ATTACHMENT 1

Sedflume Data Collection

D.1 DATA COLLECTION OVERVIEW

Eight Sedflume cores were collected as part of the East Waterway (EW) Sediment Transport Evaluation (STE) to provide in situ sediment properties and empirical site-specific estimates of critical shear stress within the EW. Sedflume cores were collected on April 19, 2010, and analyzed on site April 20 through April 21, 2010, by Sea Engineering, Inc. (SEI; 2010). The cores were collected using a deep-water coring system that does not require the use of divers. The system includes a pneumatic piston mounted on an aluminum frame with weighted horizontal legs for stability. Sedflume core barrels are inserted into the frame beneath the piston and the corer system is lowered to the sea bed from an A-frame on the bow of the research vessel. The piston forces the core barrel into the sediment and then reverses direction to extract the core from the sediment bed. A spring-loaded door closes after core extraction to ensure that no sediment is lost as the core is brought to the surface. Detailed descriptions of core collection and Sedflume analysis procedures are provided on pages 5 and 6 of the SEI report (included in this appendix as Attachment 2). Table D-1 provides the locations and approximate water depths at the time of retrieval for each Sedflume core. Figure 2-3 in the main body of the report shows the locations of collected cores.

Table D-1
Sampling Locations of Sedflume Cores

Core Location	Latitude (ºN)	Longitude (ºW)	Coring Date	Time (PDT)	Depth ft (m)[a]
SF_1	47.57415	122.3445	4/19/2010	12:20	46.0 (14.0)
SF_2	47.57628	122.3446	4/19/2010	10:40	48.0 (14.6)
SF_3	47.57265	122.345	4/19/2010	12:55	32.0 (9.8)
SF_4	47.57125	122.3455	4/19/2010	13:40	7.5 (2.3)
SF_5	47.57187	122.3452	4/19/2010	14:20	17.0 (5.2)
SF_6	47.5801	122.3447	4/19/2010	15:05	52.0 (15.8)
SF_7	47.58915	122.3447	4/19/2010	17:00	57.0 (17.4)
SF_8	47.58492	122.3449	4/19/2010	18:30	59.0 (18.0)

Notes:
a. Depths are measured at time of deployment from the water surface and are not corrected to any datum.

D.2 DATA OVERVIEW

For each of the eight Sedflume cores collected, erosion rate, grain size distribution, and bulk density were evaluated at various vertical intervals in the core down to approximately 20 centimeters (cm) below mudline. Data summary tables and associated laboratory reports (provided by SEI) are included in this appendix as Attachment 3. A summary of observations and results of data analyses for each core are provided in the Executive Summary of the SEI report (Attachment 2 in this appendix). Additional data evaluation, which included estimates of critical shear stress based on measured erosion rates, was also completed by SEI using regression techniques. This information is also provided in detail in the attached SEI report. Anchor QEA, LLC, completed an additional evaluation (also using regression techniques) to evaluate critical shear stress from erosion rates provided by the Sedflume analysis. This information is provided in Section 6.1 in the main body of the report.

D.3 DEVIATIONS FROM THE SEDIMENT TRANSPORT CHARACTERIZATION QAPP

Procedures for Sedflume core collection and laboratory testing are outlined in the Sediment Transport Characterization Quality Assurance Project Plan (QAPP; Anchor QEA 2009). Sections 3.1.2 and 3.2.4 in the QAPP outline the required data collection locations and procedures, respectively, for Sedflume data collection. There were no significant deviations from the QAPP that altered the quality of data collected. However, there were several deviations from the QAPP that should be noted.

The QAPP required collection of seven Sedflume cores (Table 3-2 in the QAPP), including one proposed for the Junction Reach (SF_6). During collection of the geochronological cores, it became apparent that bottom sediments in the Junction Reach were primarily consolidated gravels and sands, which would make collection of a Sedflume core in that location prohibitively difficult. Through discussions with the U.S. Environmental Protection Agency (EPA), it was decided that core SF_6 would be moved out into the Main Body Reach, where there was a higher expectation of successful retrieval. In addition, another core location was added (SF_8) to a deeper area within the EW to increase spatial resolution of the dataset. Water depths and locations proposed in the QAPP (Table 3-2) for the Sedflume cores varied slightly from actual values due to updated bathymetry (collected as part of the STE), variability in bed elevation, and navigation concerns during core collection. None of these changes are significantly different than proposed. Table D-1 provides the actual locations and water depths for each Sedflume core.

The QAPP required the use of piston coring, which would be employed by divers for collection of the Sedflume cores. Deep water depths at some locations (approximately 60 feet) and navigation concerns within the EW, produced concerns regarding the efficiency and safety of using divers to extract the Sedflume cores. Therefore, through discussions with SEI and EPA, the coring method was changed to a remote coring system that employed piston coring methods as required by the QAPP, but was set up to extract and retrieve cores at depth without the use of divers. The collection procedure is outlined in detail in the SEI report (Attachment 2), and has been used successfully at other sites for Sedflume core collection.

REFERENCES

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

SEI, 2010. Sea Engineering Inc. East Waterway Sedflume Analysis. Prepared for Anchor QEA, LLC. June 2010.

ATTACHMENT 2

DRAFT

East Waterway Sedflume Analysis, Washington

June 2010

Prepared for:

Anchor QEA, LLC.

Prepared by:
Sea Engineering, Inc.
200 Washington Street, Suite 210
Santa Cruz, CA 95060
Tel: (831) 421-0871
Fax: (831) 421-0875

Executive Summary

Sea Engineering, Inc. (SEI) conducted a Sedflume analysis for Anchor QEA on eight (8) sediment cores obtained from the East Waterway in the Port of Seattle, Washington. These cores were collected in areas where depths ranged to 18 m of water depth. The primary goal of this work was to characterize the erosion properties of the sediments within the East Waterway. The Sedflume analysis determines sediment erosion rates, critical shear stress, particle size and wet bulk density at depth intervals down-core. The following is a brief physical description of the cores. The report below contains the data from the comprehensive Sedflume analysis:

- Core SF-1 was collected in approximately 14.0 m water depth. The material consisted of silts and sandy silts. Stringy, organic material became exposed when the surrounding finer sediments were scoured away. Several (4-6) larger worms existed to the 4 cm depth. Erosion was uneven and clumpy. A few worms were visible near a depth of 10 cm. Deeper than 15 cm of depth, the material was very difficult to erode. The erosion rate data shows evidence of typical consolidated core material: the material, in general, becomes stiffer with increasing depth. The mean d_{50} in the core is 11.65 μm, fine silt. The mean bulk density in the core is 1.38 g/cm^3.

- Core SF-2 was collected in approximately 14.6 m water depth. The material consisted of silts and sandy silts. A very stiff layer of sediment was encountered at the bottom of the core, preventing any deeper push coring. A large amount of stringy organic material was encountered beneath the surface as fine particulates were scoured away. The organic material persisted until approximately 5 cm, where an easier to erode layer was encountered. Erosion was uneven and clumpy. The erosion rates remain relatively constant down-core, but increase by two orders of magnitude deeper than 20 cm into the core. The mean d_{50} in the core is 21.4 μm, fine silt. The bulk densities averaged 1.47 g/cm^3 in the core.

- Core SF-3 was collected in approximately 9.8 m water depth. Upon extraction, the core consisted of an undisturbed sediment surface comprising small surface debris (e.g. small twigs) and approximately 1 cm of light brown and orange colored fine sediment. Small pebbles (~1 cm diameter) were observed within the top 5 cm. Some worms and stringy organic material became visible in this layer as well, as the finer particulates were eroded. At depths greater than 16 cm, a large amount of woody debris and organic detritus was encountered. Erosion occurred in clumps. The erosion rate data shows evidence of easier-to-erode sediment with increasing depth, which is not typical of consolidated core material. The erosion rates remain relatively constant down-core until a depth of approximately 10 cm, where the increasing erosion rate trend begins. The mean particle size in the core is 11.5 μm. The mean bulk density in the core is 1.44 g/cm^3.

- Core SF-4 was collected in approximately 2.3 m water depth. The core was collected from a very shallow area beneath the bridges connecting Seattle to Harbor Island and West Seattle (West Seattle Bridge). It was difficult to collect a large amount of sediment in the core at this location because of the material composition. The core was driven to refusal several times. Upon extraction, the core consisted of an undisturbed sediment surface comprising 5 cm of fine, lighter-colored sediments. Below the surface layer, shell hash and coarser sands were visible mixed with silts. At the bottom of the core, a visible fine to medium sand layer (2-4 cm thick) was observed. During the analysis, some red-colored grass was visible within the surface layer. Small benthic organisms and worms

were visible. Erosion was clumpy near the top of the core due to the organic material that added strength to the sediment. Near the bottom, erosion was very uneven, eroding the center of the core faster than the sides. The erosion rate data shows evidence of typical consolidated core material: the material, though variable down-core, generally becomes stiffer with increasing depth. The mean d_{50} in the core was 21.0 μm. The mean bulk density in the core is 1.46 g/cm^3.

- Core SF-5 was collected in approximately 5.2 m water depth. The core was collected from a relatively shallow region immediately north of the Harbor Island and West Seattle bridges. It was difficult to collect a large amount of sediment in the core at this location because the material composition was, again, very prohibitive. The core was driven to refusal twice with the subsequent extracted depth similar to the first. The core consisted of an undisturbed sediment surface comprising 1-2 cm of fine, lighter-colored sediments. Below the surface layer, fine to medium sands were visible mixed with silts. At the bottom of the core, a darker colored material was observed, likely the material which prevented a deeper core from being extracted. Many (20-30) 1 cm to 2 cm long, small diameter worms were observed on the surface. The top 1 cm of sediment was difficult to erode because the organic material and benthic organisms added strength to the sediment. Down-core erosion was clumpy and uneven. The erosion rate data shows evidence of wide variation in erosion rates down-core. The core mean value of d_{50} is 23.9 μm. The mean bulk density in the core is 1.53 g/cm^3.

- Core SF-6 was collected in approximately 15.8 m water depth. The core was collected from a central channel location, approximately midway between the West Seattle Bridge to the south and the East Waterway mouth to the north. Upon extraction, the core consisted of an undisturbed, uneven sediment surface comprising benthic organisms and worms over 5 cm of silt and fine sand. Beneath the surface layer a 5-6 cm layer of fine to medium sand and shell hash was clearly visible. Below the sand lens, the sediments comprised darker-colored silty material. Some organic detritus and fine stringy organic material was observed when the fine particulates were scoured away. The erosion rate data shows variation in erosion rates down-core as a result of different material consistencies. The erosion rates increased when the fine to medium sand layer was encountered and at the very bottom of the core, when clumpy erosion caused larger amounts of sediment to be removed. At layers in between the sandy layer and the bottom of the core, the material is stiffer and more difficult-to-erode, resulting in relatively lower erosion rates. The mean d_{50} in the core is 42.5 μm. The mean bulk density in the core is 1.64 g/cm^3.

- Core SF-7 was collected in approximately 17.4 m water depth. The core was collected near the mouth of the East Waterway. This core required 5 attempts to extract a sufficient core. The material consisted of an uneven, undisturbed, 2-3 cm sandy silt layer with some shell hash and organic detritus. Below this layer was a darker-colored stiff clayey silt material. Several worms and worm tubes were observed on the surface layer and throughout the core. An easier-to-erode surface layer gave way to veins of a stiffer layer below, which resulted in uneven erosion. The sediment consistency beneath the surface was stiff, clayey-silt, which tended to erode in clumps. The erosion rate data shows a general increase in erosion rate near a depth of 5 cm before becoming more difficult to erode deeper than 8 cm. The mean d_{50} in the core is 55.5 μm (sandy silt). The mean bulk density in the core is 1.72 g/cm^3.

- Core SF-8 was collected in approximately 18.0 m water depth. The core was collected from a central channel location, between the coring locations of SF-6 and SF-7. This core also required several attempts to collect a sufficient amount of material. Upon extraction, the core consisted of an uneven, but undisturbed, 1 cm light-colored layer of fine sediment over seemingly stiffer, darker-colored silts and sandy silts. Larger, unconsolidated clumps of sediment were distinct within the core. Some benthic organisms were visible on the surface. Some 1-2 cm long worms and tubes were also observed while sediments were eroding. Erosion was clumpy and required manual leveling of the sediment surface during the analysis. The material was stiff clayey-silt near the bottom of the core. The erosion rate data shows variation in erosion rates down-core as a result of different material consistencies. The erosion rates were low on the surface but increased beneath the surface layer before decreasing again down-core. The mean core d_{50} value was 19.8 μm. The mean bulk density in the core is 1.55 g/cm^3.

CONTENTS

Introduction

Sea Engineering, Inc. (SEI) conducted a Sedflume analysis for Anchor QEA on eight (8) sediment cores obtained from the East Waterway in the Port of Seattle, Washington. These cores were collected in areas where depths ranged to 18 m of water depth. The primary goal of this work was to characterize the stability of the sediments within the East Waterway. The cores were eroded using Sedflume to determine erosion rates as a function of shear stress and depth. In addition, each core was sub-sampled periodically to determine sediment wet bulk density and particle size distribution at specific depths within the core. Critical shear stresses were determined through two interpolation techniques for each vertical interval sampled. The following report outlines the procedures used in the Sedflume analysis, presents the Sedflume data, and provides a description of the results.

Experimental Procedures

A detailed description of Sedflume and its application are given in McNeil et al (1996) and Roberts et al (1998). The following section provides a general description of the Sedflume analysis conducted for this study.

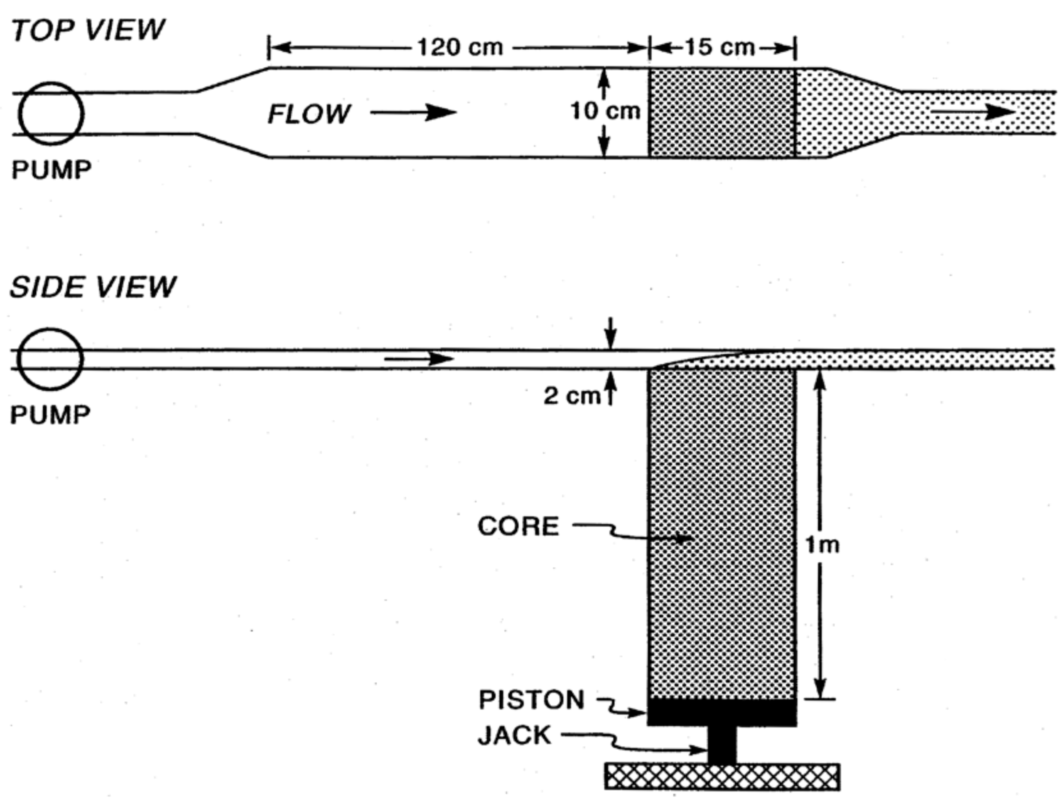

Figure 1. Sedflume Diagram

Description of Sedflume

Sedflume is shown in Figure 1 and is essentially a straight flume that has a test section with an open bottom through which a rectangular cross-section core containing sediment can be inserted. The main components of the flume are the core; the test section; an inlet section for uniform, fully-developed, turbulent flow; a flow exit section; a water storage tank; and a pump to force water through the system. The coring tube, test section, inlet section, and exit section are made of clear acrylic so that the sediment-water interactions can be observed. The coring barrel has a rectangular cross-section, 10 cm by 15 cm, and can be up to 1 m in length.

Water is pumped through the system from a 300 gallon storage tank, through a 5 cm diameter pipe, and then through a flow converter into the rectangular duct shown. This duct is 2 cm in height, 10 cm in width, and 120 cm in length; it connects to the test section, which has the same cross-sectional area and is 15 cm long. The flow converter changes the shape of the cross-section from circular to the rectangular duct shape while maintaining a constant cross-sectional area. A ball valve regulates the flow so that the flow into the duct can be carefully controlled. Also, there is a small valve in the duct immediately downstream from the test section that is opened at higher flow rates to keep the pressure in the duct and over the test section at atmospheric conditions.

At the start of each test, a core containing sediments collected from the site is prepared. The core and the sediment it contains are then inserted into the bottom of the test section. An operator moves the sediment upward using a piston that is inside the core and is connected to a hydraulic jack with a 1 m drive stroke. The jack is driven by the release of pressure that is regulated with a switch and valve system. By this means, the sediments can be raised and made level with the bottom of the test section. The speed of the hydraulic jack movement can be controlled at a variable rate in measurable increments as small as 0.5 mm.

Water is forced through the duct and the test section over the surface of the sediments. The shear produced by this flow causes the sediments to erode. As the sediments in the core erode, they are continually moved upward by the operator so that the sediment-water interface remains level with the bottom of the test and inlet sections. The erosion rate is recorded as the upward movement of the sediments in the coring tube over time.

Sedflume Core Collection

The sediment cores were collected from the East Waterway in Washington by SEI personnel. At each coring location, a GPS system was used to position the vessel at a fixed sampling station. An innovative deep-water coring system was implemented to collect all cores. The deep-water corer consisted of a pneumatic piston mounted on an aluminum frame which had lead-weighted horizontal legs at its base for roll stability. Sedflume core barrels were inserted in the frame beneath the piston. The corer was lowered to the sea bed from an A-frame on the bow of the vessel. The pneumatic piston forced the core barrel into the sediment bed and reversed to extract the sediment core. A valve on top provided the necessary suction to extract the sediment from the bed. After extraction a spring-loaded door closed beneath the sediment to prevent sediment loss as the system was raised to the water surface. The process was repeated as necessary until a sufficient amount of sediment was extracted in a core (typically at least 30 cm, but less than 100 cm). At times, the bottom sediments were difficult to penetrate to sufficient depths. Shorter were accepted if, after several attempts, at least 30 cm of sediment could not be extracted.

After cores reached the water surface, they were immediately inspected visually for length and quality. Undisturbed surface sediments were present in the cores. The cores were capped and photographed and secured to the vessel to minimize disturbance. Cores were transferred from the vessel to a padded shipping container for transport to SEI's mobile Sedflume laboratory. All cores were collected in one day and were processed within 5 days of collection. All cores arrived at the mobile laboratory intact with sediment structure and surface preserved.

Measurements of Sediment Erosion Rates

The sediment core was inserted into the Sedflume test section using the hydraulic jack until the sediment surface was even with the bottom of the Sedflume channel. A measurement was made of the core length. The flume was then run at a specific flow rate corresponding to a particular shear stress (McNeil et al., 1996). Erosion rates are obtained by measuring the core length at different time intervals, taking the difference between each successive measurement, and dividing by the time interval as shown in Equation 1:

$$E = \frac{\Delta z}{T} \qquad (1)$$

E = Erosion rate
Δz = Amount of sediment eroded
T = Time

In order to measure erosion rates at several different shear stresses using only one core, the following procedure was used. Starting at a low shear stress, the flume was run sequentially at higher shear stresses with each succeeding shear stress being twice the previous one. Generally, a flow rate was applied until 10 minutes had expired or 2 cm of sediment had eroded. The shear stress cycle was halted if the next increase in shear stress would erode more than 2 cm in 20 seconds (for this analysis, measurements less than 20 seconds in duration are not considered to hold a high degree of accuracy). The time interval was recorded for each run with a stopwatch.

This cycle was repeated until all of the sediment had eroded from the core. If after three cycles a particular shear stress showed a rate of erosion less than 10^{-4} cm/s, it was dropped from the cycle; if after many cycles the erosion rates decreased significantly, a higher shear stress was included in the cycle. If the composition of the material changes at a sediment interface resulting in an observable change of erosion properties, the present cycle was stopped and a new cycle started at the lowest shear stress.

Determination of Critical Shear Stress

The critical shear stress of a sediment bed, τ_{cr}, is defined quantitatively as the shear stress at which a very small, but accurately measurable, rate of erosion occurs. For Sedflume studies, this rate of erosion has been practically defined as 10^{-4} cm/s. This represents 1 mm of erosion in approximately 15 minutes. Since it is difficult to measure τ_{cr} exactly at 10^{-4} cm/s, erosion rates were determined above and below 10^{-4} cm/s. The τ_{cr} was then determined by two interpolation techniques, linear and power law regression.

Measurement of Sediment Bulk Properties

In addition to erosion rate measurements, samples were collected at periodic intervals to determine the water content, bulk density, and particle size distribution of the sediments. Sub-samples were collected from the undisturbed sediment surface as well as the sediment surface at the end of each shear stress cycle. This allowed 4-5 samples to be collected approximately every 5 cm for analysis.

Bulk density was determined in the SEI mobile Sedflume laboratory by water content analysis using methods outlined in Hakanson and Jansson (2002). This consisted of determining the wet and dry weight of the collected sample to determine the water content, W, from Equation 2.

$$W = \frac{M_w - M_d}{M_w} \qquad (2)$$

W = water content
M_w = wet weight of sample
M_d = dry weight of sample

Once the water content was calculated, the bulk density, ρ_b, was determined from Equation 3.

$$\rho_b = \frac{\rho_w \rho_s}{\rho_w + (\rho_s - \rho_w)W} \qquad (3)$$

ρ_w = density of water (1 g/cm^3)
ρ_s = density of sediment particle (2.65 g/cm^3)

Particle size distributions were determined using laser diffraction analysis in the SEI Santa Cruz, CA laboratory. Samples collected from the Sedflume core were prepared and inserted into a Beckman Coulter LS 13 320. Each sample was analyzed in three 1-minute intervals and the results of the three analyses were averaged. This method is valid for particle sizes between 0.04 and 2000 μm. Any fraction over 2000 μm was weighed and compared to total sample weight to determine the weight percentage greater than 2000 μm. Table 1 summarizes all measurements conducted during the Sedflume analysis.

Table 1. Parameters measured and computed for the Olympia, WA, Site.

Measurement	Definition	Units	Detection Limit
Bulk Density, ρ_b (wet/dry weight)	$\rho_b = \frac{\rho_w \rho_s}{\rho_w + (\rho_s - \rho_w)W}$	g/cm^3	Same as water content
Water Content	$W = \frac{M_w - M_d}{M_w}$	unit less	0.1g in sample weight ranging from 10 to 50 g
Particle Size Distribution	Distribution of particle sizes by volume percentage using laser diffraction	μm	0.04 μm – 2000 μm
Erosion Rate	$E = \Delta z/T$	cm/s	$\Delta z > 0.5$mm $T > 15$s
Critical Shear Stress τ_{cr}	Shear stress when erosion rate equals 10^{-4} cm/s	N/m^2	0 to 10.0 N/m^2 This value is interpolated as described in the text.

W = water content
M_w = wet weight of sample
M_d = dry weight of sample
Δz = amount of sediment eroded
T = time
ρ_w = density of water (1 g/cm^3)
ρ_s = density of sediment (2.65 g/cm^3)

Erosion Rate Comparisons

A useful method of analyzing sediment characteristics at a specific site is to compare the inter-core and intra-core Sedflume erosion rates. This method provides a means to quantify the erosion susceptibility within each core as well as the general erosion susceptibility of the coring site. In this analysis, each core has been sub-sampled into approximately five separate depth intervals (shear cycles). Following the methods of Roberts et al (1998), the erosion rate for each interval can be approximated by

$$E = A\tau^n \rho^m \tag{4}$$

where E is the erosion rate (cm/s), τ is the shear stress (N/m^2) and ρ is the sediment bulk density (g/cm^3). A, n and m are constants that depend on the sediment characteristics. The equation used in this analysis is an abbreviated variation of Equation 4:

$$E = A\tau^n \tag{5}$$

where the sediment bulk density parameter is a function of the constant A. The variation of erosion rate with density cannot be typically determined in the field due to natural variation in other sediment properties (e.g. mineralogy and particle size). Therefore, the density term for a particular interval of approximately constant density is lumped into the constant A. For each depth interval, the measured Sedflume erosion rates (E) and applied shear stresses (τ) were used to determine the A and n constants that provide a best fit power law curve to the data for that interval. With good fits (i.e $r^2 > 0.8$), these parameters can be used to predict erosion rates for the core interval of interest. A correlation of 0.8 was used as a criteria threshold for acceptance.

From this process an average erosion rate for a particular core can also be determined, and the erosion rate at each depth interval can be directly compared to this average. The result is an erosion rate ratio which provides an estimation of the erosion susceptibility of each depth interval relative to the core average. This procedure highlights the depths of the core that will erode more rapidly, and those that will tend to resist erosion, relative to the other intervals in the core. Intervals for which the r^2 is less than 0.8 or containing less than three data points are omitted from this comparison and will show up as blank intervals in the following bar plots.

In addition, a site-wide erosion rate average can be estimated that incorporates the interval data from all sampled cores. The erosion rate for each depth interval within a core is compared to the site-wide average and a graph of the erosion rate ratios for all of the cores is created. Again, the procedure highlights the cores and depth intervals at which the most rapid erosion would be expected (relative to the other core locations), and a spatial assessment of erosion probability can be generated.

In this analysis, two interpolation techniques were used to determine values of critical shear stress: a power law interpolation and a linear interpolation. For the former, a power law curve was created (in the form of Equation 5) by solving for the variables A and n by maximizing the correlation (r^2) to the measured data points. A solution for the critical shear stress can then be computed from Equation 5 by inserting an erosion rate of 10^{-4} cm/s. For the latter, a simple linear interpolation solves for the critical shear stress at an erosion rate of 10^{-4} cm/s based on the measured Sedflume data.

Results and Discussion

Figure 2 shows a map of the coring site with the coring locations. Table 2 provides the core location, coordinates, coring date and the depth of water for the East Waterway cores.

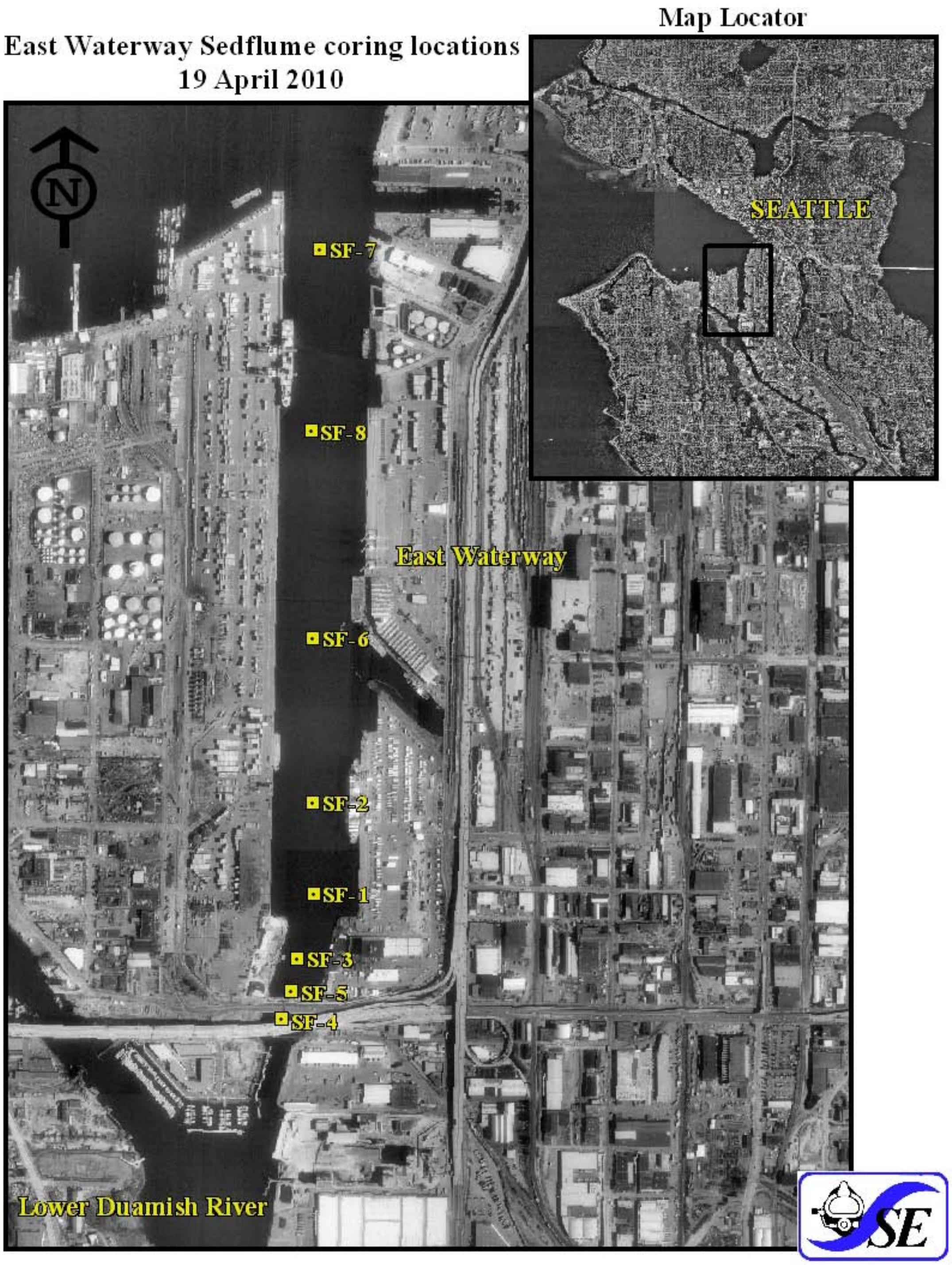

Figure 2. Map of core locations (aerial photo from seamless.usgs.gov).

Table 2. Core collection information.

Core Location	Lat (ºN)	Long (ºW)	Coring Date	Time (PDT)	Depth ft (m)*
SF-1	47.57415	122.3445	4/19/2010	12:20	46.0 (14.0)
SF-2	47.57628	122.3446	4/19/2010	10:40	48.0 (14.6)
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SF-8	47.58492	122.3449	4/19/2010	18:30	59.0 (18.0)

* Depths are measured from the water surface and are not corrected to any datum.

Core SF-1

Core SF-1 was collected in approximately 14.0 m water depth. Upon extraction, the core consisted of light brown colored, fine sediment in the top 5 cm of the core. The lighter sediment color likely indicates greater oxidation of the sediments near the surface. Some small worm tubes and organic debris were visible on the core surface upon coring implying a relatively undisturbed surface. Beneath the surface layer, dark and lighter colored silts and sandy silts were visible down-core.

During the analysis, benthic activity was observed on the surface and within the first 4 centimeters. Stringy, organic material became exposed when the surrounding finer sediments were scoured away. Several (4-6) larger worms existed to the 4 cm depth. At deeper depths, the material consisted of darker colored, silt and clayey silt, of a thicker consistency. Erosion was uneven and clumpy. A few worms were visible near a depth of 10 cm. Deeper than 15 cm of depth, the material was very difficult to erode: The highest shear stresses were applied and erosion continued to be uneven. Some organic material was observed in the material at these depths (e.g. sticks).

Figure 3 shows a photo of core SF-1 prior to the analysis aligned vertically with the measured erosion rate data. The plot shows each shear stress applied to the core, ranging from 0.1 to 10.0 Pa, as a function of depth. In order to visualize the data on a log-scale, erosion rates of zero are plotted as 1×10^{-5} cm/s on the graph. The sediment surface (depth = 0) is plotted at the top of the graph with depth into the sediments increasing down the Y-axis. Variations in erosion rate for each applied shear stress are shown. Figure 4 shows the bulk density and D_{50} (median particle size) as a function of depth.

The erosion rate data shows evidence of typical consolidated core material: the material, in general, becomes stiffer with increasing depth. At depths of approximately 10 cm and 13 cm, small lenses of easier-to-erode sediment are encountered. The median particle sizes remain relatively constant with depth, varying between 10.2 μm and 12.4 μm. The mean d50 in the core is 11.65 μm, fine silt. The bulk densities also remain relatively constant with depth, after increasing from the surface value. They ranged from 1.27

g/cm^3 to 1.41 g/cm^3, with a core average of 1.38 g/cm^3. The interpolated critical shear stresses varied down-core for both manners of computing critical shear. The lowest value computed was 0.26 Pa and the highest value computed was 0.66 Pa. The core average critical shear stresses were 0.53 Pa and 0.37 Pa for the power law and linear interpolation critical shear estimates, respectively.

Figure 5 displays the erosion susceptibility for the depth intervals in core SF-1. The bars represent the starting depth of the different intervals (shear stress cycles) within each core. The vertical dashed line denotes an average erosion rate ratio of 1 (the core average erosion rate). Ratios above this line denote intervals that are more susceptible to rapid erosion than ratios below this line. Missing bars denote data that failed to meet quality threshold criteria (i.e. power law fits that had a correlation (r^2) less than 0.80 with data were omitted). The plot shows that the first and third depth intervals are more susceptible to rapid erosion than the second and fourth intervals. This information agrees with the measured erosion rates, which showed increases in erosion rates corresponding to the same depth intervals more susceptible to rapid erosion. There is also correlation between decreasing erosion rates and depth intervals less susceptible to erosion.

Table 3 summarizes the variables resulting from the power law fit to the data in each shear stress cycle. A and n values for which the correlation was less than 0.80 are omitted. Table 4 summarizes the bulk density, D_{50}, and interpolated critical shear stresses, τ_{cr}, for specific core depths.

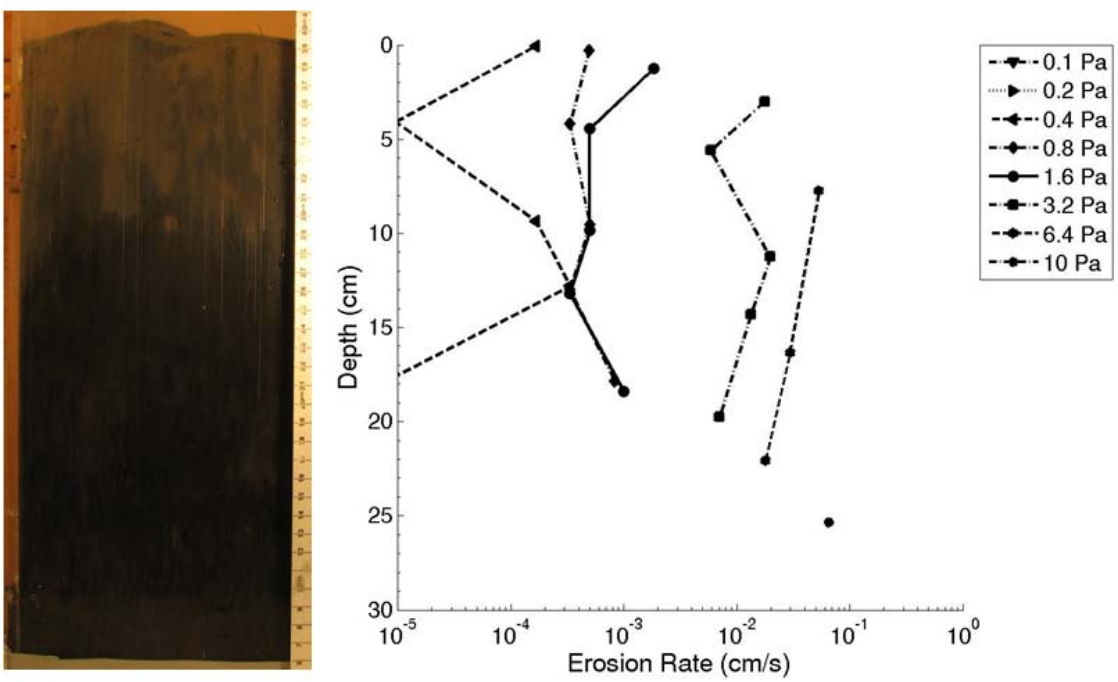

Figure 3. Picture of core SF-1 aligned with Sedflume erosion rate data.

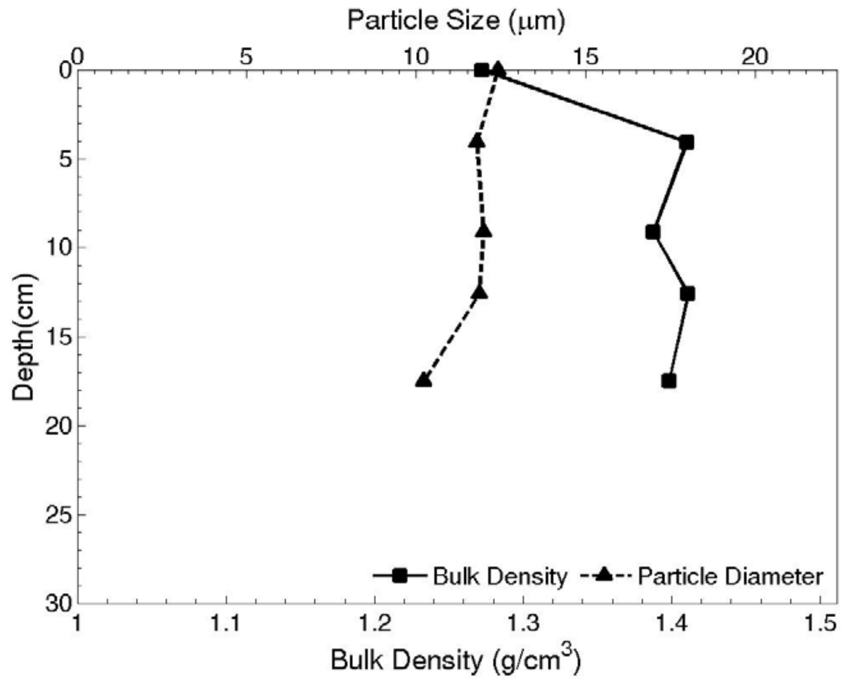

Figure 4. Bulk density and median particle size (d_{50}) with depth for core SF-1.

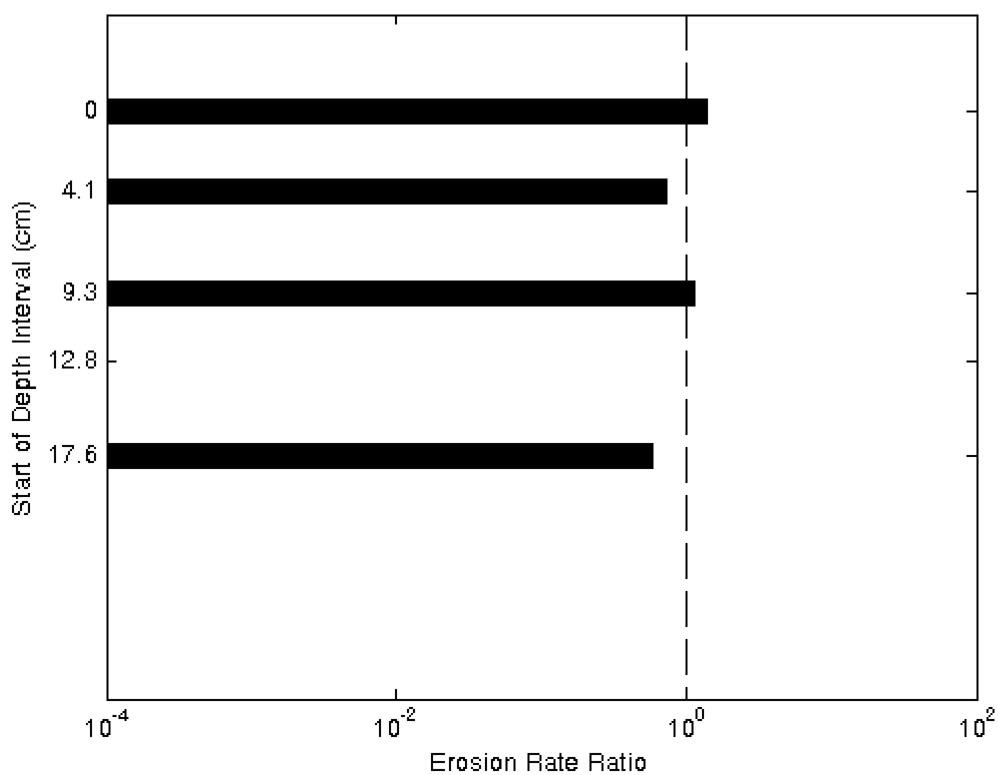

Figure 5. Intra-core erosion rate ratios for core SF-1. Dashed line is core average erosion rate.

Table 3. Power law best-fit variables for specified depth intervals in core SF-1.

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0.00	3.00	0.0009	2.25	0.96
2	4.10	7.75	0.0003	2.59	0.95
3	9.30	11.25	0.0006	2.36	0.89
4	12.80	16.35	-	-	0.79
5	17.60	25.35	0.0003	2.41	0.91

Table 4. Bulk density, $D_{50,}$ critical shear stress with depth for SF-1.

Depth (cm)	D_{50} (µm)	ρ_b (g/cm^3)	Power Law τ_{cr} (Pa)	Linear Interpolation τ_{cr} (Pa)
0.00	12.40	1.27	0.38	0.32
4.05	11.78	1.41	0.66	0.52
9.10	11.98	1.39	0.46	0.32
12.60	11.85	1.41	-	0.26
17.50	10.22	1.40	0.63	0.45
Mean	**11.65**	**1.38**	**0.53**	**0.37**

Core SF-2

Core SF-2 was collected in approximately 14.6 m water depth. Upon extraction, the core consisted of an uneven sediment surface comprising fine sediment, some small shell hash and one large worm tube (1/2 cm diameter, approximately). Down-core the color of the sediment varied between light and dark brown colored silt and sandy silt. A very stiff layer of sediment was encountered at the bottom of the core, preventing any deeper push coring.

During the analysis, a large amount of stringy organic material was encountered beneath the surface as fine particulates were scoured away. The organic material persisted until approximately 5 cm, where an easier to erode layer was encountered. Beneath this layer, fine silt and sandy silt material was observed, and a few small worms were visible to a depth of 10 cm. The material began to erode unevenly in clumps, at times pulling 2-3 cm diameter clumps of sediment upwards into the flume. Near the bottom of the core a large layer (~3cm) of sediment was dislodged upwards and plugged the flume, eliminating the undisturbed characteristics of the sediment, so the analysis was halted at this depth. The material comprised dark gray-colored clayey silt that eroded easier than layers above.

Figure 6 shows a photo of core SF-2 prior to the analysis aligned vertically with the measured erosion rate data. Figure 7 shows the bulk density and D_{50} (median particle size) as a function of depth.

The erosion rate data shows evidence of relatively consistent sediment strength characteristics with increasing depth. The erosion rates remain relatively constant down-core, but increase by two orders of magnitude deeper than 20 cm. The reason for this sharp increase in erosion rate is uncertain as the bulk densities and median particle sizes remain relatively constant down-core. The mean d50 in the core is 21.4 µm, fine silt, and ranges between 15.1 µm and 27.2 µm. The bulk densities ranged from a surface value of 1.27 g/cm^3 to 1.57 g/cm^3, with a core average of 1.47 g/cm^3.

The interpolated critical shear stresses increased, in general, down to the final depth interval, where the critical shear stresses decreased when the sediment became easier to erode. The surface critical shear stresses were 0.42 Pa and 0.26 Pa for the power law interpolation and linear interpolation, respectively. The highest critical shear stresses were 1.21 Pa and 1.28 Pa for each, at a depth of approximately 15 cm. The mean values of the critical shear stresses in the core were similar, 0.81 Pa and 0.72 Pa, for the power law and linear interpolations, respectively.

Figure 8 displays the erosion susceptibility for the depth intervals in core SF-2. The plot shows that, relative to the core average erosion rate, the deepest depth interval is more susceptible to rapid erosion than the shallower four intervals. These results correspond to the erosion rate plot in which the down-core erosion rates were relatively constant until the deepest interval, which showed a 2 order of magnitude increase in erosion rates.

Table 5 summarizes the variables resulting from the power law fit to the data in each shear stress cycle. Shear stress cycles for which only two applied shear stresses existed (i.e. $r^2 = 1.00$) are omitted from the table. Table 6 summarizes the bulk density, D_{50}, and interpolated critical shear stresses, τ_{cr}, for specific core depths.

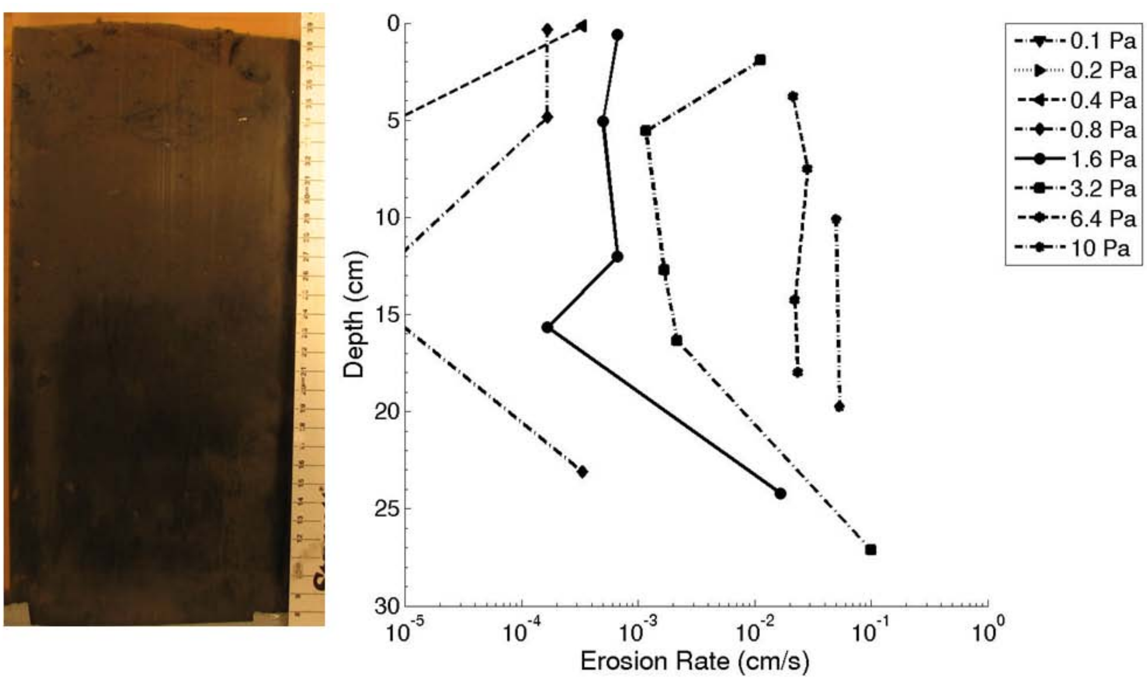

Figure 6. Picture of core SF-2 aligned with Sedflume erosion rate data.

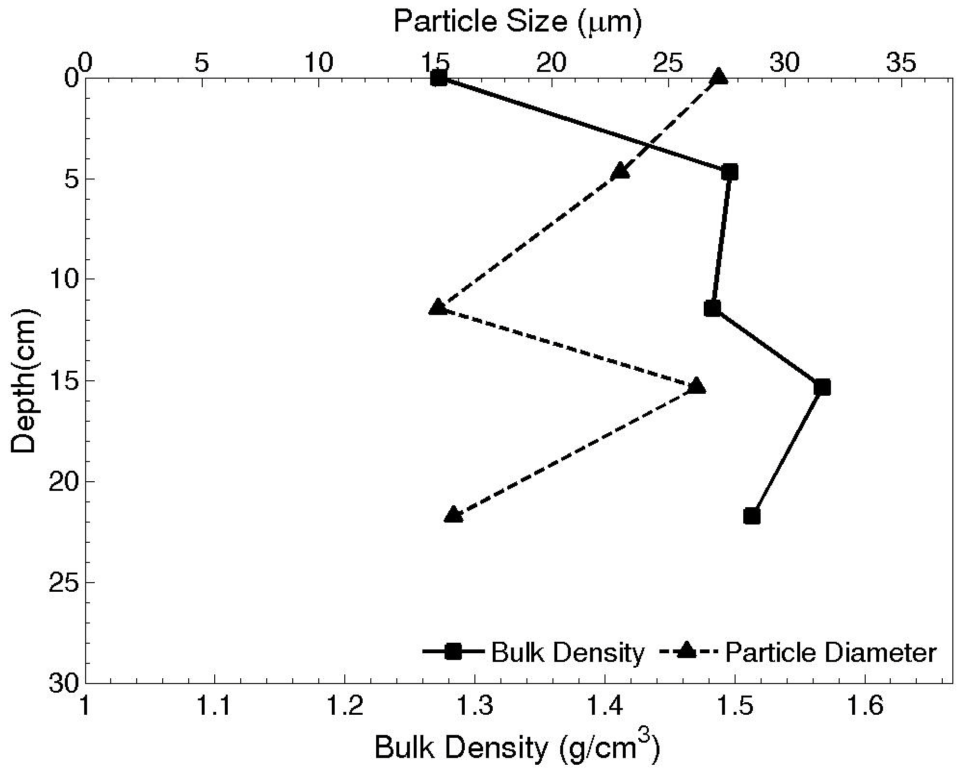

Figure 7. Bulk density and D_{50} with depth for core SF-2.

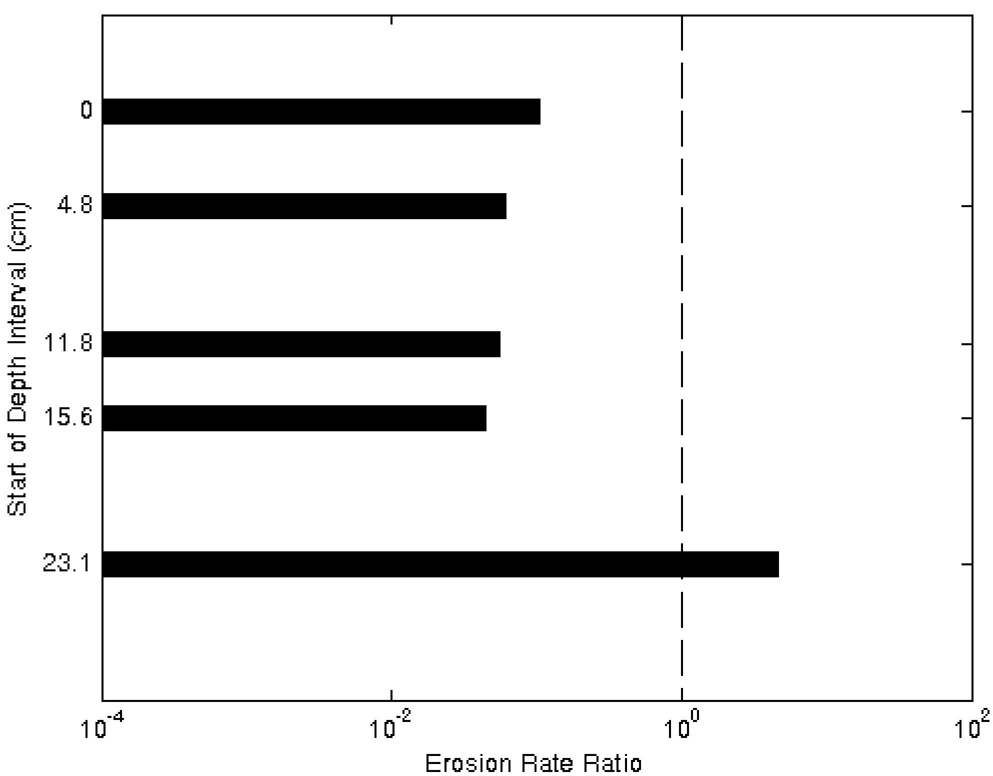

Figure 8. Intra-core erosion rate ratios for core SF-2.

Table 5. Power law best-fit variables for specified depth intervals in core SF-2.

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0.00	3.80	0.0006	1.96	0.92
2	4.80	10.10	0.0002	2.34	0.96
3	11.80	14.25	0.0001	2.98	0.93
4	15.60	19.75	0.0001	3.01	0.96
5	23.10	27.10	0.0012	4.11	0.96

Table 6. Bulk density, $D_{50,}$ critical shear stress with depth for SF-2.

Depth (cm)	D_{50} (μm)	ρ_b (g/cm^3)	Power Law τ_{cr} (Pa)	Linear Interpolation τ_{cr} (Pa)
0.00	27.17	1.27	0.42	0.26
4.70	22.93	1.50	0.75	0.64
11.45	15.12	1.48	1.11	0.92
15.35	26.21	1.57	1.21	1.28
21.75	15.78	1.51	0.55	0.52
Mean	**21.44**	**1.47**	**0.81**	**0.72**

Core SF-3

Core SF-3 was collected in approximately 9.8 m water depth. Upon extraction, the core consisted of an undisturbed sediment surface comprising small surface debris (e.g. small twigs) and approximately 1 cm of light brown and orange colored fine sediment. Beneath the surface layer, light and dark-colored brown silt and sandy silt were observed down-core. Near the bottom of the core, some woody debris was visible in the material.

During the analysis, small pebbles (~1 cm diameter) were observed within the top 5 cm. Some worms and stringy organic material became visible in this layer as well, as the finer particulates were eroded. Beneath this layer, fine silt material was mixed with coarser sandy material and a few larger pebble sized sediment. Two to 3 pebbles were removed from the flume manually as they were too large to be eroded by the flow, and were causing uneven scouring of the finer material around their perimeters. Near depths greater than 16 cm, a large amount of woody debris and organic detritus was encountered. The surrounding dark clayey-silt eroded in clumps, and became easier to erode as depths increased further.

Figure 9 shows a photo of core SF-3 prior to the analysis aligned vertically with the measured erosion rate data. Figure 10 shows the bulk density and D_{50} (median particle size) as a function of depth.

The erosion rate data shows evidence of easier-to-erode sediment with increasing depth, which is not typical of consolidated core material. The erosion rates remain relatively constant down-core until a depth of approximately 10 cm, where the increasing erosion rate trend begins. The median particle size down-core does not fluctuate greatly, varying between 10.0 μm and 12.8 μm. The mean particle size in the core is 11.5 μm. The bulk densities varied down-core, increasing from a surface value of 1.41 g/cm^3 to 1.59 g/cm^3 before decreasing to 1.32 g/cm^3. The mean bulk density in the core is 1.44 g/cm^3.

The interpolated critical shear stresses increase from the surface value to a maximum at a depth of 10 cm; then they decrease to the bottom of the core. The surface values are 0.44 Pa and 0.32 Pa for the power law and linear interpolation, respectively. The maximum values are 0.97 Pa and 0.85 Pa. At the deepest depths, the values are approximately 0.25 Pa for each. The core average values are 0.55 Pa and 0.44 Pa, for the power law and linear interpolations, respectively.

Figure 11 displays the erosion susceptibility for the depth intervals in core SF-3. The plot shows that, relative to the core average erosion rate, the deepest depth interval is more susceptible to rapid erosion than the shallower four intervals. These results correspond to the erosion rate plot in which the down-core erosion rates showed a general down-core trend of increasing erosion rates. The deepest interval is also the location at which the lowest critical shear stresses were computed, implying more susceptibility to rapid erosion.

Table 7 summarizes the variables resulting from the power law fit to the data in each shear stress cycle. Shear stress cycles for which only two applied shear stresses existed (i.e. $r^2 = 1.00$) are omitted from the table. Table 8 summarizes the bulk density, D_{50}, and interpolated critical shear stresses, τ_{cr}, for specific core depths.

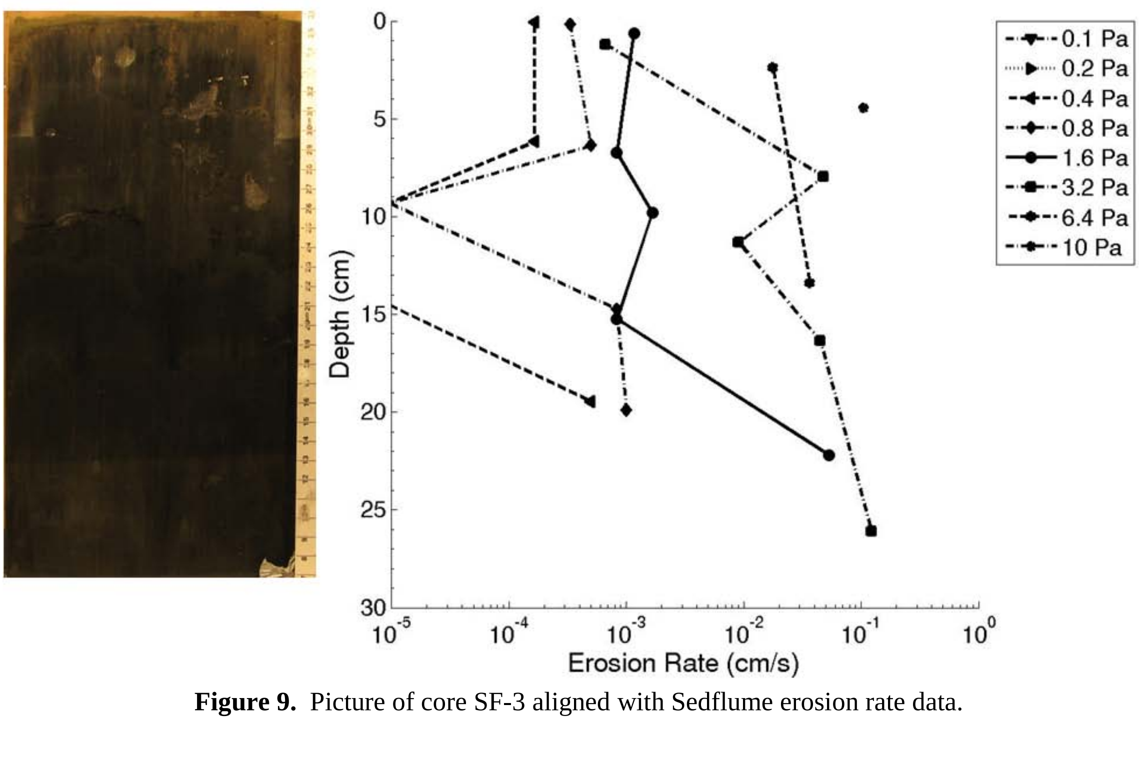

Figure 9. Picture of core SF-3 aligned with Sedflume erosion rate data.

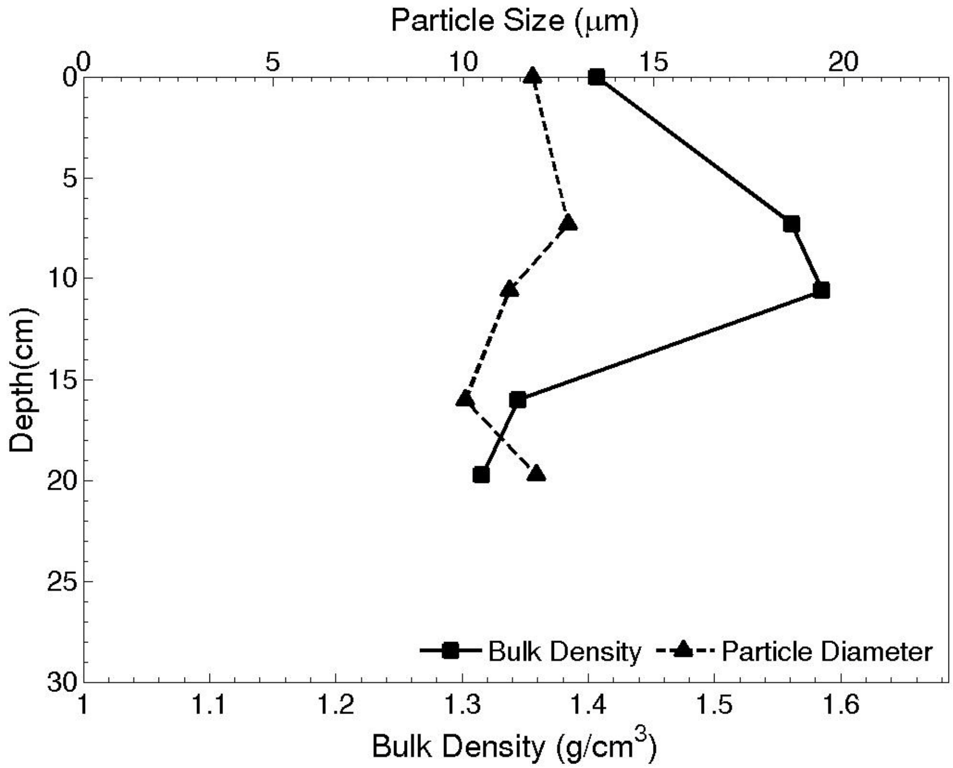

Figure 10. Bulk density and D_{50} with depth for core SF-3.

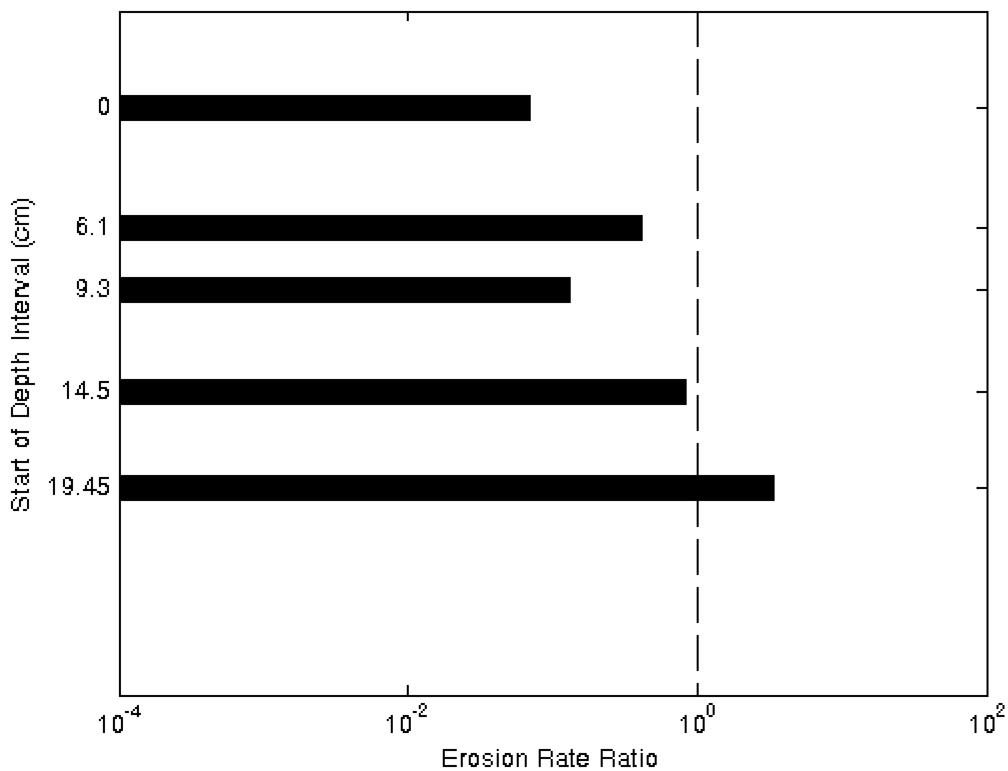

Figure 11. Intra-core erosion rate ratios for core SF-3.

Table 7. Power law best-fit variables for specified depth intervals in core SF-3.

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0.00	4.45	0.0005	1.90	0.92
2	6.10	7.95	0.0009	2.69	0.92
3	9.30	13.40	0.0001	3.37	0.92
4	14.50	16.35	0.0005	3.66	0.90
5	19.45	26.10	0.0053	2.95	0.91

Table 8. Bulk density, D_{50}, critical shear stress with depth for SF-3.

Depth (cm)	D_{50} (μm)	ρ_b (g/cm^3)	Power Law τ_{cr} (Pa)	Linear Interpolation τ_{cr} (Pa)
0.00	11.82	1.41	0.45	0.32
7.30	12.75	1.56	0.44	0.32
10.60	11.20	1.59	0.97	0.85
16.00	10.04	1.34	0.66	0.45
19.75	11.91	1.32	0.26	0.24
Mean	**11.54**	**1.44**	**0.55**	**0.44**

Core SF-4

Core SF-4 was collected in approximately 2.3 m water depth. The core was collected from a very shallow area beneath the bridges connecting Seattle to Harbor Island and West Seattle (West Seattle Bridge). It was difficult to collect a large amount of sediment in the core at this location because the material composition was very prohibitive. The core was driven to refusal several times, to the extent of causing the coring apparatus to lift itself off the bed. Upon extraction, the core consisted of an undisturbed sediment surface comprising 5 cm of fine, lighter-colored sediments. Below the surface layer, shell hash and coarser sands were visible mixed in with silts. At the bottom of the core, a visible fine to medium sand layer (2-4 cm thick) was observed, likely the material which prevented a deeper core from being extracted.

During the analysis, some red-colored grass was visible within the surface layer, which acted to withstand erosion and hold particles together. Small benthic organisms and small worms were visible. Below the top 1 cm, 6-8 ½-cm diameter worm tubes were observed, approximately 2 cm in length. Within the top 5 cm of sediment, shell pieces and hash were observed eroding as well as a large amount of organic detritus. Erosion was clumpy near the top of the core due to the organic material that added strength to the sediment. Deeper than 5 cm, the organic debris persisted, several large sticks were observed (3-5 cm in length) along with several large worms (3-5 cm in length) mixed in with sandy and silty material. A seemingly more difficult-to-erode layer was encountered near depths of 7-13 cm, with erosion rates increasing deeper than this. At depths deeper than 13 cm, the material contained silt and sand as well as a large amount of wood pieces that required manual removal. Large worms were still observed in the sediment at these depths as well as the red-colored grass and shell pieces. The material at this depth contained striations of stiff material and easier-to-erode sands. The erosion was very uneven, eroding the center of the core faster than the sides.

Figure 12 shows a photo of core SF-4 prior to the analysis aligned vertically with the measured erosion rate data. Figure 13 shows the bulk density and D_{50} (median particle size) as a function of depth.

The erosion rate data shows evidence of typical consolidated core material: the material, though variable down-core, generally becomes stiffer with increasing depth. A more difficult-to-erode layer was encountered near depths of 7-13 cm, resulting in the application of higher shear stresses. Deeper than this, however, the material becomes slightly easier to erode due to the rapid erosive characteristics of sand versus clayey silt. The median particle size down-core varies between 12.5 μm and 35.5 μm, with a core mean value of 21.0 μm. The bulk densities generally increased with depth from 1.36 g/cm^3 to 1.52 g/cm^3. The mean bulk density in the core is 1.46 g/cm^3.

The interpolated critical shear stresses were lowest on the surface (0.11 Pa) and increased with depth to the maximum value of 0.46 Pa. This corresponds well to the general decrease of erosion rate with depth. This core exhibits typical signs of consolidated core material at deeper depths. The mean critical shear stress value for the core was 0.24 Pa. The only valid manner used to compute critical shear stress for core SF-4 was linear interpolation because a power law fit of good correlation was not possible for any of the depth intervals. All r^2 values were less than the quality threshold criteria of 0.80. Therefore, there is no erosion susceptibility plot for core SF-4.

Table 9 summarizes the variables resulting from the power law fit to the data in each shear stress cycle. Shear stress cycles for which only two applied shear stresses existed (i.e. $r^2 = 1.00$) are omitted from the table. Table 10 summarizes the bulk density, D_{50}, and interpolated critical shear stresses, τ_{cr}, for specific core depths.

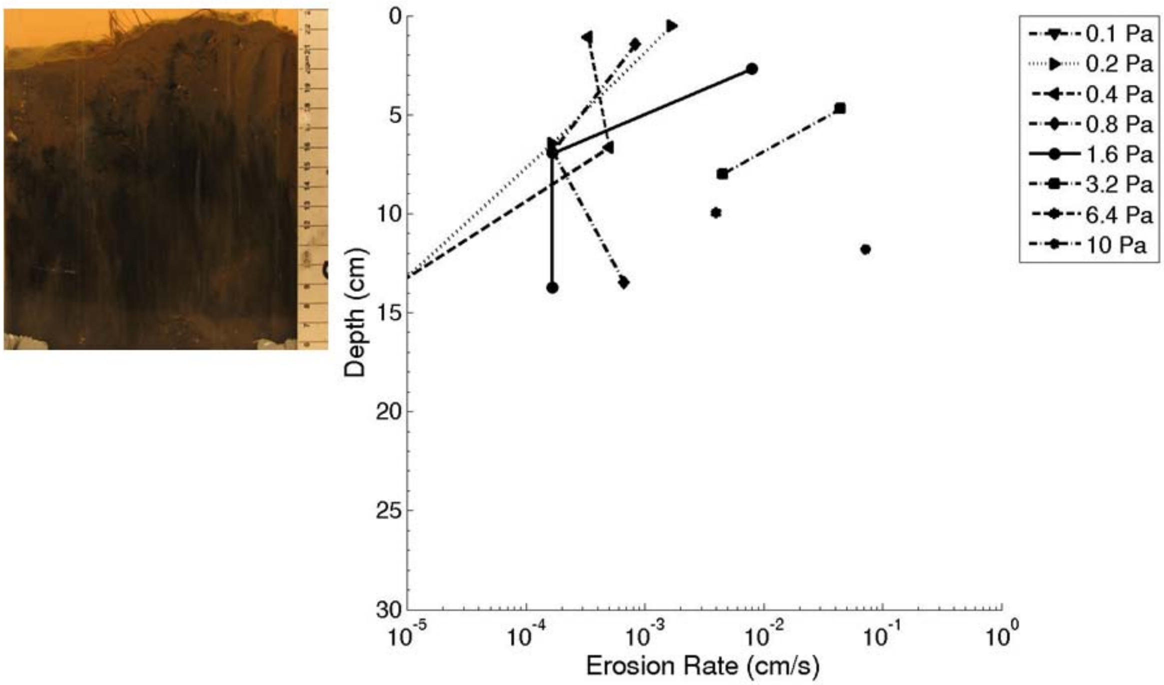

Figure 12. Picture of core SF-4 aligned with Sedflume erosion rate data.

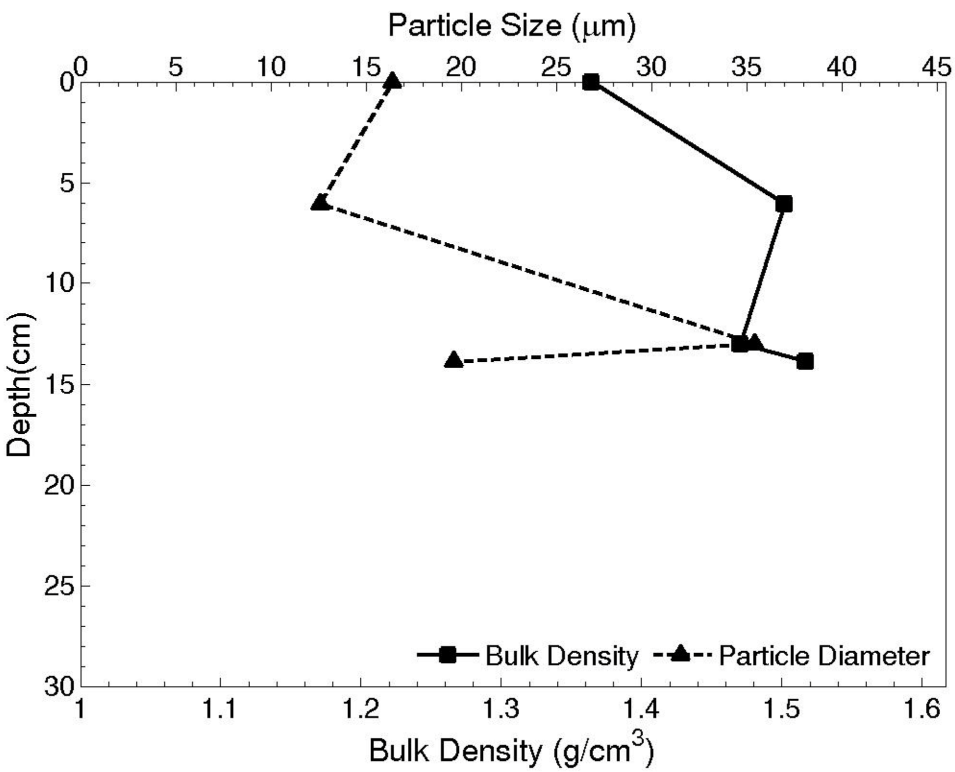

Figure 13. Bulk density and D_{50} with depth for core SF-4.

Table 9. Power law best-fit variables for specified depth intervals in core SF-4.

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0	4.7	-	-	0.78
2	6.45	11.8	-	-	0.69
3	13.3	13.75	-	-	0.61

Table 10. Bulk density, $D_{50,}$ critical shear stress with depth for SF-4.

Depth (cm)	D_{50} (μm)	ρ_b (g/cm^3)	Power Law τ_{cr} (Pa)	Linear Interpolation τ_{cr} (Pa)
0	16.38	1.36	-	0.11
6.05	12.58	1.50	-	0.16
13	35.45	1.47	-	0.46
13.9	19.64	1.52	-	-
Mean	**21.01**	**1.46**	**-**	**0.24**

Core SF-5

Core SF-5 was collected in approximately 5.2 m water depth. The core was collected from a relatively shallow region immediately north of the Harbor Island and West Seattle bridges. It was difficult to collect a large amount of sediment in the core at this location because the material composition was, again, very prohibitive. The core was driven to refusal twice with the subsequent extracted depth similar to the first. Upon extraction, the core consisted of an undisturbed sediment surface comprising 1-2 cm of fine, lighter-colored sediments. Below the surface layer, fine to medium sands were visible mixed with silts. At the bottom of the core, a darker colored material was observed, likely the material which prevented a deeper core from being extracted.

During the analysis, many (20-30) 1 cm to 2 cm long, small diameter worms were observed on the surface. There was one clump of organic material that was removed from the surface before the analysis began. The clump was approximately 3 cm in diameter and was loosely resting on the surface. It was removed so it would not negatively impact the measured erosion rates of the surrounding fine sediments. The top 1 cm of sediment was difficult to erode because the organic material and benthic organisms added strength to the sediment. Deeper than 1 cm, organic detritus was observed with several long worms. The erosion became uneven as organic material eroded from certain locations, but not others. Deeper than 4 cm, the material is comprised of silts, sandy silts and organic material. The erosion was clumpy and uneven. Deeper than 7 cm, the material was a stiff, dark-colored silt, clayey silt and sandy silt, with highly variable erosion. A large erosion hole formed in the core due to the existence of an easier-to-erode layer of sandy-silt. The hole caused erosion down to the bottom of the core material. The test was halted when this occurred and a new layer composition (sandier silt) was encountered.

Figure 14 shows a photo of core SF-5 prior to the analysis aligned vertically with the measured erosion rate data. Figure 15 shows the bulk density and D_{50} (median particle size) as a function of depth.

The erosion rate data shows evidence of wide variation in erosion rates down-core. Beneath the surface, the erosion rates fluctuate between easier- and more difficult-to-erode with each new layer encountered. The median particle size down-core varies between 14.5 μm and 33.1 μm, with a core mean value of 23.9 μm. The bulk densities vary with depth from 1.42 g/cm^3 to 1.68 g/cm^3. The mean bulk density in the core is 1.53 g/cm^3. The interpolated critical shear stresses show a general increase with depth into the core. The surface values are 0.43 Pa and 0.26 Pa for the power law and linear interpolations, respectively. The maximum values were near the deepest part of the core and were 0.68 Pa and 0.52 Pa. The mean core values are 0.54 Pa and 0.38 Pa for the power law and linear interpolations, respectively.

Figure 16 displays the erosion susceptibility for the depth intervals in core SF-5. Table 11 summarizes the variables resulting from the power law fit to the data in each shear stress cycle. Shear stress cycles for which only two applied shear stresses existed (i.e. $r^2 = 1.00$) are omitted from the table. Table 12 summarizes the bulk density, D_{50}, and interpolated critical shear stresses, τ_{cr}, for specific core depths.

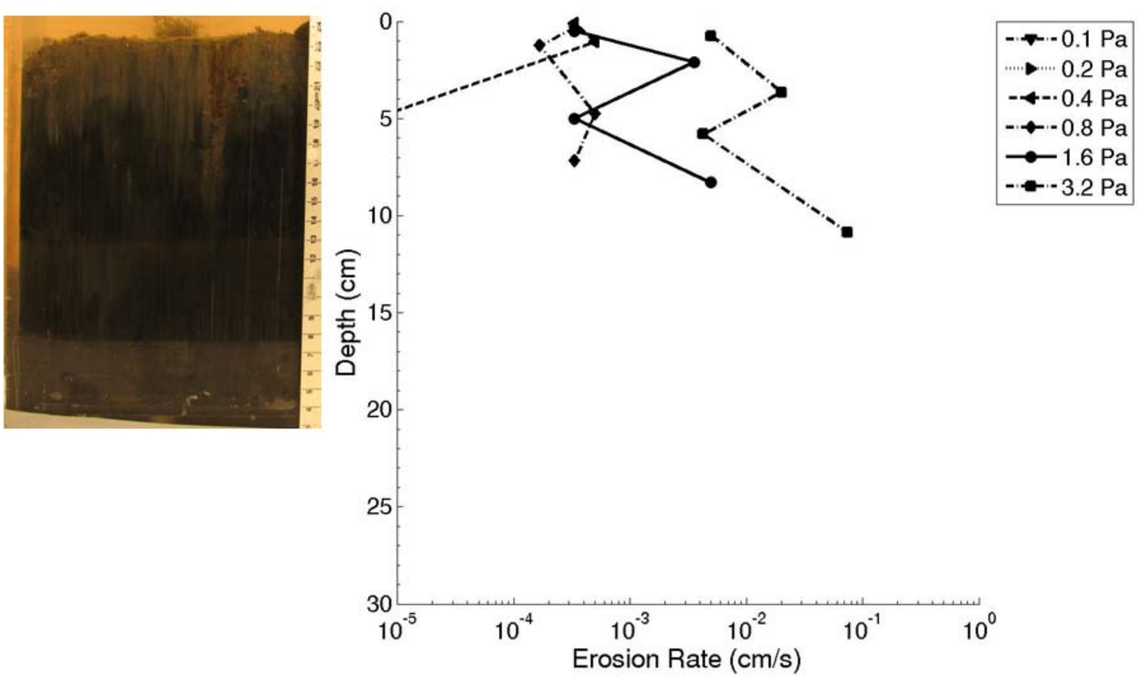

Figure 14. Picture of core SF-5 aligned with Sedflume erosion rate data.

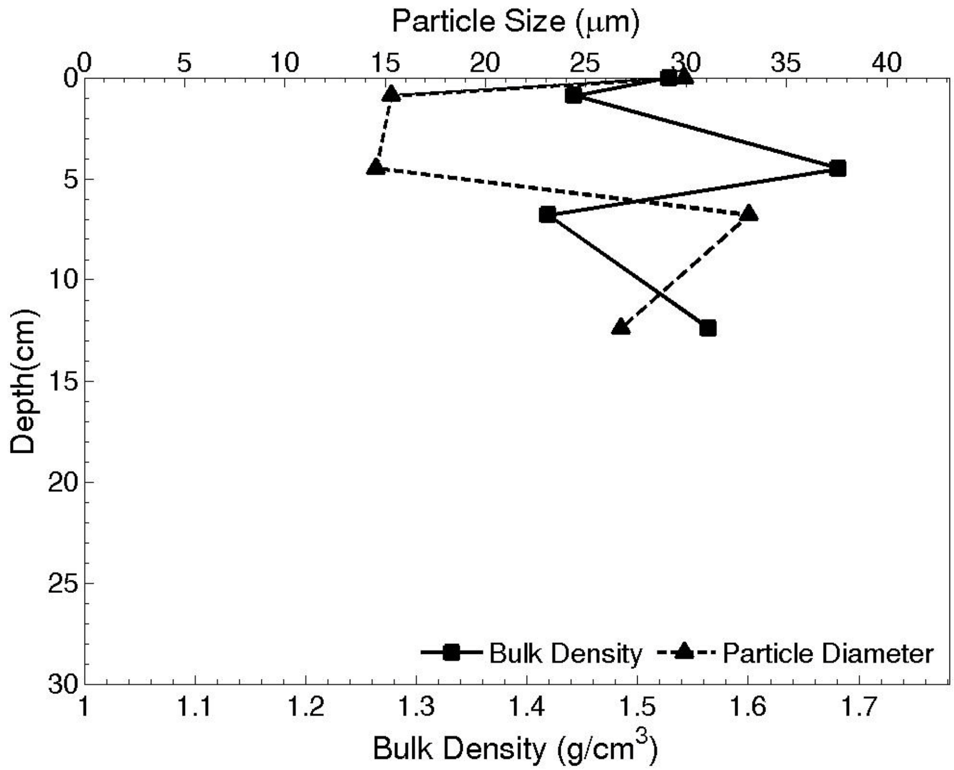

Figure 15. Bulk density and D_{50} with depth for core SF-5.

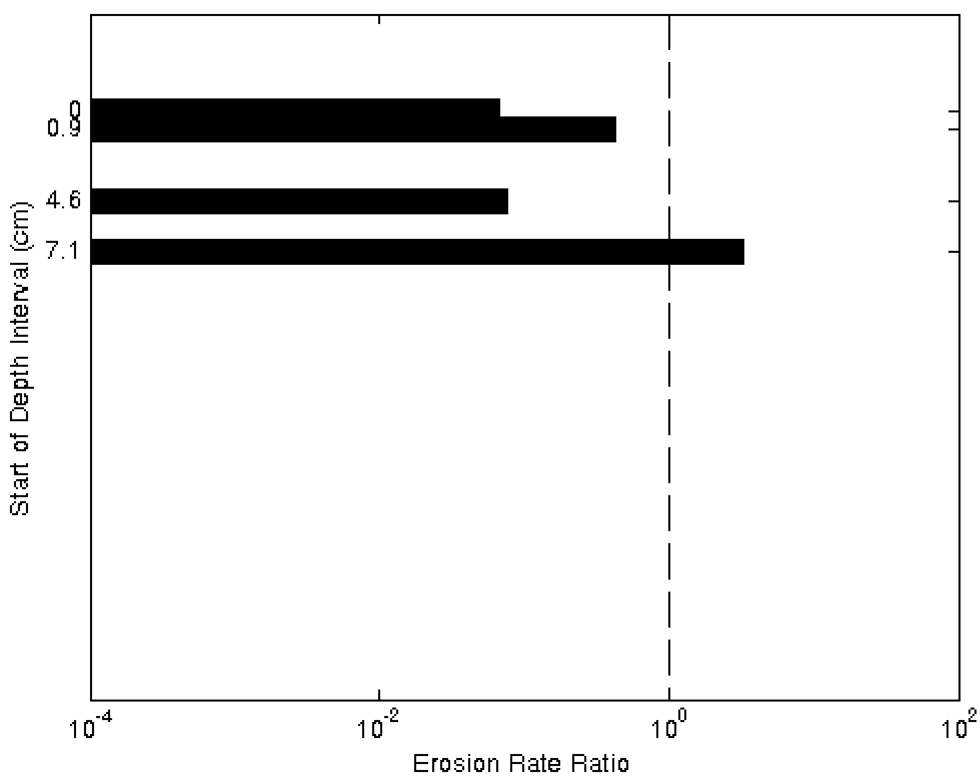

Figure 16. Intra-core erosion rate ratios for core SF-5.

Table 11. Power law best-fit variables for specified depth intervals in core SF-5.

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0.00	0.75	0.0004	1.73	0.86
2	0.90	3.65	0.0010	2.49	0.87
3	4.60	5.80	0.0002	2.27	0.87
4	7.10	10.85	0.0006	4.27	0.99

Table 12. Bulk density, $D_{50,}$ critical shear stress with depth for SF-5.

Depth (cm)	D_{50} (µm)	ρ_b (g/cm^3)	Power Law τ_{cr} (Pa)	Linear Interpolation τ_{cr} (Pa)
0.00	29.93	1.53	0.43	0.26
0.90	15.30	1.44	0.40	0.24
4.50	14.54	1.68	0.68	0.48
6.80	33.11	1.42	0.65	0.52
12.40	26.76	1.56	-	-
Mean	**23.93**	**1.53**	**0.54**	**0.38**

Core SF-6

Core SF-6 was collected in approximately 15.8 m water depth. The core was collected from a central waterway location, approximately midway between the West Seattle Bridge to the south and the waterway mouth to the north. Upon extraction, the core consisted of an undisturbed, uneven sediment surface comprising benthic organisms and worms over 5 cm of silt and fine sand. Beneath the surface layer a 5-6 cm layer of fine to medium sand and shell hash was clearly visible. Below the sand lens, the sediments comprised darker-colored silty material.

During the analysis, some organic detritus and fine stringy organic material was observed when the fine particulates were scoured away. The material eroded in particulates and small clumps down to a depth of 7 cm. At this depth, the fine to medium sand was encountered and persisted to a depth of 15 cm, when a more difficult-to-erode clayey-silt and sandy silt layer was encountered. Deeper than 15 cm, the material was a more difficult-to-erode composition.

Figure 17 shows a photo of core SF-6 prior to the analysis aligned vertically with the measured erosion rate data. Figure 18 shows the bulk density and D_{50} (median particle size) as a function of depth.

The erosion rate data shows variation in erosion rates down-core as a result of different material consistencies. The erosion rates increased when the fine to medium sand layer was encountered and at the very bottom of the core, when clumpy erosion caused larger amounts of sediment to be removed. The sediments collected from the sandy layer were required to be passed through a 2000 sieve before processing with the particle laser diffractor. The sediment sample contained approximately 4% by weight of sediment larger than 2000 um. The material sieved out at this size was mostly shell fragments and shell hash. The remaining samples in the core contained sediments that were smaller than 2000 um.

At layers in between the sandy layer and the bottom of the core, the material is stiffer and more difficult-to-erode, resulting in relatively lower erosion rates. The median particle size in the core varied from sandy silt (59.6 μm) at the surface to fine sand immediately below (106.90 μm) down to fine silt near the bottom (12.8 μm). The mean d_{50} in the core is 42.5 μm. The bulk densities varied between 1.50 g/cm^3 and 1.94 g/cm^3. The mean bulk density in the core is 1.64 g/cm^3. The interpolated critical shear stresses were lowest on the surface and in the first layer below the surface, where the sediment type was a coarser material (sand) than other layers. The minimum critical shear stresses in these tope two layers was 0.36 Pa and 0.32 Pa for the power law and linear interpolations, respectively. The highest shear stresses were 1.93 Pa and 1.92 Pa, respectively, near depths of 15 cm. Deeper than 20 cm, the critical shear stresses were slightly lower (1.29 Pa and 1.04 Pa, respectively). The mean values of the critical shear stresses in the core are 1.03 Pa and 0.90 Pa, for the power law and linear interpolations, respectively.

Figure 19 displays the erosion susceptibility for the depth intervals in core SF-6. The plot shows a high susceptibility to rapid erosion at a depth of 7 cm, which is where the coarse sandy material was observed and measured. This is easily understood since the coarser material is less cohesive and requires less shear stress to initiate motion. If the sandier layer is not considered, then the remaining depth intervals are relatively similar in erosion susceptibility. The fourth depth interval is least susceptible. This is the location of the highest critical shear stresses and corresponds to a decrease in measured erosion rate.

Table 13 summarizes the variables resulting from the power law fit to the data in each shear stress cycle. Shear stress cycles for which only two applied shear stresses existed (i.e. $r^2 = 1.00$) are omitted from the table. Table 14 summarizes the bulk density, D_{50}, and interpolated critical shear stresses, τ_{cr}, for specific core depths.

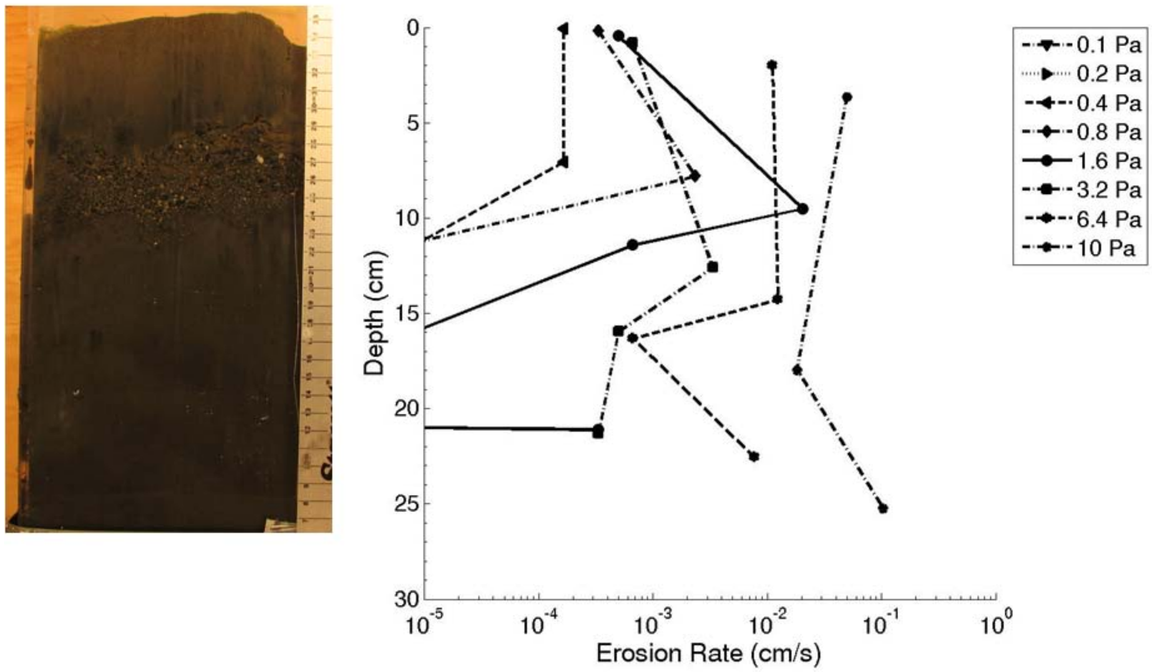

Figure 17. Picture of core SF-6 aligned with Sedflume erosion rate data.

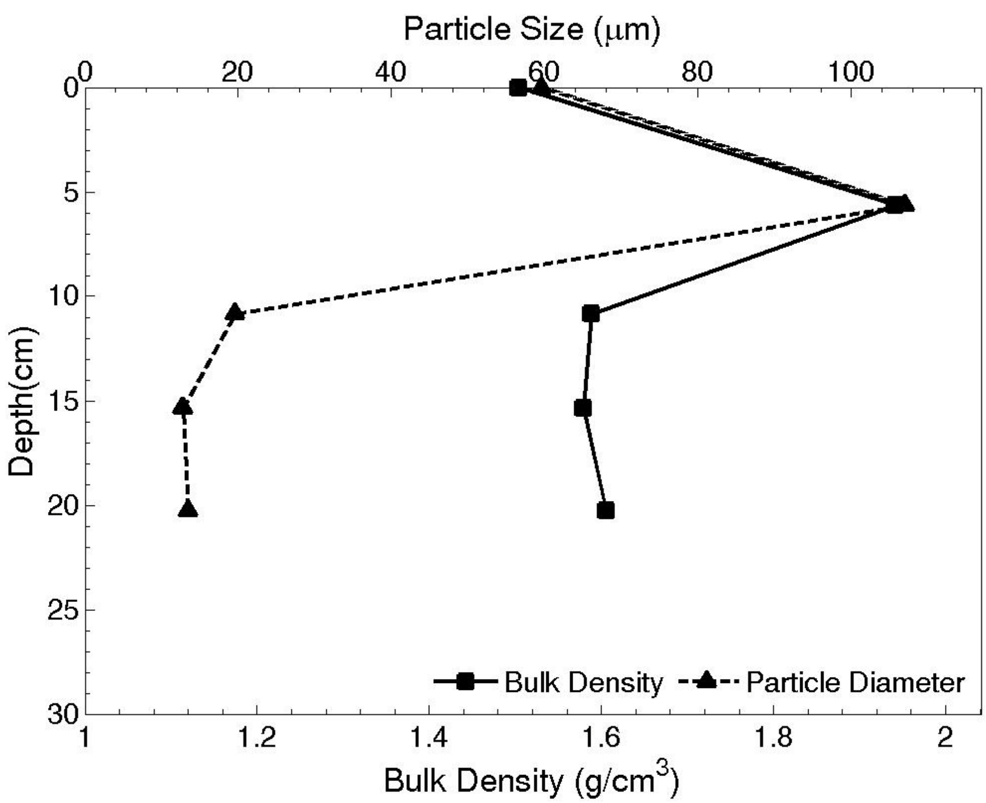

Figure 18. Bulk density and D_{50} with depth for core SF-6.

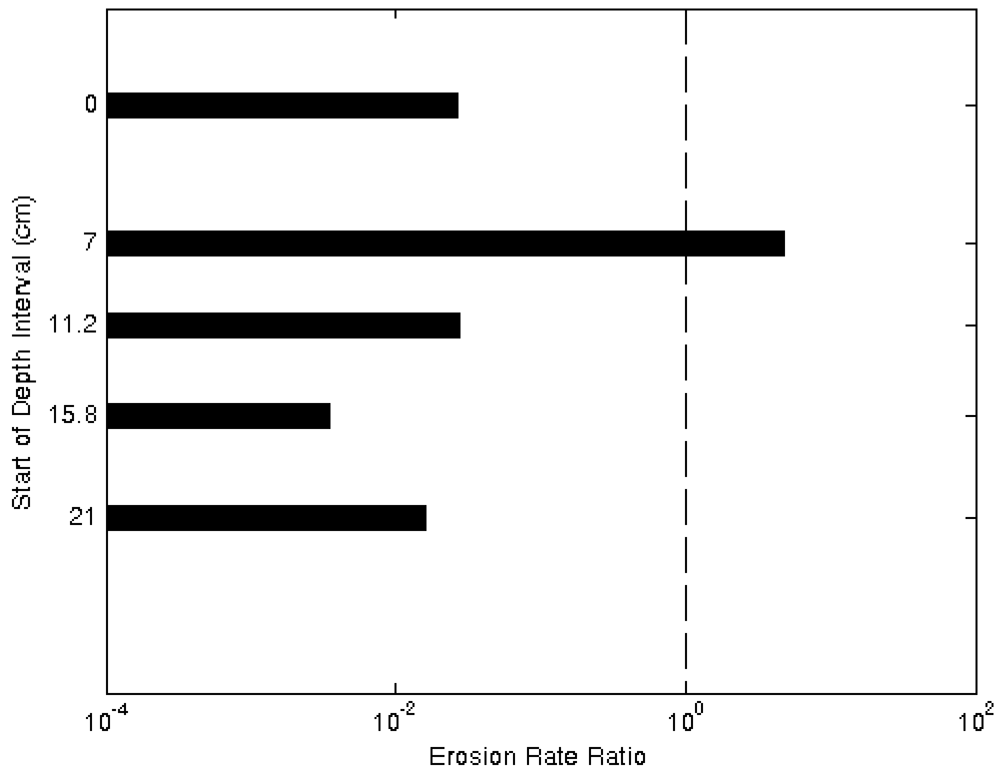

Figure 19. Intra-core erosion rate ratios for core SF-6.

Table 13. Power law best-fit variables for specified depth intervals in core SF-6.

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0.00	3.65	0.0004	1.76	0.93
2	7.00	9.50	0.0043	3.70	1.00
3	11.20	14.25	0.0001	2.92	0.93
4	15.80	18.00	0.0000	2.33	0.83
5	21.00	25.25	0.0000	2.86	0.92

Table 14. Bulk density, $D_{50,}$ critical shear stress with depth for SF-6.

Depth (cm)	D_{50} (μm)	ρ_b (g/cm^3)	Power Law τ_{cr} (Pa)	Linear Interpolation τ_{cr} (Pa)
0.00	59.60	1.50	0.49	0.32
5.65	106.90	1.94	0.36	0.32
10.85	19.57	1.59	1.10	0.92
15.35	12.81	1.58	1.93	1.92
20.25	13.48	1.61	1.29	1.04
Mean	**42.47**	**1.64**	**1.03**	**0.90**

Core SF-7

Core SF-7 was collected in approximately 17.4 m water depth. The core was collected near the mouth of the East Waterway. This core required 5 attempts to extract a sufficient core. The first two attempts resulted in insufficient material recovery. The third attempt resulted in a cracked core due to the stiffness of the bottom material. The fourth attempt returned a cobble-sized piece of cinder block material in the core. Upon extracting the final core, it consisted of an uneven, undisturbed, 2-3 cm sandy silt layer with some shell hash and organic detritus. Below this layer was a darker-colored stiff appearing, silty material. The core material extracted was less than preferred for this analysis; however, this recovery was the best of five attempts and was limited by the stiff bottom sediment characteristics.

During the analysis, several worms and worm tubes were observed on the surface layer. One large vertical worm was removed from the material manually prior to the analysis so that it did not have any negative impacts on the measured erosion rates of the sediments. In addition, a 3-4 cm piece of gravel was removed prior to the analysis. An easier-to-erode surface layer gave way to veins of a stiffer layer below, which resulted in uneven erosion. The sediment consistency beneath the surface was stiff, clayey-silt, which tended to erode in clumps. Worms were observed throughout the core material.

Figure 20 shows a photo of core SF-7 prior to the analysis aligned vertically with the measured erosion rate data.Figure 21 shows the bulk density and D_{50} (median particle size) as a function of depth.

The erosion rate data shows a general increase in erosion rate near a depth of 5 cm before becoming more difficult to erode at depths deeper than approximately 8 cm. The median particle size in the core was in the range of sandy silt (53.9 μm) to fine sand (86.1 μm) until a depth of 15 cm, where the material d_{50} was fine silt (22.4 μm). The mean d_{50} in the core is 55.5 μm (sandy silt). The bulk densities increased, in general, with depth from 1.61 g/cm^3 to 1.81 g/cm^3. The mean bulk density in the core is 1.72 g/cm^3. The interpolated critical shear stresses were lowest on the surface and increased with depth, typical of consolidated core material. The surface critical shear stresses were 0.34 Pa and 0.24 Pa for the power law and linear interpolations, respectively. The maximum critical shear stresses near the bottom of the cored material were 0.68 Pa and 0.52 Pa. The mean values of the critical shear stresses in the core are 0.47 N/m^2 and 0.36 N/m^2, for the power law and linear interpolations, respectively.

Figure 22 displays the erosion susceptibility for the depth intervals in core SF-7. The plot shows that the 5 cm depth interval is more susceptible to rapid erosion than the surface and deeper interval, which agrees with the measured erosion rate data.

Table 15 summarizes the variables resulting from the power law fit to the data in each shear stress cycle. Shear stress cycles for which only two applied shear stresses existed (i.e. $r^2 = 1.00$) are omitted from the table. Table 16 summarizes the bulk density, D_{50}, and interpolated critical shear stresses, τ_{cr}, for specific core depths.

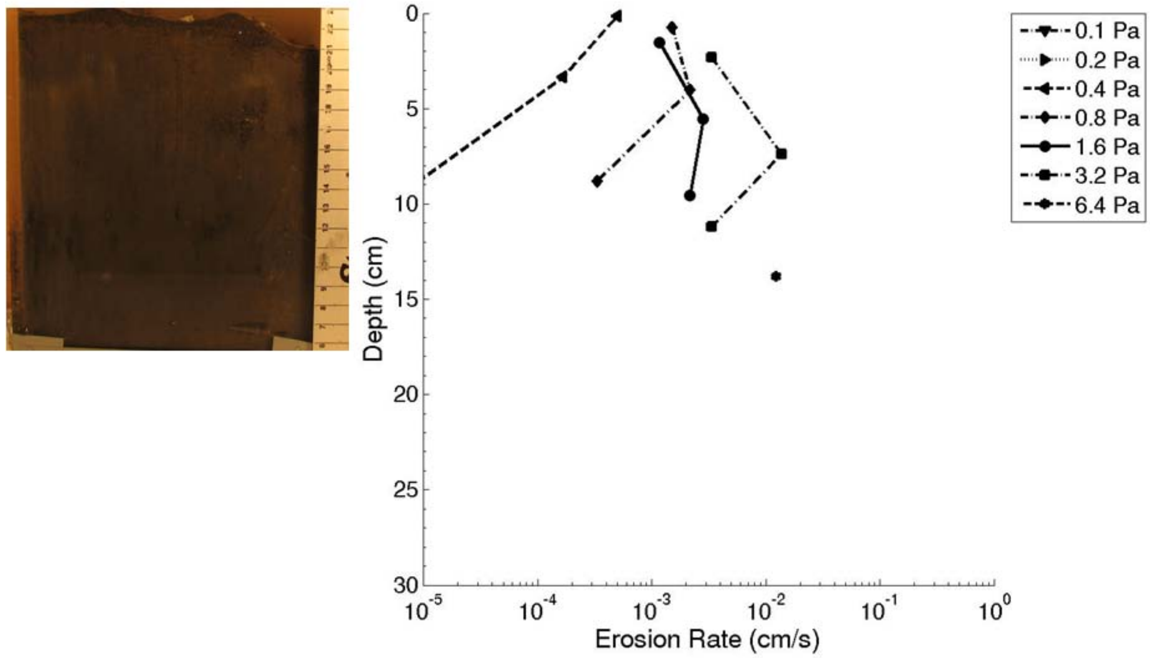

Figure 20. Picture of core SF-7 aligned with Sedflume erosion rate data.

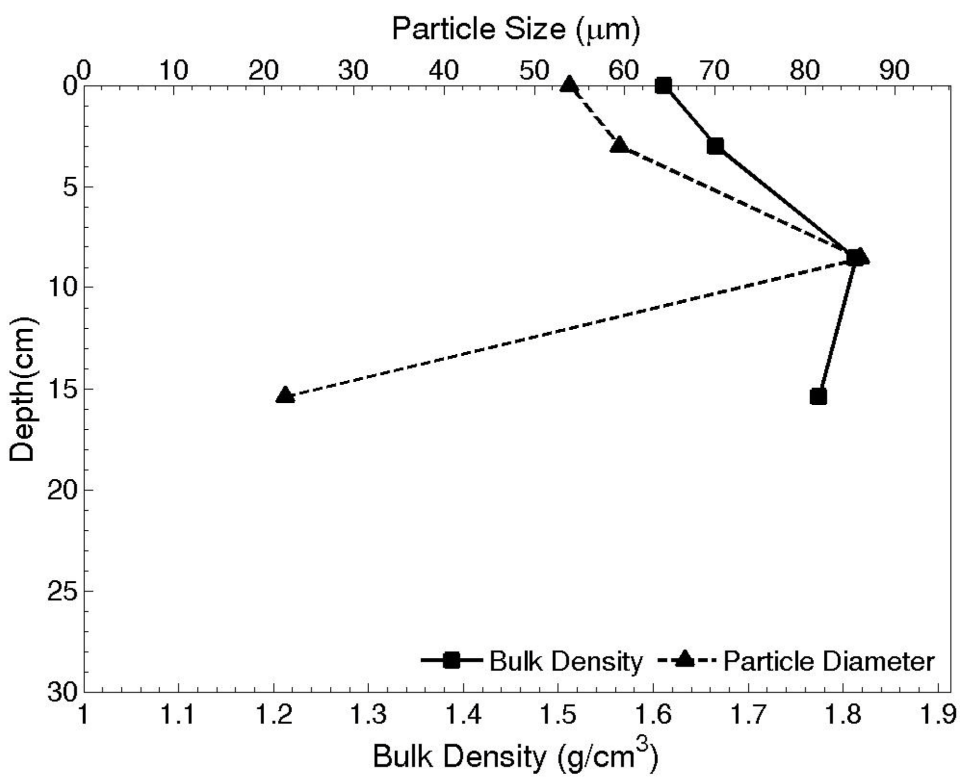

Figure 21. Bulk density and D_{50} with depth for core SF-7.

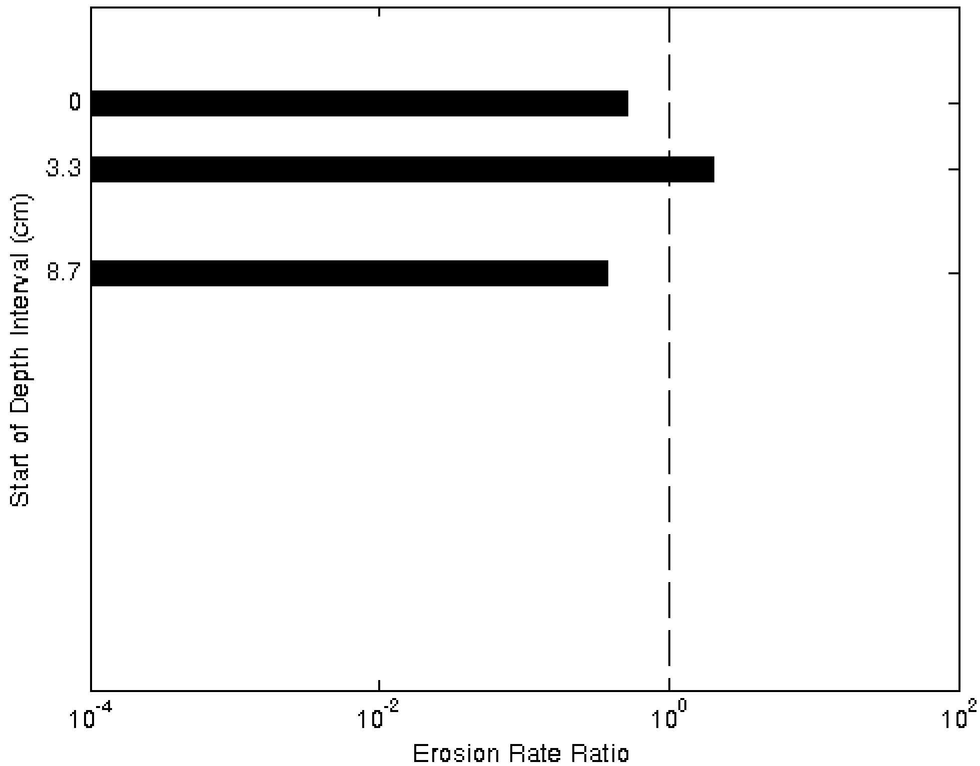

Figure 22. Intra-core erosion rate ratios for core SF-7.

Table 15. Power law best-fit variables for specified depth intervals in core SF-7.

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0.00	2.30	0.0007	1.85	0.84
2	3.30	7.40	0.0012	2.51	0.93
3	8.70	13.80	0.0003	2.40	0.89

Table 16. Bulk density, $D_{50,}$ critical shear stress with depth for SF-7.

Depth (cm)	D_{50} (μm)	ρ_b (g/cm^3)	Power Law τ_{cr} (Pa)	Linear Interpolation τ_{cr} (Pa)
0.00	53.87	1.61	0.34	0.24
3.00	59.43	1.67	0.38	0.32
8.55	86.12	1.81	0.68	0.52
15.40	22.37	1.77	-	-
Mean	**55.45**	**1.72**	**0.47**	**0.36**

Core SF-8

Core SF-8 was collected in approximately 18.0 m water depth. The core was collected from a central channel location, between the coring locations of SF-6 and SF-7. This core also required several attempts to collect a sufficient amount of material. Upon extraction, the core consisted of an uneven, but undisturbed, 1 cm light-colored layer of fine sediment over seemingly stiffer, darker-colored silts and sandy silts. Larger, unconsolidated clumps of sediment were distinct within the core, possibly from suspension and re-settlement (i.e. dredging operations).

During the analysis, some benthic organisms were visible on the surface. Some 1-2 cm long worms and tubes were also observed while sediments were eroding. Down-core the material comprised silty material with some fine sand and fine organic material. Erosion was clumpy and caused manual leveling of the sediment surface during the analysis. The material was stiff clayey-silt near the bottom of the core. A large clump of material eroded into the flume at the bottom of the core, plugging the flume. This caused disturbance of the sediment consolidation characteristics and a manual clean out of the flume. Since it was the bottom of the core, the analysis was halted at that point.

Figure 23 shows a photo of core SF-8 prior to the analysis aligned vertically with the measured erosion rate data. Figure 24 shows the bulk density and D_{50} (median particle size) as a function of depth.

The erosion rate data shows variation in erosion rates down-core as a result of different material consistencies. The erosion rates were low on the surface but increased beneath the surface layer before decreasing again down-core. The sediments collected from the surface layer were required to be passed through a 2000 sieve before processing with the particle laser diffractor. Approximately 20% by weight of the sediments sampled at this layer were larger than 2000 um. The remaining samples contained sediments that were smaller than 2000 um.

The median particle size in the core varied down-core, but remained within the silt range (11.7 μm to 34.4 μm) with a mean core value of 19.8 μm. The bulk densities decreased beneath the surface layer before increasing with depth. The range was between 1.41 g/cm^3 and 1.64 g/cm^3. The mean bulk density in the core is 1.55 g/cm^3. The surface of the core was more difficult to erode than the layer beneath. The calculated linear interpolated critical shear stress was 0.94 Pa. The power law interpolation did not yield a critical shear stress due to a poor correlation between the data and regression line. The critical shear stresses were lower beneath the surface, down to a depth of approximately 10 cm (0.32Pa to 0.42 Pa for both manners of interpolation). At a depth of 10 cm, the critical shear stresses were 0.94 Pa and 1.28 Pa for the power law and linear interpolation, respectively. The mean values of the critical shear stresses in the core are 0.58 N/m^2 and 0.66 N/m^2, for the power law and linear interpolations, respectively.

Figure 25 displays the erosion susceptibility for the depth intervals in core SF-8. Only three of the five depth intervals met the criteria for computing an erosion rate (depths of 2.0 cm, 5.4 cm and 10.4 cm). Based on these results, the layer at a depth of 2 cm is more susceptible to erosion than the layers below. This depth correlates with the lowest critical shear stress as well as a high erosion rate. At a depth of 5.4 cm, one would expect the erosion susceptibility to be high as well; however, this isn't the case and is unexplainable at the present time.

Table 17 summarizes the variables resulting from the power law fit to the data in each shear stress cycle. Shear stress cycles for which only two applied shear stresses existed (i.e. $r^2 = 1.00$) are omitted from the table. Table 18 summarizes the bulk density, D_{50}, and interpolated critical shear stresses, τ_{cr}, for specific core depths.

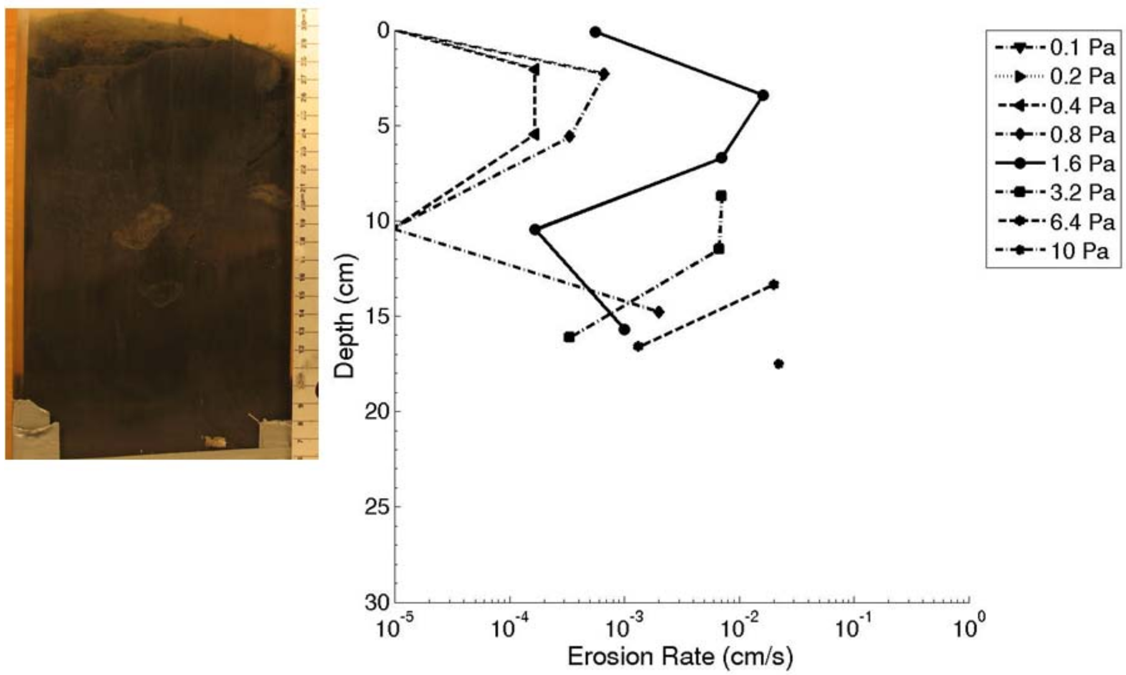

Figure 23. Picture of core SF-8 aligned with Sedflume erosion rate data.

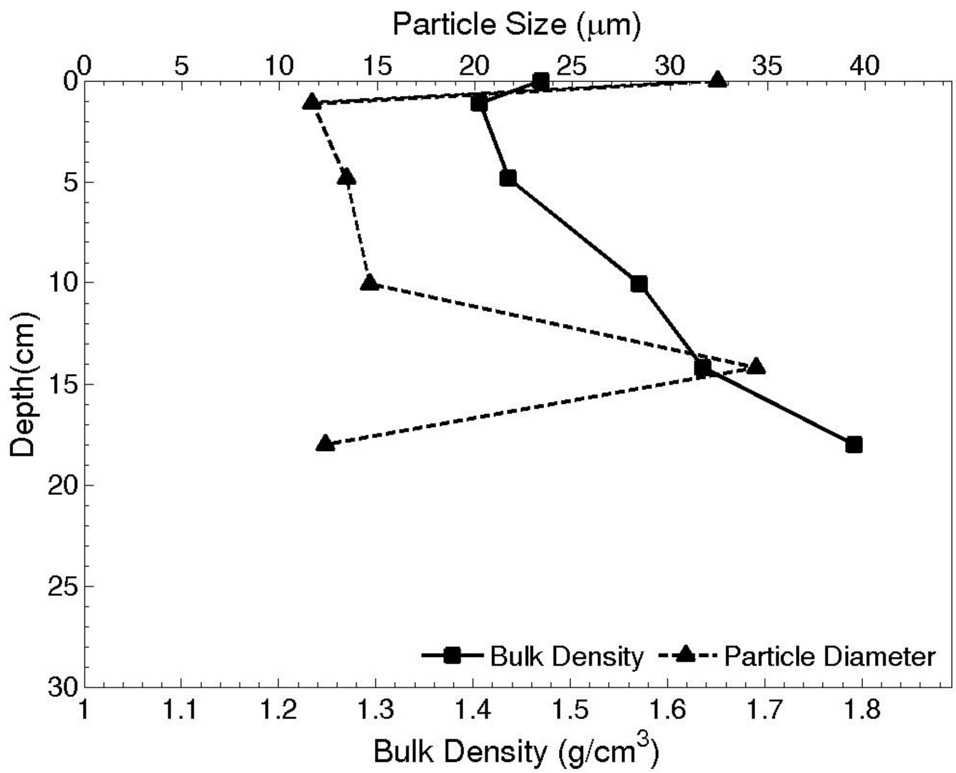

Figure 24. Bulk density and D_{50} with depth for core SF-8.

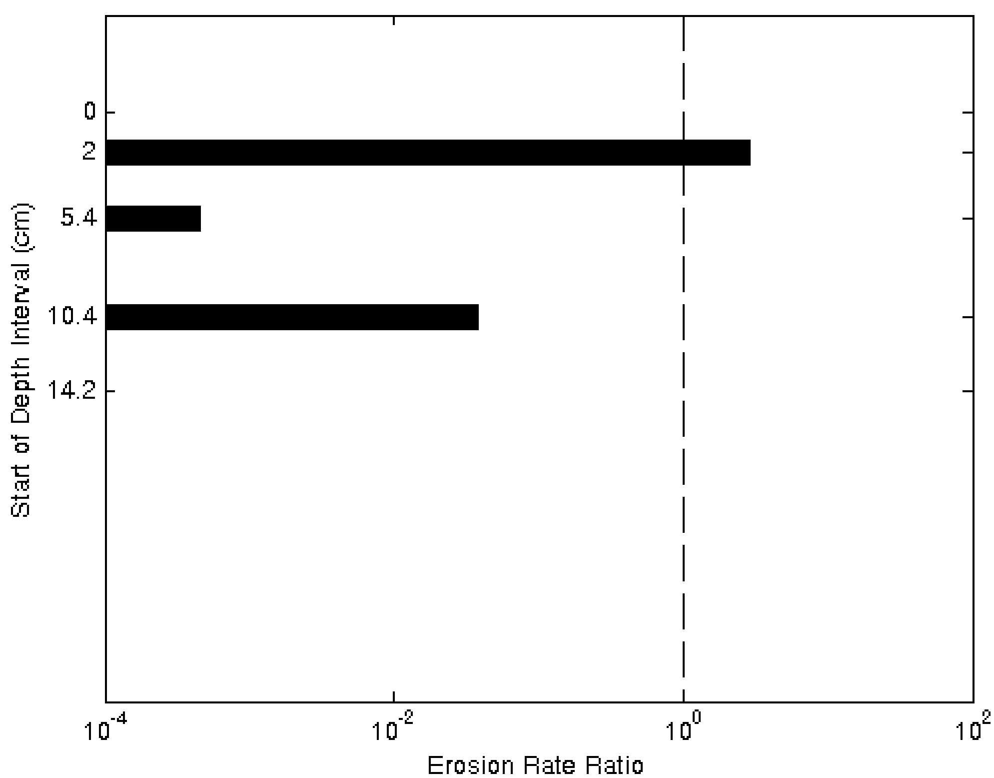

Figure 25. Intra-core erosion rate ratios for core SF-8.

Table 17. Power law best-fit variables for specified depth intervals in core SF-8.

Interval	Depth Start (cm)	Depth Finish (cm)	A	n	r^2
1	0.00	0.10	-	-	0.50
2	2.00	3.40	0.0025	3.42	0.98
3	5.40	8.70	0.0008	2.45	0.93
4	10.40	13.35	0.0001	2.51	0.86
5	14.20	17.50	-	-	0.56

Table 18. Bulk density, $D_{50,}$ critical shear stress with depth for SF-8.

Depth (cm)	D_{50} (µm)	ρ_b (g/cm^3)	Power Law τ_{cr} (Pa)	Linear Interpolation τ_{cr} (Pa)
0.00	32.45	1.47	-	0.94
1.10	11.67	1.41	0.39	0.32
4.85	13.42	1.44	0.42	0.32
10.05	14.62	1.57	0.93	1.28
14.20	34.40	1.64	-	0.42
18.00	12.37	1.79	-	-
Mean	**19.82**	**1.55**	**0.58**	**0.66**

Summary

Sea Engineering, Inc. (SEI) conducted a Sedflume analysis for Anchor QEA on eight (8) sediment cores obtained from the East Waterway in the Port of Seattle, Washington. These cores were collected in areas where depths ranged to approximately 18 m of water depth. Sediment compositions were mostly silts, clayey-silts and sandy silts. Many of the cores harbored a great deal of benthic organisms and organic material, which often hindered the erosion of sediments. The primary goal of this work was to characterize the stability of the sediments in the East Waterway. The cores are described in detail in the report.

References

Hakanson, L., and M. Jansson, 2002, Principles of Lake Sedimentology. Blackburn Press, Caldwell, New Jersey, USA.

Jepsen, R., J. Roberts, and W. Lick, 1997, Effects of bulk density on sediment erosion rates, Water, Air and Soil Pollution, 99:21-31.

McNeil, J., C. Taylor, and W. Lick, 1996, Measurements of erosion of undisturbed bottom sediments with depth, J. Hydr. Engr., 122(6):316-324.

Roberts, J., R. Jepsen, D. Gotthard, and W. Lick, 1998, Effects of particle size and bulk density on erosion of quartz particles, J. Hydr. Engrg., 124(12):1261 1267.

Appendix A – Particle Size Distributions

ATTACHMENT 3

Project Location:	**Seattle East Waterway**
Core ID:	**SF1**
Sample Date:	**4/19/2010**
Sample Time:	**12:20**
Analysis Date:	**4/21/2010**
Analysis Time:	**13:00**
Reference:	**J. Magalen**
Core Height (cm):	**39.00**
Reference Height (cm):	**0.00**

Sedflume Data

Cycle Number	Shear Stress (dynes/cm^2)	Starting Height (mm)	Ending Height (mm)	Time (min)	Time (sec)	Core Depth (cm)	Shear Stress (N/m^2)	Erosion Rate (cm/s)
1	1	0.0	0.0	10	30	**0.00**	**0.1**	**0.0000**
2	2	0.0	0.0	10	0	**0.00**	**0.2**	**0.0000**
3	4	0.0	1.0	10	0	**0.05**	**0.4**	**0.0002**
4	8	1.0	5.0	13	30	**0.30**	**0.8**	**0.0005**
5	16	5.0	20.0	13	30	**1.25**	**1.6**	**0.0019**
6	32	20.0	40.0	1	52	**3.00**	**3.2**	**0.0179**
7	2	41.0	41.0	10	0	**4.10**	**0.2**	**0.0000**
8	4	41.0	41.0	10	0	**4.10**	**0.4**	**0.0000**
9	8	41.0	43.0	10	0	**4.20**	**0.8**	**0.0003**
10	16	43.0	46.0	10	0	**4.45**	**1.6**	**0.0005**
11	32	46.0	66.0	5	40	**5.60**	**3.2**	**0.0059**
12	64	66.0	89.0	0	43	**7.75**	**6.4**	**0.0535**
13	2	93.0	93.0	10	0	**9.30**	**0.2**	**0.0000**
14	4	93.0	94.0	10	0	**9.35**	**0.4**	**0.0002**
15	8	94.0	97.0	10	0	**9.55**	**0.8**	**0.0005**
16	16	97.0	100.0	10	0	**9.85**	**1.6**	**0.0005**
17	32	100.0	125.0	2	7	**11.25**	**3.2**	**0.0197**
18	4	127.0	129.0	10	0	**12.80**	**0.4**	**0.0003**
19	8	129.0	131.0	10	0	**13.00**	**0.8**	**0.0003**
20	16	131.0	133.0	10	0	**13.20**	**1.6**	**0.0003**
21	32	133.0	153.0	2	30	**14.30**	**3.2**	**0.0133**
22	64	153.0	174.0	1	11	**16.35**	**6.4**	**0.0296**
23	4	176.0	176.0	10	0	**17.60**	**0.4**	**0.0000**
24	8	176.0	181.0	10	0	**17.85**	**0.8**	**0.0008**
25	16	181.0	187.0	10	0	**18.40**	**1.6**	**0.0010**
26	32	187.0	208.0	5	0	**19.75**	**3.2**	**0.0070**
27	64	208.0	234.0	2	25	**22.10**	**6.4**	**0.0179**
28	100	234.0	273.0	1	0	**25.35**	**10.0**	**0.0650**

New shear cycle begins. Sediment samples taken for particle size and bulk density measurements.

Project Location:	**Seattle East Waterway**
Core ID:	**SF1**
Sample Date:	**4/19/2010**
Sample Time:	**12:20**
Analysis Date:	**4/21/2010**
Analysis Time:	**13:00**
Reference:	**J. Magalen**
$\rho_{sediment\ (g/cm^3)}$	**2.65**
$\rho_{water\ (g/cm^3)}$	**1.00**

Particle Size and Bulk Density Data

Sample Number	Tray Wt. (g)	Wet Wt. (g)	Dry Wt. (g)	Water Content	Depth (cm)	Particle Size (μm)	Bulk Density (g/cm^3)
1	1.282	7.089	3.277	0.66	0.00	12.4000	1.27
2	1.289	12.690	6.614	0.53	4.05	11.7800	1.41
3	1.291	15.440	7.637	0.55	9.10	11.9800	1.39
4	1.292	14.725	7.576	0.53	12.60	11.8500	1.41
5	1.288	16.995	8.471	0.54	17.50	10.2200	1.40

Project Location:	**Seattle East Waterway**
Core ID:	**SF2**
Sample Date:	**4/19/2010**
Sample Time:	**10:40**
Analysis Date:	**4/22/2010**
Analysis Time:	**8:00**
Reference:	**J. Magalen**
Core Height (cm):	**36.00**
Reference Height (cm):	**0.00**

Sedflume Data

Cycle Number	Shear Stress (dynes/cm^2)	Starting Height (mm)	Ending Height (mm)	Time (min)	Time (sec)	Core Depth (cm)	Shear Stress (N/m^2)	Erosion Rate (cm/s)
1	1	0.0	0.0	10	0	**0.00**	**0.1**	**0.0000**
2	2	0.0	0.0	10	0	**0.00**	**0.2**	**0.0000**
3	4	0.0	3.0	15	0	**0.15**	**0.4**	**0.0003**
4	8	3.0	4.0	10	0	**0.35**	**0.8**	**0.0002**
5	16	4.0	8.0	10	0	**0.60**	**1.6**	**0.0007**
6	32	8.0	30.0	3	15	**1.90**	**3.2**	**0.0113**
7	64	30.0	46.0	1	15	**3.80**	**6.4**	**0.0213**
8	2	48.0	48.0	10	0	**4.80**	**0.2**	**0.0000**
9	4	48.0	48.0	10	0	**4.80**	**0.4**	**0.0000**
10	8	48.0	49.0	10	0	**4.85**	**0.8**	**0.0002**
11	16	49.0	52.0	10	0	**5.05**	**1.6**	**0.0005**
12	32	52.0	59.0	10	0	**5.55**	**3.2**	**0.0012**
13	64	59.0	91.0	1	52	**7.50**	**6.4**	**0.0286**
14	100	91.0	111.0	0	40	**10.10**	**10.0**	**0.0500**
15	4	118.0	118.0	10	0	**11.80**	**0.4**	**0.0000**
16	8	118.0	118.0	10	0	**11.80**	**0.8**	**0.0000**
17	16	118.0	122.0	10	0	**12.00**	**1.6**	**0.0007**
18	32	122.0	132.0	10	0	**12.70**	**3.2**	**0.0017**
19	64	132.0	153.0	1	35	**14.25**	**6.4**	**0.0221**
20	4	156.0	156.0	10	0	**15.60**	**0.4**	**0.0000**
21	8	156.0	156.0	10	0	**15.60**	**0.8**	**0.0000**
22	16	156.0	157.0	10	0	**15.65**	**1.6**	**0.0002**
23	32	157.0	170.0	10	0	**16.35**	**3.2**	**0.0022**
24	64	170.0	190.0	1	25	**18.00**	**6.4**	**0.0235**
25	100	190.0	205.0	0	28	**19.75**	**10.0**	**0.0536**
26	8	230.0	232.0	10	0	**23.10**	**0.8**	**0.0003**
27	16	232.0	252.0	2	0	**24.20**	**1.6**	**0.0167**
28	32	252.0	290.0	0	38	**27.10**	**3.2**	**0.1000**

New shear cycle begins. Sediment samples taken for particle size and bulk density measurements.

Project Location:	**Seattle East Waterway**
Core ID:	**SF2**
Sample Date:	**4/19/2010**
Sample Time:	**10:40**
Analysis Date:	**4/22/2010**
Analysis Time:	**8:00**
Reference:	**J. Magalen**
$\rho_{sediment\ (g/cm^3)}$	**2.65**
$\rho_{water\ (g/cm^3)}$	**1.00**

Particle Size and Bulk Density Data

Sample Number	Tray Wt. (g)	Wet Wt. (g)	Dry Wt. (g)	Water Content	Depth (cm)	Particle Size (µm)	Bulk Density (g/cm^3)
1	1.299	8.609	3.812	0.66	0.00	27.1700	1.27
2	1.295	10.373	6.131	0.47	4.70	22.9300	1.50
3	1.285	15.474	8.706	0.48	11.45	15.1200	1.48
4	1.289	10.215	6.479	0.42	15.35	26.2100	1.57
5	1.285	16.089	9.352	0.46	21.75	15.7800	1.51

Project Location:	**Seattle East Waterway**
Core ID:	**SF3**
Sample Date:	**4/19/2010**
Sample Time:	**12:55**
Analysis Date:	**4/22/2010**
Analysis Time:	**15:00**
Reference:	**J. Magalen**
Core Height (cm):	**37.00**
Reference Height (cm):	**1.50**

Sedflume Data

Cycle Number	Shear Stress (dynes/cm^2)	Starting Height (mm)	Ending Height (mm)	Time (min)	Time (sec)	Core Depth (cm)	Shear Stress (N/m^2)	Erosion Rate (cm/s)
1	1	15.0	15.0	10	0	**0.00**	**0.1**	**0.0000**
2	2	15.0	15.0	10	0	**0.00**	**0.2**	**0.0000**
3	4	15.0	16.0	10	0	**0.05**	**0.4**	**0.0002**
4	8	16.0	18.0	10	0	**0.20**	**0.8**	**0.0003**
5	16	18.0	25.0	10	0	**0.65**	**1.6**	**0.0012**
6	32	25.0	29.0	10	0	**1.20**	**3.2**	**0.0007**
7	64	29.0	49.0	1	52	**2.40**	**6.4**	**0.0179**
8	100	49.0	70.0	0	20	**4.45**	**10.0**	**0.1050**
9	2	76.0	76.0	10	0	**6.10**	**0.2**	**0.0000**
10	4	76.0	77.0	10	0	**6.15**	**0.4**	**0.0002**
11	8	77.0	80.0	10	0	**6.35**	**0.8**	**0.0005**
12	16	80.0	85.0	10	0	**6.75**	**1.6**	**0.0008**
13	32	85.0	104.0	0	40	**7.95**	**3.2**	**0.0475**
14	4	108.0	108.0	10	0	**9.30**	**0.4**	**0.0000**
15	8	108.0	108.0	10	0	**9.30**	**0.8**	**0.0000**
16	16	108.0	118.0	10	0	**9.80**	**1.6**	**0.0017**
17	32	118.0	138.0	3	40	**11.30**	**3.2**	**0.0091**
18	64	138.0	160.0	1	0	**13.40**	**6.4**	**0.0367**
19	4	160.0	160.0	10	0	**14.50**	**0.4**	**0.0000**
20	8	160.0	165.0	10	0	**14.75**	**0.8**	**0.0008**
21	16	165.0	170.0	10	0	**15.25**	**1.6**	**0.0008**
22	32	170.0	187.0	0	38	**16.35**	**3.2**	**0.0447**
23	4	208.0	211.0	10	0	**19.45**	**0.4**	**0.0005**
24	8	211.0	217.0	10	0	**19.90**	**0.8**	**0.0010**
25	16	217.0	257.0	1	15	**22.20**	**1.6**	**0.0533**
26	32	257.0	295.0	0	31	**26.10**	**3.2**	**0.1226**

New shear cycle begins. Sediment samples taken for particle size and bulk density measurements.

Project Location:	**Seattle East Waterway**
Core ID:	**SF3**
Sample Date:	**4/19/2010**
Sample Time:	**12:55**
Analysis Date:	**4/22/2010**
Analysis Time:	**15:00**
Reference:	**J. Magalen**
$\rho_{sediment\ (g/cm^3)}$	**2.65**
$\rho_{water\ (g/cm^3)}$	**1.00**

Particle Size and Bulk Density Data

Sample Number	Tray Wt. (g)	Wet Wt. (g)	Dry Wt. (g)	Water Content	Depth (cm)	Particle Size (µm)	Bulk Density (g/cm^3)
1	1.295	7.045	3.964	0.54	0.00	11.8200	1.41
2	1.288	19.122	11.583	0.42	7.30	12.7500	1.56
3	1.284	7.927	5.222	0.41	10.60	11.2000	1.59
4	1.292	12.488	5.900	0.59	16.00	10.0400	1.34
5	1.272	9.949	4.615	0.61	19.75	11.9100	1.32

Project Location:	**Seattle East Waterway**
Core ID:	**SF4**
Sample Date:	**4/19/2010**
Sample Time:	**13:40**
Analysis Date:	**4/20/2010**
Analysis Time:	**16:00**
Reference:	**J. Magalen**
Core Height (cm):	**17.00**
Reference Height (cm):	**16.40**

Sedflume Data

Cycle Number	Shear Stress (dynes/cm^2)	Starting Height (mm)	Ending Height (mm)	Time (min)	Time (sec)	Core Depth (cm)	Shear Stress (N/m^2)	Erosion Rate (cm/s)
1	1	164.0	164.0	10	0	**0.00**	**0.1**	**0.0000**
2	2	164.0	174.0	10	0	**0.50**	**0.2**	**0.0017**
3	4	174.0	176.0	10	0	**1.10**	**0.4**	**0.0003**
4	8	176.0	181.0	10	0	**1.45**	**0.8**	**0.0008**
5	16	181.0	201.0	4	12	**2.70**	**1.6**	**0.0079**
6	32	201.0	221.0	0	45	**4.70**	**3.2**	**0.0444**
7	2	228.0	229.0	10	0	**6.45**	**0.2**	**0.0002**
8	4	229.0	232.0	10	0	**6.65**	**0.4**	**0.0005**
9	8	232.0	233.0	10	0	**6.85**	**0.8**	**0.0002**
10	16	233.0	234.0	10	0	**6.95**	**1.6**	**0.0002**
11	32	234.0	254.0	7	25	**8.00**	**3.2**	**0.0045**
12	64	254.0	273.0	8	0	**9.95**	**6.4**	**0.0040**
13	100	273.0	291.0	0	25	**11.80**	**10.0**	**0.0720**
14	2	297.0	297.0	10	0	**13.30**	**0.2**	**0.0000**
15	4	297.0	297.0	10	0	**13.30**	**0.4**	**0.0000**
16	8	297.0	301.0	10	0	**13.50**	**0.8**	**0.0007**
17	16	301.0	302.0	10	0	**13.75**	**1.6**	**0.0002**
18*	32	302.0	303.0	5	30	**13.85**	**3.2**	**0.0003**

New shear cycle begins. Sediment samples taken for particle size and bulk density measurements.

*** Additional sediment sample taken after shear cycle for particle size and bulk density measurements.**

Project Location:	**Seattle East Waterway**
Core ID:	**SF4**
Sample Date:	**4/19/2010**
Sample Time:	**13:40**
Analysis Date:	**4/20/2010**
Analysis Time:	**16:00**
Reference:	**J. Magalen**
$\rho_{sediment\ (g/cm^3)}$	**2.65**
$\rho_{water\ (g/cm^3)}$	**1.00**

Particle Size and Bulk Density Data

Sample Number	Tray Wt. (g)	Wet Wt. (g)	Dry Wt. (g)	Water Content	Depth (cm)	Particle Size (µm)	Bulk Density (g/cm^3)
1	1.286	7.336	3.881	0.57	0.00	16.3800	1.36
2	1.286	13.812	8.005	0.46	6.05	12.5800	1.50
3	1.287	15.625	8.654	0.49	13.00	35.4500	1.47
4	1.288	10.630	6.398	0.45	13.90	19.6400	1.52

Project Location:	**Seattle East Waterway**
Core ID:	**SF5**
Sample Date:	**4/19/2010**
Sample Time:	**14:20**
Analysis Date:	**4/21/2010**
Analysis Time:	**8:30**
Reference:	**J. Magalen**
Core Height (cm):	**21.00**
Reference Height (cm):	**15.10**

Sedflume Data

Cycle Number	Shear Stress (dynes/cm^2)	Starting Height (mm)	Ending Height (mm)	Time (min)	Time (sec)	Core Depth (cm)	Shear Stress (N/m^2)	Erosion Rate (cm/s)
1	1	151.0	151.0	10	0	**0.00**	**0.1**	**0.0000**
2	2	151.0	151.0	10	0	**0.00**	**0.2**	**0.0000**
3	4	151.0	153.0	10	0	**0.10**	**0.4**	**0.0003**
4	8	153.0	155.0	10	0	**0.30**	**0.8**	**0.0003**
5	16	155.0	157.0	10	0	**0.50**	**1.6**	**0.0003**
6	32	157.0	160.0	1	0	**0.75**	**3.2**	**0.0050**
7	2	160.0	160.0	10	0	**0.90**	**0.2**	**0.0000**
8	4	160.0	163.0	10	0	**1.05**	**0.4**	**0.0005**
9	8	163.0	164.0	10	0	**1.25**	**0.8**	**0.0002**
10	16	164.0	180.0	7	30	**2.10**	**1.6**	**0.0036**
11	32	180.0	195.0	1	15	**3.65**	**3.2**	**0.0200**
13	2	197.0	197.0	10	0	**4.60**	**0.2**	**0.0000**
14	4	197.0	197.0	10	0	**4.60**	**0.4**	**0.0000**
15	8	197.0	200.0	10	0	**4.75**	**0.8**	**0.0005**
16	16	200.0	202.0	10	0	**5.00**	**1.6**	**0.0003**
17	32	202.0	216.0	5	30	**5.80**	**3.2**	**0.0042**
18	4	222.0	222.0	10	0	**7.10**	**0.4**	**0.0000**
19	8	222.0	224.0	10	0	**7.20**	**0.8**	**0.0003**
20	16	224.0	244.0	6	45	**8.30**	**1.6**	**0.0049**
21	32	244.0	275.0	0	42	**10.85**	**3.2**	**0.0738**

New shear cycle begins. Sediment samples taken for particle size and bulk density measurements.

Project Location:	**Seattle East Waterway**
Core ID:	**SF5**
Sample Date:	**4/19/2010**
Sample Time:	**14:20**
Analysis Date:	**4/21/2010**
Analysis Time:	**8:30**
Reference:	**J. Magalen**
$\rho_{sediment\ (g/cm^3)}$	**2.65**
$\rho_{water\ (g/cm^3)}$	**1.00**

Particle Size and Bulk Density Data

Sample Number	Tray Wt. (g)	Wet Wt. (g)	Dry Wt. (g)	Water Content	Depth (cm)	Particle Size (μm)	Bulk Density (g/cm^3)
1	1.294	11.594	7.013	0.44	0.00	29.9300	1.53
2	1.278	8.127	4.651	0.51	0.90	15.3000	1.44
3	1.281	11.316	7.813	0.35	4.50	14.5400	1.68
4	1.293	10.495	5.655	0.53	6.80	33.1100	1.42
5	1.290	25.249	15.169	0.42	12.40	26.7600	1.56

Project Location:	**Seattle East Waterway**
Core ID:	**SF6**
Sample Date:	**4/19/2010**
Sample Time:	**15:05**
Analysis Date:	**4/23/2010**
Analysis Time:	**8:00**
Reference:	**J. Magalen**
Core Height (cm):	**33.00**
Reference Height (cm):	**3.00**

Sedflume Data

Cycle Number	Shear Stress (dynes/cm^2)	Starting Height (mm)	Ending Height (mm)	Time (min)	Time (sec)	Core Depth (cm)	Shear Stress (N/m^2)	Erosion Rate (cm/s)
1	1	30.0	30.0	10	0	**0.00**	**0.1**	**0.0000**
2	2	30.0	30.0	10	0	**0.00**	**0.2**	**0.0000**
3	4	30.0	31.0	10	0	**0.05**	**0.4**	**0.0002**
4	8	31.0	33.0	10	0	**0.20**	**0.8**	**0.0003**
5	16	33.0	36.0	10	0	**0.45**	**1.6**	**0.0005**
6	32	36.0	40.0	10	0	**0.80**	**3.2**	**0.0007**
7	64	40.0	60.0	3	0	**2.00**	**6.4**	**0.0111**
8	100	60.0	73.0	0	26	**3.65**	**10.0**	**0.0500**
9	2	100.0	100.0	10	0	**7.00**	**0.2**	**0.0000**
10	4	100.0	101.0	10	0	**7.05**	**0.4**	**0.0002**
11	8	101.0	115.0	10	0	**7.80**	**0.8**	**0.0023**
12	16	115.0	135.0	1	38	**9.50**	**1.6**	**0.0204**
13	4	142.0	142.0	10	0	**11.20**	**0.4**	**0.0000**
14	8	142.0	142.0	10	0	**11.20**	**0.8**	**0.0000**
15	16	142.0	146.0	10	0	**11.40**	**1.6**	**0.0007**
16	32	146.0	166.0	10	0	**12.60**	**3.2**	**0.0033**
17	64	166.0	179.0	1	45	**14.25**	**6.4**	**0.0124**
18	4	188.0	188.0	10	0	**15.80**	**0.4**	**0.0000**
19	8	188.0	188.0	10	0	**15.80**	**0.8**	**0.0000**
20	16	188.0	188.0	10	0	**15.80**	**1.6**	**0.0000**
21	32	188.0	191.0	10	0	**15.95**	**3.2**	**0.0005**
22	64	191.0	195.0	10	0	**16.30**	**6.4**	**0.0007**
23	100	195.0	225.0	2	44	**18.00**	**10.0**	**0.0183**
24	4	240.0	240.0	10	0	**21.00**	**0.4**	**0.0000**
25	8	240.0	240.0	10	0	**21.00**	**0.8**	**0.0000**
26	16	240.0	242.0	10	0	**21.10**	**1.6**	**0.0003**
27	32	242.0	244.0	10	0	**21.30**	**3.2**	**0.0003**
28	64	244.0	267.0	5	0	**22.55**	**6.4**	**0.0077**
29	100	267.0	298.0	0	30	**25.25**	**10.0**	**0.1033**

New shear cycle begins. Sediment samples taken for particle size and bulk density measurements.

Project Location:	**Seattle East Waterway**
Core ID:	**SF6**
Sample Date:	**4/19/2010**
Sample Time:	**15:05**
Analysis Date:	**4/23/2010**
Analysis Time:	**8:00**
Reference:	**J. Magalen**
$\rho_{sediment\ (g/cm^3)}$	**2.65**
$\rho_{water\ (g/cm^3)}$	**1.00**

Particle Size and Bulk Density Data

Sample Number	Tray Wt. (g)	Wet Wt. (g)	Dry Wt. (g)	Water Content	Depth (cm)	Particle Size (µm)	Bulk Density (g/cm^3)
1	1.299	8.069	4.944	0.46	0.00	59.6000	1.50
2	1.290	15.052	12.006	0.22	5.65	106.9000	1.94
3	1.296	15.378	9.677	0.40	10.85	19.5700	1.59
4	1.291	19.591	12.071	0.41	15.35	12.8100	1.58
5	1.295	19.642	12.406	0.39	20.25	13.4800	1.61

Project Location:	**Seattle East Waterway**
Core ID:	**SF7**
Sample Date:	**4/19/2010**
Sample Time:	**17:10**
Analysis Date:	**4/23/2010**
Analysis Time:	**13:00**
Reference:	**J. Magalen**
Core Height (cm):	**27.00**
Reference Height (cm):	**15.60**

Sedflume Data

Cycle Number	Shear Stress (dynes/cm^2)	Starting Height (mm)	Ending Height (mm)	Time (min)	Time (sec)	Core Depth (cm)	Shear Stress (N/m^2)	Erosion Rate (cm/s)
1	1	156.0	156.0	10	30	**0.00**	**0.1**	**0.0000**
2	2	156.0	156.0	10	0	**0.00**	**0.2**	**0.0000**
3	4	156.0	159.0	10	0	**0.15**	**0.4**	**0.0005**
4	8	159.0	168.0	10	0	**0.75**	**0.8**	**0.0015**
5	16	168.0	175.0	10	0	**1.55**	**1.6**	**0.0012**
6	32	175.0	183.0	4	0	**2.30**	**3.2**	**0.0033**
7	2	189.0	189.0	10	0	**3.30**	**0.2**	**0.0000**
8	4	189.0	190.0	10	0	**3.35**	**0.4**	**0.0002**
9	8	190.0	203.0	10	0	**4.05**	**0.8**	**0.0022**
10	16	203.0	220.0	10	0	**5.55**	**1.6**	**0.0028**
11	32	220.0	240.0	2	26	**7.40**	**3.2**	**0.0137**
12	4	243.0	243.0	10	0	**8.70**	**0.4**	**0.0000**
13	8	243.0	245.0	10	0	**8.80**	**0.8**	**0.0003**
14	16	245.0	258.0	10	0	**9.55**	**1.6**	**0.0022**
15	32	258.0	278.0	10	0	**11.20**	**3.2**	**0.0033**
16	64	278.0	310.0	4	21	**13.80**	**6.4**	**0.0123**

New shear cycle begins. Sediment samples taken for particle size and bulk density measurements.

Project Location:	**Seattle East Waterway**
Core ID:	**SF7**
Sample Date:	**4/19/2010**
Sample Time:	**17:10**
Analysis Date:	**4/23/2010**
Analysis Time:	**13:00**
Reference:	**J. Magalen**
$\rho_{sediment\ (g/cm^3)}$	**2.65**
$\rho_{water\ (g/cm^3)}$	**1.00**

Particle Size and Bulk Density Data

Sample Number	Tray Wt. (g)	Wet Wt. (g)	Dry Wt. (g)	Water Content	Depth (cm)	Particle Size (µm)	Bulk Density (g/cm^3)
1	1.288	7.856	5.289	0.39	0.00	53.8700	1.61
2	1.280	24.715	16.318	0.36	3.00	59.4300	1.67
3	1.288	25.886	19.001	0.28	8.55	86.1200	1.81
4	1.291	27.873	19.917	0.30	15.40	22.3700	1.77

Project Location:	**Seattle East Waterway**
Core ID:	**SF8**
Sample Date:	**4/19/2010**
Sample Time:	**18:30**
Analysis Date:	**4/20/2010**
Analysis Time:	**10:00**
Reference:	**J. Magalen**
Core Height (cm):	**30.00**
Reference Height (cm):	**7.80**

Sedflume Data

Cycle Number	Shear Stress (dynes/cm^2)	Starting Height (mm)	Ending Height (mm)	Time (min)	Time (sec)	Core Depth (cm)	Shear Stress (N/m^2)	Erosion Rate (cm/s)
1	1	78.0	78.0	10	0	**0.00**	**0.1**	**0.0000**
2	2	78.0	78.0	10	0	**0.00**	**0.2**	**0.0000**
3	4	78.0	78.0	10	0	**0.00**	**0.4**	**0.0000**
4	8	78.0	78.0	10	0	**0.00**	**0.8**	**0.0000**
5	16	78.0	80.0	6	0	**0.10**	**1.6**	**0.0006**
6	2	98.0	98.0	10	0	**2.00**	**0.2**	**0.0000**
7	4	98.0	99.0	10	0	**2.05**	**0.4**	**0.0002**
8	8	99.0	103.0	10	0	**2.30**	**0.8**	**0.0007**
9	16	103.0	121.0	1	52	**3.40**	**1.6**	**0.0161**
10	2	132.0	132.0	10	0	**5.40**	**0.2**	**0.0000**
11	4	132.0	133.0	10	0	**5.45**	**0.4**	**0.0002**
12	8	133.0	135.0	10	0	**5.60**	**0.8**	**0.0003**
13	16	135.0	155.0	4	45	**6.70**	**1.6**	**0.0070**
14	32	155.0	175.0	4	45	**8.70**	**3.2**	**0.0070**
16	2	182.0	182.0	10	0	**10.40**	**0.2**	**0.0000**
17	4	182.0	182.0	10	0	**10.40**	**0.4**	**0.0000**
18	8	182.0	182.0	10	0	**10.40**	**0.8**	**0.0000**
19	16	182.0	183.0	10	0	**10.45**	**1.6**	**0.0002**
20	32	183.0	203.0	5	0	**11.50**	**3.2**	**0.0067**
21	64	203.0	220.0	1	25	**13.35**	**6.4**	**0.0200**
22	4	220.0	220.0	10	0	**14.20**	**0.4**	**0.0000**
23	8	220.0	232.0	10	0	**14.80**	**0.8**	**0.0020**
24	16	232.0	238.0	10	0	**15.70**	**1.6**	**0.0010**
25	32	238.0	240.0	10	0	**16.10**	**3.2**	**0.0003**
26	64	240.0	248.0	10	0	**16.60**	**6.4**	**0.0013**
27	100	248.0	258.0	0	45	**17.50**	**10.0**	**0.0222**

New shear cycle begins. Sediment samples taken for particle size and bulk density measurements.

Project Location:	**Seattle East Waterway**
Core ID:	**SF8**
Sample Date:	**4/19/2010**
Sample Time:	**18:30**
Analysis Date:	**4/20/2010**
Analysis Time:	**10:00**
Reference:	**J. Magalen**
$\rho_{sediment\ (g/cm^3)}$	**2.65**
$\rho_{water\ (g/cm^3)}$	**1.00**

Particle Size and Bulk Density Data

Sample Number	Tray Wt. (g)	Wet Wt. (g)	Dry Wt. (g)	Water Content	Depth (cm)	Particle Size (µm)	Bulk Density (g/cm^3)
1	1.295	18.114	9.929	0.49	0.00	32.4500	1.47
2	1.287	17.279	8.714	0.54	1.10	11.6700	1.41
3	1.289	14.384	7.681	0.51	4.85	13.4200	1.44
4	1.287	24.000	14.549	0.42	10.05	14.6200	1.57
5	1.285	25.272	16.270	0.38	14.20	34.4000	1.64
6	1.281	23.237	16.864	0.29	18.00	12.3700	1.79