APPENDIX B – SEDIMENT MODELING MEMORANDA

EAST WATERWAY OPERABLE UNIT FEASIBILITY STUDY

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PART 1: ADDITIONAL SEDIMENT TRANSPORT MODELING

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LIST OF ACRONYMS AND ABBREVIATIONS

3-D	three-dimensional
BMP	best management practice
City	City of Seattle
cm	centimeter
County	King County
CSO	combined sewer overflow
DMR	Discharge Monitoring Report
EFDC	Environmental Fluid Dynamics Code
EW	East Waterway
FS	Feasibility Study
ISGP	Industrial Stormwater General Permit
kg	kilogram
LDW	Lower Duwamish Waterway
m^3	cubic meter
NPDES	National Pollutant Discharge Elimination System
Port	Port of Seattle
PTM	particle tracking model
SD	storm drain
SRI	Supplemental Remedial Investigation
STE	sediment transport evaluation
STER	Sediment Transport Evaluation Report
SWAC	spatially-weighted average concentration
TSS	total suspended solids

1 PURPOSE OF ADDITIONAL SEDIMENT TRANSPORT MODELING

The spatial distribution of sediments deposited within the East Waterway (EW) from lateral sources (i.e., storm drain [SD] and combined sewer overflow [CSO] outfalls located along the length of the EW) was estimated using the particle tracking model (PTM) developed by the U.S. Army Corps of Engineers (USACE; McDonald et al. 2006). The purpose of the PTM effort was to inform the Physical Conceptual Site Model developed in the EW Supplemental Remedial Investigation (SRI; Windward and Anchor QEA 2014) and to provide information that could be used to evaluate site trends over time following remediation and the potential for recontamination in the EW Feasibility Study (FS) due to sediment loads from identified lateral sources within the EW.

The initial modeling effort, discussed in the EW Sediment Transport Evaluation Report (STER; Anchor QEA and Coast & Harbor Engineering 2012), was completed using current conditions solids loads for EW lateral sources as inputs to the PTM. Three scenarios were evaluated for current conditions solids loads: a base case (best estimate), and high and low bounding cases based on 25th and 75th percentile total suspended solids (TSS) data. The development of these solids loads are discussed in detail in Section 7.2 and Appendix F of the STER. The additional modeling effort conducted as part of this FS, and discussed in this appendix, was completed to assess projected future conditions solids loads for EW lateral sources. As with the initial modeling work, a base case (best estimate) and high and low bounding cases for solids loads were evaluated. The purpose of this additional modeling effort was to provide information to evaluate site performance over time and recontamination potential in the EW (post-construction) considering future source control efforts.

This appendix provides information about the estimation of solids inputs from EW lateral sources (SDs and CSOs) for likely future conditions and the results of the PTM based on projected future conditions. The development of chemistry assumptions, methodology for using the results of the PTM to complete the site performance and recontamination potential evaluation, and results of the recontamination potential evaluation are provided in Sections 5 and 9 and Appendix J of the FS.

2 OVERVIEW OF INITIAL MODELING APPROACH

The initial modeling effort was completed as part of the sediment transport evaluation (STE) and is discussed in detail in Section 4 (hydrodynamic model) and Section 7 (PTM) of the EW STER (Anchor QEA and Coast & Harbor Engineering 2012). A brief overview of the technical approach is provided in this section. This approach reflects previously approved methods used in the STER. Development of solids loads from EW lateral sources (SDs and CSOs) for current and future conditions is discussed in Section 3 herein, and results of the additional PTM effort are provided in Section 4.

The PTM uses a Lagrangian method to simulate the transport of discrete particles within the modeling domain (McDonald et al. 2006). The PTM uses the output from the hydrodynamic model (e.g., current velocities) to simulate the transport of suspended particles (from lateral sources) within the EW. The hydrodynamic model utilized in the EW STE was developed through modification of an existing model used to evaluate hydrodynamics in the Lower Duwamish Waterway (LDW; Windward and QEA 2008). The model utilizes the three-dimensional (3-D) Environmental Fluid Dynamics Code (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 as part of the EW STE to increase the grid resolution within the EW (see Figure 1[1]) and calibrated with data from the EW. The hydrodynamic model simulations used as input to the PTM included a constant inflow at the upstream boundary equal to the mean annual flow[2], and tidal downstream boundary conditions using representative spring tide conditions[3]. The mean annual flow and spring tide conditions were used to represent annual average hydrodynamic conditions in the EW (see Section 7.3.1 of the STER; Anchor QEA and Coast & Harbor Engineering 2012).

[1] Figure 1 shows the model grid within the EW only. The complete model grid extends to the north and south of the EW.

[2] Mean annual flow is 1,330 cubic feet per second based on data from the U.S. Geological Survey gage at Auburn, Washington.

[3] Tidal elevations were taken from verified 6-minute data from the National Oceanic and Atmospheric Administration tide station in Elliott Bay (#9447130) from June 1 to July 31, 2009.

The PTM 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 or leaves the model domain. 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. The PTM tracks the movement of parcels of sediment with a set mass, as opposed to individual particles. The parcel size was set to 0.5 kilogram (kg) for all simulations, and the standard deviation of the particle size distribution was set to 0.8 φ[4]. These values are commonly accepted values for this application (McDonald et al. 2006) and were validated through a sensitivity analysis completed as part of the EW STE.

The particle deposition predicted by the PTM represents the initial deposition of the particles within the EW and does not take into account resuspension of the particles due to current velocities or vessel operations (e.g., propeller wash [propwash]). Resuspension processes in the PTM were not included in the simulations because:

- Resuspension of sediments due to tidal and riverine currents is expected to be small, due to low predicted near-bed currents in the EW (see Section 6 of the STER; Anchor QEA and Coast & Harbor Engineering 2012).
- Resuspension of sediments in the EW is dominated by vessel activity (propwash). The hydrodynamic model does not include the prediction or influence of vessel induced currents; therefore, resuspension from these activities cannot be modeled numerically with the PTM. In addition, the influence of vessel wakes was not modeled. The influence of vessel wakes is confined to the shallow water areas of the site, which are primarily engineered surfaces (e.g., riprap without accumulated sediment).

The effect of resuspension on sediment deposition is to redistribute (i.e., mix) depositing sediment. Therefore, the PTM shows more localized and concentrated deposition (i.e., closer to outfalls) than expected in the EW when considering resuspension.

[4] Chosen parameters used for the modeling were determined through a sensitivity analysis conducted as part of the EW STER (Anchor QEA and Coast & Harbor Engineering 2012).

The PTM is best suited for simulating relatively short-term sediment transport events such as discharge from outfalls, and resuspension due to dredging. Conducting a long-term, multi-year PTM simulation is impractical due to exceedingly long runtimes as increasing numbers of particles are created within the model. Thus, PTM simulations covering a shorter simulation time were conducted, and the results were assumed to be representative of long-term average conditions (based on input conditions, which were representative of annual average values). For both the initial and additional PTM effort, the model simulation time was set to 42 days total—28 days with solids being released into the EW and an additional 14 days with the mass flux into the EW set to 0 to allow finer particles in suspension to settle prior to the end of the simulation time period[5].

The results of the PTM simulations were post-processed within a GIS environment to produce maps of initial solids deposition (in kg and centimeters [cm] per year) within the EW from lateral sources (provided in Section 4 of this appendix). The solids deposition was combined with chemistry information to evaluate the potential for post-construction recontamination within the EW; chemistry assumptions and the recontamination evaluation are discussed in Section 4 and Appendix J of the FS.

[5] Additional information regarding the development, input data, and results for the hydrodynamic model and PTM can be found in Sections 4 and 7 of the EW STER, respectively (Anchor QEA and Coast & Harbor Engineering 2012).

3 FUTURE CONDITION INPUTS TO THE EAST WATERWAY

Lateral sources of sediment to the EW include SDs and CSOs. Currently, 39 outfalls (36 SDs, one CSO, and two CSO/SDs) to the EW have been identified (Anchor QEA and Windward 2009). Locations and ownership information for each of these SDs and CSOs, and associated drainage basins, is shown in Figure 2. Drainage basins and outfalls are identified with a numbering system created during development of the *Initial Source Evaluation and Data Gaps Memorandum* (Anchor QEA and Windward 2009). Bridges and port aprons are identified with a number that corresponds to the closest SD[6]. Two of the outfalls (at S Hinds Street and S Lander Street) are shared discharge points for separated SD basins and CSOs. These outfalls are referred to as CSO/SD outfalls. Solids loading for current conditions for the stormwater and CSO components of the discharge are discussed in detail in Sections 7.2.1.1 and 7.2.1.2, respectively, of the EW STER (Anchor QEA and Coast & Harbor Engineering 2012).

The source control strategy for the EW, including a summary of ongoing and future source control activities and programs, is summarized in Section 2.12 of the FS. For modeling purposes, future source control conditions solids load from EW laterals (SDs and CSOs) were estimated based on ongoing and likely future source control measures to be implemented by the Port of Seattle (Port), City, and King County (County). Future efforts include installing storage or treatment to control CSOs and installing treatment or continued implementation of source control activities (e.g., business inspections, line cleaning, clean-outs, source tracing, etc.) to reduce pollutant contributions from SDs in the EW. Where needed, the type and efficiency of treatment assumed for the different SDs and CSOs is dependent on permitting requirements, likely treatment technologies, the size of the basin, and the type of basin (e.g., bridge, port apron, etc.). Therefore, treatment option assumptions are not the same for all EW lateral sources.

The upstream inputs to the EW, which are from the Green River and the LDW, were not tracked within the PTM and, therefore, were not varied as part of this analysis. However,

[6] The apron and bridge loads were input at the closest SD and were not tracked separately; however, their future input conditions were calculated separately.

the influence of uncertainty in upstream inputs on the EW were evaluated as part of the sensitivity analysis in Appendix J of the FS.

3.1 Storm Drains

Anticipated future changes to City and Port SDs for purposes of PTM evaluation are discussed below. No changes are assumed for this analysis for private SDs, SW Florida Street SDs, or U.S. Coast Guard SDs (see Figure 2).

3.1.1 City of Seattle

The City is currently not required to treat stormwater discharges from its municipal separated storm system. Instead, the Phase 1 Municipal Stormwater permit requires the City to develop and implement a stormwater management program to reduce the discharge of pollutants from the City drainage system. The program includes a number of elements to reduce pollution such as controlling runoff from new and redevelopment projects, requiring source controls for all existing development, and identifying and eliminating illicit connections and discharges to the City's drainage system. The City is currently in compliance with its permit. The City has also implemented an aggressive source control program in the EW. Therefore, for this analysis, it is assumed that solids loading from City SDs will not change in the future (see Appendix F of the STER; Anchor QEA and Coast & Harbor Engineering 2012). Instead, for future scenarios, it is assumed that the chemical concentrations of the solids in the discharge from City SDs will decline over time as a result of the City's ongoing source control program (see Table 1 for specific City SDs this applies to). Changes in stormwater solids chemistry are estimated using the data collected to date and considering that specific sources found to date will be controlled (see Appendix J of the FS for more detailed discussion on chemistry assignments). This updated chemistry will be applied to the following City SD outfalls as part of the recontamination evaluation.

- S Hinds St SD
- S Lander St SD
- SW Florida St SD (B-21)
- SW Spokane St PS 73 EOF/SD (B-5)
- SW Spokane St SD (B-4)
- S Spokane St SD (B-36).

- S Massachusetts St SD (B-25)
- BR-4 and BR-34

Chemistry assumptions applied to modeling efforts are provided in Section 5 of the FS.

3.1.2 Port of Seattle

The Port leases nearshore properties to private terminal operators. The terminal operators are required to operate the facilities in accordance with the NPDES Industrial Stormwater General Permit (ISGP), which is administered by the Washington State Department of Ecology. The ISGP includes discharge water quality benchmarks that are reported to the state on a quarterly basis by the submittal of Discharge Monitoring Reports (DMRs). If benchmarks are exceeded, the ISGP prescribes the implementation of operational, structural, and treatment best management practices (BMPs). Port properties that are not leased to private operators are covered under the Port's Municipal Stormwater Permit, with the exception of the Port's maintenance facility which is an industrial operation covered by an ISGP.

Port terminal tenants discharging to the EW under the ISGP are required to comply with all Corrective Actions (Level 1, 2, and 3), including the construction and operation of Level 3 treatment BMPs. The assumed design criterion, for Level 3 treatment BMPs, is to treat 91% of the stormwater flows from the entire property or portion of the property where monitoring data trigger a Level 3 Corrective Action. Based on the implementation of treatment BMPs at similar terminal operations in the area, stormwater treatment is likely required, to some extent, at all of these facilities to meet the ISGP benchmarks. Therefore, it is assumed for this analysis that the terminal operations discharging to the EW will install and operate stormwater treatment in the future to comply with the ISGP requirements. Table 1 presents the storm drain areas where stormwater flows are assumed to require treatment in the future.

For future source control conditions solids loads, Port basins that are assumed to have stormwater treatment installed based on ISGP conditions had adjustments made to both TSS and particle size distribution. Table 2 summarizes assumed removal efficiencies of solids by grain size (four size classes) and provides the resultant particle size distributions used to develop future source control solids loading for the base and low and high bounding runs from the current solids loading. The future conditions solids loading were calculated by applying a reduction scaling factor to current conditions solids loads. The current conditions solids loads were developed as part of the EW STE using a hydrologic model (see Appendix F of the STER; Anchor QEA and Coast & Harbor Engineering 2012). The chemical concentrations in solids are not expected to change as a result of corrective actions; however, the total contaminant mass is reduced proportional to reductions in solids loading. The method used to develop future conditions solids load for each SD is described below:

1. Removal efficiencies (Table 2) are used to calculate the total percent reduction in solids loads for Port SDs
   - The cumulative reduction factor for the base case is 83%
   - The cumulative reduction factor for the low bounding case is 91%
   - The cumulative reduction factor for the high bounding case is 74%
2. The future source control total solids load for each Port SD receiving treatment is estimated by applying the reduction factors in step 1 to the estimates of total solids load for current conditions (see Appendix F of the STER; Anchor QEA and Coast & Harbor Engineering 2012)
3. The total solids load for each SD (for future source control conditions from step 2) is parsed out over the four sediment size classes based on assumed particle size distributions following treatment (Table 2).

3.2 Combined Sewer Overflows

3.2.1 City of Seattle and King County

The City and County are required under their respective CSO NPDES permits to reduce the number of CSO discharges to, on average, one untreated event per year per outfall, which significantly reduces the total load of solids (and associated contaminants) to the EW. Table 3 identifies PTM assumptions for each CSO basin, including treatment scenarios used to develop future source control solids inputs for the base case and low and high bounding runs for EW CSOs.

The S Hinds CSO is being evaluated as part of the City's Long Term Control Plan. The City plans to install storage to control overflows from the Hinds CSO. Storage will allow flows[7] to be stored until the Elliott Bay Interceptor has capacity available to receive flows to be transported to the West Point Wastewater Treatment Plant. The Hinds CSO will, therefore, be modeled with reduced flow for future source control conditions. No changes to either chemistry or particle size distributions were assumed for the future Hinds CSO discharge.

The County will meet this requirement for the Lander and Hanford #2 CSOs by building a CSO treatment system that will remove solids and provide disinfection from the majority of the flow (King County 2012). This system will combine and treat discharges from the Hanford, Lander, Kingdome, and King CSOs. The discharge location for this combined treatment facility has not been determined at this time; for the purposes of this modeling effort, it was assumed to be the current discharge location for the Hanford #2 CSO. In addition to this combined treated discharge through the Hanford #2 outfall, one untreated discharge, on average, per year could occur through the Lander and Hanford #2 outfalls. Therefore, the PTM will include both treated and untreated discharges for these CSOs for future source control conditions. Additional information on how the removal efficiencies and particle size distributions were developed for the PTM for County CSOs is provided in Attachment 1 to this document.

3.3 Comparison of Current and Future (Source Control) East Waterway Lateral Solids Inputs

The future solids loading for all modeled basins and outfalls identified in Figure 2 were calculated based on the methodology discussed in Sections 3.1 and 3.2. The total solids loading for current and future conditions for each modeled outfall shown in Figure 2 are summarized in Table 4. Table 4 also includes the reductions in loading from current to future conditions for each modeled outfall. The cumulative reduction in solids loading from current conditions for all EW lateral sources is 34% for the base case, 51% for the low bounding run, and 23% for the high bounding run.

[7] Storage is designed such that only one discharge event on average per year would occur, because very large storm events can still overwhelm the system.

4 PARTICLE TRACKING MODEL RESULTS

The PTM was used to evaluate initial deposition of solids from identified EW lateral sources for both current and future conditions. This section focuses on future conditions because the current conditions are presented in the EW SRI (Windward and Anchor QEA 2014) and EW STER (Anchor QEA and Coast & Harbor Engineering 2012). As with the current condition model simulations, three future condition cases were run: a base case representing the best estimate and a low and high bounding run to capture the uncertainty in this estimate. The low bounding run for future conditions represents the highest anticipated removal of solids (the smallest solids load to the EW for future conditions), and the high bounding run represents the lowest anticipated removal of solids (the largest solids load to the EW for future conditions). Table 5 provides a summary of the EW lateral total solids input to the PTM and the total solids deposited in the EW for all current and future condition PTM simulations. This information will be used for evaluation of site trends over time following remediation and potential for recontamination in the EW FS due to sediment loads from identified lateral sources within the EW (see Section 5 and Appendix J). In general, results of the PTM suggest that between 70% and 75% of the solids from EW lateral sources deposits in the EW for current conditions, and between 67% and 71% deposits for future conditions. This reduction in lateral solids depositing in the EW is due to the finer-skewed particle size distribution of the future conditions as a result of stormwater and CSO treatment resulting in lower settling velocities and more particle transport out of the EW.

Figures 3, 4, and 5 show the initial deposition in kg over the simulation time period for the current conditions base case, low bounding, and high bounding runs, respectively. Figures 6, 7, and 8 show the initial deposition in kg per cell over the simulation time period for the future source control base case, low bounding, and high bounding runs, respectively.

PTM output for current and future (source control) solids loading conditions was also processed to develop maps of predicted average annual deposition rates from EW lateral sources within the EW. The annual deposition rates were calculated from the initial mass deposition raster maps (kg/simulation period) at the same resolution (50 feet by 50 feet) using the following steps:

1. Extrapolate the initial mass deposited over the simulation period (28 days) out to mass deposited over 1 year (365 days)[8]
2. Convert mass in kg to volume in cubic meters (m^3) using an assumed density[9] of 1.5 g/cm^3
3. Covert volume in m^3 to thickness (cm) in raster cell by dividing the volume by the surface area of the raster cell[10]

Figures 9, 10, and 11 provide maps of deposition rates (in cm/year) estimated from results of the initial PTM for current solids loading (see Section 7 of the EW STER; Anchor QEA and Coast & Harbor Engineering 2012) for the base case, low bounding, and high bounding runs, respectively. Figures 12, 13, and 14 provide maps of annual deposition rates for future source control conditions loading for base case, low bounding, and high bounding runs, respectively. Annual deposition rates and patterns shown on Figures 12 through 14 represent "worst case" deposition for surface concentrations due ignoring the influence of resuspension and spreading due to propwash. Resuspension and lateral transport from propwash (i.e., dispersion) will tend to distribute sediments more widely than shown on Figures 12 through 14. In areas near outfalls, dispersion will tend to reduce the contribution of lateral loads to the localized area and, therefore, reduce concentrations (because some laterals move farther from outfalls). Farther from outfalls, dispersion will tend to increase contribution of lateral loads and, therefore, could increase concentrations. The net impact of dispersion on the predicted RAL exceedance area (e.g., see Figure 9-7 of the FS) will depend on location-specific conditions, but is more likely to result in a net reduction in predicted exceedance areas.

[8] This was done using a scaler multiplication factor of 28/365 = 13.05. The average yearly deposition pattern is assumed to be the same as the 2-month pattern and the pattern does not change over different hydrographic years.
[9] The density of sediment used in this calculation was taken from measured densities of site-specific SEDflume cores (see Section 6 of the EW STER; Anchor QEA and Coast & Harbor Engineering 2012).
[10] The surface area of each 50-foot by 50-foot raster cell is approximately 232.3 square meters.

5 UNCERTAINTY DISCUSSION

The PTM methods and associated assumptions result in some uncertainties in final amount and disposition of particles. The sources of uncertainty are described below. Some inherent randomness exists within the model related to the "random walk" in the particle paths that exists within the model itself. The randomness was shown to be insignificant with respect to the initial deposition location and amount in areas where there is relatively high deposition as part of the initial modeling effort (Section 7 of the STER; Anchor QEA and Coast & Harbor Engineering 2012). Since the purpose of the PTM is to identify areas where mass contribution from lateral sources may be significant enough to present recontamination potential, the uncertainty in estimates within low deposition areas is not a serious concern for this application.

The model also 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 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 simulations, which plays a larger role in ultimate disposition of particles in the EW. These last two uncertainties would further spread the depositional pattern and reduce the concentrations of contaminants near outfalls, where marginal exceedances of the RALs are more likely. A wider distribution of this mass will not significantly change the spatially-weighted average concentration (SWAC) estimates because the deposited sediment largely remains near the surface. Therefore, the exclusion of initial particle velocity and propwash effects results in a conservative estimate of recontamination potential but has little effect on future SWAC estimates (see Appendix J of the FS).

Additional uncertainties exist within the lateral source input data assumptions developed for the PTM, including removal efficiencies for future treatment options, particle size distributions, stormwater and CSO flows, and TSS and chemistry 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; see Section 4 of the EW STER; Anchor QEA and Coast & Harbor Engineering 2012).

As discussed, shorter-term simulations were performed to provide data that can be used to evaluate long-term conditions. Therefore, there is some uncertainty in the predictions of long-term deposition patterns due to this extrapolation. These simulations 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.

6 REFERENCES

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TABLES

Table 1
Future Conditions for East Waterway Lateral Sources

Modeled Outfall	Untreated Basin that Discharges through Modeled Outfall[a]	Treated Basin that Discharges through Modeled Outfall[a]	Source Control Measure Solids		Source Control Measure Chemistry
			Particle Size Distribution	Annual Flow Volume	
1	A1	B1	--	--	--
2		BR2	--	--	--
4		BR4 + B4 (SW Spokane St SD)	--	--	SCP
5		BR5 + B5 (SW Spokane St EOF/SD)	--	--	SCP
6	A6	A6	--	--	--
7		B7	ISGP	--	--
10	A10	B10	ISGP	--	--
11	A11	B11	ISGP	--	--
12	A12	B12	ISGP	--	--
13	A13	B13	ISGP	--	--
14	A14	B14	ISGP	--	--
16	A16	B16	ISGP	--	--
17	A17	B17	ISGP	--	--
18	A17	B18	ISGP	--	--
19	A19	B19	ISGP	--	--
21		B21, SW Florida St SD	--	--	SCP
22	A22	B22	ISGP	--	--
23	A23	B23	ISGP	--	--
24	A24	B24	ISGP	--	--
25		B25, S Massachusetts St SD	--	--	SCP
26	A26	B26	ISGP	--	--
27	A27	B27	ISGP	--	--
28	A28	B28	ISGP	--	--
29	A29	B29	ISGP	--	--
30	A30	B30 + BR27	ISGP	--	--
31	A31	B31	ISGP	--	--
32	A32	B32	ISGP	--	--
33	A33	B33	ISGP	--	--
34	B34		--	--	--
36		S Spokane St SD	--	--	SCP
37	B37		--	--	--
39	BR39		--	--	--
39		B39	ISGP	--	--
40	B40		--	--	--
41	B41		--	--	--
42	B42		--	--	--
43	B43		--	--	--
Hinds_Storm		S Hinds St SD	--	--	SCP
Lander_Storm		S Lander St SD	--	--	SCP
Hanford		Hanford CSO	CSO treatment	--	--
Hinds		Hinds CSO	--	CSO storage	--
Lander		Lander CSO	CSO treatment	--	--

Notes:
a. See Figure 2, map of drainage basins and modeled outfalls.
Basin naming "A" refers to pier Apron locations, "B" refers to drainage Basins, and "BR" refers to Bridge locations.
"--" designates no change from current conditions.
SCP: A reduction in chemical concentrations is expected in the future as a result of the City of Seattle's ongoing source control program.
ISGP: Changes in particle size distribution and total solids loading (from current conditions) because the site will have reached Level 3 corrective action and is required under ISGP to install stormwater treatment best management practices. The solids chemistry is not expected to change as a result of corrective actions. The particles that do not get removed by stormwater facilities typically have the same concentration as prior to filtering.
CSO storage: Annual discharge volume is reduced because Seattle Public Utilities plans to install a storage tank to reduce the number of CSO discharges to the East Waterway to one uncontrolled event (on average) per year as required under the CSO National Pollutant Discharge Elimination System permit.
CSO treatment: Changes for particle size distribution and reduction in solids because King County plans to install a CSO treatment system to reduce the number of untreated CSO events to one uncontrolled event (on average) per year. Treatment can also reduce chemistry, but none was assumed for this evaluation.

CSO – combined sewer overflow
EOF – emergency overflow
ISGP – industrial stormwater general permit
SCP – source control program
SD – storm drain

Table 2
Assumed Future Conditions for Treated Port Storm Drains
(Presented as a Percent Reduction from Current Conditions)

Particle Size Class	Treated Flow (91% of total)			Untreated Flow (9% of total)
	Base Case Median TSS (43 mg/L)	**Low Bounding Case 25th Percentile TSS (20 mg/L)**	**High Bounding Case 75th Percentile TSS (60 mg/L)**	**For All Cases**
Removal Efficiencies				
< 5 µm (1A)	70%	80%	60%	0%
20 µm to 129 µm (1B)	80%	90%	70%	0%
130 µm to 539 µm (2)	80%	90%	70%	0%
> 540 µm (3)	90%	95%	80%	0%
Particle Size Distributions				
< 5 µm (1A)	26%	32%	22%	15%
20 µm to 129 µm (1B)	26%	24%	25%	23%
130 µm to 539 µm (2)	29%	27%	28%	26%
> 540 µm (3)	20%	18%	25%	35%

Notes:
Only 91% of total flow is treated; 9% of total flows retain current solids conditions.
µm – micrometer
mg/L – milligram per liter
TSS – total suspended solids

Table 3
Future Conditions for East Waterway Combined Sewer Outfalls

Outfall	Treatment	Flow Volume (million gallons/year)			TSS (mg/L)	Future Removal Efficiency (%)				Future Particle Size Distribution (%)[e]			
		Current	Future	Note		Class 1A	Class 1B	Class 2	Class 3	Class 1A	Class 1B	Class 2	Class 3
Base Case Run													
Hanford #2	Untreated (volume reduced through treatment)	74.3	1.0	a	86	--	--	--	--	42	41	17	0
Lander	Untreated (volume reduced through treatment)	39.8	0.6	b	86	--	--	--	--	42	41	17	0
Hanford #2	Treated Flow (70% removal efficiency)	0	164	c	25.8	70	100	100	100	100	0	0	0
Hinds	Untreated (volume reduced through storage)	1.0	0.6	d	86	--	--	--	--	42	41	17	0
Lower Bounding Run													
Hanford #2	Untreated (volume reduced through treatment)	74.3	1.0	a	65.3	--	--	--	--	42	41	17	0
Lander	Untreated (volume reduced through treatment)	39.8	0.6	b	65.3	--	--	--	--	42	41	17	0
Hanford #2	Treated Flow (90% removal efficiency)	0	164	c	6.53	90	100	100	100	100	0	0	0
Hinds	Untreated (Volume Reduced through Storage)	1.0	0.6	d	65.3	--	--	--	--	42	41	17	0
Upper Bounding Run													
Hanford #2	Untreated (volume reduced through treatment)	74.3	1.0	a	106	--	--	--	--	42	41	17	0
Lander	Untreated (volume reduced through treatment)	39.8	0.6	b	106	--	--	--	--	42	41	17	0
Hanford #2	Treated Flow (50% removal efficiency)	0	164	c	53	70	85	95	100	60	30	10	0
Hinds	Untreated (volume reduced through storage)	1.0	0.6	d	106	--	--	--	--	42	41	17	0

Notes:

a. This volume represents one untreated CSO event per year (on average) at Hanford #2, which meets Washington State Law. The remainder of the flow will be treated.

b. This volume represents one untreated CSO event per year (on average) at Lander, which meets Washington State Law. The remainder of the flow will be treated and discharged through Hanford #2 outfall.

c. A treatment facility will be constructed to treat flow from four CSOs (Hanford #2 and Lander [within the EW], and Kingdome and King [north of the EW]). The location of the discharge has yet to be determined by King County, but is assumed to be Hanford #2 outfall for this evaluation.

d. A storage tank will be constructed to store flow from Hinds CSO so that there is only one CSO discharge per year (on average), which meets Washington State Law.

e. Projections of particle size distribution of less then 0.01% are presented as 0; particle size distribution classes are the same as shown in Table 2.

µm – micrometer
mg/L – milligram per liter
EW - East Waterway
TSS – total suspended solids

Particle Size Classes

Class 1A: < 5 µm
Class 1B: 20 µm to 129 µm
Class 2: 130 µm to 539 µm
Class 3: > 540 µm

Table 4
Comparison of Predicted Current and Future East Waterway Lateral Solids Inputs

				Annual Average Total Solids Load (kg)								
Modeled Outfall	Type	Owner	Drainage Basins[a]	Base Case Current (kg)	Base Case Future Source Control (kg)	% Reduction (% by mass)	Lower Bound Current (kg)	Lower Bound Future Source Control (kg)	% Reduction (% by mass)	Upper Bound Current (kg)	Upper Bound Future Source Control (kg)	% Reduction (% by mass)
Sum of all East Waterway Lateral Sources				**113,093**	**74,605**	**34%**	**63,874**	**31,017**	**51%**	**150,961**	**116,025**	**23%**
1	SD	POS	A1 + B1	171	51	70%	79	18	77%	239	94	61%
2	SD	POS	BR2	29	29	none	13	13	none	40	40	none
4	SD	SPU	BR4 + B4 (SW Spokane St SD)	1,468	1,468	none	689	689	none	2,079	2,079	none
5	SD	SPU	BR5 + B5 (SW Spokane St EOF/SD)	643	643	none	305	305	none	832	832	none
6	SD	Private	A6	590	590	none	271	271	none	932	932	none
7	SD	POS	A6 + B7	1,632	571	65%	761	217	71%	2,284	1,005	56%
10	SD	POS	A10 + B10	1,032	480	54%	480	198	59%	1,440	776	46%
11	SD	POS	A11 + B11	5,223	1,544	70%	2,429	549	77%	7,287	2,868	61%
12	SD	POS	A11 + B12	923	424	54%	429	174	59%	1,288	688	47%
13	SD	POS	A 13 + B13	725	250	66%	337	95	72%	1,012	441	56%
14	SD	POS	A13 + B14	276	161	42%	128	69	46%	386	247	36%
16	SD	POS	A16 + B16	550	206	63%	255	83	67%	767	362	53%
17	SD	POS	A 17 + B17	306	142	53%	142	59	59%	427	231	46%
18	SD	POS	A18 + B18	933	368	61%	434	145	67%	1,303	623	52%
19	SD	POS	A19 + B19	752	367	51%	349	153	56%	1,049	586	44%
21	SD	SPU	B21, SW Florida St SD	1,408	1,408	none	655	655	none	1,965	1,965	none
22	SD	POS	A22 + B22	1,519	603	60%	706	238	66%	2,119	1,018	52%
23	SD	POS	A23 + B23	1,410	573	59%	655	228	65%	1,967	962	51%
24	SD	POS	A 24 + B24	1,209	532	56%	562	216	62%	1,687	874	48%
25	SD	SPU	B25, S Massachusetts St SD	657	657	none	328	328	none	987	987	none
26	SD	POS	A 26 + B26	1,519	495	67%	706	183	74%	2,120	889	58%
27	SD	POS	A27 + B27	981	419	57%	456	169	63%	1,368	694	49%
28	SD	POS	A28 + B28	552	278	50%	257	117	55%	771	441	43%
29	SD	POS	A29 + B29	1,073	405	62%	498	157	68%	1,497	694	54%
30	SD	POS	A 30 + B30 + BR27	866	355	59%	403	142	65%	1,210	596	51%
31	SD	POS	A31 + B31	1,147	397	65%	533	150	72%	1,601	700	56%
32	SD	POS	A32 + B32	491	207	58%	228	83	64%	685	343	50%
33	SD	POS	A33 + B33	1,549	625	60%	720	248	66%	2,162	1,051	51%
34	SD	POS	B34	2,457	726	70%	1,129	255	77%	3,884	636	84%
36	SD	SPU	S Spokane St SD	1,061	1,061	none	502	502	none	1,399	1,399	none
37	SD	POS	B37	689	204	70%	320	72	77%	962	378	61%
39	SD	SPU	BR39	234	234	none	107	107	none	369	369	none
39	SD	POS	B39	225	67	70%	105	24	77%	314	124	61%
40	SD	Private	B40	449	449	none	239	239	none	650	650	none
41	SD	Private	B41	857	857	none	394	394	none	1,354	1,354	none
42	SD	Private	B42	86	86	none	39	39	none	136	136	none
43	SD	Private	B43	1,071	1,071	none	492	492	none	1,694	1,694	none
Hanford #2[b]	CSO	KC	Hanford CSO	24,188	16,342	32%	18,366	4,301	77%	29,813	33,304	-12%
Hinds[c,e]	CSO	SPU	Hinds CSO	326	207	36%	247	207	16%	401	207	48%
Lander[d]	CSO	KC	Lander CSO	12,957	195	98%	9,838	148	98%	15,970	241	98%
Hinds_Storm	SD	SPU	S Hinds St SD	6,920	6,920	none	3,215	3,215	none	10,231	10,231	none
Lander_Storm	SD	KC	S Lander St SD	31,940	31,940	none	15,070	15,070	none	42,279	42,279	none

Table 4
Comparison of Predicted Current and Future East Waterway Lateral Solids Inputs

Notes:
a. See Figure 2 for a map of basins and outfall locations. See Table 1 for a list of treatment options for each basin assigned to a modeled outfall.
b. Future conditions for Hanford #2 include re-routing of treated discharges from Lander, Kingdome, and King CSOs through the Hanford #2 discharge location.
c. The Future Source Control reduction in solids load for Hinds CSO is due to reduction in flow (storage).
d. The Future Source Control reduction in solids load for Lander CSO is due to treated flows being discharged through Hanford #2 outfall.
e. This flow represents one untreated CSO discharge into the EW per year for the Hanford, Lander, and Hinds CSOs, as allowed by the National Pollutant Discharge Elimination System.
Basin naming "A" refers to pier Apron locations, "B" refers to drainage Basins, and "BR" refers to Bridge locations.
CSO – combined sewer overflow
EOF – emergency overflow
EW - East Waterway
KC – King County
kg – kilogram
POS – Port of Seattle
SD – storm drain
SPU – Seattle Public Utilities

Table 5
Summary of Particle Tracking Model Results for East Waterway Lateral Loads

Model Run	Total Mass (kg) Input into Model over Simulation Period[1]	Total Mass Deposited in EW at End of Simulation[2]		Total Mass in Suspension in EW at End of Simulation[3]		Total Mass that has Left the EW at End of Simulation	
		kg	% of total input	kg	% of total input	kg	% of total input
Base Case, Current	8,626	6,490	75%	411	5%	1,725	20%
Lower Bound, Current	4,855	3,487	72%	254	5%	1,114	23%
Upper Bound, Current	11,560	8,751	76%	538	5%	2,271	20%
Base Case, Future	5,651	3,798	67%	323	6%	1,530	27%
Lower Bound, Future	2,313	1,655	72%	130	6%	528	23%
Upper Bound, Future	8,803	6,193	70%	452	5%	2,158	25%

Notes:

1. The simulation period included 28 days, with 14 additional days (spin down) with loading sources set to 0 to allow finer particles released into the model to settle.
2. This value represents initial deposition within the EW and does not include resuspension due to propeller wash or other vessel operations.
3. This value represents particles that were still in suspension above the bed in the model after the total 42 days of simulation time (including the 14 days of spin-down time).

Summary of PTM Results - Estimated Annual EW Lateral Loads

Model Run	Annual[1] Input (kg)	Total Mass Deposited in EW Annually[1] (kg)	Mass Deposited in EW from CSOs (kg)	Mass Deposited in EW from SDs (kg)
Base Case, Current	112,483	84,630	21,819	62,811
Lower Bound, Current	63,309	45,475	16,372	29,103
Upper Bound, Current	150,742	114,117	26,659	87,457
Base Case, Future	73,689	49,527	3,153	46,374
Lower Bound, Future	30,162	21,578	1,016	20,561
Upper Bound, Future	114,791	80,760	14,528	66,231

Note:

1. The simulation period included 28 days. To estimate annual loads, the simulation period results were multiplied by 13.04.

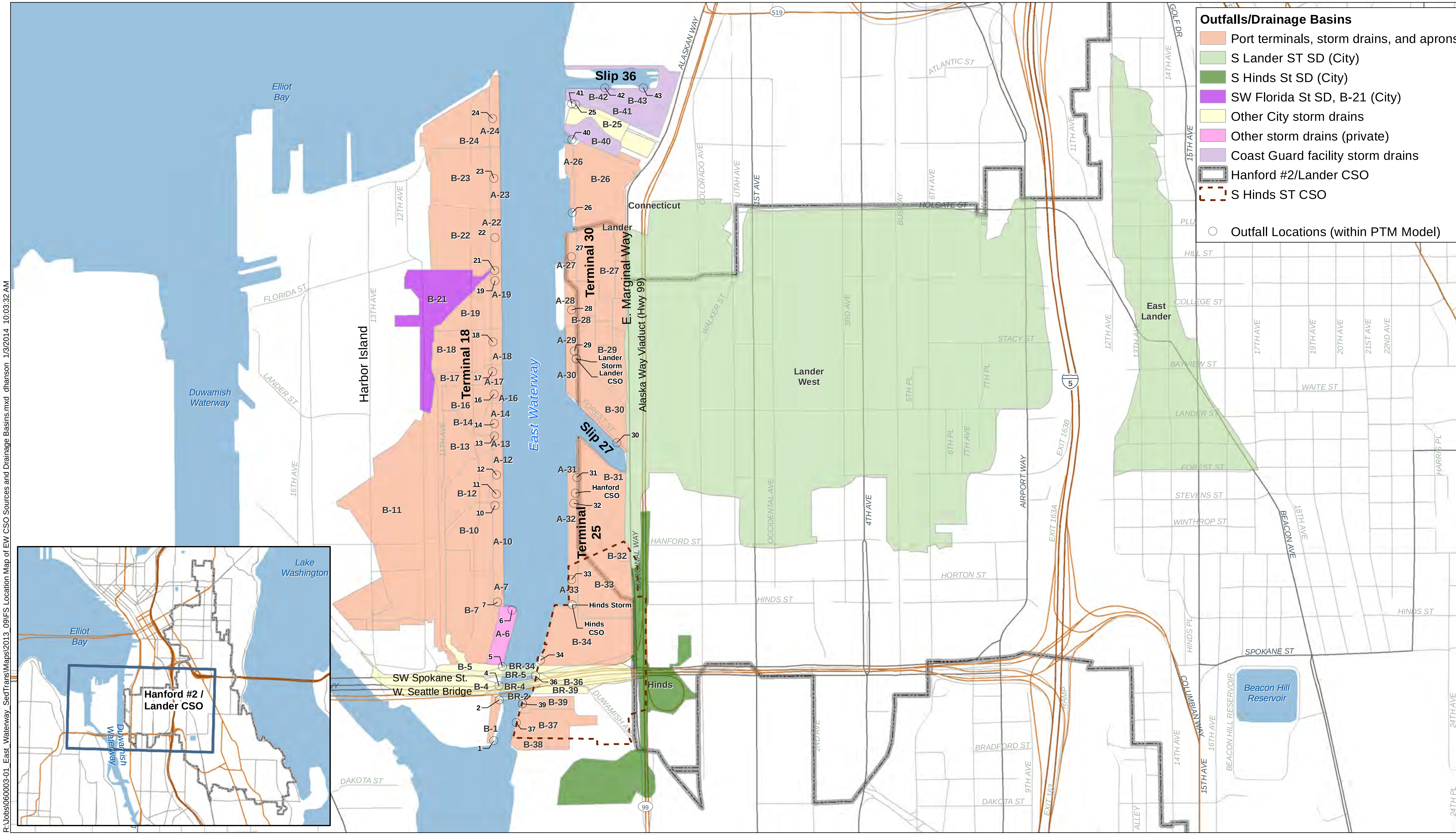
Notes:

CSO – combined sewer overflow
EW – East Waterway
kg – kilogram
PTM – particle tracking model
SD – storm drain

FIGURES

NOTE: Aerial photo is NAIP, 2011.

Figure 1
Hydrodynamic Model Grid within the EW
Feasibility Study - Appendix B, Part 1
East Waterway Study Area

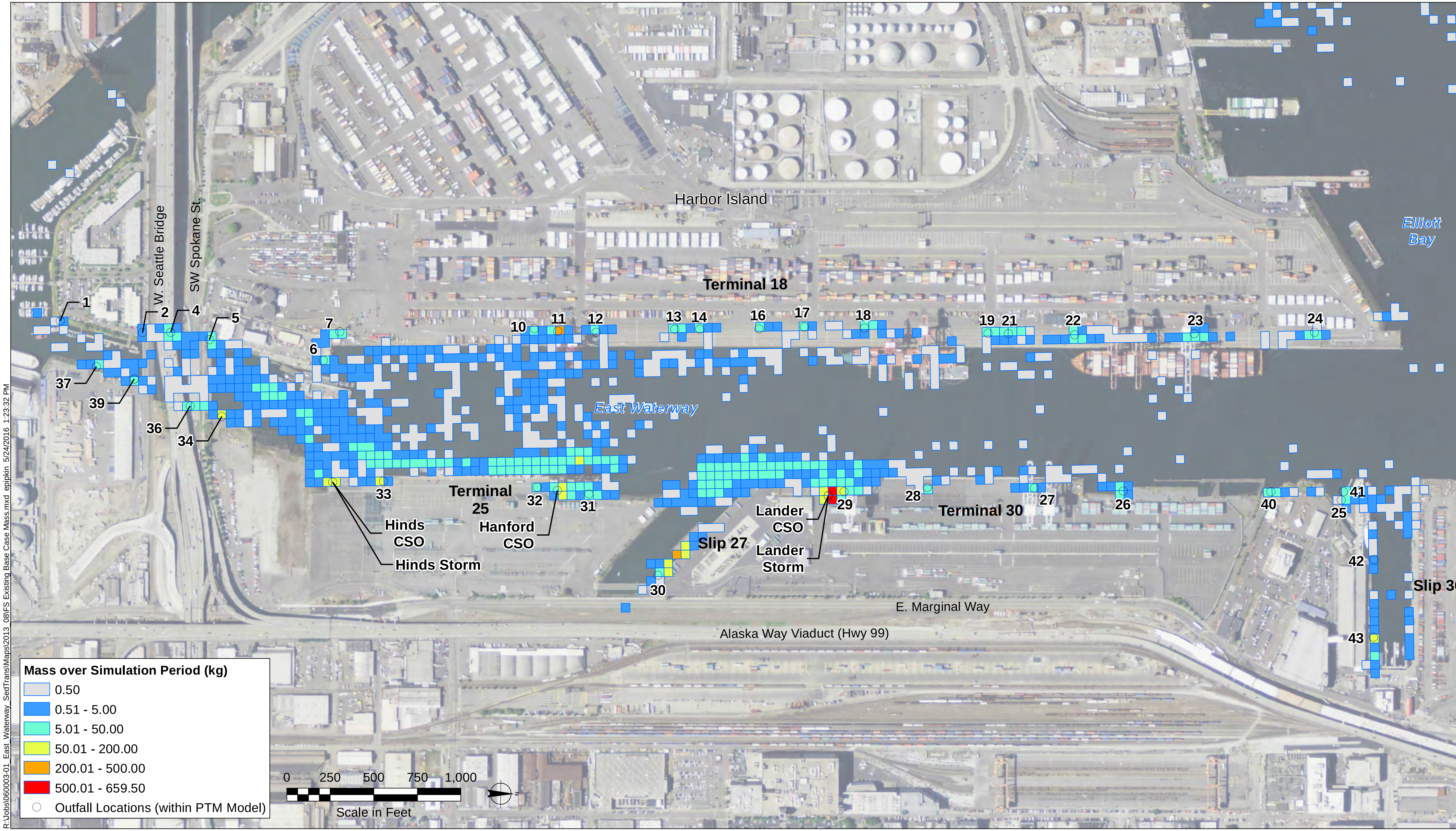


0 500 1,000 1,500 2,000

Scale in Feet

Figure 2
Location Map of EW Storm Drain and CSO Basins and Outfalls
Feasibility Study - Appendix B, Part 1
East Waterway Study Area

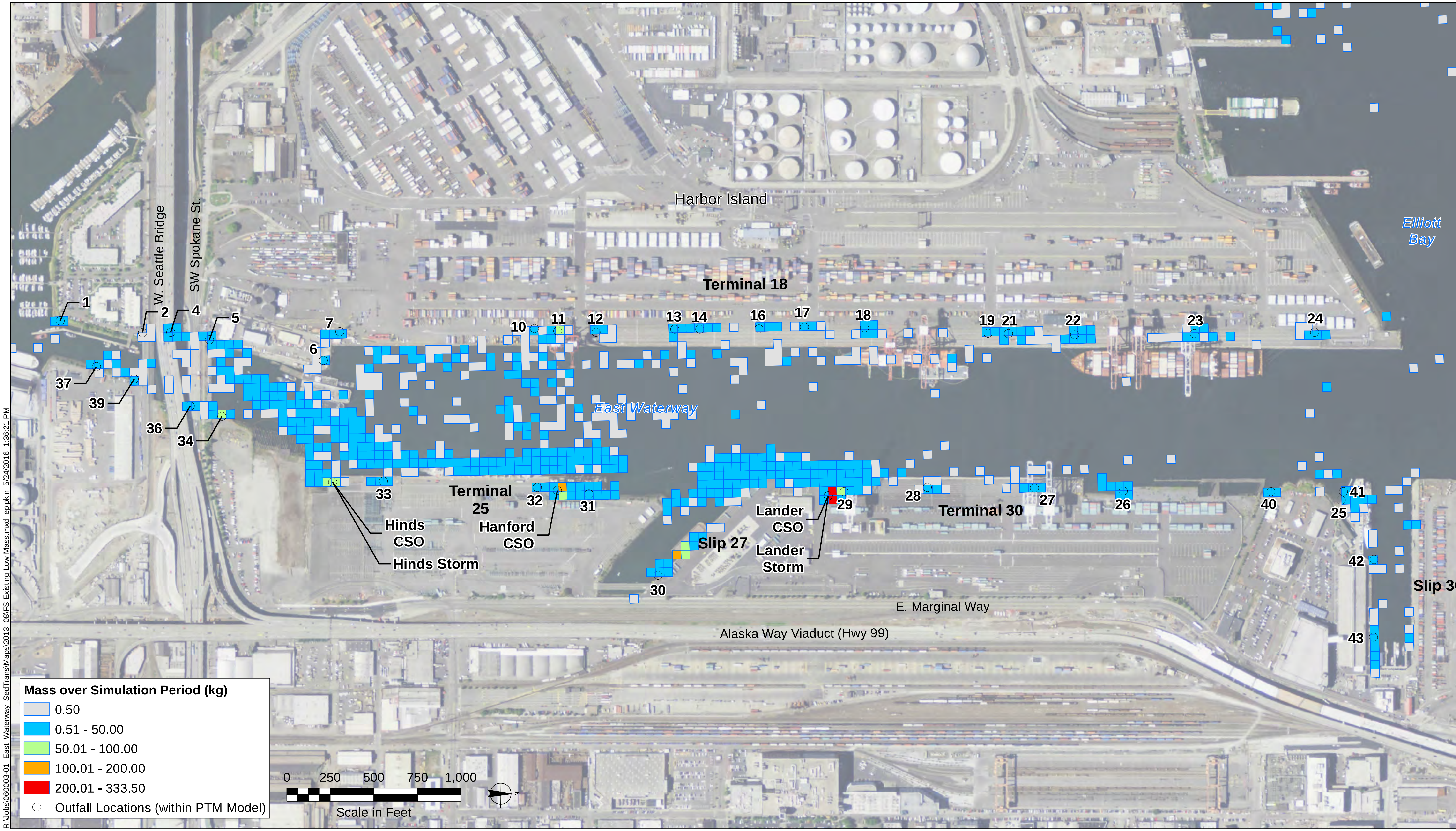
R:\Jobs\060003-01_East_Waterway_SedTrans\Maps\2013_09\FS Location Map of EW CSO Sources and Drainage Basins.mxd dhanson 1/3/2014 10:03:32 AM



R:\Jobs\060003-01_East_Waterway_SedTrans\Maps\2013_08\FS Existing Base Case Mass.mxd epipkin 5/24/2016 1:23:32 PM

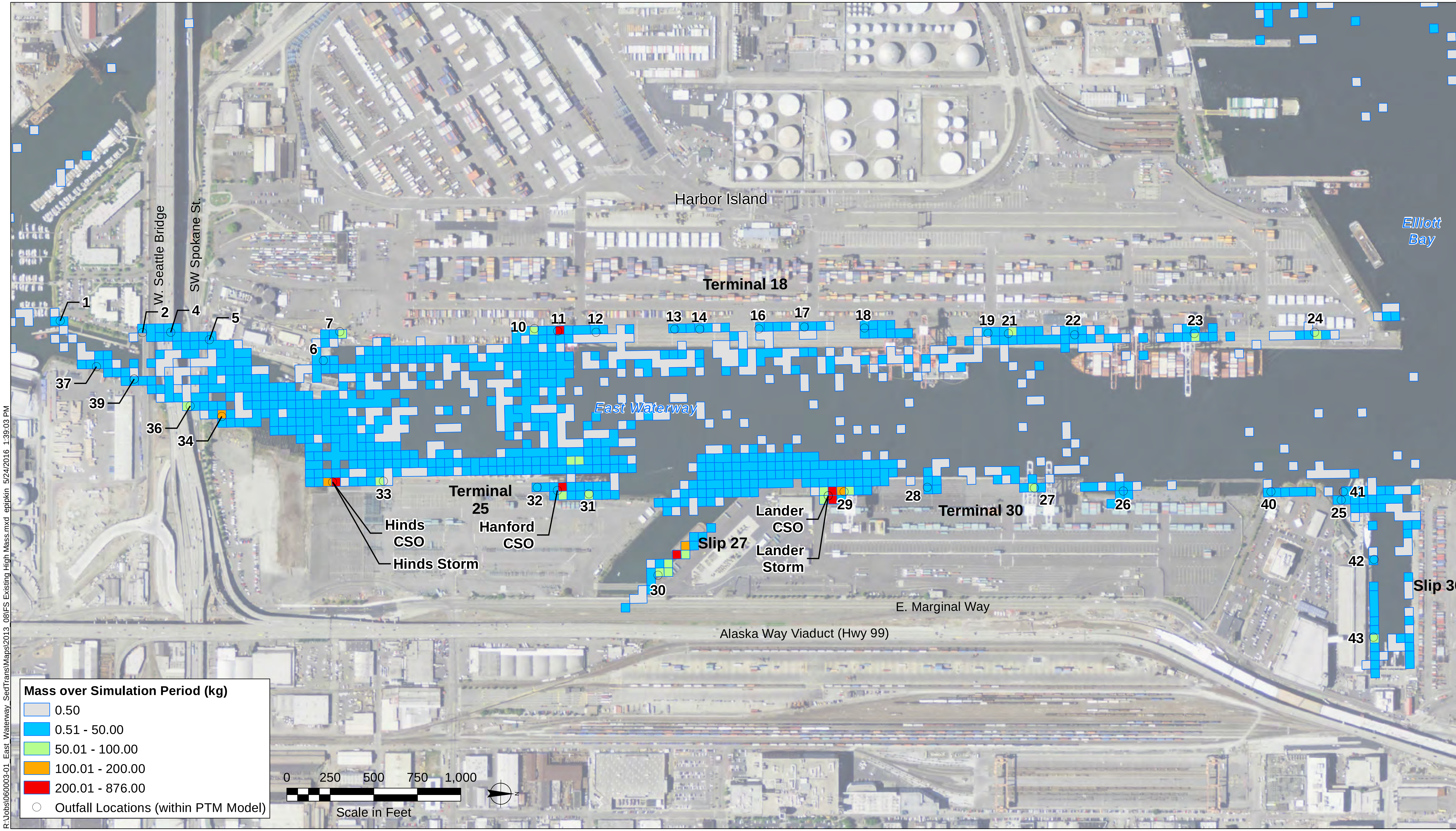
NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Raster cell size is 50' x 50'.
3. Aerial photo is NAIP, 2011.
4. The simulation period includes 28 days of loading from laterial inputs plus 14 days without loading to allow finer particles to settle.
5. Simulation for EW lateral loads only.

Figure 3
PTM Model Simulation Existing Source Control Base Case - Mass Accumulation during Simulation Period (kg)
Feasibility Study - Appendix B, Part 1
East Waterway Study Area



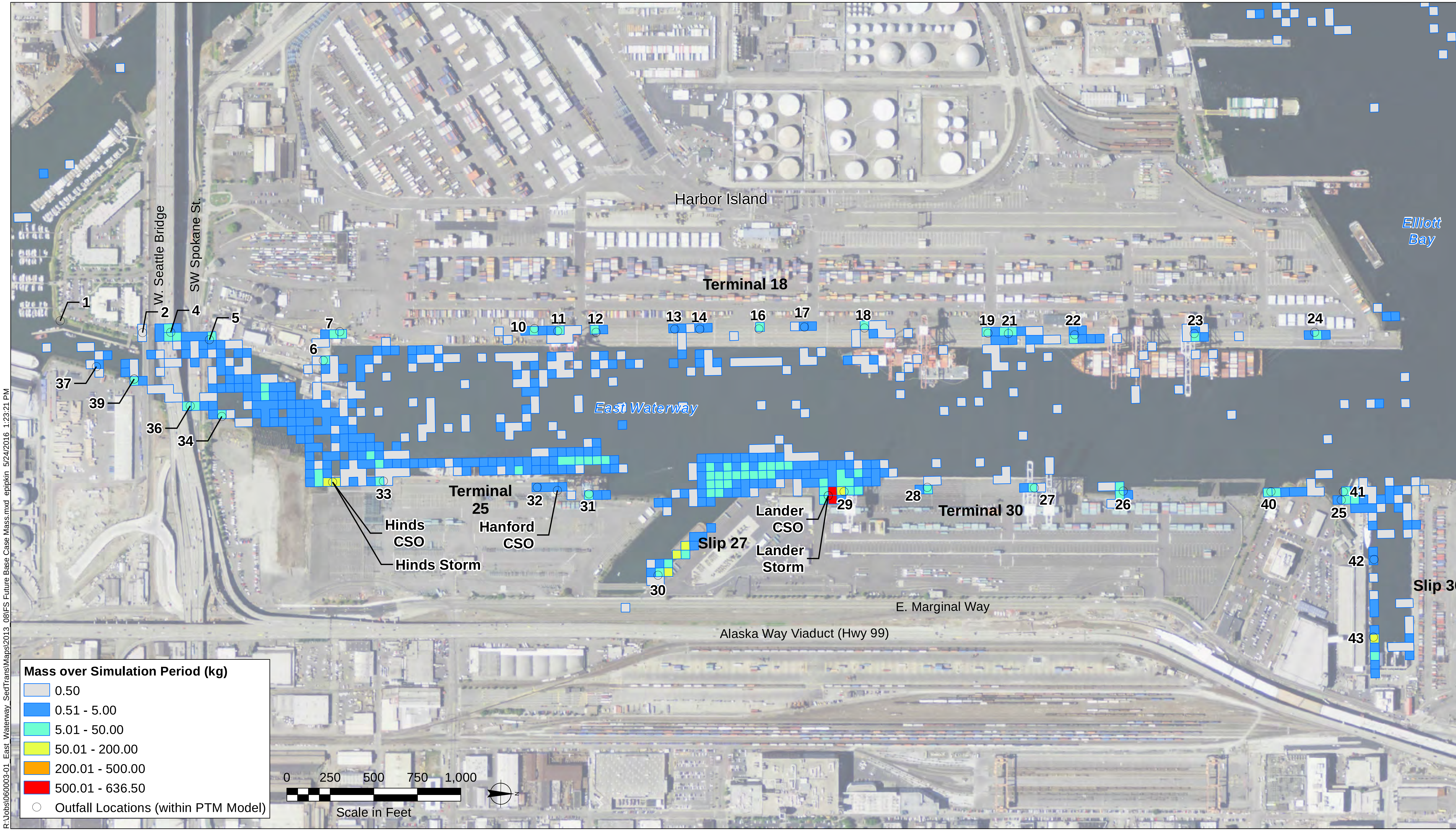
NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Raster cell size is 50' x 50'.
3. Aerial photo is NAIP, 2011.
4. The simulation period includes 28 days of loading from laterial inputs plus 14 days without loading to allow finer particles to settle.
5. Simulation for EW lateral loads only.

Figure 4
PTM Model Simulation Existing Source Control Low Bounding Case - Mass Accumulation during Simulation Period (kg)
Feasibility Study - Appendix B, Part 1
East Waterway Study Area



NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Raster cell size is 50' x 50'.
3. Aerial photo is NAIP, 2011.
4. The simulation period includes 28 days of loading from laterial inputs plus 14 days without loading to allow finer particles to settle.
5. Simulation for EW lateral loads only.

Figure 5
PTM Model Simulation Existing Source Control High Bounding Case - Mass Accumulation during Simulation Period (kg)
Feasibility Study - Appendix B, Part 1
East Waterway Study Area



NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Raster cell size is 50' x 50'.
3. Aerial photo is NAIP, 2011.
4. The simulation period includes 28 days of loading from laterial inputs plus 14 days without loading to allow finer particles to settle.
5. Simulation for EW lateral loads only.

Figure 6
PTM Model Simulation Future Source Control Base Case - Mass Accumulation during Simulation Period (kg)
Feasibility Study - Appendix B, Part 1
East Waterway Study Area

NOTES:

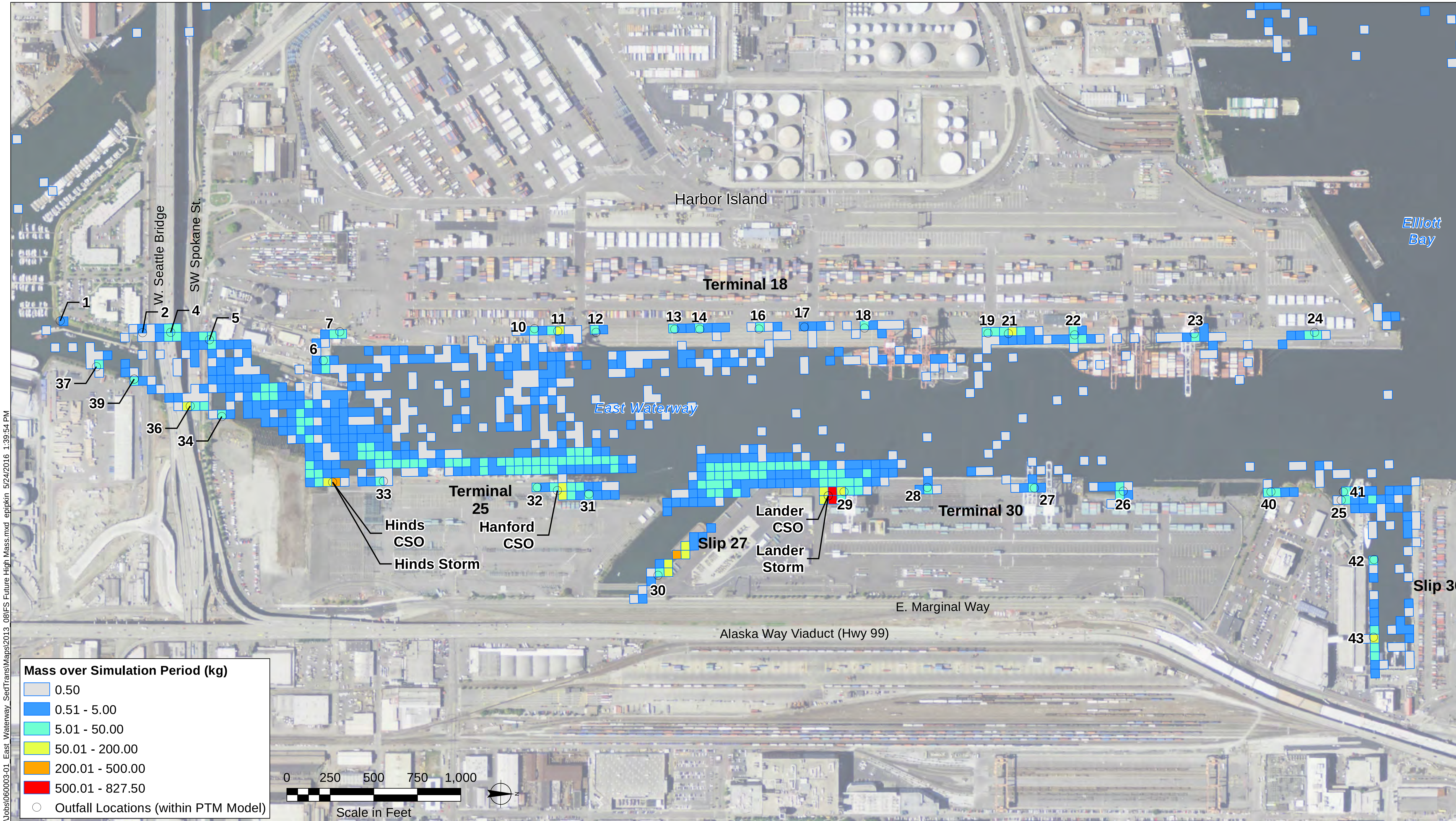
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Raster cell size is 50' x 50'.
3. Aerial photo is NAIP, 2011.
4. The simulation period includes 28 days of loading from laterial inputs plus 14 days without loading to allow finer particles to settle.
5. Simulation for EW lateral loads only.

Figure 7

PTM Model Simulation Future Source Control Low Bounding Case - Mass Accumulation during Simulation Period (kg)

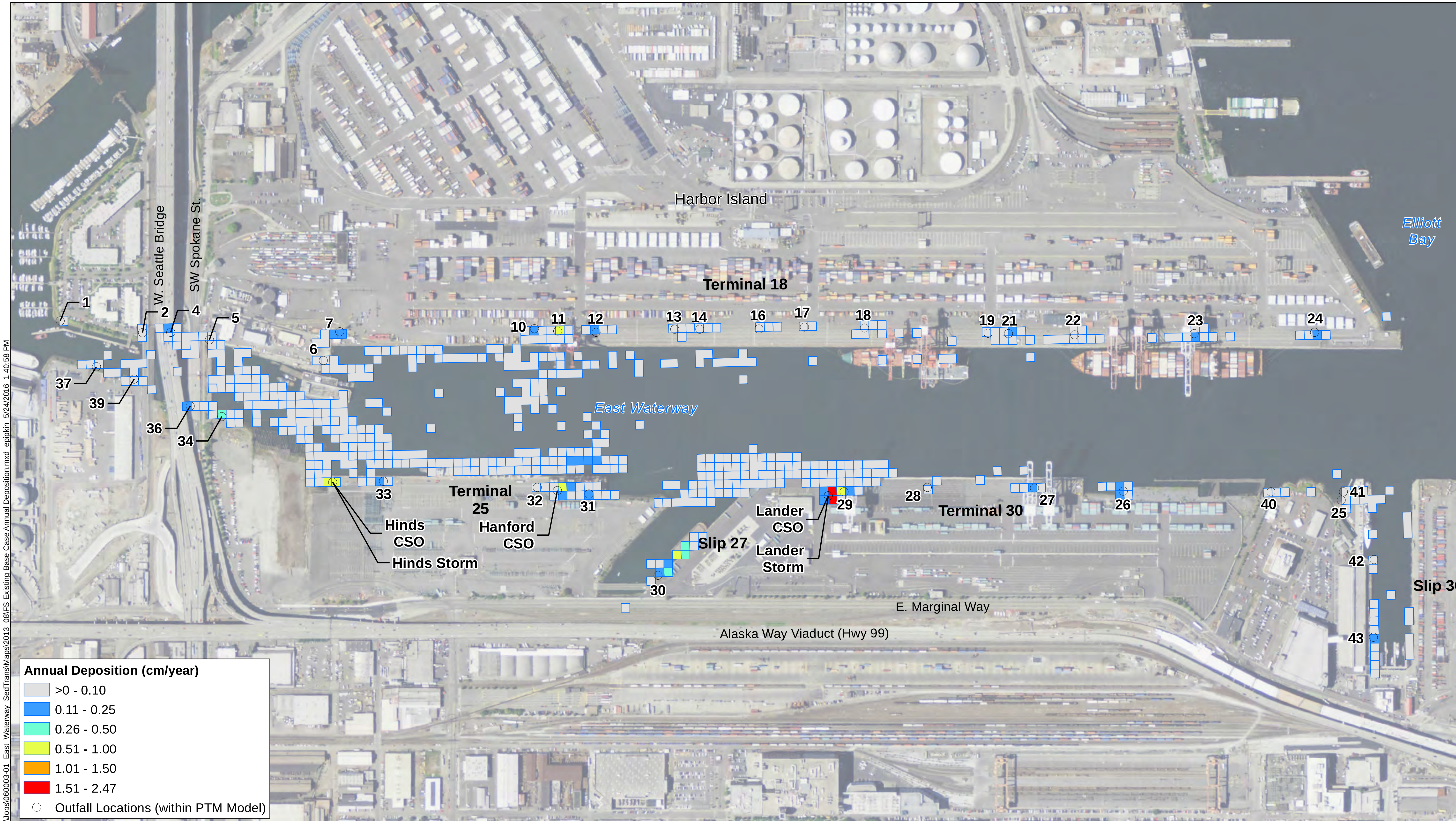
Feasibility Study - Appendix B, Part 1

East Waterway Study Area



NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Raster cell size is 50' x 50'.
3. Aerial photo is NAIP, 2011.
4. The simulation period includes 28 days of loading from laterial inputs plus 14 days without loading to allow finer particles to settle.
5. Simulation for EW lateral loads only.

Figure 8
PTM Model Simulation Future Source Control High Bounding Case - Mass Accumulation during Simulation Period (kg)
Feasibility Study - Appendix B, Part 1
East Waterway Study Area



NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Raster cell size is 50' x 50'.
3. Aerial photo is NAIP, 2011.

0 250 500 750 1,000
Scale in Feet

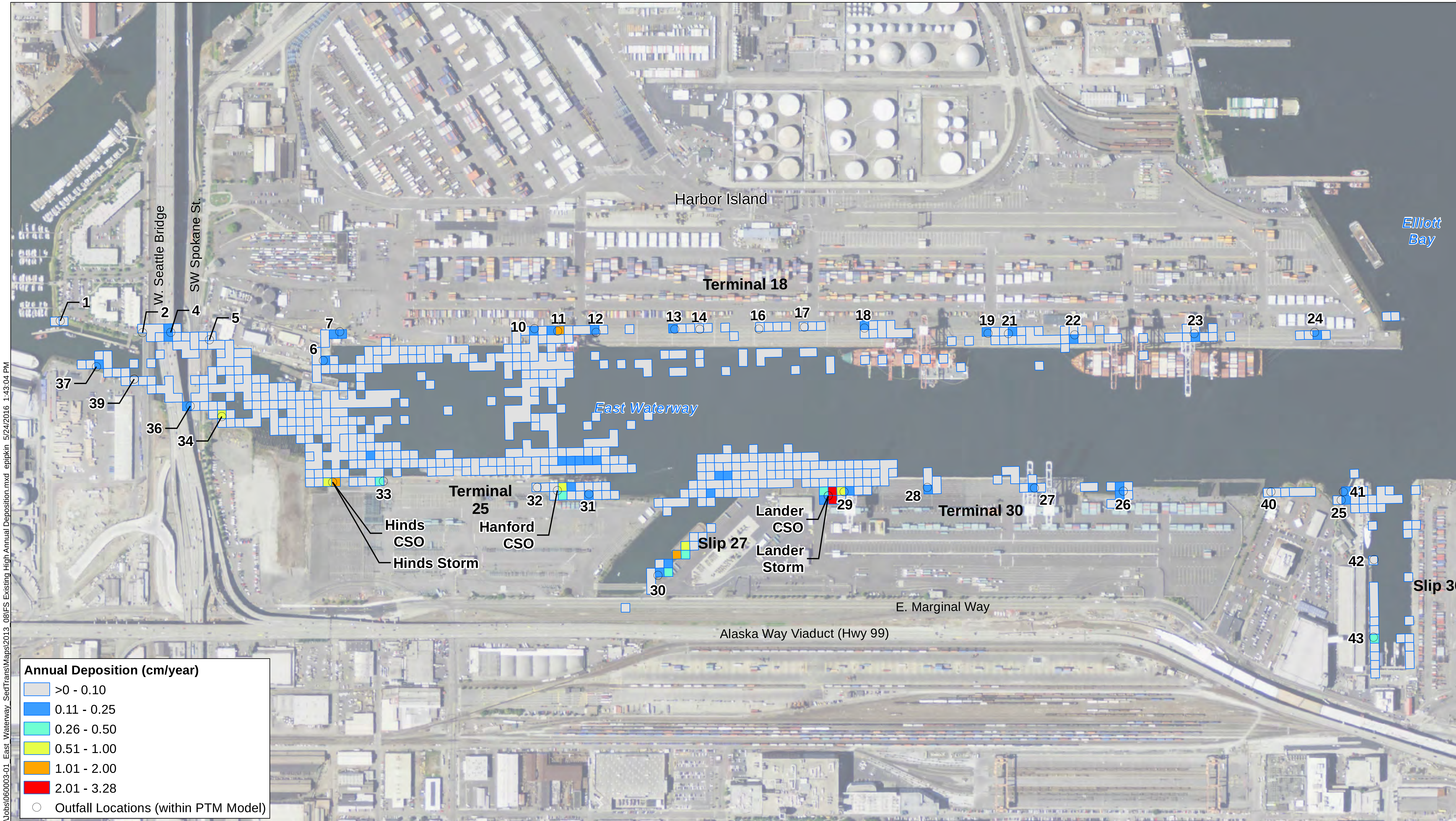
Figure 9
PTM Model Simulation Current Conditions Base Case - Annual Initial Deposition (cm/year)
Feasibility Study - Appendix B, Part 1
East Waterway Study Area

R:\Jobs\060003-01_East_Waterway_SedTrans\Maps\2013_08\FS Existing Low Annual Deposition.mxd epipkin 5/24/2016 1:41:48 PM

NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Raster cell size is 50' x 50'.
3. Aerial photo is NAIP, 2011.

0 250 500 750 1,000
Scale in Feet

Figure 10
PTM Model Simulation Current Conditions Low Bounding Case - Annual Initial Deposition (cm/year)
Feasibility Study - Appendix B, Part 1
East Waterway Study Area



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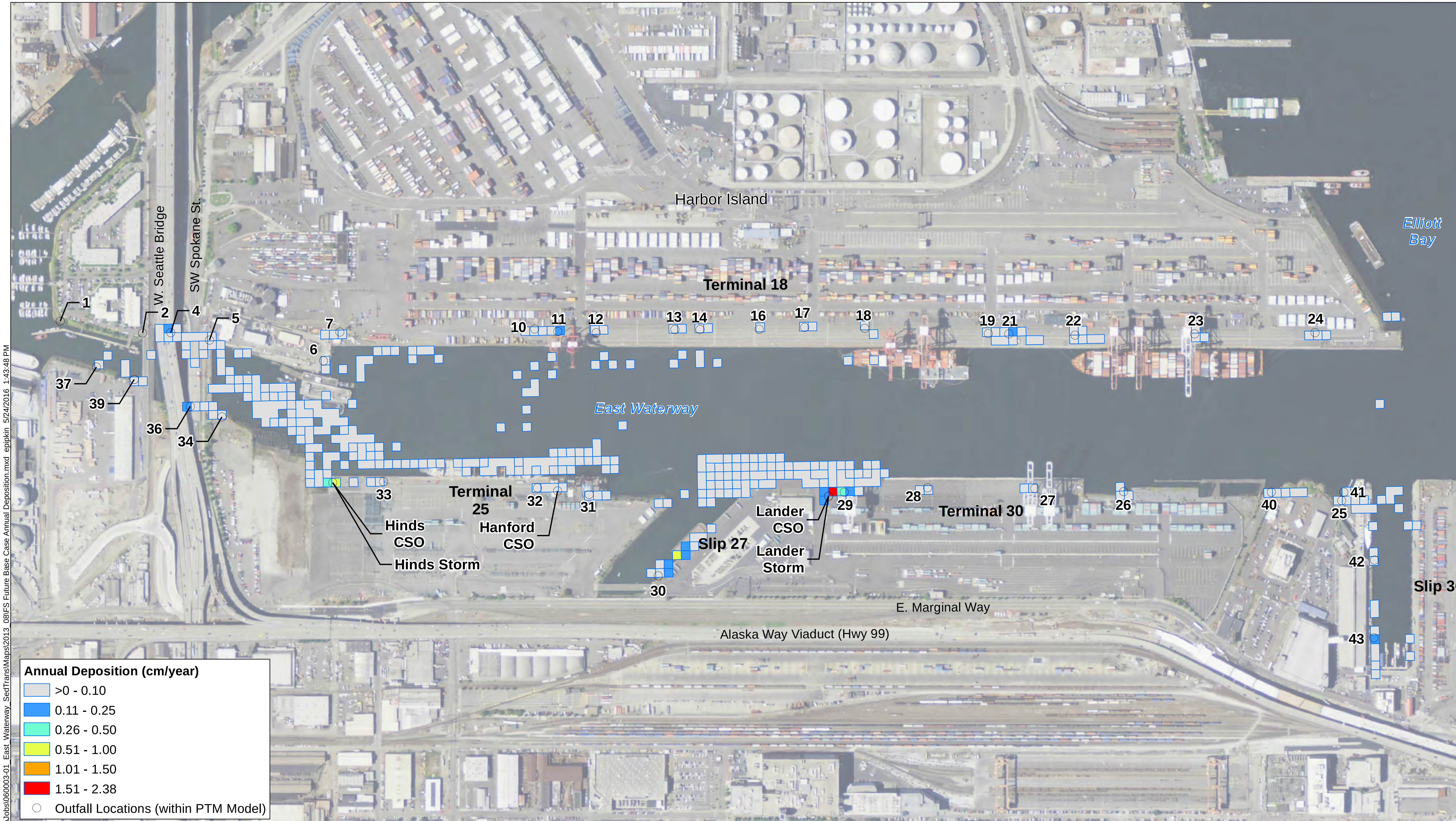
NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Raster cell size is 50' x 50'.
3. Aerial photo is NAIP, 2011.

0 250 500 750 1,000

Scale in Feet

Figure 11
PTM Model Simulation Current Conditions High Bounding Case - Annual Initial Deposition (cm/year)
Feasibility Study - Appendix B, Part 1
East Waterway Study Area



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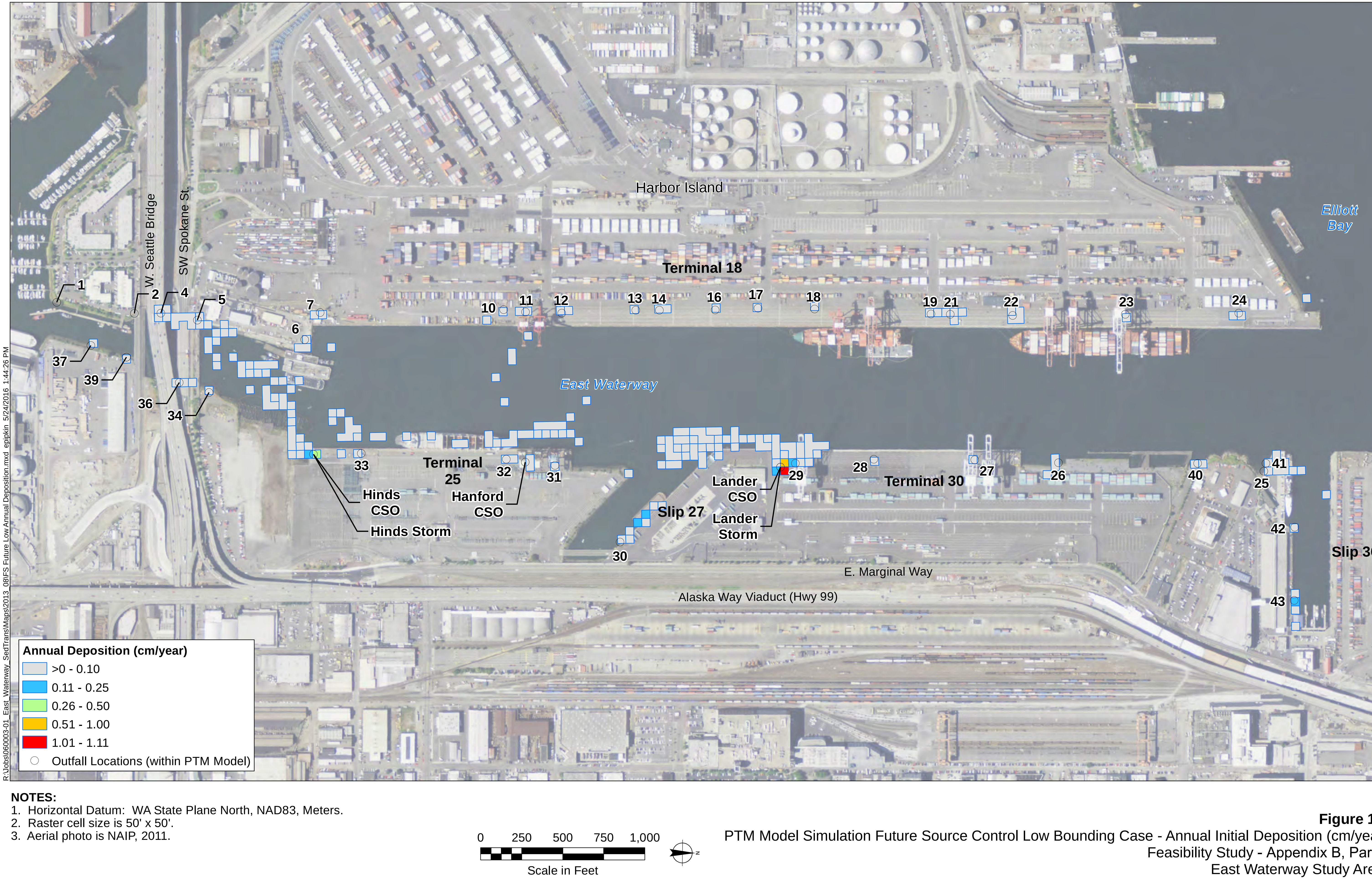
NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Raster cell size is 50' x 50'.
3. Aerial photo is NAIP, 2011.

0 250 500 750 1,000
Scale in Feet

Figure 12
PTM Model Simulation Future Source Control Base Case - Annual Initial Deposition (cm/year)
Feasibility Study - Appendix B, Part 1
East Waterway Study Area



NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Raster cell size is 50' x 50'.
3. Aerial photo is NAIP, 2011.

Figure 13
PTM Model Simulation Future Source Control Low Bounding Case - Annual Initial Deposition (cm/year)
Feasibility Study - Appendix B, Part 1
East Waterway Study Area

NOTES:
1. Horizontal Datum: WA State Plane North, NAD83, Meters.
2. Raster cell size is 50' x 50'.
3. Aerial photo is NAIP, 2011.

0 250 500 750 1,000
Scale in Feet

Figure 14
PTM Model Simulation Future Source Control High Bounding Case - Annual Initial Deposition (cm/year)
Feasibility Study - Appendix B, Part 1
East Waterway Study Area

ATTACHMENT 1

King County
Department of Natural Resources and Parks
Wastewater Treatment Division
King Street Center, KSC-NR-0500
201 South Jackson Street
Seattle, WA 98104-3855

MEMO

Date: May 20, 2013

TO: Jeff Stern-Sediment Management Program Manager, Wastewater Treatment Div, DNRP
Debra Williston, Toxicology and Contaminant Assessment Grp, Water and Land Resources Div, DNRP

Cc: Kathy Ketteridge, Anchor QEA

FM: Bruce Nairn, Modeling and GIS, Wastewater Treatment Div, DNRP

RE: **Methodology to determine grain size following CSO treatment for use in East Waterway Feasibility Study modeling**.

This Memo describes the approach used to estimate the grain size distributions from combined sewer overflow (CSO) discharges following CSO treatment for Hanford #2 and Lander CSOs that discharge to East Waterway (EW). The grain size distributions are applied to the size distributions used for the Particle Tracking Model (PTM) used in the EW Feasibility Study.

For the purposes of the EW Feasibility Study, the particulate size of solids in the CSO discharge is represented by a fixed number of size classes described by a characteristic settling velocity. The sediment represented by each settling velocity is termed a sediment class. Distributions of particles in untreated CSO discharges were estimated based on past sampling of CSO effluent in several King County studies. The data were collected from four County CSO systems, and distributions were determined as a cumulative percentage of the total mass of solids (Battelle 2006). The PTM grain size distributions used for the current CSO conditions (i.e., no treatment) were presented and discussed in the EW Sediment Transport Evaluation Report (Anchor QEA and Coast & Harbor Engineering 2012).

Preliminary screening of potential CSO treatment technologies suggests that the most likely type of treatment technology is a variation of a sedimentation process. These technologies range from primary sedimentation to high-rate sedimentation. For this modeling assessment, three levels of treatment effectiveness were assumed: 50%, 70%, and 90% total suspended solids (TSS) removal. Grain size distribution following CSO treatment was estimated by applying the specified removal efficiency with the characteristics of an ideal settling process to the untreated CSO grain size distribution.

To simulate removal efficiencies of the treatment technology, an idealized plug-flow reactor was assumed. In an idealized plug-flow reactor, water enters a tank and flows through it without mixing. Particles are evenly distributed in the flow as they enter the tank and those that reach the bottom before exiting are captured. The design parameter for a plug-flow reactor is the surface overflow rate (v_o). If a particle's settling velocity (w_s) is greater than the overflow rate, all particles are removed. Otherwise the removal rate is proportional to the settling velocity:

$w_s > v_o$: capture = 100 %
$w_s < v_o$: capture = $100*(w_s / v_o)$ %

The approach was to determine the surface overflow rate that resulted in 50%, 70%, or 90% TSS removal for the CSO settling velocity distribution. This resulted in the relative fraction of particulate mass in each size class as shown in Table 1. This particulate fraction is applied to the average CSO TSS concentration, so removal of particulates by CSO treatment results in a total fraction less than 100 percent.

Table 1. Settling Velocity Distributions by Cumulative Mass Percentage for Three CSO Treatment Efficiencies

		Fraction in Range (%)			
Sediment Class	**Settling Velocity (m/s)**	**No removal**	**50% removal**	**70% removal**	**90% removal**
3	$1.18x10^{-1}$	0	-	-	-
2	$8.9x10^{-3}$	17.0	-	-	-
1B	$2.4x10^{-4}$	41.0	10.0	-	-
1A	$1.5x10^{-5}$	42.0	40.0	30.0	10.0
	Total	**100.0**	**50.0**	**30.0**	**10.0**

No processes such as particle flocculation or disaggregation that could modify the particle settling velocity were assumed. An investigation into particle flocculation during the discharge of untreated CSO effluent into marine waters found that the particle flocculation models considered did not predict flocculation to occur (Battelle, 2006). Flocculation occurs within many treatment processes which has the potential to increase the settling velocity of the particles in the discharged effluent. As no information is available on how treatment processes might alter the settling velocity of particles in the discharged effluent, the particle settling velocities were assumed to be unaffected by the treatment process.

How well the actual treatment process will approach the theoretical removal efficiencies is currently unknown. King County did pilot a high rate sedimentation process (King County, 2010) in which total removal rates and particle size distributions were measured. Removal rates of 75% - 100% were observed over a range of operating conditions. The pilot study did not measure settling velocity or particle density, making it impossible to relate measured particle sizes into sediment classes. Particles in sewage and CSOs are primarily organic with specific gravities much lower than sand or clay. Thus using the specific gravity of sand/clay and the particle diameters to estimate settling velocity significantly overestimates the actual settling velocity.

To model size distributions in the EW Feasibility Study, a base assumption of 70% TSS removal is recommended. King County's CSO Control Plan (2012) proposes high rate clarification to treat CSO discharges at Hanford and Lander CSOs. This type of technology should be able to obtain more than seventy percent TSS removal, making this a conservative estimate. The uncertainty in the treatment process removal rates, in addition to uncertainty in the composition of the untreated CSO particles was included in the sediment classes for the upper and lower bounding runs (Table 2). The lower bound corresponds to 90% TSS removal, while the upper bound corresponds to 50% TSS removal with a shift to more large particles released. This shift is intended to capture variations in CSO particle distributions as well as incomplete removal in the treatment process.

Table 2. Settling Velocity Distributions for Upper and Lower Bounding Runs

		Fraction in Range (%)			
Sediment Class	**Settling Velocity (m/s)**	**No removal**	**Base Assumption[1]**	**Lower Bound[2]**	**Upper Bound[3]**
3	1.18×10^{-1}	0	-	-	-
2	8.9×10^{-3}	17.0	-	-	5.0
1B	2.4×10^{-4}	41.0	-	-	15.0
1A	1.5×10^{-5}	42.0	30.0	10.0	30.0
	Total	**100.0**	**30.0**	**10.0**	**50.0**

[1] Based on 70% removal efficiency of TSS.
[2] Based on 90% removal efficiency of TSS.
[3] Based on 50% removal efficiency of TSS.

<u>Citations</u>

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PART 2: SCOUR DEPTH ANALYSIS MEMORANDUM

Technical Memorandum

Port of Seattle, East Waterway Scour Analysis

1. Introduction

This technical memorandum summarizes the results of analysis conducted by Coast & Harbor Engineering (CHE) to estimate a scour depth due to propwash from vessels maneuvering in the East Waterway, Port of Seattle.

2. Methodology and Input Data

Propwash generated scour depth was computed using the modified analytical method of de Graauw and Pilarcyzk (1980) calibrated with historical bathymetric survey data in the East Waterway and data from Sedflume experiments (LDWG 2007[1], Anchor QEA and CHE 2012).

Analysis of the East Waterway historical bathymetry survey data has identified localized areas of bottom depressions that were assumed to be generated by propwash activities from various ships maneuvering in the waterway. Figure 1 shows identified depressions at Berths 1 and 2 on the northern end of Terminal 18 (T18). The bathymetric survey data in this area was used for calibration of site specific constants in the modified computation method developed by Graauw and Pilarcyzk, 1980 to account for site specific conditions within the EW. The calibrated methodology was then applied to compute potential scour depths within the East Waterway based on vessel operations identified in the EW Sediment Transport Evaluation Report (STER, Anchor QEA and Coast and Harbor Engineering, 2012).

Critical shear stress values for sediment samples taken from various locations within the East Waterway were measured as part of the sediment transport evaluation and are summarized in Section 6.1 of the STER. The critical shear stress values of eight cores from the East Waterway were depth averaged by CHE and are assumed to represent the sediment strength within each of the operational areas, which were cross-referenced with the locations of cores tested in the Sedflume experiments.

Bottom velocities and bed shear stress values, determined by a previous vessel hydrodynamic modeling study (see Section 5.2 and Appendix H of the STER, Anchor QEA and Coast and Harbor Engineering, 2012), were used as input into the scour model.

[1] Calibration was also based on the data presented in Appendix G of this report.

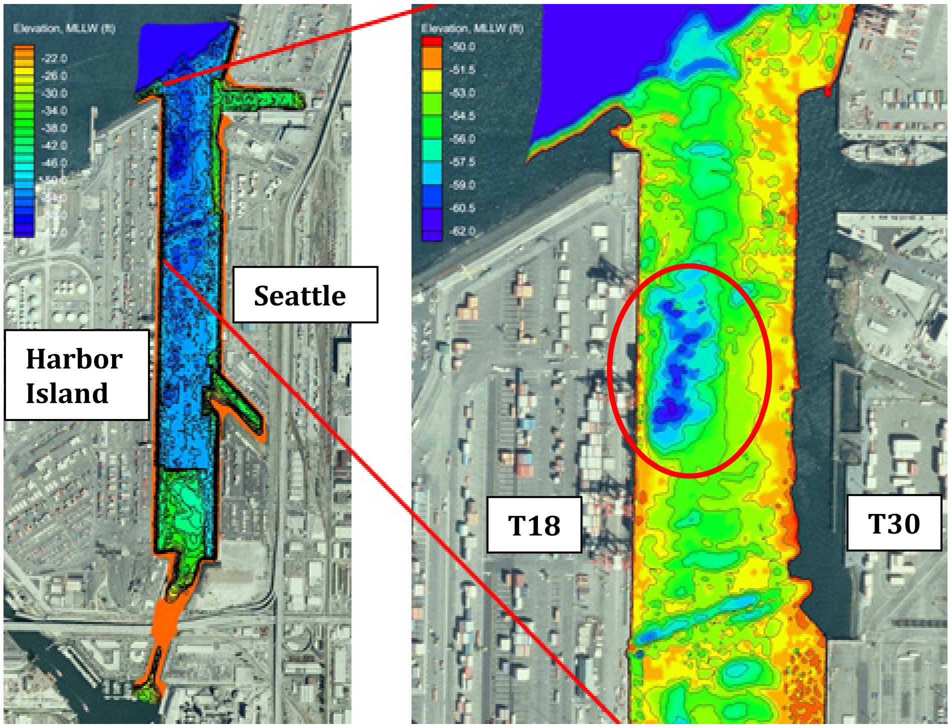

Figure 1. Bathymetric survey of East Waterway at Port of Seattle. Deep blue colors indicate deeper depths. Depressions at Berths 1 and 2 (circled in red).

Scour depth was calculated for each delineated operational area shown in Figure 2. The boundaries of the areas and corresponding maneuvering operations were coordinated by the Project Team, and are nearly the same as those from the previous CHE study (see Appendix H of the STER, Anchor QEA and Coast and Harbor Engineering, 2012).

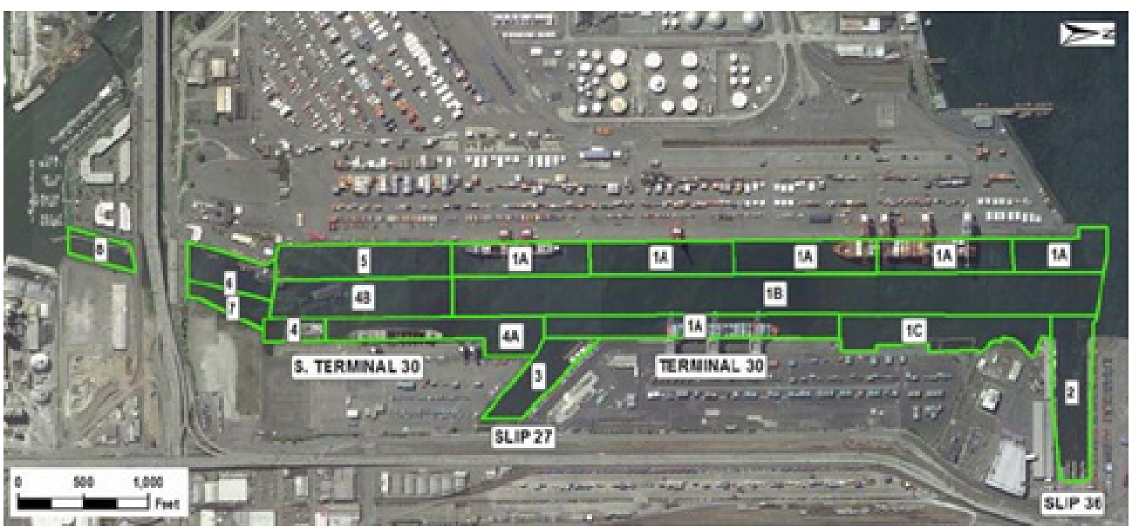

Figure 2. Delineated operational areas for scour prediction values

The largest ships represented by Xin Mei Zhou are assumed to dock only at the northern end of Terminal 18, which is in three of the delineated areas "1A." Depressions of deeper bathymetry are also located in this area. At all other 1A areas, the limiting ship is the smaller Margit Rickmers. These assumptions are consistent with vessel operations outlined in Section 5 of the Final Sediment Transport Evaluation Report (Anchor QEA and Coast and Harbor Engineering, 2012).

As ships pass over potential scour locations, the near bottom velocities due to propwash at a single point change over time. The assumed conservative estimate of sideways ship velocity within the East Waterway is 2 feet per second. Therefore, the JETWASH velocity at a single point changes over time and is sensitive to ship speed.

Because the scour scenarios were evaluated at several extreme (MLLW, thruster/prop power) and unique (exact berthing location) conditions, the probability of such conditions occurring together multiple times is very low (i.e., 10% * 10% * 10% = 0.1%). This technical memorandum determines scour from a single, conservative, and rare event.

3. Results

Based on this analysis, depth of scour in the East Waterway will range from 4.7 ft on the high end for container ships, to 0.3 ft on the low end for tugs in deep water. Because scour is extremely complicated, a range of scour depth values for each location was determined based on a range of values for empirical coefficients. Presented here are results based on applying the conservative value of that range.

Results of scour depth calculation for each operational area are shown in Figure 3 in color format. Please note that the color represents the maximum localized depth of scour that may occur inside the delineated area. It other words, the computed depth of scour presented here would occupy a much smaller area than that shown in the figure.

The results of computation demonstrate that the greatest depth of scour (4.7 ft) would occur at Berths 1 and 2 of Terminal 18 due to bow thrusters. The scoured areas shown in the figure in red (0.3 ft) and orange (0.7 ft) resulted from tugs. The tugs operate in deep water with shallower propeller draft, thus generating much less scour. Area 6 is an exception. In this location, tugs operate by docking barges in relatively shallow water (20 ft), which results in 2.9 ft of scour, much more than other tug cases.

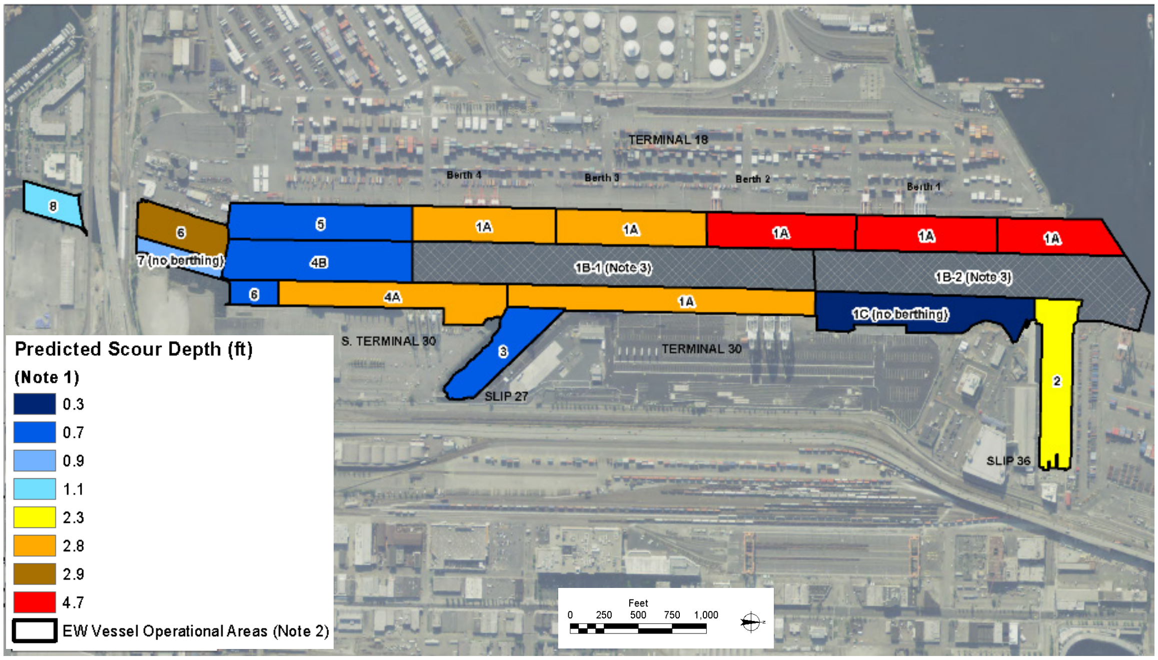

Figure 3. Predicted scour depths from vessel operations

Notes:

1. Calculations for scour depths provided in Attachment 4 of Appendix F.
2. EW Vessel Operational Areas developed as part of the EW STER (Anchor QEA and Coast and Harbor Engineering, 2012); see Section 5.1.2 of the STER.
3. Areas 1B-1 and 1B-2 represent the navigation area between Terminal 18 and 30 berthing areas. Since berthing maneuvers may begin within the navigation channel depending on weather or other site conditions, this area is expected to experience similar scour depths as the berthing areas.

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PART 3A: DREDGE RESIDUALS AND REPLACEMENT VALUE ESTIMATES

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1 INTRODUCTION

As described in Section 5.2 of the East Waterway (EW) Feasibility Study (FS), replacement values represent the estimated chemical concentrations in the top 10 centimeters (cm) of sediment following remediation. The replacement value only represents the initial (or Time 0) sediment condition in the top 10 cm following completion of remediation. The replacement values are influenced by the type of remediation performed (i.e., dredging, capping, in situ treatment, enhanced natural recovery [ENR], monitored natural recovery [MNR], or no action), pre-remediation conditions (e.g., concentrations prior to remediation), physical site conditions (e.g., sediment mixing during placement of residuals management cover [RMC]), and type of remediation performed in adjacent areas. This appendix describes the rationale for the estimate of replacement values for the human health risk-driver contaminants of concern (COCs; total polychlorinated biphenyls [PCBs], arsenic, carcinogenic polycyclic aromatic hydrocarbons [cPAHs], and dioxins/furans) to predict concentrations following construction and serve as inputs for model-predicted long-term concentrations for the purpose of comparing FS alternatives.

2 REMOVAL AREAS

All remedial alternatives use dredging (i.e., removal) as a primary remediation technology (FS Section 8). As described in Appendix B, Part 5, and FS Section 7.2.6.5, the generation of dredging residuals is inherent to the dredging process, due to the loss and redeposition of sediment during each dredging pass. All dredging projects result in some degree of resuspension, release, and residuals (NRC 2007). Generated dredging residuals are the sediment that is resuspended during dredging due to removal equipment limitations in preventing loss of particulate material during the action of dredging. The particulate material that settles is the generated residuals. Estimating the concentration and thickness in dredging residuals is important for estimating the concentrations in sediment that can be achieve following environmental dredging. Note that this appendix only calculates generated residuals and assumes the undisturbed residuals, or missed inventory, are addressed before the end of construction. In this appendix, the general term "residuals" is used to signify generated residuals only. The following section describes the estimate of generated dredging residuals concentration and thickness, and the resulting replacement values in dredging areas. Section 3 of this appendix describes replacement values for other technology areas.

2.1 Estimating Dredging Residuals

As described in FS Appendix B, Part 5, the nature and extent of residuals is dependent on the dredging equipment and methods, the sediment geotechnical characteristics, the magnitude and distribution of sediment contaminants, and the physical site conditions (e.g., erosional/depositional regime, and presence of rock, debris, and bedrock). Due to this complex interrelationship, there are no commonly used numerical methods or models to reliably predict post-dredging residual concentrations with a high level of accuracy. In the absence of predictive models, "bounding-level" estimates of the thickness and chemical composition of the post-dredging residual layer may be developed using standard mass balance equations and site-specific physical and chemical properties, as described in Patmont and Palermo (2007), and USACE (2008a, 2008b). Generally, bounding-level estimates of COC concentrations are calculated based on the average sediment concentration in the final production cut. If multiple dredge passes have occurred, the generated residuals from the previous passes are estimated and included in the profile of the final production cut, which is then used to estimate the final residual concentrations (Patmont and Palermo 2007; USACE 2008a). As such, these dredge residual estimates are intended to provide a general approximation of the range of *potential* residual thicknesses and concentrations that may be generated by remedial dredging of the EW.

The dredge residuals estimate developed for the EW FS for total PCBs, cPAHs, and arsenic uses the following approach (dioxins/furans are discussed in Section 2.1.6 herein):

1. Select the representative area of interest and the sediment cores for performing the analysis.
2. Estimate the dredge depth based on contamination thickness and number of dredge passes for each core location.
3. Estimate the dredge residuals thickness and concentration for each core location based on an estimated percent loss of dredge material during each dredge pass (the best estimate is 5% loss of dredged material, based on case studies).
4. Calculate the spatially-weighted average residuals thickness and concentration within the area of interest.
5. Revise the input parameters analysis for the purpose of sensitivity and bounding runs.

The following sections describe these steps.

2.1.1 Selection of Cores for Analysis

The representative area of interest for this analysis is the area exceeding the remedial action levels (RALs) for all COCs, including using 12 milligrams per kilogram (mg/kg) organic carbon (OC) for PCBs (FS Section 6). This representative area of interest encompasses 121 of 156 acres of the waterway, and is the remediation footprint for the majority of alternatives developed in the FS. Sediment cores in the FS baseline dataset within this area that have not been dredged since samples have been collected were included in the analysis.

All sediment cores within the representative area of interest were used as a single set of cores, which was considered representative of all alternatives for this analysis because all FS alternatives rely primarily on dredging (from 68 acres 139 acres of removal depending on the alternative; FS Section 8). Moreover, an exploratory analysis found that restricting the analysis to cores within each alternative's specific removal area only made a minor difference on the residuals concentration and thickness estimate, due to steep horizontal and vertical concentration gradients in the EW. The exploratory analysis found that the differences in residuals concentrations and thicknesses between alternatives was less than the range in the sensitivity evaluation (Section 2.1.5). Therefore, the sensitivity analysis encompasses the potential range in residuals concentrations and thicknesses for all the alternatives, and a single set of cores is appropriate for all alternatives.

2.1.2 Dredging Methodology Assumptions

As described in FS Appendix F, the dredge prism is designed to remove sediments exceeding RALs. To estimate the thickness and concentration of post-dredging residuals, the contaminated sediment neatline surface was used to estimate the depth of contamination and thus the estimated dredge cut thickness and the number of potential dredge passes at each core location, assuming 1 foot of overdredge (FS Appendix F develops the contaminated neatline surface). The final required dredge elevations and the overdredge allowance will be specified in design.

Dredging assumptions used in the residuals calculations are the following:

- The maximum lift of contaminated sediment removed in any individual dredging pass will be 4 feet.
- The first pass cut for the removal of contaminated sediment was estimated to be from mudline to the base of the contaminated neatline surface plus 1 foot of overdredge, but not greater than 4 feet.
- The second pass for the removal of contaminated sediment, if necessary, was estimated to be from the base of the first dredge cut (4 feet) to the base of the contaminated neatline surface plus 1 foot of overdredge. This cut consists of the residual layer generated during the first pass, additional contaminated sediment targeted for removal, and overdredge material (less than the RAL).
- Additional passes for the removal of contaminated sediment, if necessary, follow the same methodology described for the second dredge pass.
- The ultimate residuals layer thickness for each location was estimated based on the thickness of sediment being removed in the last dredge pass and the assumed percent

material lost as generated residuals. Because the thickness of the residual layer is based on the percent of material lost in the final dredging pass, areas with more sediment removal in the last dredge pass are predicted to have a thicker residuals layer.

2.1.3 Estimating the Residual Layer Thickness and Concentration

Figure 1 provides a graphical description of the approach for calculating the estimated concentration of COCs in the generated residuals. The residuals calculations for the EW were estimated using the vertically-weighted average concentration of sample intervals within each dredge cut. Sediment core intervals that were not analyzed were assumed to have the contaminant concentration of the sediment core interval analyzed immediately above. In addition, cores that did not extend down to the full dredging depth (i.e., cores that did not reach the base of contamination because they exceed RALs in the deepest sample interval analyzed) were assumed to have the concentration of the sediment core interval analyzed immediately above all the way down to the contaminated neatline surface. Below the contaminated neatline surface (i.e., within the overdredge interval), sediment does not exceed RALs, and cores without concentration data were assumed to equal have the site-wide average concentration in sediment below the neatline surface.

In the areas that were assumed to require only a single dredging pass, the estimated residual concentration is equal to the depth-weighted average of the sediment in the first full dredge cut. In the areas that were assumed to require two or more dredging passes, the influence of generated residuals from the first pass was considered in the depth-weighting averaging of the second and final residuals concentrations. Ultimately, a single residual layer of estimated thickness (based on dredge depth, number of dredge passes, and assumed residuals generation rates) with unique concentrations for each COC was determined at each core location.

For a single-pass dredging location, the residuals thickness is estimated as follows:

$$Tr_1 = L_U Td_1$$

For a dredging location with two or more dredge passes, the residuals thickness is calculated for each dredge cut in series, considering the residuals from the previous dredge cut as follows:

$$Tr_n = L_U Td_n + L_R L_U Td_{(n-1)}$$

where:

Tr_1	=	thickness of the residual layer after first dredge pass
Tr_n	=	thickness of the residual layer after the n^{th} dredge pass
L_U	=	percent loss of undredged native material (best estimate = 5%)
L_R	=	percent loss of redredged residuals material (50%)
Td_1	=	thickness of first dredge pass
Td_n	=	thickness of the n^{th} dredge pass

The final residuals thickness is the thickness following the last dredge pass in a location. As discussed in Section 2.2 of this appendix, case studies indicate that an average of 5% of the contaminant mass in a dredge cut will be lost and will resettle as a post-dredge residual layer. Case studies also show the diminishing returns of redredging deposited residuals; therefore, redredging is expected to result in more loss of the deposited residuals from previous dredge cuts at that location. This is primarily due to the unconsolidated nature of the dredge residuals layer, which make it more prone to loss during the dredging process. For this project, a loss rate of 50% of the redredged residuals layer is modeled.

Contingency redredging of dredge residuals (after completion of production dredging) could affect site-wide post-dredging surface sediment concentrations. However, redredging is not included in the calculations of post-dredge residuals concentration and thickness for the remedial alternatives. FS Appendix B, Part 5, describes the range of dredging residuals management approaches, including redredging, that could be developed during design and construction to manage dredge residuals and ultimately affect site-wide post-construction concentrations. In general, redredging for residual management will remove additional contaminant mass, but is ineffective at reducing surface sediment concentrations (Patmont and Palermo 2007). Other methods, such as placement of RMC, have been shown to be more effective at reducing site-wide concentrations than additional redredge passes after completion of production dredging (e.g., Esquimalt Graving Dock Remediation project [British Columbia; Berlin et al. 2017], Lower Fox River [Wisconsin], Hudson River Phase 2 [New York], and others [Patmont et al., 2017; Bridges et al., 2010]).

2.1.4 Calculating Site-wide Average Thickness and Concentration of the Residuals Layer

After the residuals concentration and thickness were calculated using the data associated with each core, the site-wide average was calculated by assigning each core to an area based on a Thiessen polygon network generated from the core locations. The area of each Thiessen polygon was used to weight each core by the relative area that the core represents to generate a spatially-weighted average for both residuals concentration and thickness.

2.1.5 Residuals Values for Sensitivity Analysis

Residuals thickness and concentration inputs were varied as part of the box model sensitivity analysis for total PCBs (FS Appendix J). Residuals thickness was varied based on the case studies presented in FS Appendix B, Part 5. The low bound sensitivity analysis was calculated assuming 3% loss of dredge material during first pass dredging. The high bound sensitivity analysis was calculated assuming 7% loss of dredge material during first pass dredging based on Patmont and Palermo (2007).

Residuals concentration was varied based on analyzing the results of the core-by-core dredge residual analysis. The low value was estimated by selecting the median concentration of cores. The high value was estimated to be the 95% upper confidence limit on the mean (UCL95) (gamma distribution) of cores.

2.1.6 Residuals Estimate for Dioxins/Furans

Dioxins/furans were analyzed in a subset of cores in the FS dataset, and thus there was not sufficient data to perform the analysis described above, which considers dredge depths, multiple dredge passes, and area-weighted averaging. As a simplified analysis, all dioxin/furan core interval samples within the area of interest were averaged. One core location, EW10-SC23, was excluded from the analysis because the core is located at the head of Slip 27 in an area that will be capped (without any dredging). The resulting average concentration for all remaining cores is 17 nanograms toxic equivalent per kilogram (ng TEQ/kg) dry weight (dw) and this value is used for the concentration of dioxins/furans in residuals.

2.2 Estimating the Replacement Value in Removal Areas

FS Appendix B, Part 5 compares a number of dredging residuals management approaches that could be developed during design and construction to manage dredge residuals. For purposes of FS alternative detailed and comparative analysis, all FS alternatives are assumed to use the same residuals management approach: a RMC layer. RMC is a thin layer (e.g., 9 inch average thickness, to be confirmed during design) of clean quarry sand designed to reduce concentrations in the biologically active zone (BAZ) following dredging. Although sand is expected to have concentrations similar to natural background, some degree of resuspension and redeposition of residuals is expected during placement because of the less consolidated nature of dredge residuals. It is estimated that 10% of the residuals layer would resuspend and redeposit on the RMC sand layer. The resulting vertically weighted average concentration in the BAZ (upper 10 cm) in sediment following placement (i.e., the "replacement value") is calculated from the following equation:

$$C_{BR} = (L_S Tr_f Cr_f + (T_{BR} - L_S Tr_f)C_{SC})/T_{BR}$$

where:

C_{BR}	=	concentration in the biologically active zone (the bed replacement value; calculated; presented in Table 1)
C_{SC}	=	concentration in residuals management cover (sediment cover; PCBs = 2 µg/kg dw, cPAHs = 9 µg TEQ/kg dw, dioxins/furans = 2 ng TEQ/kg dw, arsenic = 4 mg/kg dw)
Cr_f	=	concentration of residuals after the final dredge pass (presented in Table 1 based on the calculation described in Section 2.1)
T_{BR}	=	thickness of the biologically active zone (thickness of the bed replacement layer = 10 cm)
Tr_f	=	thickness of the residual layer after the final dredge pass (5.1 cm for the best estimate)
L_S	=	percent of residuals resuspension and redeposition during residuals management cover placement (10% of the residuals thickness layer [Tr_f])

2.3 Estimating the Replacement Value Adjacent to Removal Areas

ENR-nav, ENR-sill, and the interior unremediated islands are all remediation areas that incorporate thin layer placement of sand (as described in FS Section 5.2, unremediated interior islands are assumed to have RMC placement, but the need for such placement will be determined during design and based on post-dredge sampling). These areas do not include removal; however, removal in adjacent areas is assumed to influence these areas from generated residuals from nearby dredging operations. For this analysis, thickness of dredging residuals is estimated to be 1/5 of the thickness of dredging residuals within the removal footprint.

2.4 Results

The results for the residuals analysis and replacement value calculation are presented in Table 1.

Table 1
Replacement Values and Residuals in Removal and Adjacent Areas

Parameter		Best Estimate	Low Sensitivity	High Sensitivity
Removal Areas				
Replacement Value for removal areas (Post-construction Concentration)	Total PCBs (µg/kg dw)	35	17	72
	cPAHs (µg TEQ/kg dw)	34	nc	nc
	Arsenic (mg/kg dw)	4.3	nc	nc
	Dioxins/furans (ng TEQ/kg dw)	2.8	nc	nc
Dredge Residuals Thickness in Dredged Areas (cm)		5.1	3.1	7.2
Dredge Residuals Concentration	Total PCBs (µg/kg dw)	640	470	980
	cPAHs (µg TEQ/kg dw)	490	nc	nc
	Arsenic (mg/kg dw)	10	nc	nc
	Dioxins/furans (ng TEQ/kg dw)	17	nc	nc

Areas Adjacent to Removal Areas (ENR-nav, ENR-sill, and Interior Unremediated Islands)				
Replacement Value (Post-construction Concentration)	Total PCBs (µg/kg dw)	8.4	5.8	11
	cPAHs (µg TEQ/kg dw)	14	nc	nc
	Arsenic (mg/kg dw)	4.1	nc	nc
	Dioxins/furans (ng TEQ/kg dw)	2.2	nc	nc
Dredge Residuals Thickness in Areas Adjacent to Dredged Areas (cm)		1.0	0.6	1.4
Dredge Residuals Concentration		Same as above		

Notes:
µg/kg – microgram per kilogram
cm – centimeter
cPAH – carcinogenic polycyclic aromatic hydrocarbon
dw – dry weight
FS – Feasibility Study
mg/kg – milligram per kilogram
nc – not calculated
ng – nanogram
PCB – polychlorinated biphenyl
TEQ – toxic equivalent

3 ALL REMEDIAL TECHNOLOGY AREAS

Table 2 presents the replacement values and rationale for all remedial technology areas for the alternatives. FS Appendix J, Table 2, presents the replacement values for all remedial technology area for all alternatives (including the alternative-specific inputs not included in Table 2 below).

Table 2
Replacement Values for Technology Areas

Technology Area	Total PCBs (µg/kg dw)	cPAHs (µg TEQ/kg dw)	Dioxins/ Furans (ng TEQ/kg dw)	Arsenic (mg/kg dw)	Rationale
Open-water Areas					
Removal	35	34	2.8	4.3	See Section 2 herein. Assume that RMC is placed following dredging.
Partial Removal and Capping	2	9	2	4	Estimated concentration in quarry sand.
Partial Removal and ENR-nav	35	34	2.8	4.3	Values assumed to be consistent with dredging.
ENR-nav, ENR-sill and Interior Unremediated Islands	8.4	14	2.2	4.1	Some influence from adjacent removal areas
Exterior Unremediated Islands	Post-construction SWAC assumed to be equal to baseline (pre-remediation) SWAC (alternative-specific).				No remediation; assume negligible influence from adjacent areas.
Underpier					
MNR	Post-construction SWAC assumed to be equal to baseline (pre-remediation) SWAC (alternative-specific)				No remediation; see Section 3 herein.
In situ Treatment	Pre-remediation SWAC reduced by 70% of original (FS Section 7.2.7.1). Alternative-specific.			Volume-weighted average dry weight-based concentration of baseline sediment plus 3 inches placement material (alternative-specific).	Underpier modeling was performed using a volume-based approach for the volume of sediment above riprap.

Technology Area	Total PCBs (µg/kg dw)	cPAHs (µg TEQ/kg dw)	Dioxins/ Furans (ng TEQ/kg dw)	Arsenic (mg/kg dw)	Rationale
Dredging Followed by In situ Treatment	Pre-remediation SWAC reduced by 70% of original (FS Section 7.2.7.1). Alternative-specific.			Volume-weighted average dry weight-based concentration of baseline sediment plus placement material (alternative-specific).	Underpier modeling was performed using a volume-based approach for the volume of sediment above riprap. Ten-centimeter depth of sediment is assumed to remain following dredging.

Notes:
See FS Appendix J, Table 2, for alternative-specific replacement values for all alternatives.
See FS Appendix J, Section 2.3, for mixing assumptions used in modeling.
µg/kg – microgram per kilogram
cm – centimeter
cPAH – carcinogenic polycyclic aromatic hydrocarbon
dw – dry weight
ENR – enhanced natural recovery
FS – Feasibility Study
mg/kg – milligram per kilogram
MNR – monitored natural recovery
ng/kg – nanogram per kilogram
PCB – polychlorinated biphenyl
RMC – residuals management cover
SWAC – spatially-weighted average concentration
TEQ – toxic equivalent

Partial dredging and capping areas are assumed to have the post-construction concentration equal to the estimated concentration in quarry material placed in these areas for capping purposes. Because of the thickness of placed capping material, dredge residuals are not anticipated to have large impact on the post-construction concentration. In addition, caps are assumed to be constructed after dredging of adjacent areas has been completed, minimizing the influence of resuspended sediment from dredging operations occurring elsewhere in the EW after cap placement. For organic compounds (total PCBs, cPAHS, and dioxins/furans), due to lack of detected concentration data in quarry material, replacement values are based on natural background. For arsenic, the concentration of 4 mg/kg dw was estimated based on the average of 22 samples provided by quarry sources from recent in-water placement projects, which ranged from 1 mg/kg dw to 7 mg/kg dw in concentration.

Partial dredging and ENR-nav areas are assumed to have the same replacement value as dredging areas because dredging followed by ENR-nav sand placement follows a similar process as full dredging followed by RMC placement.

The replacement value estimates for ENR-nav, ENR-sill, and the interior unremediated islands are based on the influence associated with extensive removal in adjacent areas, as described in Section 2.3. These areas are assumed to have a thin layer of dredging residuals (1 cm for the best estimate) followed by sand placement. The replacement values include the influence or resuspended dredge residuals and the concentration in sand cover.

Exterior unremediated islands are only adjacent to dredging operations on one side, as opposed to interior unremediated islands that are surrounded by dredging operations on all sides. Therefore, exterior unremediated islands are assumed to be negligibly influenced by dredge residuals from adjacent areas, and therefore are assumed to not require RMC placement. Consequently, the areas are assumed to have the concentrations equivalent to pre-construction conditions.

Underpier modeling was performed using a volume-based approach for the volume of sediment above riprap (see FS Appendix J, Section 2.3.5). The volume-based approach was developed to accommodate the modeling of exchange of sediments between open-water areas and underpier areas. The average thickness of sediment deposited on underpier riprap is 2.3 feet (see FS Section 8.1.1.6 and Appendix F for additional detail), generally consistent with the box-model mixing depth in areas adjacent to underpier areas.

Underpier MNR areas are assumed to be minimally influenced by dredge residuals from adjacent areas because pre-construction sediment concentrations in underpier areas are similar to predicted concentrations in residuals and because adjacent dredging occurs only along one edge of the underpier areas.

Underpier in situ treatment areas are assumed to have a reduction of 70% from pre-construction concentrations for hydrophobic organic compounds (total PCBs, cPAHs, and dioxins/furans) based on pilot studies, bench studies, and guidance considering the potential for burial, mixing, and loss of AC material from propwash forces (FS Section 7.2.7.1). For arsenic, replacement value concentrations are based on the volume-weighted average dry weight-based concentration of baseline sediment plus 3 inches of in situ treatment placement material.

Underpier hydraulic dredging areas are assumed to result in 10 cm of residuals left behind that have concentrations equivalent to pre-dredging volume-weighted concentrations. When in situ treatment follows hydraulic dredging, the post-construction concentrations are calculated consistent with in situ treatment described above (but with the reduction in initial volume).

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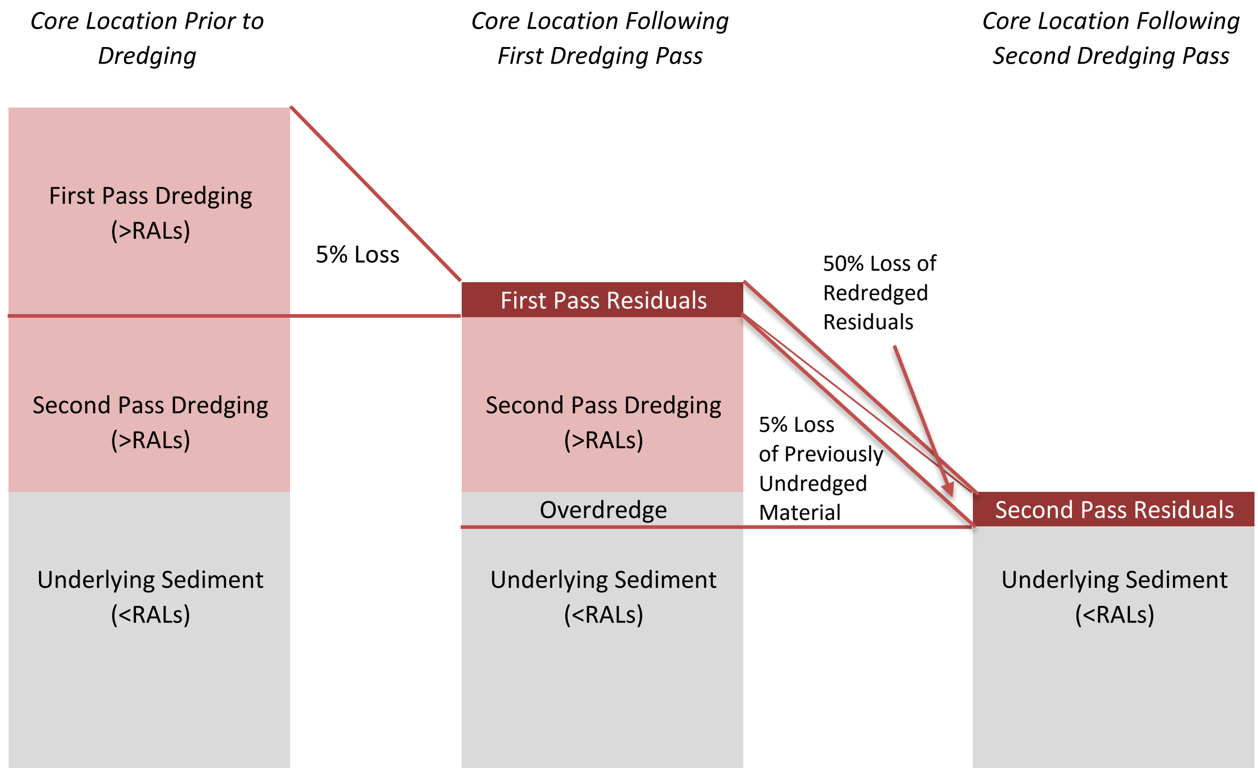
FIGURE



Notes and Assumptions

1. The residuals analysis was performed at each core located within the RAL footprint (using 12 mg/kg OC for PCBs; FS Section 6).
2. The number of dredge passes at each core location was based on a 4-foot maximum dredge cut (e.g., cores with dredge depths from 4 to 8 feet required two dredge passes).
3. The concentration in residuals resulting from the first dredge pass was equal to the vertical weighted average concentration in the core sample intervals that overlap with the first pass dredge interval.
4. The thickness of residuals resulting from the first dredge pass was based on 5% loss of dredged material.
5. The concentration in residuals resulting from subsequent dredge passes (i.e., two or more dredge passes) was equal to the vertical weighted average concentration in the core sample intervals that overlap with the dredge interval, averaged with residuals from the first dredge pass. The dredge interval material and the first pass residuals were weighted appropriately based on the starting thickness and
6. The thickness of residuals resulting from subsequent dredge passes (i.e., two or more dredge passes) was based on 5% loss of previously undredged material plus 50% loss of redredged residuals. The loss of redredged residuals was based on empirical evidence from other projects of diminishing returns from redredging.
7. The last dredge cut included an additional 1 foot of overdredge based on a typical construction tolerance.
8. The average sediment PCBs concentration in underlying sediment below the contaminated neatline surface was 15 µg/kg dw.
9. The area-wide average residuals concentration and thickness were calculated based on the concentration and thickness in each core following the last dredge pass, then area-weighted averaged based on Theissen polygon areas.

µg/kg – microgram per kilogram
dw – dry weight
FS – Feasibility Study
mg/kg – milligram per kilogram
OC – organic carbon
PCB – polychlorinated biphenyl
RAL – remedial action level

Figure 1

Example Diagram Showing Residuals Calculation for Location with Two Dredge Passes

PART 3B: GREEN RIVER INPUTS

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1 INTRODUCTION

Contaminant concentrations associated with Green River solids were compiled from various data sources from the Lower Duwamish Waterway (LDW) Feasibility Study (FS) (AECOM 2012). These data provide multiple lines of evidence that characterize the contaminant concentrations associated with sediments entering the LDW from the Green River, which can also be used to estimate the Green River concentrations entering the East Waterway (EW). A detailed description and detailed evaluation is presented in the LDW FS (AECOM 2012; Section 5.2.3.1 and Appendix C, Part 3), which was the result of an extensive data screening and evaluation process in consultation with EPA. Estimates for concentrations of sediments entering the EW rely on much of the analysis performed for the LDW, and are therefore referenced where appropriate.

Arsenic, total PCB (polychlorinated biphenyl), dioxin and furans (dioxin/furans), and carcinogenic polycyclic aromatic hydrocarbons (cPAHs) upstream values were presented in the LDW FS (AECOM 2012; Tables 5-2a through 5-2d). Upstream data presented in the LDW FS baseline dataset (AECOM 2012) were further evaluated specifically for use in the EW for arsenic, total PCBs[1], dioxin/furans, and cPAHs (human health risk driver contaminants of concern [COCs]) for evaluation of the remedial action objectives (RAOs) 1 and 2 (human health resident seafood consumption and direct contact pathways, respectively) and recontamination potential. Five additional benthic invertebrate risk driver COCs—bis(2-ethylhexyl)phthalate (BEHP), low-molecular-weight polycyclic aromatic hydrocarbon (LPAH), high-molecular-weight polycyclic aromatic hydrocarbon (HPAH), mercury, and 1,4-dichlorobenzene—were also evaluated for RAO 3 (protection of benthic community) and recontamination potential. Data from the various upstream datasets were used to develop a range of values for the EW (Table 1).

[1] Total PCBs is also a risk driver COC for fish receptors of concern English sole and brown rockfish (RAO 4).

2 SUMMARY OF THE DATA SOURCES

As described in the LDW FS (AECOM 2012), the upstream data sources included the following:

- **Upstream whole water samples collected by King County.** Concentrations associated with suspended solids in the Green/Duwamish River inflow, based on upstream water quality monitoring data collected by King County from 2001 through 2008 (AECOM 2012; LDW FS baseline database).
- **Upstream centrifuged suspended solids samples collected by the Washington State Department of Ecology (Ecology).** Data from centrifuged solids samples collected in the Duwamish River upstream of the LDW by Ecology in 2008 and 2009 (Ecology 2009, as presented in the LDW FS baseline database).
- **Upstream surface sediment samples (containing fines greater than 30%) collected by Ecology.** Surface sediment samples collected in 2008 between river mile (RM) 4.9 and RM 6.5 by Ecology (AECOM 2012; LDW FS baseline database).
- **LDW RM 4.3 to 4.75 U.S. Army Corps of Engineers (USACE) core data.** USACE dredged material characterization core data collected from the upper reach of the LDW between RM 4.3 and RM 4.75 from 1990 through 2009 (USACE 2009a, 2009b, as presented in the LDW FS baseline database).

Each of these datasets is briefly summarized below. A detailed description and evaluation is presented in the LDW FS Section 5.2.3.1 and Appendix C, Part 3.

King County whole water samples were collected from two sampling locations that were located approximately 1.3 miles (Duwamish River at Marginal Way; RM 6.3) and 5.9 miles (Green River at Fort Dent; RM 10.9) upstream of the LDW. These samples were collected as part of King County's routine monthly stream sampling and as part of targeted wet weather event sampling. The upstream King County whole water concentrations were normalized to the value of the concurrently collected total suspended solids (TSS), so that the concentration units were comparable with the sediment concentration units (i.e., both on a dry weight basis)[2].

Centrifuged solids data were collected by Ecology (Ecology 2009), upstream of the LDW at RM 6.7. Samples of suspended material were collected during seven sampling events at this location during varying flow conditions and during one storm event. These Ecology samples are generally representative of sediments suspended mid-channel in the Green River that could settle in both LDW and EW.

A subset of the Ecology upstream surface sediment data was developed by excluding samples that contained less than 30% fines. This approach acknowledges the systematic differences in grain size distributions between upstream sediment data and average sediment conditions in the LDW and EW. This dataset represents sediments just upstream of the LDW that can be resuspended under high-flow conditions, transported, and redeposited downstream.

The subsurface sediment cores collected by USACE from RM 4.3 to 4.75 represent sediment from the Green River that settles in the upper reach of the LDW, since the upper reach functions as a sediment trap for approximately one-third of the upstream sediment. Because dredging is conducted every 2 to 4 years from RM 4.0 to 4.75, this area is a good indicator of recent suspended solids from the Green River (AECOM 2012). However, the majority of the solids that settle in this area are coarser grain material than sediment typically found farther downstream in the rest of the LDW and the EW.

Since the development of the Green River datasets used for the LDW FS, new data have been collected on the Green River, including the four human health risk driver contaminants (King County 2016; USGS 2016). No additional modeling that would include these new data has been undertaken, for several reasons:

- The U.S. Geological Survey is still reviewing and processing their data, and will present their estimates of upstream concentrations.

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

- Based on a review of the preliminary USGS data and King County data, these data are within the range of values previously used in the modeling, and therefore incorporating these data would not change the concentration range presented in the sensitivity and bounding analysis in Section 2.3 of FS Appendix J.
- Any minor changes in results from incorporating these data into an additional modeling effort would have an equal bearing on all alternatives, and therefore would not affect the conclusions of the EW FS.

A summary of the preliminary data, and a comparison of these data with original FS box model inputs, is provided in Table 3.

3 CHEMICAL CONCENTRATIONS

The selected upstream solids values were based on these four datasets to represent the best estimate concentrations of the four human health risk driver COCs and five additional benthic risk driver COCs entering the EW. These datasets are considered reasonable lines of evidence for developing incoming concentrations to the EW from the Green River, although each type of data collection tends to bias the results toward lower or higher values (e.g., low percent fines versus high percent fines; single collection events versus seasonal collection events; and the potential influence of sources). In general, the value representing a mid-range of the various lines of evidence was considered for the input value, and then values representing upper and lower bounds were selected for the high and low sensitivity input values, respectively. One goal of including a range in the input values is to account for uncertainty in all the datasets representing upstream inputs from the Green River, and show how these data ranges affect the predictions of long-term site performance for the remedial alternatives.

The input values are presented as dry weight concentrations for the selected COCs. Dry weight concentrations may be biased low and may underrepresent the concentrations associated with the fraction of solids entering the EW that have finer grain size and higher organic carbon concentrations. Silt- and clay-sized suspended solids are estimated to be 67% of the sediment entering the LDW, but more than 99% of the sediment entering the EW (Anchor QEA and Coast & Harbor Engineering 2012). Additional discussion of the data evaluation and selection process for upstream chemistry inputs used in the LDW is provided in the LDW FS Section 5.3.3 and Appendix C, Part 3 (AECOM 2012).

3.1 Human Health Risk Driver COCs

For total PCBs and cPAHs, the means of the combined Ecology centrifuged TSS data and King County whole water data were selected as the upstream input values (42 microgram per kilogram dry weight [µg/kg dw] and 140 µg toxic equivalent [TEQ]/kg dw, respectively). For the LDW FS (AECOM 2012), total PCBs and cPAHs were estimated using the mean of the LDW RM 4.3 to 4.75 USACE core data. However, the Ecology centrifuged TSS data and King County whole water data are more appropriate to estimate the concentration of Green River solids entering the EW because of the high percentage of fine-grained sediment (silt/clay) that enters the EW. Based on the LDW Sediment Transport Model (STM), little to no coarse-grained particles (i.e., sand) enter the EW (less than 1%), which contrasts with the LDW where coarse-grained particles make up approximately 33% of sediment input from the Green River.

To address sensitivity around the mid-range value for both total PCBs and cPAHs, the low upstream input values were the means of the Ecology upstream surface sediment sample data containing fines greater than 30% (5 µg/kg dw and 40 µg TEQ/kg dw, respectively). The high upstream input values were the 95% upper confidence limit on the means (UCL95) of the TSS-normalized King County whole water datasets (80 µg/kg dw and 270 µg TEQ/kg dw, respectively). These low and high concentrations are consistent with the values used in the LDW FS.

For arsenic, the selected upstream input value was the mean (9 milligrams per kilogram dry weight [mg/kg dw]) of the Ecology upstream sample data containing fines greater than 30%. The mean of the LDW RM 4.3 to 4.75 USACE core data (7 mg/kg dw) was selected as the low sensitivity value. The high sensitivity value (10 mg/kg dw) was the UCL95 of the Ecology upstream sediment sample data containing fines greater than 30%. All arsenic concentrations are consistent with the values used in the LDW FS[3].

For dioxin/furans, the mean of the Ecology centrifuged TSS data was selected as the input value (6 ng TEQ/kg dw). For the LDW FS, dioxin/furans were estimated using the mean of the Ecology centrifuged TSS data and the Ecology upstream sediment samples containing greater than 30% fines. The Ecology centrifuged TSS data is more appropriate to estimate the concentration of Green River solids entering the EW because of the high percentage of fine-grained sediment (silt/clay) that enters the EW. The low sensitivity value is the mean of the Ecology upstream sediment sample data containing fines greater than 30% (2 ng TEQ/kg

[3] As described in LDW FS (AECOM 2012; Section 5.2.3.1), King County surface water TSS-normalized data and Ecology centrifuged solids data were not used in the selection of upstream values for arsenic because the UCL95 for both of these datasets would have resulted in much higher modeled surface sediment concentrations than in the EW and LDW baseline datasets. It is likely that these two datasets, especially the surface water dataset, contain very fine particulates (e.g., clays) with higher arsenic concentrations than those that deposit in the EW and LDW. Very fine particles (e.g., clays) tend not to settle in the EW and LDW.

dw); and the high sensitivity value is the midpoint between the mean and UCL95 of the Ecology upstream centrifuged solids dataset (8 ng TEQ/kg dw). These low and high concentrations are consistent with the values used in the LDW FS (AECOM 2012).

3.2 Benthic Risk Driver COCs

Only the best estimate input values (no low or high sensitivity values) were presented in the LDW FS (AECOM 2012) for a limited number of SMS chemicals. Low and high sensitivity values were not developed for non-human health risk drivers because they were not evaluated as part of the upstream chemistry sensitivity analysis. Of the SMS chemicals evaluated in the LDW FS (see LDW FS Table 5-3), only BEHP and mercury inputs were evaluated in the EW. The best estimate Green River input concentrations for the EW were unchanged from the LDW FS for these COCs. Best estimate Green River input concentrations were also estimated for LPAH, HPAH, and 1,4-dichlorobenzene for the EW. Statistics on the lines of evidence considered for benthic risk driver COCs are presented in Table 2. Selected base case Green River input concentrations for the EW are listed below:

- For HPAHs, the means of the combined Ecology centrifuged TSS data and King County whole water data were selected as the upstream input values (1,300 µg/kg dw). This value was selected because the King County whole water data and Ecology centrifuged TSS data measurements include a high percentage of fine-grained sediment (silt/clay) that is more representative of what enters the EW than other datasets.
- For LPAHs, the selected upstream input value was the mean of the Ecology centrifuged TSS data (130 µg/kg dw). This value was selected because the Ecology centrifuged TSS data measure a high percentage of fine-grained sediment (silt/clay) that is representative of what enters the EW. The King County whole water data were not included in this estimate based on project experience and best professional judgement. The whole water data include both dissolved and particulate-bound LPAHs and, therefore, whole water data tend to bias the estimated particulate concentrations high. Consistent with this interpretation, the estimated particulate concentration based on the King County whole water data were greater than EW baseline mean sediment concentrations. For these reasons, whole water data were not used for estimating upstream solids concentrations in LPAHs.

- For BEHP, the means of the combined Ecology upstream sample data containing fines greater than 30% and LDW RM 4.3 to 4.75 USACE core data were selected as the upstream input values (120 µg/kg dw), which is the same value used in the LDW FS. For BEHP, both datasets are valid for estimating the upstream load to the EW, so both datasets were retained. This is considered a reasonable best estimate from best professional judgement and project experience.
- For 1,4-dichlorobenzene, the means of the combined Ecology upstream sample data containing fines greater than 30% and LDW RM 4.3 to 4.75 USACE core data were selected as the upstream input values (1.2 µg/kg dw). This was selected based on analysis of all available data and for consistency with BEHP.
- For mercury, the selected upstream input value was the median of the LDW RM 4.3 to 4.75 USACE core data (0.1 mg/kg dw), consistent with the LDW FS (AECOM 2012). The median value was used to minimize the impact of outliers, which are common in sediment datasets for mercury.

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TABLES

Table 1
Green River Input Chemistry Used in East Waterway Modeling

Analyte	Best Estimate	Low	High	Basis for Input and Sensitivity Values
Total PCBs (µg/kg dw)	*42*	**5**	**80**	*Input: Mean of Ecology centrifuged TSS data and King County whole water data combined (see LDW Table 5-2a). Whole water data were used instead of LDW turning basin data (as used for the LDW FS) to account for finer fractions of sediment settling in the EW.* **Low: Mean of Ecology upstream sediment sample data containing fines >30% (see LDW Table 5-2a).** **High: UCL95 of TSS-normalized King County whole water data (value from LDW Table 5-2a; 82 rounded to 80 µg/kg dw).**
cPAHs (µg TEQ/kg dw)	*140*	**40**	**270**	*Input: Mean of Ecology centrifuged TSS data and King County whole water data combined (value from LDW Table 5-2c; 135 rounded to 140 µg TEQ/kg dw).* **Low: Mean of Ecology upstream sediment sample data containing fines >30% (value from LDW Table 5-2c; 37 rounded to 40 µg dw).** **High: UCL95 of TSS-normalized King County whole water data (value from LDW Table 5-2c; 269 rounded to 270 µg dw).**
Arsenic (mg/kg dw)	**9**	**7**	**10**	**Input: Mean of Ecology upstream sediment sample data containing fines >30% (see LDW Table 5-2b).** **Low: Mean of LDW RM 4.3 to 4.75 USACE (2001 to 2009) core data (see LDW Table 5-2b).** **High: UCL95 of Ecology upstream sediment sample data containing fines >30% (see LDW Table 5-2b).**
Dioxin/Furan (ng TEQ/kg dw)	*6*	**2**	**8**	*Input: Mean of Ecology centrifuged TSS data (see LDW Table 5-2d).* **Low: Mean of Ecology upstream sediment sample data containing fines >30% (see LDW Table 5-2d).** **High: Midpoint between mean and UCL95 of Ecology centrifuged solids data (see LDW Table 5-1a and LDW Table 5-2d).**
HPAHs (µg/kg dw)	1,300	NC	NC	Input: Mean of Ecology centrifuged TSS data and King County whole water data combined (calculated using LDW dataset).
LPAHs (µg/kg dw)	130	NC	NC	Input: Mean of Ecology centrifuged TSS data and King County whole water data combined (calculated using LDW dataset).
BEHP (µg/kg dw)	**120**	NC	NC	Input: Mean of combined Ecology upstream sediment sample data containing fines >30% and USACE RM 4.3 to 4.75 core data (calculated using LDW FS dataset).
1,4-dichlorobenzene (µg/kg dw)	1.2	NC	NC	Input: Mean combined of Ecology upstream sediment sample data containing fines >30% and USACE RM 4.3 to 4.75 core data (calculated using LDW FS dataset).
Mercury (mg/kg dw)	**0.1**	NC	NC	Input: Median of LDW RM 4.3 to 4.75 USACE (2008 to 2009) core data (calculated using LDW FS dataset).

Notes:

Italic = Presented in the LDW FS (AECOM 2012; Tables 5-2a, 5-2b, 5-2c, 5-2d, and 5-3).

Bold = Same as input values selected for LDW FS (LDW FS Table 5-1a through 5-1d or Table 5-3). The BEHP input value matched the LDW value, but was derived considering additional data.

In the LDW FS, Green River input values are as follows: total PCBs = 35 µg/kg dw, cPAHs = 70 µg TEQ/kg dw, arsenic = 9 mg/kg, dioxin/furan = 4 ng TEQ/kg dw, and BEHP = 120 µg/kg dw.

Non-detects were treated as 1/2 the reporting limit when calculating the mean and UCL95.

Data source: AECOM 2012. LDW Final FS Baseline Data Set. Available at http://ldwg.org/Assets/FS/Final_2012-10-31/LDW%20Final%20FS%20Baseline%20Dataset%20Files.zip.

NC = not calculated. Non-human health risk drivers were not evaluated as part of the upstream chemistry sensitivity analysis.

µg – microgram
BEHP – bis(2-ethylhexyl) phthalate
cPAH – carcinogenic polycyclic aromatic hydrocarbon
dw – dry weight
Ecology – Washington State Department of Ecology
EW – East Waterway
FS – Feasibility Study
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
kg – kilogram
LDW – Lower Duwamish Waterway
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
mg – milligram
ng – nanogram
PCB – polychlorinated biphenyl
RM – river mile
TEQ – toxic equivalent
TSS – total suspended solids
UCL95 – 95% upper confidence limit on the mean
USACE – U.S. Army Corps of Engineers

Table 2
Green River Input Chemistry Lines of Evidence for Benthic Risk Drivers

Chemical	Dataset	Count	Mean	Median	90th Percentile
Total HPAH (µg/kg dw)	King County Whole Water Data	19	1,320	563	4,359
	Ecology Centrifuged TSS Data	7	1,134	448	2,886
	Combined Datasets	**26**	**1,270**	**452**	**4,381**
	USACE LDW RM 4.3 to 4.75 Core Data	22	646	554	965
	Ecology Upstream Sediment Sample Data (Containing Fines >30)	72	156	39	460
	Combined Datasets	**94**	**280**	**98**	**859**
Total LPAH (µg/kg dw)	King County Whole Water Data	19	2,970	1,106	7,846
	Ecology Centrifuged TSS Data	7	130	60	315
	Combined Datasets	**26**	**2,205**	**439**	**7,218**
	USACE LDW RM 4.3 to 4.75 Core Data	22	79	69	117
	Ecology Upstream Sediment Sample Data (Containing Fines >30)	72	17	5	47
	Combined Datasets	**94**	**33**	**12**	**81**
1,4 DCB[1] (µg/kg dw)	USACE LDW RM 4.3 to 4.75 Core Data	22	0.9	0.8	2
	Ecology Upstream Sediment Sample Data (Containing Fines >30)	49	1.3	0.5	6
	Combined Datasets	**71**	**1.2**	**0.5**	**2**
BEHP[1] (µg/kg dw)	USACE LDW RM 4.3 to 4.75 Core Data	22	224	210	305
	Ecology Upstream Sediment Sample Data (Containing Fines >30)	49	75	16	232
	Combined Datasets	**71**	**121**	**20**	**260**
Mercury[1] (mg/kg dw)	USACE LDW RM 4.3 to 4.75 Core Data	22	0.18	0.09	0.12
	Ecology Upstream Sediment Sample Data (Containing Fines >30)	49	0.06	0.02	0.10
	Combined Datasets	**71**	**0.10**	**0.03**	**0.12**

Table 2
Green River Input Chemistry Lines of Evidence for Benthic Risk Drivers

Notes:

Selected as the best estimate of Green River input concentration for East Waterway Feasibility Study modeling.

1. 1,4 DCB, BEHP, and mercury were not analyzed in the King County whole water and the Ecology centrifuge studies.

µg/kg – micrograms per kilogram
BEHP – bis(2-ethylhexyl)phthalate
DCB – dichlorobenzene
dw – dry weight
Ecology – Washington State Department of Ecology
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LDW – Lower Duwamish Waterway
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
mg/kg – milligrams per kilogram
RM – river mile
TSS – total suspended solids
USACE – U.S. Army Corps of Engineers

Table 3
Preliminary Results for Recent Green River Sediment Input Concentrations - Comparison of East Waterway Box Model Inputs, King County (2016), and U.S. Geological Survey (2013-2015)

Analyte	East Waterway Box Model Inputs			King County (2016) Green River (Foster Links)				USGS (2016) Green River Progress Report Filtered Solids Golf Course at Tukwila (Data Series 880 and 973 combined)			
				Sediment Traps		Filtered Solids					
	Low	Base	High	Jar-style (mean)	Baffle-style (mean)	Baseflow (mean)	Storm (mean)	(mean)	(median)	(minimum)	(maximum)
Arsenic (mg/kg dw)	7	9	10	11	8.9	40	14	14	12	6.6	28
Total cPAHs (µg/kg TEQ dw)	40	135	270	54	45	36	160	80	48	3.7	292
Total PCBs (µg/kg dw)	5	42	80	13	5.3	7.8	30	12	4.8	0.4	84
Dioxin/furans (ng TEQ/kg dw)	2	6	8	3.0	1.9	3.5	7.1	4.8	3.1	0.5	19

Notes:
µg – microgram
cPAH – carcinogenic polycyclic aromatic hydrocarbon
dw – dry weight
kg – kilogram
mg – milligram
ng – nanogram
PCB – polychlorinated biphenyl
TEQ – toxic equivalent
USGS – U.S. Geological Survey

PART 4: STORM DRAIN AND COMBINED SEWER OVERFLOW CHEMISTRY DATA AND ANALYSIS FOR EW LATERAL INPUTS USED IN FS MODELING

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1 INTRODUCTION

This appendix describes the East Waterway (EW) storm drain and combined sewer overflow source chemistry data used in the different Feasibility Study (FS) modeling approaches (i.e., box model, point mixing model, and recontamination evaluation) (see Section 5.3, 5.4, and 5.5 of the FS). The process for assigning the chemical input concentrations for EW lateral inputs are described following presentation of updated source control chemical datasets from source tracing activities in storm drain (SD) and combined sewer overflow (CSO) systems that discharge to the EW.

2 NEW SOURCE DATA INCLUDED IN FEASIBILITY STUDY MODELING

The City of Seattle, King County, and the Port of Seattle conduct source-tracing sampling to identify potential contaminant sources by collecting samples of solids that accumulate within the storm drainage/combined sewer systems. Data collection is ongoing. Source tracing data, along with efforts to reduce and control contamination in these basins are discussed in Section 9 and Appendix F of the EW supplemental remedial investigation (SRI) (Windward and Anchor QEA 2014). The SRI included data collected through 2010. Since then, new data collected through 2012[1] has been incorporated in the source control dataset to be used in the FS. This section describes these new data. Only results for the key risk driver contaminants of concern (COCs) that are modeled in the FS are summarized in this section. All COCs will be considered during the design and implementation of the cleanup.

2.1 City of Seattle Source Data

The City of Seattle has collected 11 storm solids samples since 2010 for inclusion in the FS. These data include three sample types: catch basins, sediment traps, and inline solids grab samples. Table 1 lists the sample locations, sample type, and results for the COCs used in FS modeling.

[1] One sample collected by City of Seattle in January 2013 is also included. The year 2012 serves as the cutoff for development of the FS, and more recent data will be evaluated in remedial design.

Table 1

Post-Supplemental Remedial Investigation Storm Drain Solids Samples Collected by the City of Seattle included in the Feasibility Study Modeling

	Sample Name	Outfall Basin	Sample Type	Date	Arsenic (mg/kg dw)	Mercury (mg/kg dw)	Total HPAHs (µg/kg dw)	Total LPAHs (µg/kg dw)	Total cPAHs (µg TEQ/kg dw)	Bis (2-ethylhexyl) phthalate (µg/kg dw)	1,4-Dichlorobenzene (µg/kg dw)	Total PCBs (µg/kg dw)
CB168	CB168-082012	S. Hinds St SD	CB SD	08/20/12	7 U	0.04	2,590	378	282 J	5,800 B	71 U	65 J
EWWST1	EWWST1-100912	S. Lander St SD	Trap SD	10/09/12	10	0.25	8,580	810	1,080	10,000 J	410 U	336
EWWST2	EWWST2-100912	S. Lander St SD	Trap SD	10/09/12	10	0.19	13,000	1,490	1,640 J	8,500 J	390 U	296
EWWST3	EWWST3-100912	S. Lander St SD	Trap SD	10/09/12	10 U	0.26	11,500	1,060	1,500 J	6,100 J	320 U	344
EWWST4	EWWST4-100912	S. Lander St SD	Trap SD	10/09/12	6 U	0.06	4,010	410	533	4,200 J	280 U	109 J
EWWST4	EWWST4-100912G	S. Lander St SD	Inline SD	10/09/12	20	0.07	1,140	70	154 J	620 J	54 U	22
EWWST5	EWWST5-100912	S. Lander St SD	Trap SD	10/09/12	10 U	0.11	4,180	410	578 J	9,300 J	430 U	126
EWWST6	EWWST6-100912	SPU Nearshore SD	Trap SD	10/09/12	20 U	0.31	8,630	810	1,210 J	10,000 J	850 U	210
RCB168	RCB168-010913	S. Hinds St SD	Inline SD	01/09/13	20	0.28	6,080	3,250	755	860 B	56 U	2,240
RCB251	RCB251-070512	Hanford/Lander/ Diagonal CSO[a]	RCB CS	07/05/12	10 U	0.06	1,600	265	152 J	7,700 B	120 U	103 J
RCB251	RCB251-042011	Hanford/Lander/ Diagonal CSO[a]	RCB CS	04/20/11	10 U	0.06	914 J	267 B	2 J	22,000	58 U	9,200
CB60	CB60-041012	S. Lander St SD	CB SD	04/10/12	10 U	0.11	5,360	1,450	506	46,000 B	170 U	52

Notes:
Samples were not analyzed for dioxins/furans.
µg/kg – micrograms per kilogram
A – Samples collected from catch basins within CSO basin are representative of SD inputs. The SD data from the Lander and Hanford #2 CSO basin datasets also include some samples that overlap with the Duwamish/Diagonal CSO basin inasmuch as these systems are connected.
B – analyte was found in the associated blank
CB – private on-site catch basin
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CS – combined sewer
CSO – combined sewer overflow
dw – dry weight
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
J – estimated value
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
mg/kg – milligrams per kilogram
PCB – polychlorinated biphenyl
RCB – right-of-way catch basin
SD – storm drain
SPU – Seattle Public Utilities
TEQ – toxic equivalent
U – non-detect

2.2 King County Source Data

King County has collected six solids samples from the Hanford #2 CSO Basin since 2010 for inclusion in the FS. All data were inline solids grab samples with the majority of samples being collected in the Hanford #2 CSO main trunk line. Table 2 lists the sample locations, sample type, and results for the COCs used in the FS modeling.

2.3 Port of Seattle Source Data

No new data have been collected since 2010 in the Port of Seattle storm drain basins. The Port continues to track deposition in storm drains that have been cleaned and will conduct sampling when accumulation is sufficient.

Table 2

Post-Supplemental Remedial Investigation Combined Sewer Overflow Solids Samples Collected by King County included in the Feasibility Study Modeling

	Sample Name	Outfall Basin	Sample Type	Date	Arsenic (mg/kg dw)	Mercury (mg/kg dw)	Total HPAHs (µg/kg dw)	Total LPAHs (µg/kg dw)	Total cPAHs (µg TEQ/kg dw)	Bis (2-ethylhexyl) phthalate (µg/kg dw)	1,4-Dichlorobenzene (µg/kg dw)	Total PCBs (µg/kg dw)
A00802	L56255-1	Hanford #2 CSO	In-Line CS	8/13/2012	2.6 J	0.30	1,490 J	271	301 J	2,800	530	241 J
A00803	L56255-3	Hanford #2 CSO	In-Line CS	8/13/2012	7.5 J	0.17	1,540 J	239	298 J	2,180	170	384 J
A00805	L56255-5	Hanford #2 CSO	In-Line CS	8/13/2012	4.2 J	1.11	3,810 J	677	626 J	3,760 J	353	445
A01101	L52476-1	Hanford #2 CSO	In-Line CS	1/20/2011	6.3 J	3.91	4,840	909	698	8,250	24,900	912
A01101	L56255-7	Hanford #2 CSO	In-Line CS	8/13/2012	6 J	111 J	4,630 J	1,390	761 J	6,540	5,790	513 J
CS030	L56255-9	Hanford #2 CSO	In-Line CS	8/13/2012	7.6 J	23.2	12,100 J	3,030	3,120 J	15,400	130 U	410 J

Notes:
Samples were not analyzed for dioxins/furans.
µg/kg – micrograms per kilogram
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CS – combined sewer
CSO – combined sewer overflow
dw – dry weight
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
J – estimated value
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
mg/kg – milligrams per kilogram
PCB – polychlorinated biphenyl
TEQ – toxic equivalent
U – non-detect

3 SOURCE DATA EXCLUDED FROM FEASIBILITY STUDY MODELING

Appendix F of the SRI describes in detail the source control actions that have been implemented by the three parties (King County, City of Seattle, and Port), including line cleaning activities and provides the data that triggered the action. This section summarizes the source data that have been excluded from FS modeling due to line cleaning along with additional reasoning for removing particular data values that are not considered to be representative of the current conditions of SD and CS inputs to the EW.

3.1 Data Excluded Due to Line Cleaning

SD and CSO solids samples collected during the SRI that contained elevated levels of contaminants triggered additional source tracing and source control actions by the owners. In some cases, specific source of contaminants were identified and controlled through implementation of appropriate best management practices. Regardless of whether or not specific sources were identified, once source tracing was complete, the owners jetted and cleaned lines and/or structures that contained elevated levels of contaminants to remove accumulated sediment. Samples collected from a SD and CSO lines that were subsequently cleaned were excluded from the source tracing dataset used in the FS because the material that had accumulated in these systems over the years has been removed and no longer constitutes a potential source to the EW.[2] Line cleaning also removes historical material that could interfere with future source tracing efforts. For SD and CSO lines that have been cleaned (see Appendix F of SRI), only data collected after the cleaning have been included in the source tracing dataset used in the FS to ensure that data are representative of current rather than historical conditions. A total of 81 data points were excluded due to line cleaning and are listed in Table B4-1 of Attachment 1.

3.2 Data Excluded Due to Control of Specific Point Source

In addition to line cleaning, the control of a known point source also resulted in the exclusion of select source data from the FS modeling. Specifically, the source of

[2] These lines are typically cleaned infrequently. Therefore, material that accumulates in the lines can represent contributions from historical sources that no longer exist and may not represent post-cleaning inputs from that line.

1,4-dichlorobenzene (1,4-DCB) within the Hanford #2 CSO basin was identified and controlled. The company using the product found a substitute product that is free of 1,4-DCB; lines on the company property and the affected city-owned combined sewer lines were cleaned to the Hanford #2 CSO trunk line in January 2012 following product substitution (see Appendix F of the SRI for further details). While samples collected prior to line cleaning were excluded as discussed in Section 3.1, additional data for 1,4-DCB was excluded from the Hanford #2 Trunk Line in the overall dataset to better portray the current conditions of CSO discharges for 1,4-DCB (see Table B4-2 in Attachment 1). These excluded data represented the system prior to the cleaning and product substitution. New data collected in 2012 from these locations are used to represent current conditions. For example, samples collected in 2008-2010 from the Hanford #2 CSO trunk line were excluded for 1,4-DCB and new data for 1,4-DCB from samples collected in 2012 were used to replace these older samples.

3.3 Data Excluded Due to Other Reasons

Mercury data for one sample collected in August 2012 from Hanford #2 CSO trunk line was excluded from the source dataset for FS modeling. This sample was determined to be an outlier based on lab triplicate results. The primary sample result for Sample L56255-7 (Locator A01101) was 111 mg/kg wet weight (ww). However, the lab triplicate results were 0.48, 2.96, and 0.29 mg/kg ww, indicating the original results was an outlier and could skew the data summaries for mercury. Mercury results collected in 2011 were used for this sample location.

4 DATA AGGREGATION IN FEASIBILITY STUDY MODELING

This section summarizes the data analysis methods used for assigning chemical concentrations to EW lateral inputs for the different FS modeling approaches. The source dataset used included new data presented in Section 2 combined with the dataset presented in the SRI changed as discussed in Section 3. Data were aggregated differently for different modeling approaches. Each method is described below. Following data aggregation used for each modeling approach, the following statistics were generated and used to estimate the concentrations for the different models:

- Base case (or best estimate): Mean
- Low bounding conditions: Median
- High bounding conditions: 90th percentile

Further details regarding modeling inputs and bounding conditions are provided in Section 5 of the FS.

4.1 Box Model

A box model evaluation was used to predict the EW site-wide spatially-weighted average concentrations (SWACs) over time (years 1 through 40 following completion) for the four human health risk driver COCs (total PCBs[3], arsenic, cPAHs, and dioxin/furan). Because the model output was site-wide SWACs (not location-specific output), it was assumed that sediment deposition from upstream and lateral sources occurs evenly throughout the EW and that the net sedimentation rate is a constant value throughout the EW (Section 5.3 of the FS). The box model evaluation averages all EW lateral solids and chemistry inputs. For this reason, EW lateral sources were not assigned a different chemical concentration per outfall. Instead, the EW laterals were divided into two categories—SDs and CSOs—and separate chemistries were developed for each category. SD and CSO chemistries were not combined because some differences were noted between the discharge types. While PCBs tend to be similar on average for the discharge types, some differences were noted for PAHs, arsenic and dioxins/furans (see Table 3). Therefore, data representing CSO discharges were compiled from solids chemistry from the Hanford, Lander, and Hinds CSO service areas and data

[3] Total PCBs is also risk driver COC for fish (RAO 4).

representing stormwater discharges were combined from all storm drainage basins including the Port terminals, City of Seattle service areas, private storm drains, and catch basins draining to CSO service areas that represent stormwater only inputs to the combined sewer. Of the aggregate data, the mean, median, and 90th percentile were calculated to determine the base (or best estimate), low, and high bounding conditions, respectively. In one case (arsenic CSO concentration), the mean is lower than the median due to the distribution of the dataset. For consistency, the median was still used as the "low" estimate, and the mean was still used as the "best" estimate. In this case, the difference is only 1 mg/kg, which is within the analytical precision of the method.

Table 3
Source Tracing Datasets Summary Statistics

Chemical	Arsenic (mg/kg dw)	Mercury (mg/kg dw)	Total HPAHs (µg/kg dw)	Total LPAHs (µg/kg dw)	Total cPAHs (µg TEQ/kg dw)	BEHP (µg/kg dw)	1,4-DCB (µg/kg dw)	Total PCBs (µg/kg dw)	Dioxin/Furan (ng TEQ/kg dw)
All CSOs									
Sample Count	26	24	24	24	24	24	16	26	4
Mean	5	1.71	4,000	870	680	6,700	820	260	16
Median	6	0.36	2,900	640	430	3,000	260	240	7.6
90th percentile	9	2.57	10,000	1,900	1,500	23,000	2,000	630	37
Lander CSO									
Sample Count	3	3	3	3	3	3	3	3	2
Mean	2	0.21	1,800	280	250	1,000	320	11	1.8
Median	2	0.25	2,200	220	300	800	230	11	1.8
90th percentile	2	0.26	2,700	500	380	1,700	560	18	2.6
Hanford #2 CSO									
Sample Count	22	20	20	20	20	20	12	22	2
Mean	6	2.00	3,900	890	670	7,700	990	270	30
Median	6	0.72	3,100	670	540	3,300	320	250	30
90th percentile	9	2.94	6,200	1,600	930	27,000	2,300	510	44
Hinds CSO									
Sample Count	1	1	1	1	1	1	1	1	0
Mean	9	0.43	13,500	2,400	2,100	5,400	190	850	na
Median	9	0.43	13,500	2,400	2,100	5,400	190	850	na
90th percentile	9	0.43	13,500	2,400	2,100	5,400	190	850	na
All Nearshore SD									
Sample Count	32	32	32	32	32	32	32	36	7
Mean	10	0.09	5,500	1,000	820	8,300	75	160	15
Median	10	0.08	4,400	740	550	6,200	17	39	7.9
90th percentile	15	0.14	14,000	1,900	2,100	19,000	180	440	32
S Lander SD									
Sample Count	56	56	55	55	55	55	55	58	2
Mean	9	0.15	14,000	2,600	2,100	12,000	110	120	68
Median	10	0.13	5,500	810	670	9,300	90	53	68
90th percentile	20	0.29	17,000	3,400	2,400	21,000	200	280	93
S Hinds SD									
Sample Count	6	6	6	6	6	6	6	6	0
Mean	15	0.11	3,500	1,200	350	6,300	65	560	na
Median	12	0.07	3,200	720	320	3,700	45	130	na
90th percentile	30	0.23	6,600	2,600	640	14,000	120	1,500	na
All Non-Nearshore SD									
Sample Count	99	99	98	98	98	98	97	101	2
Mean	10	0.19	10,000	2,000	1,400	19,000	140	290	68
Median	7	0.12	4,000	680	450	9,400	90	58	68
90th percentile	20	0.32	11,000	3,400	1,700	24,000	280	460	93
All SDs									
Sample Count	131	131	130	130	130	130	129	137	9
Mean	10	0.17	9,000	1,800	1,280	16,000	120	250	27
Median	9	0.10	4,000	680	480	9,10	73	55	12
90th percentile	20	0.30	13,000	3,000	1,900	22,000	270	450	53
All CSO and SD Data									
Sample Count	163	161	154	159	159	159	158	168	13
Mean	9	0.40	8,200	1,600	1,200	14,000	1,200	300	23
Median	7	0.12	3,800	650	440	7,100	90	64	12
90th percentile	20	0.67	12,300	2,400	1,800	22,000	570	520	46

Notes:
µg/kg – micrograms per kilogram
1,4-DCB – 1,4-dichlorobenzene
BEHP – bis(2-ethylhexyl)phthalate
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CSO – combined sewer overflow
dw – dry weight
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
mg/kg – milligrams per kilogram
na – not applicable
ng/kg – nanograms per kilogram
PCBs – polychlorinated biphenyls
SD – storm drain
TEQ – toxic equivalent

4.2 Point Mixing Model and Recontamination Evaluation

The point mixing model and the recontamination evaluation applied chemistry concentrations for lateral loads to a finer resolution than the box model. The point mixing model is the method used in the FS to assess MNR performance for RAO 3. Specifically, it is used to predict location specific EW surface sediment concentrations over time for the key benthic risk driver COCs where MNR is the remedial technology (see FS Section 5.5 for a description of the point mixing model and FS Section 9 for the results). The recontamination evaluation is the method used in the FS to identify areas within the EW that have the potential to recontaminate over time (see FS Section 5.4 for a description of the model and FS Appendix J for a presentation of the results). Both evaluations used the results of numerical modeling (i.e., the PTM) as an input to a GIS-based grid model[4] to estimate deposited sediment concentrations post-remediation for nine key risk driver COCs (Section 5.4 of the FS and Appendix J).

Since the point mixing model and recontamination evaluation calculates surface concentrations based on a model cell-by-cell basis based on initial deposition patterns predicted by the PTM output, it was necessary to break down EW lateral sources into finer resolution for chemistry assumptions. Using individual results for each basin was not possible because data were not available to adequately characterize each individual basin. For example, often a basin only had one result or no results so assignment of chemistry could not be made in this approach. In other cases, lines throughout a basin had been cleaned and either no samples or only one sample were available since the line cleaning. Therefore, chemistry assumptions applied to the PTM solids output for the point mixing model and the recontamination potential evaluation were assigned based on the following six basin-type categories:

- Hinds CSO
- Lander CSO
- Hanford #2 CSO
- Nearshore SDs (storm drains serving Port terminals and other similar areas)
- Non-nearshore SDs (storm drains serving other non-terminal areas like bridges,

[4] The grid model divides the EW into contiguous square cells with a 50-foot x 50-foot resolution for use in the recontamination evaluation (grid model evaluation).

roadways, and other upland properties, including private storm drain systems)
- S Lander St SD.

Source data were aggregated based on similarities in outfall types/basin land uses rather than assigning data for each individual outfall. The rationale for this is summarized below.

4.2.1 CSO Chemistry Data Assignments

Data as amended in Section 3 for each CSO basin were summarized and reviewed as mean, median and 90th percentile data summaries (see Table 3). Source tracing data results for each basin and number of samples were considered when deciding how to assign chemistry for each CSO. Solids source tracing data collected from Lander CSO basin showed much lower concentrations of most contaminants then Hanford #2 CSO basin. Therefore, it was not appropriate to include samples collected in Hanford #2 CSO basin with the Lander CSO basin and thus, the source datasets were used independently to assign chemistry for each basin. The Hinds CSO basin, which is much smaller than the other two CSO basins, had only one sample available. Because of the limited data for this basin, data for all CSO combined (same as that used for the box model) was assigned to Hinds CSO. This may overestimate or underestimate (depending on the contaminant) the contaminant concentrations being discharged from Hinds CSO.

4.2.2 Storm Drain Chemistry Data Assignments

Data as amended in Section 3 for each SD basin of similar land uses, size, or categories were summarized and reviewed as mean, median and 90th percentile data summaries (see Table 3). Source tracing data results for each similar basin and number of samples per basin were considered when deciding how to assign chemistry for SD outfalls.

Data for samples collected from storm drains serving Port terminals and other similar areas were combined into the nearshore SD category. These include the SW Florida St SD (B-21), B-25, all Port SDs, and all private SDs along waterfront (A-6, B-40, B-41, B-42, B-43) (see Figure 2 in Appendix B, Part 1). These nearshore SDs have similar land use and there were not enough samples collected from individual drainage systems to support calculating separate chemistry inputs for the PTM. All nearshore SD concentrations were assumed equal and aggregated because of: 1) the limited sampling; and 2) post-sampling line cleaning, which would change measured concentrations. Summaries were developed for the aggregated dataset. This may overestimate or underestimate (depending on the contaminant) of the contaminant concentrations being discharged from an individual basin.

Data for samples collected from storm drains serving roadways, bridges, and upland industrial properties other than Port terminals (e.g., U.S. Coast Guard and Olympic Tug and Barge) were combined into the non-nearshore SDs category which includes the S Hinds St SD, SW Spokane St emergency overflow/SD (B-5), SW Spokane St SD (B-4), S Spokane St SD (B-36), and all bridges (BR-2, BR-4, BR-34, BR-39). With the exception of the S Hinds St SD (39.5 acres), these outfalls serve small drainage areas (<1 - 13 acres) and none had sufficient samples to support calculating separate chemistry inputs for the PTM. Because the land use in these basins is significantly different from nearshore SDs, the solids chemistry inputs were calculated separately from the nearshore SDs. S Hinds St SD data were combined with the non-nearshore SDs because only one inline sample has been collected after cleaning (RCB168) and data for the private on-site catch basins in the S Hinds St SD (CB59, CB134, CB135, CB168) were not considered representative of the solids discharges from this outfall because catch basins collect runoff from a fairly small catchment area (less than 1 ac) and may not be representative of the basin as a whole.

The S Lander St storm drain was handled separately for the PTM, because this system is unique in that it serves a much larger (442 acres) and diverse drainage basin than the other non-nearshore SDs. Existing data were also sufficiently robust (59 samples) to characterize the solids chemistry in this basin.

5 CURRENT AND FUTURE EAST WATERWAY LATERAL CONDITIONS

The box model, point mixing model and recontamination evaluation all included an analysis of both current and potential future source control conditions for EW laterals. Current conditions for modeling purposes were defined as now through 10 years post-construction of the remedy, and future conditions were defined as 10 years and beyond post-construction of the remedy. This was to acknowledge the uncertainty in the timing of known future source controls. Current and potential future conditions chemistry assumptions were developed for EW laterals (i.e., SDs and CSOs). The current chemistry conditions are based on the data analysis discussed thus far in this appendix (e.g., consideration of current source control actions). Chemistry values for potential future conditions differed compared to current conditions for some COCs for SDs based on likely future source control efforts. The following summarizes how future chemistry conditions were treated for CSOs and SDs.

5.1 Future Conditions (CSOs)

Changes in chemistry were not assumed for CSO basins for the following reasons:

- **Hinds CSO.** The City currently plans to control overflows from the Hinds CSO through a system retrofit that should not substantially change the discharge composition and therefore no changes in chemistry are assumed at this stage. Rather the discharge volume will be reduced to on average one uncontrolled event per year as required under the City's National Pollutant Discharge Elimination System (NPDES) permit.[5]
- **Hanford #2 and Lander CSOs.** The current CSO control plan by King County is to install a wet weather treatment plant to control overflows from these two CSOs. Because most treatment technologies function by removing solids rather than removing chemicals from the solids, the modeling included a reduction in solids but did not assume any change in chemistry on the solids remaining after treatment. Treatment could result in some reductions in chemistry but none were estimated for

[5] For the PTM, it was assumed that annual discharge volumes would be reduced from approximately 1 to 0.6 million gallons per year. The City has not completed modeling the Hinds CSO system. Therefore, reductions in overflow volumes were conservatively estimated. Available information suggests that approximately 5 overflows currently occur per year.

the FS modeling[6]. By assuming no change in chemistry, the analysis should provide a conservative estimate for CSOs following treatment. Note there remains on average one untreated event per year at these outfalls in addition to the treated flows. These untreated flows also did not assume any change in chemistry.

5.2 Future Conditions (Port-owned Storm Drains)

Changes in chemistry were not assumed for Port-owned SD basins because changes in chemistry could not be predicted based on additional source control actions. The FS instead assumed that the stormwater treatment to be installed by the tenants as required under their NPDES industrial stormwater permits is expected to reduce solids load from these basins. Most stormwater treatment technologies function by removing solids present in stormwater, but and are not effective removing the contaminants adsorbed to the solids. Therefore, the modeling assumed a reduction in solids concentrations and did not assume any change in chemistry on the solids remaining after treatment. While treatment could potentially result in reductions in chemistry, none were assumed for the FS modeling.

5.3 Future Conditions (City-owned Storm Drains)

For the City-owned storm drains, future lateral inputs were estimated by adjusting the solids chemistry concentrations to reflect improvements that are expected to occur as a result of ongoing source control efforts in the EW drainage basin. To simulate lateral inputs after the implementation of source control measures, the source tracing dataset for City-owned storm drains was screened by replacing all values above a set replacement concentration with the replacement concentration (see Table 4). This approach assumes that the existing source(s) are not entirely eliminated, but are reduced via source control actions. For arsenic and mercury, the replacement concentrations were selected based on the screening levels currently used to screen for and trace sources (i.e., CSL or the Second Lowest Apparent Effects Threshold [2LAET] dry weight equivalent). For LPAH, HPAH, BEHP, PCBs, and 1,4-DCB, higher concentrations were used because these chemicals have been shown to be harder to control in urban settings. For these chemicals, the replacement values were set

[6] Reductions in source inputs from CSO treatment were accounted for through removal of solids (and particle-associated chemistry) and changes to particle sizes of solids discharged (see Appendix B, Part 1).

based on the distribution of concentrations in the source tracing dataset and best professional judgment regarding the likely impact of source control efforts.

Following replacement, mean, median, and 90th percentile concentrations were recalculated from the dataset and used as the best estimate, low, and high estimated lateral loads, respectively (see FS Table 5-7).

Table 4
Replacement Values to Approximate Results of Future Source Control Actions in City Storm Drains

	Arsenic (mg/kg dw)	Mercury (mg/kg dw)	Total LPAHs (µg/kg dw)	Total HPAH (µg /kg dw)	BEHP (µg /kg dw)	Total PCBs (µg /kg dw)	1,4-DCB (µg /kg dw)
CSL/2LAET	93	0.59	5,000	17,000	1,900	1,000	110
Replacement Concentration[a]	**93**	**0.59**	**15,000**	**50,000**	**100,000**	**2,000**	**1,000**
Samples modified	None	CB16-020904	CB26-031504	CB26-031504	CB27B-081210	RCB251-042011	CB22-030204
		CB26-031504	CB54-020905	CB151-111209	CB30-091610	CB22-030204	
		CB30-043004				RCB168-010913	
		CB30-091610					

Notes:
CSL/2LAET shown for reference.
a. The concentration that was substituted for all values exceeding this value.
µg/kg – micrograms per kilogram
1,4-DCB – 1,4-dichlorobenzene
2LAET – Second Lowest Apparent Effects Threshold
BEHP – bis(2-ethylhexyl)phthalate
CSL – Cleanup Screening Level
dw – dry weight
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
mg/kg – milligrams per kilogram
PCB – polychlorinated biphenyl

6 REFERENCE

Windward and Anchor QEA, 2014. Supplemental Remedial Investigation. East Waterway Operable Unit Supplemental Remedial Investigation/Feasibility Study. Final. January 2014.

ATTACHMENT 1
SAMPLES REMOVED FROM FS DATASET DUE TO LINE CLEANING AND SOURCE CONTROL

Table B4-1
Storm/CSO Solids Samples Removed from FS Dataset due to Line Cleaning

Location Name	Sample Name	Outfall Basin	Sample Type	Date	Arsenic (mg/kg dw)	Mercury (mg/kg dw)	Total HPAHs (µg/kg dw)	Total LPAHs (µg/kg dw)	Total cPAHs (µg TEQ/kg dw)	Bis (2-ethylhexyl) phthalate (µg/kg dw)	1,4-Dichlorobenzene (µg/kg dw)	Total PCBs (µg/kg dw)	Dioxins/furans TEQ (ng TEQ/kg dw)
CB133	CB133-012009	S Hinds St SD	SD CB	01/20/09	6 UJ	0.04 U	19 U	19 U	17	26	19 U	20 U	
MH113	MH113-050310	S Hinds St SD	SD Inline	05/03/10	20	0.7	5,000 J	1,680	330 J	9,000	270 U	260	81.9
RCB138	RCB138-050108	S Hinds St SD	SD Inline	05/01/08	20	0.69	1,460 J	659 J	139 J	1,200	99 U	1,140	
MH109	MH109-111209	S Hinds St SD	SD Inline	11/12/09	14.4	0.52 J	10,500 J	1,540 J	1,580 J	3,800	60 U	208	
MH107	MH107-111209	S Hinds St SD	SD Inline	11/12/09	10	0.16 J	11,005 J	2,490 J	1,170 U	47,000	300 U	705	
RCB168	RCB168-041009	S Hinds St SD	SD Inline	04/10/09	10 U	0.04	148 J	28	24 J	290	20 U	20 U	
MH104	MH104-072709	S Hinds St SD	SD Inline	07/27/09	7	0.12	9,250 J	2,410	897 J	3,200	57 J	60	
RCB46	RCB46-082405	S Hinds St SD	SD RCB	08/24/05	10 U	0.05 U	2,340	350	297	3,000 B	120 U	250	
MH114	MH114-050610	Hanford #2 CSO	CS Inline	05/06/10	80	6.6	38,240 J	8,250	5,220 J	1,500 J	57 J	41,300	
MH115	MH115-052510	Hanford #2 CSO	CS Inline	05/25/10	32	9.2	18,600	4,640 J	2,400	1,400	100 U	1,470	
RCB135	RCB135-031408	Nearshore SD	SD Inline	03/14/08	12.7	0.3	8,040 J	1,300	1,020 J	33,000	1,000 U	285	
MH133	MH133-050310	SW Spokane St SD, B-4	SD Inline	05/03/10	10	0.17	11,400 J	1,810 J	972 J	33,000	230 U	284	34.6
RCB133	RCB133-031408	SW Spokane St SD, B-4	SD Inline	03/14/08	12.3	0.35	10,800 J	1,450	1,240 J	45,000	1,200 U	376	
CB19	CB19-021204	Hanford/Lander/ Diag CSO	CS CB	02/12/04	25	1.82	9,620 J	3,200	1,210 J	53,000	1,200 U	289	
CB27B	CB27-032604	Hanford/Lander/ Diag CSO	CS CB	03/26/04	20 U	0.1 U	18,900	2,800 U	2,760	140,000	2,800 U	68 J	
CB60	CB60-031705	S Lander St SD	SD CB	03/17/05	11	0.08	9,200	7,300	1,640	160,000	1,800 U	320 Y	
CB65	CB65-032205	Port SD, B-11	SD CB	03/22/05	10	0.27	3,030 J	420	289 J	19,000	140 U	2,110	25.6 J
CB65	CB65-112910	Port SD, B-11	SD CB	01/29/10	7.7	0.23	3,060 J	420	666 J	36,000	230 U	3,000	
A00709	L49290-1	Hanford #2 CSO*	CS Inline	10/13/2009								347,000 J	
A00929	L49290-2	Hanford #2 CSO*	CS Inline	10/13/2009								178,000	
A00818	L49290-4	Hanford #2 CSO	CS Inline	10/14/2009	6.93 J	0.77	51,400	9,900	8,080	6,890	88 J	1,640	
A00817	L48945-4	Hanford #2 CSO	CS Inline	9/1/2009	6 J	2.3 J	1,440	179	204	2,370	1,370,000	152 J	
A00817	L50935-7	Hanford #2 CSO	CS Inline	9/1/2009									
A00817	L50935-8	Hanford #2 CSO	CS Inline	9/1/2009									
A00903	L48945-11	Hanford #2 CSO	CS Inline	9/2/2009	7.8 U	0.33 J	1,680	611	299	5,220	44,500,000		
A00904	L48945-9	Hanford #2 CSO	CS Inline	9/2/2009			3,830	1,100	507	4,380	2,680,000		
A00904	L50498-6	Hanford #2 CSO	CS Inline	9/2/2009	19	6.40 J						1,100	
A00904	L50935-25	Hanford #2 CSO	CS Inline	9/2/2009									
A00904	L50935-26	Hanford #2 CSO	CS Inline	9/2/2009									
A00918	L48945-7	Hanford #2 CSO	CS Inline	9/1/2009	9.73	16.7	17,300	5,700	2,150	996	390	12,100 J	
A00918	L48945-8	Hanford #2 CSO	CS Inline	9/1/2009	12.3		22,000	6,220	2,840	1,310	56	36,700 J	

Table B4-1
Storm/CSO Solids Samples Removed from FS Dataset due to Line Cleaning

Location Name	Sample Name	Outfall Basin	Sample Type	Date	Arsenic (mg/kg dw)	Mercury (mg/kg dw)	Total HPAHs (µg/kg dw)	Total LPAHs (µg/kg dw)	Total cPAHs (µg TEQ/kg dw)	Bis (2-ethylhexyl) phthalate (µg/kg dw)	1,4-Dichlorobenzene (µg/kg dw)	Total PCBs (µg/kg dw)	Dioxins/furans TEQ (ng TEQ/kg dw)
A00918	L50935-11	Hanford #2 CSO	CS Inline	9/2/2009		4.83 J							
A00918	L50935-12	Hanford #2 CSO	CS Inline	9/2/2009									
A00918	L50935-13	Hanford #2 CSO	CS Inline	9/2/2009									
A00918	L50935-14	Hanford #2 CSO	CS Inline	9/2/2009									
A01010	L51483-3	Hanford #2 CSO	CS Inline	8/10/2010	3.6 J	0.30 J							
A01010	L51483-4	Hanford #2 CSO	CS Inline	8/10/2010									
EW08-B7-CB01	EW08-B7-CB01	Port SD, B-7	SD CB	12/7/2008			14,500 J	4,800	1,180 J	21,000 J	6 U		
EW08-B7-CB02	EW08-B7-CB02	Port SD, B-7	SD CB	12/7/2008			6,200 J	1,130	686 J	13,000	12 U		
EW08-B7-CB03	EW08-B7-CB03	Port SD, B-7	SD CB	12/7/2008			10,400 J	1,900 J	947 J	17,000	7 U		
EW08-B7-CB04	EW08-B7-CB04	Port SD, B-7	SD CB	12/7/2008			6,200 J	1,120 J	576 J	39,000	6 U		
EW08-B7-CB05	EW08-B7-CB05	Port SD, B-7	SD CB	12/7/2008			16,200 J	2,300	1,850 J	11,000	6 U		
EW08-B7-CB06	EW08-B7-CB06	Port SD, B-7	SD CB	12/7/2008			10,200 J	4,200	335 J	75,000	58 U		
EW08-B7-CB-COMP01	EW08-B7-CB-COMP01	Port SD, B-7	SD CB	12/7/2008	8 U	0.1	17,300 J	4,500 J	1,550 J	39,000 J	59 U	54	
EWWST7-040110-comp	EWWST7-040110-comp	Port SD, B11	SD Inline	4/1/2010									82.4
EW10-B11-MH01	EW10-B11-MH01	Port SD, B-11	SD Inline	3/31/2010								7,200 J	
EW10-B11-MH02	EW10-B11-MH02	Port SD, B-11	SD Inline	3/31/2010								320	
EW10-B11-MH03	EW10-B11-MH03	Port SD, B-11	SD Inline	3/31/2010								86,000	
EW10-B11-MH08	EW10-B11-MH08	Port SD, B-11	SD Inline	3/31/2010								860	
EW10-B11-MH09	EW10-B11-MH09	Port SD, B-11	SD Inline	3/31/2010								1,040	
EWWST7	EWWST7-032709	Port SD, B-11	SD Trap	3/27/2009								240	
	EWWST7-032709G	Port SD, B-11	SD Inline	3/27/2009	20	0.2	1,590	150	245	2,300	150 U	530	
	EWWST7-040110	Port SD, B-11	SD Trap	4/1/2010	20	0.18	10,900 J	860	1,210 J	24,000	330 U	740	
	EWWST7-040110G	Port SD, B-11	SD Inline	4/1/2010	30	0.32	7,900	610 J	894	17,000	160 U	1,800	
	EWWST7-111708G	Port SD, B-11	SD Inline	11/17/2008	20 U	0.37 J	3,510	430	503	6,600	61 U	780	
EW10-B37-MH01	EW10-B37-MH01	Port SD, B-37	SD inline	4/20/2010	30 U	0.45	12,100	4,400	1,410	10,000	34 U	180	80.8 J
EW10-B34-MH01	EW10-B34-MH01	Port SD, B34	SD inline	4/20/2010	88	1.27	8,000 J	470	1,020 J	3,600	30	10,100	784 J
EW08-B32-CB01	EW08-B32-CB01	Port SD, B32	SD CB	12/9/2008	20 U	0.6						660 J	
EW08-B32-CB02	EW08-B32-CB02	Port SD, B32	SD CB	12/9/2008	16	0.06 U						59 J	
EW08-B32-CB03	EW08-B32-CB03	Port SD, B32	SD CB	12/9/2008	8	0.08						20 U	
EW08-B32-CB04	EW08-B32-CB04	Port SD, B32	SD CB	12/9/2008	20 U	0.09						20 U	
EW08-B32-CB05	EW08-B32-CB05	Port SD, B32	SD CB	12/9/2008	13	12.7						670 J	

Table B4-1
Storm/CSO Solids Samples Removed from FS Dataset due to Line Cleaning

Location Name	Sample Name	Outfall Basin	Sample Type	Date	Arsenic (mg/kg dw)	Mercury (mg/kg dw)	Total HPAHs (µg/kg dw)	Total LPAHs (µg/kg dw)	Total cPAHs (µg TEQ/kg dw)	Bis (2-ethylhexyl) phthalate (µg/kg dw)	1,4-Dichlorobenzene (µg/kg dw)	Total PCBs (µg/kg dw)	Dioxins/furans TEQ (ng TEQ/kg dw)
EW08-B32-CB06	EW08-B32-CB06	Port SD, B32	SD CB	12/9/2008	9 U	0.18						310 J	
EW08-B32-CB-COMP01	EW08-B32-CB-COMP01	Port SD, B32	SD CB	12/9/2008	20 U	2.57	6,500	1,320 J	914	14,000	63 U	153	
EW08-B24-CB-COMP01	EW08-B24-CB-COMP01	Port SD, B24	SD CB	12/7/2008	7 U	0.08 U	6,400 J	1,600 J	811 J	11,000	48 U	39	
EW10-B7-MH01	EW10-B7-MH01	Port SD, B7	SD Inline	4/22/2010	10	0.03	1,350 J	170 J	120 J	980	6 U	40	
EW10-B24-MH01	EW10-B24-MH01	Port SD, B24	SD Inline	4/22/2010	31	0.44	2,880 J	300 J	423 J	3,100	7	1,200	
EW10-B32-MH01	EW10-B32-MH01	Port SD, B32	SD inline	4/20/2010	20	0.04	2,100 J	410 J	209 J	5,200	18 U	93	
EW10-MH-comp1	EW10-MH-comp1	Port SD, B1, B37	SD Inline	4/20/2010									110 J
EW10-B1-MH01	EW10-B1-MH01	Port SD, B1	SD Inline	4/22/2010	15	0.13	8,600 J	2,800	667 J	11,000	6 U	260	148 J
EW10-B16-MH01	EW10-B16-MH01	Port SD, B16	SD Inline	4/22/2010	30	0.26	4,110 J	380 J	233 J	2,000	6 U	2,800	44.5
CB27b	CB27B-081210	Hanford/Lander/Diag CSO	CS CB	08/12/10	5	0.1 U	20,900 J	2,400	2,560 J	1,400,000 B	2,100 U	330	
CB141	CB141-050409	Port SD, B37	SD CB	05/04/09	10 U	0.39 J	9,910 J	3,310 J	752 J	16,000	330 U	131 J	
CB68	CB68-042805	Port SD, B7	SD CB	04/28/05	10 U	0.1 U	440 J	330	163	8,800	180 U	67	
CB71	CB71-052505	Port SD, B16	SD CB	05/25/05	8	0.07	1,830	400	218	5,300	220 U	58 J	
CB66	CB66-032505	Port SD, B37	SD CB	03/25/05	13	0.28	7,010 J	3,740 J	1,030 J	22,000	1,100 U	140 Y	
CB65	CB65-032205	Port SD, B11	SD CB	03/22/05	10	0.27	3,030 J	420	289 J	19,000	140 U	2,110	25.6 J
CB65	CB65-112910	Port SD, B11	SD CB	01/29/10	7.7	0.23	3,060 J	420	666 J	36,000	230 U	3,000	
CB60	CB60-041012	Lander SD	SD CB	04/10/12	10 U	0.11	5,360	1,450	506	46,000 B	170 U	52	
CB22	CB22-030204	Hanford/Lander/Diag CSO	CS CB	03/02/04	20 U	0.16	39 U	39 U	35 U	410	520,000	3,200	
CB19	CB19-070910	Hanford/Lander/Diag CSO	CS CB	07/09/10	10 U	0.31	2,285 J	305 J	199 J	30,000	160 U	210 J	
CB124	CB124-082908	Port SD, B37	SD CB	08/29/08	9	0.17	6,410	17,900 J	748	60,000	770 U	120	

Notes:
* Sampled from private lines on Rainier Commons
µg/kg – micrograms per kilogram
BEHP – bis(2-ethylhexyl)phthalate
cPAH – carcinogenic polycyclic aromatic hydrocarbon
CSO – combined sewer overflow
dw – dry weight
FS – Feasibility Study
HPAH – high-molecular-weight polycyclic aromatic hydrocarbon
J – estimated value
LPAH – low-molecular-weight polycyclic aromatic hydrocarbon
mg/kg – milligrams per kilogram
ng/kg – nanograms per kilogram
PCB – polychlorinated biphenyl
SD – storm drain
TEQ – toxic equivalent
U – non-detect

Table B4-2
CSO Solids Samples Removed from FS Dataset due to Source Control of 1,4-Dichlorobenzene

Location Name	Sample Name	Outfall Basin	Sample Type	Date	1,4-Dichlorobenzene (µg/kg dw)
A00802	L48945-6	Hanford #2 CSO	Inline CS	9/1/2009	52,900
A00803	L48945-5	Hanford #2 CSO	Inline CS	9/1/2009	547
A00805	L48945-1	Hanford #2 CSO	Inline CS	9/1/2009	8,070
A00805	L48945-2	Hanford #2 CSO	Inline CS	9/1/2009	9,090
A01101	L52476-1	Hanford #2 CSO	Inline CS	1/20/2011	24,900
ST805-L1-1	L50498-1	Hanford #2 CSO	Trap CS	4/23/2009	628
ST805-L1-3	L50498-3	Hanford #2 CSO	Trap CS	2/19/2010	60,900
ST805-L2-1	L50498-4	Hanford #2 CSO	Trap CS	2/19/2010	3,680

Notes:
All other data analyzed were retained. Only 1,4-dichlorobenzene was removed as discussed in Section 3.2.
µg/kg – micrograms per kilogram
CS – combined sewer
CSO – combined sewer overflow
dw – dry weight
FS – Feasibility Study

PART 5: CONSIDERATIONS FOR MANAGEMENT OF DREDGING RESIDUALS

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LIST OF ACRONYMS AND ABBREVIATIONS

μg/kg	microgram per kilogram
BAZ	biologically active zone
BMP	best management practices
COC	contaminant of concern
dw	dry weight
ENR	enhanced natural recovery
EW	East Waterway
FS	Feasibility Study
MNR	monitored natural recovery
NRC	U.S. National Research Council
PCB	polychlorinated biphenyl
RAL	remedial action level
RMC	residuals management cover
SWAC	spatially-weighted average concentration
TOC	total organic carbon
USACE	U.S. Army Corps of Engineers

1 INTRODUCTION

This appendix provides a summary of considerations related to the management of dredging residuals generated during dredging activities proposed in East Waterway (EW) Feasibility Study (FS) remedial alternatives. The generation of dredging residuals is inherent to the dredging process, due to the loss and re-deposition of sediment during each dredging pass. Generated dredging residuals can result in elevated surface sediment contaminants of concern (COC) concentrations and associated risks that exceed the project performance goals. Therefore, dredging best management practices (BMPs) will be needed to meet risk-based performance goals following remediation. During remedial design, an adaptive residuals management decision framework will be developed that will specify triggers (e.g., post-dredging concentrations), and resulting residuals management measures (e.g., the placement of residuals management cover [RMC]) that will be implemented as part of dredging.

This appendix summarizes the state of knowledge of dredging residuals, including a description of the processes that generate residuals and residuals management approaches that have been used at other dredging sites (Section 2). Additionally, this appendix summarizes and compares dredging BMPs and contingency measures that are likely to be part of the residuals management decision framework developed in design (Section 3). Finally, this appendix summarizes the common assumptions selected for residuals management for modeling and costing the FS alternatives (Section 4).

2 DREDGING RESIDUALS

Meeting remedial objectives for a contaminated sediment remediation program is often defined by the level of contamination remaining in the surficial sediments after the remediation effort, rather than by the mass of contaminants removed. Reliable characterization and an accurate dredging prism design are key elements to the success of a remediation effort; however, complete removal of contaminated sediments within an aquatic environment is limited by the technical and logistical limitations of the environmental dredging equipment and methods, and the characteristics of the aquatic environment.

2.1 Types of Dredging Residuals

Residuals are grouped into two categories: 1) undisturbed residuals, also referred to as “missed inventory”; and 2) generated residuals (Figure 2-1).

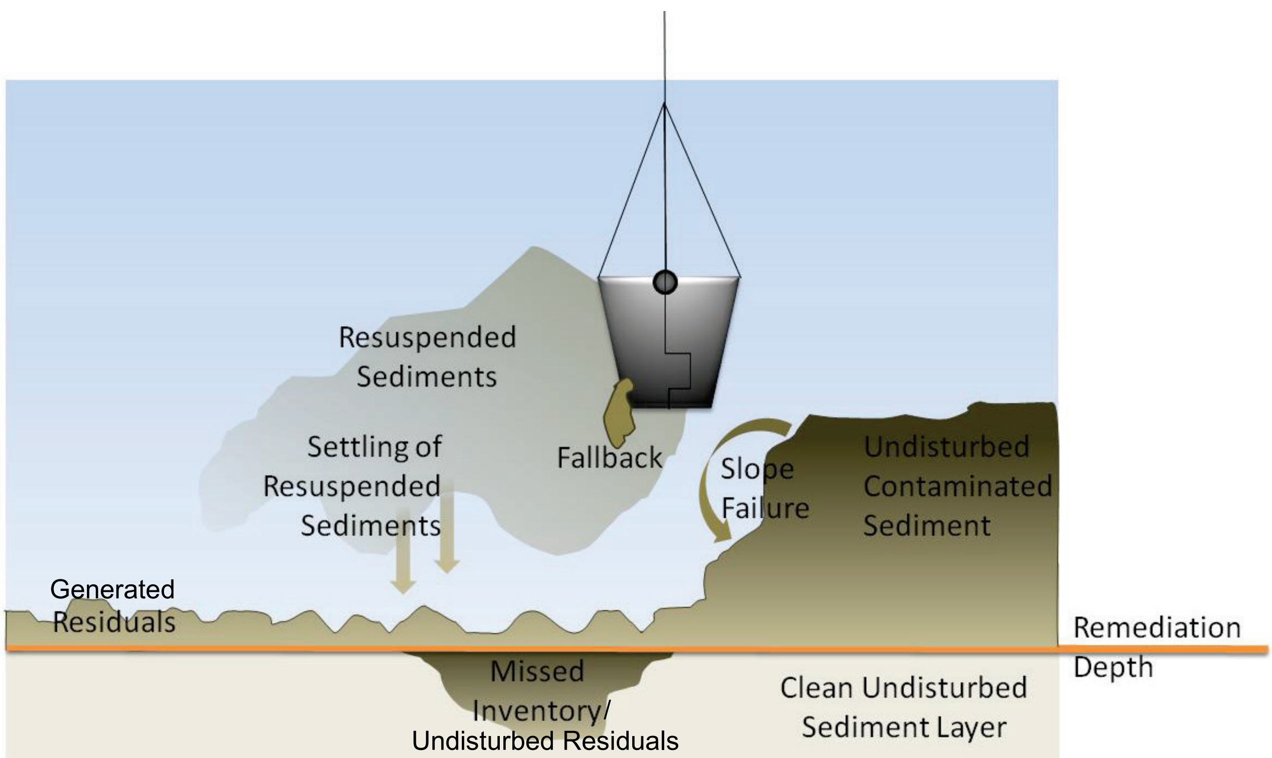

Figure 2-1

Residuals from Sediment Remediation Processes with Mechanical Dredging

Undisturbed residuals refers to contaminated sediments that have been uncovered but not removed. The primary causes of undisturbed residuals are: 1) incomplete characterization, resulting in inaccurate remediation designs (missed inventory); and 2) incomplete dredging due to technical and logistical limitations (e.g., structural setbacks). In an effort to minimize the potential for undisturbed residuals, lateral and vertical characterization of chemical and geotechnical gradients will be completed during remedial design for the EW. Although a certain amount of undisturbed residuals is anticipated due to technological limitations of dredging equipment, geotechnical and structural stability, and limitations in contaminant characterization, this memorandum focuses on generated dredge residuals and associated BMPs. Addressing undisturbed residuals is important for achieving dredging goals, and undisturbed residuals will be investigated during post-dredge sampling and addressed as part of contingency actions.

Generated dredge residuals are a byproduct of all dredging operations and result from the physical processes of moving sediment underwater with large equipment. Both hydraulic and mechanical dredging activities generate residuals, although this memorandum focuses on mechanical dredging methods that are anticipated to be used in the EW. In general, mechanical dredging is expected to control residuals better than hydraulic dredging in sediments containing debris, loose rock, or vegetation (USACE 2008a).

The U.S. Army Corps of Engineers (USACE; 2008a) describes the physical processes of the different types of mechanical dredges and the associated generated residuals (Figure 2-1 depicts the generation of residuals during mechanical dredging). Sediments are inherently mobilized during the dredging process; they are resuspended in the water column as the dredging bucket penetrates the sediment surface, and as clumps of sediment fall from the equipment as it moves across the sediment or through the water. The degree of disturbance is dependent on the conditions of the site (e.g., slope, current, structures, and presence of bedrock and debris), the type of bucket, and operator performance (e.g., speed, overfilling, or over-penetration of the bucket). Incomplete closure of the bucket from debris and rocks will result in sediment leaking from the bucket. Additionally, during dredging some amount of fallback, sloughing, or sediment slope failure following a dredge cut is also to be expected. After dredging, a new surficial sediment layer is formed from the accumulation of disturbed sediments and the settling of resuspended sediments, referred to as the generated dredging residuals layer.

2.2 Relevant Studies and Guidance

Multiple case study documents and guidance documents related to the management of dredging residuals have been published in the past decade. These documents discuss how to estimate the quantity of dredging residuals, dredging operational factors and site conditions that affect the generation of residuals, and approaches to adaptively manage residuals following dredging through monitoring and contingency actions.

The U.S. Environmental Protection Agency regards post-dredging residuals as a high research priority in its Superfund program (EPA 2009). The USACE Engineering and Research Development Center led scientific workgroup meetings and subsequent publications focusing on post-dredging residuals. This scientific workgroup contributed to multiple peer-review publications and scientific conferences, and two USACE guidance documents: *The Four Rs of Environmental Dredging: Resuspension, Release, Residual, and Risk* (USACE 2008b) and *Technical Guidelines for Environmental Dredging of Contaminated Sediments* (USACE 2008a). In addition to efforts led by USACE, the U.S. National Research Council (NRC) Committee on Sediment Dredging at Superfund Megasites developed the *Sediment Dredging at Superfund Megasites: Assessing the Effectiveness* report in 2007 (NRC 2007), which focuses particular attention on the assessment and management of post-dredging residuals.

2.2.1 Estimating Generated Residuals

A key source of case study information is Patmont and Palermo (2007), which summarized case histories and calculated the amount of generated residuals relative to the mass of contaminant dredged for multiple projects. This work was subsequently updated by Desrosiers and Patmont (2009) and Patmont, LaRosa, and Narayanan (2015). These studies have examined more than 50 sediment remediation programs with post-dredge residuals data to assess dredging effectiveness and residuals generation estimates. These documents developed the methods used for estimating dredging residuals used in this FS (see also FS Appendix B, Part 3A). They identified more than 15 environmental dredging projects that had relatively robust pre- and post-dredge datasets, enabling reliable mass-balance calculations to estimate the loss of sediment during dredging. These sites represent different areas of North America, various types and concentrations of COCs, and a range of project sizes and dredging methodologies. Patmont and Palermo (2007) and Desrosiers and Patmont

(2009) then developed bounding-level estimates of residuals using a mass-balance approach by comparing pre-dredge data to post-dredge data. They summarize the factors that impact generation of residuals as follows:

- Contaminant concentrations in residuals approximate the average concentration of COCs in dredged material.
- Generated residuals represent the majority of residuals contaminant mass, while undisturbed residuals contributed a minor amount of contaminant mass.
- Generated residuals range from 1% to 11% and averaged 5% of the mass that was present in the last dredge cut.

2.2.2 Operational Factors and Site Conditions that Affect Generated Residuals

Operational factors and site conditions that affect residuals were discussed in a number of the documents reviewed for this summary. Patmont and Palermo (2007) found that the average dry density of the sediments and the presence of debris and/or bedrock or hardpan were two important factors impacting the mass of contaminants in the residuals layer. Low solids content and the presence of more debris, bedrock, or hardpan contribute to higher generated residuals. NRC (2007) also describes that the magnitude of residuals can be higher in the presence of debris or when site conditions make it infeasible to overdredge into clean material. Cieniawski et al. (2009) found that low residuals concentrations were achievable in an area with extensive bedrock only through extensive re-dredging using specialized hydraulic dredging equipment.

Fuglevand and Webb (2009) highlight the equipment and operational factors that influence residuals, including equipment selection, size of the dredge bucket or cutter head, the accuracy of positioning, and the overlap of dredge bucket cuts. Additional operational factors discussed in these documents include number of dredge passes, selection of intermediate and final cutline elevations, allowable overdredging, dredging production rates, slopes and sloughing, experience of operator, and sequence of operations.

2.2.3 Residuals Management Decision Frameworks and Contingency Measures

A primary focus of case study and guidance documents is the adaptive management decision framework and contingency measures that can be implemented to manage dredging residuals. USACE (2008b) summarizes potential residuals management contingency actions as follows:

> *Generated residuals and undisturbed residuals should be managed based on an operational evaluation of what can practically be done (i.e., cost benefit analysis). Management options include:*
>
> - *Operational controls to reduce residuals as a part of operations*
> - *If cleanup levels are not met – possible management options include:*
>   - *Monitored natural recovery – consider burial and mixing*
>   - *Residual covers (e.g., 6 in. of sand or topsoil) – long-term intention may be sediment dilution, but can also be designed and constructed as necessary to provide an isolation component*
>   - *Engineered caps – intention is physical and chemical isolation*
>   - *Re-dredging (if practicable; re-dredging will likely be less effective for generated residuals, but may be a reasonable management option if significant thicknesses of undisturbed residuals are present)*

USACE (2008a) emphasizes that the nature and extent of residuals and site conditions should determine residuals management actions used following dredging. NRC (2007) reviewed a number of case studies of environmental dredging and highlight the use of placing a RMC to manage residuals as follows:

> *Generally, control of residuals is achieved by adding backfill or thin-layer capping; this has clear advantages in achieving bulk sediment contaminant concentration targets even if the backfill layer is intermixed with the residual sediments.*

Patmont and Palermo (2007) reached a similar conclusion regarding the use of residuals management methods as follows:

> *Performance requirements for multiple passes of the dredge to achieve a very low residual concentration have often been inefficient and costly, with little or no discernable benefit in the form of reduced generated residual concentrations or thicknesses. Placement of a residual cover or cap of clean material has provided greater certainty in achieving residual performance standards at the case study project sites.*

Other studies summarized project-specific examples of residuals management sampling and adaptive management approaches. McGee et al. (2011) and Cieniawski et al. (2009) provided case studies for cleanups that relied primarily on hydraulic dredging in riverine environments shallower than the EW. For the Fox River OU3 project, a tiered approach to sampling and triggering residuals management re-dredging and/or cover was used to achieve project objectives (McGee et al. 2011). For the Ashtabula River project, an extensive re-dredging strategy with specialized hydraulic dredging equipment was used (Cieniawski et al. 2009). For the Esquimalt Graving Dock Remediation project, an intensive sampling program and combined approach of selective mechanical redredging and placement of RMC were employed, showing placement of RMC to be more effective at reducing site-wide concentrations than additional redredge passes after completion of production dredging (Berlin et al. 2017).

3 RESIDUALS MANAGEMENT STRATEGIES

Successful dredging residuals strategies for contaminated sediment remediation projects commonly involve an adaptive approach that is based on monitoring data collected during and after dredging. The monitoring approach relies on detailed data relevant to potential residuals generation are gathered in dredge prisms during remedial design sampling. The residuals management decision framework for EW dredging will be established in remedial design and will include appropriate dredging performance standards and controls during dredging, post-dredging monitoring methods and decision criteria, and contingency residuals management measures such as RMC and re-dredging. Table 3-1 summarizes common residuals management tools used for environmental dredging, which includes BMPs used during dredging and post-dredging residuals management actions. The effectiveness, implementability, and cost of the residuals management tools are discussed to provide considerations for developing the residuals management framework during remedial design, and to provide context for the FS assumptions that are applied to the remedial alternatives.

Table 3-1
Summary of Tools for Management of Generated Residuals

Residuals Management Tool	Description	Effectiveness	Implementability	Cost
Standard BMPs specified in typical environmental dredging projects used during dredging, transport, and offloading	Dredging, transport, and offloading BMPs (e.g., equipment, operational controls, and monitoring) are typically defined in the Remedial Design phase. Standard BMPs include the following (see also FS Section 7.5.3): • Select appropriate dredge method and adjust methods in changing site conditions (e.g., dry excavation, environmental bucket, or digging bucket). • Select dredge methods to increase accuracy and minimize releases. Use equipment positioning methods that provide real-time positioning. Minimize slope failure; preclude underwater stockpiling or re-grading. • Perform tiered water quality monitoring during dredging and barge dewatering activities. Adjust dredging methods (e.g., cycle times) as necessary based on water quality measurements. • Control and filter release of barge effluent. • Use spill prevention measures during offloading and transloading.	• Standard BMPs are used to minimize sediment loss during environmental dredging activities, while some also help to ensure that removal extents are achieved. • Project-specific cleanup goals (e.g., RALs) may be achievable using standard BMPs, although additional residuals management tools are often required in some areas.	• Standard BMPs are a routine element of remedial dredging operations and are considered highly implementable. • Environmental closed buckets are implementable for softer sediment but are less effective at removing denser sediments.	Standard BMPs are the least costly, relative to the other residuals management tools.
Specialized BMPs specified in some environmental dredging projects	Specialized BMPs are sometimes specified during Remedial Design. Use of specialized BMPs may sometimes be effective at reducing suspended sediments (depending upon site conditions), but typically comes with trade-offs to production rates, costs, and design and construction complexity. Specialized equipment may include the following: • Silt curtain • Watertight barge and treatment of barge effluent	• Specialized BMPs have not been demonstrated to be better at limiting residuals than standard BMPs. • Project-specific cleanup goals (e.g., RALs) may be achievable using standard and specialized BMPs, although additional residuals management tools are often required in some areas. • Specialized equipment has not proven itself to be consistently more effective than standard BMPs at reducing loss of sediment during dredging activities under all site conditions; however, specialized equipment has the potential to reduce sediment loss when applied to appropriate site conditions.	• Site conditions (e.g., physical conditions of sediments, currents) dictate whether specific specialized equipment is implementable. • Full-length silt curtains are not considered implementable in high velocities, large tidal elevation changes, or deeper water depths (e.g., greater than 30 feet of water depth). • Watertight barges and water treatment are implementable but result in substantially more complex water management systems.	Additional specialized BMPs are moderately costly compared to other residuals management tools. Specialized BMPs could significantly increase base construction costs (e.g., collection and treatment of barge effluent).

Table 3-1

Summary of Tools for Management of Generated Residuals

Residuals Management Tool	Description	Effectiveness	Implementability	Cost
Monitored Natural Recovery	MNR is the process by which contaminant concentrations in sediment are reduced through a combination of physical, biological, and chemical processes so that surface sediment concentrations are reduced to acceptable levels within a specified timeframe. Natural recovery processes that could reduce generated residuals concentrations over time in the EW include sedimentation and mixing. MNR includes monitoring to measure progress toward performance goals, and adaptive management to determine if additional contingency remedial actions are necessary.	• MNR is similar to no action (following dredging), but includes monitoring and potential longer-term contingency actions to achieve performance goals. • MNR is likely to be more effective for concentrations marginally above performance goals in the EW, but is dependent on rates of sedimentation as well as mixing with deeper and cleaner undredged sediment.	• MNR is highly implementable following construction. • Potential contingency actions could lead to additional mobilizations for residuals management.	Low cost compared to other post-construction residuals management tools.
RMC over generated residuals	RMC is the placement of a thin layer of clean sand, similar to enhanced natural recovery cover, to cover and mix with the generated residuals in order to lower the surface concentrations post-construction. RMC layer thickness is typically 6 to 12 inches. The need for RMC is typically determined based on post-dredging sediment sampling.	• RMC placement is a common method for addressing elevated generated dredge residuals concentrations, and is considered highly effective based on demonstrated success at a wide range of sites. • RMC placement is typically used when standard BMPs are not sufficiently effective at minimizing the amount of generated residuals. • RMC placement provides a relatively high degree of predictability and confidence for post-construction concentrations because the thickness and chemical concentration of RMC materials is established prior to use. • RMC may be less effective for thick residuals or very high residuals concentrations.	• RMC is implementable and is commonly used to manage generated residuals in remedial dredging projects. • RMC placement adds construction time to environmental dredging above standard BMPs, but less than re-dredging. • The need for RMC placement would be determined based on post-dredge sampling.	RMC is a moderately costly post-construction residuals management tool, compared to re-dredging. Guidance documents identify RMC as very cost effective.
Re-dredging of generated residuals	Re-dredging is the attempted removal of the layer of generated residuals to lower the surface concentrations, should the surface concentration from generated residuals be over an unacceptable threshold concentration. 1 foot of sediment would likely be targeted for dredging and 2 feet of sediment would likely be removed when including allowable overdredge to account for construction tolerance.	• Re-dredging of thick layers of generated residuals may be effective (e.g., greater than 1 foot), but would have limited effectiveness for thin deposits due to the inability to capture the material in the dredge bucket. • The effectiveness of re-dredging generated residuals is highly uncertain due to the difficulty of capturing a thin layer of low-density generated residuals by mechanical dredging methods. Generated residuals are typically predominantly fine-grained sediment (silts and clays) that have been disturbed during dredging, and suspended into the water column, forming a very low-density nepheloid layer.	• Re-dredging is implementable and is sometimes used to manage generated residuals in remedial dredging projects, when the residuals layer is very thick or concentrations are very high. • Effective removal of a thin layer of generated residuals is challenging to implement due to the limits of dredge accuracy, difficulty in capturing low-density material, and the potential to displace and suspend residuals as a result of dredge bucket action. • Re-dredging could add multiple construction seasons due to the low production rate typical of performing thin dredge cuts.	Re-dredging is many times more expensive (approximately one order of magnitude) than the other residuals management tools.

Notes:
BMP – best management practice
EW – East Waterway
FS – Feasibility Study
MNR – monitored natural recovery
RAL – remedial action level
RMC – residuals management cover

3.1 Best Management Practices During Dredging

During environmental dredging, techniques, controls, and monitoring feedback are used to improve the accuracy of dredging (i.e., reduce the quantity of undisturbed residuals) and to minimize releases (i.e., generated residuals). Operational controls impose limitations on the operation of the equipment being used for removal activities. Standard BMPs are defined as those that are widely used in environmental dredging projects in the Puget Sound region. Specialized BMPs are defined as those that are used infrequently in the Puget Sound region and are less likely to be used on the EW project. All BMPs will be determined in remedial design.

3.1.1 Standard BMPs

For mechanical dredging, operational control BMPs that reduce re-suspension and loss of contaminated sediments may include the following (see also FS Section 7.5.3):

- **Select appropriate dredge equipment and adjust methods in changing site conditions**
  - Conduct intertidal sediment and shoreline bank soil excavation "in the dry" to the degree reasonably possible using land-based equipment.
  - Include an option for an environmental or sealed bucket, where practicable (proper sediment conditions exist).
  - Properly select the dredge bucket for site conditions (i.e., soft sediment versus debris and/or hard digging) to maximize sediment capture and optimize fill efficiency. Adjust methods in changing site conditions.
- **Select dredge methods to increase accuracy and minimize releases**
  - Perform dredging to the design dredge elevation in a single dredge event, as verified by periodic bathymetric surveys. Use sub-foot accuracy GPS for accurate bucket positioning.
  - Require a debris sweep prior to dredging in known debris areas (debris caught in dredging equipment can cause additional re-suspension and release of contaminated sediments).
  - Minimize the potential for slope failures by maintaining stable side slopes during dredging, including limiting the cut thickness of initial cut depths to avoid sloughing of the cut bank.

- Start dredging in upslope areas and move downslope to minimize sloughing.
- Slow the rate of dredge bucket descent and retrieval (increasing dredge cycle time).
- Limit operations during relatively high water velocity conditions (turbulence in the vicinity of the dredge bucket during high flow conditions can cause additional re-suspension and release of contaminated sediments).
- Prevent “sweeping” or leveling by pushing bottom sediments around with dredge equipment to achieve required elevations.
- Prevent interim stockpiling of dredge material under water.
- Prevent the overfilling of conventional clamshell (i.e., “open”) buckets.
- Require the slow release of excess bucket water at the water surface.
- Contain drippage during the overwater swing of a filled bucket (e.g., by placing an empty barge or apron under the swing path during offloading or loading containers directly on barges).

- **Water quality monitoring**
  - Perform water quality monitoring during dredging to adaptively manage dredging operations and to comply with water quality requirements.
  - Adjust dredging methods (e.g., cycle times) as necessary based on water quality measurements.
- **Control dewatering operations**
  - Control and reduce the silt burden in runoff from barges using weirs, filtration, and settling.
  - Time water discharges to maximize settlement and filtration efficiency.
  - Prevent overfilling of barges to minimize spillage from barges.
- **Control transload operations**
  - Use barges that can be watertight during transit and transloading to collect and treat generated water.
  - Control and reduce the silt burden in runoff from rehandling areas, using filtration.
  - Use spill plates and spill prevention measures.

The effectiveness, implementability, and cost for standard BMPs, operational controls, and monitoring during dredging are presented in Table 3-1. Standard BMPs have been developed over the course of many environmental dredging projects, which, depending on site-specific factors, can be effective at reducing impacts to the environment during dredging and reducing the quantity of generated dredging residuals. Dredge residuals predictions for the EW and project experience shows that post-dredging performance goals (e.g., remedial action levels) are likely to be achieved in some locations and not achieved in other locations using only standard BMPs.

Standard BMPs are routinely implemented on environmental dredging projects in Puget Sound and are the least costly of the residuals management tools discussed in this appendix.

3.1.2 Specialized BMPs

Specialized BMPs have been developed for environmental dredging projects but have been used on a more limited basis. Specialized BMPs include silt curtains (a fabric enclosure to trap suspended sediment within the construction zone), and active treatment of barge effluent during dewatering operations.

Silt curtains and screens are specialized BMPs that have proven effective in reducing surface water turbidity in relatively quiescent environments and are a common BMP used to retain suspended sediment plumes at environmental dredging sites located in low-energy environments without deep water (Francingues and Palermo 2005). Water passes below or around fabric curtains because they are not typically sealed with the bottom. Water also discharges around the curtains when they are opened to allow the necessary passage of work equipment. As discussed in Bridges et al. (2010), based on a review of the available data, there is uncertainty as to whether silt curtains are effective in retaining contaminants within the curtain footprint, and there are also concerns that contaminants can migrate below the bottom of the curtain while the curtain is in place or upon curtain removal. Patmont and Palermo (2007) note that there are possible adverse impacts of enclosures on generated residuals because they contain suspended sediments and therefore concentrate residuals within the enclosure footprint.

Use of watertight barges to contain sediment and water and associated water treatment has been employed in recent environmental dredging projects on the Lower Duwamish Waterway during removal in Early Action Areas where high levels of contaminants were present in the sediment. The purpose of containing water on watertight barges is to help meet water quality standards for dissolved and suspended constituents. This approach can, to a limited degree, also reduce the load of suspended sediment in the construction area, thereby reducing the mass of suspended sediment redeposited as generated residuals; however, this would not likely reduce the sediment load substantially more than the standard BMP requirement of filtering barge runoff prior to discharge.

Table 3-1 summarizes the effectiveness, implementability, and cost for specialized BMPs. These BMPs have not been shown to significantly reduce the mass of generated residuals. Silt curtains could actually increase the thickness of generated residuals that settle in the dredging area by concentrating suspended solids. Water treatment can reduce the total mass of suspended sediment in the water column, but the contribution of dewatering activities to suspended solids load is typically small compared to the disturbance of the sediment by the dredge bucket. Therefore, use of watertight barges to contain sediment and water is unlikely to significantly reduce the mass of generated residuals.

In addition, these specialized BMPs are both difficult to implement and costly. Silt curtains would be a significant challenge to implement in the tidally influenced and deep waters of the EW, and use of water treatment would require the construction and maintenance of a complex and expensive treatment system.

3.2 Post-dredging Residuals Management Contingency Actions

BMPs employed during dredging will reduce the quantity of generated residuals, compared to standard maintenance dredging practices; however, the post-dredging performance goals are unlikely to be met in all locations. Therefore, a residuals management decision framework with contingency actions will be developed during remedial design. The decision framework will include a sampling plan and COC-specific triggers for contingency actions. A typical residuals management decision framework is tiered with appropriate contingency actions targeted for specific post-dredging conditions. The tiered framework could include no action, monitored natural recovery (MNR), RMC, and/or re-dredging for progressively higher post-dredging concentrations or thicker deposits of dredging residuals. As discussed below, re-dredging is only likely to be cost effective for very high concentrations or thick deposits of residuals.

The following sections describe the residuals management contingency actions that are commonly used on dredging projects for areas above contingency action criteria.

3.2.1 Monitored Natural Recovery

MNR is the process by which contaminant concentrations in sediment are reduced through a combination of physical, biological, and chemical processes so that surface sediment concentrations are reduced to acceptable levels within a specified timeframe. Natural recovery processes that could reduce generated residuals concentrations over time in the EW include sedimentation and mixing with recently deposited and deeper, undredged sediments. MNR includes monitoring to measure progress toward performance goals, and adaptive management to determine if additional contingency remedial actions are necessary. MNR as a remedial technology is described in FS Section 7.2.3.

The effectiveness, implementability, and cost for MNR placement are presented in Table 3-1. In the EW, the concentration in the biological active zone is likely to decrease over time due to natural recovery processes (e.g., mixing and sedimentation). In addition, MNR includes monitoring and potential contingency actions to meet performance goals. Contingency actions could include additional monitoring, placement of RMC, or re-dredging. MNR is likely to be more effective for concentrations marginally above performance goals in the EW, but is dependent on rates of sedimentation and mixing.

MNR is highly implementable. Monitoring can be incorporated into the long-term post-construction monitoring program (FS Appendix G). However, MNR could result in an additional mobilization should contingency actions become necessary.

MNR is the lowest-cost option of the post-dredging residuals management tools.

3.2.2 Residuals Management Cover

RMC refers to the placement of sand, similar to enhanced natural recovery (ENR), following dredging to reduce the effect of residuals on surface sediment concentrations. The short- and long-term mixing of the clean cover layer into underlying residuals can achieve remedial action levels and accelerate the natural recovery process in the biologically active zone. EW sediments are subject to regular mixing as a result of bioturbation and propeller wash (propwash) forces, and therefore the clean cover layer is anticipated to mix relatively quickly to enhance the recovery process and lower surface sediment concentrations, as illustrated in Figure 3-1. For dredging of the EW, which will take place over many construction seasons, RMC placement would likely occur at the end of all dredging, but depends on the decision framework developed in design.

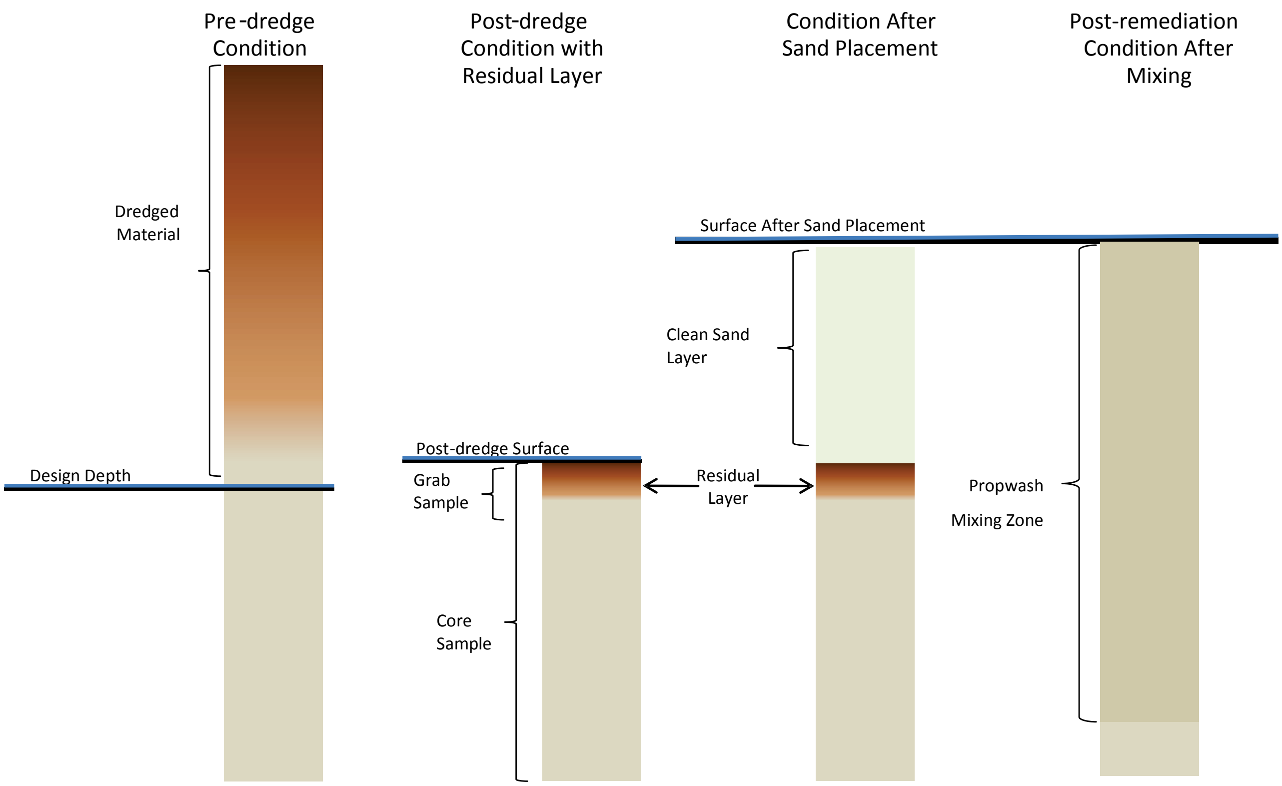

Figure 3-1

Conceptual Sediment Profiles to Illustrate Required Dredging, Placement of Residuals Management Sand Cover, and Post-remediation Mixing

The effectiveness, implementability, and cost for RMC placement are presented in Table 3-1. Case studies and guidance documents have highlighted that RMC has been effectively used for remediating thin layers of residuals. RMC has generally provided greater certainty in achieving project remedial objectives than natural recovery or re-dredging. RMC is less certain for remediating thick residuals layers or very high residuals concentrations where mixing would result in persistent elevated concentrations of contaminants.

Maintaining the native organic carbon content in the biologically active zone (BAZ) is important for reducing bioavailability of hydrophobic organic compounds that may persist at low levels after remediation (e.g., polychlorinated biphenyls [PCBs]). RMC is typically specified with low organic carbon content to minimize loss to the water column and minimize the generation of turbidity plumes during construction; however, total organic carbon (TOC) levels have rebounded to pre-construction levels in the EW and at nearby sites in 1 to 2 years following construction. Table 3-2 presents the average, maximum, and minimum TOC percentages for placement areas in the EW (following the 2005 Phase 1 Removal and RMC placement), and in the Lower Duwamish Waterway (Duwamish/Diagonal removal and capping/ENR areas and Slip 4 removal and backfill). All year 0 post-construction data collected show low TOC concentrations immediately after construction. In year 1 post-placement, three of four datasets have TOC concentrations in the range of pre-construction concentrations. By year 2 post-placement, all four areas increased to within the range of pre-construction concentrations. The mechanisms for TOC rebound are thought to be: a) biological activity during benthic recolonization; b) sedimentation of sediment with higher TOC concentrations; and c) mixing with native sediments (in the case of RMC and ENR).

Table 3-2

Total Organic Carbon Over Time in Sand Placement Areas for the EW and Nearby Areas

Parameter	Summary of %TOC Results						
	Pre-construction	Year 0 Post-placement	Year 1 Post-placement	Year 2 Post-placement	Year 3 Post-placement	Year 4 Post-placement	Year 5 Post-placement
East Waterway - Phase 1 Removal and RMC Area[a]							
Average	1.4		1.1	1.1	1.5		
Maximum	2.3		2.3	1.9	2.8		
Minimum	0.6		0.4	0.5	0.1		
n	29		15	17	11		
Duwamish Diagonal Capping and ENR Areas[b]							
Capping Area							
Average	2.6	0.3	1.9	1.6	1.7	1.7	1.7
Maximum	9.0	0.6	5.7	3.0	2.9	3.6	2.8
Minimum	0.2	0.0	0.1	0.1	0.3	0.1	0.2
n	43	7	7	8	8	8	8
ENR Area							
Average	1.5	0.1	0.3	1.1	0.9	1.3	
Maximum	1.8	0.3	0.6	1.5	1.3	1.7	
Minimum	1.1	0.0	0.1	0.7	0.3	0.6	
n	7	7	7	7	7	7	
Slip 4 Early Action Area[c]							
Average	2.9	0.2	2.9	3.2	2.6		
Maximum	11.5	0.4	3.8	6.3	6.9		
Minimum	0.8	0.1	1.5	0.8	0.2		
n	41	12	13	33	26		

Notes:

a. All data from East Waterway Phase 1 Removal Action Recontamination Monitoring Data Reports (Windward 2007, 2008a, 2008b).
b. All data from Lower Duwamish Waterway Feasibility Study (LDW FS) Dataset (AECOM 2012). Pre-construction data for the Duwamish Diagonal capping area were based on the LDW FS baseline dataset and were collected to support cleanup of the Early Action Area. All other data were collected from sampling stations established for the purpose of long-term cap and ENR monitoring.
c. Pre-construction data were based on the LDW FS baseline dataset (AECOM 2012) and were collected to support cleanup of the Slip 4 Early Action Area. All other data were collected for the purpose of long-term monitoring (Integral 2015).

Blank cell – data not collected
ENR – enhanced natural recovery
EW – East Waterway
n – count
RMC – residuals management cover
TOC – total organic carbon

RMC is highly implementable and is commonly employed in the Puget Sound region for environmental dredging projects and for meeting anti-degradation standards for maintenance dredging projects. RMC placement adds construction time to remediation projects, but less than re-dredging.

RMC is moderately costly compared to the other residuals management tools, and guidance documents identify RMC as very cost-effective for managing dredging residuals.

3.2.3 Re-dredging

Re-dredging is another commonly employed residuals management contingency measure, typically reserved for undisturbed residuals, areas of very high generated residuals concentrations, or areas with thick generated residuals deposits. Additional dredging of discrete areas can be conducted to remove contaminant mass left behind after the first round of dredging operations are complete. Re-dredging is also referred to as a "cleanup pass" and is usually conducted in such a way as to attempt to remove only a thin surficial layer of material, with the intent of removing the residuals layer and a minimal thickness of underlying clean material. Due to typical dredge equipment tolerances, 1 foot of sediment would typically be targeted for dredging and 2 feet of sediment would typically be removed when including an allowance for overdredging.

Re-dredging has had mixed success on remediation projects. Patmont and Palermo (2007) report that performing multiple passes and cleanup passes to control residuals have often been inefficient and ineffective. Contingent cleanup passes are typically reserved for remediation areas above contingency re-dredge criteria, where COC concentrations are usually several times above action levels and are not complicated by underlying bedrock, hardpan surfaces, or very soft sediments.

Re-dredging is implementable; however, accurately targeting a thin layer of low-density sediment in deep water is challenging and may require reduced dredging cycle times, slower production rates, and unnecessary removal of a relatively large volume of clean overdredge material. Re-dredging can add multiple dredging seasons to a large remediation project.

Re-dredging is the most costly of the residuals management measures, and many times more costly than RMC placement.

4 CONCEPTUAL QUANTITATIVE ANALYSIS

A conceptual quantitative analysis was performed to compare residuals management contingency actions to inform FS modeling, construction timeframe, and cost estimates. The quantitative analysis may also inform the residuals management decision framework developed during remedial design. As discussed above, dredge areas within the EW will likely include multiple residuals management approaches, depending on location-specific conditions following dredging. Therefore, this analysis is intended to compare the relative benefits and costs of different residuals management actions, but the analysis is not appropriate for use in selecting a single residuals management approach to be used across the EW.

4.1 Estimate of Post-construction Concentrations for Residuals Management Contingency Actions

Table 4-1 presents a series of calculations for estimating the relative range of post-construction concentrations for residuals management contingency actions in dredged areas, including: 1) standard BMPs during dredging (no active residuals management contingency actions after dredging); 2) contingency RMC (9-inch average thickness) after dredging; 3) contingency RMC (18-inch average thickness) after dredging; 4) contingency re-dredging; and 5) contingency re-dredging followed by RMC (9-inch average). Consistent with sensitivity analyses presented in FS Appendix J, only total PCBs were analyzed because it contributes the most to site risks and is distributed throughout much of the waterway. The predicted concentrations were estimated using a consistent set of assumptions; however, many factors affect the actual concentrations measured as part of confirmatory sampling, including actual number of dredge cuts, dredge equipment, timing of contingency dredging and cover placement, timing of confirmatory sampling, vessel activity and associated propwash during dredging and RMC placement, bulk density of residuals layer, and other factors.

Table 4-1
Comparison of Estimated Total PCB Sediment Concentrations Associated with Residual Management Tools

Item No.	Item	Unit	Low Loss	Medium Loss	High Loss
1	***Standard BMPs During Dredging (No Active Residuals Management Contingency Measures Following Dredging [i.e., MNR])***				
1.01	Thickness of Residuals	cm	3.1	5.1	7.2
1.02	Concentration of Residuals	µg/kg	470	640	980
1.03	Concentration of Underlying Sediment	µg/kg	15	15	15
1.04	**Concentration of the BAZ**	**µg/kg**	**160**	**330**	**710**
1.05	**Concentration in the Upper 2 Feet**	**µg/kg**	**38**	**67**	**129**
2	***Contingency Residuals Management Cover (9 Inches Average)***				
2.01	Percent of Resuspended Residuals during Sand Placement	%	10%	10%	10%
2.02	Thickness of Resuspended Residuals during Sand Placement	cm	0.31	0.51	0.72
2.03	Concentration of Residuals	µg/kg	470	640	980
2.04	Thickness of RMC	in	9	9	9
2.05	Concentration of Underlying RMC	µg/kg	2	2	2
2.06	Concentration of Underlying Sediment	µg/kg	15	15	15
2.07	**Concentration of the BAZ**	**µg/kg**	**17**	**35**	**72**
2.08	**Concentration in the Upper 2 Feet**	**µg/kg**	**12**	**15**	**22**
3	***Contingency Residuals Management Cover (18 Inches Average)***				
3.01	Percent of Resuspended Residuals during Sand Placement	%	10%	10%	10%
3.02	Thickness of Resuspended Residuals during Sand Placement	cm	0.31	0.51	0.72
3.03	Concentration of Residuals	µg/kg	470	640	980
3.04	Thickness of RMC	in	18	18	18
3.05	Concentration of Underlying RMC	µg/kg	2	2	2
3.06	Concentration of Underlying Sediment	µg/kg	15	15	15
3.07	**Concentration of the BAZ**	**µg/kg**	**17**	**35**	**72**
3.08	**Concentration in the Upper 2 Feet**	**µg/kg**	**7.6**	**10**	**17**
4	***Contingency Re-dredging***				
4.01	Thickness of Re-dredging	ft	2.0	2.0	2.0
4.02	Contribution from Underlying Sediment				
4.03	Thickness of Underlying Sediment Dredged	cm	57.9	55.9	53.8
4.04	Percent Loss of Underlying in situ Material Dredged	%	3%	5%	7%
4.05	Residuals Contribution from Underlying Sediment	cm	1.7	2.8	3.8
4.06	Concentration of Underlying Sediment	µg/kg	15	15	15
4.07	Contribution from Re-dredged Residuals				
4.08	Thickness of Re-dredged Residuals	cm	3.1	5.1	7.2
4.09	Percent Loss of Re-dredged Residuals	%	20%	50%	80%
4.10	Residuals Contribution from Re-dredged Residuals	cm	0.6	2.6	5.8
4.11	Concentration of Re-dredged Residuals	µg/kg	470	640	980
4.12	Weighted Average Values				
4.13	Thickness of Residuals	cm	2.4	5.3	9.5
4.14	Concentration of Residuals	µg/kg	135	313	599
4.15	Concentration of Underlying Sediment	µg/kg	15	15	15
4.16	**Concentration of the BAZ**	**µg/kg**	**43**	**170**	**570**
4.17	**Concentration in the Upper 2 Feet**	**µg/kg**	**20**	**41**	**110**
5	***Contingency Re-dredging followed by Residuals Management Cover (9 Inches Average)***				
5.01	Percent of Resuspended Residuals during Sand Placement	%	10%	10%	10%
5.02	Thickness of Resuspended Residuals during Sand Placement	cm	0.24	0.53	0.95
5.03	Concentration of Residuals	µg/kg	135	313	599
5.04	Thickness of RMC	in	9	9	9
5.05	Concentration of Underlying RMC	µg/kg	2	2	2
5.06	Concentration of Underlying Sediment	µg/kg	15	15	15
5.07	**Concentration of the BAZ**	**µg/kg**	**5**	**19**	**59**
5.08	**Concentration in the Upper 2 Feet**	**µg/kg**	**11**	**13**	**19**

Notes:
Calculated values are rounded to two significant digits.
µg/kg – micrograms per kilogram
BAZ – biologically active zone
BMP – best management practice
cm – centimeter
ft – foot
in – inch
MNR – monitored natural recovery
PCB – polychlorinated biphenyl
RMC – residuals management cover

As discussed above, the concentration and thickness of generated residuals under any residuals management contingency approach will vary across the site, based on the location-specific concentration profile, dredging depth, and conditions (e.g., debris, riprap, and structural setbacks). For this analysis, the range of box model inputs for low, medium, and high estimates of residuals thickness and concentration (FS Appendix J) was used to estimate the range of residuals that could remain in various locations across the site. The concentrations presented in Table 4-1 are not representative of predicted site-wide concentrations, but rather represent the post-construction conditions that could be encountered in any given location of the EW during confirmatory sampling, depending on location-specific conditions.

The first section of Table 4-1 presents the estimated range of total PCB concentrations that could be observed following dredging using standard BMPs during dredging, followed by MNR without contingency residuals management actions. Following completion of required dredging, the total PCB concentrations in the biological active zone could range from 160 to 710 micrograms per kilogram (µg/kg) dry weight (dw). Because of the impact of vessel scour on the site, the location-specific concentrations were also calculated, assuming 2 feet of propwash mixing, resulting in a range of total PCB concentrations from 38 to 130 µg/kg dw. Location-specific total PCB concentrations therefore may range from 38 to 710 µg/kg dw, depending on the concentration and thickness of generated residuals and the degree of propwash.

Section 2 of Table 4-1 estimates the location-specific concentrations following the placement of RMC using the replacement values calculation methodology developed in this FS, which estimates a percentage of the residuals layer resuspended during RMC placement and deposited on the surface of the RMC (9-inch average RMC layer thickness; see FS Appendix B, Part 3A). Consistent with the literature discussions cited above, RMC is predicted to significantly reduce post-construction concentrations and the range of uncertainty in those concentrations. The range of post-placement total PCB concentrations is estimated from 17 to 72 µg/kg dw in the BAZ and 12 to 22 µg/kg dw following 2 feet of mixing, for a total range of 12 to 72 µg/kg dw, depending on the starting thickness and concentration of the residuals layer and the depth of mixing following placement. It is important to note that the lower predicted concentrations of the ranges stated above are below that which are predicted to be achieved on a site-wide basis due to removal limitations associated with structural setbacks and the presence of riprap keyways and underpier slopes (see FS Appendix A, Section 4.1.1). The site-wide lowest achievable total PCBs spatially-weighted average concentration (SWAC) was estimated to be 57 μg/kg dw, with an effective bioavailable concentration of 34 μg/kg dw (FS Appendix A).

RMC is likely to meet the post-construction performance goals and will result in concentrations in most RMC placement locations that are below the site-wide lowest possible achievable SWAC. Low concentrations are predicted following RMC placement because, while the generated residuals layer has relatively high concentrations of total PCBs (compared to post-remediation goals), the predicted generated residuals layer is thin and does not represent a large mass of contamination. It is also important to note that the biological active zone is expected to rebound to baseline levels of organic carbon within a few years following RMC placement, due to organic carbon in incoming sediment, and the load of organic material that accumulates from biological activity at the site.

Section 3 of Table 4-1 estimates the concentration following placement of a thicker layer of RMC. The range of post-placement total PCB concentrations is estimated from 17 to 72 μg/kg dw in the BAZ, 7.6 to 17 μg/kg dw following 2 feet of mixing, for a total range of 7.6 to 72 μg/kg dw, depending on the starting thickness and concentration of the residuals layer and the depth of mixing following placement. The predicted concentration range is very similar to the thinner layer of RMC because the thicker RMC layer is similar in concentration to the concentration of sediment located below the required dredge elevation (e.g., native sediment) that underlies the residuals layer and therefore does not substantially reduce the mixed concentration.

Section 4 of Table 4-1 estimates the concentration following re-dredging of the generated residuals layer. The range of post-placement total PCB concentrations is estimated from 43 to 570 μg/kg dw in the BAZ, 20 to 110 μg/kg dw following 2 feet of mixing, for a total range of 20 to 570 μg/kg dw, depending on the starting thickness and concentration of the residuals layer and the depth of mixing following placement. Consistent with the literature discussions cited above, effectiveness of re-dredging is predicted to have a higher degree of uncertainty because the low-density residuals layer is more likely to be not captured by or re-released from the dredge bucket. The percent loss of the low-density residuals layer during the contingency re-dredge pass was estimated to range from 20 to 80% for this reason (line item 4.09). Note that the timing of re-dredging will affect the degree to which the residuals layer will have consolidated or mixed with deeper, undredged sediment prior to re-dredging.

Section 5 of Table 4-1 assumes that re-dredging is followed by RMC placement for management of residuals. The range of post-placement total PCB concentrations is estimated from 5 to 59 µg/kg dw in the BAZ, 7.9 to 37 µg/kg dw following 2 feet of mixing, for a total range of 7.9 to 59 µg/kg dw, depending on the starting thickness and concentration of the residuals layer and the depth of mixing following placement. The same uncertainties discussed above for RMC and re-dredging will both apply. Note that, as discussed above, these concentrations are below the site-wide lowest possible achievable SWAC when considering constructability (FS Appendix A); concentrations this low may or may not be observed in a given area of the EW as part of confirmatory sampling. This approach has the largest construction timeframe and cost implications, as discussed in the following section.

4.2 Estimate of Construction Timeframe and Cost for Residuals Management Contingency Actions

The construction timeframes and costs were estimated for the residuals management contingency actions normalized to 100 acres of remediation. For RMC, all unit costs and durations were consistent with the FS Alternatives (FS Appendix E). For re-dredging, the construction duration was assumed to be half the FS estimate of 1,100 cy/day because of the additional time required for thin-lift precision dredging. Re-dredging was assumed to target 1 foot of removal and result in 2 feet of removal due to overdredging. The unit cost for disposal of dredged sediment was not changed from FS Appendix E. The resulting construction timeframes and costs for the residuals management contingency actions are presented in Table 4-2.

The costs and construction times associated with the use of standard BMPs (line item 1) are not quantified for this analysis because the use of these measures is already incorporated into the base dredging costs and construction timeframes for the alternatives.

The unit construction timeframe and cost to complete 100 acres of RMC placement (line item 2) is 1.3 construction seasons and $7.8 million dollars. Doubling the RMC placement thickness approximately doubles the construction time and costs (line item 3). One hundred acres of contingency re-dredging (line item 4) is estimated to take 5.9 years and cost $72 million dollars, which is considered disproportionately costly compared to the anticipated reduction in concentrations associated with that contingency action. Combining re-dredging and RMC (line item 5) results in 7.2 years of construction and $79 million dollars for 100 acres of action. Although this combination results in the lowest anticipated concentrations of the contingency measures presented here, costs are considered disproportionate to the reduction in concentrations, especially considering the conditions of the EW that also influence the final concentrations of sediments in the waterway as a whole, such as propwash mixing, incoming sediment concentrations, underpier remediation, and structural setbacks.

Table 4-2
Residuals Management Contingency Measures Construction Timeframes and Costs Normalized to 100 Acres

Description	Construction Timeframe (years per 100 acres)	Cost ($ millions per 100 acres)
1. Standard BMPs during Dredging (No Active Residuals Management Contingency Measures Following Dredging)	0[a]	$0[a]
2. Contingency Residuals Management Cover (9 Inches Average)	1.3	$7.8
3. Contingency Residuals Management Cover (18 Inches Average)	2.6	$16
4. Contingency Re-dredging	5.9	$72
5. Contingency Re-dredging followed by Residuals Management Cover (9 Inches Average)	7.2	$79

Notes:
a. Standard environmental BMPs increase the construction duration and costs for dredging above maintenance dredging, but the additional time and costs are not quantified here. The FS base cost and construction timeframe estimates (FS Appendix E) assume that standard BMPs would be used.

BMP – best management practice
FS – Feasibility Study

5 SUMMARY AND CONCLUSIONS

This appendix provides a review of literature and studies of dredging residuals, presents qualitative information on dredging residuals estimates, and quantitative comparison of residuals management contingency measures. In summary, this information supports the placement of a thin sand layer, RMC, as the most cost-effective way to reliably reduce surface sediment concentrations following dredging. Therefore, the FS alternatives assume that RMC will be placed over the entire dredge footprint as well as undredged areas adjacent to dredged areas (the "interior unremediated islands"; see Section 2.3). These assumptions are used to develop the box model predictions, construction times, and costs for comparing the alternatives on a common basis.

Actual residuals management actions will be based on the residuals management framework, to be developed during design and confirmatory sampling results following dredging. It is expected that more than one residuals management contingency action will be employed; however, the SWACs, costs, and construction timeframes for the remedial alternatives are based on the application of RMC in all dredging areas. Additional evaluation of potential residuals management contingency actions will be addressed following additional data collection that will be conducted during design.

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