APPENDIX D – CAP MODELING
EAST WATERWAY OPERABLE UNIT FEASIBILITY STUDY

Prepared for
Port of Seattle

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June 2019

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1 INTRODUCTION

Capping is a remedial technology component of all active remedial alternatives being developed and evaluated for cleanup of contaminated sediments in the East Waterway (EW) Operable Unit (OU). Gaining a Feasibility Study (FS)-level understanding of how this technology is expected to perform under conditions within the EW OU is an essential consideration in assessing its technical feasibility and effectiveness. One key consideration to be addressed during design is the potential for contaminants originating from buried sediments or groundwater to emerge through the cap into the biologically active zone (BAZ) and overlying water column (i.e., by diffusion and groundwater advection) at levels that constitute an unacceptable risk. To this end, porewater contaminant concentrations within a hypothetical sediment cap were modeled and are presented in this appendix.

2 MODEL SELECTION AND TECHNICAL APPROACH

A one-dimensional steady state model (version 1.19, 2012) developed by Lampert and Reible (2009) for chemical transport within sediment caps was used for the chemical isolation evaluation. This model simulates the time-variable fate and transport of chemicals (dissolved and sorbed phases) through the processes of advection, diffusion, dispersion, biodegradation, bioturbation/biodiffusion (in the biologically active zone), and exchange with the overlying surface water. This model is consistent with U.S. Environmental Protection Agency and U.S. Army Corps of Engineers guidance for cap design (Palermo et al. 1998a, 1998b). The model is a spreadsheet analysis and, therefore, easily manipulated for investigating various scenarios consistent with an FS-level analysis. This model has been used for cap evaluations for other contaminated sediments sites, including the Lower Duwamish Waterway (LDW; AECOM 2012), and for cap design at numerous sites across the United States. The model was used to evaluate total polychlorinated biphenyls (PCBs) and mercury in the EW OU because they are key contaminants of concern at the site with different properties affecting transport. In addition, the analysis for PCBs can be generalized to be representative of other hydrophobic organic compounds, such as carcinogenic polycyclic aromatic hydrocarbons (cPAHs) and dioxins/furans (Section 5.2). Additional contaminants may be evaluated during design.

3 INPUT PARAMETERS

Model input parameters are listed in Table 1. Each parameter has a best-estimate value, and low and high values were identified for select parameters. The best-estimate parameter values represent the best-estimate of conditions in the EW OU. The low and high values represent the uncertainty in conditions occurring in the EW OU based on uncertainty in parameter estimates or variability in site conditions. The basis for each parameter value is listed in Table 1, and several important input parameters are discussed in the text of this section.

The Lampert and Reible (2009) spreadsheet model uses porewater concentration within the sediments below the cap as a boundary condition (constant concentration is conservatively assumed, which results in an infinite source assumption). Limited porewater data were available to characterize the EW OU; therefore, the porewater boundary concentration beneath the cap was computed based on measured contaminant concentrations in bulk sediment and the equilibrium partitioning coefficient (K_d).

The model was set up for evaluation of organic compounds for which the K_d is assumed to equal the chemical's organic carbon partition coefficient (K_{oc}) times the fraction of organic carbon (f_{oc}). However, for metals, the K_d is assumed to be constant with f_{oc}. Therefore, to run the model for mercury, the f_{oc} and K_{oc} values were input so that the model would run at the appropriate K_d value.

The FS assumes that the cap would be 5 feet thick to account for 1.5 feet of armor stone, 1 foot of filter material, and 2.5 feet of isolation material. However, the thickness of the cap was assumed to be 2 feet in the model, to approximate the minimum thickness of the isolation layer in the cap. This is very conservative because the isolation thickness would be more than 2 feet in most locations, and because the filter layer would provide more attenuation than just the isolation layer (i.e., the added separation distance associated with the armor and filter layers would reduce the concentration gradient and thereby reduce diffusive transport) and retard the flux of contaminants (i.e., especially if the layers contain any total organic carbon). Thinner cap layers may be appropriate in some locations, depending on actual contaminant concentrations, erosion protection requirements, and the composition of the isolation layer (i.e., addition of cap amendments).

The concentration of contaminated sediment underlying the cap (i.e., source concentration) will vary by location. For this analysis, three values were considered for the concentration under the cap. These are 1) the maximum concentration of samples underlying the proposed capping areas for any alternative in the FS, 2) the average of samples underlying capping areas, and 3) the assumed concentration of dredge residuals (almost all locations would undergo partial dredging prior to capping). These values are presented in Table 1; only the maximum concentrations were carried forward in the modeling as a conservative approach.

Based on the behavior of the Lampert and Reible (2009) model (e.g., see the sensitivity analysis in Appendix C, Part 8 of the LDW FS [AECOM 2012]), the following four parameters were identified as key factors to be varied in the scenario analysis:

- Partitioning/distribution coefficient
- Groundwater flow (Darcy velocity)
- Sedimentation rate (depositional velocity)
- Fraction of organic carbon in the cap material (for PCBs only)

4 SELECTION OF OUTPUT PARAMETERS AND EVALUATION CRITERIA

The model output used in this analysis is referred to as the "characteristic time to ~1% of steady-state." This output represents an approximation of the time at which 1% of the steady-state concentration at the top of the cap's chemical isolation layer (i.e., the base of the BAZ) would be reached. One percent of the steady-state concentration is not necessarily of interest to this analysis, because the time to reach steady state for sorptive contaminants such as PCBs and mercury can be hundreds or even thousands of years. However, this output parameter provides a surrogate for the time that contamination would be expected to "break through" the cap and was, therefore, deemed appropriate for an FS-level analysis. For this analysis, 100 years was considered a reasonable breakthrough time for the sediment cap effectiveness evaluation; breakthrough time less than 100 years was considered ineffective, and breakthrough time greater than 100 years was considered effective. One hundred years is considered a reasonable design life for a sediment cap given the conservatism of model parameters, the potential to refine the cap during design, and cap monitoring and maintenance activities following construction. This analysis does not focus on outputs after the 100-year evaluation threshold because waterway conditions, site use, and knowledge and practices in sediment remediation are likely to change in the next century, and because uncertainty in model inputs and calculations are compounded through time.

5 RESULTS

5.1 Scenarios

The scenarios include a total of 16 model runs as shown on Table 2: four model runs for intertidal capping areas and four model runs for subtidal capping areas, for both PCBs and mercury. Scenario 1 uses the best-estimate input parameters, and is representative of the best-estimate of conditions in the EW OU. In all four cases for Scenario 1 (intertidal/subtidal, PCBs/mercury), there is no breakthrough predicted through the cap; therefore, the isolation layer of the cap is anticipated to be effective beyond the 100-year assumed design life (and actually in perpetuity).

Scenarios 2 through 4 included variation of key parameters as a sensitivity analysis; the partitioning coefficient, Darcy velocity, and net sedimentation rate were individually varied in Scenarios 2, 3, and 4, respectively. The parameters were varied in each of these scenarios so as to decrease contaminant breakthrough time (i.e., less sorption, faster groundwater flow, and no sedimentation, respectively). For PCBs intertidal Scenarios 2 and 4, the model predicted breakthrough is prior to the 100-year benchmark, with an f_{oc} in the cap of 1%. Therefore, as shown in Table 2a, the f_{oc} has been adjusted for these scenarios until the design life equals 100 years. The level of organic carbon predicted to be required in these scenarios is reasonable and has been demonstrated to be attainable and effective on similar sediment caps using organic carbon or other material (such as activated carbon), if determined to be necessary during remedial design.

For PCBs in the subtidal areas and for mercury in both intertidal and subtidal locations, breakthrough for Scenarios 2 through 4 was not predicted to occur prior to the 100-year benchmark, indicating that a 2-foot isolation layer is likely to be effective.

5.2 Generalizing the Results for Other Organic Contaminants

The results of this analysis for total PCBs can be generalized to apply to other organic compounds that have K_{oc} values similar to, or greater than, total PCBs (i.e., that migrate at a similar or slower rate than PCBs). This includes cPAHs and dioxins/furans. Table 3 shows the K_{oc} values for PCBs, PAHs, and dioxins/furans for comparison. Compounds with K_{oc} values higher than those used in this analysis will migrate more slowly than PCBs and, therefore, a 2-foot isolation layer is likely to be effective over the 100-year evaluation period. Compounds with lower K_{oc} values than those used in this analysis will migrate more quickly than PCBs; other compounds will be evaluated as necessary in remedial design during location-specific capping evaluations.

5.3 Conclusions

This analysis indicates that a 2-foot cap isolation layer thickness is a reasonable assumption for the EW OU FS. This thickness is predicted to meet performance goals under the best estimate of waterway conditions, even with multiple conservative assumptions being used for modeling, such as ignoring the attenuation benefits provided by the cap filter and armoring layers, and modeling the maximum concentration measured in potential capping areas. For two hypothetical conditions in intertidal areas, the fraction of organic carbon would need to be specified at minimum levels (e.g., 1.3% organic carbon in the worst-case scenario) to meet performance criteria. The final cap isolation layer thickness and composition will be determined during remedial design based on additional testing and analysis.

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TABLES

Table 1
Input Values

Parameter	Units	Input Value(s) Best Estimate	Low[a]	High[a]	Basis
Contaminant Properties					
Organic carbon partition coefficient for PCBs, log K_{oc}	log L/kg	5.91	5.0	6.5	Based on MTCA and Mackay et al. (2006), consistent with LDW assumptions (AECOM 2012)
Partition coefficient for PCBs, K_d	L/kg	calculated	calculated	calculated	$K_d = 10^{(\log K_{oc})} \times f_{oc(bio)}$ for organic compounds
Partition coefficient for mercury, log K_d	log L/kg	4.9	3.8	6.0	Mean, low, and high values of 2 values for sediment partitioning in Allison and Allison (2005)
Colloidal organic carbon partition coefficient	log L/kg	calculated	calculated	calculated	log K_{doc} = log K_{oc}-0.37 (Lampert and Reible model [2009] default). Used for PCBs but not Hg
Water diffusivity	cm^2/s	5.0×10^{-6}	n/a	n/a	Consistent with LDW assumptions (AECOM 2012)
Cap decay rate	yr^{-1}	0	n/a	n/a	Conservatively assume no degradation
Bioturbation layer decay rate	yr^{-1}	0	n/a	n/a	Conservatively assume no degradation
Contaminant concentration in sediment	µg/kg dw (PCBs)	7,600 µg/kg dw	n/a	n/a	Maximum concentration from samples underlying the capping area for any FS alternative: 7,600 µg/kg dw; conservatively use this maximum value for all scenarios for this FS-level evaluation
	mg/kg dw (Hg)	2.5 mg/kg dw	n/a	n/a	Maximum concentration from samples underlying the capping area for any FS alternative: 2.5 mg/kg dw; conservatively use this maximum value for all scenarios for this FS-level evaluation
Contaminant porewater concentration	µg/L	calculated	calculated	calculated	$C_{0(pw)} = C_{0(sed)}/K_d$
Sediment Properties					
Biological active zone fraction organic carbon	%	1.6%	n/a	n/a	1.6% based on conditions in the EW OU (FS Section 2)
Colloidal organic carbon concentration	mg/L	2	n/a	n/a	Consistent with LDW assumptions (AECOM 2012). Sorption to porewater dissolved organic matter not simulated for mercury
Intertidal Darcy velocity, *(positive is upwelling)*	cm/yr	3,200	1,000	11,000	Based on EW SRI Section 2.6.1 (Windward and Anchor QEA 2014). Darcy velocity = porewater velocity x porosity
Subtidal Darcy velocity *(positive is upwelling)*	cm/yr	250	106	590	Based on Fabritz et al. (1998); site-specific information has not been collected. Groundwater flux is lower in deeper areas in the Duwamish Basin compared to shallow intertidal areas, but additional information may be required during design
Net sedimentation rate$_p$	cm/yr	1.2	0	1.8	0 to 1.8 cm/yr based on conditions in the EW OU (FS Section 2). Best estimate and high values are consistent with those determined for site-wide predictive modelling (see Section 5.1.2). Low value set equal to 0 for a location-specific potential minimum value as a worst-case scenario [b]
Bioturbation layer thickness	cm	10	n/a	n/a	10 cm is the bioturbation layer thickness for all areas of the EW OU; cap thickness would also be designed to protect for additional thickness in clamming areas (25 cm)
Porewater biodiffusion coefficient	cm^2/yr	100	n/a	n/a	Typical/recommended value Reible (2012)
Particle biodiffusion coefficient	cm^2/yr	1	n/a	n/a	Typical/recommended value Reible (2012)
Cap Properties					
Cap thickness (isolation layer)	ft	2	n/a	n/a	Assume 2-foot chemical isolation layer that could be modified during design; conservatively assume filter and armor layers provide no chemical isolation/ attenuation
Cap materials – Granular (G) or Consolidated Silty/Clay (C)	--	G	n/a	n/a	Assume granular cap
Cap consolidation depth	cm	0	n/a	n/a	Assume no consolidation (typical for sand)
Underlying sediment consolidation due to cap placement	cm	23	n/a	n/a	Consistent with LDW assumptions (AECOM 2012) and EW conditions
Porosity	--	0.4	n/a	n/a	Typical value for sand
Particle Density	g/cm^3	2.6	n/a	n/a	Typical value for sand
Fraction organic carbon, *(f_{oc})*	%	1%	n/a	variable	Value represents sorptive capacity of cap for organics; can be modified during remedial design

Notes:

a. Results of model runs for sensitivity inputs values are not presented in Table 2 if they do not provide additional information. For example, the best estimate conditions predict no contaminant breakthrough; therefore, model runs with high K_{oc} values would also result in no contaminant breakthrough and are not shown. However, all sensitivity values are presented in this table for completeness.

b. The range of average site-wide net sedimentation rates used in the box model is 0.5, 1.2, and 1.8 cm/yr. A low-end net sedimentation rate of 0 cm/yr is used for cap modeling to represent a worst-case scenario that may occur in localized capping areas.

% – percent
µg/kg – microgram per kilogram
µg/L – microgram per liter
cm – centimeter
cm/yr – centimeter per year
cm^2/s – square centimeter per second
dw – dry weight
EW – East Waterway
f_{oc} – fraction of organic carbon
FS – Feasibility Study
ft – feet
g/cm^3 – gram per cubic centimeter
Hg – mercury
K_d – equilibrium partitioning coefficient
K_{oc} – organic carbon partitioning coefficient
L/kg – liter per kilogram
LDW – Lower Duwamish Waterway
log – logarithm
mg/kg – milligram per kilogram
mg/L – milligram per liter
MTCA – Model Toxics Control Act
n/a – sensitivity not run for parameter
OU – Operable Unit
PCB – polychlorinated biphenyl
SRI – Supplemental Remedial Investigation
yr^{-1} – per year

Table 2a
Cap Model Results for PCBs

	Scenario	Select Input Parameters: Cap Isolation Layer Thickness (feet)	log K_{oc} (log L/kg)	Darcy Velocity (cm/yr)	Net Sedimentation Rate (cm/yr)	Cap f_{oc} (%)	Output Parameter: Characteristic Time to ~1% of Steady State (Time to Breakthrough [years])
Intertidal							
1	Best-estimate conditions	2	5.9	3,200	1.2	1.0%	No Breakthrough
2	Best-estimate conditions with low K_{oc}; f_{oc} varied to achieve 100-year design life		5.0	3,200	1.2	1.6%[a]	100
3	Best-estimate conditions with high Darcy velocity		5.9	11,000	1.2	1.0%	No Breakthrough
4	Best-estimate conditions with no sedimentation; f_{oc} varied to achieve 100-year design life		5.9	3,200	0.0	1.1%[a]	100
Subtidal							
1	Best-estimate conditions	2	5.9	250	1.2	1.0%	No Breakthrough
2	Best-estimate conditions with low K_{oc}		5.0	250	1.2	1.0%	No Breakthrough
3	Best-estimate conditions with high Darcy velocity		5.9	590	1.2	1.0%	No Breakthrough
4	Best-estimate conditions with no sedimentation		5.9	250	0.0	1.0%	1,100

Table 2b
Cap Model Results for Mercury

	Scenario	Select Input Parameters: Cap Isolation Layer Thickness (feet)	log K_d (log L/kg)	Darcy Velocity (cm/yr)	Depositional Velocity (cm/yr)	Cap f_{oc} (%)	Output Parameters: Characteristic Time to ~1% of Capped Sediment (Time to Breakthrough [years])
Intertidal							
1	Best-estimate conditions	2	4.9	3,200	1.2	n/a	No Breakthrough
2	Best-estimate conditions with low K_d		3.8	3,200	1.2	n/a	No Breakthrough
3	Best-estimate conditions with high Darcy velocity		4.9	11,000	1.2	n/a	No Breakthrough
4	Best-estimate conditions with no sedimentation		4.9	3,200	0.0	n/a	1,500
Subtidal							
1	Best-estimate conditions	2	4.9	250	1.2	n/a	No Breakthrough
2	Best-estimate conditions with low K_d		3.8	250	1.2	n/a	No Breakthrough
3	Best-estimate conditions with high Darcy velocity		4.9	590	1.2	n/a	No Breakthrough
4	Best-estimate conditions with no sedimentation		4.9	250	0.0	n/a	18,000

Notes:
a. f_{oc} was adjusted upward from 1% to meet a design life of 100 years.
(shaded) Input values varied from the best-estimate conditions
% – percent
cm/yr – centimeter per year
f_{oc} – fraction of organic carbon
K_d – equilibrium partitioning coefficient
K_{oc} – organic carbon partitioning coefficient
L/kg – liter per kilogram
log – logarithm
n/a – not applicable
PCB – polychlorinated biphenyl

Table 3

K_{oc} Values for Select Organic Compounds

Compound	Log K_{oc}
PCBs	
Modeled values for this analysis	**5.0, 5.91, 6.5**
PCB-Aroclor 1016	5.04 [a]
PCB-Aroclor 1260	5.91 [a]
PCBs (generic mixture)	5.49 [a]
cPAHs	
Benzo[a]anthracene	5.56 [a]
Benzo[a]pyrene	5.99 [a]
Benzo[b]fluoranthene	6.08 [a]
Benzo[k]fluoranthene	6.08 [a]
Chrysene	5.60 [a]
Dibenz[a,h]anthracene	6.26 [a]
Indeno[1,2,3-cd]pyrene	6.54 [a]
cPAH weighted average based on TEQ	6.02
Dioxins/furans	
TCDD; 2,3,7,8-	6.7 [b]

Notes:
a. From Washington State Department of Ecology Cleanup Levels and Risk Calculation Database (CLARC), accessed July 2013.
b. Average of values listed in Mackay et al. (2006).
cPAH – carcinogenic polycyclic aromatic hydrocarbon
K_{oc} – organic carbon partitioning coefficient
Log – logarithm
PCB – polychlorinated biphenyl
TEQ – toxic equivalent

ATTACHMENT 1
CAP ARMOR EVALUATION

1 METHODOLOGY TO EVALUATE STABLE SEDIMENT GRAIN SIZE DUE TO VESSEL ACTIVITY

Bed sediments in the East Waterway (EW) are subject to current velocities due to tidal and riverine currents and intermittent high velocities due to vessel activity (propeller wash, or propwash). Engineered caps proposed for the EW need to be sized such that they remain stable under these velocities.

An evaluation was conducted as part of the EW Sediment Transport Evaluation Report (STER) to calculate the near-bed velocities caused by tidal/riverine currents and propwash (Anchor QEA and Coast & Harbor Engineering 2012). Based on the results of this evaluation, bed velocities due to propwash were found to be significantly higher than those due to riverine and tidal currents (even at the 100-year flow). Therefore, the stability evaluation of proposed engineered caps used predicted velocities from the propwash modeling to estimate a stable grain/rock size for each operational area in the EW.

Bottom velocities were calculated for various operational areas and vessels. The operational areas were established based on interviews and personal conversations with organizations, agencies, and companies that operate vessels within the EW (see Section 5.1.2 of the STER; Anchor QEA and Coast & Harbor Engineering 2012). The bottom velocities were calculated based on the appropriate vessels and operations taking place in each operational area. Figure 1-1 shows operational areas.

The stable sediment size for each operational area was calculated using an equation established by Blaauw et al. (1984). This method assumes zero movement of the sediment/rock under the applied velocity. This method requires inputs of maximum bottom velocity, gravitational constant, stone and water unit weights, and an experimentally developed constant that is dependent on the amount of sediment movement allowable.

$$V_{bmax} = C_3\left(g\ddot{A}D_{50}\right)^{1/2} \quad 1$$

Where:

V_{bmax} = maximum bottom velocity

C_3 = experimentally developed constant that was found to be 0.55 for no movement and 0.70 for small transport; 0.55 was used for this evaluation

$\ddot{A}$ = $(a_s-a_w)/a_w$; where a_s is the unit weight of stone and a_w is the unit weight of water

g = gravitational constant

D_{50} = represents the median diameter where 50% of the material is finer based on the total weight of the sample

The equation is used to estimate the median diameter (D_{50}) that would be stable under the representative near-bed velocity due to propwash.

2 RESULTS

Table 1-1 presents the maximum near-bed velocity and the corresponding stable grain size for each operational area and vessel operation scenario.

Table 1-1
Maximum Near-bed Velocity and Stable Grain Size for Operational Area and Vessel Operation Scenarios

Area[1]	Vessel[2]	Maximum Near-bed Velocity (feet/second)	D_{50} (feet)	D_{50} (inches)
Terminal 18, Berths 1 and 2 Area 1A	Scenario 2	11.4	n/a[3]	n/a[3]
Terminal 18, Berths 3 and 4 Area 1A	Scenario 5	7.1	3.2	39.3
Area 1B	Scenario 13	3	0.5	7.0
Area 1C	Scenario 13	3	0.5	7.0
Slip 36 Area 2	Scenario 6	6.5	2.7	32.9

Area[1]	Vessel[2]	Maximum Near-bed Velocity (feet/second)	D_{50} (feet)	D_{50} (inches)
Slip 27 Area 3	Scenario 8	3	0.5	7.0
South Terminal 30 Area 4A	Scenario 9	3	0.5	7.0
South Terminal 30 Area 4A	Future Conditions Scenario 15	9	n/a[3]	n/a[3]
South Terminal 30 Area 4	Scenario 9	3	0.5	7.0
Area 4B	Scenario 9	3	0.5	7.0
Area 5	Scenario 9	3	0.5	7.0
Area 6	Scenario 10	10.6	n/a[3]	n/a[3]
Area 7	Scenario 11	4.7	1.4	17.2
Area 8	Scenario 12	4.2	1.1	13.7

Notes:
1. See Figure 1-1 for areas.
2. See Section 5.1.3 of the STER for operational area and vessel scenarios that were evaluated.
3. These scenarios are outside of the range of applicability for the methodology due to proximity of propeller to the bottom.
D_{50} – median diameter
Shaded areas have caps in one or more of the proposed FS alternatives.

Stable rock sizes predicted by Equation 1 range from 0.5 feet to more than 3 feet based on the assumption of zero movement of material under applied velocities. Several scenarios were outside the predictive range of the method and would require additional numerical modeling to evaluate; however, it is anticipated that predicted stable rock sizes would be the same or larger than the maximum size predicted for the scenarios that were evaluated (approximately 3 feet).

The maximum armor rock size was not applied to cap thickness assumptions for the EW Feasibility Study (FS). The highest armor rock sizes would be required in Areas 1A (in Terminal-18 berth areas), Area 2 (Slip 36), and Area 6 (near Olympic Tug and Barge). Capping has not been selected for any of the remedial alternatives for Areas 1A and 2. An armored cap comprised of armor rock in the 3-foot range could result in a cap thickness of approximately 8 to 9 feet, depending on the filter layer thickness between the armor and the sand cover, which would require removal of all contaminated sediment in most areas of the waterway, including Area 6. In addition, placing large rock in the navigable areas of the EW could pose a hazard for vessels operating at very low tides. However, capping was retained in Area 6 because of the large variation in mudline elevation in the area and the potential to cap deeper areas in the center of the channel. Additional analysis will be necessary during design.

For the FS analysis, a single armor size for the entirety of the EW Operable Unit was estimated to have a median diameter of 7 inches based on the stable rock size estimated for the majority of the scenarios evaluated. This armor material would require a filter material with a median diameter of approximately 0.85 inches (USACE 1992) based on methodology outlined in Ahrens (1981); a filter material with a D_{50} of 1 inch has been assumed for the EW FS. Based on these armor and filter requirements and the isolation requirements discussed in the main body of this appendix, the FS assumes that the engineered cap would have a thickness of 5 feet, comprised of a 1.5-foot-thick layer of armor material with a D_{50} of 7 inches, a 1-foot-thick layer of filter material with a D_{50} of 1 inch, and a 2.5-foot-thick layer of isolation material (see main Appendix D text).

The cap design will be further refined in remedial design with additional testing and/or evaluations for specific locations. Thicker or thinner caps may be designed based on stability considerations, contaminant breakthrough considerations, habitat considerations, and the final materials selected for construction.

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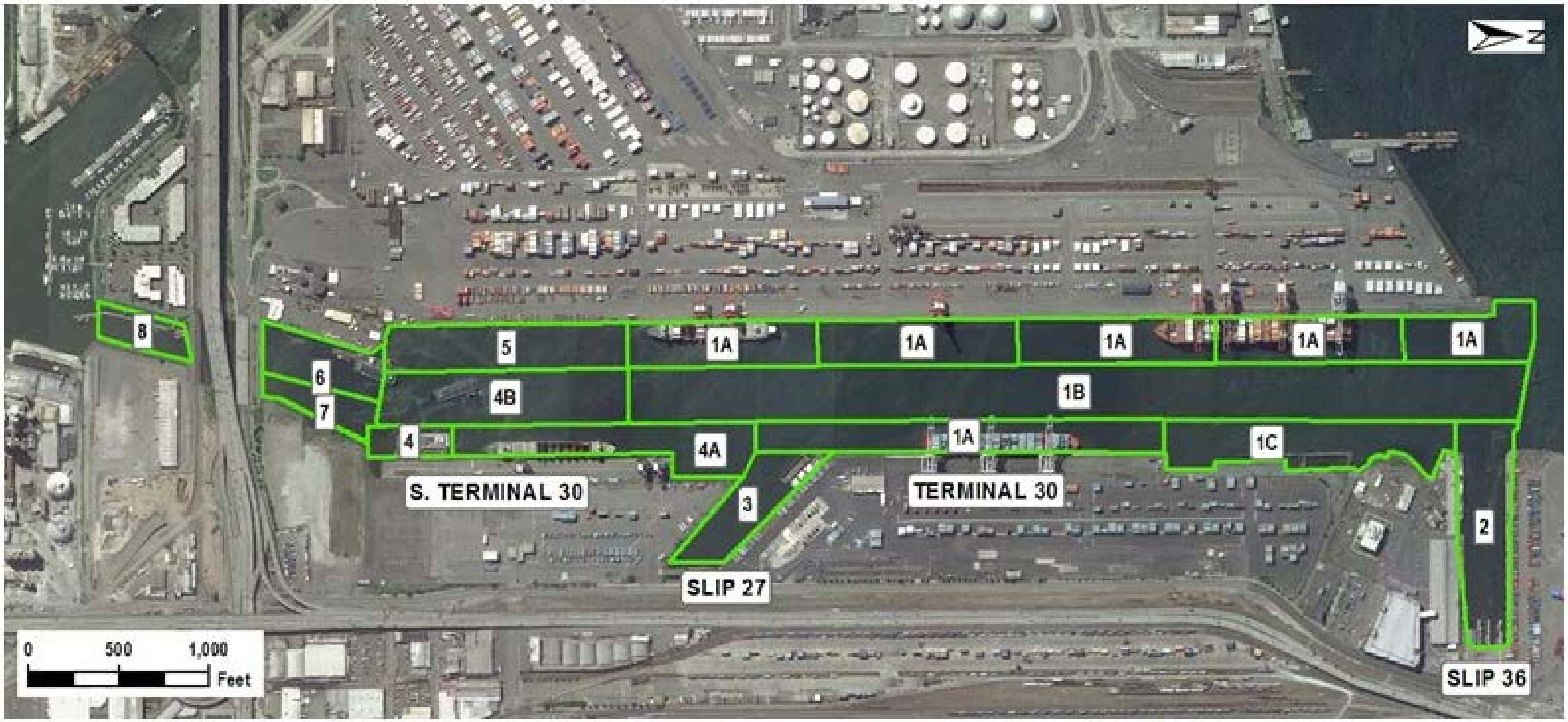
FIGURE



Legend

Operational Area

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Figure 1-1
Operational Propwash Areas
Feasibility Study - Appendix D
East Waterway Study Area