.01	140.92	0.05	0.04	0.06
A-16	0.66			0.44	0.37	0.54	73.17	61.58	89.45	0.03	0.03	0.04
A-17	0.68			0.46	0.38	0.56	76.11	64.06	93.04	0.03	0.03	0.04
A-18	1.20			0.80	0.67	0.98	133.86	112.66	163.65	0.06	0.05	0.07
A-19	1.89			1.26	1.06	1.54	210.61	177.26	257.48	0.10	0.08	0.12
A-22	2.01			1.34	1.13	1.64	223.89	188.44	273.71	0.10	0.09	0.12
A-23	2.05			1.37	1.15	1.67	227.91	191.82	278.62	0.10	0.09	0.13
A-24	2.29			1.53	1.28	1.87	254.64	214.32	311.31	0.12	0.10	0.14
A-26	0.60			0.40	0.34	0.49	66.57	56.03	81.39	0.03	0.03	0.04
A-27	1.70			1.13	0.95	1.38	188.67	158.80	230.66	0.09	0.07	0.10
A-28	1.50			1.00	0.84	1.22	167.20	140.73	204.41	0.08	0.06	0.09
A-29	1.15			0.76	0.64	0.93	127.60	107.40	155.99	0.06	0.05	0.07
A-30	1.30			0.87	0.73	1.06	145.02	122.06	177.29	0.07	0.06	0.08
A-31	0.76			0.51	0.43	0.62	84.94	71.49	103.84	0.04	0.03	0.05
A-32	0.80			0.54	0.45	0.65	89.39	75.24	109.28	0.04	0.03	0.05
A-33	2.19			1.46	1.23	1.78	243.19	204.69	297.31	0.11	0.09	0.13
BR-39	1.25			0.83	0.83	1.02	236.69	199.21	289.39	0.11	0.09	0.13
BR-2	0.27	1,266,955.62	211,835.26	0.18	0.15	0.22	29.71	25.01	36.33	0.01	0.01	0.02
total	29.24			19.49	16.53	23.82	3,349.96	2,819.52	4,095.44	1.52	1.28	1.86

1. Horizontal North American Datum of 1983,1991 adjustment; basins with no X, Y coordinates do not drain to an outfall
2. Metric Ton = 2,204.62 lbs

Stormwater runoff and solids loading estimates for EWW storm drain basins (25th percentile estimate; TSS values updated 2/7/2011)

Runoff and TSS from Private Basins

		Outfall Coordinates[1]		Annual Runoff in Million gallons			Annual Average TSS in lbs			Annual Average TSS in metric tons[2]		
Basin	Area (Acres)	X coordinate	Y coordinate	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)
A-6	3.16	1,267,133.00	212,871.00	2.10	1.77	2.57	597.30	502.72	730.22	0.27	0.23	0.33
B-40	3.26	1,268,082.43	218,293.18	2.04	1.71	2.53	528.33	442.97	654.46	0.24	0.20	0.30
B-41	5.46	1,268,032.50	218,704.86	3.64	3.06	4.45	869.02	869.02	1,262.46	0.39	0.39	0.57
B-42	0.46	1,268,376.87	218,781.63	0.31	0.26	0.38	87.30	73.48	106.73	0.04	0.03	0.05
B-43	5.74	1,268,824.23	218,875.21	3.83	3.22	4.68	1,085.50	913.62	1,327.05	0.49	0.41	0.60
total	18.08			11.92	10.02	14.60	3,167.45	2,801.81	4,080.92	1.44	1.27	1.85

1. Horizontal North American Datum of 1983,1991 adjustment
2. Metric Ton = 2,204.62 lbs

25th percentile estimate: TSS Concentrations in mg/L (All POS basins [except B-34], SPU basin: B-21)

Land Use	ROW	Industrial	MFR	Commercial	Open	SFR
Estimated Concentration (mg/L)	34	20	39	31	8	24

MFR= Mulitiple Family Residential, SFR= Single Family Residential

25th percentile estimate: TSS Concentrations in mg/L (All SPU basins [except B-21], POS basin B-34, all Private basins)

Land Use	ROW	Industrial	MFR	Commercial	Open	SFR
Estimated Concentration (mg/L)	34	34	39	31	8	24

Stormwater runoff and solids loading estimates for EWW storm drain basins (Base Case estimate; TSS values updated 2/7/2011)

Runoff and TSS from SPU Basins (Low Runoff Assumption for Partially Separated Basins)[1]

		Outfall Coordinates[3]		Annual Runoff in Million gallons			Annual Average TSS in lbs			Annual Average TSS in metric tons[2]		
Basin	Area (Acres)	X coordinate	Y coordinate	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)
B-21	12.98	1,267,025.76	216,799.42	8.65	7.28	10.58	3,105.09	2,613.43	3,796.06	1.41	1.19	1.72
B-25	4.20	1,268,053.11	218,669.74	2.69	2.26	3.32	1,449.33	1,217.23	1,785.00	0.66	0.55	0.81
B-36	5.35	1,267,380.50	212,096.91	3.32	2.77	4.09	1,992.07	1,666.98	2,456.30	0.90	0.76	1.11
B-4	7.11	1,266,960.50	211,998.11	4.58	3.85	5.64	2,774.44	2,330.43	3,415.52	1.26	1.06	1.55
B-5	2.15	1,266,985.87	212,222.84	1.37	1.15	1.69	825.47	692.86	1,018.75	0.37	0.31	0.46
Lander[4] (SPU)	438.34	1,267,839.97	215,762.30	118.25	99.23	146.06	69,548.30	58,369.41	85,863.49	31.55	26.48	38.95
Hinds	39.50	1,267,870.96	212,912.61	24.99	20.99	30.57	15,253.42	12,814.71	18,659.98	6.92	5.81	8.46
total	509.62			163.84	137.53	201.95	94,948.12	79,705.06	116,995.11	43.07	36.15	53.07

1. Low and high values are provided to account for the uncertainty in how much area outside the right-of-way has been disconnected from the combined sewer and plumbed to the drainage system in partially separated areas. Low corresponds to 25 percent for Lander West and 15 percent for Lander East, and high corresponds to 75 percent for Lander West and 65 percent for Lander East.
2. Metric Ton = 2,204.62 lbs
3. Horizontal North American Datum of 1983,1991 adjustment
4. Lander drainage basin includes east and west sub-basins that discharge to the Lander St outfall; the Port Lander sub-basin is addressed in the POS Basins table below.

Runoff and TSS from SPU Basins (High Runoff Assumption for Partially Separated Basins)[1]

		Outfall Coordinates[3]		Annual Runoff in Million gallons			Annual Average TSS in lbs			Annual Average TSS in metric tons[2]		
Basin	Area (Acres)	X coordinate[3]	Y coordinate[3]	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)
B-21	12.98	1,267,025.76	216,799.42	8.65	7.28	10.58	3,105.09	2,613.43	3,796.06	1.41	1.19	1.72
B-25	4.20	1,268,053.11	218,669.74	2.69	2.26	3.32	1,449.33	1,217.23	1,785.00	0.66	0.55	0.81
B-36	5.35	1,267,380.50	212,096.91	3.32	2.77	4.09	1,992.07	1,666.98	2,456.30	0.90	0.76	1.11
B-4	7.11	1,266,960.50	211,998.11	4.58	3.85	5.64	2,774.44	2,330.43	3,415.52	1.26	1.06	1.55
B-5	2.15	1,266,985.87	212,222.84	1.37	1.15	1.69	825.47	692.86	1,018.75	0.37	0.31	0.46
Lander[4] (SPU)	438.34	1,267,839.97	215,762.30	222.70	186.98	274.59	129,846.09	109,051.39	159,923.03	58.90	49.46	72.54
Hinds	39.50	1,267,870.96	212,912.61	24.99	20.99	30.57	15,253.42	12,814.71	18,659.98	6.92	5.81	8.46
total	509.62			268.30	225.28	330.47	155,245.91	130,387.03	191,054.65	70.42	59.14	86.66

1. Low and high values are provided to account for the uncertainty in how much area outside the right-of-way has been disconnected from the combined sewer and plumbed to the drainage system in partially separated areas. Low corresponds to 25 percent for Lander West and 15 percent for Lander East, and high corresponds to 75 percent for Lander West and 65 percent for Lander East.
2. Metric Ton = 2,204.62 lbs
3. Horizontal North American Datum of 1983,1991 adjustment
4. Lander drainage basin includes east and west sub-basins that discharge to the Lander St outfall; the Port Lander sub-basin is addressed in the POS Basins table below.

Runoff and TSS from SPU Bridges

		Outfall Coordinates[1]		Annual Runoff in Million gallons			Annual Average TSS in lbs			Annual Average TSS in metric tons[2]		
Basin	Area (Acres)	X coordinate	Y coordinate	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)
BR-34	0.95			0.59	0.49	0.73	348.20	291.75	432.26	0.16	0.13	0.20
BR-4	1.23			0.77	0.65	0.96	462.62	387.96	572.66	0.21	0.18	0.26
BR-5	1.61			1.00	0.84	1.24	592.66	496.59	735.74	0.27	0.23	0.33
total	3.80			2.36	1.98	2.93	1,403.48	1,176.31	1,740.66	0.64	0.53	0.79

1. Horizontal North American Datum of 1983,1991 adjustment; basins with no X, Y coordinates do not drain to an outfall
2. Metric Ton = 2,204.62 lbs

Stormwater runoff and solids loading estimates for EWW storm drain basins (Base Case estimate; TSS values updated 2/7/2011)

Runoff and TSS from POS Basins

		Outfall Coordinates[1]		Annual Runoff in Million gallons			Annual Average TSS in lbs			Annual Average TSS in metric tons[2]		
Basin	Area (Acres)	X coordinate	Y coordinate	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)
B-1	1.58	1,266,887.46	211,399.22	1.05	0.89	1.29	378.31	318.41	462.50	0.17	0.14	0.21
B-10	7.23	1,266,968.30	214,087.50	4.82	4.06	5.89	1,730.00	1,456.08	2,114.98	0.78	0.66	0.96
B-11	48.14	1,266,995.91	214,238.77	32.08	27.00	39.22	11,514.20	9,691.04	14,076.43	5.22	4.40	6.38
B-12	6.53	1,266,956.70	214,443.80	4.35	3.66	5.32	1,561.90	1,314.59	1,909.47	0.71	0.60	0.87
B-13	6.22	1,267,027.00	214,961.90	4.15	3.49	5.07	1,487.82	1,252.24	1,818.90	0.67	0.57	0.83
B-14	1.52	1,267,051.30	215,033.60	1.01	0.85	1.24	362.71	305.28	443.43	0.16	0.14	0.20
B-16	4.41	1,266,993.70	215,373.60	2.94	2.48	3.60	1,055.58	888.44	1,290.47	0.48	0.40	0.59
B-17	2.14	1,267,002.40	215,678.30	1.43	1.20	1.74	511.87	430.82	625.77	0.23	0.20	0.28
B-18	7.41	1,266,983.00	215,983.87	4.94	4.16	6.04	1,771.99	1,491.41	2,166.30	0.80	0.68	0.98
B-19	5.04	1,267,000.61	216,655.64	3.36	2.83	4.11	1,205.26	1,014.42	1,473.46	0.55	0.46	0.67
B-22	11.99	1,266,996.20	217,188.40	7.99	6.72	9.77	2,867.31	2,413.30	3,505.37	1.30	1.09	1.59
B-23	10.95	1,267,011.30	217,914.40	7.30	6.14	8.92	2,618.07	2,203.53	3,200.67	1.19	1.00	1.45
B-24	8.86	1,267,046.27	218,573.28	5.90	4.97	7.22	2,118.74	1,783.26	2,590.22	0.96	0.81	1.17
B-26	13.41	1,268,013.00	217,447.20	8.94	7.52	10.92	3,206.70	2,698.95	3,920.28	1.45	1.22	1.78
B-27	7.35	1,268,014.70	216,941.70	4.90	4.12	5.99	1,757.11	1,478.89	2,148.12	0.80	0.67	0.97
B-28	3.59	1,268,001.70	216,332.40	2.40	2.02	2.93	859.74	723.61	1,051.06	0.39	0.33	0.48
B-29	8.75	1,268,024.30	215,844.00	5.83	4.91	7.13	2,091.80	1,760.59	2,557.29	0.95	0.80	1.16
B-30	6.69	1,268,481.10	214,909.20	4.46	3.75	5.45	1,599.92	1,346.59	1,955.95	0.73	0.61	0.89
B-31[3]	9.81	1,267,827.60	214,382.65	6.54	5.51	8.00	2,347.59	1,975.87	2,869.99	1.06	0.90	1.30
B-32	3.73	1,267,816.51	214,084.19	2.48	2.09	3.04	891.45	750.30	1,089.83	0.40	0.34	0.49
B-33	12.11	1,267,802.40	213,205.40	8.06	6.79	9.86	2,893.76	2,435.58	3,537.41	1.31	1.10	1.60
B-34	13.33	1,267,445.56	212,282.86	8.77	7.38	10.71	5,416.50	4,556.07	6,612.13	2.46	2.07	3.00
B-37	6.41	1,267,196.82	211,561.15	4.23	3.56	5.17	1,519.48	1,277.72	1,856.20	0.69	0.58	0.84
B-39	2.08	1,267,224.50	211,803.70	1.38	1.16	1.69	496.68	417.92	607.15	0.23	0.19	0.28
B-7	13.93	1,266,941.40	212,971.90	9.29	7.81	11.35	3,332.20	2,804.58	4,073.71	1.51	1.27	1.85
Lander (POS)[4]	3.62	1,267,839.97	215,762.30	2.41	2.03	2.95	864.93	727.98	1,057.40	0.39	0.33	0.48
total	226.80			151.01	127.09	184.59	56,461.63	47,517.48	69,014.48	25.61	21.55	31.30

1. Horizontal North American Datum of 1983,1991 adjustment
2. Metric Ton = 2,204.62 lbs
3. Basin B-31 includes basin BR-27
4. Lander (POS) sub-basin discharges to the Lander St outfall. Lander East and West (SPU) also discharge to this outfall, and are addressed in the SPU Basins table above

Runoff and TSS from POS Aprons

		Outfall Coordinates[1]		Annual Runoff in Million gallons			Annual Average TSS in lbs			Annual Average TSS in metric tons[2]		
Basin	Area (Acres)	X coordinate	Y coordinate	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)
A-7	1.16			0.77	0.65	0.94	276.74	232.92	338.32	0.13	0.11	0.15
A-10	2.28			1.52	1.28	1.86	546.48	459.95	668.09	0.25	0.21	0.30
A-12	1.98			1.32	1.11	1.61	473.63	398.64	579.03	0.21	0.18	0.26
A-13	0.47			0.31	0.26	0.38	112.51	94.70	137.55	0.05	0.04	0.06
A-14	1.04			0.69	0.58	0.84	247.82	208.58	302.97	0.11	0.09	0.14
A-16	0.66			0.44	0.37	0.54	157.31	132.40	192.31	0.07	0.06	0.09
A-17	0.68			0.46	0.38	0.56	163.63	137.72	200.04	0.07	0.06	0.09
A-18	1.20			0.80	0.67	0.98	287.80	242.23	351.84	0.13	0.11	0.16
A-19	1.89			1.26	1.06	1.54	452.81	381.11	553.58	0.21	0.17	0.25
A-22	2.01			1.34	1.13	1.64	481.36	405.14	588.47	0.22	0.18	0.27
A-23	2.05			1.37	1.15	1.67	490.00	412.41	599.03	0.22	0.19	0.27
A-24	2.29			1.53	1.28	1.87	547.48	460.80	669.31	0.25	0.21	0.30
A-26	0.60			0.40	0.34	0.49	143.13	120.47	174.98	0.06	0.05	0.08
A-27	1.70			1.13	0.95	1.38	405.65	341.42	495.92	0.18	0.15	0.22
A-28	1.50			1.00	0.84	1.22	359.49	302.57	439.48	0.16	0.14	0.20
A-29	1.15			0.76	0.64	0.93	274.34	230.90	335.39	0.12	0.10	0.15
A-30	1.30			0.87	0.73	1.06	311.79	262.42	381.17	0.14	0.12	0.17
A-31	0.76			0.51	0.43	0.62	182.61	153.70	223.25	0.08	0.07	0.10
A-32	0.80			0.54	0.45	0.65	192.19	161.76	234.96	0.09	0.07	0.11
A-33	2.19			1.46	1.23	1.78	522.86	440.07	639.22	0.24	0.20	0.29
BR-39	1.25			0.83	0.83	1.02	515.04	433.48	629.71	0.23	0.20	0.29
BR-2	0.27	1,266,955.62	211,835.26	0.18	0.15	0.22	63.88	53.77	78.10	0.03	0.02	0.04
total	29.24			19.49	16.53	23.82	7,208.56	6,067.14	8,812.71	3.27	2.75	4.00

1. Horizontal North American Datum of 1983,1991 adjustment; basins with no X, Y coordinates do not drain to an outfall
2. Metric Ton = 2,204.62 lbs

Stormwater runoff and solids loading estimates for EWW storm drain basins (Base Case estimate; TSS values updated 2/7/2011)

Runoff and TSS from Private Basins

		Outfall Coordinates[1]		Annual Runoff in Million gallons			Annual Average TSS in lbs			Annual Average TSS in metric tons[2]		
Basin	Area (Acres)	X coordinate	Y coordinate	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)
A-6	3.16	1,267,133.00	212,871.00	2.10	1.77	2.57	1,300.01	1,094.17	1,589.30	0.59	0.50	0.72
B-40	3.26	1,268,082.43	218,293.18	2.04	1.71	2.53	989.75	829.85	1,226.01	0.45	0.38	0.56
B-41	5.46	1,268,032.50	218,704.86	3.64	3.06	4.45	1,890.30	1,890.30	2,746.09	0.86	0.86	1.25
B-42	0.46	1,268,376.87	218,781.63	0.31	0.26	0.38	190.01	159.93	232.30	0.09	0.07	0.11
B-43	5.74	1,268,824.23	218,875.21	3.83	3.22	4.68	2,362.56	1,988.47	2,888.29	1.07	0.90	1.31
total	18.08			11.92	10.02	14.60	6,732.63	5,962.71	8,681.99	3.05	2.70	3.94

1. Horizontal North American Datum of 1983,1991 adjustment
2. Metric Ton = 2,204.62 lbs

Base Case estimate: TSS Concentrations in mg/L (All POS basins [except B-34], SPU basin: B-21)

Land Use	ROW	Industrial	MFR	Commercial	Open	SFR
Estimated Concentration (mg/L)	71	43	68	58	13	48

MFR= Mulitiple Family Residential, SFR= Single Family Residential

Base Case estimate: TSS Concentrations in mg/L (All SPU basins [except B-21], POS basin B-34, all Private basins)

Land Use	ROW	Industrial	MFR	Commercial	Open	SFR
Estimated Concentration (mg/L)	71	74	68	58	13	48

Stormwater runoff and solids loading estimates for EWW storm drain basins (75th percentile estimate; TSS values updated 3/10/2011)

Runoff and TSS from SPU Basins (Low Runoff Assumption for Partially Separated Basins)[1]

		Outfall Coordinates[3]		Annual Runoff in Million gallons			Annual Average TSS in lbs			Annual Average TSS in metric tons[2]		
Basin	Area (Acres)	X coordinate	Y coordinate	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)
B-21	12.98	1,267,025.76	216,799.42	8.65	7.28	10.58	4,332.69	3,646.65	5,296.83	1.97	1.65	2.40
B-25	4.20	1,268,053.11	218,669.74	2.69	2.26	3.32	2,176.91	1,828.47	2,680.23	0.99	0.83	1.22
B-36	5.35	1,267,380.50	212,096.91	3.32	2.77	4.09	2,663.49	2,229.89	3,281.45	1.21	1.01	1.49
B-4	7.11	1,266,960.50	211,998.11	4.58	3.85	5.64	3,922.91	3,296.06	4,824.57	1.78	1.50	2.19
B-5	2.15	1,266,985.87	212,222.84	1.37	1.15	1.69	1,117.56	938.30	1,377.85	0.51	0.43	0.62
Lander[4] (SPU)	438.34	1,267,839.97	215,762.30	118.25	99.23	146.06	94,210.02	79,084.60	116,222.52	42.73	35.87	52.72
Hinds	39.50	1,267,870.96	212,912.61	24.99	20.99	30.57	22,556.03	18,955.43	27,575.91	10.23	8.60	12.51
total	509.62			163.84	137.53	201.95	130,979.61	109,979.39	161,259.36	59.41	49.89	73.15

1. Low and high values are provided to account for the uncertainty in how much area outside the right-of-way has been disconnected from the combined sewer and plumbed to the drainage system in partially separated areas. Low corresponds to 25 percent for Lander West and 15 percent for Lander East, and high corresponds to 75 percent for Lander West and 65 percent for Lander East.
2. Metric Ton = 2,204.62 lbs
3. Horizontal North American Datum of 1983,1991 adjustment
4. Lander drainage basin includes east and west sub-basins that discharge to the Lander St outfall; the Port Lander sub-basin is addressed in the POS Basins table below.

Runoff and TSS from SPU Basins (High Runoff Assumption for Partially Separated Basins)[1]

		Outfall Coordinates[3]		Annual Runoff in Million gallons			Annual Average TSS in lbs			Annual Average TSS in metric tons[2]		
Basin	Area (Acres)	X coordinate[3]	Y coordinate[3]	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)
B-21	12.98	1,267,025.76	216,799.42	8.65	7.28	10.58	4,332.69	3,646.65	5,296.83	1.97	1.65	2.40
B-25	4.20	1,268,053.11	218,669.74	2.69	2.26	3.32	2,176.91	1,828.47	2,680.23	0.99	0.83	1.22
B-36	5.35	1,267,380.50	212,096.91	3.32	2.77	4.09	2,663.49	2,229.89	3,281.45	1.21	1.01	1.49
B-4	7.11	1,266,960.50	211,998.11	4.58	3.85	5.64	3,922.91	3,296.06	4,824.57	1.78	1.50	2.19
B-5	2.15	1,266,985.87	212,222.84	1.37	1.15	1.69	1,117.56	938.30	1,377.85	0.51	0.43	0.62
Lander[4] (SPU)	438.34	1,267,839.97	215,762.30	222.70	186.98	274.59	187,734.56	157,701.21	231,058.76	85.16	71.53	104.81
Hinds	39.50	1,267,870.96	212,912.61	24.99	20.99	30.57	22,556.03	18,955.43	27,575.91	10.23	8.60	12.51
total	509.62			268.30	225.28	330.47	224,504.15	188,596.00	276,095.60	101.83	85.55	125.24

1. Low and high values are provided to account for the uncertainty in how much area outside the right-of-way has been disconnected from the combined sewer and plumbed to the drainage system in partially separated areas. Low corresponds to 25 percent for Lander West and 15 percent for Lander East, and high corresponds to 75 percent for Lander West and 65 percent for Lander East.
2. Metric Ton = 2,204.62 lbs
3. Horizontal North American Datum of 1983,1991 adjustment
4. Lander drainage basin includes east and west sub-basins that discharge to the Lander St outfall; the Port Lander sub-basin is addressed in the POS Basins table below.

Runoff and TSS from SPU Bridges

		Outfall Coordinates[1]		Annual Runoff in Million gallons			Annual Average TSS in lbs			Annual Average TSS in metric tons[2]		
Basin	Area (Acres)	X coordinate	Y coordinate	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)
BR-34	0.95			0.59	0.49	0.73	421.76	353.39	523.58	0.19	0.16	0.24
BR-4	1.23			0.77	0.65	0.96	592.62	497.08	733.09	0.27	0.23	0.33
BR-5	1.61			1.00	0.84	1.24	717.87	601.51	891.19	0.33	0.27	0.40
total	3.80			2.36	1.98	2.93	1,732.26	1,451.98	2,147.86	0.79	0.66	0.97

1. Horizontal North American Datum of 1983,1991 adjustment; basins with no X, Y coordinates do not drain to an outfall
2. Metric Ton = 2,204.62 lbs

Stormwater runoff and solids loading estimates for EWW storm drain basins (75th percentile estimate; TSS values updated 3/10/2011)

Runoff and TSS from POS Basins

		Outfall Coordinates[1]		Annual Runoff in Million gallons			Annual Average TSS in lbs			Annual Average TSS in metric tons[2]		
Basin	Area (Acres)	X coordinate	Y coordinate	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)
B-1	1.58	1,266,887.46	211,399.22	1.05	0.89	1.29	527.88	444.29	645.34	0.24	0.20	0.29
B-10	7.23	1,266,968.30	214,087.50	4.82	4.06	5.89	2,413.96	2,031.73	2,951.13	1.09	0.92	1.34
B-11	48.14	1,266,995.91	214,238.77	32.08	27.00	39.22	16,066.33	13,522.39	19,641.53	7.29	6.13	8.91
B-12	6.53	1,266,956.70	214,443.80	4.35	3.66	5.32	2,179.40	1,834.31	2,664.37	0.99	0.83	1.21
B-13	6.22	1,267,027.00	214,961.90	4.15	3.49	5.07	2,076.02	1,747.31	2,538.00	0.94	0.79	1.15
B-14	1.52	1,267,051.30	215,033.60	1.01	0.85	1.24	506.11	425.98	618.74	0.23	0.19	0.28
B-16	4.41	1,266,993.70	215,373.60	2.94	2.48	3.60	1,472.90	1,239.68	1,800.66	0.67	0.56	0.82
B-17	2.14	1,267,002.40	215,678.30	1.43	1.20	1.74	714.24	601.14	873.17	0.32	0.27	0.40
B-18	7.41	1,266,983.00	215,983.87	4.94	4.16	6.04	2,472.54	2,081.04	3,022.75	1.12	0.94	1.37
B-19	5.04	1,267,000.61	216,655.64	3.36	2.83	4.11	1,681.75	1,415.47	2,055.99	0.76	0.64	0.93
B-22	11.99	1,266,996.20	217,188.40	7.99	6.72	9.77	4,000.90	3,367.40	4,891.21	1.81	1.53	2.22
B-23	10.95	1,267,011.30	217,914.40	7.30	6.14	8.92	3,653.13	3,074.69	4,466.05	1.66	1.39	2.03
B-24	8.86	1,267,046.27	218,573.28	5.90	4.97	7.22	2,956.38	2,488.27	3,614.26	1.34	1.13	1.64
B-26	13.41	1,268,013.00	217,447.20	8.94	7.52	10.92	4,474.46	3,765.98	5,470.16	2.03	1.71	2.48
B-27	7.35	1,268,014.70	216,941.70	4.90	4.12	5.99	2,451.79	2,063.57	2,997.38	1.11	0.94	1.36
B-28	3.59	1,268,001.70	216,332.40	2.40	2.02	2.93	1,199.64	1,009.69	1,466.59	0.54	0.46	0.67
B-29	8.75	1,268,024.30	215,844.00	5.83	4.91	7.13	2,918.80	2,456.63	3,568.31	1.32	1.11	1.62
B-30	6.69	1,268,481.10	214,909.20	4.46	3.75	5.45	2,232.45	1,878.96	2,729.23	1.01	0.85	1.24
B-31[3]	9.81	1,267,827.60	214,382.65	6.54	5.51	8.00	3,275.70	2,757.03	4,004.64	1.49	1.25	1.82
B-32	3.73	1,267,816.51	214,084.19	2.48	2.09	3.04	1,243.89	1,046.93	1,520.69	0.56	0.47	0.69
B-33	12.11	1,267,802.40	213,205.40	8.06	6.79	9.86	4,037.80	3,398.49	4,935.93	1.83	1.54	2.24
B-34	13.33	1,267,445.56	212,282.86	8.77	7.38	10.71	8,563.92	7,203.52	10,454.32	3.88	3.27	4.74
B-37	6.41	1,267,196.82	211,561.15	4.23	3.56	5.17	2,120.21	1,782.87	2,590.05	0.96	0.81	1.17
B-39	2.08	1,267,224.50	211,803.70	1.38	1.16	1.69	693.04	583.15	847.19	0.31	0.26	0.38
B-7	13.93	1,266,941.40	212,971.90	9.29	7.81	11.35	4,649.58	3,913.37	5,684.25	2.11	1.78	2.58
Lander (POS)[4]	3.62	1,267,839.97	215,762.30	2.41	2.03	2.95	1,206.88	1,015.78	1,475.44	0.55	0.46	0.67
total	226.80			151.01	127.09	184.59	79,789.69	67,149.67	97,527.36	36.19	30.46	44.24

1. Horizontal North American Datum of 1983,1991 adjustment
2. Metric Ton = 2,204.62 lbs
3. Basin B-31 includes basin BR-27
4. Lander (POS) sub-basin discharges to the Lander St outfall. Lander East and West (SPU) also discharge to this outfall, and are addressed in the SPU Basins table above

Runoff and TSS from POS Aprons

		Outfall Coordinates[1]		Annual Runoff in Million gallons			Annual Average TSS in lbs			Annual Average TSS in metric tons[2]		
Basin	Area (Acres)	X coordinate	Y coordinate	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)
A-7	1.16			0.77	0.65	0.94	386.15	325.01	472.08	0.18	0.15	0.21
A-10	2.28			1.52	1.28	1.86	762.53	641.79	932.22	0.35	0.29	0.42
A-12	1.98			1.32	1.11	1.61	660.88	556.24	807.95	0.30	0.25	0.37
A-13	0.47			0.31	0.26	0.38	156.99	132.13	191.93	0.07	0.06	0.09
A-14	1.04			0.69	0.58	0.84	345.80	291.04	422.75	0.16	0.13	0.19
A-16	0.66			0.44	0.37	0.54	219.50	184.74	268.34	0.10	0.08	0.12
A-17	0.68			0.46	0.38	0.56	228.32	192.17	279.12	0.10	0.09	0.13
A-18	1.20			0.80	0.67	0.98	401.58	337.99	490.94	0.18	0.15	0.22
A-19	1.89			1.26	1.06	1.54	631.83	531.79	772.43	0.29	0.24	0.35
A-22	2.01			1.34	1.13	1.64	671.66	565.31	821.12	0.30	0.26	0.37
A-23	2.05			1.37	1.15	1.67	683.72	575.46	835.86	0.31	0.26	0.38
A-24	2.29			1.53	1.28	1.87	763.93	642.97	933.93	0.35	0.29	0.42
A-26	0.60			0.40	0.34	0.49	199.72	168.09	244.16	0.09	0.08	0.11
A-27	1.70			1.13	0.95	1.38	566.02	476.40	691.98	0.26	0.22	0.31
A-28	1.50			1.00	0.84	1.22	501.61	422.19	613.23	0.23	0.19	0.28
A-29	1.15			0.76	0.64	0.93	382.80	322.19	467.98	0.17	0.15	0.21
A-30	1.30			0.87	0.73	1.06	435.05	366.17	531.86	0.20	0.17	0.24
A-31	0.76			0.51	0.43	0.62	254.81	214.46	311.51	0.12	0.10	0.14
A-32	0.80			0.54	0.45	0.65	268.17	225.71	327.85	0.12	0.10	0.15
A-33	2.19			1.46	1.23	1.78	729.58	614.06	891.93	0.33	0.28	0.40
BR-39	1.25			0.83	0.83	1.02	813.30	684.51	994.35	0.37	0.31	0.45
BR-2	0.27	1,266,955.62	211,835.26	0.18	0.15	0.22	89.14	75.03	108.98	0.04	0.03	0.05
total	29.24			19.49	16.53	23.82	10,153.09	8,545.44	12,412.50	4.61	3.88	5.63

1. Horizontal North American Datum of 1983,1991 adjustment; basins with no X, Y coordinates do not drain to an outfall
2. Metric Ton = 2,204.62 lbs

Stormwater runoff and solids loading estimates for EWW storm drain basins (75th percentile estimate; TSS values updated 3/10/2011)

Runoff and TSS from Private Basins

		Outfall Coordinates[1]		Annual Runoff in Million gallons			Annual Average TSS in lbs			Annual Average TSS in metric tons[2]		
Basin	Area (Acres)	X coordinate	Y coordinate	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)	1986 (Average Water Year)	1993 (Dry Water Year)	2002 (Wet Water Year)
A-6	3.16	1,267,133.00	212,871.00	2.10	1.77	2.57	2,055.42	1,729.96	2,512.81	0.93	0.78	1.14
B-40	3.26	1,268,082.43	218,293.18	2.04	1.71	2.53	1,434.63	1,202.86	1,777.07	0.65	0.55	0.81
B-41	5.46	1,268,032.50	218,704.86	3.64	3.06	4.45	2,984.44	2,984.44	4,335.46	1.35	1.35	1.97
B-42	0.46	1,268,376.87	218,781.63	0.31	0.26	0.38	300.43	252.86	367.28	0.14	0.11	0.17
B-43	5.74	1,268,824.23	218,875.21	3.83	3.22	4.68	3,735.40	3,143.94	4,566.63	1.69	1.43	2.07
total	18.08			11.92	10.02	14.60	10,510.31	9,314.05	13,559.24	4.77	4.22	6.15

1. Horizontal North American Datum of 1983,1991 adjustment
2. Metric Ton = 2,204.62 lbs

75th percentile estimate: TSS Concentrations in mg/L (All POS basins [except B-34], SPU basin: B-21)

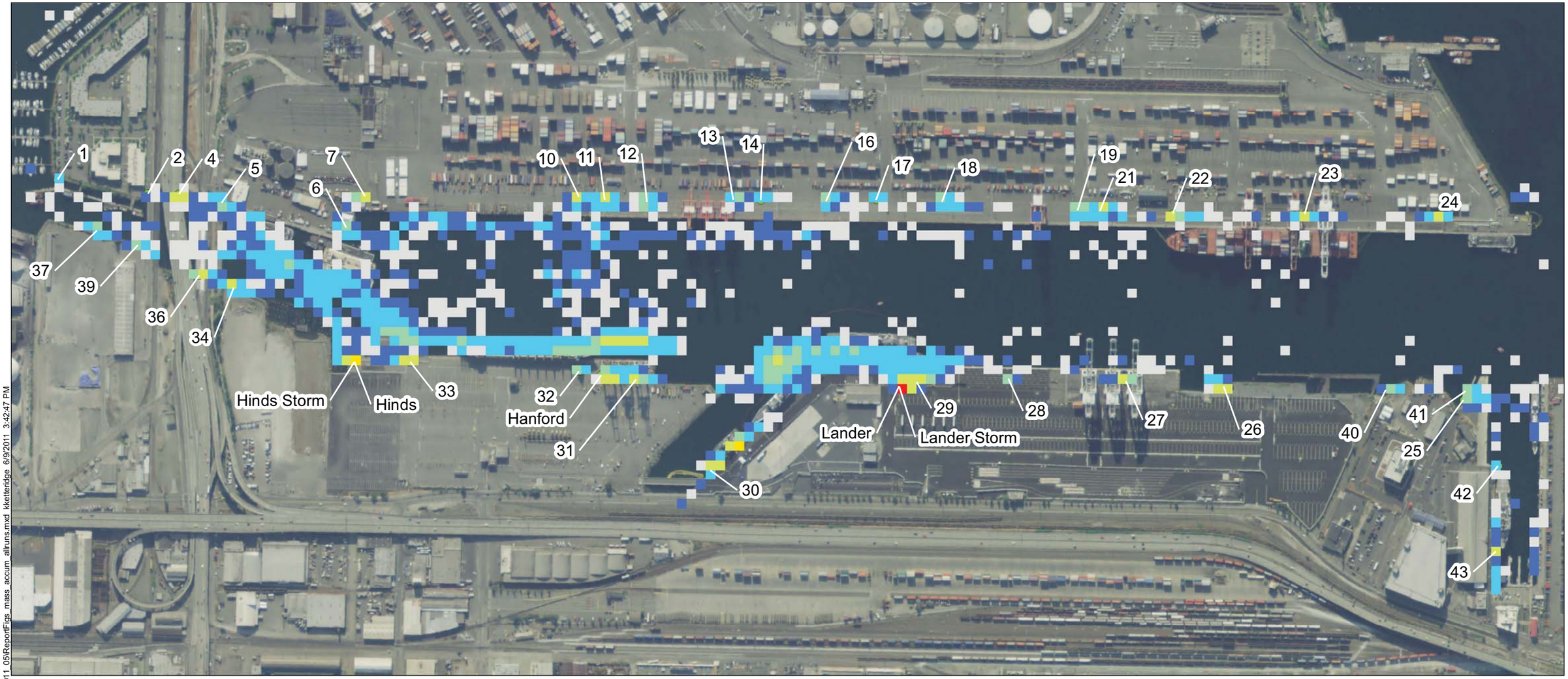
Land Use	ROW	Industrial	MFR	Commercial	Open	SFR
Estimated Concentration (mg/L)	86	60	101	84	18	70

MFR= Mulitiple Family Residential, SFR= Single Family Residential

75th percentile estimate: TSS Concentrations in mg/L (All SPU basins [except B-21], POS basin B-34, all Private basins)

Land Use	ROW	Industrial	MFR	Commercial	Open	SFR
Estimated Concentration (mg/L)	86	117	101	84	18	70

APPENDIX G
PTM MODEL SENSITIVITY ANALYSIS



LEGEND

- PTM Outfall Locations

kg / sq ft

0	0.01 - 0.01	0.02 - 0.05	0.06 - 0.1	0.11 - 1	1.01 - 2	2.01 - 4	4.01 - 8

Feet
0 250 500 750 1,000

NOTES:
1. Deposition data (points) output from PTM model simulation has been represented by a 50 ft x 50 ft resolution raster map of mass accumulation per unit area (kg/sq ft)
2. Mass accumulation represents deposition over the simulation time (1 month with sources included, 2 weeks with sources turned off, for a total of 42 days).
3. Lander, Hanford, and Hines are CSOs.
4. Outfall numbers (names) cooresponds to drainage basins.

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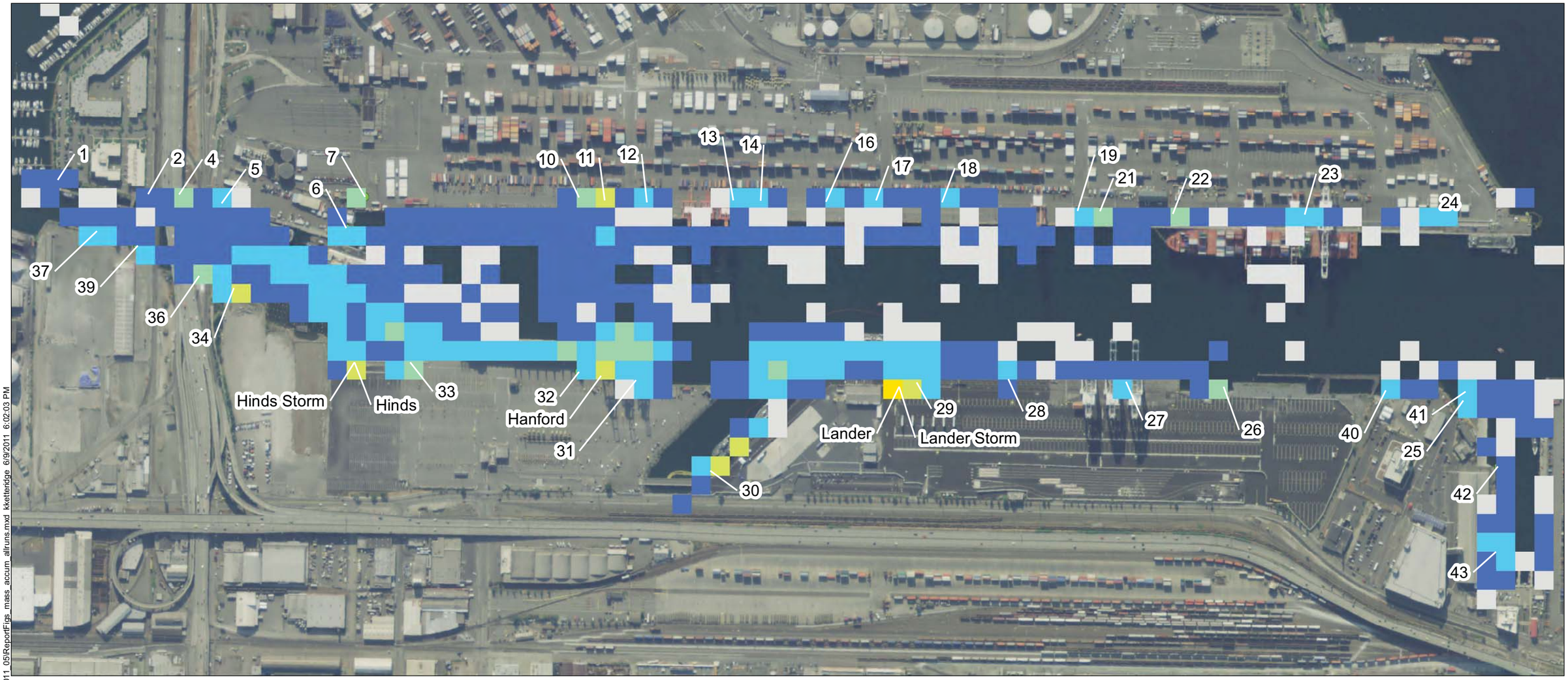
ANCHOR QEA

Figure G-1
PTM Model Base Case Run Results, 50'x50' Raster Representation (kg/sq ft)
Sediment Transport Evaluation Report
East Waterway Operable Unit



LEGEND

PTM Outfall Locations

kg / sq ft

0 | 0.01 - 0.01 | 0.02 - 0.05 | 0.06 - 0.1 | 0.11 - 1 | 1.01 - 2 | 2.01 - 4 | 4.01 - 8

Feet

0 250 500 750 1,000

NOTES:

1. Deposition data (points) output from PTM model simulation has been represented by a 100 ft x 100 ft resolution raster map of mass accumulation per unit area (kg/sq ft)
2. Mass accumulation represents deposition over the simulation time (1 month with sources included, 2 weeks with sources turned off, for a total of 42 days).
3. Lander, Hanford, and Hines are CSOs.
4. Outfall numbers (names) coorespond to drainage basins.

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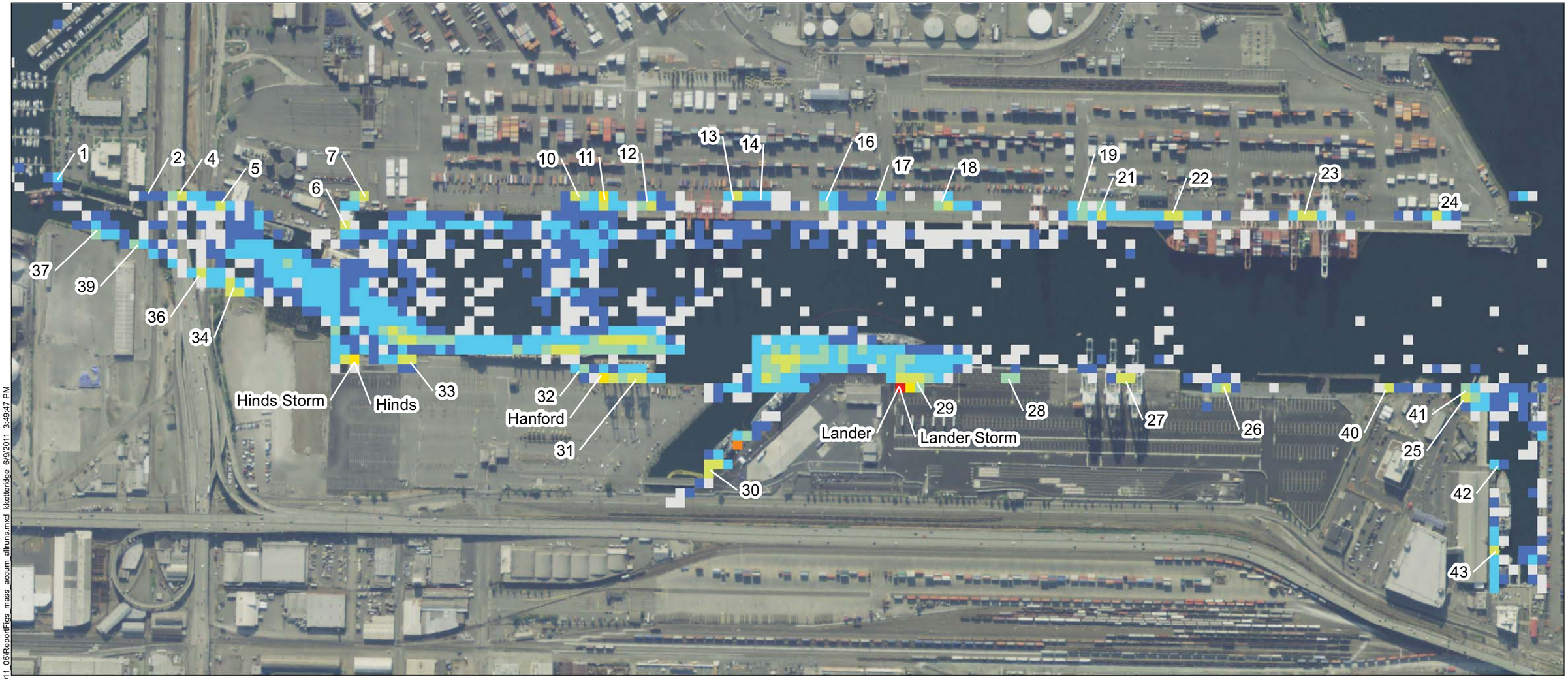
Figure G-2
PTM Model Base Case Simulation (Run 1) Results, 100'x100' Raster Representation (kg/sq ft)
Sediment Transport Evaluation Report
East Waterway Operable Unit



LEGEND

- PTM Outfall Locations

kg/ sq ft

0	0.01 - 0.01	0.02 - 0.05	0.06 - 0.1	0.11 - 1	1.01 - 2	2.01 - 4	4.01 - 8

Feet

0 250 500 750 1,000

NOTES:

1. Deposition data (points) output from PTM model simulation has been represented by a 50 ft x 50 ft resolution raster map of mass accumulation per unit area (kg/sq ft)
2. Mass accumulation represents deposition over the simulation time (1 month with sources included, 2 weeks with sources turned off, for a total of 42 days).
3. Lander, Hanford, and Hines are CSOs.
4. Outfall numbers (names) cooresponds to drainage basins.

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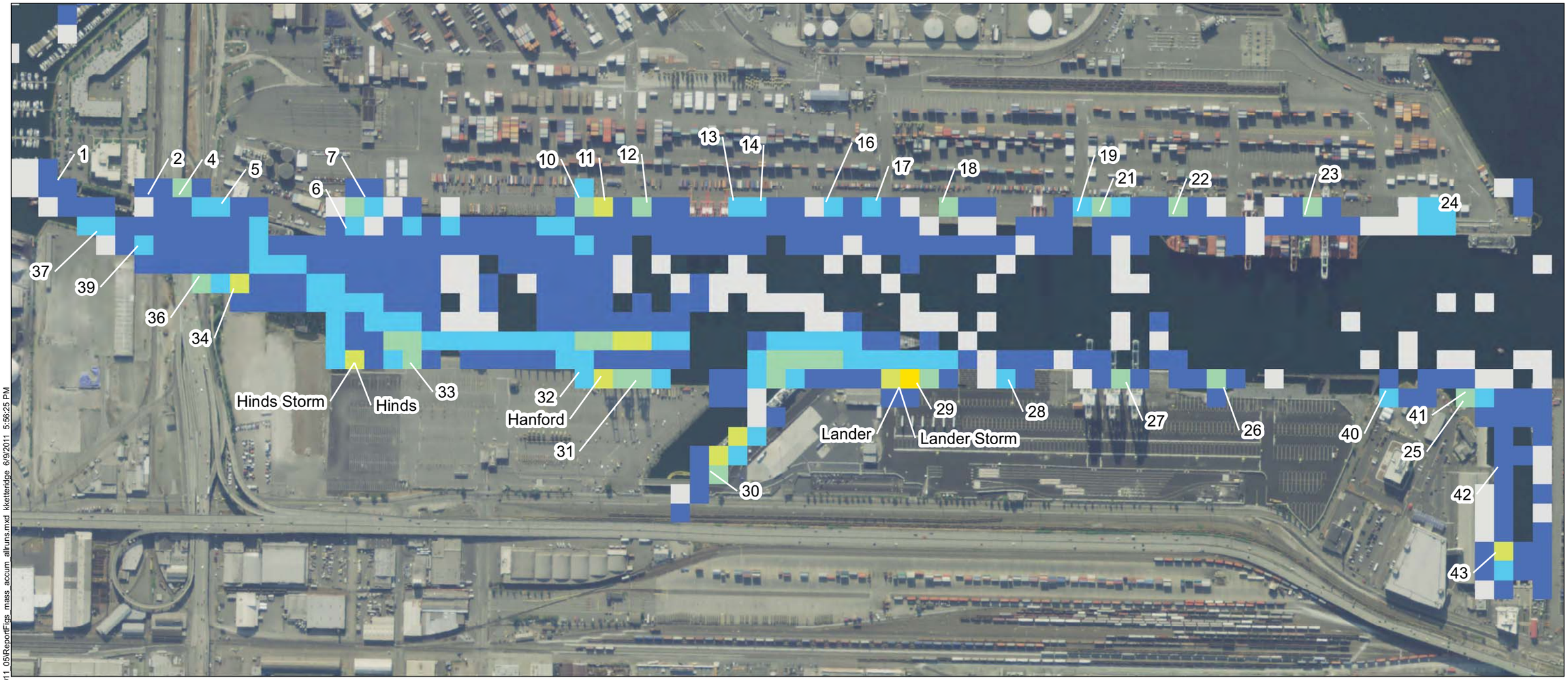
Figure G-3
PTM Model Simulation 5 (75% TSS loading) Results, 50'x50' Raster Representation (kg/sq ft)
Sediment Transport Evaluation Report
East Waterway Operable Unit



LEGEND

- PTM Outfall Locations

kg / sq ft

0	0.01 - 0.01	0.02 - 0.05	0.06 - 0.1	0.11 - 1	1.01 - 2	2.01 - 4	4.01 - 8

Feet

0 250 500 750 1,000

NOTES:

1. Deposition data (points) output from PTM model simulation has been represented by a 100 ft x 100 ft resolution raster map of mass accumulation per unit area (kg/sq ft)
2. Mass accumulation represents deposition over the simulation time (1 month with sources included, 2 weeks with sources turned off, for a total of 42 days).
3. Lander, Hanford, and Hines are CSOs.
4. Outfall numbers (names) coorespond to drainage basins.

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Figure G-4
PTM Model Simulation 5 (75% TSS loading) Results, 100'x100' Raster Representation (kg/sq ft)
Sediment Transport Evaluation Report
East Waterway Operable Unit

LEGEND

PTM Outfall Locations

Mass Accumulation (kg)

0.5 | 0.6 - 2.5 | 2.6 - 5 | 5.1 - 10 | 10.1 - 25 | 25.1 - 50 | 50.1 - 75 | 75.1 - 100 | 100.1 - 250 | 250.1 - 500 | 1,293.4

Feet
0 250 500 750 1,000

NOTES:
1. Deposition data (points) output from PTM model simulation has been represented by a 50 ft x 50 ft resolution raster map of mass accumulation (kg)
2. Mass accumulation represents deposition over the simulation time (1 month with sources included, 2 weeks with sources turned off, for a total of 42 days).
3. Lander, Hanford, and Hines are CSOs.
4. Outfall numbers (names) coorespond to drainage basins.

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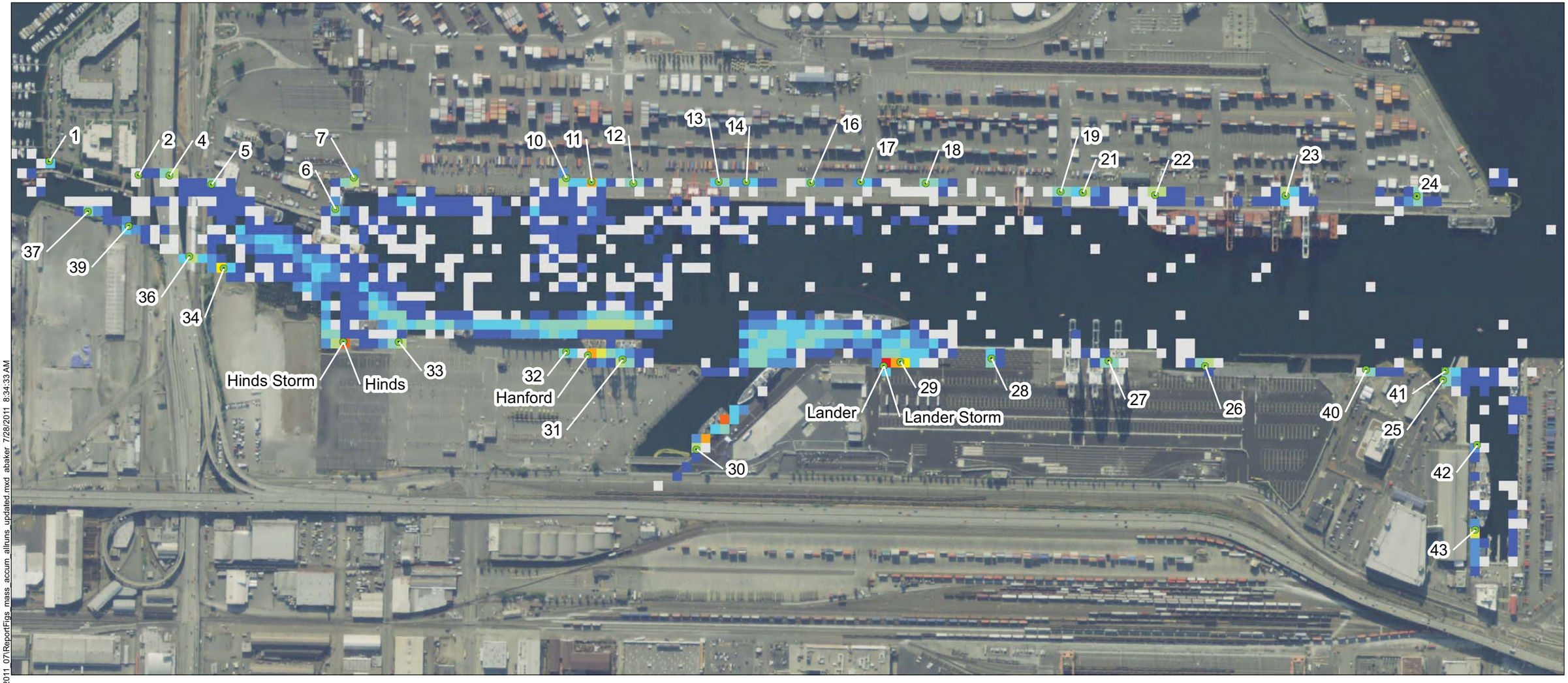
Figure G-5
PTM Model Base Case Simulation (Run 1) Results, 50'x50' Raster Representation (kg)
Sediment Transport Evaluation Report
East Waterway Operable Unit



LEGEND

- PTM Outfall Locations

Mass Accumulation (kg)

0.5 | 0.6 - 2.5 | 2.6 - 5 | 5.1 - 10 | 10.1 - 25 | 25.1 - 50 | 50.1 - 75 | 75.1 - 100 | 100.1 - 250 | 250.1 - 500 | 1,293.4

Feet
0 250 500 750 1,000

NOTES:
1. Deposition data (points) output from PTM model simulation has been represented by a 50 ft x 50 ft resolution raster map of mass accumulation (kg)
2. Mass accumulation represents deposition over the simulation time (1 month with sources included, 2 weeks with sources turned off, for a total of 42 days).
3. Lander, Hanford, and Hines are CSOs.
4. Outfall numbers (names) coorespond to drainage basins.

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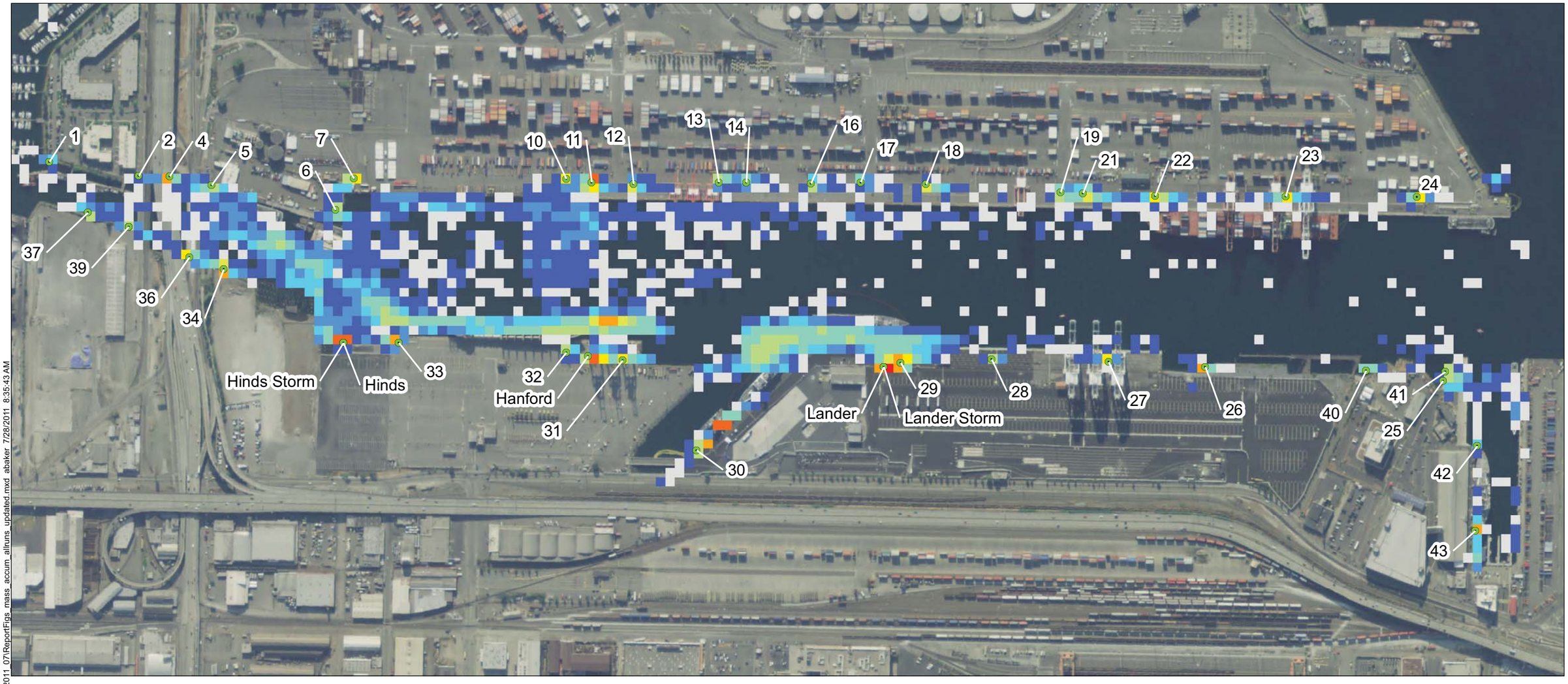
Figure G-6
PTM Model Simulation 2 Results, 50'x50' Raster Representation (kg)
Sediment Transport Evaluation Report
East Waterway Operable Unit



LEGEND

PTM Outfall Locations

Mass Accumulation (kg)

0.5 | 0.6 - 2.5 | 2.6 - 5 | 5.1 - 10 | 10.1 - 25 | 25.1 - 50 | 50.1 - 75 | 75.1 - 100 | 100.1 - 250 | 250.1 - 500 | 2,558.5

Feet
0 250 500 750 1,000

NOTES:
1. Deposition data (points) output from PTM model simulation has been represented by a 50 ft x 50 ft resolution raster map of mass accumulation (kg)
2. Mass accumulation represents deposition over the simulation time (1 month with sources included, 2 weeks with sources turned off, for a total of 42 days).
3. Lander, Hanford, and Hines are CSOs.
4. Outfall numbers (names) coorespond to drainage basins.

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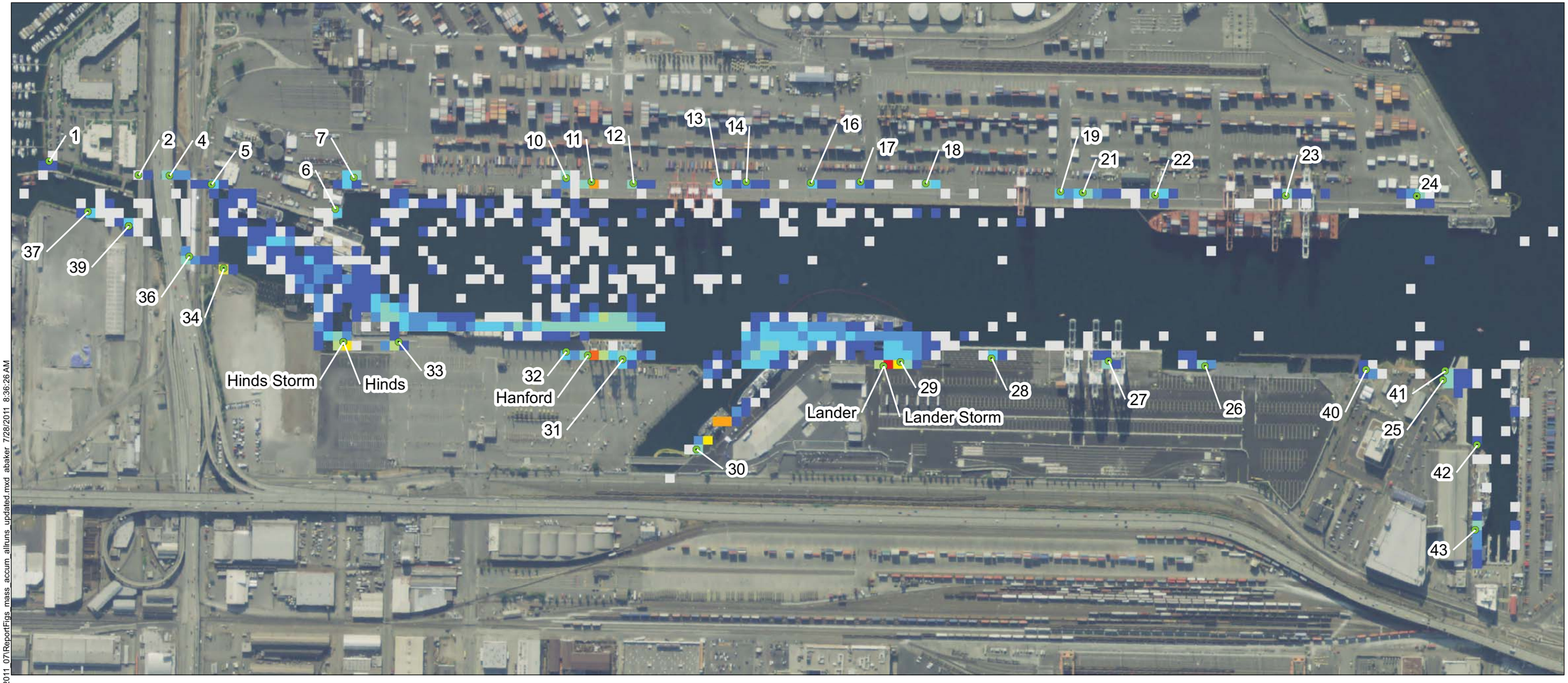
Figure G-7
PTM Model Simulation 3 Results, 50'x50' Raster Representation (kg)
Sediment Transport Evaluation Report
East Waterway Operable Unit



LEGEND

PTM Outfall Locations

Mass Accumulation (kg)

0.5 | 0.6 - 2.5 | 2.6 - 5 | 5.1 - 10 | 10.1 - 25 | 25.1 - 43.8 | 43.9 - 74.4 | 74.5 - 97.4 | 97.5 - 186.6 | 186.7 - 500 | 650.7

Feet
0 250 500 750 1,000

NOTES:
1. Deposition data (points) output from PTM model simulation has been represented by a 50 ft x 50 ft resolution raster map of mass accumulation (kg)
2. Mass accumulation represents deposition over the simulation time (1 month with sources included, 2 weeks with sources turned off, for a total of 42 days).
3. Lander, Hanford, and Hines are CSOs.
4. Outfall numbers (names) coorespond to drainage basins.

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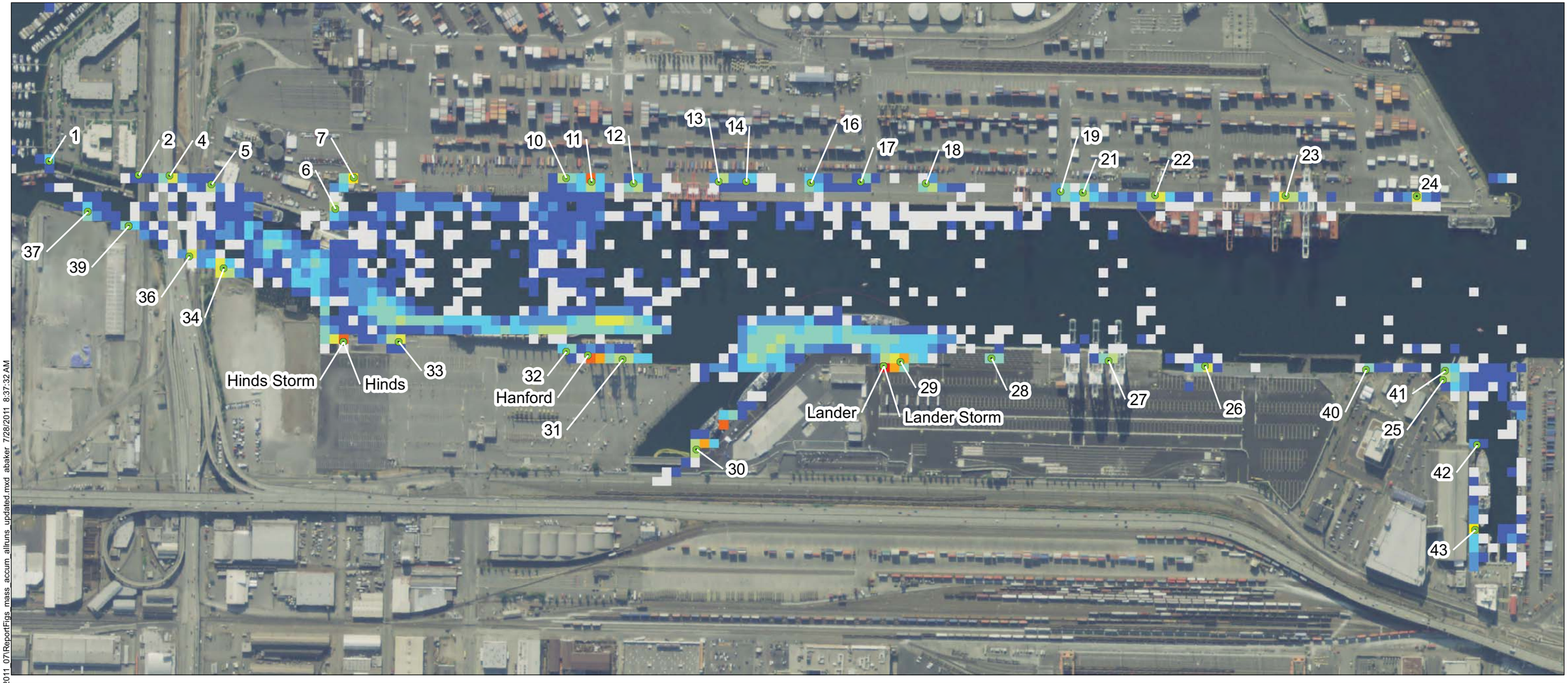
Figure G-8
PTM Model Simulation 4 Results, 50'x50' Raster Representation (kg)
Sediment Transport Evaluation Report
East Waterway Operable Unit



LEGEND

- PTM Outfall Locations

Mass Accumulation (kg)

0.5 | 0.6 - 2.5 | 2.6 - 5 | 5.1 - 10 | 10.1 - 25 | 25.1 - 50 | 50.1 - 75 | 75.1 - 100 | 100.1 - 250 | 250.1 - 500 | 1,678

Feet
0 250 500 750 1,000

NOTES:
1. Deposition data (points) output from PTM model simulation has been represented by a 50 ft x 50 ft resolution raster map of mass accumulation (kg)
2. Mass accumulation represents deposition over the simulation time (1 month with sources included, 2 weeks with sources turned off, for a total of 42 days).
3. Lander, Hanford, and Hines are CSOs.
4. Outfall numbers (names) coorespond to drainage basins.

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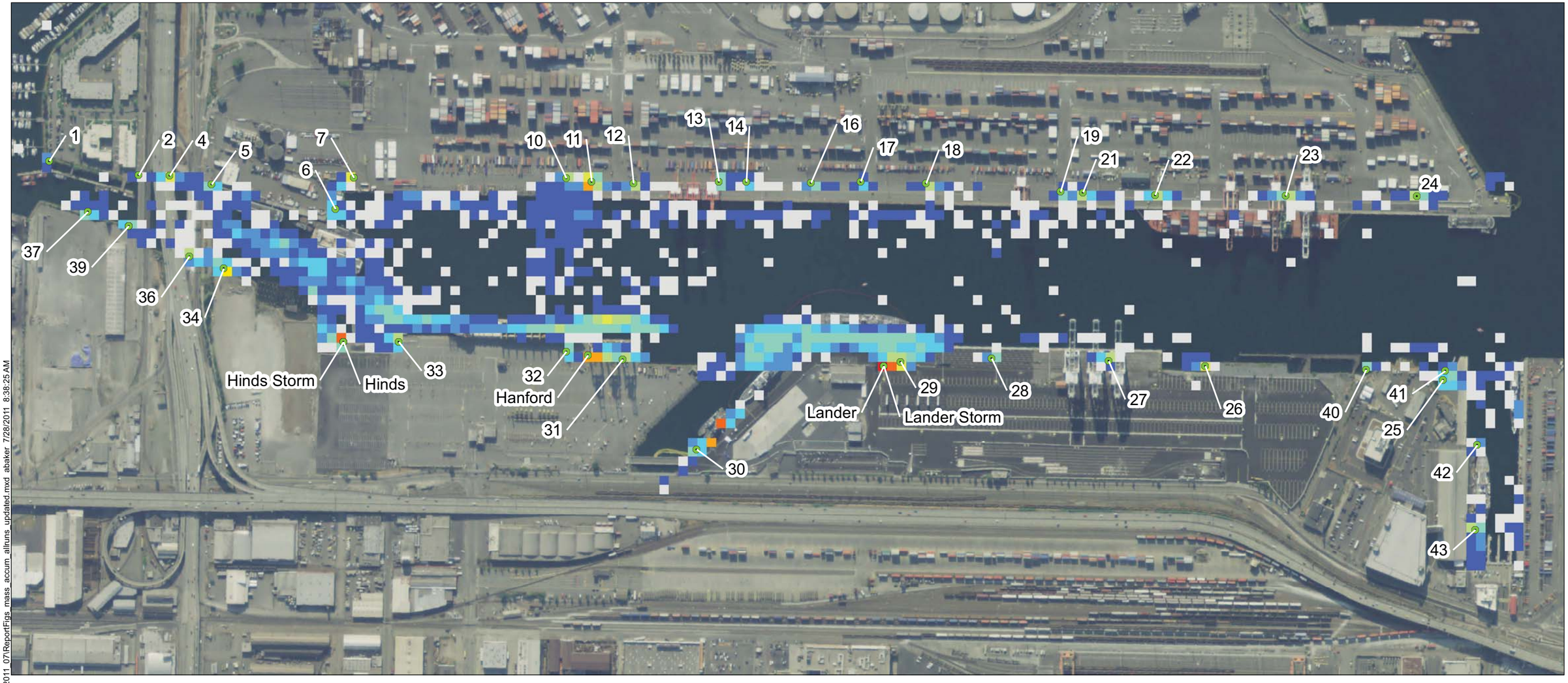
Figure G-9
PTM Model Simulation 5 Results, 50'x50' Raster Representation (kg)
Sediment Transport Evaluation Report
East Waterway Operable Unit



LEGEND

- PTM Outfall Locations

Mass Accumulation (kg)

0.5 | 0.6 - 2.5 | 2.6 - 5 | 5.1 - 10 | 10.1 - 25 | 25.1 - 50 | 50.1 - 75 | 75.1 - 100 | 100.1 - 250 | 250.1 - 500 | 1,092.5

Feet
0 250 500 750 1,000

NOTES:
1. Deposition data (points) output from PTM model simulation has been represented by a 50 ft x 50 ft resolution raster map of mass accumulation (kg)
2. Mass accumulation represents deposition over the simulation time (1 month with sources included, 2 weeks with sources turned off, for a total of 42 days).
3. Lander, Hanford, and Hines are CSOs.
4. Outfall numbers (names) coorespond to drainage basins.

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Figure G-10
PTM Model Simulation 6 Results, 50'x50' Raster Representation (kg)
Sediment Transport Evaluation Report
East Waterway Operable Unit

LEGEND

- PTM Outfall Locations

Mass Accumulation (kg)

0.5 | 0.6 - 2.5 | 2.6 - 5 | 5.1 - 10 | 10.1 - 25 | 25.1 - 50 | 50.1 - 75 | 75.1 - 100 | 100.1 - 250 | 250.1 - 500 | 1,293.4

Feet
0 250 500 750 1,000

NOTES:
1. Deposition data (points) output from PTM model simulation has been represented by a 50 ft x 50 ft resolution raster map of mass accumulation (kg)
2. Mass accumulation represents deposition over the simulation time (1 month with sources included, 2 weeks with sources turned off, for a total of 42 days).
3. Lander, Hanford, and Hines are CSOs.
4. Outfall numbers (names) coorespond to drainage basins.

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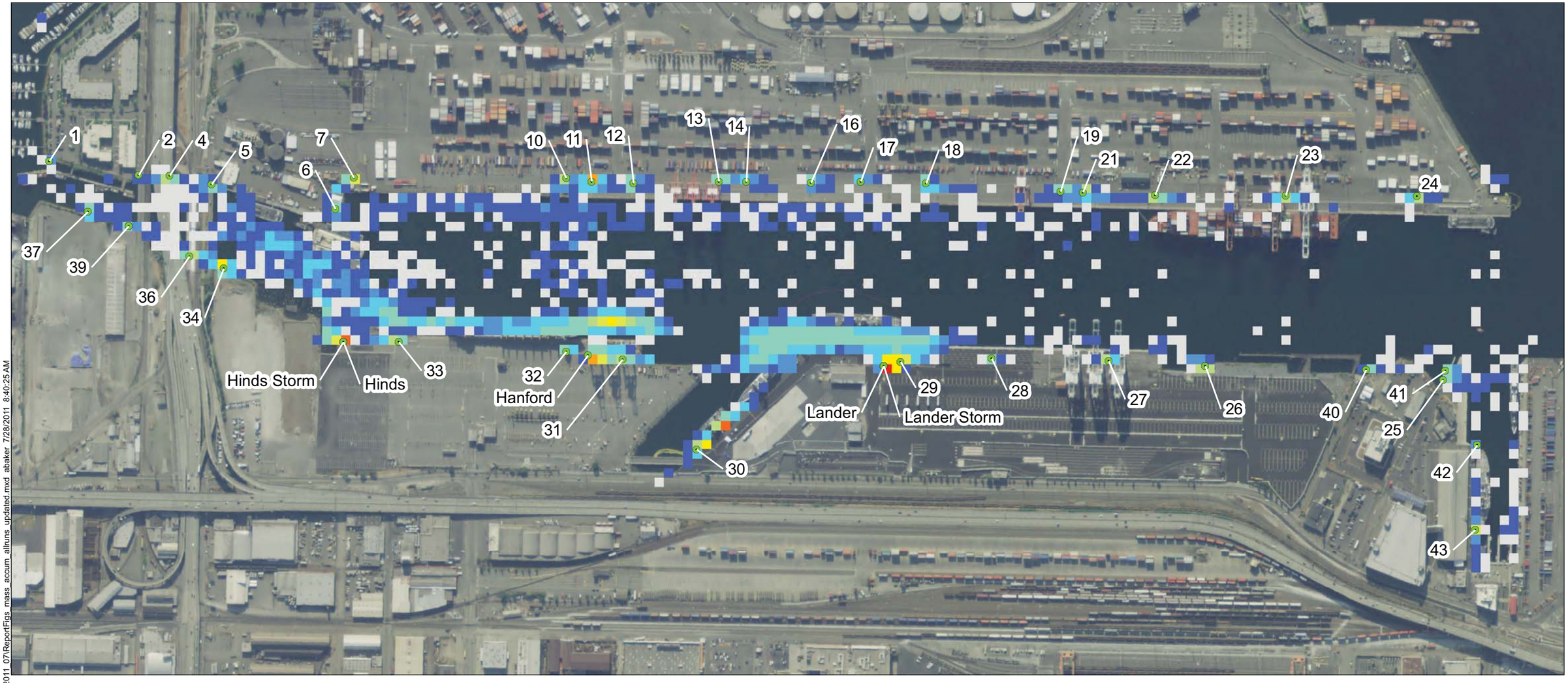
Figure G-11
PTM Model Simulation 7 Results, 50'x50' Raster Representation (kg)
Sediment Transport Evaluation Report
East Waterway Operable Unit



LEGEND

- PTM Outfall Locations

Mass Accumulation (kg)

0.5 | 0.6 - 2.5 | 2.6 - 5 | 5.1 - 10 | 10.1 - 25 | 25.1 - 50 | 50.1 - 75 | 75.1 - 100 | 100.1 - 250 | 250.1 - 500 | 1,293.4

Feet
0 250 500 750 1,000

NOTES:
1. Deposition data (points) output from PTM model simulation has been represented by a 50 ft x 50 ft resolution raster map of mass accumulation (kg)
2. Mass accumulation represents deposition over the simulation time (1 month with sources included, 2 weeks with sources turned off, for a total of 42 days).
3. Lander, Hanford, and Hines are CSOs.
4. Outfall numbers (names) coorespond to drainage basins.

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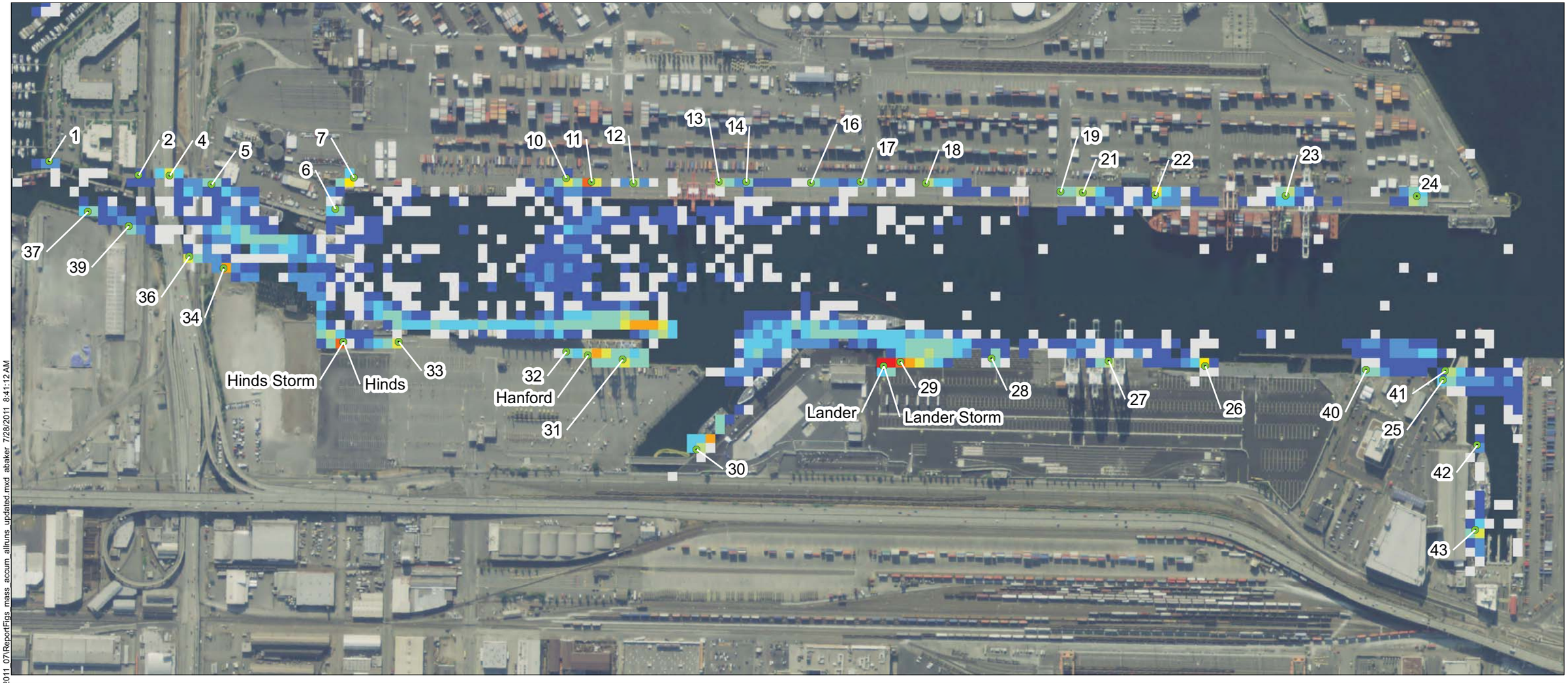
Figure G-12
PTM Model Simulation 8 Results, 50'x50' Raster Representation (kg)
Sediment Transport Evaluation Report
East Waterway Operable Unit



LEGEND

- PTM Outfall Locations

Mass Accumulation (kg)

0.5 | 0.6 - 2.5 | 2.6 - 5 | 5.1 - 10 | 10.1 - 25 | 25.1 - 50 | 50.1 - 75 | 75.1 - 100 | 100.1 - 250 | 250.1 - 500 | 1,013.5

Feet
0 250 500 750 1,000

NOTES:
1. Deposition data (points) output from PTM model simulation has been represented by a 50 ft x 50 ft resolution raster map of mass accumulation (kg)
2. Mass accumulation represents deposition over the simulation time (1 month with sources included, 2 weeks with sources turned off, for a total of 42 days).
3. Lander, Hanford, and Hines are CSOs.
4. Outfall numbers (names) coorespond to drainage basins.

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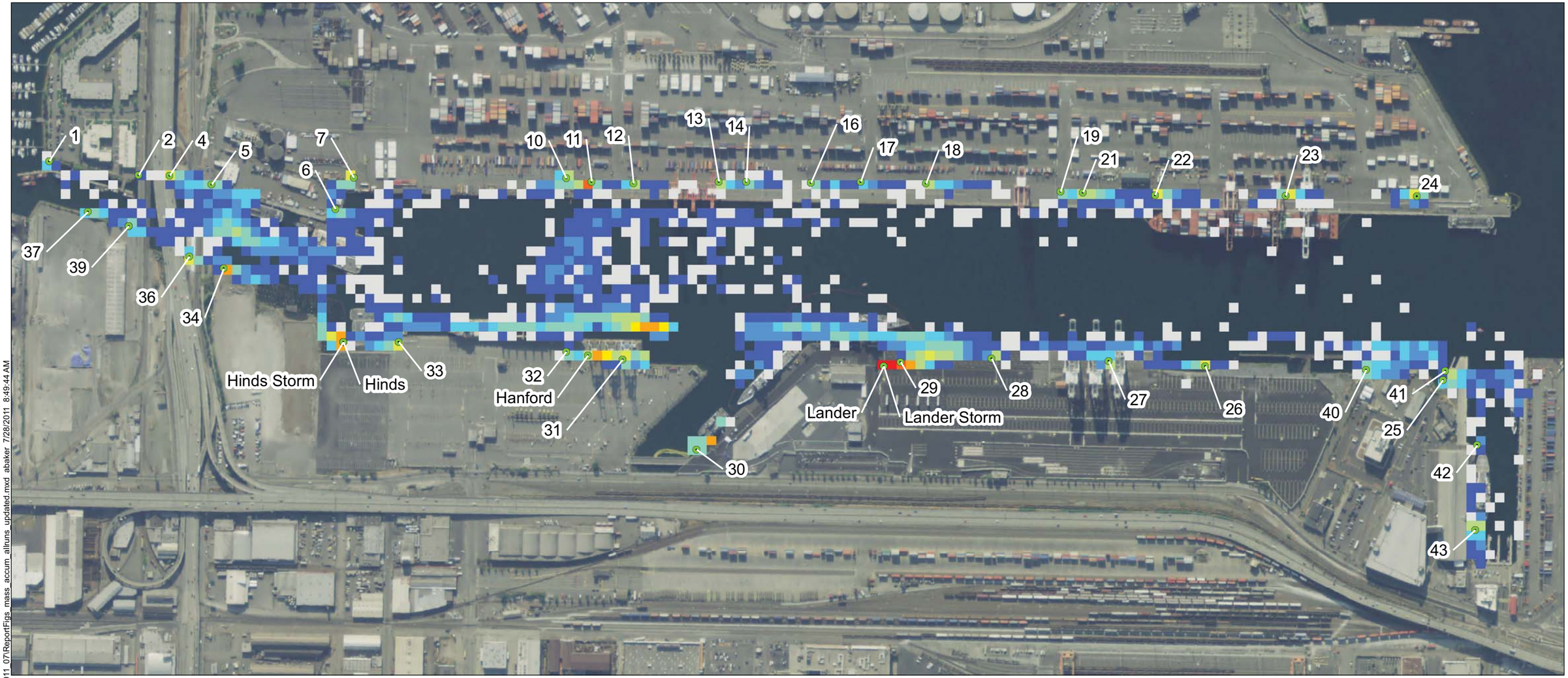
Figure G-13
PTM Model Simulation 9 Results, 50'x50' Raster Representation (kg)
Sediment Transport Evaluation Report
East Waterway Operable Unit



LEGEND

PTM Outfall Locations

Mass Accumulation (kg)

0.5 | 0.6 - 2.5 | 2.6 - 5 | 5.1 - 10 | 10.1 - 25 | 25.1 - 50 | 50.1 - 75 | 75.1 - 100 | 100.1 - 250 | 250.1 - 500 | 500.1 - 835

Feet
0 250 500 750 1,000

NOTES:
1. Deposition data (points) output from PTM model simulation has been represented by a 50 ft x 50 ft resolution raster map of mass accumulation (kg)
2. Mass accumulation represents deposition over the simulation time (1 month with sources included, 2 weeks with sources turned off, for a total of 42 days).
3. Lander, Hanford, and Hines are CSOs.
4. Outfall numbers (names) coorespond to drainage basins.

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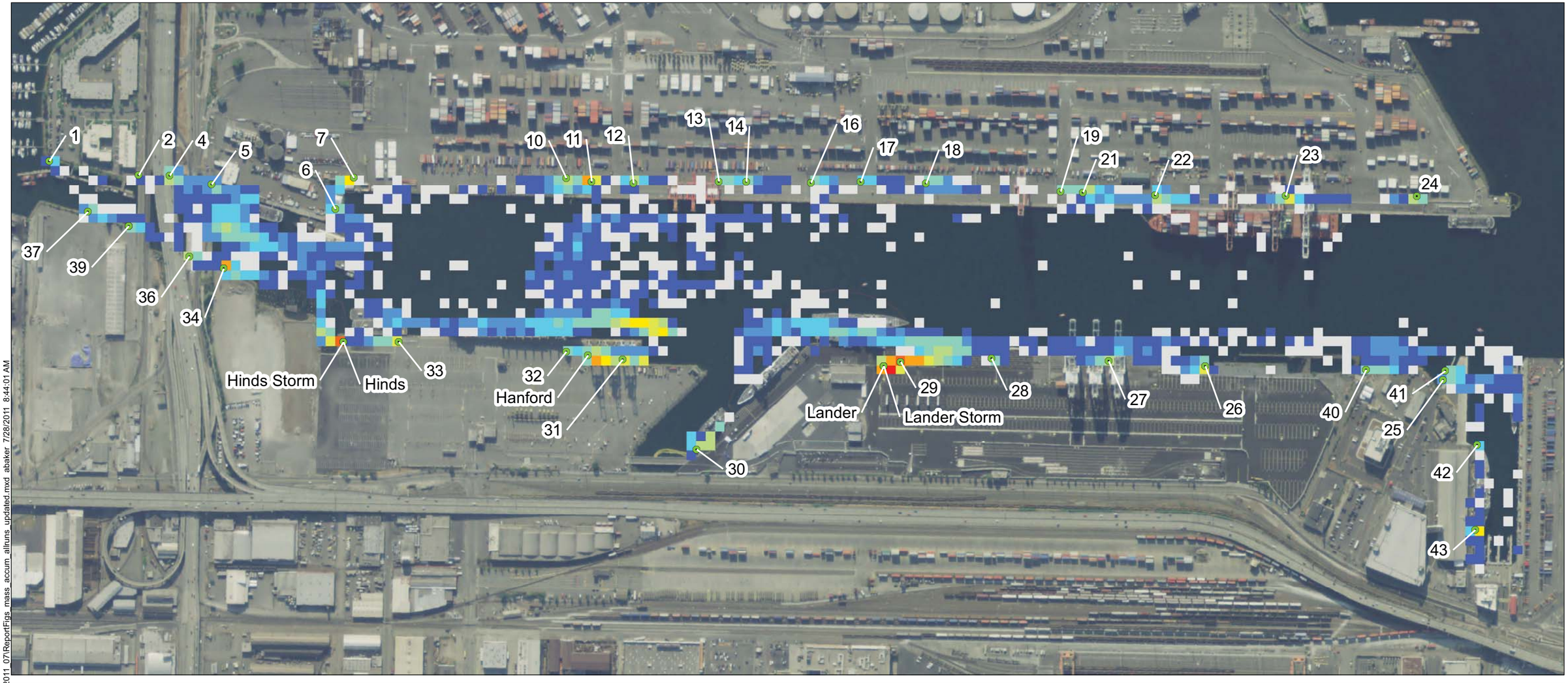
ANCHOR QEA

Figure G-14
PTM Model Simulation 10 Results, 50'x50' Raster Representation (kg)
Sediment Transport Evaluation Report
East Waterway Operable Unit



LEGEND

- PTM Outfall Locations

Mass Accumulation (kg)

0.5 | 0.6 - 2.5 | 2.6 - 5 | 5.1 - 10 | 10.1 - 25 | 25.1 - 50 | 50.1 - 75 | 75.1 - 100 | 100.1 - 250 | 250.1 - 500 | 904.5

Feet
0 250 500 750 1,000

NOTES:
1. Deposition data (points) output from PTM model simulation has been represented by a 50 ft x 50 ft resolution raster map of mass accumulation (kg)
2. Mass accumulation represents deposition over the simulation time (1 month with sources included, 2 weeks with sources turned off, for a total of 42 days).
3. Lander, Hanford, and Hines are CSOs.
4. Outfall numbers (names) coorespond to drainage basins.

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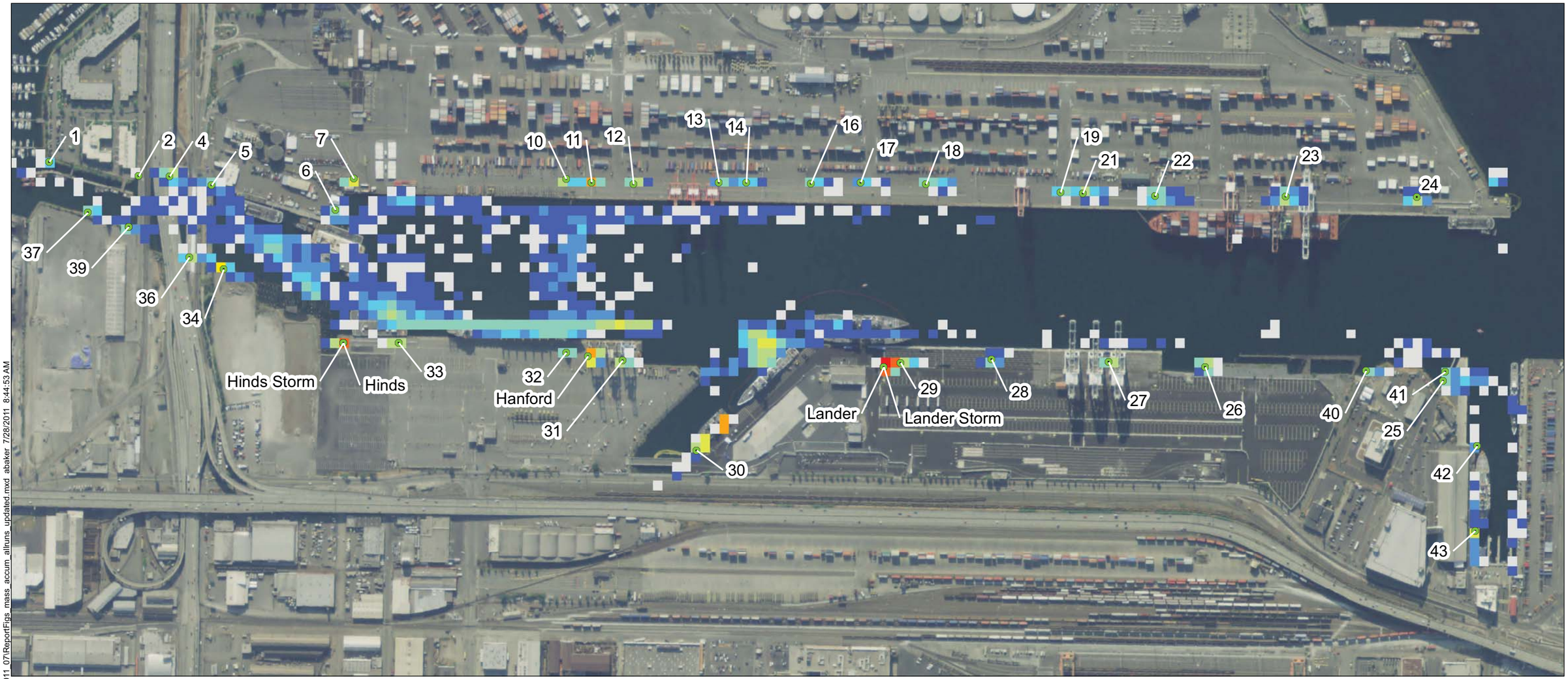
ANCHOR QEA

Figure G-15
PTM Model Simulation 11 Results, 50'x50' Raster Representation (kg)
Sediment Transport Evaluation Report
East Waterway Operable Unit



LEGEND

PTM Outfall Locations

Mass Accumulation (kg)

0.5 | 0.6 - 2.5 | 2.6 - 5 | 5.1 - 10 | 10.1 - 25 | 25.1 - 50 | 50.1 - 75 | 75.1 - 100 | 100.1 - 250 | 250.1 - 500 | 1,024.5

Feet
0 250 500 750 1,000

NOTES:
1. Deposition data (points) output from PTM model simulation has been represented by a 50 ft x 50 ft resolution raster map of mass accumulation (kg)
2. Mass accumulation represents deposition over the simulation time (1 month with sources included, 2 weeks with sources turned off, for a total of 42 days).
3. Lander, Hanford, and Hines are CSOs.
4. Outfall numbers (names) cooresponds to drainage basins.

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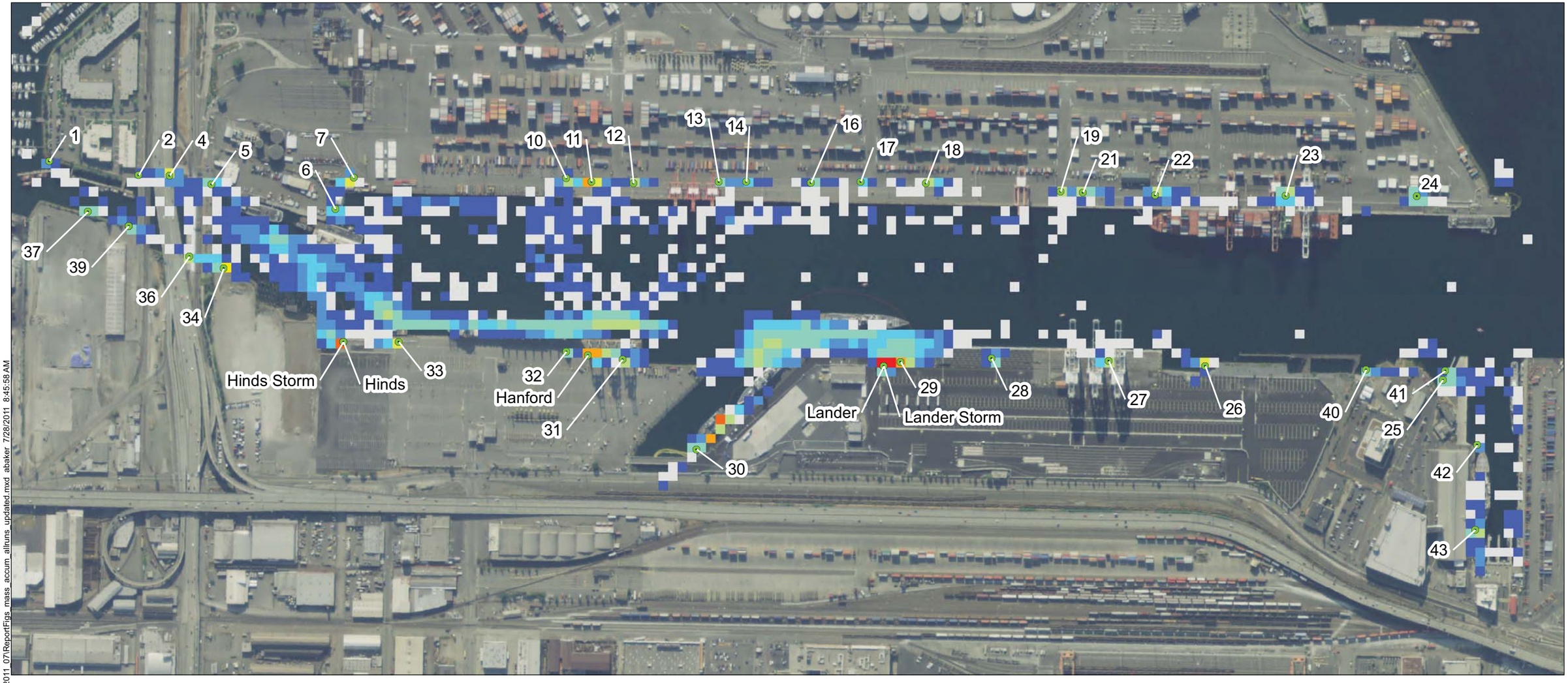
Figure G-16
PTM Model Simulation 12 Results, 50'x50' Raster Representation (kg)
Sediment Transport Evaluation Report
East Waterway Operable Unit



LEGEND

PTM Outfall Locations

Mass Accumulation (kg)

0.5
0.6 - 2.5
2.6 - 5
5.1 - 10
10.1 - 25
25.1 - 50
50.1 - 75
75.1 - 100
100.1 - 250
250.1 - 500
500.1 - 1,784.5

Feet
0 250 500 750 1,000

NOTES:
1. Deposition data (points) output from PTM model simulation has been represented by a 50 ft x 50 ft resolution raster map of mass accumulation (kg)
2. Mass accumulation represents deposition over the simulation time (1 month with sources included, 2 weeks with sources turned off, for a total of 42 days).
3. Lander, Hanford, and Hines are CSOs.
4. Outfall numbers (names) cooresponds to drainage basins.

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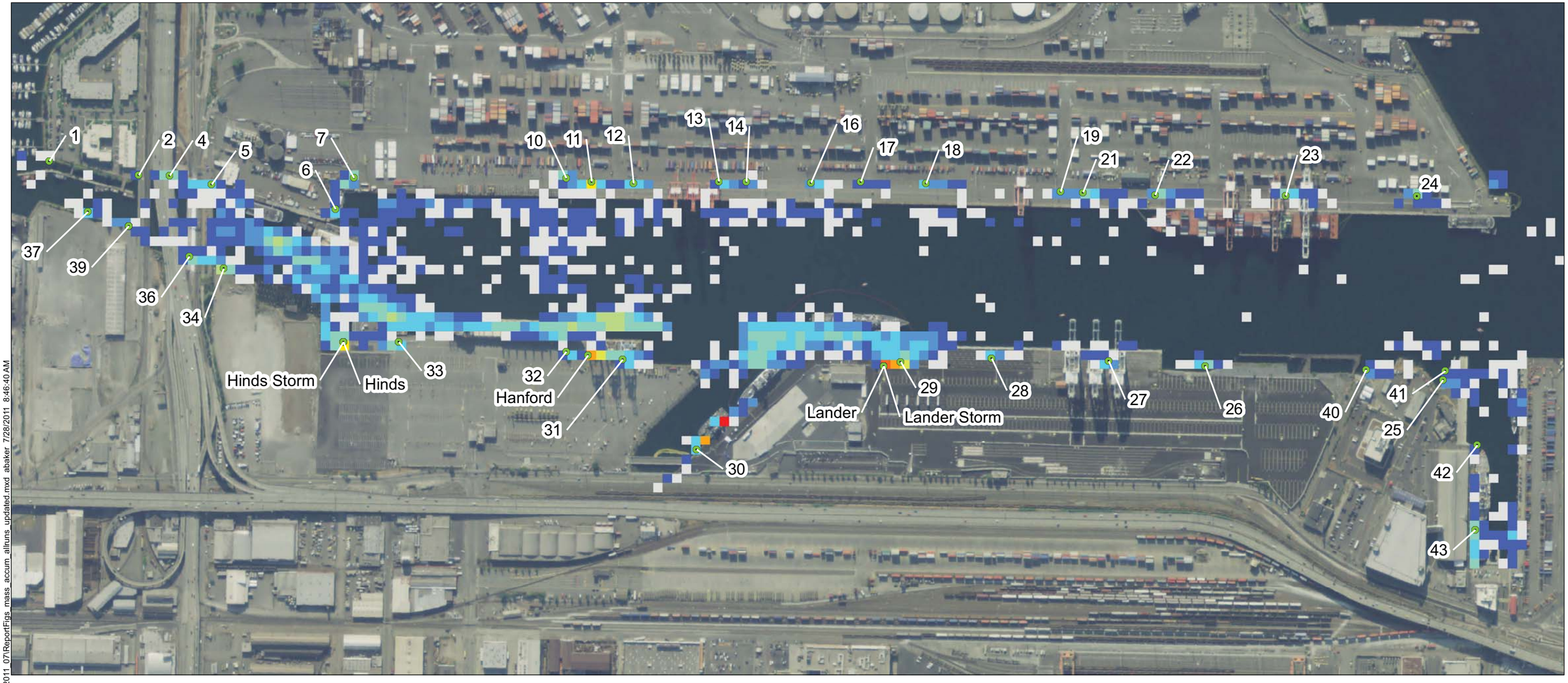
Figure G-17
PTM Model Simulation 13 Results, 50'x50' Raster Representation (kg)
Sediment Transport Evaluation Report
East Waterway Operable Unit



LEGEND

PTM Outfall Locations

Mass Accumulation (kg)

0.5 | 0.6 - 2.5 | 2.6 - 5 | 5.1 - 10 | 10.1 - 25 | 25.1 - 50 | 50.1 - 75 | 75.1 - 100 | 100.1 - 250 | 250.1 - 500 | 512.5

Feet
0 250 500 750 1,000

NOTES:
1. Deposition data (points) output from PTM model simulation has been represented by a 50 ft x 50 ft resolution raster map of mass accumulation (kg)
2. Mass accumulation represents deposition over the simulation time (1 month with sources included, 2 weeks with sources turned off, for a total of 42 days).
3. Lander, Hanford, and Hines are CSOs.
4. Outfall numbers (names) coorespond to drainage basins.

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ANCHOR QEA

Figure G-18
PTM Model Simulation 14 Results, 50'x50' Raster Representation (kg)
Sediment Transport Evaluation Report
East Waterway Operable Unit

APPENDIX H
PROPWASH MODELING TECHNICAL APPENDICES

ATTACHMENT 1

COAST & HARBOR ENGINEERING

Technical Memorandum 5

JETWASH Model Boundary Layer Development Analysis

A boundary layer is the zone of flow in the immediate vicinity of the bottom surface in which the motion of the fluid is affected by the frictional resistance exerted by the bottom. Schematically, the boundary layer for propwash flow is shown in Figure 1.

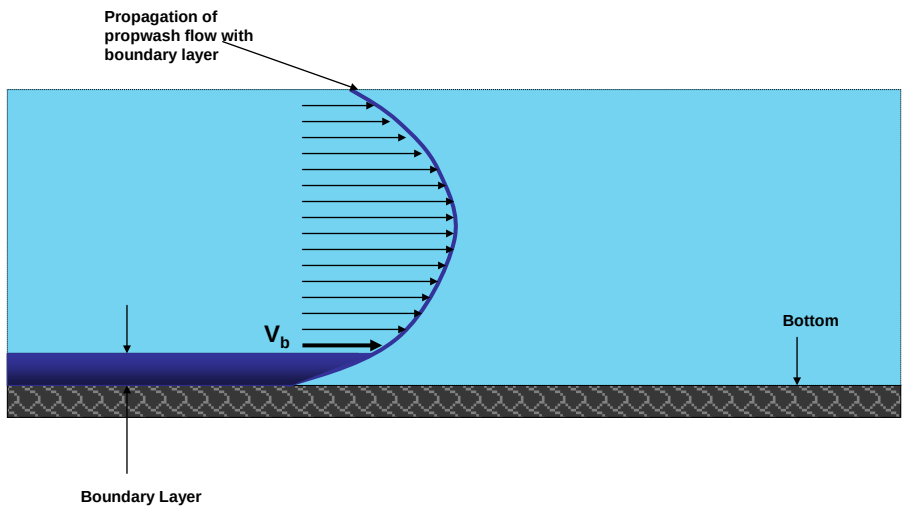

Figure 1. Schematic of propagation of propwash flow with boundary layer

For still water (when flow velocity equals zero) the boundary layer does not exist. The boundary layer forms as a consequence of the boundary's frictional resistance applied to the flowing fluid.

Theoretically, it should take some period of time to form a fully developed boundary layer after flow suddenly starts in still water (for example, a boat producing propwash moves over the lake). If it were possible to measure propwash velocity during boundary layer development, it is likely that this velocity would be larger than the velocity at the same elevation in the case with fully developed the boundary layer. Figure 2 shows schematically the theoretical differences in propwash velocities for flows with and without a boundary layer.

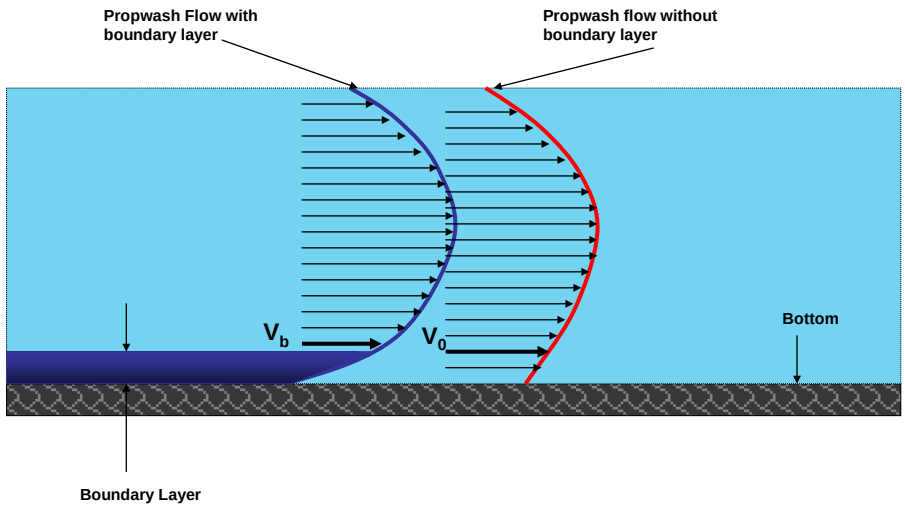

Figure 2. Propagation of propwash flow with and without a boundary layer

The JEWASH model does not account directly for existence of a boundary layer. It does; however, include other conservative factors that indirectly account for the boundary layer. Therefore, there has been concern that actual propwash flow with a non-established boundary layer (initial impingement of the jet at the bottom) may affect bottom sediment (cap material) with larger shear stress than that calculated with velocities predicted by JETWASH at specified heights above the bottom.

At present, no methods exist for assessing boundary layer development for conditions such as propeller wash impinging on the sediment bed. Shear stress in the non-fully developed boundary layer is a fundamental theoretical problem that cannot be solved in the scope of current study. However, it can be demonstrated that JETWASH results are sufficiently conservative to compensate for boundary layer development effects. To do this, Coast & Harbor Engineering (CHE) assumed that shear stress at the bottom is proportional to bottom flow velocity at a small distance above the bed. JETWASH velocity results calculated for cases near a bottom boundary and with no bottom boundary were compared. It can be reasonably assumed that near-bottom velocities during boundary layer development will not be greater than those from the no bottom boundary case. The goal of the following discussion is to 1) demonstrate that JETWASH conditions with a boundary produce higher velocities at water depths near the boundary than the no-boundary conditions. From this, it can then be demonstrated that 2) bottom shear stress is greater in JETWASH than for the comparable estimates for the period during boundary layer development due to the built-in conservatism in JETWASH. A height above the sediment bed of 15 cm was selected as the height at which velocities were compared, and is defined herein as the "near-bottom" velocity from which bottom shear stress is calculated. This height is sufficiently close to the bottom so that shear stress estimates will be conservative, both under developing and developed boundary layer conditions.

Denoting instantaneous actual bottom propwash velocity without a boundary layer (infinite water depth) as V_0 and JETWASH predicted velocity at the same elevation as Vj, the evaluation can be summarized as follows:

- If $V_0 > V_j$, then JETWASH may not be conservative enough and additional analysis of sediment stability is required.
- If $V_0 < V_j$, JETWASH is conservative enough and can be used for the design of cap layer.

The objective of the analysis is to determine the difference between propwash velocity at the bottom with a not fully-developed boundary layer and propwash velocity (of the same source) predicted by the JETWASH model.

No reliable and commonly accepted methods (formulae, models) exist to compute flow velocity for developing boundary layer conditions during jet impingement. Therefore, the above described JETWASH comparison tests were applied. The test includes computing near-bottom velocity with JETWASH at the existing water depth (boundary layer included), and at the same elevation but with the bottom moved to infinite depth. Figure 3 schematically shows the infinite depth concept for this evaluation.

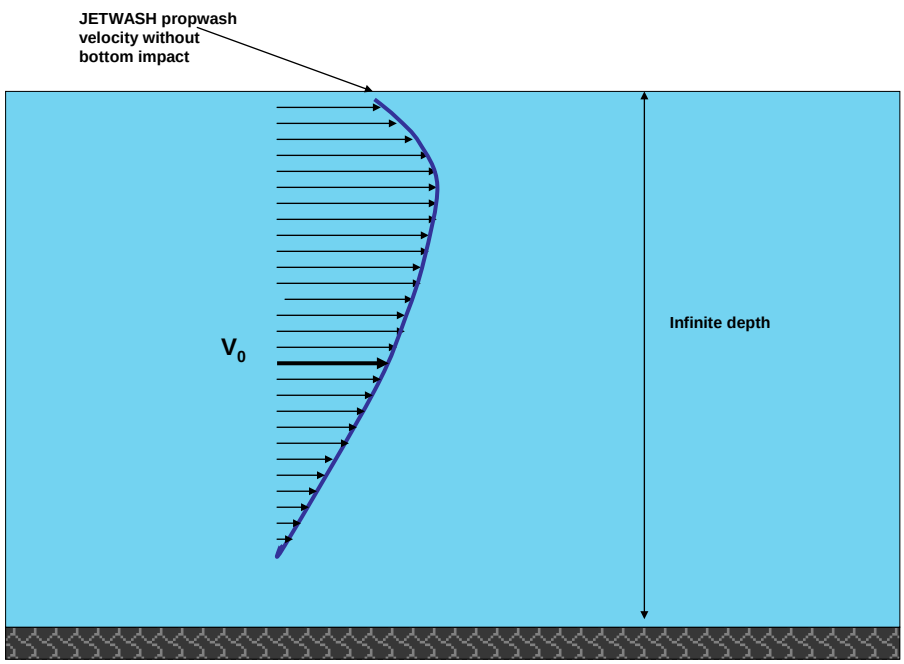

Figure 3. Schematic of computational test, flow velocity at a fixed elevation with bottom moved to infinite depth

A standard definition for a bottom boundary layer is: "…zone of flow in the immediate[1] vicinity of bottom surface in which the motion of the fluid is affected by the frictional resistance exerted by the bottom" (Middleton and Southard 1984). Therefore, velocity V_0 is not affected by frictional resistance of the bottom, and we can assume V_0 is equal

[1] For certain conditions it may influence much of the water column

to or greater than the near-bed velocity in developing boundary layer conditions. This evaluation includes computing bottom velocity with JETWASH for various conditions (including a Fox River example that is used in Technical Memo 3) and repeating the computations for cases with the bottom at such depth that it does not affect the flow. JETWASH algorithms are designed such that the propeller-induced total flux for each case (depth-limited and infinite depth) is equal (assuming identical prop conditions). Therefore, JETWASH forces the depth-limited case to include increased near-bottom velocities to compensate for areas in the infinite depth case that are below the natural water depth in the depth-limited case but where flux still occurs (i.e., JETWASH reflects the additional flux back up into the near-bottom layer of the depth-limited case; thus, the built in near-bottom conservatism). The results of a sample computation are presented in Table 1. Figure 1 is an example of velocity profile computations at 5.9 ft behind the prop showing velocities at heights of 5 to 30 cm above the bottom for 5-ft water depth conditions. The built-in conservatism of JETWASH can be seen in the depth-limited profile, which does not fit the 'typical' near-bottom velocity profile where there is a rapid decrease near-bottom. This is due to the reflection of the infinite-depth case velocities back into the boundary layer.

Table 1, Results of JETWASH computational test

Monterey, 5-ft water depth	**Velocity at 15 cm above bottom (ft/sec)**	
Distance behind prop (ft)	**With bottom**	**No bottom effect**
4.8	5.907	5.907
5.9	11.489	9.549
7.1	13.205	10.600

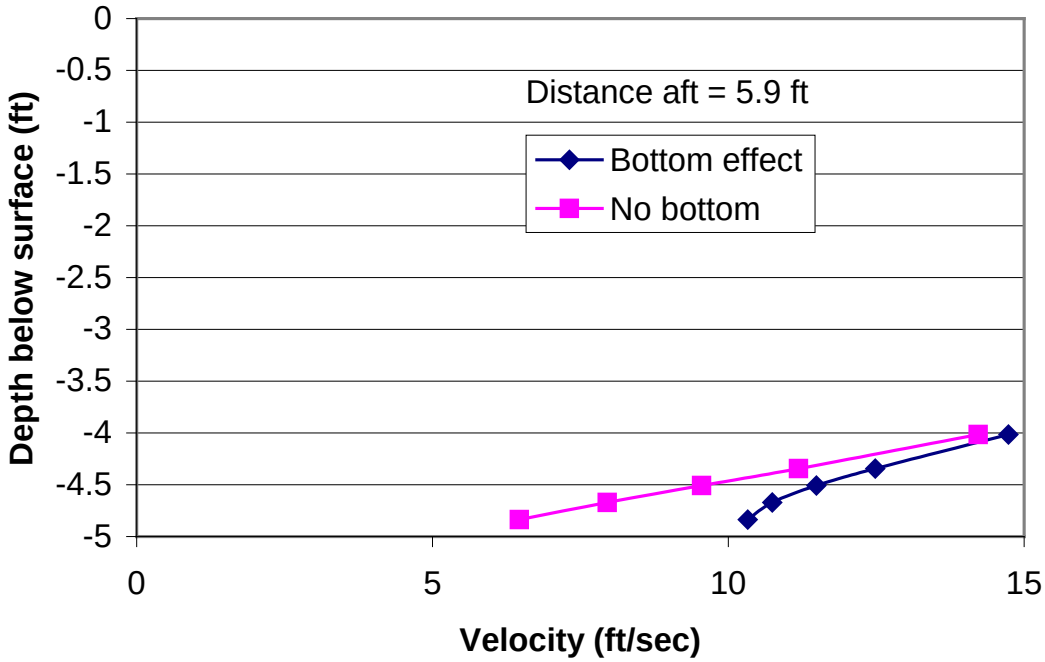

Figure 4. Example of JETWASH computational test, Monterey boat in 5-ft depth

Based on the computational test, it is concluded that because the JETWASH model incorporates enough conservative assumptions, the calculated bottom velocity is higher than that for the case of a non-developed boundary layer. Based on these computational tests and the JETWASH algorithms that inherently increase near-bottom velocities to account for flux balance, it can be concluded that the JETWASH assumptions will always provide conservative bottom shear stress during both developing and developed boundary layer calculations. Therefore, the JETWASH model is considered appropriately conservative for the Fox River propwash analysis without modifications.

REFERENCE

Middleton, Gerard V. and Southard, John B. 1984. Mechanics of Sediment Movement. S.E.P.M. Short Course No. 3, 2nd Edition. SEPM Tulsa, OK 74159-0756

ATTACHMENT 2

PROPWASH AND VESSEL HYDRODYNAMICS STUDY
EAST WATERWAY OPERABLE UNIT SRI/FS
SEDIMENT TRANSPORT EVALUATION

COAST & HARBOR
ENGINEERING

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COAST & HARBOR ENGINEERING

Technical Report

Propwash and Vessel Hydrodynamics Study – East Waterway Operable Unit SRI/FS Sediment Transport Evaluation

1. Introduction

This Technical Report presents the modeling approach and results of propwash and pressure field analyses conducted by Coast & Harbor Engineering, Inc. (CHE) for the Port of Seattle, as part of the project team performing a SRI/FS for the East Waterway Operable Unit. Propwash modeling results are presented as near bottom velocities and bed shear stresses for each modeled scenario. The information and data from this technical report was the basis for Section 5, Propwash Modeling and Vessel Operations in the East Waterway of the Supplemental Remedial Investigation Feasibility Study Report, Sediment Transport Evaluation Report

Impact analysis from vessel hydrodynamics on bottom sediment was limited in this study to propwash and pressure field. The study purpose is to develop information for characterizing sediment transport dynamics in East Waterway. Figure 1 shows the study area location.

Figure 1. Location of East Waterway study area for vessel hydrodynamics

2. Propwash Modeling Methodology

2.1. Propwash Analysis Areas

The East Waterway was divided into areas in which activities and vessel types were similar. Fourteen separate areas and subareas were identified and provided by AnchorQEA. Figure 2 shows the areas in the waterway identified by number for developing analysis scenarios.

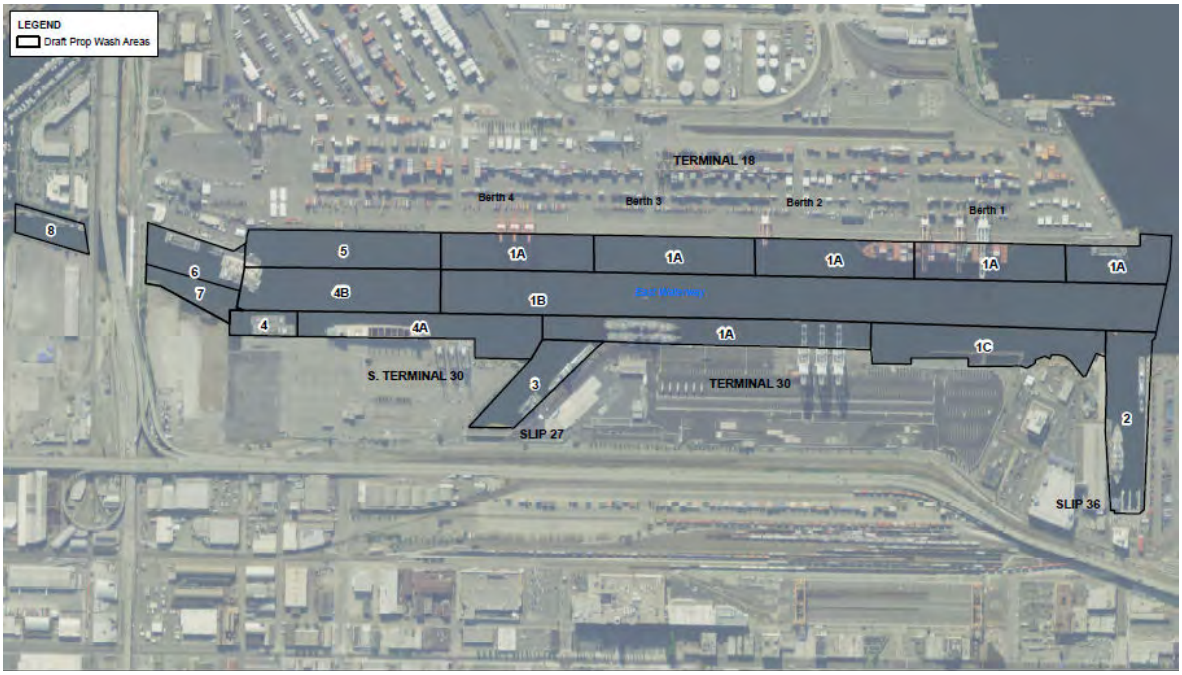


Figure 2. Study areas comprising the propwash modeling analysis of East Waterway (source: Anchor QEA)

The largest ships in the waterway are container carriers that call at the northern half of Terminal 18, on the west side of the waterway (Area 1a—see Figure 2). Berths are located at the terminal according to stationing from the northern end. Berths 1 and 2 handle the largest ships and extend from Station 500 to Station 2600 feet. Berths 3 and 4, which handle smaller container ships, extend from Station 2700 to Station 4800 feet and are also designated Area 1a. Ships approach these berths bow-first, under the assistance of at least two tugs. The ship's bow thruster is used to help steer the ship in the waterway. These vessels are turned in Elliott Bay, not in the waterway.

Farther south at Terminal 18 the pier is less used, and is the location where a 600-ft-long ship with one specific cargo calls approximately four times per year (Area 5). The ship is moved only under tug power.

The north end of the waterway on the east side is the location of Slip 36, where Coast Guard vessels dock (Area 2).

Container ships call at Terminal 30 (Area 1a), and are moved into the waterway stern-first using at least two tugs. The ship's bow thruster is used to help steer the ship within the waterway.

The part of Terminal 30 shown in Figure 2 as Area 1c is not used for berthing container ships, but the bottom sediment in Area 1c could be subjected to velocities generated by vessels transiting the waterway (Area 1b) or maneuvering while approaching a nearby berth.

Farther south, Slip 27 is the location where tugs and empty barges may be temporarily stored (Area 3).

The area southward of Slip 27 to the south end of the pier is now called South T30, but had an earlier designation of Terminal 25. The southern 400 feet (Area 4) is leased to Harley Marine Services (formerly Olympic Tug and Barge). Smaller container ships are expected to berth in the future between Areas 3 and 4 in an area designated Area 4a. Area 4b is affected by in-channel operations of vessels maneuvering at berths in Areas 4 and 5.

Southward from this area to the West Seattle Bridge, the west half of the channel is designated Area 6, and contains mooring facilities for oil barges and tugs owned by Harley Marine Services. The eastern half of this waterway is designated Area 7 and has no berths.

South of the bridge dominant use of Area 8 is for port facilities for Western Towboat tugs.

2.2. Propwash Numerical Models

Propwash modeling has been performed using two modeling systems: two-dimensional steady hydrodynamic model JETWASH, and three-dimensional (3-D) fully unsteady hydrodynamic model VH-PU. JETWASH modeling was conducted assuming that propeller (or any other source of propwash) and velocity field from this propeller is steady (no translation) relative to the bottom slope. Propwash simulations with VH-PU model have been conducted for conditions of propwash flow field moving with the propeller relative to the bottom surface at East Waterway[1].

[1] Results of simulation with VH-PU will be presented at the next phase of the study in relationship to depth of scour and sediment stability.

2.2.1. JETWASH

The modeling tool applied to determine near-bottom velocities, required for calculating bottom sediment transport and bottom shear stress, is the two-dimensional model JETWASH (CHE 2003). The JETWASH model simulates the velocity field created by propulsion systems and accounts for interaction of the velocity jet with the bottom boundary. The model and data requirements were summarized in a Technical Memorandum *Modeling Scenarios for East Waterway* (CHE 2011). The JETWASH model is based on a well-established and empirically verified theory of flow produced by a momentum jet. JETWASH has been tested and proven to be a reasonable engineering tool for propwash analysis. The JETWASH model has been accepted by EPA Region 8 and U.S. Army Corps of Engineers for analysis of sediment stability under impact from propwash of vessels ranging in size from small recreational boats to large ships. JETWASH also has been successfully applied for cases of ships equipped with thrusters.

The following describes the JETWASH model governing equations:

$$V_x = 2.78 * U_0 * \frac{D_0}{X} Exp(-15.43(\frac{z}{X})^2) + V_\alpha + V_\beta$$

Where:

U_0 = Jet velocity exiting propeller, computed with either of the following equations, depending on data availability:

$$U_0 = C_2 (P_d / D_p{}^2)^{1/3}$$

$$U_0 = 1.6 / D_p (T / p)^{1/2}$$

$$U_0 = 1.6 * n * D_p \sqrt{K_{tp}}$$

V_α = Additive velocities due to propeller shaft angle to the horizontal. It is always positive for angles between 0 and 180 degrees. V_α is a function of V_x (shaft parallel to the bottom) and angle of the shaft. Please note that V_α in the governing equation above is described conceptually. In computer code it is included in the first component of the equation[2].

V_β = Additive velocity due to bottom slope. It is equal to "0" for flat bottom (Fox River conditions).

[2] Based on propeller shaft angle, the radial distance from centerline to bottom is adjusted (reduced) which increases bottom velocity for positive angles.

Symbols in JETWASH and EMAP governing equations are identical and are described below:

V_x = Velocity at coordinate x and z

U_0 = Jet velocity exiting propeller

X = Horizontal distance from propeller

z = Radial distance from axis of propeller

D_p = Propeller diameter

$D_0 = 0.71 \cdot D_p$ for non-ducted propeller

P_d = Applied engine power

K_{tp} = Thrust coefficient

n = Propeller rps

T = Thrust

C_2 = Empirical coefficient

2.2.2. Unsteady Propwash Simulation

VH-PU is a 3-D curvilinear fully non-steady 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 VH-PU model was developed and tested with the support of a U.S. Civilian Research and Development Foundation grant.

VH-PU has been successfully used for various projects in the states of Washington, California, Texas, and Louisiana, and at overseas locations to determine propeller bottom scour and stability of under pier structures exposed to propeller wash effects from ferries, tug boats, and deep draft vessels. The VH-PU model accounts for the variable boundary layer conditions through the length scale of turbulent fluctuations in the boundary layer (equations 5 and 6 below) and friction velocity (equation 15 below).

The VH-PU model describes 3-D fields of velocities generated by ship propellers, including turbulence intensity and length scale in a given domain of arbitrary bottom topography. The model was developed on the basis of non-hydrostatic extension of the Princeton Ocean Model (POM) described by Blumberg and Mellor (1987).

2.2.3. Basic Equations

In the model the 3-D Reynolds averaged Navier-Stokes equations are used:

$$\frac{\partial u_i}{\partial xi} = 0, \qquad (1)$$

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho_0}\frac{\partial p}{\partial x_j} - \frac{\partial \overline{u_i u_j}}{\partial x_j} - g_j, \tag{2}$$

Where: $x_i = (x, y, z)$ are spatial coordinates, axis z is directed upward, $u_j = (u, v, w)$ are components of velocity, p is pressure, $g_j = (0, 0, g)$ is gravity, ρ_0 is constant density in Boussinesq approximation. The Reynolds stresses are modeled using the eddy viscosity approach:

$$\overline{u_i u_j} = -K_M \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) + \frac{1}{3} q^2 \delta_{ij}, \tag{3}$$

Where: eddy viscosity coefficient $K_M = S_M q\, l$ is related with kinetic energy of turbulence $\frac{1}{2} q^2 = \overline{u_i u_i}$ and length scale l. Here S_M is a model constant.

The model of turbulence is q-$q^2\, l$, which is a 3-D extension of the model of Mellor and Yamada (1982):

$$\frac{\partial q^2}{\partial t} + u_j \frac{\partial q^2}{\partial x_j} = -2\overline{u_i u_j}\frac{\partial u_j}{\partial x_j} + \frac{\partial}{\partial x_j} S_q q l \frac{\partial q^2}{\partial x_j} - 2\frac{q^3}{B_1 l}, \tag{4}$$

$$\frac{\partial q^2 l}{\partial t} + u_j \frac{\partial q^2 l}{\partial x_j} = -E_1 l \overline{u_i u_j}\frac{\partial u_j}{\partial x_j} + \frac{\partial}{\partial x_j} S_l l q \frac{\partial q^2}{\partial x_j} - \frac{q^3}{B_1}\left[1 + E_2\left(\frac{1}{\kappa L}\right)\right], \tag{5}$$

In equation (5) the last term in square brackets is the wall function, which is necessary in a q-$q^2\, l$ model to correctly describe flow near the solid boundary. According to Mellor and Yamada (1982), the distance from a solid boundary L is:

$$L^{-1}(\mathbf{r}) = \frac{1}{2\pi}\iint \frac{dA(\mathbf{r}_0)}{[\mathbf{r} - \mathbf{r_0}]^3}, \tag{6}$$

Where: $\mathbf{r}$ is the radius vector for a given point, $\mathbf{r_0}$ is solid boundary. When the scale of computational domain is mainly a horizontal scale, then approximately:

$$L^{-1} = z^{-1} + (H - z)^{-1} \tag{7}$$

The constants of the turbulence model S_M, B_1, E_1, E_2 and S_l were determined by Mellor and Yamada (1982).

2.2.4. Boundary Conditions

The kinematic condition at the water surface z = $\eta(x,y,t)$ is:

$$\frac{\partial \eta}{\partial t} + u\frac{\partial \eta}{\partial x} + v\frac{\partial \eta}{\partial y} = w \tag{8}$$

The dynamic condition is:

$$k_m \frac{\partial \mathbf{V_h}}{\partial z} = \frac{\boldsymbol{\tau_0}}{\rho_o} \tag{9}$$

Where $\mathbf{V_h} = (u,v)$; $\boldsymbol{\tau} = (\tau^{(x)}, \tau^{(y)})$, is wind stress.

At the nearest computational layer $z = H + z_b$,

$$-u\frac{\partial H}{\partial x} - v\frac{\partial H}{\partial y} = w \tag{10}$$

and

$$k_m \frac{\partial \mathbf{V}_h}{\partial z} = \frac{\boldsymbol{\tau}_b}{\rho_o}, \tag{11}$$

Where:

$$\boldsymbol{\tau}_\mathbf{b} = \rho_0 C_D \left|\mathbf{V_b}\right| \mathbf{V_b}, \tag{12}$$

$$C_D = \max\left(0.0025; \left(\frac{1}{\kappa}\ln\left(\frac{z_b + z_o}{z_o}\right)\right)^{-2}\right) \tag{13}$$

The relevant boundary conditions for equations (4) - (5) at the surface and bottom are:

$$(q^2(\eta), q^2 l(\eta)) = (B_1^{2/3} u_\tau^2(0), 0) \tag{14}$$

$$(q^2(-H), q^2 l(-H)) = (B_1^{2/3} u_\tau^2(-H), 0),$$

$$(Q^2(-H), Q^2 l(-H)) = (B_1^{2/3} u_\tau^2(-H), 0) \tag{15}$$

Where $u_1(0)$ and $u_1(-H)$ are friction velocities.

The lateral conditions are given at the solid boundary and at the open boundary (see Figure 3). At the solid boundaries the non-slip conditions are used. At the open boundary a new boundary condition is used. It is based on a Newtonian relaxation technique for sea level. The computational domain is a closed area that is divided into an internal zone and relaxation zones along the open boundaries. The boundary conditions at the outer boundary of relaxation zones are non-slip conditions. The equation for surface elevation was derived by the integration of continuity equation (1) from bottom to surface. The modified equation is:

$$\frac{\partial \eta}{\partial t} + \frac{\partial \overline{u}(H+\eta)}{\partial x} + \frac{\partial \overline{v}(H+\eta)}{\partial y} = -\frac{\eta - \eta_B}{T}\alpha \tag{16}$$

The right hand side is a Newtonian relaxation term, where α is a relaxation parameter ($\alpha = 1$ in the relaxation zone and $\alpha = 0$ outside). η_b is prescribed elevation at the boundary and T is relaxation time, a parameter chosen to satisfy non-reflecting condition incoming in relaxation zone disturbances.

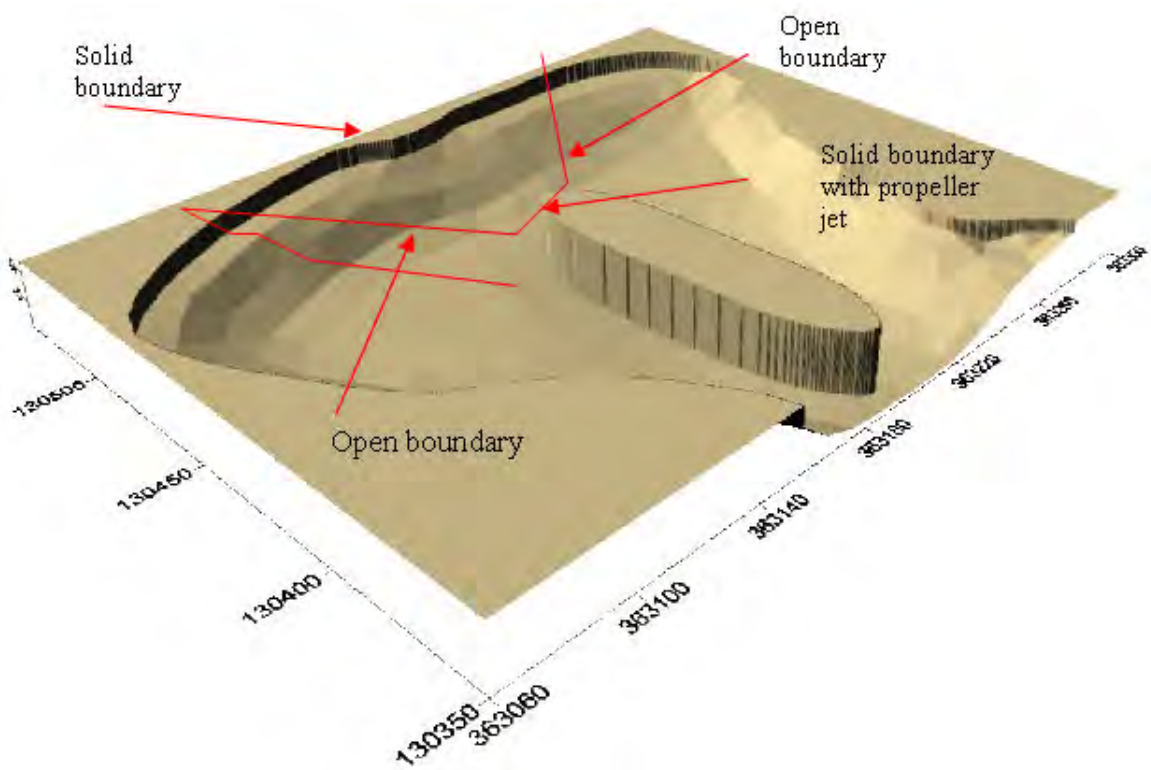


Figure 3. Scheme of computational area with different types of boundary

2.3. Shear Stresses Technical Approach

The approach to estimating the magnitude and location of bottom scour by ships' propulsion is to first simulate the flow velocity pattern created by the specific source installed on the ship, incorporating the channel depth at separate locations in the waterway. The second step is to apply the maximum bottom velocity in each location to determine the bottom shear stress.

The term near bottom velocity used in this report refers to velocity at 26 cm above bottom, which is applied in calculating critical shear stress of a bed surface particle. The height of 26 cm is arbitrary, but was the height of a velocimeter used in CHE field studies for validating the JETWASH model and has remained the reference height for calculating threshold of motion of bottom material. A logarithmic velocity profile is assumed to exist between the point of propwash velocity specification and the bottom (USACE, 2002). Shear stresses developed in the near-bottom propwash velocity field were calculated using the assumptions of rough, turbulent flow, logarithmic velocity profile, and the roughness factor k_s described below.

Bed shear stress τ_b developed by near bottom velocity is computed using modeled velocity U_{zref} at a specified height above the bottom, reference height z_{ref}, and assumes that a logarithmic velocity profile develops in the flow near the bottom. The velocity profile for dynamically rough flow over a granular boundary is

$$\frac{U_{zref}}{U_*} = 5.75 \cdot \log_{10}\left(\frac{Zref}{k_s}\right) + 8.5$$

Where,

U_{zref} is velocity at height $Zref$ above bottom

U_* is shear velocity = $\sqrt{\frac{\tau_b}{\rho}}$

$Zref$ is specified height above bottom (26 cm in this study)

κ_s is roughness length ($2 \cdot D_{90}$ in this study)

τ_b is bottom boundary shear stress = $\rho \cdot U_*^2$

Bottom roughness for use in calculating shear stress at the bottom of the East Waterway is assumed to be a function of sediment size. In the absence of bedforms, the roughness factor k_s has been variously defined by researchers as equal to the mean particle size or some other statistic. For example the original studies leading to the Karman-Prandtl logarithmic velocity profile equated k_s with the sediment diameter. Another example is a study by Gilliani *et al.* (2007) in which k_s was taken to be three times the D_{90} particle diameter for sediments having a D_{50} less than 0.05 mm. For consistency, the value of roughness for shear stress developed by bottom velocity due to propwash was defined as $2 \cdot D_{90}$ and adopted from bottom sediment characteristics presented by Anchor QEA in Section 6.2 of the main Sediment Transport Evaluation Report.

2.4. Test Matrix and List of Scenarios

Fifteen scenarios were developed for analyzing propwash effects. The scenarios consist of maneuvers of docking, undocking, and navigating the waterway; using ship's main power and thrusters; and using various types of tugs. Vessel types, maneuvers, area characteristics, and certain propwash parameters were specified for each area and were coordinated with the study team through a Technical Memorandum prepared by CHE (2011) and further developed in subsequent team discussions. Specifics of vessel types and propulsion were collected from public information of shipping lines, tug companies, and CHE archives. All simulations assumed the tide level was mean lower low water (MLLW). Simulations of all vessels, including tugs, in the docking and undocking maneuver assumed the source of propwash was stationary. Tugs transiting the waterway were assumed to make way at 4 knots. The total of 15 simulation scenarios and pertinent model input parameters are listed in Table 1.

Table 1. Modeling scenarios for East Waterway

Scenario Number	Propwash Area / Terminal	Depth at MLLW (ft)	Vessel Type / Name	Maneuver	Propulsion Type	Power Applied (kW)	Prop Speed (r.p.m.)	Prop Dia-meter (ft)	Depth Blw Prop Center (ft)
1	Area 1a, T 18 Berths 1 and 2	50	Container / Xin Mei Zhou	Docking	Ship's main power	6852	35	30.1	22
2	Area 1a, T 18 Berths 1 and 2	50	Container / Xin Mei Zhou	Undocking	Bow Thruster	3145	216	9.8	12.4
3	Areas 1a, 1b	50	Tractor Tug / Garth Foss	Docking a container ship	Voith-Schneider	2952	204	8.6	37.5
4	Area 1a, T 18 Berths 1, 2; T 30	50	Container / Margrit Rickmers	Docking	Ship's main power	4113	25	26.5	25.2
5	Area 1a, T 18 Berths 1, 2; T 30	50	Container / Margrit Rickmers	Undocking	Bow Thruster	3000	216	9.8	19.3
6	Area 2, Slip 36	40	USCG Ice Breaker Polar Star	Docking	3 Controllable pitch props	2238	200	16	18.2
7	Area 2, Slip 36	40	USCG Cutter Hamilton Class	Docking	2 Controllable Pitch props	1343	200	13	27.2
8	Area 3, Slip 27	30	Tug / Hunter D	Docking a barge	2 Standard props	1276	160	6.2	30.1
9	Area 4, 4a, 4b, 5	40	Tug / Eagle	Docking a barge	Twin ducted props	1119	160	6.4	27.7
10	Area 6	20	Tug / Eagle	Docking a barge	Twin ducted props	1119	160	6.4	7.7
11	Area 7	30	Tug / Eagle	Docking a barge	Twin ducted props	1119	160	6.4	17.7
12	Area 8	20	Tug / Alaska Mariner	Docking	2 Nautican Nozzle	149	50	8.7	5.0
13	Area 1b, 1c Terminals 18, 30	50	Tug / Garth Foss	Assist container ship navigating waterway	Voith-Schneider	1968	140	8.6	37.5
14	Area 4a, South T30 (future)	46	Container / Margrit Rickmers	Docking	Ship's main power	4113	35	26.5	21.2
15	Area 4a, South T30 (future)	46	Container / Margrit Rickmers	Undocking	Bow Thruster	3000	216	9.8	15.3

3. JETWASH Modeling Results

3.1. Scenario 1 Area 1a Terminal 18 Berths 1 and 2

The largest container ships in the waterway call at Berths 1 and 2 and are represented by the Xin Mei Zhou, a 102,453 DWT vessel. This ship has a capacity of 8,530 TEU and is pictured in Figure 4. Propwash generated by the ship's main propulsion is simulated for Scenario 1. The area of propwash modeling is Berths 1 and 2 of Terminal 18, as shown in Figure 5, was assumed for this propwash study. In simulating propwash of the Xin Mei Zhou a minimum underkeel clearance of 4 feet was assumed, corresponding to a draft of 46 feet.

Modeled propwash velocity generated by the ship's main propulsion during docking is shown in Figure 5. The figure shows the horizontal plane of the pattern of near-bottom velocity. The maximum near-bottom velocity is simulated equal to 9.3 ft/sec. The bottom boundary shear stress corresponding to this velocity is 0.32 lbs/ft^2 (15 Pa).

Figure 4. Container ship Xin Mei Zhou (area 1) (photo credit: Tony Finnerty)

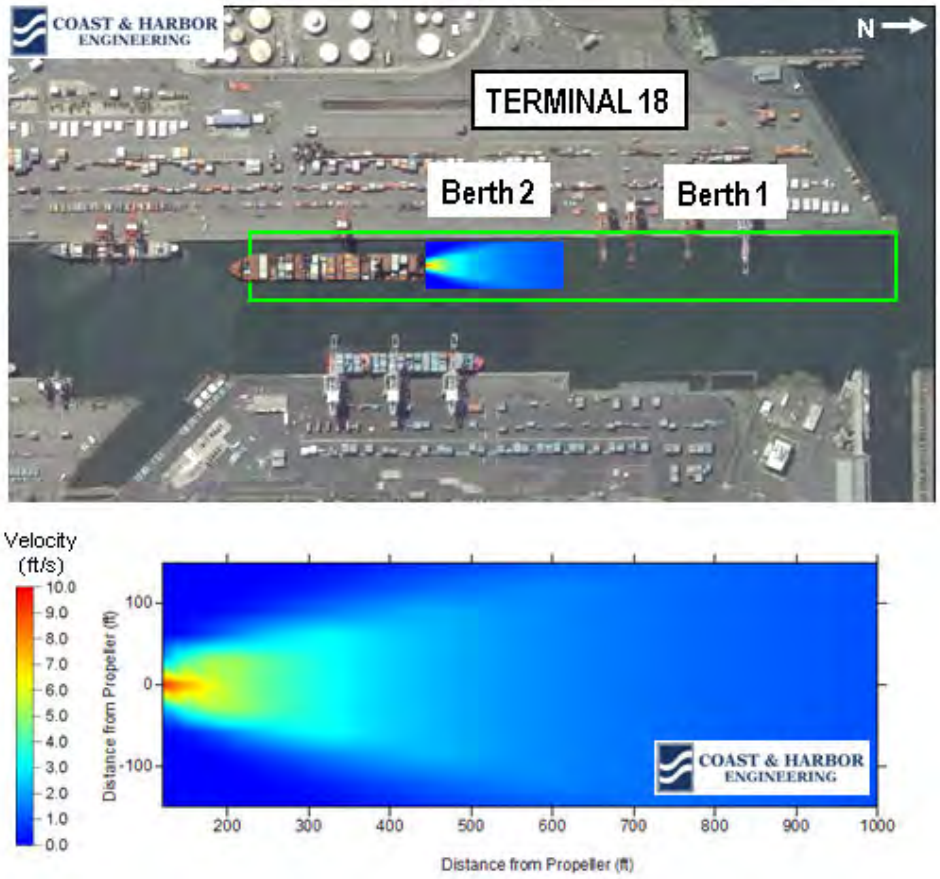


Figure 5. Scenario 1 propwash modeling area and bottom velocity pattern in Area 1a

3.2. Scenario 2 Area 1a Terminal 18 Berths 1 and 2

The vessel Xin Mei Zhou is assumed to undock using the bow thruster initially at full power. All container ships operating in the waterway are assumed to be fitted with a bow thruster and the Xin Mei Zhou represents the most powerful thruster and that located closest to the channel bottom. For conservatively examining propwash generated bottom velocity, the vessel draft upon departing was assumed to be the same as when arriving. A diagram illustrating the size and location of a bow thruster on a container ship is shown in Figure 6. Thruster wash generated by the bow thruster is simulated in Scenario 2. Modeled velocity generated by the ship's thruster during undocking is shown in Figure 7. The figure shows the horizontal plane of the pattern of near-bottom velocity in two zones of intensity. The maximum near-bottom velocity is 11.4 ft/sec. The bottom boundary shear stress corresponding to this velocity is 0.48 lbs/ft^2 (23 Pa). The figure illustrates the concept that as the ship moves farther from the berth the thruster power is reduced, resulting in zone of bottom velocity less than the maximum nearer the channel center.

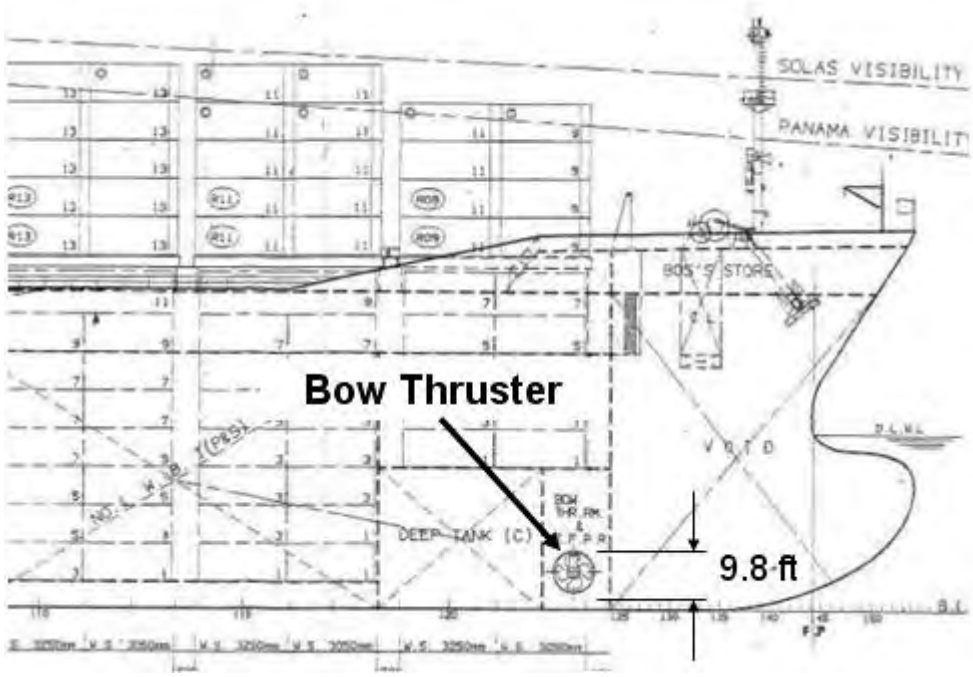


Figure 6. Bow thruster configuration on container ship hull

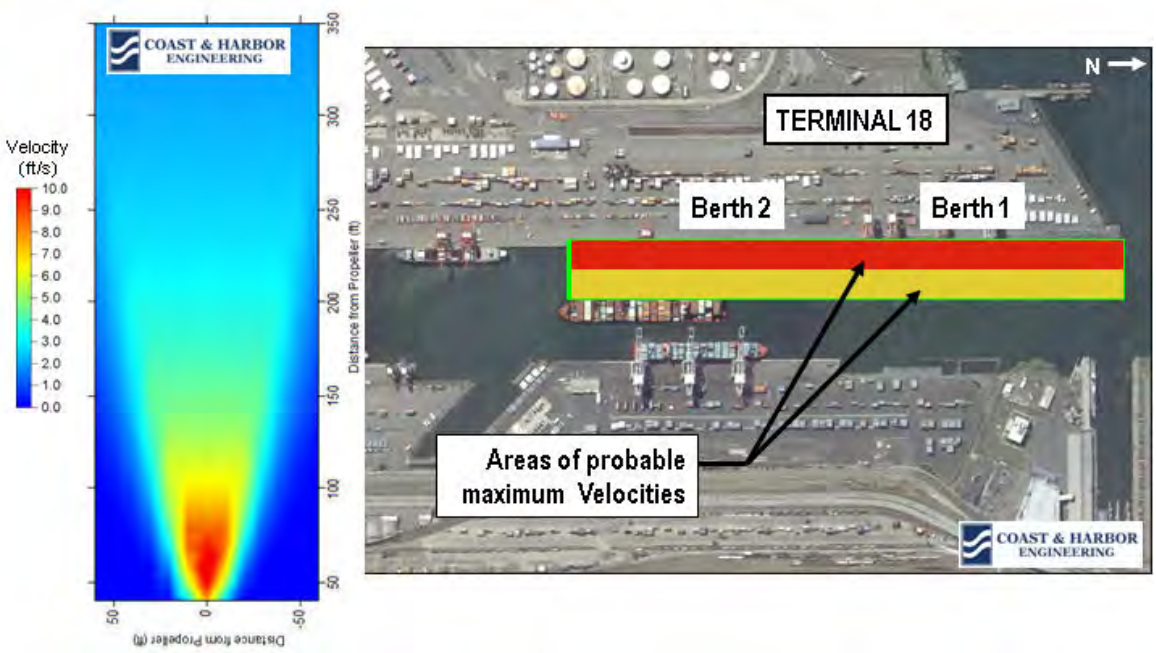


Figure 7. Scenario 2 thruster wash modeling area and bottom velocity pattern in Area 1a

3.3. Scenario 3 Areas 1a, 1b

Tugs assisting container ships during docking, undocking, and navigating in the waterway are represented by the tug Garth Foss shown in Figure 8. The tug is powered by Voith-Schneider Propulsors and can develop 7,600 horsepower. Propwash generated by the two propulsors is simulated in Scenario 3.

Modeled velocity generated by the tug during application of 50 percent power is shown in Figure 9. The figure shows the horizontal plane of the pattern of near-bottom velocity. The maximum near-bottom velocity is 3.6 ft/s. The bottom boundary shear stress corresponding to this velocity is 0.05 lbs/ft^2 (2 Pa).

Figure 8. Tug representative of Garth Foss, assisting container ships (photo credit: Peter Kim)

Figure 9. Pattern of near-bottom velocity of tug Garth Foss in Area 1a, 1b

3.4. Scenario 4 Area 1a Terminal 18 Berths 3 and 4, Terminal 30

A container ship representing those calling at Berths 3 and 4 and at Terminal 30 is the Margrit Rickmers, a 67,550 DWT vessel. This ship has a capacity of 5,080 TEU and is pictured in Figure 10. The maximum draft is 39.1 ft. Propwash generated by this ship's main propulsion is simulated for Scenario 4. The area of propwash modeling is Berths 3 and 4 and Terminal 30 in Area 1a, as shown in Figure 11.

Modeled propwash velocity generated by the ship's main propulsion during docking is shown in Figure 11. The figure shows the horizontal plane of the pattern of near-bottom velocity. The maximum near-bottom velocity is 6.3 ft/sec. The bottom boundary shear stress corresponding to this velocity is 0.15 lbs/ft^2 (7 Pa).

Figure 10. Container ship Margrit Rickmers (area 1a)

3.5. Scenario 5 Area 1a Terminal 18 Berths 3 and 4, Terminal 30

The vessel Margrit Rickmers is assumed to undock using the bow thruster at full power. The position and dimensions of the bow thruster are shown in Figure 6. Thruster wash generated by the bow thruster is simulated in Scenario 5. For conservatively examining propwash generated bottom velocity, the vessel draft upon departing was assumed to be the same as when arriving. The area of thrusterwash modeling is Berths 3 and 4 of Terminal 18 and all of Terminal 30 in Area 1a, as shown in Figure 12.

Modeled velocity generated by the ship's thruster during undocking is shown in Figure 12. The figure shows the horizontal plane of the pattern of near-bottom velocity. The maximum near-bottom velocity is 7.1 ft/sec. The bottom boundary shear stress corresponding to this velocity is 0.19 lb/ft^2 (9 Pa).

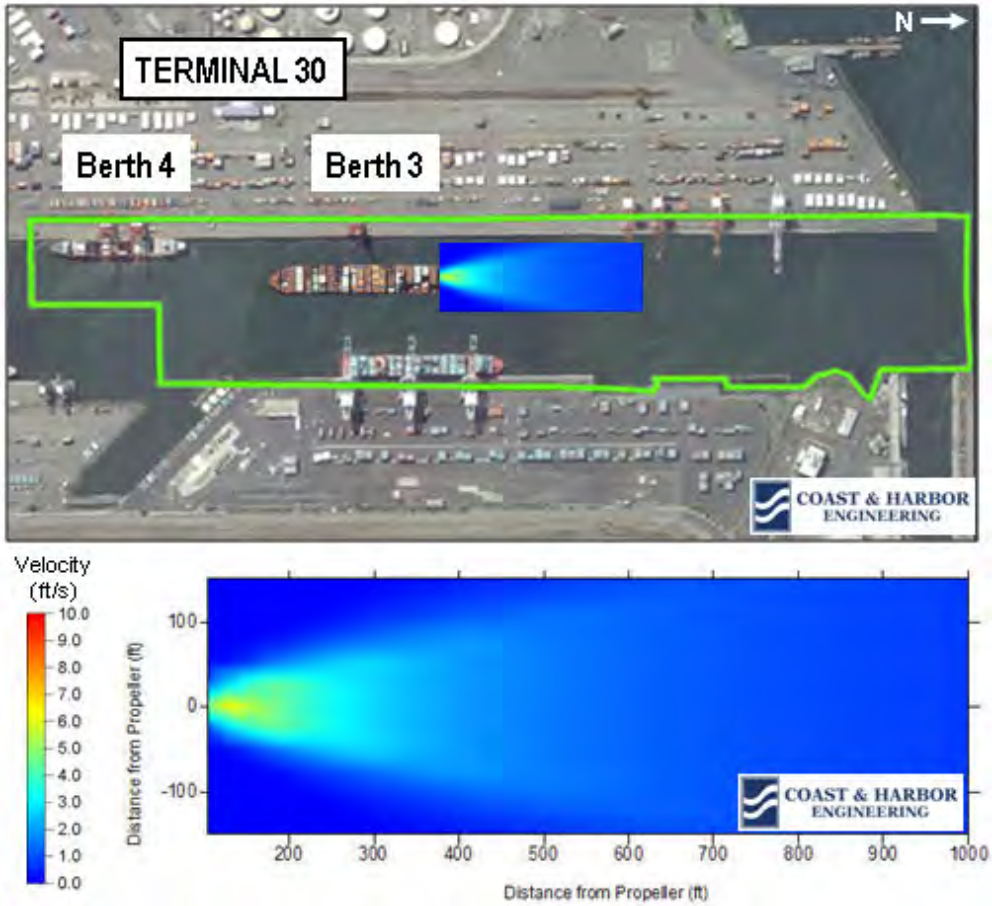


Figure 11. Pattern of near-bottom velocity of Margrit Rickmers main propulsion in Area 1a

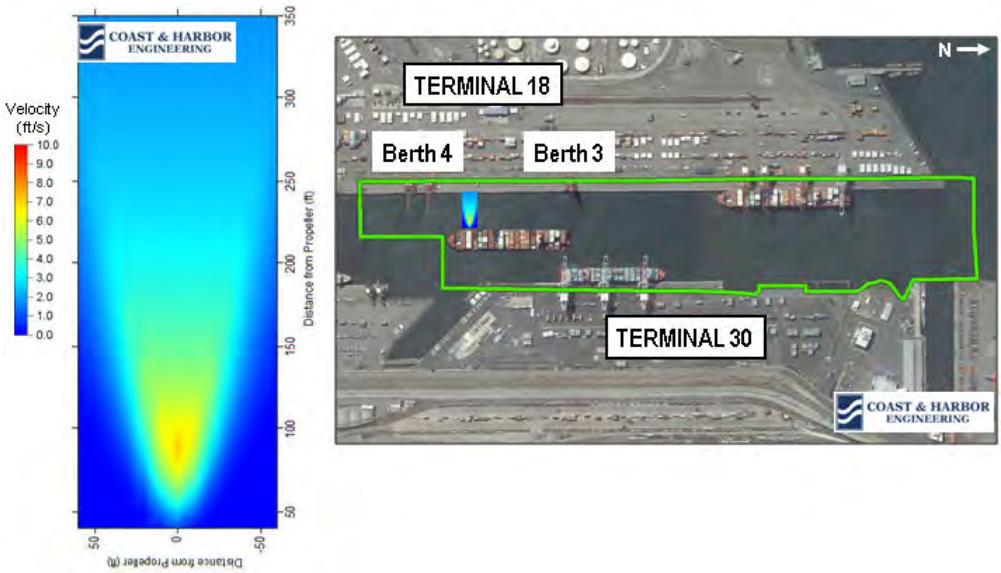


Figure 12. Pattern of near-bottom velocity of Margrit Rickmers bow thruster in Area 1a

3.6. Scenario 6 Area 2 Slip 36

Coast Guard vessels identified as sources of propwash having the potential for initiating bottom sediment movement Area 2 are the Polar class icebreakers and the Hamilton class high endurance cutters. The icebreakers have a loaded draft of 32 ft and have three controllable pitch propellers arranged as shown in a photograph of the Polar Sea, Figure 13. The area of propwash modeling is Slip 36, as shown in Figure 14.

Modeled propwash velocity generated by the main propulsion of the Polar class icebreaker during docking is shown in Figure 14. The figure shows the horizontal plane of the pattern of near-bottom velocity. The maximum near-bottom velocity is 6.5 ft/sec. The bottom boundary shear stress corresponding to this velocity is 0.16 lb/ft^2 (8 Pa).

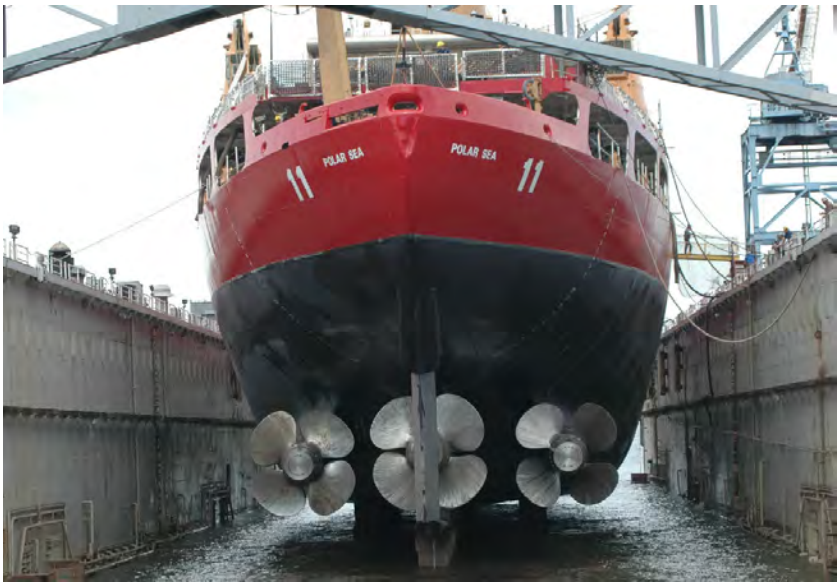


Figure 13. Polar Sea in dry dock showing propellers and rudder (area 2)

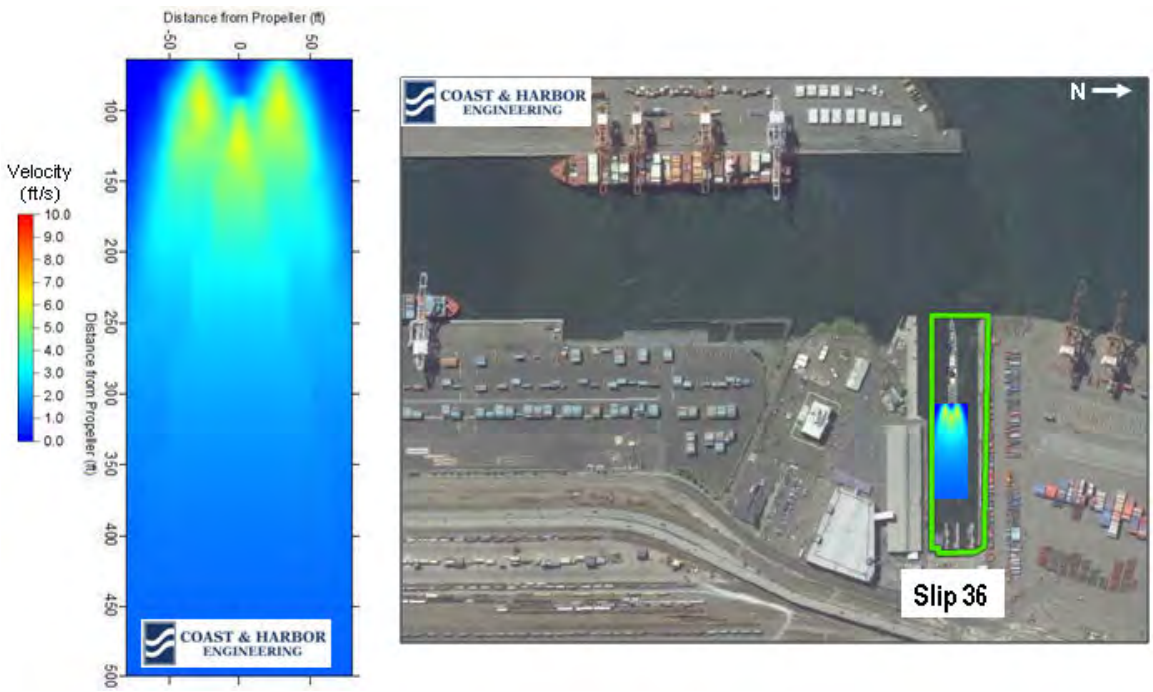


Figure 14. Pattern of near-bottom velocity of Polar class icebreaker propwash in Area 2

3.7. Scenario 7 Area 2 Slip 36

The Hamilton class Coast Guard cutter has a draft of 20 ft and has twin controllable pitch propellers. The cutter was modeled for determining the potential for initiating bottom sediment movement Area 2. The ship profile is shown in Figure 15. These cutters are fitted with retractable thrusters that are capable of outputting 350 horsepower, which was not simulated because the power is small relative to the main propulsion. The area of propwash modeling is Slip 36, as shown in Figure 16.

Modeled propwash velocity generated by the main propulsion of the Hamilton class cutter during docking is shown in Figure 16. The figure shows the horizontal plane of the pattern of near-bottom velocity. The maximum near-bottom velocity is 4.5 ft/sec. The bottom boundary shear stress corresponding to this velocity is 0.08 lbs/ft^2 (4 Pa).

Figure 15. Ship profile of Hamilton class cutter (area 2)

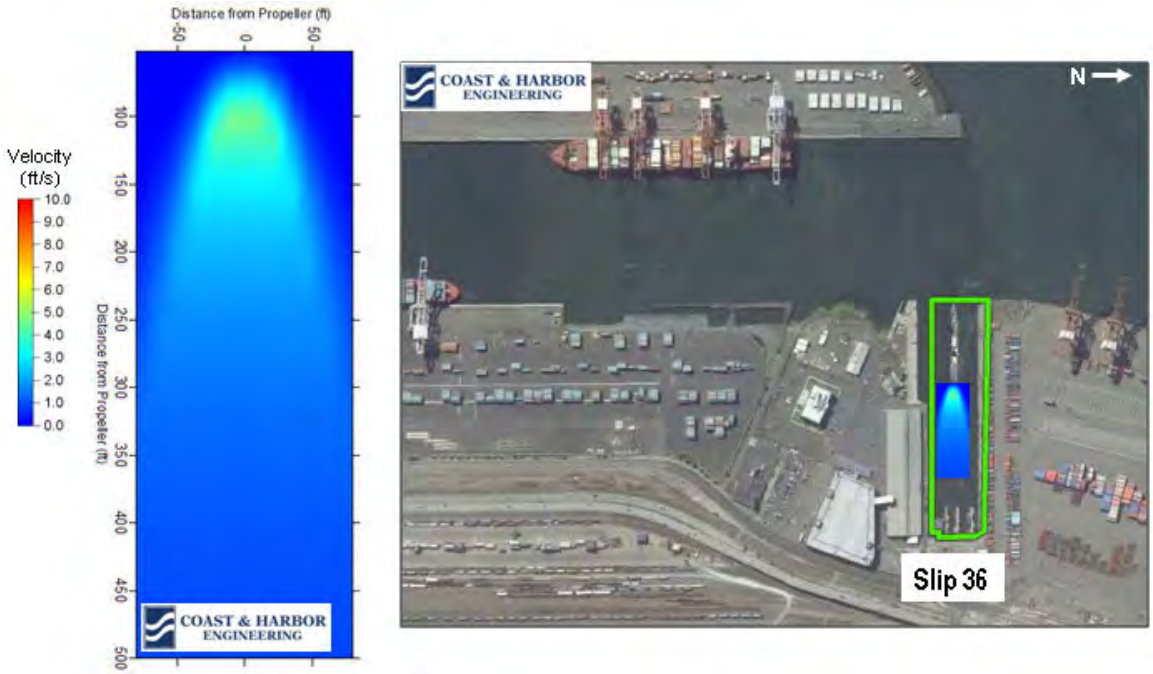


Figure 16. Pattern of near-bottom velocity of Cutter Hamilton propulsion in Area 2

3.8. Scenario 8 Area 3 Slip 27

Vessel activity at Area 3 consists of tugs taking barges to and moving barges from the slip, represented by the tug Hunter D. The tug is pictured in Figure 17. The Hunter D has a draft of 14.1 ft and is powered by two engines that can develop 3,420 horsepower each. The area of propwash modeling is Slip 27, as shown in Figure 18.

Modeled propwash velocity generated by the tug Hunter D during maneuvering is shown in Figure 18. The figure shows the horizontal plane of the pattern of near-bottom velocity. The maximum near-bottom velocity is 3.0 ft/sec. The bottom boundary shear stress corresponding to this velocity is 0.03 lb/ft^2 (2 Pa).

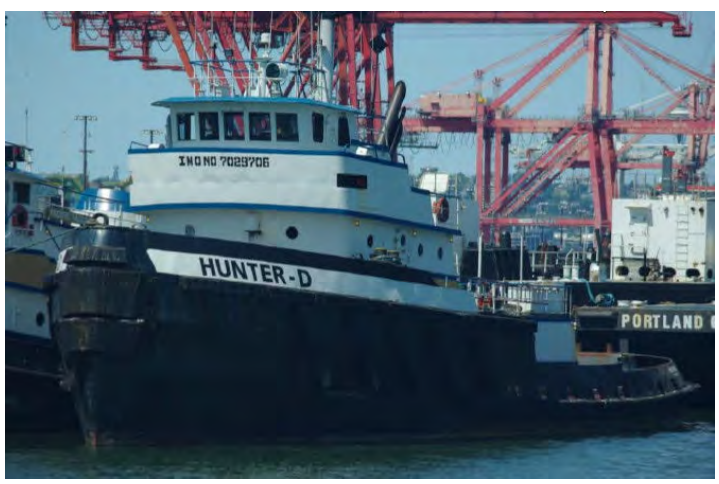


Figure 17. Tug Hunter D (Area 3)

Figure 18. Pattern of near-bottom velocity of Tug Hunter D in Area 3

3.9. Scenario 9 Areas 4, 4a, 4b and 5

The tug Eagle represents tugs that maneuver barges at South Terminal 30 (Area 4 and 4a) and that assist bulk carriers that call at the south end of Terminal 18 (Area 5). Area 4b is assumed to be subjected to similar propwash velocity from vessels maneuvering at adjacent areas. The tug is pictured in Figure 19. The Eagle has a draft of 16.5 ft and is powered by two engines that can develop 3,000 horsepower each. The tug is assumed to apply 75 percent of available power in these areas.

Modeled propwash velocity generated by the tug Eagle during maneuvering in Areas 4, 4a, 4b, and 5 is shown in Figure 20. Bottom elevation in these areas is -40 ft. The figure shows the horizontal plane of the pattern of near-bottom velocity. The maximum near-bottom velocity is 3.0 ft/sec. The bottom boundary shear stress corresponding to this velocity is 0.03 lb/ft2 (2 Pa).

Figure 19. Tug Eagle (Areas 4, 4a, 4b and 5)

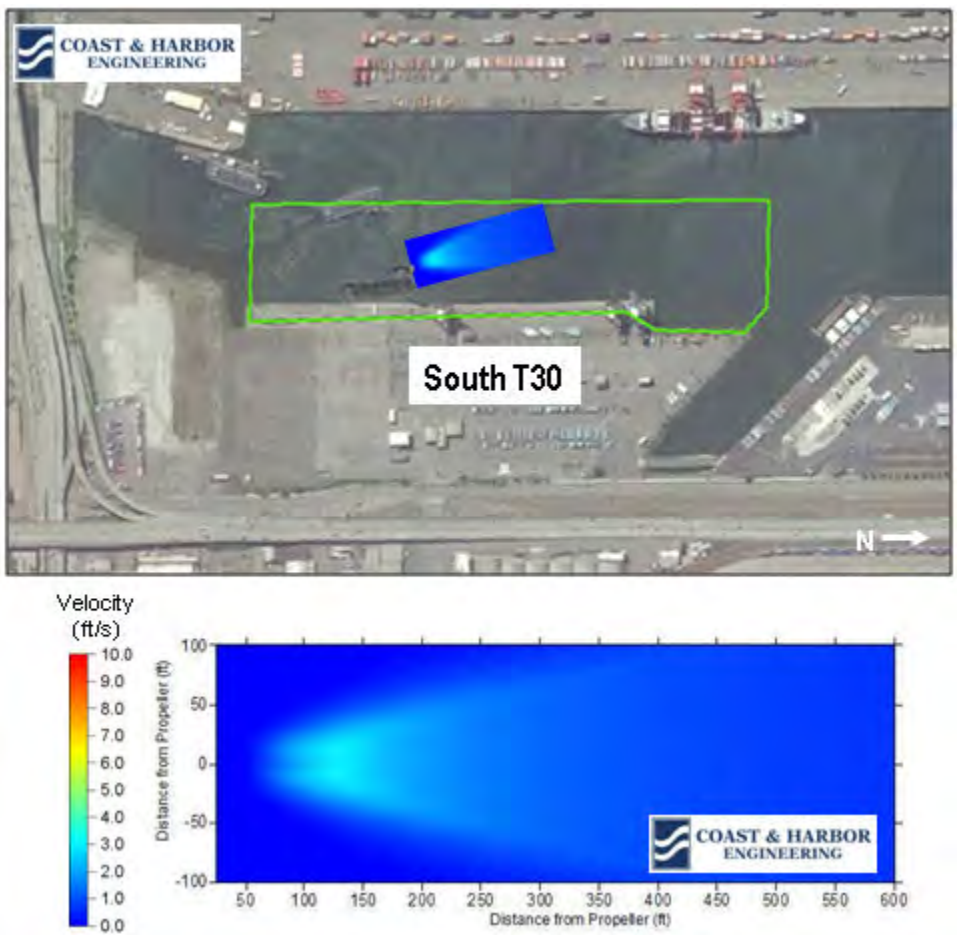


Figure 20. Pattern of near-bottom velocity of tug Eagle in Areas 4, 4a, 4b and 5

3.10. Scenario 10 Area 6

The tug Eagle represents tugs that maneuver at the west side of the waterway north of the West Seattle Bridge (Area 6). The tug is pictured in Figure 19. The Eagle is assumed to apply 50 percent of available power in this area. Area 6 for propwash modeling is shown in Figure 21.

Modeled propwash velocity generated by the Tug Eagle during maneuvering is shown in Figure 21. Bottom elevation in this area is -20 ft. The figure shows the horizontal plane of the pattern of near-bottom velocity. The maximum near-bottom velocity is 10.6 ft/sec. The bottom boundary shear stress corresponding to this velocity is 0.45 lb/ft^2 (22 Pa).

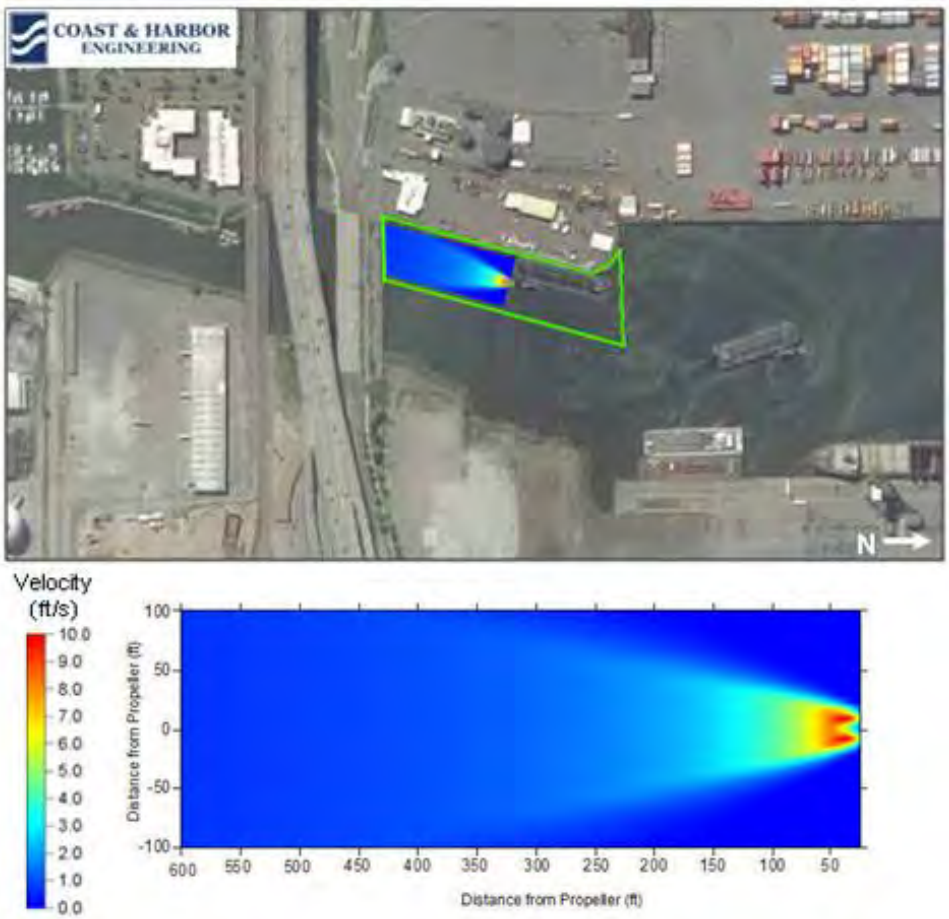


Figure 21. Pattern of near-bottom velocity of Tug Eagle in Area 6

3.11. Scenario 11 Area 7

The tug Eagle represents tugs that transit this eastern part of the waterway north of the bridge (Area 7). The tug is pictured in Figure 19. The Eagle is assumed to apply 50 percent of available power in this area. Area 7 for propwash modeling is shown in Figure 22.

Modeled propwash velocity generated by the tug Eagle during maneuvering is shown in Figure 22. Bottom elevation in this area is -30 ft. The figure shows the horizontal plane of the pattern of near-bottom velocity. The maximum near-bottom velocity is 4.7 ft/sec. The bottom boundary shear stress corresponding to this velocity is 0.08 lb/ft^2 (4 Pa).

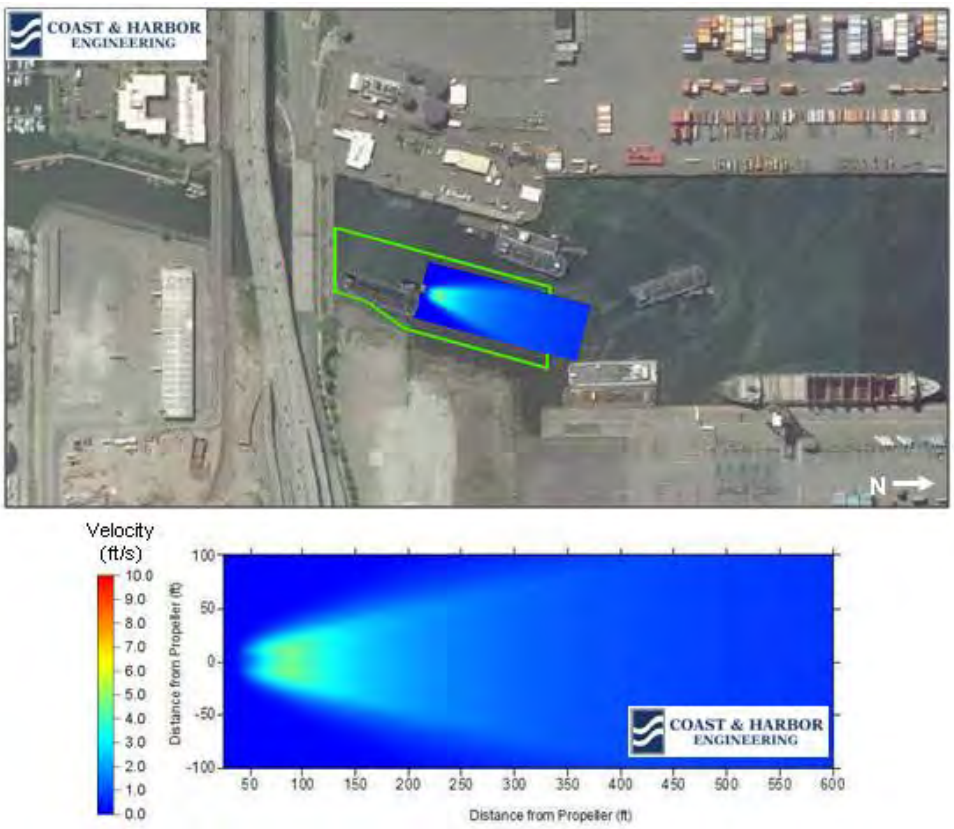


Figure 22. Pattern of near-bottom velocity of Tug Eagle in Area 7

3.12. Scenario 12 Area 8

The tug Alaska Mariner represents the largest of the Western Towboat fleet that moors in Area 8. This tug has a draft of 14.1 ft and is powered by twin engines each developing 2,260 horsepower. The Alaska Mariner is pictured in Figure 23. The area of propwash modeling is shown in Figure 24.

Modeled propwash velocity generated by the tug Alaska Mariner during maneuvering in Area 8 is shown in Figure 24. Bottom elevation in this area is -20 ft. The figure shows the horizontal plane of the pattern of near-bottom velocity. The maximum near-bottom velocity is 4.2 ft/sec. The bottom boundary shear stress corresponding to this velocity is 0.07 lb/ft^2 (3 Pa).

Figure 23. Tug Alaska Mariner (area 8)

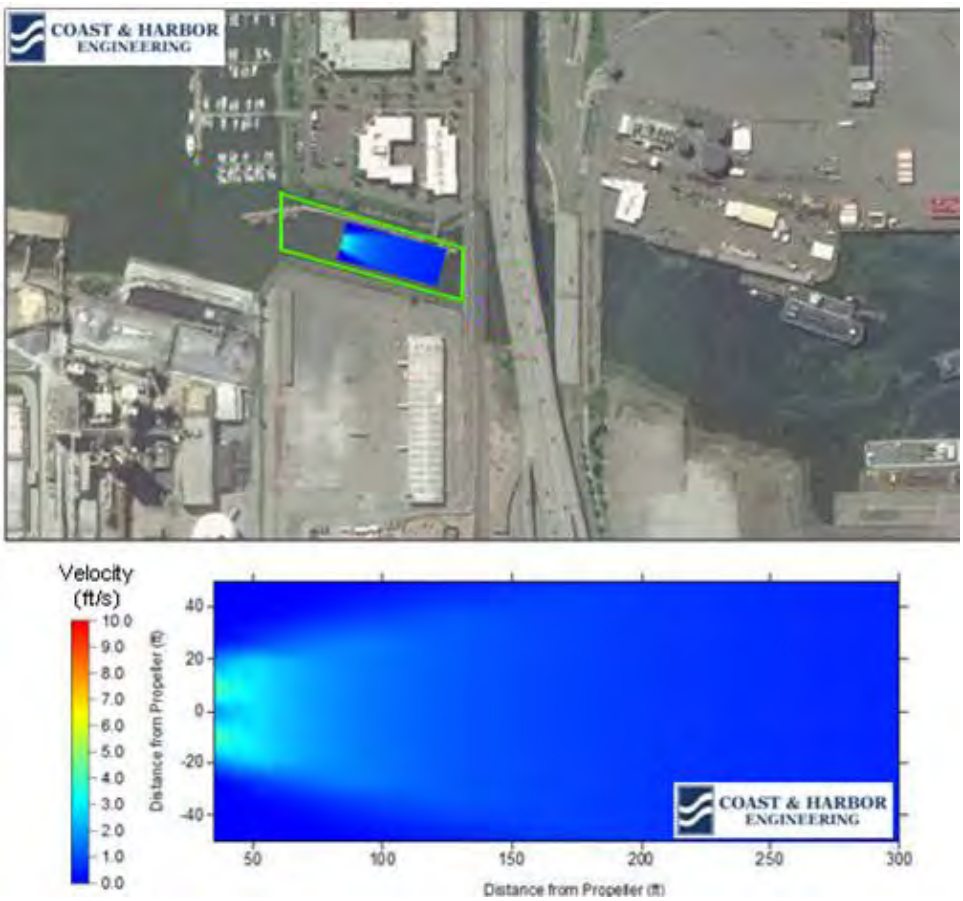


Figure 24. Pattern of near-bottom velocity of Tug Alaska Mariner in Area 8

3.13. Scenario 13 Navigating in East Waterway

Container ships are moved into East Waterway bow first by at least two tugs when mooring at Terminal 18. Tugs are at the bow and stern, and the ship's thruster aids in steering the ship in the waterway. Container ships mooring at Terminal 30 enter the waterway stern-first, under the assistance of at least two tugs. The tug Garth Foss (see Figure 8) represents tugs that assist ships in the East Waterway. Tug speed is assumed to be 4 knots and the maximum power applied while moving a ship into or out of the waterway is assumed to be 50 percent of available power.

Modeled propwash velocity generated by the tug Garth Foss during assisting in Area 1b using the steady-state JETWASH model is shown in Figure 25. Bottom elevation in this area is -50 ft. The figure shows the horizontal plane of the pattern of near-bottom velocity. The maximum near-bottom velocity computed with JETWASH is 3.0 ft/sec. The bottom boundary shear stress corresponding to this velocity is 0.03 lbs/ft^2 (2 Pa). These values are considered to be conservative. Fully accounting for vessel speed will reduce these values of velocity and stress. Because of the limitation of the JETWASH model in simulating effects of moving vessels, and the availability of the unsteady model VH-PU to simulate this condition, the next phase of the study will employ VH-PU. Values calculated with the tool that incorporates vessel movement are expected to be less than that illustrated in Figure 25.

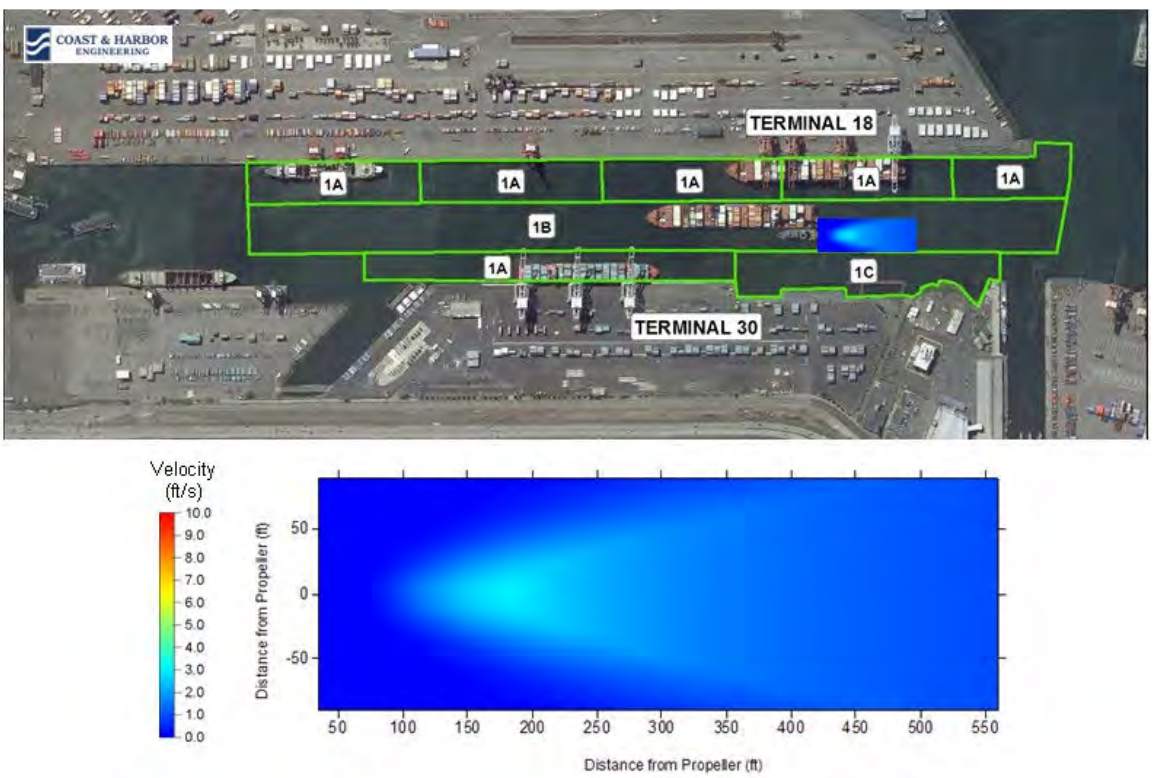


Figure 25. Pattern of near-bottom velocity of Tug Garth Foss while assisting a ship in Area 1b

3.14. Scenario 14 Area 4a

Scenario 14 is developed to represent future conditions at South Terminal 30. It is assumed that berthing area at the terminal will be dredged to -46 ft MLLW to accommodate a container ship Margrit Rickmers, a 67,550 DWT of 5,080 TEU capacity vessel (see Figure 10). The maximum draft of the ship of this scenario is assumed at 39.1 ft.

Modeled propwash velocity generated by the ship's main propulsion during docking is shown in Figure 26. The figure shows the horizontal plane of the pattern of near-bottom velocity. The maximum near-bottom velocity is 7.0 ft/sec. The bottom boundary shear stress corresponding to this velocity is 0.18 lbs/ft^2 (9 Pa).

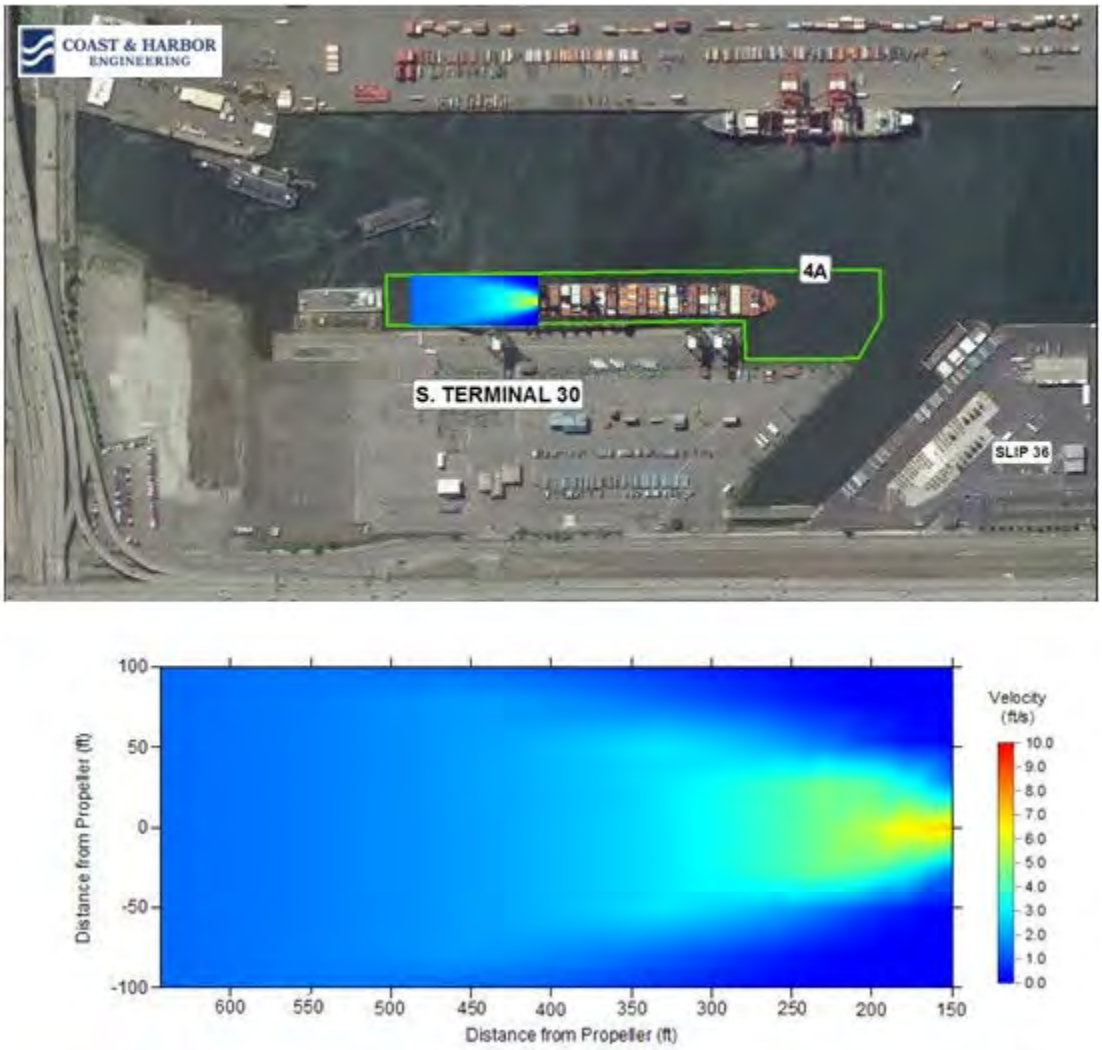


Figure 26. Pattern of near-bottom velocity of Margrit Rickmers main propulsion in Area 4, docking

3.15. Scenario 15 Area 4a, South Terminal 30

Scenario 15, similar to Scenario 14 was developed to represent future conditions at South Terminal 30. Similar to the other scenario a berthing area at the terminal is dredged in the model to -46 ft MLLW to accommodate a container ship Margrit Rickmers.

The vessel Margrit Rickmers is assumed to undock using the bow thruster at full power. The position and dimensions of the bow thruster are shown in Figure 27. For conservatively examining propwash generated bottom velocity, the vessel draft upon departing was assumed to be the same as when arriving.

Modeled velocity generated by the ship's thruster during undocking is shown in Figure 27. The figure shows the horizontal plane of the pattern of near-bottom velocity. The maximum near-bottom velocity is 9.0 ft/sec. The bottom boundary shear stress corresponding to this velocity is 0.30 lbs/ft^2 (14 Pa).

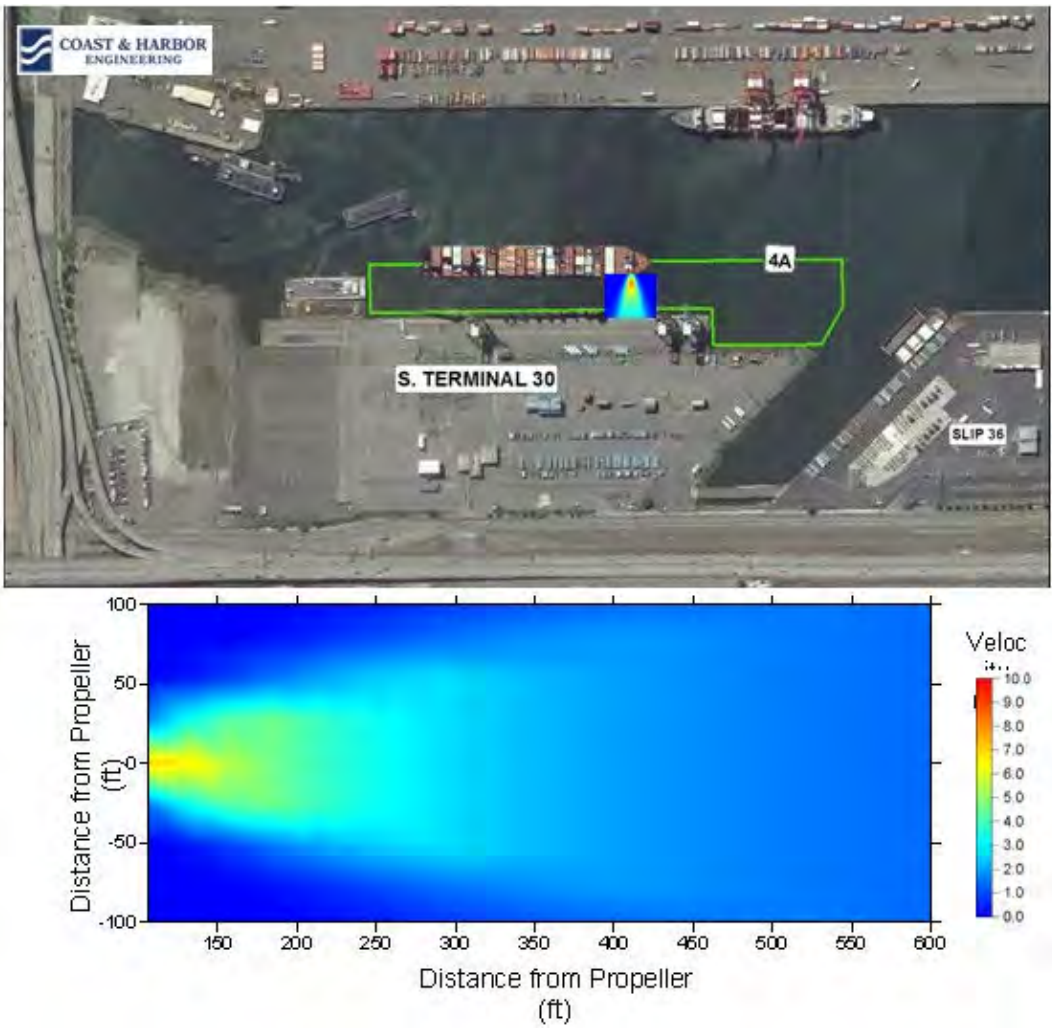
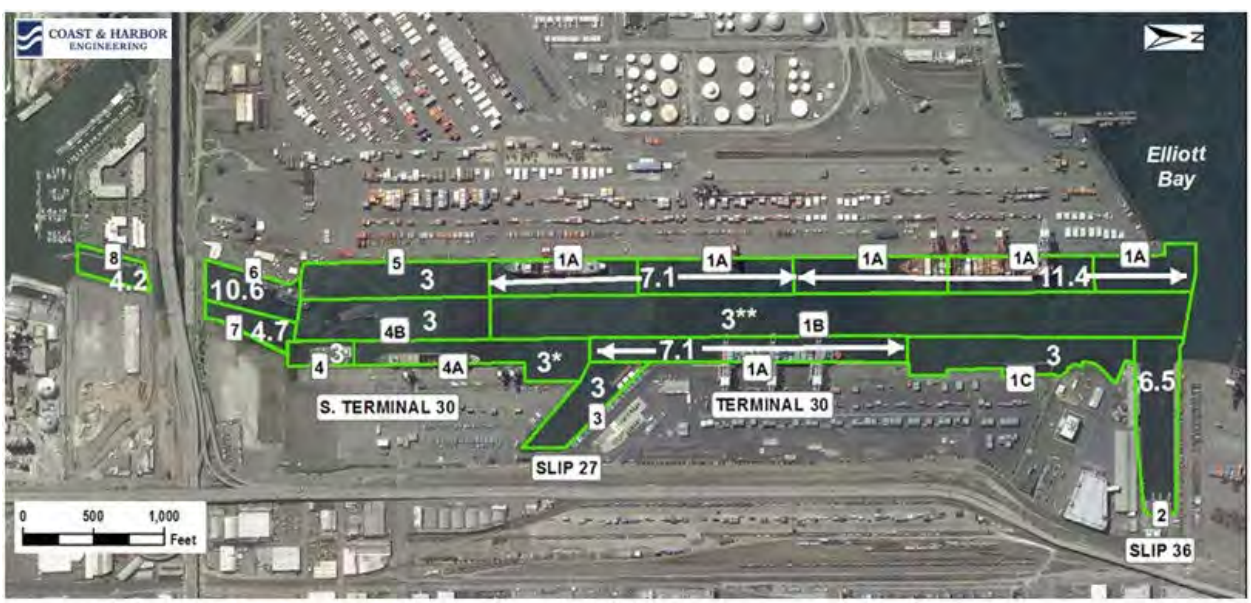


Figure 27. Pattern of near-bottom velocity of Margrit Rickmers bow thrusters in Area 4a, undocking

3.16. Propwash Modeling Summary Results

Simulated maximum near-bottom velocities of these 15 scenarios are shown in the respective analysis areas in Figure 28. As noted in Section 3.13, the listed velocity and shear stress values are conservative and will refined in a future study phase using an unsteady model that better simulates the effect of vessel movement. As noted in Sections 3.14 and 3.15, future conditions of ship berthing in Area 4a were simulated. Figure 28 lists velocities for current conditions, with notes referring to velocities for future conditions. The listed velocity magnitudes apply to each entire analysis area because it is not known where the vessel can be positioned within the area. Figures 29 and 30 summarize the bottom shear stress in units of pounds per square foot and Pascals, respectively, corresponding to the propwash-induced velocities.

Area 1b was designated as the central part of the Waterway where ships navigate to or from the berths. Bottom velocities modeled for Area 1b, presented in Section 3.13 are lower than in adjacent areas. The boundary between Area 1b and Area 1a, however, is not clearly defined. It is possible, and is conservatively assumed, that vessel maneuvers simulated for Area 1a extend into Area 1b and the greater velocities of the two apply to Area 1b. Therefore, the part of Area 1b adjacent to Terminal 18 berths 1 and 2 should be assumed to experience bottom velocity up to 11.4 ft/sec and corresponding bottom shear stress of 0.48 lbs/sq ft (23 Pa). Similarly, bottom velocity up to 7.1 ft/sec may affect the part of Area 1b adjacent to berths 3 and 4, with corresponding bottom shear stress of 0.19 lb/sq ft (9 Pa).

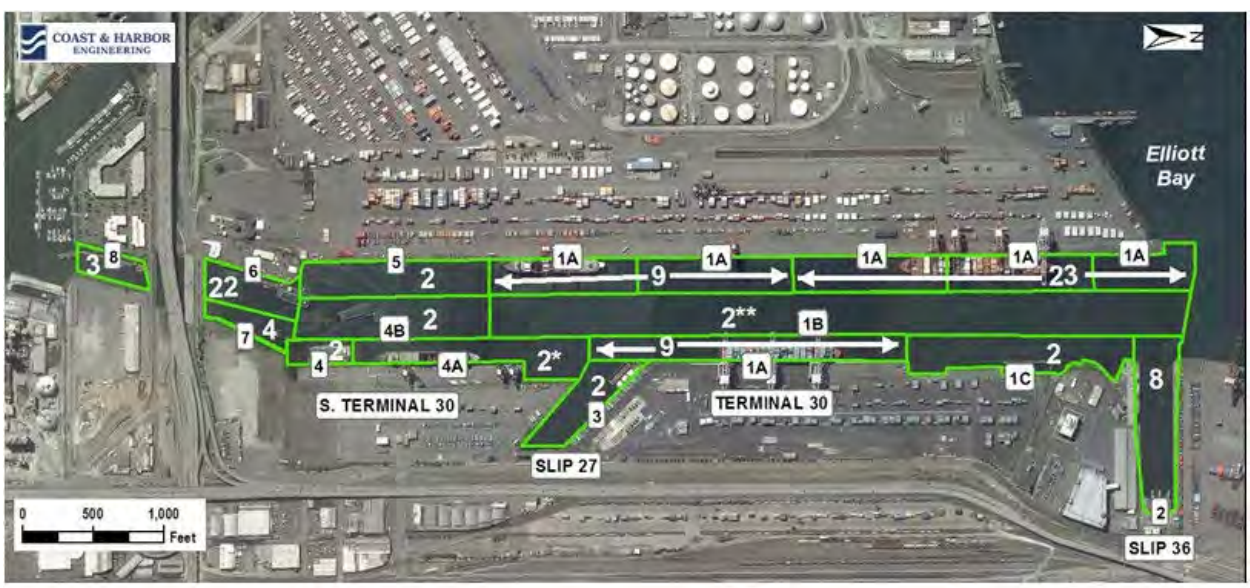


Note: *Future case of Area 4a = 9.0 ft/sec
** Bottom velocity from moving vessel to be refined in unsteady analysis in future phase of study

Figure 28. Summary of near-bottom velocities, all scenarios

Note: *Future case of Area 4a = 0.30 lbs/sq ft
** Bottom shear stress from moving vessel to be refined in unsteady analysis in future phase of study

Figure 29. Summary of bottom shear stresses (lbs/sq ft), all scenarios



Note: *Future case of Area 4a = 14 Pa
** Bottom shear stress for moving vessel to be refined in unsteady analysis in future phase of study

Figure 30. Summary of bottom shear stresses (Pascals), all scenarios

4. Pressure Field Modeling

Water velocity generated beneath a moving vessel might be an agent for mobilizing sediment on the channel bottom surface if the velocity has sufficient magnitude. Bottom velocity generated by a ship being assisted by a tug along the waterway is investigated in this section. Vessel pressure field hydrodynamic forces were calculated using the Vessel Hydrodynamics Longwave Unsteady (VH-LU) model (Shepsis 2001). The VH-LU model predicts water level and velocity fluctuations surrounding a moving ship and the resulting velocity beneath the hull. The main factors that determine the magnitude of the pressure wave generated by the moving form are the ship's length, beam, draft, shape, and speed at which it moves relative to the water, among other factors.

A container ship representative of those calling at Berths 3 and 4 of Terminal 18 and the assisting tug are vessels selected for pressure field analysis. Analysis results include bottom velocity at a point as the vessel passes above. Channel depth and dimensions are nearly uniform along the length of East Waterway. Therefore, the vessel induced bottom velocity at one location along the sailing line is similar to that at other locations and a single snapshot of velocity pattern is sufficient to characterize conditions in the waterway. Figure 31 shows the bathymetry within the hydrodynamic modeling domain and vessel route. Vessel speed while moving in the waterway is assumed to be 4 knots or less.

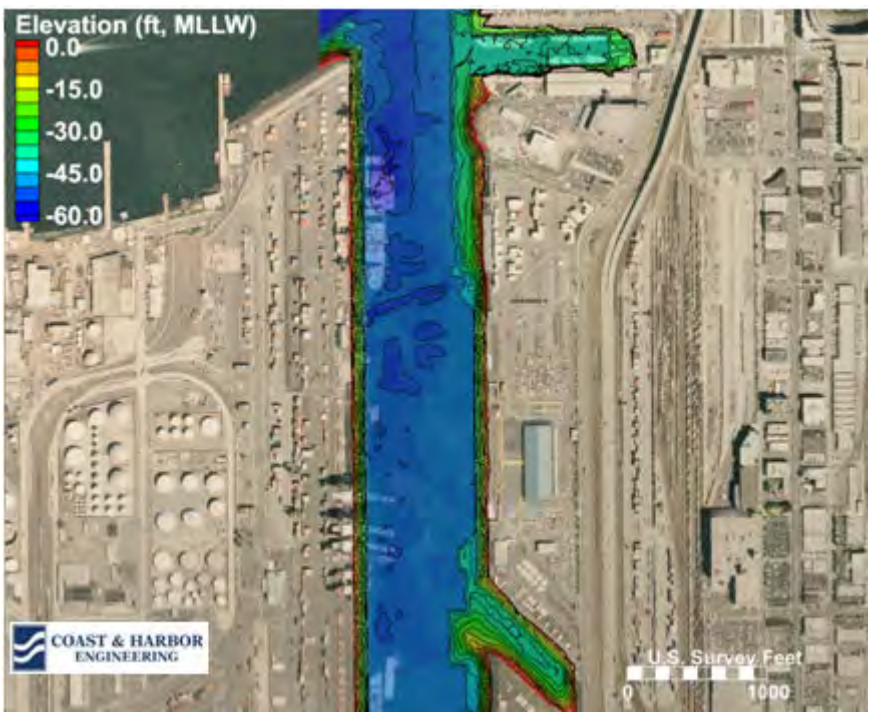


Figure 31. Bathymetry of East Waterway

Figure 32 shows velocity output at a single location of pressure field modeling of a container ship moving inbound along the channel centerline at 4 knots. For this container ship simulation, the maximum water velocity relative to the stationary bed was 1.3 ft/sec, averaged in the 12.9-ft vertical distance between the hull and the bottom. The bottom boundary shear stress corresponding to this velocity is 0.0063 lb/ft^2 (0.30 Pa).

Figure 33 shows the velocity output similarly derived for a tug that would assist the ship in the East Waterway. The assumed tug characteristics are those listed in Table 1. For this tug simulation, the maximum water velocity relative to the stationary bed was less than 1.3 ft/sec, averaged in the 35.5-ft vertical distance between the tug hull and the bottom. The bottom boundary shear stress corresponding to this velocity is 0.0063 lb/ft^2 (0.30 Pa).

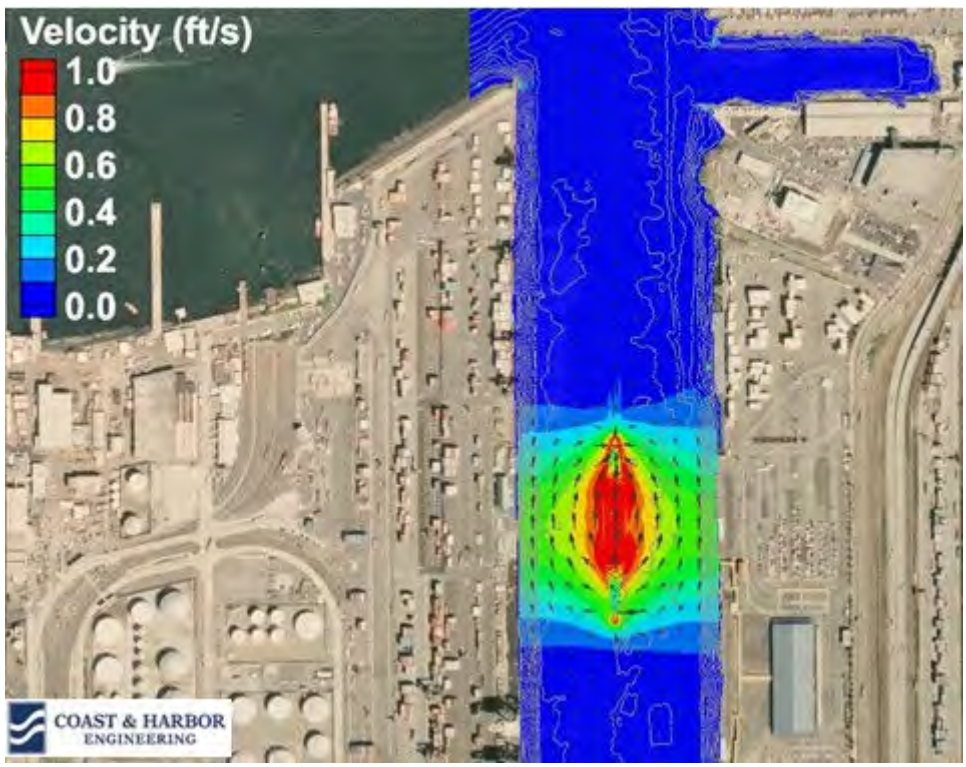


Figure 32. Bottom velocity generated by Margrit Rickmers at 4-knot speed

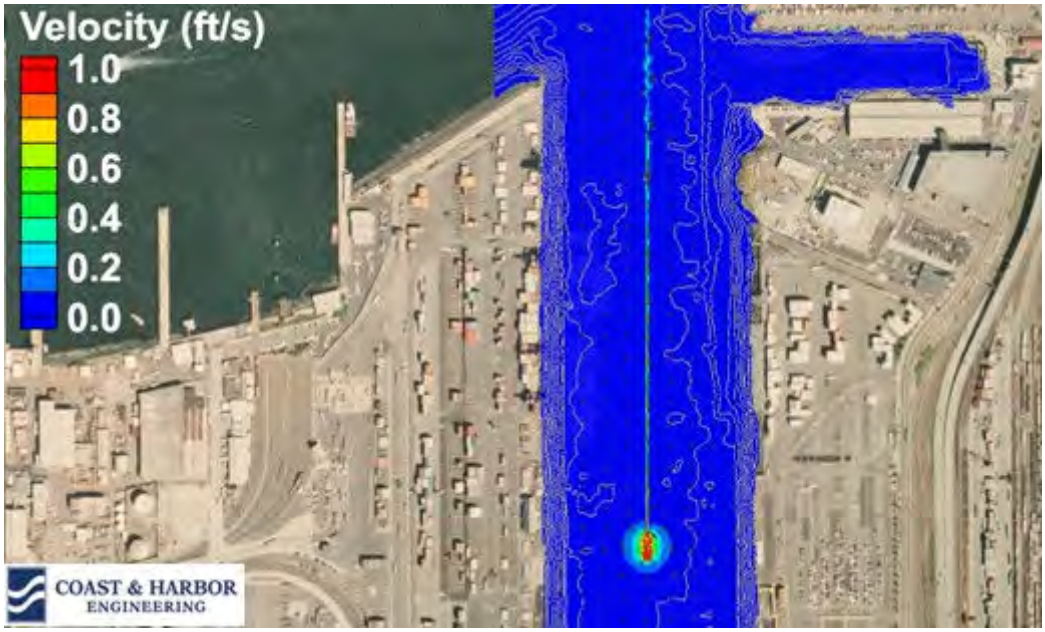


Figure 33. Bottom velocity generated by Garth Foss at 4-knot speed

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