Evaluation of Erosion Potential of Estuarine Sediment in New York and New Jersey Harbor Using an Advanced Ex-situ Erosion Testing Method

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Executive Summary

Significant attention has been paid to the erodibility and transport behavior of contaminated sediments which are found within the estuarine and riverine environments surrounding the P~~p~~ort ~~complex~~ of New York and ~~/~~ New Jersey. As managers attempt to balance the economic viability and dredging~~e~~ engineering of the P~~p~~ort with requirements for environmental stewardship, they are faced with~~re exists~~ an ever growing need for more and better data regarding the behavior of sediment particles in general ~~transport~~ and ~~specifically~~ the transport risk of contaminated particles in particular.~~sediment movement. It has been the thought of~~ M~~m~~any who are involved in this industry believe that the current ~~testing~~ methods for assessing erodibility and transport of sediment particles require enhancements.~~ to better assess the risk of erosion for fine grained sediment beds and~~ T~~t~~o this end, Rutgers CAIT was funded by NJDOT Office of Maritime Resources to evaluate an experimental device originally developed by Prechtl Laboratories of Austria, deemed the EX-Situ Erosion Testing Machine (ESETM).

The ESETM is a linear recirculating flume device which was designed specifically to evaluate~~address~~ the erosion/ scour behavior of fine grained sediments. Several such Ex-Situ devices have previously been built and deployed for this purpose, and are all (including the ESETM) predicated on the same basic experiment design, that is the application of hydraulic force parallel to a sediment bed (or surface) and subsequent measurement of the rate of erosion.

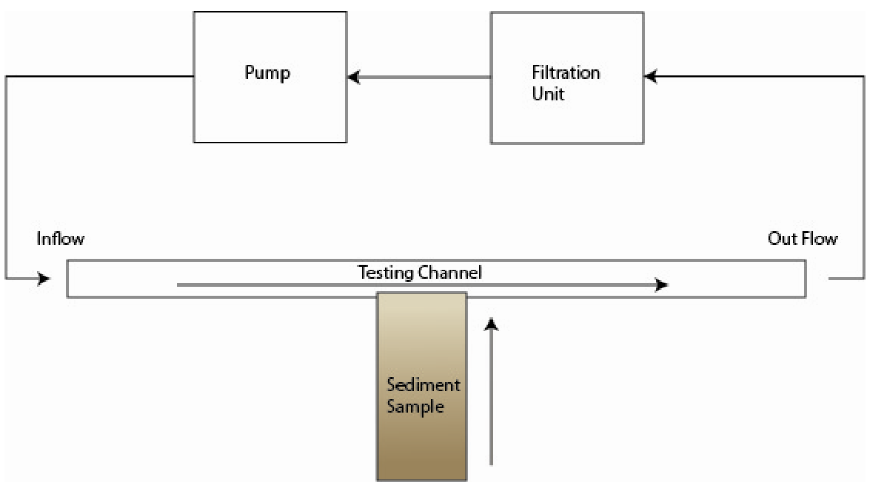

Figure 1- Conceptual Diagram of a Linear Recirculating Flume

Accurate measurement and prediction of Erosion potential for cohesive sediments using an Ex-Situ or flume based method is known to present many challenges for researchers due to several key factors that are implicit to these testing schemes and the properties of fine grained material, including:

1) Representative simulation of hydraulic regime / flow condition (as found in nature)
2) Implicit disruption of coring/ sampling material from the field
3) Heterogeneity of sediment with depth and location (density, particle size, etc.)

4) Uncertain relationship between applied flow velocity and applied hydraulic force / shear stress
5) Measurement subjectivity (in methods where user observation of erosion depth is required)
6) Measurement of Erosion for Field samples cannot be scientifically controlled for (no two samples are exactly the same) and no test can be repeated due to the destructive nature of erosion.

Thus the ESETM was designed with several key components which are novel to this type of flume system in order to better address several of the concerns listed above. They include-

1) Band Drive- A spinning band that is edged with plastic teeth. When the band drive is initiated it is intended to modify the water's velocity profile over the sediment sample so as to achieve a coquette or open channel type flow regime.
2) Shear Stress Sensor- A servo-mechanical device on which the sediment sample is mounted that directly measures the applied shear (x-direction) force applied by the water onto the sediment.
3) Lift / Weight Sensor- A sub component of the shear stress sensor which is oriented so as to measure vertical lift (z- direction) forces applied to the sample under flow conditions and also the change in submerged weight of the sample when flow is stopped.
4) Real Time Data Acquisition and Control System- All components of the device which control flow or measure forces/ weights are automated by LabView allowing input/output in real time, removing subjective observation

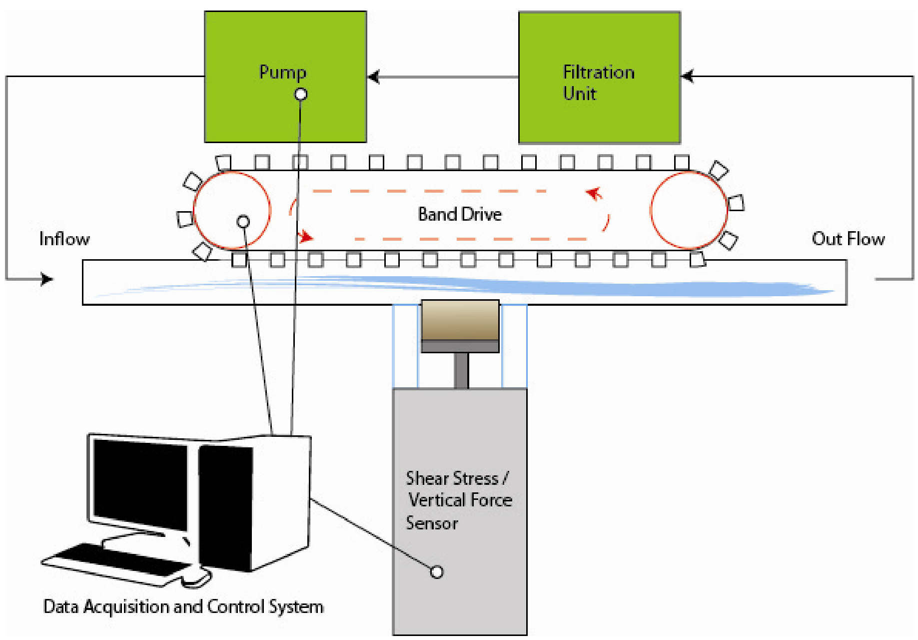

Figure 2- ESETM Conceptual Diagram

Upon receipt of the device from Prechtl Laboratories, the Rutgers CAIT research team set forth a process of:

1) engineering the data acquisition and control systems
2) verifying and calibrating the device
3) designing the experiments to be run
4) modifying the device to allow for the experiment designs
5) acquiring fine grained material from field sites in and around Newark Bay
6) testing field cores in the ESETM and by standard geotechnical testing methods
7) comparing our data to that of comparable research methods
8) analyzing the results via a hydrodynamic model

A detailed research plan was developed and carried out to assess the use of the ESETM for its capacity to

1) be a repeatable method for the measurement of fine grained sediment erosion,

2) produce results which fit theoretical models for sediment transport based on the geotechnical index properties of the sediment being tested and

3) prove more precise and accurate than other comparable ex-situ testing methods, specifically the Sediment Erosion by Depth Flume (SED-Flume) in its prediction and measurement of erodibility.

In addition to the research plan and the experiment designs which were developed for use of the device, several major device modifications and usage methods were developed in order to facilitate the experimental requirements. These included the addition of a submerged scale, the inclusion "changeable bottom surfaces"- meaning interchangeable Plexiglas plates which could be fixed to the bottom surface of the flume test channel in order to generate more realistic flow conditions, the addition of a pitot tube apparatus within the flow chamber to accurately measure the flow profile and velocity over the sediment sample without use of more sophisticated means (LDV/PIV). These modifications are detailed in the report.

In this document the steps taken and results obtained are detailed, however the following conclusions can be made as a result of this study:

1) Erosion rate data acquired by ESETM method (direct weight measurement) is demonstrated to be less subjective and significantly more precise than that of SED-Flume. Accuracy of the eroded mass measurement is shown to be excellent when the presence of entrained gas or air is absent or controlled by laboratory means. For undisrupted field cores the accuracy is shown to be variable due to the effect of buoyancy on submerged sample weight.

2) The ESETM sampling and preparation method is demonstrated to be more disruptive to the sediment sample prior to testing than that of SED-Flume due to the geometric configuration and smaller size of the sample holder.

3) Data acquired from the ESETM in its current configuration cannot yet be demonstrated to provide a better (more accurate) estimate of fine grained sediment erodibility for undisrupted field cores than other comparable flume based methods.

4) The ESETM is considered by the investigating team to have limited applicability for the study of the erodibility of estuarine sediments. The device, originally designed for studying bridge scour under high velocity flows, has been demonstrated to be significantly less applicable for the study of loose estuarine sediments under low flow velocities. While the use of the device for studying high velocity erosion for stab~~i~~le (compacted) sediments was not studied during this project, the two primary claims around which the device was designed are refuted by this study for estuarine conditions:

   a. **Claim 1: The ESETM is capable of generating a "more representative simulation of natural hydraulic conditions."**

      This claim has been shown by hydrodynamic analysis to be unsubstantiated for estuarine flow conditions. In estuaries the flow generally results from tidal, wind, and wave forces resulting in low benthic flow velocities as compared with river/ stream systems where flow is gravity driven. A thorough investigation of the band drive component of the device, while generally increasing the fluid velocity within the log-law section of the boundary layer (as would be expected in an open channel flow), also greatly increases the turbulence or Reynolds Flow value within the boundary condition, creating abnormal conditions respective to what would be found in a natural estuarine condition. Therefore it is concluded that application of the band drive is typically inappropriate for the simulation of estuarine type flow.

   b. Claim 2: The ESTM is capable of directly measuring shear stress applied to the sediment sample.

      After repeated testing, this claim cannot be supported except for under very specific experimental parameters that cannot be met when testing "undisrupted" field cores. In short, the mechanism for deriving shear-stress is predicated upon measuring the applied hydraulic force and dividing that by the effective area of the sample (approximately 28 cm^2). While in theory this approach would appear to be well designed for such an experiment, in reality, it fails to account for the fact that shear stress comes in two forms: skin friction and form drag. Skin friction is the hydraulic force that is translated from the water molecules directly to the sediment particles and is predicated on the electromagnetic behavior of the material and will remain the same for any homogenous material. Form drag however is dependent on the topology or shape of the material being testing. In the case of a "perfectly flat" sample form drag should be zero. During repeated experiments with a flat aluminum puck it was found that this is sometimes, but not always the case because the elevation of the sample relative to the bottom of the test channel has an extreme effect on the measurement, findings indicated that even very small deviations (50 um / .5mm) were adequate to change the measured shear stress by an order of magnitude at low velocities. While this could be largely controlled with a flat puck, it was found to be impossible for undisturbed field samples due to changes in the sample topology as the sample eroded, since~~as~~ the sample surface could not be made to be flat without significant disruption. Furthermore the data analysis shows a very poor correlation between shear stress and erosion rate that does not correspond to the widely held theories of fine grained sediment erosion behavior.

5) For future test methods used to assess the erodibility of fine grained sediments, the ESETM has lead the research team to make the following recommendations:

   a. A larger sample size is needed to make accurate predictions due to the turbulent effects created by edge disruptions between the sample surface and the testing channel. Also a larger sample is likely to be less disrupted and more statistically representative of a given sediment bed.
   b. In-Situ testing should be preferred to Ex-Situ testing if possible given the likelihood of disruption and the entrainment of gasses implicit in sediment coring.
   c. Measurement of shear stress/ lift force should be calculated based on precise flow measurements provided by Laser Doppler Velocimetry or by Particle Image Velocimetry rather than by servo-mechanical means.
   d. A deterministic transport model is limited in its applicability to the large scale transport behavior of fine grained sediment. Due to the heterogeneity that is naturally found in sediment beds and the wide range of indeterminable variables affecting sediment transport behavior a probabilistic analysis method will provide more meaningful results.
   e. Flow turbulence is highly significant in its relationship with erosion rate. The Reynolds flow number must be experimentally determined in situ under varying flow velocities for given sediment beds of interest and then repeated within the same order of magnitude to produce similar erosion results in laboratory / Ex- Situ testing. Outer flow (log-law zone) turbulence is shown both experimentally and theoretically to have a significant effect on sediment erosion behavior.
   f. Any further study involving the applicability of Ex-Situ Erosion testing should be complimented by a field monitoring program by which predicted results can be verified or calibrated to infield observation. This is likely best accomplished by means of Acoustic Doppler Velocimetry (ADV.)

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I. Project Background

The Port of NY and NJ will soon complete a $1.9 billion construction project to deepen the shipping channels that provide access to NY Harbor from 45 to 50 feet. Over 55 million cubic yards of sediment will have been removed to improve~~create~~ the ~~new~~ channels. While having deeper~~these new~~ channels will certainly provide significantly increased shipping efficiencies, there is a downside. These new channels must be maintained through periodic dredging to remove accumulated fine grained sediments. Managers need to predict the amount of sedimentation that will occur in order to plan for the expense and environmental liability created by legacy contamination in the P~~p~~ort's watershed. Previously, the responsibility for channel maintenance ~~is~~ has fallen solely to the US Army Corps of Engineers. However, channels deeper than 45 feet require a local cost share of 50%. Thus, u~~U~~nderstanding and predicting sediment transport has gone from curious scientific trivia to critical economic parameter ~~overnight~~.

An even more important consideration is revealed when one looks at some of the data collected in the NY/NJ Harbor over the last decade. Thanks to work sponsored by the States and the Port Authority, we now can definitively say that the quality of sediment in the Harbor is driven more by existing sediment contamination than by ongoing sources for most chemicals of concern. These legacy sediments exist both on the surface and at depth, and while most surficial sediments are contaminated, the nature and extent of each contaminant is unique. Because of changing hydrodynamic characteristics of estuaries and channels, we know that newly deepened channels attract more sediment than existing channels. Since the cost of management is driven by contaminant load and the subsequent disposal cost, it becomes important to be able to predict this load for a better approximation of future cost. The problem is that we do not know where these new sediments will come from. Will the newly deposited sediment come only from the incoming riverine load? Or will it be eroded from mudflats and riverbanks~~s~~?

The 2008 Regional Sediment Management Plan developed by the Harbor Estuary Program calls for active sediment remediation to improve the ecosystem and to reduce costs of transportation infrastructure maintenance. Unfortunately, there are insufficient resources to clean up all the contaminated sediment in the Harbor. Therefore, an action prioritization is needed to ensure that available dollars are spent on the most urgent projects first – those projects that have the greatest potential to reduce or prevent the migration of legacy sediment contamination. This action plan will require that those contaminated sediments that are most mobile, or have the greatest potential to migrate are identified. In addition, remedial measures need to be identified that are appropriate for reduction of the risks posed by these sediments. Should they be stabilized in situ, capped, armored, or removed? Will there need to be an increased vigilance in the watershed to reduce erosion into the rivers and streams that lead to the Harbor, or is this an insignificant threat? The best modeling, supported by the most recent scientific data must be used to develop this action list.

II. Project Objectives

The following study was undertaken to address the following objectives put forth by the funding partner NJDOT Office of Maritime Resources. Due to some knowledge of the device under development by FHWA for bridge scour evaluation it was believed that the ESETM would provide a higher quality picture of fluvial erosion within e~~E~~stuarine environments.

1. Design and run experiments to measure sediment erosion rates for the specified site more accurately than all previous erosion measurement tests.

2. Interpret the test results and compare it to sediment erosion rates estimated by previous methods.

3. Apply the new erosion parameters to create hydrodynamic models of the specified site. Investigate the effectiveness of capping with and without in-situ stabilization on reducing erosion potential of highly erodible zones in the specified site.

III. Project Tasks

The following project tasks acted as the rough guideline by which the aforementioned project objectives were to be addressed:

Task 1. Literature search

Task 2. Design of experiments

Task 3. Acquisition and set up of ESETM device

Task 4. Site identification and sampling.

Task 5. SED-flume and ESETM testing.

Task 6. Site specific hydrodynamic modeling and model calibration using ESETM results.

Task 7. Analysis of results.

Task 8. Evaluation of effectiveness of capping.

Task 9. Final report.

IV. Literature Search

The literature search~~, which began prior to the acquisition of the device~~ was broken down into three major sections:

1) Sediment Physics
2) Alternative Test Methods
3) Data Analysis Methods

While considerably more research was done outside of this basic scope, including an extensive search of electro-mechanical force and shear stress testing methods, computer programming via National Instruments Labview, sediment coring techniques, estuarine sediment ecology, and the pre-requisite ASTM tests which were required to catalogue the geotechnical index properties of the core samples being tested, for purposes of refining the total scope of the literature search, these sections are left out (however discussed later.)

Sediment Physics

Primary sources for the team's understanding of sediment properties and physics within a brackish, estuarine environment such as is found in and surrounding the NY/NJ harbor complex, included papers by Winterverp, Sanford, Chant, and Partheinades. They each describe ~~the study of~~ cohesive sediments as being a highly complex system ~~endeavor~~ in which a great multitude of uncontrollable factors influence the erosion behavior including—~~characteristics~~ chemical, physical, and biological characteristics. Moreover, the erosion behavior of sediments in the~~ir~~ field has been shown by study to also be dependent on ~~both its~~ intrinsic material properties and the ever-~~-~~changing environment in which they are~~it is~~ found including flow rate/ profile, water chemistry/ salinity, and the consequences of flow disruptions up and down stream of the site under study (dredging, upstream sedimentation, damming, boat traffic etc.).

~~Perhaps most useful, in the conceptual understanding of fine grained sediment erosion, was to develop~~ In order to determine how best the ESETM could be used to further our understanding of cohesive sediment, it was necessary to first develop a~~a~~ road map of where the larger scientific knowledge is still incomplete.~~ and where, as a practical testing method and device for basic research, the ESETM could be applied most beneficially.~~ San~~d~~ford, in his paper "A Unified Erosion Formulation for Fine Sediments" (Sanford et al. 2003) suggests many questions which have been answered by~~in the subsequent research attempts have been made to address through~~ measurement or direct observation, ~~and~~ while many still remain only partially understood. T~~, t~~he literature review helped to guide the research team in developing what was needed ~~to~~ and what could be studied by use of ESETM, these include

1) What is the dominant mechanism of sediment transport—dense particle flocculates along the bottom or suspended particles in the water column?
2) What is the effect of surface roughness? Is boundary flow velocity significant versus average velocity? Is flow turbulence and Reynolds flow number significant to erosion?
3) How significant are vertical or lift forces to the initiation of sediment transport?
4) What are the effects of "stress history" on sediments- do sediments loose strength over repeated forcing events the way steel or concrete might- what are the magnitude of forces required for a loss in erosion resistance?
5) What is the significance of rehydration and density changes in subsequent sediment layers?

~~Thorough discussion of the results and hypothesized answers to these questions can be found in section VII (Discussion.)~~

Test Methods

Since~~As~~ the ESETM is similar in configuration to SED-Flume and other methods, it was considered ne~~ss~~cessary to understand how these other methods ~~y~~ worked, along with the basis of their experimental design, in order to determine the best way to proceed with evaluating the ~~on which to predicate the usage of the~~ ESETM. A primary document used in determining how SED-Flume was applied to fine grained sediments, including system configuration, experimental methodology, and data analysis ~~procedure~~ was the 2008 Erodibility of Passaic River Sediments by Use of USACE SED-Flume, Army Corps of Engineers (Gailani et al. 2008.) Research into this area showed several key parameters which could be included in the experiment design that were very similar between the two devices and could stand as the basis for comparison.

~~Study of the USACE reports on SED-Flume became the underlying tenet for~~ T~~t~~he later application of hydraulic force onto the sample ~~in later testing, which~~ was performed using the USACE method~~by and large done via the same method~~, starting at a low fluid velocity and increasing in discrete intervals. By use of these means it was also possible to plot a linear relationship (in many experiments) between velocity/ shear stress, and the mean erosion rate allowing for back calculation of the critical shear stress which is for most SED-Flume experiments derived by the same method.

~~Preliminary data from running early experiments with the device lead to a second literature search to investigate the applicability and usage of the "floating shear gauge" method for the determination of hydraulic shear stress, the findings of this review are detailed below in the device assessment section (p.16-17).~~

Data Analysis Methods

Finding a method for analyzing data from the ESETM was a significant concern in the primary testing phase of the project as it became clear from early use of the device that data derived from the machine was not of the type which is expected for SED-Flume and other such erosion devices. Ultimately the research team devised their own method of analysis as the data did not readily fit any of the conventional empirical methods which have been used in the past for predicting large scale sediment transport based on data taken from field cores. Moreover, it was a goal of this project to attempt to determine a relationship between the material characteristics (geotechnical index properties) and the erosion properties that would be expected. The findings of this goal are discussed at length in discussion.

What was ultimately taken away from this search was that 1) while there are many existing empirically defined equations for relating sediment properties to erodibility, most were not compatible for the range of data which was taken from the ESETM system and thus it would be required to ascertain additional information about each sediment core we were testing in order to make unit conversions/ modifications to the data to fit the initial assumptions of these models. 2) It is likely true that a number of the assumptions which are taken into empirical models do not universally hold true (i.e. surficial sediments are constituted of only water and sediment particles, was found to be contradicted by the presence of entrained and dissolved gasses in the sediment matrix. Additionally the difficulties presented by the presence of biota acting both as stabilizers and disruptors of the sediment bed added a level of complexity that could not be fully addressed within the purview of this study.

V. Device Assessment

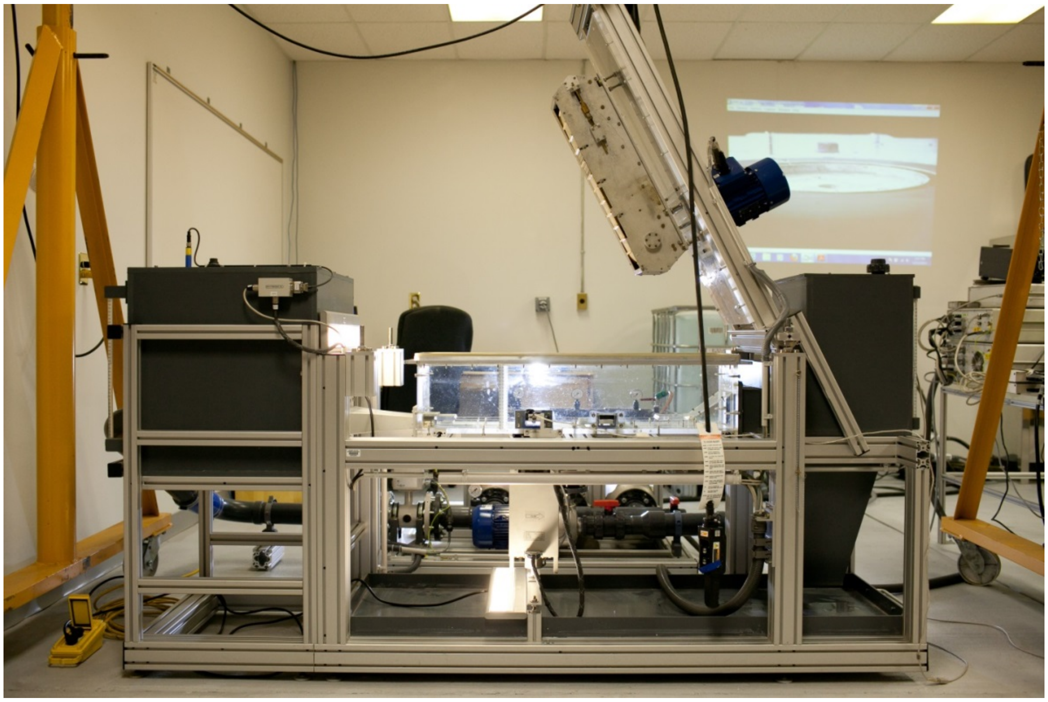

Figure 3- The Ex-Situ Erosion Testing Machine

The ESETM includes a number of special controls and sensors which are novel to the device as compared to other flume based systems. The following section details these components, their principles of operation, functionality, and overall assessment regarding their ability to produce more scientifically rigorous and ultimately better quality data.

Shear Stress and Vertical Force Sensor

Principle of Operation

The shear sensor developed for the ESETM follows the principles of the "floating type direct shear gauge" [Winters et al.] with a number of additional modifications designed by FHWA and Prechtl Labs intended to allow the measurement of vertical forces applied to the sample and improve accuracy and repeatability under turbulent hydro-dynamic conditions. [Wagner, Prechtl 2008] While the assembly is referred to as a "shear stress sensor" there are three distinct mechanisms associated with it-:

1) Elevation and Tilt Controls (which are common to both measurement components)~~.~~,

2) Vertical Force Transducer, and

3) Servo-electric shear stress transducer.

Elevation and Tilt Controls

Tilt Control (Probe Head) ~~-~~ – (t~~T~~he section of the sensor on which a sediment sample is~~can be~~ mounted). It is a crucial component that allows for the translation of hydraulic forces applied to the sample onto the transducer assembly while keeping the assembly effectively removed from flow conditions that could adversely impact measurement accuracy. The relative tilt of the probe head can be adjusted, however experiments have shown that not only the elevation of the probe head but also the tilt have a significant effect on readings taken by the device.

Alignment- (a~~A~~ set screw assembly which mounts the head cap onto the probe arm and allows the sample's top surface to be precisely leveled with the aperture ring / channel bottom). In order to achieve alignment the researching team used the following procedure.

1) When the cap was believed to be level, by visual observation, a rigid strip of Plexiglas was placed across the aperture ring and the elevator mechanism was raised in 10 micron increments.
2) When contact was made between the probe head and the Plexiglas a measurement would be registered, this process was repeated by moving the Plexiglas strip around the perimeter of the aperture gap and the set screws adjusted until all sides of the probe head indicated mechanical contact at the same relative elevation.

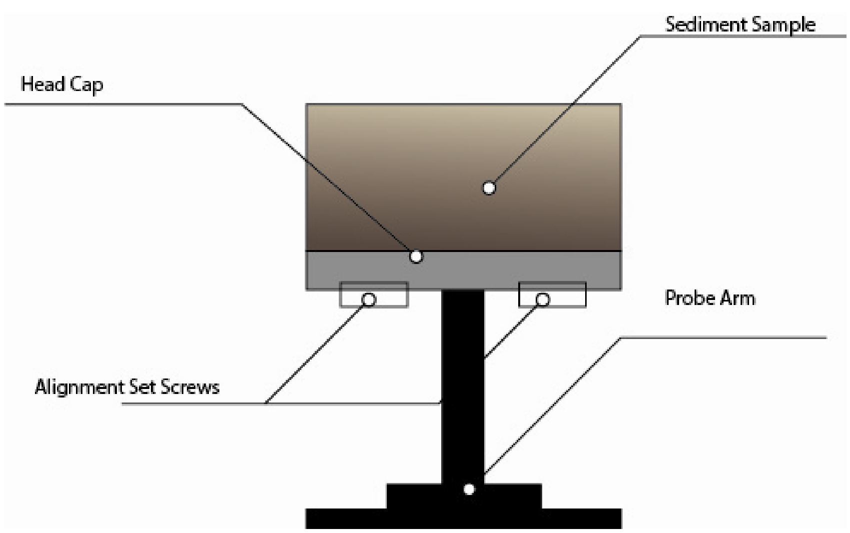

Figure 4-Probe Head Configuration

Elevation Control- Sample elevation is controlled by a precision stepper motor which receives inputs of +/- 5 v~~V~~olt impulses. Each pulse corresponds to 10 microns (.1mm) up or down therefore the height of the sample surface can theoretically be kept even with the testing channel within a very narrow margin- assuming a level surface. The method for leveling the elevation is done by means of a rigid Plexiglas strip that is placed over the aperture ring and extends to the sample. While this method is generally useful for beginning erosion experiments at a known datum point, relative sample elevation and topography have also been shown (see shear stress measurement evaluation) to produce an extreme effect on the registered shear, lift, and erosion rate values.

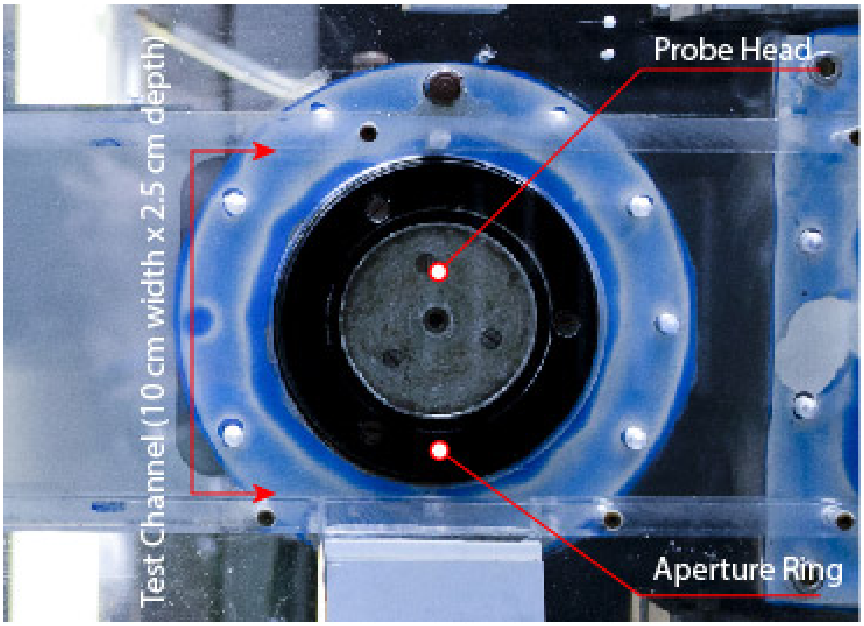

Figure 5- Sensor Probe Head

Vertical Force Measurement

The mechanism works on the basis of a rigid spring plate attached to the floating shear-stress transducer assembly. The design attempts to isolate vertical and horizontal force vectors applied to the sediment surface because the leaf spring is fixed as to allow deflections only along the z-measurement axis. Vertical lift forces are known to be significant in the initiation of sediment transport, as noted by Bordreau "the combination of water flow and sediment surface topography induces lateral pressure gradients that drive advective flows through the upper centimeters to decimeters."

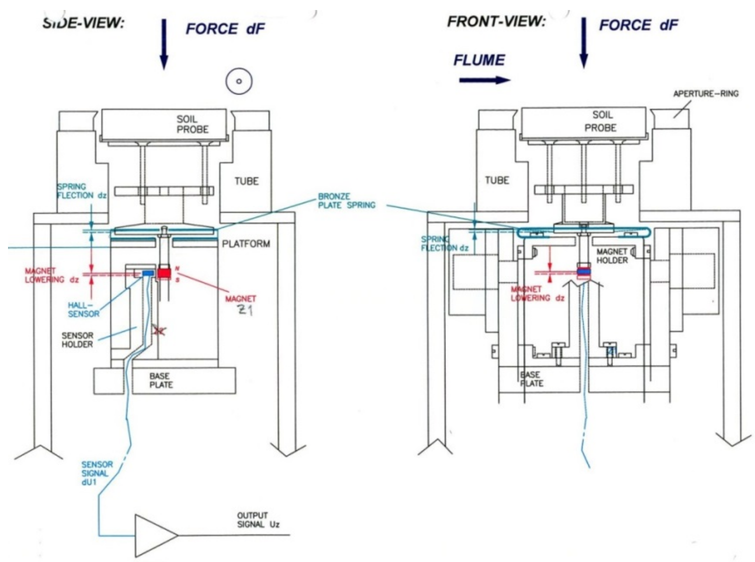

Figure 6- Vertical Force Sensor Diagram

Measurement- the Z force sensor in principle is intended to measure two separate phenomena which occur along the vertical axis. The first and simplest is mass, which can only be done under conditions of zero flow whereas there are no lift forces affecting the force of gravity. Expressed over time a change in mass is expressed as erosion rate. Secondarily it is intended to measure the summed average of hydraulic lift forces which are drawing sediment particles up as a result of form drag and the negative pressure differentials which are generated by the turbulent nature of fluids moving over an irregular surface. These measurements must be taken in real time as flow is applied to the sample. It is believed that benthic flow generally produces lift forces, or pockets of decreased pressure above the bed relative the static fluid pressure as a function of depth.

Calibration- The unit allows for a direct calibration in which the signal can be zeroed when the sample is loaded. When a calibration weight is placed on the probe head the outgoing signal amplitude is then multiplied by a summing op-amp whose incoming voltage is controlled by the user, the signal is repeatedly modified until the outgoing voltage reading is equal to the calibration weight. Numerous experiments have shown a linear response however the accuracy of the assembly is subject to scrutiny.

Potential Sources of Error- While the linearity of the sensor's electrical response has been verified to an acceptable level of accuracy (+/- .5 grams) experimentally by calibrating the sensor using small weights, there are a number of other sources of error which ultimately make the vertical force data (both as real-time measurement and static measurement) unreliable.

Y-Axis Torqueing- Under static experimental conditions (no flow) early testing with the device showed that the same calibration weight, when placed on different locations around the center of the probe head, significant deviations in measured weight resulted. Further testing indicated that due to the floating nature of the sensor sitting on the z-spring plate, very small deflections made rotationally along the y-axis (side to side/ perpendicular to the direction of flow), were sufficient to displace the magnet either closer or farther from the hall sensor face and could result in significant z-force measurement inaccuracies. As the sensor works only on relative electrical resistance within a charged field, it cannot discern between vertical and side to side deflections. The research team attempted to resolve this problem by replacing the leaf spring with a precision linear sleeve bearing and linear compression spring which would act to resolve y- axis displacements, however further testing of this system indicated that the friction forces generated by the bearing sleeve were sufficient as to induce a non-linear response in the sensor, resulting in unrepeatable measurements under static hydraulic conditions. Based on the presence of significant deviations from expected results during static conditions, it was assumed that such erratic behavior would also be present during measurement of hydraulically generated lift forces due to the non-uniform distribution of such forces over the sample surface.

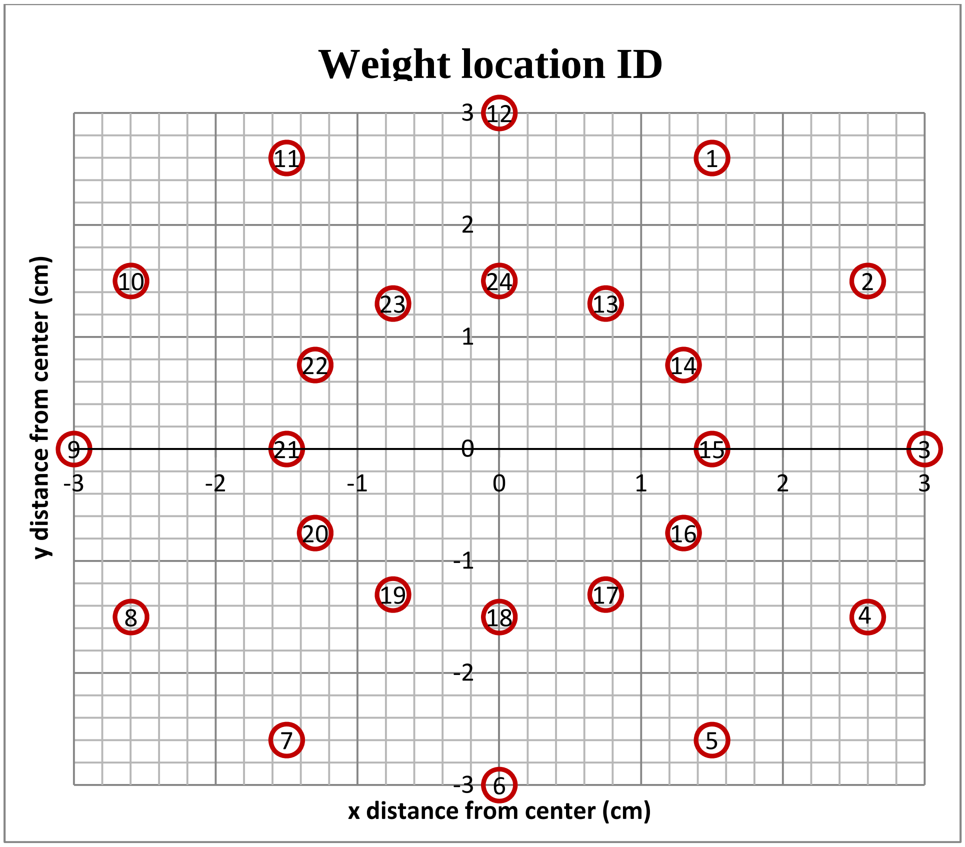

Figure 7-Location ID for Weight measurements taken from probe head

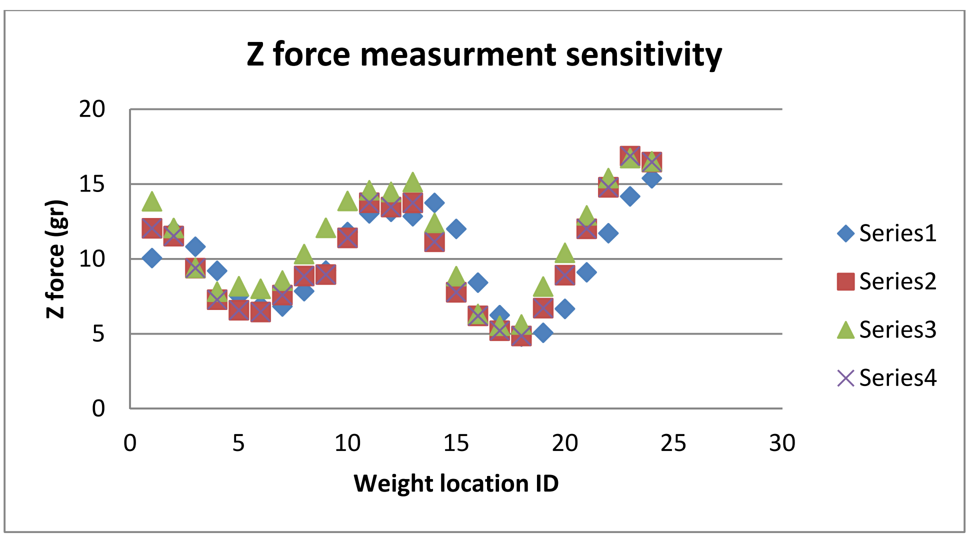

Figure 8-Variation in weight measurements as a function of distance from center for a 17.8 gram weight (submerged)

Stochastic Drift- Aside from errors associated with un-resolved y-axis deflections, the z-sensor also showed signs of stochastic electrical drift. Over numerous experiments where data was logged over periods ranging from 10 minutes to 24 hours, it was shown that the vertical force measurement was subject to randomly increase and decrease. Additionally this effect was worsened when a mechanical force was applied to the sensor head, it was experimentally verified that after logging a reading of greater than 10 Newtons, the likelihood of the sensor returning to 0+/- .5 N of the initial reading was probable but not guaranteed. Despite numerous experiments and electrical diagnostic reviews, in conjunction with the FHWA researchers and the device manufacturer to determine the cause and extent electrical drift, no controlling parameter could be determined.

Through diagnostic testing it was shown that there were no defects in the PTC-linked temperature sensor or the associated wiring, nor was the signal deviance, in the short term, a result of temperature or incoming electrical interference in the sensor housing. The effect is believed to result from a combination of permanent micro-bending in the vertical spring plate (the spring does not return exactly to its initial position after a mechanical deflection, as evinced by the fact that the return error was generally higher when a larger weight was placed on the sensor) and of minute temperature variations along the wiring and internal circuitry where the incoming voltages are magnified by several orders of magnitude by the amplifying board. Due to the extreme precision of the sensor head itself pre-amplification, a .1 micron deflection would be sufficient to produce a 10 gram measurement error (Prechtl). Therefore it is highly likely that the source of the error is predominantly generated by the mechanical design of the device and the structural limitations of the materials chosen.

Shear/ X-Axis Interference- The device is provided with an electrical mechanism which is intended to negate the impact of x-axis rotations (provided by shear forces) upon the vertical force measurement. The manufacturer assumed that there would, similar to the y- axis torqueing issue, be minor rotational displacements around the x-axis as a result of applied shear force and the bending of the vertical spring plate, therefore a cross-link between the circuits was added which could be used to subtract deflections generated by shear force from the z-force measurement. The manufacturer states that in calibrating the sensor, when applying direct horizontal shear forces of a set magnitude, simultaneous vertical measurements were taken. The linear relationship between applied shear force and vertical force error was then used to determine a multiplier to correct the z-force measurements in real time as a function of the incoming shear data and was thus built into the circuitry. However it has been shown by the evaluating laboratory team that use of such a multiplier can only be held as true when the sensor is experiencing pure shear forces directly along the x-axis, once a hydraulically generated lift force is applied and the summed force vector deviates from the horizontal plane the linear relationship cannot be experimentally verified under dynamic conditions.

Assessment-The evaluating team determined that an effective re-design of the z-force sensor would be required to acquire meaningfully accurate data. As the culmination of error sources listed above, especially for base flow rate measurements (between .1- .5 m/s) where the vertical force is theoretically estimated at < 5 Newtons makes the current design of the electro-mechanical systems un-suitable for studying the erosion behavior of loose cohesive sediments. *Perhaps more importantly was the presence of visible erosion during experiments where no measurement, or positive measurements, for mass loss were recorded.*

Alternative methods- Given that the samples were confined using the ring and puck system, static weight loss measurements were taken during the no-flow portion of each erosion cycle throughout each experiment, such readings were acquired using an adjacent laboratory scale with a submerged hanging basket, which was shown to have far greater precision and accuracy than the vertical force sensor or the weight loss sensor (Please see section VII for further discussion). In regards to the measurement of minute lift forces acting on the sediment surface during flow conditions the following modifications are recommended-

Y and X Axis Error- In a future update of the device an additional two hall sensors could be integrated within the vertical force measurement transducer system, mounted rotationally and equidistant to the permanent magnet relative to the current hall sensor. Their electrical outputs could therefore be used to triangulate the position of the magnet along the horizontal plane. When this is known the true extent of electrical field error can be assessed, however the exact design of such a system is beyond the expertise of the evaluating team.

Drift Error- Resolving the drift issue is likely much more complicated than resolving the torqueing problem. Because the initial voltage differential resultant from mechanical displacements of the permanent z-magnet within the hall sensor field is incredibly small and must travel through the sensor board and into the control mainframe prior to amplification it is likely that even microscopic changes in the position of the magnet will yield significant variation in results. The author is willing the speculate that a looped servo-mechanism, such as is found in the shear-stress force transduction assembly, capable of negating mechanical displacement while simultaneously capable of measurement is required for heightened accuracy.

Servo-Electric Shear Stress Measurement

The shear stress sensor assembly contains three permanent magnets which are rigidly affixed to a central mounting bracket which is seated upon two leaf- springs that allow for mechanical deflection, in the flow-wise direction under shearing conditions. Winter and Aracharya et al. [xx] describe shear stress sensors of the type deployed in the ESETM as “Floating Type Direct Measurement Sensors.” The aim of the array is to derive shear force as the horizontal component of the total applied force (vertical and horizontal). The bottom magnet and hall sensor are responsible for the actual horizontal position measurement, in turn it is connected to a servo-electric solenoid, positioned up-stream relative to the direction of flow, on a continuous feed-back look. A current which is proportional to the force being measured is shunted from the shear force hall sensor to this solenoid which produces an attractive magnetic field capable of returning the sensor platform (a bracket on which all permanent magnets associated with force measurement are mounted) to its initial position

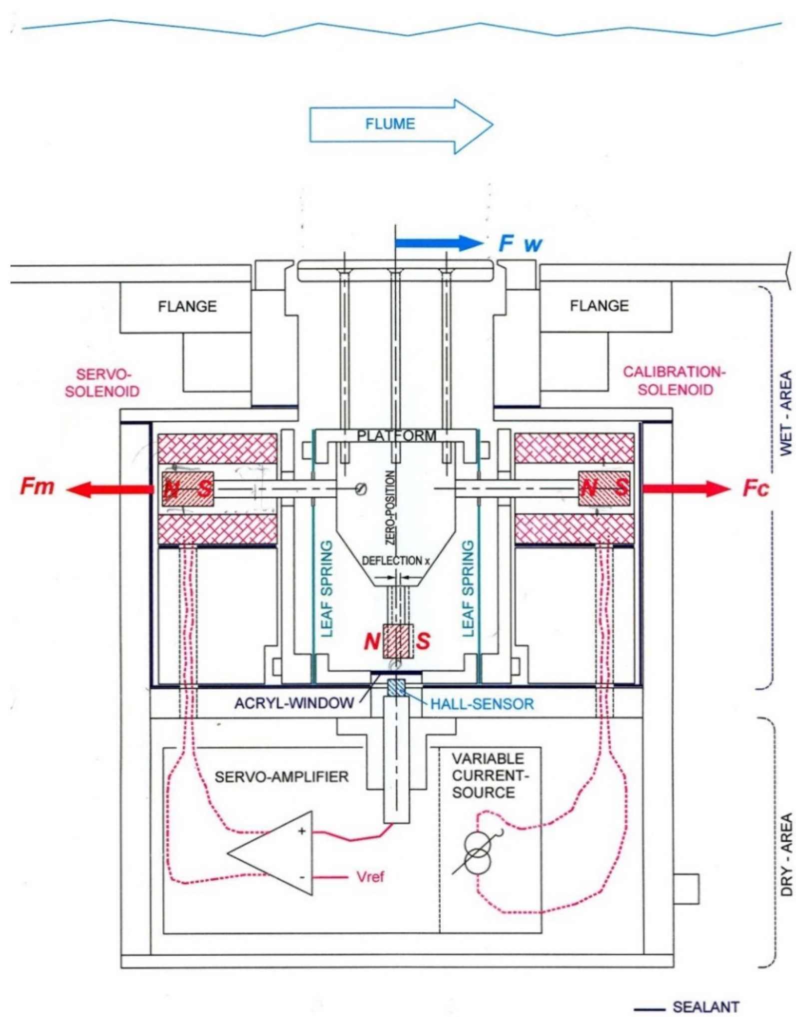

Figure 9-Shear Force Sensor Principle of Operation Diagram

Measurement- When hydraulic flow passes over the sample surface, shearing forces are provided to the sediment in two ways: Skin Friction and Form Drag. Skin friction is a measure of the friction force which occurs between water molecules and the surface of individual sediment particles which are exposed to flow, its effects are most pronounced on the micro-scale, however skin friction is given to be a material property unique to sediment mineralogy, particle size and texture, and may have a broader application in defining both the relationship between geotechnical properties and erosion behavior along with strongly influencing the development of bed-forms. Moreover skin friction is believed to be more useful as an erosion model parameter as bed forms are highly irregular, ephemeral in nature, and cannot be readily measured or mapped for large scale systems. Both are known to have modifying effects to the flow regime in proximity to the bed; however it is generally agreed that skin friction effects are limited to the viscous sub-layer whereas bed-form protrusions can affect the flow regime throughout the entire boundary condition.

> "Bed-forms influence flow structure and shear stress. The increased roughness created by the bed-form acts to increase total bed shear stress in the region away from the bed (the outer flow). Form drag acting on the bed-form, however, decreases the ability of flow shear to impact sediment grains on the bed, by decreasing the skin friction component of the total shear stress. From the last point, it follows that the shear stress felt at the bed (called the skin friction shear stress) is not equal to the spatially-averaged total shear stress (the bed shear stress). The difference between the skin friction shear and the total shear is the form drag the skin friction component is less than the total shear stress. Only for a perfectly level bed will the skin friction shear stress equal the total shear stress. The strength of the skin friction and form drag components of shear stress vary over the wavelength of a bed-form. The skin friction shear stress acts tangential to the local bed surface." [Nielson]

Given that the ESETM measures the entire hydraulic force applied to the sediment sample, which is then divided by the sample surface area to derive Pascals, the measurement can be taken as the spatially averaged total shear stress or bed-shear stress for the sample. Samples tested in the device may be mechanically flattened or cut, however advantageous for arriving at the skin friction shear stress which is generated by a given material for sub-critical shear force, it is considered to be highly disruptive to the naturally occurring sediment structure for cohesive material, and cannot be applied to the determination of erosion rate as a function of skin friction shear stress because the very act of erosion will modify the surface form and texture.

Calibration- The designers of the ESETM provisioned the system with an additional solenoid (positioned downstream relative to the flow direction) and associated electrical controls which allow for internal calibration of the shear sensor. A variable current source generator provides an exact electrical impulse to the calibration solenoid (see p. 16 in ESETM Manual Volume 1 for details) attracting the calibration magnet as to simulate the physical deflection which would be provided by a horizontal shear force. The out-coming voltage registered by the hall sensor is then sent to a summing variable op-amp (used to zero out the incoming voltage under no-flow conditions), and to a multiplying op-amp which works as the calibration control by multiplying the voltage registered against a user defined multiplier intended to modify the out coming reading until it is equal to the calibration value desired. The device can be calibrated to 10,20,50, or 100 Pascals, depending on the range of shear forces to be measured as the smaller ranges also provide higher measurement precision, however all measurement ranges have been shown to exhibit a high degree of linearity in their response.

Verification- The device is also periodically verified using a NIST traceable dynamometer which is capable of providing precise forces directly onto the probe head along the x-axis. By conducting an initialization of the device using the calibration method described above, the dynamometer can then be used to apply forces equal to the initial calibration values. In general the device has shown excellent compliance between the calibration value and verification value. Rarely has the variance been found to be greater than 5% of full scale (.5 Pa for a 10 Pa Calibration, 1 Pa for a 20 Pa Calibration, etc.). In such cases the potentiometer governing the variable current generator, providing the calibration force, has been adjusted to assure compliance.

Hydrodynamic verification- While static determination of shear measurement is apparently well aligned with the values provided by the dynamometer, the team has also attempted to verify the readings during flow conditions by modeling the channel in Computation Hydro-Dynamics Software. As can be seen by comparing table 2 (Shear Stress results) against the ESETM results there is a reasonable match in results for multiple runs between .5 m/s and 1.0 m/s readings. The data reinforces two simple assumptions that are made in doing any such comparison 1) Hydrodynamic Models in all cases represent a simplification of the natural system, whereas secondary flows (water movement under and around the probe head in this case) are negated and very small (below 1 mm) eddying behavior is ignored. 2) The large scale effects of Brownian motion between water particles make impossible the exact recreation of hydro-dynamic conditions. While statistical average of the data generated by the ESETM indicated a close match to the estimated values (.88 and 2.8 Pa respectively), there exists a clear trend for an increase of measured error (standard deviation) as a function of applied hydraulic velocity which should be expected due to the increase in turbulent forces.

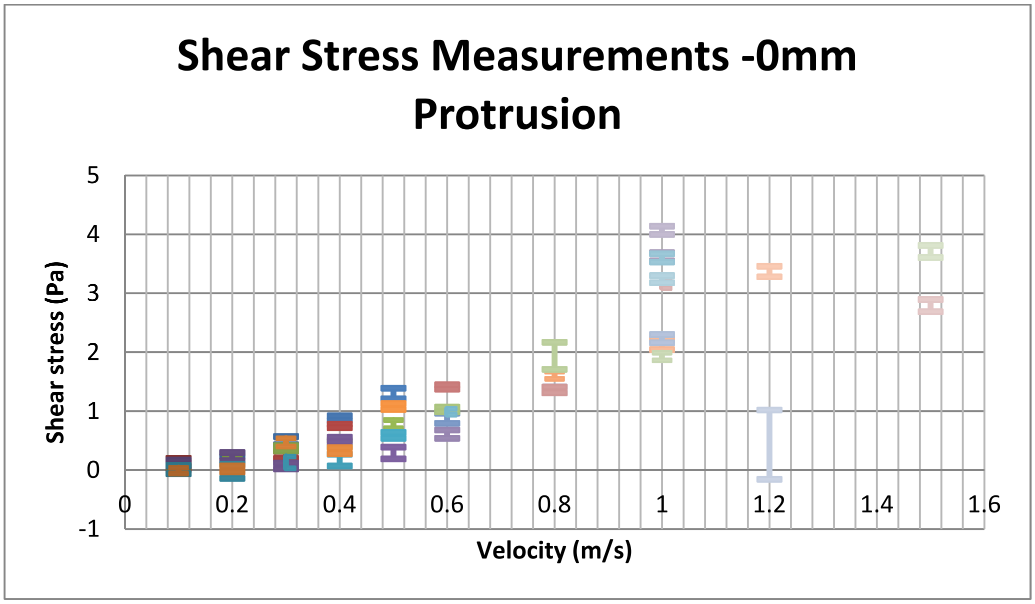

Figure 10- ESETM Calibration Results with Flat Aluminum Puck

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TABLE 1. Flow Conditions

Location	*Quantity*	*Value*
Flow	Fluid	water
	Ref pressure (atm)	1.0
	Ref temperature (deg C)	25
	Turbulence model	$k-\omega$
Inflow		
	Velocity (m/s)	0.5 and 1.5
	Turbulence intensity	1%
	Turbulence length (mm)	1.0
Outflow	Method	Average pressure
	Blend	0.05
Wall	Type	Solid
	Option	Smooth
Numerics	Advection	High resolution
	Turbulence	First order
	Inner loop convergence	10^{-4}

TABLE 2. Shear Stress

Velocity (m/s)	*Shear Stress (Pa)*
0.5	0.88
1.0	2.80
1.5	5.95

Figure 11- Predicted Shear Stress Measurements by Computational Fluid Mechanics Software (compare with above)

Above (See figures 10 and 11) it is clear that the magnitude of shear stress error is proportional to velocity for the flat puck scenario. Greater velocities appear to create a larger range of possible results. However since the flow conditions are believed to be uniform based on readings from both pitot tube and flow meter, it can be concluded that some form of error is being generated by the sensor and its relative position in the flow.

Potential Sources of Error-The following potential sources of error are discussed at length for measurements of shear forces in aero-dynamic's practices; however such generalized critiques can be applied to hydro-dynamic conditions as it can be assumed that such errors will also be pronounced by the viscosity of the fluid. The following potential sources follow from the paper by Winters and Arachya:

"Provision of a transducer for measuring small forces or deflections, and the compromise between the requirement to measure local properties and the necessity of having an element of sufficient size that the force on it can be measured accurately." (Winters 1993)

In the case of the ESETM the sample diameter and mass are restricted by both practical application needs, and the minimum precision levels, needed to assess the forces generated under low flow conditions, available even in high end force transducers. As can be imagined, a very small sample would be ideal for determining the erosion response for a given material, as the localization of distinct parameters, particle size and angularity, form, cohesion, could be more readily generalized for that very specific site however there would exist some critical threshold whereas the forces involved would become so small that they fell below the linear resolution of any such magnetic force transduction system. In larger samples, the heterogenaety of a given material is exposed, meaning items such as gravel, large bed forms, and organic detritus contribute to an average shear-stress value for the sample which is highly distorted by the presence of such outlying structures whose distribution could not be integrated within a predictive model. Moreover a very large sample represents particular difficulties for mass loss measurement as the precision and maximum capacities of most laboratory scales follow an inverse relationship."

> The effect of necessary gaps around the floating element- The present of gaps which exist between the aperture ring and the probe head element (=1.5 mm) are crucial for the application of sediment erosion measurement. The first and primary concern, which arises from the presence of gaps and the induction of relative pressure differentials between the sediment sample and the surrounding Plexiglas channel, is the potential for secondary flows to occur. During periods of flow it should be considered that the fiction and form of the sediment sample is causing a relative slowing of hydraulic velocity along the boundary layer, creating a zone of positive pressure before the sample and a zone of

lower pressure behind the sample. While these forces are expected to develop relative to the sample it should be noted that in this instance where the probe itself remains submerged that there may be a potential for secondary flow, which is flow which occurs beneath the probe head and through the gaps affecting the accuracy or measurement. This presence of this type of flow has been suspected due to anomalies that are sometimes seen is the shear data, such as negative readings, or readings that decrease as velocity is increased. While the mechanical and spatial limitation of the sensor made the direct observation of this hypothesis impossible within the context of the current study, it follows logically that since electro-mechanical errors were ruled out by repeated testing and calibration that there must exist some force which is acting against the direction of primary flow and can only be accounted for by the presence of a secondary flow moving between the gap spaces. The servo-solenoid mechanism is helpful for allowing a minimization of the gap diameter however given the nature of the material to be studied such as loose heterogeneous mud, sands and gravels that tend to erode non-uniformly there must be some gap as to offer space through which small particles slaking from the sample can fall without artificially displacing the probe head by mechanical means. Moreover the effects of misalignment and pressure differentials are made significantly worse as the gaps are made smaller as the velocity of secondary flow will increase with the decrease in hydraulic diameter though which fluid can move.

The effect of misalignment of the floating element and the hydraulic development of pressure differentials- Alignment concerns are primary for shear force measurements (reference velocity vs. shear stress chart) as form drag is known to be a major component of the total measured stress. Moreover vertical alignment gives rise to significant pressure differentials, turbulent zones, and the potential for forces to be applied directly to the front surface of the sample rather than friction forces taken directly along the top, forces which do not represent a natural hydraulic condition. Moreover the forces and pressure differentials produced by misalignment may be significantly greater than the skin friction or "surface form drag." Keeping the sediment probe/ sample aligned during testing for erodible material presents its own challenges as the exposed surface is irregular in geometry and little control is available to the operator to level the sample without significantly disturbing the sediment structure, moreover as previously discussed, in the event of prolonged experiments where the sample experiences significant erosion, the sample must be re-leveled with the channel bottom. Numerous attempts were made to develop mechanisms though which the relative position of the sample could be maintained throughout testing via a scientifically objective and rigorous method although each method was shown to have its own shortcomings. See Experiment design p xx for further details.

The effects of Temperature Gradients- The device as mentioned came equipped with a temperature sensor mounted in the sensor housing along with the electrical components to resolve the effects of temperature fluctuations on electrical conductivity by shunting a proportional voltage governed by the temperature sensor onto the shear stress sensor output line. The resulting measurements have been shown to retain their calibration to a high degree of accuracy within a +/- 5 degree F window from a temperature of 70F. As the room is climate controlled it is highly unlikely that a fluid temperature change of greater than 5 degrees would occur within the duration of a single experiment or for a given calibration.

Assessment- The evaluating team regards the shear stress sensor overall as being capable of providing real time spatially averaged force readings as applied to cohesive sediment samples measurements for non-fluidized core samples taken from the field. However it is important to note that the measurements taken are highly variable due to the contribution of form drag and likely do not represent intrinsic material characteristics, but more a measure of the geo-structural artifacts of ongoing erosion processes in the field, coring, sub sampling. The device is largely capable of providing similar data for the skin friction of manufactured samples with perfectly level surface geometry however the conditions of leveling the sample exactly with the channel bottom may give rise to some form generated error which is beyond the current specifications of the device to assess. Future modifications or alternative systems should, via Laser Doppler Velocimetry or other imaging system be capable of 1) deriving spatially averaged values for skin friction separate from form drag and 2) provide a mechanism for measuring the average surface elevation in reference to the channel bottom. As it is far more likely that geotechnical material parameters are relatable to skin friction than they are to form drag. For the purposes of predicting erosion in large scale systems it should be known, for a given material, the magnitude of forces associated with skin friction which as mentioned should have a much better quantitative relationship with erosion rate and material parameters because it is believed to be largely dependent on particle size, shape/ angularity, and minerology, and density (void space per unit volume) which are far more temporally static than bed forms that tend to change much more rapidly as a function of season, local ecology, storm induced flow behavior, man-made obtrusions, and base rate flow though at a smaller scale. Because there is a pragmatic compromise between measuring the shear stress at a very small scale, and the requirement to test sections that can be considered representative of the bed (see above section d-1) the skin friction of a particular material under hydraulic stress should be known for a spectrum of velocities. In the case of a particular bed or site in study, the averaged skin friction values could potentially be used across each grid in the entire mesh grid found to meet similar geotechnical parameters. Bed form drag is much more feature dependent and given that bed forms are often orders of magnitude larger than ESETM samples, the component of “total bed shear” which is derived from form drag should likely be modeled rather than measured using precision Lidar or sonar bathymetry methods.

Fluidized material- In the case of fluidized or suspended material found at the boundary layer in nature it is considered beyond the capability of the device to effectively measure the true extent of shear forces needed to produce transport behavior as those forces are not implicitly transferred through the material to any significant depth. (Insert diagram explaining relationship between boundary flow velocity and

Alternate Methods

Spatially Averaged Skin Friction – There exist a number of laser/ optical methods including Laser doppler velocimetry and Particle Image Velocimetry which are specially designed for acquiring velocity data through a defined (usually 5-50 micron) section of the boundary flow layer. The application of this information can be used to align a theoretical velocity curve which can

Flow Controls and Measurement

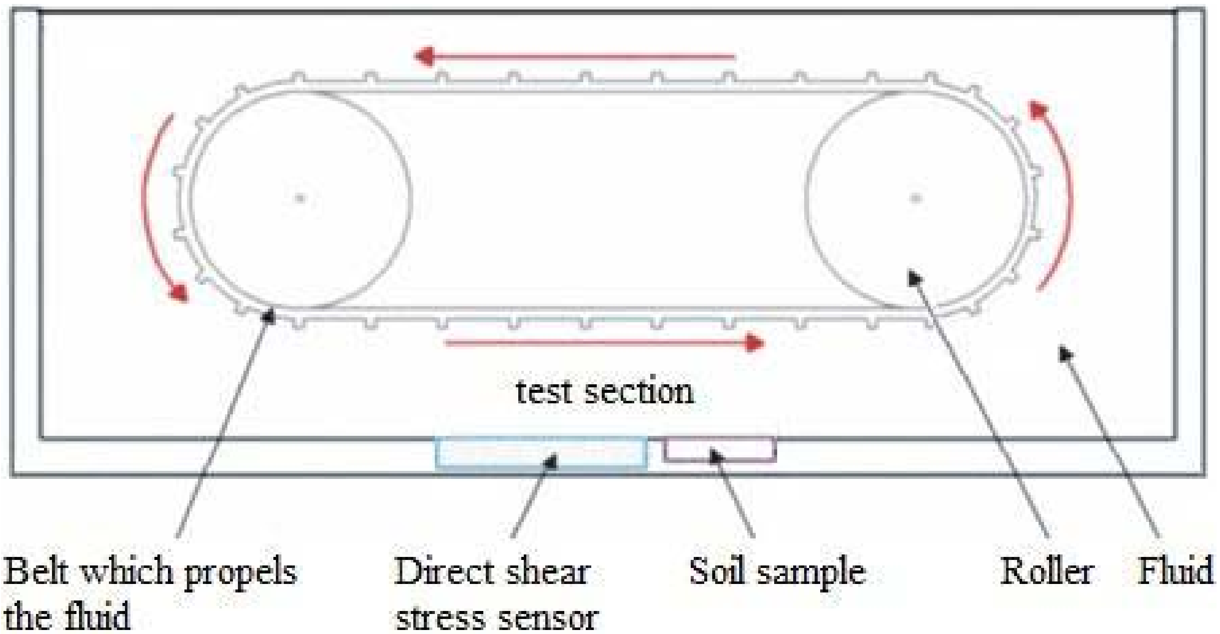


Figure 12- Band Drive Schematic

While it is clear that the geotechnical and chemical properties of estuarine sediments is of great significance in determining their erosion behavior under a given shear stress-the significance of flow regime is often overlooked in erosion experiments. The designers of the ESETM took into account that the applied shear stress acting on a given sediment sample could be significantly different for different flow profiles that all had the same average flow velocity. Hydrodynamic theory has shown that the applied shear stress is proportional to the slope of the flow velocity as a function of height within the laminar or diffusive boundary layer. As depicted below ~~in~~ (figure 13), three different flow regimes each with the same average flow velocity (given as volume per unit time moving through a pipe or channel) can have significantly different velocity profiles especially near the boundary conditions. In diagram a, an open channel or “Couette” flow is depicted whereas the velocity of the flow decreases from it maximum value at the surface and decreases to zero at the bed or boundary condition. Conversely in a “Poiseuille” flow or pipe flow regime, the velocity is highest in the center, and decreases as it approaches the boundaries or pipe walls. In diagram C, a blend of these two conditions is depicted. The designers of the ESETM aimed to create a condition such as this as it is largely thought that the turbulence found in the Logarithmic flow layer acts as a type of boundary, therefore giving rise to a flow profile in the viscous-sub-layer that is most similar to Couette-Poiseuille conditions. (Wagner 2010)

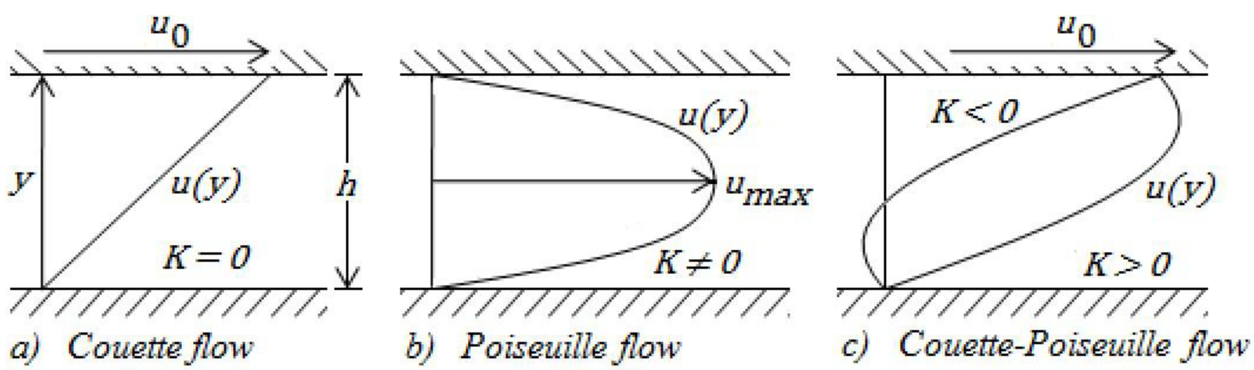


Figure 13- Unidirectional Planar Flow Scenarios

Theoretical Principle of Flow Generation-

The ESETM is equipped with two primary mechanisms for the creation of a couette or open channel type flow within the main testing channel. As opposed to a Poiselle or pipe flow which is found in traditional sed flume, the design of the ESETM provides for a band drive within the sealable main testing chamber which is capable of modifying the flow profile by increasing the flow velocity along the top edge of the test channel while continuous flow is provided to the inlet of the main testing chamber by a pump.

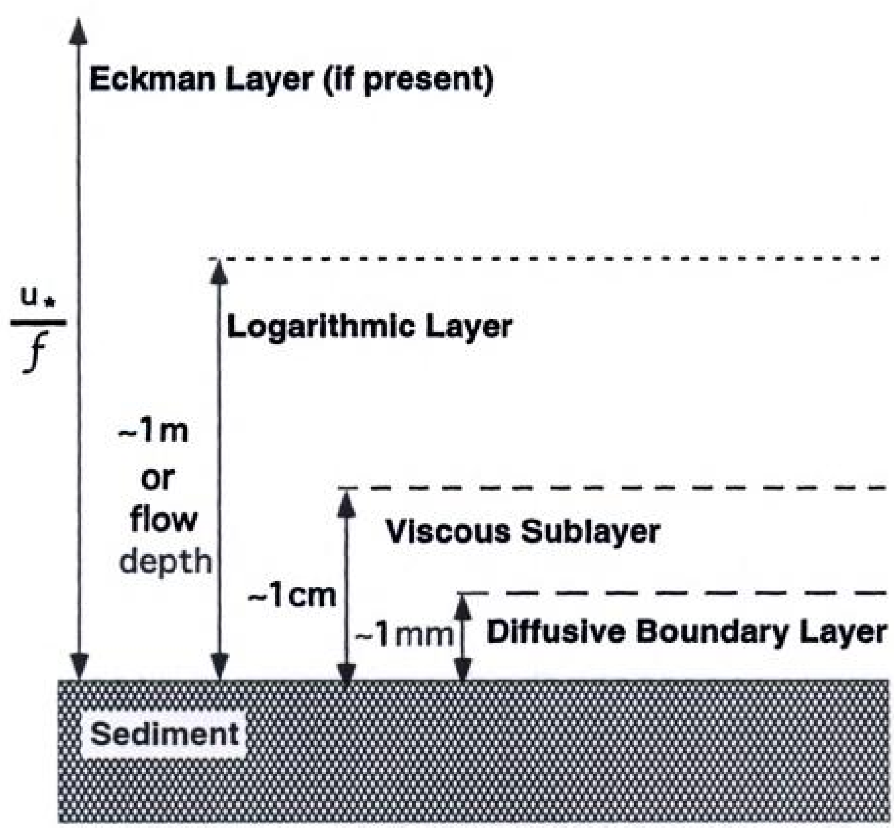


Figure 14- Anatomy of the Benthic Boundary Layer

The intention of the band drive is to develop a laminar/ boundary flow condition which is quite similar to natural boundary flow conditions. As can be expected not all flows are created equal. In the case of a pipe type flow one would expect the highest velocity in the center with decreasing velocity toward the sides. Given that the flow meter of the device provides output in units of volume/ time, a simple conversion is made between the cross-sectional area of the flow meter inlet and the cross sectional area of the main testing channel. Empirical calculations are employed to determine both the average and peak velocity of flow moving though the main channel as the volume per unit time is known. By applying band generated flow, the volume moving through the channel per unit time is increased, however the flow profile through the boundary region is elongated on the velocity axis as a function of height. Therefore, given similar flow velocity before the main channel and band drive, we can assume that dUbar/ dh or Ubar/ height for the couette flow would derive a higher average shear stress along the sample surface as opposed to a pipe type flow.

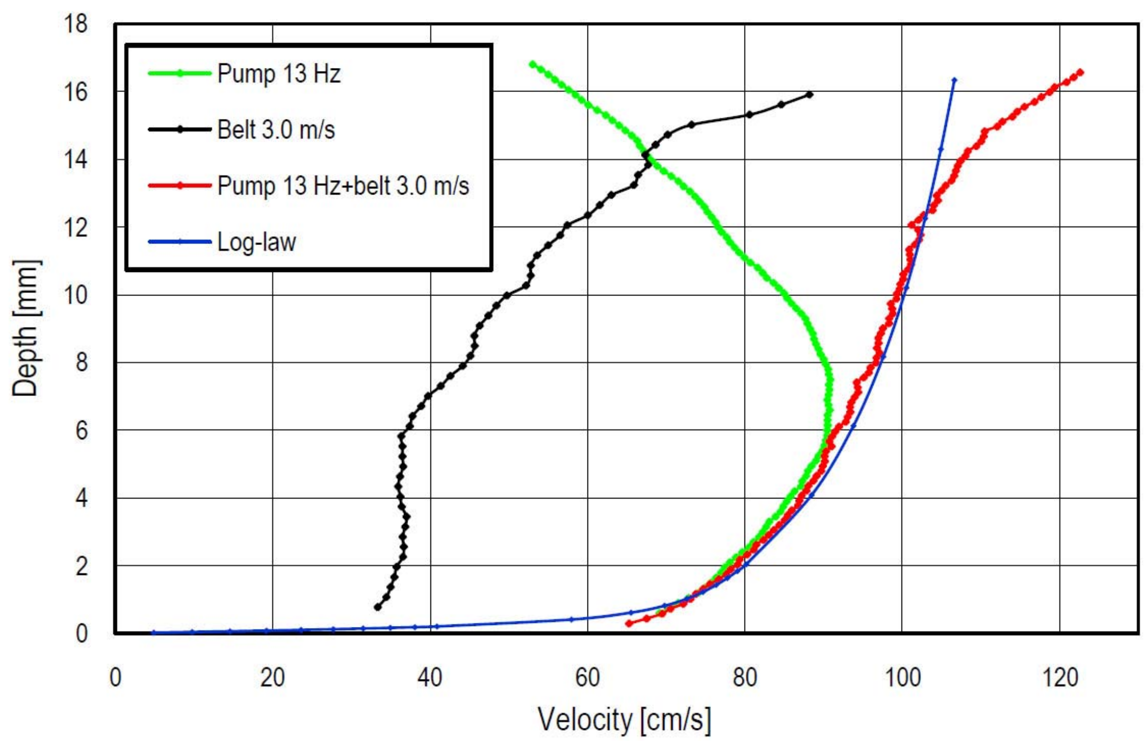


Figure 15- Flow Velocity Relative to Depth for the 2 cm Channel (FHWA)

During the development of the device, numerous measurements of the flow velocities were taken and provided to the Rutgers Team (See Figure 15) as a means of calibrating the device (as Rutgers was not equipped with a LDV or PIV system to take finite velocity measurements). However as a result of~~in~~ the structural differences between the two devices it was found that these calibration standards did not apply accurately. Moreover, data derived when running the band indicated much higher variability in the shear stress measurements taken by the sensor, leading to the conclusion that for relatively low velocity experiments such as should be conducted to measure erosion in estuarine conditions, ~~that~~ the resultant increase of turbulence at an unknown magnitude generated by the belt, and the difficulty presented that would be required to calibrate the belt to a flow regime (requiring precision in field-study of benthic flow conditions for a particular site) it was thus concluded to forego the use of the band drive for the bulk of experiments performed with the ESETM.

Flow Meter

The device is equipped with a high precision electromagnetic flow meter from Seimens. (Documentation to be found in Volume 3 of the ESETM Users Manual.) This flow meter provides volumetric data which is then via the hydraulic diameter of the pipe converted into flow velocity (m/s.) The flow meter also provides real time flow data directly to the lab view data acquisition system at a rate of 10 hz.

Pitot tube

In order the verify the flow velocity of fluid moving within the test channel a specialty pitot tube system was integrated directly into the device that allowed for comparison between the flow meter value (which was positioned prior to the flow channel.)

VI. Experiment Design

Sample Acquisition

Sediment Sampling

As the name implies, the Ex-Situ Erosion Testing Machine (ESETM) requires a repeatable methodology for acquisition of sediment samples from the field and their return to a controlled laboratory setting. Special care must be taken to ensure that the native structure, stratification, density and material properties (biotic and otherwise) of the specimen are retained during the course of sampling, transport, storage and sample preparation. The following section will detail the procedure and quality control, and classification practices used to ensure that samples tested in the device retain material properties as close to field conditions as possible.

In order to effectively acquire sediments from channels, wetlands, harbors, mudflats and a list of other aquatic and tidal environs, a boat with a shallow draft and crane arm is required. The CAIT laboratory team has used a standard mono-hull 16' boat with a 3 foot draft and a 3 ' radial crane arm mounted to the bow of the vessel (See image 1).

The coring device used is a KC-Denmark, HAPS Suction coring device which provides samples of a 5" diameter and varying depth from 4"-16" (See Figure 2). The use of vibra-coring devices or Ekman-Birge type devices is not generally advised as the risk of extensive sediment disruption is increased by the mechanical action in such corers. Among the devices commercially available, the KC-Denmark HAPS device allows for minimally disturbed cores by reducing mechanical action such as shoveling, scooping or shaking, which may alter the density and internal structure of the sediment prior to retrieval. The principle of operation depends on allowing water to escape from the top of coring cylinder via a moving suction plate (Figure 3)as it sinks into the sediment. When the device is raised, via the crane) the suction plate is forced over the top of the coring cylinder by water pressure (one limitation of the device is that deeper/ heavier samples generally need be taken from a deeper depth in order to achieve adequate pressure against the suction place to dislodge the sediment. Also if the sample is of particularly high moisture content throughout >90%, the internal structure may be inadequate to act as a plug in which low pressure can develop.) Thus a water tight seal is created around the cylinder generating the required suction to lift the sample. Upon returing the probe to the foredeck of the sampling vessel, samples should first be visually verified for acceptability. The most visually appearant marker of excessive disruption is surface water turbidity (Figure 4). In the event that the sample is returned with an appearantly clear water top phase a laboratory syringe should be used to take a 100 ml water sample from above the core in the cylinder approximately 2" above the sediment surface for laboratory testing (See Figure 5). As the literature indicates that salt and brackish water is generally known to contain <5000 mg/L TDS, it is advised that clear phase water coming from sediment samples not exceed this value or it can be assumed that significant disruption and re-suspension has occurred.

Transportation and Storage Procedure

Once a sample had~~s~~ been acquired, transporting it to the laboratory was~~is~~ a secondary concern. CAIT researchers ~~have u~~sed an insulated plastic cooler ~~which is~~ filled with native water for submerging and transporting the cylinders (See figure 4). Filling the chamber with native water was~~is~~ crucial as it is important to ensure the nutrient/ salinity balance for naturally occurring biota and for dampening the vibrations that may adversely affect the sediment while in transit.

Upon reaching the testing facility, the research team ~~should either~~ removed the sediment from the transportation tank and placed it into a temperature controlled aquatic storage unit (environmental chamber) or ~~as we have done,~~ prepared the transportation vessel to be directly connected to a cooling system. Benthic muds containing aquatic biota are ideally preserved at around 4C or 38F.

Sample Preparation

The Ex-Situ Erosion Testing Machine is equipped with a sediment probe capable of holding a 60mm diameter sample of 25 mm depth. Since cores are not field sampled in this geometry it is necessary~~ssecary~~ to cut them to size using a sequence of rings and slicing devices (See Figure 6). When the sample cylinder is mounted on the ejection aggregate, the sample is raised approximately .5" (12-14mm) above the top rim into an affixed sample ring 1" Height x 5" Diameter.

Figure 16- Cutting Ring and Base Puck

Using a filet knife, sharpened spatula, or comparably sized razor blade, the sediment should be cut gently, making sure that large particles, branches, leaves, roots and miscellaneous debris is severed and not dragged across the sample causing large scale disruption to its interior. Once the sample is cut for height, a holding plate must be slid underneath of the consolidating sample ring between the two sections of sediment, again this should be done very gently. When the sample has been prepared to this extent, a specialty aluminum cutting ring should be used to cut two 60mm samples out of the 5” section. Retain the sample within the ring, then slide the sample off of the holding plate directly onto the mounting disk and slide the aluminum ring down onto the disk until exactly 2 mm of sediment are exposed beyond the ring. Assuming the surface texture will never be entirely flat, determine the height of the sample above the ring from the lowest point on the samples external periphery to ensure that the ring is never protruding beyond the sample surface.

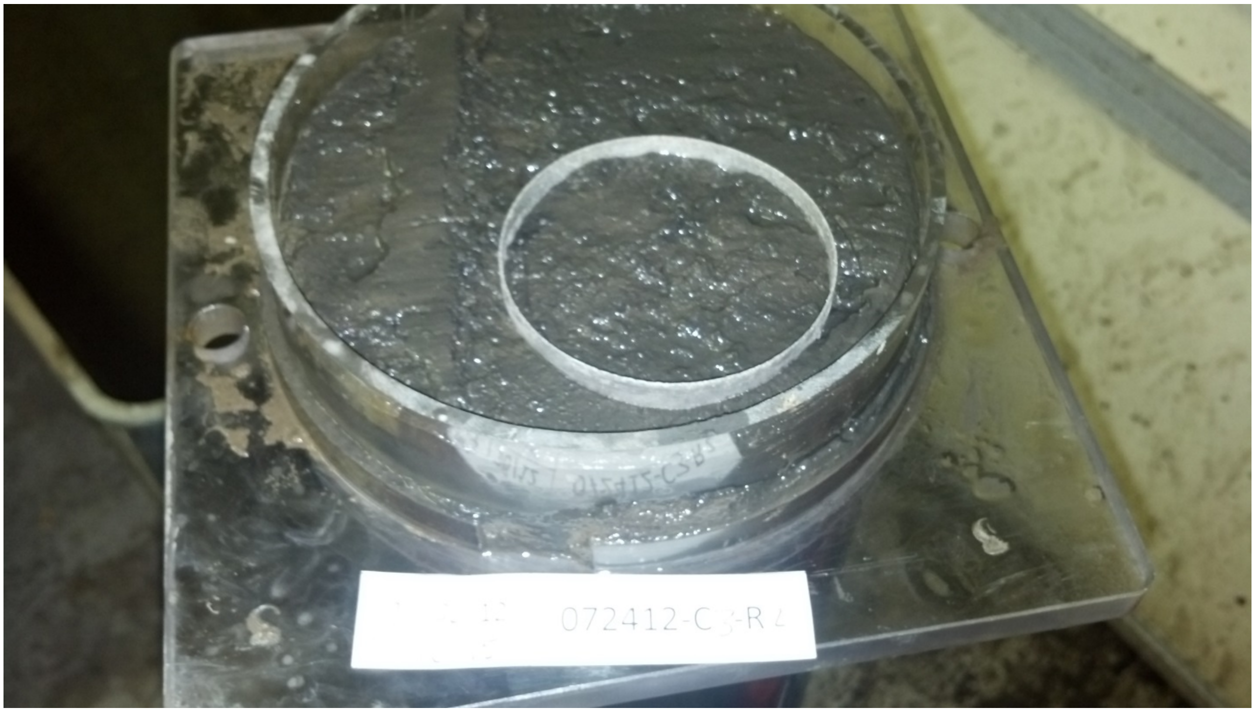


Figure 17- Extruded Sample with Cutting Ring

Place the sample within the main tank of the ESETM. The sample should be allowed to initially hydrate within the testing channel for a period of ten minutes, and then weighed on a submerged scale mounted above the ESETM main testing channel, repeating at intervals of 10 minutes until the measured weight no longer increases (to a precision of .1 grams) to ensure that the sample is fully hydrated. Special care should be taken that no portion of the sample be exposed to air during the entire course of the calibration and testing phase. After taking the initial weight ensure that the elevator of the sediment probe is completely raised and screw the sediment sample (aligning the screw of the mounting disk) onto the probe until snug.

Figure 18- Completed Sample With Ring and Puck

Device Calibration and Preparation

Prior to installing the mounting disk it is important to verify the calibration of both the shear stress sensor and the z force sensor. This should be done using a 20 gram weight and the built in shear stress calibration function in the device main control box. (Follow instructions as per ESETM Manual) After installing the mounting disk, the sample should be lowered using the elevator to its bottom most position. At this time the main channel may then be sealed. Using the elevator and the set pin assembly, raise the sample until 1.00 mm of sediment remains exposed to the flow. (This will mean that the consolidation ring should be 1.00 mm below the upper edge of the aperture ring). Such a height can be verified by inserting the set pin assembly and slowly raising the elevator until a measurement on the z-force sensor is first registered, this indicates that the ring and pins have come into contact and are thus at the correct height to begin a test. Should the z-force or shear stress deviate from 0, use the control program to re-zero the initial measurement but do not touch the calibration dials.

Test Set Up and Controls

The ESETM Labview Control program was~~is currently~~ equipped for two distinct master tests. The first was~~is~~ determination of critical shear stress range, which is intended~~should only~~ to be run when investigating new sediments as a starting point for which to run erosion rate tests, by ~~it should~~ informing the user of the minimum velocity required to initiate sediment transport. The second was~~is~~ an erosion rate test that should supply the data needed to define a curve of erosion rate (g/hour as a function of shear stress) as well as a materially dependent curve of shear stress as a function of velocity.

Critical Shear Stress Test

This test ~~will~~ provided an automated flow ramping effect in progressive increments of 5 minutes and then returned~~ing~~ to a condition of 0 flow velocity for an additional 2 minutes. We e~~E~~nsured that the acceleration of the flow was~~is~~ limited to 5% of the maximum requested value for each increment and did ~~s to~~ not exceed the maximum value (failing to do so would have~~ill~~ caused ~~for~~ an erroneous calculation~~onclusion~~ of the critical shear stress as the flow would have~~may significantly~~ exceeded the requested maximum rate in coming to hydraulic equilibrium if the acceleration rate was set~~is~~ too high.) The critical shear stress value may be verified by two methods 1) Visual confirmation of particle motion via the pen camera, 2) A measured reduction in shear stress values during the course of one interval (such a reduction should follow a negative hyperbolic function and settle on a constant value, indicating that erosion has had a "smoothing" effect on the sediment surface thus reducing shear forces measured.) Assessing the CSS may be done using~~by~~ either of the aforementioned criteria, however CSS~~it~~ should be validated by removing the sample and mounting plate from the sediment probe and measuring the~~a statistically significant~~ reduction in weight.

Erosion Rate Test

The erosion rate test designed for the ESETM was implicitly based on the design of the SED-Flume erosion rate test with some modifications to control for the variables of interest. As has been noted the ESETM erosion rate measurement is predicated on mass loss rather than on volumetric change, hence in order to determine the weight of any material that had eroded in any step of the procedure it was required to stop the flow and take a weight measurement.

The typical experiment consisted of multiple intervals, usually of about ten minutes, or other discrete durations of time.

When a new sample, after being prepared was placed in the chamber, commonly an "experiment sequence" would begin by determining the critical shear stress or "critical velocity" required for incipient sediment erosion. Once that velocity was determined using the ramping function as described above, that velocity would then be applied constantly to the sample for a set duration, a weight measurement taken, and then replaced in the sample holder before increasing the velocity in a subsequent interval.

A typical test was conducted in this manner:~~run as such~~

1) Cut and prepare sample, take measurements on dry weight, bulk density and moisture content.
2) Submerge sample, measure submerged weight after 10 minutes. Repeat after 20 minutes to ensure that submerged weight is consistent and sample is saturated.
3) Provide ramping velocity to sample (.05 m/s/s) starting from 0 to the sample until erosion is visually verified.
4) Reweigh sample.
5) Apply 10 minute interval of flow to sample at the velocity where erosion was first observed.
6) Reweigh sample.
7) Apply additional 10 minutes of flow to sample at a velocity .1 m/s greater than the initial value.
8) Reweight sample and adjust collar and sample elevation as required to maintain a level relation with the tank bottom/ aperture ring.
9) Repeat until sample is eroded or destroyed.

Several other tests were designed using the same basic method as described above. The difference usually being that velocities were repeated to determine the relative change in eroda~~i~~bility with respect to time rather than respect to velocity/ shear stress.

Additional Experiment Designs

Bio-Film Study

Bio film experiments were conducted much in the same way that the critical shear stress and erosion rate experiments were done. The first aim was to determine if the presence of biofilm lead to an increased critical shear stress, and subsequently if the presence of EPS decreased erosion of underlying sediments.

Shortly into this kind of experiment it was discovered that much like a skin, the biofilm could quite easily be sub-ducted by flow around the edge of the sample and consequently de-laminted from the sample. As this seemed to be non-representative of a natural condition where biofilm mats tend to be quite large and have few defined edges, a new sample cap device was manufactured in order than the edges of the biofilm could not be exposed to flow. Never-theless, it was found by repeat experimentation that obtaining, transporting, preparing and testing an intact piece of biofilm was extremely difficult and was only able to be successfully completed on a handful of tests.

Figure 19- BioFilm Sample with Edge-Ring

Erodibility of Stabilized/ Amended Sediment (Capping) Study

The experiment design for the creation and testing of amended sediment samples required that the research team considered the implications of an in-situ stabilization procedure in reality. In the field, sediments are mixed and then allowed to cure in an aqueous environment usually with overburde~~r~~n pressure applied by sediments and water above. For the purposes of our testing, the research team attempted to develop cyli~~e~~nde~~a~~rs in which the amended material could be cured with similar pa~~e~~rameters (rather than allowing air curing) and then testing in the device with minimum disruption. Twenty eight (28) of these curing chambers were constructed to allow for 4 different dosages of

Portland cement (0%, 3%, 8%, 12%) along with different curing times (0,1,7,14,28,60,90 days).~~ to be tested.~~

Sediment was mixed with the appropriate amount of Portland cement, and then sandwiched between two roughly 20 cm high pieces of untreated sediment, then an overburden weight placed on top. This was intended to simulate the conditions that would be found in the field as opposed to~~and not induce~~ the kind of curing behavior that would be seen in a more oxygen-~~-~~rich environment.

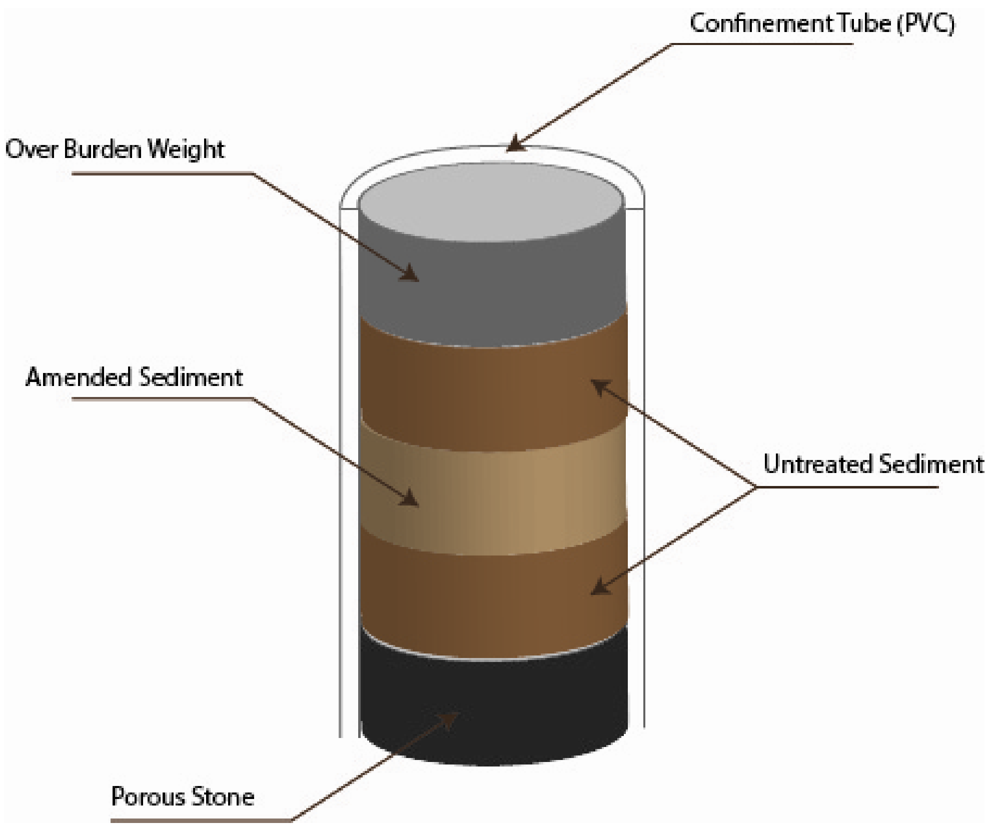


Figure 20- Curing Chamber

After ~~the ~~sufficient curing time had elapsed, the samples were removed, and the untreated sediment cut away from the treated sediment prior to testing which occurred as detailed in the erosion and critical shear stress tests described above.

Figure 21- Cement Treated Sample

SED-Flume and ESETM Comparison Study

Baseline Comparison

The baseline for comparison included the ~~baseline~~ testing of several manufactured sediment cores, consolidated in the laboratory from loose grab material that had~~s~~ been sieved and well mixed to ensure even particle size distribution and moisture content. This material, after preparation in the Rutgers Lab, and being sealed in moisture tight canisters, was randomly separated and half of the canisters sent to Sea Engineering. The objective of this testing procedure was to determine the general comparability of the two devices by evaluating erosion initiation of similar samples. ~~The thresholds at which they begin to measure erosion will be recorded and the data they generate prior to more detailed type testing which can best assess the relative strengths and weaknesses of the two devices and in which scenarios, if any, one is more applicable than the other for accurate and reliable erosion data will be reported.~~

Consolidation Apparatus

A custom consolidation apparatus was required for the comparison in order to ensure that the same sediment with uniform properties was~~is being~~ tested by both groups. The device was~~ill be~~ developed by the Rutgers team within the standard Sed-Flume coring box. (See figure 1 below). Sediment for making the cores was~~will be~~ supplied from the Rutgers Lab. The original location of that sediment was~~is from~~ the Arthur Kill south of Newark ~~bay~~Bay. It ~~is~~ was a fine~~-~~-grained cohesive sediment that had been screened for particles larger than 1mm.

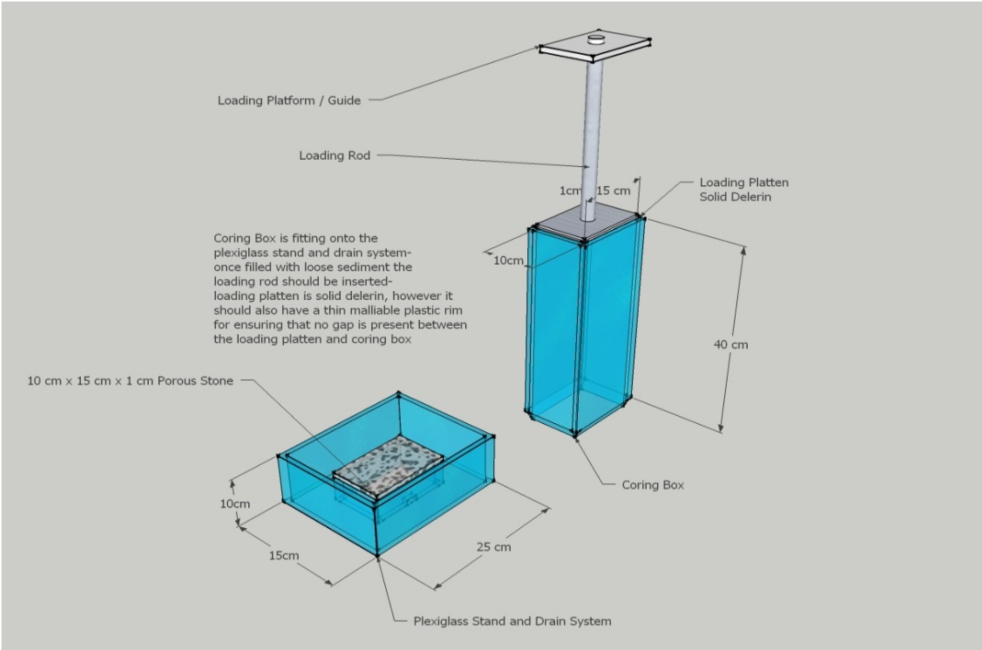


Figure 22-Consolidation Chamber Schematic

Test Procedure

An initial core type, each with a duplicate, was~~ill be~~ tested for a total of four cores (two per team). After each core was~~is~~ consolidated within its coring tube to an approximate height of 15cm, the tube was~~should be~~ immediately installed onto the sediment flume or sub-sampled for ESETM method. Only relatively small sections in the top middle and bottom of core ~~w~~was~~ill be~~ tested for comparison purposes.

SED-Flume Team

The following chart was used to report applied flow conditions in terms of channel flow velocity (see below Figure 2.) Each cycle will begin with the lowest hydraulic shear stress the device can provide, shear stresses from the cycle will not be automatically dropped until it has been confirmed via testing that there is no measureable erosion rate. As per standard procedure, the applied shear stress was~~ill be~~ increased and the time required to erode 1mm of sediment for each flow condition up to 1.5 m/s recorded. Intermediate values ~~should~~ included .25, .5, .75, 1, and 1.25 m/s.

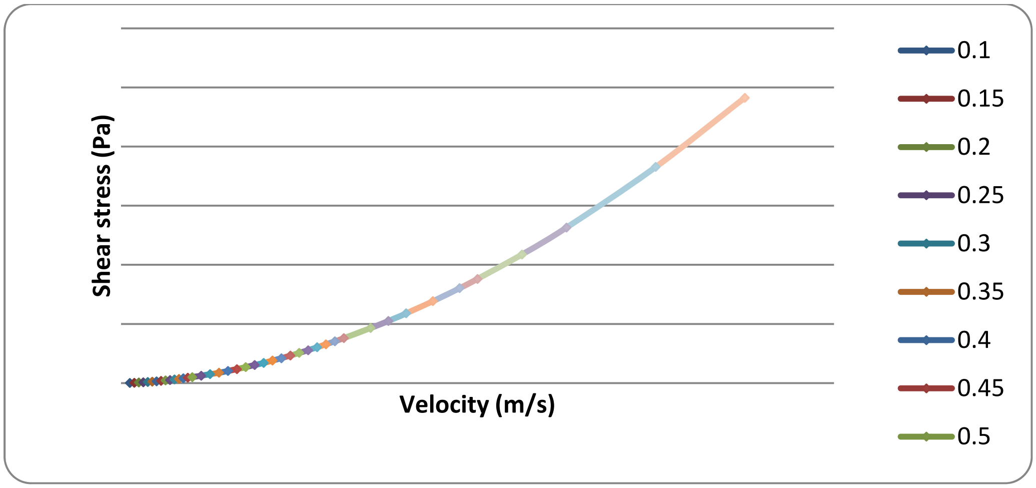


Figure 2- Implicit Relationship between wall shear-stress and mean channel flow velocity for an arbitrary cross section

After completing such a cycle for the surface material, erosion rate was~~will be~~ reported in terms of mass loss (g/m^2/hr). Five (5) cm of material was~~will be~~ extruded and discarded. The flow conditions described above were~~ill be~~ repeated for the middle of the sample, and finally after removing another 5 cm for the bottom of the core, the remaining 5 cm of material was~~ill be~~ discarded.

ESETM Team

This testing consisted of 8 sub-samples per core. A surface sample was taken from the consolidated core that is 2 cm deep. After installing the sample in the device and taking initial weight and density measurements, the team followed the SED-Flume procedure of applying the hydraulic flow velocities in 10-minute intervals and measuring the mass eroded. The measured average shear stresses were~~as also~~ recorded and the elevator and confinement ring elevations adjusted as needed ~~be~~ between erosion cycles. This process was repeated by taking subsequent sub samples from 5 and 10 cm of depth.

Core #	Consolidation Weight	Consolidation Duration	Consolidation Displacement	Sample Height
1	5 lbs	20 hrs	xx	xx
2	5 lbs	20 hrs	xx	xx
3	20 lbs	20 hrs	xx	xx
4	20 lbs	20 hrs	xx	xx

Figure 3- Consolidation Data Sheet (example)

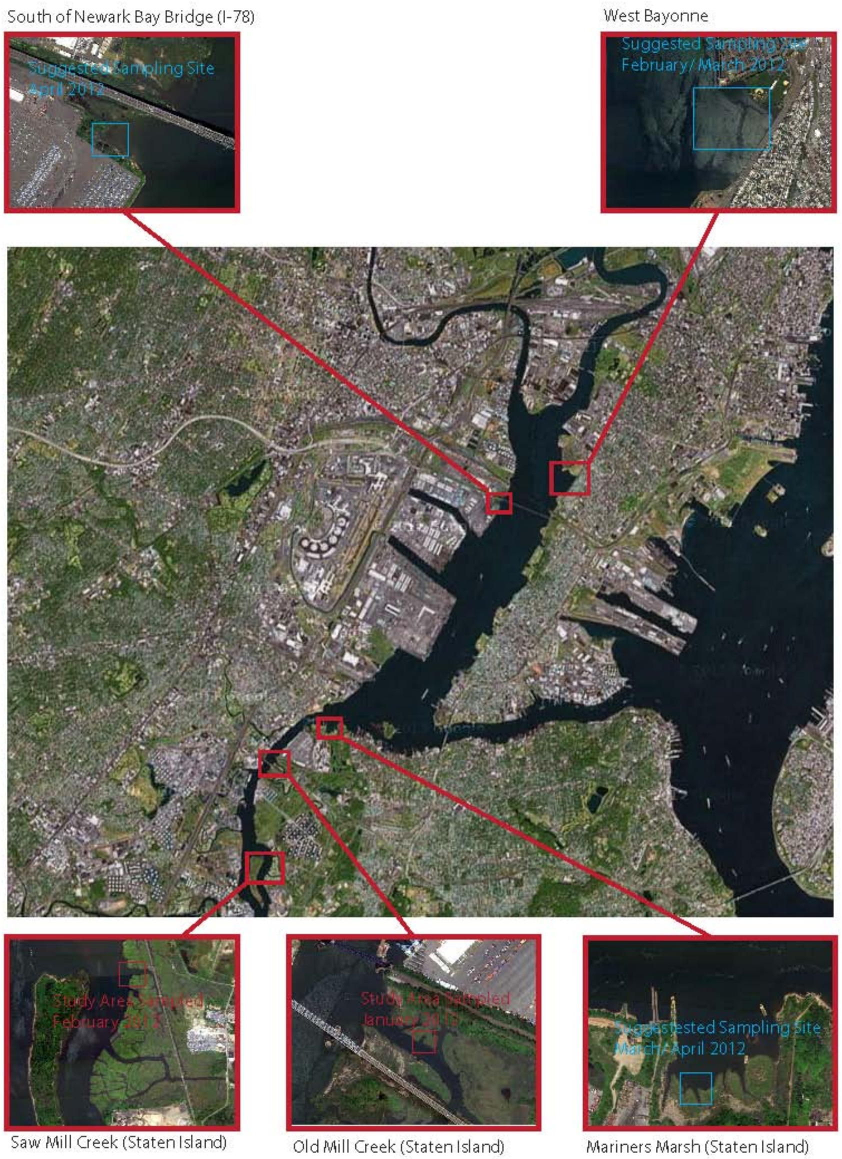
SED-Flume Team

After determining the critical shear stress required to produce measureable for the 2 material densities in baseline testing, that value was~~ill be~~ used as the starting shear stress. This erosion experiment required~~s~~ the use of time as the controlling factor rather than displacement. The initial velocity was~~ill be~~ applied again for a period of 10 minutes and the depth of erosion measured ~~will be recorded~~. Then, the initial velocity was~~ill be~~ applied for another 10 minutes and results ~~will be~~ recorded. This procedure was~~ill be~~ repeated until an hour of testing has elapsed (6 times). ~~Following,~~ T~~t~~he procedure was~~ill be~~ repeated at double and quadruple the initial SS value. The entire

VII. Results

Erodibility of Estuarine Sediments Study

During the Spring and Summer of 2012 a ~~full scale~~ field investigation was carried out to evaluate the erodibility of various sediment types within Newark Bay and its surrounding estuaries. Several Sampling Sites were



Erodibility results from extended use of the ESETM are best characterized as stochastic, that is when looking at the data from a macro-scale, there is little correlation in the data to suggest an overall trend between erosion behavior and applied shear stress. It stands to reason since there are many variables which affect the erodibility of fine grained sediments, that some of the randomness which was observe~~re~~d was~~is~~ the direct result of the randomness implicit to the material, such as:

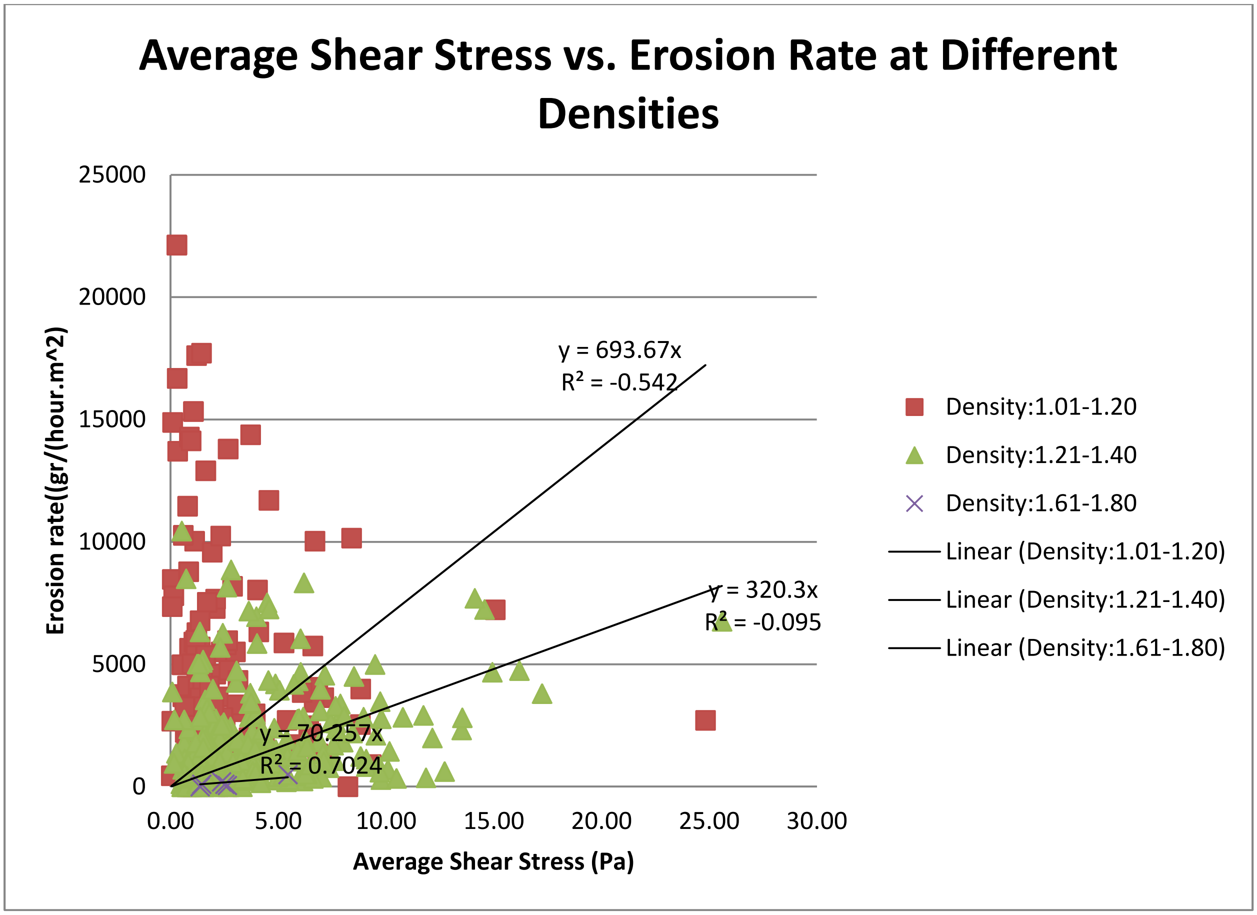
1) gas and liquid pockets
2) density variability
3) mineral variability,
4) micro-cracking in the sediment form,
5) bio-turbation/ stabilization

~~Additional~~ T~~t~~here are also randomizing variables implicit to the device and method:

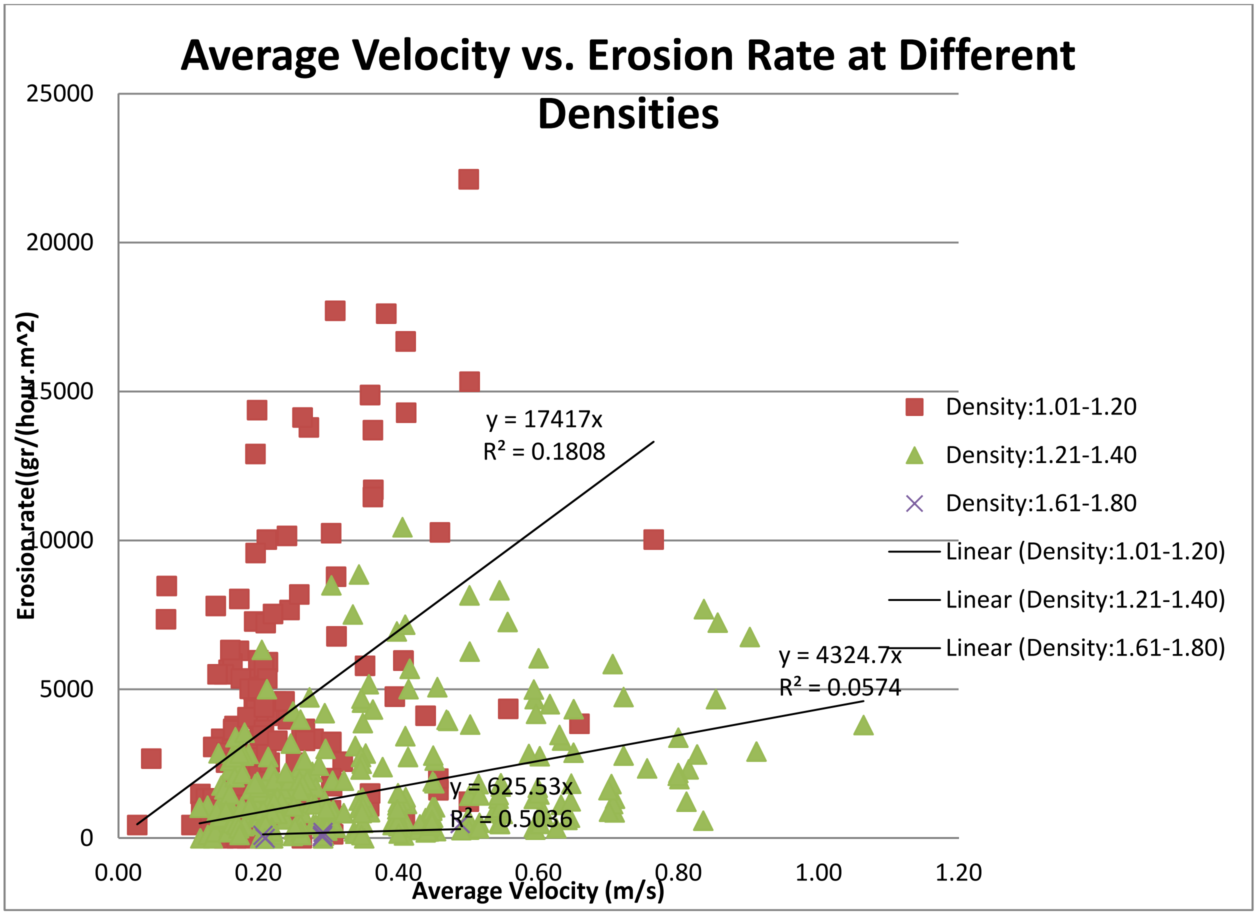
1) Disruption of the sediment structure as a result of coring and subsampling
2) Flow turbulence
3) Effects of buoyancy
4) Edge flow effects

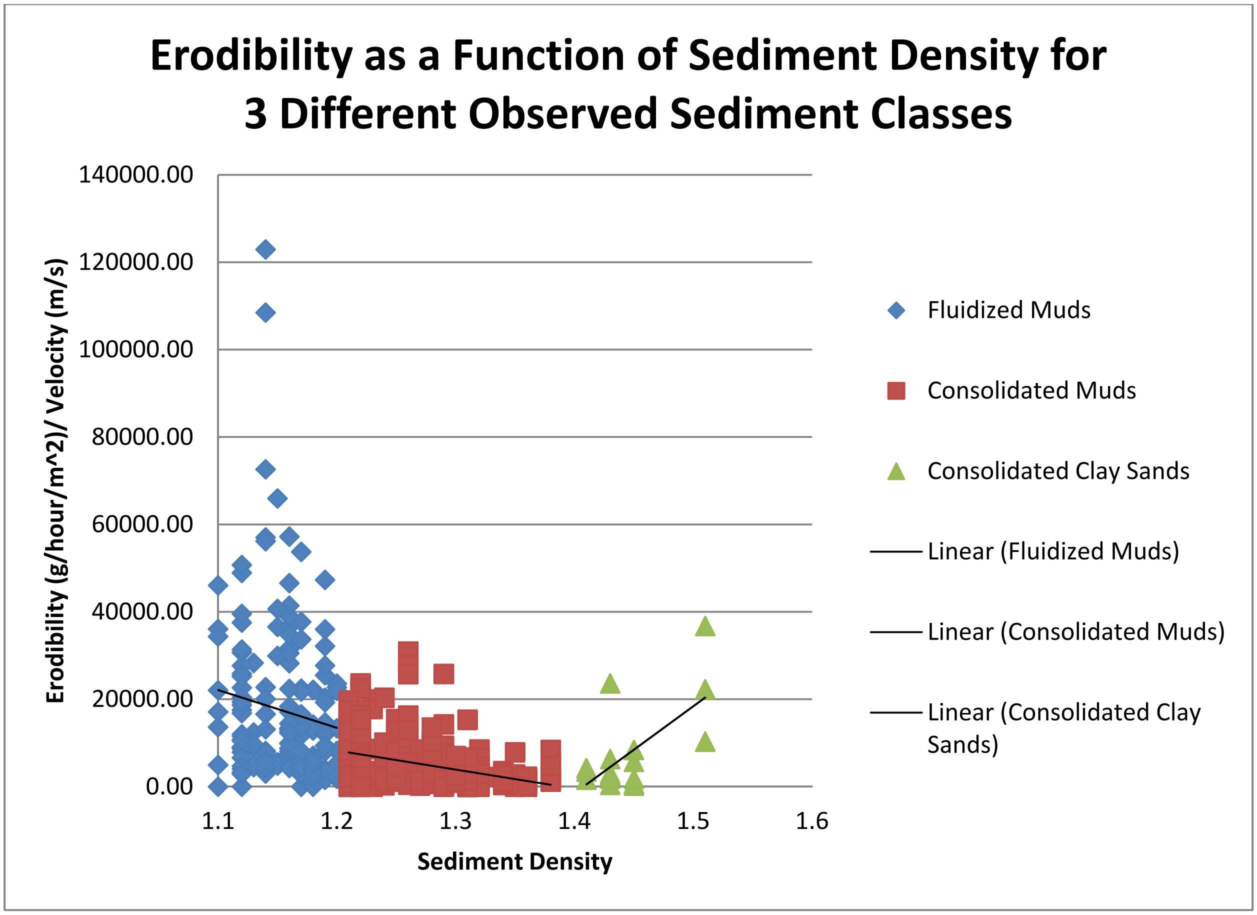
Since these issues are detailed above in the device assessment, they will not be rediscussed in detail, except for to say that no experimental method yet devised, including the ESETM, is able to isolate their effective importance. Moreover, many of the implicit sediment variables are impossible to ascertain without first destroying the sample- as a result it is nearly impossible to determine the exact geotechnical characteristics for each sample in order~~an attempt~~ to normalize the data~~ by some variable~~.

While it is difficult to state that the ESETM data directly reflects some "objective reality" about the nature of erosion that occurs in the field, it is important to note that some of the data sets which were acquired did in fact appear indicative of trends which are widely believed to be characteristic of such sediment. Therefore, it should be considered that while the data is largely unable to fulfil a predictive need on a macro-scale.



Average Shear Stress vs. Erosion Rate at Different Densities
25000
20000
15000
10000
5000
0
Erosion rate((gr/(hour.m^2)
y = 693.67x
R² = -0.542
y = 320.3x
R² = -0.095
y = 70.257x
R² = 0.7024
0.00
5.00
10.00
15.00
20.00
25.00
30.00
Average Shear Stress (Pa)
Density:1.01-1.20
Density:1.21-1.40
Density:1.61-1.80
Linear (Density:1.01-1.20)
Linear (Density:1.21-1.40)
Linear (Density:1.61-1.80)


Average Velocity vs. Erosion Rate at Different Densities
Erosion rate((gr/(hour.m^2)
Average Velocity (m/s)
25000
20000
15000
10000
5000
0
0.00
0.20
0.40
0.60
0.80
1.00
1.20
y = 17417x
R² = 0.1808
y = 4324.7x
R² = 0.0574
y = 625.53x
R² = 0.5036
Density:1.01-1.20
Density:1.21-1.40
Density:1.61-1.80
Linear (Density:1.01-1.20)
Linear (Density:1.21-1.40)
Linear (Density:1.61-1.80)



Bio-Film Study

Erodibility of Stabilized/ Amended Sediment (Capping) Study

The overall success of the project, to evaluate the erosion potential of fine grained estuarine sediments by use of the ESETM, is appearantly mixed. While it has been shown that a number of the results which are derived from the system are either unable to be verified, or shown to be inaccurate on either theoretical or empirical grounds, it is nonetheless true that use of the device has shown future potential in two methodological attributes on which the device is predicated:

1) Determination of erosion rate by direct mass measurement
2) Determination of overall

Biofilm Study

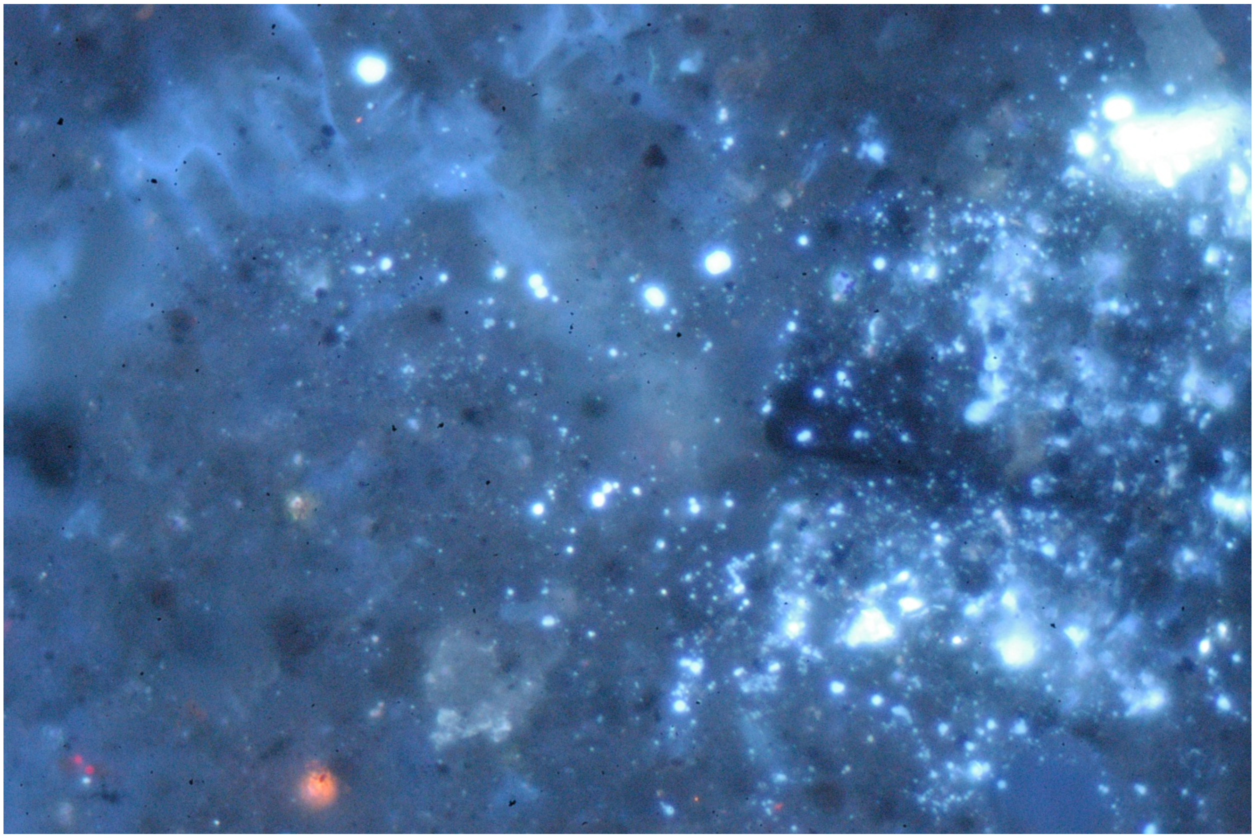


Figure 23- Surficial Biofilm and Sediment Matrix at 300x Magnification

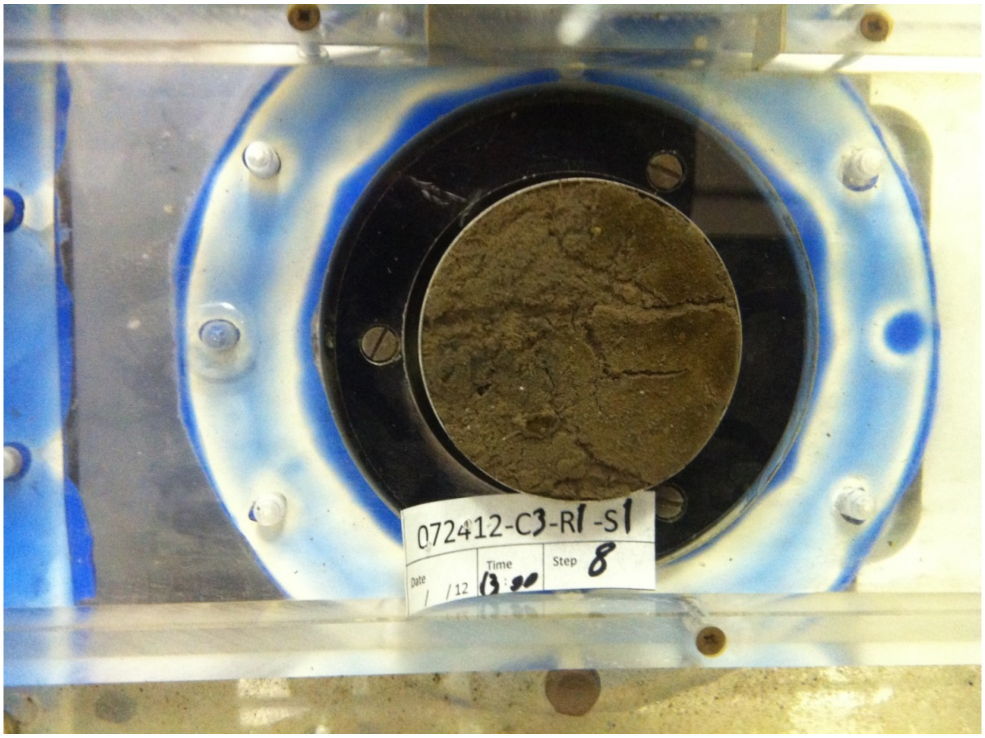
The effect of biofilms on the erodibility of sediments has been a topic of much study and debate due to the wide variation in experimental results. Much of this variety is speculated to be a result of bacterial species, ecosystem, depth, water chemistry and salinity, pollution, bioturbation etc, even time of day and time of year. Hence many scientists consider the shear strength or capacity to resist erosive behavior of a given biofilm (or site) to be largely unpredictable *a priori* based upon limited information such as sediment type, grain size, location etc. As this is the case, in-situ and sometimes ex-situ (flume based) experiments are conducted to directly measure that resistive ability. It should be noted that especially in the case of bio-films, disruption to the sediment surface via coring and sampling (pre-requisite to all ex-situ tests) is known to change the behavior by 1) creating edges through which flow can subduct the film, moving between it and the "sediment surface", 2) transport and storage induce, turbation, temperature change, lighting change, water chemistry change, all of which will have some direct effect on the bacterial that generate the film.

Biofilms are believed to be predominantly constituted by large extra-cellular polysaccharide chains (EPS). These chains are able to link together forming a saturated gel matrix in which sediment particles (seen in Figure 18 as black dots), blue/green algae, and a host of other benthic micro organisms are found. The growth of biofilm, so far as is known, is dependant on the commensalistic relationship between photosynthesizers on the sediment surface and the bacterial colonizers who secrete the substance, who consume the autotrophs in order to obtain their nutrition. This is thought to be the reason that significant concentrations of surface EPS are typically not found at any significant depth below the tidal zone in estuarine eco-systems as the turbidity level at depth significantly decreases the amount of light available to photo-synthetic algae and thus a decreased bacterial population.

With regard to this particular study, it was desired to determine 1) the mechanisms by which bio-films help to increase the stability and 2) the rough magnitude of any potential increase of critical shear stress for the sediment surface / increased shear strength and 3) the subsequent erosion rate of the underlying sediments/ biofilm.

In approaching this task ~~of the study~~, Rutgers CAIT, approached Dr. Gary Taghon from Rutgers Instit~~t~~ute of Coastal and Marine Sciences to consult on this phase. Dr. Taghon, working with CAIT researchers, established the following procedure for acquiring and testing bio-film. As biological testing was not performed, ~~within the purview of the study it was impossible to identify~~ the species of bacteria~~l~~ were not identified, neither was the concentrations of EPS determined, nor were the rheological properties of the EPS bound sediment determined.

1) Identify and core mud flats which are believed to contain biofilms.
2) Verify the presence of EPS within sediment surface using UV microscope
3)



Discussion

Sample Acquisition Methods

Experimental Methods

Determination of Eroded Sediment Mass by Direct Submerged Weight Measurement

The ESETM procedure calls for 10 minute continuous intervals of un-interrupted flow to be applied to a sediment sample of approximately 60 mm in diameter and 20 mm in depth. After the 10 minutes is elapsed flow is stopped and the mass is recorded directly via a submerged scale. The precision of the experiment is based directly on the precision of the scale, for the purposes of this paper the scale used had a .01 gram resolution. Calculating the transport rate is significantly easier in this instance as there is no volumetric or density conversion.

$$E_r = \frac{m_i - m_f}{t}$$

Whereas

E_r = *Erosion Rate*

m_i = *initial mass*

m_f = *final mass*

t = *time of interval*

Since the minimum value that could be recorded for the mass term would be .01 grams and the surface area of the sample probe is held constant at 28.26 cm^2.

The dimensional analysis yields

$$= \frac{.01\ grams}{10\ minutes/_{28.26\ cm^3}} \times \frac{6\ (10\ Minute\ Intervals)}{1\ Hour} \times \frac{28.26\ cm^3}{sample} \times \frac{353.85\ samples}{m^2}$$

$$= \frac{21.23\ g_{sub}}{\frac{Hr}{m^2}}$$

However it should be noted that this mass is taken in a submerged environment and is therefore subject to the effects of buoyancy. We should therefor use the general equation

$$\frac{\rho}{\rho_w} = \frac{m_{sat}}{m_w}$$

For each 1 g unit of saturated sediment we again assume moisture content of 32% however in the laboratory the actual water content is experimentally derived for each sample. Therefore, for every 1 gram of sediment, 68% of its saturated mass is sediment particles which displace water, meaning the weight of displaced fluid equals .68 grams sediment/ gram saturated sample. We should use the following equation to solve for saturated mass.

$$\frac{\rho}{\rho_w} \times m_w = m_{sat}$$

In this instance where ρ_w =1.05 g/ cm^3 and ρ = 1.30 g/ cm^3 and the mass of water displaced per gram of sediment is .68 grams water, our final conversion factor is .84 g_{sub}/ gram. Therefore our final conversion should include

$$= \frac{21.23\ g_{sub}}{\frac{Hr}{m^2}} \times \frac{1\ g_{sat}}{.84\ g_{sub}}$$

$$= 25.27\ g_{sat}\ /\ hr/\ m^2$$

Lastly we should note that this is the wet weight of sediment out of water. For dry sediments the final value must again be multiplied by the ratio or dry mass to total weight, in this case .68 g_{dry} / 1 g_{sat}.

$$= 37.16 \text{ grams dry sediment / hr/ m}^2$$

One of the primary benefits of the ESETM method is the use of a submerged weight sensor which is thought to significantly increase the precision of erosion measurements and simultaneously decrease the subjectivity of experiments. Nonetheless, there are several additional problems that make exact determination of the mass of eroded solids difficult using this approach. The problem, in short is the inability to accurately correct for variations in sample buoyancy as the experiment is conducted~~run~~. This problem is in theory constituted by four separate variables that were not possible to ascertain during this study and may not be pragmatically obtainable by any known laboratory method. They include:

1) Presence of entrained gasses.
2) Variable size and location of gas pockets
3) Inability to know exact sediment particle density of eroded sediment flocculates.
4) Inability to know exact moisture content of eroded sediment flocculates.

It has been shown several times in this study~~e results~~ that an ~~appearent~~ apparent mass gain was observed ~~measured~~ resulting in the calculation of a negative erosion rate even though this is ~~in theory not~~ impossible~~ by the experiment method~~. ~~Accordingly~~ These data~~this phenomenon~~ can~~ould~~ only be explained by ~~accounted for by~~ a loss of buoyancy in the sample. As hydraulic lift or ~~in this case~~ suction forces act upon the sample, disrupting it by erosion and creating pockets of negative pressure above its surface, ~~it is concluded that~~ small pockets of entrained gas are able to escape the particle matrix thereby increasing the bulk density of the sample and decreasing its buoyancy.

At this time it is difficult to ascertain whether or not these gas pockets are the result of biological activity (metabolic waste gasses from microbes and other benthic organisms), or from temperature changes that occur when ~~result from moving~~ the sample in moved from the field to the laboratory, resulting ~~as~~ in dissolved gasses coming out of suspension. Since m~~M~~ost gasses are more solu~~a~~ble at colder temperatures it is possible that ~~hence~~ keeping the samples in the chiller may have induced free gas to dissolve into the storage water. When the samples were placed into the warmer environment of the ESETM the gasses were forced back out of solution. and then return to a gas state when placed in the ESETM~~warmer non-temperature controlled machine~~. Alternatively, ~~Additionally~~ gas in the sample may be ~~result as~~ an artifact of the coring process or the sub sampling process, despite having ~~however as discussed in the experiment method above, steps were~~ taken steps at all stages of sample preparation to ensure that the sediments were kept submerged and saturated.

Taken on their own it would be possible to imagine that the presence of gas could be corrected for by means of a phase diagram. If the sample submerged weight, particle specific gravity (Gmm), bulk sediment density and moisture content are known, the total gas/ air content of the sample can be calculated. As all of these factors can be determined in the laboratory it is consequently possible to apply a correction factor if we assume that the loss of gas is occurring at a regular rate or proportional to the magnitude of induced flow/ pressure differential. However this assumption is likely to be false since we know that the sediment structure is ~~likely to be~~ variable and the presence and amount of gas released is unknown for any given interval. ~~believed to occur in a random spatial distribution meaning that air/ buoyancy loss for any erosion interval (exposure to flow for a given duration) is impossible to ascertain to any degree of certainty~~.

The following procedure was used to determine the air content of samples **by** using the given and previously measured values;

Sample Bulk density, ρ_{bulk}

Submerged weight, W_{sub}

Water content, ω

Specific Gravity, G_s

Step 1. By using the ρ_{bulk} ➔ $\Upsilon_{bulk} = \rho_{bulk} * g$

Step 2. $\Upsilon_{bulk} = \frac{W}{V} = \frac{G_s * \Upsilon_w + \Upsilon_w * e * S}{1+e}$ since $S = \frac{G_S * \omega}{e}$

➔ $\Upsilon_{bulk} = \frac{G_S * (1+\omega) * \Upsilon_W}{1+e}$

By using the formula above void ratio e can be calculated

By using the equation below degree of saturation S can be calculated;

$$G_s * \omega = S * e$$

Step 4. Air Content $= \frac{V_a}{V} = \frac{e*(1-S)}{1+e}$

Several additional methods were introduced during various experiments in order to control for this effect including 1) removing entrained gas using a vacuum chamber at low pressure. 2) affixing catchment system onto the

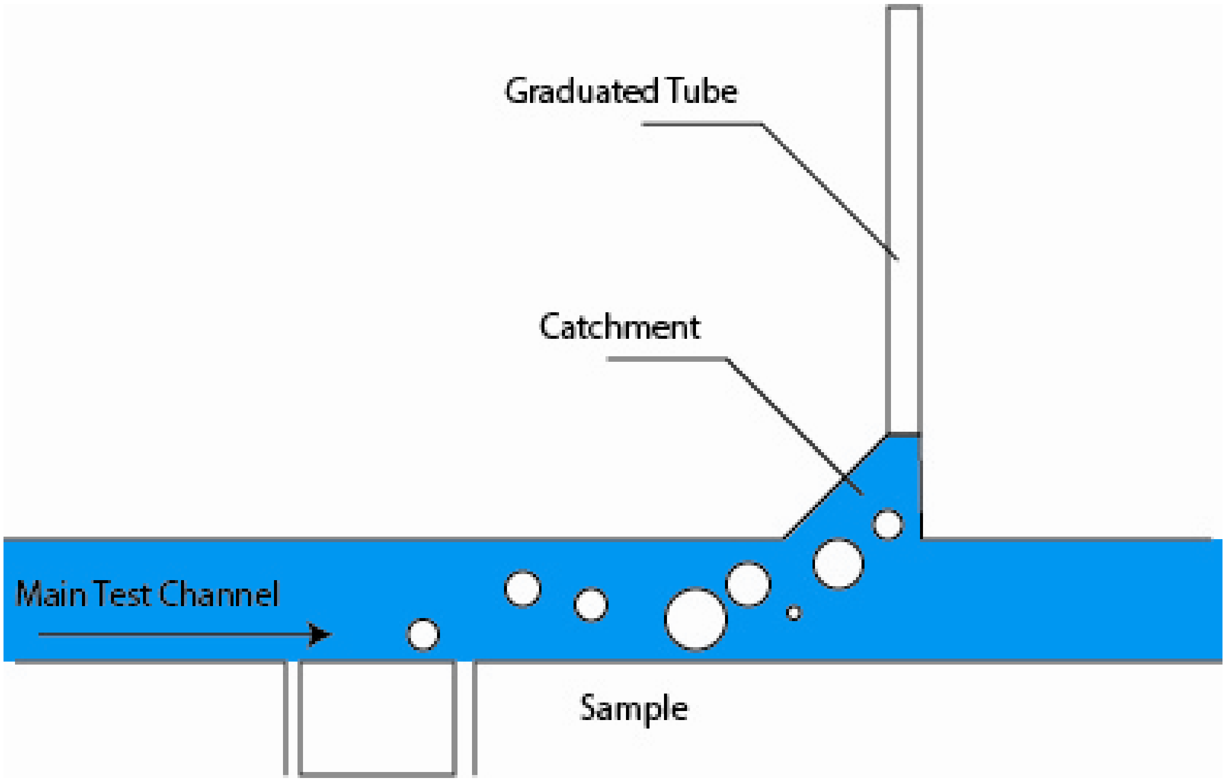


Figure 24- Air Catchment Device

Analysis Methods

There exist two critical problems for the interpretation and comparison of erosion rate measurement for fine grained sediments taken by varied test methods and procedures: [1] such measurements are evaluated by one of four different generalized analysis methods [2] the nature of erosion testing is destructive, making application of multiple forcing scenarios to the same sample [as per the initial field condition] an impossibility. Aberle et al. [2004] categorized the approaches used to interpret erosion data in the literature as such: [1] Initial peak erosion rate after application of a new bed shear stress [2] Rate of Erosion after some pre-defined initial response has passed [3] Average erosion rate over an entire test interval [4] Inclusion of a time factor in erosion rate prediction equations. As there is no standard analytical procedure for interpreting and reporting erosion data it varies by testing device, test procedure used, and laboratory—thereby obscuring a true comparison of results. In this paper a new approach is taken to convert erosion rate measurement data into information describing the erosion probability for different "material clusters" assumed to constitute the studied bed/ sample surface. The advantage of such an approach over that of using discrete erosion behavior parameters for each level or interval of shear stress is that the results obtained by this method are not dependent on any particular or arbitrarily defined testing arrangement and can be used to predict erosion behavior in new flow sequences and levels to which the erodible material is exposed: facilitating a standardization of results which are obtained by different devices, test methods, and procedural sequences.

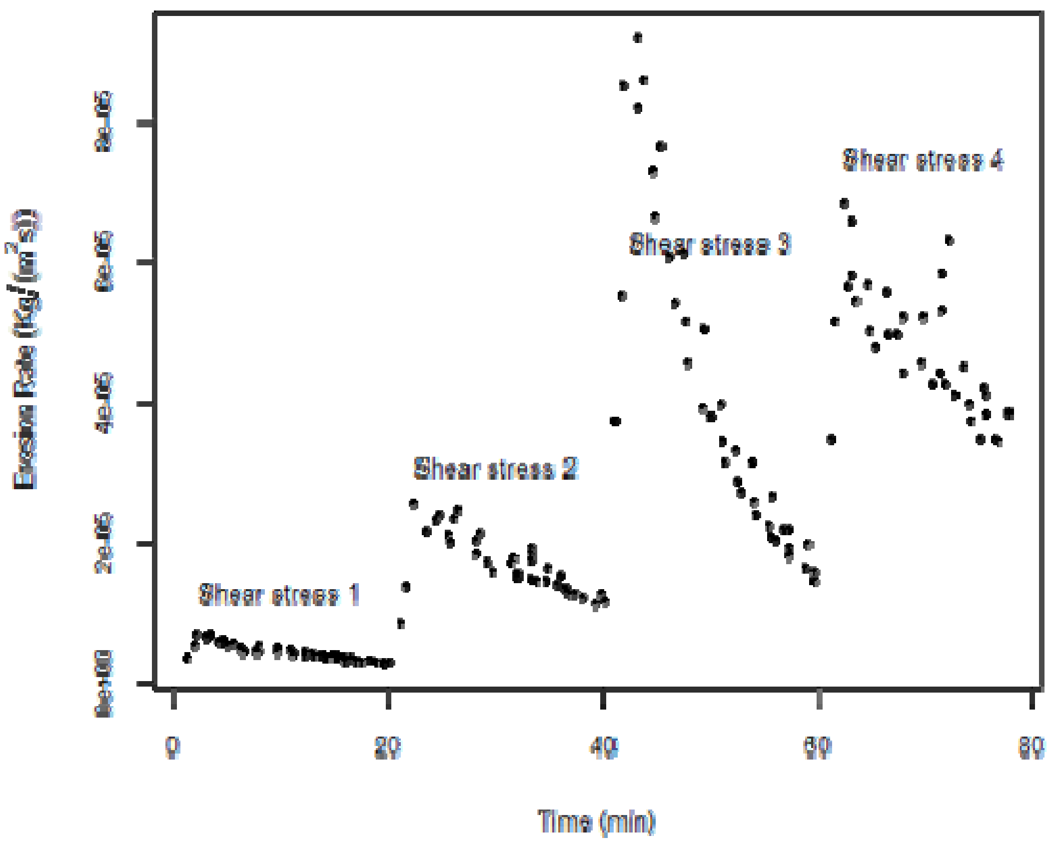


Figure 25- Typical Type 1 Erosion Patterns

Figure [12] illustrates the pattern typical to erosion rate measurements for Type 1 erosion, as described by Mehta and Parthenaides [1982]: "erosion rate reducing with time at constant forcing." As is standard for most test procedures successive intervals of increasing shear stress are applied to the sample over arbitrarily defined time intervals of erosion testing. The erosion rate for a given shear stress covers a range of values which are poorly defined by peak, average, or "data cropping" methods.

The interval time, should it increase or decrease, will significantly affect average erosion rate values. Moreover, the length of each interval will have some effect on the erosion rate measured in the subsequent interval meaning [1] that the peak value would be affected in the subsequent interval and [2] that the selection of different shear stress level arrangements will also generate different results in continued testing scenarios (shear stress history dependence). For example if the third step of the test had a shear stress level very close to the second level (or even equal to that), the observed points would be scattered below the second step points and as a continuation of that; resulting lower erosion rates for almost similar shear stress levels. The first three aforementioned interpretation methods are therefore more subjective measures and more sensitive to arbitrary test procedures and interpretation decisions. The fourth method (inclusion of a time factor) resolves the issue of dependence of erosion rate on time but the results still remain sensitive to shear stress history.

The erosion behavior, illustrated in Figure 1, is thought to be the result of an increasing critical shear stress with depth resultant from the density gradient and strength of inter-particle bonds and has been well observed in cohesive sediments. However, a bed surface is constituted by many particles and floccules~~ations~~ of particles each with their own erosion behavior as a result of bed-form generated turbulence and the heterogeneous nature of the sediment structure which is ill-suited for deterministic prediction in laboratory or field study.

In the cluster method the sediment bed is treated as a layer of height [h], containing a discrete number of subsets or "clusters" of material categorized by their similarity in erosion properties. A reiterative algorithm is utilized to relate a series of matrices to define the probability for any particle within each cluster to erode under a given stress/ velocity between each step of testing. Given the erosion rate and shear stress level, the cluster method is applied to define a series of matricies for each interval of testing, these include a probability matrix, [P] defining the probability of a particle within each cluster eroding at any given step of a test, a shear stress level vector [S], which defines the level of forcing at each step, a ratio matrix [R] defining the proportion of particles in each cluster at the start of each step, an available material vector [AM] defining the amount of material available for erosion at the start of each step, a cluster erosion matrix [CE] defining the amount of material eroded from each cluster in the prior step, and an eroded material vector [EM] equal to the total material from all clusters during the prior step. The assembled algorithm uses these terms to define the size of each cluster, the probability of any given particle eroding from it, and the total quantity of erosion. [Insert algorithm here]

The cluster method was applied to erosion rate and shear stress data from other researchers [Zreik, Sanford, Mehta et al.] to predict the erosion behavior of similar materials under differing experimental conditions. In figure 2, erosion rate data from two experiments by Zriek et al. 1998 are compared to simulated values generated by the cluster method. As per the test method, erosion rate was measured for two nearly identical manufactured samples (observations 1 and 2 in figure) under different test conditions. For sample 1, shear stress was incrementally increased over

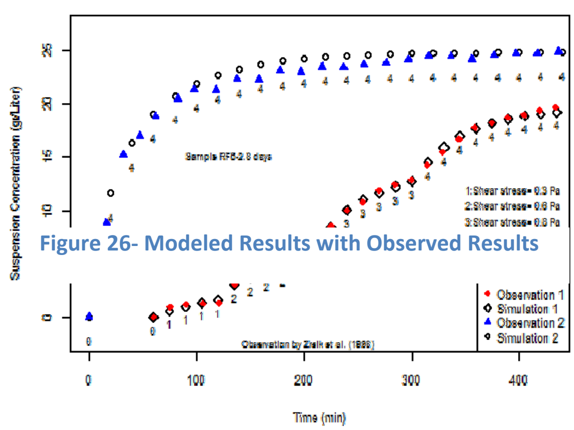


Figure 26- Modeled Results with Observed Results

four intervals from .3 Pa up to 1 Pa. For sample 2, shear stress was held constant at 1 Pa for the same time duration as in the test of sample 1. Observed data from sample 1 was applied to the cluster method to model the "simulation 2" curve, it is shown in Figure 2 compared to the observed results from the test of sample 2, illustrating the potential of the cluster method to simulate differing test conditions with a limited data set (Sample 1 data). Multiple such data sets are modeled by the cluster method in the full paper.

The cluster method can be used to simulate or predict erosion patterns for differing test procedures that cannot be directly observed on the same test sample due to the destructive nature of erosion testing. Moreover it offers significant utility for quantifying erosion measurements in terms of less subjective or time dependent than has been previously shown. However future refinements to the method still remain: [1] Given the numerous parameters used to define the algorithm, the problem is ill-posed as typical for inverse problems as there is no optimal unique solution. Nevertheless it is believed that modifications in the design of laboratory experiments and the shear stress level steps therein, can make it possible to extract the most interpretable result from the set of possible solutions. [2]Further research into the application of a probabilistic model must include further optimization of the algorithm structure and a proportionality assigned to the shear stress vector.

SedFlume Study

SED-Flume and ESETM Comparison Study

The 2006 Army Corps of Engineers Erodability of Passaic River Sediments Using USACE Sed-Flume report reads, "If a particular shear stress eroded less than 10-4 cm/s after two cycles, it was dropped from the cycle." Moreover in all of the reported data, no chart or graph indicates any report of erosion rates less than 10-4 cm/s. (1)

The geometry of the sediment samples is given as "Lexan coring tubes, 10 cm in diameter, were manually pushed directly into the sediment bed to the maximum possible depth." Additionally a box corer of dimensions 10~~cm~~ x 15cm is discussed as being used in deeper water. Because the cross sectional area term will eventually cancel in the following equations it can be assumed that the box corer and cylindrical corer will provide virtually identical mass erosion values. Since the diameter is given one can easily convert the value of 10-4 cm/s of erosion in depth into erosion in volume. Assuming that the bulk density of the average fine grained sediment is between 1.3-1.7 g/cm3 we can therefore solve for mass.

Conversion from Depth to Volume

$$V = h\,\pi r^2$$

$$= 10^{-4} cm \times \pi \times 5\ cm^2$$

$$= 7.85\ x\ 10^{-3}\ cm^3$$

Conversion from Volume to Mass

$$= \frac{7.85 \times 10^{-3}\ \text{cm}^3}{1\text{s}/\text{core}} \times \frac{1.3\ \text{grams}}{1\ \text{cm}^3} = 1.02\ \times 10^{-2}\ \text{grams}\Big/ 1\ \text{s}/_{\text{core}}$$

Conversion from Seconds to Hours

$$= \frac{1.02 \times 10^{-2}\ \text{grams}}{1\text{s}} \times \frac{3600\ \text{s}}{1\text{hr}} = 36.73\ \text{grams}\Big/ 1\ \text{hr}/_{\text{core}}$$

Because the core is only 78.5 cm^2 or 7.85 x 10^{-5} m^2 *in surface area* the value of 36.73 grams/ hr / core should also be multiplied by the ratio of its surface area to 1 m^2.

$$= \frac{10{,}000\ cm^2}{1m^2} \times \frac{1\ core}{78.5\ cm^2} = 127.38\ ^{core\ surfaces}/_{m^2}$$

Lastly we should multiple the ratio of cores / m^2 to with grams/hr/core.

$$= \frac{36.73\ \text{grams}}{1\ \text{HR}/_{\text{core surface}}} \times \frac{127\ \text{core surfaces}}{\text{m}^2} = \mathbf{4664.71\ grams}\Big/ \mathbf{m^2}/_{\mathbf{1\ hr}}$$

Likewise if we assume a bulk density of closer to 1.7 for more dense sediments, that value would increase to 6119.58 grams / m^2 / hour The authors note that the Army corps assumes a density of 2.65 grams / cm^3 for all sediment particles. Given that the bulk density, and of sediment particles and water is given by the equation

$$\rho = \frac{\rho_w \rho_s}{\rho_s + (\rho_s - \rho_w)W}$$

Whereas:

$$W = Water\ Content$$

$$\rho = bulk\ density$$

$$\rho_w = Density\ of\ Water$$

$\rho_s = Density\ of\ Sediment$

Water content is also provided for by the equation

$$W = \left(\frac{m_w - m_d}{m_w} \right)$$

$W = Water\ Content$

$m_w = Wet\ mass$

$m_d = Dry\ mass$

For a single unit calculation assuming a bulk density of 1.30 g/ cm^3 water content would be 31.85%. Therefore to calculate the final dry mass of sediment transport via army corps method we should negate the 32% of the mass we are assuming to be water. This would leave us with a final value of **3179.0 grams / hour/ m^2 of dry sediment** being transported at the lowest level of measurement.

For purposes of comparison the smallest measurement of sediment transport by dry weight as offered by sed-flume, using the 10 cm diameter core at a density of 1.3 g/cm^3 , is 8500% greater than the value offered by direct weight measurement in ESETM.

VIII. Conclusions-

The CAIT research team has made the following conclusions as a result of their technical and field activities with the ESETM:

1) With regard to sampling, in-situ devices should generally be preferred to ex-situ devices.
2) With regard to erosion rate measurement, direct mass measurement should be preferred over volumetric approximation.
3) With regard to shear stress measurement, the use of a floating type shear gauge is inapplicable to this type of research, hydraulic forcing should be determined by use of Laser Doppler Velocimetry or Particle Image Velocimetry.
4) Estuarine sediments are found by ESETM method to be significantly less erodible than is estimated by SED-Flume method.

5)

6) With regard to the “simulation of a natural hydraulic condition” by use of the band drive, the researching team found:
    a. This claim was not possible to conclusively verify due to the lack of either Particle Image Velocimetry (PIV) or Laser Doppler Velocimetry (LDV), both technologies which would allow for a thorough analysis of the flow behavior and profile within the test section. While PIV was used to calibrate the initial device at FHWA, no such device was accessible for the Rutgers ESETM due to cost and technical expertise prohibitions.
    b. ~~Assuming~~ Simulation of “natural hydraulic conditions” would need to be site “specific” requiring ~~the added cost, time, and expertise for~~ acquiring flow data from the field over a host of flow conditions.
    c. Observation and Computer Aided Fluid Dynamic (CFD) modeling of the device has indicated that the use of the band drive increases flow turbulence, generating Reynolds values which would be highly atypical of estuarine flow conditions (however possibly applicable to non-tidal river and stream flow.)
    d. Literature research also indicates that the shear stress applied to the bed (or sediment sample) surface is not intrinsically made more “accurate” depende~~a~~nt on the nature of the flow (open channel/ river vs. closed channel/ pipe)and is rather much more highly dependent on “flow development” and the flow Reynolds value over the sediment/ sample. For a flume device such as the ESETM these parameters are predicated on
        i. Average flow velocity
        ii. Length of the entry flow
        iii. Surface roughness of the entry flow
        iv. Fluid viscosity

7) With regard to the measurement of vertical (z-axis forcing) and weight measurement-
    a. The ESETM is not capable of accurately measuring vertical lift forces.
    b. The ESETM Z force sensor is not capable of precisely measuring the sample (submerged) weight. Total weight as measured by the weight sensor was found to be highly dependent on sample weight distribution.
    c. The ESETM was later modified by the Rutgers research team to include an underwater hanging scale which greatly increased the level of accuracy and precision for the measurement of submerged sample weight and the calculation of erosion rate.

i. Submerged weight measurement, while completely objective, is subject to measurement problems arising from buoyancy. Due to the presence of entrained gasses (arising from biological activity or as an artifact of the coring and sub sampling process) measured losses in weight (erosion) can

is able to measure hydraulic forces acting in the flow-wise direction against the sediment sample, however this is not equivalent to shear stress. Data analysis indicates a poor relationship between average hydraulic velocity and measured “shear stress”, as does measured “shear stress”

8) In conclusion the ESETM device is considered to be ill-suited for the study of cohesive sediments found in estuarine environments.

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Appendix A

Quality Control Data and Indicators

Appendix B

Field Core Erosion and Geotechnical Data

Appendix A

Test Results:

Newark Bay Undisturbed Samples

February 2012

Table 1

Date	2/16/2012		Test ID	021612-020112-C01-R01-S1			
Initial height	12.55	Ring	6	Min Thick	8.9	Total sub. WL	0.26
Initial volume (cubic centimeter)	36.66	Puck	1	Max Thick	13.76	Total unsub. WL	1.62
Initial un-submerged weight (gr)	124.44	Ring sub	2.22	EE1		Lost volume	1.36
Final non submerged weight (gr)	122.82	Puck sub	48.28	EE2		Estimated Density	1.19
Density method 1	1.19	Ring unsu	3.53	ΔH	0.3	Image Files	
Density method 2	1.19	Puck unsu	77.37	SS avg			
Average density	1.19	R01-S1		SS sd			
Pump Power %	3.00		Start time		12:45		
Ramp up speed (1/s)	0.1		End time		14:10		
First time weight measurment	57.48	57.63	57.47				
Time (min)	5.00	10.00	20.00				
Test duration (min)	5	5	10				
Pump Power %	2	2	2				
Ramp up time (s)	20	20	20				
Initial weight(gr)	57.47	57.39	57.26				
Final weight(gr)	57.39	57.26	57.21				
weight loss(gr)	0.08	0.13	0.05				
Accumulative weight loss	0.08	0.21	0.26				
intact sample?	Y	N	N				
Temperature (F)	64.9	64.9	64.9				
Test validity							
Erosion rate (gr/(hour.m^2)	2068	3361	646				
Average shear stress (Pa)	0.65	0.95	0.72				
Shear stress std	0.12	0.17	0.10				
Average velocity (m/s)	0.17	0.16	0.16				
Velocity std	0.01	0.01	0.01				
Average tank level	11.70	11.73	11.75				
Tank level std	0.02	0.02	0.02				
Average Z Force (grams)	-0.29	-0.44	-0.36				
Z Force std (grams)	0.10	0.10	0.10				
Comment on the step							
Sample Description	The surface was smooth and uniform and of a good quality. There was not much root in it.						
Test Description/purpose	To figure out how the erosion resistance varies with depth.						
Conclusion/Comment/Decision							

Table 2

Date	2/16/2012		Test ID	021612-020112-C01-R01-S2				
Initial height	18.14	Ring	3	Min Thick	11	Total sub. WL		1.17
Initial volume (cubic centimeter)	52.99	Puck	2	Max Thick	17	Total unsub. WL		9.69
Initial un-submerged weight (gr)	144.47	Ring sub	2.4	EE1		Lost volume		8.52
Final non submerged weight (gr)	134.78	Puck sub	48.12	EE2		Estimated Density		1.14
Density method 1	1.20	Ring unsu	3.83	ΔH		Image Files		
Density method 2	1.20	Puck unsu	77.29	SS avg				
Average density	1.20	R01-S2		SS sd				
Pump Power %	3.00		Start time		14:15			
Ramp up speed (1/s)	0.1		End time		16:45			
First time weight measurment	61.01	60.99	60.88	60.90	60.93			
Time (min)	5.00	10.00	20.00	30.00	40.00	50.00	60.00	
Test duration (min)	5	5	10	10	10	10	10	
Pump Power %	2	2	2	2	2.5	2.5	2.5	
Ramp up time (s)	20	20	20	20	25	25	25	
Initial weight(gr)	60.93	60.83	60.74	60.68	60.61	60.24	59.89	
Final weight(gr)	60.83	60.74	60.68	60.61	60.24	59.89	59.76	
weight loss(gr)	0.10	0.09	0.06	0.07	0.37	0.35	0.13	
Accumulative weight loss	0.10	0.19	0.25	0.32	0.69	1.04	1.17	
intact sample?	Y	N	N	N	N	N	N	
Temperature (F)	65.5							
Test validity								
Erosion rate (gr/(hour.m^2)	2507	2256	752	877	4637	4387	1629	
Average shear stress (Pa)	0.66	0.67	0.58	0.79	1.21	1.54	1.06	
Shear stress std	0.11	0.13	0.10	0.11	0.11	0.19	0.11	
Average velocity (m/s)	0.16	0.17	0.17	0.16	0.19	0.20	0.20	
Velocity std	0.02	0.01	0.01	0.01	0.02	0.01	0.02	
Average tank level	11.65	11.67	11.92	11.85	11.74	11.75	11.75	
Tank level std	0.02	0.02	0.03	0.02	0.02	0.02	0.02	
Average Z Force (grams)	0.02	-0.27	-1.90	-0.01	0.24	-0.02	0.11	
Z Force std (grams)	0.12	0.11	0.32	0.11	0.10	0.15	0.16	
Comment on the step								
Sample Description								
Test Description/purpose	To figure out how the erosion resistance varies with depth.							
Conclusion/Comment/Decision								

Table 3

Date	2/17/2012		Test ID	021712-020112-C01-R02-S1			
Initial height	19.83	Ring	4	Min Thick		Total sub. WL	0.42
Initial volume (cubic centimeter)	57.92	Puck	1	Max Thick		Total unsub. WL	145.59
Initial un-submerged weight (gr)	145.59	Ring sub	2.09	EE1		Lost volume	145.17
Final non submerged weight (gr)		Puck sub	48.28	EE2		Estimated Density	1.00
Density method 1	1.15	Ring unsu	1.81	ΔH		Image Files	
Density method 2	1.20	Puck unsu	77.37	SS avg			
Average density	1.17	R02-S1		SS sd			
Pump Power %	3.00		Start time		12:00		
Ramp up speed (1/s)	0.1		End time				
First time weight measurment	62.06	61.87					
Time (min)	5.00	10.00	20.00				
Test duration (min)	5	5	10				
Pump Power %	2	2	2				
Ramp up time (s)	20	20	20				
Initial weight(gr)	61.87	61.67	61.54				
Final weight(gr)	61.67	61.54	61.45				
weight loss(gr)	0.20	0.13	0.09				
Accumulative weight loss	0.20	0.33	0.42				
intact sample?	Y	N	N				
Temperature (F)							
Test validity							
Erosion rate (gr/(hour.m^2)	5584	3630	1256				
Average shear stress (Pa)	0.86	0.56	0.86				
Shear stress std	0.12	0.10	0.20				
Average velocity (m/s)	0.16	0.16	0.16				
Velocity std	0.01	0.01	0.01				
Average tank level	11.59	11.59	11.53				
Tank level std	0.02	0.02	0.03				
Average Z Force (grams)	-0.15	-0.48	0.06				
Z Force std (grams)	0.11	0.13	0.15				
Comment on the step							
Sample Description							
Test Description/purpose	To figure out how the erosion resistance varies with depth.						
Conclusion/Comment/Decision							

Table 4

Date	2/17/2012		Test ID	021712-020112-C01-R02-S2			
Initial height	19.86	Ring	1	Min Thick	15.27	Total sub. WL	0.14
Initial volume (cubic centimeter)	58.01	Puck	2	Max Thick	19.63	Total unsub. WL	0.52
Initial un-submerged weight (gr)	144.90	Ring sub	2.53	EE1		Lost volume	0.38
Final non submerged weight (gr)	144.38	Puck sub	48.12	EE2		Estimated Density	1.37
Density method 1	1.10	Ring unsu	4.02	ΔH		Image Files	
Density method 2	1.17	Puck unsu	77.29	SS avg			
Average density	1.13	R02-S2		SS sd			
Pump Power %	3.00		Start time		12:00		
Ramp up speed (1/s)	0.1		End time				
First time weight measurment	60.62	60.56	60.56				
Time (min)	5.00	10.00	20.00				
Test duration (min)	5	5	10				
Pump Power %	2	2	2				
Ramp up time (s)	20	20	20				
Initial weight(gr)	60.56	60.50	60.46				
Final weight(gr)	60.50	60.46	60.42				
weight loss(gr)	0.06	0.04	0.04				
Accumulative weight loss	0.06	0.10	0.14				
intact sample?	Y	N	N				
Temperature (F)							
Test validity							
Erosion rate (gr/(hour.m^2)	2093	1395	698				
Average shear stress (Pa)	0.87	0.73	0.95				
Shear stress std	0.10	0.12	0.11				
Average velocity (m/s)	0.16	0.16	0.16				
Velocity std	0.01	0.02	0.02				
Average tank level	11.48	11.49	11.48				
Tank level std	0.03	0.03	0.03				
Average Z Force (grams)	-0.29	-0.20	-0.17				
Z Force std (grams)	0.11	0.12	0.14				
Comment on the step							
Sample Description							
Test Description/purpose	To figure out how the erosion resistance varies with depth.						
Conclusion/Comment/Decision							

Table 5

Date	2/20/2012		Test ID	022012-020112-C01-R03-S1				
Initial height	16.34	Ring	3	Min Thick	9.34	Total sub. WL		0.95
Initial volume (cubic centimeter)	47.73	Puck	1	Max Thick	15.15	Total unsub. WL		#VALUE!
Initial un-submerged weight (gr)	137.46	Ring sub	2.4	EE1		Lost volume		#VALUE!
Final non submerged weight (gr)	-	Puck sub	48.28	EE2		Estimated Density		#VALUE!
Density method 1	1.18	Ring unsu	3.83	ΔH	0.3	Image Files		
Density method 2	1.19	Puck unsu	77.37	SS avg				
Average density	1.19	R03-S1		SS sd				
Pump Power %	3.00		Start time		12:00			
Ramp up speed (1/s)	0.1		End time					
First time weight measurment	59.84	59.87	59.83					
Time (min)	5.00	10.00	20.00	25.00	30.00	35.00		
Test duration (min)	5	5	10	5	5	5		
Pump Power %	2	2	2	3	3	3		
Ramp up time (s)	20	20	20	30	30	30		
Initial weight(gr)	59.83	59.67	59.66	59.64	59.25	59.09		
Final weight(gr)	59.67	59.66	59.64	59.25	59.09	58.88		
weight loss(gr)	0.16	0.01	0.02	0.39	0.16	0.21		
Accumulative weight loss	0.16	0.17	0.19	0.58	0.74	0.95		
intact sample?	Y	N	N	N	N	N		
Temperature (F)	63.3							
Test validity								
Erosion rate (gr/(hour.m^2)	4206	263	263	10252	4206	5520		
Average shear stress (Pa)	1.14	0.74	0.79	1.11	0.78	1.02		
Shear stress std	0.14	0.11	0.10	0.12	0.12	0.10		
Average velocity (m/s)	0.16	0.16	0.16	0.21	0.21	0.21		
Velocity std	0.01	0.01	0.01	0.01	0.01	0.01		
Average tank level	10.70	10.69	10.69	10.55	10.55	10.57		
Tank level std	0.03	0.02	0.02	0.02	0.03	0.02		
Average Z Force (grams)	-0.31	-0.01	-0.12	-0.42	-0.55	-0.29		
Z Force std (grams)	0.13	0.11	0.12	0.11	0.11	0.10		
Comment on the step								
Sample Description	Only one good quality sample could be taken out of Ring 3							
Test Description/purpose	To figure out how the erosion resistance varies with depth.							
Conclusion/Comment/Decision								

Table 6

Date	2/20/2012		Test ID	022012-020112-C01-R04-S1				
Initial height	12.80	Ring	5	Min Thick	9.6	Total sub. WL		0.65
Initial volume (cubic centimeter)	37.39	Puck	2	Max Thick	12.89	Total unsub. WL		4.89
Initial un-submerged weight (gr)	127.68	Ring sub	2.45	EE1		Lost volume		4.24
Final non submerged weight (gr)	122.79	Puck sub	48.12	EE2		Estimated Density		1.15
Density method 1	1.25	Ring unsu	3.81	ΔH	1	Image Files		
Density method 2	1.19	Puck unsu	77.29	SS avg		0220121435-0221121250		
Average density	1.22	R04-S1		SS sd				
Pump Power %	3.00		Start time		14:35			
Ramp up speed (1/s)	0.1		End time		16:45			
First time weight measurment	57.53	57.69	57.56					
Time (min)	5.00	10.00	20.00	25.00	30.00	40.00		
Test duration (min)	5	5	10	5	5	10		
Pump Power %	2	2	2	3	3	3		
Ramp up time (s)	20	20	20	30	30	30		
Initial weight(gr)	57.56	57.45	57.35	57.40	57.18	57.06		
Final weight(gr)	57.45	57.35	57.40	57.18	57.06	56.91		
weight loss(gr)	0.11	0.10	-0.05	0.22	0.12	0.15		
Accumulative weight loss	0.11	0.21	0.16	0.38	0.50	0.65		
intact sample?	Y	N	N	N	N	N		
Temperature (F)	64.4							
Test validity								
Erosion rate (gr/(hour.m^2)	2540	2309	-577	5080	2771	1732		
Average shear stress (Pa)	0.85	0.90	0.81	1.22	1.92	0.71		
Shear stress std	0.12	0.11	0.10	0.10	0.10	0.14		
Average velocity (m/s)	0.16	0.16	0.16	0.21	0.21	0.21		
Velocity std	0.01	0.01	0.01	0.01	0.01	0.01		
Average tank level	10.71	10.63	10.58	10.58	10.60	10.48		
Tank level std	0.02	0.03	0.02	0.02	0.02	0.02		
Average Z Force (grams)	0.18	-2.40	0.04	0.08	-0.81	-0.62		
Z Force std (grams)	0.12	0.09	0.13	0.13	0.10	0.15		
Comment on the step								
Sample Description								
Test Description/purpose	To figure out how the erosion resistance varies with depth.							
Conclusion/Comment/Decision								

Table 7

Date	2/21/2012		Test ID	022112-020112-C01-R04-S2				
Initial height	14.12	Ring	3	Min Thick	9.08	Total sub. WL		0.68
Initial volume (cubic centimeter)	41.24	Puck	1	Max Thick	13.05	Total unsub. WL		6.32
Initial un-submerged weight (gr)	131.01	Ring sub	2.4	EE1		Lost volume		5.64
Final non submerged weight (gr)	124.69	Puck sub	48.28	EE2		Estimated Density		1.12
Density method 1	1.21	Ring unsu	3.83	ΔH	0.3	Image Files		
Density method 2	1.18	Puck unsu	77.37	SS avg		0220121435-0221121250		
Average density	1.19	R04-S2		SS sd				
Pump Power %	3.00		Start time		10:45			
Ramp up speed (1/s)	0.1		End time		12:50			
First time weight measurment	57.91	57.92	57.90	57.90				
Time (min)	5.00	10.00	20.00	25.00	30.00	40.00		
Test duration (min)	5	5	10	5	5	10		
Pump Power %	2	2	2	3	3	3		
Ramp up time (s)	20	20	20	30	30	30		
Initial weight(gr)	57.90	57.98	57.76	57.72	57.49	57.46		
Final weight(gr)	57.98	57.76	57.72	57.49	57.46	57.22		
weight loss(gr)	-0.08	0.22	0.04	0.23	0.03	0.24		
Accumulative weight loss	-0.08	0.14	0.18	0.41	0.44	0.68		
intact sample?	Y	N	N	N	N	N		
Temperature (F)	69.8					69.6		
Test validity								
Erosion rate (gr/(hour.m^2)	-2046	5627	512	5882	767	3069		
Average shear stress (Pa)	0.98	0.87	0.85	1.07	0.91	1.02		
Shear stress std	0.10	0.11	0.11	0.13	0.13	0.11		
Average velocity (m/s)	0.16	0.16	0.15	0.21	0.21	0.21		
Velocity std	0.01	0.01	0.01	0.01	0.01	0.01		
Average tank level	10.51	10.51	10.49	10.55	10.60	10.62		
Tank level std	0.03	0.02	0.02	0.03	0.02	0.02		
Average Z Force (grams)	-0.18	-0.26	-0.41	-0.87	-0.66	-0.64		
Z Force std (grams)	0.09	0.11	0.12	0.12	0.10	0.10		
Comment on the step								
Sample Description								
Test Description/purpose	To figure out how the erosion resistance varies with depth.							
Conclusion/Comment/Decision								

Table 8

Date	2/21/2012		Test ID	022112-020112-C01-R05-S1				
Initial height	20.18	Ring	3	Min Thick	17.35	Total sub. WL		0.67
Initial volume (cubic centimeter)	58.95	Puck	1	Max Thick	20.49	Total unsub. WL		3.48
Initial un-submerged weight (gr)	156.29	Ring sub	2.4	EE1		Lost volume		2.81
Final non submerged weight (gr)	152.81	Puck sub	48.28	EE2		Estimated Density		1.24
Density method 1	1.27	Ring unsu	3.83	ΔH	0.3	Image Files		
Density method 2	1.25	Puck unsu	77.37	SS avg		0221121400-0221121811		
Average density	1.26	R05-S1		SS sd				
Pump Power %	3.00		Start time		14:00			
Ramp up speed (1/s)	0.1		End time		16:20			
First time weight measurment	65.38	65.24	65.21	65.21				
Time (min)	5.00	10.00	20.00	25.00	30.00	40.00		
Test duration (min)	5	5	10	5	5	10		
Pump Power %	2	2	2	3	3	3		
Ramp up time (s)	20	20	20	30	30	30		
Initial weight(gr)	65.21	65.15	65.08	64.93	64.75	64.72		
Final weight(gr)	65.15	65.08	64.93	64.75	64.72	64.54		
weight loss(gr)	0.06	0.07	0.15	0.18	0.03	0.18		
Accumulative weight loss	0.06	0.13	0.28	0.46	0.49	0.67		
intact sample?	Y	N	N	N	N	N		
Temperature (F)	69.3					69.3		
Test validity								
Erosion rate (gr/(hour.m^2)	1194	1393	1492	3581	597	1791		
Average shear stress (Pa)	0.72	0.96	0.85	1.36	1.66	2.17		
Shear stress std	0.10	0.11	0.11	0.12	0.09	0.11		
Average velocity (m/s)	0.16	0.15	0.15	0.20	0.21	0.21		
Velocity std	0.01	0.02	0.01	0.02	0.01	0.01		
Average tank level	10.32	10.30	10.31	10.30	10.31	10.31		
Tank level std	0.02	0.03	0.02	0.02	0.02	0.02		
Average Z Force (grams)	-0.26	-0.41	-0.41	-0.77	-0.76	-0.85		
Z Force std (grams)	0.12	0.09	0.10	0.10	0.09	0.10		
Comment on the step								
Sample Description	Only one sample was taken out of Ring 5							
Test Description/purpose	To figure out how the erosion resistance varies with depth.							
Conclusion/Comment/Decision								

Table 9

Date	2/21/2012		Test ID	022112-020112-C01-R06-S1				
Initial height	19.90	Ring	5	Min Thick	17.56	Total sub. WL		0.08
Initial volume (cubic centimeter)	58.13	Puck	2	Max Thick	19.27	Total unsub. WL		-0.07
Initial un-submerged weight (gr)	149.12	Ring sub	2.45	EE1		Lost volume		-0.15
Final non submerged weight (gr)	149.19	Puck sub	48.12	EE2		Estimated Density		0.47
Density method 1	1.17	Ring unsu	3.81	ΔH	0.1	Image Files		
Density method 2	1.17	Puck unsu	77.29	SS avg		0221121400-0221121811		
Average density	1.17	R06-S1		SS sd				
Pump Power %	3.00		Start time		16:20			
Ramp up speed (1/s)	0.1		End time		18:11			
First time weight measurment	60.69	60.71	60.69	60.69				
Time (min)	5.00	10.00	20.00	25.00	30.00	40.00		
Test duration (min)	5	5	10	5	5	10		
Pump Power %	2	2	2	3	3	3		
Ramp up time (s)	20	20	20	30	30	30		
Initial weight(gr)	60.69	60.67	60.68	60.68	60.63	60.60		
Final weight(gr)	60.67	60.68	60.68	60.63	60.60	60.61		
weight loss(gr)	0.02	-0.01	0.00	0.05	0.03	-0.01		
Accumulative weight loss	0.02	0.01	0.01	0.06	0.09	0.08		
intact sample?	Y	N	N	N	N	N		
Temperature (F)	69.3					68.8		
Test validity								
Erosion rate (gr/(hour.m^2)	559	-280	0	1399	839	-140		
Average shear stress (Pa)	0.93	0.82	0.74	1.52	1.74	1.61		
Shear stress std	0.09	0.10	0.10	0.11	0.10	0.12		
Average velocity (m/s)	0.15	0.15	0.15	0.20	0.21	0.21		
Velocity std	0.02	0.01	0.02	0.02	0.01	0.02		
Average tank level	10.26	10.24	10.24	10.25	10.24	10.25		
Tank level std	0.03	0.02	0.02	0.02	0.02	0.02		
Average Z Force (grams)	-0.33	-0.24	-0.21	-0.45	-0.63	-0.87		
Z Force std (grams)	0.10	0.11	0.09	0.10	0.11	0.12		
Comment on the step								
Sample Description	Only one sample was taken out of Ring 6							
Test Description/purpose	To figure out how the erosion resistance varies with depth.							
Conclusion/Comment/Decision								

Table 10

Date	2/22/2012		Test ID	022212-020112-C02-R01-S1				
Initial height	12.10	Ring	1	Min Thick	9.8	Total sub. WL		0.52
Initial volume (cubic centimeter)	35.34	Puck	1	Max Thick	12.3	Total unsub. WL		10.93
Initial un-submerged weight (gr)	121.27	Ring sub	2.53	EE1		Lost volume		10.41
Final non submerged weight (gr)	110.34	Puck sub	48.28	EE2		Estimated Density		1.05
Density method 1	1.13	Ring unsu	4.02	ΔH	0.47	Image Files		
Density method 2	1.12	Puck unsu	77.37	SS avg				
Average density	1.13	R01-S1		SS sd				
Pump Power %	3.00		Start time		12:00			
Ramp up speed (1/s)	0.1		End time		13:20			
First time weight measurment	55.29	55.25	55.17	55.16				
Time (min)	5.00	10.00	20.00	25.00	30.00	40.00		
Test duration (min)	5	5	10	5	5	10		
Pump Power %	2	2	2	3	3	3		
Ramp up time (s)	20	20	20	30	30	30		
Initial weight(gr)	55.16	55.00	55.02	54.98	54.82	54.75		
Final weight(gr)	55.00	55.02	54.98	54.82	54.75	54.64		
weight loss(gr)	0.16	-0.02	0.04	0.16	0.07	0.11		
Accumulative weight loss	0.16	0.14	0.18	0.34	0.41	0.52		
intact sample?	Y	N	N	N	N	N		
Temperature (F)	67.5					67.6		
Test validity								
Erosion rate (gr/(hour.m^2)	5886	-736	736	5886	2575	2023		
Average shear stress (Pa)	0.95	0.39	0.34	1.37	1.44	1.39		
Shear stress std	0.19	0.11	0.12	0.15	0.11	0.13		
Average velocity (m/s)	0.15	0.15	0.14	0.20	0.20	0.20		
Velocity std	0.02	0.01	0.01	0.02	0.01	0.02		
Average tank level	10.19	10.18	10.15	10.13	10.09	10.05		
Tank level std	0.02	0.02	0.03	0.03	0.02	0.02		
Average Z Force (grams)	-0.32	-0.28	-0.74	-0.49	-0.49	-0.52		
Z Force std (grams)	0.10	0.10	0.13	0.13	0.11	0.10		
Comment on the step								
Sample Description								
Test Description/purpose	To figure out how the erosion resistance varies with depth.							
Conclusion/Comment/Decision								

Table 11

Date	2/22/2012		Test ID	022212-020112-C02-R01-S2				
Initial height	11.41	Ring	2	Min Thick	4.5	Total sub. WL		1.02
Initial volume (cubic centimeter)	33.33	Puck	2	Max Thick	10.5	Total unsub. WL		9.56
Initial un-submerged weight (gr)	120.97	Ring sub	3.63	EE1		Lost volume		8.54
Final non submerged weight (gr)	111.41	Puck sub	48.12	EE2		Estimated Density		1.12
Density method 1	1.14	Ring unsu	5.7	ΔH	2	Image Files		
Density method 2	1.13	Puck unsu	77.29	SS avg				
Average density	1.14	R01-S2		SS sd				
Pump Power %	3.00		Start time		13:30			
Ramp up speed (1/s)	0.1		End time		16:25			
First time weight measurment	56.18	56.23	56.24	56.22				
Time (min)	5.00	10.00	20.00	25.00	30.00	40.00	50.00	60.00
Test duration (min)	5	5	10	5	5	10	10	10
Pump Power %	2	2	2	3	3	3	3	3.5
Ramp up time (s)	20	20	20	30	30	30	30	35
Initial weight(gr)	56.22	56.12	56.02	55.95	55.52	55.40	55.20	53.12
Final weight(gr)	56.12	56.02	55.95	55.52	55.40	55.20	55.12	54.68
weight loss(gr)	0.10	0.10	0.07	0.43	0.12	0.20	0.08	-1.56
Accumulative weight loss	0.10	0.20	0.27	0.70	0.82	1.02	1.10	-0.46
intact sample?	Y	N	N	N	N	N	N	N
Temperature (F)								
Test validity								
Erosion rate (gr/(hour.m^2)	3413	3413	1195	14676	4096	3413	1365	-26621
Average shear stress (Pa)	4.04	3.18	3.74	3.71	1.27	1.35	1.13	1.67
Shear stress std	0.16	0.48	0.11	0.09	0.13	0.14	0.11	0.11
Average velocity (m/s)	0.15	0.15	0.14	0.20	0.20	0.20	0.20	0.23
Velocity std	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01
Average tank level	10.00	10.00	9.99	9.99	9.98	9.99	10.01	10.02
Tank level std	0.02	0.02	0.02	0.03	0.02	0.02	0.03	0.03
Average Z Force (grams)	-0.38	-0.01	-0.63	-0.84	-0.52	-0.21	-0.59	-1.00
Z Force std (grams)	0.16	0.32	0.10	0.12	0.11	0.10	0.11	0.12
Comment on the step								
Sample Description	It was full of roots. They stopped the shear sensor from working properly.							
Test Description/purpose	To figure out how the erosion resistance varies with depth.							
Conclusion/Comment/Decision	When we removed the 55.12 gr sample at the end of the test to measure the unsubmurged weight, we decided to continue testing at 3.5% so we put it back to the water and surprisingly it had lost two grams. (considering the density of the sample , 2 gr submerged weight loss equals 16 gr unsumberged weight loss of material. Which makes us sure is not the case. We have lost two grams of water as we removed the sample out of water. We let it submerge for 10 minutes but no weight gain happened so we ran a test at 3.5% and the sample gained 1.56 gr which means that air bubbles in the sample have been replaced by air.							

Table 12

Date	2/24/2012		Test ID	022412-020112-C02-R02-S1				
Initial height	17.56	Ring	3	Min Thick	12.18	Total sub. WL		0.67
Initial volume (cubic centimeter)	51.29	Puck	2	Max Thick	18.01	Total unsub. WL		7.08
Initial un-submerged weight (gr)	138.00	Ring sub	2.4	EE1		Lost volume		6.41
Final non submerged weight (gr)	130.92	Puck sub	48.12	EE2		Estimated Density		1.10
Density method 1	1.11	Ring unsu	3.83	ΔH	0.3	Image Files		
Density method 2	1.13	Puck unsu	77.29	SS avg		0224121130-0224121605		
Average density	1.12	R02-S1		SS sd				
Pump Power %	3.00		Start time		11:30			
Ramp up speed (1/s)	0.1		End time		13:45			
First time weight measurment	57.12	57.10	57.06	57.07				
Time (min)	5.00	10.00	20.00	25.00	30.00	40.00		
Test duration (min)	5	5	10	5	5	10		
Pump Power %	2	2	2	3	3	3		
Ramp up time (s)	20	20	20	30	30	30		
Initial weight(gr)	57.07	56.99	56.96	56.93	56.68	56.49		
Final weight(gr)	56.99	56.96	56.93	56.68	56.49	56.40		
weight loss(gr)	0.08	0.03	0.03	0.25	0.19	0.09		
Accumulative weight loss	0.08	0.11	0.14	0.39	0.58	0.67		
intact sample?	Y	N	N	N	N	N		
Temperature (F)	67.3							
Test validity								
Erosion rate (gr/(hour.m^2)	3106	1165	582	9708	7378	1747		
Average shear stress (Pa)	0.96	1.16	1.09	1.93	2.07	1.51		
Shear stress std	0.08	0.09	0.11	0.10	0.11	0.10		
Average velocity (m/s)	0.14	0.15	0.14	0.20	0.19	0.20		
Velocity std	0.01	0.01	0.01	0.02	0.02	0.01		
Average tank level	11.61	11.59	11.59	11.58	11.56	11.57		
Tank level std	0.03	0.02	0.02	0.02	0.02	0.03		
Average Z Force (grams)	-0.05	-0.03	0.00	-0.01	-0.03	-0.04		
Z Force std (grams)	0.11	0.10	0.10	0.11	0.10	0.11		
Comment on the step								
Sample Description								
Test Description/purpose	To figure out how the erosion resistance varies with depth.							
Conclusion/Comment/Decision								

Table 13

Date	2/24/2012		Test ID	022412-020112-C02-R02-S2				
Initial height	18.35	Ring	1	Min Thick	10.12	Total sub. WL		1.13
Initial volume (cubic centimeter)	53.60	Puck	1	Max Thick	15.79	Total unsub. WL		9.63
Initial un-submerged weight (gr)	142.32	Ring sub	2.53	EE1		Lost volume		8.50
Final non submerged weight (gr)	132.69	Puck sub	48.28	EE2		Estimated Density		1.13
Density method 1	1.14	Ring unsu	4.02	ΔH		Image Files		
Density method 2	1.15	Puck unsu	77.37	SS avg		0224121130-0224121605		
Average density	1.15	R02-S2		SS sd				
Pump Power %	3.00		Start time		13:50			
Ramp up speed (1/s)	0.1		End time		16:05			
First time weight measurment	59.21	59.15	59.09	59.09				
Time (min)	5.00	10.00	20.00	25.00	30.00	40.00		
Test duration (min)	5	5	10	5	5	10		
Pump Power %	2.5	2.5	2.5	3	3	3		
Ramp up time (s)	25	25	25	30	30	30		
Initial weight(gr)	59.09	58.88	58.68	58.62	58.43	58.02		
Final weight(gr)	58.88	58.68	58.62	58.43	58.02	57.96		
weight loss(gr)	0.21	0.20	0.06	0.19	0.41	0.06		
Accumulative weight loss	0.21	0.41	0.47	0.66	1.07	1.13		
intact sample?	Y	N	N	N	N	N		
Temperature (F)	68							
Test validity								
Erosion rate (gr/(hour.m^2)	6787	6464	970	6141	13252	970		
Average shear stress (Pa)	1.95	1.21	0.92	1.16	1.62	1.34		
Shear stress std	0.11	0.14	0.11	0.14	0.13	0.10		
Average velocity (m/s)	0.17	0.17	0.17	0.20	0.20	0.20		
Velocity std	0.01	0.01	0.01	0.01	0.01	0.01		
Average tank level	11.48	11.47	11.42	11.41	11.35	11.35		
Tank level std	0.02	0.02	0.02	0.03	0.02	0.02		
Average Z Force (grams)	0.01	-0.02	0.03	0.02	-1.66	-0.02		
Z Force std (grams)	0.12	0.09	0.10	0.11	0.10	0.10		
Comment on the step								
Sample Description								
Test Description/purpose	To figure out how the erosion resistance varies with depth.							
Conclusion/Comment/Decision								

Table 14

Date	2/27/2012		Test ID	022712-020112-C02-R03-S1			
Initial height	21.00	Ring	1	Min Thick	16.61	Total sub. WL	0.81
Initial volume (cubic centimeter)	61.34	Puck	1	Max Thick	21.72	Total unsub. WL	5.07
Initial un-submerged weight (gr)	154.13	Ring sub	2.53	EE1		Lost volume	4.26
Final non submerged weight (gr)	149.06	Puck sub	48.28	EE2		Estimated Density	1.19
Density method 1	1.19	Ring unsu	4.02	ΔH		Image Files	
Density method 2	1.18	Puck unsu	77.37	SS avg		0227121140-0227121550	
Average density	1.18	R03-S1		SS sd			
Pump Power %	3.00		Start time		11:40		
Ramp up speed (1/s)	0.1		End time				
First time weight measurment	62.08	61.80	61.88	61.81			
Time (min)	5.00	10.00	20.00	25.00	30.00	40.00	
Test duration (min)	5	5	10	5	5	10	
Pump Power %	2.5	2.5	2.5	3	3	3	
Ramp up time (s)	25	25	25	30	30	30	
Initial weight(gr)	61.81	61.64	61.60	61.33	61.23	61.18	
Final weight(gr)	61.64	61.60	61.33	61.23	61.18	61.00	
weight loss(gr)	0.17	0.04	0.27	0.10	0.05	0.18	
Accumulative weight loss	0.17	0.21	0.48	0.58	0.63	0.81	
intact sample?	Y	N	N	N	N	N	
Temperature (F)					64.4		
Test validity							
Erosion rate (gr/(hour.m^2)	4524	1064	3592	2661	1330	2395	
Average shear stress (Pa)	1.39	1.29	1.35	1.55	1.63	1.79	
Shear stress std	0.11	0.13	0.12	0.12	0.09	0.13	
Average velocity (m/s)	0.16	0.17	0.16	0.19	0.19	0.19	
Velocity std	0.01	0.01	0.01	0.01	0.01	0.02	
Average tank level	11.63	11.56	11.45	11.40	11.35	11.31	
Tank level std	0.02	0.02	0.03	0.02	0.02	0.02	
Average Z Force (grams)	0.00	-0.03	-0.03	-0.04	0.01	0.00	
Z Force std (grams)	0.11	0.11	0.12	0.12	0.10	0.11	
Comment on the step							
Sample Description							
Test Description/purpose							
Conclusion/Comment/Decision							

Table 15

Date	2/27/2012		Test ID	022712-020112-C02-R04-S1			
Initial height	21.30	Ring	3	Min Thick	18.2	Total sub. WL	0.58
Initial volume (cubic centimeter)	62.22	Puck	2	Max Thick	26.4	Total unsub. WL	2.04
Initial un-submerged weight (gr)	159.32	Ring sub	2.4	ΔH		Lost volume	1.46
Final non submerged weight (gr)	157.28	Puck sub	48.12	Age-1		Estimated Density	1.40
Density method 1	1.26	Ring unsu	3.83	Age-2		Image Files	
Density method 2	1.17	Puck unsu	77.29	avg depth		0227121140-0227121550	
Average density	1.21	R04-S1					
Pump Power %	3.00		manometer depth				
Ramp up speed (1/s)	0.1	Start time	13:45	End time	15:50		
First time weight measurment	61.49	61.28	61.26	61.24			
Time (min)	5.00	10.00	20.00	25.00	30.00	40.00	
Test duration (min)	5	5	10	5	5	10	
Pump Power %	2.5	2.5	2.5	3	3	3	
Ramp up time (s)	25	25	25	30	30	30	
Initial weight(gr)	61.24	60.91	60.80	60.71	60.76	60.64	
Final weight(gr)	60.91	60.80	60.71	60.76	60.64	60.66	
weight loss(gr)	0.33	0.11	0.09	-0.05	0.12	-0.02	
Accumulative weight loss	0.33	0.44	0.53	0.48	0.60	0.58	
intact sample?	Y	N	N	N	N	N	
Temperature (F)						65.1	
Test validity							
Erosion rate (gr/(hour.m^2)	7673	2558	1046	-1163	2790	-233	
Average shear stress (Pa)	9.28	7.68	7.64	9.23	8.95	9.42	
Shear stress std	0.15	0.12	0.14	0.13	0.14	0.14	
Average velocity (m/s)	0.16	0.16	0.16	0.19	0.19	0.18	
Velocity std	0.01	0.01	0.01	0.01	0.01	0.01	
Average tank level	11.16	11.16	11.15	11.15	11.14	11.14	
Tank level std	0.02	0.02	0.02	0.03	0.03	0.02	
Average Z Force (grams)	-0.07	0.00	0.03	-0.03	-0.01	0.01	
Z Force std (grams)	0.12	0.11	0.10	0.10	0.10	0.11	
Comment on the step							
Sample Description							
Test Description/purpose							
Conclusion/Comment/Decision							

Table 16

Date	2/28/2012		Test ID	022812-020112-C02-R05-S1					
Initial height	15.88	Ring	3	Min Thick	0	Total sub. WL		0.54	
Initial volume (cubic centimeter)	46.39	Puck	2	Max Thick	12.28	Total unsub. WL		131.28	
Initial un-submerged weight (gr)	131.28	Ring sub	2.4	ΔH	0	Lost volume		130.74	
Final non submerged weight (gr)		Puck sub	48.12	Age-1		Estimated Density		1.00	
Density method 1	1.08	Ring unsu	3.83	Age-2		Image Files			
Density method 2	1.12	Puck unsu	77.29	avg depth					
Average density	1.10	R05-S1							
Pump Power %	3.00		manometer depth						
Ramp up speed (1/s)	0.1	Start time	13:00	End time	15:25				
First time weight measurment	56.22	56.12	56.09	56.08					
Time (min)	5.00	10.00	20.00	25.00	30.00	40.00	45.00	50.00	60.00
Test duration (min)	5	5	10	5	5	10	5	5	10
Pump Power %	2.5	2.5	2.5	3	3	3	3.5	3.5	3.5
Ramp up time (s)	25	25	25	30	30	30	35	35	35
Initial weight(gr)	56.08	55.90	55.77	55.65	55.56	55.54	55.54	55.38	55.32
Final weight(gr)	55.90	55.77	55.65	55.56	55.54	55.54	55.38	55.32	53.2
weight loss(gr)	0.18	0.13	0.12	0.09	0.02	0.00	0.16	0.06	2.12
Accumulative weight loss	0.18	0.31	0.43	0.52	0.54	0.54	0.70	0.76	2.88
intact sample?	Y	N	N	N	N	N	N	N	N
Temperature (F)				68.5					
Test validity									
Erosion rate (gr/(hour.m^2)	8089	5842	2696	4044	899	0	7190	2696	47632
Average shear stress (Pa)	4.71	5.26	5.40	6.83	9.31	8.23	15.06	24.83	
Shear stress std	0.11	0.13	0.12	0.12	0.13	0.13	0.15	0.54	
Average velocity (m/s)	0.16	0.16	0.16	0.18	0.18	0.18	0.21	0.20	
Velocity std	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.01	
Average tank level	11.29	11.26	11.24	11.19	11.22	11.24	11.22	11.20	
Tank level std	0.02	0.02	0.02	0.03	0.03	0.02	0.03	0.03	
Average Z Force (grams)	0.03	0.01	-0.01	-0.01	0.01	0.06	-0.02	0.05	
Z Force std (grams)	0.09	0.09	0.09	0.11	0.10	0.10	0.08	0.09	
Comment on the step									
Sample Description	The sample was destroyed and moved as a whole during the last step.								
Test Description/purpose									
Conclusion/Comment/Decision									

Table 17

Date	2/29/2012		Test ID	022912-020112-C03-R01-S1				
Initial height	17.60	Ring	2	Min Thick	-	Total sub. WL		0.79
Initial volume (cubic centimeter)	51.41	Puck	2	Max Thick	-	Total unsub. WL		#VALUE!
Initial un-submerged weight (gr)	143.00	Ring sub	3.63	ΔH		Lost volume		#VALUE!
Final non submerged weight (gr)	-	Puck sub	48.12	Age-1		Estimated Density		#VALUE!
Density method 1	1.17	Ring unsu	5.7	Age-2		Image Files		
Density method 2	1.16	Puck unsu	77.29	avg depth				
Average density	1.16	R01-S1						
Pump Power %	3.00		manometer depth					
Ramp up speed (1/s)	0.1	Start time	12:20	End time	15:10			
First time weight measurment	59.77	59.88	59.82	59.85				
Time (min)	5.00	10.00	20.00	30.00	40.00	50.00	55.00	60.00
Test duration (min)	5	5	10	10	10	10	5	5
Pump Power %	2	2	2	2.25	2.5	2.5	2.75	3
Ramp up time (s)	20	20	20	22.5	30	30	35	35
Initial weight(gr)	59.85	59.67	59.62	59.56	59.51	59.14	59.06	58.97
Final weight(gr)	59.67	59.62	59.56	59.51	59.14	59.06	58.97	58.70
weight loss(gr)	0.18	0.05	0.06	0.05	0.37	0.08	0.09	0.27
Accumulative weight loss	0.18	0.23	0.29	0.34	0.71	0.79	0.88	1.15
intact sample?	Y	N	N	N	N	N	N	N
Temperature (F)			67.3					
Test validity								
Erosion rate (gr/(hour.m^2)	5292	1470	882	735	5439	1176	2646	7938
Average shear stress (Pa)	1.79	1.78	2.15	2.85	2.34	2.17	2.53	4.03
Shear stress std	0.09	0.10	0.11	0.10	0.12	0.11	0.10	0.12
Average velocity (m/s)	0.12	0.12	0.12	0.14	0.15	0.15	0.16	0.17
Velocity std	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01
Average tank level	11.47	11.38	11.21	11.12	11.02	10.98	10.90	10.84
Tank level std	0.03	0.02	0.03	0.02	0.03	0.03	0.02	0.02
Average Z Force (grams)	-0.04	-0.01	0.01	-0.10	0.01	-0.01	-0.02	0.01
Z Force std (grams)	0.09	0.09	0.10	0.09	0.11	0.10	0.11	0.11
Comment on the step								
Sample Description	The sample was destroyed accidently before making the final measurments.							
Test Description/purpose								
Conclusion/Comment/Decision								

Table 18

Date	2/29/2012		Test ID	022912-020112-C03-R01-S2			
Initial height	16.53	Ring	3	Min Thick	9.83	Total sub. WL	57.72
Initial volume (cubic centimeter)	48.28	Puck	1	Max Thick	16.7	Total unsub. WL	4.50
Initial un-submerged weight (gr)	134.15	Ring sub	2.4	ΔH	0	Lost volume	-53.22
Final non submerged weight (gr)	129.65	Puck sub	48.28	Age-1		Estimated Density	-0.08
Density method 1	1.10	Ring unsu	3.83	Age-2		Image Files	
Density method 2	1.15	Puck unsu	77.37	avg depth		0229121220-0229121717	
Average density	1.12	R01-S2					
Pump Power %	3.00		manometer depth				
Ramp up speed (1/s)	0.1	Start time	15:30	End time	17:17	.	
First time weight measurment	57.71	57.77	57.73	57.72			
Time (min)	10.00	20.00	30.00	40.00	50.00		
Test duration (min)	10	10	10	10	10		
Pump Power %	2	2.25	2.5	2.75	3		
Ramp up time (s)	20	22.5	25	27.5	30		
Initial weight(gr)	57.72	57.63	57.56	57.40	57.54		
Final weight(gr)	57.63	57.56	57.40	57.54	57.21		
weight loss(gr)	0.09	0.07	0.16	-0.14	0.33		
Accumulative weight loss	0.09	0.16	0.32	0.18	0.51		
intact sample?	Y	N	N	N	N		
Temperature (F)				67.8			
Test validity							
Erosion rate (gr/(hour.m^2)	1710	1330	3040	-2660	6270		
Average shear stress (Pa)	1.89	2.51	3.08	3.41	4.09		
Shear stress std	0.10	0.10	0.10	0.11	0.12		
Average velocity (m/s)	0.11	0.12	0.14	0.15	0.16		
Velocity std	0.01	0.01	0.01	0.01	0.02		
Average tank level	10.89	10.84	10.77	10.75	10.71		
Tank level std	0.02	0.02	0.02	0.02	0.02		
Average Z Force (grams)	0.00	-0.03	0.04	0.02	-0.01		
Z Force std (grams)	0.09	0.09	0.10	0.11	0.09		
Comment on the step							
Sample Description							
Test Description/purpose							
Conclusion/Comment/Decision							

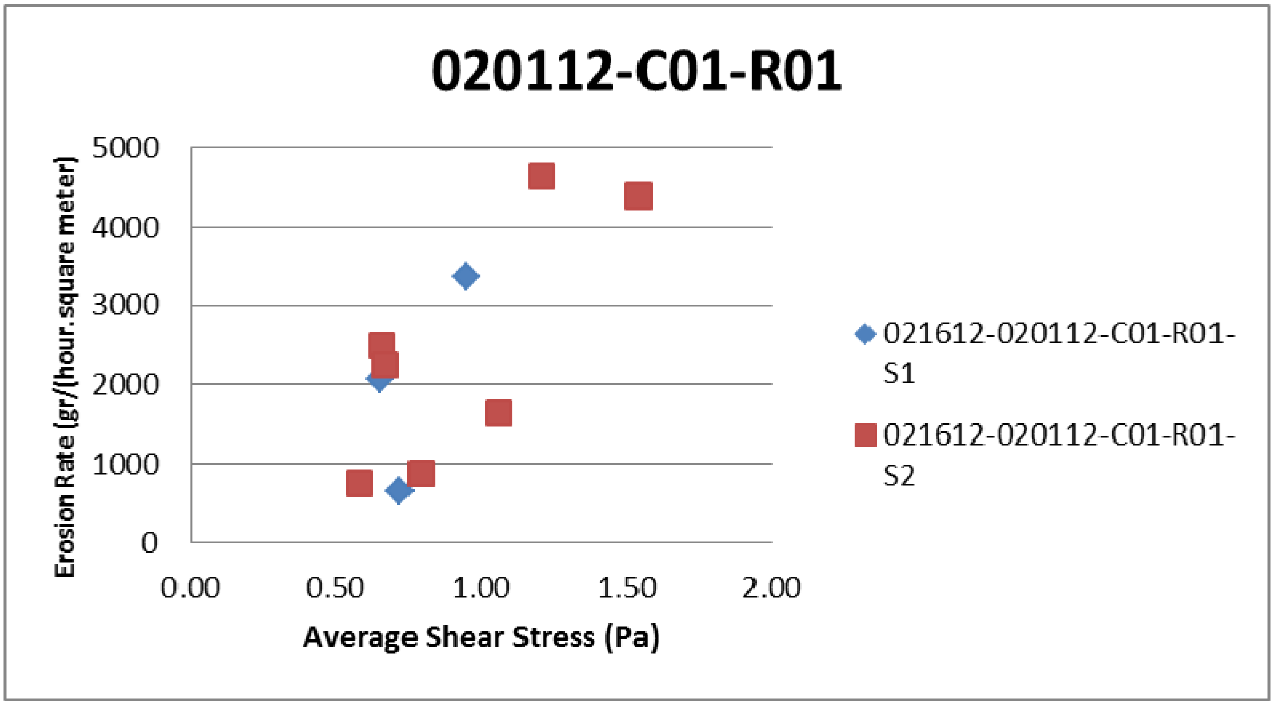


Figure 27

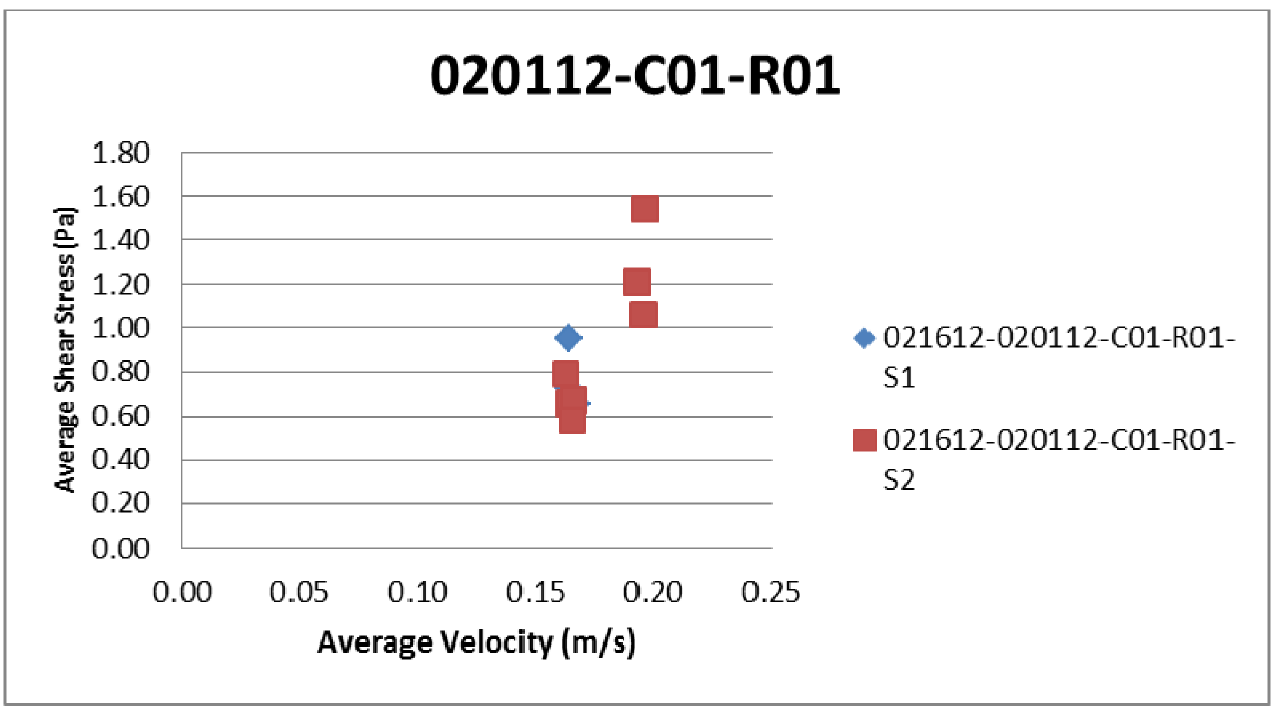


Figure 28

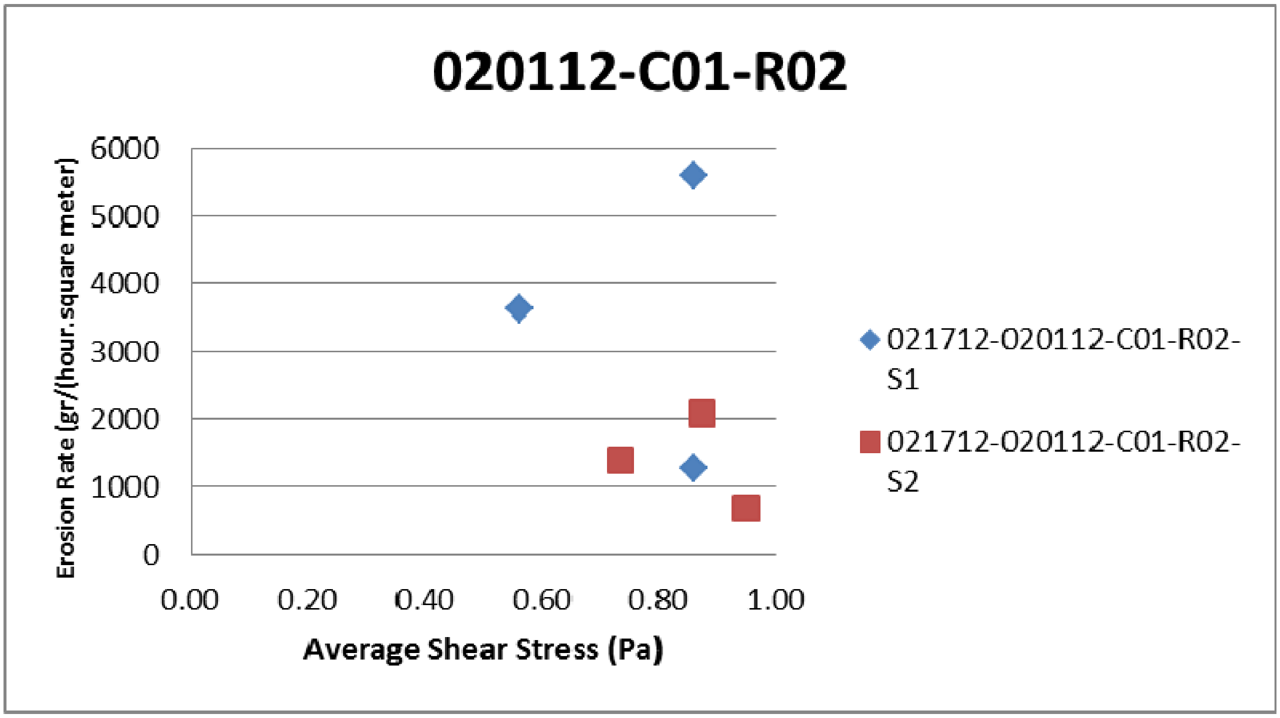


Figure 29

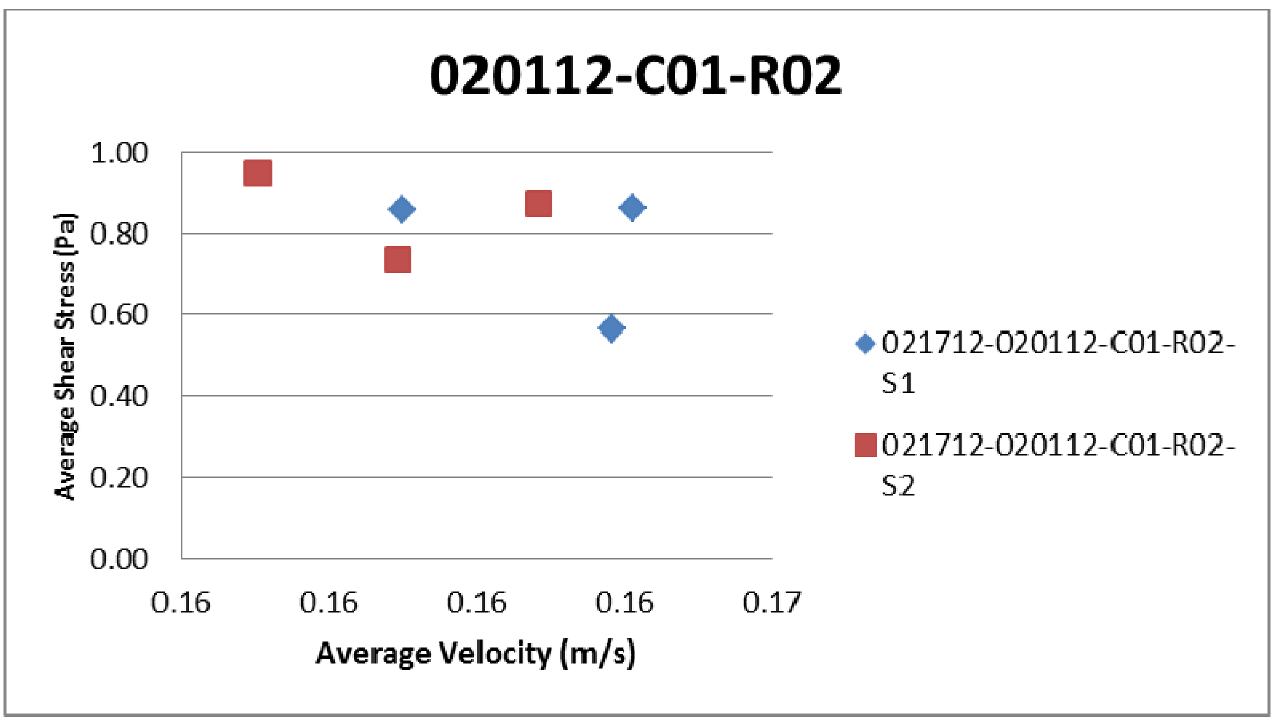


Figure 30

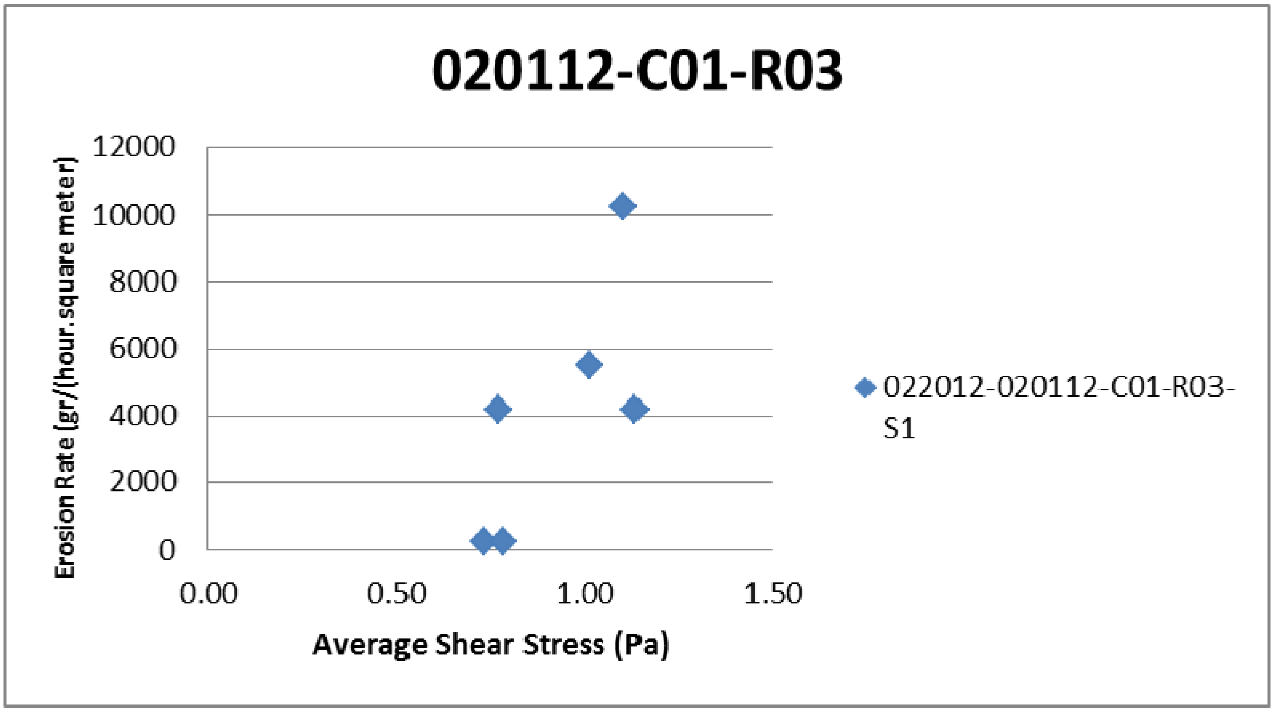


Figure 31

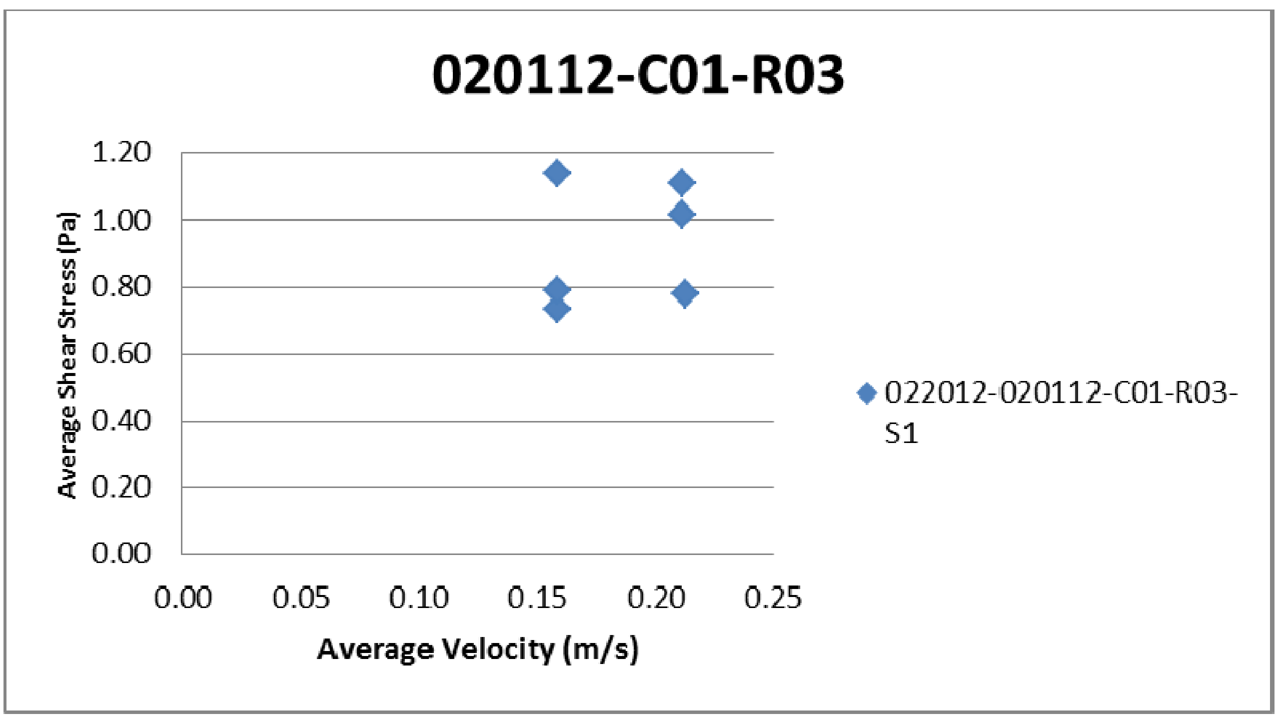


Figure 32

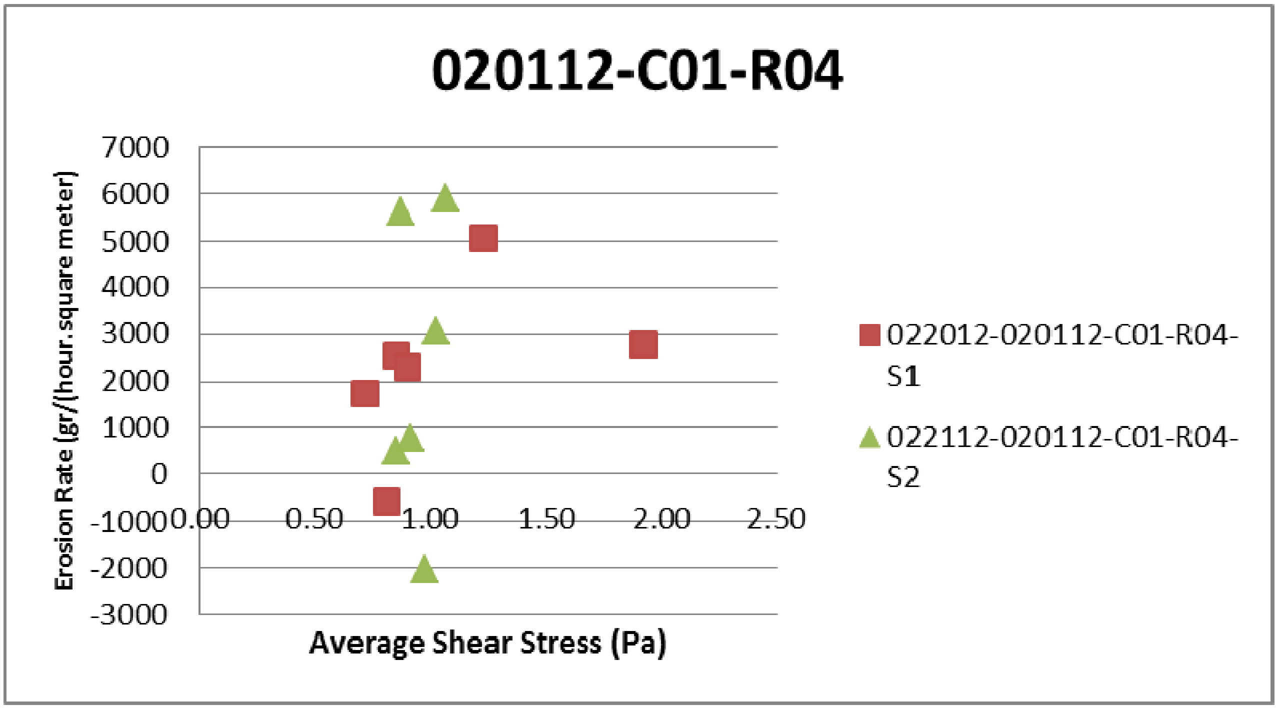


Figure 33

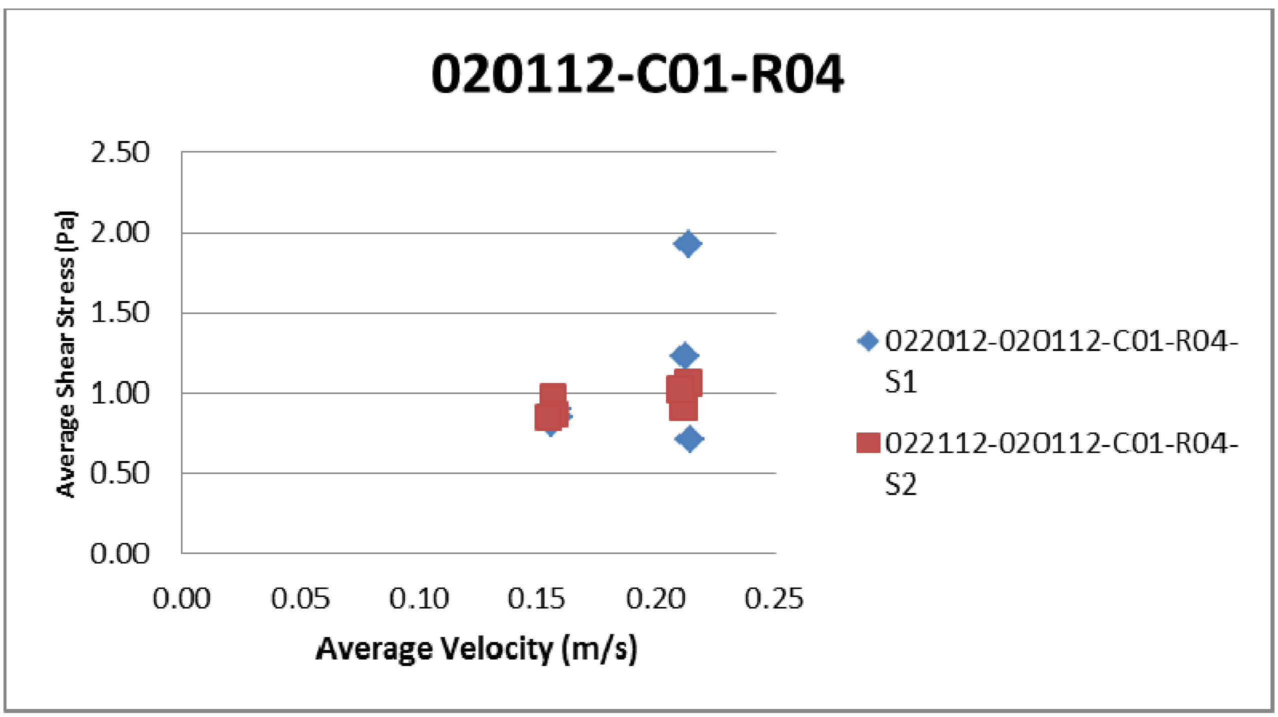


Figure 34

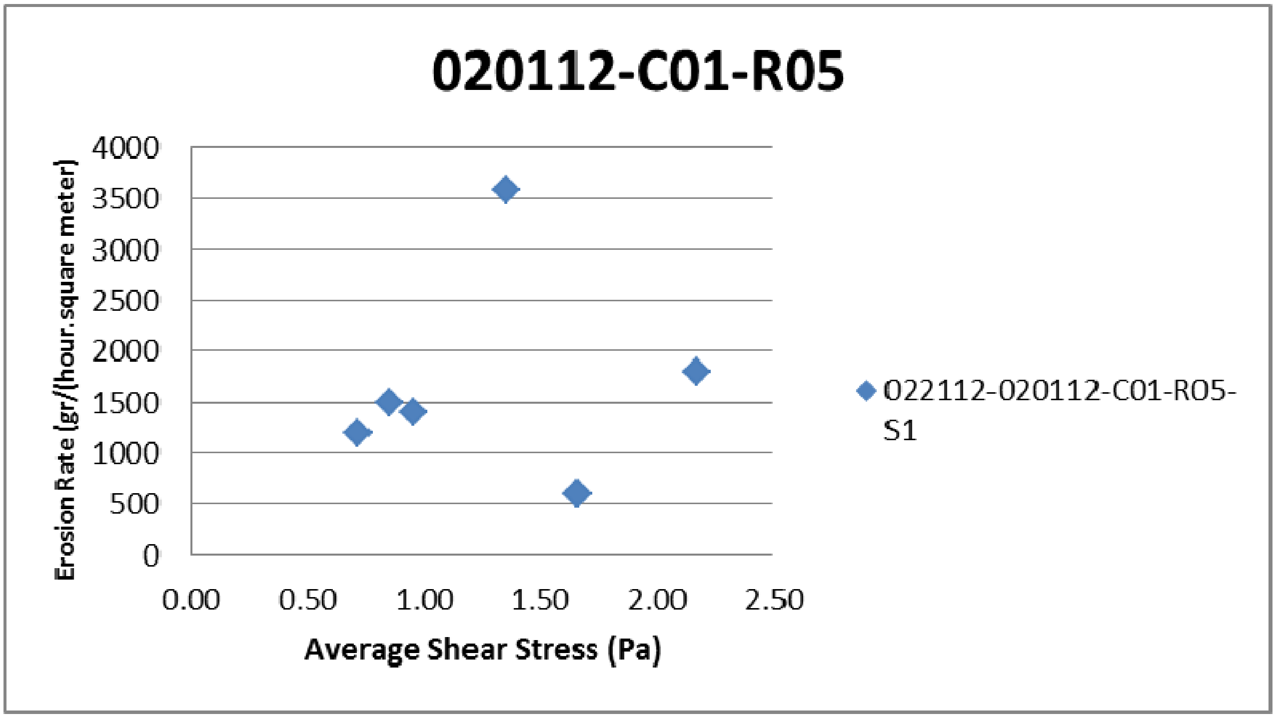


Figure 35

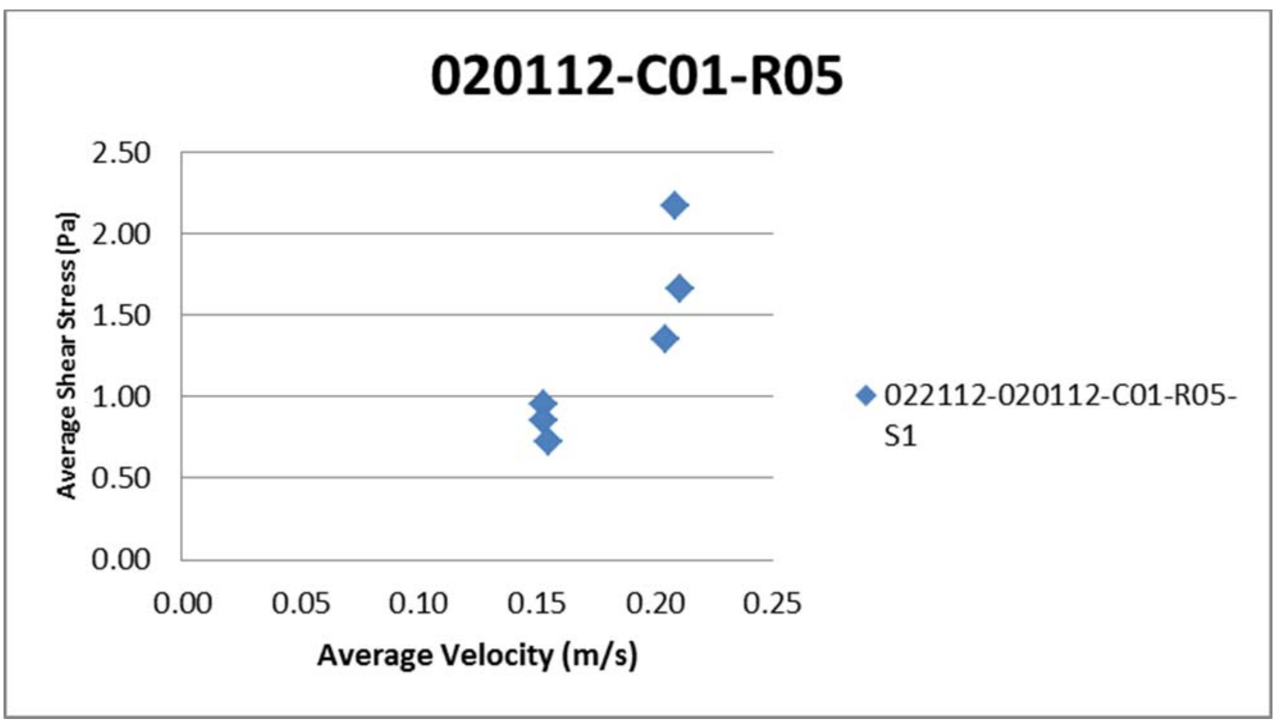


Figure 36

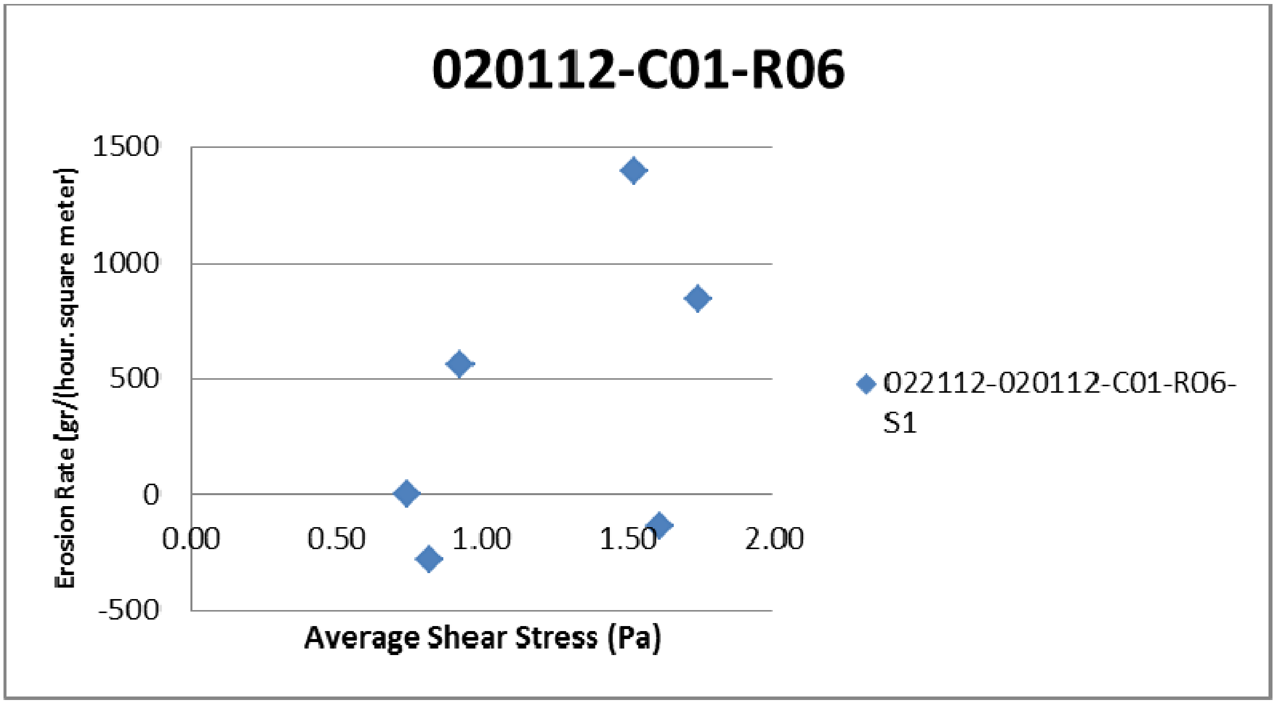


Figure 37

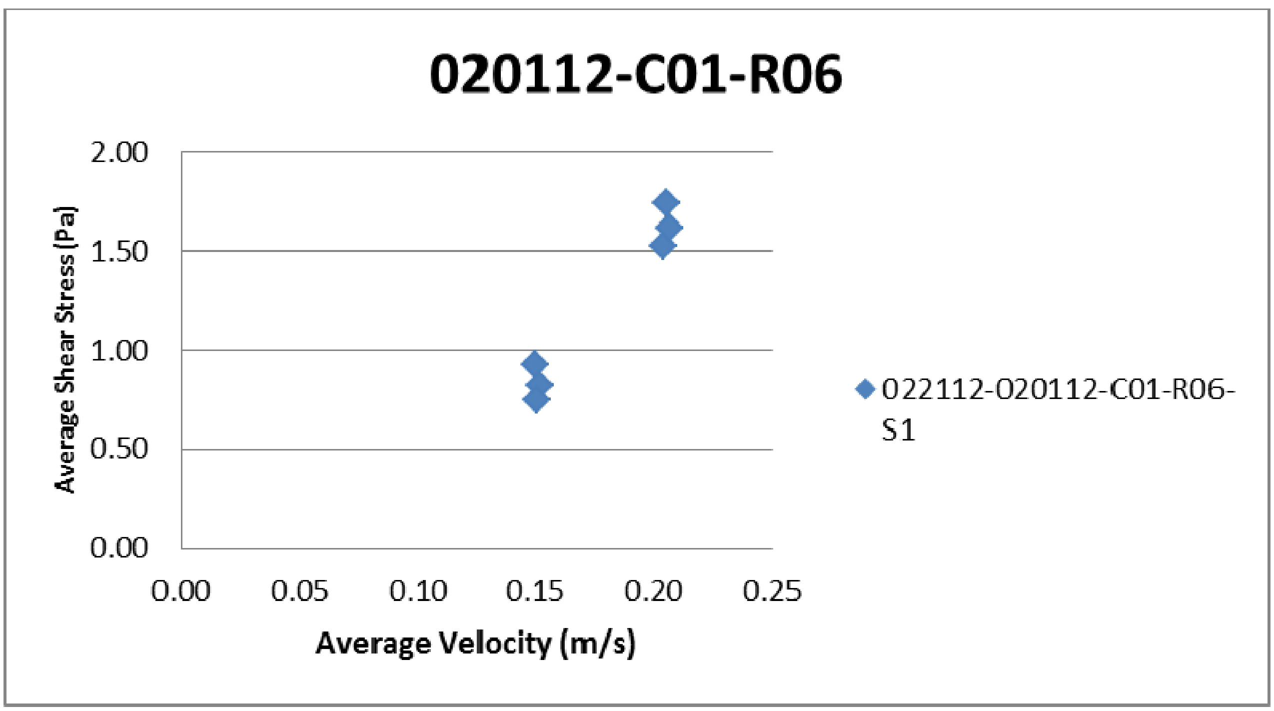


Figure 38

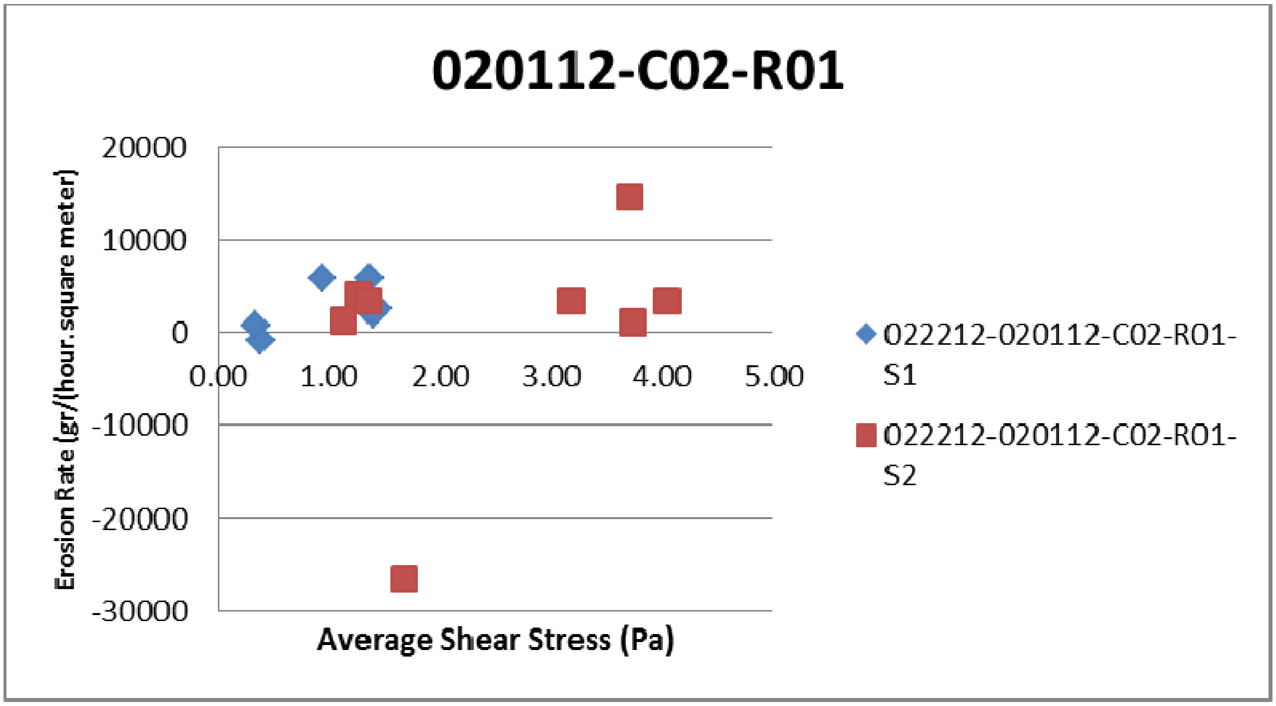


Figure 39

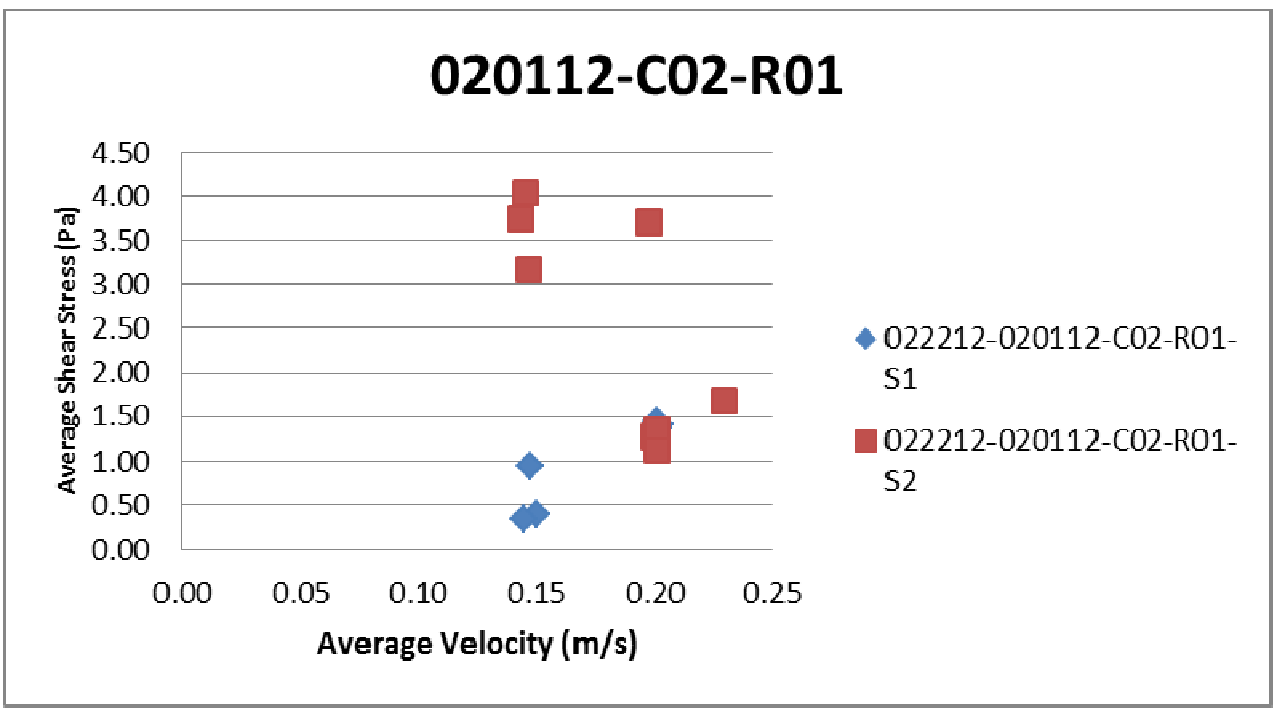


Figure 40

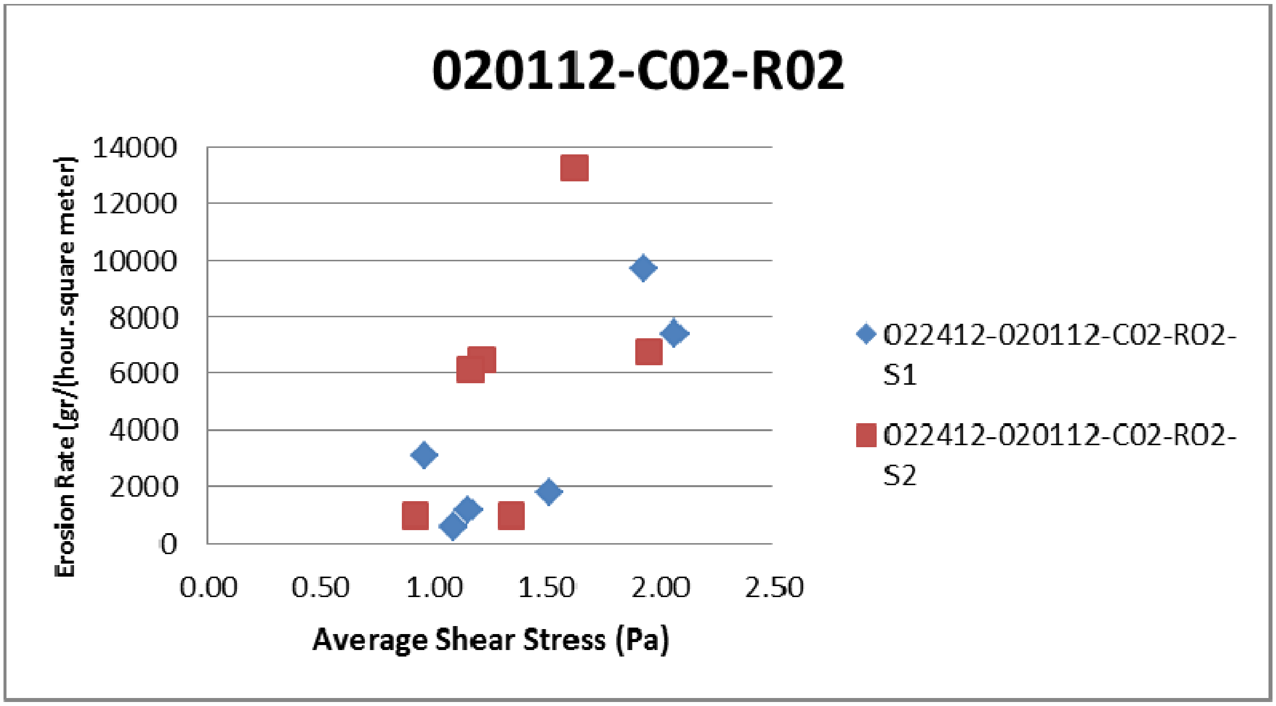


Figure 41

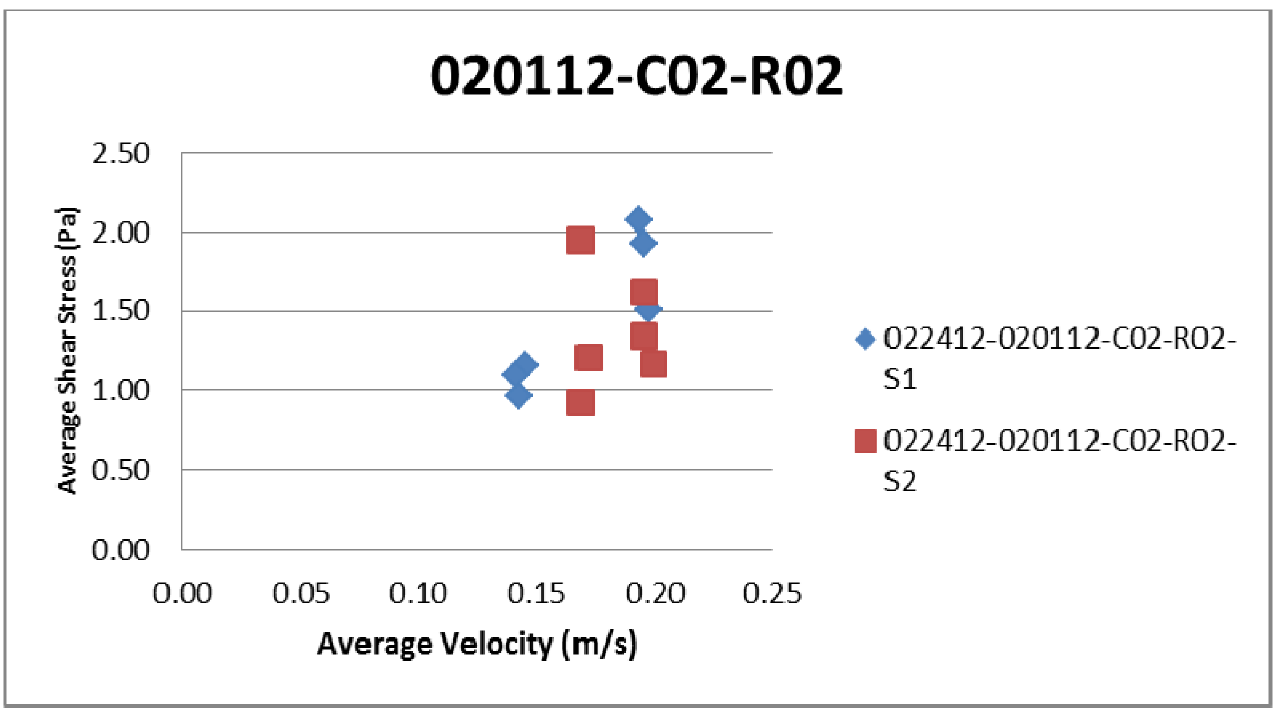


Figure 42

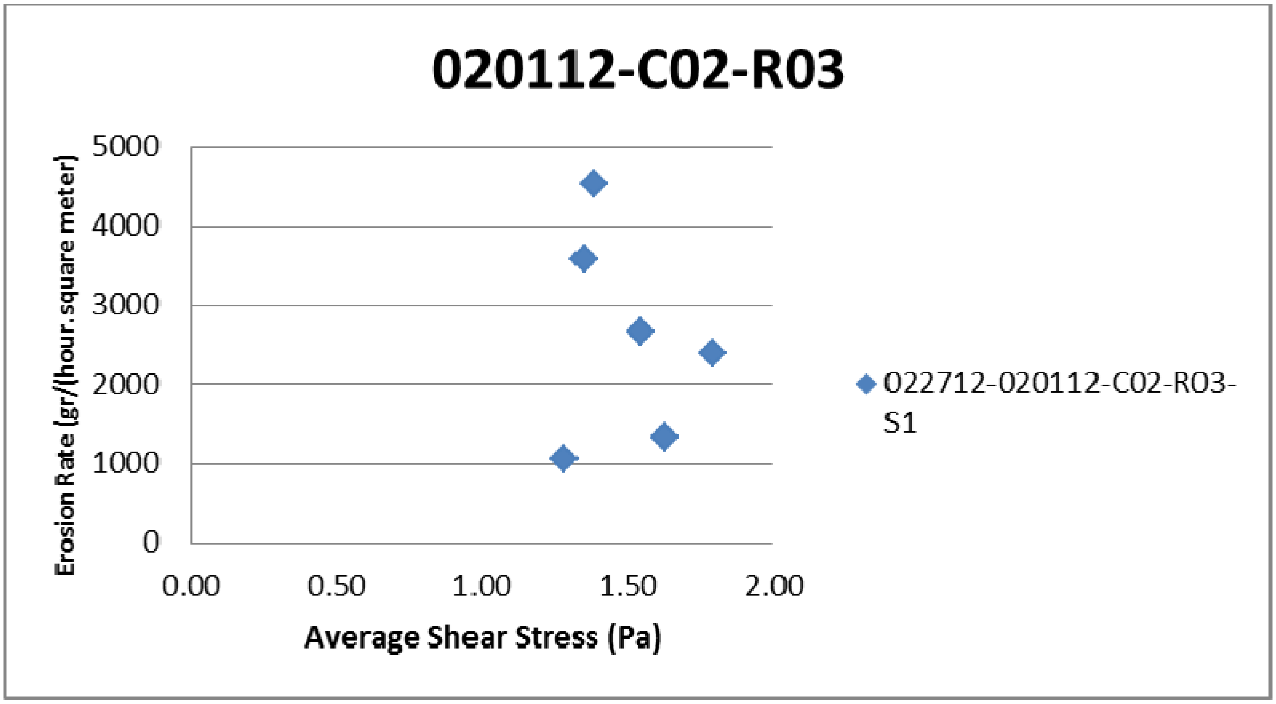


Figure 43

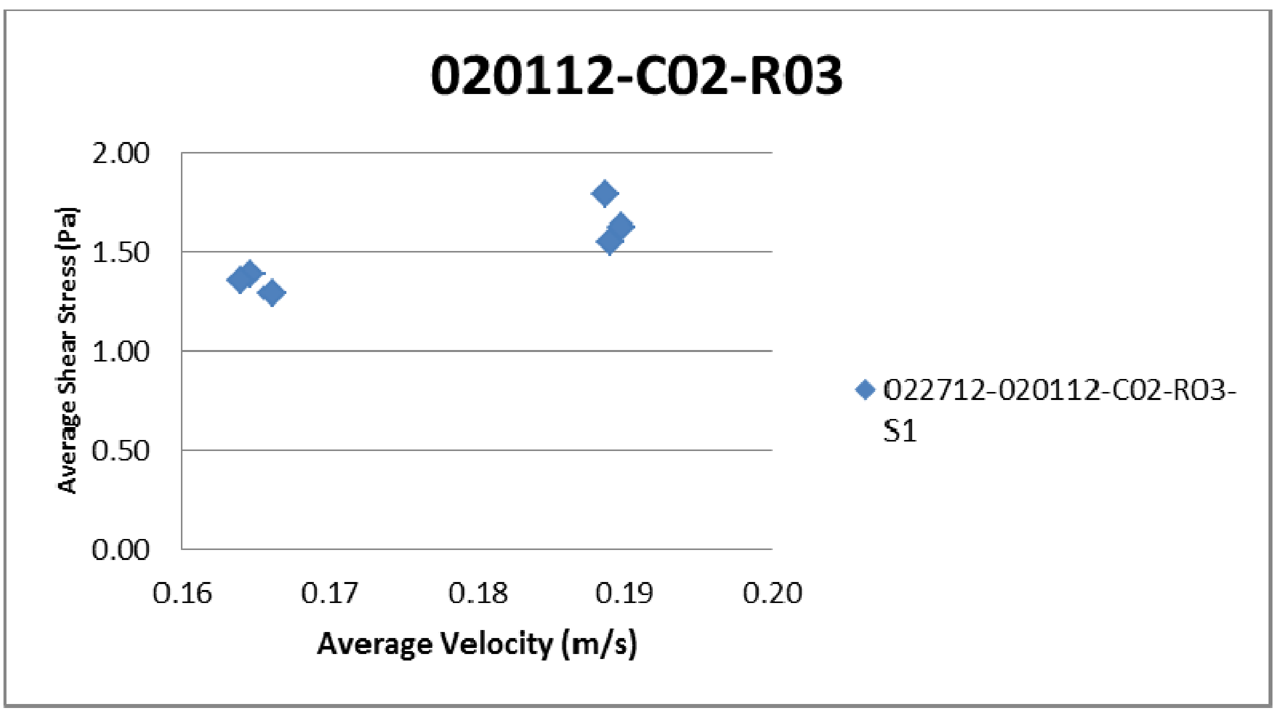


Figure 44

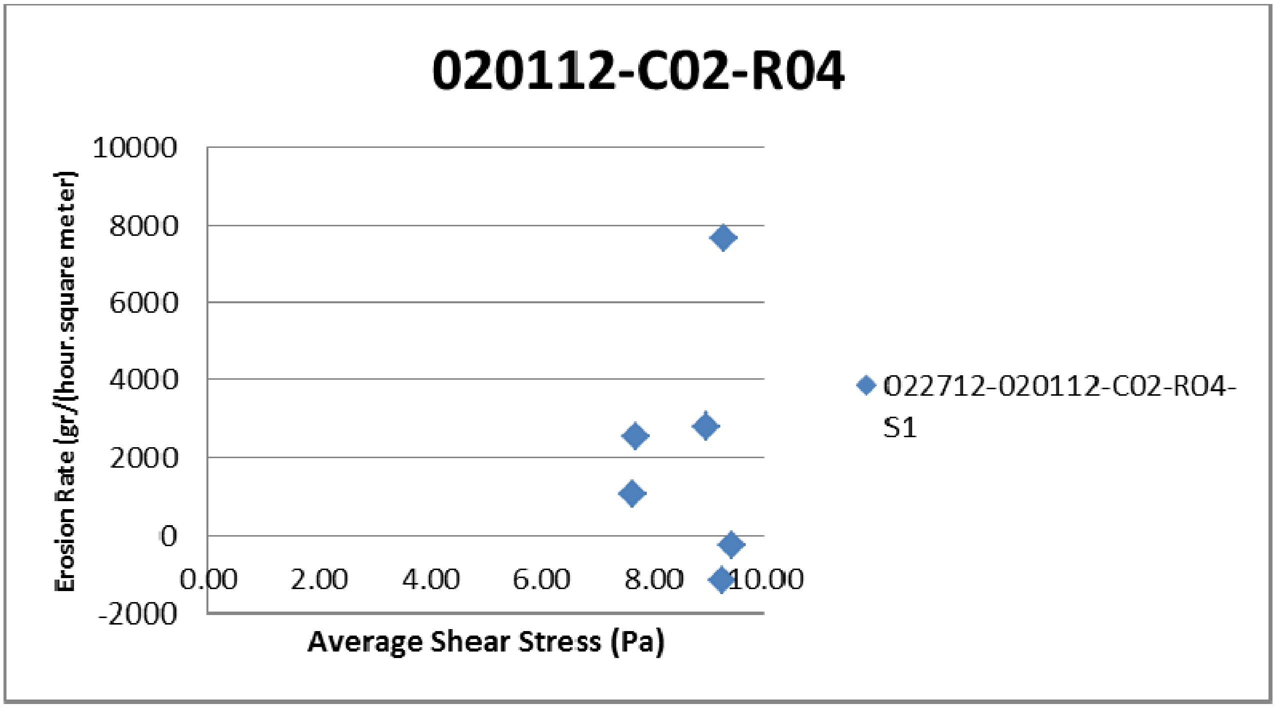


Figure 45

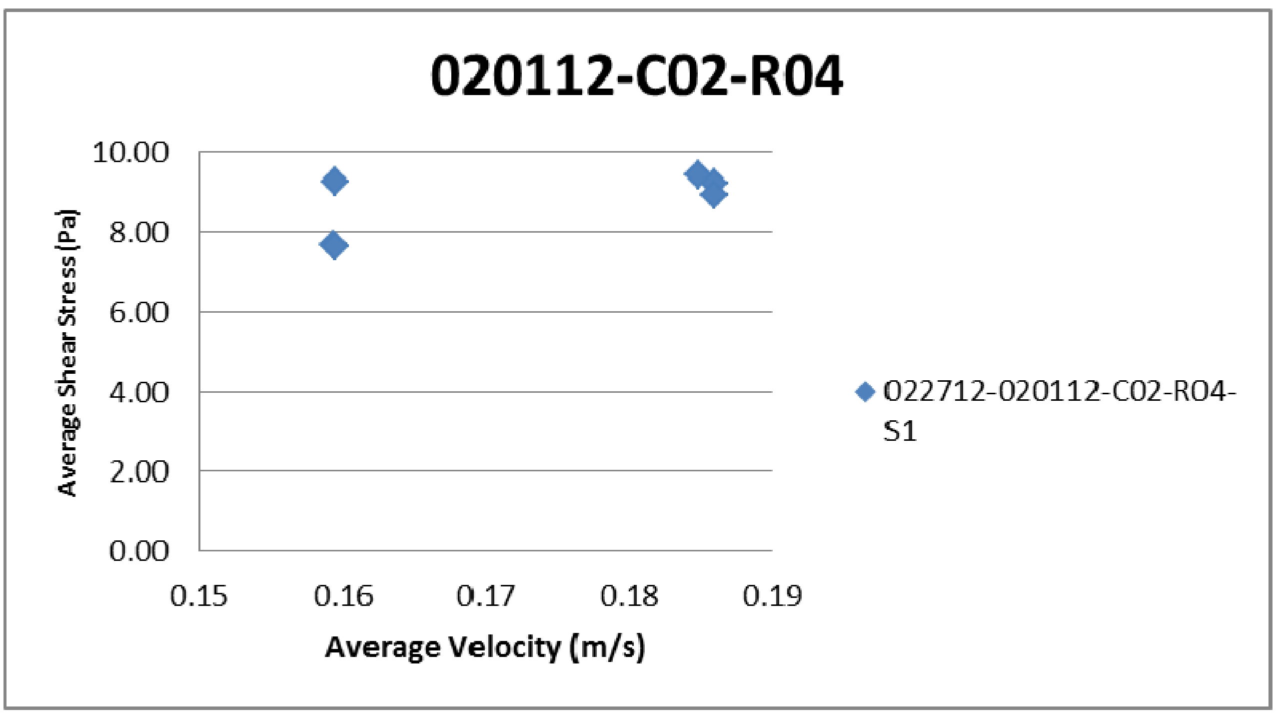


Figure 46

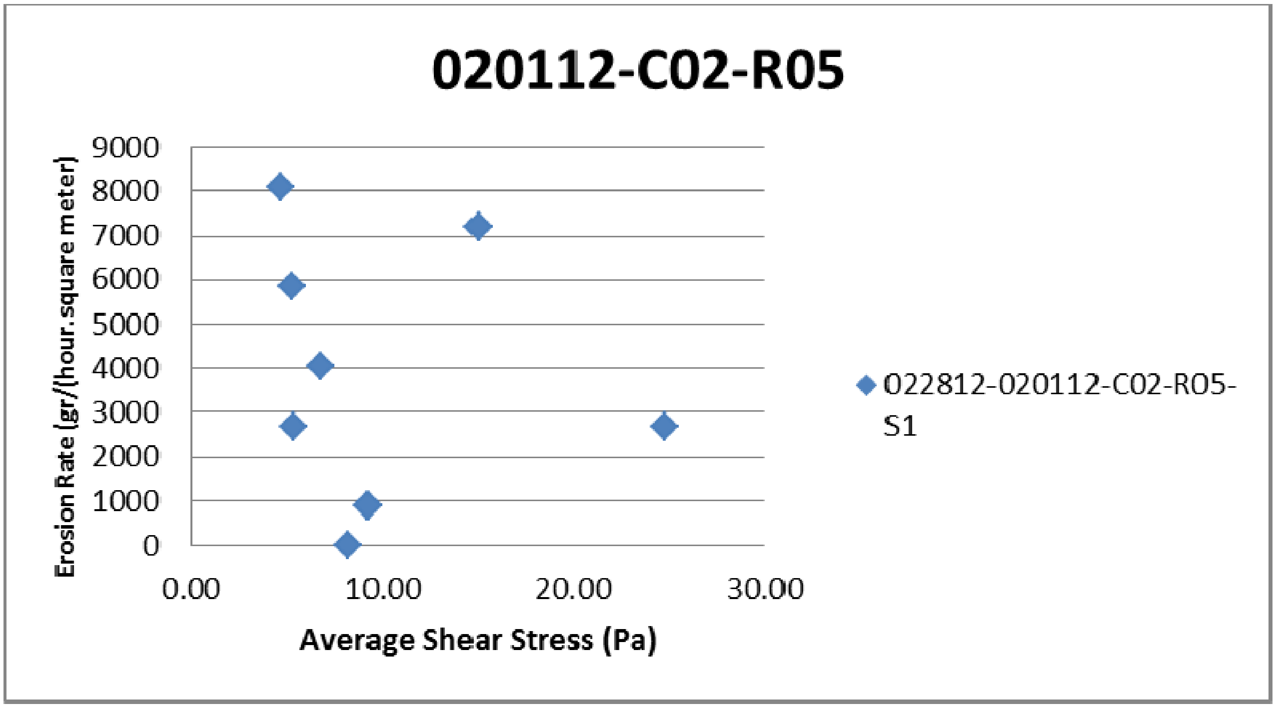


Figure 47

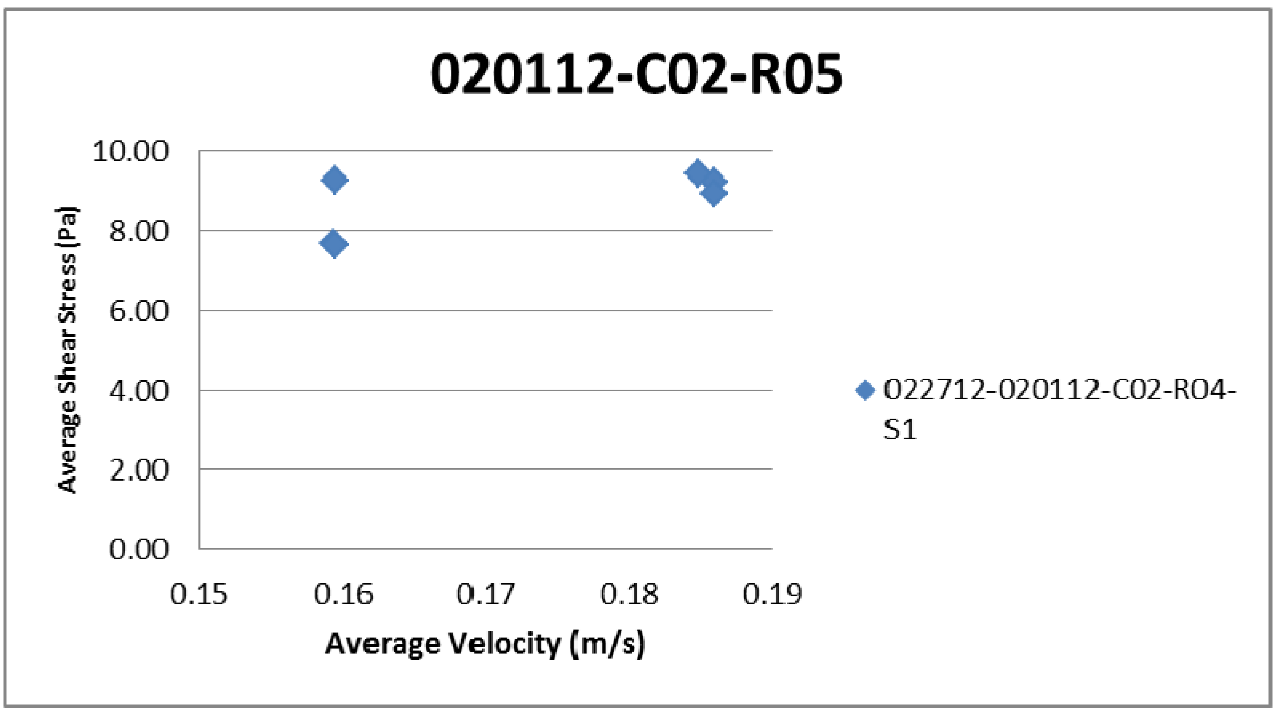


Figure 48

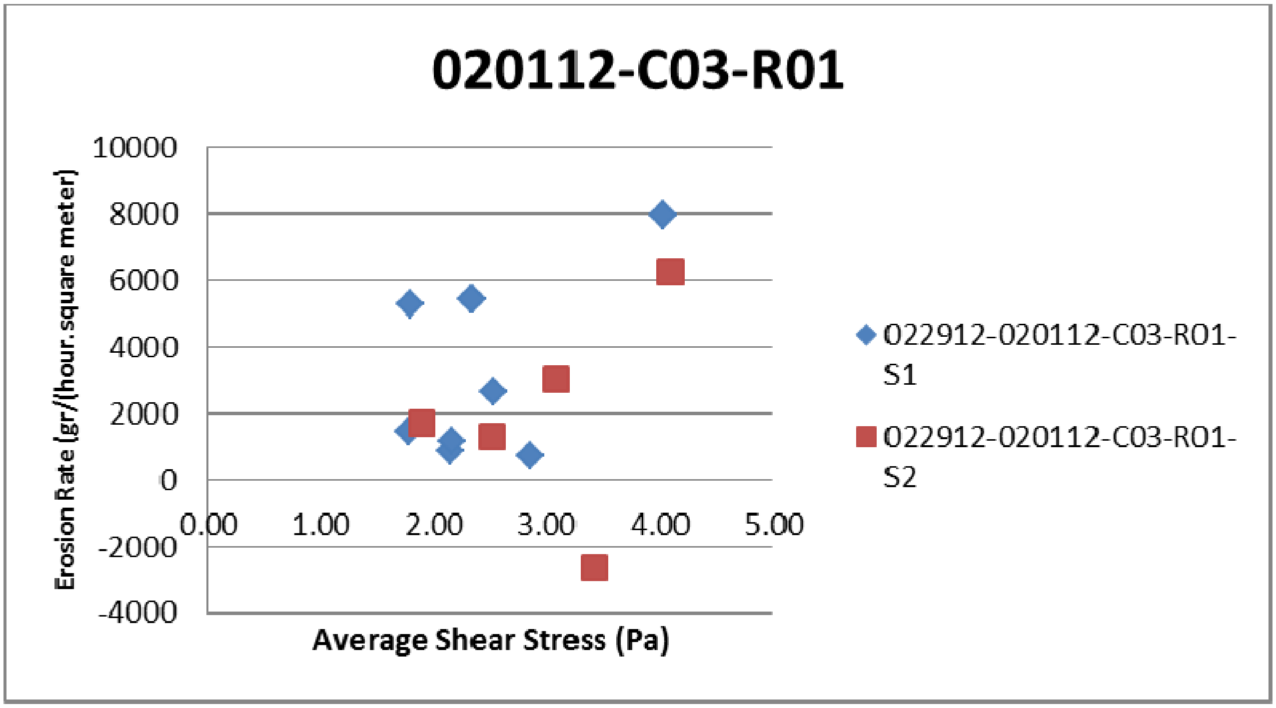


Figure 49

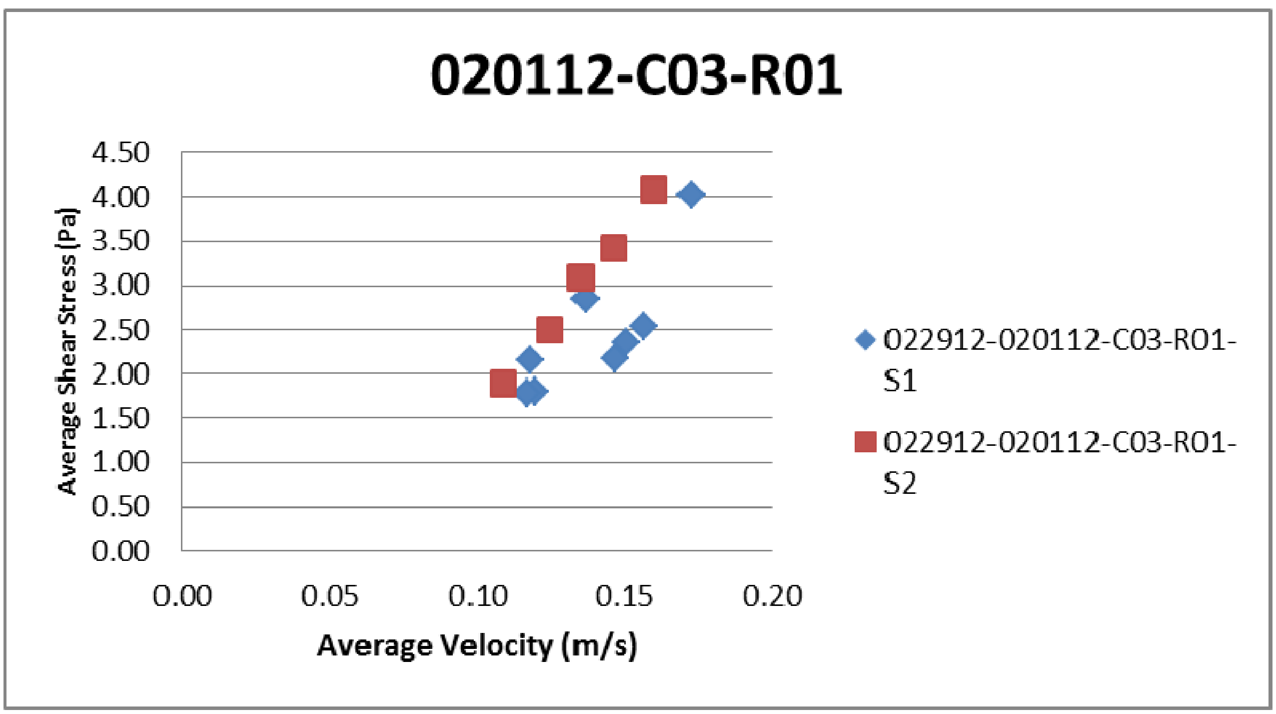


Figure 50

Test Results: Manufactured Samples

February 2012

Table 19

Date	2/3/2012		ID	020212-020112-03-2						
Sample Description	Like 2/2/2012 manufactured sample									
Initial height	15.0									
Initial volume (cubic centimeter)	43.81									
Initial non-submerged weight	73.54									
Density method 1	1.68									
Density method 2	1.60									
Average density	1.64									
First time weight measurment	77.08	77.16	77.10							
Pump Power	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%
Initial weight(gr)	77.10	76.79	76.3	75.73	75.44	75.2	74.73	74.35	73.89	73.46
Final weight (gr)	76.79	76.3	75.73	75.44	75.2	74.73	74.35	73.89	73.46	73.05
weight loss(gr)	0.31	0.49	0.57	0.29	0.24	0.47	0.38	0.46	0.43	0.41
Test duration (min)	5	5	5	5	5	5	5	5	5	5
intact sample?	Y	N	N	N	N	N	N	N	N	N
Temperature (F)	68									
Test validity										
Comments on the step										
Erosion rate (gr/(hour.m^2)	3265.86	5162.16	6004.97	3055.16	2528.41	4951.46	4003.31	4846.11	4530.06	4319.36
Average shear stress (Pa)	0.337160846	0.310627	2.388672	-0.22256	-0.71537	-0.01884	98.99697	0.193525798	0.305359	94.01893
Average velocity_corrected(m/s)	0.338846754	0.338544	0.337733	0.339439	0.339308	0.340209	0.34016	0.336006311	0.338148	0.33666
Average Tank level	11.71061331	11.73742	11.74547	11.76572	11.77173	11.77505	11.79426	11.80838904	11.81474	11.81802
Average Z force	74.86234296	-3.30403	-0.33016	-0.87054	-1.18432	-0.11633	4.502318	-0.948418851	-0.8376	-16.5782
shear stress std	0.116979726	0.123028	4.922111	0.114862	0.105726	0.127406	0.110806	0.112898746	0.150875	0.241615
velocity std	0.014944931	0.014163	0.013514	0.013637	0.014114	0.013152	0.012833	0.014777669	0.013805	0.013836
Tank level std	0.022127899	0.019298	0.020615	0.021874	0.021508	0.021049	0.02265	0.018582162	0.022226	0.019002
Z force std	0.095186958	0.103629	0.725495	0.111737	0.110919	0.122965	0.151287	0.146017422	0.12327	0.130519
Comments										

Table 20

Date	2/3/2012		ID	020212-020112-03-3	
Sample Description	Like 2/2/2012 manufactured sample				
Initial height	15.0				
Initial volume (cubic centimeter)	43.81				
Initial non-submerged weight	154.24				
Density method 1	3.52				
Density method 2	2.75				
Average density	3.13				
First time weight measurment	76.58	76.58			
Pump Power	6%	6%	6%	6%	6%
Initial weight(gr)	76.58	75.99	75.48	74.68	73.64
Final weight (gr)	75.99	75.48	74.68	73.64	72.42
weight loss(gr)	0.59	0.51	0.8	1.04	1.22
Test duration (min)	10	10	10	10	10
intact sample?	Y	N	N	N	N
Temperature (F)	69.8				
Erosion rate (gr/(hour.m^2)	1779.82	1538.49	2413.31	3137.31	3680.30
Average shear stress (Pa)	1.075176892	0.592944	1.179969	1.216164	2.183546
Average velocity (m/s)	0.337025182	0.338938	0.33647	0.33519	0.336145
Average tank level	11.81757148	11.84768	11.88381	11.90016	11.9104
Average z-force	78.27648741	-0.59223	-0.15916	-1.39333	-2.33783
shear stress std	0.118029939	3.431128	0.103215	0.107327	0.216214
velocity std	0.013892298	0.013135	0.014196	0.014621	0.013917
tank level std	0.022044311	0.022561	0.017384	0.01913	0.022978
z-force std	0.112613641	1.064064	0.103832	0.110822	0.240633
comments					

Table 21

Date	2/6/2012		ID	020612-020312-03-1								
Sample Description	Manufactured and consolidated for 2 days using sieve No 200 as the bottom porous stone											
Initial height	20.0			Ring	1							
Initial volume (cubic centimeter)	58.42			Puck	1							
Initial non-submerged weight (gr)	183.24											
Final non submerged weight (gr)	161.52											
Density method 1	1.74											
Density method 2	1.61											
Average density	1.68											
Pump Power %	6.00											
Ramp up time (s)	30											
First time weight measurment	86.86	86.72	86.71									
Initial weight(gr)	86.71	85.93	85.28	84.65	84.16	83.47	82.95	82.22	81.44	81.08	80.69	80.11
Final weight (gr)	85.93	85.28	84.65	84.16	83.47	82.95	82.22	81.44	81.08	80.69	80.11	79.46
weight loss(gr)	0.78	0.65	0.63	0.49	0.69	0.52	0.73	0.78	0.36	0.39	0.58	0.65
Accumulative weight loss (gr)	0.78	1.43	2.06	2.55	3.24	3.76	4.49	5.27	5.63	6.02	6.6	7.25
Test duration (min)	5	5	5	5	5	5	5	5	5	5	5	5
	10		20		30		40		50		60	
weight loss(gr)	1.43		1.12		1.21		1.51		0.75		1.23	
Dummy erosion rate	7264		5689		6146		7670		3810		6248	
Accumulative weight loss (gr)	1.43		2.55		3.76		5.27		6.02		7.25	
	15			30			45			60		
	2.06			1.7			1.87			1.62		
	2.06			3.76			5.63			7.25		
	30						60					
	3.76						3.49					
	3.76						7.25					
Time (min)	5	10	15	20	25	30	35	40	45	50	55	60
intact sample?	Y	N	N	N	N	N	N	N	N	N	N	N
Temperature (F)												
Test validity												
Comments on the step												
Erosion rate (gr/(hour.m^2)	7923.91	6603.26	6400.08	4977.84	7009.61	5282.60	7415.96	7923.91	3657.19	3961.95	5892.14	6603.26
Average shear stress (Pa)			Unknown		Unknown							
Average velocity (m/s)												
	ΔH	3.6	Min Elev.	14	Max Elev.	19	Avg SS	2	sd	+- 0.5		
Average shear stress (Pa)	2.10	2.46	0.51	1.88	-3.38	3.27	1.58	1.74	1.44	1.56	1.27	1.84
Average velocity (m/s)	0.34	0.34	0.34	0.33	0.34	0.34	0.33	0.33	0.33	0.33	0.33	0.33
Average tank level	13.27	12.87	12.86	12.82	12.77	12.70	12.70	12.70	12.64	12.66	12.66	12.68
Average z-force	76.07	-1.60	2.06	1.13	-0.31	-2.53	-1.33	-1.51	-4.99	-0.99	-1.81	-1.60
shear stress std	0.11	0.15	0.32	0.10	3.27	0.08	0.18	0.44	0.13	0.15	0.22	0.18
velocity std	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
tank level std	0.02	0.04	0.05	0.05	0.05	0.05	0.06	0.07	0.04	0.04	0.04	0.04
z-force std	0.12	0.14	0.13	0.12	0.46	0.12	0.13	0.25	0.08	0.11	0.17	0.10
comments												

Table 22

Date	2/7/2012		ID	020612-020312-03-2		
Sample Description	Manufactured and consolidated for 2 days using sieve No 200 as the bottom porous stone					
Initial height	19.0			Ring	2	
Initial volume (cubic centimeter)	55.50			Puck	2	
Initial non-submerged weight (gr)	180.72					
Final non submerged weight (gr)	157.97					
Density method 1	1.76					
Density method 2	1.63					
Average density	1.69					
Pump Power %	6.00					
Ramp up time (s)	30					
First time weight measurment	86.76	86.55	86.57			
Initial weight(gr)	86.57	85.74	84.07	82.1	81.13	80
Final weight (gr)	85.74	84.07	83.63	81.13	80	78.97
weight loss(gr)	0.83	1.67	0.44	0.97	1.13	1.03
Accumulative weight loss	0.83	2.5	2.94	3.91	5.04	6.07
Test duration (min)	10	10	10	10	10	10
Time (min)	10	20	30	40	50	60
intact sample?	Y	N	N	N	N	N
Temperature (F)	70.5					
Test validity						
Comments on the step						
Erosion rate (gr/(hour.m^2)	4160.93	8371.99	2205.79	4862.77	5664.88	5163.56
Average shear stress (Pa)	Unknown		Unknown			
Average velocity (m/s)						
	ΔH	3.8	Min Elev.	12.5	Max Elev.	18.7
Average shear stress (Pa)	-10.72	-0.76	2.36	1.81	0.93	-0.70
Average velocity (m/s)	0.33	0.33	0.33	0.32	0.32	0.32
Average tank level	12.62	12.62	12.60	12.69	12.69	12.75
Average z-force	-1.50	0.91	70.54	-1.07	-1.23	-2.06
shear stress std	0.24	4.43	0.14	0.11	0.27	0.72
velocity std	0.01	0.01	0.01	0.01	0.01	0.01
tank level std	0.07	0.08	0.08	0.05	0.06	0.04
z-force std	0.57	8.80	0.14	0.26	0.24	0.58
comments						

Total sub	6.07
Total non	22.75
Lost volume	16.68
Estimated Density	1.363909

Table 23

Date	2/7/2012		ID	020612-020312-03-3					
Sample Description	Manufactured and consolidated for 2 days using sieve No 200 as the bottom porous stone								
Initial height	21.5			Ring	3				
Initial volume (cubic centimeter)	62.80			Puck	1				
Initial non-submerged weight (gr)	183.77						Total sub		5.66
Final non submerged weight (gr)							Total non		183.77
Density method 1	1.63						Lost volume		178.11
Density method 2	1.59						Estimated Density		1.031778
Average density	1.61								
Pump Power %	6.00								
Ramp up time (s)	30								
First time weight measurment	87.29	87.47	87.45						
Initial weight(gr)	87.45	85.94	84.4	82.95					
Final weight (gr)	85.94	84.4	82.95	81.79					
weight loss(gr)	1.51	1.54	1.45	1.16					
Accumulative weight loss	1.51	3.05	4.5	5.66					
Test duration (min)	15	15	15	15					
Time (min)	15	30	45	60					
intact sample?	Y	N	N	N					
Temperature (F)									
Test validity	+	+	+	+					
Comments on the step									
Erosion rate (gr/(hour.m^2)	5461	5570	5244	4195					
Average shear stress (Pa)	Unknown		Unknown						
Average velocity (m/s)									
	ΔH	2.51	Min Elev.	13.1	Max Elev.	20.3			
Average shear stress (Pa)	1.93	0.98	1.74	1.28					
Average velocity (m/s)	0.32	0.32	0.31	0.31					
Average tank level	12.68	12.71	12.82	12.76					
Average z-force	-2.53	-1.38	0.14	-1.52					
shear stress std	0.36	0.76	0.47	0.29					
velocity std	0.01	0.01	0.01	0.01					
tank level std	0.10	0.10	0.06	0.03					
z-force std	1.00	0.14	0.24	0.35					
comments									

Table 24

Date	2/7/2012		ID	020612-020312-03-4				
Sample Description	Manufactured and consolidated for 2 days using sieve No 200 as the bottom porous stone							
Initial height	21.0			Ring	4			
Initial volume (cubic centimeter)	61.34			Puck	1			
Initial non-submerged weight (gr)	179.40						Total sub	8.54
Final non submerged weight (gr)	153.80						Total non	25.60
Density method 1	1.63						Lost volume	17.06
Density method 2	1.56						Estimated Density	1.500586
Average density	1.60							
Pump Power %	6.00							
Ramp up time (s)	30							
First time weight measurment	84.77	84.75						
Initial weight(gr)	84.75	80.89						
Final weight (gr)	80.89	76.21						
weight loss(gr)	3.86	4.68						
Accumulative weight loss	3.86	8.54						
Test duration (min)	30	30						
Time (min)	30	60						
intact sample?	Y	N						
Temperature (F)	72.8							
Test validity	-	-						
Comments on the step								
Erosion rate (gr/(hour.m^2)	7069	8571						
	ΔH	2						
Average shear stress (Pa)	9.08	4.68						
Average velocity (m/s)	0.32	0.31						
Average tank level	12.28	12.43						
Average z-force	-6.86	-3.36						
shear stress std	0.77	1.63						
velocity std	0.01	0.01						
tank level std	0.03	0.03						
z-force std	0.51	1.04						
comments	there was a big discrepency in the shear stress graph in step 1 so we selected data to the right of it during the first step							

Date	2/8/2012		ID	020612-020312-03-5				
Sample Description	Manufactured and consolidated for 2 days using sieve No 200 as the bottom porous stone							
Initial height	22.7			Ring	5			
Initial volume (cubic centimeter)	66.31			Puck	2			
Initial non-submerged weight (gr)	190.21						Total sub	9.04
Final non submerged weight (gr)								
Density method 1	1.65							
Density method 2	1.57							
Average density	1.61							
Pump Power %	6.00							
Ramp up time (s)	30							
First time weight measurment	88.83	88.67						
Initial weight(gr)	88.67							
Final weight (gr)	79.63							
weight loss(gr)	9.04							
Accumulative weight loss	9.04							
Test duration (min)	60							
Time (min)	60							
intact sample?	Y							
Temperature (F)	69.1							
Test validity	-							
Comments on the step								
Erosion rate (gr/(hour.m^2)	8168							
Average shear stress (Pa)	-							
Average velocity (m/s)								
	ΔH	2.8	Min Elev.	14.4	Max Elev.	20.7		
Comments	o maintain the level of shear stress. The initial shear stress was around 4 Pa. When the test was done, the sample was weigh							

Table 25

Date	2/9/2012		ID	020612-020312-03-6					
Sample Description	Manufactured and consolidated for 3 days using sieve No 200 as the bottom porous stone								
Initial height	23.6			Ring	6	2.22	3.53		
Initial volume (cubic centimeter)	68.94			Puck	2	48.12	77.29		
Initial non-submerged weight (gr)	186.94						Total sub		2.06
Final non submerged weight (gr)	157.28						Total non		29.66
Density method 1	1.54						Lost volume		27.60
Density method 2	1.54						Estimated Density		1.074638
Average density	1.54								
Pump Power %	6.00								
Ramp up time (s)	30								
First time weight measurment	87.84	87.82	87.69						
Initial weight(gr)	87.69	85.63	82.73	80.45					
Final weight (gr)	85.63	82.73	80.45	77.96					
weight loss(gr)	2.06	2.9	2.28	2.49					
Accumulative weight loss	2.06	4.96	7.24	9.73					
Test duration (min)	5	10	15	30					
Time (min)	5	15	30	60					
intact sample?	Y	Y	Y	Y					
Temperature (F)	65.1								
Test validity									
Erosion rate (gr/(hour.m^2)	24117	16976	8898	4859					
	ΔH	3.4	Min Elev.	13.5	Max Elev.	20.55			
Average shear stress (Pa)	2.39	1.46	-3.66	-0.20					
Average velocity (m/s)	0.30	0.30	0.29	0.28					
Average tank level	11.97	11.93	11.86	12.01					
Average z-force	-2.50	-2.55	-0.14	-3.01					
shear stress std	0.49	0.28	4.99	0.73					
velocity std	0.01	0.01	0.01	0.01					
tank level std	0.02	0.02	0.02	0.06					
z-force std	0.10	0.29	1.04	1.00					
comments									

Table 26

Date	2/13/2012		ID	[021312-mixed] mixedinterval-consolidated-elizabeth-600gr					
Sample Description	Manufactured and consolidated for 3 days using								
Initial height	16.0			Ring	6	2.22	3.53		
Initial volume (cubic centimeter)	46.82			Puck	2	48.12	77.29		
Initial non-submerged weight (gr)	153.71			Photos			Total sub		0.61
Final non submerged weight (gr)	149.47						Total non		4.24
Density method 1	1.56						Lost volume		3.63
Density method 2	1.54						Estimated Density		1.168044
Average density	1.55								
Pump Power %	3.00								
Ramp up time (s)	30								
First time weight measurment	75.42	75.48	75.48						
Time (min)	0.00	0.00	5.00						
Initial weight(gr)		75.46	75.34	75.04	74.87	74.87	74.59	74.21	
First weight(gr)	75.48	75.36	74.99	74.89	74.87	74.63	74.23	73.91	
Second weight (gr)	75.46	75.34	75.04	74.87	74.87	74.59	74.21	73.89	
Replacement weight loss (gr)	0.02	0.02	-0.05	0.02	0	0.04	0.02	0.02	
weight loss(gr)		0.10	0.35	0.15	0.00	0.24	0.36	0.30	
Accumulative weight loss		0.1	0.45	0.60	0.60	0.84	1.20	1.50	
Test duration (min)	0	5	5	5	5	10	15	15	
intact sample?	Y	Y	Y	Y	Y	Y	Y	Y	
Temperature (F)	64.4								
Test validity									
Comments on the step									
Erosion rate (gr/(hour.m^2)		1162	4067	1743	0	1395	1395	1162	
	ΔH	1.95	Min Elev.	14.04	Max Elev.	14.13			
Average shear stress (Pa)		1.15	0.58	0.50	0.64	1.07	1.06	0.84	
Average velocity (m/s)		0.22	0.22	0.22	0.22	0.22	0.22	0.22	
Average tank level		13.80	13.65	13.59	13.55	13.51	13.46	13.44	
Average z-force		-0.07	-1.02	-1.04	-2.27	-2.10	-0.09	-2.70	
shear stress std		0.24	0.10	0.09	0.09	0.10	0.10	0.09	
velocity std		0.01	0.01	0.02	0.01	0.01	0.01	0.01	
tank level std		0.03	0.02	0.02	0.02	0.02	0.02	0.02	
z-force std		0.44	0.10	0.10	0.10	0.11	0.12	0.10	
comments	The edges were trimmed in the side towards the entrance								

Table 27

Date	2/14/2012		Test ID	[021412-shear search] misedinterval-consolidated-elizabeth-600gr#1				
Initial height	15.8	Ring	2	Min Thick	12.62	Total sub. WL		0.51
Initial volume (cubic centimeter)	46.24	Puck	1	Max Thick	16.53	Total unsub. WL		
Initial non-submerged weight (gr)	153.71	Ring sub	3.63	EE1		Lost volume		
Final non submerged weight (gr)	156.53	Puck sub	48.28	EE2		Estimated Density		
Density method 1	1.53	Ring unsu	5.7	ΔH	0.1	Image Files		
Density method 2	1.56	Puck unsu	77.37	SS avg				
Average density	1.54			SS sd				
Pump Power %	Mixed	1						
Ramp up time (s)	%.2 /s							
First time weight measurment	77.68	77.67						
Time (min)	5.00	10.00	15.00	20.00	25.00	30.00	35.00	
Pump Power %	1.80	2.00	2.20	2.40	2.60	2.80	3.00	
Test duration (min)	5	5	5	5	5	5	5	
Initial weight(gr)	77.67	77.65	77.61	77.48	77.43	77.32	77.28	
Final weight (gr)	77.65	77.61	77.48	77.43	77.32	77.28	77.16	
weight loss(gr)	0.02	0.04	0.13	0.05	0.11	0.04	0.12	
Accumulative weight loss	0.02	0.06	0.19	0.24	0.35	0.39	0.51	
intact sample?	Y	Y	Y	Y	Y	Y	Y	
Temperature (F)	68							
Test validity								
Erosion rate (gr/(hour.m^2)	234	467	1519	584	1285	467	1402	
Average shear stress (Pa)	0.38	0.44	0.45	0.52	0.62	0.51	0.61	
Average velocity (m/s)	0.15	0.16	0.17	0.19	0.20	0.21	0.22	
Average tank level	13.08	13.03	13.01	12.99	12.91	12.86	12.83	
Average z-force	-0.03	-0.69	-0.02	-0.37	-0.18	-0.36	-0.27	
shear stress std	0.09	0.08	0.08	0.09	0.12	0.10	0.14	
velocity std	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
tank level std	0.02	0.02	0.02	0.02	0.02	0.02	0.02	
z-force std	0.10	0.09	0.11	0.10	0.10	0.10	0.13	
Comments on the step								
Sample Description								
Test Description/purpose								
Conclusion/Comment/Decision								

Table 28

Date	2/14/2012		Test ID	021412-shear search 2] misedinterval-consolidated-elizabeth-600gr#				
Initial height	16.5	Ring	3	Min Thick	12.62	Total sub. WL		0.55
Initial volume (cubic centimeter)	48.20	Puck	2	Max Thick	16.53	Total unsub. WL		2.75
Initial non-submerged weight (gr)	159.28	Ring sub	2.4	EE1		Lost volume		2.20
Final non submerged weight (gr)	156.53	Puck sub	48.12	EE2		Estimated Density		1.25
Density method 1	1.62	Ring unsu	3.83	ΔH		Image Files		
Density method 2	1.55	Puck unsu	77.29	SS avg				
Average density	1.59	2		SS sd				
Pump Power %	Mixed							
Ramp up time (s)	%.2 /s							
First time weight measurment	77.03	76.99						
Time (min)	5.00	10.00	15.00	20.00	25.00	30.00	35.00	
Pump Power %	1.80	2.00	2.20	2.40	2.60	2.80	3.00	
Test duration (min)	5	5	5	5	5	5	5	
Initial weight(gr)	76.99	76.92	76.87	76.73	76.66	76.60	76.52	
Final weight (gr)	76.92	76.87	76.73	76.66	76.6	76.52	76.44	
weight loss(gr)	0.07	0.05	0.14	0.07	0.06	0.08	0.08	
Accumulative weight loss	0.07	0.12	0.26	0.33	0.39	0.47	0.55	
intact sample?	Y	Y	Y	Y	Y	Y	Y	
Temperature (F)	68							
Test validity								
Erosion rate (gr/(hour.m^2)	779	556	1558	779	668	890	890	
Average shear stress (Pa)	0.34	0.55	0.50	0.58	0.57	0.71	0.75	
Shear stress std	0.09	0.09	0.10	0.09	0.12	0.08	0.11	
Average velocity (m/s)	0.16	0.16	0.18	0.19	0.20	0.21	0.22	
Velocity std	0.01	0.01	0.01	0.01	0.01	0.02	0.02	
Average tank level	12.84	12.84	12.81	12.80	12.80	12.80	12.80	
Tank level std	0.02	0.02	0.03	0.03	0.02	0.02	0.02	
Average Z Force (grams)	0.09	-0.22	-0.20	-0.38	-0.37	-0.30	-0.63	
Z Force std (grams)	0.11	0.13	0.12	0.09	0.09	0.11	0.12	
Comment on the step								
Sample Description								
Test Description/purpose								
Conclusion/Comment/Decision								

Table 29

Date	2/15/2012		Test ID	21512-shear search (3)] misedinterval-consolidated-elizabeth-600gr				
Initial height	16.65	Ring	5	Min Thick	13.85	Total sub. WL		1.43
Initial volume (cubic centimeter)	48.63	Puck	1	Max Thick	16.68	Total unsub. WL		5.57
Initial non-submerged weight (gr)	157.29	Ring sub	2.45	EE1		Lost volume		4.14
Final non submerged weight (gr)	151.72	Puck sub	48.28	EE2		Estimated Density		1.345410628
Density method 1	1.56	Ring unsu	3.81	ΔH	0.13	Image Files		
Density method 2	1.53	Puck unsu	77.37	SS avg	0.2			
Average density	1.55	3		SS sd				
Pump Power %	Mixed		Start time					
Ramp up time (s)	%.2 /s		End time					
First time weight measurment	76.52	76.46	76.40	76.32				
Time (min)	5.00	10.00	15.00	20.00	25.00	30.00	35.00	
Pump Power %	1.80	2.00	2.20	2.40	2.60	2.80	3.00	
Test duration (min)	5	5	5	5	5	5	5	
Initial weight(gr)	76.32	76.05	75.91	75.74	75.56	75.37	75.12	
Final weight (gr)	76.05	75.91	75.74	75.56	75.37	75.12	74.89	
weight loss(gr)	0.27	0.14	0.17	0.18	0.19	0.25	0.23	
Accumulative weight loss	0.27	0.41	0.58	0.76	0.95	1.20	1.43	
intact sample?	Y	Y	Y	Y	Y	Y	Y	
Temperature (F)	66.2							
Test validity								
Erosion rate (gr/(hour.m^2)	3142	1629	1979	2095	2211	2910	2677	
Average shear stress (Pa)	0.38	0.30	0.16	0.15	0.22	0.39	0.32	
Shear stress std	0.09	0.09	0.10	0.13	0.13	0.09	0.10	
Average velocity (m/s)	0.16	0.17	0.17	0.19	0.20	0.21	0.22	
Velocity std	0.01	0.01	0.02	0.02	0.01	0.02	0.01	
Average tank level	12.44	12.44	12.51	12.42	12.39	12.37	12.36	
Tank level std	0.02	0.03	0.02	0.03	0.02	0.03	0.02	
Average Z Force (grams)	-0.50	-0.56	-0.80	0.61	0.10	0.30	0.88	
Z Force std (grams)	0.09	0.14	0.18	0.12	0.11	0.09	0.19	
Comment on the step								
Sample Description								
Test Description/purpose								
Conclusion/Comment/Decision								

Table 30

Date	2/15/2012		Test ID	021512-021012-D1-S01				
Initial height	16.71	Ring	1	Min Thick	12.28	Total sub. WL		2.24
Initial volume (cubic centimeter)	48.81	Puck	2	Max Thick	16.33	Total unsub. WL		6.31
Initial un-submerged weight (gr)	153.18	Ring sub	2.53	EE1		Lost volume		4.07
Final non submerged weight (gr)	146.87	Puck sub	48.12	EE2		Estimated Density		1.55
Density method 1	1.47	Ring unsu	4.02	ΔH	0.83	Image Files		
Density method 2	1.51	Puck unsu	77.29	SS avg				
Average density	1.49			SS sd				
Pump Power %	3.00	2	Start time		14:10			
Ramp up time (s)	15		End time					
First time weight measurment	75.49	75.95	75.35	75.31				
Time (min)	5.00	10.00	15.00	20.00	25.00	35.00	50.00	65.00
Test duration (min)	-	5	5	5	5	10	15	15
Initial weight(gr)		75.31	74.89	74.77	74.60	74.25	74.00	73.61
First final weight(gr)	75.31	74.89	74.79	74.65	74.32	73.98	73.61	73.43
Second final weight (gr)	-	74.89	74.77	74.6	74.25	74	73.61	73.31
Replacement weight loss (gr)	-	0.00	0.02	0.05	0.07	-0.02	0.00	0.12
weight loss(gr)	-	0.42	0.10	0.12	0.28	0.27	0.39	0.18
Accumulative weight loss	-	0.42	0.52	0.64	0.92	1.19	1.58	1.76
intact sample?	-	Y	N	N	N	N	N	N
Temperature (F)								
Test validity								
Erosion rate (gr/(hour.m^2)	-	5255	1251	1501	3503	1689	1627	751
Average shear stress (Pa)		1.84	0.58	0.41	1.06	0.53	0.23	0.35
Shear stress std		0.13	0.10	0.09	0.11	0.11	0.11	0.11
Average velocity (m/s)		0.22	0.22	0.22	0.22	0.22	0.22	0.22
Velocity std		0.01	0.01	0.02	0.01	0.02	0.01	0.01
Average tank level		12.03	12.05	12.08	12.01	12.01	12.04	12.08
Tank level std		0.02	0.02	0.03	0.02	0.02	0.02	0.03
Average Z Force (grams)		-0.35	-0.41	-0.66	-0.54	-0.36	-0.30	-0.33
Z Force std (grams)		0.11	0.09	0.11	0.10	0.15	0.12	0.12
Comment on the step								
Sample Description								
Test Description/purpose								
Conclusion/Comment/Decision								

Table 31

Date	2/17/2012		Test ID	021712-021012-D1-S04			
Initial height	15.89	Ring	1	Min Thick	12.28	Total sub. WL	6.70
Initial volume (cubic centimeter)	46.41	Puck	2	Max Thick	16.33	Total unsub. WL	
Initial un-submerged weight (gr)	147.32	Ring sub	2.53	EE1		Lost volume	
Final non submerged weight (gr)	-	Puck sub	48.12	EE2		Estimated Density	
Density method 1	1.42	Ring unsu	4.02	ΔH	0.83	Image Files	
Density method 2	1.48	Puck unsu	77.29	SS avg			
Average density	1.45			SS sd			
Pump Power %	6.00	3	Start time		9:15		
Ramp up time (s)	15		End time				
First time weight measurment	72.94	72.89	72.91				
Time (min)	5.00	10.00	15.00	20.00			
Test duration (min)	5	5	5	5			
Initial weight(gr)	72.91	71.50	69.79	68.15			
First final weight(gr)	71.50	69.79	68.15	66.21			
weight loss(gr)	1.41	1.71	1.64	1.94			
Accumulative weight loss	1.41	3.12	4.76	6.70			
intact sample?	Y	N	N	N			
Temperature (F)	65.7						
Test validity							
Erosion rate (gr/(hour.m^2)	18640	22605	21680	25646			
Average shear stress (Pa)	1.77	1.94	1.82	1.57			
Shear stress std	0.22	0.27	0.19	0.44			
Average velocity (m/s)	0.40	0.39	0.39	0.40			
Velocity std	0.01	0.01	0.01	0.01			
Average tank level	11.77	11.83	11.85	11.83			
Tank level std	0.02	0.02	0.02	0.02			
Average Z Force (grams)	-2.83	-2.72	-2.93	-3.24			
Z Force std (grams)	0.13	0.43	0.30	0.43			
Comment on the step							
Sample Description							
Test Description/purpose							
Conclusion/Comment/Decision	There was a mistake in setting the pump power. It was supposed to be 3%						

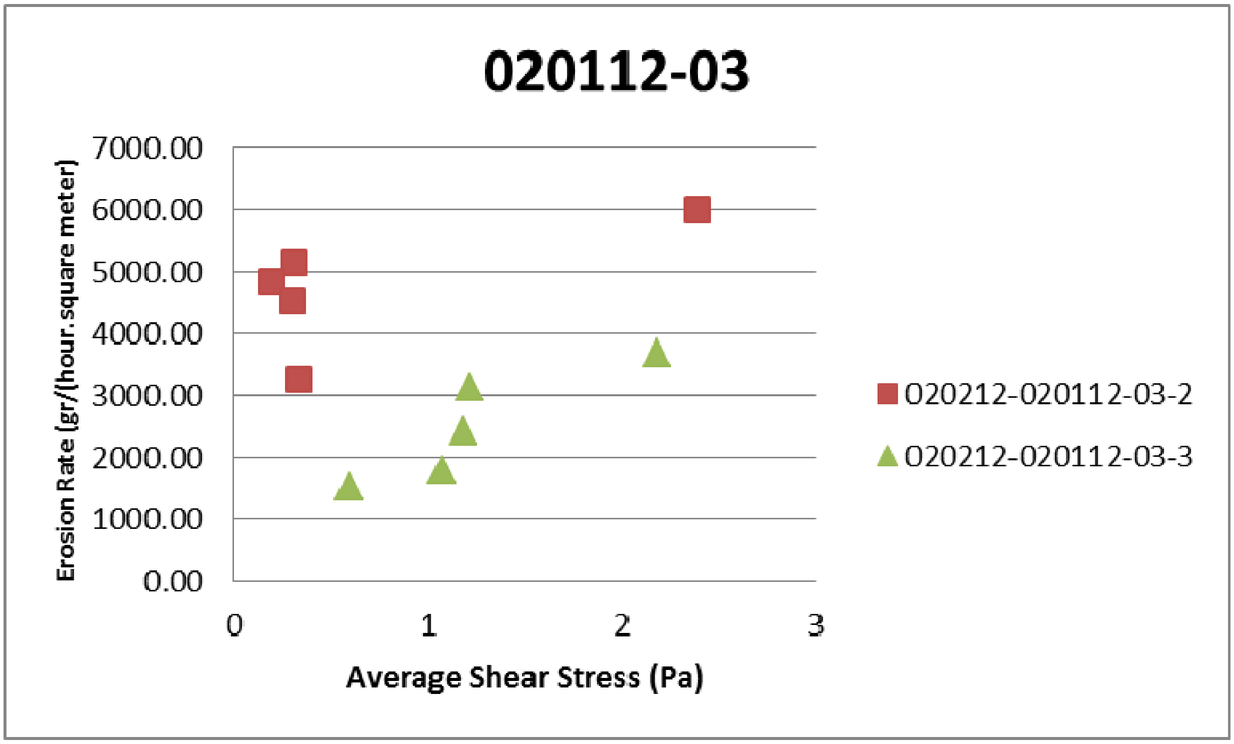


Figure 51

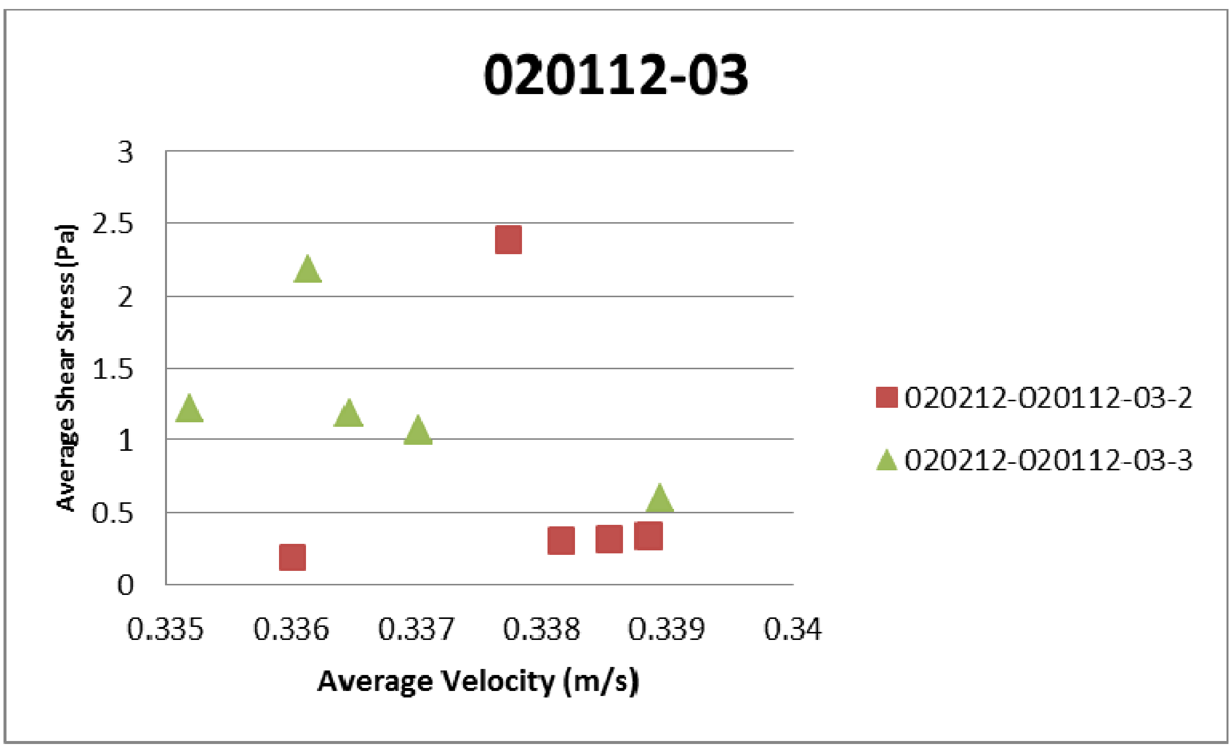


Figure 52

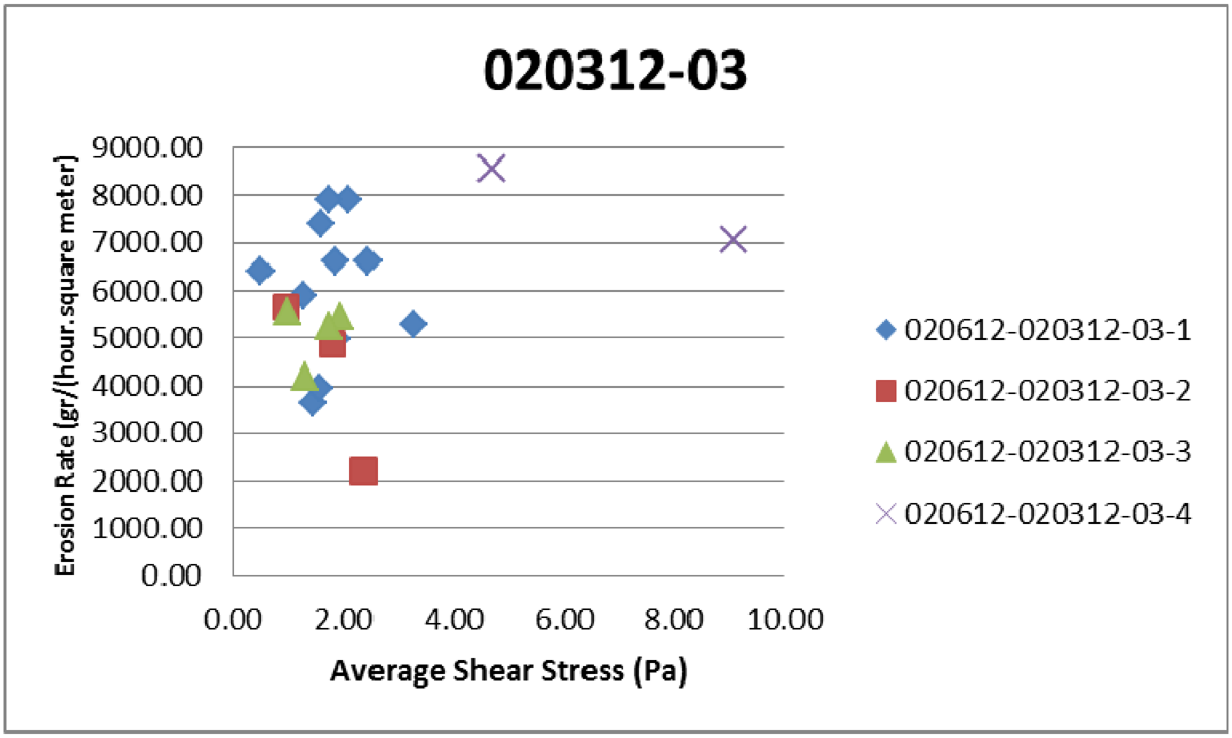


Figure 53

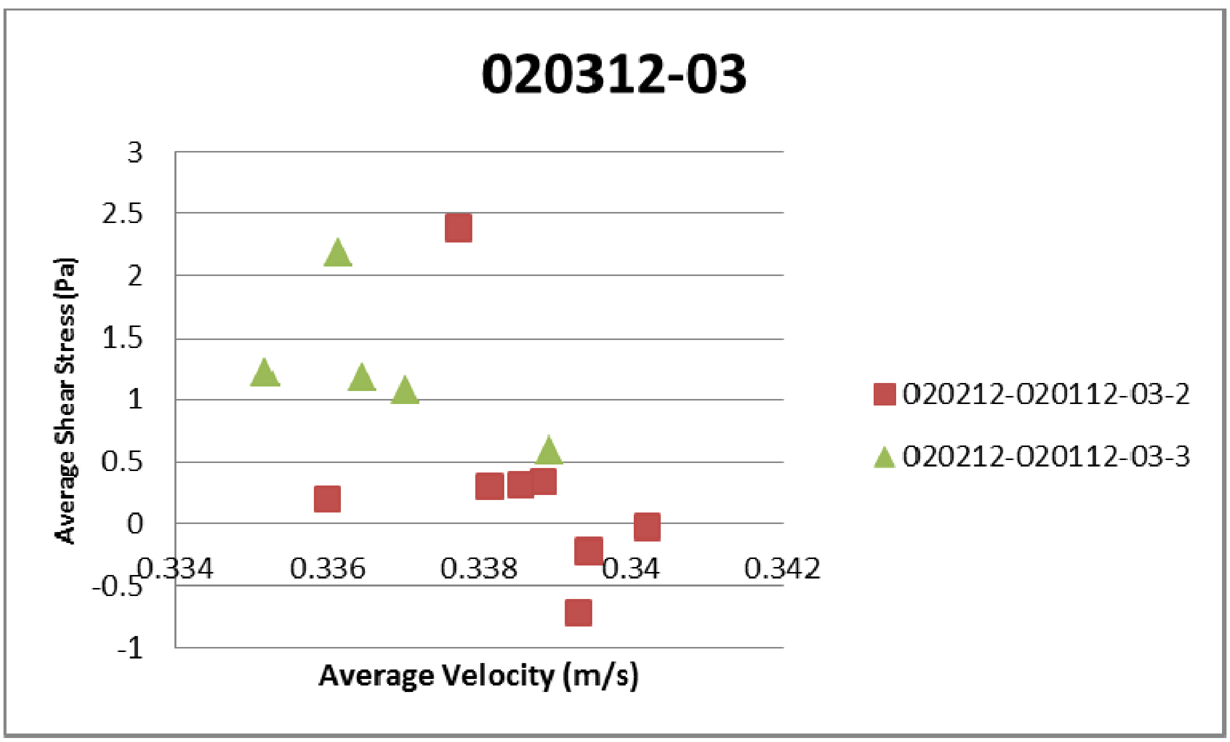


Figure 54

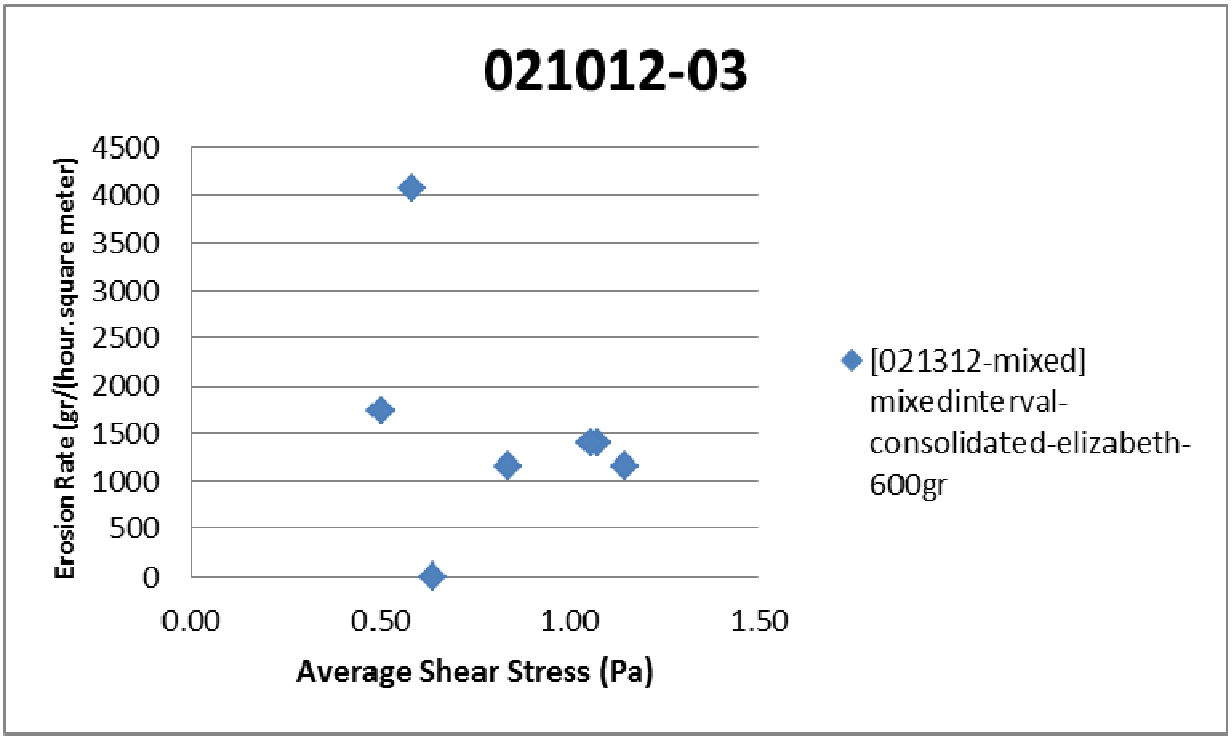


Figure 55

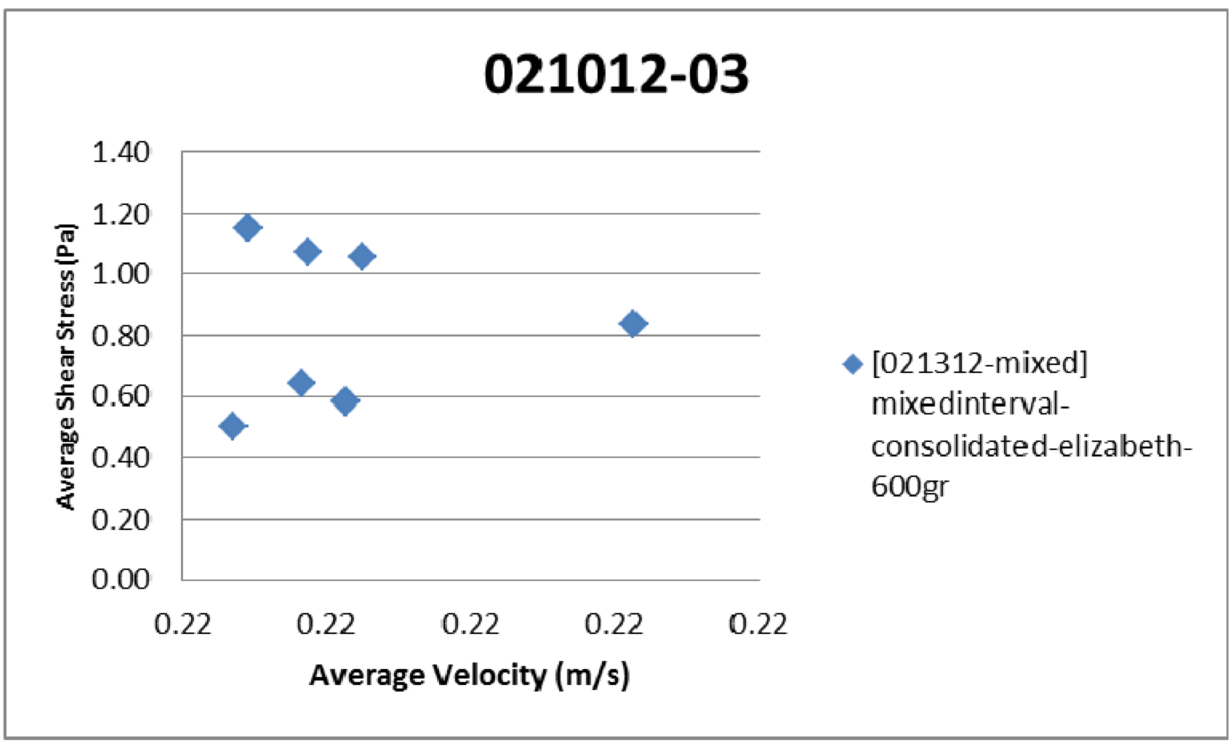


Figure 56

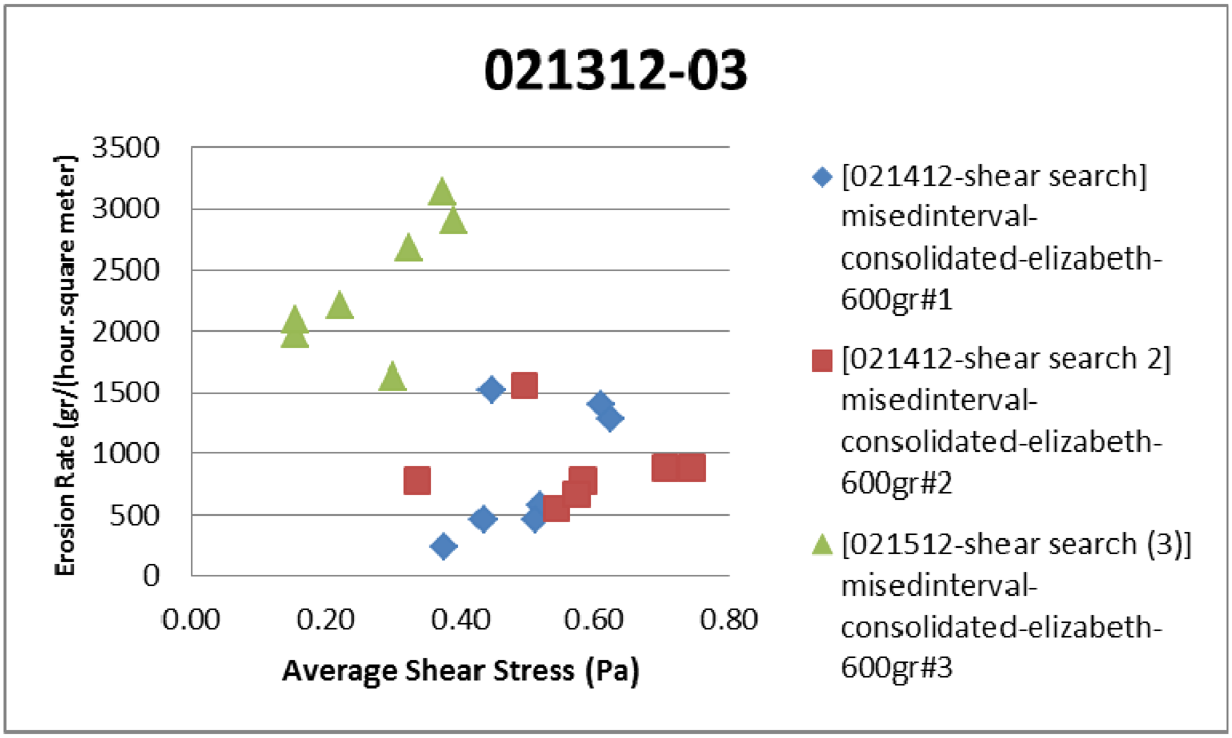


Figure 57

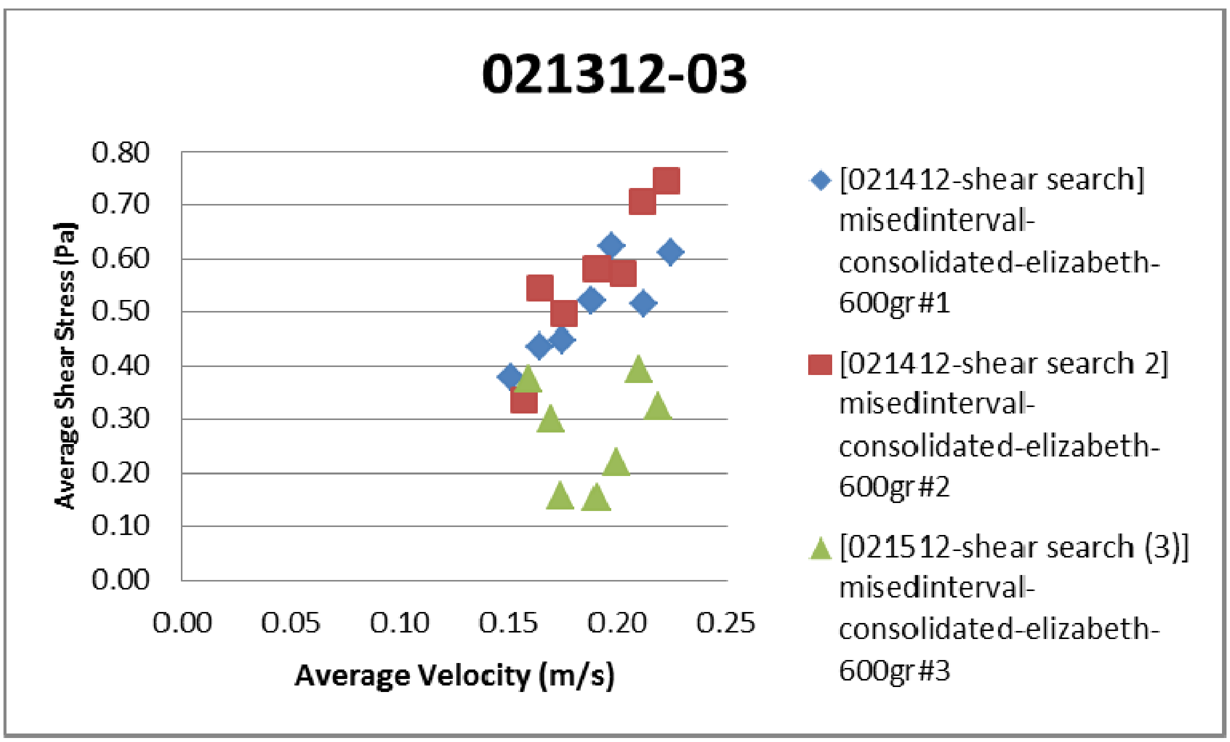


Figure 58

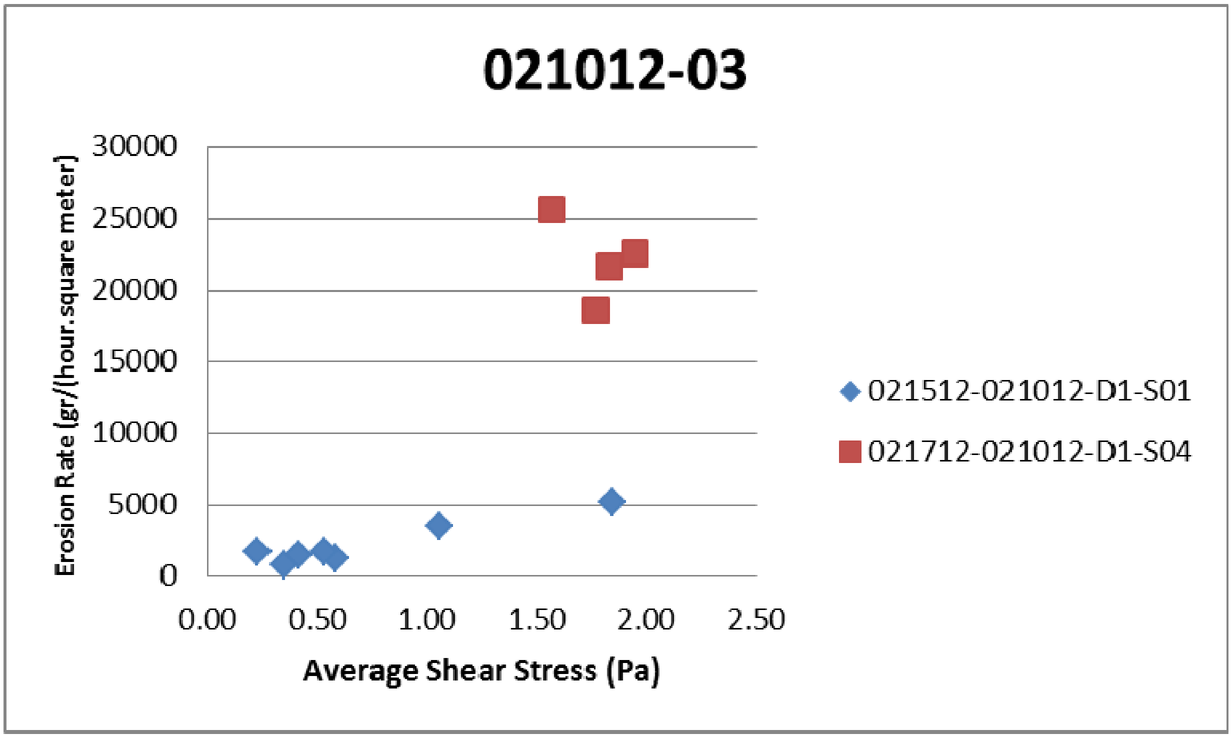


Figure 59

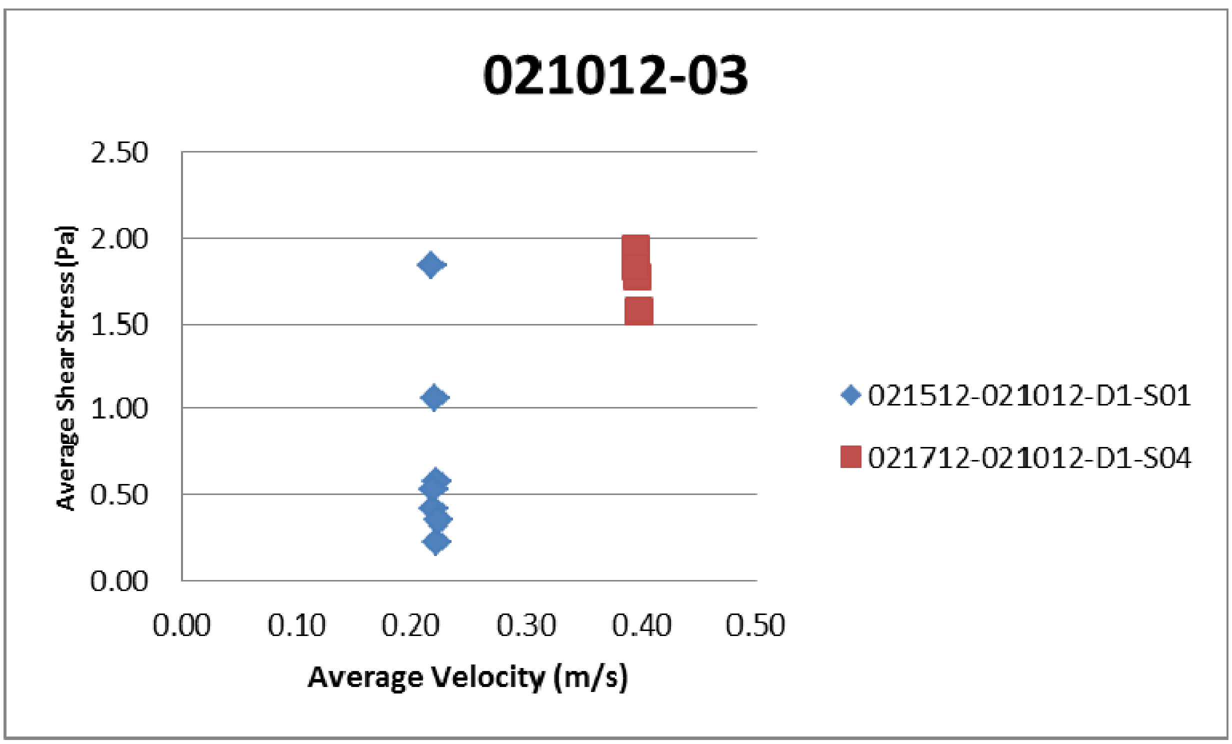


Figure 60

Test Results:

Newark Bay Undisturbed Samples

March 2012

Table 32

Date	3/1/2012		Test ID	03012-020112-C03-R01-S2-1								
Initial height	14.35	Ring	3	Min Thick	6.65	Total sub. WL		0.26				
Initial volume (cubic centimeter)	41.92	Puck	1	Max Thick	15.24	Total unsub. WL		7.11				
Initial un-submerged weight (gr)	127.08	Ring sub	2.4	ΔH	0.3	Lost volume		6.85				
Final non submerged weight (gr)	119.97	Puck sub	48.28	Age-1		Estimated Density		1.04				
Density method 1	1.09	Ring unsu	3.83	Age-2		Image Files						
Density method 2	1.15	Puck unsu	77.37	avg depth		0229121220-0229121717						
Average density	1.12	R01-S2										
Pump Power %	var		manometer depth									
Ramp up speed (1/s)	0.1	Start time	11:30	End time	16:17	.						
First time weight measurment	56.95	57.14	57.12	57.04								
Time (min)	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00	90.00	100.00	110.00	120.00
Test duration (min)	10	10	10	10	10	10	10	10	10	10	10	10
Pump Power %	2.75	3	3.25	3.25	3.5	3.5	3.5	3.75	3.75	3.75	3.75	4
Ramp up time (s)	27.5	30	32.5	32.5	35	35	35	37.5	37.5	37.5	37.5	40
Initial weight(gr)	57.04	56.95	56.98	56.95	56.99	56.87	56.78	56.69	56.39	56.20	56.02	55.95
Final weight(gr)	56.95	56.98	56.95	56.99	56.87	56.78	56.69	56.39	56.20	56.02	55.95	55.82
weight loss(gr)	0.09	-0.03	0.03	-0.04	0.12	0.09	0.09	0.30	0.19	0.18	0.07	0.13
Accumulative weight loss	0.09	0.06	0.09	0.05	0.17	0.26	0.35	0.65	0.84	1.02	1.09	1.22
intact sample?	Y	N	N	N	N	N	N	N	N	N	N	N
Temperature (F)	66.6											68
Test validity												
Comments on the step												
Erosion rate (gr/(hour.m^2)	1686	-562	562	-749	2248	1686	1686	5620	3559	3372	1311	2435
Average shear stress (Pa)	2.2097576	2.633358	2.905237	2.9128636	3.802439	3.940848	5.641664	6.595426	7.104392	6.658271	6.824393	6.404706
Shear stress std	0.0408251	0.037461	0.037516	0.0485635	0.080524	0.047279	0.058491	0.24194	0.073839	0.11115	0.083008	0.061234
Average velocity (m/s)	0.1481724	0.16324	0.175073	0.1742665	0.192111	0.19036	0.191106	0.207706	0.207675	0.204827	0.203067	0.214634
Velocity std	0.0143559	0.014693	0.013951	0.0149918	0.014387	0.015881	0.013991	0.014725	0.013903	0.014542	0.016609	0.015163
Average tank level	11.310504	11.32643	11.34805	11.377446	11.40109	11.42329	11.43276	11.42648	11.4189	11.44231	11.45793	11.47575
Tank level std	0.02114	0.022222	0.02325	0.0243274	0.023234	0.023219	0.02154	0.024095	0.022555	0.02677	0.022061	0.024067
Average Z Force (grams)	0.0130259	-0.00659	-0.00715	0.0102217	0.007479	0.003785	-0.04289	0.005665	-0.01113	-0.04727	0.003641	0.003984
Z Force std (grams)	0.0453661	0.04185	0.036285	0.0362158	0.045447	0.036693	0.037797	0.03839	0.041164	0.037176	0.035427	0.035614
Sample Description												
Test Description/purpose												
Conclusion/Comment/Decision												

Table 33

Date	3/5/2012	Test ID	0305012-020112-C03-R01-s2-2				
Initial height	12.83	Ring	3	Min Thick	5.17	Total sub. WL	0.65
Initial volume (cubic centimeter)	37.48	Puck	1	Max Thick	16.4	Total unsub. WL	3.71
Initial un-submerged weight (gr)	117.85	Ring sub	2.4	ΔH	0	Lost volume	3.06
Final non submerged weight (gr)	114.14	Puck sub	48.28	Age-1		Estimated Density	1.21
Density method 1	0.98	Ring unsu	3.83	Age-2		Image Files	
Density method 2	1.14	Puck unsu	77.37	avg depth			
Average density	1.06	R01-S2-2					
Pump Power %	3.00		manometer depth				
Ramp up speed (1/s)	0.1	Start time	10:13	End time	12:41	.	
First time weight measurment	55.93	55.90	55.90	55.94			
Time (min)	10.00	20.00	30.00	40.00	50.00	60.00	
Test duration (min)	10	10	10	10	10	10	
Pump Power %	3	3.5	4	4.5	4.5	4.75	
Ramp up time (s)	30	35	40	45	45	47.5	
Initial weight(gr)	55.94	55.84	55.78	55.75	55.47	55.36	
Final weight(gr)	55.84	55.78	55.75	55.47	55.36	55.29	
weight loss(gr)	0.10	0.06	0.03	0.28	0.11	0.07	
Accumulative weight loss	0.10	0.16	0.19	0.47	0.58	0.65	
intact sample?	Y	N	N	N	N	N	
Temperature (F)	65.1					63.7	
Test validity							
Erosion rate (gr/(hour.m^2)	3678	2207	1103	10298	4046	2574	
Average shear stress (Pa)	4.4642604	6.504525	7.235818	8.3974109	8.822567	8.802676	
Shear stress std	0.0831662	0.237542	0.062282	0.1406988	0.330592	0.06027	
Average velocity (m/s)	0.1552369	0.181749	0.214421	0.2406869	0.242093	0.253473	
Velocity std	0.0143297	0.014261	0.013886	0.0144877	0.013712	0.015145	
Average tank level	11.58844	11.548	11.49869	11.476713	11.4707	11.45566	
Tank level std	0.021022	0.022096	0.024224	0.0248176	0.02219	0.023069	
Average Z Force (grams)	-0.038251	-0.03185	0.008164	0.005395	0.008174	0.027428	
Z Force std (grams)	0.0246176	0.083562	0.031394	0.0225616	0.023466	0.01985	
Comments on the step							
Sample Description							
Test Description/purpose							
Conclusion/Comment/Decision							

Table 34

Date	3/5/2012		Test ID	0305012-020112-C03-R02-S1				
Initial height	18.48	Ring	4	Min Thick	11.2	Total sub. WL		0.60
Initial volume (cubic centimeter)	53.98	Puck	2	Max Thick	18.87	Total unsub. WL		6.74
Initial un-submerged weight (gr)	141.39	Ring sub	2.09	ΔH	0	Lost volume		6.14
Final non submerged weight (gr)	134.65	Puck sub	48.12	Age-1		Estimated Density		1.10
Density method 1	1.15	Ring unsu	1.81	Age-2		Image Files		
Density method 2	1.17	Puck unsu	77.29	avg depth				
Average density	1.16	R02-S1						
Pump Power %	3.00		manometer depth					
Ramp up speed (1/s)	0.1	Start time	13:00	End time	16:00	.		
First time weight measurment	59.20	59.25	59.17	59.19				
Time (min)	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00
Test duration (min)	10	10	10	10	10	10	10	10
Pump Power %	2	2.2	2.4	2.6	2.8	3	3.2	3.4
Ramp up time (s)	20	22	24	26	30	31	32	33
Initial weight(gr)	59.19	59.12	59.09	59.14	59.05	58.68	58.59	58.39
Final weight(gr)	59.12	59.09	59.14	59.05	58.68	58.59	58.39	58.28
weight loss(gr)	0.07	0.03	-0.05	0.09	0.37	0.09	0.20	0.11
Accumulative weight loss	0.07	0.10	0.05	0.14	0.51	0.60	0.80	0.91
intact sample?	Y	N	N	N	N	N	N	N
Temperature (F)	63.3		62.6	62.6		62.6		62.2
Test validity								
Erosion rate (gr/(hour.m^2)	1042	446	-744	1339	5506	1339	2976	1637
Average shear stress (Pa)	1.6454072	1.608084	2.06669	2.3079629	3.002135	3.155894	3.919118	4.344252
Shear stress std	0.0412677	0.031318	0.041258	0.038791	0.048833	0.049202	0.047626	0.058105
Average velocity (m/s)	0.1033809	0.104133	0.125018	0.1344799	0.141393	0.152833	0.16216	0.166121
Velocity std	0.0140023	0.01163	0.013876	0.0129454	0.015709	0.013548	0.014051	0.014985
Average tank level	11.228866	11.20171	11.18783	11.180439	11.18133	11.17888	11.17122	11.16909
Tank level std	0.0210783	0.022439	0.022733	0.02171	0.020318	0.021509	0.023775	0.021246
Average Z Force (grams)	0.0089411	0.018303	-0.01191	0.0014008	0.009978	0.040492	0.027831	-0.04058
Z Force std (grams)	0.0207731	0.027262	0.027248	0.0215007	0.031493	0.018268	0.030746	0.029418
Comments on the step								
Sample Description								
Test Description/purpose								
Conclusion/Comment/Decision								

Table 35

Date	3/6/2012		Test ID	030612-020112-C03-R03-S1						
Initial height	19.64	Ring	3	Min Thick	14.22	Total sub. WL		0.33		
Initial volume (cubic centimeter)	57.37	Puck	2	Max Thick	19.72	Total unsub. WL		3.57		
Initial un-submerged weight (gr)	149.81	Ring sub	2.4	ΔH	1.24	Lost volume		3.24		
Final non submerged weight (gr)	146.24	Puck sub	48.12	Age-1		Estimated Density		1.10		
Density method 1	1.20	Ring unsu	3.83	Age-2		Image Files				
Density method 2	1.22	Puck unsu	77.29	avg depth						
Average density	1.21	R03-S1								
Pump Power %	var		manometer depth							
Ramp up speed (1/s)	0.1	Start time	10:18	End time		.				
First time weight measurment	63.26	63.38	63.35	63.33						
Time (min)	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00	90.00	100.00
Test duration (min)	10	10	10	10	10	10	10	10	10	10
Pump Power %	2	2.25	2.5	2.75	3	3.25	3.5	3.75	4	4
Ramp up time (s)	20	22.5	25	27.5	30	32.5	35	37.5	40	40
Initial weight(gr)	63.33	63.23	63.23	63.22	63.22	63.07	63.00	62.80	62.73	62.67
Final weight(gr)	63.23	63.23	63.22	63.22	63.07	63.00	62.80	62.73	62.67	62.51
weight loss(gr)	0.10	0.00	0.01	0.00	0.15	0.07	0.20	0.07	0.06	0.16
Accumulative weight loss	0.10	0.10	0.11	0.11	0.26	0.33	0.53	0.60	0.66	0.82
intact sample?	Y	N	N	N	N	N	N	N	N	N
Temperature (F)	63		62.6			61.9				61.5
Test validity										
Comments on the step										
Erosion rate (gr/(hour.m^2)	1182	0	118	0	1773	827	2364	827	709	1891
Average shear stress (Pa)	0.269211	0.50923	0.471843	0.5099691	0.622155	0.748282	0.834464	1.476705	0.550669	1.463745
Shear stress std	0.0259855	0.026831	0.03626	0.0354189	0.038902	0.046536	0.764683	0.033675	0.177826	0.05929
Average velocity (m/s)	0.1010733	0.116913	0.127548	0.1348027	0.147079	0.162096	0.173888	0.188227	0.197335	0.198351
Velocity std	0.013312	0.013852	0.014181	0.01414	0.014039	0.015249	0.014776	0.014352	0.014462	0.015124
Average tank level	10.840666	10.84349	10.93625	11.033221	11.07083	11.06187	11.03247	11.02299	10.96087	10.97465
Tank level std	0.0223331	0.021865	0.020496	0.0354622	0.020265	0.023943	0.023092	0.023392	0.021326	0.023973
Average Z Force (grams)	-0.020326	0.265296	-0.31617	0.2279757	-0.16593	-0.26636	0.007858	0.044286	0.016642	0.003899
Z Force std (grams)	0.0904317	0.138788	0.084397	0.1005704	0.111737	0.101782	0.11173	0.095665	0.097082	0.092403
Sample Description										
Test Description/purpose										
Conclusion/Comment/Decision										

Table 36

Date	3/6/2012		Test ID	030612-020112-C03-R03-S2			
Initial height	13.62	Ring	4	Min Thick	8.8	Total sub. WL	57.68
Initial volume (cubic centimeter)	39.78	Puck	1	Max Thick	14.6	Total unsub. WL	5.28
Initial un-submerged weight (gr)	130.28	Ring sub	2.09	ΔH	0.35	Lost volume	-52.40
Final non submerged weight (gr)	125.00	Puck sub	48.28	Age-1		Estimated Density	-0.10
Density method 1	1.28	Ring unsu	1.81	Age-2		Image Files	
Density method 2	1.18	Puck unsu	77.37	avg depth			
Average density	1.23	R03-S2					
Pump Power %	3.00		manometer depth				
Ramp up speed (1/s)	0.1	Start time	14:19	End time	16:00	.	
First time weight measurment	58.26	57.72	57.70	57.68			
Time (min)	10.00	20.00	30.00	40.00	50.00		
Test duration (min)	10	10	10	10	10		
Pump Power %	2.5	2.75	3	3.25	3.5		
Ramp up time (s)	25	27.5	30	32.5	35		
Initial weight(gr)	57.68	57.64	57.54	57.28	57.23		
Final weight(gr)	57.64	57.54	57.28	57.23	56.96		
weight loss(gr)	0.04	0.10	0.26	0.05	0.27		
Accumulative weight loss	0.04	0.14	0.40	0.45	0.72		
intact sample?	Y	N	N	N	N		
Temperature (F)	60.8		62.1				
Test validity							
Comments on the step							
Erosion rate (gr/(hour.m^2)	433	1083	2815	541	2924		
Average shear stress (Pa)	1.5115468	2.29519	3.646506	3.501383	3.930935		
Shear stress std	0.0361813	0.21574	0.069929	0.0472034	0.053587		
Average velocity (m/s)	0.1194049	0.12728	0.142964	0.1535812	0.16663		
Velocity std	0.0133455	0.014896	0.014003	0.0138099	0.015432		
Average tank level	10.690526	10.56173	10.55765	10.530501	10.55421		
Tank level std	0.023431	0.022296	0.018506	0.0212117	0.021859		
Average Z Force (grams)	-0.082539	-0.04765	-0.07902	-0.074794	0.023258		
Z Force std (grams)	0.0943357	0.093807	0.103585	0.0911863	0.081774		
Sample Description							
Test Description/purpose							
Conclusion/Comment/Decision							

Table 37

Date	3/7/2012		Test ID	030712-020112-C03-R04-S1					
Initial height	20.59	Ring	3	Min Thick	15.05	Total sub. WL		0.86	
Initial volume (cubic centimeter)	60.14	Puck	2	Max Thick	19.44	Total unsub. WL		7.35	
Initial un-submerged weight (gr)	158.20	Ring sub	2.4	ΔH	0.5	Lost volume		6.49	
Final non submerged weight (gr)	150.85	Puck sub	48.12	Age-1		Estimated Density		1.13	
Density method 1	1.28	Ring unsu	3.83	Age-2		Image Files			
Density method 2	1.23	Puck unsu	77.29	avg depth					
Average density	1.25	R05-S1							
Pump Power %	3.00		manometer depth						
Ramp up speed (1/s)	0.1	Start time	8:50	End time	12:33	.			
First time weight measurment	64.32	64.32	64.25	64.22					
Time (min)	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00	90.00
Test duration (min)	10	10	10	10	10	10	10	10	10
Pump Power %	2	2.5	3	3.25	3.5	3.75	4	4.25	4.5
Ramp up time (s)	20	25	30	32.5	35	37.5	40	42.5	45
Initial weight(gr)	64.22	64.11	64.01	63.99	63.83	63.63	63.36	63.20	63.09
Final weight(gr)	64.11	64.01	63.99	63.83	63.63	63.36	63.20	63.09	62.87
weight loss(gr)	0.11	0.10	0.02	0.16	0.20	0.27	0.16	0.11	0.22
Accumulative weight loss	0.11	0.21	0.23	0.39	0.59	0.86	1.02	1.13	1.35
intact sample?	Y	N	N	N	N	N	N	N	N
Temperature (F)	61.7						62.1		
Test validity									
Comments on the step									
Erosion rate (gr/(hour.m^2)	1113	1012	202	1619	2024	2732	1619	1113	2226
Average shear stress (Pa)	0.4667479	0.934923	1.342342	1.6843163	2.0232	2.096788	2.109897	2.260061	1.710903
Shear stress std	0.0402394	0.038067	0.033464	0.0460637	0.037576	0.05	0.033722	0.053692	0.392209
Average velocity (m/s)	0.0913339	0.115814	0.138502	0.1511232	0.165948	0.179087	0.189335	0.198626	0.21867
Velocity std	0.0149026	0.015217	0.014076	0.0145926	0.015543	0.0153	0.014962	0.014133	0.014938
Average tank level	10.8734	10.73983	10.7104	10.697581	10.67932	10.64008	10.59879	10.5444	10.53266
Tank level std	0.0235965	0.026335	0.020683	0.0243398	0.023179	0.022851	0.021083	0.020775	0.02559
Average Z Force (grams)	-0.027521	-0.05992	0.067353	-0.006151	-0.03187	-0.00463	-0.05834	-0.06094	-0.04594
Z Force std (grams)	0.1073492	0.097282	0.09839	0.1090588	0.101869	0.110566	0.085848	0.114373	0.096219
Sample Description									
Test Description/purpose									
Conclusion/Comment/Decision	keep track of velocity as pump power did not represent due to buildup in filter								

Table 38

Date	3/7/2012		Test ID	030712-020112-C03-R05-S1					
Initial height	20.65	Ring	4	Min Thick	16.54	Total sub. WL		0.18	
Initial volume (cubic centimeter)	60.32	Puck	1	Max Thick	22.17	Total unsub. WL		3.48	
Initial un-submerged weight (gr)	156.00	Ring sub	2.09	ΔH	0	Lost volume		3.30	
Final non submerged weight (gr)	152.52	Puck sub	48.28	Age-1		Estimated Density		1.05	
Density method 1	1.27	Ring unsu	1.81	Age-2		Image Files			
Density method 2	1.21	Puck unsu	77.37	avg depth					
Average density	1.24	R05-S1							
Pump Power %	3.00		manometer depth						
Ramp up speed (1/s)	0.1	Start time	12:53	End time	16:34	.			
First time weight measurment	63.59	62.88	62.89	62.83					
Time (min)	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00	90.00
Test duration (min)	10	10	10	10	10	10	10	10	10
Pump Power %	2	2.5	3	3.25	3.5	3.75	4	4.25	4.5
Ramp up time (s)	20	25	30	32.5	35	37.5	40	42.5	45
Initial weight(gr)	62.83	62.73	62.74	62.76	62.70	62.62	62.65	62.54	62.47
Final weight(gr)	62.73	62.74	62.76	62.70	62.62	62.65	62.54	62.47	62.37
weight loss(gr)	0.10	-0.01	-0.02	0.06	0.08	-0.03	0.11	0.07	0.10
Accumulative weight loss	0.10	0.09	0.07	0.13	0.21	0.18	0.29	0.36	0.46
intact sample?	Y	N	N	N	N	N	N	N	N
Temperature (F)	63					64.4			64.4
Test validity									
Comments on the step									
Erosion rate (gr/(hour.m^2)	1061	-106	-212	637	849	-318	1167	743	1061
Average shear stress (Pa)	0.8285567	1.322158	1.958511	2.2048142	3.40543	4.108524	4.870226	4.107146	4.633266
Shear stress std	0.0349931	0.031008	0.033708	0.046498	0.056682	0.099292	0.055987	0.075926	0.041782
Average velocity (m/s)	-0.011655	0.107546	0.132315	0.1421887	0.157163	0.171309	0.19509	0.201734	0.225188
Velocity std	0.0152408	0.014182	0.014167	0.0149327	0.015161	0.014626	0.014279	0.013996	0.013546
Average tank level	10.423381	10.44789	10.46017	10.473969	10.48041	10.49016	10.39385	11.78287	11.79965
Tank level std	0.0228197	0.022469	0.021926	0.0239711	0.023083	0.026175	0.018866	0.024097	0.026413
Average Z Force (grams)	0.0039196	-0.00047	0.007046	-0.009345	0.004475	0.014646	-0.04997	0.012145	0.036434
Z Force std (grams)	0.0225352	0.021	0.01825	0.0225696	0.02163	0.019929	0.026789	0.02447	0.022046
Sample Description									
Test Description/purpose									
Conclusion/Comment/Decision	keep track of velocity as pump power did not represent due to buildup in filter								

Table 39

Date	3/20/2012	Test ID		032012-031912-C01-R01-S1									
Initial height	23.00	Ring	4	Min Thick	16.58	Total sub. WL	1.85						
Initial volume (cubic centimeter)	67.18	Puck	1	Max Thick	22.9	Total unsub. WL	12.75						
Initial un-submerged weight (gr)	163.78	Ring sub	2.09	ΔH	0	Lost volume	10.90						
Final non submerged weight (gr)	151.03	Puck sub	48.28	Age-1		Estimated Density	1.17						
Density method 1	1.26	Ring unsu	1.81	Age-2		Image Files							
Density method 2	1.23	Puck unsu	77.37	avg depth		0320121200-0320121705							
Average density	1.24	R01-S1											
Pump Power %	3.00												
Ramp up speed (1/s)	0.1	Start time	12:00	End time	17:05	.							
First time weight measurment	65.48	65.58	65.60	65.57									
Time (min)	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00	90.00	100.00	110.00	120.00	130.00
Test duration (min)	10	10	10	10	10	10	10	10	10	10	10	10	10
Pump Power %	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4
Ramp up time (s)	16	18	20	22	24	26	28	30	32	34	36	38	40
Initial weight(gr)	65.57	65.21	65.30	64.98	64.88	64.79	64.71	64.56	64.44	64.38	64.24	64.16	63.95
Final weight(gr)	65.21	65.30	64.98	64.88	64.79	64.71	64.56	64.44	64.38	64.24	64.16	63.95	63.72
weight loss(gr)	0.36	-0.09	0.32	0.10	0.09	0.08	0.15	0.12	0.06	0.14	0.08	0.21	0.23
Accumulative weight loss	0.36	0.27	0.59	0.69	0.78	0.86	1.01	1.13	1.19	1.33	1.41	1.62	1.85
intact sample?	Y	N	N	N	N	N	N	N	N	N	N	N	N
Temperature (F)	71.12			72.5								68	69
Test validity													
Comments on the step													
Erosion rate (gr/(hour.m^2)	3786	-946	3365	1052	946	841	1577	1262	631	1472	841	2208	2419
Average shear stress (Pa)	2.6131208	2.954162	3.630158	3.5499199	3.274404	3.092966	3.277552	3.263829	3.651209	3.721363	3.563244	3.781061	2.771571
Shear stress std	0.055607	0.124106	0.074264	0.0439347	0.080674	0.062294	0.05905	0.065895	0.040765	0.126201	0.05583	0.063743	0.180858
Average velocity (m/s)	0.151704	0.155213	0.166982	0.1764099	0.191792	0.202757	0.205094	0.2281	0.239046	0.247091	0.262901	0.276959	0.286551
Velocity std	0.0153564	0.014538	0.014496	0.0148496	0.014782	0.015089	0.014409	0.014427	0.014689	0.013958	0.01577	0.013361	0.015208
Average tank level	11.7214	11.72001	11.64337	11.631942	11.70835	11.70624	11.69697	11.63041	11.65573	11.67582	11.73538	11.70023	11.72375
Tank level std	0.0244271	0.023998	0.026222	0.0298701	0.030441	0.025887	0.031797	0.025306	0.025978	0.049662	0.032933	0.024919	0.032779
Average Z Force (grams)	-0.047511	-0.00488	0.161375	0.0060132	0.029652	-0.01216	0.024753	-0.03859	0.001258	0.035873	0.274872	-0.32181	0.01032
Z Force std (grams)	0.1191284	0.127317	0.115126	0.1179152	0.112254	0.124023	0.108649	0.11742	0.118579	0.104421	0.109698	0.120045	0.116694
Sample Description													
Test Description/purpose													
Conclusion/Comment/Decision													

Table 40

Date	3/21/2012		Test ID	032112-031912-C01-R01-S1-1								
Initial height	19.73	Ring	4	Min Thick	8.7	Total sub. WL		4.03				
Initial volume (cubic centimeter)	57.63	Puck	1	Max Thick	17.11	Total unsub. WL		21.76				
Initial un-submerged weight (gr)	149.26	Ring sub	2.09	ΔH	2.55	Lost volume		17.73				
Final non submerged weight (gr)	127.50	Puck sub	48.28	Age-1		Estimated Density		1.23				
Density method 1	1.22	Ring unsu	1.81	Age-2		Image Files						
Density method 2	1.22	Puck unsu	77.37	avg depth		0321121013-0321121630						
Average density	1.22	R01-S1-1										
Pump Power %	3.00											
Ramp up speed (1/s)	0.1	Start time	10:13	End time	16:30	.						
First time weight measurment	62.98	63.11	63.06	63.15								
Time (min)	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00	90.00	100.00	110.00	120.00
Test duration (min)	10	10	10	10	10	10	10	10	10	10	10	10
Pump Power %	3.8	4	4.2	4.4	4.6	4.8	5	5.2	5.4	5.6	5.8	6
Ramp up time (s)	38	40	42	44	46	48	50	52	54	56	58	60
Initial weight(gr)	63.15	62.86	62.71	62.60	62.43	62.26	61.60	61.20	60.95	60.57	60.36	59.75
Final weight(gr)	62.86	62.71	62.60	62.43	62.26	61.60	61.20	60.95	60.57	60.36	59.75	59.12
weight loss(gr)	0.29	0.15	0.11	0.17	0.17	0.66	0.40	0.25	0.38	0.21	0.61	0.63
Accumulative weight loss	0.29	0.44	0.55	0.72	0.89	1.55	1.95	2.20	2.58	2.79	3.40	4.03
intact sample?	Y	N	N	N	N	N	N	N	N	N	N	N
Temperature (F)	72.9				71.4			71.6				
Test validity												
Comments on the step												
Erosion rate (gr/(hour.m^2)	3317	1716	1258	1945	1945	7549	4575	2860	4347	2402	6978	7206
Average shear stress (Pa)	3.5778484	3.971461	4.111893	4.493348	5.383505	4.472939	7.153942	6.151716	5.91815	4.805062	3.977845	3.623501
Shear stress std	0.0569408	0.04879	0.050669	0.0515476	0.073747	0.386282	0.385697	0.077179	0.092201	0.07358	0.683709	0.33552
Average velocity (m/s)	0.2689142	0.28189	0.29465	0.3057196	0.321922	0.334805	0.34776	0.353144	0.363482	0.377293	0.397619	0.409594
Velocity std	0.013785	0.014488	0.015318	0.0156693	0.015408	0.014174	0.013196	0.014518	0.015952	0.015404	0.014877	0.014973
Average tank level	11.707715	11.72969	11.72314	11.727174	11.70296	11.67883	11.68072	11.61259	11.60999	11.60862	11.64666	11.71887
Tank level std	0.0271298	0.028879	0.024526	0.0266184	0.026276	0.024453	0.022652	0.027314	0.024942	0.023032	0.029408	0.037722
Average Z Force (grams)	-0.182619	-0.03536	0.124023	0.002832	-0.01822	-0.05622	-0.04803	0.006301	-0.03442	0.175513	0.055165	0.070756
Z Force std (grams)	0.0402584	0.045305	0.042019	0.0474589	0.040618	0.041065	0.047884	0.044216	0.040197	0.041699	0.043901	0.055472
Sample Description												
Test Description/purpose												
Conclusion/Comment/Decision												

Table 41

Date	3/22/2012		Test ID	032212-031912-C01-R01-S2									
Initial height	22.40	Ring	6	Min Thick	15.28	Total sub. WL		3.05					
Initial volume (cubic centimeter)	65.43	Puck	2	Max Thick	22.41	Total unsub. WL		19.33					
Initial un-submerged weight (gr)	149.67	Ring sub	2.22	ΔH	6.4	Lost volume		16.28					
Final non submerged weight (gr)	130.34	Puck sub	48.12	Age-1		Estimated Density		1.19					
Density method 1	1.05	Ring unsu	3.53	Age-2		Image Files							
Density method 2	1.18	Puck unsu	77.29	avg depth	11.2	0322121100-0322121720							
Average density	1.12	R01-S2											
Pump Power %	3.00												
Ramp up speed (1/s)	0.1	Start time	11:00	End time	17:20	.							
First time weight measurment	62.21	62.14	62.16										
Time (min)	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00	90.00	100.00	110.00	120.00	130.00
Test duration (min)	10	10	10	10	10	10	10	10	10	10	10	10	10
Pump Power %	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4
Ramp up time (s)	16	18	20	22	24	26	28	30	32	34	36	38	40
Initial weight(gr)	62.16	62.11	61.96	61.97	61.43	61.17	61.06	60.78	60.54	60.30	59.90	59.90	59.18
Final weight(gr)	62.11	61.96	61.97	61.69	61.17	61.06	60.78	60.54	60.30	59.90	59.90	59.18	59.11
weight loss(gr)	0.05	0.15	-0.01	0.28	0.26	0.11	0.28	0.24	0.24	0.40	0.00	0.72	0.07
Accumulative weight loss	0.05	0.20	0.19	0.47	0.73	0.84	1.12	1.36	1.60	2.00	2.00	2.72	2.79
intact sample?	Y	N	N	N	N	N	N	N	N	N	N	N	N
Temperature (F)					73.6								
Test validity													
Comments on the step													
Erosion rate (gr/(hour.m^2)	985	2954	-197	5514	5120	2166	5514	4726	4726	7877	0	14178	1378
Average shear stress (Pa)	0.5975213	0.661077	0.90513	1.1685456	0.516487	1.325448	1.617116	1.803701	2.091101	2.084045	2.645662	2.664519	1.023602
Shear stress std	0.127455	0.035771	0.085741	0.0507327	0.086888	0.050233	0.099856	0.05666	0.0526	0.079166	0.179488	0.056866	0.228074
Average velocity (m/s)	0.150952	0.1542	0.166072	0.1747799	0.192814	0.199935	0.212606	0.225366	0.237213	0.244346	0.261886	0.271976	0.285043
Velocity std	0.0154158	0.014944	0.014523	0.0163816	0.015057	0.017326	0.01607	0.016565	0.01527	0.014655	0.015318	0.0156	0.015112
Average tank level	11.316542	11.30743	11.27971	11.267111	11.25404	11.26105	11.22363	11.17884	11.19972	11.22846	11.23076	11.2526	11.27504
Tank level std	0.0284893	0.028308	0.028201	0.0268714	0.026184	0.026458	0.025435	0.026869	0.027104	0.025207	0.031402	0.028432	0.026111
Average Z Force (grams)	0.0132453	-0.01346	-0.03813	-0.130068	-0.02364	-0.00752	-0.14822	0.005135	-0.04314	-0.01917	0.000523	-0.08785	-0.77605
Z Force std (grams)	0.0274312	0.022754	0.024308	0.0223069	0.025152	0.025358	0.063054	0.045022	0.025896	0.027944	0.029036	0.024279	0.030311
Sample Description													
Test Description/purpose													
Conclusion/Comment/Decision													

Table 42

Date	3/23/2012		Test ID	032312-031912-C02-R01-S1				
Initial height	22.40	Ring	6	Min Thick		Total sub. WL		56.08
Initial volume (cubic centimeter)	65.43	Puck	2	Max Thick		Total unsub. WL		19.33
Initial un-submerged weight (gr)	149.67	Ring sub	2.22	ΔH		Lost volume		-36.75
Final non submerged weight (gr)	130.34	Puck sub	48.12	Age-1		Estimated Density		-0.53
Density method 1	1.05	Ring unsu	3.53	Age-2		Image Files		
Density method 2	1.09	Puck unsu	77.29	avg depth		0322121100-0322121720		
Average density	1.07	R01-S1						
Pump Power %	3.00							
Ramp up speed (1/s)	0.1	Start time	10:30	End time		.		
First time weight measurment	55.84	56.08	56.08					
Time (min)	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00
Test duration (min)	10	10	10	10	10	10	10	10
Pump Power %	1.6	1.8	2	2.2	2.4	2.6	2.8	3
Ramp up time (s)	16	18	20	22	24	26	28	30
Initial weight(gr)	56.08	55.98	56.06	56.05	55.46	55.30	55.14	55.00
Final weight(gr)	55.98	56.06	56.05	55.96	55.30	55.14	55.00	54.76
weight loss(gr)	0.10	-0.08	0.01	0.09	0.16	0.16	0.14	0.24
Accumulative weight loss	0.10	0.02	0.03	0.12	0.28	0.44	0.58	0.82
intact sample?	Y	N	N	N	N	N	N	N
Temperature (F)								
Test validity								
Comments on the step								
Erosion rate (gr/(hour.m^2)	3140	-2512	314	2826	5024	5024	4396	7536
Average shear stress (Pa)	0.4642512	0.723014	0.915349	1.0571106	0.990467	0.988784	1.479905	1.692166
Shear stress std	0.032874	0.030632	0.033458	0.0318601	0.041757	0.037833	0.061955	0.048584
Average velocity (m/s)	0.1464453	0.15255	0.160198	0.1704892	0.187367	0.199232	0.20787	0.220712
Velocity std	0.0147133	0.014151	0.013826	0.0154266	0.014806	0.012917	0.016603	0.01462
Average tank level	11.924222	12.10323	12.269	12.360287	12.47864	12.47922	12.56324	12.67086
Tank level std	0.0327451	0.030122	0.027563	0.0294715	0.034533	0.031	0.052021	0.026993
Average Z Force (grams)	0.0269709	-0.02784	-0.00343	0.0405668	-0.01046	0.005631	0.053039	0.10438
Z Force std (grams)	0.1228728	0.117201	0.12613	0.1275157	0.102434	0.118539	0.132126	0.121511
Sample Description								
Test Description/purpose								
Conclusion/Comment/Decision	Critical Shear Stress Achieved at 2.2% Pump Power							

Table 43

Date	3/26/2012		Test ID	032612-031912-C02-R01-S2									
Initial height	11.17	Ring	3	Min Thick	0	Total sub. WL							
Initial volume (cubic centimeter)	32.63	Puck	1	Max Thick	11.3	Total unsub. WL		16.15					
Initial un-submerged weight (gr)	120.74	Ring sub	2.4	ΔH	2.16	Lost volume		16.15					
Final non submerged weight (gr)	104.59	Puck sub	48.28	Age-1		Estimated Density		1.00					
Density method 1	1.21	Ring unsu	3.83	Age-2		Image Files							
Density method 2	1.21	Puck unsu	77.37	avg depth									
Average density	1.21	R01-S2											
Pump Power %	3.00												
Ramp up speed (1/s)	0.1	Start time	11:30	End time	4:30	.							
First time weight measurment	57.54	57.60	57.69	57.55									
Time (min)	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00	90.00	100.00	110.00	120.00	130.00
Test duration (min)	10	10	10	10	10	10	10	10	10	10	10	10	10
Pump Power %	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4
Ramp up time (s)	16	18	20	22	24	26	28	30	32	34	36	38	40
Initial weight(gr)	57.69	57.56	57.50	57.47	57.24	56.94	56.83	56.70	56.66	56.50	56.36	56.00	55.79
Final weight(gr)	57.56	57.50	57.47	57.24	56.94	56.83	56.70	56.66	56.50	56.36	56.00	55.79	55.39
weight loss(gr)	0.13	0.06	0.03	0.23	0.30	0.11	0.13	0.04	0.16	0.14	0.36	0.21	0.40
Accumulative weight loss	0.13	0.19	0.22	0.45	0.75	0.86	0.99	1.03	1.19	1.33	1.69	1.90	2.30
intact sample?	Y	N	N	N	N	N	N	N	N	N	N	N	N
Temperature (F)				70			70.9			70.9			72
Test validity													
Comments on the step													
Erosion rate (gr/(hour.m^2)	1519	701	350	2687	3504	1285	1519	467	1869	1635	4205	2453	4673
Average shear stress (Pa)	0.9759392	1.077226	0.825101	1.400734	1.597621	1.954742	1.768523	2.110386	2.557156	2.198009	3.036312	2.028042	3.055617
Shear stress std	0.0343056	0.033468	0.046041	0.048472	0.202541	0.041961	0.25659	0.042742	0.05292	0.039684	0.07604	0.053582	0.077666
Average velocity (m/s)	0.1409565	0.146645	0.15775	0.164058	0.180139	0.192644	0.203505	0.215775	0.227354	0.23376	0.249414	0.261445	0.272885
Velocity std	0.0141756	0.014659	0.013123	0.0151547	0.0155	0.014358	0.014948	0.014785	0.015959	0.0149	0.015175	0.015067	0.014644
Average tank level	12.97411	12.89951	12.85912	12.782838	12.73496	12.61281	12.61744	12.60918	12.64083	12.62022	12.61725	12.6098	12.53888
Tank level std	0.0254331	0.025498	0.026517	0.0253435	0.025981	0.023699	0.024173	0.026337	0.027526	0.030032	0.022621	0.026538	0.023207
Average Z Force (grams)	-0.034311	-0.00917	-0.00316	-0.147096	-0.02679	0.016418	-0.04465	-0.03151	-0.02298	-0.01625	-0.07414	-0.01497	-0.02984
Z Force std (grams)	0.1159634	0.113853	0.116101	0.1138223	0.111546	0.11666	0.130989	0.111974	0.130294	0.118126	0.117327	0.108651	0.108675
Sample Description													
Test Description/purpose													
Conclusion/Comment/Decision													

Table 44

Date	3/27/2012		Test ID	032712-031912-C03-R01-S1									
Initial height	13.10	Ring	3	Min Thick	6.7	Total sub. WL							
Initial volume (cubic centimeter)	38.26	Puck	1	Max Thick	11.18	Total unsub. WL		11.61					
Initial un-submerged weight (gr)	129.69	Ring sub	2.4	ΔH	2.02	Lost volume		11.61					
Final non submerged weight (gr)	118.08	Puck sub	48.28	Age-1		Estimated Density		1.00					
Density method 1	1.27	Ring unsu	3.83	Age-2		Image Files							
Density method 2	1.24	Puck unsu	77.37	avg depth									
Average density	1.25	R01-S1											
Pump Power %	3.00												
Ramp up speed (1/s)	0.1	Start time	11:41	End time		.							
First time weight measurment	59.95	59.94	59.93	59.94									
Time (min)	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00	90.00	100.00	110.00	120.00	130.00
Test duration (min)	10	10	10	10	10	10	10	10	10	10	10	10	10
Pump Power %	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4
Ramp up time (s)	16	18	20	22	24	26	28	30	32	34	36	38	40
Initial weight(gr)	59.94	59.79	59.70	59.68	59.63	59.59	59.49	59.42	59.31	59.12	59.04	58.73	58.50
Final weight(gr)	59.79	59.70	59.68	59.63	59.59	59.49	59.42	59.31	59.12	59.04	58.73	58.50	58.31
weight loss(gr)	0.15	0.09	0.02	0.05	0.04	0.10	0.07	0.11	0.19	0.08	0.31	0.23	0.19
Accumulative weight loss	0.15	0.24	0.26	0.31	0.35	0.45	0.52	0.63	0.82	0.90	1.21	1.44	1.63
intact sample?	Y	N	N	N	N	N	N	N	N	N	N	N	N
Temperature (F)	73	71.6	71.2	71.1	70.9	70.7	70.2	70.2	70	69.8	69.8	69.8	69.8
Test validity													
Comments on the step													
Erosion rate (gr/(hour.m^2)	1518	911	202	506	405	1012	709	1113	1923	810	3138	2328	1923
Average shear stress (Pa)	0.6661988	0.679907	0.941694	0.833535	1.24494	1.367104	1.302219	1.618323	1.630201	1.845344	1.682803	2.188622	2.272869
Shear stress std	0.058593	0.037325	0.046559	0.0520362	0.034061	0.03283	0.031842	0.040018	0.032646	0.034405	0.260924	0.037031	0.1158
Average velocity (m/s)	0.1409375	0.143799	0.156113	0.1629679	0.179703	0.190641	0.201981	0.214167	0.224853	0.226999	0.24618	0.259526	0.269657
Velocity std	0.0143087	0.015478	0.013914	0.0162094	0.015196	0.014433	0.015139	0.014808	0.015235	0.018254	0.014668	0.013662	0.015139
Average tank level	13.180573	13.06979	12.99053	12.963845	12.92949	12.88199	12.84181	12.80698	12.78489	12.75269	12.73036	12.72439	12.70443
Tank level std	0.0534511	0.023736	0.024001	0.0244325	0.024961	0.023657	0.025525	0.021912	0.023082	0.02646	0.024878	0.026131	0.026543
Average Z Force (grams)	-0.069166	0.0494	-0.00521	-0.004428	0.001224	-0.00263	0.003728	-0.03445	-0.01232	-0.01145	-0.08224	-0.11104	0.053432
Z Force std (grams)	0.0418381	0.043514	0.041605	0.0420165	0.043417	0.040816	0.04525	0.037582	0.049526	0.044807	0.044125	0.042381	0.041085
Sample Description													
Test Description/purpose													
Conclusion/Comment/Decision													

Table 45

Date	3/28/2012		Test ID	032812-031912-C03-R01-S2									
Initial height	16.07	Ring	1	Min Thick	7.68	Total sub. WL							
Initial volume (cubic centimeter)	46.94	Puck	2	Max Thick	15.13	Total unsub. WL		9.99					
Initial un-submerged weight (gr)	138.60	Ring sub	2.53	ΔH	1.93	Lost volume		9.99					
Final non submerged weight (gr)	128.61	Puck sub	48.12	Age-1		Estimated Density		1.00					
Density method 1	1.22	Ring unsu	4.02	Age-2		Image Files							
Density method 2	1.22	Puck unsu	77.29	avg depth									
Average density	1.22	R01-S2											
Pump Power %	3.00												
Ramp up speed (1/s)	0.1	Start time	10:40	End time	3:00	.							
First time weight measurment	61.04	61.05	61.03	61.09									
Time (min)	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00	90.00	100.00	110.00	120.00	130.00
Test duration (min)	10	10	10	10	10	10	10	10	10	10	10	10	10
Pump Power %	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4
Ramp up time (s)	16	18	20	22	24	26	28	30	32	34	36	38	40
Initial weight(gr)	61.09	61.09	61.01	61.03	60.90	60.71	60.62	60.47	60.45	60.28	60.16	59.99	59.82
Final weight(gr)	61.09	61.01	61.03	60.90	60.71	60.62	60.47	60.45	60.28	60.16	59.99	59.82	59.59
weight loss(gr)	0.00	0.08	-0.02	0.13	0.19	0.09	0.15	0.02	0.17	0.12	0.17	0.17	0.23
Accumulative weight loss	0.00	0.08	0.06	0.19	0.38	0.47	0.62	0.64	0.81	0.93	1.10	1.27	1.50
intact sample?	Y	N	N	N	N	N	N	N	N	N	N	N	N
Temperature (F)	75	74.5	74.1	73.9	73.8	73.4	73.4	73	72.9	72.9	72.5	72.3	72.3
Test validity													
Comments on the step													
Erosion rate (gr/(hour.m^2)	0	906	-227	1473	2153	1020	1699	227	1926	1360	1926	1926	2606
Average shear stress (Pa)	0.6013926	0.695468	0.763737	1.0919358	1.561837	1.432573	1.879981	1.583486	1.65562	1.488965	1.61831	1.495386	2.458585
Shear stress std	0.0319389	0.044977	0.030456	0.0299624	0.157211	0.075765	0.126146	0.033112	0.035914	0.077669	0.172342	0.106414	0.052414
Average velocity (m/s)	0.1366815	0.140349	0.15098	0.1591425	0.177047	0.186964	0.200431	0.210785	0.222009	0.226852	0.244883	0.258441	0.265849
Velocity std	0.0130905	0.015043	0.013655	0.0142468	0.013828	0.015328	0.014828	0.014917	0.014034	0.015086	0.015763	0.014126	0.015276
Average tank level	13.3865	13.47523	13.57477	13.653727	13.68434	13.71638	13.74746	13.78669	13.79645	13.8655	13.87018	13.89116	13.88005
Tank level std	0.0344074	0.025415	0.03053	0.0274644	0.023442	0.027048	0.026433	0.028822	0.026845	0.032344	0.026092	0.027456	0.02603
Average Z Force (grams)	0.0013063	-0.00346	-0.03077	0.0513642	0.066222	0.016535	-0.02733	-0.01755	0.055489	0.188356	-0.30941	0.01468	-0.03529
Z Force std (grams)	0.1117307	0.120711	0.112378	0.1171846	0.1191	0.131044	0.126427	0.1091	0.10757	0.114325	0.120589	0.114736	0.119695
Sample Description													
Test Description/purpose													
Conclusion/Comment/Decision													

Table 46

Date	3/29/2012	Test ID	032912-031912-C04-R01-S1										
Initial height	20.69	Ring	4	Min Thick	13.93	Total sub. WL							
Initial volume (cubic centimeter)	60.44	Puck	2	Max Thick	19.08	Total unsub. WL	6.91						
Initial un-submerged weight (gr)	148.29	Ring sub	2.09	ΔH	1.33	Lost volume	6.91						
Final non submerged weight (gr)	141.38	Puck sub	48.12	Age-1		Estimated Density	1.00						
Density method 1	1.14	Ring unsu	1.81	Age-2		Image Files							
Density method 2	1.20	Puck unsu	77.29	avg depth									
Average density	1.17	R01-S1											
Pump Power %	3.00												
Ramp up speed (1/s)	0.1	Start time	11:00	End time	16:12	.							
First time weight measurment	62.40	62.39	62.31	62.25									
Time (min)	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00	90.00	100.00	110.00	120.00	130.00
Test duration (min)	10	10	10	10	10	10	10	10	10	10	10	10	10
Pump Power %	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4
Ramp up time (s)	16	18	20	22	24	26	28	30	32	34	36	38	40
Initial weight(gr)	62.25	62.20	62.13	62.06	61.88	61.80	61.75	61.67	61.63	61.45	61.40	61.35	61.27
Final weight(gr)	62.20	62.13	62.06	61.88	61.80	61.75	61.67	61.63	61.45	61.40	61.35	61.27	61.02
weight loss(gr)	0.05	0.07	0.07	0.18	0.08	0.05	0.08	0.04	0.18	0.05	0.05	0.08	0.25
Accumulative weight loss	0.05	0.12	0.19	0.37	0.45	0.50	0.58	0.62	0.80	0.85	0.90	0.98	1.23
intact sample?	Y	N	N	N	N	N	N	N	N	N	N	N	N
Temperature (F)	72.3	71.8	71.6	71.4	71.1	71.1	71.1	70.9	71.1	70.9	70.5	70.5	70.7
Test validity													
Comments on the step													
Erosion rate (gr/(hour.m^2)	700	980	980	2519	1119	700	1119	560	2519	700	700	1119	3498
Average shear stress (Pa)	0.5995573	0.611572	0.974058	0.7711474	1.006153	1.089628	1.047993	1.135303	1.219411	1.294713	1.651611	1.693087	1.808741
Shear stress std	0.0319989	0.114046	0.03034	0.0357912	0.044865	0.039422	0.033338	0.036307	0.030292	0.034522	0.05863	0.145179	0.043078
Average velocity (m/s)	0.1300496	0.131068	0.144172	0.1536755	0.171052	0.18206	0.193626	0.204806	0.215878	0.22234	0.238882	0.249018	0.26142
Velocity std	0.0155164	0.014131	0.012822	0.0144005	0.013406	0.014298	0.014295	0.014051	0.014176	0.01431	0.014405	0.015069	0.01501
Average tank level	14.297816	14.23754	14.16256	14.157056	14.1077	14.04443	14.00839	14.01505	14.07014	14.05033	14.01866	13.99463	13.97741
Tank level std	0.0258952	0.024372	0.026929	0.0309165	0.023308	0.023441	0.023149	0.026096	0.024255	0.022891	0.026895	0.023536	0.024276
Average Z Force (grams)	0.011644	0.018924	0.037459	0.0306219	-0.04221	0.060801	0.039519	0.021158	0.018806	-0.01981	0.00537	-0.01738	0.040487
Z Force std (grams)	0.1124493	0.129696	0.109945	0.1194556	0.108461	0.110095	0.10797	0.122428	0.109607	0.111835	0.12206	0.107349	0.116415
Sample Description													
Test Description/purpose													
Conclusion/Comment/Decision													

Table 47

Date	3/30/2012		Test ID	033012-031912-C04-R01-S2			
Initial height	22.29	Ring	3	Min Thick		Total sub. WL	
Initial volume (cubic centimeter)	65.11	Puck	1	Max Thick		Total unsub. WL	150.04
Initial un-submerged weight (gr)	150.04	Ring sub	2.4	ΔH		Lost volume	150.04
Final non submerged weight (gr)		Puck sub	48.28	Age-1		Estimated Density	1.00
Density method 1	1.06	Ring unsu	3.83	Age-2		Image Files	
Density method 2	1.19	Puck unsu	77.37	avg depth			
Average density	1.12	R01-S2					
Pump Power %	3.00						
Ramp up speed (1/s)	0.1	Start time	10:45	End time		.	
First time weight measurment	62.80	62.80	62.80				
Time (min)	10.00	20.00	30.00				
Test duration (min)	10	10	10				
Pump Power %	1.6	1.8	2				
Ramp up time (s)	#REF!	#REF!	#REF!				
Initial weight(gr)	62.80	62.89	62.78				
Final weight(gr)	62.89	62.78	62.76				
weight loss(gr)	-0.09	0.11	0.02				
Accumulative weight loss	-0.09	0.02	0.04				
intact sample?	Y	N	N				
Temperature (F)	70.9						
Test validity							
Comments on the step							
Erosion rate (gr/(hour.m^2)	-25	31	6				
Average shear stress (Pa)		0.819111	0.719229				
Shear stress std		0.03466	0.024539				
Average velocity (m/s)		0.126984	0.130945				
Velocity std		0.015158	0.014513				
Average tank level		12.94842	12.9558				
Tank level std		0.024763	0.02374				
Average Z Force (grams)		-0.011	-0.03513				
Z Force std (grams)		0.104156	0.119644				
Sample Description							
Test Description/purpose							
Conclusion/Comment/Decision							

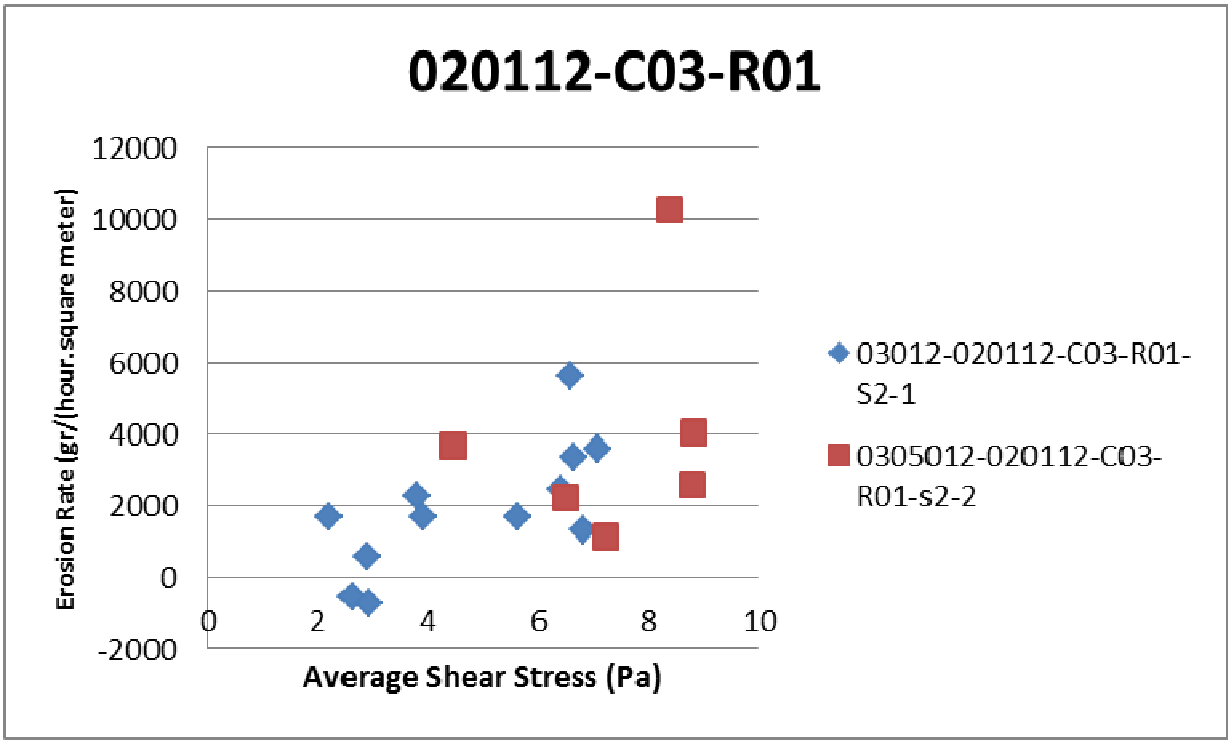


Figure 61

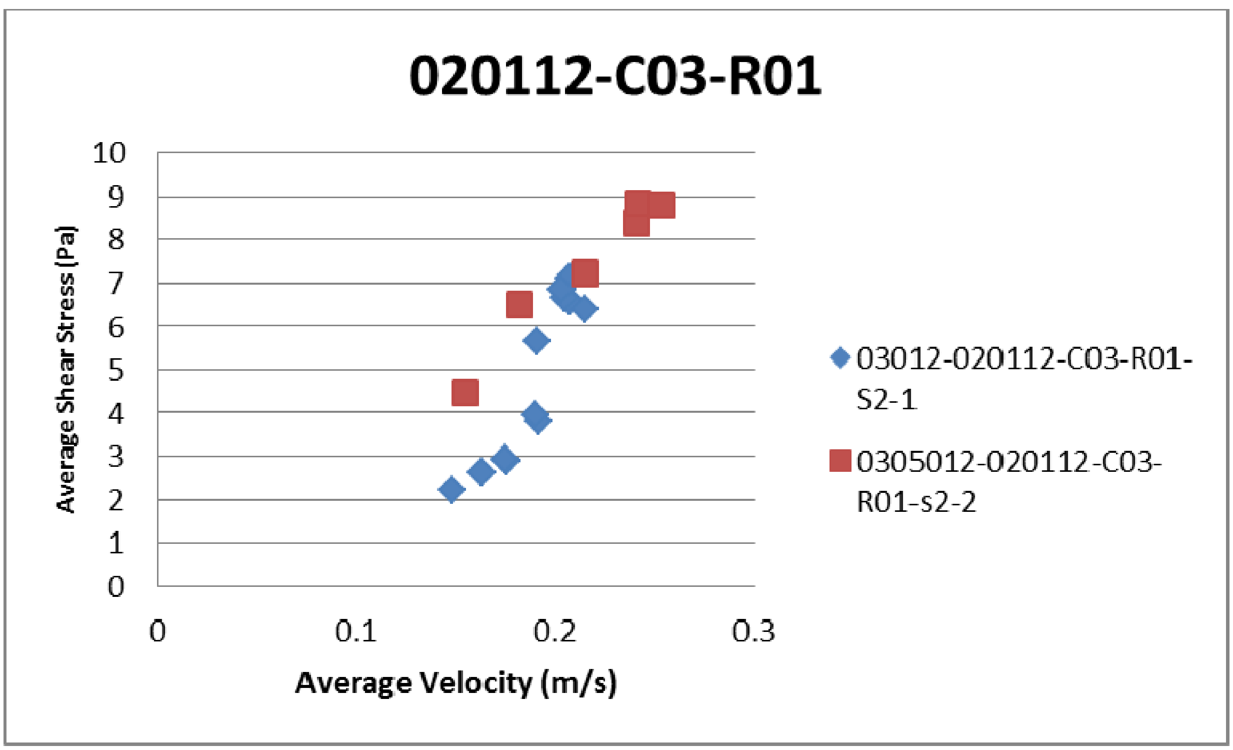


Figure 62

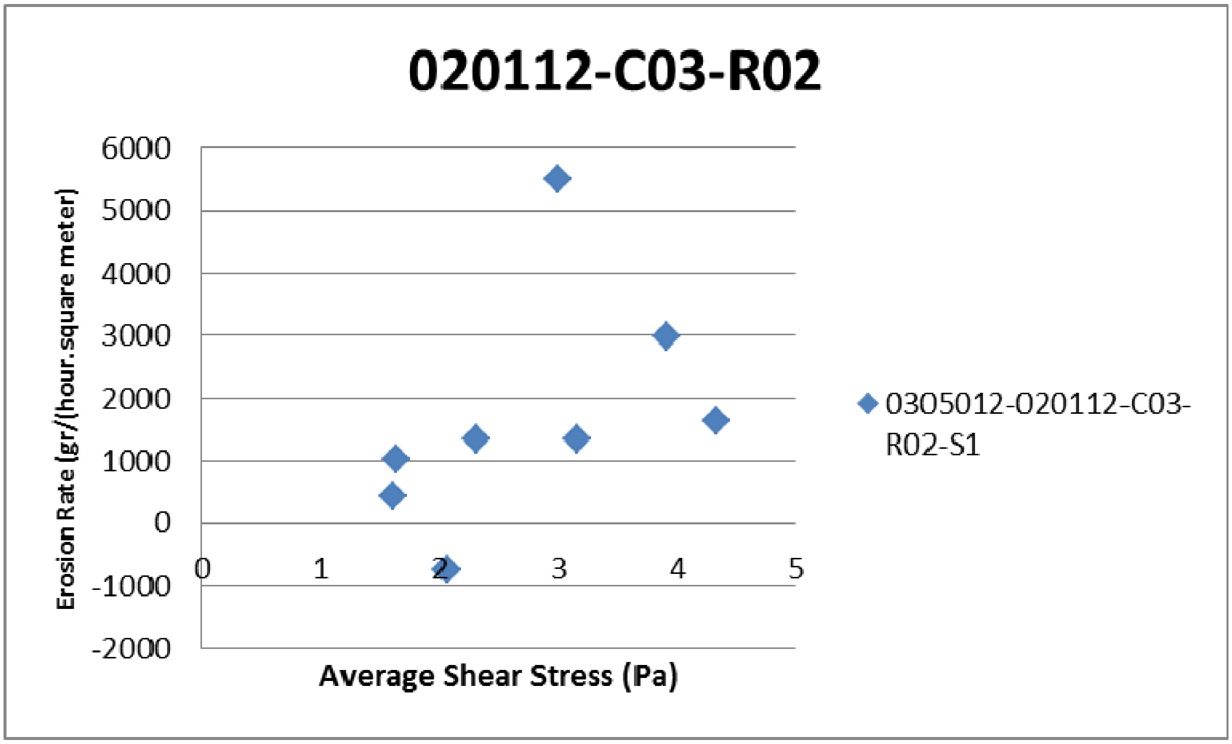


Figure 63

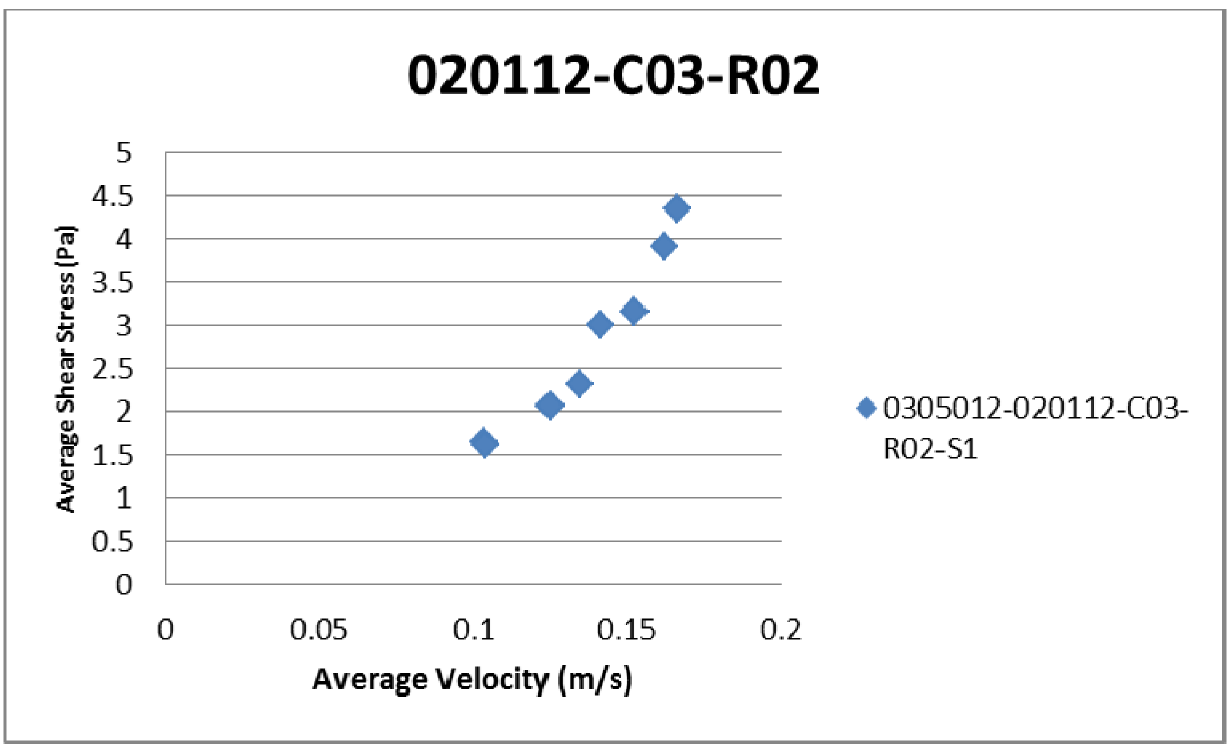


Figure 64

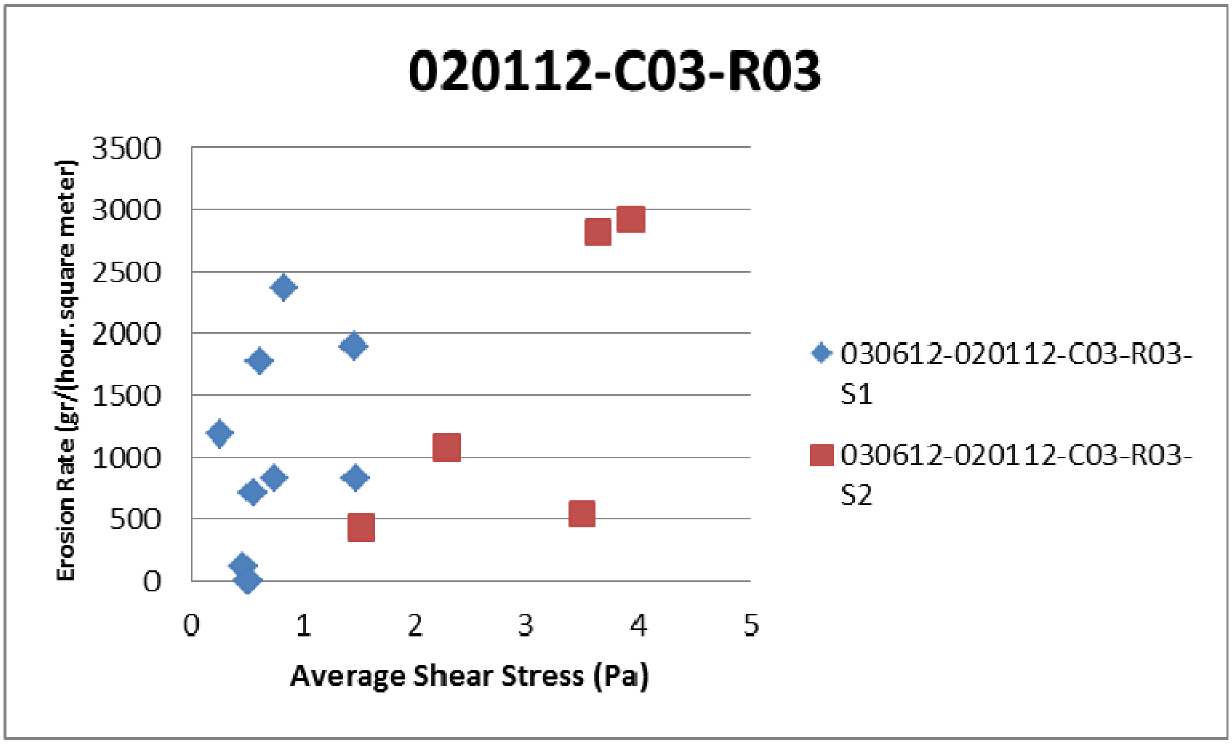


Figure 65

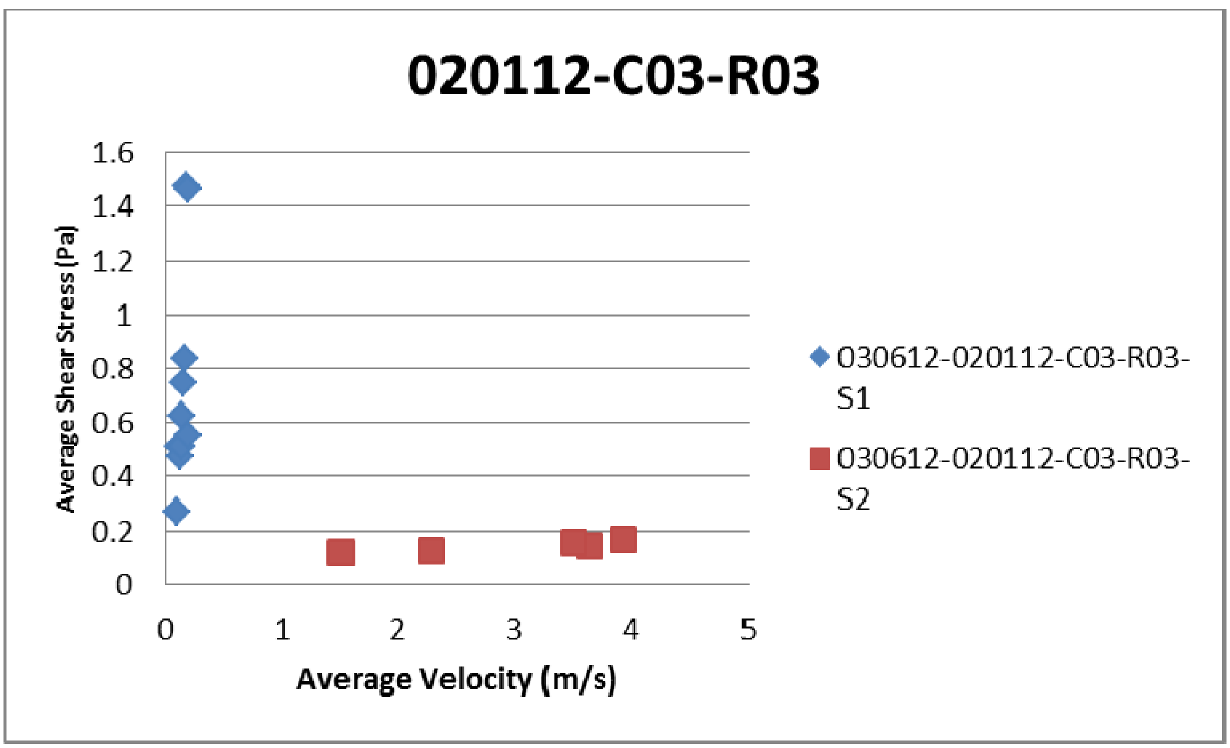


Figure 66

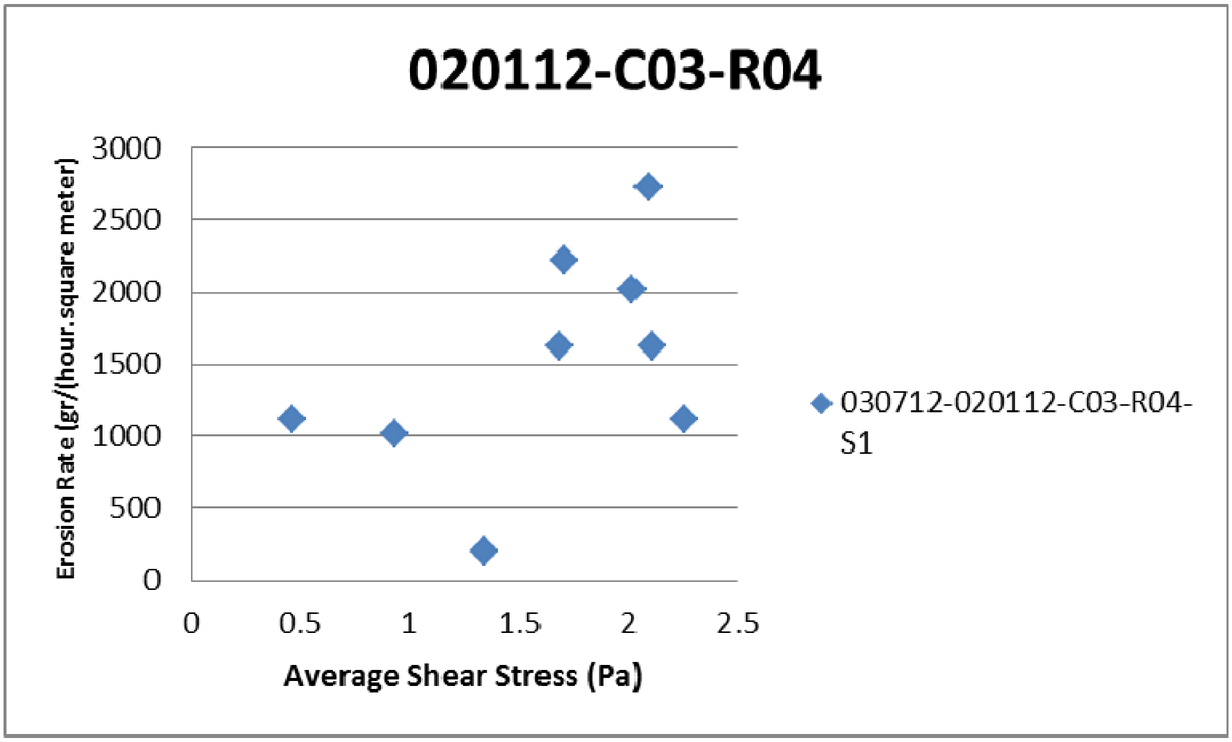


Figure 67

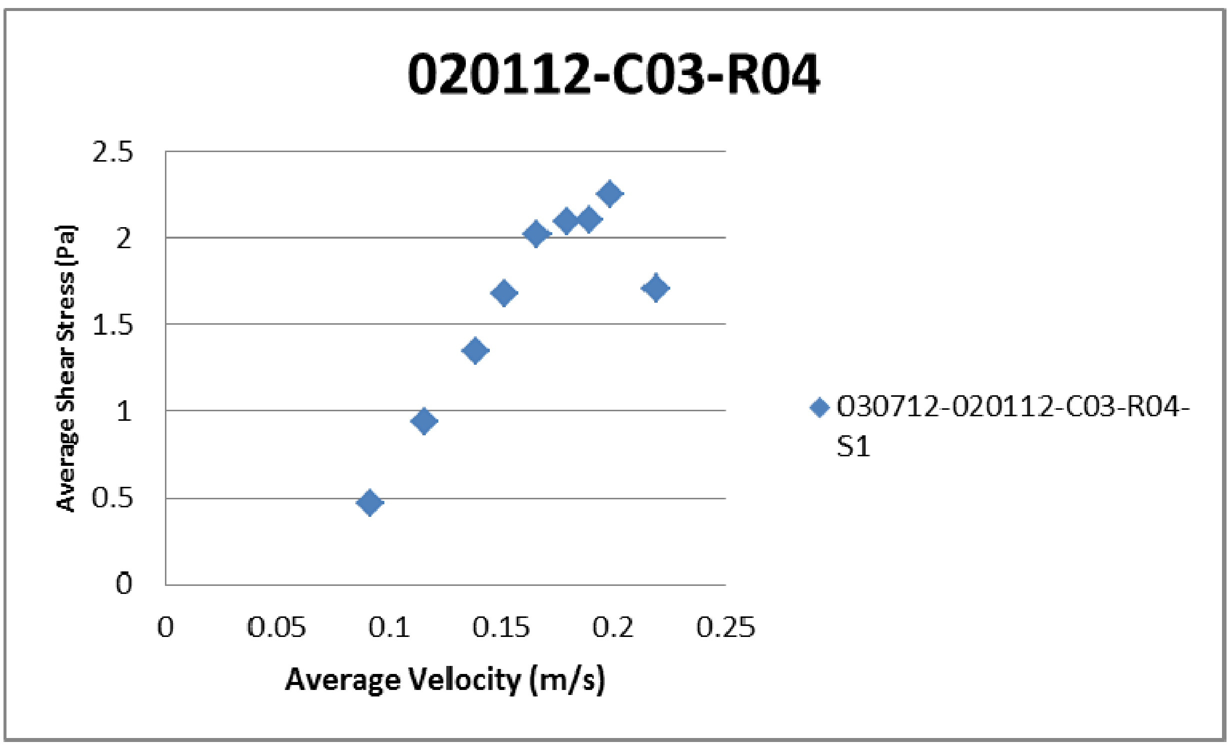


Figure 68

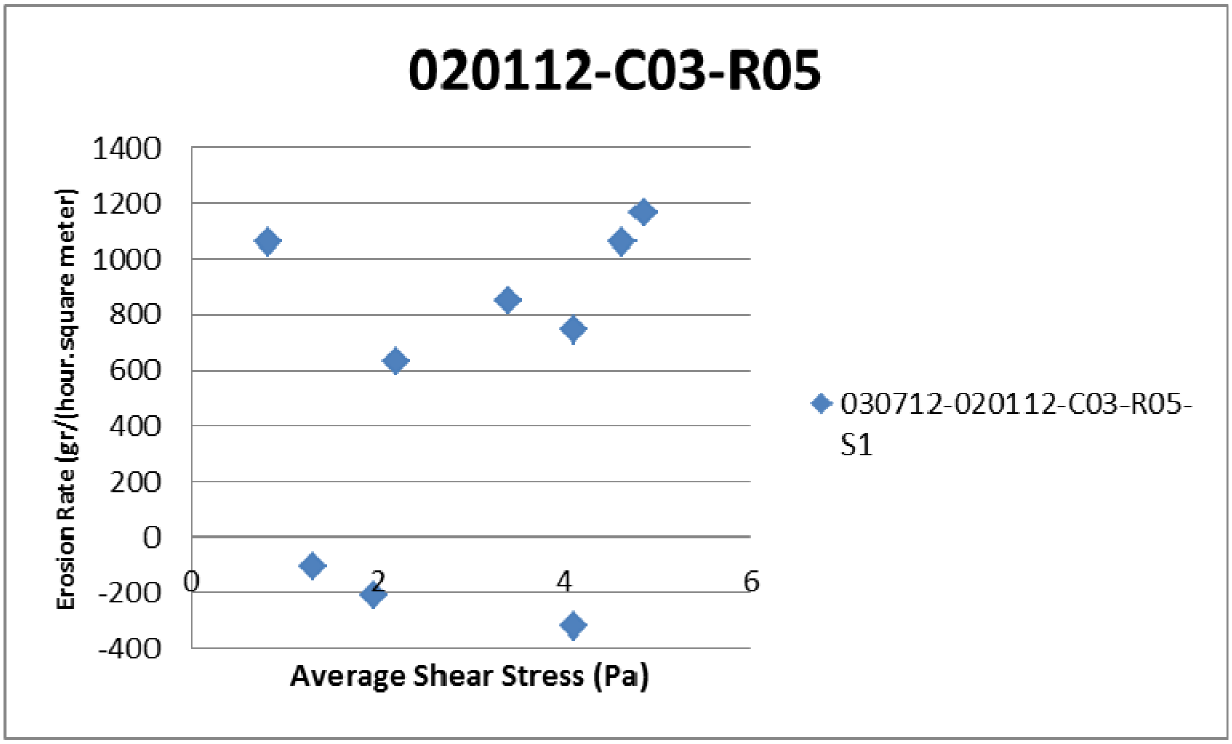


Figure 69

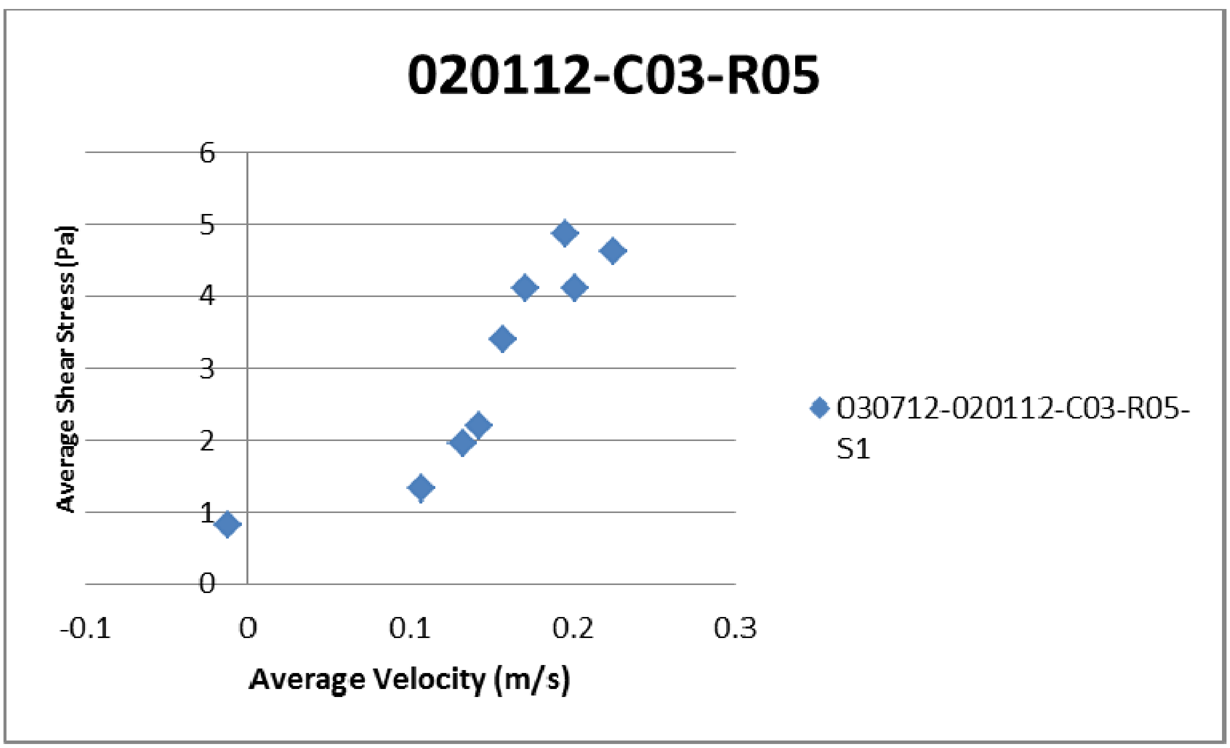


Figure 70

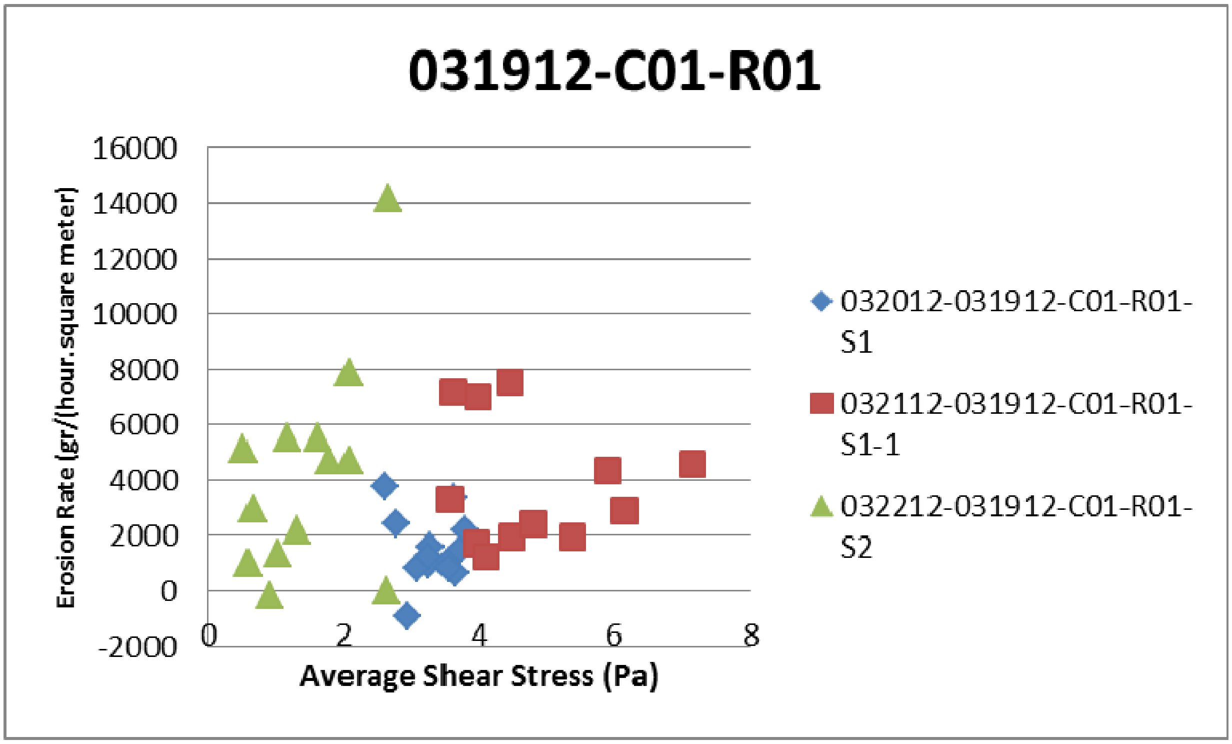


Figure 71

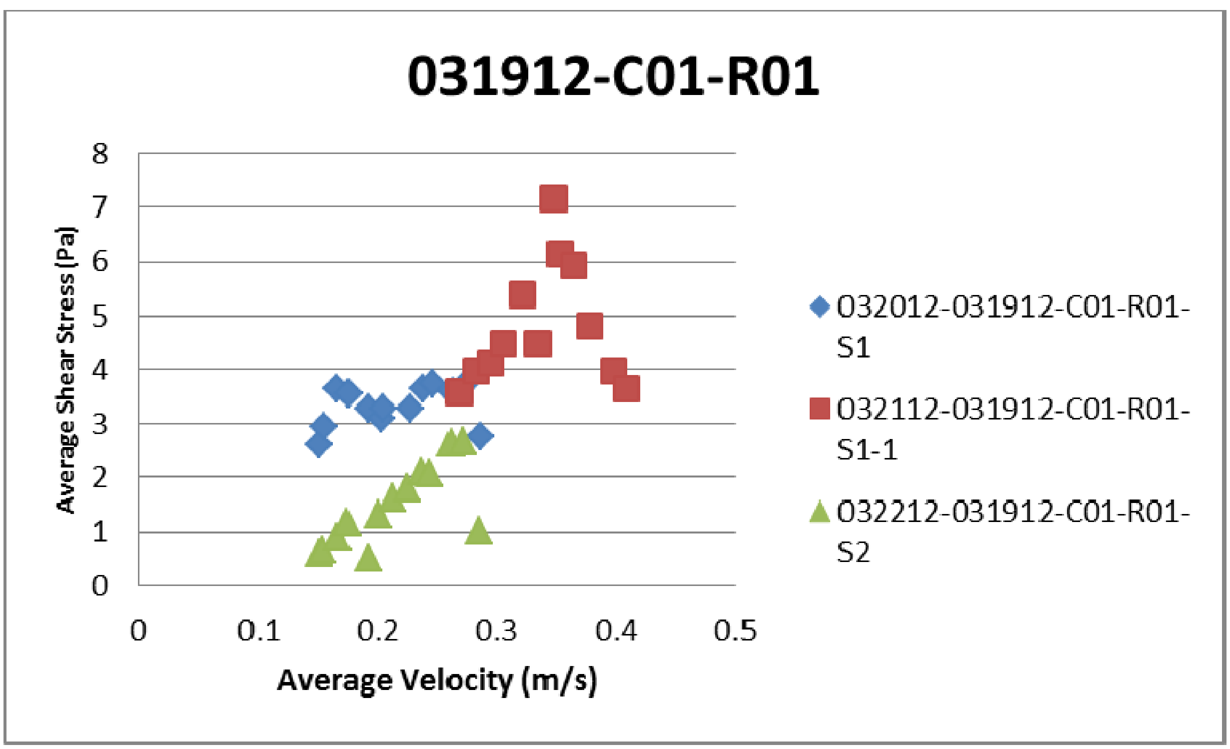


Figure 72

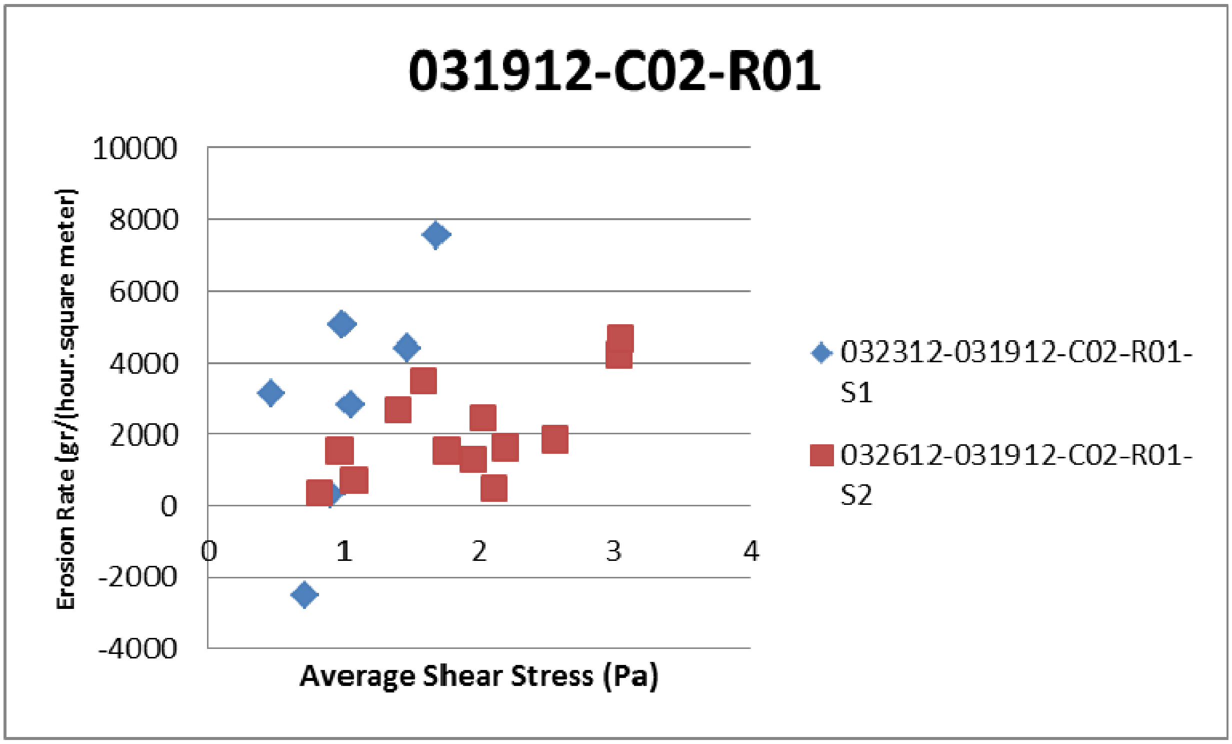


Figure 73

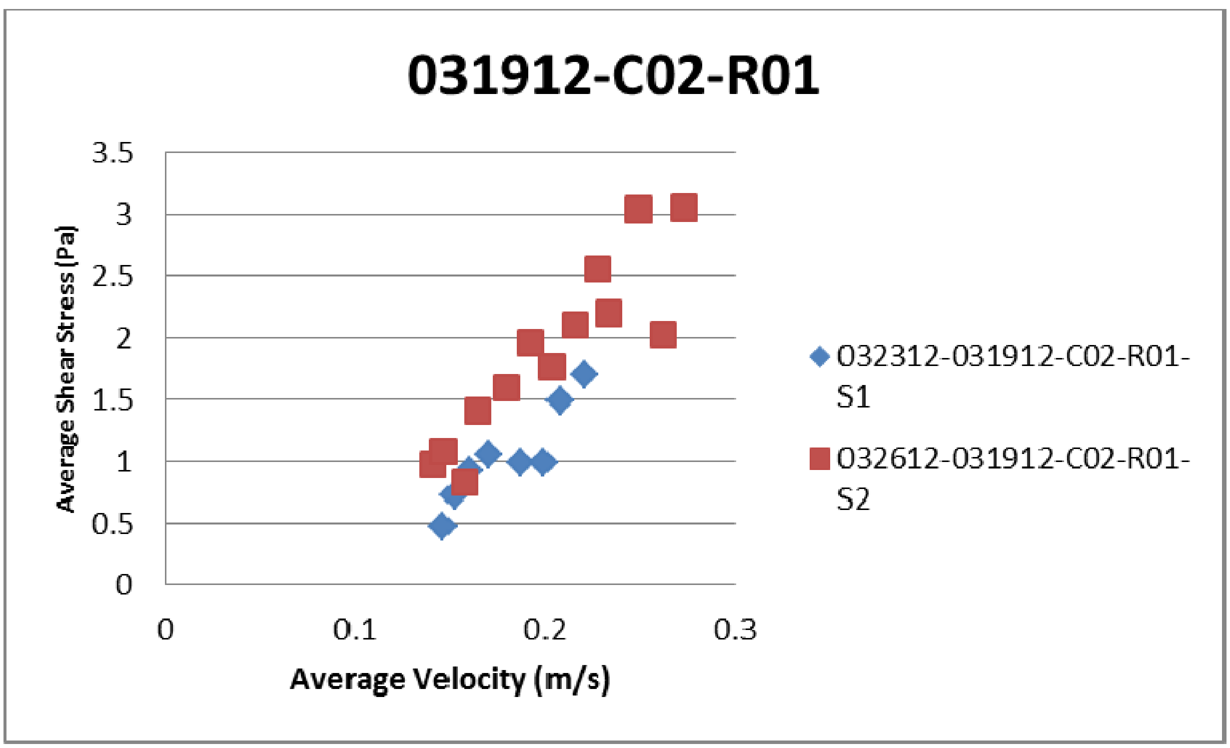


Figure 74

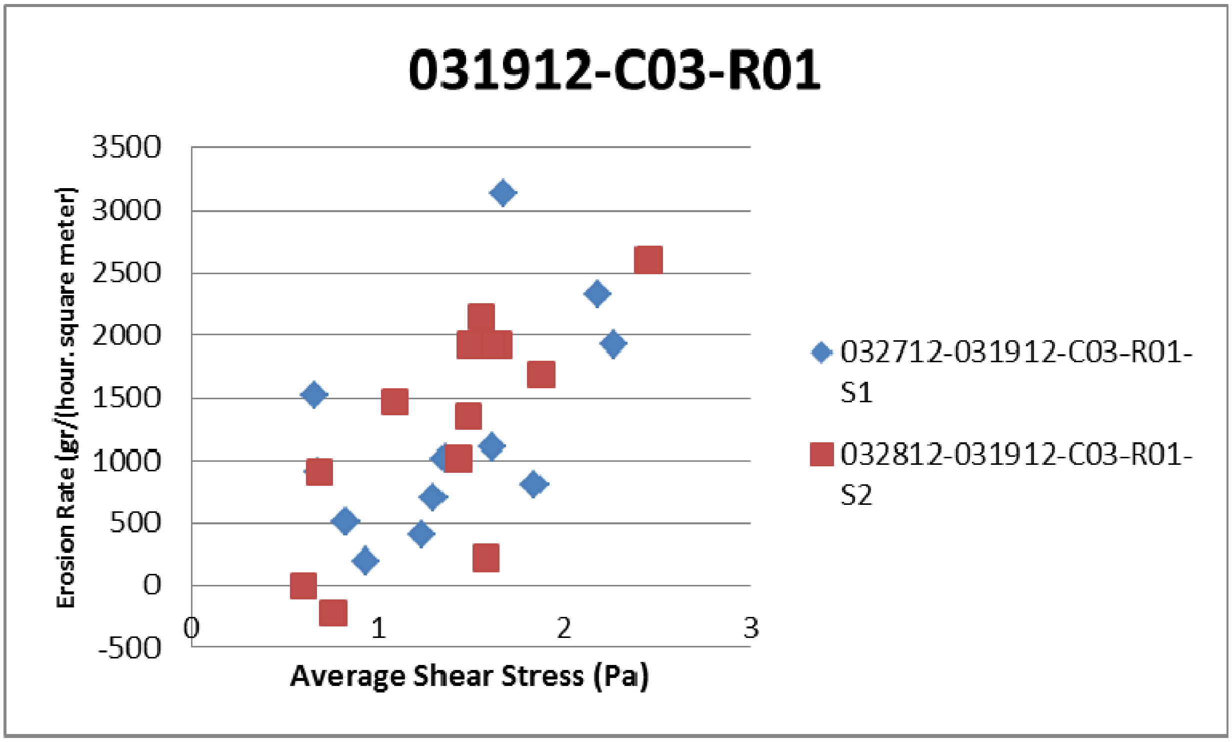


Figure 75

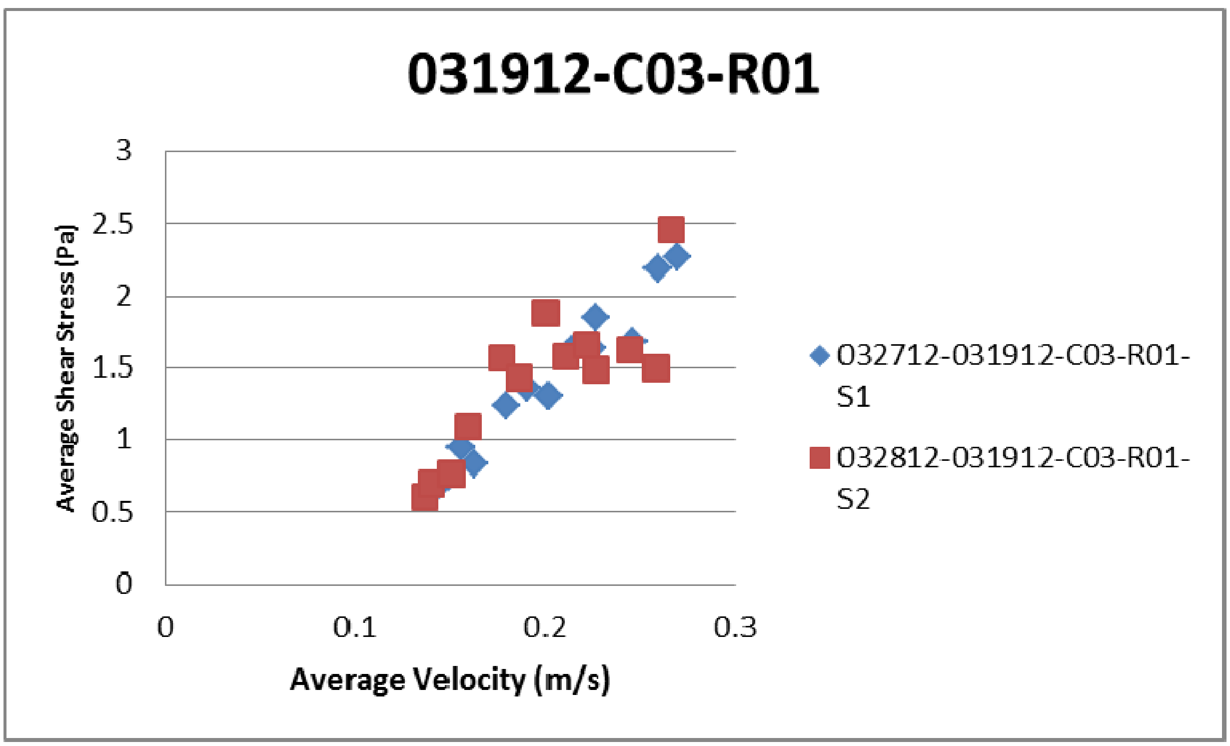


Figure 76

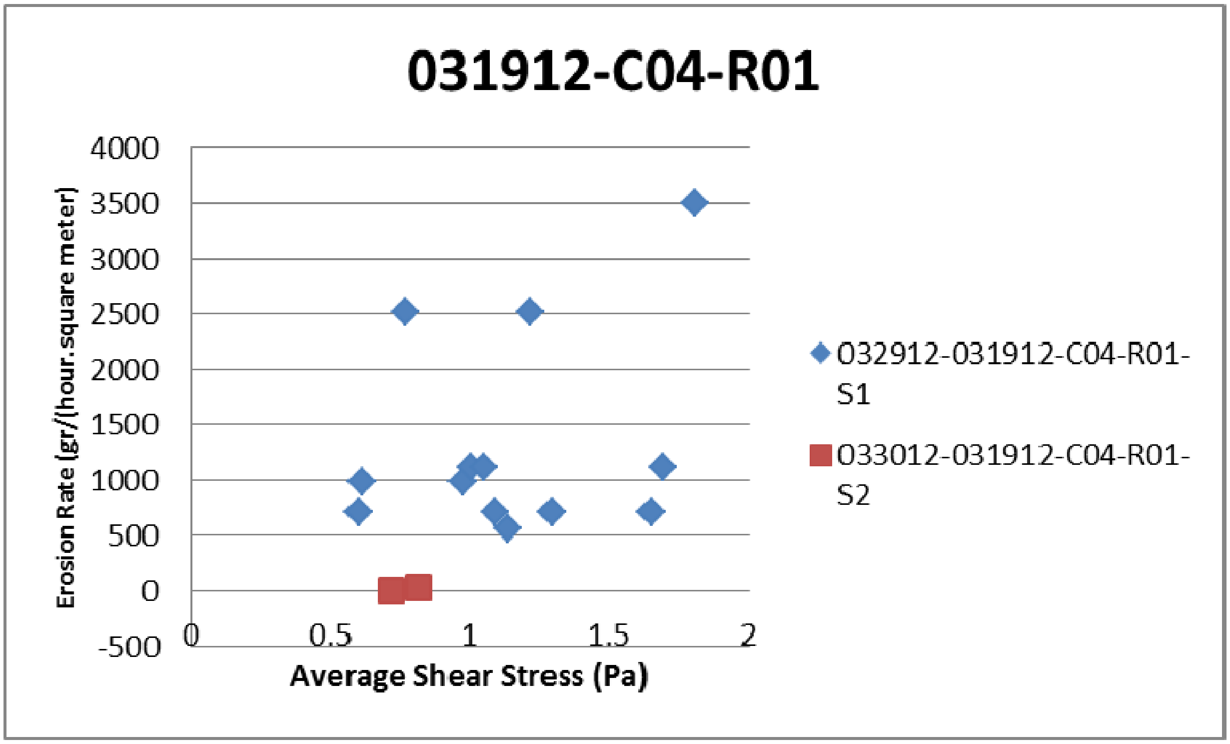


Figure 77

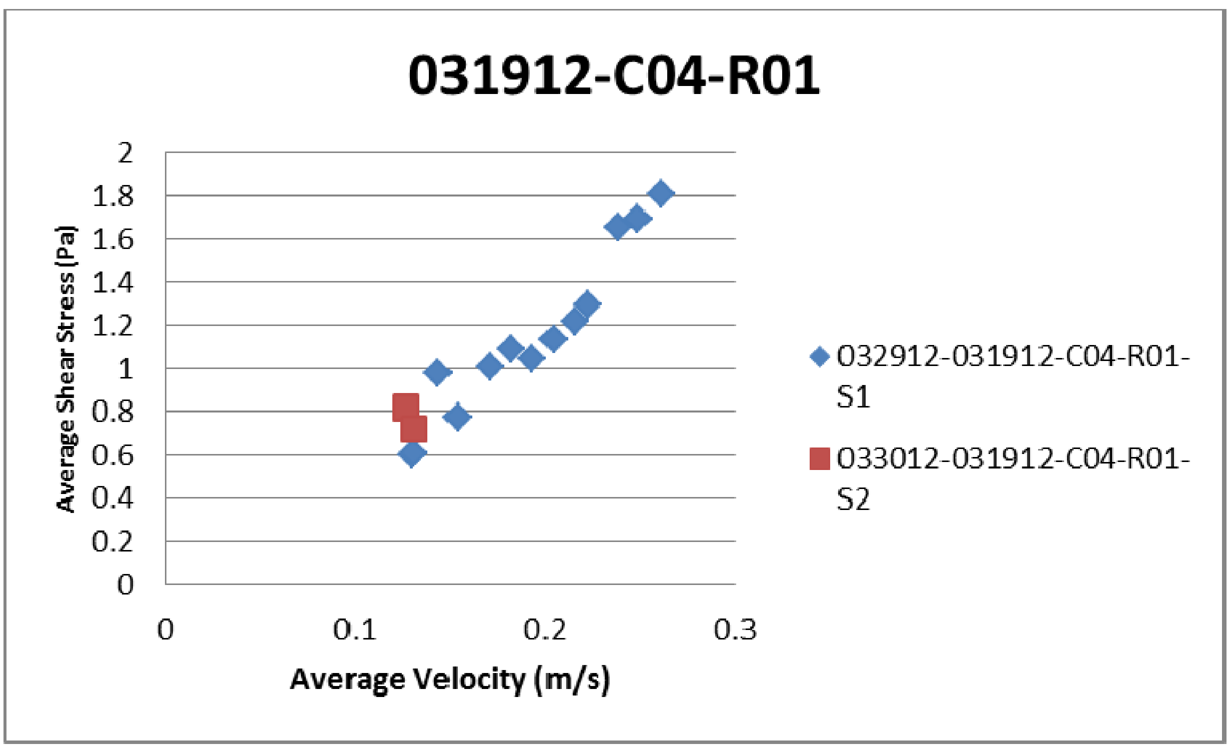


Figure 78

Test Results: Manufactured Samples

April 2012

Table 48

Date	4/23/2012		Test ID	042312-041612-01-01			
Initial height	13.00	Ring	2	Min Thick	12.96	Total sub. WL	0.65
Initial volume (cubic centimeter)	37.97	Puck	1	Max Thick	12.96	Total unsub. WL	1.51
Initial un-submerged weight (gr)	136.88	Ring sub	3.63	EE1		Lost volume	0.86
Final non submerged weight (gr)	135.37	Puck sub	48.28	EE2		Estimated Density	1.76
Density method 1	1.42	Ring unsu	5.7	ΔH		Image Files	
Density method 2	1.34	Puck unsu	77.37	SS avg			
Average density	1.38			SS sd			
Pump Power %	var	1	Start time		15:06		
Ramp up time (s)	var		End time		16:30		
Pump Power %	4	6	8	10			
Ramp up time (s)	8	12	16	20			
First time weight measurment	64.84	64.85	64.77				
Time (min)	5.00	10.00	15.00	20.00			
Test duration (min)	5	5	5	5			
Initial weight(gr)	64.77	64.68	64.56	64.33			
Final weight(gr)	64.68	64.56	64.33	64.12			
weight loss(gr)	0.09	0.12	0.23	0.21			
Accumulative weight loss	0.09	0.21	0.44	0.65			
intact sample?	Y	N	N	N			
Temperature (F)	75.2			75.2			
Test validity							
Comments on the step							
Erosion rate (gr/(hour.m^2)	1348	1798	3445	3146			
Average shear stress (Pa)	1.187561	2.516073	3.119416	2.318006			
Shear stress std	0.0337	0.051711	0.14107	0.573273			
Average velocity (m/s)	0.240017	0.344596	0.460173	0.576016			
Velocity std	0.015251	0.015357	0.015984	0.015772			
Average tank level	11.75841	11.84346	11.86172	11.99941			
Tank level std	0.031012	0.020416	0.032318	0.026242			
Average Z Force (grams)	-0.10358	-0.05454	0.027552	-0.03154			
Z Force std (grams)	0.046479	0.024245	0.033635	0.024655			
Comments on the step							
Sample Description	Army core comparison - AC31						
Test Description/purpose							
Conclusion/Comment/Decision							

Table 49

Date	4/23/2012		Test ID	042312-041612-02-01			
Initial height	18.40	Ring	3	Min Thick	16.88	Total sub. WL	0.35
Initial volume (cubic centimeter)	53.75	Puck	1	Max Thick	16.88	Total unsub. WL	0.30
Initial un-submerged weight (gr)	152.96	Ring sub	2.4	EE1		Lost volume	-0.05
Final non submerged weight (gr)	152.66	Puck sub	48.28	EE2		Estimated Density	-6.00
Density method 1	1.34	Ring unsu	3.83	ΔH		Image Files	
Density method 2	1.34	Puck unsu	77.37	SS avg			
Average density	1.34			SS sd			
Pump Power %	var	2	Start time		16:50		
Ramp up time (s)	var		End time		18:00		
Pump Power %	4	6	8	10			
Ramp up time (s)	8	12	16	20			
First time weight measurment	68.75	68.75					
Time (min)	5.00	10.00	15.00	20.00			
Test duration (min)	5	5	5	5			
Initial weight(gr)	68.75	68.77	68.65	68.56			
Final weight(gr)	68.77	68.65	68.56	68.40			
weight loss(gr)	-0.02	0.12	0.09	0.16			
Accumulative weight loss	-0.02	0.10	0.19	0.35			
intact sample?	Y	N	N	N			
Temperature (F)				75.9			
Test validity							
Comments on the step							
Erosion rate (gr/(hour.m^2)	-327	1962	1471	2615			
Average shear stress (Pa)	1.234496	1.936038	2.056899	1.945534			
Shear stress std	0.028405	0.057595	0.152031	0.212945			
Average velocity (m/s)	0.241506	0.345695	0.462148	0.575548			
Velocity std	0.01702	0.016136	0.016453	0.017484			
Average tank level	11.95957	11.95185	12.00815	12.11233			
Tank level std	0.029863	0.029797	0.039688	0.058152			
Average Z Force (grams)	-0.0046	-0.02077	-0.00313	-0.00654			
Z Force std (grams)	0.024923	0.029636	0.024661	0.053287			
Comments on the step							
Sample Description	Army core comparison - AC 32						
Test Description/purpose							
Conclusion/Comment/Decision							

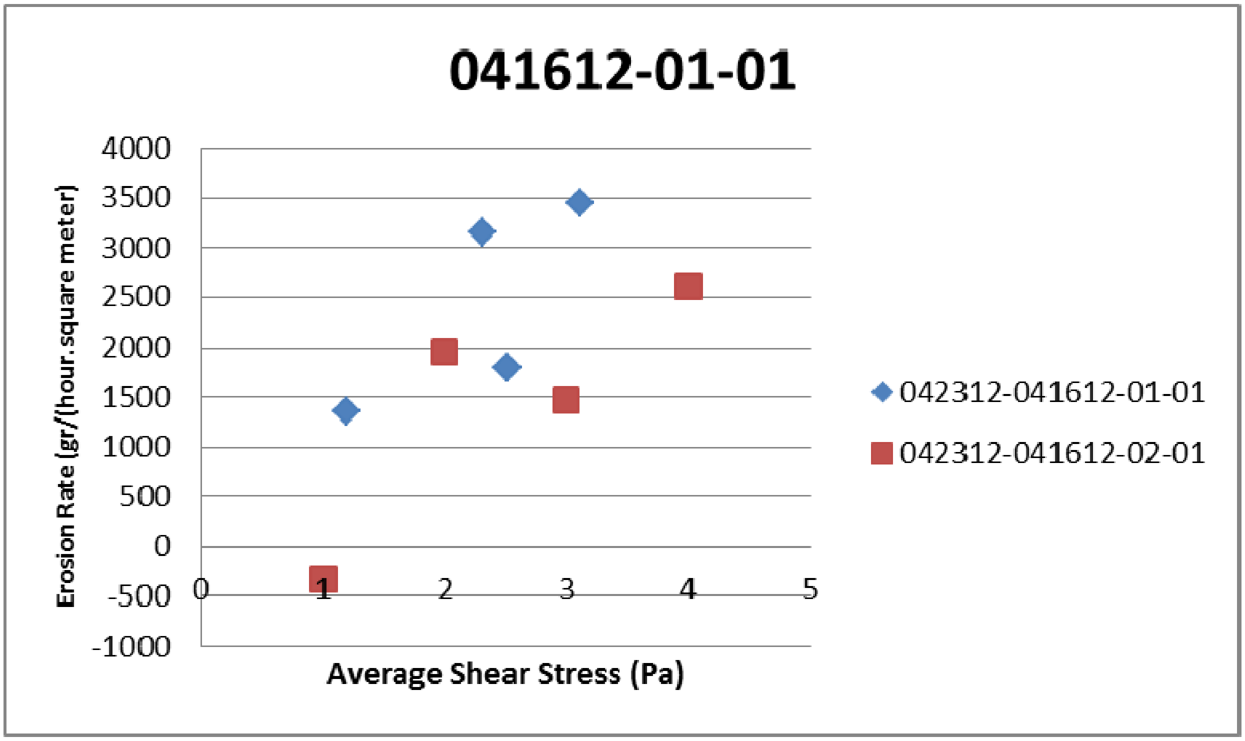


Figure 79

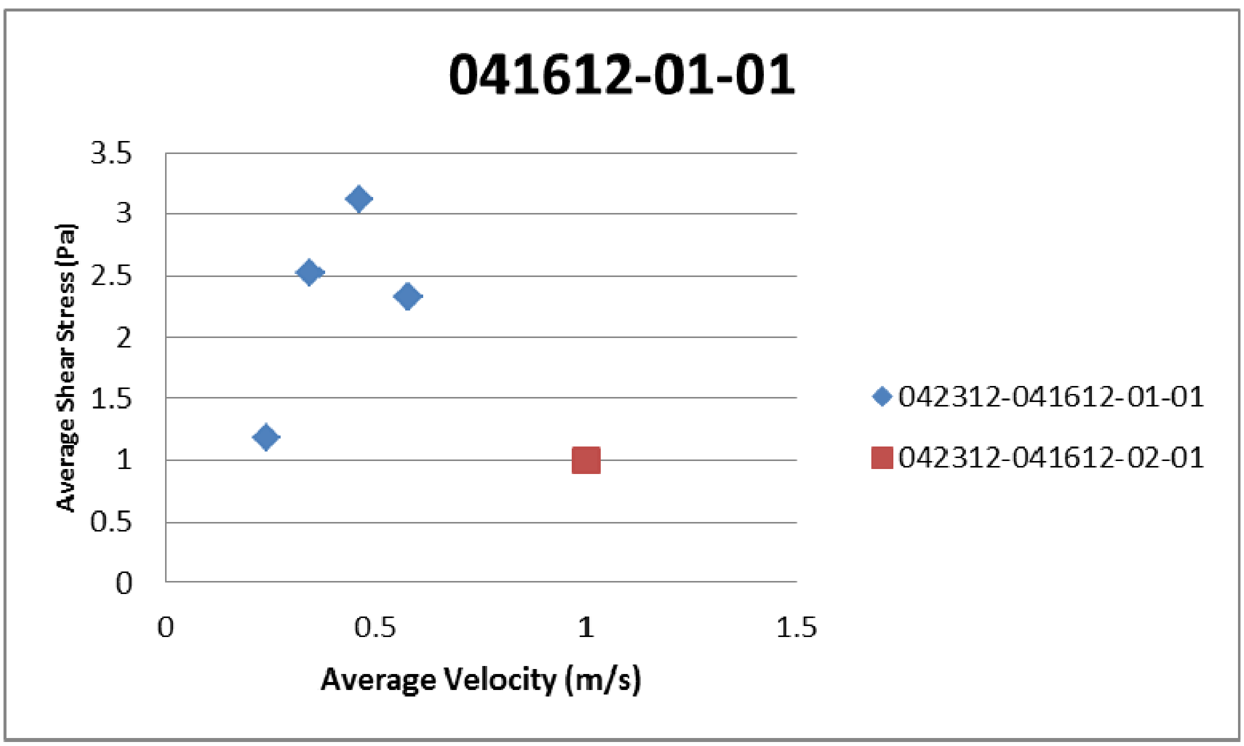


Figure 80

Test Results: Manufactured Samples

May 2012

Table 50

Date	5/11/2012		Test ID	051112-050912-01-3				
Initial height	14.75	Ring	6	Min Thick		Total sub. WL		0.64
Initial volume (cubic centimeter)	43.08	Puck	1	Max Thick		Total unsub. WL		138.03
Initial un-submerged weight (gr)	138.03	Ring sub	2.22	EE1		Lost volume		137.39
Final non submerged weight (gr)		Puck sub	48.28	EE2		Estimated Density		1.00
Density method 1	1.33	Ring unsu	3.53	ΔH		Image Files		
Density method 2	1.28	Puck unsu	77.37	SS avg				
Average density	1.30			SS sd				
Pump Power %	var		Start time		12:30			
Ramp up time (s)	var		End time		15:00			
Pump Power %	2	2.5	3	3.5	4	4.5		
Ramp up time (s)	20	25	30	35	40	45		
First time weight measurment	62.75	62.75	62.75	62.72	62.72	62.72		
Time (min)	10.00	20.00	30.00	40.00	51.00	63.00		
Test duration (min)	10	10	10	10	11	12		
Initial weight(gr)	62.72	62.63	N/A	62.41	62.04	61.22		
Final weight(gr)	62.63	62.66	62.41	62.08	61.74	61.02		
weight loss(gr)	0.09	-0.03	N/A	0.33	0.30	0.20		
Accumulative weight loss	0.09	0.06	N/A	0.39	0.69	0.89		
intact sample?	Y	N	N	N	N	N		
Temperature (F)								
Test validity								
Comments on the step								
Erosion rate (gr/(hour.m^2)	791	-264	N/A	2902	2398	1465		
Average shear stress (Pa)	1.092445	1.457931	1.481337	2.283157	1.869421	3.718077		
Shear stress std	0.021074	0.031717	0.026969	0.031333	0.048224	0.040312		
Average velocity (m/s)	0.148788	0.177392	0.197022	0.228876	0.2531	0.273369		
Velocity std	0.009919	0.009199	0.00893	0.008934	0.009488	0.008384		
Average tank level	12.21675	12.17303	12.2332	12.30278	12.35503	12.37651		
Tank level std	0.037114	0.052636	0.046328	0.05388	0.048852	0.094654		
Average Z Force (grams)	0.329856	0.375581	0.518108	0.755801	0.780662	1.051673		
Z Force std (grams)	0.027402	0.075982	0.034749	0.051344	0.03338	0.028771		
Comments on the step								
Sample Description	Army core comparison - AC1 consolidated under the rod weight only							
Test Description/purpose								
Conclusion/Comment/Decision								

Table 51

Date	5/15/2012	Test ID		051512-051412-01-2			
Initial height	15.20	Ring	5	Min Thick		Total sub. WL	5.30
Initial volume (cubic centimeter)	44.40	Puck	1	Max Thick		Total unsub. WL	138.22
Initial un-submerged weight (gr)	138.22	Ring sub	2.45	EE1		Lost volume	132.92
Final non submerged weight (gr)		Puck sub	48.28	EE2		Estimated Density	1.04
Density method 1	1.28	Ring unsu	3.81	ΔH		Image Files	
Density method 2	1.31	Puck unsu	77.37	SS avg		0515121630-0515121900	
Average density	1.30			SS sd			
Pump Power %	var		Start time		16:30		
Ramp up time (s)	var		End time		19:00		
Pump Power %	2	2.5	4				
Ramp up time (s)	20	25	40				
First time weight measurment	64.43	64.42					
Time (min)	5.00	15.00	25.00				
Test duration (min)	10	10	10				
Initial weight(gr)	64.42	62.85	59.27				
Final weight(gr)	64.41	62.77	59.12				
weight loss(gr)	0.01	0.08	0.15				
Accumulative weight loss	0.01	0.09	0.24				
intact sample?	Y	Y	Y				
Temperature (F)							
Test validity							
Erosion rate (gr/(hour.m^2)	90	719	1347				
Average shear stress (Pa)	0.213633	0.158231	0.145698				
Shear stress std	0.021324	0.022417	0.030627				
Average velocity (m/s)	0.152426	0.180102	0.252386				
Velocity std	0.009845	0.009508	0.009718				
Average tank level	11.77554	11.81947	11.94907				
Tank level std	0.020183	0.028506	0.019929				
Average Z Force (grams)	-0.00062	-0.01652	0.56384				
Z Force std (grams)	0.02975	0.029437	0.017959				
Comments on the step							
Sample Description	Army core comparison - AC 3						
Test Description/purpose							
Conclusion/Comment/Decision	The weight measurment basket was modified to reduce its sensitivity to water level						

Table 52

Date	5/16/2012		Test ID	051612-051412-01-3				
Initial height	14.72	Ring	6	Min Thick		Total sub. WL		3.19
Initial volume (cubic centimeter)	43.00	Puck	1	Max Thick		Total unsub. WL		21.37
Initial un-submerged weight (gr)	137.08	Ring sub	2.22	EE1		Lost volume		18.18
Final non submerged weight (gr)	115.71	Puck sub	48.28	EE2		Estimated Density		1.18
Density method 1	1.31	Ring unsu	3.53	ΔH		Image Files		
Density method 2	1.32	Puck unsu	77.37	SS avg		0516121045-0516121700		
Average density	1.31			SS sd				
Pump Power %	var		Start time		10:45			
Ramp up time (s)	var		End time		17:00			
Pump Power %	2	3	4	5	6	7		
Ramp up time (s)	20	30	40	50	60	70		
First time weight measurment	64.07	64.10	64.11	64.09				
Time (min)	5.00	25.00	55.00	85.00	115.00	145.00		
Test duration (min)	10	20	30	30	30	30		
Initial weight(gr)	64.09	62.72	61.89	61.09	60.36	59.04		
Final weight(gr)	64.08	62.67	61.83	60.90	59.91	58.41		
weight loss(gr)	0.01	0.05	0.06	0.19	0.45	0.63		
Accumulative weight loss	0.01	0.06	0.12	0.31	0.76	1.39		
intact sample?	Y	Y	Y	Y	Y	Y		
Temperature (F)					83.5			
Test validity								
Comments on the step								
Erosion rate (gr/(hour.m^2)	87	216	173	548	1298	1817		
Average shear stress (Pa)	0.99667	1.503619	2.624413	3.08884	4.77133	2.387816		
Shear stress std	0.024048	0.028743	0.029455	0.035897	0.066066	0.151346		
Average velocity (m/s)	0.151046	0.199184	0.257114	0.304478	0.359583	0.417911		
Velocity std	0.009578	0.009796	0.00963	0.0101	0.00899	0.009088		
Average tank level	11.70282	11.77699	11.86943	11.94247	12.07133	12.24644		
Tank level std	0.016399	0.017641	0.02263	0.019859	0.019757	0.015436		
Average Z Force (grams)	0.541413	0.635966	-1.31474	1.918074	2.441147	1.212401		
Z Force std (grams)	0.03518	0.027954	0.033629	0.073317	0.044424	0.091413		
Comments on the step								
Sample Description	Army core comparison - AC 3							
Test Description/purpose								
Conclusion/Comment/Decision								

Table 53

Date	5/17/2012		Test ID	051712-051412-01-4			
Initial height	14.14	Ring	5	Min Thick		Total sub. WL	5.04
Initial volume (cubic centimeter)	41.30	Puck	1	Max Thick		Total unsub. WL	20.12
Initial un-submerged weight (gr)	137.24	Ring sub	2.45	EE1		Lost volume	15.08
Final non submerged weight (gr)	117.12	Puck sub	48.28	EE2		Estimated Density	1.33
Density method 1	1.36	Ring unsu	3.81	ΔH		Image Files	
Density method 2	1.32	Puck unsu	77.37	SS avg		0517121430-0517121800	
Average density	1.34			SS sd			
Pump Power %	var		Start time		14:30		
Ramp up time (s)	var		End time		18:00		
Pump Power %	2	3	5	6			
Ramp up time (s)	20	30	50	60			
First time weight measurment	63.83	63.84	63.83				
Time (min)	5.00	35.00	65.00	95.00			
Test duration (min)	30	30	30	30			
Initial weight(gr)	63.83	63.20	61.21	60.06			
Final weight(gr)	63.91	63.17	60.88	58.79			
weight loss(gr)	-0.08	0.03	0.33	1.27			
Accumulative weight loss	-0.08	-0.05	0.28	1.55			
intact sample?	Y	Y	Y	Y			
Temperature (F)							
Test validity							
Comments on the step							
Erosion rate (gr/(hour.m^2)	-217	81	896	3448			
Average shear stress (Pa)	1.002278	1.969785	2.7784	4.911756			
Shear stress std	0.035387	0.028384	0.07592	0.135764			
Average velocity (m/s)	0.149889	0.202018	0.307254	0.36002			
Velocity std	0.009383	0.009591	0.0097	0.009558			
Average tank level	11.2964	11.27533	11.48262	11.60288			
Tank level std	0.02129	0.02388	0.019103	0.01572			
Average Z Force (grams)	0.120373	-21.0574	1.64355	2.292637			
Z Force std (grams)	0.115784	0.106804	0.036939	0.039065			
Comments on the step							
Average shear stress (Pa)							
Average velocity (m/s)							
Sample Description	Army core comparison - AC 3						
Test Description/purpose							
Conclusion/Comment/Decision							

Table 54

Date	5/18/2012		Test ID	051812-050912-01-4				
Initial height	14.38	Ring	4	Min Thick		Total sub. WL		2.02
Initial volume (cubic centimeter)	42.00	Puck	2	Max Thick		Total unsub. WL		135.98
Initial un-submerged weight (gr)	135.98	Ring sub	2.09	EE1		Lost volume		133.96
Final non submerged weight (gr)		Puck sub	48.12	EE2		Estimated Density		1.02
Density method 1	1.35	Ring unsu	1.81	ΔH		Image Files		
Density method 2	1.28	Puck unsu	77.29	SS avg		0518121000-0518121715		
Average density	1.32			SS sd				
Pump Power %	var		Start time		10:00			
Ramp up time (s)	var		End time		17:15			
Pump Power %	2	3	4	5	6	7	8	9
Ramp up time (s)	20	30	40	50	60	70	80	90
First time weight measurment	61.96	61.95	61.95					
Time (min)	5.00	35.00	65.00	95.00	125.00	155.00	185.00	
Test duration (min)	30	30	30	30	30	30	30	
Initial weight(gr)	61.95	61.18	60.82	60.30	58.78	57.73	56.26	
Final weight(gr)	61.94	61.12	60.75	59.93	57.97	56.37	54.81	
weight loss(gr)	0.01	0.06	0.07	0.37	0.81	1.36	1.45	
Accumulative weight loss	0.01	0.07	0.14	0.51	1.32	2.68	4.13	
intact sample?	Y	Y	Y	Y	Y	Y	Y	
Temperature (F)						80.8		
Test validity								
Comments on the step								
Erosion rate (gr/(hour.m^2)	28	171	199	1053	2305	3870	4126	
Average shear stress (Pa)	1.027768	1.717898	2.474055	3.469107	4.263772	8.177001	11.29933	
Shear stress std	0.023165	0.035448	0.032456	0.0376	0.068585	0.336958	0.283368	
Average velocity (m/s)	0.147634	0.197756	0.254687	0.306045	0.356595	0.415808	0.470132	
Velocity std	0.009582	0.009723	0.008882	0.010021	0.009247	0.009766	0.010207	
Average tank level	11.04471	11.1058	11.17681	11.26035	11.4117	11.66297	11.82954	
Tank level std	0.015363	0.017813	0.017871	0.017446	0.017831	0.023789	0.01856	
Average Z Force (grams)	1.205025	1.171238	-0.62309	1.757424	1.830885	2.136777	5.253976	
Z Force std (grams)	0.083524	0.053325	0.035307	0.038063	0.175206	0.118561	0.153528	
Comments on the step								
Sample Description	Army core comparison - AC 1							
Test Description/purpose								
Conclusion/Comment/Decision	The sample was lost so the final unsubmerged weight could not be found for test 9							

Table 55

Date	5/22/2012		Test ID	052212-SH01-L			
Initial height	13.16	Ring	5	Min Thick		Total sub. WL	0.01
Initial volume (cubic centimeter)	38.44	Puck	2	Max Thick		Total unsub. WL	131.17
Initial un-submerged weight (gr)	131.17	Ring sub	2.45	EE1		Lost volume	131.16
Final non submerged weight (gr)		Puck sub	48.12	EE2		Estimated Density	1.00
Density method 1	1.30	Ring unsu	3.81	ΔH		Image Files	
Density method 2	1.27	Puck unsu	77.29			0522121220-0522121715	
Average density	1.29	01	SSCL:20	ZFCL:0.5			
Pump Power %	var		Start time		12:20		
Ramp up time (s)	var		End time		17:15		
Pump Power %	2	5	7				
Ramp up time (s)							
First time weight measurment	60.93	60.91					
Time (min)	120.00	160.00	180.00				
Test duration (min)	120	40	20				
Initial weight(gr)	60.91	61.02	60.93				
Final weight(gr)	61.02	60.93	60.90				
weight loss(gr)	-0.11	0.09	0.03				
Accumulative weight loss	-0.11	-0.02	0.01				
intact sample?							
Temperature (F)	78.4						
Test validity							
Erosion rate (gr/(hour.m^2)	-85	208	139				
Average shear stress (Pa)	0.34	0.68452	0.948742				
Shear stress std	0.020172	0.02978	0.042056				
Average velocity (m/s)	0.141583	0.29711	0.407757				
Velocity std	0.009322	0.009621	0.009725				
Average tank level	11.5161	11.69446	11.91616				
Tank level std	0.016393	0.015698	0.037782				
Average Z Force (grams)	-0.57093	0.09189	0.67177				
Z Force std (grams)	0.045557	0.063107	0.023744				
Comments on the step							
Sample Description	The material comes from the bottom of AC 3 sample (upside down) 051412-01-5						
Test Description/purpose							
Conclusion/Comment/Decision							

Table 56

Date	5/22/2012		Test ID	052212-SH01-U			
Initial height	15.08	Ring	2	Min Thick		Total sub. WL	0.38
Initial volume (cubic centimeter)	44.05	Puck	1	Max Thick		Total unsub. WL	143.94
Initial un-submerged weight (gr)	143.94	Ring sub	3.63	EE1		Lost volume	143.56
Final non submerged weight (gr)		Puck sub	48.28	EE2		Estimated Density	1.00
Density method 1	1.38	Ring unsu	5.7	ΔH		Image Files	
Density method 2	1.25	Puck unsu	77.37			0522121730-0522121900	
Average density	1.32		SSCL:20	ZFCL: -			
Pump Power %	var	02	Start time		17:30		
Ramp up time (s)	var		End time		19:00		
Pump Power %	5	7					
Ramp up time (s)	50	70					
First time weight measurment	63.08						
Time (min)	40.00	60.00					
Test duration (min)	40	20					
Initial weight(gr)	63.08	63.00					
Final weight(gr)	63.00	62.70					
weight loss(gr)	0.08	0.30					
Accumulative weight loss	0.08	0.38					
intact sample?	Y	N					
Temperature (F)	78.4						
Test validity							
Average shear stress (Pa)	0.629092	1.261516					
Shear stress std	0.055207	0.151243					
Average velocity (m/s)	0.295571	0.408197					
Velocity std	0.009291	0.009227					
Average tank level	11.58911	11.88505					
Tank level std	0.028747	0.036804					
Average Z Force (grams)	0.284521	1.04905					
Z Force std (grams)	0.038887	0.058174					
Comments on the step							
Erosion rate (gr/(hour.m^2)	170	1278					
Sample Description	The material comes from the bottom of AC 3 sample (upside down) 051412-01-6						
Test Description/purpose							
Conclusion/Comment/Decision							

Table 57

Date	5/23/2012		Test ID	052312-SH02-L1				
Initial height	11.63	Ring	6	Min Thick		Total sub. WL		0.32
Initial volume (cubic centimeter)	33.97	Puck	2	Max Thick		Total unsub. WL		128.85
Initial un-submerged weight (gr)	128.85	Ring sub	2.22	EE1		Lost volume		128.53
Final non submerged weight (gr)		Puck sub	48.12	EE2		Estimated Density		1.00
Density method 1	1.41	Ring unsu	3.53	ΔH		Image Files		
Density method 2	1.31	Puck unsu	77.29			05231209300-0523121945		
Average density	1.36	03	SSCL:20	ZFCL: -				
Pump Power %	var		Start time		9:30			
Ramp up time (s)	var		End time		14:00			
Pump Power %	2	3	5					
Ramp up time (s)	20	30	50					
First time weight measurment	60.91	60.92	60.92					
Time (min)	120.00	135.00	150.00					
Test duration (min)	120	15	15					
Initial weight(gr)	60.92	60.83	60.65					
Final weight(gr)	60.83	60.65	60.60					
weight loss(gr)	0.09	0.18	0.05					
Accumulative weight loss	0.09	0.27	0.32					
intact sample?	Y	N	N					
Temperature (F)	79.7							
Test validity								
Erosion rate (gr/(hour.m^2)	58	926	257					
Average shear stress (Pa)	0.636721	1.799876	4.185394					
Shear stress std	0.034323	0.030365	0.040447					
Average velocity (m/s)	0.140906	0.190981	0.294239					
Velocity std	0.009671	0.009271	0.0091					
Average tank level	11.13508	11.20641	11.40115					
Tank level std	0.016728	0.020776	0.020274					
Average Z Force (grams)	1.261818	1.104241	2.094094					
Z Force std (grams)	0.197153	0.039321	0.03484					
Comments on the step								
Sample Description	The material comes from the bottom of AC 1 sample (upside down) 050912-01-5							
Test Description/purpose								
Conclusion/Comment/Decision								

Table 58

Date	5/23/2012		Test ID	052312-SH02-L2				
Initial height	12.22	Ring	1	Min Thick		Total sub. WL		61.63
Initial volume (cubic centimeter)	35.69	Puck	1	Max Thick		Total unsub. WL		-0.47
Initial un-submerged weight (gr)	127.44	Ring sub	2.53	EE1		Lost volume		-62.10
Final non submerged weight (gr)	127.91	Puck sub	48.28	EE2		Estimated Density		0.01
Density method 1	1.29	Ring unsu	4.02	ΔH		Image Files		
Density method 2	1.30	Puck unsu	77.37			05231209300-0523121945		
Average density	1.30	04	SSCL:20	ZFCL: -				
Pump Power %	var		Start time		14:00			
Ramp up time (s)	var		End time		18:00			
Pump Power %	3							
Ramp up time (s)	30							
First time weight measurment	61.67	61.63	61.63					
Time (min)	120.00	135.00	150.00					
Test duration (min)	120	15	15					
Initial weight(gr)	61.63	61	61					
Final weight(gr)	61.23	61.14	61.03					
weight loss(gr)	0.40	0.09	0.11					
Accumulative weight loss	0.40	0.49	0.60					
intact sample?	Y	N	N					
Temperature (F)	79.7							
Test validity								
Erosion rate (gr/(hour.m^2)	299	539	658					
Average shear stress (Pa)	2.095492	1.270789	2.021766					
Shear stress std	0.032578	0.022697	0.028303					
Average velocity (m/s)	0.191469	0.194995	0.296333					
Velocity std	0.009175	0.009602	0.009849					
Average tank level	11.15994	11.17503	11.36971					
Tank level std	0.01598	0.019978	0.021617					
Average Z Force (grams)	0.730633	0.589332	1.721341					
Z Force std (grams)	0.038012	0.043547	0.034843					
Comments on the step								
Sample Description	The material comes from the bottom of AC 1 sample (upside down) 050912-01-6							
Test Description/purpose								
Conclusion/Comment/Decision								

Table 59

Date	5/23/2012		Test ID	052312-SH02-U				
Initial height	11.46	Ring	3	Min Thick		Total sub. WL		61.15
Initial volume (cubic centimeter)	33.47	Puck	2	Max Thick		Total unsub. WL		0.13
Initial un-submerged weight (gr)	127.29	Ring sub	2.4	EE1		Lost volume		-61.02
Final non submerged weight (gr)	127.16	Puck sub	48.12	EE2		Estimated Density		0.00
Density method 1	1.38	Ring unsu	3.83	ΔH		Image Files		
Density method 2	1.32	Puck unsu	77.29			05231209300-0523121945		
Average density	1.35	05	SSCL:20	ZFCL: -				
Pump Power %	var		Start time		18:55			
Ramp up time (s)	var		End time		19:45			
Pump Power %	3	4						
Ramp up time (s)	30	40						
First time weight measurment	61.15							
Time (min)	15.00	30.00						
Test duration (min)	15	15						
Initial weight(gr)	61.15	61						
Final weight(gr)	61.10	60.75						
weight loss(gr)	0.05	0.25						
Accumulative weight loss	0.05	0.30						
intact sample?	Y	N						
Temperature (F)	79.7							
Test validity								
Erosion rate (gr/(hour.m^2)	265	1325						
Average shear stress (Pa)	1.186714	1.18232						
Shear stress std	0.037543	0.024473						
Average velocity (m/s)	0.18857	0.293393						
Velocity std	0.009024	0.009237						
Average tank level	11.13272	11.25286						
Tank level std	0.017548	0.023181						
Average Z Force (grams)	0.708666	1.323004						
Z Force std (grams)	0.046047	0.078521						
Comments on the step								
Sample Description	The material comes from the bottom of AC 1 sample (upside down) 050912-01-7							
Test Description/purpose	e sample was submerged for 3 hours before the test to be compared with the 04 and							
Conclusion/Comment/Decision								

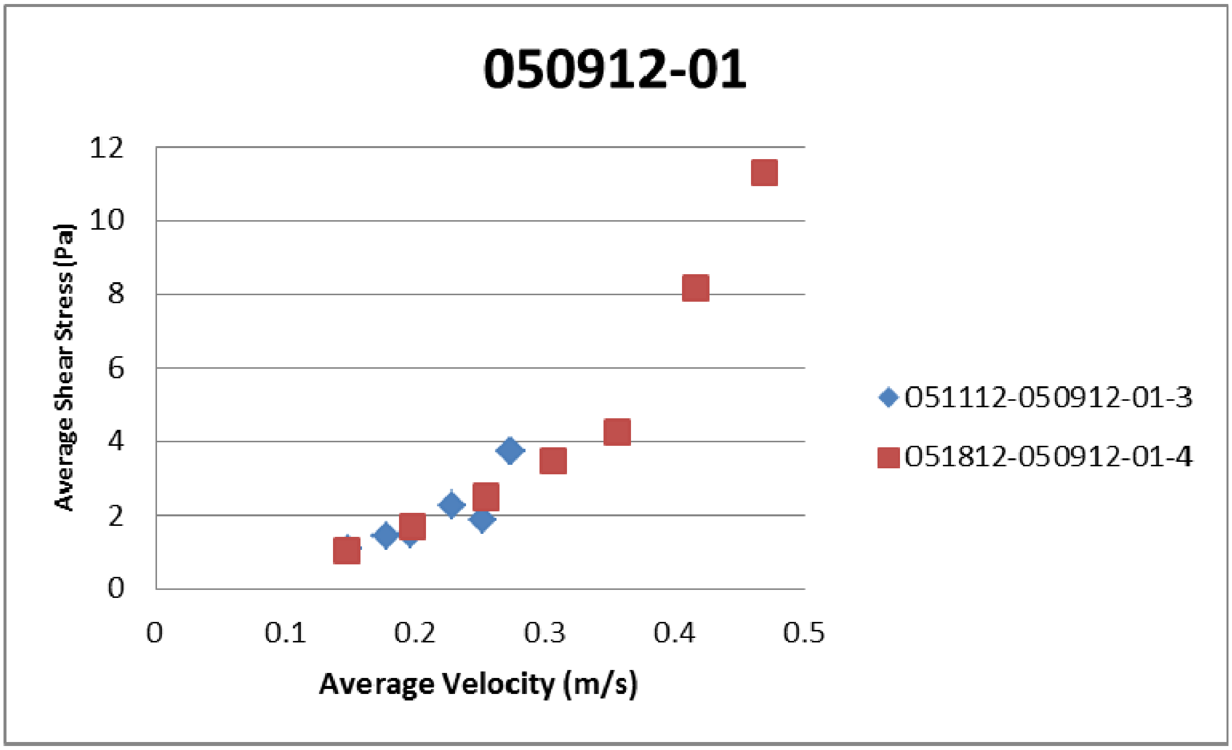


Figure 81

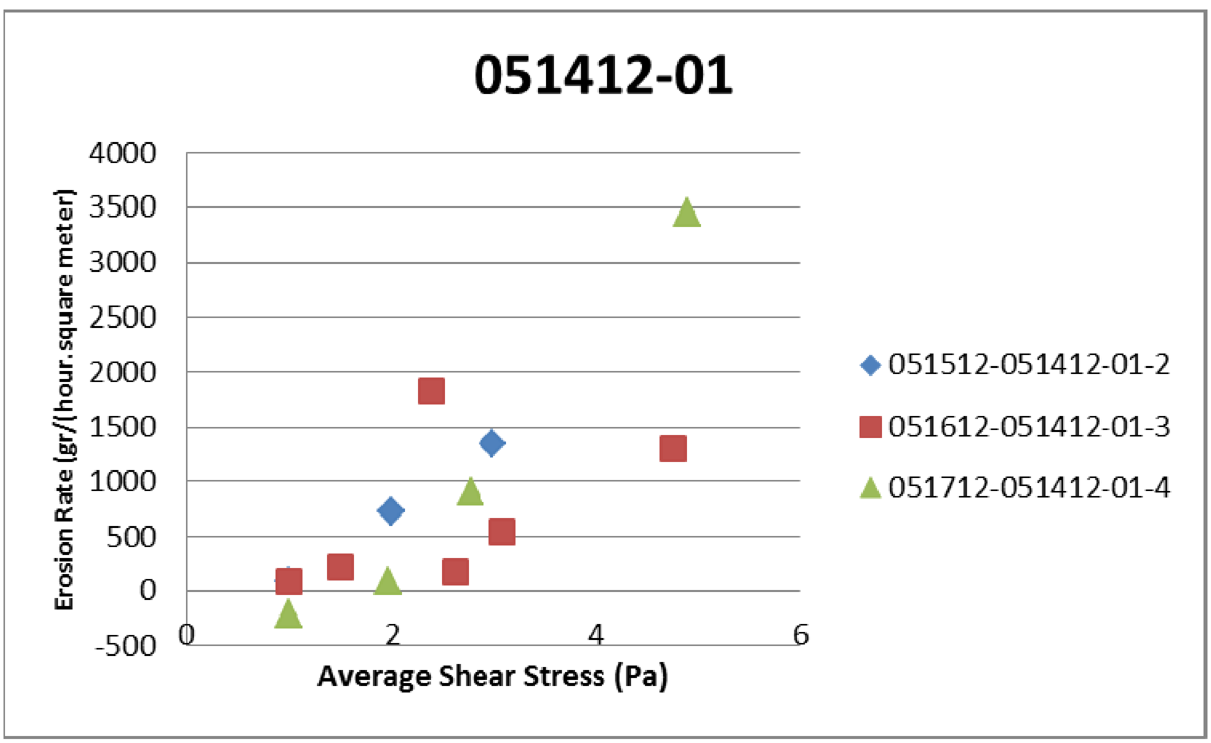


Figure 82

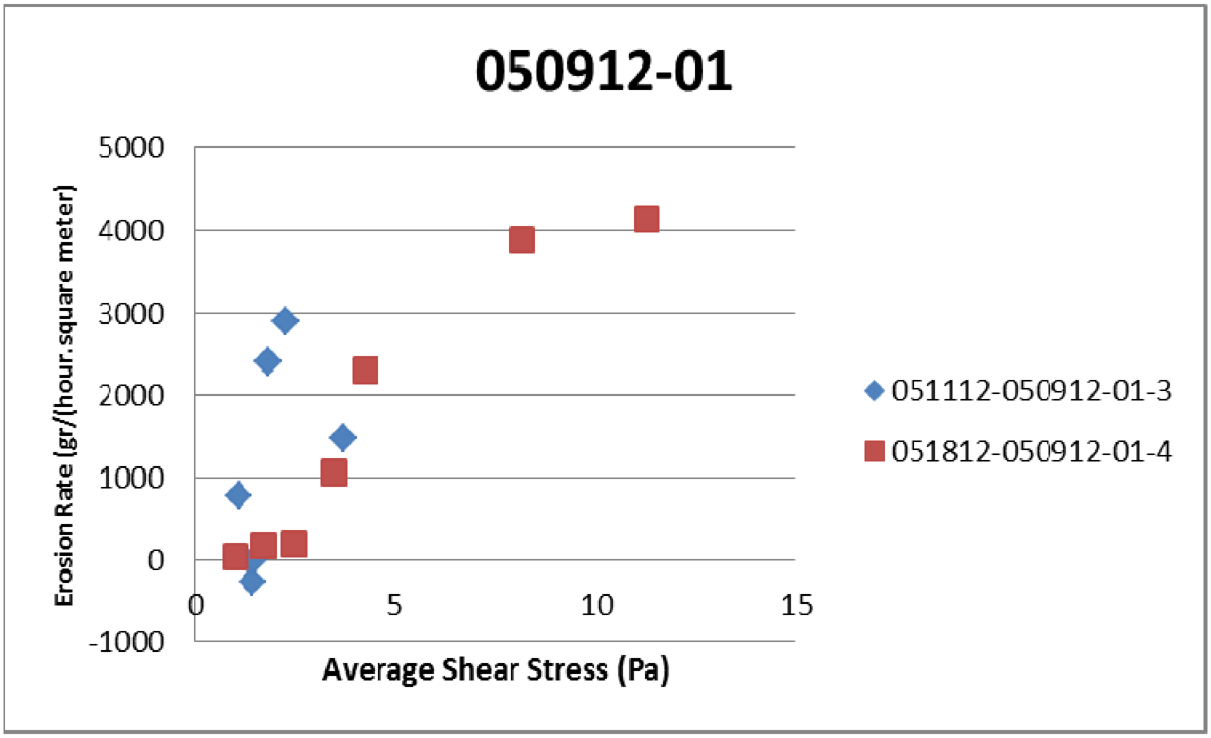


Figure 83

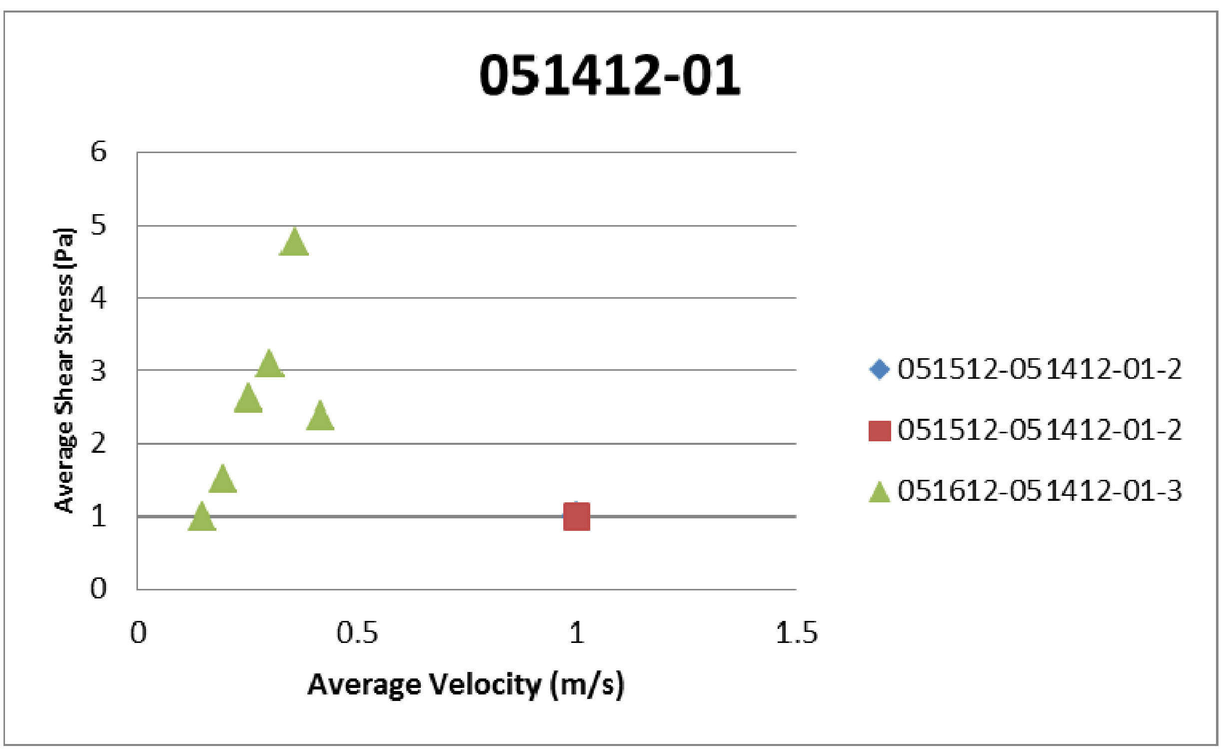


Figure 84

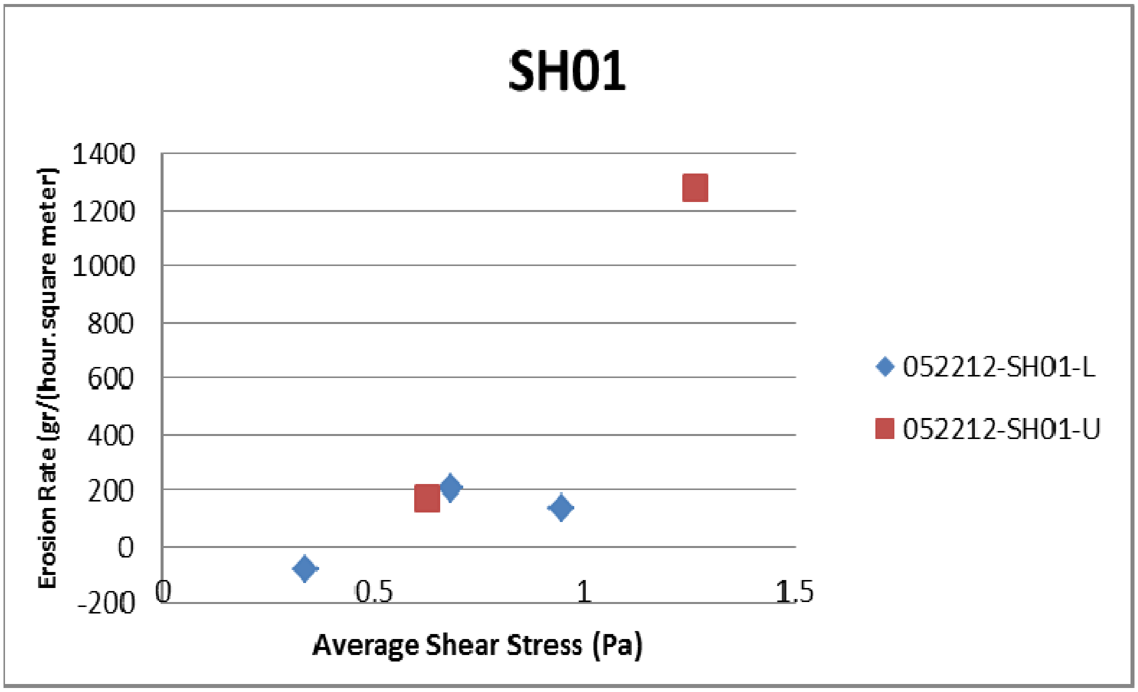


Figure 85

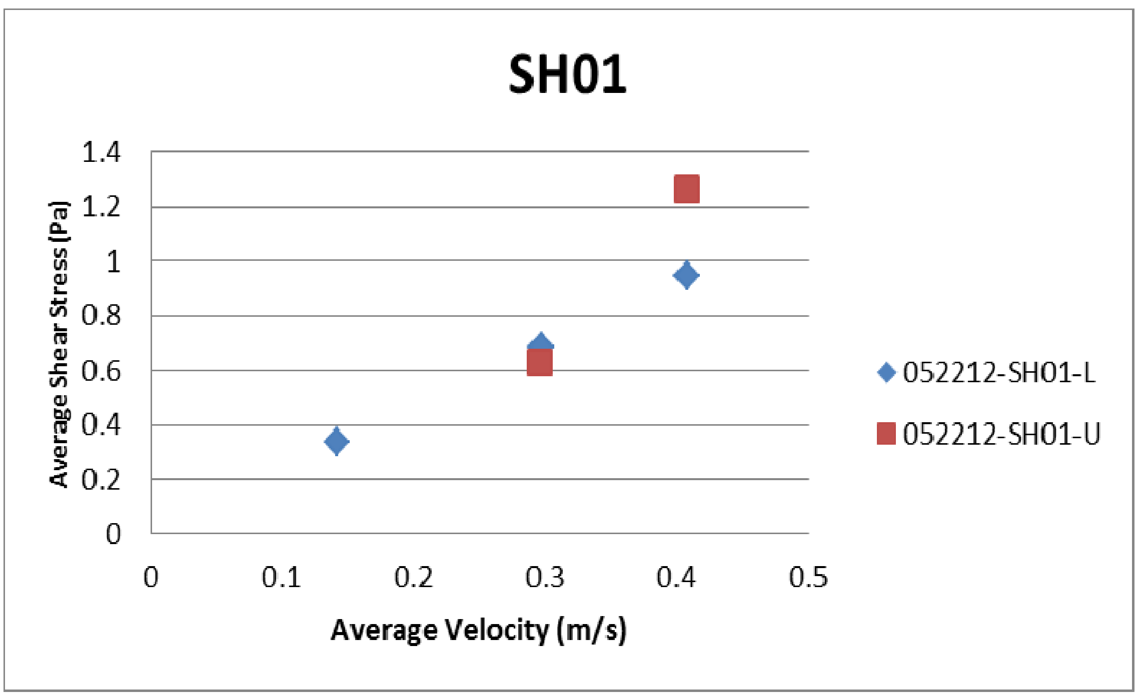
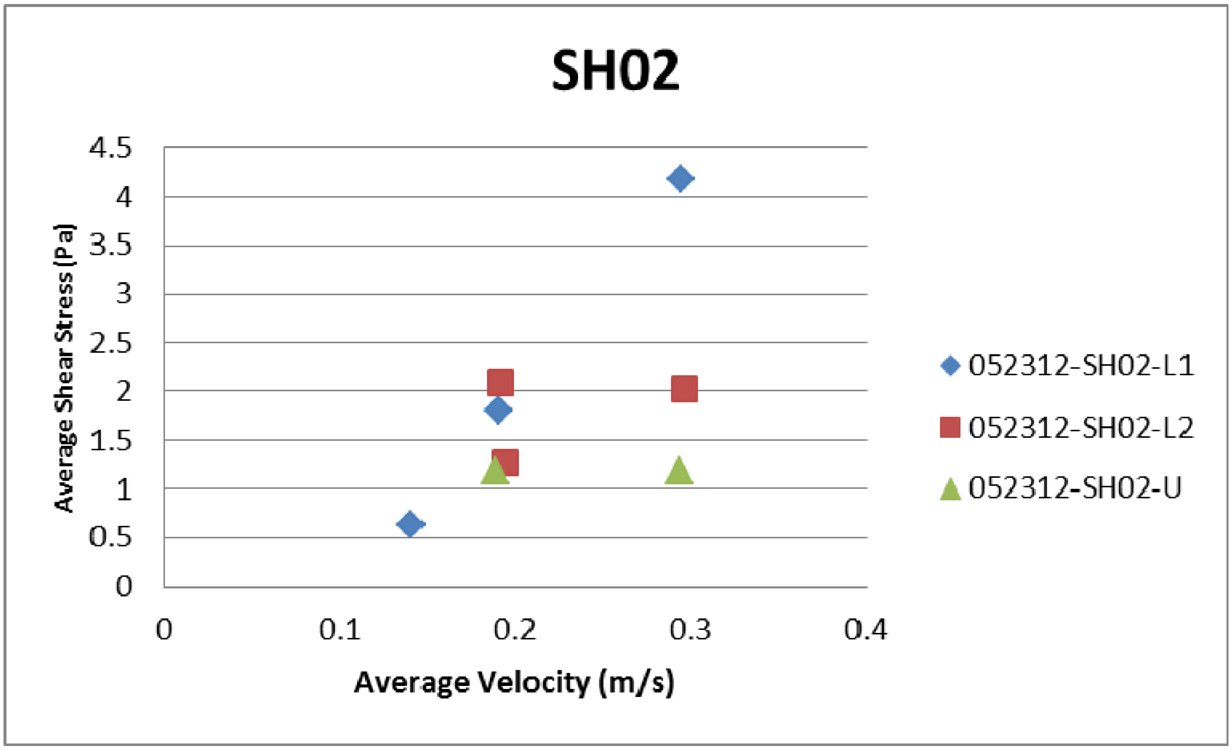
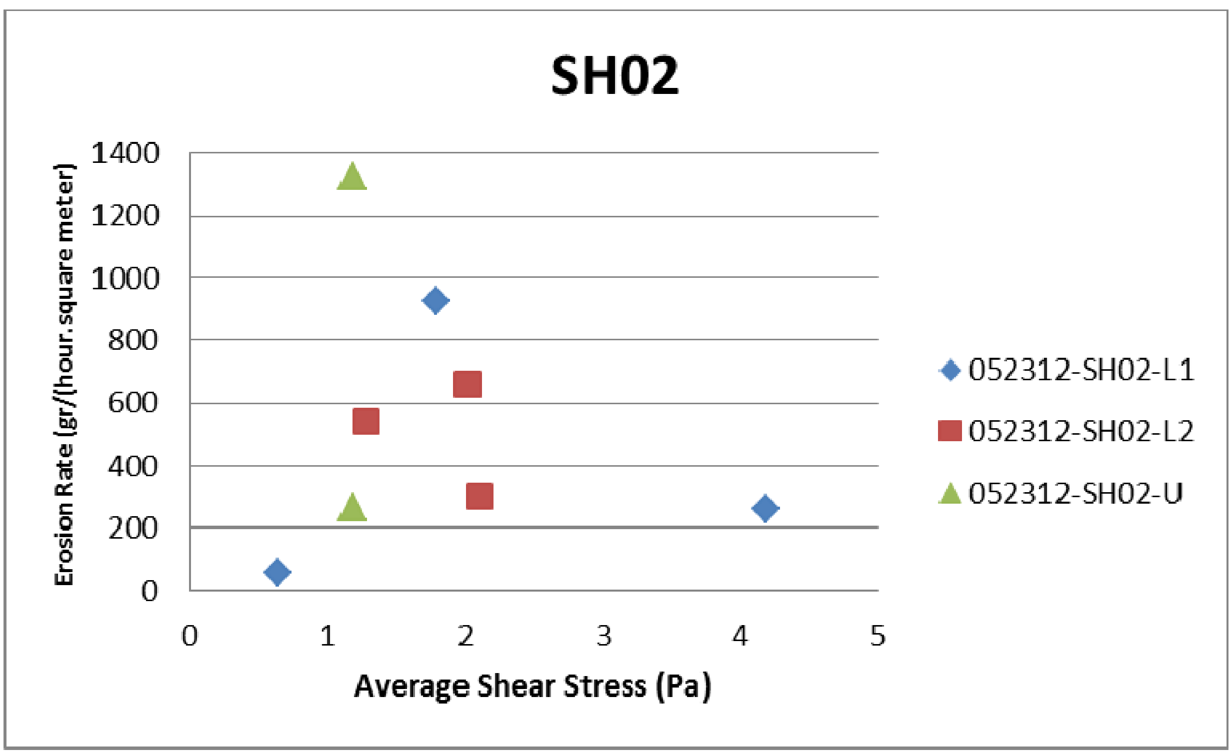


Figure 86



SH02
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.1
0.2
0.3
0.4
Average Shear Stress (Pa)
Average Velocity (m/s)
052312-SH02-L1
052312-SH02-L2
052312-SH02-U

Figure 87



SH02
1400
1200
1000
800
600
400
200
0
0
1
2
3
4
5
Erosion Rate (gr/(hour.square meter)
Average Shear Stress (Pa)
052312-SH02-L1
052312-SH02-L2
052312-SH02-U

Test plots

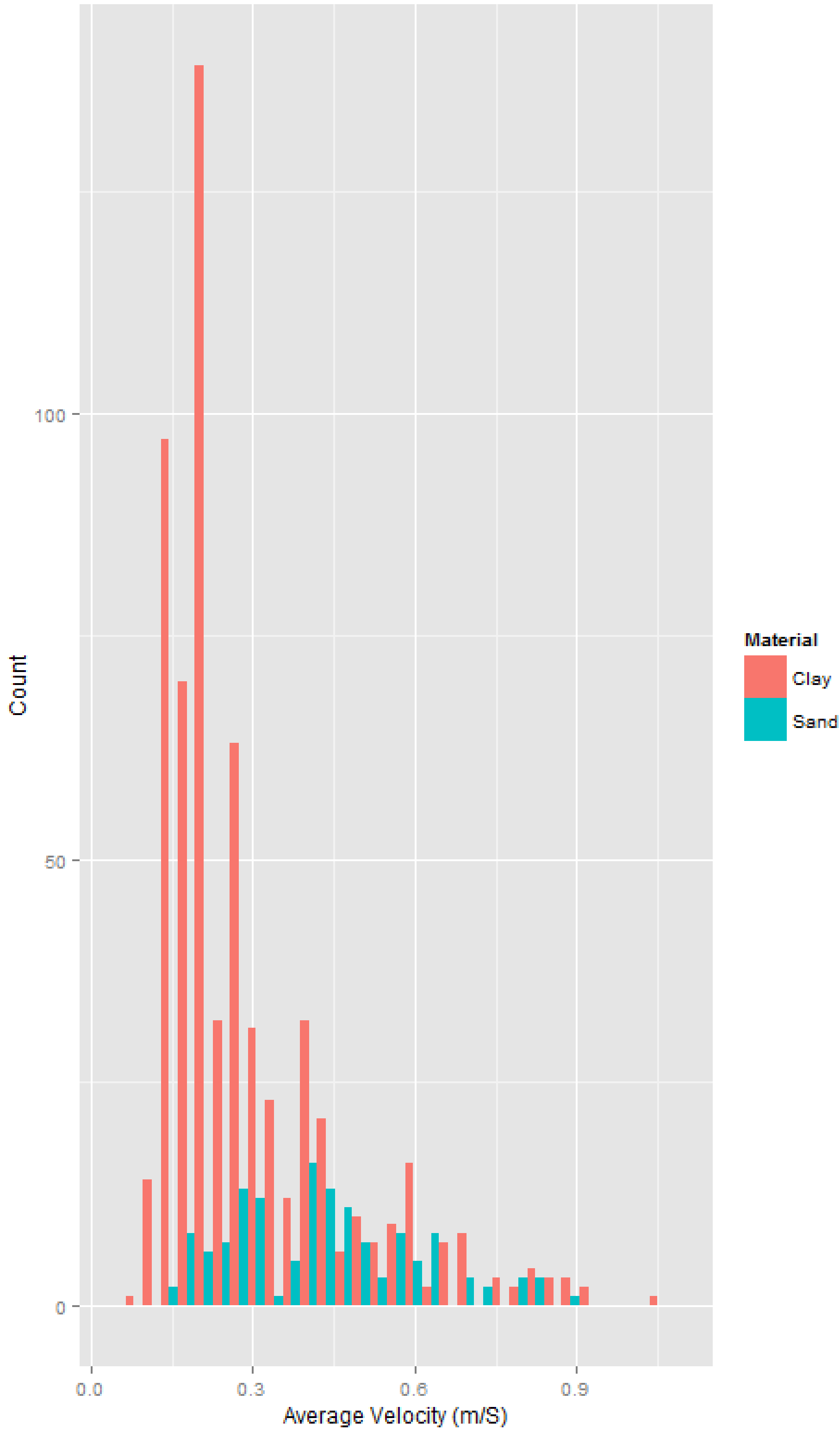

Count
100
50
0
0.0
0.3
0.6
0.9
Average Velocity (m/S)
Material
Clay
Sand

Figure 88

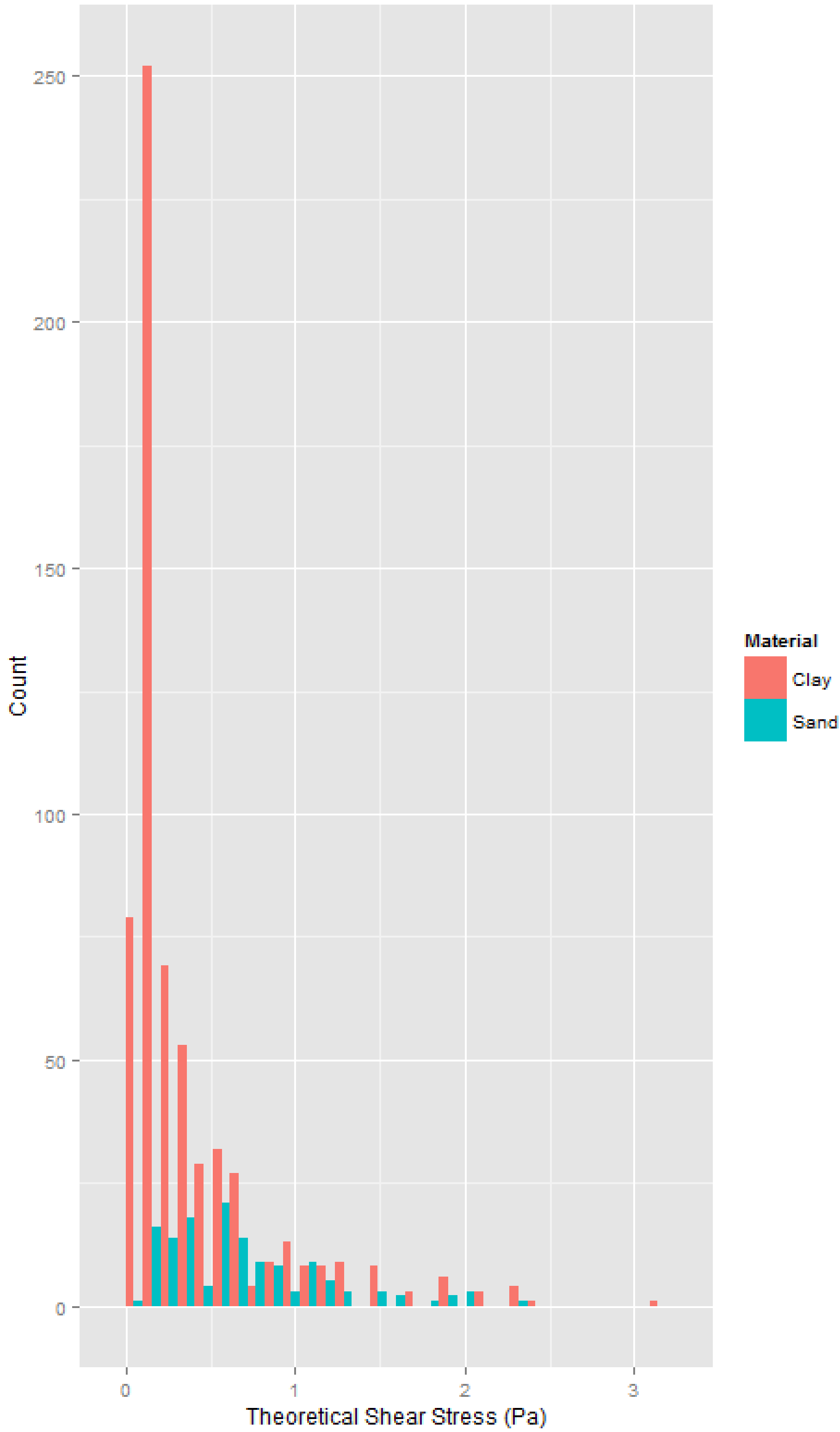

250
200
150
100
50
0
Count
0
1
2
3
Theoretical Shear Stress (Pa)
Material
Clay
Sand

Figure 89

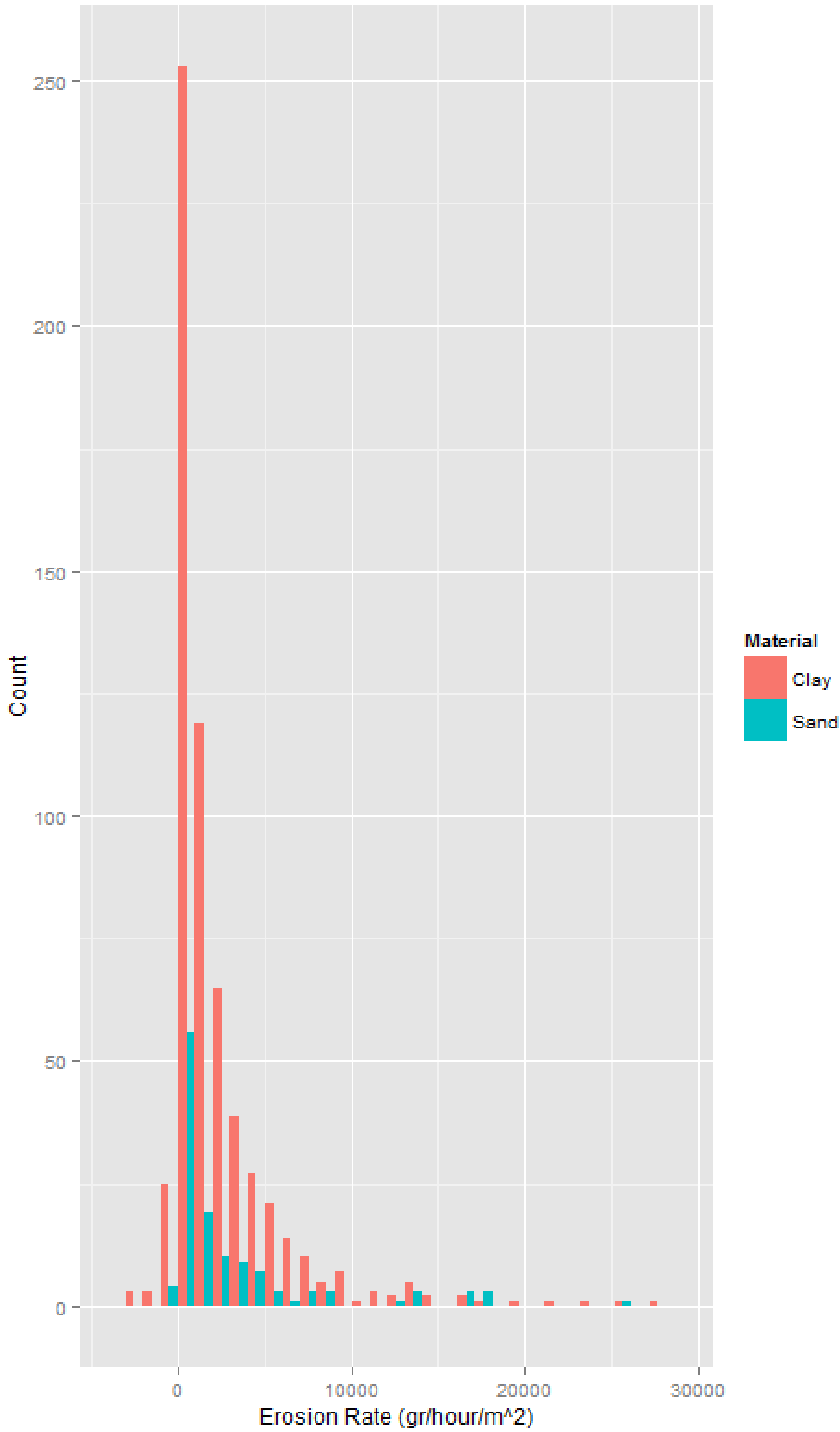
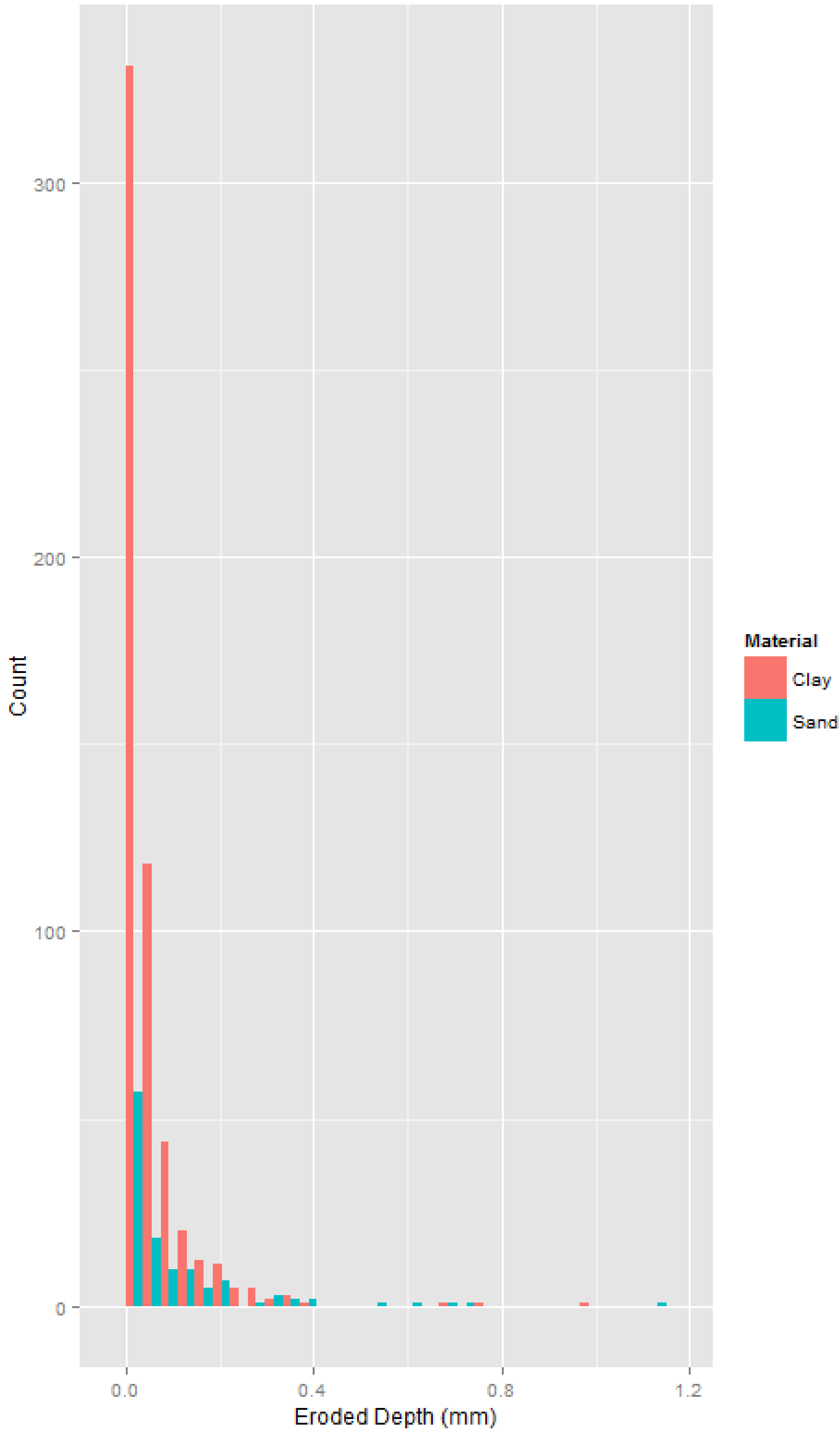

250
200
150
100
50
0
Count
0
10000
20000
30000
Erosion Rate (gr/hour/m^2)
Material
Clay
Sand

Figure 90



Count
300
200
100
0
0.0
0.4
0.8
1.2
Eroded Depth (mm)
Material
Clay
Sand

Figure 91

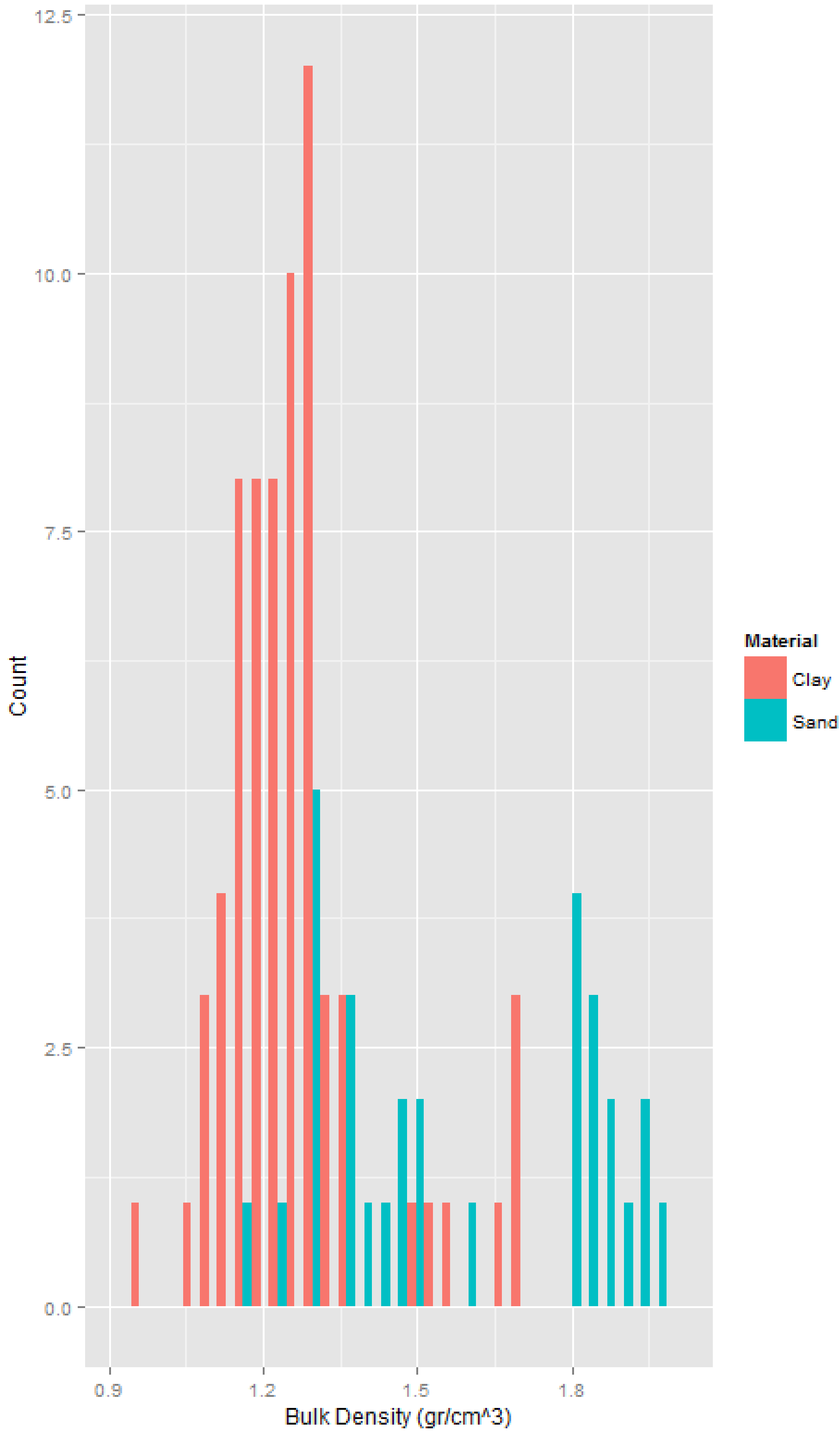

12.5
10.0
7.5
5.0
2.5
0.0
Count
0.9
1.2
1.5
1.8
Bulk Density (gr/cm^3)
Material
Clay
Sand

Figure 92

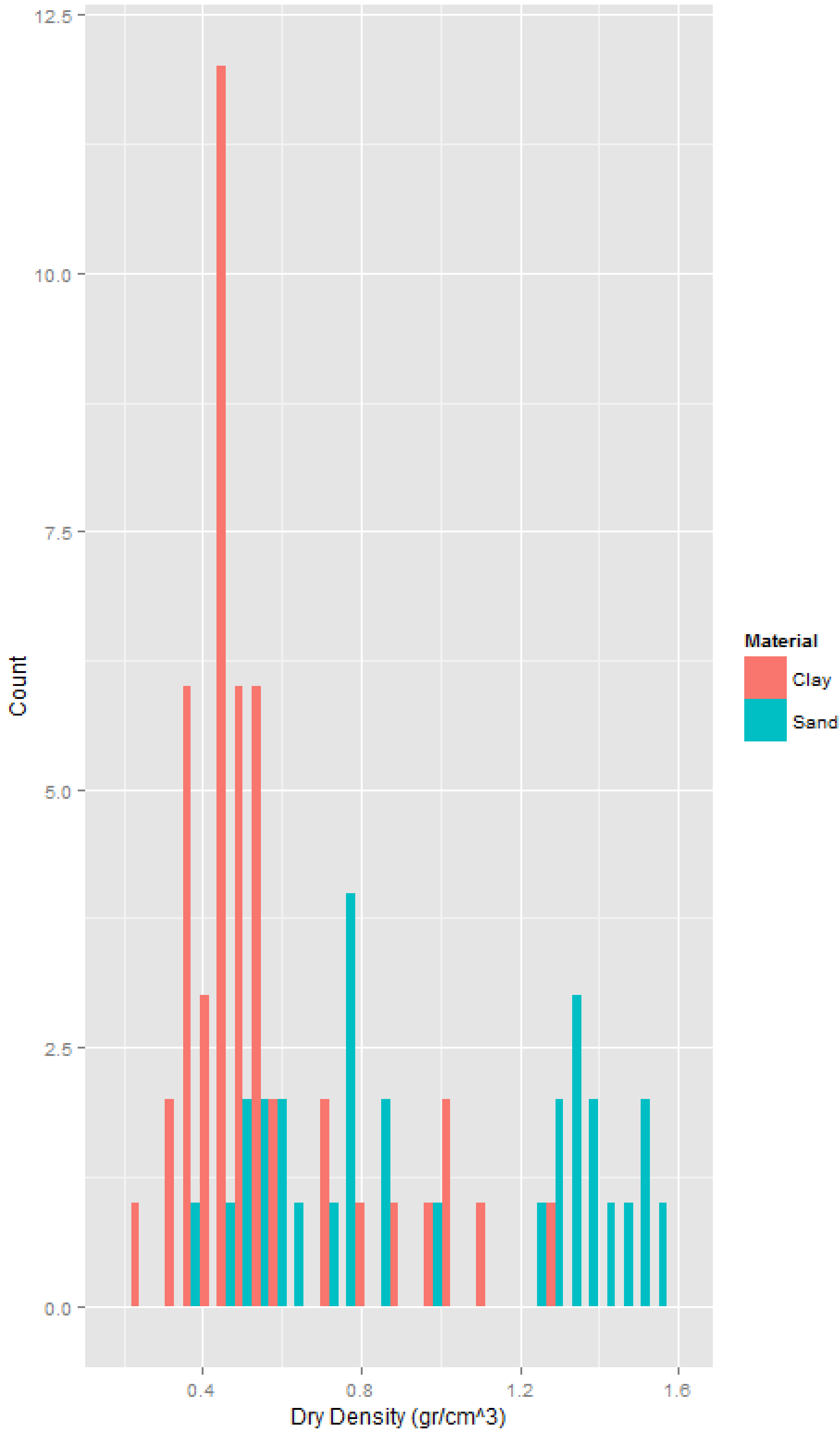

12.5
10.0
7.5
5.0
2.5
0.0
Count
0.4
0.8
1.2
1.6
Dry Density (gr/cm^3)
Material
Clay
Sand

Figure 93

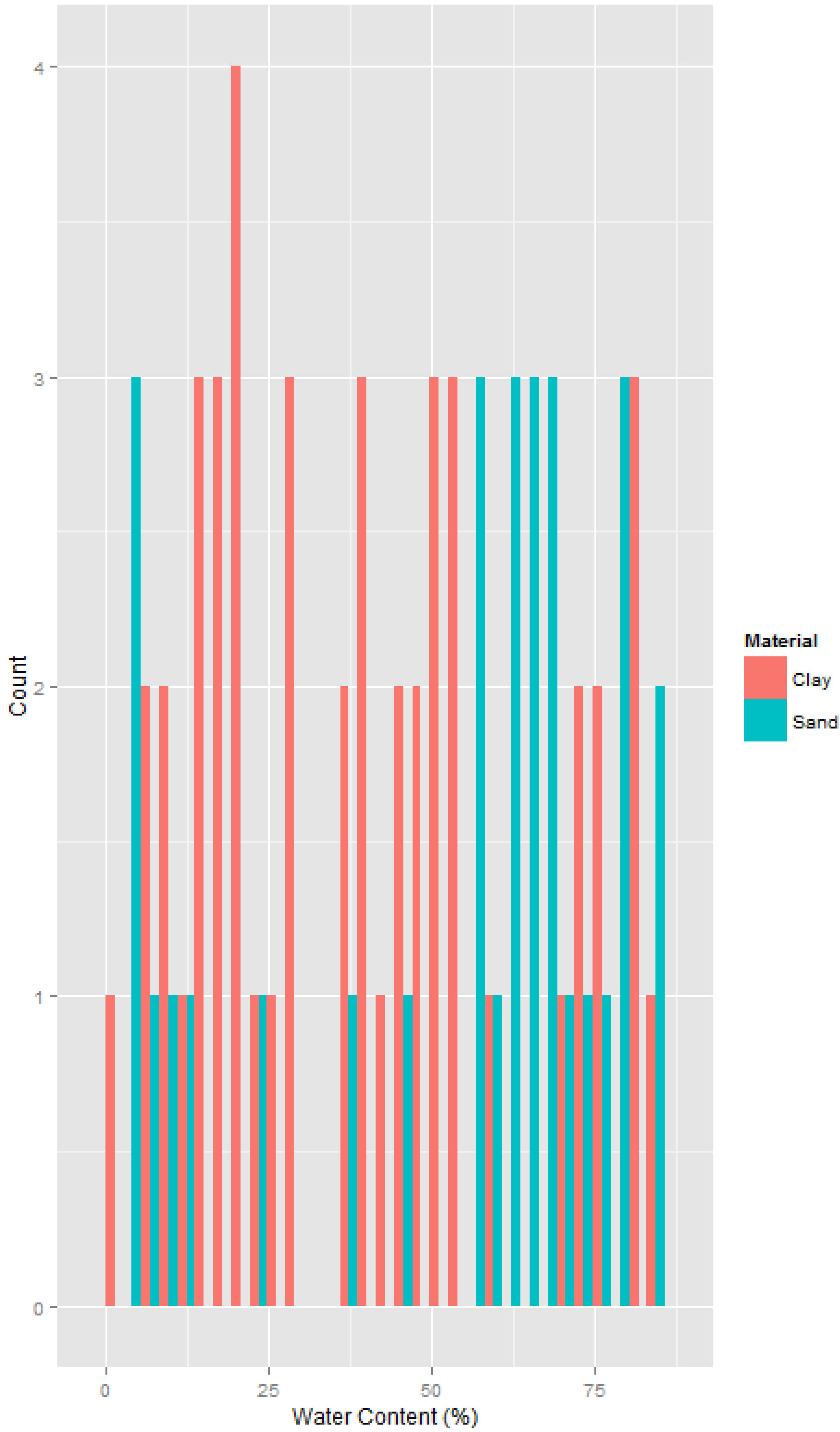
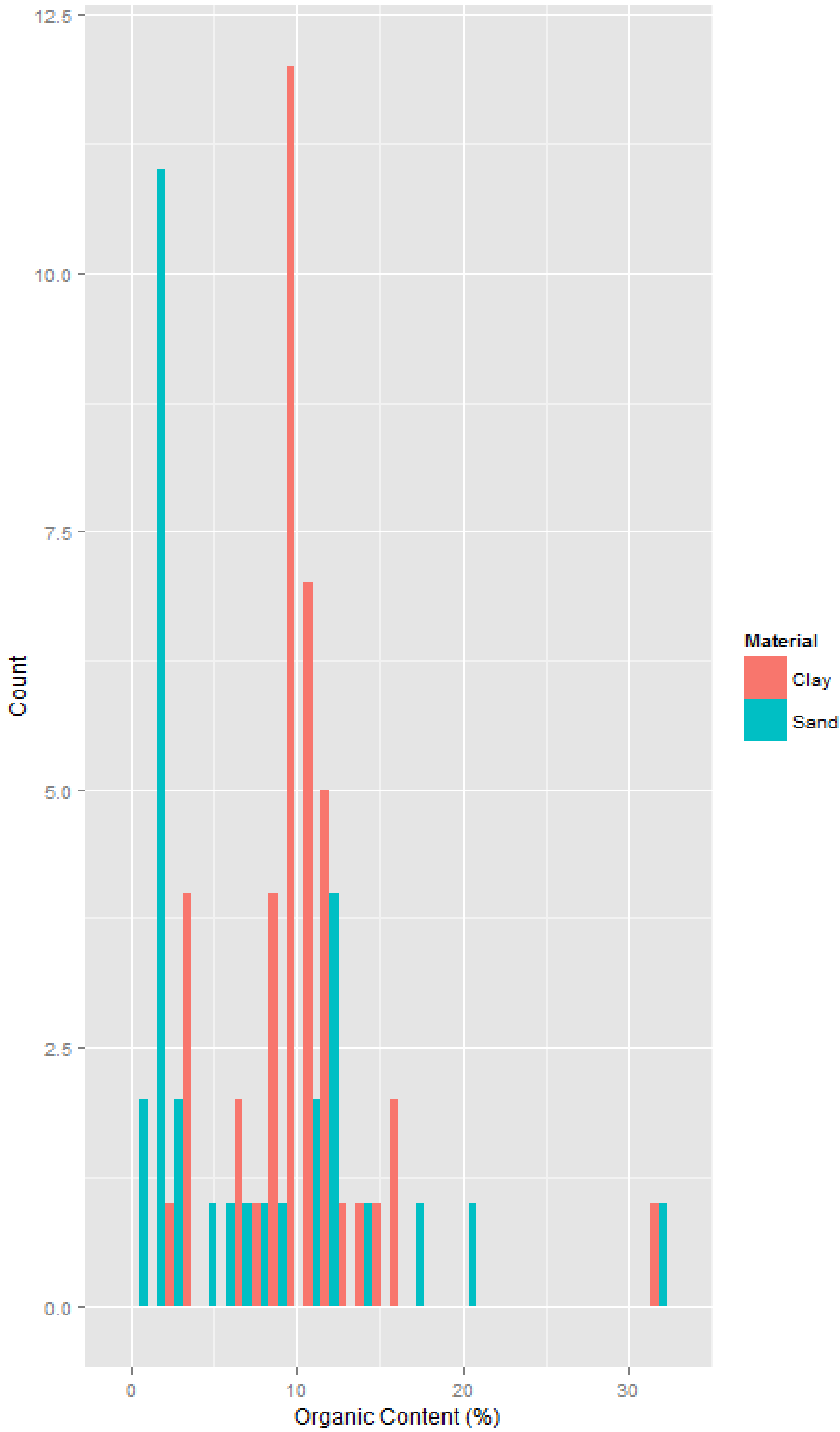


Figure 94



12.5
10.0
7.5
5.0
2.5
0.0
Count
0
10
20
30
Organic Content (%)
Material
Clay
Sand

Figure 95

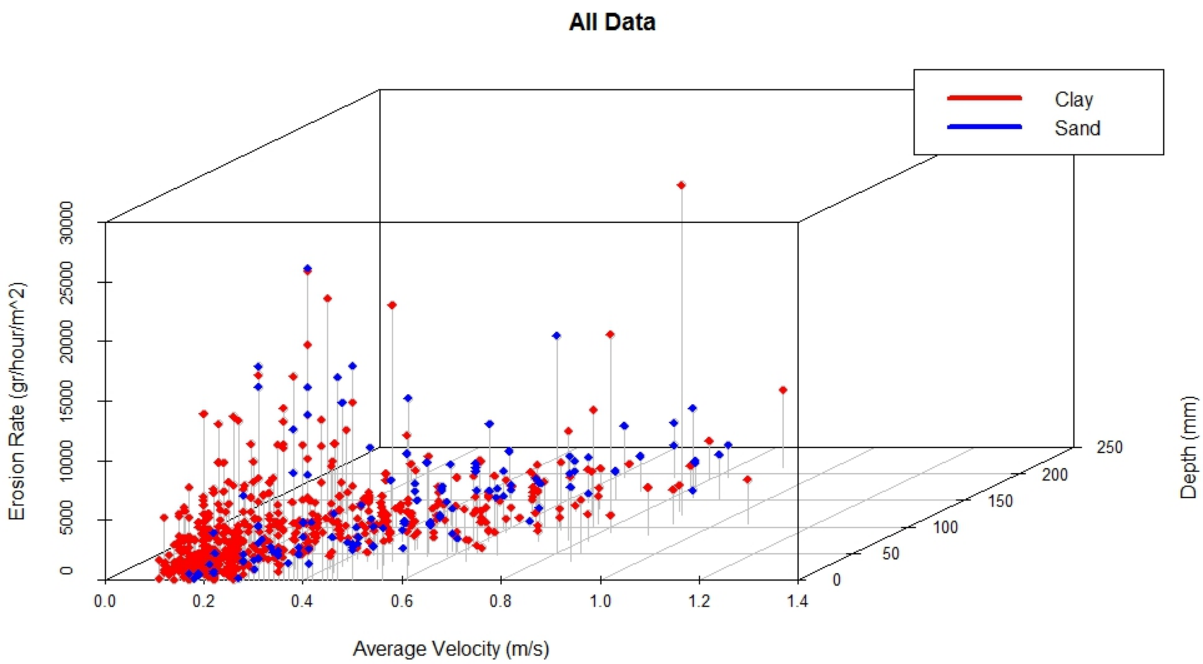


Figure 96

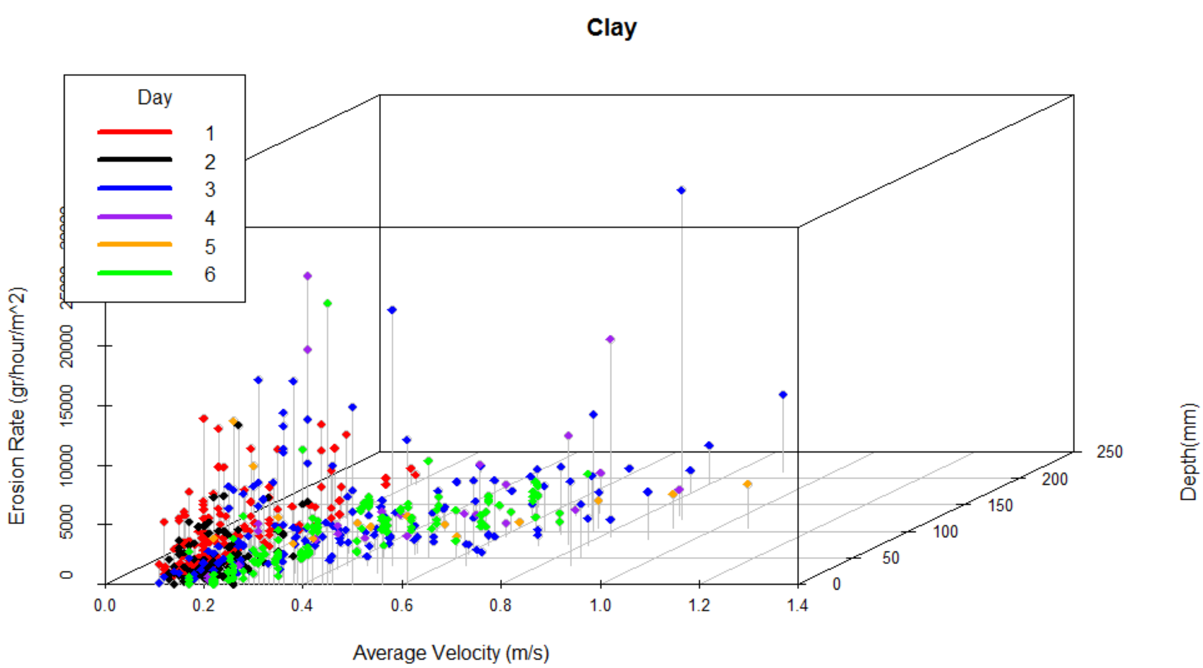


Figure 97

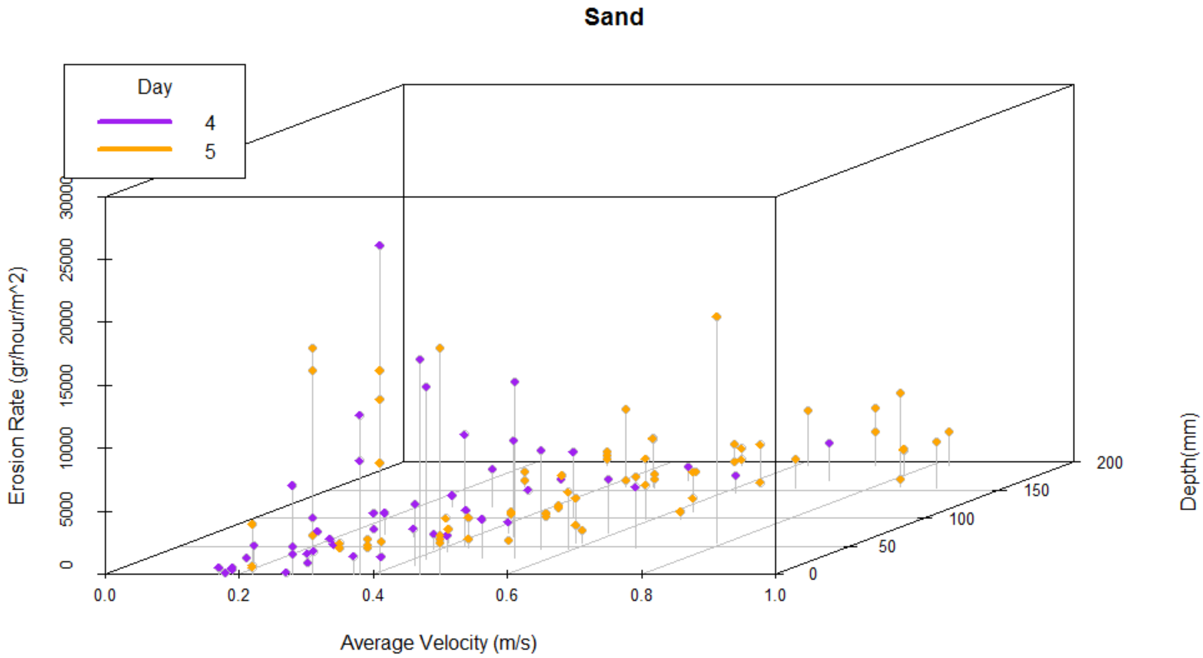


Figure 98

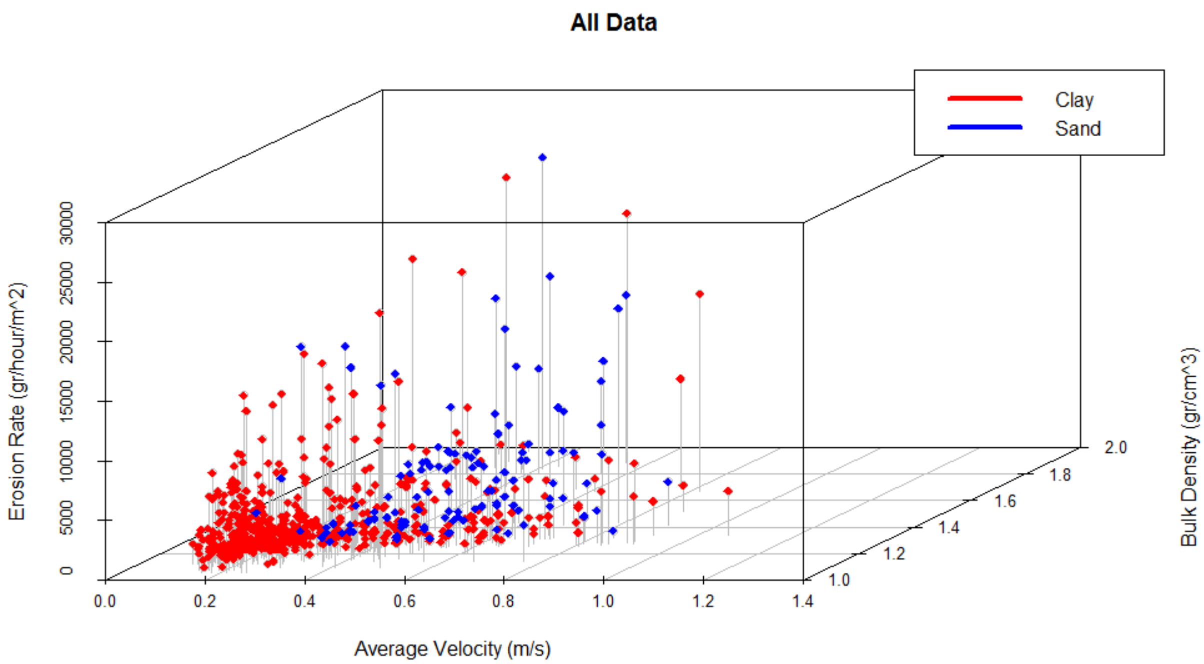


Figure 99

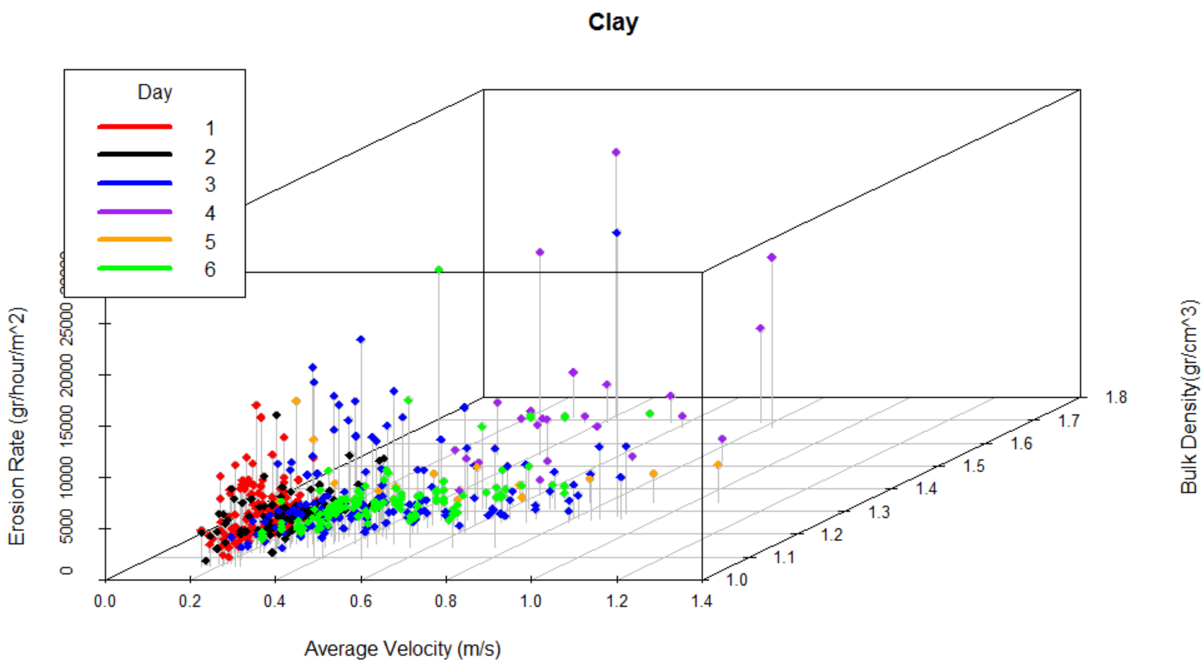


Figure 100

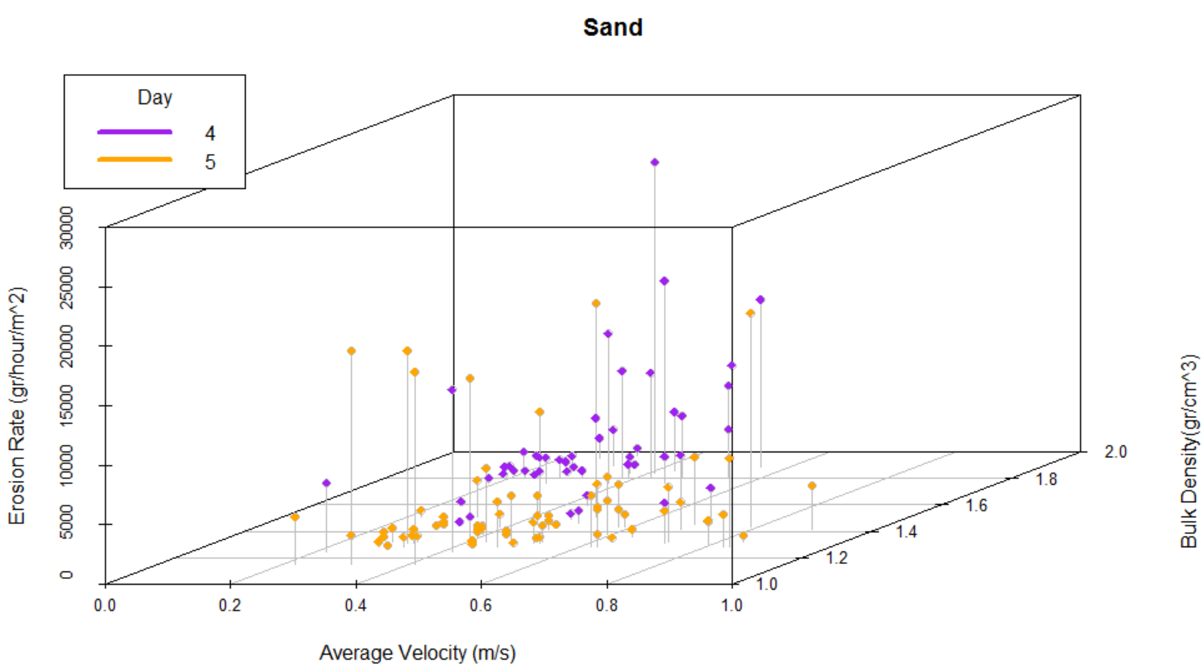


Figure 101

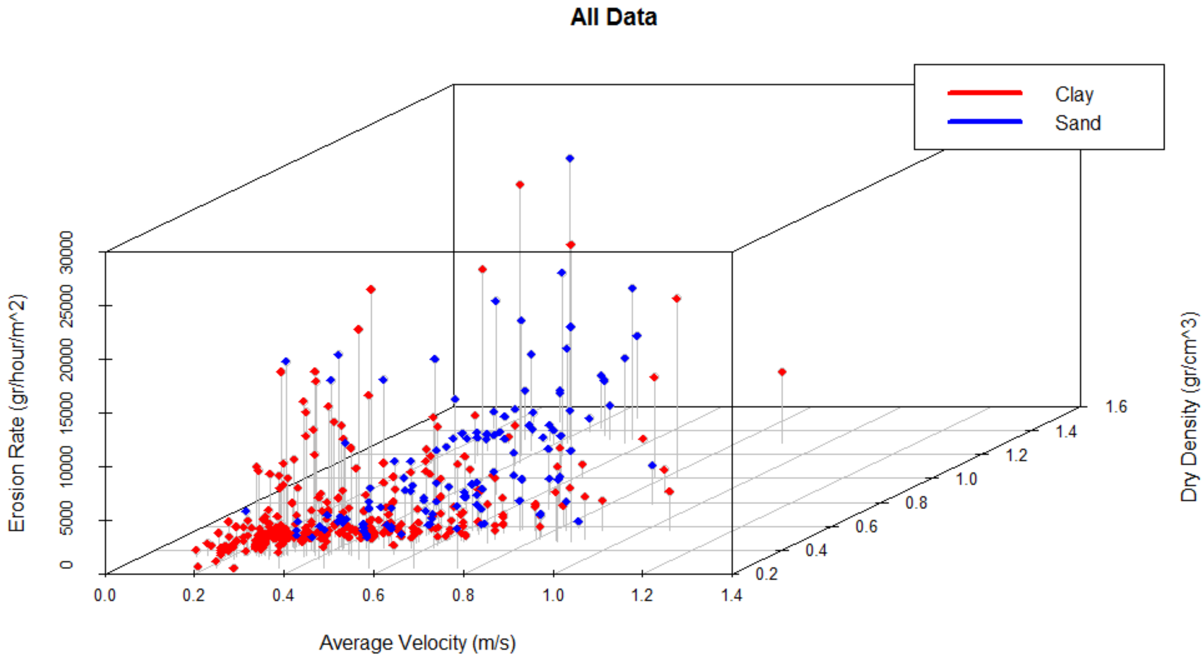


Figure 102

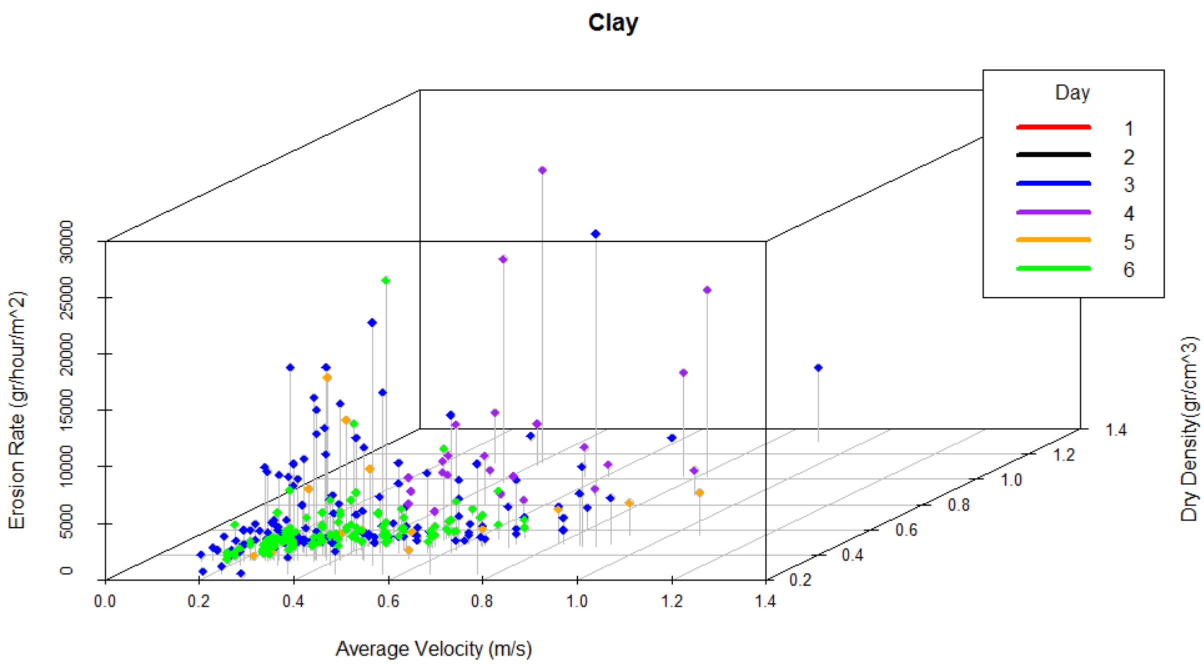


Figure 103

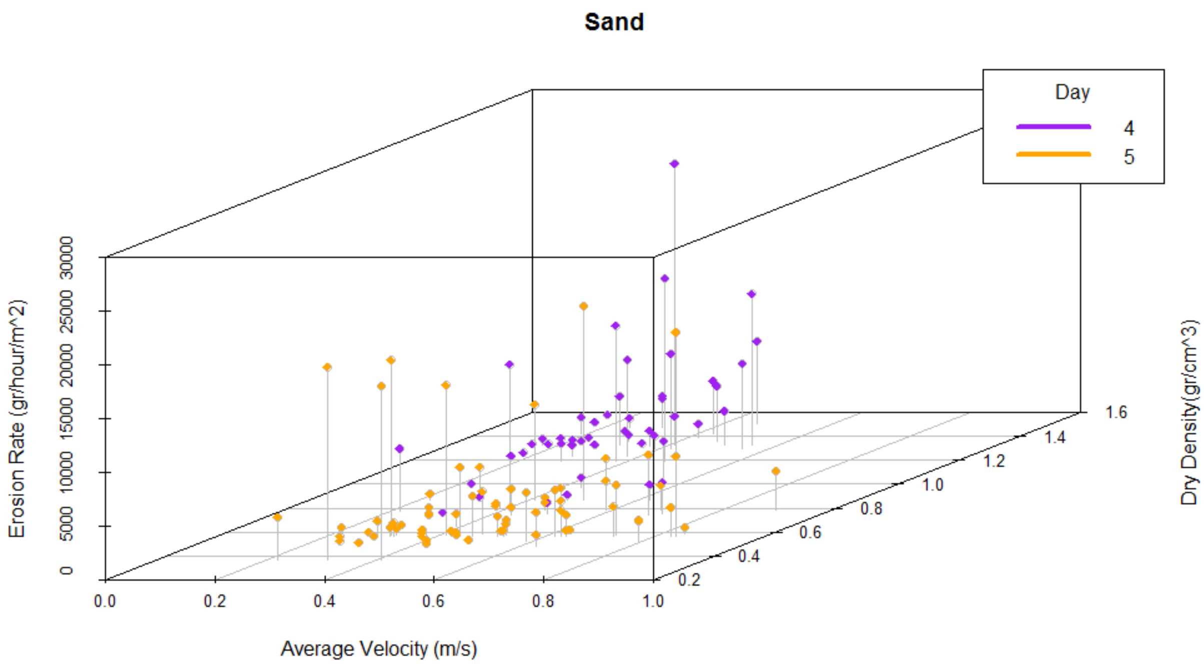

Sand
Day
4
5
Erosion Rate (gr/hour/m^2)
0
5000
10000
15000
20000
25000
30000
0.0
0.2
0.4
0.6
0.8
1.0
Average Velocity (m/s)
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
Dry Density(gr/cm^3)

Figure 104

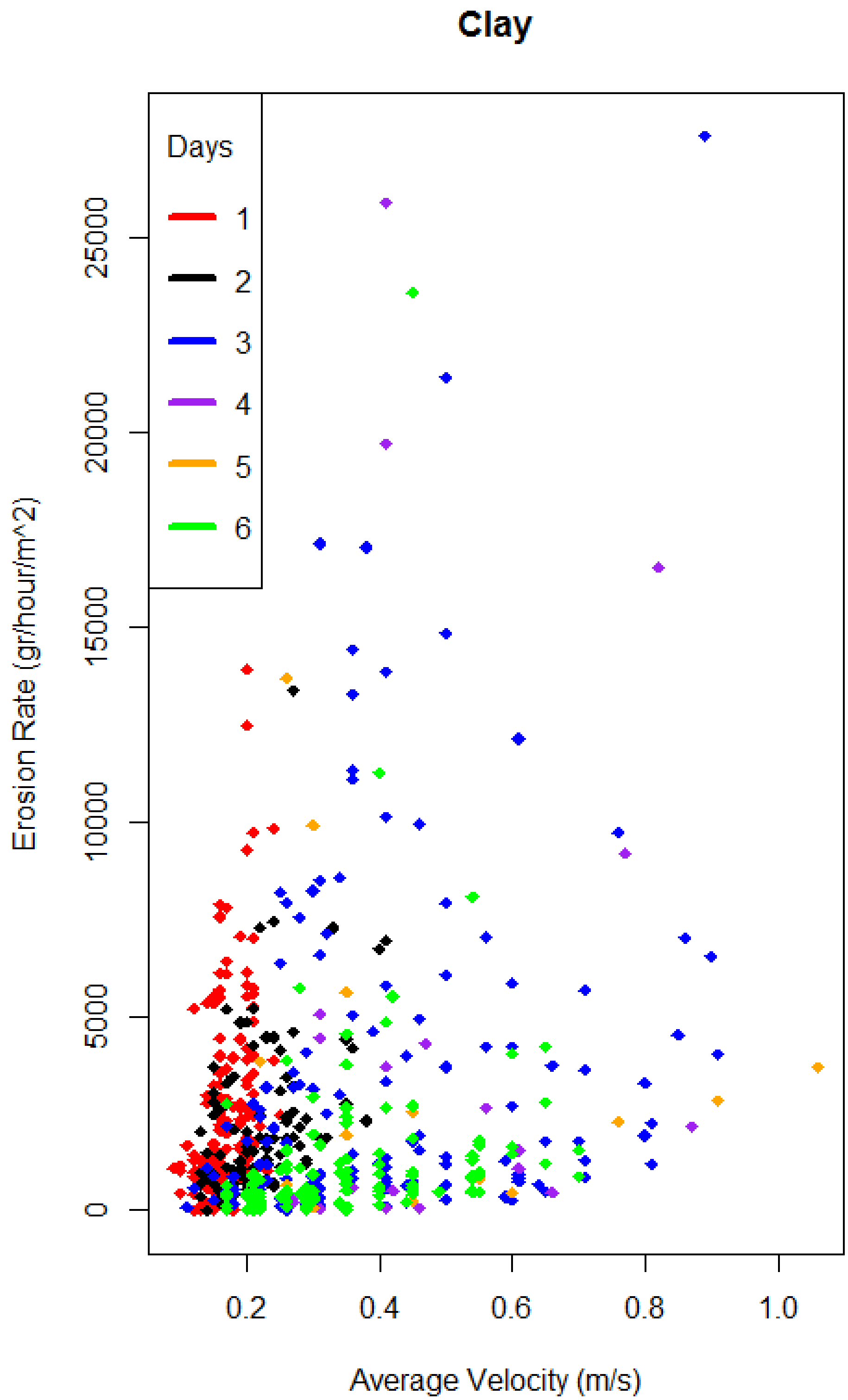

Clay
Days
1
2
3
4
5
6
Erosion Rate (gr/hour/m^2)
0
5000
10000
15000
20000
25000
0.2
0.4
0.6
0.8
1.0
Average Velocity (m/s)

Figure 105

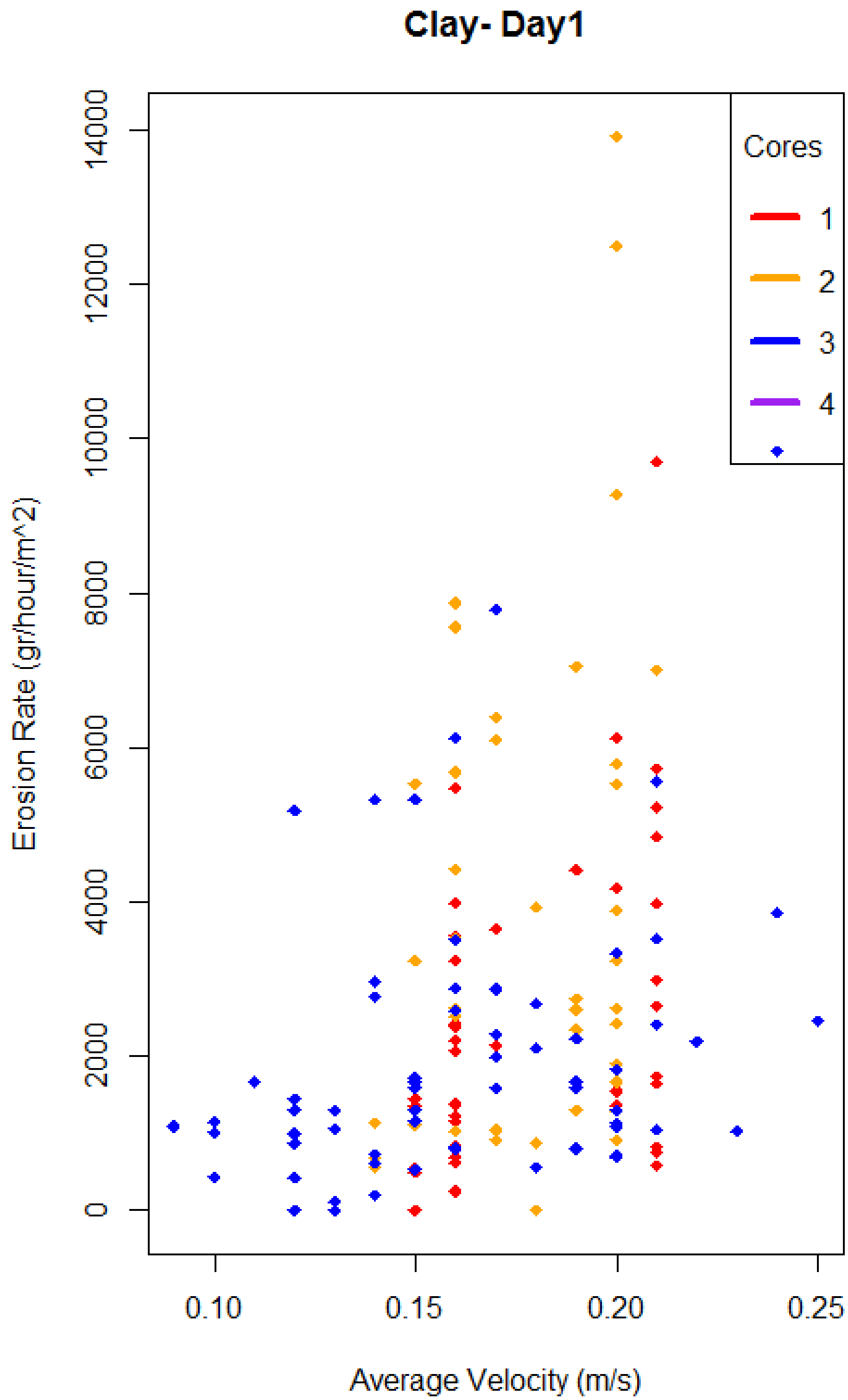
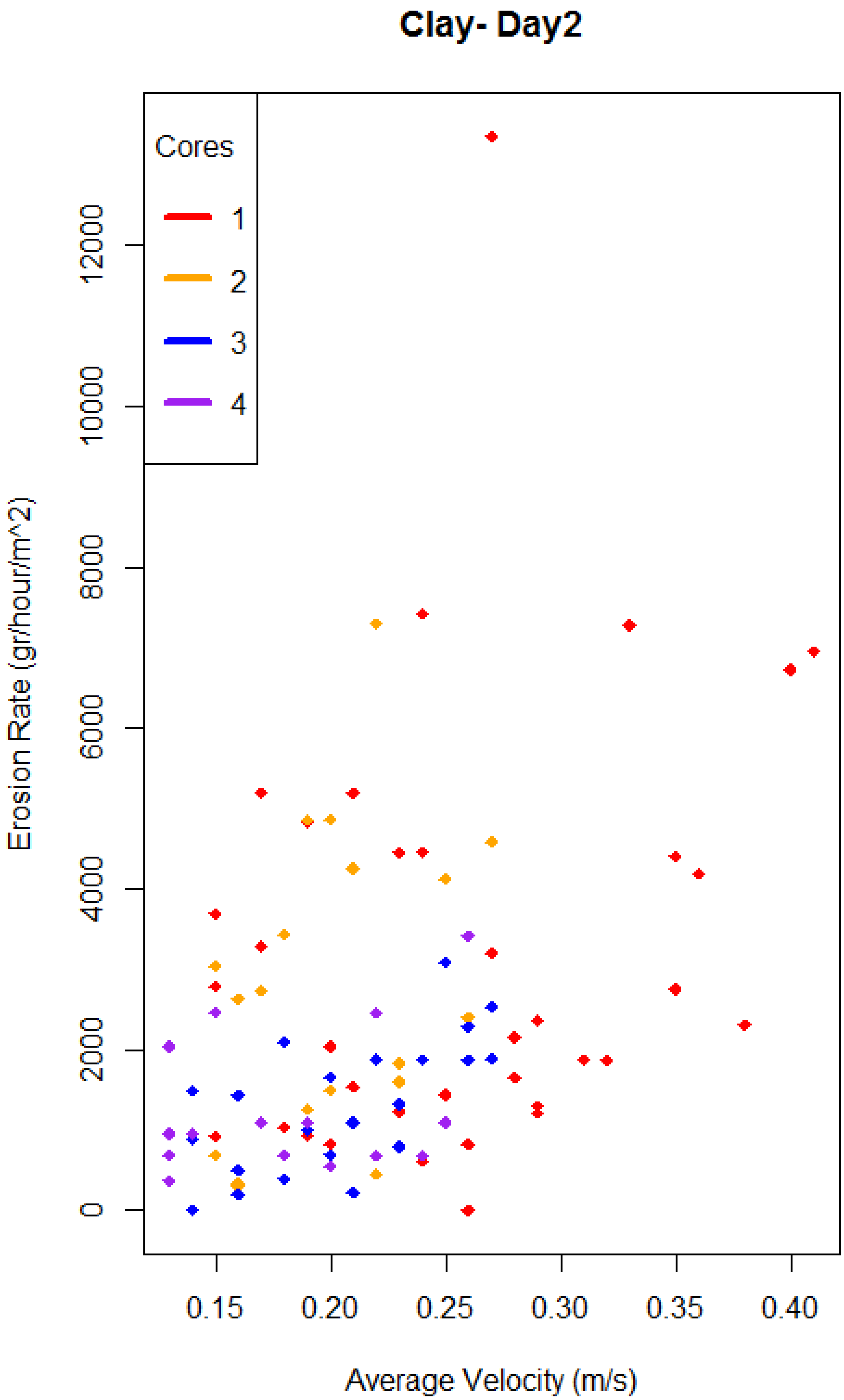

Clay- Day1
Cores
1
2
3
4
Erosion Rate (gr/hour/m^2)
0
2000
4000
6000
8000
10000
12000
14000
0.10
0.15
0.20
0.25
Average Velocity (m/s)

Figure 106



Clay- Day2
Cores
1
2
3
4
Erosion Rate (gr/hour/m^2)
0
2000
4000
6000
8000
10000
12000
0.15
0.20
0.25
0.30
0.35
0.40
Average Velocity (m/s)

Figure 107

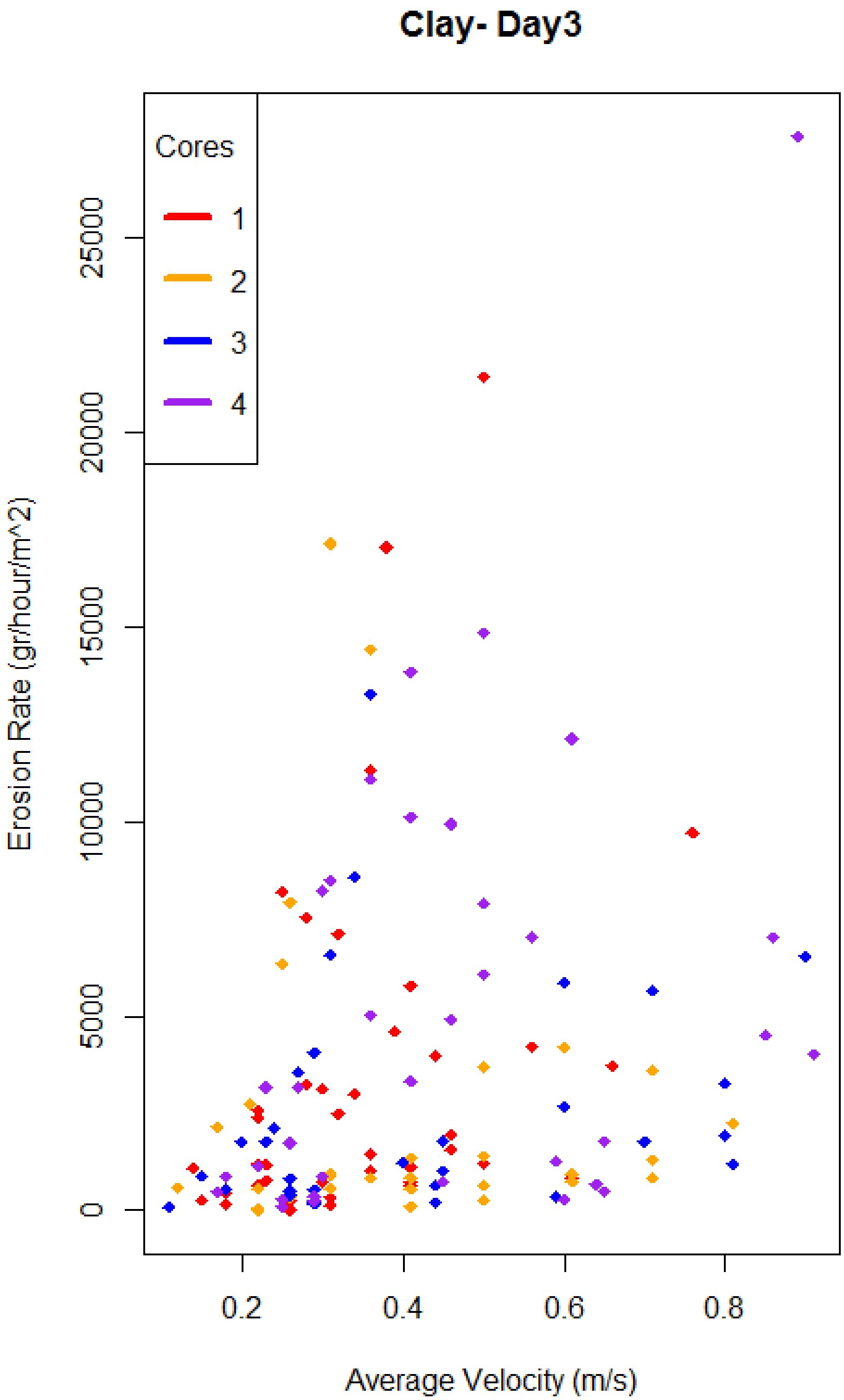
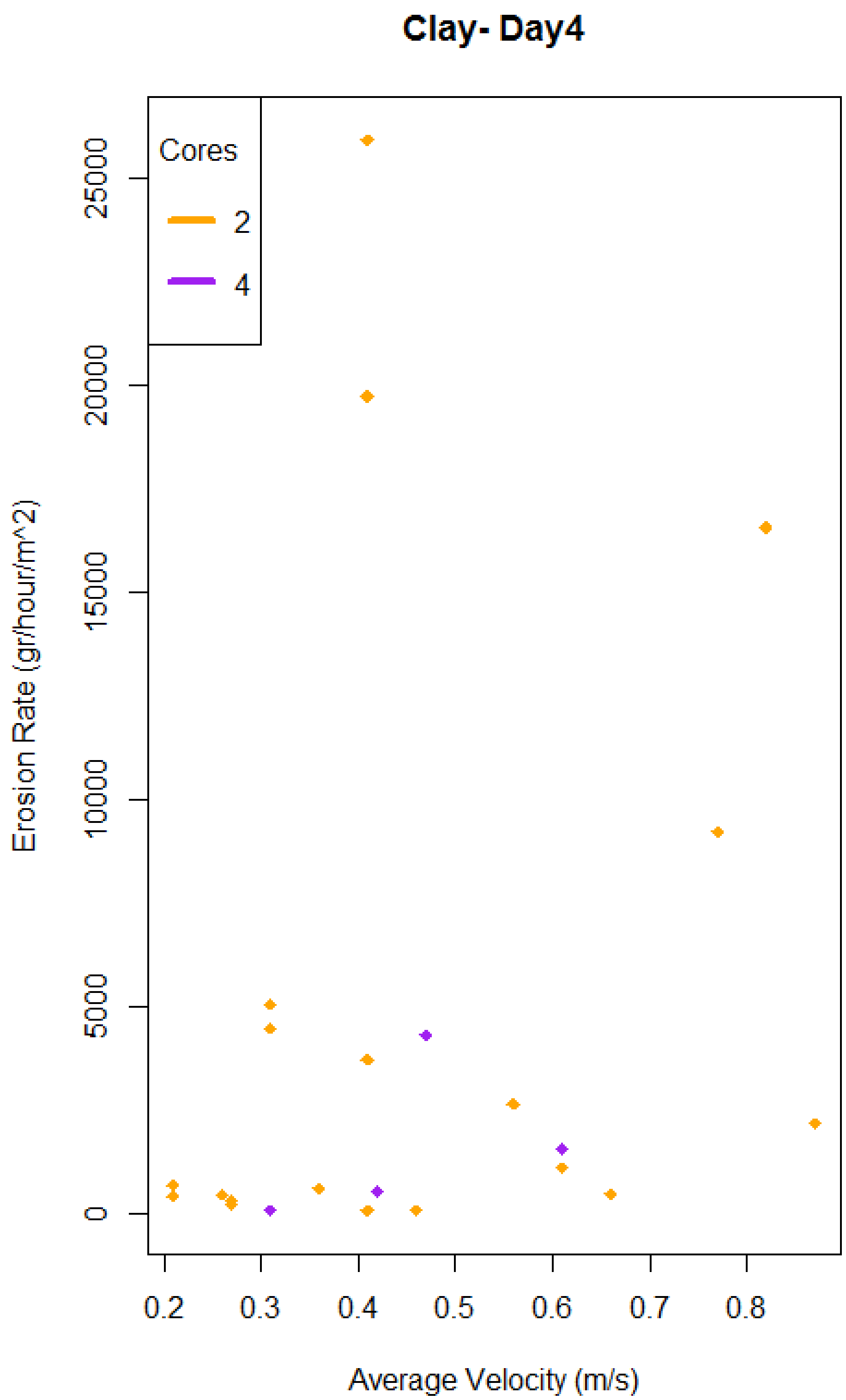

Clay- Day3
Cores
1
2
3
4
Erosion Rate (gr/hour/m^2)
0
5000
10000
15000
20000
25000
0.2
0.4
0.6
0.8
Average Velocity (m/s)

Figure 108



Clay- Day4
Cores
2
4
Erosion Rate (gr/hour/m^2)
0
5000
10000
15000
20000
25000
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Average Velocity (m/s)

Figure 109

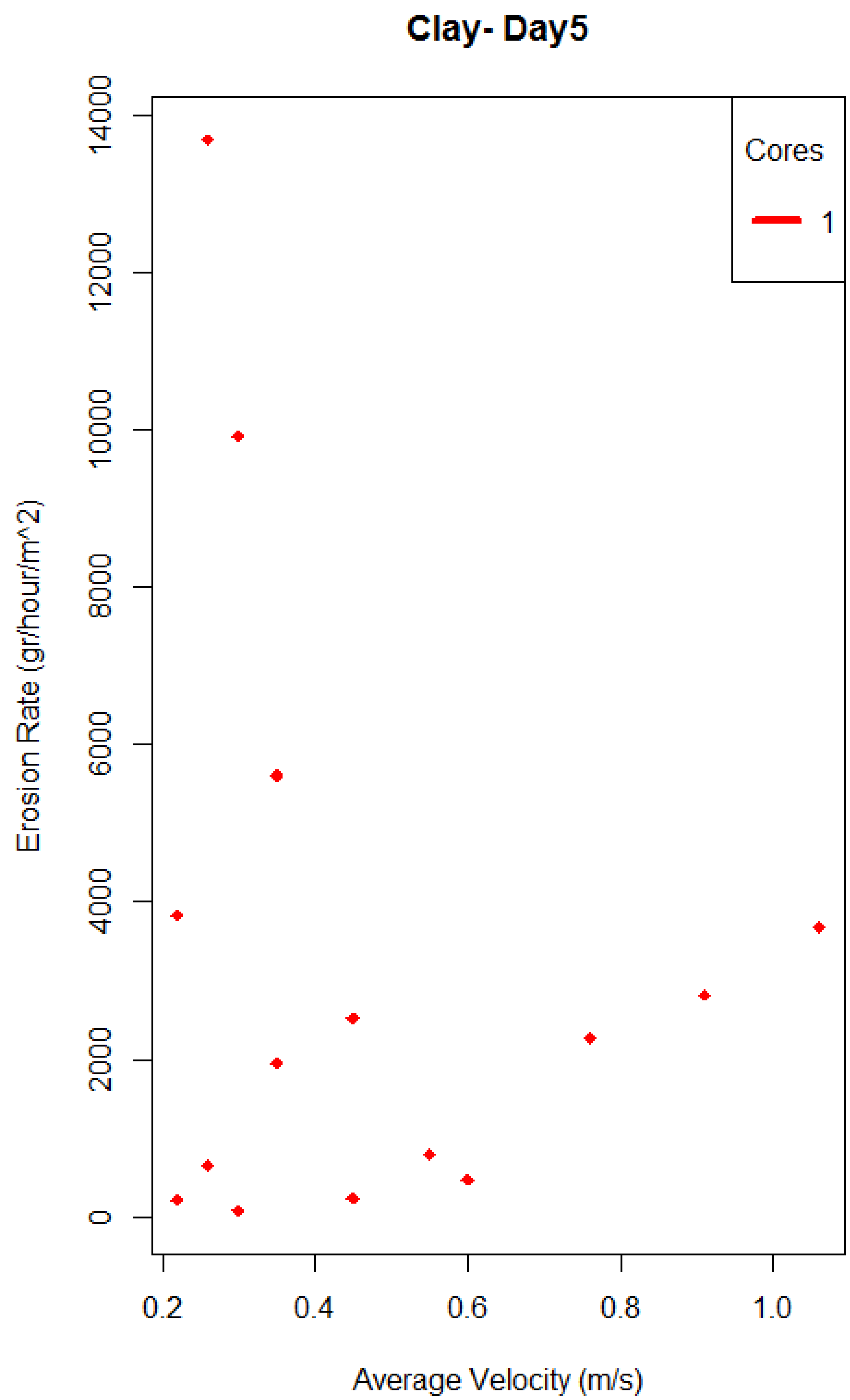
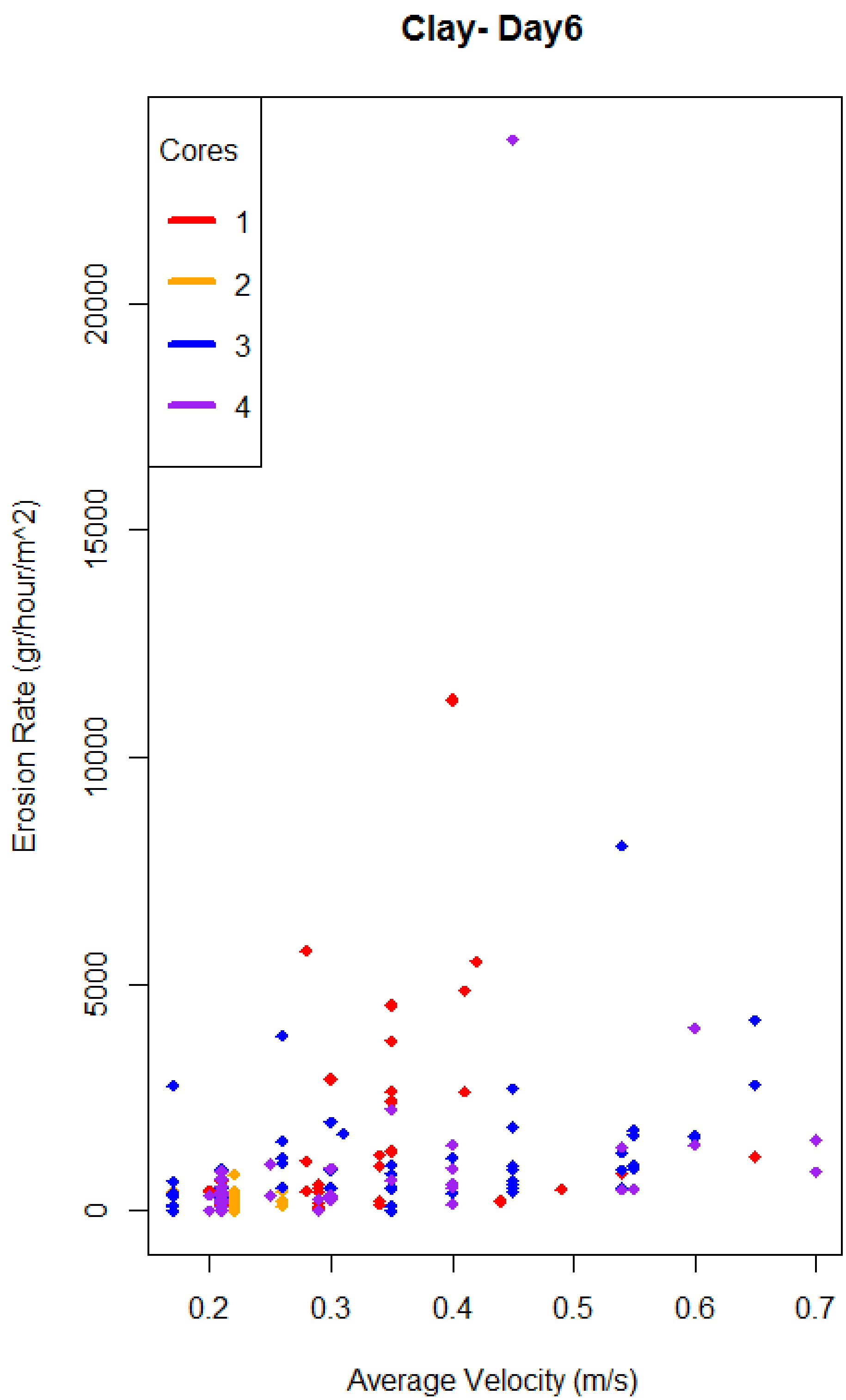

Clay- Day5
Cores
1
Erosion Rate (gr/hour/m^2)
0
2000
4000
6000
8000
10000
12000
14000
0.2
0.4
0.6
0.8
1.0
Average Velocity (m/s)

Figure 110



Clay- Day6
Cores
1
2
3
4
Erosion Rate (gr/hour/m^2)
0
5000
10000
15000
20000
Average Velocity (m/s)
0.2
0.3
0.4
0.5
0.6
0.7

Figure 111

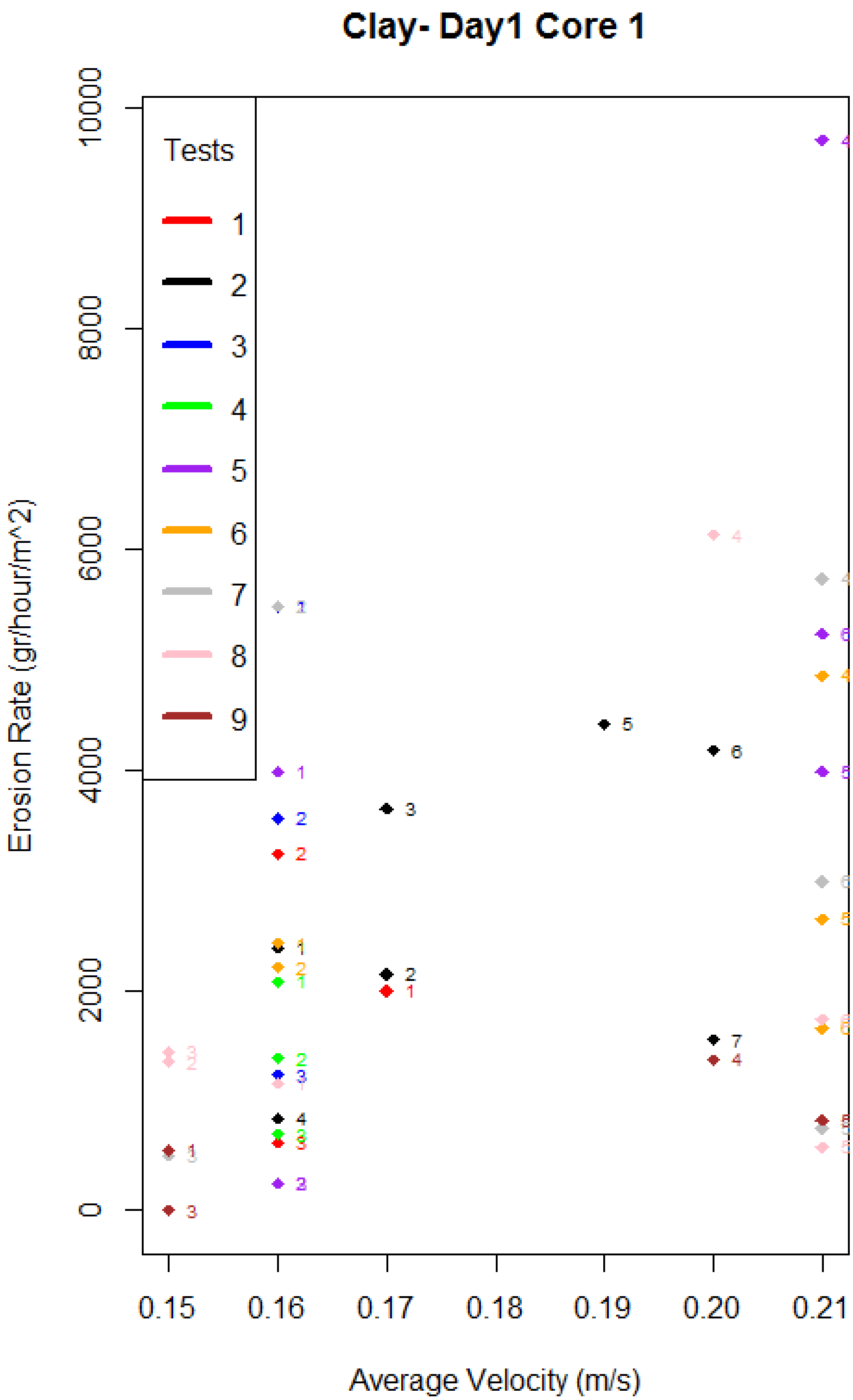
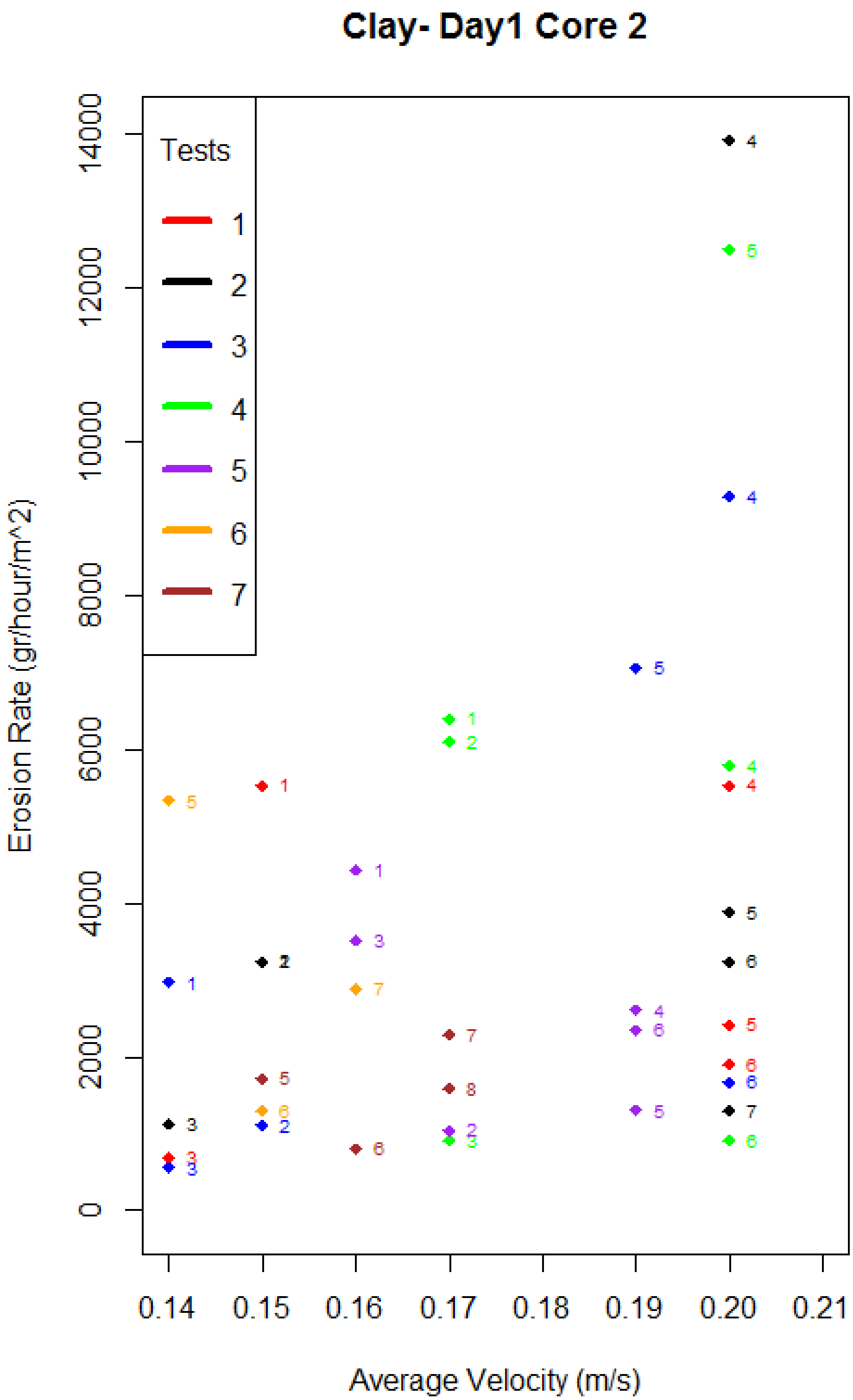

Clay- Day1 Core 1
Tests
1
2
3
4
5
6
7
8
9
Erosion Rate (gr/hour/m^2)
Average Velocity (m/s)
0
2000
4000
6000
8000
10000
0.15
0.16
0.17
0.18
0.19
0.20
0.21

Figure 112



Clay- Day1 Core 2
Tests
1
2
3
4
5
6
7
Erosion Rate (gr/hour/m^2)
Average Velocity (m/s)
0
2000
4000
6000
8000
10000
12000
14000
0.14
0.15
0.16
0.17
0.18
0.19
0.20
0.21

Figure 113

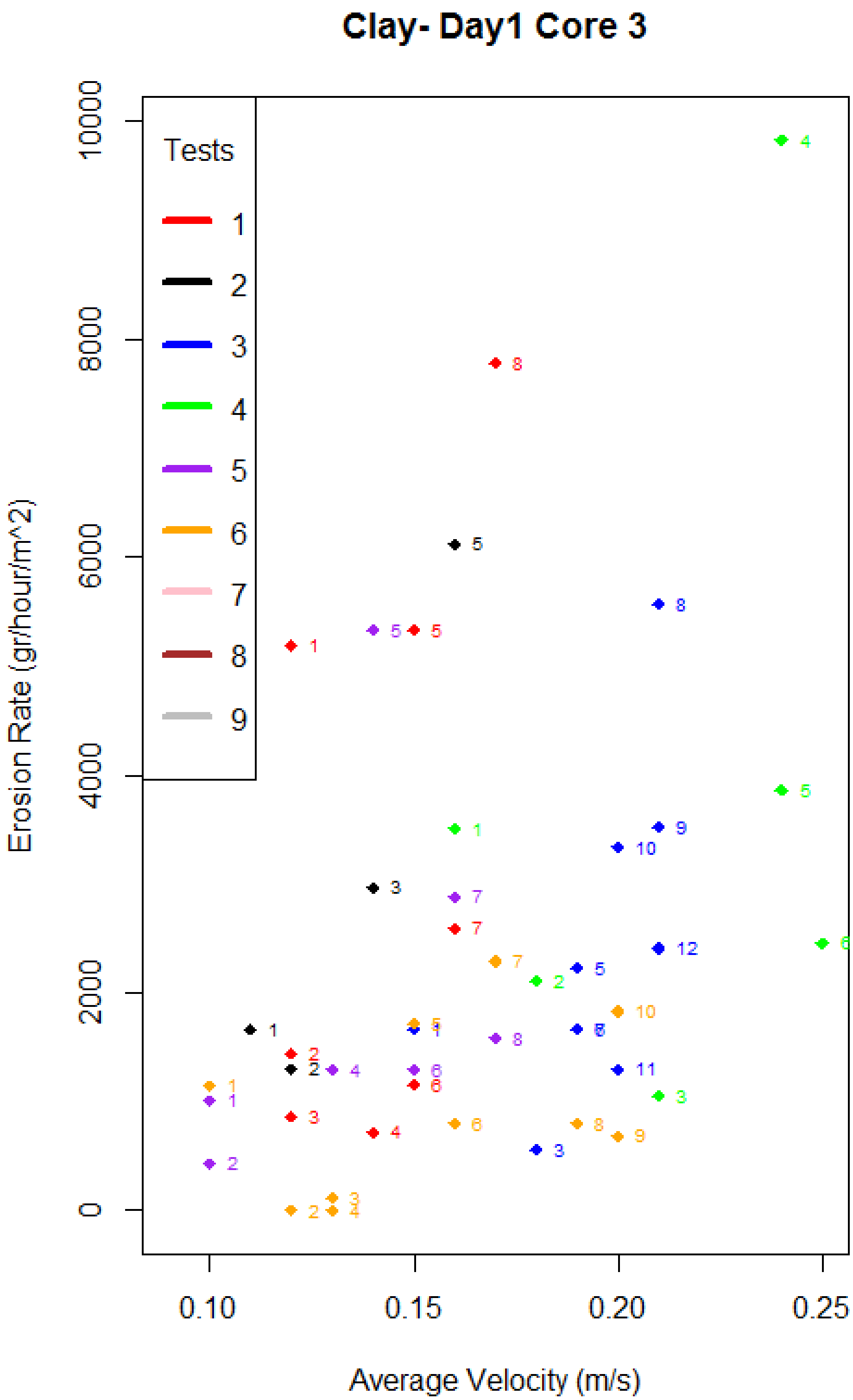

Clay- Day1 Core 3
Tests
1
2
3
4
5
6
7
8
9
Erosion Rate (gr/hour/m^2)
Average Velocity (m/s)
0
2000
4000
6000
8000
10000
0.10
0.15
0.20
0.25

Figure 114

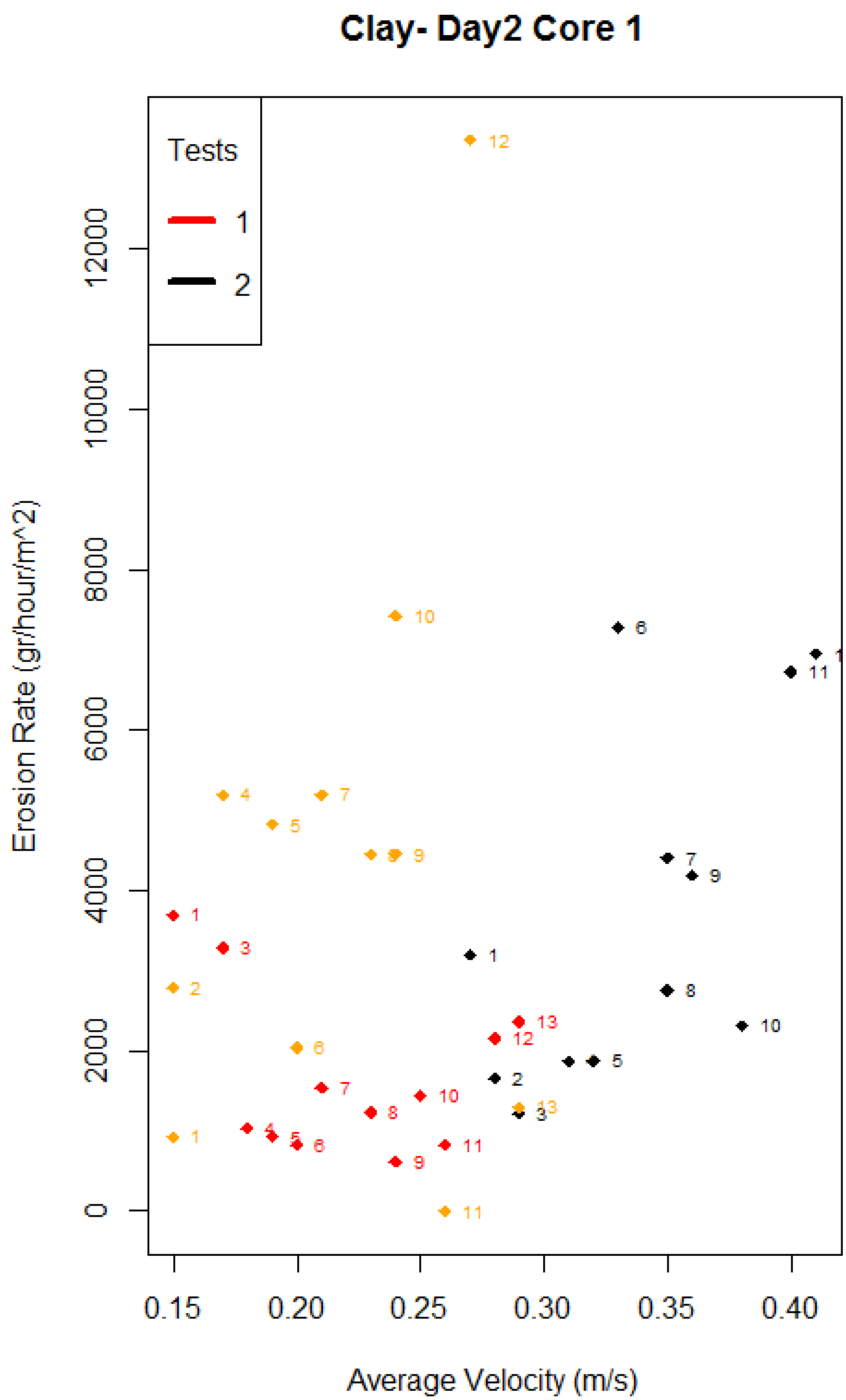

Clay- Day2 Core 1
Tests
1
2
Erosion Rate (gr/hour/m^2)
Average Velocity (m/s)
0
2000
4000
6000
8000
10000
12000
0.15
0.20
0.25
0.30
0.35
0.40

Figure 115

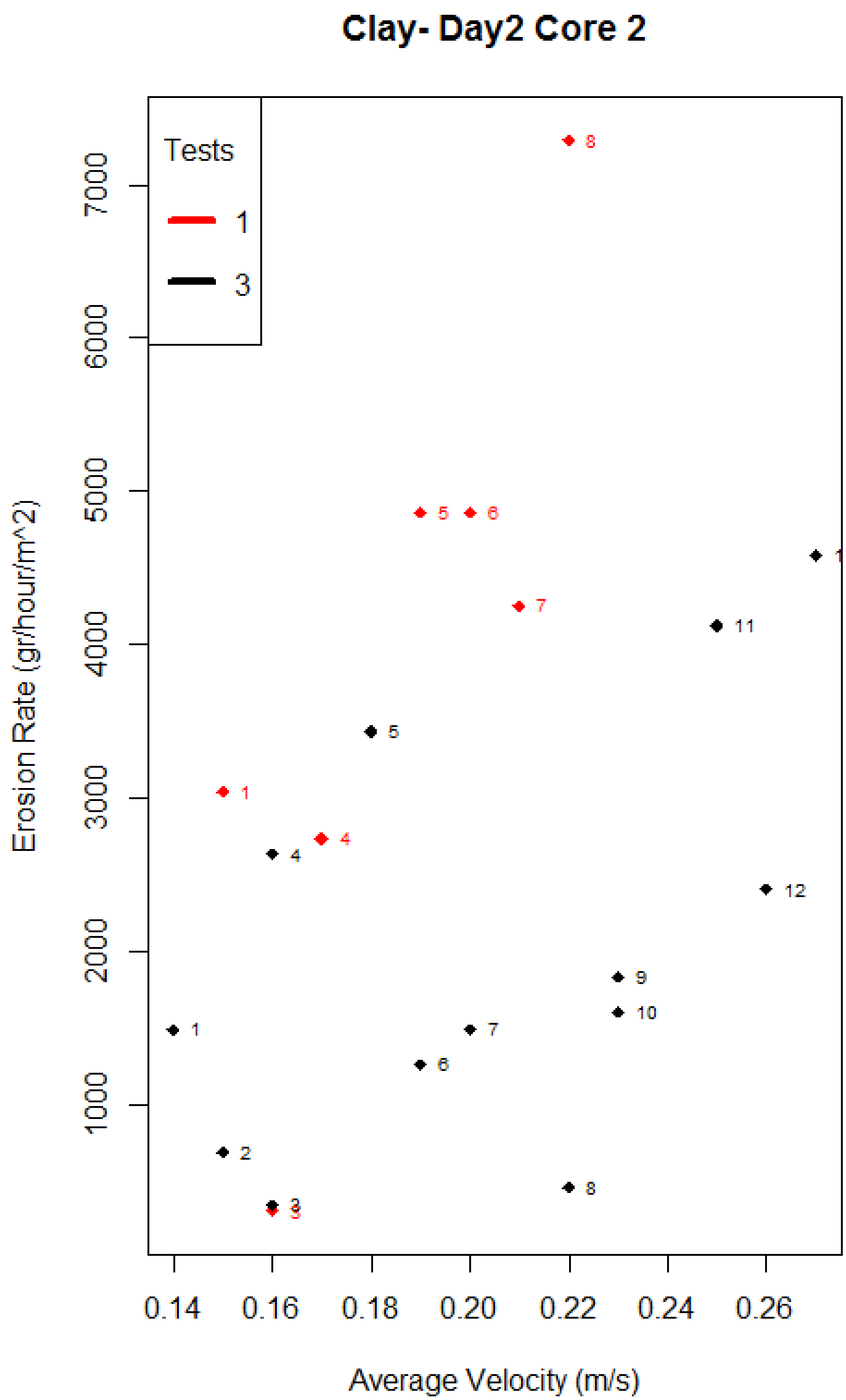

Clay- Day2 Core 2
Tests
1
3
Erosion Rate (gr/hour/m^2)
Average Velocity (m/s)
0.14
0.16
0.18
0.20
0.22
0.24
0.26
1000
2000
3000
4000
5000
6000
7000
8
5
6
7
1
4
11
5
12
9
10
7
6
2
3
8

Figure 116

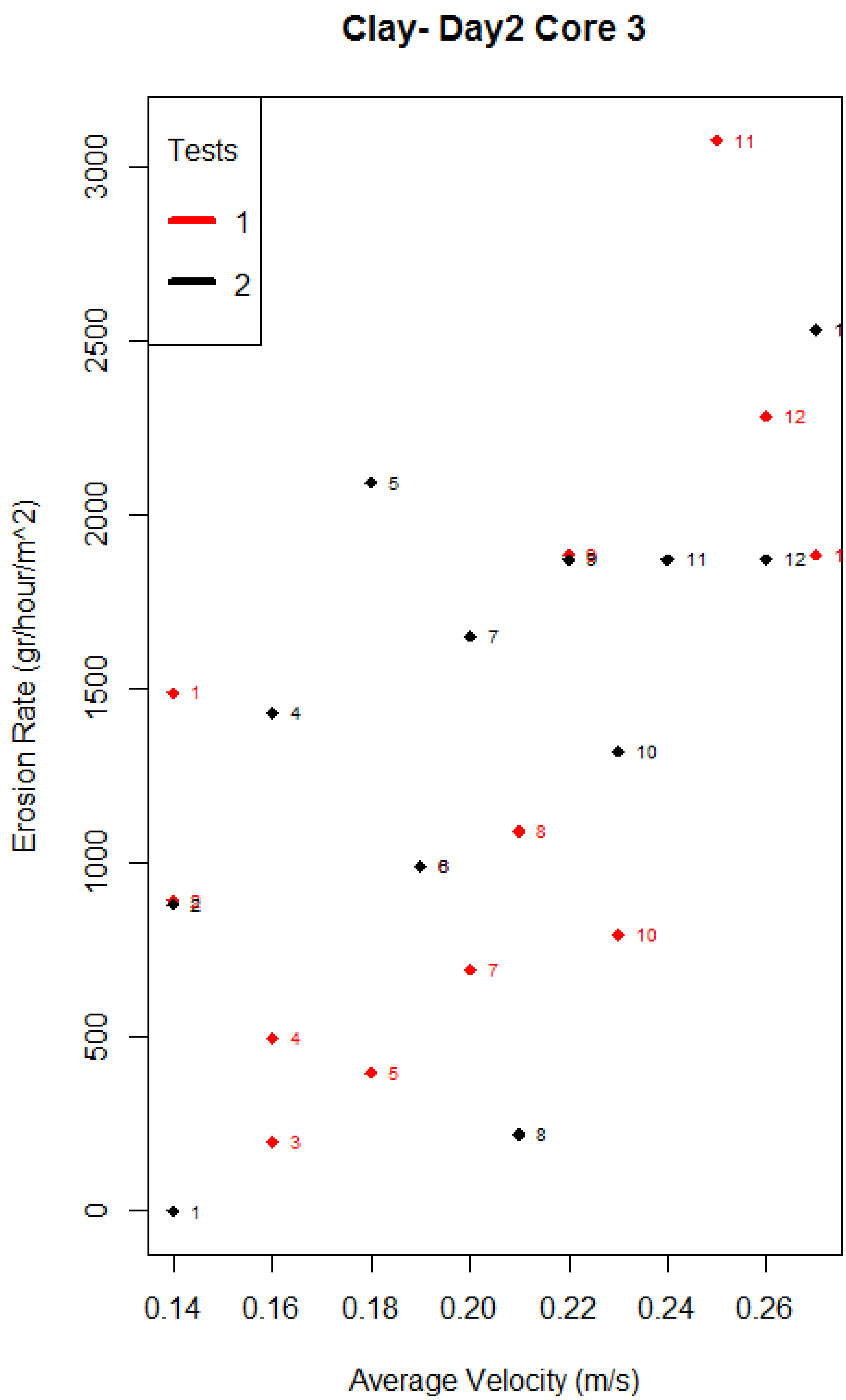
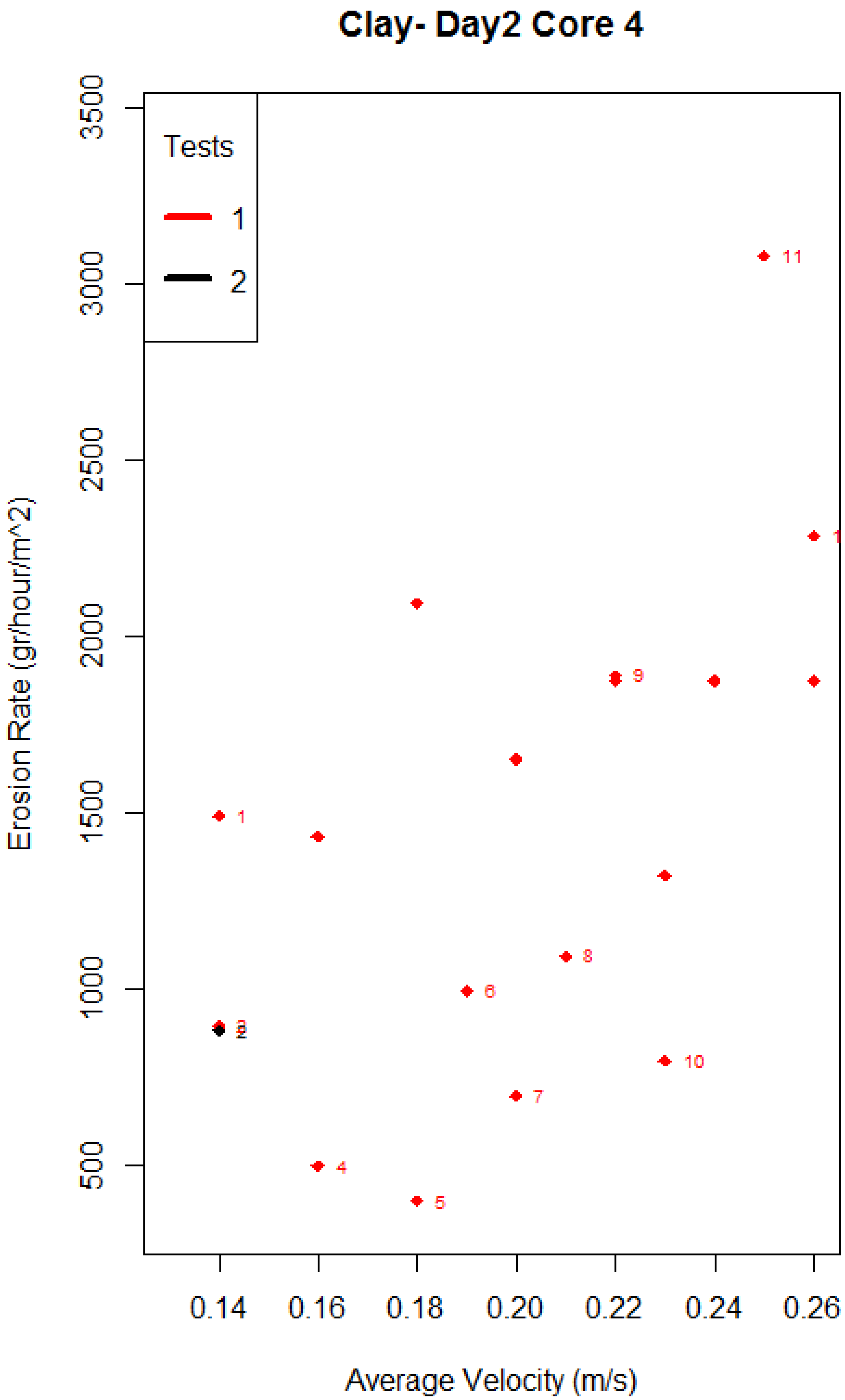
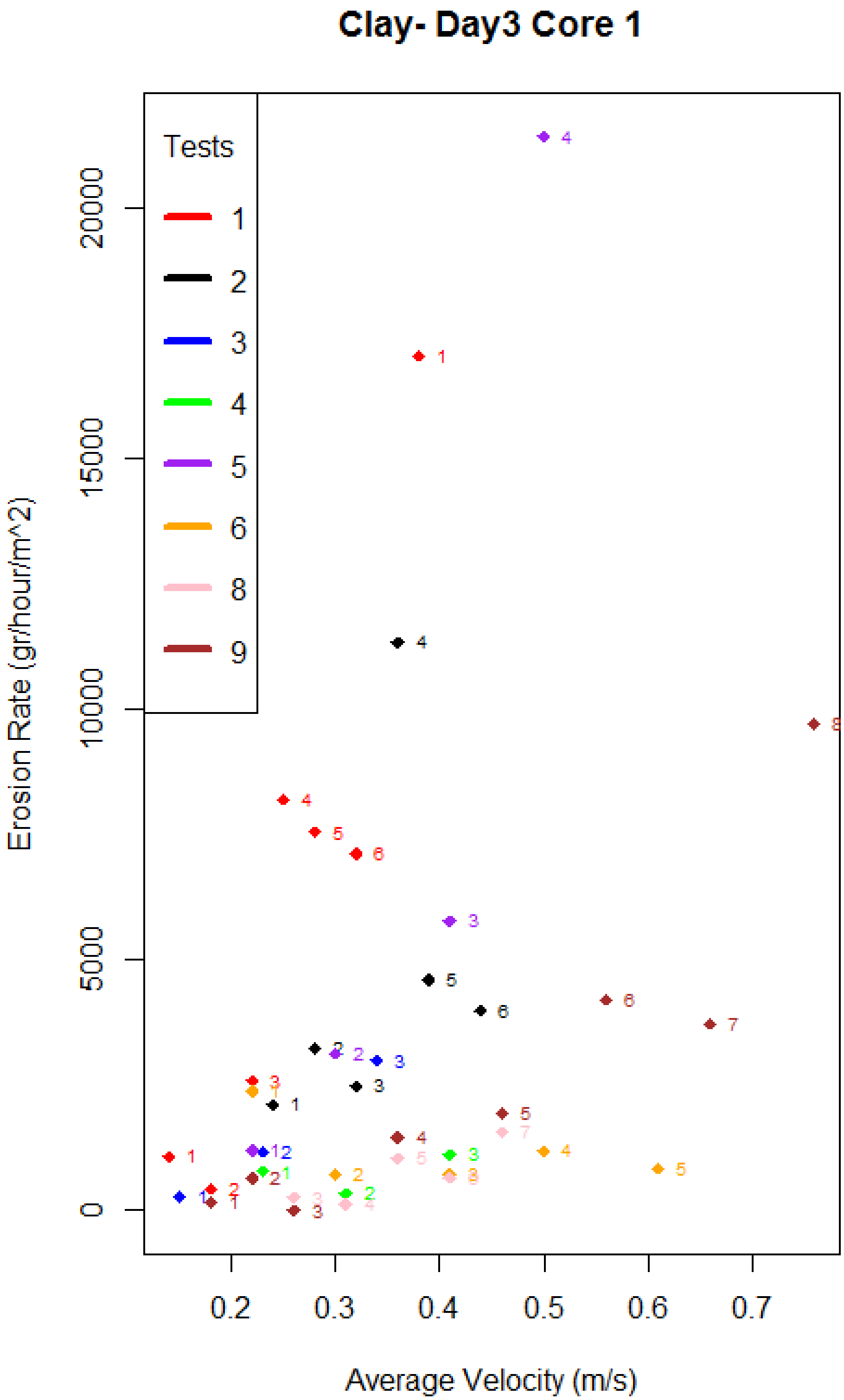

Clay- Day2 Core 3
Tests
1
2
Erosion Rate (gr/hour/m^2)
Average Velocity (m/s)
0
500
1000
1500
2000
2500
3000
0.14
0.16
0.18
0.20
0.22
0.24
0.26

Figure 117



Clay- Day2 Core 4
Tests
1
2
Erosion Rate (gr/hour/m^2)
Average Velocity (m/s)
0.14
0.16
0.18
0.20
0.22
0.24
0.26
500
1000
1500
2000
2500
3000
3500
11
9
1
8
6
10
7
4
5

Figure 118



Clay- Day3 Core 1
Tests
1
2
3
4
5
6
8
9
Erosion Rate (gr/hour/m^2)
Average Velocity (m/s)
0
5000
10000
15000
20000
0.2
0.3
0.4
0.5
0.6
0.7

Figure 119

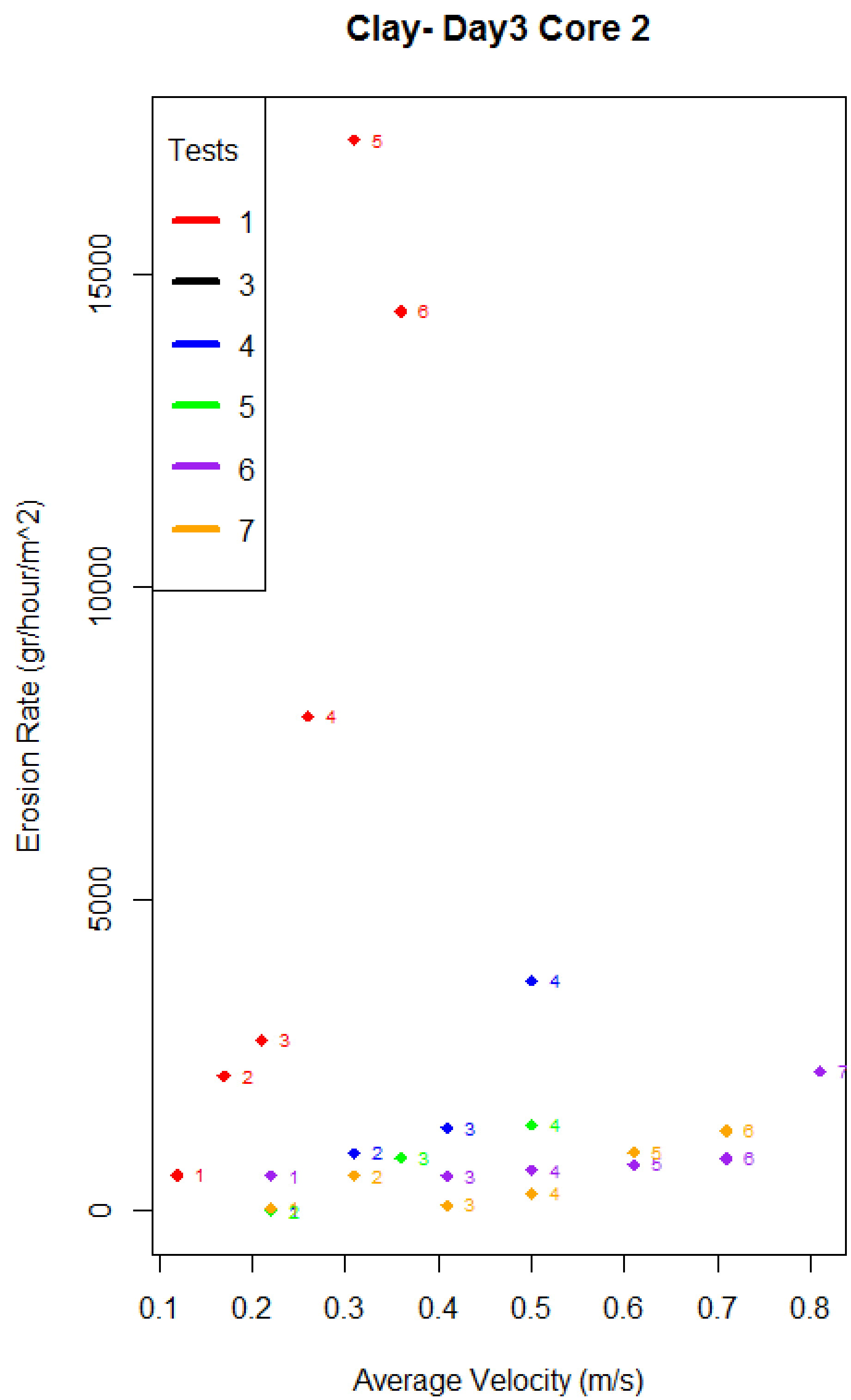
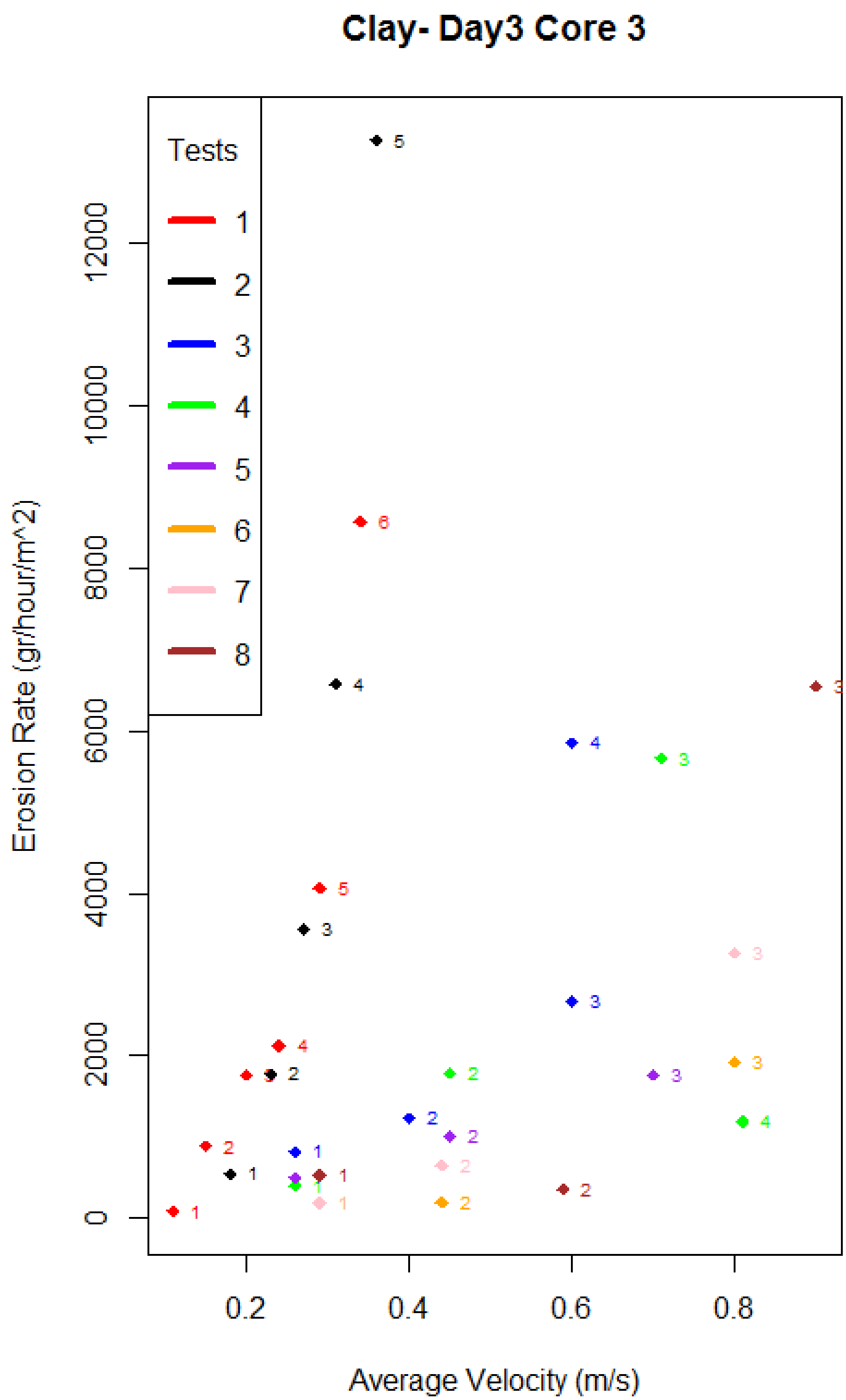

Clay- Day3 Core 2
Tests
1
3
4
5
6
7
Erosion Rate (gr/hour/m^2)
0
5000
10000
15000
Average Velocity (m/s)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

Figure 120



Clay- Day3 Core 3
Tests
1
2
3
4
5
6
7
8
Erosion Rate (gr/hour/m^2)
0
2000
4000
6000
8000
10000
12000
0.2
0.4
0.6
0.8
Average Velocity (m/s)

Figure 121

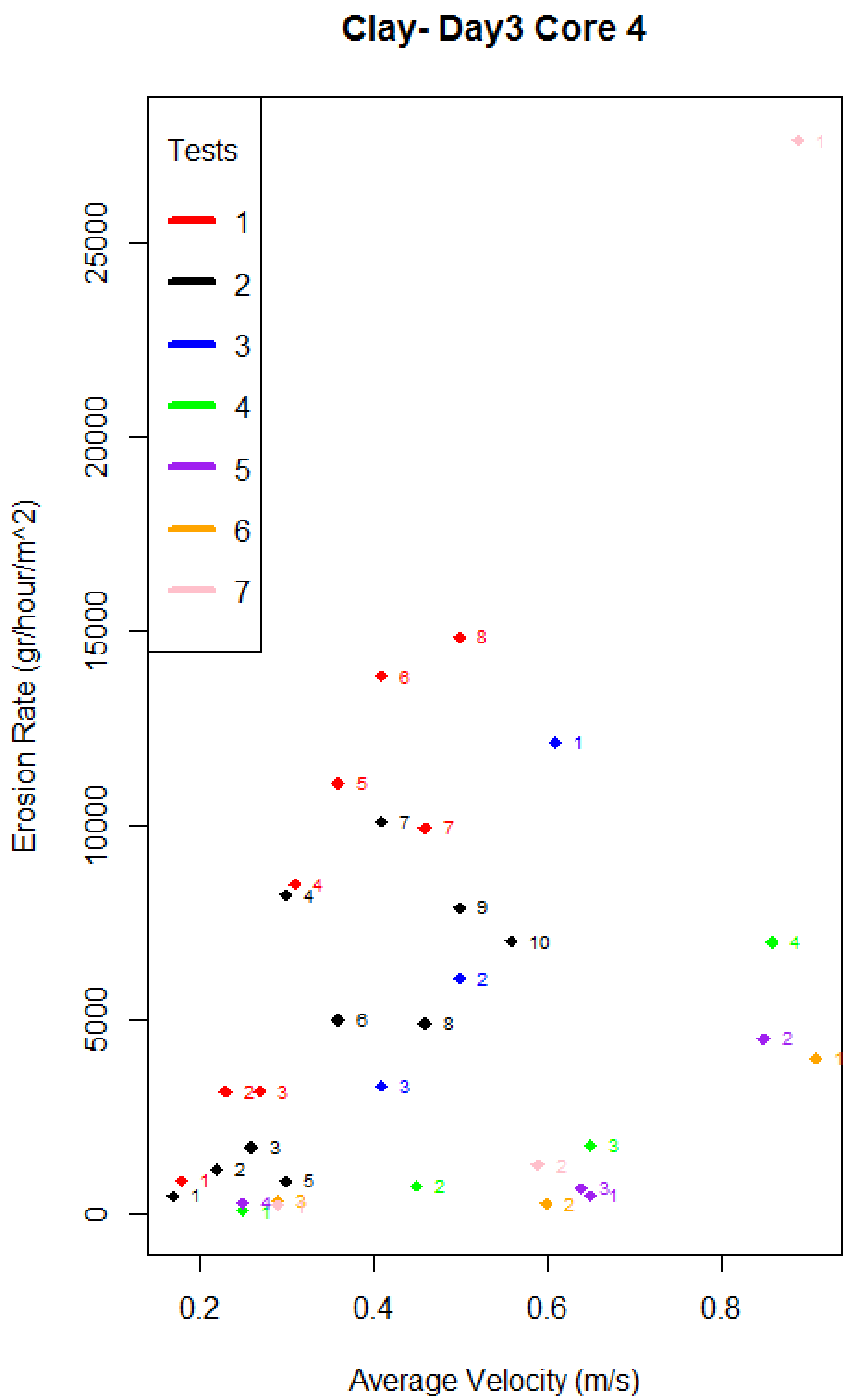
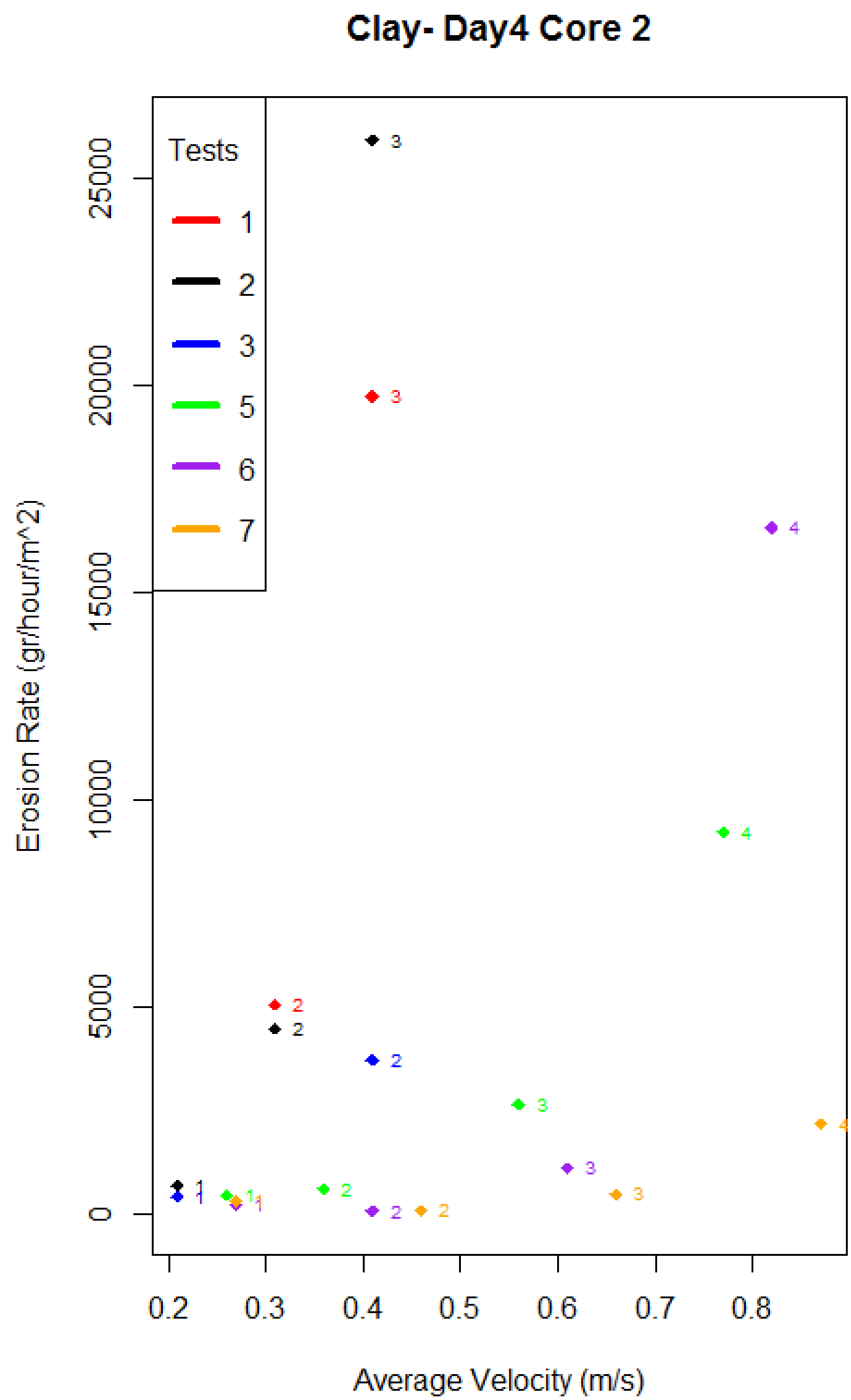

Clay- Day3 Core 4
Tests
1
2
3
4
5
6
7
Erosion Rate (gr/hour/m^2)
0
5000
10000
15000
20000
25000
0.2
0.4
0.6
0.8
Average Velocity (m/s)

Figure 122



Clay- Day4 Core 2
Tests
1
2
3
5
6
7
Erosion Rate (gr/hour/m^2)
0
5000
10000
15000
20000
25000
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Average Velocity (m/s)

Figure 123

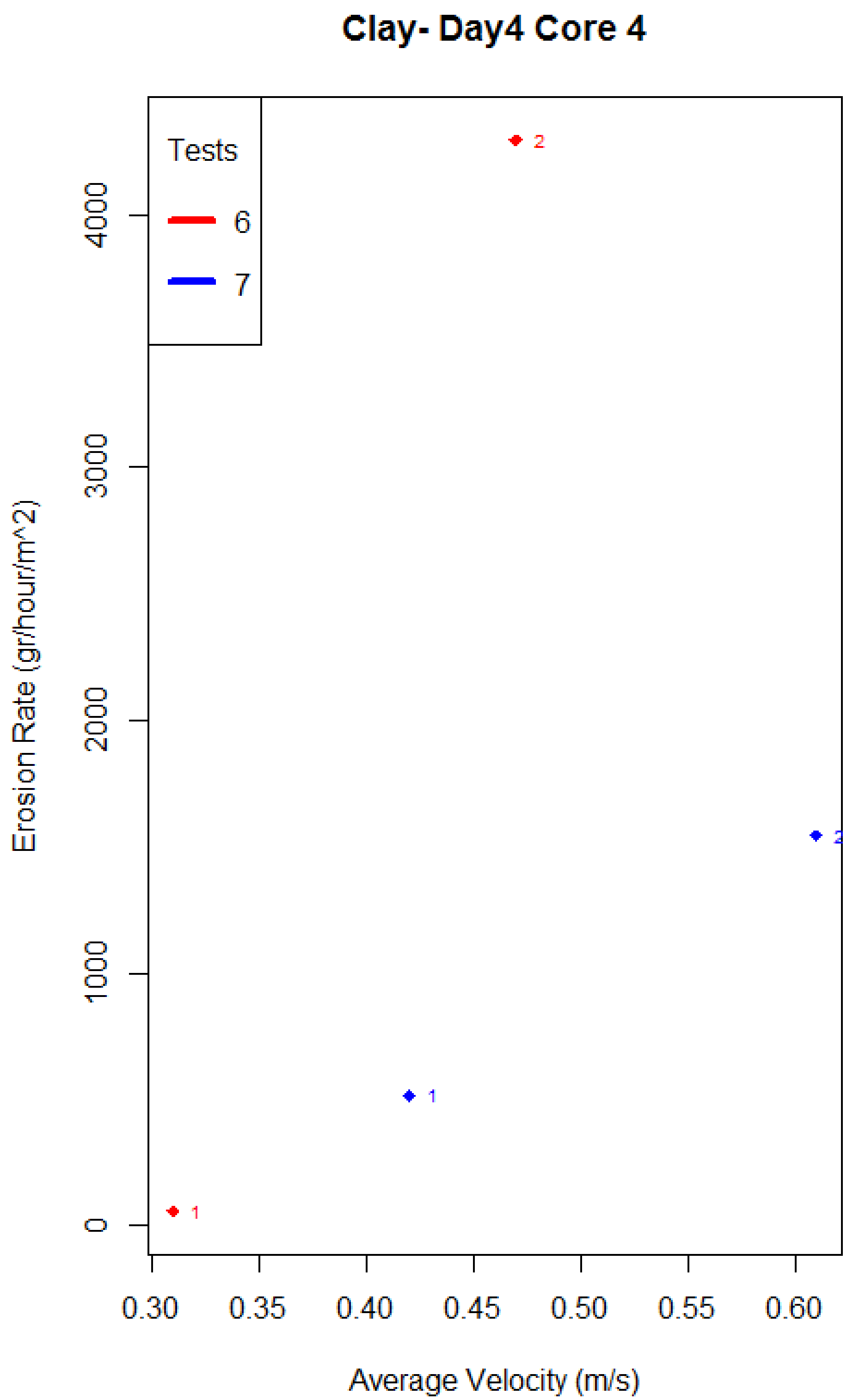

Clay- Day4 Core 4
Tests
6
7
2
2
1
1
4000
3000
2000
1000
0
Erosion Rate (gr/hour/m^2)
0.30
0.35
0.40
0.45
0.50
0.55
0.60
Average Velocity (m/s)

Figure 124

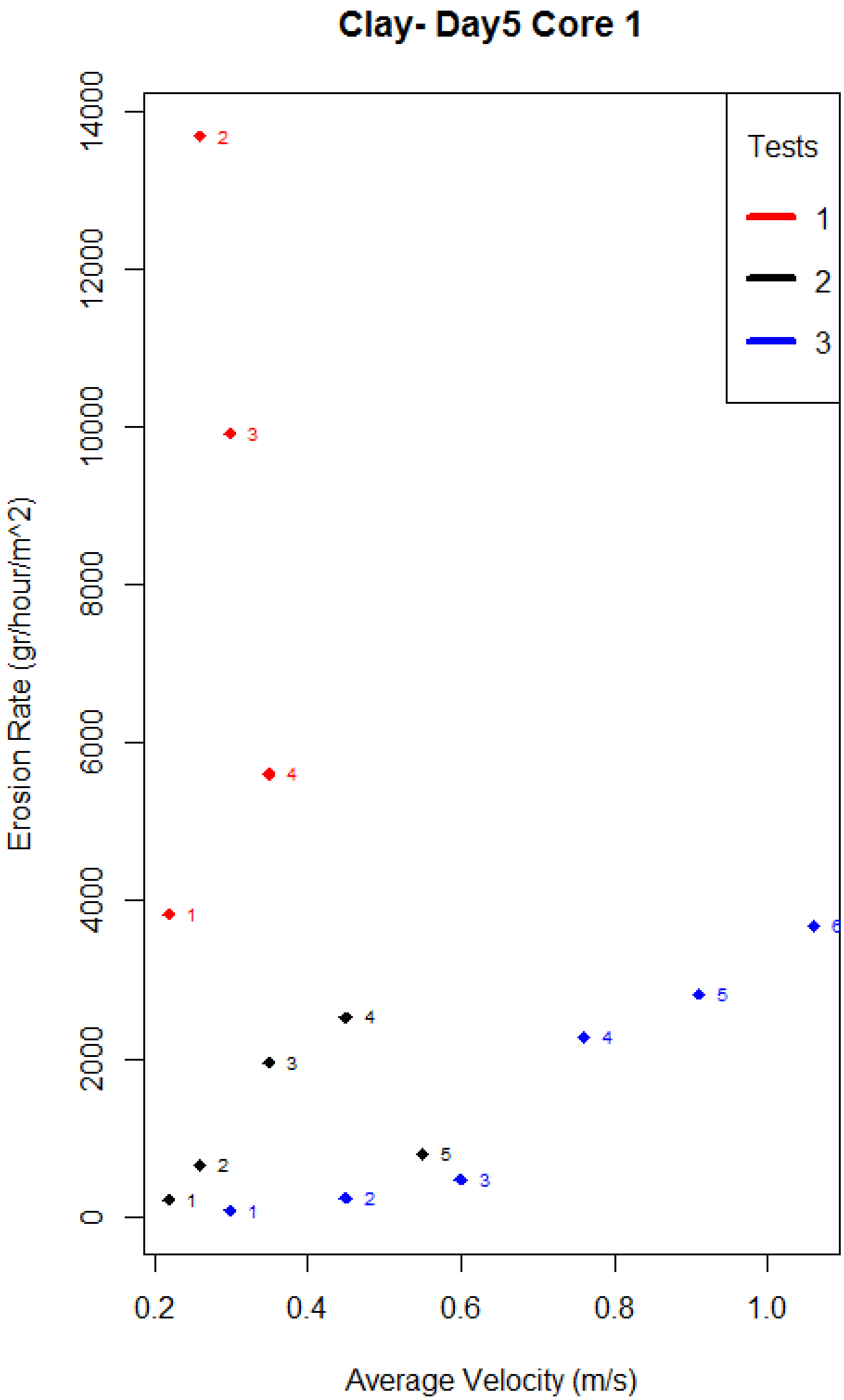
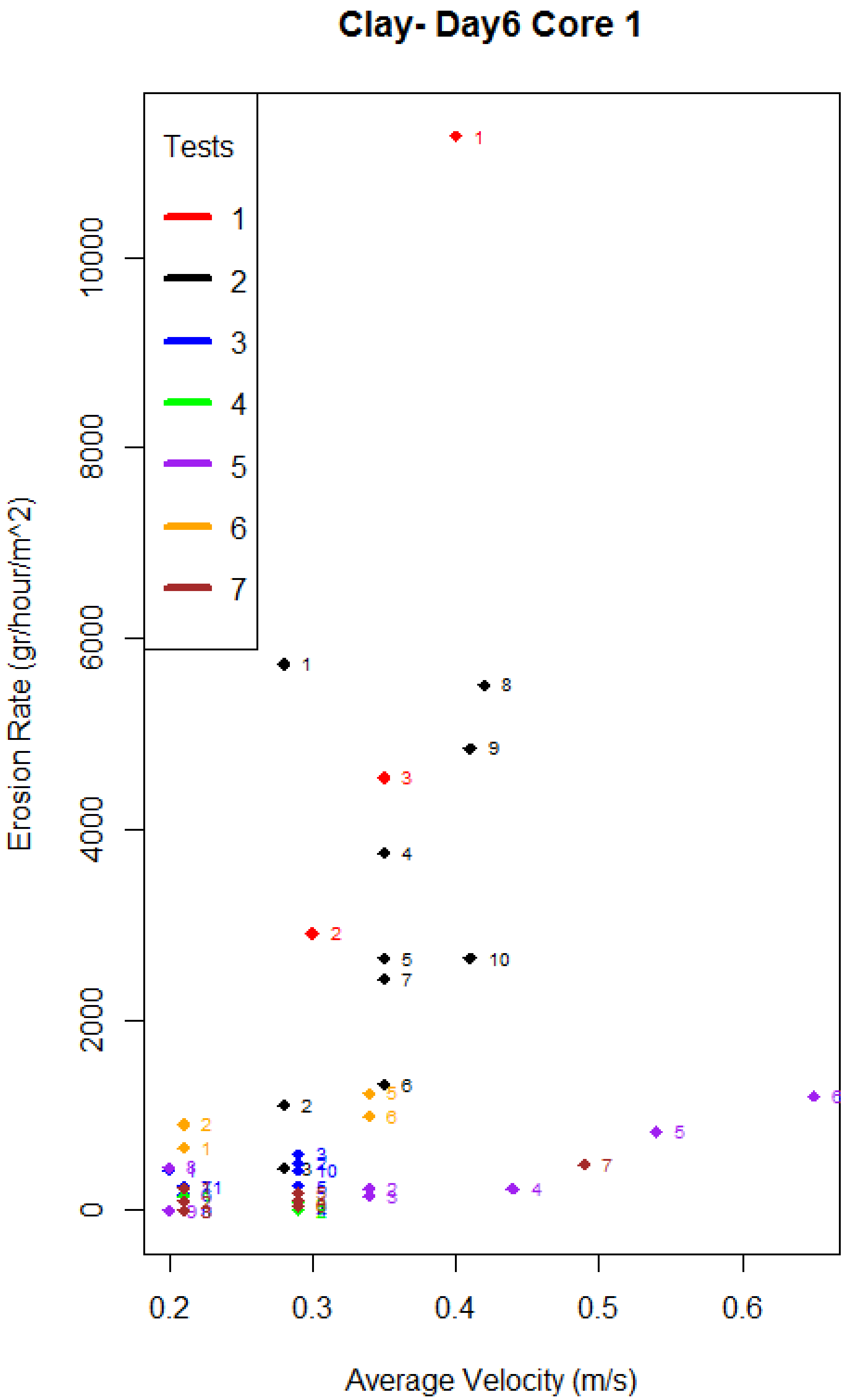
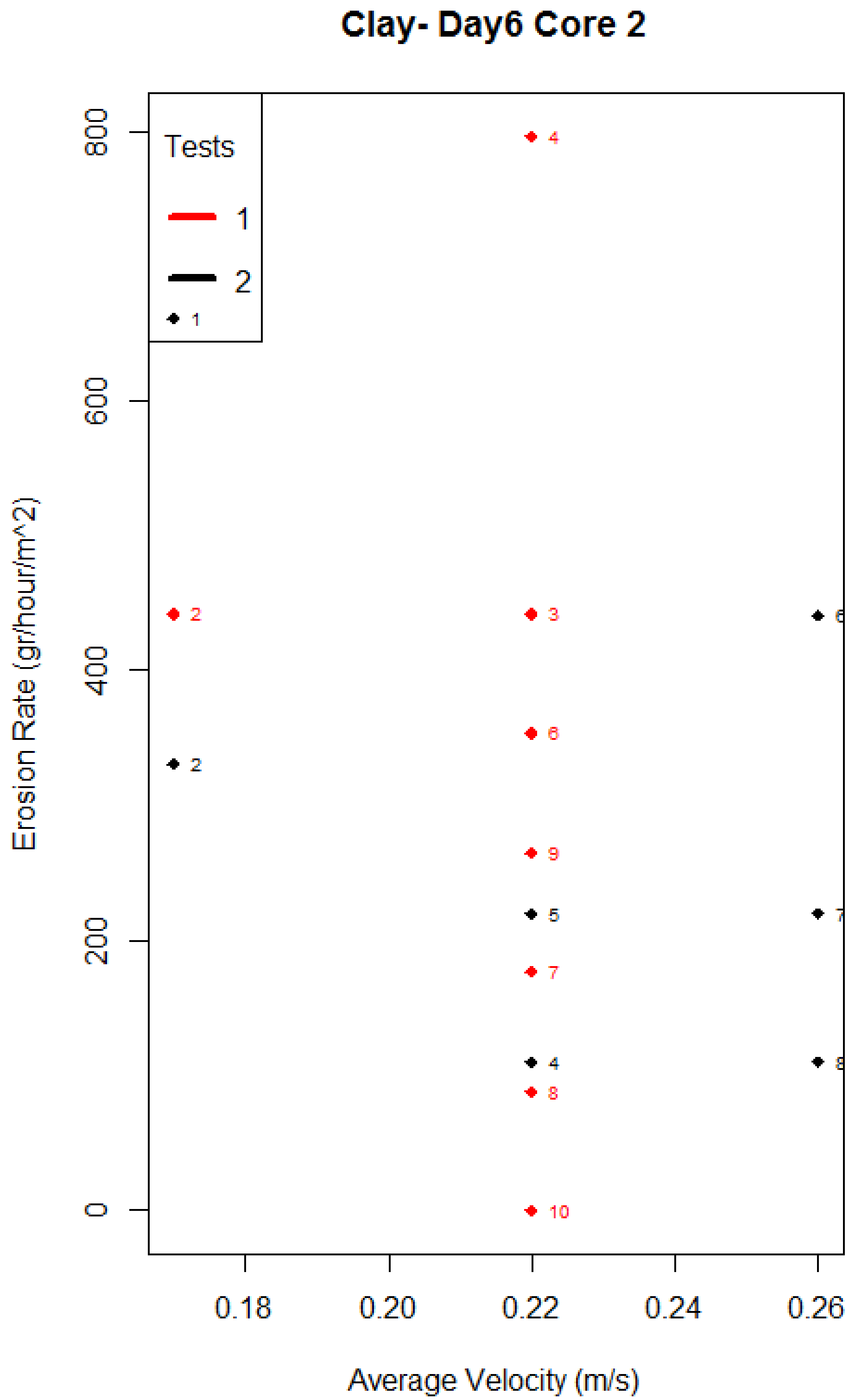

Clay- Day5 Core 1
Tests
1
2
3
Erosion Rate (gr/hour/m^2)
0
2000
4000
6000
8000
10000
12000
14000
0.2
0.4
0.6
0.8
1.0
Average Velocity (m/s)

Figure 125



Clay- Day6 Core 1
Tests
1
2
3
4
5
6
7
Erosion Rate (gr/hour/m^2)
0
2000
4000
6000
8000
10000
0.2
0.3
0.4
0.5
0.6
Average Velocity (m/s)

Figure 126



Clay- Day6 Core 2
Tests
1
2
Erosion Rate (gr/hour/m^2)
Average Velocity (m/s)
0
200
400
600
800
0.18
0.20
0.22
0.24
0.26

Figure 127

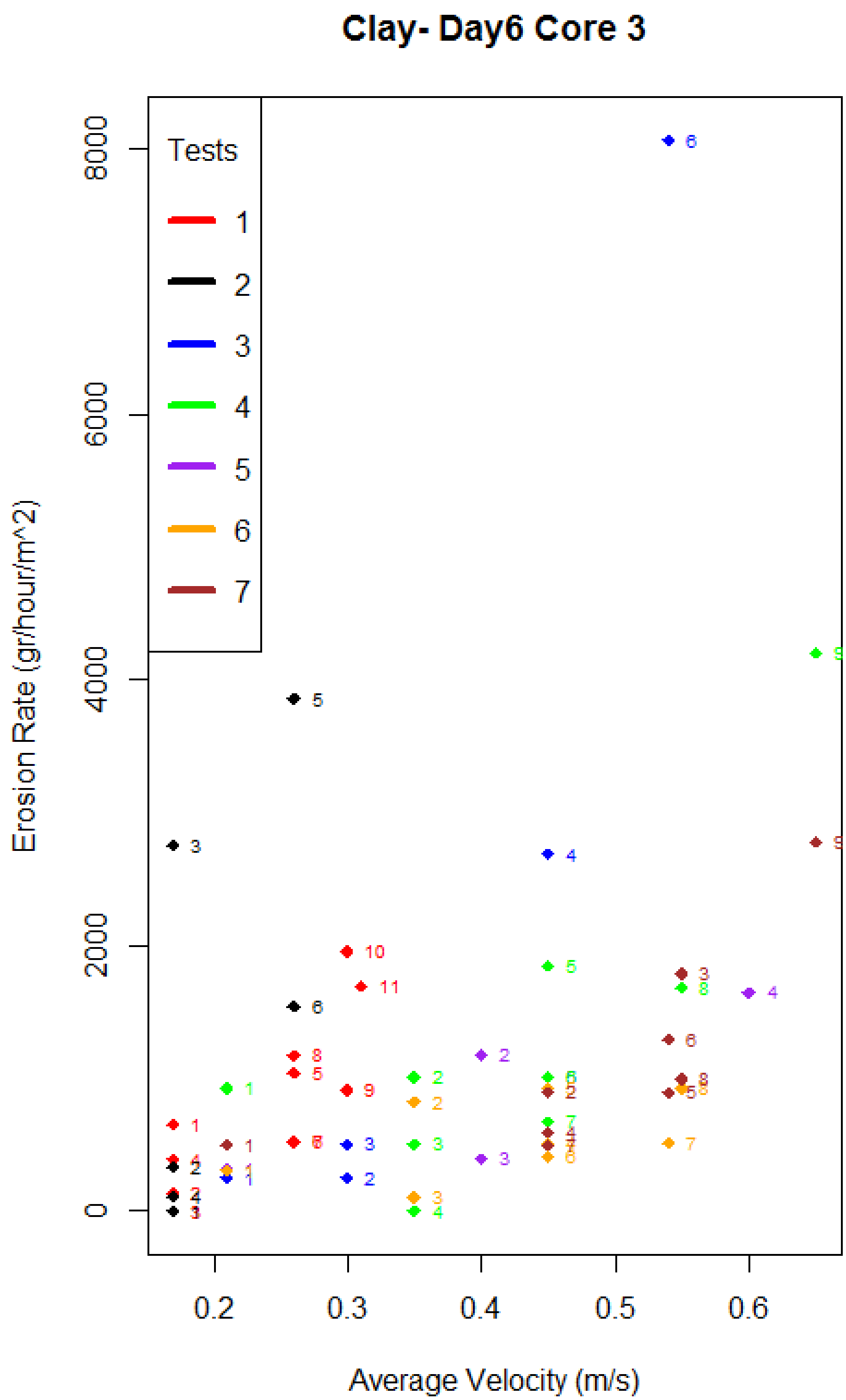
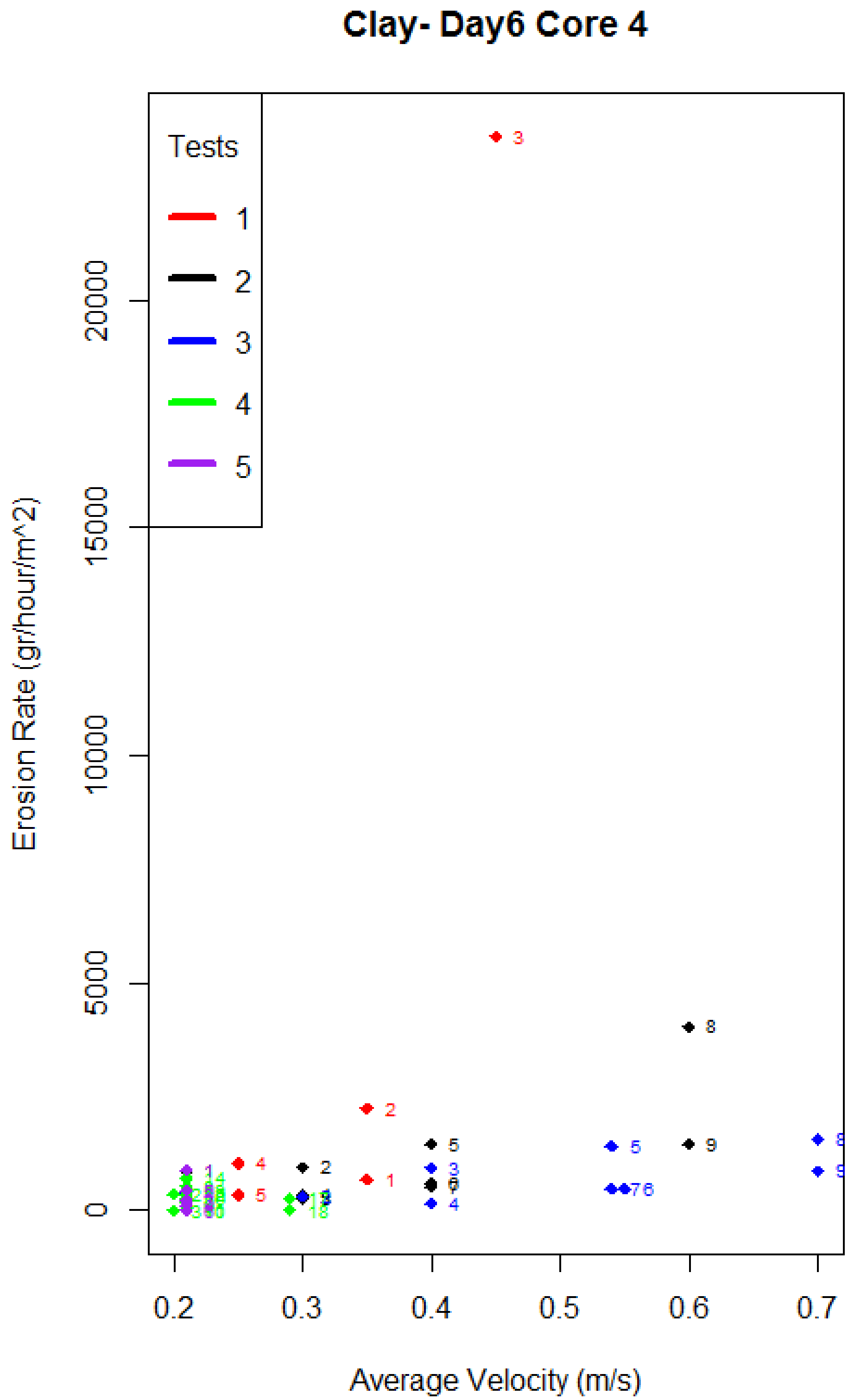

Clay- Day6 Core 3
Tests
1
2
3
4
5
6
7
Erosion Rate (gr/hour/m^2)
Average Velocity (m/s)
0
2000
4000
6000
8000
0.2
0.3
0.4
0.5
0.6

Figure 128



Clay- Day6 Core 4
Tests
1
2
3
4
5
Erosion Rate (gr/hour/m^2)
Average Velocity (m/s)
0
5000
10000
15000
20000
0.2
0.3
0.4
0.5
0.6
0.7

Figure 129

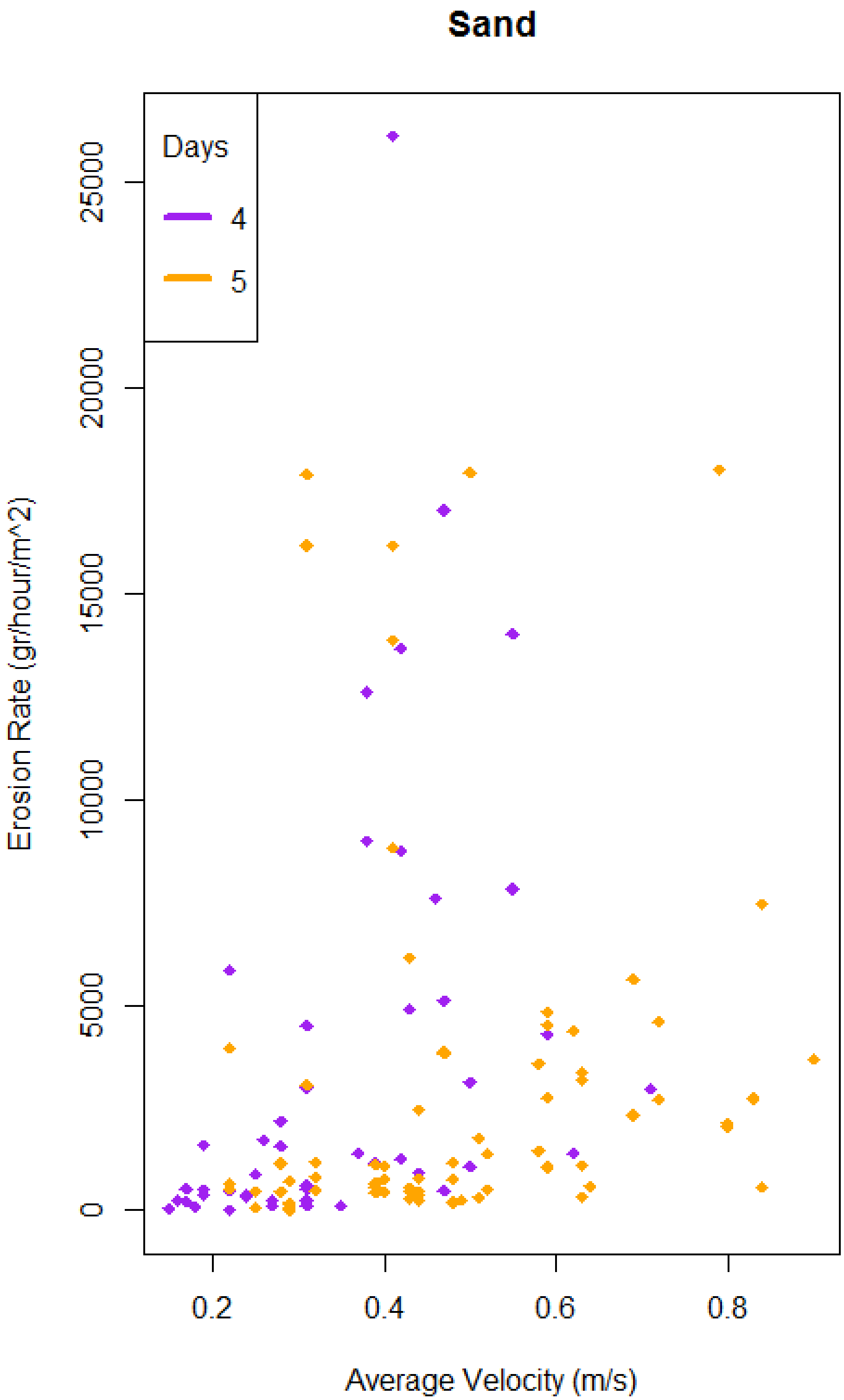

Sand
Days
4
5
Erosion Rate (gr/hour/m^2)
0
5000
10000
15000
20000
25000
0.2
0.4
0.6
0.8
Average Velocity (m/s)

Figure 130

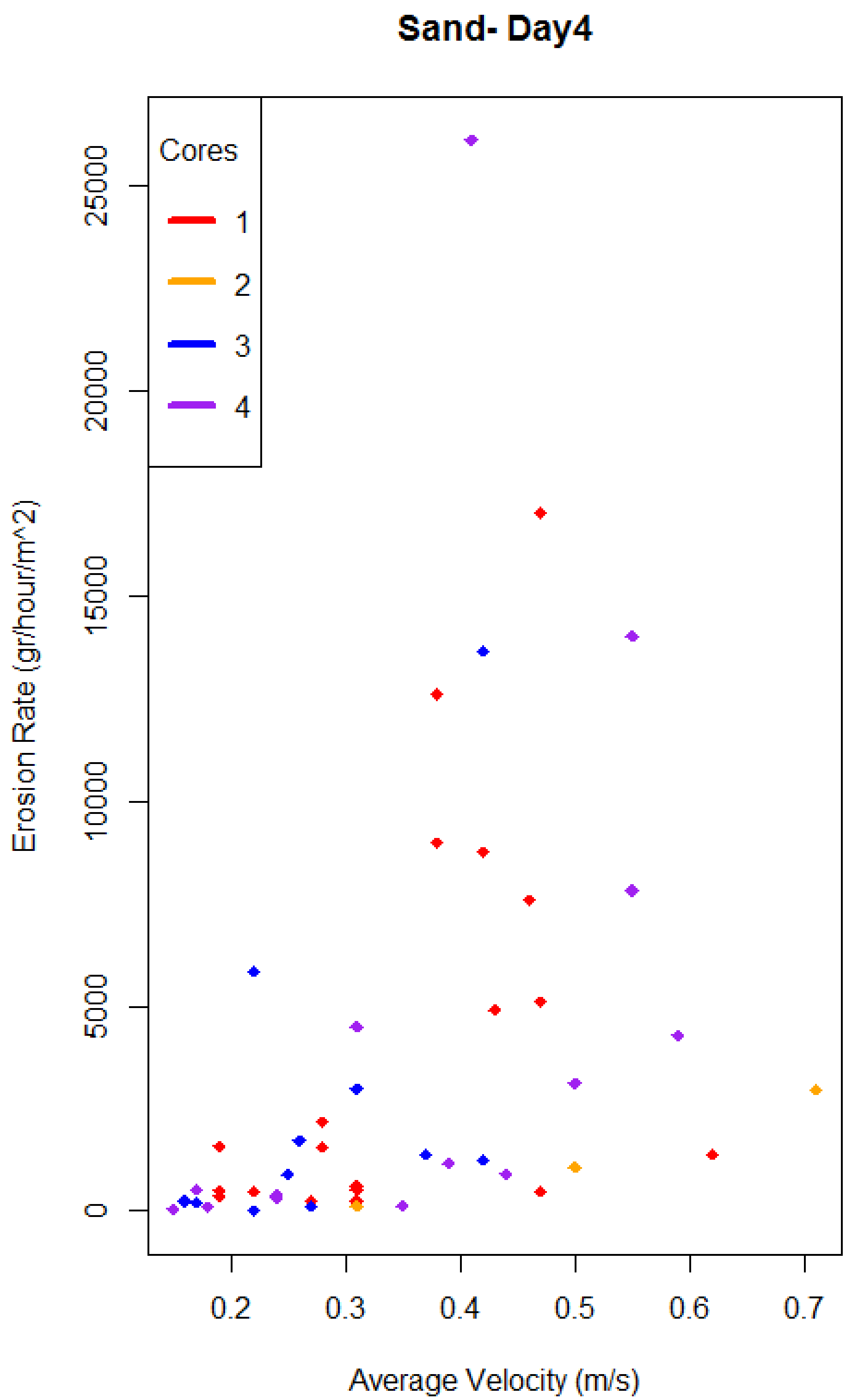
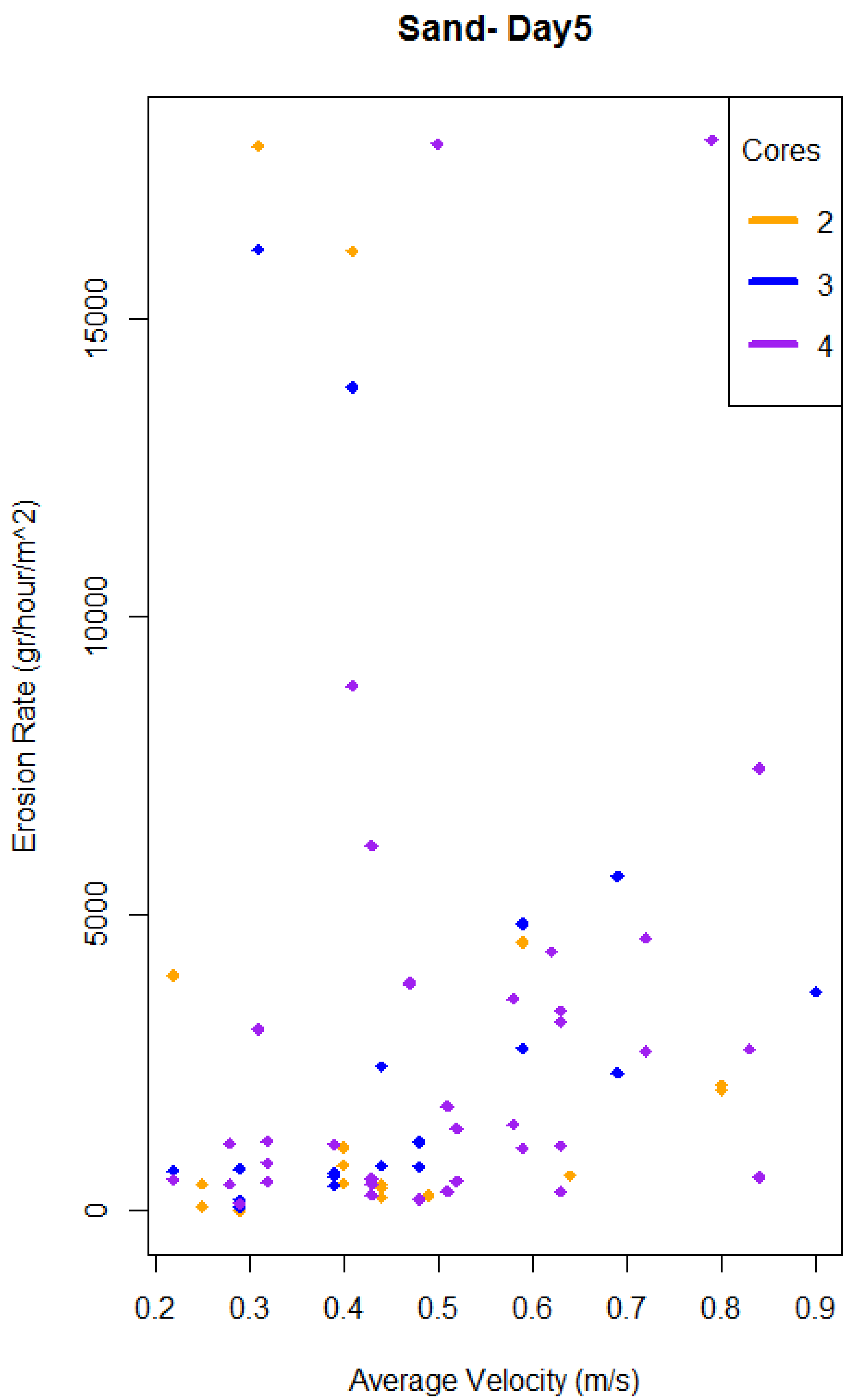

Sand- Day4
Cores
1
2
3
4
Erosion Rate (gr/hour/m^2)
0
5000
10000
15000
20000
25000
0.2
0.3
0.4
0.5
0.6
0.7
Average Velocity (m/s)

Figure 131



Sand- Day5
Cores
2
3
4
Erosion Rate (gr/hour/m^2)
0
5000
10000
15000
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Average Velocity (m/s)

Figure 132

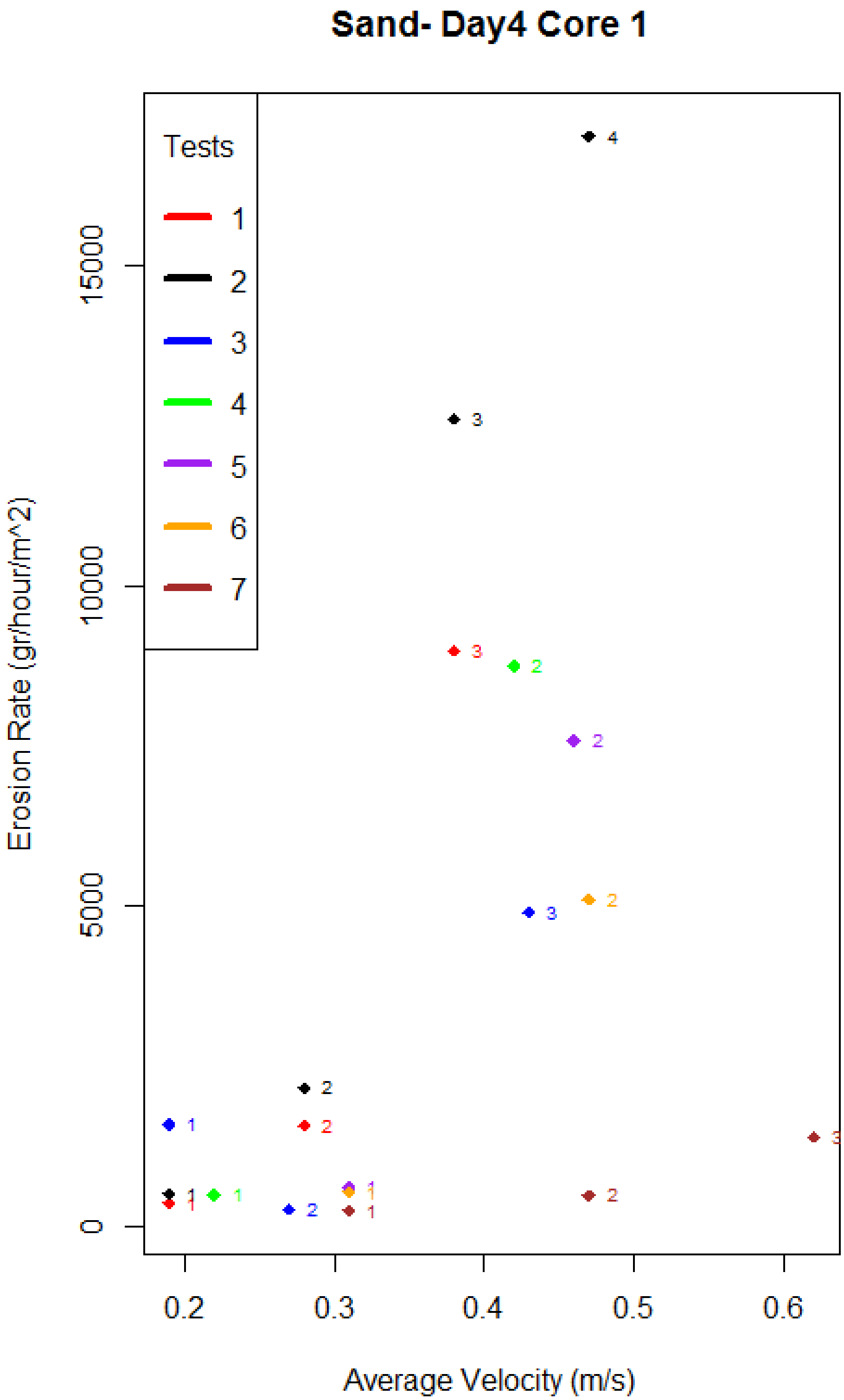

Sand- Day4 Core 1
Tests
1
2
3
4
5
6
7
Erosion Rate (gr/hour/m^2)
0
5000
10000
15000
0.2
0.3
0.4
0.5
0.6
Average Velocity (m/s)

Figure 133

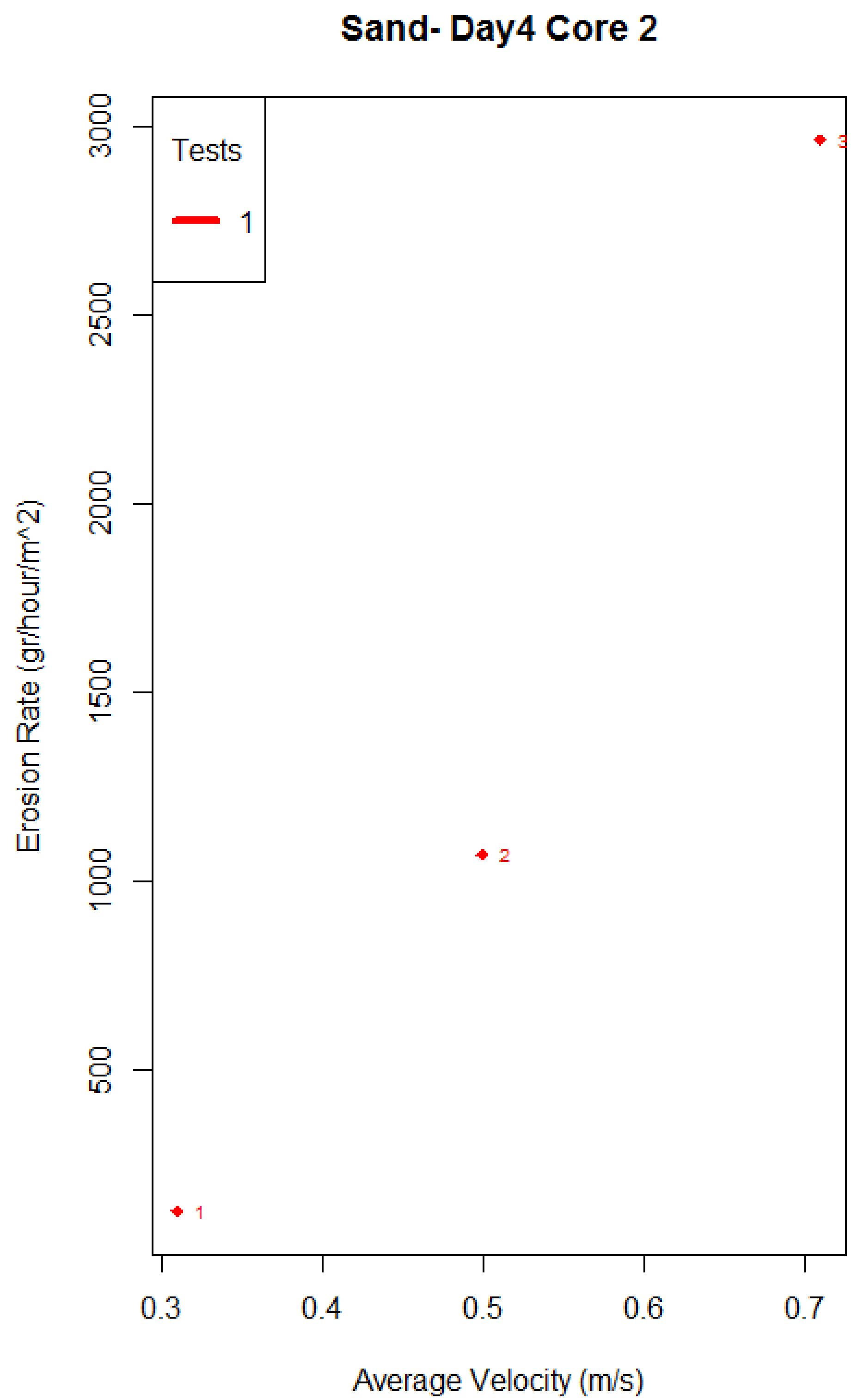

Sand- Day4 Core 2
Tests
1
3000
2500
2000
1500
1000
500
Erosion Rate (gr/hour/m^2)
3
2
1
0.3
0.4
0.5
0.6
0.7
Average Velocity (m/s)

Figure 134

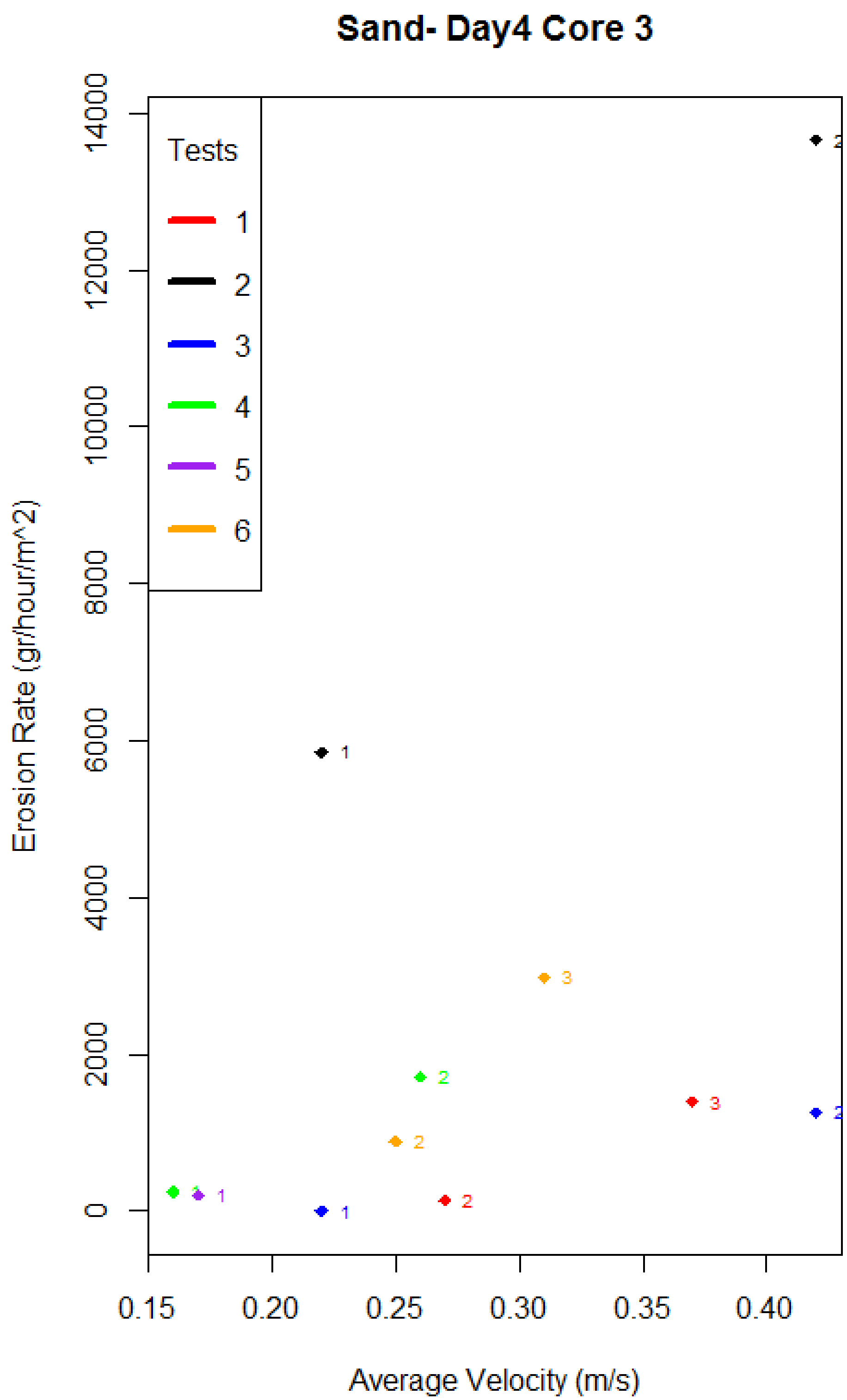

Sand- Day4 Core 3
Tests
1
2
3
4
5
6
Erosion Rate (gr/hour/m^2)
Average Velocity (m/s)
0
2000
4000
6000
8000
10000
12000
14000
0.15
0.20
0.25
0.30
0.35
0.40

Figure 135

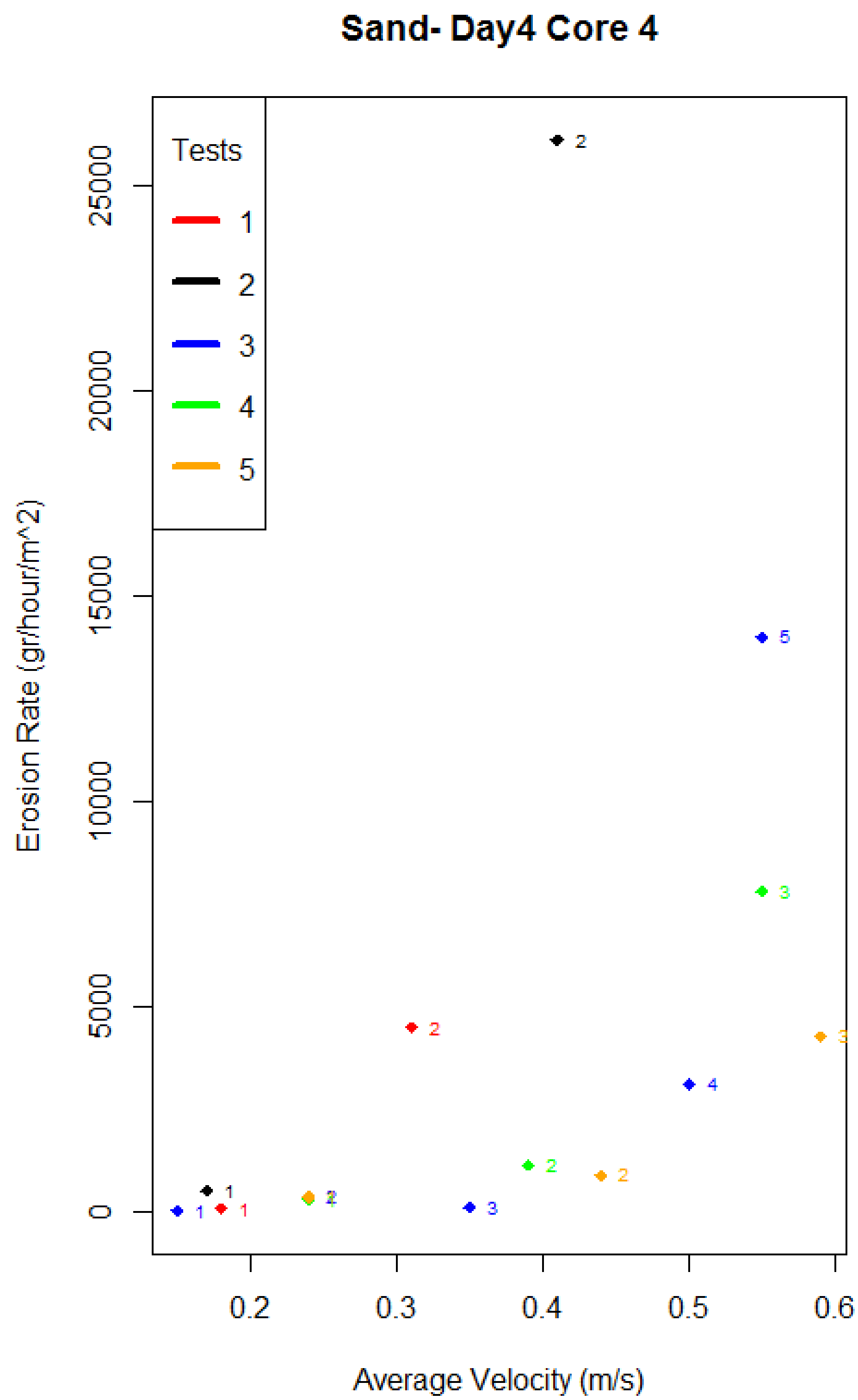

Sand- Day4 Core 4
Tests
1
2
3
4
5
Erosion Rate (gr/hour/m^2)
25000
20000
15000
10000
5000
0
0.2
0.3
0.4
0.5
0.6
Average Velocity (m/s)

Figure 136

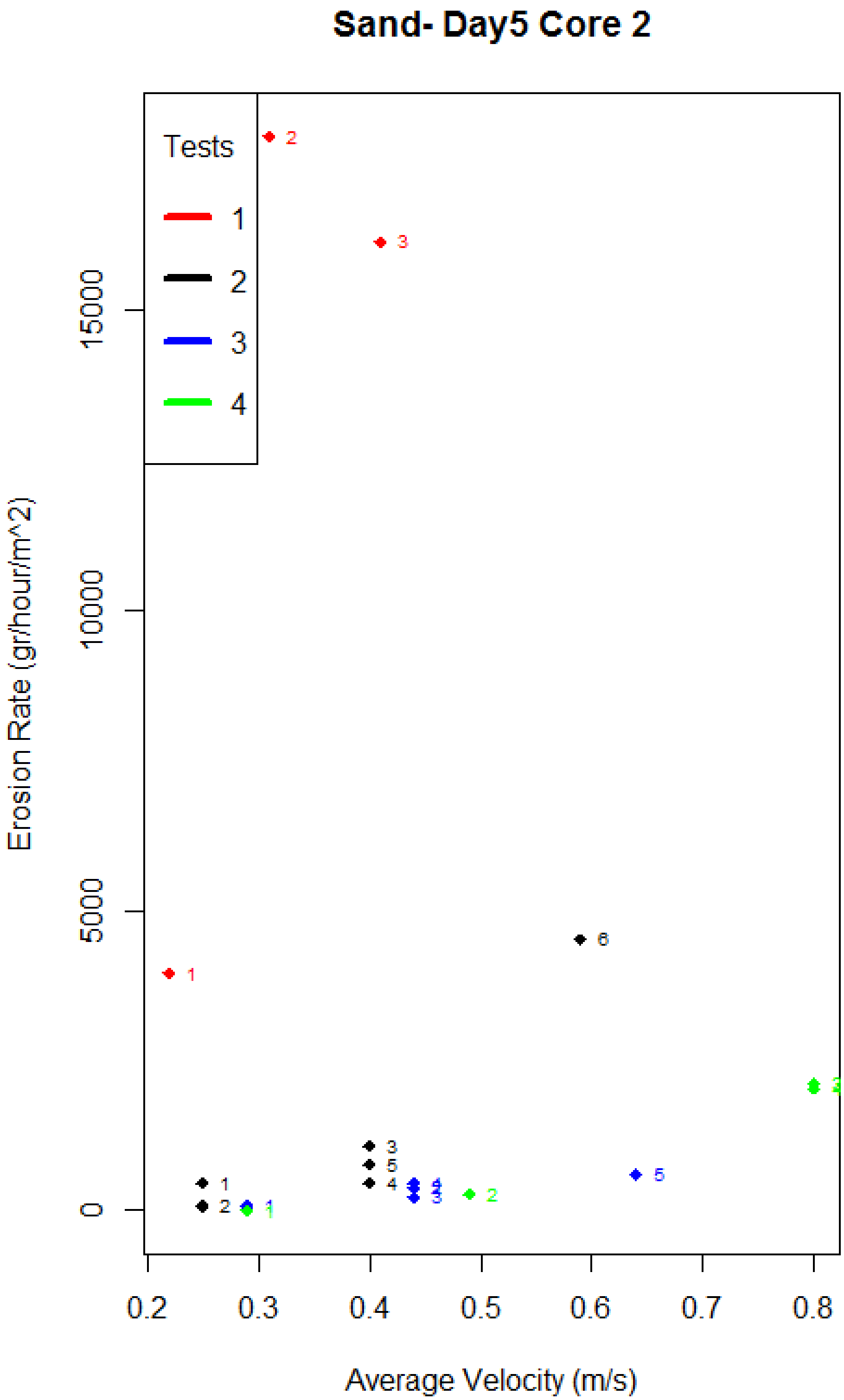

Sand- Day5 Core 2
Tests
1
2
3
4
Erosion Rate (gr/hour/m^2)
15000
10000
5000
0
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Average Velocity (m/s)

Figure 137

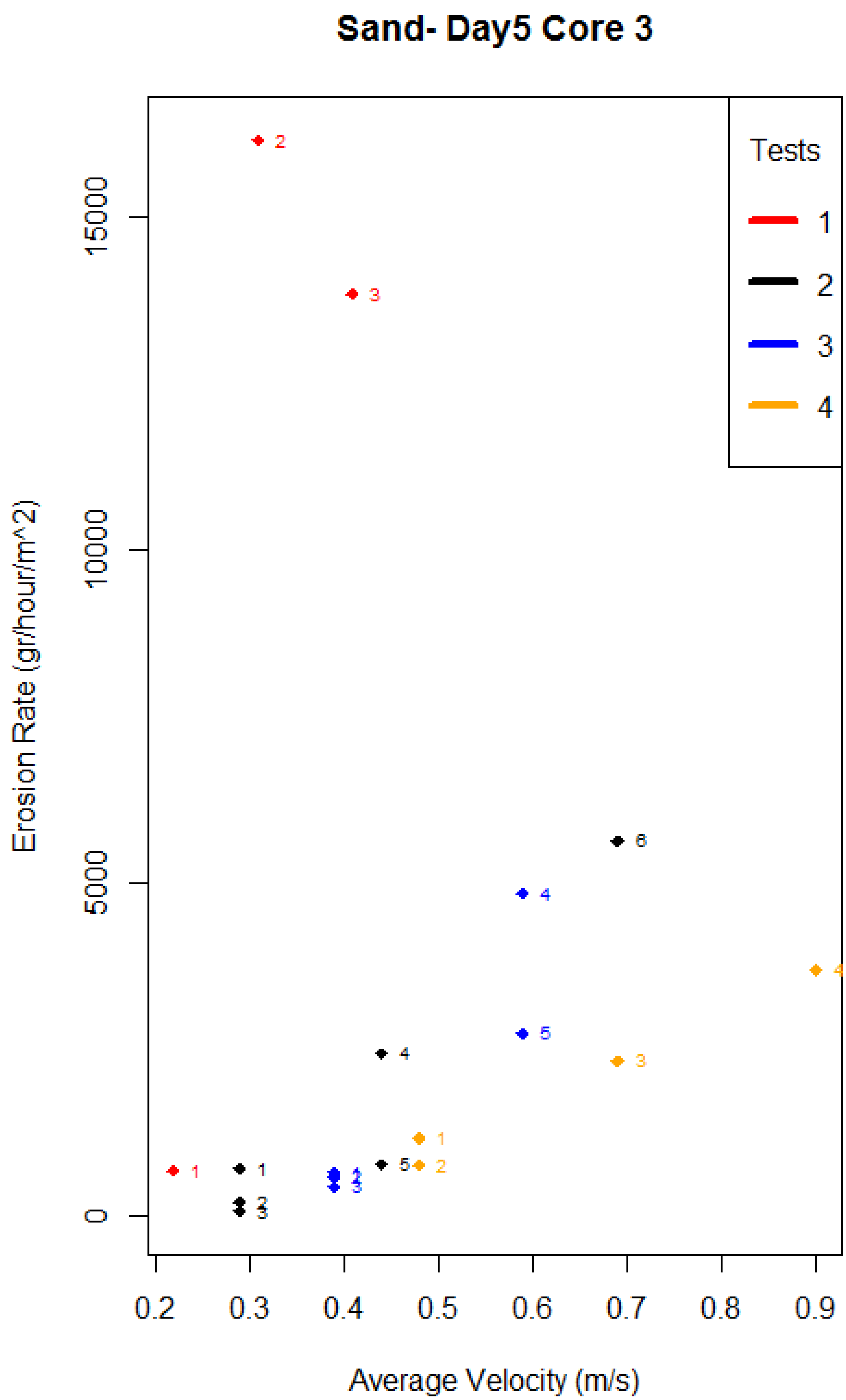
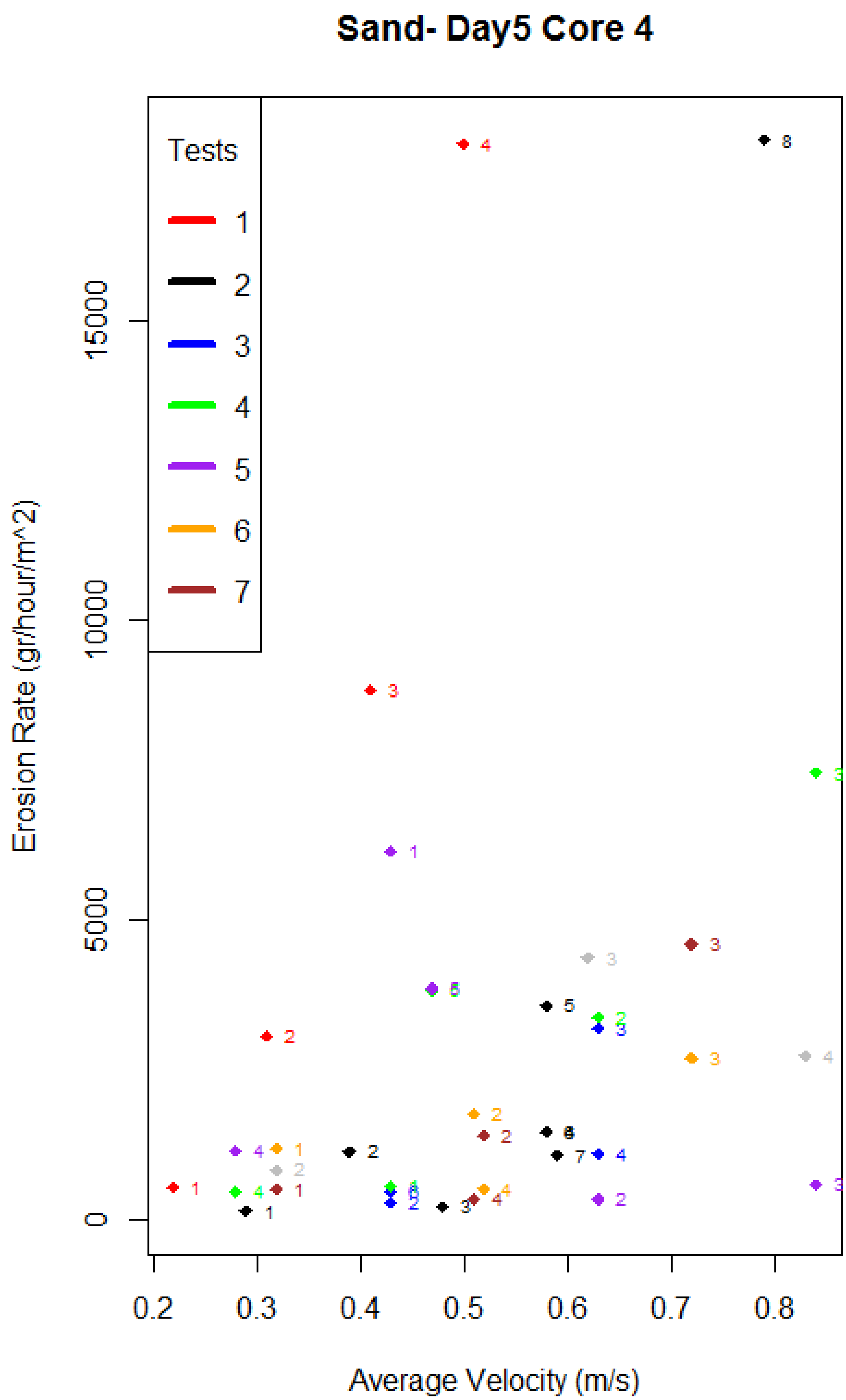

Sand- Day5 Core 3
Tests
1
2
3
4
Erosion Rate (gr/hour/m^2)
0
5000
10000
15000
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Average Velocity (m/s)

Figure 138



Sand- Day5 Core 4
Tests
1
2
3
4
5
6
7
Erosion Rate (gr/hour/m^2)
Average Velocity (m/s)
0
5000
10000
15000
0.2
0.3
0.4
0.5
0.6
0.7
0.8

Figure 139

Appendix C

ESETM Users Manual and Device Documentation