PORTLAND HARBOR RI/FS

APPENDIX C

TECHNOLOGY ASSIGNMENT SUPPORTING DOCUMENTATION

FEASIBILITY STUDY

June 2016

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C1. INTRODUCTION

This appendix presents supporting information for the technology assignment process described in Section 3 of the Feasibility Study (FS). A technology assignment process using a multi-criteria decision matrix was applied in the intermediate region. The technology assignment process utilized multi-criteria decision matrix components (FS Section 3.3.2) and a geographic information system (GIS) based tool to score the various technologies. The application of this initial process determined the best site-specific technology to apply in the intermediate region of the Portland Harbor Superfund site (Site). Further refinements and modifications to these initial technology assignments (FS Section 3.3.3) in the intermediate and other regions (Shallow, Navigation/FMD) were determined under a set of rules that are provided in Attachment C-1.

Information is provided for the following criteria used for the decision tree and matrix criterion technology assignment process:

Areas Excluded from Technology Assignment Process

- Navigation Channel and Future Maintenance Dredge Region
- Shallow Region
- Final CERCLA Remedies

Multi-Criteria Decision Matrix

- Hydrodynamic Characteristics
    - Sediment Deposition Rate
        - Deposition Based on Bathymetric Surveys
        - Ratio of Subsurface to Surface Sediment Concentrations
    - Sediment Erosion Potential
        - Wind and Wake Generated Waves
        - Shear-Stress on Bottom Sediments
    - Shallow Water Depth
- Sediment Bed Characteristics
    - Sediment Slope
- Anthropogenic Influences
    - Structures and Pilings
    - Debris
    - Propeller wash

C2. TECHNOLOGY ASSIGNMENT PROCESS

C2.1 AREAS EXCLUDED FROM TECHNOLOGY ASSIGNMENT PROCESS

The sources of information used to define the navigation channel, future maintenance dredge areas, the shallow region and final remedy areas are provided below.

C2.1.1 Navigation Channel and Future Maintenance Dredge Region

Congress authorized the federal navigation project within the Willamette River and defined the boundaries of the federal navigation channel. A GIS layer used to define the navigation channel and future maintenance dredge areas was developed by the LWG and provided to EPA in May 2012.

Future maintenance dredge areas were identified through a site use survey distributed to LWG members in November 2008 to gather information on existing and future activities at various locations along the Superfund Site to inform FS site use assumptions. Topics addressed in the survey included vessel activity, number and type of dock structures, shoreline characteristics, outfall locations, potential restoration areas, and potential future development or in-water construction. Information obtained from the survey related to dock configuration and future site uses was used to develop estimates of likely future navigation depth requirements and potential future maintenance dredging depths near and around docks. EPA has not seen or reviewed this survey but considers the results reasonable and adequate for an FS-level evaluation. More specificity regarding maintenance dredge areas will be evaluated in remedial design.

C2.1.2 Shallow Region

The shallow region was identified using January 2009 bathymetry data and identifying areas at or greater than 4 feet NAVD88. The shallow water criterion of 4 feet NAVD88 was based on an assumed cap thickness of 3 feet and a mean lower low water (MLLW) elevation of 7 feet NAVD88. This allows for construction of a 3-foot cap that remains submerged at the MLLW.

Technology assignments in the shallow region were made based on the presence or absence of functional or permanent structures and the depth of contamination. Contamination below functional or permanent structures was assumed to be capped. The components of the cap are determined based on the presence or absence of PTW and groundwater plumes.

In areas were the sediment contamination exceeding either the RAL or PTW threshold is greater than 5’ below mudline, contaminated sediments are assumed to be removed to a depth of 3’ followed placement of a 3’ cap. The components of the cap are determined based on the presence or absence of PTW and groundwater plumes. In areas where the sediment contamination is less than 5’ below mudline, the sediment contamination is assumed to be removed to the greater of the depth of contamination exceeding the RAL or PTW threshold.

C2.1.3 Final CERCLA Remedies

The McCormick and Baxter cap represents the only final remedy area located within the Site. The cap was placed over contaminated sediments in September 2005; subsequent modifications were made to the cap in October 2005 and July 2007. The cap design incorporated different types of armoring in the nearshore areas to reduce erosion (DEQ 2005). The GIS layer identifying the final remedy area at the McCormick and Baxter site was provided by LWG as part of their "Dredge/Cap Areas" GIS layer.

C2.2 HYDRODYNAMIC CHARACTERISTICS

The sources of information used to define sediment deposition rates, sediment erosion potential and wind/wave zones, and shallow water depths are provided below.

C2.2.1 Sediment Deposition Rate

Sediment deposition rate was evaluated based on two lines of evidence: quantitative evaluation of the difference between bathymetric surveys conducted at the site, and the ratio of subsurface to surface sediment concentrations, which assumes that depositional processes have led to cleaner sediments overlying more contaminated sediments.

C2.2.1.1 Deposition Based on Bathymetric Surveys

Sediment deposition or erosion has been measured empirically at the Site through bathymetric surveys conducted in January 2002, May 2003, and January 2009. Based on the accuracy of the survey (+/- 0.5 feet) and the time frame being considered (7 years or 5.67 years depending on whether the January 2002 or May 2003 is selected as the initial survey date), the minimum detectable sediment deposition rate was estimated to range between 2.2 and 2.7 centimeters per year (cm/yr). Thus, a sediment deposition rate of 2.5 cm/year was identified as the threshold for establishing an area as depositional based on this line of evidence. Areas with deposition greater than 2.5 cm/yr received a value of 1 (indicating a depositional environment) while other areas received a 0 when constructing the technology assignment GIS layer. This information was used in the final depositional criteria process.

C2.2.1.2 Ratio of Subsurface to Surface Sediment Concentrations

The ratio of subsurface to surface sediment concentrations was determined by calculating the average subsurface (greater than 40 cm depth) and surface sediment concentrations for PCBs, PCDD/PCDFs, PAHs, and DDx. Gridded GIS surfaces, also known as rasters, were developed using a natural neighbor interpolation of surface and subsurface sediment concentrations. Interpolated subsurface concentrations were divided by the corresponding interpolated surface concentration for each of the focused COCs, and were then combined and a mean calculated to create a new raster layer. The resulting raster was reclassified to identify all areas where the concentration ratio of was greater than two. Areas where the ratio was greater than two were assigned a value of 1, indicating a depositional environment. Areas where the ratio was less than two were assigned a value of 0. This information was used in the final depositional criteria process. Where the concentration in surface sediment was less than the COC-specific G-RAL, surface-subsurface concentration ratios were not calculated.

C2.2.2 Sediment Erosion Potential

Two lines of evidence were used to indicate whether an area was erosive; wind and vessel wake generated waves, and shear-stress on bottom sediments during high flow events. This evaluation was limited to the intermediate area. Because capping is not considered implementable in the navigation channel and FMD areas, erosions potential was considered for this region. Wind and vessel wake generated waves were considered in technology assignment process for the shallower portion of the intermediate region.

C2.2.2.1 Wind- and Wake-Generated Waves

The LWG conducted a wave analysis using information on waterway traffic obtained from the U.S. Army Corps of Engineers (USACE), Port of Portland, and correspondence with other property owners. The analysis considered both wind-generated (wave) and vessel-generated (wake) wave heights at variable river stage elevations to define wind- and wake-generated wave zones and derive a GIS layer.

Surface wave heights generated by wind conditions and vessel activity in various locations of the Site were estimated. Evaluation of wind-induced wave heights included meteorological data acquisition and wave hindcasting to develop significant wave heights and peak wave periods. Evaluation of vessel-induced wave heights included research of vessel traffic and vessel-wake generation to develop wake heights produced by design vessels operating at various speeds and water depths. These were used in combination with the water levels to determine the wave zones.

Design Water Levels
Water levels in the lower reach of the Willamette River exhibit an average 2-foot fluctuation due to tidal influence. They are also affected by the stage in the Columbia River, which is regulated by the Bonneville Dam upstream, and by runoff during extreme rainfall-runoff events. LWG obtained the U.S. Geological Survey (USGS) maximum and minimum daily stage river data (USGS gage 14211720, Willamette River at Portland, Oregon), and the maximum and minimum extreme stage data from the USACE for the 1973 to 2003 period (USACE 2004). The USACE defined the ordinary high water mark (OHW) at 19.8 feet North American Vertical Datum of 1988 (NAVD88) (14.8 feet Columbia River datum[CRD]). The minimum extreme stage in the river was estimated at 4.5 feet NAVD88 (-0.5 feet CRD). LWG limited the study to the river water levels between minimum extreme stage (4.5 feet NAVD88) and 13 feet NAVD88.

Evaluation of Wind-Induced Waves

Wind-generated waves are anticipated to be small compared to vessel-generated wakes along the Site. This is primarily due to the short fetch distances (distance over water that the wind can blow without being impeded by land) at the Site, which will limit the size of wind-generated waves that can develop in the lower Willamette River. To a lesser extent, the sinuosity of the lower Willamette River also limits wind-generated wave growth and propagation by limiting the straight line distances along which waves can develop and propagate. The methodology and results for the wind-induced wave evaluation are described below:

Wind Data Sources and Pre-processing

Wind data were obtained for the Portland International Airport from the National Climatic Data Center (http://www.ncdc.noaa.gov/oa/ncdc.html; 1976 to 2004) and the Meteorological Resource Center (http://www.webmet.com/; 1961 to 1990). Data were compiled into a single set and wind speeds were adjusted to two-minute averages at a 10-meter above ground elevation for analysis using methodology outlined in the USACE Coastal Engineering Manual (CEM) (USACE 2002). The use of 2-minute averages was chosen to provide a conservative estimate of wind-generated wave heights. A wind rose of the combined dataset is shown on **Figure C-1**. Dominant wind directions at these locations are from the northwest and southeast.

100-Year Return Period Wind Speeds

Twelve wind direction zones were defined, each encompassing a 30° range starting from 0°N. The annual maximum wind speed for each year from 1961 to 2004 with a direction falling within each zone was identified. A Rayleigh distribution curve was fitted to the annual maxima data and the 100-year return period wind speed was extrapolated for each directional zone. This distribution produced a good fit to the wind dataset with correlation coefficients ranging from 0.84 to 0.98, with an average of 0.94. The 100-year wind speed and Rayleigh correlation coefficient for each directional bin are presented in **Table C-1**.

Fetch Length Determination

Fetch lengths were measured for each wind directional zone that has the potential for wind waves to develop and impact the shoreline in various locations of the Site. Fetch measurements were completed based on methodology outlined in the CEM (USACE 2002). These fetch lengths and associated directions are listed in **Table C-2**.

Estimates of Wind-Generated Wave Heights/Periods

The 100-year return period wave heights and periods for each relevant directional zone were calculated based on the restricted-fetch wave growth formulation in the Automated Coastal Engineering System (ACES) developed by the USACE (1992). The 100-year significant wave heights and periods are presented in **Tables C-3** and **C-4**, respectively, for each directionally applicable combination of 100-year wind speed and fetch length. Maximum significant wave heights and periods developed in various locations of the Site are presented in **Table C-5**, and ranged from 1.4 feet to 2.2 feet. Associated wave periods ranged from 2.0 to 2.5 seconds. The variation in 100-year significant wave height along the project reach is estimated to be only about 0.8 feet; therefore, the design wind-generated significant wave height and period for evaluation of shoreline armoring along the entire project reach is defined as 2.2 feet and 2.5 seconds, respectively.

Evaluation of Vessel-Generated Waves
Estimates of vessel-induced wave heights were completed through an evaluation of ship traffic patterns within the Site and analytical calculations of vessel wakes based on type of vessel, operational speed, and water depths.

Information on waterway traffic at the Site was obtained from the following sources:

- USACE website database on annual trips and drafts of vessels on the lower Willamette River (USACE 2006)
- USACE website database on vessels residing in the Port of Portland (USACE 2007)
- Port of Portland documentation on arrivals and departures of all industrial vessels in 2008 (Port of Portland 2009)
- LWG property owner Site Use Survey
- Other sources, including correspondence with Foss Maritime Company and Portland Spirit

Commercial vessel traffic between Terminal 2 (RM 10) and Terminal 4 (RM 4.5) was used as representative of commercial vessel operations at the Site within the Willamette River. Commercial vessels operating in this area range from larger cargo vessels and tankers with drafts of less than 40 feet, to smaller push-boats, tugboats, and passenger ships/ferryboats with drafts of less than 18 feet. Overall, 51 percent of commercial vessel traffic consists of tugboats, tows, and push-boats; 44 percent consists of cargo ships; and only 5 percent consists of tankers. Excursion jet boats operated by the Portland Spirit and Willamette Jetboat Excursions travel through the Site several times daily during the summer season (approximately April through September). No available count was found for smaller recreational boats; however, wakes from these vessels are expected to be small compared to those produced by commercial vessels and excursion jet boats.

Estimates of Wakes from Commercial Vessels
The Weggel-Sorensen model (Weggel and Sorensen 1986) calculates wave height generated at a vessel bow as a function of the vessel speed, distance from the sailing line, water depth, vessel displacement volume, and vessel hull geometry (vessel length, beam, and draft). This method has been widely accepted and used for calculating vessel wakes from commercial vessels. Model inputs include water depth, vessel displacement, distance from the sailing line, vessel speed, and bow geometry (or hull form) coefficients. The model results include the wave height and period for the selected distance from the sailing line. The model was applied for all commercial vessels (except for high-speed excursion jet boats, covered in the following section). The results of these calculations for

all design conditions are provided in **Attachment C-1**. The maximum wake height calculated for each area studied is presented in **Table C-6**.

Maximum wake heights in various locations of the Site were due to one of three design vessels (pushboat, passenger ferry, or fireboat) at relatively high speeds. Estimated wake heights ranged from 2.0 to 2.8 feet due to differences in vessel operations, water depth, and river width along the project reach and wake periods were on the order of 3 to 4 seconds. The maximum wake height of 2.8 feet is taken as the design wake height from commercial vessels.

Estimates of Wakes from Excursion Vessels (Jetboats)
The Weggel-Sorensen model (Weggel and Sorensen 1986) for evaluating ship wakes tends to over-predict wakes created by faster moving recreation vessels. Therefore, a different methodology was used to estimate wakes produced by the excursion jet boats that operate in the Willamette River and throughout the Site in the summer season.

Many recent studies have addressed estimates of waves generated by different recreational ships, including numerous research studies by Maritime and Coastal Agency (MCA). Their most recent study included evaluation of wakes created by fast moving ferries (catamarans and mono-hull vessels) in water depths up to 20 meters (MCA 2009). The vessels and vessel operating conditions evaluated in this study are very similar to the jet boat operation within the Site. Therefore, the methodology developed by the MCA in the referenced report was used to estimate wakes created by the jet boat operations.

Estimates of waves generated by high-speed excursion boats, such as the Portland Spirit Outrageous Jetboat, were performed for two conditions: 1) jet boat traveling along the center line of the navigation channel, considered the most representative condition, and (2 jet boat traveling half-way between the channel centerline and the bank, considered a rare operating conditions. The results of these calculations are presented in **Table C-7**.

Wake heights range from 2.0 feet to 2.9 feet for the representative condition for jet boats and from 2.4 feet to 3.6 feet for the rare condition. The wake period of 4.0 seconds estimated for commercial vessels, is assumed to be the same for the jet boat excursion vessels to be conservative.

Findings
The analysis shows that erosion caused by wind and wake generated waves is likely limited to areas of the Site along the shoreline above 0 feet NAVD88. Within this zone, there is an area of likely heavier wave/wake action from 6 to 13 feet NAVD88 and area of likely less forceful wave/wake action from 0 to 6 feet NAVD88. Wave erosion effects above 13 feet NAVD88 were not evaluated.

C2.2.2.2 Shear Stress on Bottom Sediments

The GIS layer used to identify areas where the shear stress of a 2-year flow event exceeds the critical shear stress of the bedded sediment was developed using results from LWG's hydrodynamic- and sediment-transport models. The 2-year return interval was considered reasonable because it delineates areas that are routinely affected by a flow event that occurs every 2 years, rather than areas that rarely (for example, every 100 years) experience flows that exceed the shear stress of the bedded sediment.

The hydrodynamic model is used to simulate temporal and spatial changes in water depth, current velocity, and bed shear stress. The sediment transport model inputs were used to determine critical bed shear stress. Erosive areas were defined as areas where the shear stress exceeded the critical bed shear stress for the 2-year recurrence flow event.

Hydrodynamic Model – Shear Stress
The Environmental Fluid Dynamics Code (EFDC) model was used for this analysis; specifically, the two-dimensional (2D) depth-averaged hydrodynamic model within EFDC was used.

The hydrodynamic model requires specification of the following time-variable boundary conditions: 1) inflow at upstream boundary in the lower Willamette River; 2) inflow at upstream boundary in the Columbia River; 3) water surface elevation at downstream boundary in the Columbia River; and 4) water surface elevation at downstream boundary of the Multnomah Channel; this information is presented on **Figure C-2**. Daily-average flow rate data collected at the USGS Portland gauging station were used to specify the inflow at the upstream boundary in the lower Willamette River for the calibration and long-term simulations. Inflows at the upstream boundary during high-flow events were specified based on the results of a flood frequency analysis. A Log-Pearson Type 3 flood frequency analysis (Helsel and Hirsch 2002) of peak flow rate data from the 36-year historical record was conducted.

A summary of the estimated flow rates for high-flow events is presented in **Table C-8**. For comparison, the annual average flow rate is 33,200 cfs.

Calibration of the hydrodynamic model was achieved using data collected with an Acoustic Doppler Current Profiler (ADCP) in the main channel of the lower Willamette River between River Mile (RM) 1 and 11. The ADCP data consisted of measurements of water depth and depth-averaged current velocity (magnitude and direction) during three different periods between 2002 and 2004. A summary of the three ADCP deployment periods is provided in **Table C-9**. Two of the survey periods in 2002 and 2003 were conducted approximately at or above the mean flow rate (26,000 to 66,000 cfs). The survey conducted in January 2004 was conducted during an approximate 2-year flood event.

The effective bed roughness (Z_0) in the hydrodynamic model, which represents the total roughness due to form drag and skin friction, was adjusted to achieve the optimum agreement between predicted and observed water depth and current velocity was the. Generally, Z_0 ranges from about 0.1 to 10 centimeters (cm). A value of 1 cm for effective bed roughness produced the best agreement between observed and predicted water depth and depth-averaged current velocity during the calibration period.

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

$$\tau_{tot} = \tau_{sf} + \tau_{fd} \qquad \text{Equation C-1}$$

Skin friction represents the shear stress generated by sediment particles, representing small-scale physical features, whereas form drag corresponds to the drag generated by bedforms (such as ripples or dunes) and other large-scale physical features. When simulating erosion, skin friction is considered the dominant component of the bed shear stress for most applications. Thus, it is a reasonable approximation, and a standard approach, to use the skin friction component and neglect form drag for calculating bed shear stress for sediment transport simulations. This approach is consistent with accepted sediment transport theory (Parker 2004). Skin friction shear stress is calculated using the quadratic stress law:

$$\tau_{sf} = \rho_w \times C_f \times U^2 \qquad \text{Equation C-2}$$

Where:

ρ_w = the density of water
C_f = the bottom friction coefficient
U = the depth-averaged current velocity.

The bottom friction coefficient is determined using (Parker 2004):

$$C_f = \kappa^2 ln^{-2}(11\ z_{ref} / k_s) \qquad \text{Equation C-3}$$

Where:

z_{ref} = a reference height above the sediment bed
k_s = the effective bed roughness
κ = von Karman's constant (0.4).

The reference height (z_{ref}) is spatially and temporally variable because it is equal to half of the water depth. Thus, the reference height properly incorporates temporal and spatial variations in water depth into the calculation of the bottom friction coefficient. The effective bed roughness is assumed to be proportional to the D_{90} of the surface sediment layer (Parker 2004; Wright and Parker 2004):

$$k_s = 2D_{90} \qquad \text{Equation C-4}$$

where D_{90} is the particle diameter representing the 90th percentile. Grain size distribution data were used to specify D_{90} values for the surface layer of sediment. The spatial variability of D_{90} in the lower Willamette River was evaluated, accounting for potential spatial variation of D_{90} in the model produces qualitatively correct results (skin friction increases as bed roughness increases).

The validity of the above approach for calculating the bottom friction coefficient is evaluated as follows. Bottom friction coefficients were calculated for the lower Willamette River, using representative D_{90} values in the cohesive and non-cohesive bed areas over a range of water depths (see **Table C-10**). The range of bottom friction coefficient values in **Table C-10** is consistent with expected values for cohesive beds (van Rijn 1993). This approach provides an objective method for estimating the effective bed roughness, which will decrease the uncertainty associated with subjective estimates of roughness.

A demonstrated accurate equation for bed shear velocity (u*) for use in sediment transport formulations is defined as (van Rijn 1993):

$$u^* = (\tau_{sf} / \rho_w)^{0.5} \qquad \text{Equation C-5}$$

Current velocity in turbulent flow, which exists in the lower Willamette River for all flow and tidal conditions, is the sum of two components: time-averaged mean velocity and turbulent fluctuations about the mean value. The bed shear velocity (u*) corresponds to the turbulent-fluctuation component of the current velocity. Thus, the skin friction shear stress is driven by the turbulent fluctuations in the flow, which are randomly variable with time.

Sediment Transport Model Input –Bed Properties
Sediment transport model inputs for sediment bed properties were used to determine critical bed shear stress across the Site. Bed properties range from bulk bed characteristics such as dry density and grain size distribution to erosion rates.

The sediment bed in the lower Willamette River was separated into three distinct types:

1) cohesive (muddy bed composed of a mixture of clay, silt, sand, and organic matter)
2) non-cohesive (sandy bed composed of sand and gravel, with small amounts of clay and silt)
3) hard bottom (no erosion or deposition)

Delineation of the sediment bed into cohesive, non-cohesive and hard bottom areas was accomplished using grain size distribution data from sediment cores collected during the GeoSea and Round 2 field studies during 2000 and 2004, respectively (GeoSea 2001; Integral 2005a, 2005b, 2006). Grain size distribution data were available at a total of 1,187 locations at the Site (see **Figures C-3a** and **C-3b**). Sediment cores were classified as cohesive using the following criteria: median particle diameter (D_{50}) less than 250 micrometers (μm); and clay/silt content greater than 15 percent (Ziegler and

Nisbet 1994). The sediment bed was assumed to be hard bottom in areas upstream of RM 12.9 in the lower Willamette River, Multnomah Channel, and the Columbia River. The bed map for the Site is shown on **Figure C-4**. Approximately 81 percent of the bed area between RMs 2 and 11 is cohesive.

The following bed property inputs within the lower Willamette River were determined for use in the sediment transport model:

1) dry (bulk) density
2) initial sediment bed composition (relative amounts of sediment sizes)
3) median particle diameter (D_{50})
4) effective bed roughness (which is proportional to D_{90})
5) erosion rate properties in cohesive bed areas

The dry density of the bed was assumed to be spatially variable within the lower Willamette River, with different values in the cohesive and non-cohesive bed areas. For cohesive bed areas, the dry density has a value of 0.72 grams per cubic centimeters (g/cm^3), which corresponds to the average value of 596 samples. Dry density in non-cohesive bed areas has a value of 1.2 g/cm^3, which corresponds to the average value of 162 samples. Dry density is assumed to be horizontally and vertically constant within all areas of a particular bed type.

Spatial distributions of D_{50} and D_{90} values were developed from the grain size distribution data collected at 1,187 locations at the Site (**Figure C-5**). Spatial distributions of bed composition were specified as initial conditions for the sediment transport model using the grain size distribution data (**Figures C-6a** through **C-6b**). As a reference, **Table C-11** presents the average values of D_{50}, D_{90}, and composition of the bed for cohesive and non-cohesive areas.

A Sedflume study was conducted during 2006 to obtain data on the erosion properties of lower Willamette River sediments. Cores were collected from 19 locations (**Figure C-7**). Details of the field study, including core collection and processing, are described in Sea Engineering (2006). Erosion rates as a function of depth in the bed and applied shear stress were measured over the top 30 cm of each core using Sedflume. Sediment samples were also obtained at 5-cm intervals from each core and analyzed for bulk (wet) density and grain size distribution.

Erosion rate data obtained from Sedflume testing were analyzed to develop an understanding of the erosion properties of lower Willamette River sediments in cohesive bed areas. The goal of this analysis was to develop a functional relationship between the gross erosion rate (E_{gross}) and bed shear stress. The site-specific parameters in the E_{gross} equation below were determined using the erosion rate data collected during the field study. Four of the 19 Sedflume cores (SF-2, SF-6, SF-7, SF-18) were determined to consist of non-cohesive (i.e., sandy) sediment and those cores were not included in the analysis as Sedflume erosion rate data are only applicable to cohesive bed sediment.

$$E_{gross} = A\tau_{sf}^{n} \quad \text{when } \tau_{sf} > \tau_{cr}$$
$$E_{gross} = 0 \quad \text{when } \tau_{sf} \leq \tau_{cr}$$

Equation C-6

Where:

E_{gross} = gross erosion rate (centimeters per second [cm/s])
τ_{sf} = skin friction shear stress (Pascal [Pa])
τ_{cr} = critical shear stress (Pa), which is the shear stress at which a small, but measurable, rate of erosion occurs (generally less than 2 millimeters per hour).

The proportionality constant (A) and exponent (n) are site-specific and may be spatially variable, both horizontally and vertically.

The erosion rate properties of the 15 cores were analyzed using the following procedure. Each core was divided into five depth intervals of 5 cm each between 0 and 25 cm. These depth intervals were chosen because the shear stress series used in the Sedflume tests, where shear stress was increased from low to high values, cycled over approximately 5 cm thick layers. The erosion rate data within each layer of a particular core were analyzed through application of a log-linear regression analysis between erosion rate and shear stress. The log-linear regression analysis produced values of A and n for each layer in a particular core. The results of this analysis for the Sedflume cores with cohesive sediment are presented in **Figures C-8** through **C-22**. The critical shear stress for each 5 cm layer was calculated as:

$$\tau_{cr} = (E_{cr} / A)^{1/n}$$

Equation C-7

Where:

E_{cr} = 0.0001 cm/s

Values for A, n, and τ_{cr} for each core within the five depth intervals are listed in **Tables C-12** through **C-16**., values of A and n in these tables correspond to units of cm/s for E_{gross} and pascal (Pa) for bed shear stress. The correlation coefficient (R^2) values presented in the tables are from the log-linear regression analysis, with perfect correlation corresponding to an R^2 value of 1.

Horizontal and vertical spatial variation in the erodibility of sediment in cohesive bed areas was evaluated as follows: average values of A and n in Equation 6 were calculated for each of the five depth intervals. Assuming a log-linear relationship (such as Equation 6), the average exponent (n_{ave}) value for a depth interval is the arithmetic average of the n values for the cores within the interval. The average proportionality constant (A_{ave}) is determined by calculating the log-average value:

$$\log(A_{ave}) = (1/K) \sum \log(A_k) \qquad \text{Equation C-7}$$

where K is equal to the number of cores. Using this approach, the average erosion parameters for the five layers in the bed model are listed in **Table C-17**.

Vertical variation in the average erosion rate properties for the five depth intervals was quantified by first calculating the average value of gross erosion rate for depth interval i (${}^{ave}E_{gross,i}$, where i ranges from 1 to 5):

$${}^{ave}E_{gross,i} = 1/N \, \Sigma \, A_{ave,i} \, \tau^{n,ave,i} \qquad \text{Equation C-8}$$

where the summation is over the bed shear stress range of 0.05 to 3 Pa in increments of 0.05 Pa, so N is equal to 60. Values of $A_{ave,i}$ and $n_{ave,i}$ for depth interval i are given in **Table C-17**. Using the values of ${}^{ave}E_{gross,i}$ for the five depth intervals, the average erosion rate ratios for depth interval i ($R_{ave,i}$) was calculated using:

$$R_{ave,i} = {}^{ave}E_{gross,i} / {}^{ave}E_{gross,1} \qquad \text{Equation C-9}$$

where i ranges from 1 through 5. Thus, $R_{ave,i}$ represents the ratio of the erodibility of depth interval i to the average erodibility of depth interval 1 (0 to 5 cm layer); $R_{ave,1}$ is equal to one. The vertical variation in $R_{ave,i}$ is shown on **Figure C-23**. These results indicate that the average erodibility of lower Willamette River sediment in cohesive bed areas tends to decrease with increasing depth in the bed, which is a typical characteristic of a cohesive sediment bed and is primarily due to increasing consolidation with increasing depth. Erodibility of the 20 to 25 cm layer is about four times less than the erodibility of the 0 to 5 cm layer.

A similar approach was used to quantify spatial differences in bed erodibility of the surface layer (i.e., 0 to 5 cm layer) within the horizontal plane in the lower Willamette River. The average gross erosion rate for layer 1 (0 to 5 cm layer) in core k was calculated as follows:

$${}^{ave}E_{gross,1,k} = 1/N \, \Sigma \, A_{1,k} \, \tau^{n,1,k} \qquad \text{Equation C-10}$$

where the summation is over the bed shear stress range of 0.05 to 3 Pa in increments of 0.05 Pa, so N is equal to 60. Values of $A_{1,k}$ and $n_{1,k}$ for layer 1 in core k are given in **Table C-12**.

Sedflume data from 15 cores are not sufficient to use standard interpolation methods to develop a reliable horizontal distribution of erosion properties. No correlation was found between erosion properties and measured bed properties (dry density, D_{50}, D_{90}, silt/clay content). Thus, developing a credible spatial distribution of erosion parameters in the horizontal plane is problematic. Therefore, it was assumed that the average erosion rate parameters (A_{ave} and n_{ave} as listed in **Table C-17**) for a given depth interval are spatially constant in the horizontal plane within cohesive bed areas. By assuming that the erosion parameters are spatially constant in the horizontal plane, the erosion parameters only vary in the vertical direction.

C2.3 SEDIMENT BED CHARACTERISTICS

Three surface bed sediment surveys have been conducted in the lower Willamette River:

- A Sediment Trend Analysis® (STA®) survey was conducted by GeoSea, Inc. (GeoSea 2001) of 935 target locations from the confluence with the Columbia River to Willamette Falls.
- As a part of Round 2 s field sampling activities (Integral Consulting 2005a), surface bed sediment samples up to 30 cm in depth were collected at a total of 523 target locations distributed from RM 2 to RM 25. All but 18 of these stations were located within the Site, and the majority were distributed over near-shore areas.
- As part of the Round 2 hydrodynamic/sediment transport modeling data collection (Integral Consulting 2006), 17 Sedflume cores were collected at locations throughout the Site.

The grain-size distribution from both the GeoSea data set and Round 2 data covers sediment size classes ranging from gravel to clay. The results of these studies showed that medium and fine sands dominate the Willamette River bed upstream of RM 16 (Ross Island). The majority of bed materials in the middle and east sections of the reach from RM 11 to RM 16 are also sands, with the percentage of silts and clays increasing in the west section of this reach. Downstream of RM 11, the bed sediments are much finer, with a significant proportion of silts and clays. From RM 4.5 to RM 11 (particularly from RM 4.5 to RM 7), more coarse sands are present in the deep channel than in the near-shore areas. However, from RM 2 to RM 4.5, the bed sediments in the deep channel are finer than in the near-shore areas. The solids density for noncohesive and cohesive classes was assigned as 2.55 and 2.32 g/cm^3, respectively, based on the Round 2 measurements in the Willamette River.

The January 2009 bathymetry data were used to identify sediment slopes within the Site. Slopes less than 15 percent, between 15 and 30 percent, and greater than 30 percent were delineated.

C2.4 ANTHROPOGENIC INFLUENCES

The sources of information used to identify structures and pilings, delineate moderate to high debris areas, and identify propeller wash areas are provided below.

C2.4.1 Structures and Pilings

The GIS layer used to identify structures and pilings at the Site was created using two layers developed by the LWG, docks and other structures and the approximate distribution of structures and debris in the river channel and along both banks of the river (based on a high resolution sidescan sonar survey in 2008) were provided in separate layers. The sidescan sonar survey area extended from RM 1 to RM 12.2, and included the half mile uppermost segment of the Multnomah Channel. A total of 7,257 discrete targets from the area surveyed were identified. A detailed presentation of targets and their locations is provided in the *Lower Willamette River Sidescan Sonar Data Report* (Anchor QEA 2009).

Approximately two thirds of the targets identified were clearly man-made objects (piers, pilings, dolphins, and structures) placed in the river for navigational, operational, or engineering purposes. Approximately 25 percent of the remaining material was broadly classified as debris. Logs accounted for approximately 5 percent of the targets. Other geologic and cultural features observed using sidescan sonar included the occurrence of gravel, depressions, anchor drags, and dredge artifacts. Targets identified as debris, logs, or other miscellaneous features were removed from the GIS layer. All remaining targets identified as structures in the queried file were buffered with a five foot radius and then combined with the docks and structures GIS layer. The combined layer was then converted to a raster file for analysis purposes.

C2.4.2 Debris

The GIS debris layer initially came from the same high resolution sidescan sonar survey described in Section E5.1 above. As discussed, approximately 25 percent of the targets identified during the sidescan sonar survey were broadly classified as debris. Debris was commonly found along the margins of dock structures, a pattern that is consistent with vessel activity patterns. The logs that accounted for approximately 5 percent of the targets were often associated with areas that are or were log booming areas.

The original GIS layer provided by LWG from the survey was modified to only include targets identified as debris, logs, or unclassified. Structures, pilings, and dolphins were removed from the debris layer. The new layer was then converted into a vector file for analysis purposes using a method called Point Density, which calculates the density of point features around each raster cell. The raster file consists of 10 foot by 10 foot cells. A neighborhood was defined as a circle with a 50 foot radius, and was based around each raster cell center. Then the number of points that fell within the circle were totaled and divided by the area of the neighborhood. The area units were set to acres, so the calculated density for each cell was multiplied by the appropriate factor and then written to the output raster. The resulting raster was reclassified so that any cell with a value less than or equal to 40 was set to 0. Any cell with a value greater than 40 was set to 1 and identified as containing moderate to heavy debris.

C2.4.3 Propeller Wash Analysis

The propeller jet of a maneuvering vessel has the potential to impact cap surfaces and may cause erosion of capping materials if they are not sized appropriately. Analyses were conducted to estimate a range of armor stone that might be needed to resist propeller-induced bottom velocities. The propeller wash analysis consisted of the following components:

- Obtaining information for the types of commercial and recreational vessels that operate in the Site and their operating characteristics
- Obtaining the vessel characteristics (draft, propeller type)
- Selecting representative reasonable conservative vessels across the range of conditions to be used in the evaluation
- Defining representative reasonable conservative case vessel operating assumptions (operating horsepower)
- Defining a range of general Site conditions for each model run (water depth)
- Based on the above range of operational and Site conditions, estimating the range of particle sizes necessary to withstand the erosive forces associated with propeller wash at various Site water depths.

C2.4.3.1 Propeller Wash Analysis Methodology

The GIS layer used to define propeller wash areas was provide by the LWG on January 22, 2014. The LWG conducted modeling to determine potential surface sediment mixing and scour depths due to propeller wash forces based on the vessels and operating parameters determined through the site use survey discussed in Section C2.1.1.

The standard predictive models for propeller-induced bottom velocities are based on jet flow for a stationary jet. Empirical relationships developed by Blaauw and van de Kaa (1978) were used for the modeling, consistent with Appendix A of the Assessment and Remediation of Contaminated Sediments (ARCS) Program Guidance for In Situ Subaqueous Capping of Contaminated Sediments (Palermo et al. 1998) and Verhey (1983). Specific inputs regarding vessel characteristics and site conditions are required to predict the maximum bottom velocity and associated grain size required to resist the long-term, steady- state propeller wash from vessels.

Use of this methodology is conservative because the propeller wash equations are based on non-maneuvering vessels (sailing speed of zero). In reality, the propeller wash force is transient in nature because the vessels typically are operating at some defined sailing speed, which acts to significantly reduce the duration and magnitude of the propeller wash acting on the river bottom. However, for purposes of the screening-level analysis, the static condition for evaluating potential propeller wash impacts was evaluated to provide a conservative assessment.

Propeller wash disturbance depths were evaluated using the following specific methods:

- Dücker and Miller (1996)
- Hamill (1988)

The Dücker and Miller (1996) method predicts the disturbance depth based on the bed sediment grain size, jet velocity at the bed, rudder angle, and distance between the propeller and bed. The Hamill (1988) method predicts disturbance depth based on the clearance of the propeller tip above the bed, the diameter of the propeller, jet velocity at the bed, sediment grain size, and time of exposure to the propeller wash (a time rate of scour). For this method, a time of exposure of 120 seconds (2 minutes) was assumed. This method is sensitive to this assumption, but 2 minutes was selected as a reasonably conservative estimate given that these propeller wash effects are usually transitory to any particular location and of much shorter duration even in the case of most docking situations.

C2.4.3.2 Range of Vessel Types and Their Specifications

The first step in the analysis was to gather information about vessels that operate in and around the Site, including specific design characteristics and typical operating procedures.

Typical operations include the use of commercial vessels, tugs, fireboats, and recreational vessels. Although specific vessel properties are typically used for propeller wash calculations, general vessel information was obtained from the Site use survey and the Columbia River Pilots' Data, which record the number and type of vessels entering the lower Willamette River. This general information was augmented by Site observations from Integral Consulting (J. Moore) based on 4 years of experience conducting studies in and acquiring familiarity with operations at the Site. The resulting information from all these sources is considered sufficient to identify the general types of vessels operating in various regions of the river and use in an FS-level of assessment.

A range of specifications for each type of vessel (including propeller diameter, vessel horsepower, and draft) were estimated both from best professional judgment as well as by reviewing vessel specification data sheets (**Table C-18**). These input parameters were selected to span a range of Site conditions that are likely representative of propeller wash forces and conditions for the Site as a whole and are representative of current vessel operations in various locations of the Site based on the site use survey, with the exception of RM 2E. The Evraz Oregon Steel Mills dock is located in this location, and the docks at RM3.5E and 7W are currently inactive. Thus, they were evaluated assuming vessels that are representative of those that may use the area in the future.

C2.4.3.3 Selection of Design Vessel

From the group of vessels in **Table C-18**, the vessel with the deepest draft and greatest horsepower was selected for input to the model to evaluate a range of potential propeller wash forces across the water depths in each represented location. While this evaluation is not indicating that vessels are necessarily restricted to just these locations, these combinations of vessels and physical conditions likely span the overall range of propeller wash conditions present at the Site. The selected vessels produce the largest propeller wash velocities due to their size, corresponding engine output, and proximity to the riverbed. Use of these design vessels yielded the largest likely propeller velocities across a range of Site conditions, consistent with a reasonable conservative approach to armor sizing.

C2.4.3.4 Vessel Operating Assumptions

Vessel operating assumptions included estimations on the percent of horsepower typically used. These estimations are based on best professional judgment and experience from other propeller wash analyses. Consistent with a reasonable conservative approach, the reasonably assumed maximum applied horsepower was used as input to the model. The maximum operating horsepower selected for use in the analysis ranged from 30 percent for the large ships to 90 percent for small pleasure crafts. Although it is technically possible for 100 percent horsepower to be applied, this scenario is assumed to be too infrequent to be relevant. An evaluation of full power application in specific locations may be appropriate during the remedial design. Values for the coefficient frequency of attack of vessel operation (C_3) were obtained from Maynord (1998). A value of 0.55 is considered appropriate in locations where repeated attack is expected and no transport/movement can be permitted. In contrast, C_3, assigned a value of 0.70, is reported as sufficient for general protection where infrequent attack is expected.

C2.4.3.5 Area-Specific Parameters

The range of water depths in the operational area of each vessel is the only area-specific input. Water depths were obtained from bathymetric maps obtained from the results of a multi-beam bathymetric survey in February/March of 2004 (Evans and Associates 2004). The shallowest and deepest water depth within the area where the vessels were estimated to be operating were used. These combinations of vessel types and water depths are expected to be representative for this force of the overall range of Site conditions. The results obtained using the shallowest water depths are reported in the results section as the shallowest water depth results in the highest propeller wash velocities at the sediment bed due to the proximity of the vessel propeller to the sediment.

C2.4.3.6 Propeller Wash Analysis Results

Estimated required grain size (ranging from coarse gravel to riprap) to ensure bed stability under propeller wash forces for a reasonably conservative set of vessels and sites is presented in **Table C-19**. This analysis provides a relatively conservative estimate of the range of cap armor sizes potentially needed to resist potential erosion due to vessel propeller induced bottom velocities.

The resulting calculated propeller wash force disturbance depths across a range of potential Site conditions are summarized in **Table C-20**. In some instances, the combination of parameters could not be used to resolve an exact disturbance depth using the Hamill method. In addition, estimates of greater than a 6-foot disturbance depth also may be beyond the range of parameters that this method can reasonably resolve, given that they differ significantly from the findings using the Dücker and Miller method.

These estimates indicate that maximum disturbance depths under most of the conditions applicable to the Site are less than 1 foot, even in heavier propeller wash locations located in relatively shallower water locations of the navigation channel and near active docks. However, in specific locations and under specific conditions, greater depths of sediment disturbance might be expected to take place. This concept is supported by bathymetry information, which indicates that so-called "scour pits" may exist in and near some berthing locations although this does not appear to occur everywhere that vessels travel or dock.

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Tables

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Table C-1
100-year Return Period Wind Speeds
Portland Harbor Superfund Site
Portland, Oregon

Directional Zone (°N)	100-year Wind Speed (mph)	Rayleigh Correlation Coefficient (R^2)
0 to 30	30	0.95
31 to 60	37	0.96
61 to 90	56	0.97
91 to 120	59	0.97
121 to 150	40	0.97
151 to 180	59	0.98
181 to 210	69	0.84
211 to 240	60	0.89
241 to 270	47	0.97
271 to 300	39	0.96
301 to 330	38	0.95
331 to 360	37	0.97

Table C-2
Fetch Lengths (in feet) and Associated Wind Parameters
Portland Harbor Superfund Site
Portland, Oregon

Start Heading (°N)		0	31	61	91	121	151	181	211	241	271	301	331
End Heading (°N)		30	60	90	120	150	180	210	240	270	300	330	360
100-year Wind Speed (mph)		30	37	56	59	40	59	69	60	47	39	38	37
Location	RM2E								4,400	2,100	2,100		3,400
	RM3.5E							3,700	1,900	1,900	4,600	4,300	
	RM3.5E						4,600	3,500	1,900	1,600	2,400	4,600	
	RM3.9W	3,100	1,800	1,900	2,400	4,200							
	RM3.9W	3,300	1,800	2,100	2,700	4,700							
	RM4.5E						4,600	3,000	1,900	2,000	2,700	5,300	
	RM5W	3,200	2,000	1,600	2,800								5,400
	RM5W	2,500	1,400	1,400	2,600								4,300
	RM6W	1,600	1,200	1,300	3,500								3,800
	RM6W	1,400	1,300	3,300	5,000							3,000	2,600
	RM5.5E						3,100	1,700	1,200	1,500	2,700	4,200	
	RM5.5E						2,600	1,800	1,200	1,400	3,200		
	RM6.5E					2,700	2,200	1,400	1,600	1,600	3,700		
	RM6.5E					3,800	3,800	1,500	1,500	2,400	2,900		
	RM7W	2,400	2,000	2,200	3,500								3,000
	RM6.5E							1,900	2,000	2,600	6,200		
	RM7W	3,200	2,700	4,200	3,800								3,800
	Swan Is						4,000	2,500	2,500	2,200	3,300		
	Swan Is								3,900	5,400			
	RM9W	2,800	1,700	2,600	3,500								4,600
	RM9W	2,100	1,900	3,100	4,400							5,900	5,900
	RM9W	1,800	1,800	3,100	3,200							3,600	3,100
	RM9E					3,800	2,800	1,700	1,900	3,500	4,300		
	RM9E					4,300	2,900	2,000	1,600	2,800	3,700		
	RM10E						2,100	1,900	1,500	2,900	5,000		
	RM10W	1,700	1,100	1,200	2,800								3,300
	RM11E					2,800	2,500	1,300	1,200	1,500	2,500		
	RM11W	1,300	1,100	1,700	2,300								3,200

Table C-3
100-year Significant Wave Heights (in feet) and Associated Wind Parameters
Portland Harbor Superfund Site
Portland, Oregon

	Start Heading (°N)	0	31	61	91	121	151	181	211	241	271	301	331
	End Heading (°N)	30	60	90	120	150	180	210	240	270	300	330	360
	100-year Wind Speed (mph)	30	37	56	59	40	59	69	60	47	39	38	37
Location	RM2E								2.0	1.0	0.8		1.0
	RM3.5E							2.2	1.3	1.0	1.2	1.1	
	RM3.5E						2.0	2.1	1.3	0.9	0.9	1.2	
	RM3.9W	0.7	0.7	1.2	1.5	1.2							
	RM3.9W	0.8	0.7	1.3	1.6	1.3							
	RM4.5E						2.0	2.0	1.3	1.0	0.9	1.3	
	RM5W	0.7	0.8	1.1	1.6								1.2
	RM5W	0.7	0.6	1.1	1.5								1.1
	RM6W	0.5	0.6	1.0	1.8								1.0
	RM6W	0.5	0.6	1.6	2.1							1.0	0.9
	RM5.5E						1.7	1.5	1.1	0.9	0.9	1.1	
	RM5.5E						1.5	1.5	1.1	0.9	1.0		
	RM6.5E					1.0	1.4	1.4	1.2	0.9	1.1		
	RM6.5E					1.1	1.8	1.4	1.2	1.1	1.0		
	RM7W	0.6	0.8	1.3	1.8								0.9
	RM6.5E							1.6	1.4	1.2	1.4		
	RM7W	0.7	0.9	1.8	1.8								1.0
	Swan Is						1.9	1.8	1.5	1.1	1.0		
	Swan Is								1.9	1.7			
	RM9W	0.7	0.7	1.4	1.8								1.1
	RM9W	0.6	0.7	1.6	2.0							1.3	1.3
	RM9W	0.6	0.7	1.6	1.7							1.0	0.9
	RM9E					1.1	1.6	1.5	1.3	1.3	1.2		
	RM9E					1.2	1.6	1.6	1.2	1.2	1.1		
	RM10E						1.4	1.6	1.2	1.2	1.3		
	RM10W	0.5	0.6	1.0	1.6								1.0
	RM11E					1.0	1.5	1.3	1.1	0.9	0.9		
	RM11W	0.5	0.6	1.2	1.4								1.0

Table C-4
100-year Significant Wave Periods (in sec) and Associated Wind Parameters
Portland Harbor Superfund Site
Portland, Oregon

Start Heading (°N)		0	31	61	91	121	151	181	211	241	271	301	331
End Heading (°N)		30	60	90	120	150	180	210	240	270	300	330	360
100-year Wind Speed (mph)		30	37	56	59	40	59	69	60	47	39	38	37
Location	RM2E								2.5	1.8	1.6		1.8
	RM3.5E							2.6	2.0	1.8	2.0	2.0	
	RM3.5E						2.5	2.6	2.0	1.7	1.7	2.0	
	RM3.9W	1.6	1.5	1.9	2.1	2.0							
	RM3.9W	1.6	1.5	2.0	2.2	2.1							
	RM4.5E						2.5	2.5	2.0	1.8	1.8	2.1	
	RM5W	1.6	1.6	1.8	2.2								2.1
	RM5W	1.5	1.4	1.8	2.2								1.9
	RM6W	1.3	1.4	1.7	2.3								1.9
	RM6W	1.3	1.4	2.2	2.6							1.8	1.7
	RM5.5E						2.3	2.1	1.8	1.7	1.8	1.9	
	RM5.5E						2.2	2.1	1.8	1.6	1.8		
	RM6.5E					1.8	2.1	2.0	1.9	1.7	1.9		
	RM6.5E					1.9	2.4	2.0	1.9	1.9	1.8		
	RM7W	1.5	1.6	2.0	2.3								1.8
	RM6.5E							2.2	2.0	1.9	2.2		
	RM7W	1.6	1.7	2.4	2.4								1.9
	Swan Is						2.4	2.3	2.2	1.8	1.9		
	Swan Is								2.4	2.3			
	RM9W	1.5	1.5	2.1	2.3								2.0
	RM9W	1.4	1.6	2.2	2.5							2.1	2.1
	RM9W	1.4	1.5	2.2	2.3							1.9	1.8
	RM9E					1.9	2.2	2.1	2.0	2.1	2.0		
	RM9E					2.0	2.2	2.2	1.9	2.0	1.9		
	RM10E						2.0	2.2	1.9	2.0	2.1		
	RM10W	1.3	1.3	1.7	2.2								1.8
	RM11E					1.8	2.1	2.0	1.8	1.7	1.7		
	RM11W	1.2	1.3	1.9	2.1								1.8

Table C-5
Maximum 100-year Wind Wave Heights and Periods
Portland Harbor Superfund Site
Portland, Oregon

Location	Significant Wave Height (ft)	Significant Wave Period (s)
RM2E	2.0	2.5
RM3.5E	2.1	2.6
RM3.5E	1.5	2.1
RM3.9W	1.6	2.2
RM3.9W	2.0	2.5
RM4.5E	1.6	2.2
RM5W	1.5	2.2
RM5W	1.8	2.3
RM6W	2.1	2.6
RM6W	1.7	2.3
RM5.5E	1.5	2.2
RM5.5E	1.4	2.1
RM6.5E	1.8	2.4
RM6.5E	1.8	2.3
RM7W	1.6	2.2
RM6.5E	1.8	2.4
RM7W	1.9	2.4
Swan Is	1.9	2.4
Swan Is	1.8	2.3
RM9W	2.0	2.5
RM9W	1.7	2.3
RM9W	1.6	2.2
RM9E	1.6	2.2
RM9E	1.6	2.2
RM10E	1.6	2.2
RM10W	1.5	2.1
RM11E	1.4	2.1
RM11W	2.0	2.5

Table C-6
Maximum Wake from Commercial Vessel Traffic
Portland Harbor Superfund Site
Portland, Oregon

Location	Vessel	Wake Height (feet)	Wake Period (sec)
RM2E	Pushboat	2.0	2.7
RM3.5E	Passenger Ferry	2.8	2.7
RM3.9W, RM4.5E, RM5W, RM5.5E	Passenger Ferry	2.8	2.7
RM6W	Passenger Ferry	2.8	2.7
RM5.5E, RM6.5E	Fireboat	2.1	4.0
RM6.5E	Pushboat	2.0	2.7
RM7W	Passenger Ferry	2.8	2.7
RM6.5E	Pushboat	2.0	2.7
RM7W	Passenger Ferry	2.8	2.7
Swan Is, RM9W	No Wake	n/a	n/a
RM9W	Passenger Ferry	2.8	2.7
RM9W	Passenger Ferry	2.7	2.7
RM9W	Pushboat	1.7	2.7
RM9E	Pushboat	1.7	2.7
RM9E, RM10E	Fireboat	2.1	4.0
RM10W	Passenger Ferry	2.8	2.7
RM11E	Passenger Ferry	2.8	2.7
RM11W	Passenger Ferry	2.8	2.7

Table C-7
Wake Heights Estimated for Excursion Jet Boats
Portland Harbor Superfund Site
Portland, Oregon

Location	REPRESENTATIVE CASE (Traveling at Center Line of Channel)				WORST CASE (Traveling 1/2 way between Center Line of Channel and Bank)			
	Water Depth (ft)	Distance from Sailing Line (ft)	Critical/ Supercritical	H (ft)	Water Depth (ft)	Distance from Sailing Line (ft)	Critical/ Supercritical	H (ft)
RM2E	49	1000	Supercritical	2.0	44	750	Supercritical	2.4
	58	1000	Supercritical	2.0	53	750	Supercritical	2.4
RM3.5E	44	900	Supercritical	2.2	44	650	Supercritical	2.6
	53	900	Supercritical	2.2	53	650	Supercritical	2.6
RM3.9W	44	900	Supercritical	2.2	49	650	Supercritical	2.6
	53	900	Supercritical	2.2	58	650	Supercritical	2.6
RM4.5E	69	750	Supercritical	2.4	59	500	Supercritical	2.9
	78	750	Supercritical	2.4	68	500	Supercritical	2.9
RM5W	44	550	Supercritical	2.8	49	350	Supercritical	3.5
	53	550	Supercritical	2.8	58	350	Supercritical	3.5
RM5.5E, RM6W	49	500	Supercritical	2.9	44	333	Supercritical	3.6
	58	500	Supercritical	2.9	53	333	Supercritical	3.6
RM5.5E	59	625	Supercritical	2.6	49	500	Supercritical	2.9
	68	625	Supercritical	2.6	58	500	Supercritical	2.9
RM6.5E	49	750	Supercritical	2.4	49	625	Supercritical	2.6
	58	750	Supercritical	2.4	58	625	Supercritical	2.6
RM7W	44	500	Supercritical	2.9	39	375	Supercritical	3.4
	53	500	Supercritical	2.9	48	375	Supercritical	3.4
RM6.5E, RM7W	49	900	Supercritical	2.2	54	600	Supercritical	2.7
	58	900	Supercritical	2.2	63	600	Supercritical	2.7
SwanIs	44	600	Supercritical	2.7	39	500	Supercritical	2.9
	53	600	Supercritical	2.7	48	500	Supercritical	2.9
RM9W	39	1100	Supercritical	2.0	29	600	Supercritical	2.7
	48	1100	Supercritical	2.0	38	600	Supercritical	2.7
RM9W	39	750	Supercritical	2.4	25	400	Supercritical	3.3
	48	750	Supercritical	2.4	33	400	Supercritical	3.3
RM9W	35	900	Supercritical	2.2	44	375	Supercritical	3.4
	43	900	Supercritical	2.2	53	375	Supercritical	3.4

Table C-7
Wake Heights Estimated for Excursion Jet Boats
Portland Harbor Superfund Site
Portland, Oregon

	REPRESENTATIVE CASE (Traveling at Center Line of Channel)				WORST CASE (Traveling 1/2 way between Center Line of Channel and Bank)			
Location	**Water Depth (ft)**	**Distance from Sailing Line (ft)**	**Critical/ Supercritical**	**H (ft)**	**Water Depth (ft)**	**Distance from Sailing Line (ft)**	**Critical/ Supercritical**	**H (ft)**
RM9E, RM10E	Ship travel at no-wake speed							
RM10W	54	1000	Supercritical	2.0	34	500	Supercritical	2.9
	63	1000	Supercritical	2.0	43	500	Supercritical	2.9
RM11E	41	700	Supercritical	2.5	42	400	Supercritical	3.3
	50	700	Supercritical	2.5	50	400	Supercritical	3.3
RM11W	44	700	Supercritical	2.5	44	400	Supercritical	3.3
	53	700	Supercritical	2.5	53	400	Supercritical	3.3

Table C-8
Estimated Lower Willamette River Flow Rates for High-flow Events
Portland Harbor Superfund Site
Portland, Oregon

Flood Return Period (Years)	Flow Rate (cfs)
2	156,000
10	252,000
25	297,000
50	329,000
100	360,000
500	428,000

Notes:
cfs = cubic feet per second

Table C-9
ADCP Data Collection Summary
Portland Harbor Superfund Site
Portland, Oregon

Survey Date	Lower Willamette River Flow Rate (cfs)	Survey Region	Number of Transects
April 19, 2002	66,000	RM 1 – 11	16
May 13, 2003	26,000	RM 2.5 – 4	4
January 31, 2004	139,000	RM 1 – 11	16

Notes:
cfs = cubic feet per second
RM = river mile

Table C-10
Bottom Friction Coefficient Values for a Range of Water Depths
Portland Harbor Superfund Site
Portland, Oregon

Water Depth (m)	Bottom Friction Coefficient: Cohesive Bed (D90 = 280 μm)	Bottom Friction Coefficient: Non-Cohesive Bed (D90 = 1,480 μm)
1	0.0016	0.0024
2	0.0014	0.0020
3	0.0013	0.0018
4	0.0012	0.0017

Notes:
μm = micrometer
m = meter

Table C-11
Average Values for Bed Properties Initial Conditions
Portland Harbor Superfund Site
Portland, Oregon

Bed Type	D_{50} (µm)	D_{90} (µm)	Class 1 Content (%)	Class 2 Content (%)	Class 3 Content (%)	Class 4 Content (%)
Cohesive	50	280	64	26	9	1
Non-Cohesive	510	1,480	13	14	64	9

Notes:
µm = micrometer
Class 1 = Clay and silt with particle diameters less than 62 µm
Class 2 = Fine sand (62 to 250 µm)
Class 3 = Medium and coarse sand (250 to 2,000 µm)
Class 4 = Gravel (greater than 2,000 µm)

Table C-12
Erosion Rate Parameters for 0 to 5 cm Layer
Portland Harbor Superfund Site
Portland, Oregon

Sediment Core ID	River Mile Location	Proportionality Constant: A	Exponent: n	Correlation Coefficient (R^2)	Critical Shear Stress (Pa)
SF-1	2.4	0.00113	2.4	0.97	0.36
SF-3	3.7	0.00504	1.6	0.96	0.09
SF-4	4.0	0.00244	2.3	0.99	0.25
SF-5	4.8	0.00137	2.0	0.94	0.27
SF-8	6.1	0.00473	2.7	0.98	0.24
SF-9	6.4	0.00081	2.0	0.80	0.35
SF-10	6.8	0.00110	2.25	0.95	0.33
SF-11	6.9	0.00025	3.1	0.98	0.73
SF-12	7.6	0.00430	1.6	0.92	0.10
SF-13	8.0	0.00218	1.3	0.76	0.10
SF-14	8.3	0.00140	1.3	0.76	0.14
SF-15	8.6	0.00546	2.1	0.96	0.15
SF-16	9.3	0.00065	2.6	0.90	0.49
SF-17	10.0	0.00061	2.9	0.96	0.54
SF-19	10.4	0.00115	2.3	0.95	0.34

Table C-13
Erosion Rate Parameters for 5 to 10 cm Layer
Portland Harbor Superfund Site
Portland, Oregon

Sediment Core ID	River Mile Location	Proportionality Constant: A	Exponent: n	Correlation Coefficient (R^2)	Critical Shear Stress (Pa)
SF-1	2.4	0.00106	2.8	0.99	0.43
SF-3	3.7	0.00056	4.6	0.99	0.69
SF-4	4.0	0.00043	3.7	0.97	0.67
SF-5	4.8	0.00014	3.2	0.96	0.89
SF-8	6.1	0.00151	2.1	0.96	0.28
SF-9	6.4	0.00015	3.1	0.99	0.86
SF-10	6.8	0.00036	3.1	0.99	0.66
SF-11	6.9	0.00002	4.4	0.97	1.33
SF-12	7.6	0.00054	2.4	0.99	0.49
SF-13	8.0	0.00115	2.6	0.95	0.38
SF-14	8.3	0.00014	1.9	0.83	0.83
SF-15	8.6	0.00117	2.1	0.96	0.32
SF-16	9.3	0.00306	2.0	0.93	0.18
SF-17	10.0	0.00047	3.0	0.98	0.59
SF-19	10.4	0.00120	2.2	0.60	0.32

Table C-14
Erosion Rate Parameters for 10 to 15 cm Layer
Portland Harbor Superfund Site
Portland, Oregon

Sediment Core ID	River Mile Location	Proportionality Constant: A	Exponent: n	Correlation Coefficient (R^2)	Critical Shear Stress (Pa)
SF-1	2.4	0.00048	3.9	0.98	0.67
SF-3	3.7	0.00608	2.8	0.98	0.23
SF-4	4.0	0.00034	2.8	0.99	0.64
SF-5	4.8	0.00026	2.6	0.99	0.68
SF-8	6.1	N/A	N/A	N/A	N/A
SF-9	6.4	0.00039	2.3	0.93	0.56
SF-10	6.8	0.00008	3.0	0.95	1.08
SF-11	6.9	0.00358	1.7	0.89	0.12
SF-12	7.6	0.00132	1.8	0.99	0.23
SF-13	8.0	0.00030	2.7	0.90	0.66
SF-14	8.3	0.00003	2.8	0.94	1.47
SF-15	8.6	0.00039	3.3	0.97	0.66
SF-16	9.3	0.00163	2.8	0.94	0.37
SF-17	10.0	0.00040	3.0	0.93	0.63
SF-19	10.4	0.00088	2.9	0.84	0.47

Table C-15
Erosion Rate Parameters for 15 to 20 cm Layer
Portland Harbor Superfund Site
Portland, Oregon

Sediment Core ID	River Mile Location	Proportionality Constant: A	Exponent: n	Correlation Coefficient (R^2)	Critical Shear Stress (Pa)
SF-1	2.4	0.00097	2.4	0.99	0.39
SF-3	3.7	0.00706	2.8	0.96	0.22
SF-4	4.0	0.00096	2.4	0.95	0.39
SF-5	4.8	0.00082	2.4	0.99	0.42
SF-8	6.1	N/A	N/A	N/A	N/A
SF-9	6.4	0.00027	2.5	0.92	0.66
SF-10	6.8	0.00004	3.1	0.99	1.30
SF-11	6.9	0.00358	1.7	0.89	0.11
SF-12	7.6	0.00090	2.8	0.99	0.45
SF-13	8.0	0.00025	3.1	0.95	0.74
SF-14	8.3	0.00003	2.7	0.88	1.54
SF-15	8.6	0.00002	4.6	0.99	1.41
SF-16	9.3	0.01233	1.1	0.86	0.02
SF-17	10.0	0.00077	2.2	0.77	0.40
SF-19	10.4	0.00409	1.8	0.82	0.13

Table C-16
Erosion Rate Parameters for 20 to 25 cm Layer
Portland Harbor Superfund Site
Portland, Oregon

Sediment Core ID	River Mile Location	Proportionality Constant: A	Exponent: n	Correlation Coefficient (R^2)	Critical Shear Stress (Pa)
SF-1	2.4	0.00049	2.8	0.96	0.56
SF-3	3.7	0.00825	2.7	0.98	0.20
SF-4	4.0	0.00056	2.9	0.95	0.55
SF-5	4.8	0.00026	3.0	0.95	0.72
SF-8	6.1	N/A	N/A	N/A	N/A
SF-9	6.4	0.00004	3.2	0.99	1.33
SF-10	6.8	0.00006	2.7	0.97	1.18
SF-11	6.9	N/A	N/A	N/A	N/A
SF-12	7.6	0.00037	3.5	0.99	0.69
SF-13	8.0	0.00011	3.7	0.84	0.97
SF-14	8.3	0.00003	2.8	0.97	1.42
SF-15	8.6	0.00006	3.1	0.99	1.13
SF-16	9.3	0.01254	1.3	0.99	0.02
SF-17	10.0	0.00003	3.9	0.99	1.36
SF-19	10.4	0.00239	2.6	0.72	0.30

Table C-17
Vertical Variation in Average Erosion Rate Parameters
Portland Harbor Superfund Site
Portland, Oregon

Depth Interval	Average Proportionality Constant: A_{ave}	Average Exponent: n_{ave}	Critical Shear Stress (Pa)
Layer 1: 0 – 5 cm	0.00155	2.2	0.28
Layer 2: 5 – 10 cm	0.00048	2.9	0.58
Layer 3: 10 – 15 cm	0.00052	2.7	0.55
Layer 4: 15 – 20 cm	0.00062	2.6	0.49
Layer 5: 20 – 25 cm	0.00032	2.9	0.66

Table C-18
Vessel Data
Portland Harbor Superfund Site
Portland, Oregon

Vessel Class	Propeller Shaft Depth (ft)	Locations Where Vessels Likely Operate	Propeller Diameter (ft)	Vessel Horse power (HP)	Maximum Reasonable HP Applied[a] (%)
Large tug	13	RM2E, RM3.5E, RM7W, SwanIs, RM9W	8 (twin)	3,300	80
Small tug	9	RM2E, RM3.9W, RM5W, RM6W, RM9W, RM11E	6 (twin)	2,000	80
Large ocean-going vessel	30 to 31	RM2E, RM11E	18	20,000	30
Medium ocean-going vessel	23	SwanIs	14	20,000	30
International cargo ship	28 to 31	RM3.5E, RM3.9W	18	20,000	30
Ocean-going hopper dredge	20	RM6W	10	15,000	30
Fishing vessel	5	SwanIs	3	250	80
Pleasure craft	5	RM5.5E	3	250	90

Notes:
[a] Maximum horsepower estimated based on reasonable maximum under typical operating conditions.

Table C-19
Stable Sediment Size under Maximum Velocity Scenario and Reasonable Conservative Case Assumptions
Portland Harbor Superfund Site
Portland, Oregon

Location	Design Vessel	Minimum Water Depth of Operation (ft)	C_3 (frequency coefficient)[b]	Max V_b (fps)	Stable Sediment Size D_{50} (in)	Sediment Description
RM2E	Large tug	30	0.7	2.8	3.5	cobbles
RM2E	Lg. ocean-going vessel	40	0.7	10.2	48.0	riprap
RM2E	Large tug	35	0.6	2.1	2.9	coarse gravel
RM2E	Small tug	40	0.5	1.2	1.2	coarse gravel
RM3.5E	Large tug	25	0.7	3.9	7.1	cobbles
RM3.5E	Int’l cargo ship	40	0.7	8.5	33.3	riprap
RM3.9W	Int’l cargo ship	45	0.7	7.3	24.5	riprap
RM3.9W	Small tug	25	0.7	2.3	2.4	coarse gravel
RM3.9W	Small tug	25	0.6	2.3	3.2	cobbles
RM5W	Small tug	20	0.5	3.3	9.7	cobbles
RM5W	Small tug	30	0.6	1.7	1.9	coarse gravel
RM6W	Small tug	20	0.5	3.3	9.7	cobbles
RM6W	Small tug	25	0.7	2.3	2.4	coarse gravel
RM6W	Ocean-going hopper dredge	45	0.7	2.4	2.7	coarse gravel
RM6W	Small tug	25	0.5	2.3	4.6	cobbles
RM5.5E	Pleasure craft	10	0.5	3.8	12.8	riprap
RM7W	Large tug	30	0.5	2.8	6.9	cobbles
SwanIs	Large tug	25	0.7	3.9	7.1	cobbles
SwanIs	Md. ocean-going vessel	50	0.7	3.5	5.6	cobbles
SwanIs	Md. ocean-going vessel	30	0.6	13.4	>60	riprap
SwanIs	Fishing vessel	10	0.5	3.6	11.8	cobbles
RM9W	Small tug	20	0.5	3.3	9.7	cobbles
RM9W	Small tug	20	0.5	3.3	9.7	cobbles
RM9W	Large tug	35	0.7	2.1	2.1	coarse gravel
RM9W	Small tug	25	0.7	2.3	2.4	coarse gravel
RM9W	Small tug	25	0.6	2.3	3.2	cobbles
RM9W	Small tug	15	0.7	6.0	16.7	riprap
RM9E	Md. ocean-going vessel	50	0.7	3.5	5.6	cobbles
RM10W	Lg. ocean-going vessel	45	0.6	7.3	33.3	riprap
RM11E	Small tug	45	0.5	1.0	0.9	coarse gravel
RM11E	Lg. ocean-going vessel	50	0.6	5.4	18.1	riprap

Notes:
a Note that there is no vessel activity reported at RM4.5E and RM6.5E.
b. The C3 parameter represents frequency of vessel operations. Infrequent = 0.7, moderate = 0.6, frequent = 0.5.

Table C-20
Summary of Prop wash Disturbance Depth Estimates Using Two Methods
Portland Harbor Superfund Site
Portland, Oregon

Location	Representative Vessel	Dücker and Miller Disturbance Depth (ft)	Hamill Disturbance Depth (ft)	Maximum Disturbance Depth (ft)
RM2E	Large tug	0.50	0.03	0.50
RM2E	Lg. ocean-going vessel	> 1*	> 1*	> 1*
RM2E	Large tug	0.34	0.01	0.34
RM2E	Small tug	0.13	< 0.01	0.13
RM3.5E	Large tug	0.68	0.12	0.68
RM3.5E	Int'l cargo ship	> 1*	> 1*	1.00
RM3.9W	Int'l cargo ship	> 1*	6.76	6.76
RM3.9W	Small tug	0.37	0.02	0.37
RM3.9W	Small tug	0.37	0.02	0.37
RM5W	Small tug	0.55	0.06	0.55
RM5W	Small tug	0.24	0.06	0.24
RM6W	Small tug	0.55	0.06	0.55
RM6W	Small tug	0.37	0.02	0.37
RM6W	Ocean-going hopper dredge	0.39	0.01	0.39
RM6W	Small tug	0.37	0.02	0.37
RM5.5E	Pleasure craft	0.66	0.24	0.66
RM7W	Large tug	0.50	0.03	0.50
SwanIs	Large tug	0.68	0.12	0.68
SwanIs	Md. ocean-going vessel	0.60	0.03	0.60
SwanIs	Md. ocean-going vessel	> 1*	> 1*	> 1*
SwanIs	Fishing vessel	0.63	0.21	0.63
RM9W	Small tug	0.55	0.06	0.55
RM9W	Small tug	0.55	0.06	0.55
RM9W	Large tug	0.34	0.01	0.34
RM9W	Small tug	0.37	0.02	0.37
RM9W	Small tug	0.37	0.02	0.37
RM9W	Small tug	> 1*	2.77	2.77
RM9E	Md. ocean-going vessel	0.60	0.03	0.60
RM10W	Lg. ocean-going vessel	> 1*	6.76	6.76
RM11E	Small tug	0.05	< 0.01	0.05
RM11E	Lg. ocean-going vessel	> 1*	0.38	> 1*

Note:
For some of the area of the Site, several locations within the Site were evaluated and these varying locations are shown above.
* For the Hamill and Dücker and Miller method, an exact depth was not resolvable for the representative vessel parameters.

Figures

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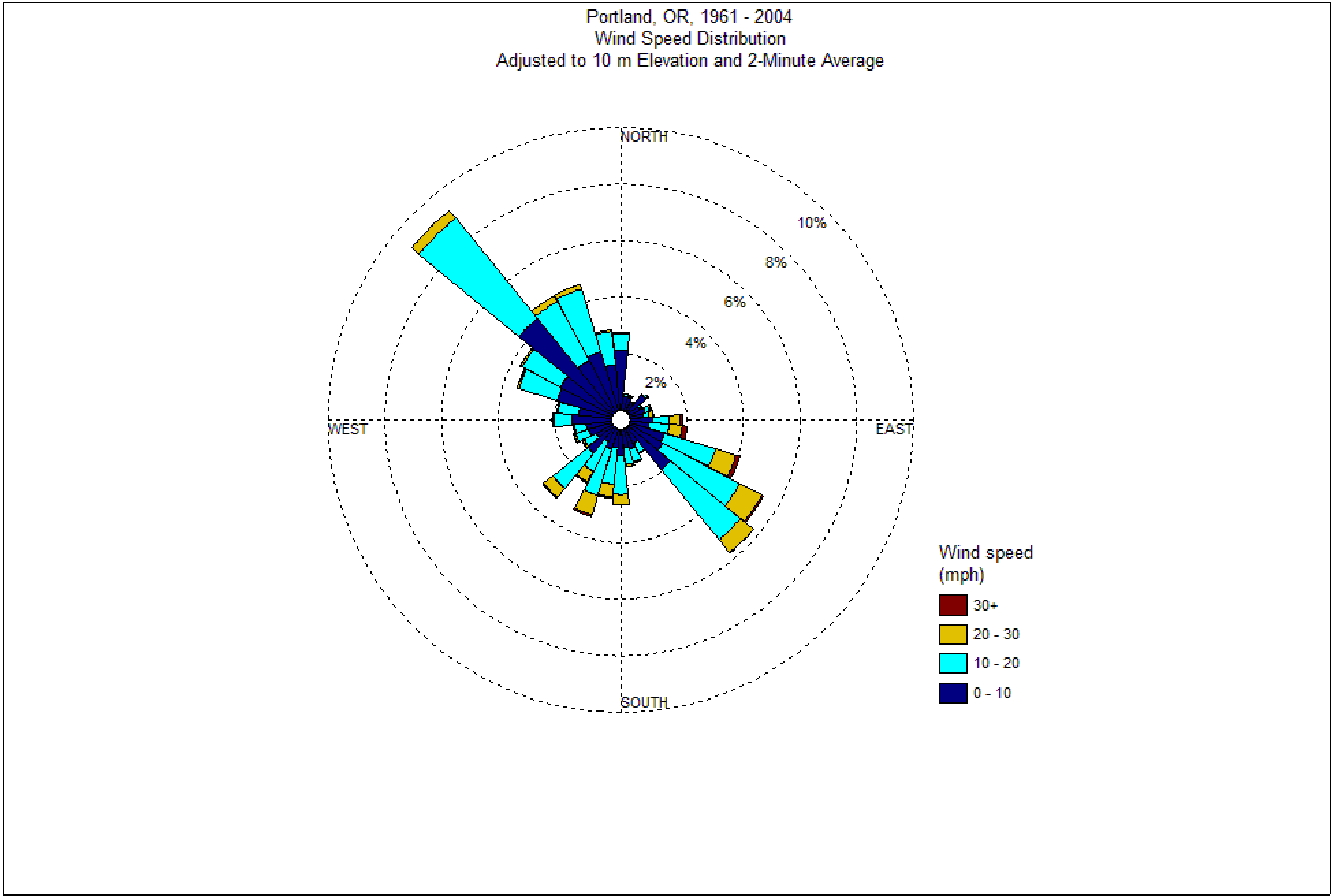

Figure C-1. Contoured Surface Sediment Texture, Percent Fines

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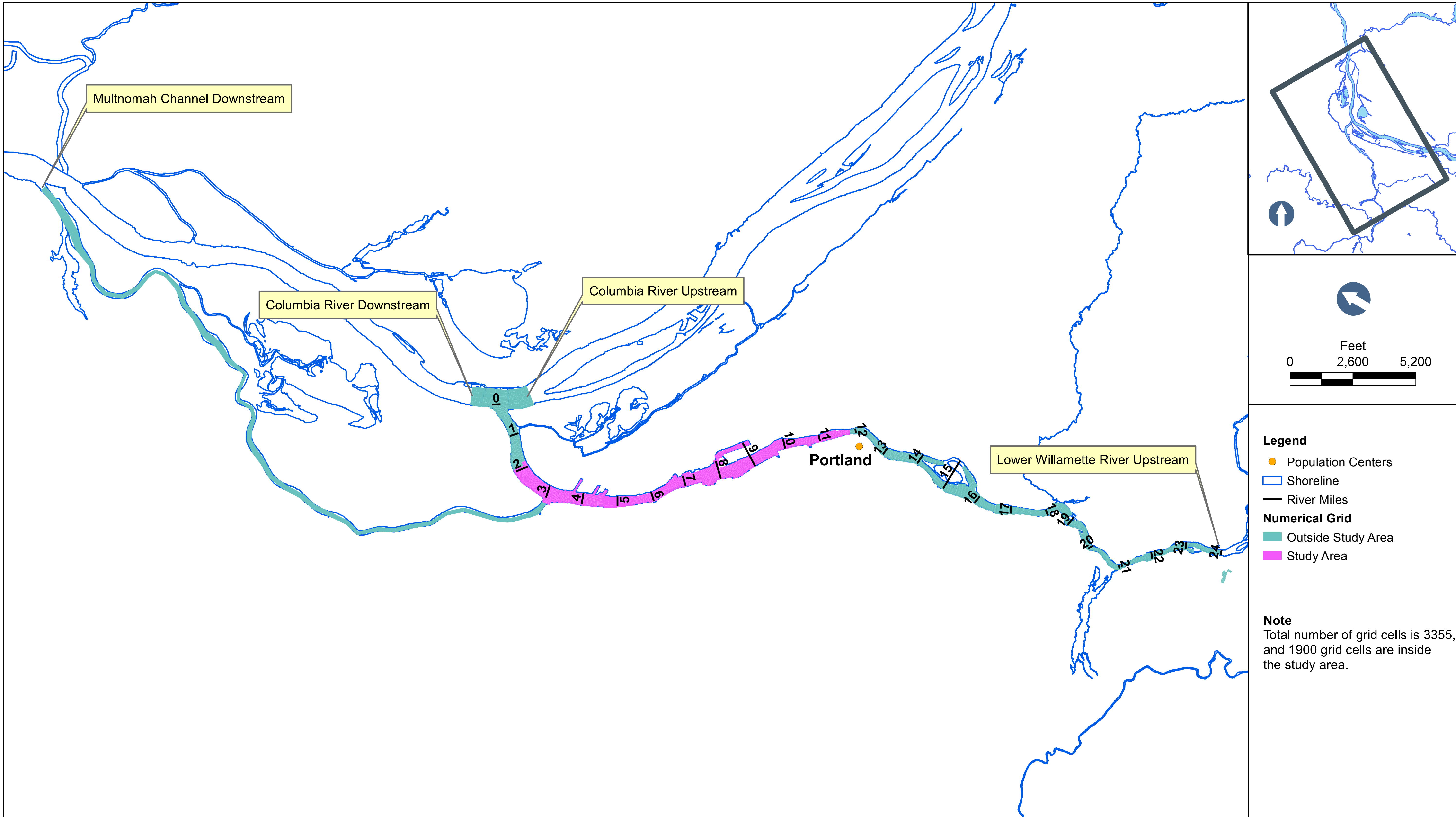

Figure C-2. Draft Feasibility Study Numerical Grid Extent

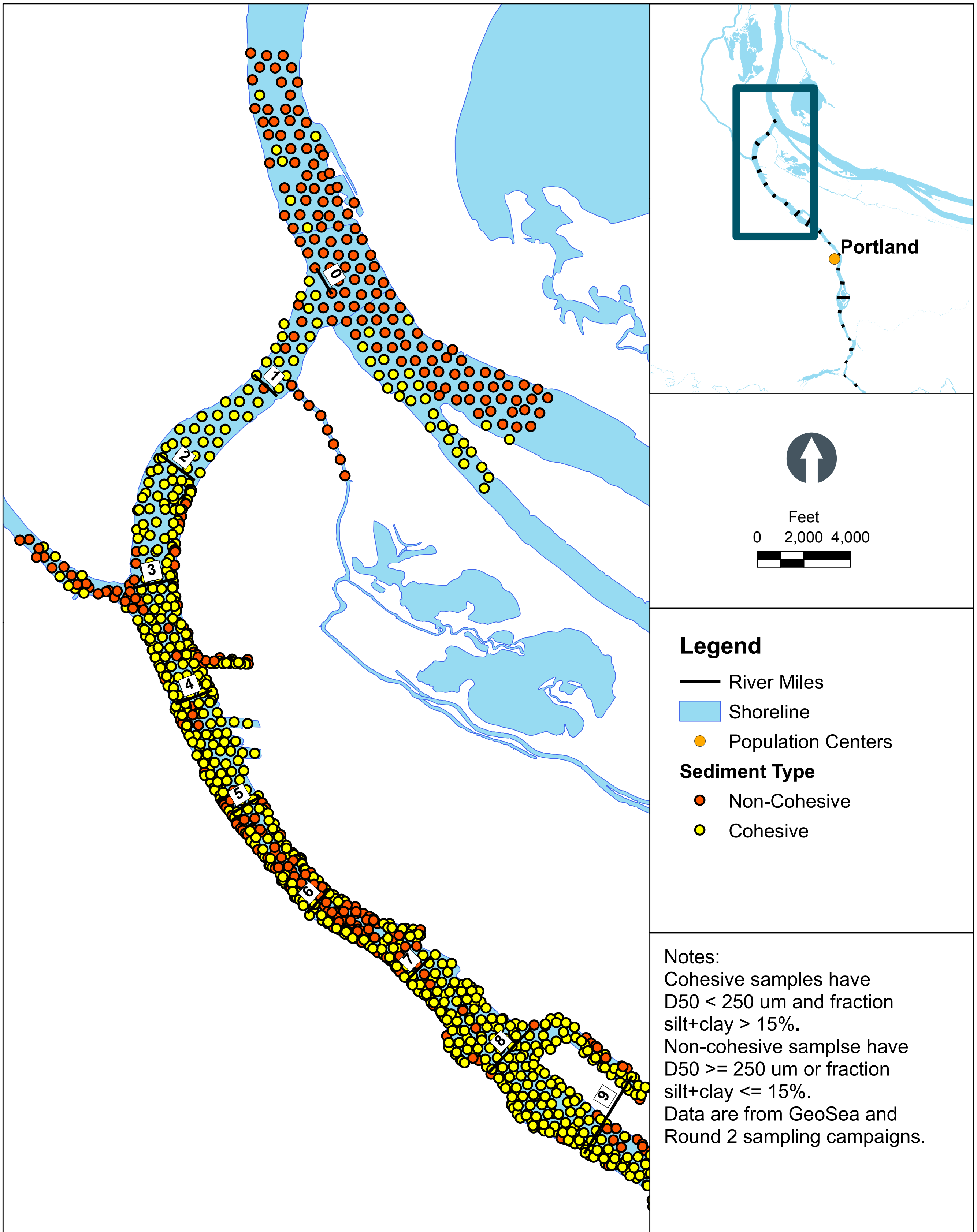

Figure C-3a. Sediment Bed Data

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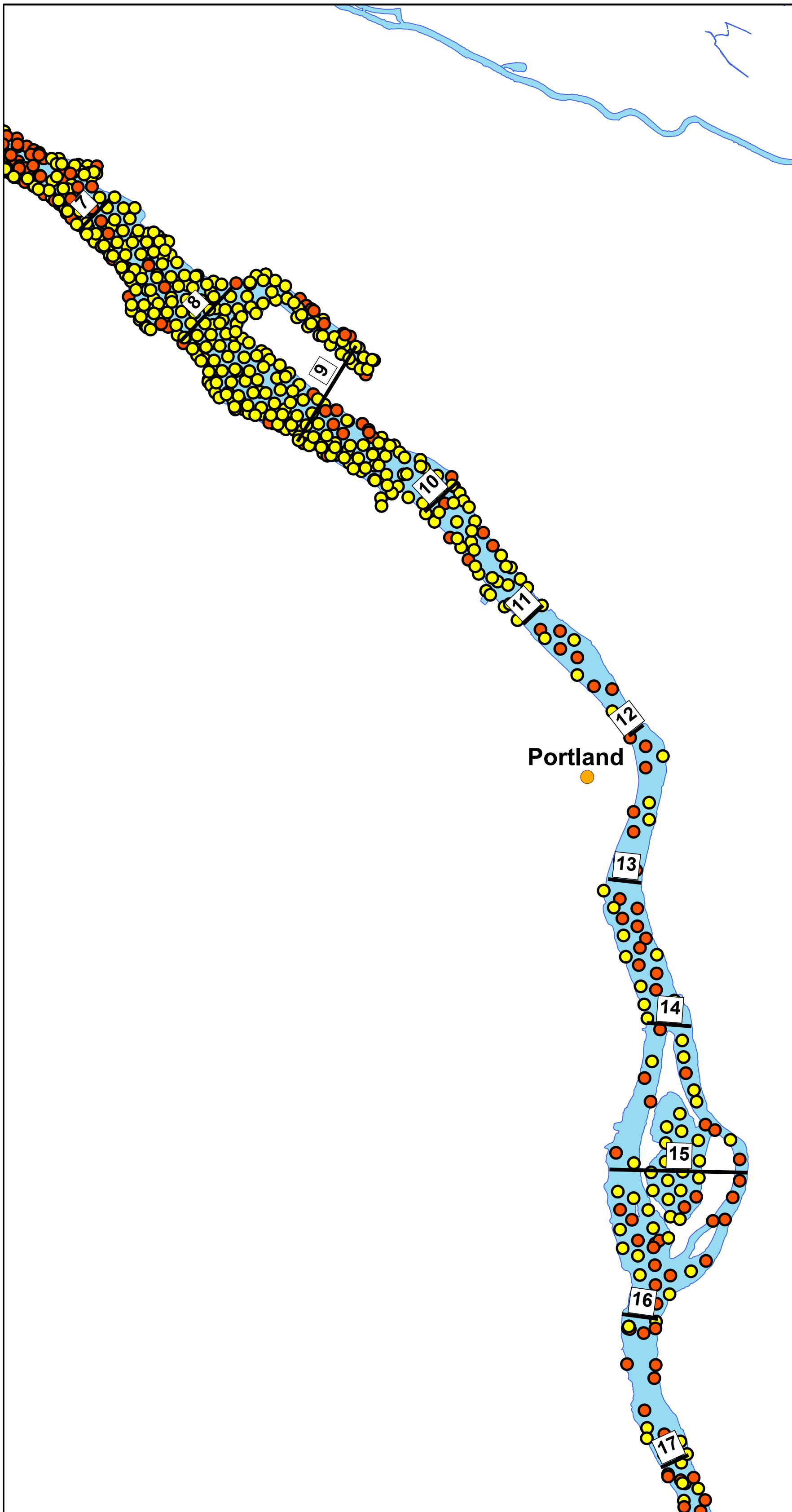

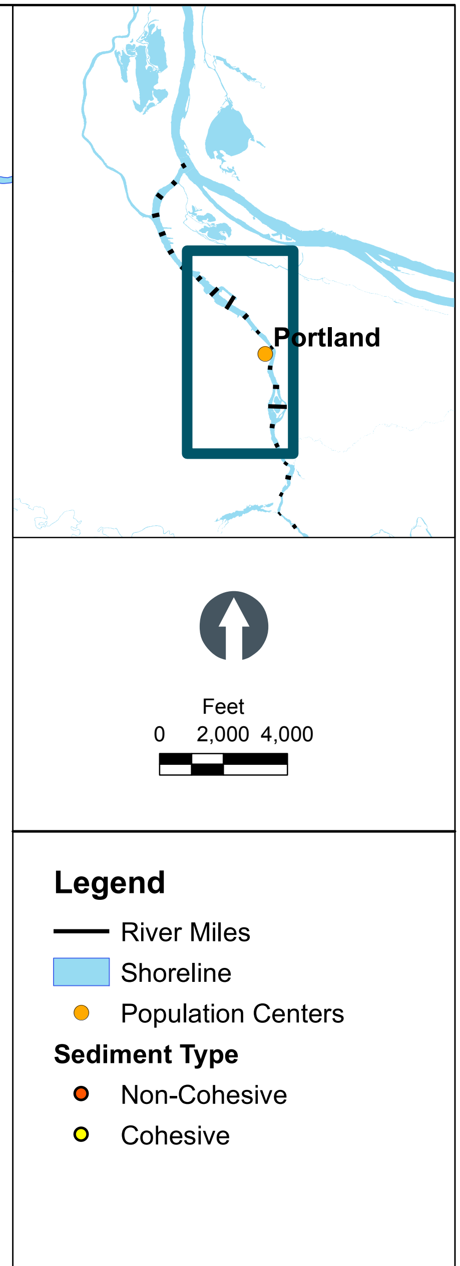

Notes:
Cohesive samples have D50 < 250 um and fraction silt+clay > 15%.
Non-cohesive samplse have D50 >= 250 um or fraction silt+clay <= 15%.
Data are from GeoSea and Round 2 sampling campaigns.

Figure C-3b. Sediment Bed Data

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Figure C-4. Spatial Distribution of the Sediment Bedmap

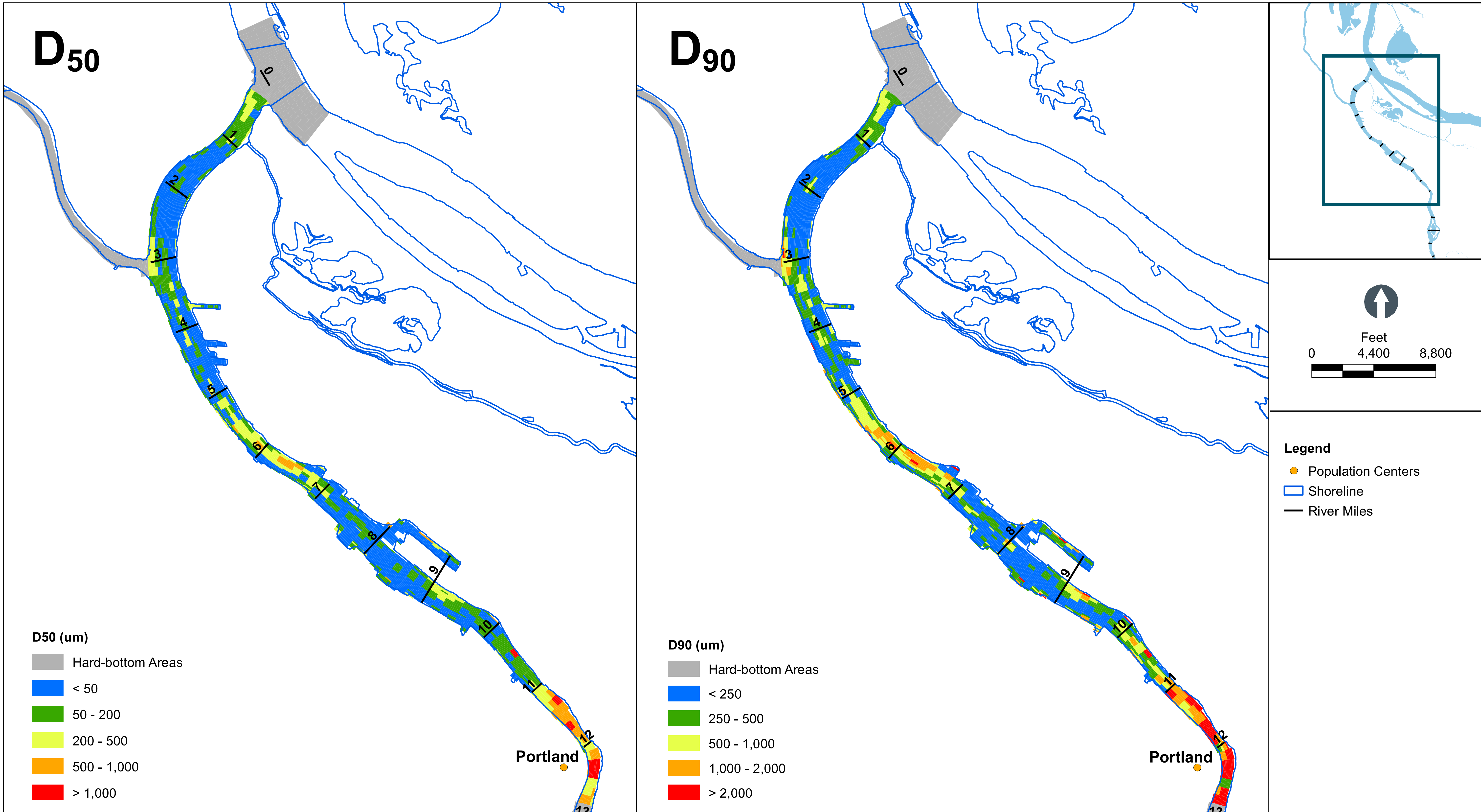

Figure C-5. Spatial Distribution of Sediment Properties

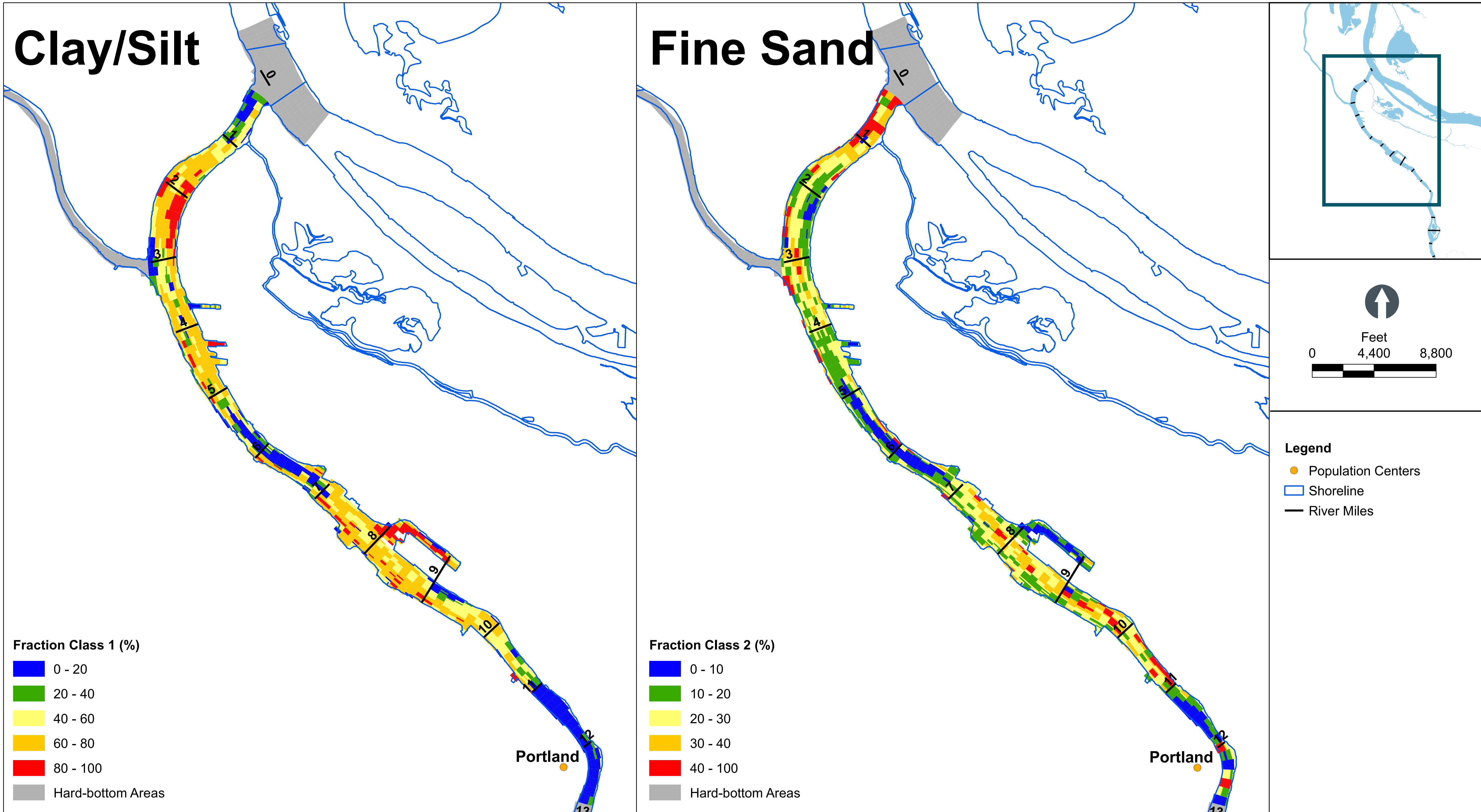

Figure C-6a. Spatial Distribution of Initial Bed Composition

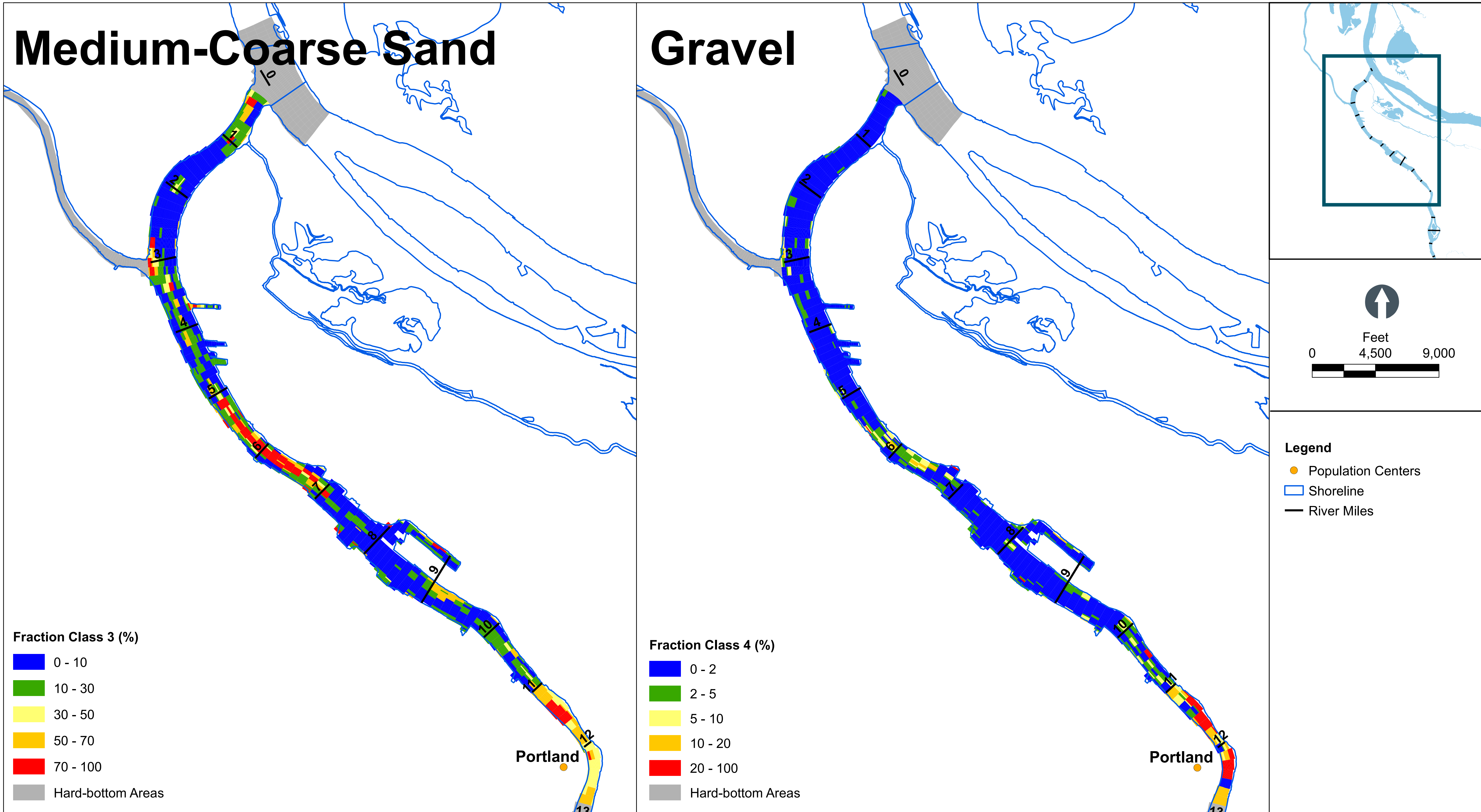

Figure C-6b. Spatial Distribution of Initial Bed Composition

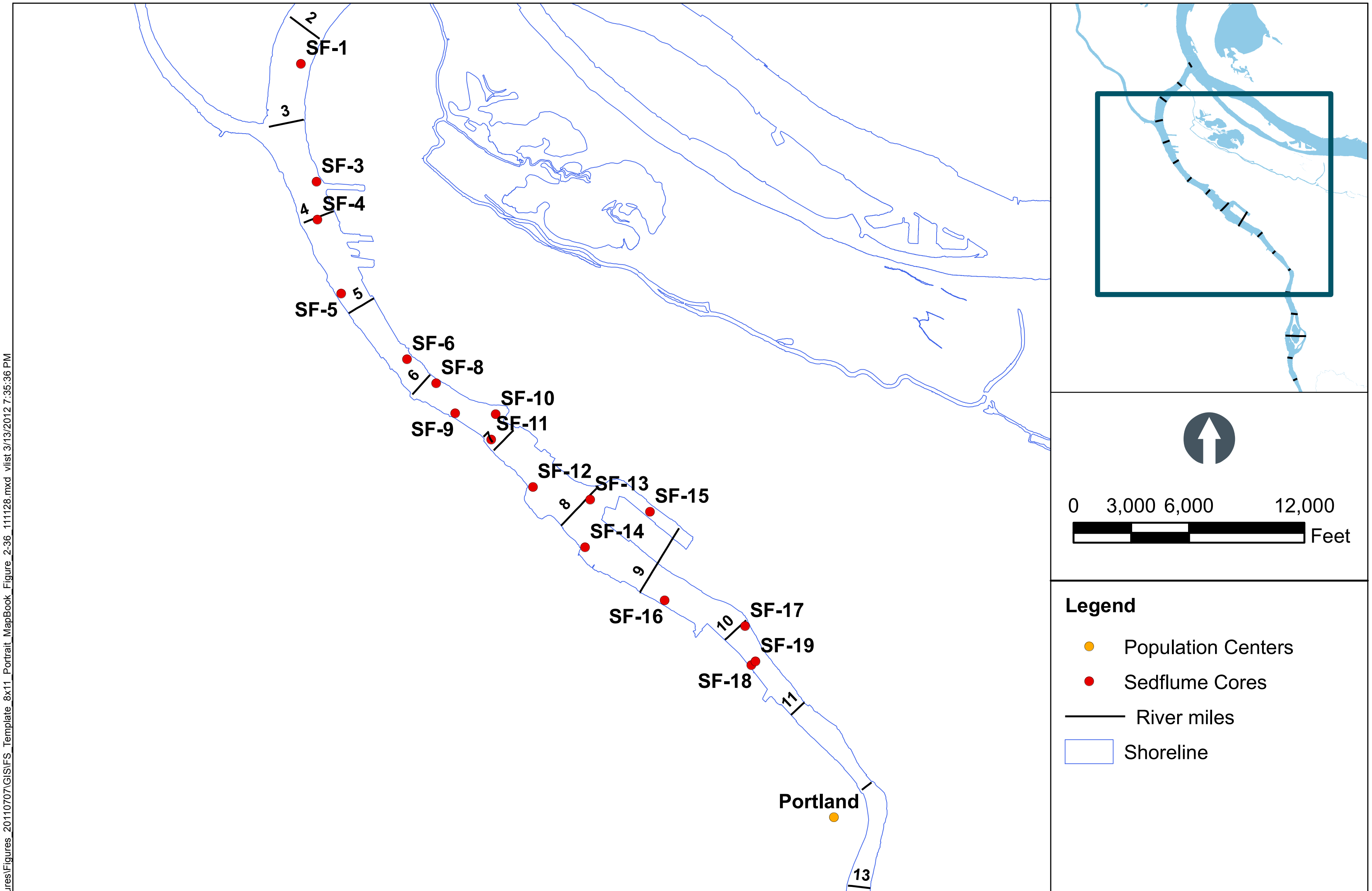

Figure C-7. Sedflume Core Locations

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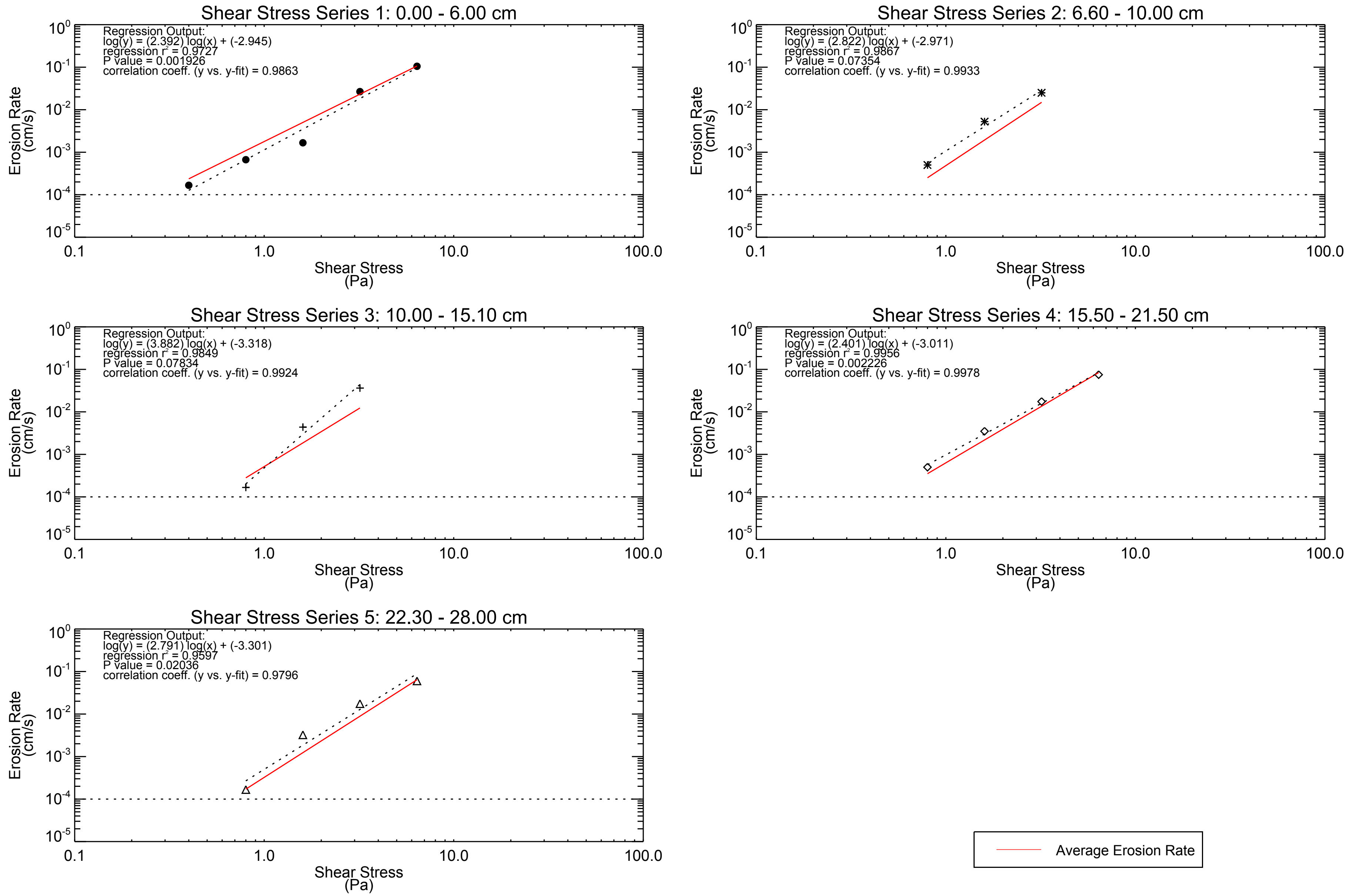

Figure C-8. Log-Linear Regression Results for Erosion Rate as a Function of Shear Stress at Various Depths in Sedflume Core SF1

The red line represents the average erosion rate for all sedflume cores for the corresponding depth interval.

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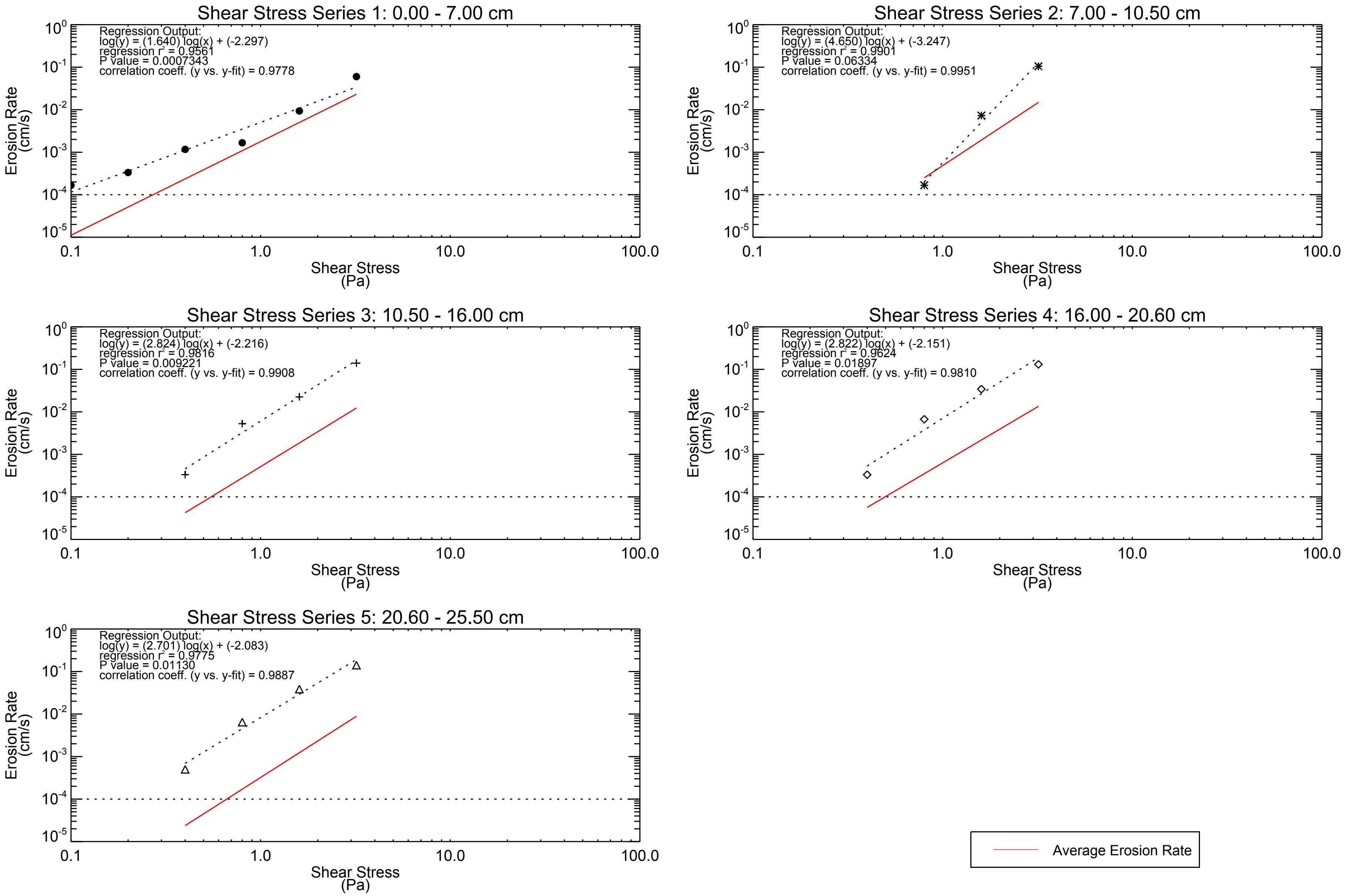

Figure C-9. Log-Linear Regression Results for Erosion Rate as a Function of Shear Stress at Various Depths in Sedflume Core SF3

The red line represents the average erosion rate for all sedflume cores for the corresponding depth interval.

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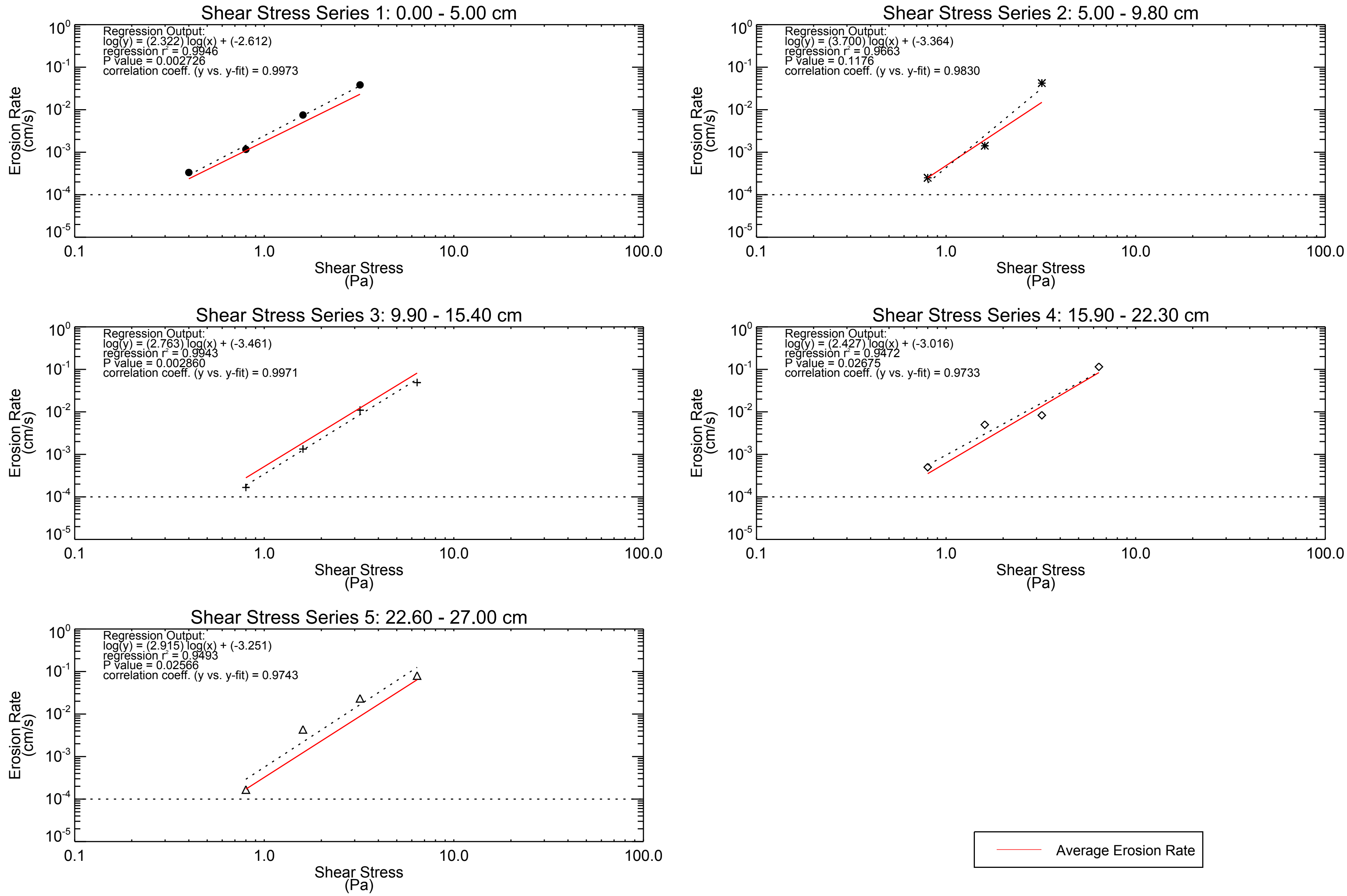

Figure C-10. Log-Linear Regression Results for Erosion Rate as a Function of Shear Stress at Various Depths in Sedflume Core SF4

The red line represents the average erosion rate for all sedflume cores for the corresponding depth interval.

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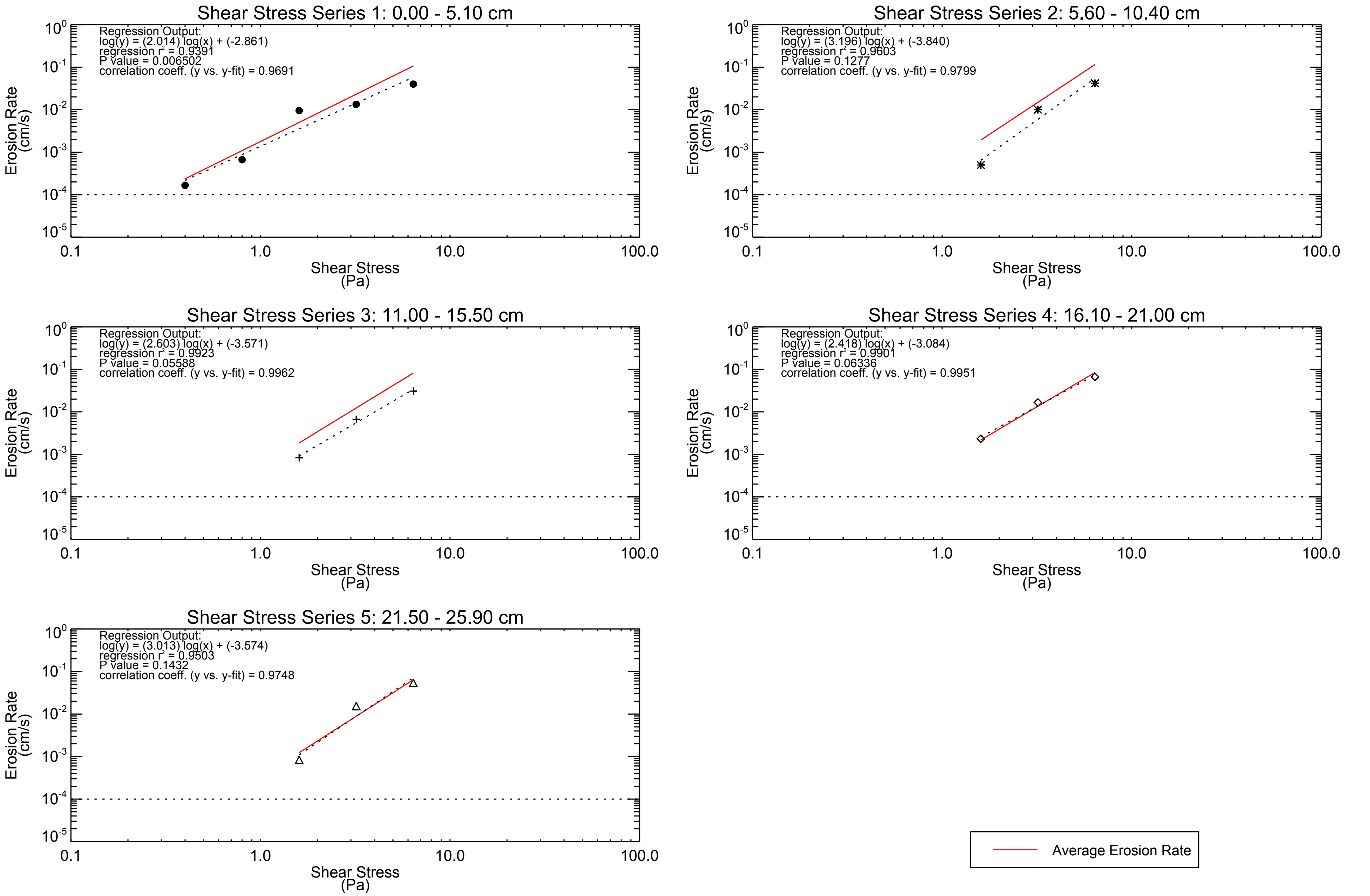

Figure C-11. Log-Linear Regression Results for Erosion Rate as a Function of Shear Stress at Various Depths in Sedflume Core SF5

The red line represents the average erosion rate for all sedflume cores for the corresponding depth interval.

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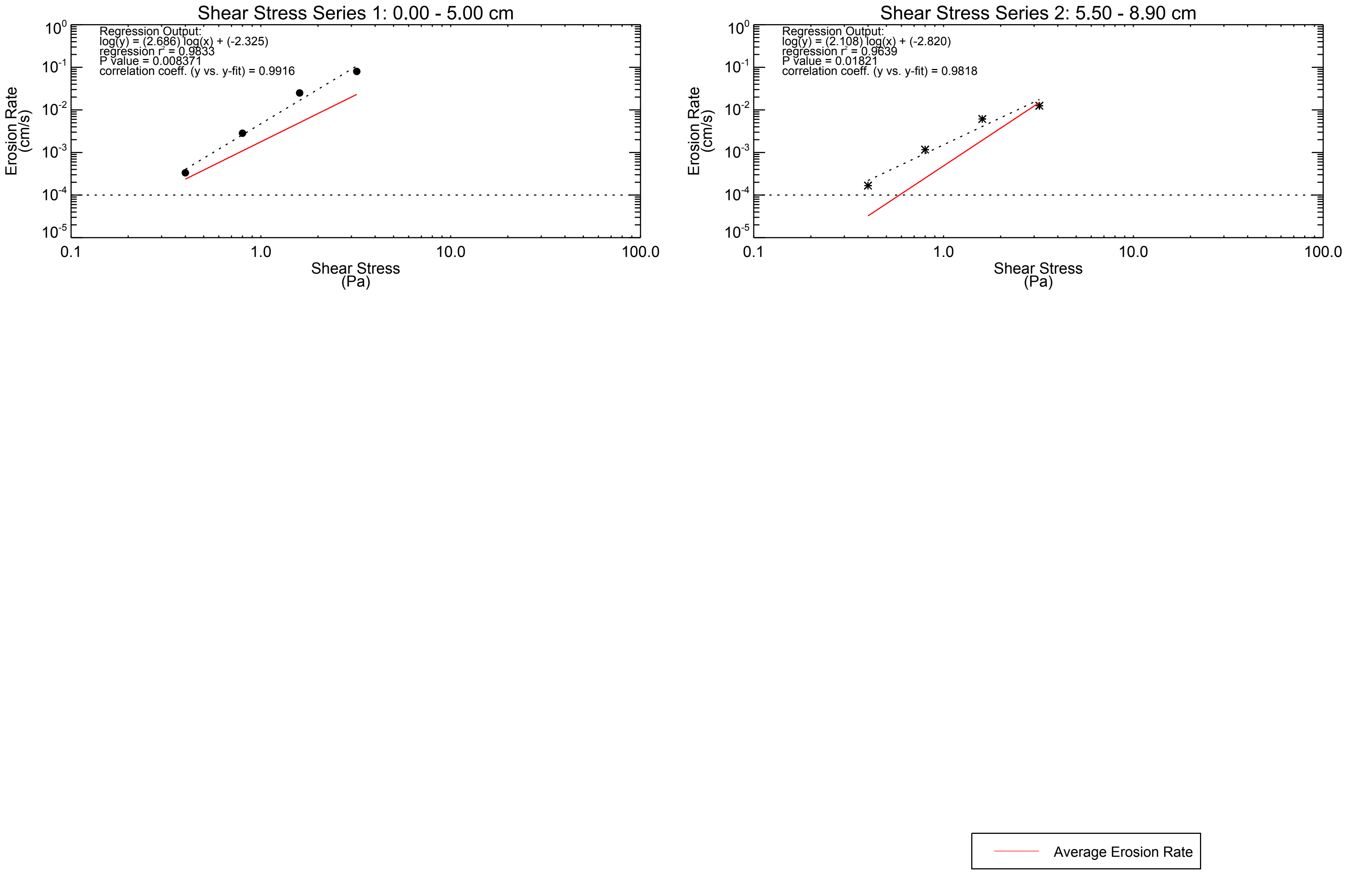

Figure C-12. Log-Linear Regression Results for Erosion Rate as a Function of Shear Stress at Various Depths in Sedflume Core SF8

The red line represents the average erosion rate for all sedflume cores for the corresponding depth interval.

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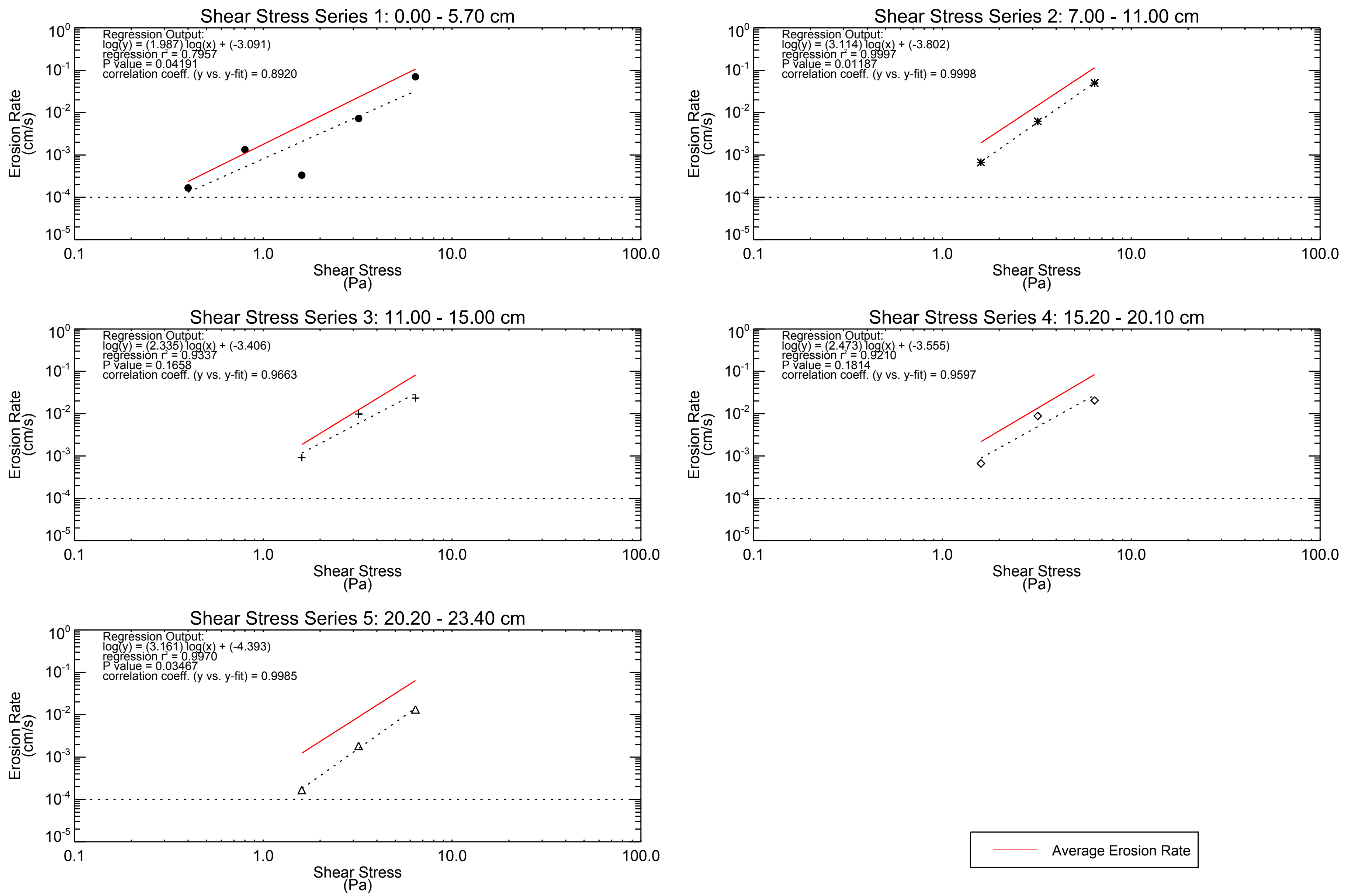

Figure C-13. Log-Linear Regression Results for Erosion Rate as a Function of Shear Stress at Various Depths in Sedflume Core SF9

The red line represents the average erosion rate for all sedflume cores for the corresponding depth interval.

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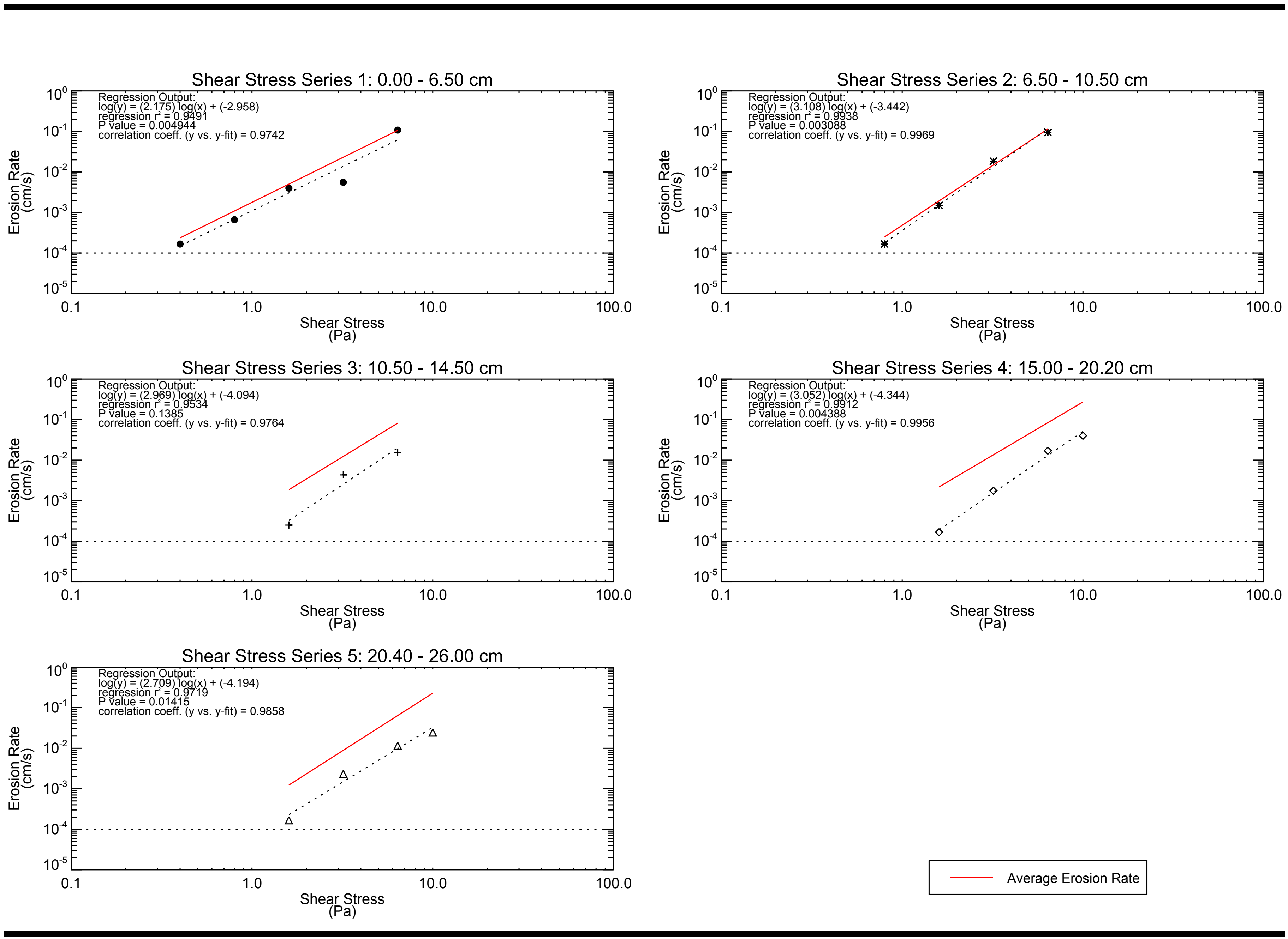

Figure C-14. Log-Linear Regression Results for Erosion Rate as a Function of Shear Stress at Various Depths in Sedflume Core SF10

The red line represents the average erosion rate for all sedflume cores for the corresponding depth interval.

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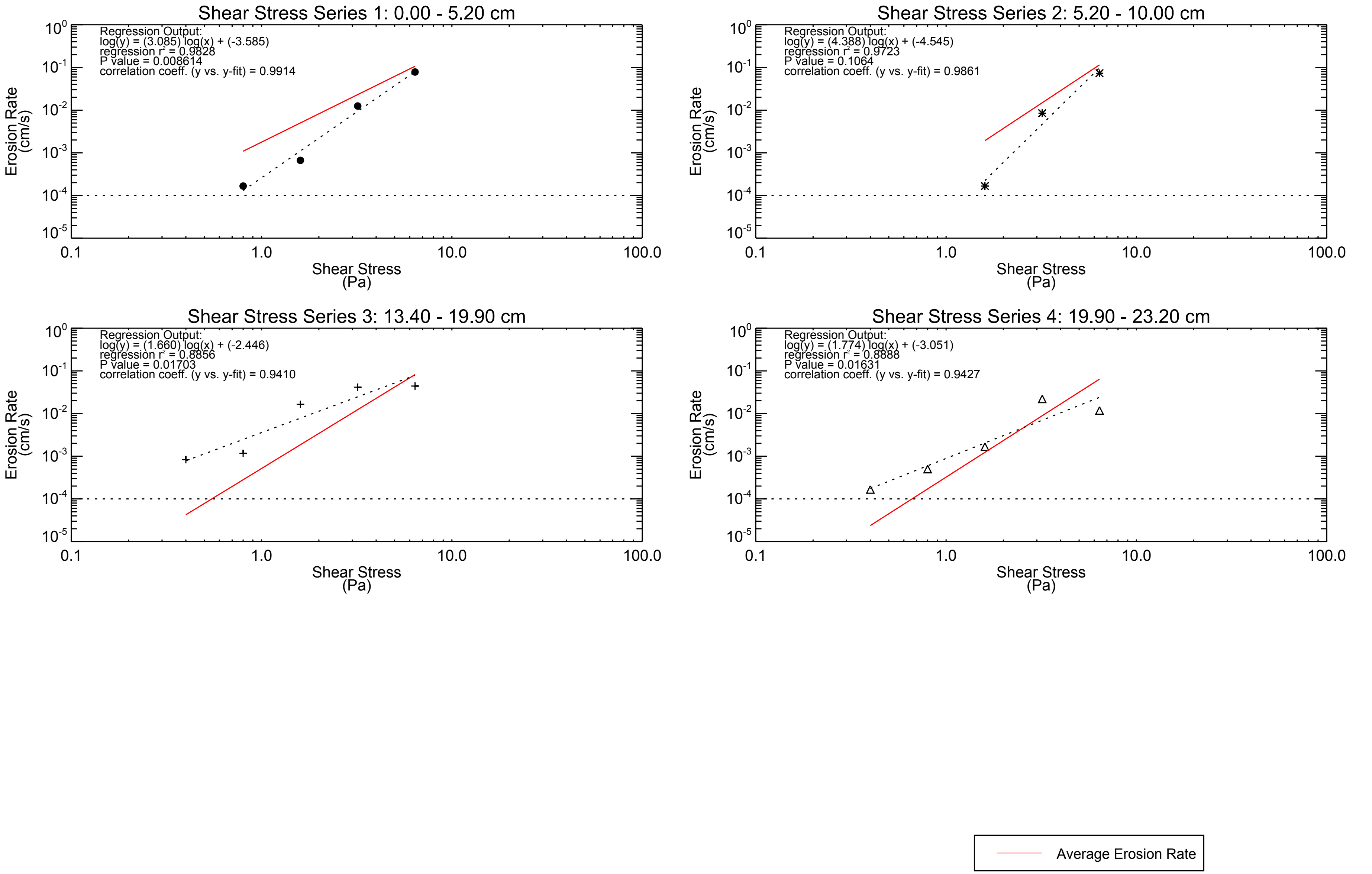

Figure C-15. Log-Linear Regression Results for Erosion Rate as a Function of Shear Stress at Various Depths in Sedflume Core SF11

The red line represents the average erosion rate for all sedflume cores for the corresponding depth interval.

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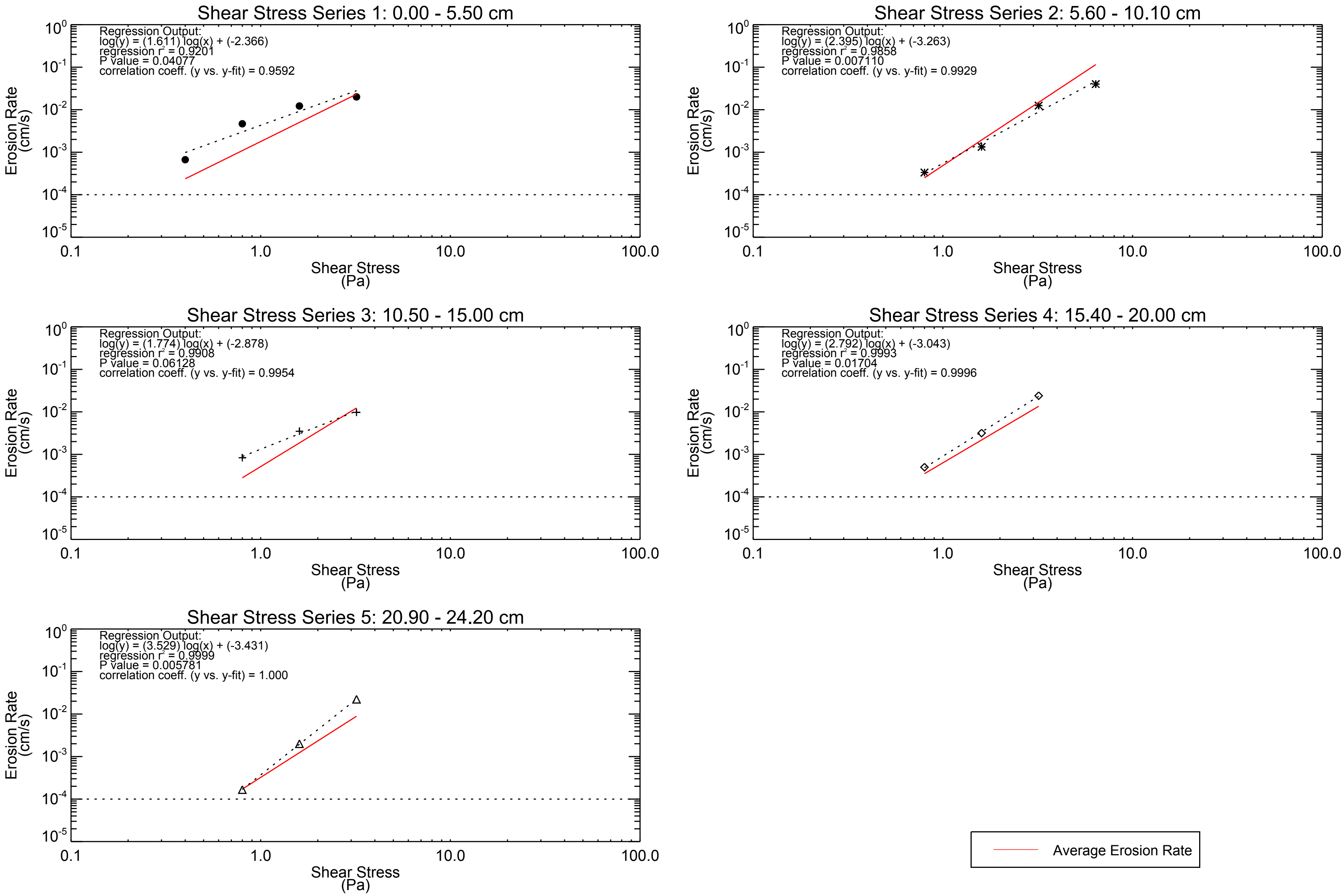

Figure C-16. Log-Linear Regression Results for Erosion Rate as a Function of Shear Stress at Various Depths in Sedflume Core SF12

The red line represents the average erosion rate for all sedflume cores for the corresponding depth interval.

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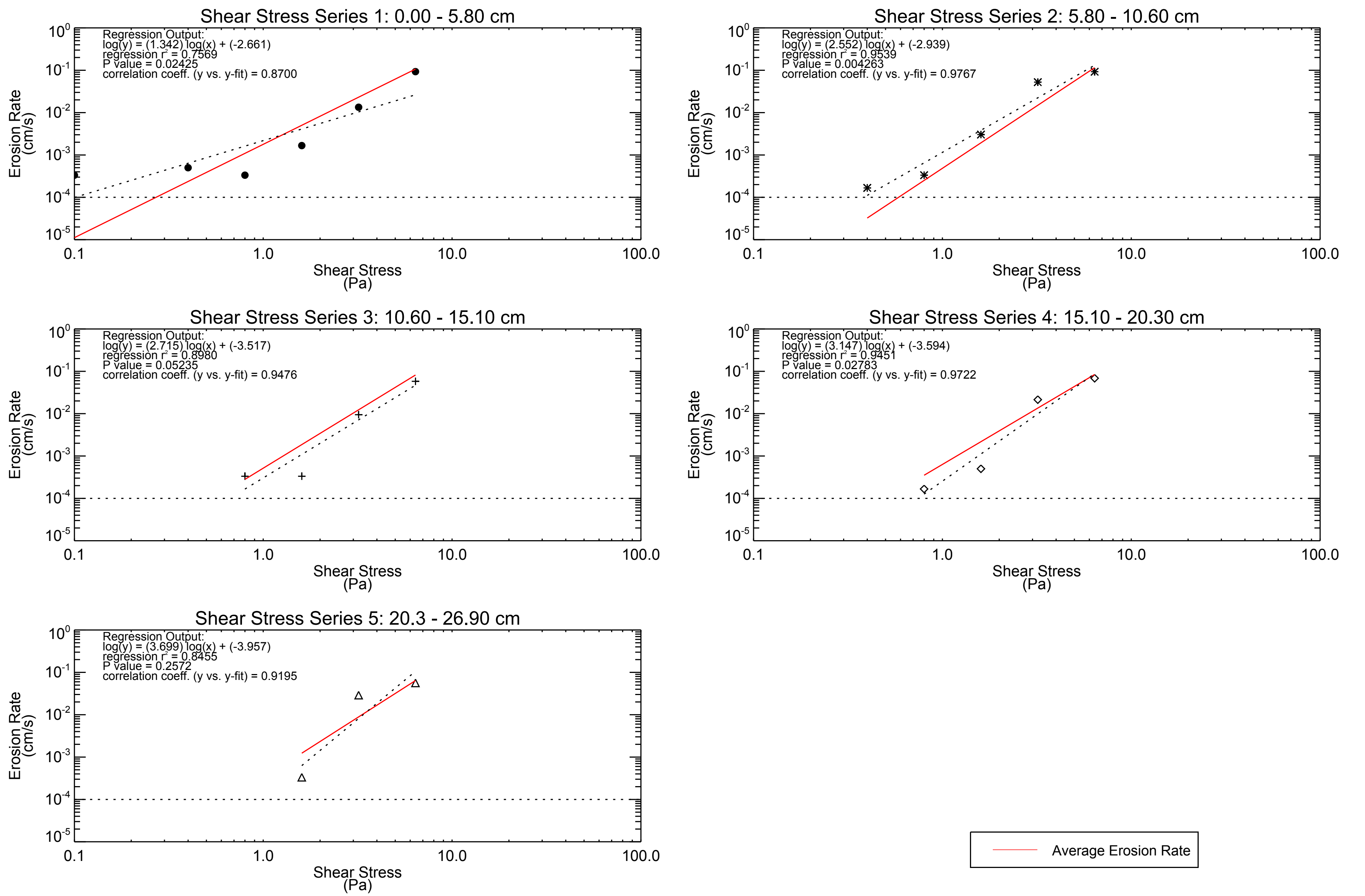

Figure C-17. Log-Linear Regression Results for Erosion Rate as a Function of Shear Stress at Various Depths in Sedflume Core SF13

The red line represents the average erosion rate for all sedflume cores for the corresponding depth interval.

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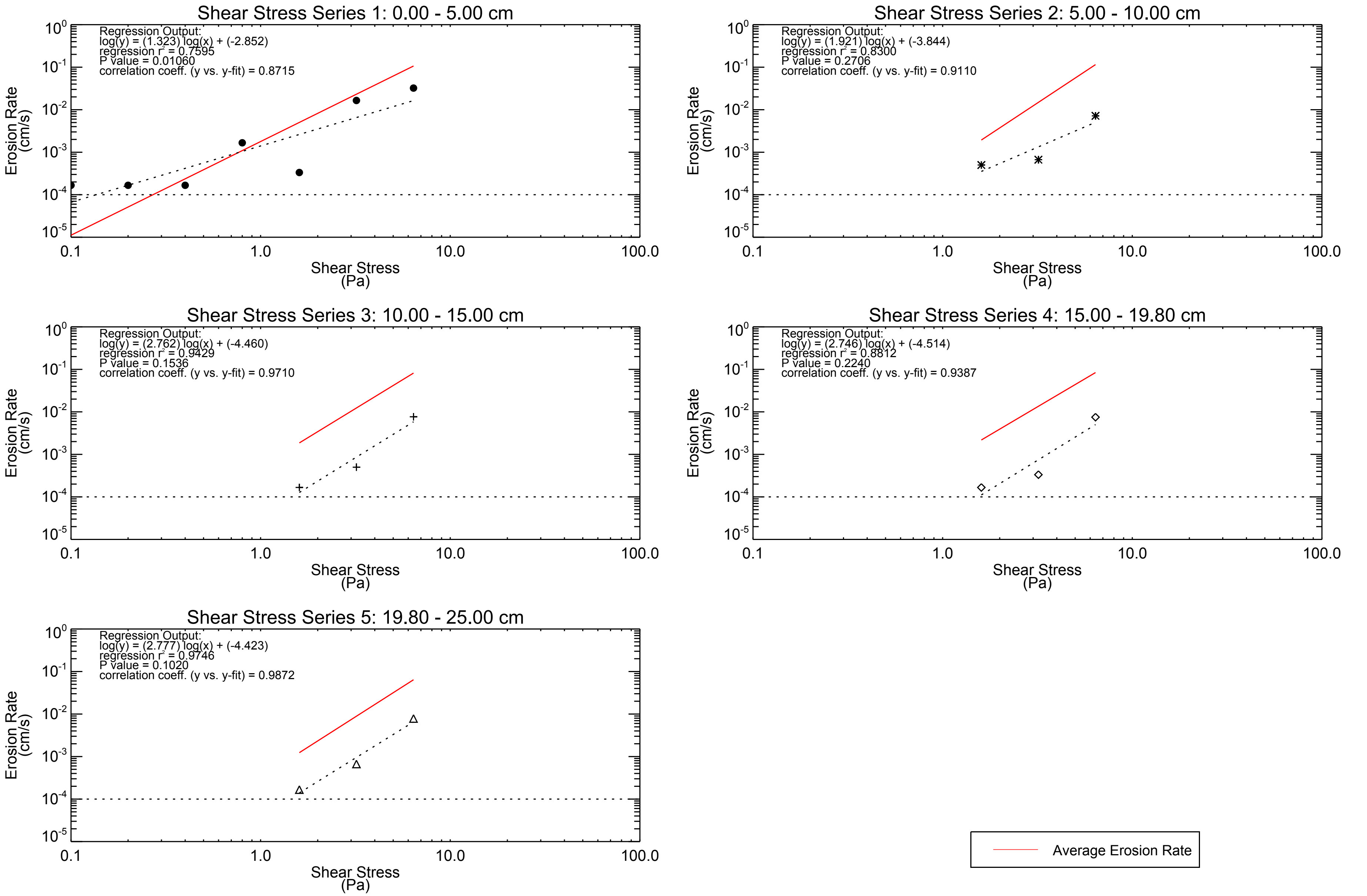

Figure C-18. Log-Linear Regression Results for Erosion Rate as a Function of Shear Stress at Various Depths in Sedflume Core SF14

The red line represents the average erosion rate for all sedflume cores for the corresponding depth interval.

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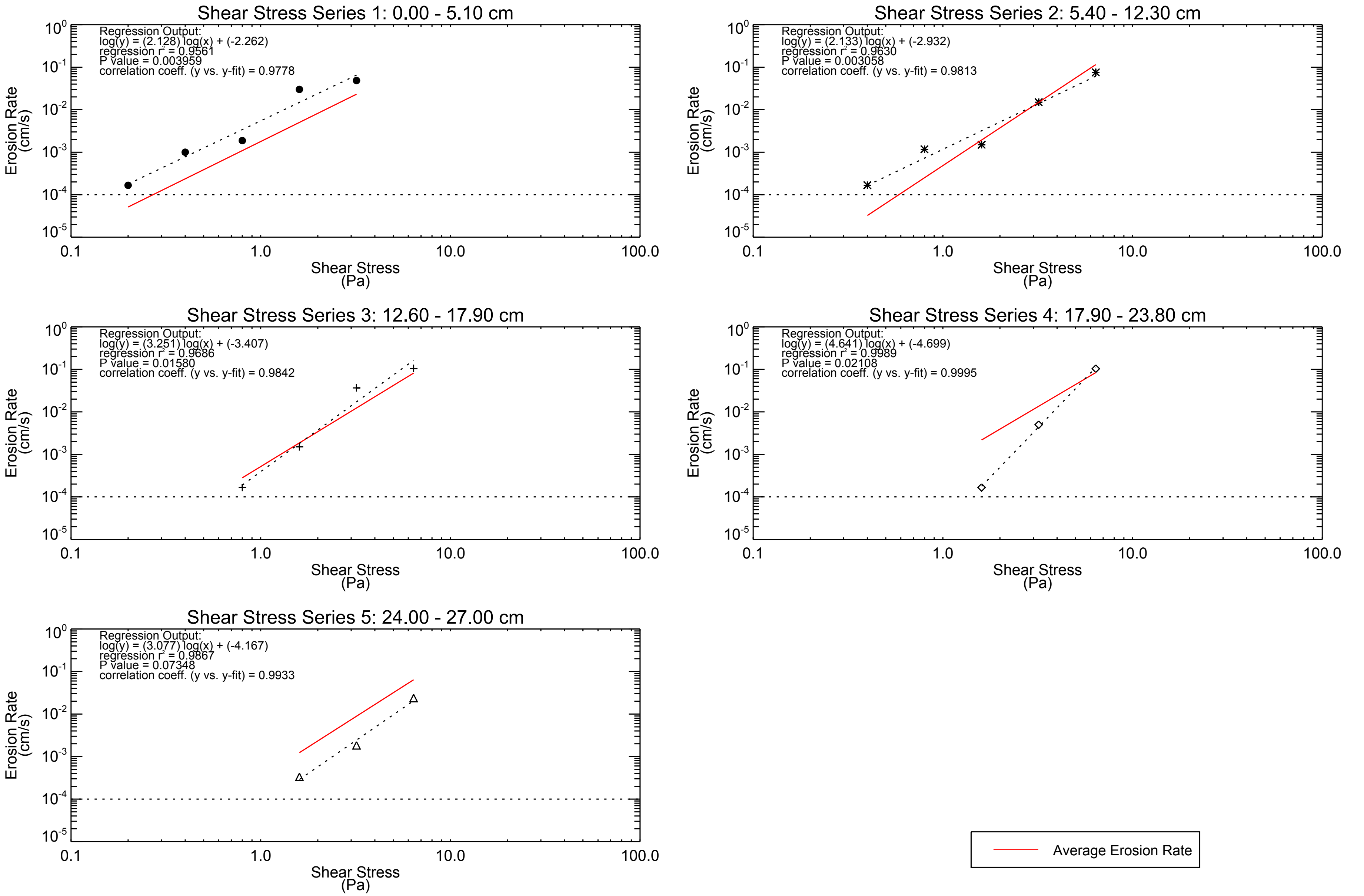

Figure C-19. Log-Linear Regression Results for Erosion Rate as a Function of Shear Stress at Various Depths in Sedflume Core SF15

The red line represents the average erosion rate for all sedflume cores for the corresponding depth interval.

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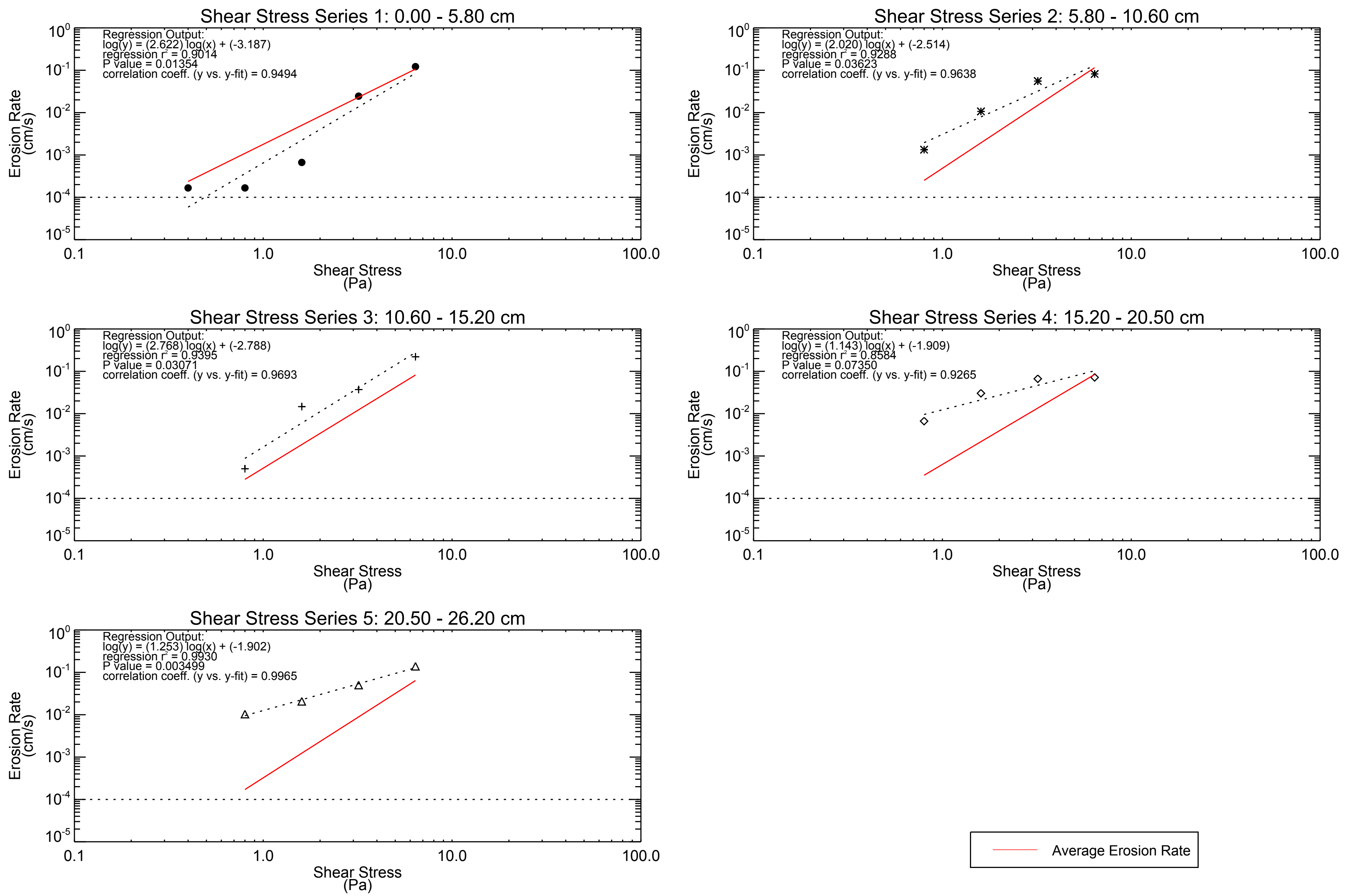

Figure C-20. Log-Linear Regression Results for Erosion Rate as a Function of Shear Stress at Various Depths in Sedflume Core SF16

The red line represents the average erosion rate for all sedflume cores for the corresponding depth interval.

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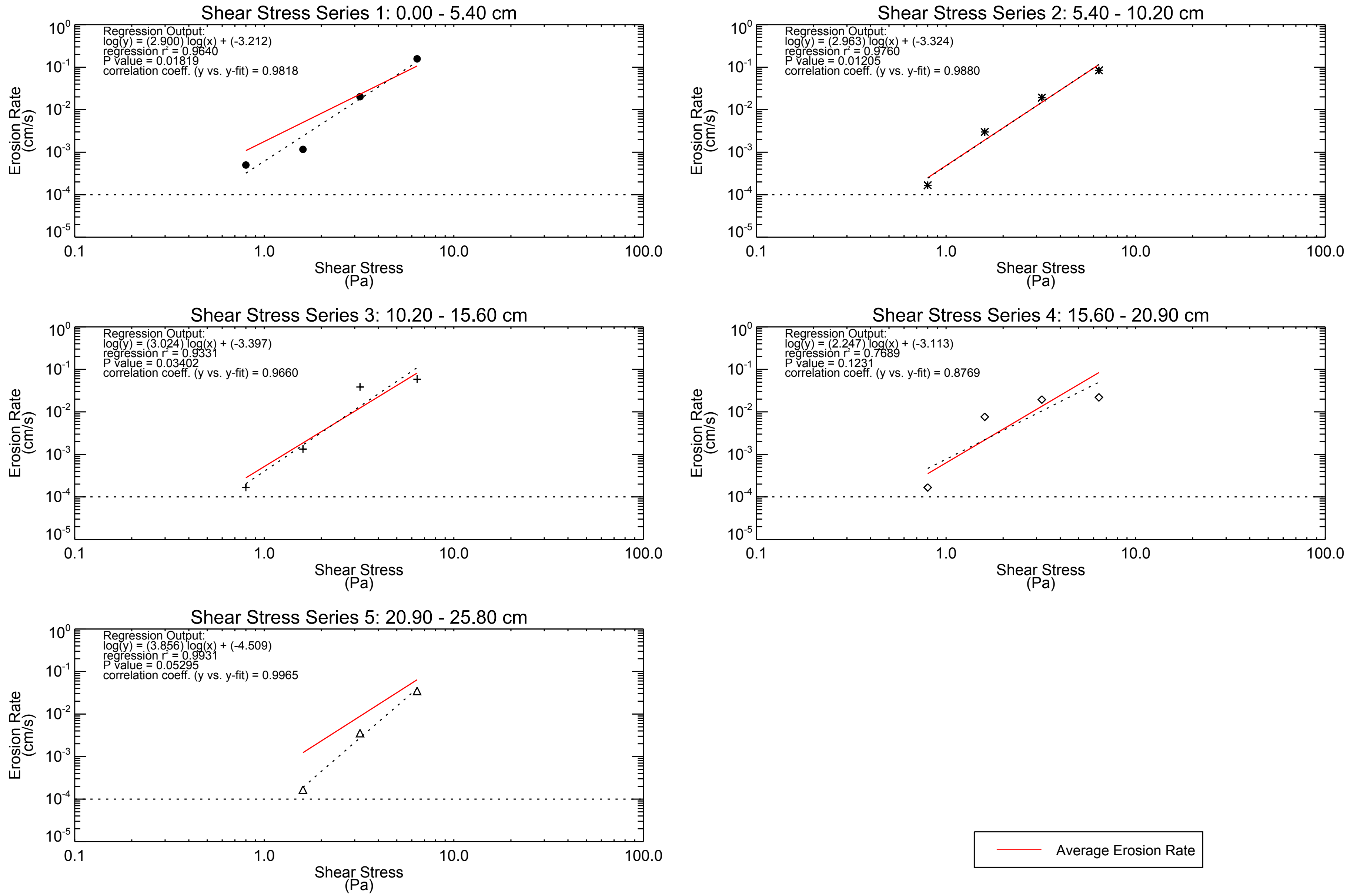

Figure C-21. Log-Linear Regression Results for Erosion Rate as a Function of Shear Stress at Various Depths in Sedflume Core SF17

The red line represents the average erosion rate for all sedflume cores for the corresponding depth interval.

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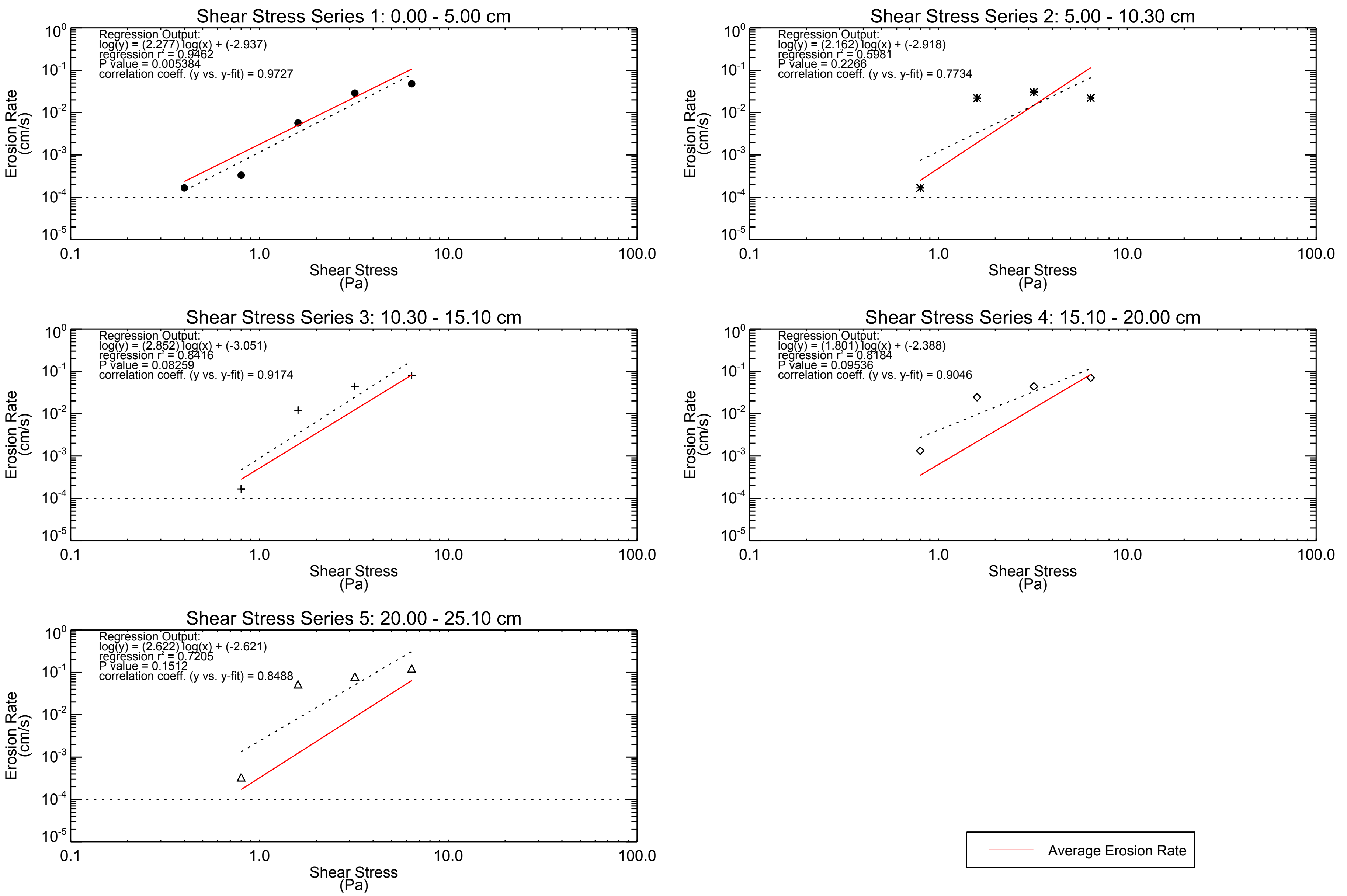

Figure C-22. Log-Linear Regression Results for Erosion Rate as a Function of Shear Stress at Various Depths in Sedflume Core SF19

The red line represents the average erosion rate for all sedflume cores for the corresponding depth interval.

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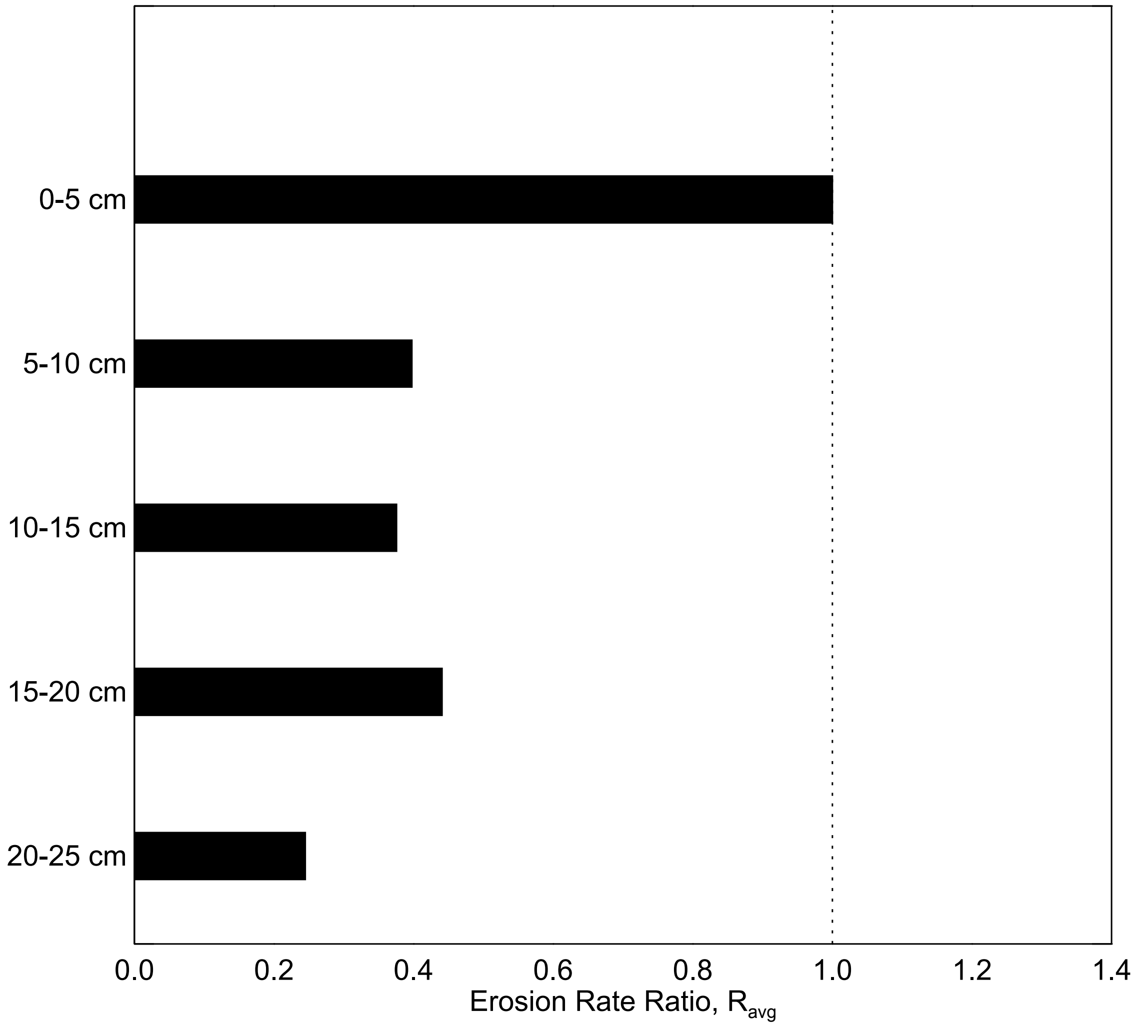

Erosion rate ratio for given layer i and shear stress τ_j is defined as $R_i(\tau_j) = E_i(\tau_j)/E_{0\text{-}5}(\tau_j)$.
$E_{0\text{-}5}(\tau_j)$ is the erosion rate of 0-5 cm layer at shear stress τ_j.
$E_i(\tau_j)$ is the erosion rate of the i^{th} layer at shear stress τ_j.
R_{avg} is the average of erosion rate ratio R for given layer with shear stress from 0.05 to 3.0 Pa and 0.05 Pa increment.

Figure C-23. Vertical Variation in Erodibility in Top 25cm of Sediment at LWG Site

Analysis is based on all cores.

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Attachment C-1
Technology Assignment Rules for R Code

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ATTACHMENT C1 TECHNOLOGY ASSIGNMENT RULES FOR R CODE - PORTLAND HARBOR SUPERFUND SITE

This document is intended to show the key assumptions and logic that goes into the R code for QA/QC purposes.

OVERARCHING KEY ASSUMPTIONS/DECISION RULES

Sitewide

- SMA footprints defined by the RALs will only be assigned dredging or capping.
- Dredge Areas
  - The maximum dredge depth is 15-19 ft.
  - If RAL depth less than maximum depth, dredge to RAL depth with residual layer.
  - If RAL depth greater than maximum depth or PTW present, dredge to maximum depth with reactive residual layer.
  - Proposed dredging rules based on the technology assignments are provided in Table C1-1.
- Cap Areas
  - To ensure sufficient thickness of each component, a 3 foot thick cap was assumed for this FS and is sufficient for an FS-level approximation. The thickness, composition and materials utilized in cap construction will be determined during remedial design.
- All PTW has a preference for treatment to the maximum extent practicable per statutory requirement
  - In-situ
    - All PTW left in place will be assigned in-situ treatment.
    - All PTW (NRC) left in will include a significantly augmented reactive cap.
  - Ex-situ
    - Any dredged material that contains PTW of any type will be evaluated for ex-situ treatment practicability.

    - Ex-situ treatment volumes will be calculated using volume of PTW estimated to be in the river subject to ex-situ treatment.

    - Only PTW (NRC or NAPL) will be subject to ex-situ treatment.

- Technology Assignment Areas less than 0.05 acres will be rounded to zero.

Under Structures

- No dredging.

- Armored caps assigned to prevent erosion due to propwash or other erosive forces.

- Solidification/stabilization (AquaBlok with some sort of cover (sand, armor stone)) assigned where all reactive caps are identified outside of groundwater plumes.

Swan Island Lagoon

- All contamination less than RAL and PTW thresholds but greater than PRGs within Swan Island Lagoon is assigned ENR, except Shallow areas

- Shallow areas outside of RAL and PTW footprints are assigned MNR due to erosive forces of wind/wave/wake.

Groundwater Plume Areas

- Reactive materials are included within all groundwater plume areas (e.g., reactive caps or reactive residual layers)

PTW Areas

- PTW (NRC or NAPL) left in place is assigned a Significantly Augmented Reactive Cap.

- PTW (highly toxic) left in place is assigned reactive cap or reactive residual layer.

- PTW (NRC or NAPL) removed is assigned ex-situ treatment.

- Due to limited data on PTW (NRC or NAPL), the depth of PTW (highly toxic) was used to represent all PTW depths.

River Banks

- Assume the same technology assignment to contaminated river banks based on adjacent RAL Boundary plus PTW (NRC or NAPL) technology assignments.

  - River banks adjacent to PTW (NRC or NAPL) areas assigned Excavation and Significantly Augmented Reactive Cap.
  - All other river bank areas assign Excavate and Cap.

Navigation Channel/FMD Area

- No Capping, ENR or backfill due to current and future land use
- Sediment contamination exceeding RALs and areas of PTW (NRC or NAPL) are assigned dredging.
  - Dredging depth will be determined based on the greater of the two criteria - maximum depth of contaminant to be removed (DOCR) or the PTW (highly toxic).
  - The maximum depth of contamination to be removed (DOCR) is less than 18 ft based on RI/FS data.
- All other areas assigned MNR

Intermediate Area

- Highly toxic PTW areas outside the RAL and PTW (NAPL or NRC) boundaries, will undergo in-situ treatment in areas designated as “cap” or MNR in areas designated as “dredge” by technology assignment matrix.
- The maximum depth of PTW (NRC or NAPL) to be removed (DOCR) is 15 ft based on engineering constraints, to limit removal of surrounding sediment and maintain side-slope stability. RI/FS data indicates that PTW (NRC or NAPL) only exceeds 15 ft within SDUs 6W and 7W.

Shallow Area

- No ENR or in-situ treatment due to erosive forces of wind/wave/wake zone.
- Sediment contamination exceeding RALs and PTW (NRC or NAPL) are assigned dredge and cap, regardless of depth.
- A surface layer consisting of 6” of beach mix will be included as a habitat armoring for wind/wake/wave erosion.
- Armored caps under heavy structures or as part of Significantly Augmented Reactive Cap.
- The maximum depth of PTW (NRC or NAPL) to be removed is 15 ft based on engineering constraints, to limit removal of surrounding sediment and maintain

side-slope stability. RI/FS data indicates that PTW (NRC or NAPL) only exceeds 15 ft within SDUs 6W and 7W.

- Maximum dredge depth of contamination (DOCR) is 5 feet based on dredge balance efficiency.

R CODE ASSIGNMENT

1. NAVIGATION CHANNEL

a. Within PTW (NAPL or NRC), **dredge to greater of DOCR or PTW (NAPL or NRC)* □Dredge with Reactive Residual Layer** (1 ft sand w/5% GAC) – KG=dredge NAV/FMD [d.rrl.1]**

b. Within RAL Boundaries and outside PTW (NAPL or NRC), **dredge to DOCR**

i. Within groundwater plume or DOCR < PTW (highly toxic) depth □**Dredge to DOCR with Reactive Residual Layer (1 ft sand w/5% GAC) – KG=dredge NAV/FMD [d.rrl.1]**

ii. Outside groundwater plume and DOCR > PTW (highly toxic) depth □**Dredge to DOCR with Residual Layer (1 ft sand w/5% GAC) – KG=dredge NAV/FMD [d.rl.1]**

c. All Other Areas: Outside RAL Boundaries and PTW (NAPL or NRC) → **MNR [mnr]**

NOTE: * Due to limited data on PTW (NRC or NAPL), the depth of PTW (highly toxic) was used to represent all PTW depths. **PTW (NAPL or NRC) that is fully removed is treated with a reactive residual layer due to the probability of PTW being left behind and potential for recontamination.

2. **FUTURE MAINTENANCE DREDGE AREA**

a. Within PTW (NAPL or NRC), **dredge to greater of DOCR or PTW (NAPL or NRC)* □Dredge with Reactive Residual Layer** (1 ft sand w/5% GAC) – KG=dredge NAV/FMD [d.rrl.1]**

b. Within RAL Boundaries and outside PTW (NAPL or NRC), **dredge to DOCR**

i. Within groundwater plume or DOCR < PTW (highly toxic) depth □**Dredge to DOCR with Reactive Residual Layer (1 ft sand w/5% GAC) – KG=dredge NAV/FMD [d.rrl.1]**

ii. Outside groundwater plume and DOCR > PTW (highly toxic) depth **Dredge to DOCR with Residual Layer (1 ft sand w/5% GAC) – KG=dredge NAV/FMD [d.rl.1]**

c. All Other Areas: Outside RAL Boundaries and PTW (NAPL or NRC)

i. Within Swan Island Lagoon SDU → **ENR (1 ft sand) – KG=ENR [enr]**

ii. All other areas → **MNR [mnr]**

NOTE: * Due to limited data on PTW (NRC or NAPL), the depth of PTW (highly toxic) was used to represent all PTW depths. **PTW (NAPL or NRC) that is fully removed is treated with a reactive residual layer due to the probability of PTW being left behind and potential for recontamination.

3. SHALLOW AREAS

d. Within PTW (NRC or NAPL)

i. If PTW (NRC or NAPL)* > 15 ft, **dredge to 15 ft with backfill and cap to maintain existing elevation → Dredge with backfill + Significantly Augmented Reactive Cap (17" fine-grained low permeability sand, 1" organoclay mat, 12" medium sand, and 6" beach mix) – KG=dredge [d.src.3.b6]**

ii. If PTW (NRC or NAPL)* ≤ 15', **dredge to depth of PTW (NRC or NAPL) w/ backfill + 6" beach mix to existing elevation → Dredge with Backfill + Reactive Residual Layer** (12" sand w/5% GAC) + 6" beach mix – KG=dredge [d.rrl.1.b6]**

iii. If PTW (NRC or NAPL)* < 3', **dredge to 3 feet with reactive cap → Dredge with Reactive Cap (12" sand w/5% GAC, 18" sand, 6" beach mix) – KG=dredge/cap [d.rc.3.b6]**

iv. If under heavy structure, cap → **Significantly Augmented Reactive Cap (17" fine-grained low permeability sand, 1" organoclay mat, 12" medium sand, and 6" armor stone) – KG=cap [c.src.3]**

NOTE: * Due to limited data on PTW (NRC or NAPL), the depth of PTW (highly toxic) was used to represent all PTW depths. **PTW (NAPL or NRC) that is fully removed is treated with a reactive residual layer due to the probability of PTW being left behind and potential for recontamination.

e. Within RAL Boundaries and outside PTW (NRC or NAPL)

i. If DOCR and PTW (highly toxic only) ≤ 5 ft, **dredge to greater of DOCR or PTW (highly toxic) and backfill with sand and 6” beach mix to existing elevation**

a) If outside groundwater plume areas
→ **Dredge with Backfill + 6” beach mix - KG=dredge [d.b6]**

b) If within groundwater plume areas
→ **Dredge with Backfill + Reactive Residual Layer (12” sand w/5% GAC) + 6” beach mix – KG=dredge [d.rrl.1.b6]**

ii. If PTW (highly toxic only) > 5 feet, **dredge to 3 feet with reactive cap → Dredge with Reactive Cap (12” sand w/5% GAC, 18” sand, 6” beach mix) – KG=dredge/cap [d.rc.3.b6]**

iii. If only DOCR > 5 feet, **dredge to 3 feet with cap**

a) If outside groundwater plume areas → **Dredge with Engineered Cap (30” sand, 6” beach mix) – KG=dredge/cap [d.c.3.b6]**

b) If within groundwater plume areas → **Dredge with Reactive Cap (12” sand w/5% GAC, 18” sand, 6” beach mix) – KG=dredge/cap [d.rc.3.b6]**

iv. If under heavy structure

a) If PTW (highly toxic) is present and outside groundwater plume area, **reactive armored cap → Solidification/stabilization (6” Aquablok, 6” beachmix) – KG=cap [c.aq6.b6**]

b) If within groundwater plume area, **reactive armored cap → Reactive Armored Cap** (**12” sand w/5% GAC, 12” sand, 12” armor stone**) **– KG=cap [c.ar.3]**

c) If no PTW is present and outside groundwater plume area, **armored cap → Armored Cap (24” sand, 12” armor stone) –KG=cap [c.a.3]**

f. Outside RAL Boundaries and PTW (NRC or NAPL) **– MNR [mnr]**

4. INTERMEDIATE AREAS

g. Within PTW (NRC or NAPL)

i. If PTW (NRC or NAPL)* > 15’, **dredge to 15 ft with cap → Dredge with Significantly Augmented Reactive Cap (17” fine-grained low permeability**

sand, 1” organoclay mat, 12” medium sand, and 6” armor stone) – KG=dredge [d.src.3]

ii. If PTW (NRC or NAPL)* ≤ 15’, **dredge to greater depth of DOCR or PTW (NRC or NAPL) with reactive residual layer → Dredge with Reactive Residual Layer** ** **(1 ft sand w/5% GAC) – KG=dredge [d.rrl.1]**

iii. If under heavy structure → **Significantly Augmented Reactive Cap (17” fine-grained low permeability sand, 1” organoclay mat, 12” medium sand, and 6” armor stone) – KG=cap [c.src.3]**

NOTE: * Due to limited data on PTW (NRC or NAPL), the depth of PTW (highly toxic) was used to represent all PTW depths. **PTW (NAPL or NRC) that is fully removed is treated with a reactive residual layer due to the probability of PTW being left behind and potential for recontamination.

h. Within RAL Boundaries and outside PTW (NRC or NAPL)

i. If pixel assigned “cap”, **engineered cap**

a) If outside groundwater plume areas → **Engineered Cap (3 ft sand) – KG=cap [c.3]**

b) If PTW (highly toxic only) or within groundwater plume area → **Reactive Cap (12” sand w/5% GAC, 24” sand) – KG=cap [c.r.3]**

ii. If pixel assigned “armored cap”, **armored cap**

a) If outside groundwater plume areas → **Armored Cap (24” sand, 12” armor stone) –KG=cap [c.a.3]**

b) If PTW (highly toxic only) or within groundwater plume area → **Reactive Armored Cap** (**12” sand w/5% GAC, 12” sand, 12” armor stone**) **– KG=cap [c.ar.3]**

iii. If pixel assigned “Dredge”, **dredge with residual layer**

a) If DOCR ≤ 15 feet, PTW (highly toxic only) within DOCR, and not in groundwater plume areas → **Dredge to DOCR with Residual Layer (1 ft sand) – KG=dredge [d.rl.1]**

b) If within in groundwater plume areas, PTW (highly toxic only) > DOCR, or DOCR > 15 ft → **Dredge to DOCR (max. 15 ft) with Reactive Residual Layer (1 ft sand w/5% GAC) – KG=dredge [d.rrl.1]**

iv. If under heavy structure, **armored cap**

a) If PTW (highly toxic only) and outside groundwater plume areas → **Solidification/stabilization (6" Aquablok, 6" armor stone) –KG=cap [c.aaq.1]**

b) If within in groundwater plume areas → **Reactive Armored Cap** (**12" sand w/5% GAC, 12" sand, 12" armor stone**) **–KG=cap [c.ar.3]**

c) If no PTW (highly toxic) is present and outside groundwater plume areas → **Armored Cap (24" sand, 12" armor stone) –KG=cap [c.a.3]**

i. Outside RAL Boundaries and in PTW (highly toxic only)

i. If pixel assigned "Cap" → **Broadcast GAC (1 ft sand w/5% GAC) -KG=PTW treatment [b.g]**

ii. Otherwise → **MNR [mnr]**

j. Outside RAL Boundaries and Outside PTW → **MNR [mnr]**

i. Area within Swan Island SDU → **ENR (1 ft sand) – KG=ENR [enr]**

ii. Otherwise → **MNR [mnr]**

5. CONTAMINATED RIVER BANKS

k. Adjacent to PTW (NRC or NAPL) areas → **Excavation and Significantly Augmented Reactive Cap (Geofabric, 17" fine-grained low permeability sand, 1" organoclay mat, 12" medium sand, and 6" armor stone)**.

l. Adjacent to RAL Boundaries and outside PTW (NRC or NAPL) → **Excavate and Cap (Geofabric, 30" sand, and 6" beachmix)**.

m. Otherwise→ **No Action**

DEFINITIONS:

a. Shallow – Bathymetric elevation > MLLW-assumed 3' design cap = 4' NAVD 88.

b. Navigation Channel – Federally authorized navigation channel.

c. Future Maintenance Dredging – Areas identified between Nav Channel and docks as developed by LWG. This includes areas in Swan Island Lagoon.

d. Intermediate Channel – Portions of river in study area that are not Navigation Channel, not FMD, and not Shallow.

e. PTW (highly toxic) – PTW as determined by interpolated surface sediment concentrations exceeding the 10^{-3} increased cancer risk for COCs.

f. PTW (NAPL) – PTW as determined by areas delineated by CDM Smith in the vicinity of Gasco and Arkema based on the presence of liquid NAPL in sediment cores at any depth. Depth of PTW (NAPL) is unknown and is estimated based on PTW (highly toxic) in the area.

g. PTW (NRC) – PTW as determined by the interpolated surface sediment concentrations determined to not be reliably capped based on the CDM Smith activated carbon cap evaluation. Depth of PTW (NAPL) is unknown and is estimated based on PTW (highly toxic) in the area.

h. Depth of Contamination Removed (DOCR) as defined by associated RAL, which is different than depth of impact (DOI) that identifies depth of contamination exceeding PRGs.

i. Groundwater plume areas – areas as defined by CDM Smith GIS file dated June 15, 2015.

j. Reactive residual layer – 12" of sand mixed with activated carbon to provide in-situ treatment post dredging for areas that previously contained PTW.

k. Residual layer – 12" of sand applied post dredging.

l. ENR – 12" of sand applied to enhance monitored natural recovery

m. Beach mix – mixture of aggregates with diameters appropriate to provide habitat in beach and nearshore areas

n. Broadcast GAC - Direct broadcasting of 12 inch layer of activated carbon and sand mixture onto the sediment surface and incorporation of that material into the sediment bed via ambient mixing processes (bioturbation).

o. MNR – monitored natural recovery

p. Engineered cap – cap constructed in areas of relatively low shear stress and comprised primarily of course sand. Beach mix applied in shallow areas.

q. Armored cap – cap constructed in areas of relatively high shear stress, wind/wave zones, or other areas likely to experience significant erosive forces that could potentially reduce the effectiveness of the containment provided by the cap.

r. Dredge – removal of contaminated sediments to the depth of contamination (DOCR). The depths vary based on the associated RALs. Proposed dredging rules based on the technology assignments are provided in Table C1-1.

s. Reactive – modifier to assigned technology that signifies addition of carbon or organoclay to provide additional measure of treatment or reduction in contaminant mobility

t. Significantly Augmented Reactive Cap – Cap constructed in areas where PTW (NRC or NAPL) is left in place. From bottom to top this includes 17" of fine-grained low permeability sand, 1" organoclay mat, 12" of medium sand and a surface stabilization layer. For intermediate, navigation channel/future maintenance dredging areas, and shallow areas beneath structures, the surface stabilization layer is defined as six inches of armor stone. For shallow areas that are not beneath structures, the surface stabilization layer is defined as six inches of beach mix.

Table C1-1
Proposed Dredging Rule based on Technology Assignments
Portland Harbor Superfund Site

Location	Presence of PTW	Depth of Impact	Proposed Dredging Rule
Navigation Channel or FMD	PTW - NRC/NAPL	NA	Dredge to greater of DOCR or depth of NRC/NAPL PTW with reactive residual layer
	No PTW - NRC/NAPL		Dredge to DOCR
Shallow Region	PTW - NRC/NAPL	PTW - NRC/NAPL > 15'	Dredge to 15' with significantly augmented reactive cap, backfill and beach mix
		PTW - NRC/NAPL > 3' and < 15'	Dredge to depth of NRC/NAPL PTW with raective residual layer, backfill and beach mix
		PTW - NRC/NAPL < 3'	Dredge to 3 feet with reactive engineered cap and beach mix
	PTW - Highly Toxic	PTW - Highly Toxic > 5'	Dredge to 3' with reactive engineered cap and beach mix
		PTW - Highly Toxic < 5'	Dredge to greater of DOCR or depth of PTW - highly toxic with backfill and beach mix
	No PTW	DOCR > 5'	Dredge to 3' with engineered cap and beach mix
		DOCR < 5'	Dredge to DOCR
Intermediate Region	PTW - NRC/NAPL	PTW - NRC/NAPL > 15'	Dredge to 15' with significantly augmented reactive cap, backfill and armor stone
		PTW - NRC/NAPL < 15'	Dredge to greater of DOCR or depth of NRC/NAPL PTW with reactive residual layer
	PTW - Highly Toxic	PTW > 15'	Dredge to 15' with reactive residual layer
		PTW < 15'	Dredge to DOCR with reactive residual layer
	No PTW	DOCR > 15'	Dredge to 15' with residual layer
		DOCR < 15'	Dredge to DOCR with residual layer

Notes:

Navigation Channel or FMD is defined as the Federally maintained navigation channel or areas identified as future maintenance dredge areas
The shallow region is defined as shoreward of the bathymetric elevation of 4 ft NAVD 88
The intermediate region is defined as outside the horizontal limits of the navigation channel and FMD areas to the bathymetric elevation of 4 ft NAVD 88
DOCR - Depth of contamination to be removed based on remedial action levels (RALs)
No dredging is required below functional structures
Caps and residual layers placed following dredging in areas with groundwater plumes will require reactive components

Attachment C-2
Wake Analysis

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Table 1.
Wake Analysis
Portland Harbor Superfund Site
Portland, Oregon

Vessel	Distance to Sail Line (feet)[1]	Water Depth (ft)	Vessel Speed (knots)	Linear Correction Coefficients[2]		Vessel- Generated Wave Height (feet)	Vessel- Generated Wave Period (seconds)
				A'	B'		
Typical Tanker	500	63	5.50	2.5	0.036	Negligible	0.00
	500	63	8.00	2.5	0.036	Negligible	0.00
	600	63	5.50	2.5	0.036	Negligible	0.00
	600	63	8.00	2.5	0.036	Negligible	0.00
	800	63	5.50	2.5	0.036	Negligible	0.00
	800	63	8.00	2.5	0.036	Negligible	0.00
Empty Tanker	350	49.5	5.50	1.8	0.025	Negligible	0.00
	350	49.5	8.00	1.8	0.025	Negligible	0.00
	350	58	5.50	1.8	0.025	Negligible	0.00
	350	58	8.00	1.8	0.025	Negligible	0.00
	500	49.5	5.50	1.8	0.025	Negligible	0.00
	500	49.5	8.00	1.8	0.025	Negligible	0.00
	500	58	5.50	1.8	0.025	Negligible	0.00
	500	58	8.00	1.8	0.025	Negligible	0.00
	800	49.5	5.50	1.8	0.025	Negligible	0.00
	800	49.5	8.00	1.8	0.025	Negligible	0.00
	800	58	5.50	1.8	0.025	Negligible	0.00
	800	58	8.00	1.8	0.025	Negligible	0.00
Largest Tanker	500	63	5.50	0.7	0.008	Negligible	0.00
	500	63	8.00	0.7	0.008	Negligible	0.00

Table 1.

Wake Analysis

Portland Harbor Superfund Site

Portland, Oregon

Vessel	Distance to Sail Line (feet)[1]	Water Depth (ft)	Vessel Speed (knots)	Linear Correction Coefficients[2]		Vessel- Generated Wave Height (feet)	Vessel- Generated Wave Period (seconds)
				A'	B'		
Largest Tug Boat	100	25	8.00	1.7	0.015	1.12	2.15
	100	45	8.00	1.7	0.015	1.29	2.15
	500	30	8.00	1.7	0.015	0.57	2.15
	500	30	10.00	1.7	0.015	1.42	2.69
	500	60	8.00	1.7	0.015	0.71	2.15
	500	60	10.00	1.7	0.015	1.58	2.69
	900	40	8.00	1.7	0.015	0.46	2.15
	900	40	10.00	1.7	0.015	1.14	2.69
	900	60	8.00	1.7	0.015	0.53	2.15
	900	60	10.00	1.7	0.015	1.24	2.69
	1100	40	8.00	1.7	0.015	0.42	2.15
	1100	40	10.00	1.7	0.015	1.06	2.69
	1100	65	8.00	1.7	0.015	0.51	2.15
	1100	65	10.00	1.7	0.015	1.18	2.69
Passenger Ferry	100	25	8.00	1.8	0.025	1.13	2.15
	100	25	10.00	1.8	0.025	2.67	2.70
	100	45	8.00	1.8	0.025	1.26	2.15
	100	45	10.00	1.8	0.025	2.83	2.69
	500	30	8.00	1.8	0.025	0.56	2.15
	500	30	10.00	1.8	0.025	1.48	2.69
	500	60	8.00	1.8	0.025	0.67	2.15
	500	60	10.00	1.8	0.025	1.60	2.69
	900	40	8.00	1.8	0.025	0.43	2.15
	900	40	10.00	1.8	0.025	1.17	2.69
	900	60	8.00	1.8	0.025	0.50	2.15
	900	60	10.00	1.8	0.025	1.25	2.69
	1100	40	8.00	1.8	0.025	0.39	2.15
	1100	40	10.00	1.8	0.025	1.08	2.69
	1100	65	8.00	1.8	0.025	0.47	2.15
	1100	65	10.00	1.8	0.025	1.18	2.69

Table 1.

Wake Analysis

Portland Harbor Superfund Site

Portland, Oregon

Vessel	Distance to Sail Line (feet)[1]	Water Depth (ft)	Vessel Speed (knots)	Linear Correction Coefficients[2]		Vessel- Generated Wave Height (feet)	Vessel- Generated Wave Period (seconds)
				A'	B'		
Largest Barge (Cargo Ship)	100	45	8.00	2.17	0.03	0.56	2.15
	500	30	8.00	2.1	0.03	0.26	2.15
	500	30	10.00	2.1	0.03	1.12	2.69
	500	60	8.00	2.1	0.03	Negligible	0.00
	500	60	10.00	2.1	0.03	0.90	2.69
	900	40	8.00	2.1	0.03	Negligible	0.00
	900	40	10.00	2.1	0.03	0.74	2.69
	900	60	8.00	2.1	0.03	Negligible	0.00
	900	60	10.00	2.1	0.03	0.68	2.69
	1100	40	8.00	2.1	0.03	Negligible	0.00
	1100	40	10.00	2.1	0.03	0.67	2.69
	1100	65	8.00	2.1	0.03	Negligible	0.00
	1100	65	10.00	2.1	0.03	0.61	2.69
Liquid Tank Barge	100	25	8.00	1.5	0.005	0.65	2.15
	100	45	8.00	1.5	0.005	0.62	2.15
	500	30	8.00	1.5	0.005	0.29	2.15
	500	30	10.00	1.5	0.005	0.97	2.69
	500	60	8.00	1.5	0.005	0.29	2.15
	500	60	10.00	1.5	0.005	0.90	2.69
	900	40	8.00	1.5	0.005	Negligible	0.00
	900	40	10.00	1.5	0.005	0.70	2.69
	900	60	8.00	1.5	0.005	Negligible	0.00
	900	60	10.00	1.5	0.005	0.69	2.69
	1100	40	8.00	1.5	0.005	Negligible	0.00
	1100	40	10.00	1.5	0.005	0.64	2.69
	1100	65	8.00	1.5	0.005	Negligible	0.00
	1100	65	10.00	1.5	0.005	0.64	2.69

Table 1.

Wake Analysis

Portland Harbor Superfund Site

Portland, Oregon

Vessel	Distance to Sail Line (feet)[1]	Water Depth (ft)	Vessel Speed (knots)	Linear Correction Coefficients[2]		Vessel- Generated Wave Height (feet)	Vessel- Generated Wave Period (seconds)
				A'	B'		
Pushboat	100	25	8.00	1.7	0.015	1.65	2.15
	100	45	8.00	1.7	0.015	2.12	2.15
	500	30	8.00	1.7	0.015	0.98	2.15
	500	30	10.00	1.7	0.015	1.71	2.69
	500	60	8.00	1.7	0.015	1.41	2.15
	500	60	10.00	1.7	0.015	1.99	2.69
	900	40	8.00	1.7	0.015	0.87	2.15
	900	40	10.00	1.7	0.015	1.48	2.69
	900	60	8.00	1.7	0.015	1.12	2.15
	900	60	10.00	1.7	0.015	1.63	2.69
	1100	40	8.00	1.7	0.015	0.80	2.15
	1100	40	10.00	1.7	0.015	1.39	2.69
	1100	65	8.00	1.7	0.015	1.12	2.15
	1100	65	10.00	1.7	0.015	1.56	2.69
Fireboat	500	40	10.00	1	0	0.98	2.69
	500	60	10.00	1	0	1.04	2.69
	500	60	15.00	1	0	2.12	4.04
	900	40	10.00	1	0	0.82	2.69
	900	60	10.00	1	0	0.86	2.69
	900	60	15.00	1	0	1.82	4.04
	1100	40	10.00	1	0	0.77	2.69
	1100	65	10.00	1	0	0.83	2.69
	1100	65	15.00	1	0	1.73	4.04

Notes:

1 Distance from shore to the travel line of the vessel.

2 Correction factors based on studies by Weggel and Sorensen (1986)