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# SEDIMENT BASED TURBIDITY ANALYSES FOR REPRESENTATIVE SOUTH CAROLINA SOILS

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A Thesis
Presented to
the Graduate School of
Clemson University

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In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Biosystems Engineering

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by
Katherine E. Resler
August 2011

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Accepted by:
Dr. Calvin B. Sawyer, Committee Chair
Dr. John C. Hayes
Dr. Charles V. Privette, III

# ABSTRACT

Construction activities have been recognized to have significant impacts on the environment. Excess sediment from construction sites is frequently deposited into nearby surface waters, negatively altering the chemical, physical and biological properties of the water body. This environmental concern has led to strict laws concerning erosion and sediment control, such as imposing permit conditions that limit the concentration of suspended solids that can be present in effluent water from construction sites. However, sediment concentration measurements are not routinely used to detect and correct short-term problems or permit violations because laboratory analysis of sediment concentrations is time-consuming and costly. Nevertheless, timely, accurate field estimation of sediment loading could be facilitated through the development of empirical relationships between suspended solids and turbidity.

Previous research indicates that turbidity measurements may be a more practical method of estimating sediment loads by indirectly relating sediment concentration to turbidity. In addition, recognition of turbidity as an indicator of pollution in surface runoff from disturbed areas has resulted in efforts by the U.S Environmental Protection Agency (EPA) to implement turbidity effluent limitation guidelines to control the discharge of pollutants from construction sites. Therefore, given the importance of a proposed turbidity limit, focus of this research is to determine relationships between representative soils and corresponding turbidity as a function of suspended sediment concentration and sediment settling. Turbidity is not only a function of suspended sediment concentration, but also of particle size, shape, and composition; so this research was needed to analyze turbidity responses based on sediment characteristics of representative South Carolina soils.

First, accuracy and precision of commercially available nephelometers needed to be quantified for use in subsequent sediment/ surface water analysis and potential regulatory compliance. Analysis of accuracy and precision for instruments showed that even though meters may be very precise, they could also be inaccurate. However, three of the four meters that performed well provided statistically accurate and precise results. It was also found that formazin calibration standards may be a better standard than AMCO EPA standards for surface water analysis.

Utilizing representative South Carolina soils, both relationships of turbidity to sediment concentration and turbidity to settling time were used to form mathematical correlations. Turbidity versus suspended sediment concentration and turbidity versus settling time correlated well when top soil and subsoils were classified based on their predominant South Carolina region and their measured clay content. Derived trends for suspended sediment concentration to turbidity correlated well with either a linear or log relationship ($R^2$ values ranging from 0.7945 to 0.9846) as opposed to previous research utilizing a power function or the assumption of a one-to-one relationship. For the correlation of turbidity and sediment settling time, trends were well correlated with a power function ($R^2$ values ranging from 0.7674 to 0.9347). This relationship suggests Stoke's Law was followed; where smaller particles remain in suspension longer and contribute more to turbidity compared to soils with less clay content.

Altogether, results of this research provide a step in determining potential site-specific equations relating sediment concentration to turbidity and sediment settling time to turbidity. With this knowledge, results could ultimately aid in the design of future sediment basins of South Carolina and provide information for potential regulatory compliance.

# DEDICATION

This thesis is dedicated, first and foremost, to my parents, Dave and Susan Resler, who passed on to me an insatiable thirst for knowledge and a desire to explore and discover. Due to their unshakable faith and support, I have learned the courage and tenacity to reach my goals and to always give my all. My work is also dedicated to my siblings, Chris, Jay, Nick, and Steph. Despite their insistence of having no involvement in my endeavor, countless phone calls providing support attest otherwise. Always ready to pick up my spirits and to offer me much needed encouragement, to my siblings I owe a debt of gratitude. And finally, I dedicate this work to my grandparents. Grandma Jane and Pop-Pop provided an irreplaceable support network close to Clemson for five years, not to mention endless hospitality, and I cannot thank them enough for the multitude of ways they have seen me through this journey.

# ACKNOWLEDGEMENTS

I first want to acknowledge the South Carolina Certified Erosion Prevention and Sediment Control Inspection Program for funding this research. Secondly, I want to express my sincere appreciation for my thesis advisor, Dr. Calvin Sawyer for the opportunity of a research assistantship. I am forever grateful for the rewarding and challenging experience. I also want to thank Dr. Sawyer as well as my committee members, Dr. John Hayes and Dr. Charles Privette for sharing their wisdom, enthusiasm and time throughout this project.

Finally, I would like to recognize several individuals that helped with the completion of this research by either assisting with soil collection or laboratory procedures. This includes Lance Beecher, Chris Bellamy, Stephen Pohlman Jr., Laurens County NRCS, SCDNR, and my fellow graduate students Clark Chewning, Zach Smoot and Elizabeth Tempel.

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**AASHTO**: American Association of State Highway and Transportation Officials
**APHA**: American Public Health Association
**ASD**: Aggregate Size Distribution
**ASTM**: American Society for Testing and Materials
**BMP**: Best Management Practice
**CWA**: Clean Water Act
**ELG**: Effluent Limitation Guideline
**EPA**: U.S. Environmental Protection Agency
**EPSC**: Erosion Prevention and Sediment Control
**JTU**: Jackson Turbidity Unit
**MCP**: Measured Clay Percentage
**NPDES**: National Pollutant Discharge Elimination System
**NPS**: Nonpoint Source
**NTU**: Nephelometric Turbidity Unit
**PCAL**: Primary Calibration Standard
**PSD**: Particle Size Distribution
**SCAL**: Secondary Calibration Standard
**SCDHEC**: South Carolina Department Health and Environmental Control
**SDVB**: Styrene Divinylbenzene
**SS**: Suspended Solids
**SSC**: Suspended Solids Concentration
**SSS**: Stock Standard Suspension
**TSS**: Total Suspended Solids
**USDA**: U.S. Department of Agriculture

# CHAPTER 1

# INTRODUCTON

Increased erosion caused by anthropogenic activities has been recognized as a priority environmental concern. Suspended solids from runoff, such as introduction through construction activity, are a potential water pollutant that can cause significant environmental impacts. Such impacts include adsorption of heavy metals, toxic substances, and biological pollutants to soil particles that are then transported to nearby waters. These chemical and biological pollutants can harm water quality and lead to fish kills and other ecological problems. This environmental concern has led to strict laws concerning erosion and sediment control. The outcome of the sediment and erosion control laws has resulted in construction sites using sediment basins as the conventional method of controlling sediment-laden runoff from these sites. Sediment basins are designed to slow the velocity of runoff and allow sediment particles to settle from the water column before discharge to surface waters offsite (Millen et al., 1997). The efficiency of these ponds is critical to controlling the amount of runoff from these sites.

Several measures can be used to determine the effectiveness of a sedimentation basin including trapping efficiency, average effluent concentration, peak effluent concentration and peak effluent settleable solids (Hoechst, 1997). Trapping efficiencies are the most common performance standard and are generally calculated with the use of sediment concentration (Mitchell, 2000). Water samples from influent and effluent of the basin must be taken to the laboratory and analyzed for sediment content. Methods to obtain the amount of solids contained in stormwater samples includes filtering water, then drying and weighing residue that has remained on a filter (Guo, 2006). Sediment concentrations from the influent and effluent waters are compared to determine the trapping efficiency of the pond using a mass balance approach (Mitchell, 2000).

Total suspended solids (TSS), resulting from erosion, are held in the water column by turbulence and encompass both inorganic solids, such as sand, silt, clay and organic solids, such as algae and detritus (Thackston and Palermo, 2000). Suspended solids measurements are not routinely used to detect and correct short-term problems or permit violations because sediment concentrations cannot be determined easily or quickly in the field, and transportation to a laboratory for analysis is time-consuming and can be costly (Thackston and Palermo, 2000). Timely, accurate field estimation of sediment loading could be facilitated through the development of precise relationships between suspended solids and turbidity. This approach has potential for monitoring any water quality constituent whose concentration is better correlated with an easily measured (in situ) parameter, such as turbidity.

Turbidity is an expression of the optical properties of a liquid that causes light rays to be scattered and absorbed rather than transmitted in straight lines through a sample (Anderson, 2005). Suspended solids have an optical impact on water quality by reducing light transmission through water; this is referred to as light attenuation (Davies-Colley and Smith, 2001). Cloudiness of water results from intense scattering of light by fine particles. Hence, waters with high concentrations of fine suspended sediment are described as turbid.

Turbidity measurements are gaining increased usage as an indicator of sediment pollution in surface runoff from disturbed areas such as active construction sites. Recent efforts by the U.S. Environmental Protection Agency (EPA) have resulted in turbidity effluent limitation guidelines and new source performance standards to control the discharge of pollutants from construction sites (EPA, 2009). Numeric turbidity limits for construction site discharge are expected to be required in the near future. Such requirements will likely include subjecting construction site stormwater discharges to a maximum allowable numeric turbidity effluent limit in nephelometric turbidity units (NTU) for sites disturbing 10 acres or more. Where turbidity output readings from nephelometers are given in nephleometric turbidity units (NTU) when scattered light is measured perpendicular to meter's incident beam.

Turbidity is not an inherent property of water, such as temperature or pH. However, the recognition of turbidity as an indicator of the environmental health of water bodies has increased, resulting in a growing demand for high-quality and objective turbidity measurements (Anderson, 2005). Therefore, given the importance of a proposed turbidity limit, the focus of this research is to better understand the relationship between turbidity and suspended sediments. To fulfill this goal, three objectives were established. These objectives are described below.

1. Compare selected turbidity meters to quantify accuracy and precision of each instrument for use in subsequent soil/water analysis objectives.
2. Establish empirically derived relationships between suspended solids concentration and turbidity for representative South Carolina soils.

3. Determine the correlation of turbidity with respect to settling time of the selected South Carolina soils.

Before relationships between turbidity and suspended sediments could be established, questions remain as to how samples should be obtained and processed to get reliable readings for future analysis. Therefore, this research will first compare the performance of various commercially available nephelometers to statistically quantify accuracy and precision of selected instruments for use in subsequent analysis and potential regulatory compliance.

A standard practice in relating suspended sediment to turbidity is to take the association as a one-to-one relationship (Hayes et al., 2001). Prior research, however, indicates this assumption is not accurate unless site-specific sampling is utilized to establish unique turbidity-suspended sediment relationships because turbidity is not only a function of TSS concentrations, but also of particle size, shape, and composition (Gippel, 1995: Hayes et al., 2001). As a result, this research is needed to analyze turbidity responses based on sediment characteristics for representative South Carolina soils.

Also, in order to separate particles from the runoff water in best management practices (BMPs) such as sediment basins, it is imperative to know sediment settling time and settling properties required to remove the particles from the water column. Accordingly, this research will also determine empirical relationships of sediment settling time to turbidity.

# CHAPTER 2

# LITERATURE REVIEW

## Suspended Solids

Increased nonpoint source (NPS) pollution in the United States has been recognized as a priority environmental concern. NPS pollution is generated from diffuse land use activities rather than originating from a single discrete point source, such as a pipe (USGAO, 1998). It is conveyed to waterways through natural processes, such as rainfall, storm runoff, or groundwater seepage that generally are associated with land management, construction, and urban runoff (USGAO, 1998). Recent studies and surveys by EPA and state water quality agencies suggest the majority of remaining water quality impairments result from nonpoint sources, urban stormwater discharges, and combined sewer overflows compared to point source pollution. Decreases in water quality from NPS pollution are generally reflected by increases of particulate matter (Packman et al., 1999) known as total suspended solids (TSS). According to the National Water Quality Inventory in 1998, suspended solids and sediment are the leading cause of water quality impairment of rivers and lakes (Swietlik, 2002).

TSS refers to the mass or concentration of both inorganic and organic solids that are held in the water column by turbulence (Thackston and Palermo, 2000). Inorganic solids can include sand, silt and clay particles, and organic solids may encompass algae, bacteria and detritus (Thackston and Palermo, 2000). Introduction of suspended solids

(SS) in the nation’s bodies of water may be caused by many sources, including (LSS, 2009):

- Soil erosion associated with agricultural practices and construction site runoff
- Domestic and industrial wastewater discharge
- Urban runoff from impervious surfaces
- Flooding and chronically increased flow rates
- Algae growth from nutrient enrichment (eutrophication)
- Dredging and channelization, and
- Removal of riparian vegetation and other stream bank disturbances

All streams carry SS under natural flow conditions. However, if concentrations are elevated from the above disturbances, this can lead to alterations to the physical, chemical and biological properties of a water body (Bilotta and Brazier, 2008).

Physical alterations caused by SS pose risks to water quality and aquatic organisms. Increased SS may result in a reduction of light penetration available for aquatic vegetation to grow by photosynthesis (LSS, 2009). A reduction in plant matter results in less energy, oxygen, and habitat for aquatic organisms. In addition, increased SS can negatively affect fish by limiting their ability to find food, increasing susceptibility to predators, and increasing gill abrasion (Packman et al., 1999). Water temperature alterations are another harmful physical stressor caused by increased TSS. Waters usually become warmer because of the greater heat absorbency of particulate matter and their ability to darken water and absorb more heat from sunlight (LSS, 2009). This thermal change can lead to negative effects on cold-water adaptive species (LSS, 2009). Lastly, upon deposition, increased SS loads can cause infilling of channels and reservoirs (Bilotta and Brazier, 2008).

Case studies involving the Chesapeake Bay, the Everglades, Milltown Reservoir, and Lake Hartwell have shown that suspended solids can be another pathway for biological and chemical contaminants to pollute the environment. Chemical contaminants are conveyed from adsorption sites on surfaces of sediments. Constituents of concern can include organic compounds, heavy metals, and some nutrients. Organic contaminants may encompass PCBs, PAHs present in fossil fuels, and pesticides from agricultural practices. Heavy metals include mercury, cadmium, lead, zinc, and chromium that could result from domestic and industrial wastes. Such contaminants are harmful because they can 1) bioaccumulate through the food chain (i.e. mercury); 2) they can settle with the sediments, where bottom-dwelling organisms are exposed to bioavailable contaminants, or 3) pollute groundwater via leaching from settled sediments (LSS, 2009). Sediments can also be a major source of the plant nutrients nitrogen, phosphorous and iron (LSS, 2009). One phenomenon, called eutrophication, is the result of waters becoming nutrient-rich, which can lead to increased biological productivity. The most severe consequence of eutrophication is the depletion of oxygen by the decomposition of organic matter (Boesch et al., 2001). Organic matter produced in surface waters sink to the bottom where it decomposes, consuming oxygen inventories that are not replenished by photosynthesis or mixing with oxygen-rich surface waters (Boesch et al., 2001). Lastly, there is a long-established link between sediment and biological pollutants, such as bacteria, in lentic systems (Sawyer, 2009). Clearly, SS are an important pollutant in surface waters; thus, quantifying and monitoring changes in suspended solids is critical for the nation's bodies of water.

TSS monitoring has become an integral part of programs to reduce nonpoint source pollution, such as those enacted by the Clean Water Act (CWA) (Dahlgren et al., 2004). The goal of the CWA is "to restore and maintain the chemical, physical and biological integrity of the Nation's waters" (EPA, 1972). The Clean Water Act is a comprehensive set of programs and requirements designed to address the complex problems caused by a wide variety of pollution sources (EPA, 1972). The primary focus of the CWA and subsequent 1977 amendments was the prevention of pollution discharges from point sources. In 1987, the act was again amended, this time to focus on non-point sources of pollution. One of the cornerstones of the Act is the National Pollutant Discharge Elimination System (NPDES), which regulates discharge of pollutants into waters of the U.S. Under the CWA, NPDES permits are issued to industrial, municipal, and other point source dischargers by either EPA or a delegated state agency (EPA, 1987).

Construction sites of a designated size or larger require NPDES permit coverage because erosion and sediment laden runoff can have a significant impact on water quality (EPA, 1987). The NPDES stormwater program requires construction site operators engaged in clearing, grading, and excavating activities that disturb one acre or more to obtain coverage under an NPDES general permit for their stormwater discharges. Most states, including South Carolina, are delegated to implement stormwater NPDES permitting programs. Permits require construction site operators to install and maintain erosion and sediment control measures to minimize stormwater from washing soil, nutrients, chemicals and other harmful pollutants into local water bodies.

## Construction Sites

According to United States General Accounting Office in 1997, without proper controls at construction sites, sediment loads can reach 35 to 45 tons per acre per year (USGAO, 1998). The two factors accounting for large amounts of sediment coming from construction sites include high erosion rates and high delivery rates.

Erosion is the wearing away of top soil and subsoil by means of running water, wind, ice or other geologic agents (EPA, 1992). The process of erosion features detachment of soil particles from a soil mass, transport of the detached sediment (i.e. via runoff) and deposition of the sediments, known as sedimentation (Johns, 1998). The two types of erosion include geologic erosion and accelerated erosion. Geologic erosion, also known as natural erosion, is caused by geological processes acting over long periods of time without human disturbance (Johns, 1998), whereas accelerated erosion is a more rapid erosion process influenced mostly by human activities (Johns, 1998). Accelerated erosion is most often caused by an alteration of the landscape, resulting from floods, earthquakes, or anthropogenic activities (Morrow et al., 2007). Hence, land disturbance from construction activity exposes large areas of bare soil to water and wind erosion, increases soil erosion rates 2,000 to 40,000 times undisturbed rates (Harbor, 1999: Johns, 1998), and results in approximately 80 million tons per year of sediment supplied to US lakes, rivers and waterways (Harbor, 1999).

More importantly, construction sites can create very high delivery rates compared to pre-construction conditions (NCDENR, 2009). During the initial phase of construction, vegetation is cleared, land is graded, and ditches or storm sewers are installed to provide good drainage. Such alterations increase runoff volume and change the timing, frequency and rate of discharge. Practices are now required to compensate for increased post-construction peak flows. However, these practices only control the rate of runoff volume leaving sites, but still allow increases in untreated runoff volume. Therefore, this drainage arrangement provides an efficient delivery system for pollutants to reach local waters.

## Sediment Control Structures

States implement specific stormwater management and sediment reduction regulations for land disturbing activities that stem from the Clean Water Act. For example, according to South Carolina’s Department of Health and Environmental Control (SCDHEC) regulations, construction site activities disturbing one acre or more require the development of erosion prevention and sediment control (EPSC) plans to achieve an 80 percent (minimum) design removal efficiency goal (SCDHEC, 2003). There are many practices that can be implemented on construction sites to reduce erosion. Consequently, even with very aggressive erosion prevention practices, soil erosion will still take place (Harbor, 1999). Therefore, to reduce eroded soil leaving sites, and meet an 80 percent removal efficiency goal, a variety of sediment trapping measures have traditionally been used. Gravitational settling from detention is the main process used to remove sediment from construction site runoff. Commonly used sediment trapping practices on sites include silt fences and sediment basins.

Silt fences are used as temporary perimeter controls that allow sediment to settle out of runoff. They are composed of a geotextile fabric with varying mesh sizes that are stretched across and attached to anchored wooden or metal stakes. The stakes are spaced at regular intervals along the site perimeter (Harbor, 1999). The bottom of the fence is buried in a trench to create a ponding area that allows time for sediment from runoff to settle before water passes through the geotextile (Harbor, 1999). If installed and maintained correctly, filtering efficiencies of silt fences can vary from 75 to 85 percent (EPA, 1992). Unfortunately, the vast majority of silt fences are installed incorrectly, resulting in ineffective sediment controls (Harbor, 1999).

Sediment basins are another common technique to capture sediment from stormwater runoff before it leaves the site. Sediment basins are engineered impoundment structures designed to temporarily detain surface runoff long enough to allow for sediments to settle out of water under the influence of gravity (Millen et al., 1997). They are installed prior to full-scale grading and remain in place until the disturbed portions of the drainage area are fully stabilized (EPA, 1993a). Sediment basins are usually used for drainage areas of five to 100 acres (EPA, 1993a) and are applicable in drainage areas where it is anticipated that controls, such as silt fences, will not be sufficient to prevent off-site transport of sediment (EPA, 1992). Sediment basins are popular with developers because they require less maintenance than other erosion and sediment control techniques and often can be converted into permanent urban runoff management ponds (Harbor, 1999). If sediment basins are converted into permanent stormwater management ponds, they must meet all regulatory requirements for wet or dry ponds (SCDHEC, 2005).

Several measures can be used to determine the effectiveness of a sedimentation basin including trapping efficiency, average effluent concentration, peak effluent concentration and peak effluent settleable solids (Hoechst, 1997). Trapping efficiencies are the most common performance standard and are generally calculated based on certain design requirements (Hoechst, 1997). For example, Figure 2.1 shows sediment basin details according to South Carolina's Regulation 61-9. The general design requirements are as follows (SCDHEC, 2005):

1. Minimum drainage area of five acres and maximum drainage area of 150 acres,
2. 80 percent design removal efficiency goal for TSS,
3. Basin Shape: The effective flow length is at least twice the effective flow width (L=2W minimum),
4. Outlet riser has discharge capacity for a 10-year, 24-hour storm event, and
5. Effluent 2-year and 10-year, 24-hour storm disturbed flow rates are less than or equal to pre-disturbance peak flow rates.

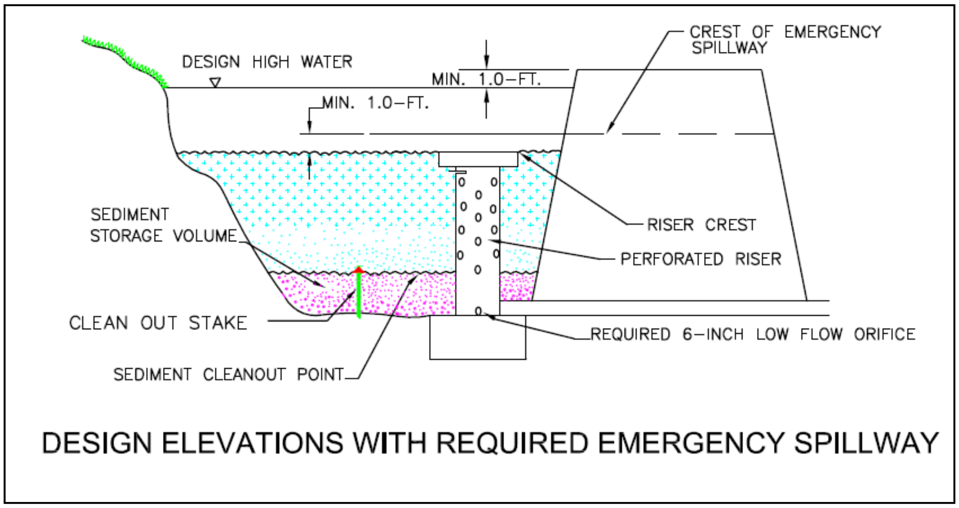

Figure 2.1. SCDHEC sediment basin specifications (SCDHEC, 2005).

For sediment basins to achieve certain sediment removal efficiencies, the basin size must be derived from calculating the rate at which sediments settle. Sediment basin settling theory is generally governed by Stokes' Law (Equation 1) to determine the settling velocity of particles (Haan et al., 1994). According to this law, a particle will settle in the vertical direction and accelerate to a constant velocity under the assumption that all particles have equal densities, are all spherical in shape, and all soil particles fall independent of each other under laminar flow conditions (Scott, 2000). The law states that particles larger in diameter sink farther and quicker than smaller particles when suspended in a liquid (Scott, 2000). Particles with greater surface area per unit of weight have greater frictional resistance and hence settle at slower velocities (Scott, 2000).

$$v_s = \frac{g(\rho_s - \rho)d^2}{18\mu} \tag{1}$$

$v_s$= settling velocity (m/s)

g= gravitational acceleration (m/s$^2$)

$\rho_s$= particle density (kg/m$^3$)

$\rho$= fluid density (kg/m$^3$)

d= particle diameter (m)

$\mu$= dynamic viscosity (Pa-s)

Along with calculating appropriate basin size, basin geometry is an important design parameter in maintaining higher sediment retention efficiencies (Millen et al., 1997). Poor efficiencies are often found in ponds that have areas of dead storage caused by short circuiting. Bypassing of these dead spaces renders these areas ineffective in the settling process (Mitchell, 2000). As such, South Carolina's R 61-9 requires the flow length to be at least twice the flow width to increase the flow path length to minimize dead spaces (SCDHEC, 2005).

Sediment basins must be maintained to work effectively. Such maintenance may include inspecting basins regularly for sediment deposition and removal of sediment once the basin reaches 50 percent of sediment storage volume (SCDHEC, 2005). Sediment basin effectiveness is a function of eroded particle size distribution of inflow sediment (Mitchell, 2000). Trapping efficiencies will be adversely affected by fine sediments that remain in suspension.

## TSS Measurements

Sediment trapping efficiency of a pond may be found by measuring the sediment concentration and flow rate of the runoff entering the structure and the sediment concentration and flow rate of the water leaving the detention structure. Total suspended solids are determined from laboratory analysis by the dry weight of suspended solids per unit volume of water, and are typically reported in milligrams of solids per liter of water (mg/L). There are three different laboratory methods to quantify the amount of solids contained in stormwater samples taken from the field (Guo, 2006). The three methods include EPA’s TSS Method (USEPA 1999), the American Public Health Association’s (APHA 1995) TSS Method (also referred to as Standard TSS Method), and American Society for Testing and Materials’ (ASTM) Suspended Sediment Concentration (SSC) Method (ASTM 1997). All three methods obtain the amount of solids contained in stormwater samples through filtering water, then drying and weighing residue that has remained on the filter (Guo, 2006). EPA’s TSS Method stirs and collects the sub-sample by pouring from the whole sample container, the Standard TSS Method stirs and collects the sub-sample using a pipette to draw from the whole sample container, and the ASTM’s SSC Method uses the whole sample (Guo, 2006).

Consequently, TSS measurements are not routinely used to detect and correct short-term problems or permit violations because sediment concentrations cannot be determined easily or quickly in the field, and transportation to a laboratory for analysis is time-consuming and can be costly (Thackston and Palermo, 2000). As a result, these laboratory methods are increasingly being replaced in favor of continuously-collected surrogate data for quantification of SSC that may be safer and (or) less expensive to obtain. Other common methods to evaluate stream-water suspended solids concentrations include transparency and turbidity measures. For example, the relation of turbidity to TSS can be used to estimate suspended loads as opposed to estimations based on water discharge from construction sites. This approach has potential for monitoring any water quality constituent whose concentration is better correlated with an easily measured parameter, such as turbidity.

## Turbidity

Turbidity is a measurement used to quantify water clarity (Davies-Colley and Smith, 2001). It is an expression of optical properties that cause light rays to be scattered and absorbed rather than transmitted in straight lines through a water sample (Anderson, 2005). Suspended solids have an optical impact on water quality by reducing light transmission through water; this is referred to as light attenuation (Davies-Colley and Smith, 2001). Materials contributing to suspended solids include soil particles (silts and clays), finely divided organic and inorganic matter, soluble organic compounds, plankton, and microscopic organisms. Typically, suspended soil particles exert the dominant influence on light attenuation in natural waters (Davies-Colley and Smith, 2001). Cloudiness of water results from intense scattering of light by fine particles typically with diameters smaller than 0.050 mm (Mitchell, 2000). Hence, waters with high concentrations of fine suspended sediment are described as turbid.

## Turbidity Measurements

From the early 20th century, turbidity was measured in Jackson turbidity units (JTU) using a Jackson Candle Turbidimeter (Borok, 2010). This method incorporated a visual method of looking at a black object at certain depths in water to determine turbidity of water (Mitchell, 2000). The turbidimeter consisted of a special candle and a flat-bottom glass tube. Measurements were made by slowly pouring a turbid sample in the tube until the image of the candle flame diffused to a uniform glow (Borok, 2010). Depth of the sample in the tube is read against the ppm-silica scale, and turbidity was measured in Jackson turbidity units (JTU). Jackson turbidimeters cannot measure turbidity lower than 25 JTU, are cumbersome, and depend on human judgment to determine the extinction point (Borok, 2010). Thus, photoelectric detectors were developed and became the accepted method to measure turbidity (Borok, 2010). Turbidity meters can be used in the field with portable meters, in the lab with benchtop meters, or as probes that can be installed in a stream or lake for continuous measurements. Turbidity is now commonly measured in nephelometric turbidity units (NTU) using nephelometric turbidimeters (Mitchell, 2000).

Nephelometric turbidimeters direct a beam of light into the side of a test sample, measure the amount of light that is reflected at a restricted range of angles (typically 90 degrees) by any particles present, and compare it to the light scattered by standard reference suspensions (Mitchell, 2000 and Borok, 2010). Figure 2.2 displays the basic design for nephelometric turbidimeters where scattered light is captured by a photodiode, which produces an electronic signal that is converted to a turbidity value reported in NTUs (ISO, 1999). Two of the most commonly used nephelometric turbidimeters include nephelometers and near infrared turbidimeters.

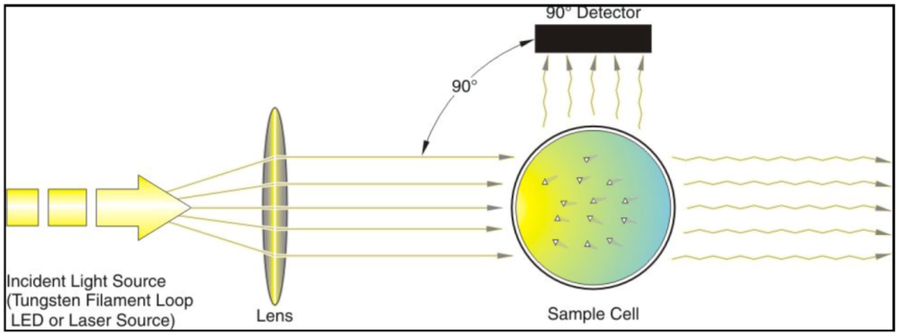

Figure 2.2. Basic turbidimeter design using nephelometric measuring technique (Sadar, 2004).

Nephelometers measure light that has been scattered at a specific angle of 90 degrees from the main light path (EPA, 1993b). Generally, commercially available nephelometers are compliant with EPA's Method 180.1 for determining turbidity by nephelometry (Borok, 2010). Along with the specified angle of 90 degrees, nephelometers under EPA's Method 180.1 require the light source to be a tungsten lamp operating at a color temperature between 2200-3000 K. The light source is a light-emitting diode where the light path is designed to minimize stray light falling on the detector (Thackston and Palermo, 2000). Therefore, a zero reading means no light scattered at 90 degrees (±30 degrees) from the main light path and implies no turbidity (Thackston and Palermo, 2000). Nephelometers must be standardized against either a primary formazin suspension with a value of 4000 NTUs (which can be diluted to desired NTU values) or a commercially available polymer standard identified as AMCO-AEPA-1 (EPA, 1993b).

Formazin was established as the first calibration standard for turbidity meters in the 1950's. Since then, machine performance and EPA approval for meters is structured around formazin as the primary calibration standard (AMCOClear, 2010). Formazin suspensions exhibit a wide range of suspended particle size and shape. Typically, formazin particles are irregular in shape and range from 0.1 to 10.0 µm in size, closely matching the range of particulates, 0.2 to 50 µm, found in real world samples (Hach, 2011). The highly predictable light-scattering properties of formazin are the basis of algorithm design for nephelometric instruments. The primary formazin suspension is a stock standard suspension (SSS) that can be prepared following standard methods (APHA, 2005). While SSS can be prepared directly in the laboratory and used to create primary calibration standards (PCALs), the process is labor intensive, time consuming, and requires precise laboratory technique (Hach, 2011). Besides being the only primary standard, formazin is also the least expensive, premixed, commercially available turbidity standard (Downing, 2005). However, routine use of formazin SSS and PCALs have several notable disadvantages that include: 1) formazin's hydrazine sulfate is a carcinogen; 2) turbidity can vary by 2% from batch-to-batch; 3) the size, shape, and aggregation of formazin particles change with temperature, time, and concentration; 4) it settles in storage and must be mixed immediately prior to use; and 5) diluted formazin standards have a storage life as short as one hour (Downing, 2005). As a result, alternative standards, known as secondary calibration standards (SCALs), are created and typically supplied with purchase of turbidity meters. SCALs have been certified by the manufacturer to provide calibration results equivalent to those obtained when the instrument was calibrated with a primary standard (APHA, 2005). Available secondary standards include commercial stock suspensions of 4000 NTU formazin (i.e. StablCal), commercial suspension of microspheres of styrene divinylbenzene (SDVB) microspheres, and items supplied by instrument manufacturers (APHA, 2005). According to Method 180.1, SCALs are acceptable as a daily calibration check, but must be monitored on a routine basis for deterioration and subsequently replaced as required. All secondary standards change with time and must be replaced when their age exceeds shelf life. Deterioration can be detected by measuring the turbidity of the standard after calibrating the instrument with a fresh formazin or microsphere suspension (APHA, 2005).

Along with formazin calibration standards, EPA approved polymer suspensions in 1984 as a secondary calibration standard for turbidity meters under the name AMCO EPA (AMCOClear, 2010). It is made from SDVB microspheres and, unlike formazin, SDVB microspheres have uniform size, shape and particle size distribution. An example is displayed in Figure 3.3 (Downing, 2005). SDVB microspheres have a particle size distribution of 0.02 to 0.2 µm with a mean size of 0.121 µm (AMCOClear, 2010). Size distribution of SDVB spheres are adjusted to produce a formazin-equivalent response from a particular turbidity meter (Downing, 2005). SDVB standards are formulated for a specific make and model of turbidimeter, and therefore, cannot be used with a different manufacturer or model even though it conforms to the same standard method (Downing, 2005). Key benefits of SDVB standards are: 1) batch-to-batch variation in turbidity is less than 1%; 2) optical properties are constant from 10 to 30ºC; 3) one-year stability is guaranteed; 4) mixing and dilution are not required, and; 5) are not toxic (Downing, 2005).

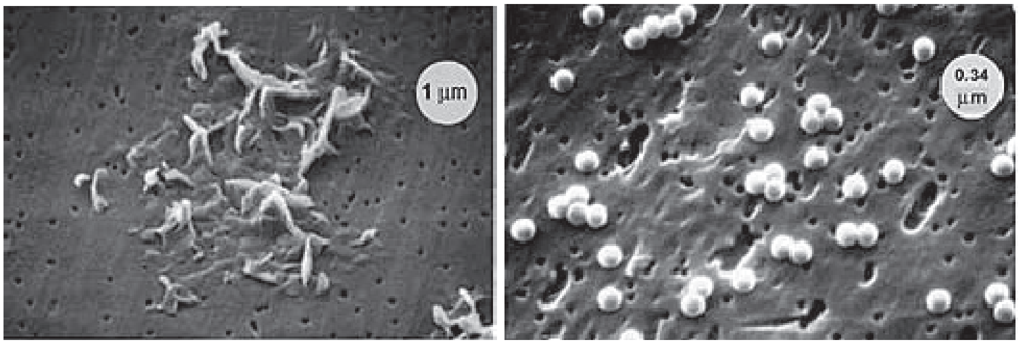

Figure 2.3. Scanning electron microscopy (SEM) images. On the left, formazin particles have many different shapes, whereas SDVB particles on the right are dimensionally uniform (Downing, 2005).

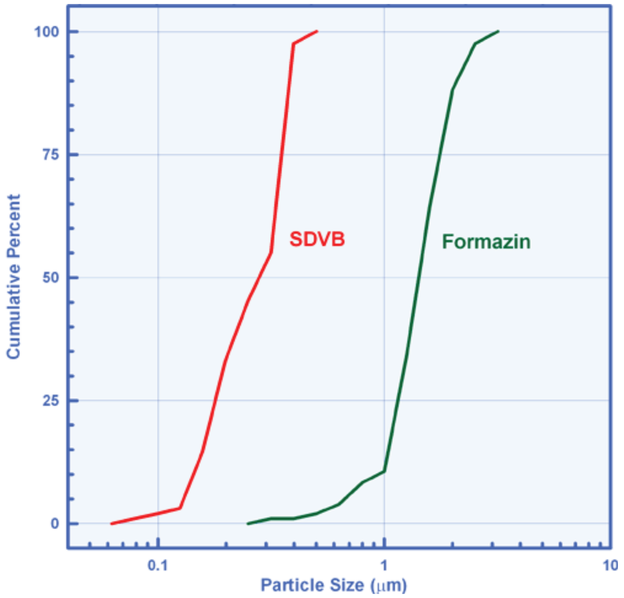

Figure 2.4. Graph compares the particle sizes of formazin and SDVB. The SDVB particles are about 1/5 that of formazin particles (Downing, 2005).

Other regularly accepted nephelometric turbidimeters are near infrared (IR) turbidimeters. These types of nephelometric turbidimeters are compliant with the International Standards Organization (ISO) standard 7027, which is commonly used in Europe (Borok, 2010). This standard requires that particle light scattering should be measured in near infrared (wavelength 860±60 nm) with a light-emitting diode (LED) as the instrument's light source (ISO, 1999). Also, the detector angle must not exceed ±2.5 degrees from the 90-degree incident path (Borok, 2010).

Turbidity meters vary in design, such as optical design of spectral power of the light source, spectral sensitivity of the detector, angular scattering range, and optical geometry (Pfankuche and Schmidt, 2003). As a result, meters are highly instrument-specific turbidity measurements in spite of identical calibration to formazin (Pfankuche and Schmidt, 2003). For example, infrared turbidimeter beams are unaffected by light absorbance of particles (usually dissolved organic compounds), whereas visible light turbidimeters are more sensitive to scattering from fines (Packman et al., 1999).

## Future Turbidity-Based Regulations

Turbidity has been recognized as an indicator of pollution in surface runoff from disturbed areas. In December 2009, EPA released turbidity effluent limitations and new source performance standards to control discharge of pollutants from construction sites (EPA, 2009). Regarding turbidity, the final rule subjected discharges from construction sites disturbing 20 or more acres of land at one time to comply with a numeric effluent limit of 280 NTU, starting in August of 2011 (EPA, 2009). By February 2014 the limitation would apply to all construction sites disturbing 10 or more acres (EPA, 2009). Interestingly, the final rule does not prescribe specific requirements, such as frequency or location of monitoring related to construction activity (EPA, 2009). Subsequent to the proposed final rule, multiple petitions for reconsideration pointed out potential error in calculating the numeric limit of 280 NTU (EPA, 2010). As a result, EPA concluded that it improperly interpreted the data and is currently reevaluating the numeric effluent limitation of 280 NTU. EPA intends to publish the corrected final rule by May 30, 2011 so that the revised limitation can be effective by June 29, 2011 for its Construction General Permit (EPA, 2010).

## Relationships to Total Suspended Solids

Optical gauges are widely used devices to monitor TSS concentrations indirectly since they are generally sensitive to a wide concentration range of TSS and are relatively inexpensive (Foster et al., 1992). Although most are suited to the concentration range of 0-1000 mg/L, higher concentrations can be determined, but these yield a decrease in sensitivity (Foster et al., 1992). Therefore, nephelometric turbidity measurements are gaining recognition because NTU units have been shown to relate to TSS concentrations in many water bodies in regions around the world (Packman et al., 1999). This is because the scattering coefficient measured at an angle of 90 degrees behaves almost proportionally to suspended particle concentration when sensors are calibrated to give a linear response to standards (Pfankuche and Schmidt, 2003). Thus, response to varying TSS concentrations should be linear if the physical properties of suspended particles are constant (Lewis, 1996). For instance, Lewis (1996) was able to estimate event sediment loads by predicting SSC from linear regressions on turbidity from five storm events on a creek.

Several other studies have illustrated adequate relationships from linear and other regression models of TSS concentration and nephelometric turbidity units in varying water bodies (Ellison et al., 2010; Grayson et al., 1995; Hayes et al., 2001; Packman et al., 1999; Pavanelli and Pagliarani, 2002; Pfankuche and Schmidt, 2003; Mitchell, 2002). However, previous research states turbidity should not be used as a substitute for sediment concentration without a careful study of the relationship between turbidity and suspended load for any proposed watershed monitoring (Pavanelli and Pagliarani, 2002). Hence, previous research stresses the importance of site-specific sampling in order to establish unique turbidity-suspended sediment relationships, (Hayes et al., 2001) because turbidity is not only a function of TSS concentrations, but also of particle size, shape and composition (Foster et al., 1992: Gippel, 1995). As a result of such site-specific properties, there are no universal relationships between turbidity and suspended solids (Borok, 2010). Variable optical properties have resulted in correlations with low coefficients of determination (Pfankuche and Schmidt, 2003). Such variability was generally attributed to changes in particle properties and particularly particle size (Pfankuche and Schmidt, 2003). Finer sediments have more reflective surfaces per unit mass, so, for constant SSC, sensor output increases as suspended sediment becomes finer (Schoellhamer and Wright, 2003), whereas a higher concentration of larger particles produces lower turbidity levels (Hayes et al., 2001). Since turbidity is often an indication of the quantity of clay particles in suspension, it would be beneficial to obtain a relationship between turbidity and particle size, as well as sediment concentration. Also, MacDonald (1991) and Lewis (1996) found that when a watershed displayed similar characteristics, such as soil type, variations either are generally not large or related to SSC, thus the relation between turbidity and SSC may be quite stable and precise (Hayes et al., 2001) .

## Particle Size Distributions & Particle Settling Velocities

In order to classify a soil for engineering purposes, one needs to know the distribution of particle sizes in a given soil mass. In order to separate particles from the runoff water in best management practices (BMPs) such as sediment basins, it is imperative to know sediment settling time and settling properties required to remove the particles from the water column (Haan et al., 1994: Tempel, 2011). As addressed earlier, particle diameter plays an irmportant role in calculating trapping efficiency of a sediment basin because particle sizes directly relate to settling velocity of the particles (Stoke's Law). Again, these velocities have an effect on required detention time and corresponding area of the pond (Mitchell, 2000).

The scope of this project is on behavior of particles smaller than 0.063 mm (silts and clays) because larger particles settle from surface water flow relatively quickly, whereas small particles remain in suspension longer, thus contributing as sources of turbidity. Therefore, along with determining the relationship between turbidity and particle size, this research will evaluate each soil's relationship of turbidity with respect to time.

A particle size distribution (PSD) curve is created to describe the range of various particle sizes in a given soil. A typical way to express particle size distribution is with a percent finer curve. Such a curve illustrates particle size weight classes versus the entire sample weight. According to the American Association of State Highway and Transportation Officials (AASHTO), particle sizes include four categories of gravel, sand, silt and clay. Their respective particle diameter sizes are listed below following USDA's particle size classification (Das, 2006).

1. Gravel: greater than 2 mm.
2. Sand: 2 mm to 0.05 mm.
3. Silt: 0.05 mm to 0.002 mm
4. Clay: less than 0.002 mm

# CHAPTER 3

# ACCURACY AND PRECISION OF PORTABLE TURBIDITY METERS

# ABSTRACT

EPA has published effluent limitation guidelines (ELGs) to control discharge of pollutants from construction sites. Numeric turbidity limits for construction site discharge are expected to be required in the near future. Such requirements will likely include subjecting construction site stormwater discharges to a maximum allowable turbidity numeric effluent limit in nephelometric turbidity units (NTUs) for sites disturbing 10 acres or more.

Turbidity is an expression of the optical properties of a liquid that causes light rays to be scattered and absorbed as measured by a nephelometer. Though constituents such as organic matter can impact water clarity, typically the inorganic fraction derived from particulate matter such as sediment dominates turbidity levels in surface waters. Recognition that water clarity is an important indicator of environmental health has increased, resulting in growing demand for high-quality and objective measurement. However, questions remain as to how samples should be obtained and processed to get reliable readings.

Given the importance of pending numeric effluent limitations related to turbidity, the focus of this research is to compare various nephelometers to quantify accuracy and precision of selected portable instruments for use in routine sediment/surface water analysis and potential regulatory compliance. Instruments were either provided with commercial stock suspensions of formazin (StablCal) or commercial suspension of microspheres of styrene divinylbenzene (SDVB) (AMCO EPA). In order to evaluate

meter accuracy and precision, experiments were conducted to compare their responses to true NTU values. This analysis examined performance of each meter when calibrated to manufacturer-supplied secondary calibration standards and when calibrated to primary calibration standards (PCALs).

Results indicated three of the four meters (Hach 1, Hach 2, and GW) were accurate and precise for both calibration studies, but did not fall within the claimed ±2% accuracy range as provided by manufacturer's specifications. The LaMotte meter did not perform as well, and even though the overall accuracies improved when calibrated to the formazin PCALs, the meter was inaccurate for higher turbidity readings. As for the meters' responses to varying field surface water samples, readings produced by the Hach 2100Q meters ('Hach 1' & 'Hach 2') had very similar results and did not change much for either calibration study, but were consistently higher than the LaMotte and GW meters. However, when meters were calibrated to PCALs, the range of readings per sample narrowed. Additionally, the LaMotte and GW meters may provide inaccurate results for higher turbidity readings that may typically contain a wider range of particle sizes. Variability among the Hach meters to the LaMotte and GW is most likely due to differences in formazin standards and SDVB standards. Results may have significant bearing on the construction and development industry as it prepares for proposed monitoring requirements associated with recently promulgated numeric effluent standards for turbidity.

# INTRODUCTION

Turbidity measurements are gaining increased usage as an indicator of pollution in surface runoff from disturbed areas such as active construction sites. Recent efforts by the EPA have resulted in proposed turbidity effluent limitations for discharge from construction sites. Turbidity is an expression of optical properties that cause light rays to be scattered and absorbed rather than transmitted in straight lines through a water sample (Anderson, 2005). Though constituents such as organic matter can impact water clarity, typically the inorganic fraction derived from particulate matter, such as sediment, dominates turbidity levels in surface waters (Davies-Colley and Smith, 2001). Cloudiness of water results from intense scattering of light by fine particles typically with diameters smaller than 0.050 mm (Davies-Colley and Smith, 2001). Hence, waters with high concentrations of fine suspended sediment are frequently described as turbid. Turbidity is a vivid visual indicator of pollution associated with sediment-laden runoff.

Turbidity is now commonly measured in nephelometric turbidity units (NTU) using nephelometric turbidity meters (Borok, 2010). Such meters direct a beam of light into the side of a test sample, measure the amount of light that is reflected at a restricted range of angles (typically 90 degrees) by any particles present, and compare it to light scattered by standard reference suspensions (Borok, 2010). Two of the most commonly used nephelometric turbidity meters include nephelometers and near infrared turbidity meters.

Nephelometers measure light that has been scattered at a specific angle of 90 degrees from the main light path (EPA, 1993b). Most commercially available meters comply with EPA's Method 180.1 for determining turbidity by nephelometry (Borok, 2010 and EPA, 1993b). Such instruments must be standardized against either a primary formazin suspension with a value of 4000 NTU (which can be diluted to desired NTU values) or a commercially available polymer standard identified as AMCO-AEPA-1 (EPA, 1993b).

Formazin was established as the first calibration standard for turbidity meters in the 1950's and since then, machine performance and EPA approval for meters is structured around formazin as the primary calibration standard (AMCOClear, 2010). Formazin suspensions are characterized by a wide range of suspended particle size and shape. Typically, formazin particles are irregular in shape and range from 0.1 to 10.0 µm in size, closely matching the range of particulates found in field samples (Hach, 2011). The highly predictable light-scattering properties of formazin are the basis of algorithm design for nephelometric instruments. The primary formazin suspension is a stock standard suspension (SSS) that can be prepared following standard methods (APHA, 2005). While SSS can be prepared directly in the laboratory and used to create primary calibration standards (PCALs), the process is labor intensive, time consuming, and requires precise laboratory technique (Hach, 2011). Besides being the only primary standard, formazin is also the least expensive premixed, commercially available turbidity standard (Downing, 2005). However, routine use of formazin SSS and PCALs have several notable disadvantages: 1) formazin's hydrazine sulfate is a carcinogen; 2) turbidity can vary by 2% from batch-to-batch; 3) the size, shape, and aggregation of formazin particles change with temperature, time, and concentration; 4) it settles in storage and must be mixed immediately prior to use; and 5) diluted formazin standards have a storage life as short as one hour (Downing, 2005).

As a result, alternative standards known as secondary calibration standards (SCALs) are created and typically supplied with purchase of turbidity meters. SCALs have been certified by the manufacturer to provide calibration results equivalent to those obtained when the instrument was calibrated with a primary standard (APHA, 2005). Available secondary standards include commercial stock suspensions of 4000 NTU formazin (i.e. StablCal), commercial suspension of microspheres of styrene divinylbenzene (SDVB) microspheres, and items supplied by instrument manufacturers (APHA, 2005). According to Method 180.1, SCALs are acceptable as a daily calibration check, but must be monitored on a routine basis for deterioration and subsequently replaced as required. All secondary standards change with time and must be replaced when their age exceeds shelf life. Deterioration can be detected by measuring the turbidity of the standard after calibrating the instrument with a fresh formazin or microsphere suspension (APHA, 2005).

Along with formazin calibration standards, EPA approved use of polymer suspensions in 1984 as a secondary calibration standard for turbidity meters under the name AMCO EPA (AMCOClear, 2010). It is made from SDVB microspheres and unlike formazin, the SDVB microspheres have uniform size, shape and particle size distribution (Downing, 2005). The SDVB microspheres have a particle size distribution of 0.02 to 0.2

µm with a mean size of 0.121 µm (AMCOClear, 2010). The size distribution of SDVB spheres is adjusted to produce a formazin-equivalent response from a particular turbidity meter (Downing, 2005). SDVB standards are formulated for a specific make and model of turbidimeter, therefore, cannot be used with one from a different manufacturer or model even though it conforms to the same standard method (Downing, 2005). The key benefits of SDVB standards are: 1) batch-to-batch variation in turbidity is less than 1%; 2) optical properties are constant from 10 to 30ºC; 3) one-year stability is guaranteed; 4) mixing and dilution are not required, and; 5) are nontoxic (Downing, 2005).

Turbidity is not an inherent property of water, such as temperature or pH, yet recognition of turbidity as an indicator of the environmental health of water bodies has increased, resulting in a growing demand for high-quality and objective turbidity measurements (Anderson, 2005). Questions remain as to how samples should be obtained and processed to get reliable readings. Therefore, given the importance of proposed turbidity limits, focus of this research is to compare various commercially available portable nephelometers to quantify accuracy and precision of the selected instruments for use in routine sediment/ surface water analysis and potential regulatory compliance.

# PROCEDURES

To evaluate instrument performance, accuracy is defined as the nearness of a measurement to the accepted or true value. Accuracy can be expressed as a range, about the true value, in which a measurement occurs. Instrument precision is defined as the tightness of measurements for one sample. Precision can be expressed as a range about the averaged reading (LaMotte, 2010).

Four commonly utilized and commercially available turbidity meters were selected for evaluation in this study (see Figure 3.1). Nephelometers chosen included two Hach 2100Q, one LaMotte 2020e and Global Water's 'GW' Turb430T[1]. Note that meters Hach 1 and 2 are the same model, and were selected to evaluate any statistical differences between two meters from the same manufacturer. Each meter specified compliance with EPA's Method 180.1, and meter specifications are provided in Table 3.1. Meters Hach 1 and 2 are both supplied with SCALs known as StablCal (a stable formazin secondary standard) to calibrate the meters, whereas the LaMotte and GW meters are supplied with AMCO EPA calibration standards. Experimental procedures are summarized and outlined in Table 3.2.

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[1] Disclaimer: Mention of a trade name does not imply endorsement of the product by Clemson University to the exclusion of others that might be available. Users are encouraged to fully evaluate the suitability of any equipment for their intended application.

Figure 3.1. Selected nephelometers. From left to right GW, Hach 1, and LaMotte.

Table 3.1. Manufacturer's provided specifications for selected meters.

| Meter | Accuracy | Precision | Price | Meter Range |
|---|---|---|---|---|
| Hach 1&2 | ±2% of true values from 0 to 1000 NTU | ±1% of the measured value | $930 | 0-1000 NTU |
| LaMotte | ±2% of true values from 0 to 100 NTU<br>±3% of true values above 100 NTU | 0.02 NTU of the measured value | $900 | 0-4000 NTU |
| GW | ±2% of true values from 0 to 500 NTU<br>±3% of true values 500 to 1100 NTU | ±1% of the measured value | $2100 | 0.01-1100 NTU |

Table 3.2. Experimental procedures summary.

| | Exp. 1 | Exp. 2 | Exp. 3a | Exp. 3b | Exp. 4a | Exp. 4b |
|---|---|---|---|---|---|---|
| Calibrated with | Supplied SCALs | Supplied SCALs | Supplied SCALs | Created PCALs | Supplied SCALs | Created PCALs |
| Tested Solution | Cecil TSS concentrations | All Supplied SCALs | Created PCALs | Created PCALs | Field Samples | Field Samples |

## Experiment 1: Concentration vs. Turbidity

Initially, known total suspended solids (TSS) concentrations of a Cecil soil series were tested in the Hach 1, LaMotte and GW meters when calibrated to their provided calibration standards. Cecil soil, a predominant sandy loam commonly found in Piedmont uplands of the southeastern U.S., was used to create several concentrations of TSS for analysis. First, a dry sieve analysis was performed where soils were oven dried at 105ºC and passed through a 230 sieve with a mesh opening of 0.063mm to obtain material for use in experimentation. Resulting soil material was weighed on an analytical balance to the nearest 0.0001 g to achieve concentrations of 3000, 2000, 1000, 500, 100, 50 and 25 mg/L. Each concentration was created individually and was mixed using a magnetic stir plate.

Each meter was calibrated as specified to the manufacturer's operating instructions and then the known concentrations were placed in corresponding sample vials for analysis. Each sample was read five times by each meter and then averaged (see Appendix A). Between each reading, the sample vial was gently agitated by inverting the vial roughly ten times to adequately suspend and disperse all sediment particles before replacing it into the turbidity meter (Hayes et al., 2001). Using standard pipette protocol, dilutions were made from the sample vial if concentrations were out of instrument turbidity range (see Table 3.1).

Meters did not produce the same turbidity readings for each known concentration and results are displayed in Figure 3.2. After performing an ANOVA two factor analysis without replication it was concluded that the meters were different (p-value less than

0.05), initially suggesting they may differ in the manufacturer’s calibration standards. Therefore, the following experiment was conducted to test the standards provided with each meter.

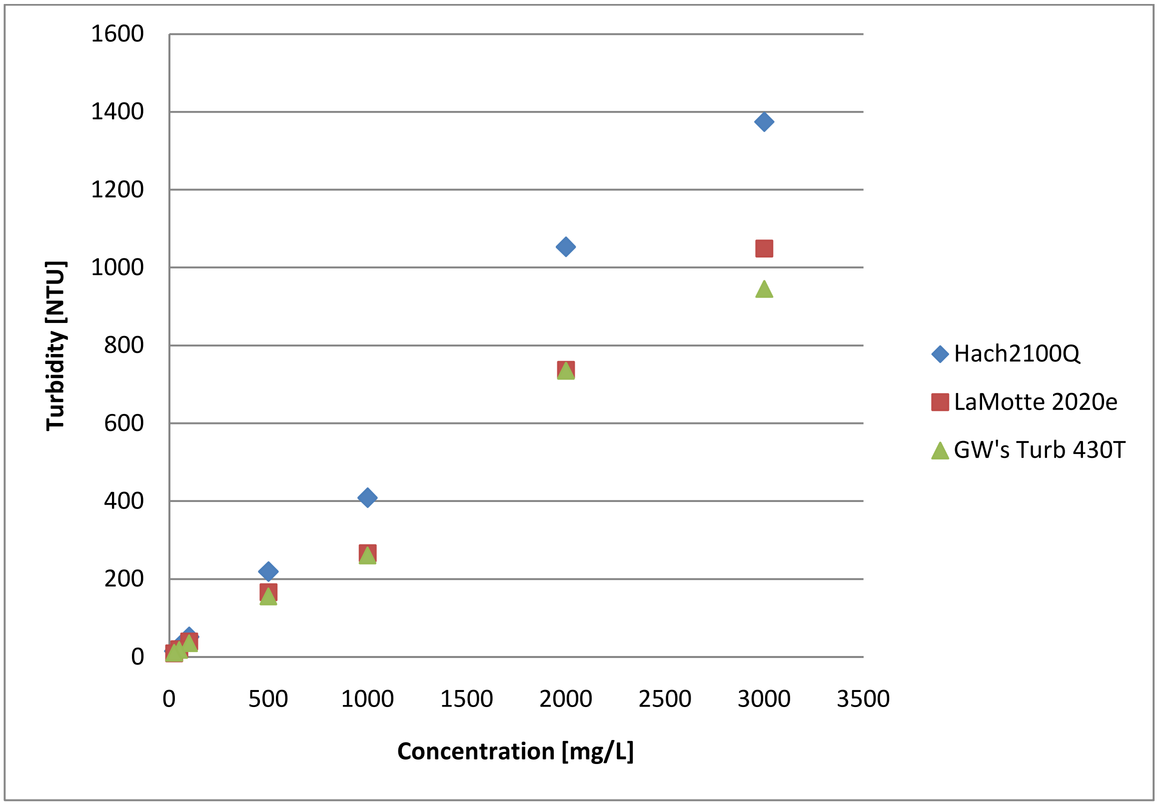

Figure 3.2. Meters’ turbidity responses to known Cecil concentrations.

## Experiment 2: Verification of Manufacturer Supplied Standards

For this experiment, meters Hach 1, LaMotte and GW were available to evaluate meter responses to all supplied calibration standards. Again, each meter was calibrated with its provided standards as specified in the manufacturer’s operating instructions.

First, standards from Hach 1 were placed in each meter (including Hach 1) to distinguish if subsequent readings gave the same result as the standard. Five readings were taken for each of Hach 1's standards, recorded and then averaged. The procedure was repeated using meters LaMotte and GW's calibration standards. Resulting tabular data are included in Appendix A.

Results indicated each meter was calibrated to its own standards. This also verifies that meters calibrated with SDVB standards (AMCO EPA) are formulated exclusively for the specified meter and cannot be used with different meters (Downing, 2005). Therefore to find true readings of each meter, the primary formazin stock standard suspension (SSS) with a value of 4000 NTUs was used for the following experiments.

## Experiment 3: Meter Accuracy and Precision

To evaluate meter accuracy and precision, the third experiment compared responses to true NTU values. This analysis examined meters' performance when calibrated to manufacturer-supplied secondary calibration standards and when calibrated to primary calibration standards (PCALs).

### *3a: Meters calibrated to supplied SCALs*

Preparation of NTU standards used the 4000 NTU primary formazin SSS. Following Standard Methods, dilutions with high-quality dilution water was used to create PCALs with values of 1, 10, 50, 100, 280, 500, 750 and 1000 NTU. First, one liter of the 1000 NTU standard was created from the 4000 NTU formazin primary standard and placed in an amber bottle. 100 milliliters of each standard was prepared from the 1000 NTU solution and placed in opaque plastic bottles to eliminate light penetration. Because hydrazine sulfate (constituent in formazin) is a carcinogen, all dilutions were executed under laboratory hood to avoid inhalation, ingestion and skin contact (APHA, 2005).

Meters were calibrated as specified in the manufacturer’s operating instructions with provided calibration standards. Each created NTU standard was placed in the meter’s specified sample vial, positioned in the turbidity meter five times, and the results were recorded. Between each reading, sample vials were carefully inverted ten times before being placed back in the meter. A replicated experiment was performed for statistical purposes. Resulting data tables are in Appendix A.

To determine meter accuracy for each sample, percent difference from the true value (value derived from formazin SSS) was calculated for each reading and then averaged among percent differences (Equation 2). Therefore meter accuracy, displayed in Table 3.3, is represented as an averaged percentage about the true value. To determine meter precision for each sample, the same five readings were utilized and averaged. Then, each reading’s percent difference from the averaged measured value was calculated and these five percent differences were averaged (Equation 3). Results are shown in Table 3.4 and are represented as an averaged percentage about the measured value.

$$Accuracy\ [\%] = \sum \overline{\left(\frac{|MR - TV|}{TV} * 100\right)}$$

(2)

MR= measured turbidity reading [NTU],

TV= true turbidity value [NTU]

$$Precision = \sum \overline{\left(\frac{MR - \overline{MR}}{\overline{MR}} * 100\right)}$$

(3)

MR= measured turbidity reading [NTU]

*3b: Meters calibrated to PCALs*

The fourth experiment was conducted to compare each meter's performance when calibrated to formazin primary calibration standards (PCALs). Therefore, values of the meters provided calibration standards created following the Standard Methods procedure above, and meters were calibrated as specified to the manufacturer's operating instructions using these PCALs.

The experiment was performed, as described above, to test each meter's readings of the created standards of 1, 10, 50, 100, 280, 500, 750 and 1000 NTU. Again, a replicated experiment for the meters calibrated to PCALs was executed for statistical purposes. To determine each meter's accuracy and precision, calculations described previously were performed with results shown in Tables 3.3 and 3.4.

### Experiment 4: Turbidity in Natural Water Samples

The final experiment was to evaluate meter response to surface water samples collected in the field from both disturbed and undisturbed sites. Since future use of these instruments will be to monitor field conditions, it was important to examine meter behavior with real surface water samples of unknown turbidity collected in the field.

Samples used for this experiment included three composites collected at the discharge point from an active construction site at varying time intervals after a rain event began, one sample from a golf course creek, and another sample from a botanical garden's pond. It was desired to get a variety of samples with varying TSS concentrations to evaluate meter range. Samples were mixed using a magnetic stir plate in the laboratory. Laboratory analysis was chosen over field practice because some of the samples needed to be diluted using laboratory techniques. This would eliminate field dilution errors when calculating actual turbidity readings.

Meters were calibrated to their provided calibration standards. Each field sample was drawn using a 10ml pipette, placed in the specified vial and positioned in the corresponding turbidity meter. Each sample was read five times and averaged. Sample vials were inverted ten times between each reading to adequately suspend and disperse all sediment particles before placing it into the turbidimeters. A total of five replications for each sample were analyzed. Dilutions were made from the main sample if the concentration was out of an instruments' turbidity range (see Table 3.1).

Finally, the same procedure was repeated except meters were calibrated to PCALs instead of the meter’s calibration standards. Resulting data tables are shown in Appendix A.

# RESULTS AND DISCUSSION

The goal of this paper was to compare accuracy and precision for selected portable turbidity meters that comply with Method 180.1. Computed results are presented in Tables 3.3-3.4 and also account for experimental error associated with the volumetric flasks used to create primary formazin standards.

In Table 3.3, for each meter, overall averaged percent error (“AVG”) from the true value was calculated. However, statistical calculations were computed without the meters’ averaged percent differences from the 1 NTU value because the low end produced a large discrepancy; and focus of this research is surface water samples that have typical values above 10 NTU. Overall accuracy improved somewhat for all meters when calibrated to the formazin PCALs by 0.34%, 0.52%, 8.57% and 1.28% for Hach 1, Hach 2, LaMotte and GW, respectively (Table 3.3). However, meters Hach 1, Hach 2, and GW for both calibration studies are slightly above the specifications’ claimed ±2%. Even though LaMotte meter improved when calibrated to the PCALs, the instrument still provided statistically inaccurate results, especially for readings above 500 NTUs. The LaMotte meter provided significantly higher percent differences compared to other meters and even deviated from single digit percent differences at higher turbidity readings.

As for the meters’ repeatability of a sample, Hach 1, Hach 2 and GW, for both calibration studies, fell within the claimed ±1% of the measured value (Table 3.4).

LaMotte was slightly above ±1% of the measured value, but improved when calibrated to PCALs.

Table 3.3. Meter Accuracy: averaged percent difference about the true value for each meter[2].

| | **Hach 1** | | **Hach 2** | | **LaMotte** | | **GW** | |
|---|---|---|---|---|---|---|---|---|
| PCAL values[3] [NTU] | Calibrated to provided SCALs | Calibrated to PCALs | Calibrated to provided SCALs | Calibrated to PCALs | Calibrated to provided SCALs | Calibrated to PCALs | Calibrated to provided SCALs | Calibrated to PCALs |
| 1 | 55.6 | 44.0 | 53.0 | 54.0 | 61.1 | 23.6 | 6.20 | 31.2 |
| 10 | 6.70 | 6.20 | 5.70 | 5.00 | 14.9 | 6.13 | 3.32 | 0.50 |
| 50 | 1.58 | 2.50 | 1.52 | 1.00 | 16.4 | 5.14 | 3.70 | 3.12 |
| 100 | 3.96 | 0.99 | 1.63 | 0.56 | 10.1 | 7.24 | 5.00 | 2.15 |
| 280 | 4.68 | 3.18 | 3.21 | 2.50 | 3.14 | 7.64 | 3.39 | 2.11 |
| 500 | 2.20 | 2.72 | 2.56 | 2.46 | 22.1 | 6.54 | 4.48 | 3.10 |
| 750 | 1.53 | 2.27 | 2.15 | 2.20 | 78.1 | 47.9 | 2.72 | 1.03 |
| 1000 | 1.12 | 1.54 | 1.24 | 0.62 | 21.3 | 24.2 | 1.11 | 2.79 |
| **AVG** | **3.11** | **2.77** | **2.57** | **2.05** | **23.7** | **14.9** | **3.39** | **2.11** |

Table 3.4. Meter Precision: averaged percent difference about measured value for each meter[4].

| | **Hach 1** | | **Hach 2** | | **LaMotte** | | **GW** | |
|---|---|---|---|---|---|---|---|---|
| PCAL values[5] [NTU] | Calibrated to provided SCALs | Calibrated to PCALs | Calibrated to provided SCALs | Calibrated to PCALs | Calibrated to provided SCALs | Calibrated to PCALs | Calibrated to provided SCALs | Calibrated to PCALs |
| 1 | 6.99 | 2.24 | 5.00 | 2.69 | 9.93 | 9.81 | 7.50 | 18.92 |
| 10 | 1.69 | 1.13 | 0.75 | 0.57 | 1.34 | 4.35 | 0.50 | 0.93 |
| 50 | 0.37 | 0.72 | 0.61 | 0.40 | 0.34 | 0.40 | 0.73 | 0.38 |
| 100 | 0.69 | 0.54 | 0.49 | 0.71 | 0.47 | 0.49 | 0.93 | 0.60 |
| 280 | 1.05 | 0.59 | 0.41 | 0.22 | 0.10 | 0.45 | 0.67 | 0.58 |
| 500 | 0.82 | 1.15 | 1.29 | 0.84 | 2.10 | 1.03 | 0.54 | 0.31 |
| 750 | 1.19 | 0.70 | 0.70 | 0.68 | 4.83 | 1.33 | 0.88 | 1.22 |
| 1000 | 1.21 | 0.77 | 0.65 | 0.46 | 1.07 | 0.42 | 0.89 | 0.99 |
| **AVG** | **1.00** | **0.80** | **0.70** | **0.56** | **1.46** | **1.21** | **0.73** | **0.72** |

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[2,4] Overall averaged percent error ('AVG') from the true value was calculated without the meters' averaged percent differences from the 1 NTU value.

[3,5] Known NTU values ('PCAL values') were derived by diluting 4000 NTU primary formazin SSS with distilled (DI) water.

Finally, meters were tested with field samples of unknown turbidity values in order to understand their behavior for future analysis. Meter responses are provided in Figure 3.3. Overall, Hach 1 and 2 meters produced very similar results, as expected, and did not change much for either calibration study. Also, it was observed from Figure 3.3 that Hach 1 and 2 consistently produced higher results compared to meters LaMotte and GW. This relationship was also shown in Experiment 1, Figure 3.2. However, when meters were calibrated to PCALs, the range of readings per sample narrowed (see Table 3.5). This may be due to formazin resembling sediment found in surface waters. Again, AMCO EPA solutions have uniform microspheres ranging from 0.02 to 0.2 µm; whereas formazin particles are irregular in shape and range from 0.1 to 10.0 µm. Suspended sediment typically contain fines (silt and clay) that range from particles less than 0.2 to 50 µm. Therefore, formazin may more closely match the range of particulates found in collected field samples.

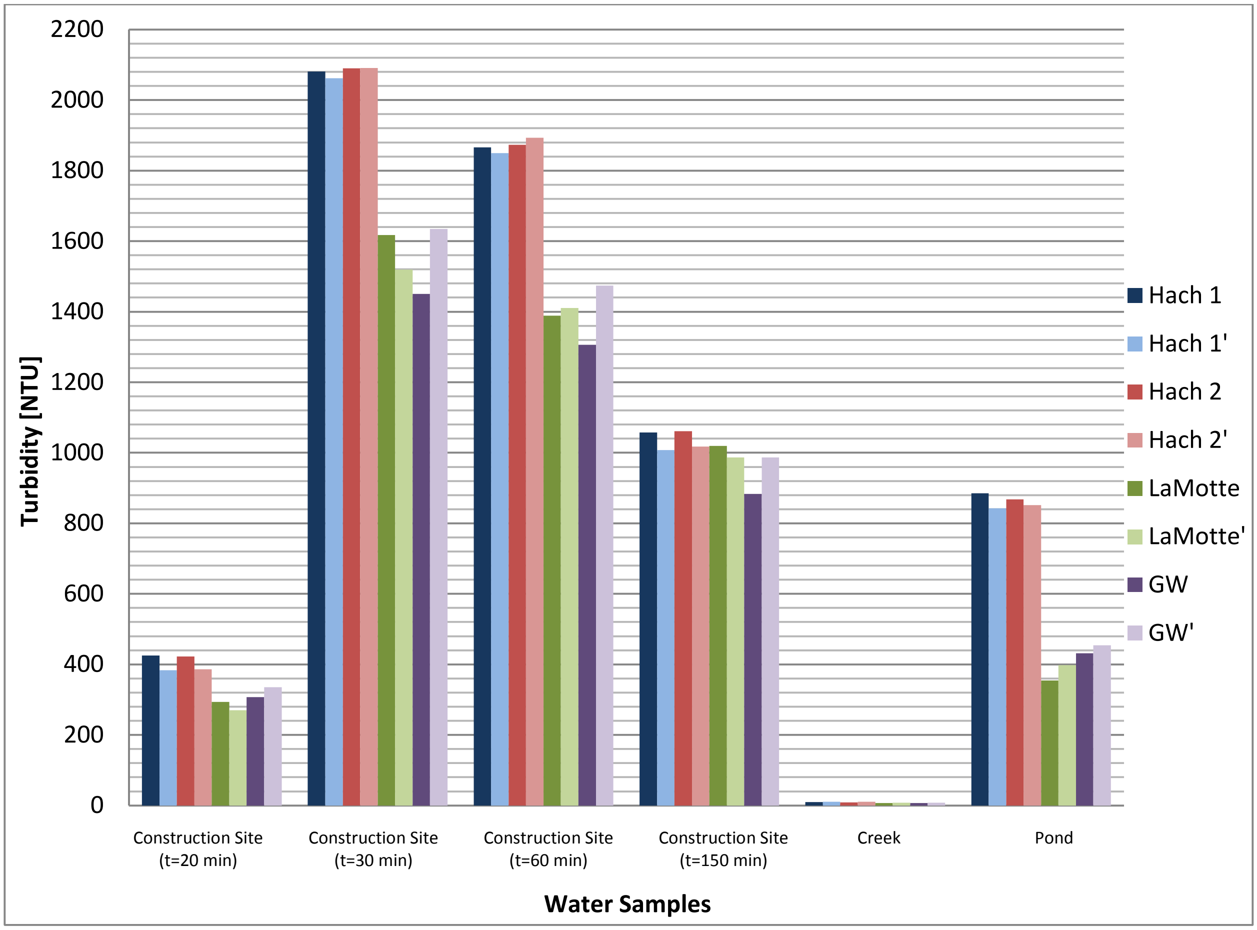

Figure 3.3. Turbidity measurements from each meter using field samples[6].

Table 3.5. Meters' standard deviation [NTU] for each field sample[7].

| | **Const. Site (t=20 min)** | **Const. Site (t=30 min)** | **Const. Site (t=60 min)** | **Const. Site (t=150 min)** | **Creek** | **Pond** |
|---|---|---|---|---|---|---|
| Calibrated with SCALs | 71.5 | 326 | 304 | 83.5 | 1.43 | 281 |
| Calibrated with PCALs | 54.2 | 292 | 250 | 15.4 | 1.40 | 244 |

---

[6] Hach 1, Hach 2, LaMotte and GW refer to the meters calibrated to their provided SCALs. Hach 1', Hach 2', LaMotte' and GW' refer the meters calibrated to the created PCALs.

[7] Derived calculations are shown in Appendix A; Table A.12 and Table A.14.

Furthermore, two sediment basin composite samples collected 30 minutes and 60 minutes after a rainfall event were relatively turbid, due to samples' initial readings exceeding Hach's instrument range, and had to be diluted by a factor of 4 and 5, respectively. According to Method 180.1, turbidity of the original sample is then computed from turbidity of the diluted sample and dilution factor (EPA, 1993b). For example, if 5 volumes of turbidity-free water were added to 1 volume of sample and the diluted sample showed a turbidity of 30 NTU, then the turbidity of the original sample was 180 NTU (EPA, 1993b). Therefore, differences between Hach meters to LaMotte and GW meters were pronounced due to the multiplication factor of the actual turbidity readings and possible errors introduced with dilution techniques.

In addition, dilution procedures did not follow Method 180.1's protocol to dilute samples until turbidity readings fell below 40 NTU mainly because of the difficulty to get field samples below this value. Turbid samples that were diluted by a factor of 4 and 5 produced turbidity readings in a range of 200 to 500 NTU before multiplication. To dilute these samples even farther to obtain values 40 or below would potentially introduce many errors. From a practical standpoint issues related to dilution and the potential for compounded error for turbid field samples need to be avoided.

However, for meters designed with the AMCO EPA standards, before and after dilution turbidity readings did not display similar proportionality. For example, as shown in Figure 3.2, pond sample turbidity for meters Hach 1, Hach 2, LaMotte and GW read 886, 868, 354, and 432 NTU, respectively. Then, samples were diluted by a factor of two. After incorporating the multiplication of two with the diluted readings, the computed actual turbidity readings were 813, 816, 534, and 619 NTU for meters Hach 1, Hach 2, LaMotte and GW. Therefore, according to EPA's Method 180.1 proportionality, meters Hach 1, Hach 2, LaMotte and GW are 8.3, 5.9, 50.7, and 43.2 percent different from the undiluted reading. Therefore, LaMotte and GW may be altogether inaccurate for higher turbidity readings of surface water samples, further supporting the design of AMCO EPA standards to specifically resemble remaining particulates in finished treated drinking water that are primarily submicron in size following filtration (AMCOClear, 2010).

# CONCLUSIONS

Given potential impact of proposed numeric effluent limitations related to turbidity on construction activities, the goal of this research was to quantify accuracy and precision of selected instruments in routine surface water analysis and potential regulatory compliance. Disclaimer: Mention of a trade name does not imply endorsement of the product by Clemson University to the exclusion of others that might be available. Users are encouraged to fully evaluate the suitability of any equipment for their intended application.

When subjected to both calibration experimental procedures, meters Hach 1, Hach 2 and GW provided accurate results for their overall averaged percent differences about true NTU values, but were not within their claimed ±2%. The LaMotte meter was not as statistically accurate by comparison. Though overall averages improved when calibrated to the PCALs, LaMotte remained inaccurate for higher turbidity readings. Possible inaccuracy results for the LaMotte may result from its provided SCALs. The highest SCAL provided was 100 NTU, even though range of the instrument is 0 to 2000 NTU.

As for meter precision, Hach 1, Hach 2, and GW were precise under both calibration studies and were overall within the claimed ±1% of measured values; whereas the LaMotte was slightly above ±1% of the measured values for both calibration studies. Analysis showed that even though meters may be very precise, the meters could be inaccurate. If inaccuracy is compounded by precision, misinterpretation of results is likely.

With an understanding of each meter’s accuracies and precisions to formazin NTU values, instruments were tested with field water samples of unknown turbidity or concentration values to observe their behavior for future analysis. Readings produced by the Hach meters had very similar results for either calibration study, but were consistently higher than the LaMotte and GW meters. However, when meters were calibrated to PCALs, the range of readings per sample narrowed, suggesting that formazin is a better calibration standard. Also, the LaMotte and GW meters may provide inaccurate results for higher turbidity readings that contain a wider range of particle sizes. This again suggests that AMCO EPA standards more adequately resemble treated drinking water samples. In addition, the collected field samples were not diluted until turbidity readings fell below 40 NTU mainly because of the difficulty to get field samples below this value. Issues related to dilution and the potential for compounded error for turbid field samples need to be avoided. Therefore, it is recommended that Method 180.1 be reevaluated in order to clarify standards used for either drinking water or surface water evaluations.

# CHAPTER 4

# TURBIDITY ANALYSES BASED ON SEDIMENT CHARACTERISTICS OF REPRESENTATIVE SOUTH CAROLINA SOILS

# ABSTRACT

EPA has published effluent limitation guidelines (ELGs) to control discharge of pollutants from construction sites. Numeric turbidity limits for construction site discharge are expected to be required in the near future Such requirements will likely include subjecting construction site stormwater discharges to a maximum allowable turbidity numeric effluent limit in nephelometric turbidity units (NTUs) for sites disturbing 10 acres or more.

Turbidity is a measurement used to quantify water clarity. Turbidity is an expression of the optical properties of a liquid that causes light rays to be scattered and absorbed as measured by a nephelometer. Though constituents such as organic matter can impact water clarity, typically the inorganic fraction derived from particulate matter such as sediment dominates turbidity levels in surface waters. Recognition that water clarity is an important indicator of environmental health has increased, resulting in growing demand for high-quality objective measurement.

Given the importance of pending numeric effluent limitations related to turbidity, focus of this research is to determine relationships between representative South Carolina soils and corresponding turbidity as a function of suspended sediment concentration and settling time.

The relationship between turbidity and suspended sediment concentration is complex. Experimental results indicate this relationship is well correlated when top soil and subsoil trends were based on predominant South Carolina region and measured clay

content. Derived trends either correlated well with a linear or a log relationship ($R^2$ values ranging from 0.7945 to 0.9846) as opposed to a power function from previous research. Therefore, for each region, research confirmed that as concentration of fines increased, turbidity increased; and soils with higher clay content produced higher turbidity values compared to soils with less clay.

As for the correlation of turbidity and settling time, top soil and subsoil results were also separated by South Carolina region and sorted based on the same measured clay content ranges formulated above. All trends correlated well with a power function ($R^2$ values ranging from 0.7674 to 0.9347). This relationship therefore followed Stoke’s Law, where smaller particles remain in suspension longer and contribute more to turbidity as opposed to soils with less clay content. Such results may have significant bearing on the construction and development industry as it prepares for proposed monitoring requirements associated with recently promulgated numeric effluent standards for turbidity.

# INTRODUCTION

Accelerated erosion due to construction can potentially cause much damage to the surrounding ecosystem (Haan et al., 1994). For example, introduction of excessive suspended solids (SS) from runoff, such as construction activity, are a potential water pollutant that can cause significant environmental impacts. All streams carry some SS under natural conditions, but if concentrations are elevated from human disturbance, it can lead to alterations to the physical, chemical and biological properties of a water body (Bilotta and Brazier, 2008). Such impacts can include the adsorption of heavy metals, toxic substances, and biological pollutants to soil particles that are then transported downstream. Chemical and biological pollutants can harm water quality and other ecological problems. Clearly, SS are an important pollutant in surface waters; thus, quantifying and monitoring changes in suspended solids is critical for the nation's bodies of water. As a result, water quality regulatory agencies often impose permit conditions that limit the concentration of suspended solids that can be present in effluent waters (Thackston and Palermo, 2000).

Total suspended solids (TSS) resulting from erosion encompass both inorganic solids and organic solids. Inorganic solids may include sand, silt, clay sediment particles, and organic solids can consist of algae and detritus. TSS is computed from laboratory analysis by the dry weight of suspended solids per unit volume of water, and is reported in milligrams of solids per liter of water (mg/L). However, TSS measurements are not routinely used to detect and correct short-term problems or permit violations because sediment concentrations cannot be determined easily or quickly in the field, and transportation to a laboratory for analysis is time-consuming and can be costly (Thackston and Palermo, 2000). As a result, these traditional methods are increasingly being replaced in favor of accurate, continuously-collected surrogate data for quantification of SSC that may be safer and (or) less expensive to obtain, such as turbidity measurements.

Turbidity measurements are gaining increased usage as an indicator of pollution in surface runoff from disturbed areas such as active construction sites. For example, timely, accurate field estimation of sediment loading could be facilitated through the development of precise relationships between suspended solids and turbidity. This approach has potential for monitoring any water quality constituent whose concentration is better correlated with an easily measured (in situ) parameter, such as turbidity.

Turbidity is an expression of the optical properties of a liquid that causes light rays to be scattered and absorbed rather than transmitted in straight lines through a water sample (Anderson, 2005). Though constituents such as organic matter can impact water clarity, typically the inorganic fraction derived from particulate matter such as sediment dominates turbidity levels in surface waters (Davies-Colley and Smith, 2001). Cloudiness of water results from intense scattering of light by fine particles typically with diameters smaller than 0.050 mm (Davies-Colley and Smith, 2001). Hence, waters with high concentrations of fine suspended sediment are frequently described as turbid. Turbidity is a vivid visual indicator of pollution associated with sediment-laden runoff.

Turbidity is now commonly measured in nephelometric turbidity units (NTU) using nephelometric turbidimeters (Mitchell, 2000), currently two of the most frequently used nephelometric turbidimeters include nephelometers and near infrared turbidimeters. For this research, nephelometers are of interest because of their common use in the U.S. as opposed to near infrared turbidimeters that are most common overseas.

Nephelometers measure light that has been scattered at a specific angle of 90 degrees from the main light path (EPA, 1993b). Generally, nephelometers are compliant with EPA Method 180.1 for determining turbidity by nephelometry (Borok, 2010). Along with the specified angle of 90 degrees, nephelometers under EPA's Method 180.1 require the light source to be a tungsten lamp operating at a color temperature between 2200-3000 K. The light source is a light-emitting diode where the light path is designed to minimize stray light falling on the detector (Thackston and Palermo, 2000). Therefore, a zero reading means no light scattered at 90 degrees (±30 degrees) from the main light path and implies no turbidity (Thackston and Palermo, 2000). Nephelometers must be standardized against either a primary formazin suspension with a value of 4000 NTUs (which can be diluted to desired NTU values) or a commercially available polymer standard identified as AMCO-AEPA-1 (EPA, 1993b).

Turbidity is not an inherent property of water, such as temperature or pH. However, the recognition of turbidity as an indicator of the environmental health of water bodies has increased, resulting in a growing demand for high-quality and objective turbidity measurements (Anderson, 2005). Therefore, given the importance of a proposed turbidity limit, the focus of this research is to determine relationships between representative sediments and corresponding turbidity as a function of suspended sediment concentration. Also, in order to separate particles from the runoff water in best management practices (BMPs) such as sediment basins, it is imperative to know sediment settling time and settling properties required to remove the particles from the water column (Haan et al., 1994: Tempel, 2011). Thus, this research will also determine if any relationship exists between turbidity and settling time of suspended sediments.

A standard practice in relating suspended sediment to turbidity is to take the association as a one-to-one relationship (Hayes et al, 2001). Prior research, however, indicates this assumption is not accurate unless site-specific sampling is utilized to establish unique turbidity-suspended sediment relationships because turbidity is not only a function of TSS concentrations, but also of particle size, shape, and composition (Foster et al., 1992: Hayes et al., 2001). Hence, this research is needed to analyze turbidity responses based on sediment characteristics for representative South Carolina soils.

# PROCEDURES

## Soil Collection

The following section describes the materials and methods used to complete the objectives of relating turbidity to suspended sediment concentration and settling time of representative South Carolina soils. First, the most representative soils for South Carolina were found using U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS) soils data for each county in South Carolina. Soils are listed by county with corresponding area provided in acres. Soil area by county was aggregated and ranked based on percent coverage for the entire state. The most predominant twenty five soils represent fifty percent of South Carolina's total area (see Table 4.1). Table 4.1 also provides the soil's predominant region, consisting of the upstate Piedmont Region, the mid-state Central region and the Coastal Plains region (see Figure 4.1) as defined by Russ (2009). Soils were located around the state in order for data collection to proceed. Most were found on Clemson University experiment stations located in various geographic regions across the state. These stations included the Simpson Experiment Station (Anderson, SC), the Pee Dee Research and Education Center (REC) (Florence, SC), and the Edisto REC (Blackville, SC). Other samples were collected in Aiken, Edgefield and Laurens counties. Each representative soil was identified at the experiment stations and other parts of the state using the Soil Conservation Service county soil surveys or NRCS's Web Soil Survey online service.

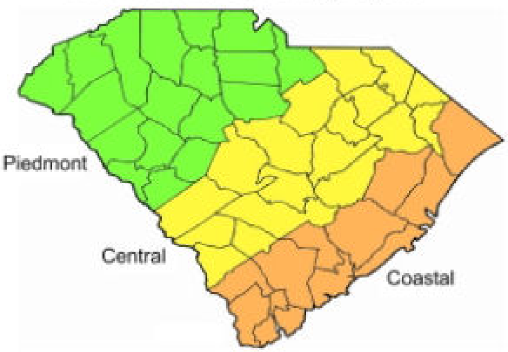

Figure 4.1. South Carolina physiographic regions (Russ, 2009).

Table 4.1. Representative South Carolina soils utilized for this research in order of area.

| | Soil Series | Percent of SC | Predominant SC Region |
|---|---|---|---|
| 1 | Cecil | 8.940 | Piedmont |
| 2 | Lakeland | 2.936 | Central |
| 3 | Goldsboro | 2.540 | Coastal |
| 4 | Pacolet | 2.507 | Piedmont |
| 5 | Madison | 2.443 | Piedmont |
| 6 | Rains | 2.327 | Coastal |
| 7 | Lynchburg | 2.164 | Coastal |
| 8 | Wilkes | 2.086 | Piedmont |
| 9 | Coxville | 1.929 | Coastal |
| 10 | Johnston | 1.674 | Central |
| 11 | Georgeville | 1.665 | Piedmont |
| 12 | Troup | 1.656 | Central |
| 13 | Norfolk | 1.617 | Coastal |
| 14 | Hiwassee | 1.441 | Piedmont |
| 15 | Cataula | 1.378 | Piedmont |
| 16 | Blanton | 1.368 | Central |
| 17 | Fuquay | 1.334 | Central |
| 18 | Dothan | 1.307 | Central |
| 19 | Ailey | 1.284 | Central |
| 20 | Vaucluse | 1.273 | Central |
| 21 | Appling | 1.205 | Piedmont |
| 22 | Bonneau | 1.156 | Central |
| 23 | Noboco | 1.149 | Coastal |
| 24 | Herndon | 1.110 | Piedmont |
| 25 | Wagram | 1.002 | Central |

When a desired soil series was identified at the sampling location, cover vegetation was removed, and a shovel was used to determine soil profile. Using a shovel, top soil was collected in a nineteen liter bucket, and subsoil was separately placed in another nineteen liter bucket. Soil collection was carefully executed to avoid mixing top soil and subsoil. Lids were tightened on each bucket, and samples were brought back to the lab for analysis.

## Data Analysis

First, a wet sieve and pipette analysis were conducted in order to obtain an aggregate size distribution (ASD) for each soil. For a primary particle size distribution, procedures require sodium hexametaphosphate to disperse aggregates formed in order to obtain all particle sizes (Das, 2006). However, samples collected were not dispersed for a primary particle size distribution. As a result, for this research, ASD analysis was conducted using representative soils as they would be found on sites across South Carolina.

### *Wet Sieve Analysis:*

Sieve analysis is applicable to separate granular material from soil mass (Das, 2006). First, 100 grams of each soil sample was measured and mixed with 600 ml of water. The mixture was washed through a series of six sieves with mesh openings of 2.0, 1.0, 0.425, 0.15, 0.075, and 0.063 mm. The procedure consisted of first passing the soil mixture through the 2.0, 1.0 and 0.425 mm mesh openings that were stacked in a five gallon bucket. Next, the sieves were placed in a second nineteen liter bucket. The first bucket was stirred and its mixture was poured over the sieves in the second bucket. The soil mixture went through these sieves three times. During this process, an additional 400 ml of water was used for the soil mixture to thoroughly pass through the sieves. After running the mixture through these three sieves three times, the sieves were removed from the bucket and the remaining three sieves, 0.15, 0.075, and 0.063 mm, were placed in the bucket. The remaining soil mixture was passed through the smaller sieves three times. The soil-water mixture left in the bucket was measured and saved for pipette analysis to determine sizes less than 0.063 mm. Approximately 1.0 L was used for each pipette analysis.

Once the mixture was passed through all the sieves, the soil remaining on each sieve was collected in a pre-weighed tin and placed in the drying oven at 105 ˚C for a minimum 24 hours (Bolton, 1979). Once dried, the tins were weighed on a balance to the nearest 0.001 gram and recorded.

*Pipette Analysis:*

As stated before, sieve analysis was used to separate gravel (particles coarser than 2 mm) from particles less than 2 mm in diameter. Percent sand was isolated by wet sieving (Scott, 2000). However, particles less than 0.063 mm were of particular interest for this work because larger particles will settle from surface water flow relatively quickly leaving smaller particles that contribute as sources of turbidity (Hayes et al., 2001). Therefore to determine the proportion of silt and clay in the sample, a pipette procedure was conducted. Silt and clay can be separated by settling in water, where the rate of settling is governed by Stoke's Law (Scott, 2000). For the pipette procedure, once the soil-water mixture had been thoroughly mixed, all particles of one size will have fallen below a certain level in the suspension after a certain amount of time has elapsed (Scott, 2000).

Therefore, the remaining 1 L soil-water mixture from the wet sieve analysis was completely mixed, collected and used for pipette analysis. Pipette withdrawals followed the schedule shown in Table 4.2 to obtain the size distribution range between 0.063 mm and 0.002 mm. Samples were assumed to be collected at a temperature of 21 degrees Celsius since this temperature was the approximate room temperature. The particular sizes displayed in Table 4.2 represent the largest particle size collected at the elapsed time (Johns, 1998). Depth is the distance the 25 ml pipette tip was lowered from the actual (declining) water surface at each sample time.

Table 4.2. Pipette analysis schedule at 21˚C (USDA, 1979)[8].

| **Sediment Size (mm)** | **0.062** | **0.031** | **0.016** | **0.008** | **0.004** | **0.002** |
|---|---|---|---|---|---|---|
| Depth (mm) | 150 | 150 | 150 | 150 | 100 | 50 |
| Time (hr:min:sec) | 0:00:42 | 0:02:48 | 0:11:14 | 0:29:58 | 1:00:00 | 4:02:00 |

Once the 25 ml sample was drawn, it was collected in a pre-weighed tin and placed in a drying oven at 105 ˚C for a minimum 24 hours to evaporate any water present (Bolton, 1979). After each sample was dried, tins were weighed on a balance to the

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[8] All tests withdrew 25 ml from the soil-water mixture

nearest 0.0001 gram and results were recorded. The remaining soil-water mixture in the 1L graduated cylinder was saved for subsequent analysis.  After the completion of the wet sieve and pipette analysis for each soil, results were computed to create an ASD. ASD examples for each region's dominant soil series are displayed in Figures 4.3 to 4.5. Figure 4.6 illustrates differences among soil's ASD and eroded PSD. Tabular data for all soil's ASDs are found in Appendix B.

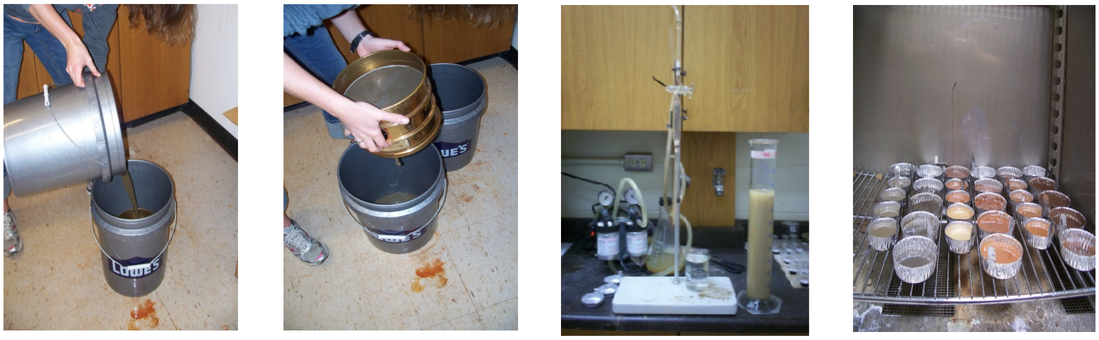

Figure 4.2 Wet sieve and pipette analysis summary photographs.

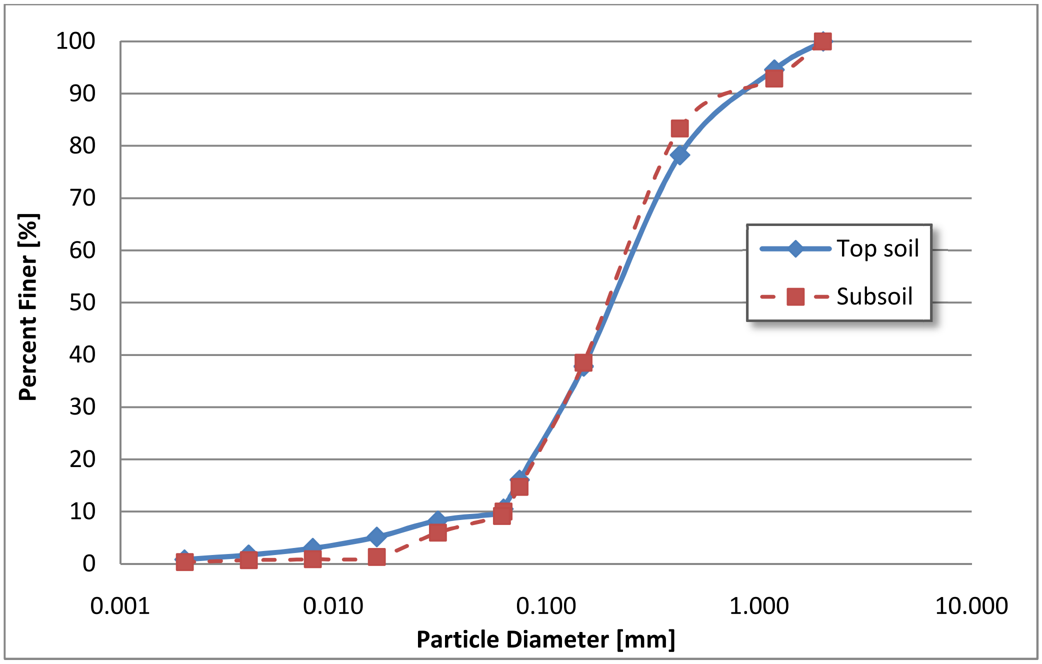

Figure 4.3. Piedmont: Cecil's aggregate size distribution (ASD).

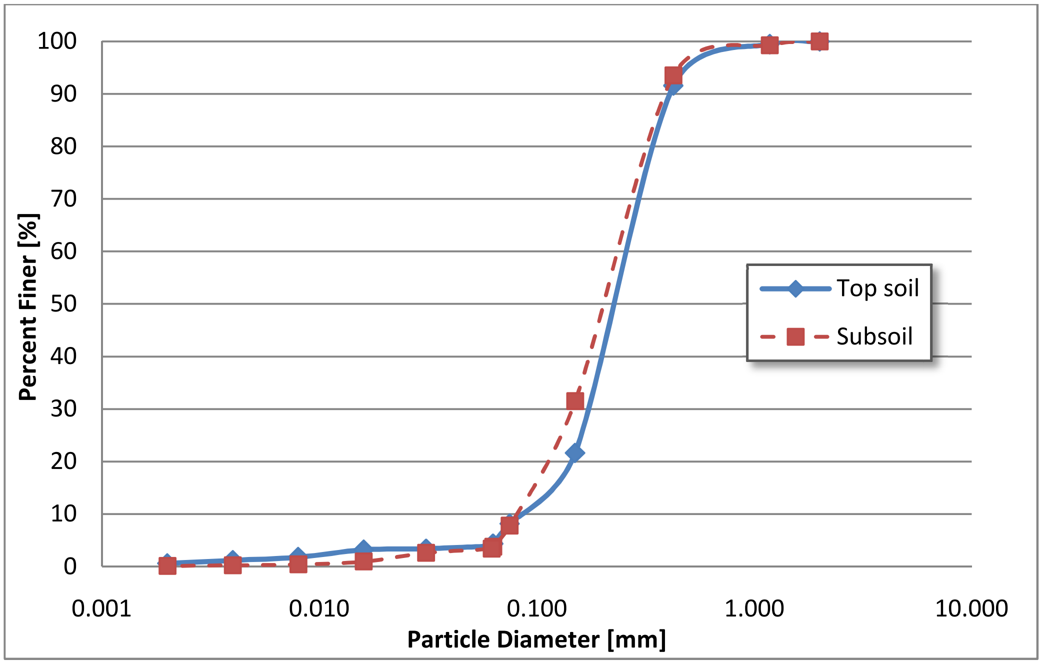

Figure 4.4. Central: Lakeland's aggregate size distribution (ASD).

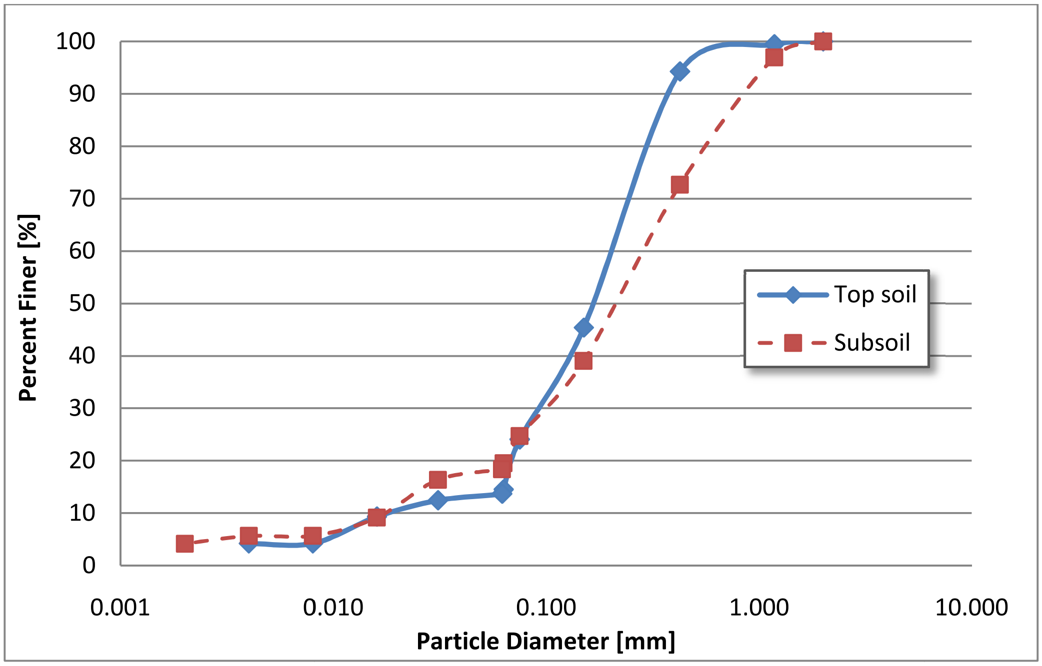

Figure 4.5. Coastal: Goldsboro’s aggregate size distribution (ASD).

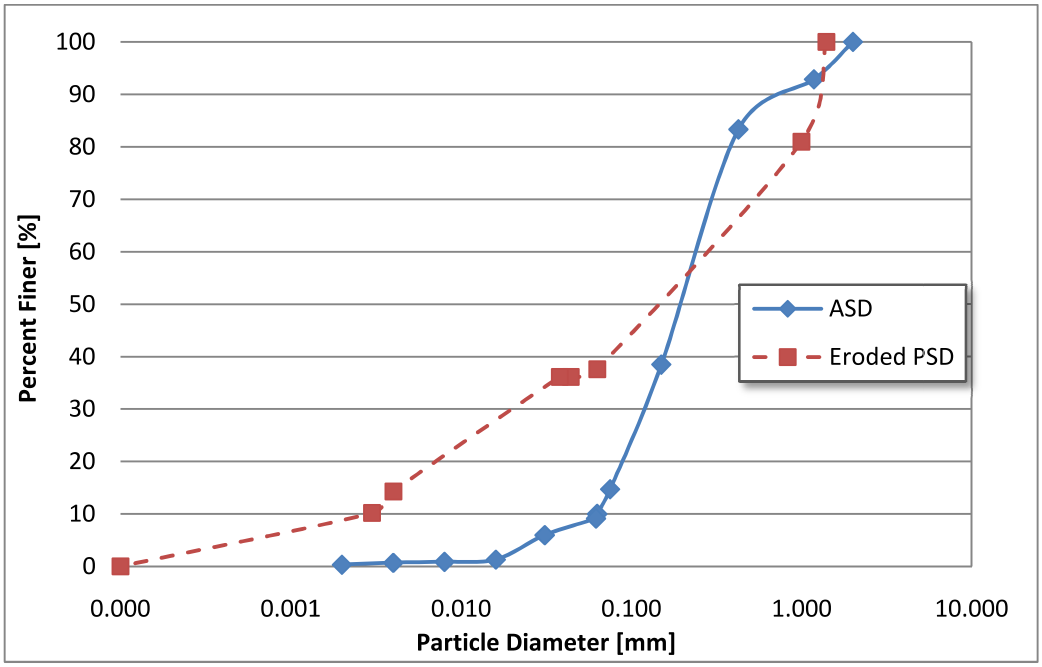

Figure 4.6. Size distribution comparison for Cecil subsoil.

### *Hydrometer Analysis*

As stated previously, the particle size distribution obtained from the wet sieve and pipette analysis was not a primary particle size distribution, but rather a modified eroded particle size distribution that would resemble sediment found in surface waters during active construction phases. To gather additional information on characteristics of each soil series, primary particle sizes of selected soils were established through performance of a hydrometer analysis (Scott, 2000). Hydrometer analysis uses a dispersed sample of soil that has been thoroughly mixed with water in a tall glass cylinder and allowed to settle. Soil particles in a dispersed state in water will settle individually according to Stoke's Law (Das, 2006). Therefore, after specified settling times, density (g/L) of each suspension is measured with a hydrometer to determine the mass of particles remaining in suspension.

For the hydrometer method, 50 g of soil for each series was used to determine soil particle analysis using an ASTM 152-H hydrometer. To achieve separation among soil particles, 40 g/L of sodium hexametaphosphate was utilized. Procedures followed ASTM's Standard Test Method for Particle-Size Analysis of Soils (ASTM D 422-63, 2004), and hydrometer readings were recorded 40 seconds and 2 hours after settling. At 40 seconds, sand-sized particles will have settled out of the suspension leaving only silt and clay sized particles. After 2 hours of settling, the silt sized particles have settled leaving the hydrometer to read the density of clays remaining in suspension. Due to hydrometers being calibrated to 20 degrees Celsius and because density and viscosity of water change with temperature, temperatures were recorded for each reading to correct the hydrometer readings (hydrometer paper). Readings were corrected for temperatures above 20 degrees Celsius using the following equation (Equation 4). The primary particle size distribution results from the hydrometer analysis are in Appendix B.

$$\begin{aligned} &Corrected\ hydrometer\ reading(g/L) \\ &\qquad = mesaured\ reading\ (g/L) \\ &\qquad + [(measured\ temperature - 20°C) * 0.36\ g/L] \end{aligned} \tag{4}$$

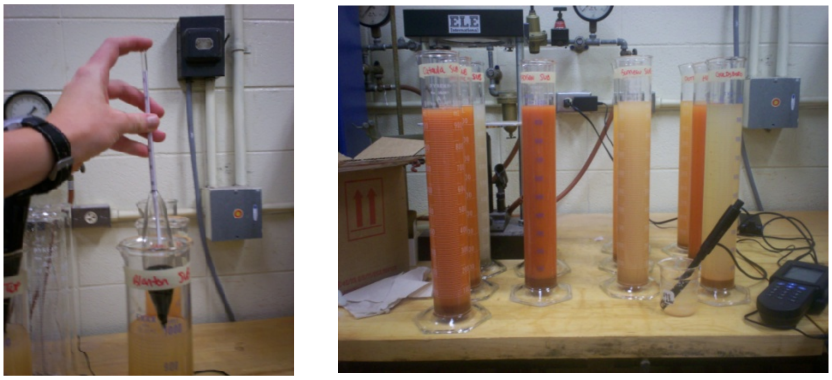

Figure 4.7. Hydrometer analysis photographs.

*Turbidity versus Settling Time*

To derive empirical relationships between turbidity and settling time of selected South Carolina soils, the procedure utilized the remaining soil-water mixtures from pipette analysis. Again, both top soil and subsoil were examined for this experiment. To obtain turbidity readings the Hach 2100Q was chosen based upon determining meter's reliable accuracies and precisions. It was also chosen because its secondary calibration standard of a stable formazin was found to be better suited to mimic sediment found in surface water samples. The Hach 2100Q was calibrated daily with its provided calibration standards (StabCal) as specified in the manufacturer's operating instructions.

Once the pipette method was complete, the graduated cylinder containing the soil-water mixture was filled back up to 1 liter with distilled (DI) water and repeatedly inverted until solution was completely mixed. Fifteen milliliters of the soil-water mixture was drawn at specified times from two inches below the surface of the sample and placed in the Hach 2100Q's cuvette. Specified times spanned two weeks and included readings taken at 0 min, 5 min, 30 min, 1 hour, 2 hour, 4 hour, 24 hours, 48 hours, 4 days, 7 days, and 14 days. A depth of two inches below the water surface level was chosen to minimize surface and edge effects from the glass cylinders. This depth would also mimic surface withdrawal from sediment basins through such practices as skimmers and flashboard risers.

The cuvette containing each sample was inverted ten times between readings to adequately resuspend and disperse all sediment particles before placement in turbidimeters (Hayes et al., 2001). The Hach 2100Q cannot measure turbidities higher than 1000 NTU. Therefore, if a reading exceeded this range, dilutions were made from the cuvette to follow EPA's Method 180.1 proportionality example to obtain sample's actual turbidity reading. For instance, if the soil-water solution was diluted by half, then the diluted sample's turbidity reading was multiplied by two. However, for all turbidity readings, dilution procedures did not follow EPA's Method 180.1 protocol to dilute samples until turbidity readings fell below 40 NTU. This was mainly because of the difficulty to get soil-water samples below this value. From a practical standpoint, issues related to dilution and the potential for compounded error for turbid samples need to be avoided.

Five readings were recorded for each sample and averaged. For each soil's top soil and subsoil, results were plotted on a graph. Each sample was saved for utilization in subsequent TSS analysis.

### *Turbidity versus Total Suspend Solids Concentration*

To develop unique relationships for concentration of South Carolina suspended sediments versus turbidity, analysis was conducted in sequence with the turbidity versus settling time procedure. After the five turbidity readings were recorded, 10 ml of each sample was drawn using a 5 ml Eppendorf Pipette, placed in a pre-weighed dish and dried in the oven at 105 degrees Celsius for a minimum of 24 hours (Bolton, 1979). After the sample was dried, tins were removed from the oven using tongs to avoid additional errors. Samples were weighed on a balance to the nearest 0.0001 gram to obtain concentrations in mg/L. Resulting concentrations were plotted on a graph versus its corresponding turbidity from the procedure above.

### *Turbidity versus Particle Size*

To better understand sediment effects on turbidity, it was important to analyze turbidity response to particle size. Particle diameters analyzed for this project were derived using the parameters selected in the turbidity versus settling time procedure.

Knowing samples were drawn from a depth of two inches below the water surface level, Stoke's Law was applied for the specified time intervals of 0 min, 5 min, 30 min, 1 hour, 2 hours, and 4 hours to calculate the particle diameters of 0.063, 0.014, 0.006, 0.004, 0.003 and 0.002 mm, respectively. Altogether, at the specified times, particle sizes were compared to their corresponding turbidities and concentrations that were determined from the above procedures. However, actual turbidity and concentration values for the particle sizes needed to be determined. This is because when samples were drawn at the given times; the particle size calculated included that size, along with any sizes smaller that also remained in suspension. Therefore, a subtraction method was adopted to determine the particle sizes true turbidity and concentration values ('Actual Conc.' and 'Actual Turb.' in Table 4.3). If the subtraction method produced a negative value, values were assigned zero, indicating that particle diameter did not contribute to turbidity. Because all soils vary in turbidity and concentrations for a given time, in order to compare all soils, each particle diameter was plotted versus the ratio of turbidity to concentration.

Table 4.3. Tabular data of a soil sample's turbidity and concentration response to particle size.

| D [mm] | Conc. [mg/L] | Actual Conc. [mg/L] | Turbidity [NTU] | Actual Turbidity [NTU] | Actual Turb/ Actual Conc |
|---|---|---|---|---|---|
| 0.063 | 6510 | 2240 | 6818 | 292 | 0.130 |
| 0.014 | 4270 | 1830 | 6526 | 2106 | 1.151 |
| 0.006 | 2440 | 720 | 4420 | 876 | 1.217 |
| 0.004 | 1720 | 210 | 3544 | 241 | 1.148 |
| 0.003 | 1510 | 450 | 3303 | 993 | 2.207 |
| 0.002 | 1060 | 1060 | 2310 | 2310 | 2.179 |

## RESULTS AND DISCUSSION

### *Turbidity with Respect to Total Suspended Solids Concentration*

Selected soils were first divided by top soil and subsoil and plotted to determine if any relationships existed between suspended solids concentration and turbidity (Figure 4.4). This approach was taken to evaluate if the representative South Carolina soils collectively could be classified by certain properties. Factors taken into consideration encompassed the experimental particle size distribution values, primary particle size distribution values from the hydrometer analysis, South Carolina region, soil classification (soil order, suborder, great group, subgroup) and soil family (particle size and mineralogy).

Measured turbidity averages and calculated sediment concentrations were plotted and used in a regression analysis to model turbidity as a function of sediment concentration. These values can be viewed in Appendix C. First, trends were arbitrarily chosen based on similar turbidity responses to suspended sediment concentration. However, trends could not be explained because there were no common denominators to classify the soils' relationship of turbidity with suspend solids concentration. As a result, top soils and subsoils were examined depending on South Carolina regions.

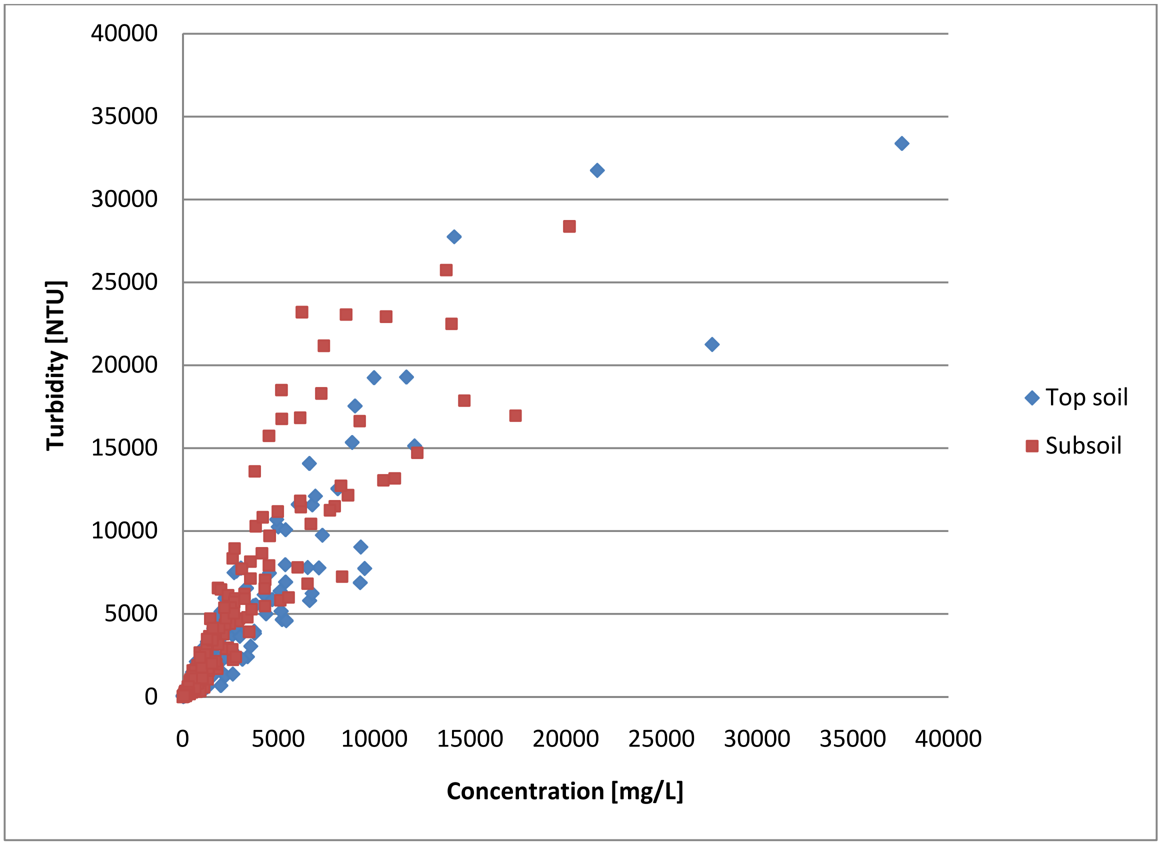

Figure 4.8. All twenty five selected top soil and subsoil's relationship of turbidity and suspended sediment concentration.

Once soils were divided by South Carolina regions, top soil and subsoils were sorted based on 1) measured clay content, 2) measured fine content, and 3) the ratio of measured clay to fines to establish any trends from each scenario. Measured values were derived from ASD. Each scenario was evaluated and it was found that for each region, trends were best formulated from soils' measured clay content compared to the other two scenarios. Fines content would be expected to explain the relationships of turbidity to concentration because both silt and clay particle sizes contribute to turbidity. However, this scenario did not rationalize the behavior of certain subsoils that aggregated and quickly settled from suspension. Aggregates formed in these subsoils contributed to a higher percentage of silt in the upper range of 0.016 to 0.05 mm, but settled rapidly, leaving very small amounts of clay in suspension. As a result, these soils would contribute to high turbidity and high concentration readings, but values would then substantially drop after the first minutes. Hence, when subsoils were sorted according to the amount of measured fines, poor correlations resulted because aggregated soils were incorrectly grouped with soils that had both higher amounts of silt and clay. Figure 4.9 depicts an example of a subsoil that aggregated and quickly settled compared to its top soil.

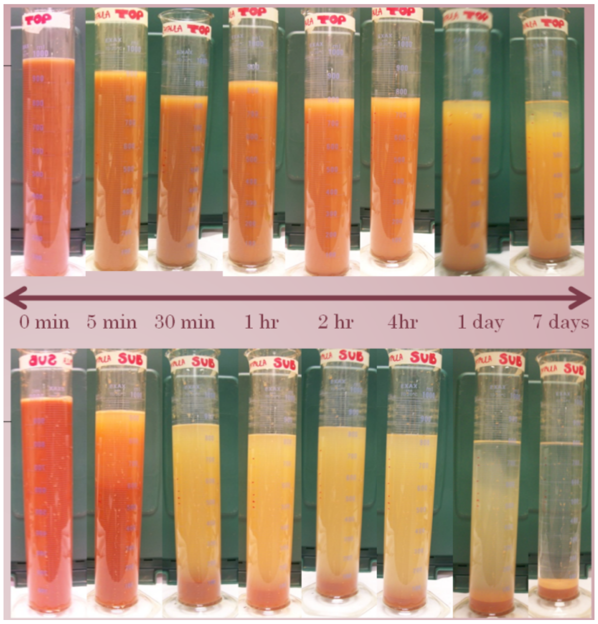

Figure 4.9. Example of a subsoil (image on bottom) that aggregated and settled quickly compared to its top soil (image on top).

Based upon correlation coefficients of the predicted equations, trends correlated well with either a linear or a log relationship. These relationships are plotted in Figures 4.10-4.15[9]. From the figures, not all results followed a one to one relationship, as previous research had assumed (Kundell, 1995). Yet, soils that did conform to a linear relationship were not far off from a one to one relationship. A power function in the form of $T=a*SS^b$ has previously been found to correlate sediment concentration and turbidity (Hayes, et al. 2001 and Mitchell 2000). However, this relationship proved inconsequential and was not utilized because, even though it produced high correlation coefficients, it did not accurately model the behavior of soils with higher clay content. For the most part, these soils in their higher turbidity and concentration range behaved asymptotically rather than turbidity continuing to increase with increasing concentration.

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[9] For Figures 4.10-4.15, n refers to the number of soil samples. Each soil sample contains 11 data points.

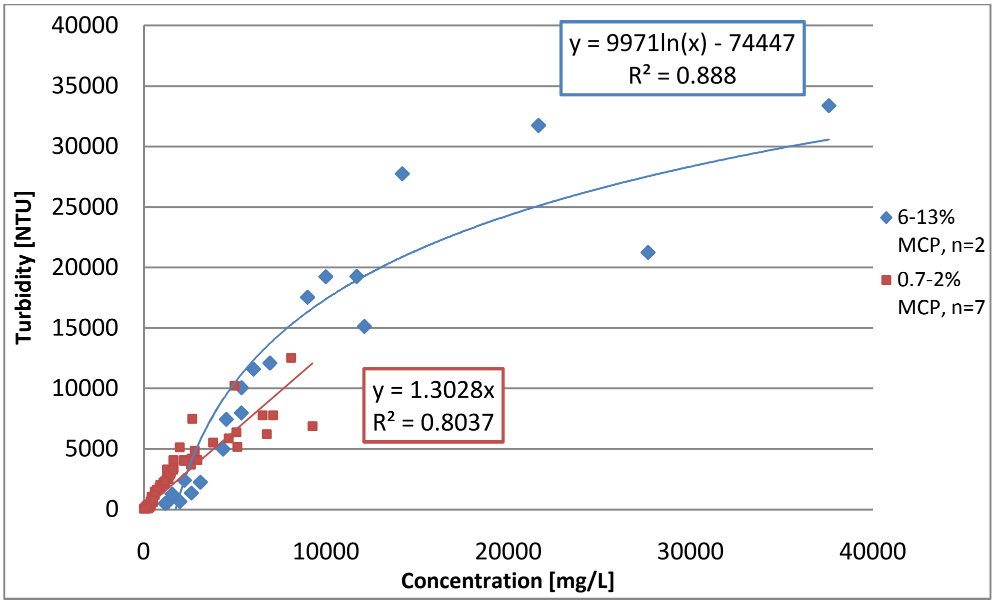

Figure 4.10. Piedmont top soils relationship of turbidity with respect to concentration (n=number of soils). Trends were formulated based on MCP.

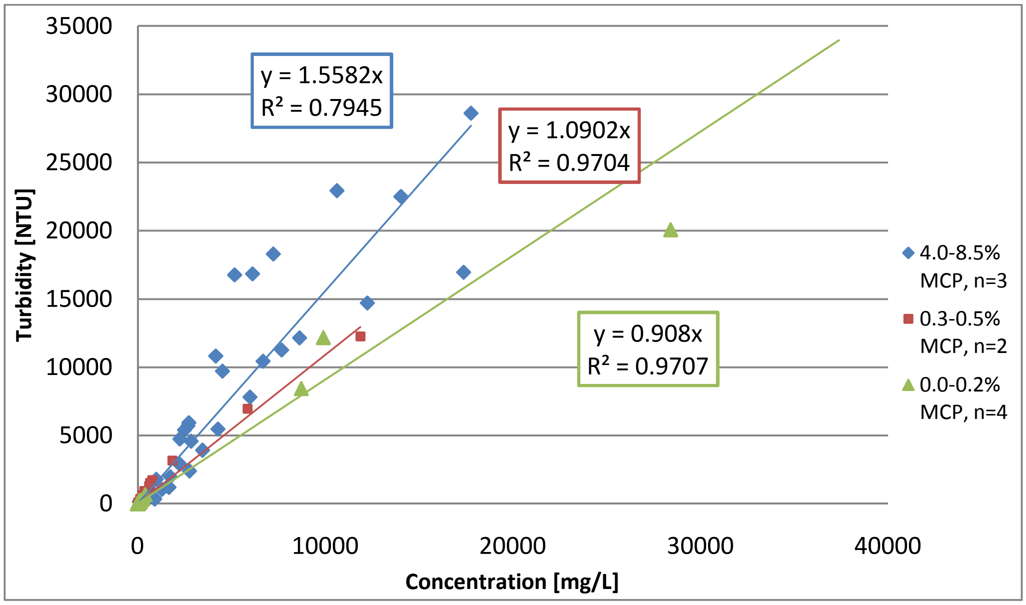

Figure 4.11. Piedmont subsoils relationship of turbidity with respect to concentration (n=number of soils). Trends were formulated based on MCP.

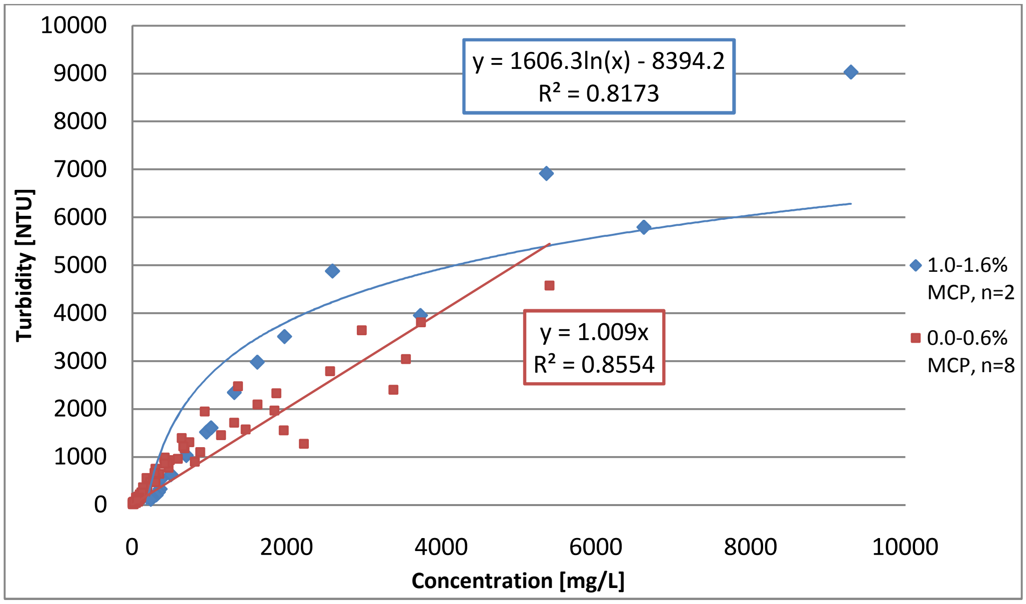

Figure 4.12. Central top soils relationship of turbidity with respect to concentration (n=number of soils). Trends were formulated based on MCP.

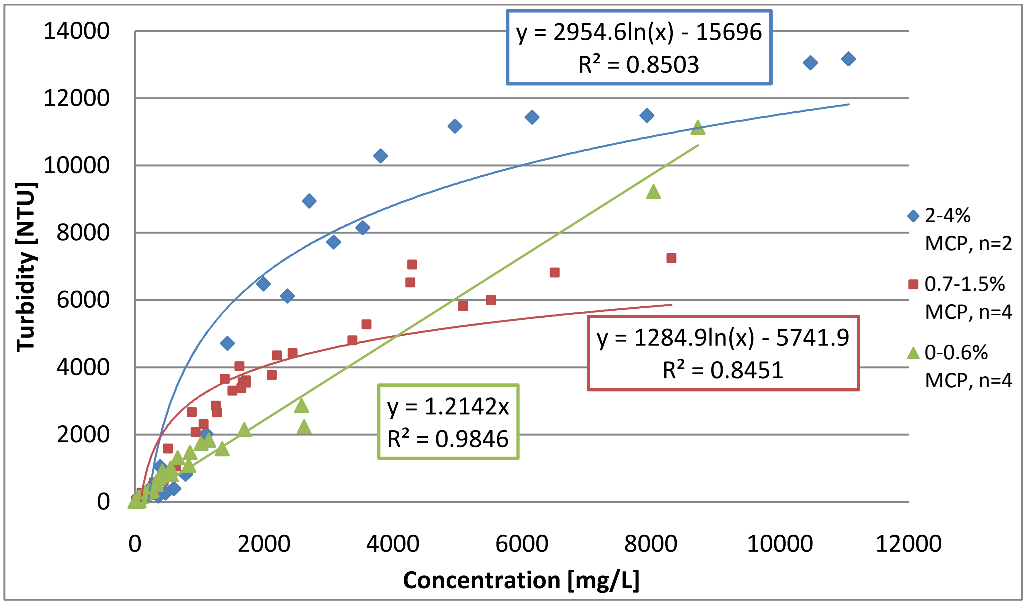

Figure 4.13. Central subsoils relationship of turbidity with respect to concentration (n=number of soils). Trends were formulated based on MCP.

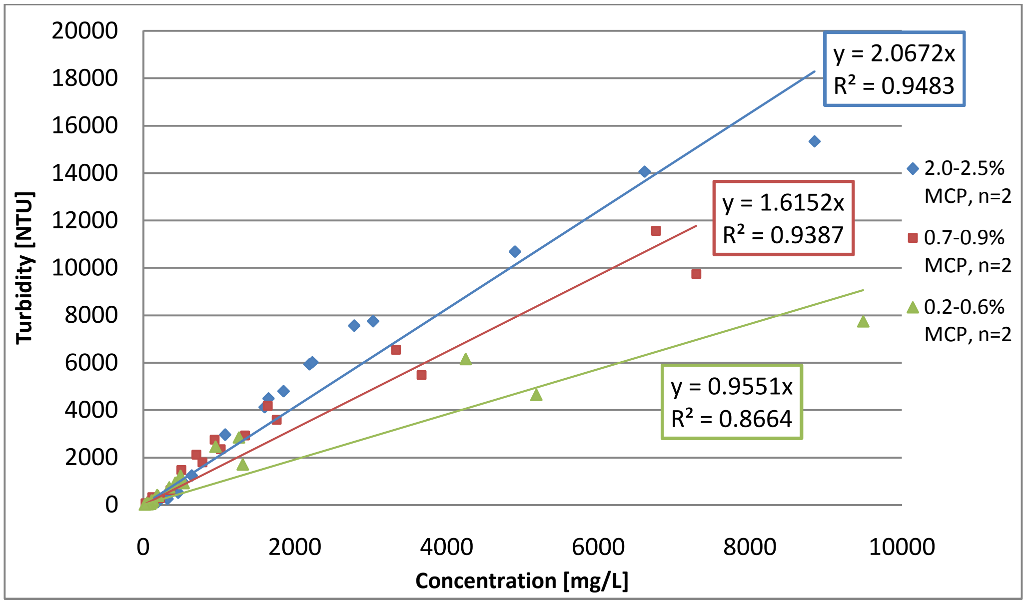

Figure 4.14. Coastal top soils relationship of turbidity with respect to concentration (n=number of soils). Trends were formulated based on MCP.

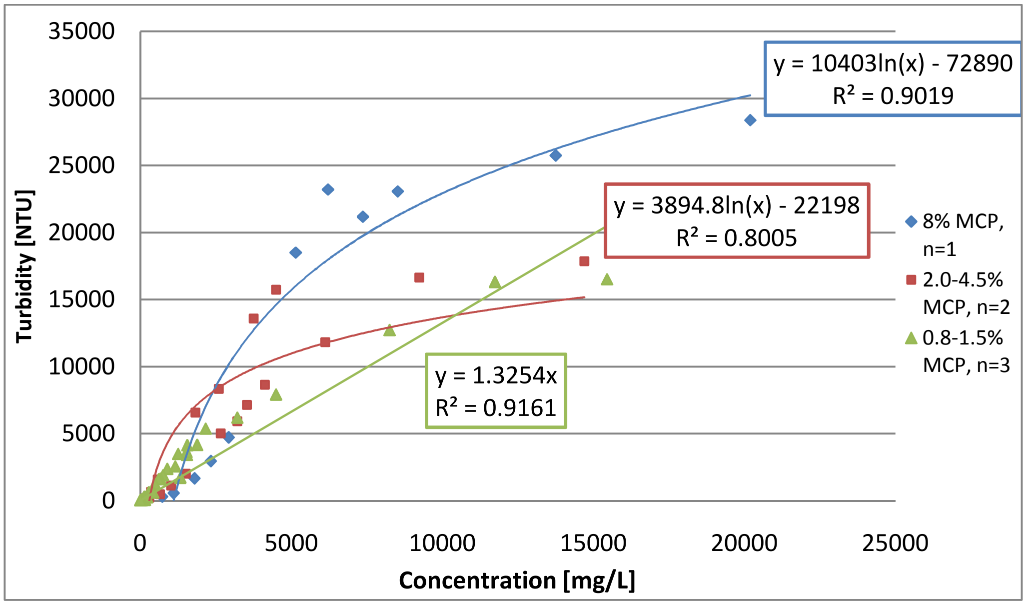

Figure 4.15. Coastal subsoils relationship of turbidity with respect to concentration (n=number of soils). Trends were formulated based on MCP.

*Turbidity with Respect to Settling Time*

To determine if an empirically derived relationship between settling time and turbidity existed for the selected soils, measured turbidity averages from above and their corresponding time values were evaluated. These values are plotted in Figure 4.16 and raw data may be viewed in Appendix D. In addition, Figure 4.16 shows that majority of the soils were not below a value of 280 NTU until 24 hours, or later, of settling. In other words, it would take longer than a day for the soils to be below EPA's effluent limitation guideline of 280 NTU.

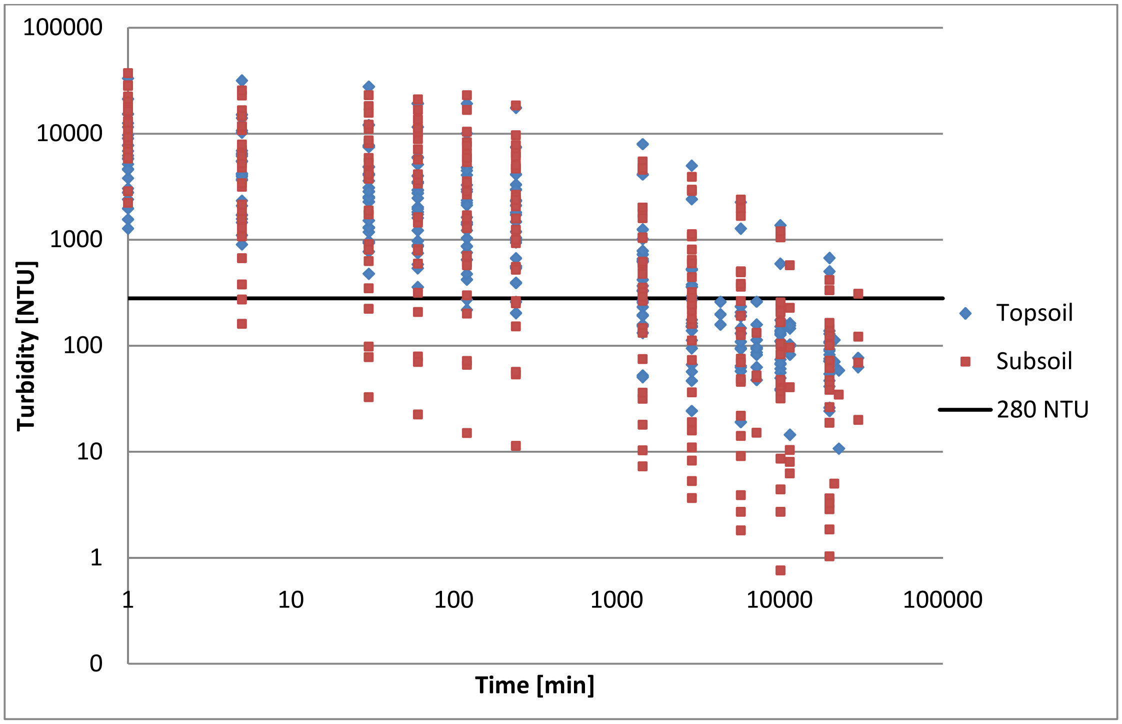

Figure 4.16. The twenty five selected South Carolina soil's top soil and subsoil's turbidity relationship to settling time[10].

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[10] For Figure 4.16, 0 minute values were plotted as 1 to be shown on logarithmic scale

To remain consistent with classifying the soils, results were divided by South Carolina regions and the top soil and subsoils were sorted based on the same measured clay content ranges formulated previously. Resembling the relationships established above from turbidity with respect to suspend sediment concentration, it was found that for each region, trends were best formulated from soils' measured clay content as well.

Based upon correlation coefficients of the predicted equations, all trends correlated well with a power function. This suggests the relationship is governed by Stoke's Law; where smaller particles remain in suspension longer and contribute more to turbidity compared to soils with less clay content. These relationships are displayed in Figures 4.17-4.22[11] on log-log plots. For Figures 4.17-4.22, 0 minute values were assigned a value of 1 in order to be able to be shown on a logarithmic scale.

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[11] For Figures 4.17-4.22, n refers to the number of soil samples. Each soil sample contains 11 data points.

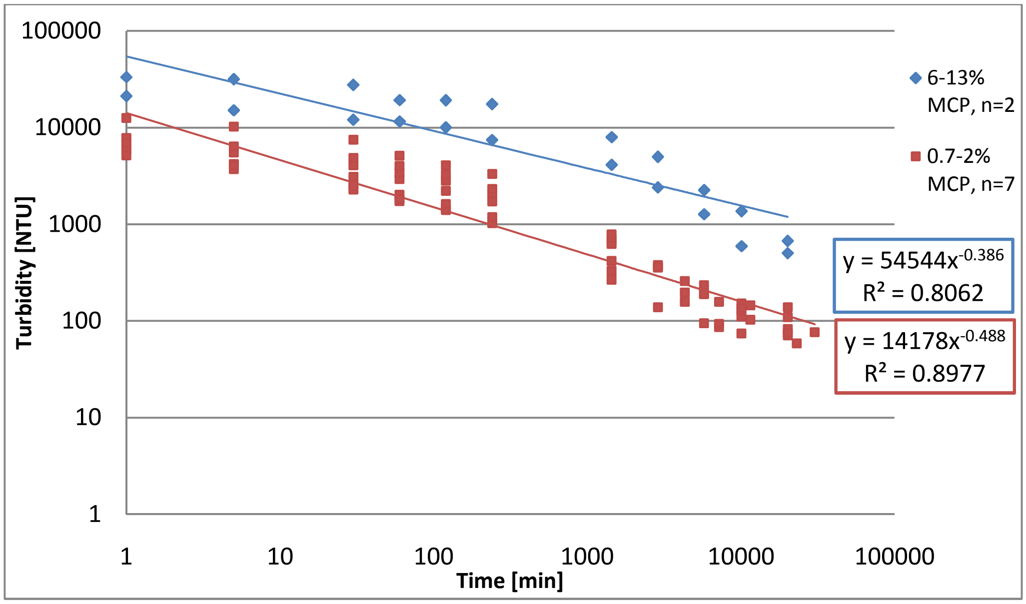

Figure 4.17. Turbidity as a function of settling time for Piedmont top soils (n= number of soils). Trends were formulated based on measured clay percentages (MCP).

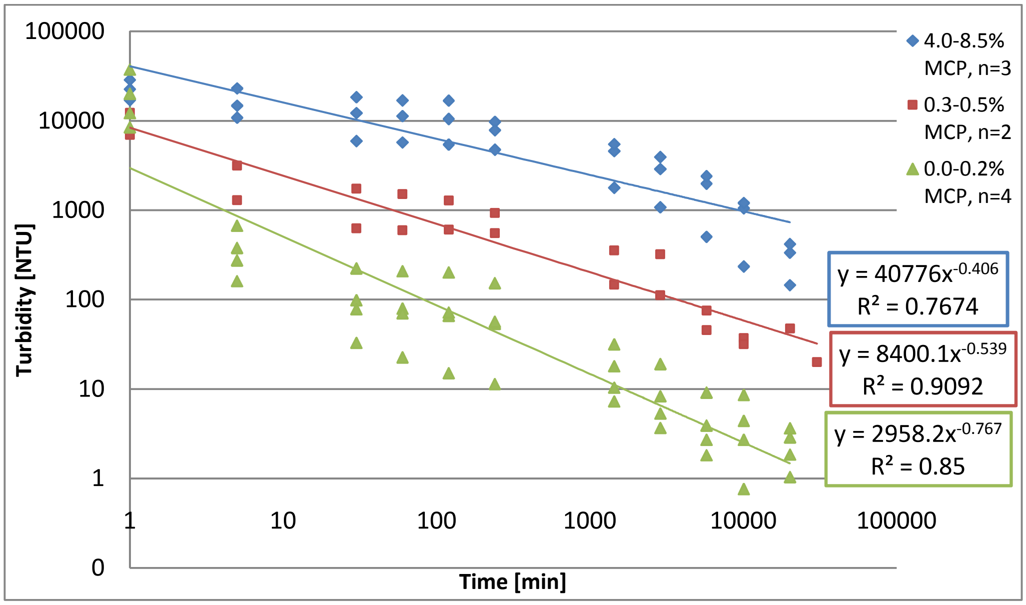

Figure 4.18. Turbidity as a function of settling time for Piedmont subsoils (n= number of soils). Trends were formulated based on measured clay percentages (MCP).

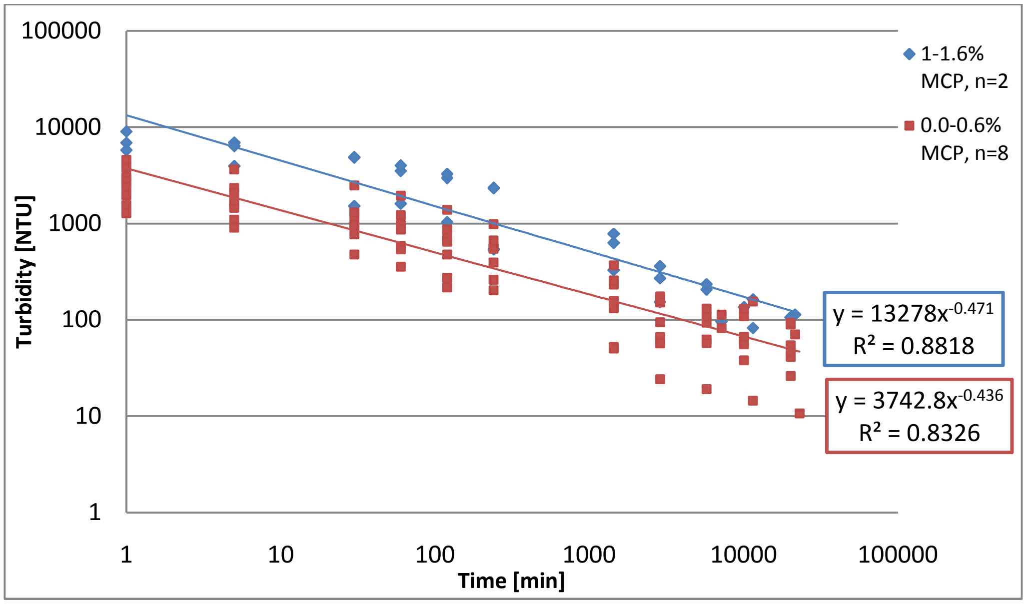

Figure 4.19. Turbidity as a function of settling time for Central top soils (n= number of soils). Trends were formulated based on measured clay percentages (MCP).

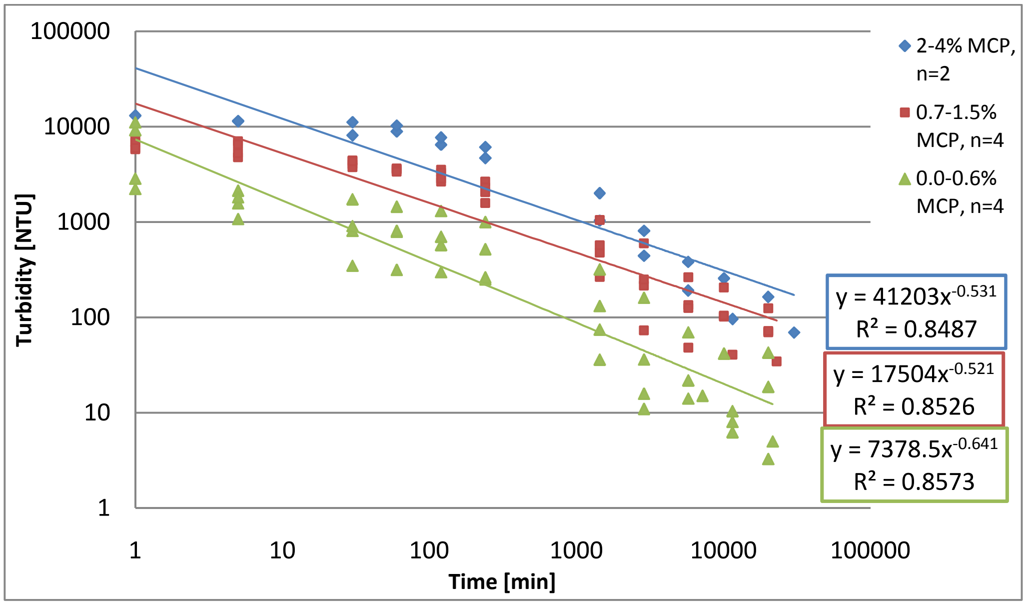

Figure 4.20. Turbidity as a function of settling time for Central subsoils (n= number of soils). Trends were formulated based on measured clay percentages (MCP).

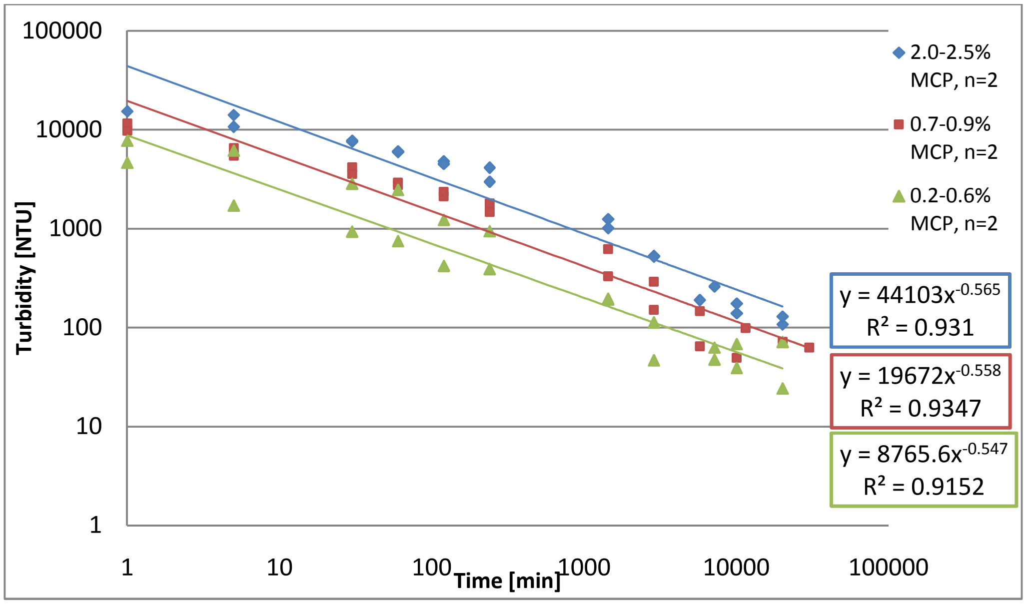

Figure 4.21. Turbidity as a function of settling time for Coastal top (n= number of soils). Trends were formulated based on measured clay percentages (MCP).

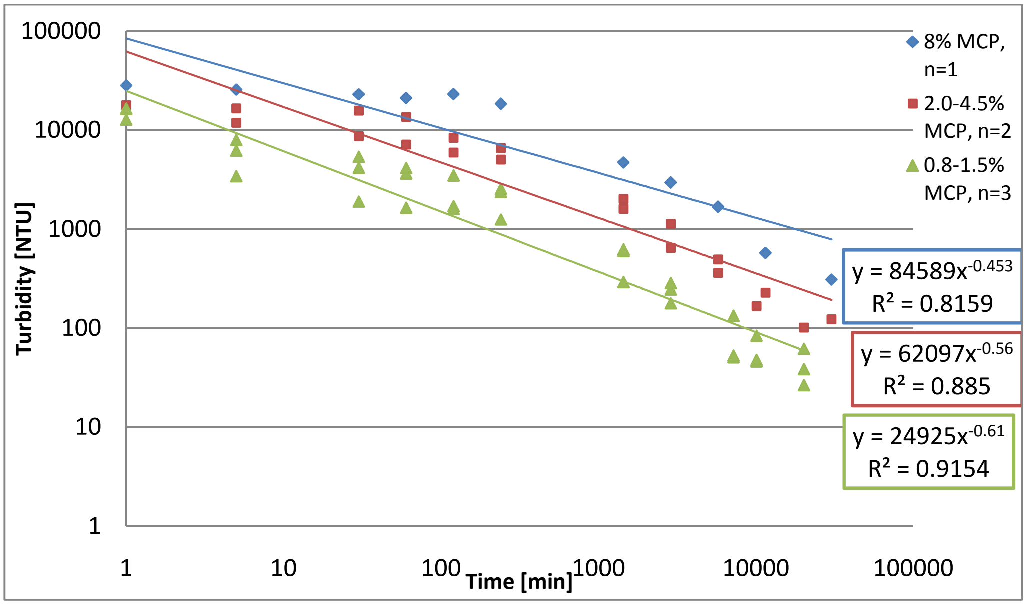

Figure 4.22. Turbidity as a function of settling time for Coastal subsoils (n= number of soils). Trends were formulated based on measured clay percentages (MCP).

Figures 4.17-4.22 illustrate noticeable differences among the smallest percentages of measured clay content. However, for both relationships of turbidity versus suspended sediment concentration and turbidity versus settling time, the trends formulated from measured clay content have gaps between the ranges. To possibly explain gaps between measured clay content or why certain soils aggregated, both soils' primary particle size distribution and eroded particle size distribution values were examined. If either of these values could describe the ranges that were formulated, then lab analysis could possibly be avoided in order to predict the behavior of all soils in the respective South Carolina regions. Nevertheless, primary particle size distribution and eroded particle size distribution values could not relate to the ranges obtained for this project (tabular data shown in Appendix B). An aggregate size distribution would have to be executed in order to use the empirically derived correlations established in this project. If this procedure is performed and the soil's ASD clay content does not follow within the empirical ranges, interpolation between trendlines could be conducted to predict the soil's behavior with respect to turbidity. However, in Figures 4.13 and 4.15, trendlines cross due to high initial values from the certain subsoils that aggregated and quickly settled. Therefore, if interpolation was needed where lines cross, still use the trendlines that the measured clay content lies between.

### *Turbidity with Respect to Particle Size*

After the fulfillment of analyzing turbidity with respect to concentration and settling time, a potential predictive model of turbidity's response to particle size was evaluated to possibly support the previous findings. Prediction models, such as SEDIMOT II, utilize particle diameters from an eroded particle size distribution to estimate effluent sediment loads from best management practices. Therefore, it would be beneficial if a correlation existed between particle diameter and turbidity for use in prediction models. As stated earlier, to be able to compare all selected soils, the ratio of turbidity to concentration was plotted versus particle diameter (see Figure 4.23).

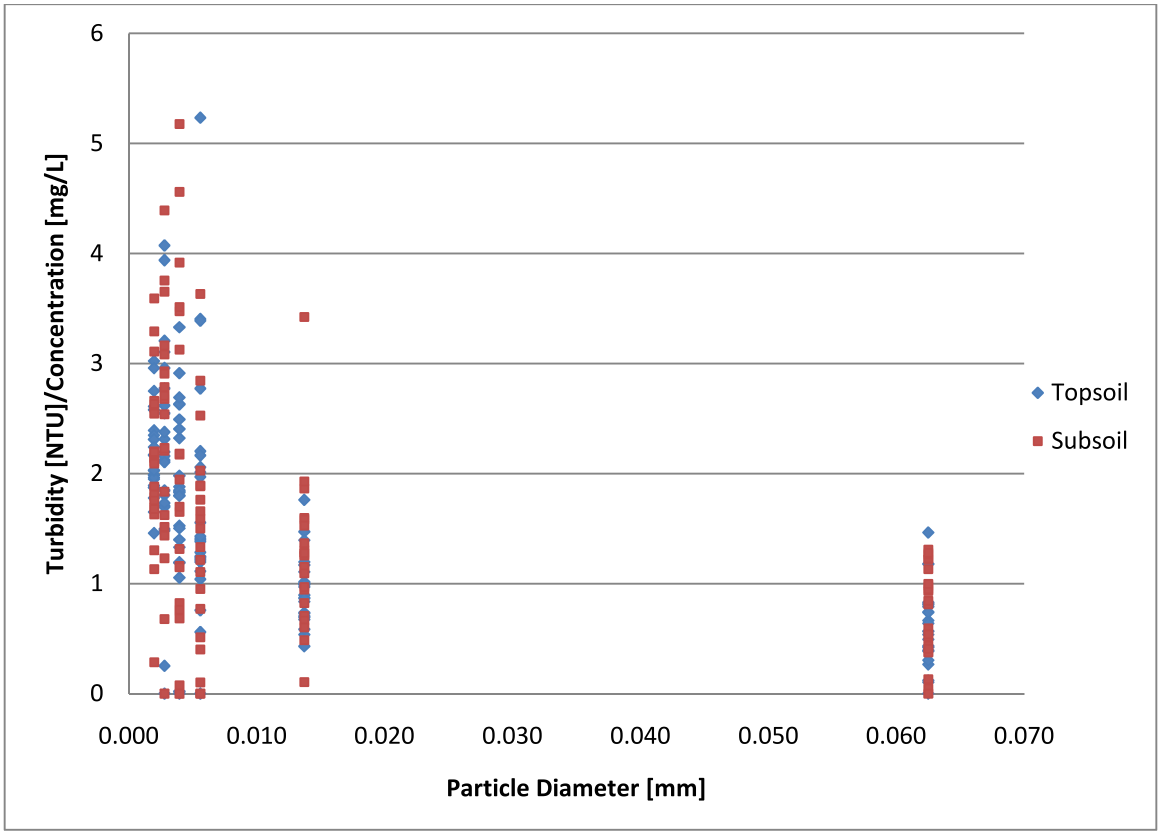

Figure 4.23. The ratio of turbidity to concentration versus particle diameter for all soils[12].

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[12] Two values above a ratio of 6 were allocated as outliers and were not plotted on Figure 4.19.

First, top soils and subsoils were evaluated collectively, but no correlations were determined. As a result, soils were once again evaluated depending on South Carolina regions, and the top soil and subsoils were sorted based on the same measured clay content ranges formulated above.  Unlike trends found in the above analyses, correlation coefficients of the predicted equations did not correlate as well with a classification based on measured clay content. These relationships are displayed in Figures 4.24-4.29. Because a ratio of zero indicated a particle diameter not contributing to turbidity, these ratios were not plotted. Appendix E contains the modified and raw data used to create Figures 4.25-4.29. For the most part, the figures seem to follow an increasing trend from larger particles to smaller particles. As particle size decreases, the ratio of turbidity to concentration increases. Soils were chosen to fit a power function as opposed to a logarithmic regression because the power function equations will not produce negative ratios if the equation was carried out for larger particle sizes. However, soils viewed individually (Appendix E) do not follow this, or any apparent, trend mainly due to the subtraction method that was computed. Errors were most likely introduced with the lab procedure of pulling a sample at a certain depth and time to calculate its corresponding particle diameter because the true amount of a particle was still unknown even though a subtraction method was performed. Hence, correlations were inconclusive and future analysis is encouraged to refine this relationship of turbidity/concentration to particle size for it to be used in prediction models.

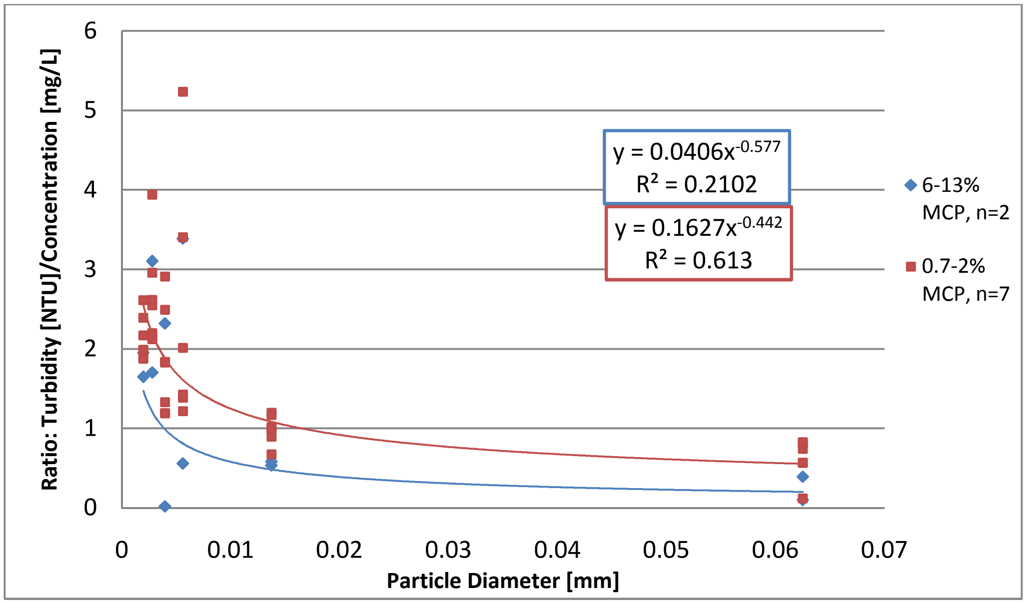

Figure 4.24. Piedmont top soil’s relationship of particle diameter to y, where y is the ratio of turbidity to concentration (n= number of soils). Trends were evaluated based on MCP.

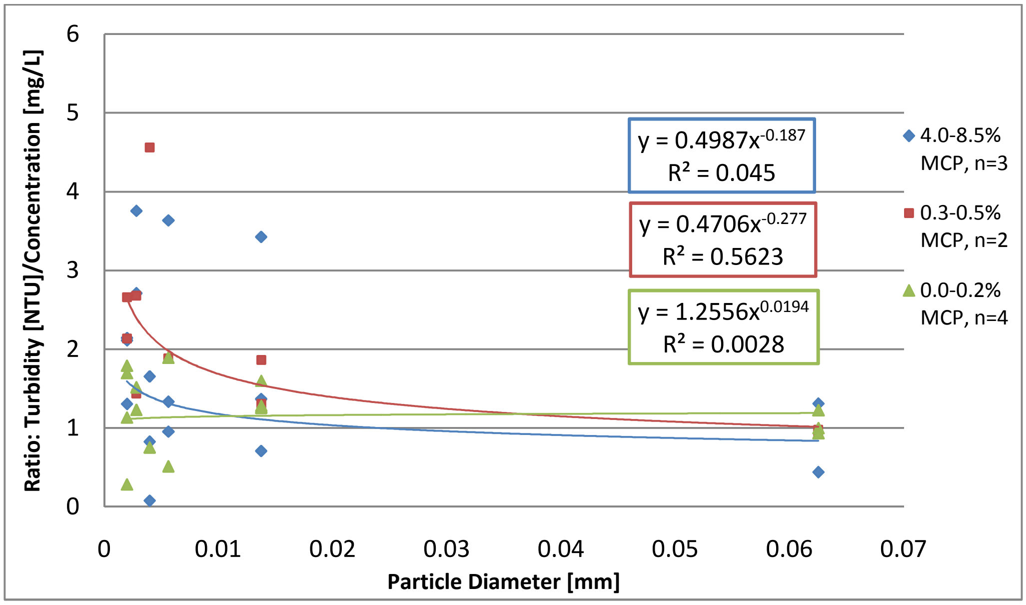

Figure 4.25. Piedmont subsoil’s relationship of particle diameter to y, where y the ratio of turbidity to concentration (n= number of soils). Trends were evaluated based on MCP

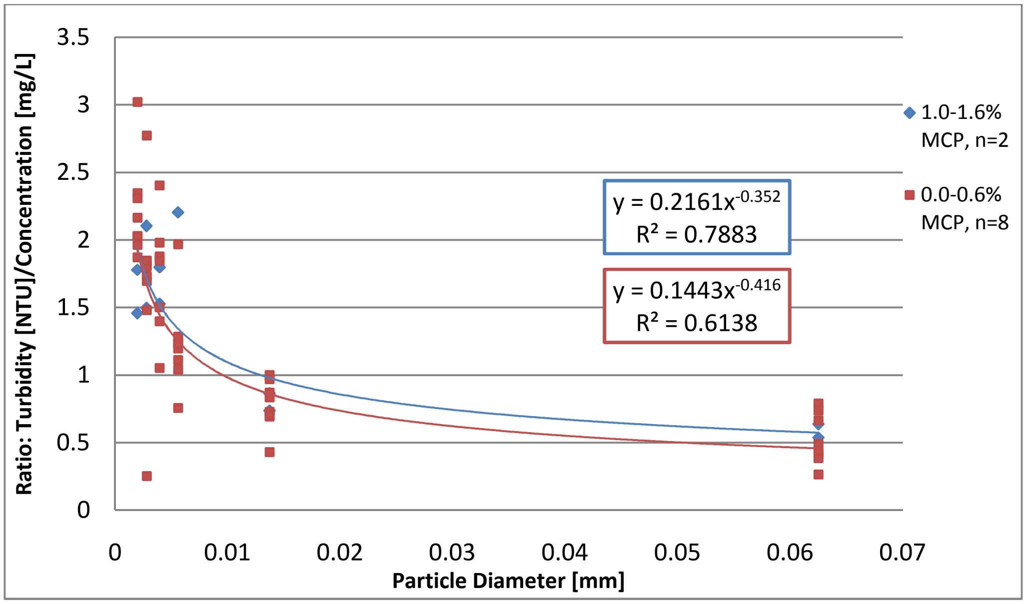

Figure 4.26. Central top soil's relationship of particle diameter to y, where y the ratio of turbidity to concentration (n= number of soils). Trends were evaluated based on MCP.

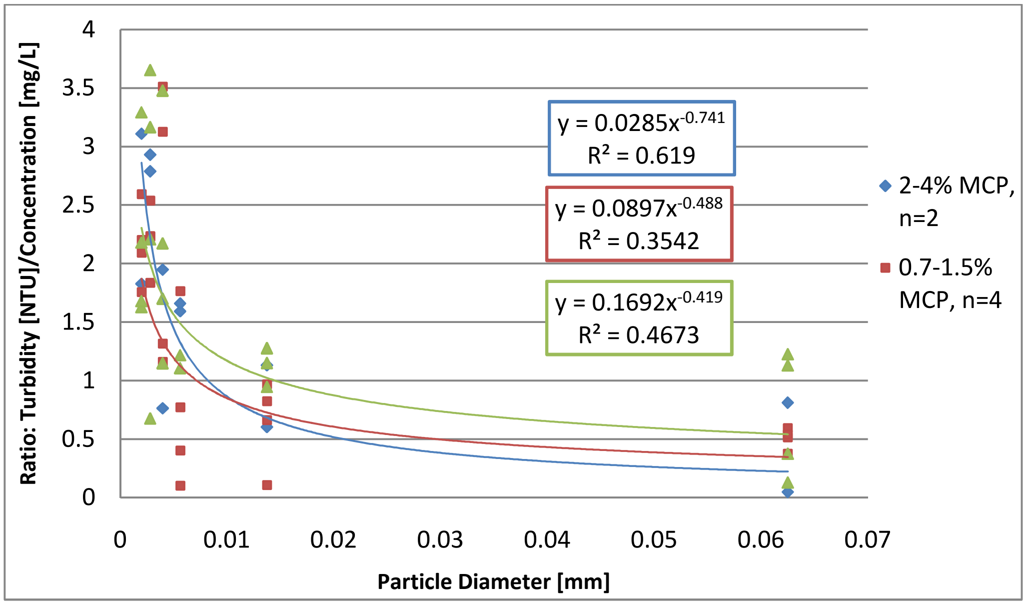

Figure 4.27. Central subsoil's relationship of particle diameter to y, where y the ratio of turbidity to concentration (n= number of soils). Trends were evaluated based on MCP.

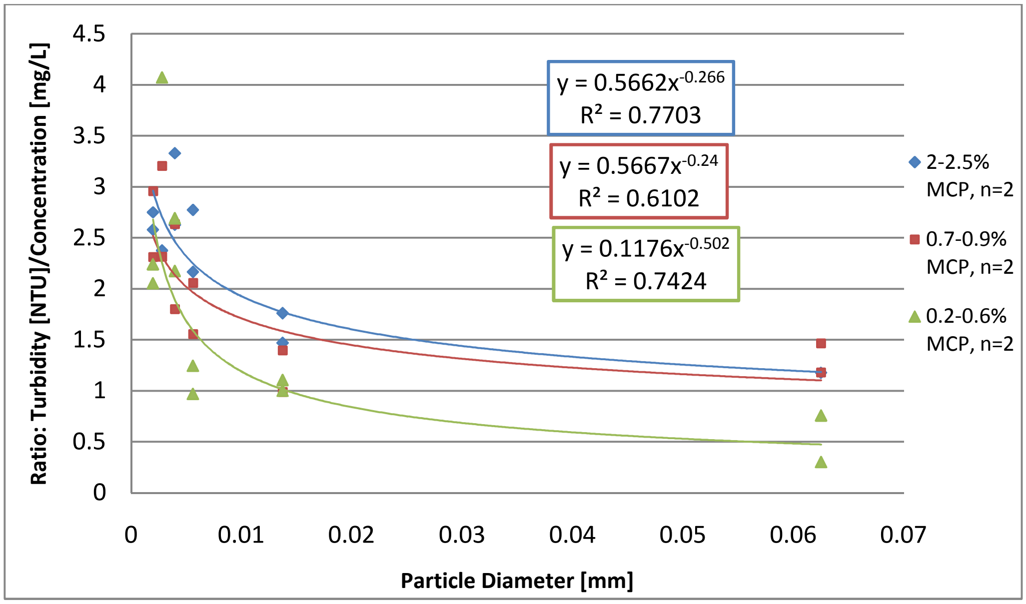

Figure 4.28. Coastal top soil's relationship of particle diameter to y, where y the ratio of turbidity to concentration (n= number of soils). Trends were evaluated based on MCP.

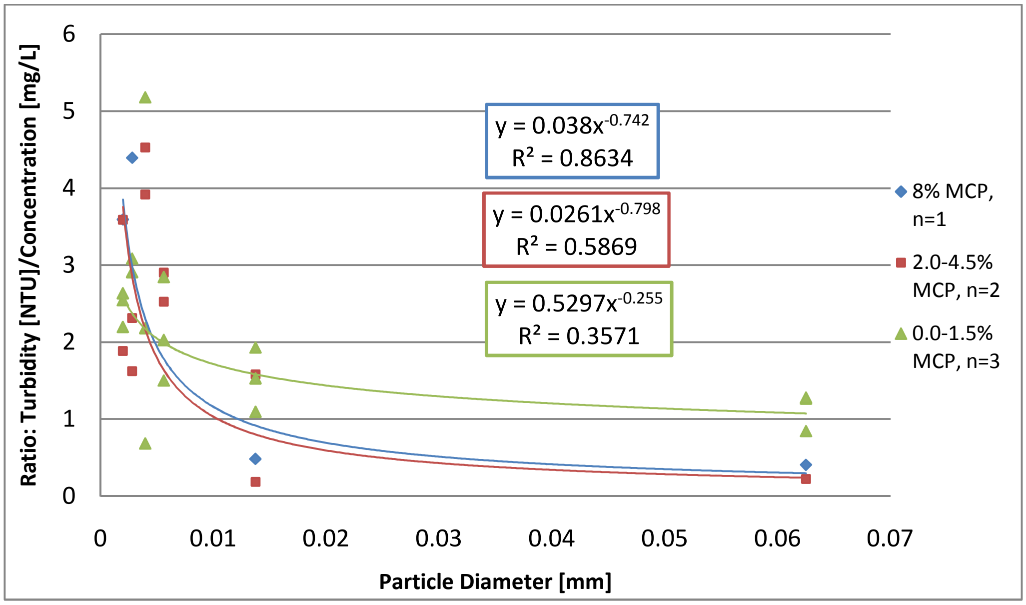

Figure 4.29. Coastal subsoil's relationship of particle diameter to y, where y the ratio of turbidity to concentration (n= number of soils). Trends were evaluated based on MCP.

# CONCLUSIONS

The goal of this research was to determine if relationships could be established to relate sediment concentration and sediment settling time to turbidity based on sediment characteristics of representative South Carolina soils.

For the relationship of suspended sediment concentration to turbidity, soils were first divided by top soils and subsoils to determine if the behavior of the selected soils could be collectively classified by soil characteristics. However, relationships found among top soils and subsoils could not be explained or classified because common physical properties could not be established. Further analysis found correlations among top soil and subsoil based on predominant South Carolina region and measured clay content. Such results are supported by previous research that relationships must be derived from site specific characteristics. Based on correlation coefficients of the predicted equations, trends correlated well with either a linear or a log relationship ($R^2$ values ranging from 0.7945 to 0.9846). Therefore, for each region, research confirmed that as concentration of fines increased, turbidity increased; and soils with higher clay content produced higher turbidity values compared to soils with less clay. As opposed to measured fines content (silt and clay), empirically derived measured clay content best modeled the behavior of soils' turbidity with respect to concentration. This was because fines content could not rationalize the behavior of soils that aggregated and quickly settled from suspension.

As for the correlation of turbidity and settling time, to remain consistent with classifying the soils, they were once again evaluated depending on the assortment determined from the above analyses. Therefore, results were separated by South Carolina region where the top soil and subsoils were sorted based on the same measured clay content ranges formulated above. Based on the correlation coefficients of the predicted equations, all trends correlated well with a power function ($R^2$ values ranging from 0.7674 to 0.9347). This relationship therefore followed Stoke's Law, where smaller particles remain in suspension longer and contribute more to turbidity as opposed to soils with less clay content.

It was also determined that majority of the selected soils did not below a value of 280 NTU until 24 hours, or later, of settling. In other words, it would take longer than a day for the soils to be below EPA's effluent limitation guideline of 280 NTU.

For both relationships of turbidity versus suspended sediment concentration and turbidity versus settling time, trends formulated from measured clay content have gaps between the ranges and could not be explained by either soil's primary or eroded particle size distributions. Therefore, if relationships formulated in this project are to be used for future predictive purposes, a modified eroded particle size distribution would be required. Also, if this procedure is performed and the soil's ASD clay content does not fall within the empirical ranges, to account for the gaps in clay content ranges, interpolation between trendlines could be conducted to predict the soil's behavior with respect to turbidity, concentration, and settling time.

Lastly, the relationship of turbidity to particle size was evaluated to potentially support findings of turbidity to sediment concentration and settling time. Once again, top soils and subsoils were examined based on South Carolina region and measured clay content. It was found that the ratio of turbidity to concentration versus particle diameter did not correlate well ($R^2$ values ranging from 0.0028 to 0.8634 from power functions), resulting in inconclusive relationships. Due to potential procedural errors, it is encouraged to refine this relationship of turbidity/concentration to particle size in order for it to be used in future prediction models. Better separation of particle sizes, as opposed to conducting a subtraction method, should yield in better results for determining particle size's effect on turbidity.

# CHAPTER 5

## SUMMARY CONCLUSIONS

The overall goal of this research was to determine relationships between turbidity and sediment concentration and sediment settling time, based on properties of representative South Carolina soils. Before this could be achieved, accuracy and precision of commercially available nephelometers were evaluated for use in subsequent analysis and potential regulatory compliance. The overall goal was met, and the following conclusions can be made from the from instrument analysis results.

1. Analysis of instruments' accuracy and precision showed that even though meters may be precise, there is potential for inaccuracy. If inaccuracy is compounded by precision, misinterpretation of results is likely.
2. Meters that performed well provided accurate and precise results for both calibration studies. As a result, secondary calibration standards (SCALs) did provide calibration results equivalent to those obtained when the instrument was calibrated with the primary calibration standard (PCAL) of formazin.
3. When subjected to varying field surface water samples, readings produced by meters calibrated to formazin standards produced higher, but consistent, NTU values compared to meters calibrated to styrene divinylbenzene (SDVB) standards. However, when all meters were calibrated to formazin PCALs, range of readings per sample narrowed. These results suggested that differences from meters are most likely due to differences in formazin standards and SDVB

standards. It was also concluded that formazin standards may be a better standard for surface water analysis.

After meter performance conclusions were determined, the following conclusions can be made from the soil-water analysis results.

4. It was found that the relationship of turbidity versus sediment concentration of selected South Carolina soils were well correlated when top soil and subsoils were classified by South Carolina physiographic region and measured clay content. As a result, for each region, research suggests that as concentration of fines increase, turbidity increases; and soils with higher clay content produce higher turbidity values compared to soils with less clay.
5. Based on correlation coefficients of the predicted equations, trends for suspended sediment concentration to turbidity correlated well with either a linear or a log relationship ($R^2$ values ranging from 0.7945 to 0.9846) as opposed to previous research utilizing a power function or the assumption of a one-to-one relationship.
6. When TSS Cecil concentrations from a dry sieve analysis were created and tested with the four commercially available turbidity meters, results were not equivalent to turbidity and concentration values that were obtained from soil-water remains of a wet sieve analysis. For example, Cecil subsoil that was dry sieved, at higher concentration values, turbidity was roughly half of its concentration value. For Cecil soil that was wet sieved, at higher concentration values, turbidity was roughly doubled its concentration value. Differences among results are most

likely due to the difference in sieve procedures. The wet sieve analysis would have disassociated more clay particles to pass through sieve openings as opposed to the dry sieve analysis.

7. Trends that correlated well with a linear relationship for suspended sediment concentration and turbidity can follow the dilution protocol in EPA's Method 180.1. Where, if a sample is diluted by half, then its turbidity reading is multiplied by two. Thus, following a linear proportionality. However, this would not be the case for trends that correlated well with a log relationship.
8. For correlations of turbidity and sediment settling time, trends also correlated well when top soil and subsoils were classified based on their predominant South Carolina physiographic region and measured clay content. From the correlation coefficients of the predicted equations ($R^2$ values ranging from 0.7674 to 0.9347), all trends correlated well with a power function. This suggests that the relationship was governed by Stoke's Law; where smaller particles remain in suspension longer. As a result, the smaller particles contributed more to turbidity compared to soils with less clay content.
9. Majority of the soils were not below a value of 280 NTU until 24 hours, or later, of settling. In other words, it would take longer than a day for the soils to be below EPA's proposed effluent limitation guideline of 280 NTU.
10. The empirical relationships found for turbidity versus suspended sediment concentration and turbidity to sediment settling time are expected to work well for predicting the behavior of all South Carolina soils. Correlations can be utilized if

soil's measured clay content is determined from an aggregate size distribution (ASD). Also, if soil's measured clay content does not fall within the empirical ranges, to account for gaps in clay content ranges, interpolation between trendlines can be conducted to predict soil's behavior with respect to turbidity, concentration and sediment settling time.

Altogether, results of this research will provide a step in determining 1) potential site-specific equations relating sediment concentration to turbidity and sediment settling time to turbidity, 2) aid in the design of future best management practices on construction sites, and 3) provide information for potential regulatory compliance. However, future analysis is encouraged to refine turbidity relationships and suggestions are listed below.

1. EPA's Method 180.1 is focused on turbidity analyses for drinking water. If future limitation guidelines are proposed for construction site activities, then revisions to EPA Method 180.1 are needed. For example, it was found that formazin may be a better standard for surface water samples as opposed to the other accepted standard, AMCO EPA. Also, it was impractical and difficult to dilute samples below a turbidity value of 40 NTU. Lastly, not all soils' relationship of turbidity and suspended sediment concentration was linear, therefore, cannot follow the dilution proportionality outlined in 180.1.
2. The research found well-correlated relationships of turbidity to sediment concentration and turbidity to sediment settling time, but these trends were formulated from specific measured clay content ranges. Therefore, further research is needed to see if the correlations found could be used to accurately

predict the responses of other South Carolina soils. It would also be of interest to evaluate if interpolation between trendlines could be executed in order to calculate relationships of other South Carolina soils that don't fall within the empirically derived clay content ranges.

3. Again, from this research it was determined that future laboratory analysis, namely conducting an aggregate size distribution, cannot be avoided if data are going to be used. However, the potential for particle diameter relating to the ratio of turbidity to concentration could be a link to explaining turbidity relationships for prediction models. It is suggested this relationship be further refined with a different lab procedure.

# APPENDICES

# APPENDIX A.

## Tabular data of Experiments 1-4 to determine meters accuracy and precision[13,14]

Appendix A contains the tabular data calculated in order to evaluate instrument performance of four commonly utilized and commercially available nephelometers. Determining meters' accuracy and precision may be found in the tables for Experiments 3a and 3b. Tabular data for meters' response to surface water samples may be found in the tables for Experiments 4a and 4b.

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[13] Meters used:
Hach 1&2= Hach 2100Q
LaMotte= LaMotte 2020e
GW= Global Water's Turb 430T

[14] Experiment 1= Meters' turbidity responses to TSS concentrations of a Cecil soil (calibrated to provided SCALs).
Experiment 2= Verification of manufacturer supplied standards (calibrated to provided SCALs)
Experiment 3a= Meter accuracy and precision (calibrated to provided SCALs)
Experiment 3b= Meter accuracy and precision (calibrated to created PCALs)
Experiment 4a= Meters' turbidity responses to natural water samples (calibrated to provided SCALs)
Experiment 4b= Meters' turbidity responses to natural water samples (calibrated to created PCALs)

Table A.1. Experiment 1: Hach 1, LaMotte and GW’s turbidity [NTU] responses to Cecil TSS [mg/L].

| **Hach 1** | | | | | | |
|---|---|---|---|---|---|---|
| **3000 mg/L** | **2000 mg/L** | **1000 mg/L** | **500 mg/L** | **100 mg/L** | **50 mg/L** | **25 mg/L** |
| 1360 | 1070 | 414 | 216 | 51.6 | 26.9 | 15.6 |
| 1385 | 1030 | 407 | 219 | 53.1 | 27 | 14.7 |
| 1375 | 1065 | 401 | 220 | 52.0 | 25.7 | 14.3 |
| 1370 | 1030 | 411 | 219 | 49.5 | 26.9 | 14.7 |
| 1380 | 1070 | 410 | 220 | 50.1 | 26.5 | 14.5 |
| **1374** | **1053** | **408.6** | **219** | **51.3** | **26.6** | **14.8** |

| **LaMotte** | | | | | | |
|---|---|---|---|---|---|---|
| **3000 mg/L** | **2000 mg/L** | **1000 mg/L** | **500 mg/L** | **100 mg/L** | **50 mg/L** | **25 mg/L** |
| 1060 | 724 | 263 | 175 | 36.9 | 18 | 9.4 |
| 1032 | 696 | 270 | 163 | 40.1 | 20.1 | 10.3 |
| 1036 | 756 | 263 | 162 | 40.1 | 19.8 | 8.1 |
| 1036 | 820 | 264 | 160 | 39.7 | 20.7 | 8.9 |
| 1080 | 692 | 271 | 172 | 40.9 | 21.2 | 9.8 |
| **1049** | **738** | **266** | **166** | **39.5** | **19.9** | **9.30** |

| **GW** | | | | | | |
|---|---|---|---|---|---|---|
| **3000 mg/L** | **2000 mg/L** | **1000 mg/L** | **500 mg/L** | **100 mg/L** | **50 mg/L** | **25 mg/L** |
| 970 | 750 | 266 | 158 | 35.5 | 18.4 | 11.0 |
| 945 | 740 | 261 | 163 | 35.5 | 18.2 | 9.5 |
| 955 | 740 | 263 | 146 | 34.6 | 16.9 | 11.4 |
| 940 | 710 | 252 | 156 | 38 | 18.6 | 9.9 |
| 915 | 735 | 262 | 154 | 30.8 | 15.8 | 11.0 |
| **945** | **735** | **261** | **155** | **34.9** | **17.6** | **10.6** |

Table A.2. Experiment 2: meter's turbidity [NTU] responses to Hach 2100Q's provided SCALs.

| **Hach 1** | | | | **LaMotte** | | | | **GW** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **10 NTU** | **20 NTU** | **100 NTU** | **800 NTU** | **10 NTU** | **20 NTU** | **100 NTU** | **800 NTU** | **10 NTU** | **20 NTU** | **100 NTU** | **800 NTU** |
| 9.79 | 20.7 | 103 | 797 | 9.83 | 22.1 | 110 | 675 | 9.43 | 20.3 | 107 | 1048 |
| 9.77 | 20.7 | 102 | 801 | 9.83 | 22.1 | 110 | 677 | 7.49 | 20.5 | 105 | 1074 |
| 9.72 | 20.7 | 103 | 796 | 9.83 | 22.1 | 111 | 677 | 7.48 | 19.3 | 107 | 1026 |
| 9.71 | 20.8 | 103 | 801 | 9.84 | 22 | 111 | 677 | 8.92 | 20.5 | 104 | 1024 |
| 9.76 | 20.8 | 102 | 805 | 9.83 | 22 | 111 | 677 | 9.22 | 20.1 | 107 | 1030 |
| **9.75** | **20.7** | **103** | **800** | **9.83** | **22.1** | **111** | **677** | **8.51** | **20.1** | **106** | **1040** |

Table A.3. Experiment 2: meter's turbidity [NTU] responses to LaMotte 2020e's provided SCALs.

| **Hach 1** | | | | **LaMotte** | | | | **GW** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **0 NTU** | **1 NTU** | **10 NTU** | **100 NTU** | **0 NTU** | **1 NTU** | **10 NTU** | **100 NTU** | **0 NTU** | **1 NTU** | **10 NTU** | **100 NTU** |
| 0.58 | 1.37 | 10.2 | 68.1 | 0.08 | 1.15 | 10.0 | 104 | 0.23 | 1.18 | 10.5 | 86.9 |
| 0.60 | 1.26 | 10.4 | 67.9 | 0.00 | 1.14 | 10.6 | 99.0 | 0.22 | 1.10 | 10.1 | 86.5 |
| 0.62 | 1.32 | 10.3 | 68.1 | 0.00 | 1.15 | 9.9 | 99.0 | 0.22 | 1.06 | 10.2 | 87.1 |
| 0.56 | 1.42 | 10.2 | 67.8 | 0.11 | 0.95 | 10.9 | 98.7 | 0.20 | 1.11 | 10.0 | 86.9 |
| 0.71 | 1.32 | 10.1 | 67.7 | 0.00 | 0.95 | 10.0 | 98.7 | 0.19 | 1.08 | 10.1 | 87.3 |
| **0.61** | **1.34** | **10.2** | **67.9** | **0.04** | **1.07** | **10.3** | **99.9** | **0.21** | **1.11** | **10.2** | **86.9** |

Table A.4. Experiment 2: meter's turbidity [NTU] responses to Global Water's provided SCALs.

| **Hach 1** | | | **LaMotte** | | | **GW** | | |
|---|---|---|---|---|---|---|---|---|
| **0.02 NTU** | **10 NTU** | **1000 NTU** | **0.02 NTU** | **10 NTU** | **1000 NTU** | **0.02 NTU** | **10 NTU** | **1000 NTU** |
| 0.33 | 10.1 | 429 | 0.00 | 10.7 | 1744 | 0.00 | 9.95 | 1000 |
| 0.34 | 10.1 | 430 | 0.12 | 10.7 | 1744 | 0.00 | 9.97 | 1001 |
| 0.32 | 10.1 | 432 | 0.03 | 10.8 | 1726 | 0.00 | 9.91 | 1001 |
| 0.26 | 10.1 | 429 | 0.03 | 10.8 | 1746 | 0.01 | 9.95 | 1000 |
| 0.30 | 10.1 | 431 | 0.08 | 10.8 | 1717 | 0.00 | 9.96 | 996 |
| **0.31** | **10.1** | **430** | **0.05** | **10.8** | **1735** | **0.00** | **9.95** | **1000** |

Table A.5. Experiment 3a, meters' averaged turbidity readings [NTU].

| | **Hach 1** | | | **Hach 2** | | | **LaMotte** | | | **GW** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **PCAL NTU** | Round A | Round B | **AVG** | Round A | Round B | **AVG** | Round A | Round B | **AVG** | Round A | Round B | **AVG** |
| **1** | 1.71 | 1.40 | **1.56** | 1.62 | 1.44 | **1.53** | 1.90 | 1.32 | **1.61** | 1.00 | 1.07 | **1.03** |
| **10** | 10.4 | 10.9 | **10.7** | 10.1 | 11.0 | **10.6** | 12.1 | 10.9 | **11.5** | 9.37 | 9.96 | **9.67** |
| **50** | 50.7 | 50.9 | **50.8** | 49.7 | 51.2 | **50.5** | 62.2 | 54.2 | **58.2** | 48.5 | 47.8 | **48.2** |
| **100** | 95.8 | 96.3 | **96.0** | 98.0 | 98.7 | **98.4** | 117 | 103 | **110** | 97.0 | 92.9 | **95.0** |
| **280** | 264 | 270 | **267** | 269 | 273 | **271** | 291 | 287 | **289** | 273 | 268 | **271** |
| **500** | 486 | 492 | **489** | 483 | 492 | **487** | 600 | 621 | **611** | 479 | 477 | **478** |
| **750** | 731 | 752 | **741** | 724 | 744 | **734** | 1411 | 1261 | **1336** | 729 | 730 | **730** |
| **1000** | 1008 | 989 | **999** | 991 | 984 | **988** | 724 | 851 | **787** | 1004 | 984 | **994** |

Table A.6. Experiment 3a, meter accuracy: averaged percent difference about the true value.

| | **Hach 1** | | | **Hach 2** | | | **LaMotte** | | | **GW** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **PCAL NTU** | Round A | Round B | **AVG** | Round A | Round B | **AVG** | Round A | Round B | **AVG** | Round A | Round B | **AVG** |
| **1** | 71.00 | 40.20 | **55.60** | 62.20 | 43.80 | **53.00** | 89.80 | 32.40 | **61.10** | 5.60 | 6.80 | **6.20** |
| **10** | 4.00 | 9.40 | **6.70** | 1.40 | 10.00 | **5.70** | 21.00 | 8.88 | **14.94** | 6.28 | 0.36 | **3.32** |
| **50** | 1.32 | 1.84 | **1.58** | 0.60 | 2.44 | **1.52** | 24.44 | 8.40 | **16.42** | 3.00 | 4.40 | **3.70** |
| **100** | 4.20 | 3.72 | **3.96** | 2.00 | 1.26 | **1.63** | 17.00 | 3.22 | **10.11** | 2.98 | 7.02 | **5.00** |
| **280** | 5.64 | 3.71 | **4.68** | 3.79 | 2.64 | **3.21** | 3.79 | 2.50 | **3.14** | 2.57 | 4.21 | **3.39** |
| **500** | 2.76 | 1.64 | **2.20** | 3.48 | 1.64 | **2.56** | 19.96 | 24.24 | **22.10** | 4.28 | 4.68 | **4.48** |
| **750** | 2.59 | 0.48 | **1.53** | 3.52 | 0.77 | **2.14** | 88.11 | 68.13 | **78.12** | 2.75 | 2.69 | **2.72** |
| **1000** | 1.16 | 1.08 | **1.12** | 0.92 | 1.56 | **1.24** | 27.64 | 14.94 | **21.29** | 0.64 | 1.58 | **1.11** |

Table A.7. Experiment 3a, meter precision: averaged percent difference about measured value.

| | **Hach 1** | | | **Hach 2** | | | **LaMotte** | | | **GW** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **PCAL NTU** | Round A | Round B | **AVG** | Round A | Round B | **AVG** | Round A | Round B | **AVG** | Round A | Round B | **AVG** |
| **1** | 11.70 | 2.28 | **6.99** | 6.66 | 3.34 | **5.00** | 9.59 | 10.27 | **9.93** | 12.00 | 3.00 | **7.50** |
| **10** | 1.92 | 1.46 | **1.69** | 0.59 | 0.91 | **0.75** | 1.65 | 1.03 | **1.34** | 0.77 | 0.24 | **0.50** |
| **50** | 0.51 | 0.24 | **0.37** | 0.40 | 0.82 | **0.61** | 0.68 | 0.00 | **0.34** | 0.62 | 0.84 | **0.73** |
| **100** | 0.52 | 0.85 | **0.69** | 0.31 | 0.67 | **0.49** | 0.00 | 0.95 | **0.47** | 0.70 | 1.16 | **0.93** |
| **280** | 1.21 | 0.89 | **1.05** | 0.59 | 0.22 | **0.41** | 0.21 | 0.00 | **0.10** | 0.66 | 0.67 | **0.67** |
| **500** | 0.99 | 0.65 | **0.82** | 1.12 | 1.46 | **1.29** | 0.37 | 3.83 | **2.10** | 0.54 | 0.55 | **0.54** |
| **750** | 1.18 | 1.20 | **1.19** | 0.75 | 0.64 | **0.70** | 8.00 | 1.67 | **4.83** | 1.04 | 0.71 | **0.88** |
| **1000** | 1.94 | 0.49 | **1.21** | 0.93 | 0.37 | **0.65** | 1.71 | 0.42 | **1.07** | 1.00 | 0.79 | **0.89** |

Table A.8. Exp. 3b, meters’ averaged turbidity readings [NTU].

| | **Hach 1** | | | **Hach 2** | | | **LaMotte** | | | **GW** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **PCAL NTU** | Round A | Round B | **AVG** | Round A | Round B | **AVG** | Round A | Round B | **AVG** | Round A | Round B | **AVG** |
| **1** | 1.33 | 1.55 | **1.44** | 1.41 | 1.67 | **1.54** | 0.79 | 1.26 | **1.03** | 1.02 | 0.41 | **0.71** |
| **10** | 10.6 | 10.7 | **10.6** | 10.9 | 10.1 | **10.5** | 10.7 | 9.49 | **10.1** | 10.0 | 10.0 | **10.0** |
| **50** | 48.9 | 51.4 | **50.2** | 49.4 | 49.6 | **49.5** | 49.3 | 45.6 | **47.4** | 48.4 | 51.5 | **49.9** |
| **100** | 99.4 | 101 | **100** | 99.6 | 99.7 | **99.6** | 99.2 | 86.4 | **92.8** | 97.1 | 101 | **99.3** |
| **280** | 267 | 275 | **271** | 270 | 276 | **273** | 274 | 243 | **259** | 272 | 284 | **278** |
| **500** | 482 | 491 | **486** | 482 | 494 | **488** | 56 | 504 | **533** | 478 | 491 | **485** |
| **750** | 725 | 741 | **733** | 725 | 742 | **734** | 1175 | 1044 | **1110** | 723 | 735 | **729** |
| **1000** | 980 | 989 | **985** | 993 | 994 | **994** | 810 | 706 | **758** | 983 | 961 | **972** |

Table A.9. Experiment 3b, meter accuracy: averaged percent difference about the true value.

| | **Hach 1** | | | **Hach 2** | | | **LaMotte** | | | **GW** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **PCAL NTU** | Round A | Round B | **AVG** | Round A | Round B | **AVG** | Round A | Round B | **AVG** | Round A | Round B | **AVG** |
| **1** | 32.8 | 55.2 | **44.0** | 40.6 | 67.4 | **54.0** | 21.0 | 26.2 | **23.6** | 3.40 | 59.0 | **31.2** |
| **10** | 5.80 | 6.60 | **6.20** | 8.60 | 1.40 | **5.00** | 6.64 | 5.62 | **6.13** | 0.38 | 0.62 | **0.50** |
| **50** | 2.12 | 2.88 | **2.50** | 1.20 | 0.80 | **1.00** | 1.40 | 8.88 | **5.14** | 3.24 | 3.00 | **3.12** |
| **100** | 0.58 | 1.40 | **0.99** | 0.40 | 0.72 | **0.56** | 0.84 | 13.64 | **7.24** | 2.90 | 1.40 | **2.15** |
| **280** | 4.57 | 1.79 | **3.18** | 3.43 | 1.57 | **2.50** | 2.14 | 13.14 | **7.64** | 2.79 | 1.43 | **2.10** |
| **500** | 3.64 | 1.80 | **2.72** | 3.64 | 1.28 | **2.46** | 12.20 | 0.88 | **6.54** | 4.44 | 1.76 | **3.10** |
| **750** | 3.39 | 1.15 | **2.26** | 3.33 | 1.07 | **2.20** | 56.67 | 39.25 | **47.9** | 0.04 | 2.03 | **1.03** |
| **1000** | 2.00 | 1.08 | **1.54** | 0.68 | 0.56 | **0.62** | 19.00 | 29.40 | **24.2** | 1.68 | 3.90 | **2.79** |

Table A.10. Experiment 3b, meter precision: averaged percent difference about measured value.

| | **Hach 1** | | | **Hach 1** | | | **LaMotte** | | | **GW** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **PCAL NTU** | Round A | Round B | **AVG** | Round A | Round B | **AVG** | Round A | Round B | **AVG** | Round A | Round B | **AVG** |
| **1** | 2.41 | 2.06 | **2.24** | 4.55 | 0.84 | **2.69** | 18.9 | 0.63 | **9.81** | 11.0 | 26.8 | **18.9** |
| **10** | 1.70 | 0.56 | **1.13** | 0.55 | 0.59 | **0.57** | 2.01 | 6.68 | **4.35** | 0.98 | 0.88 | **0.93** |
| **50** | 0.74 | 0.70 | **0.72** | 0.40 | 0.40 | **0.40** | 0.00 | 0.79 | **0.40** | 0.37 | 0.39 | **0.38** |
| **100** | 0.48 | 0.59 | **0.54** | 0.10 | 1.32 | **0.71** | 0.91 | 0.07 | **0.49** | 0.62 | 0.59 | **0.60** |
| **280** | 0.45 | 0.73 | **0.59** | 0.22 | 0.22 | **0.22** | 0.00 | 0.90 | **0.45** | 0.81 | 0.35 | **0.58** |
| **500** | 1.49 | 0.81 | **1.15** | 1.00 | 0.69 | **0.84** | 1.07 | 0.99 | **1.03** | 0.38 | 0.24 | **0.31** |
| **750** | 0.63 | 0.76 | **0.70** | 0.69 | 0.67 | **0.68** | 1.45 | 1.21 | **1.33** | 1.61 | 0.84 | **1.22** |
| **1000** | 1.22 | 0.32 | **0.77** | 0.28 | 0.64 | **0.46** | 0.00 | 0.85 | **0.42** | 1.14 | 0.83 | **0.99** |

Table A.11. Experiment 4a, meters' averaged turbidity readings. Each repetition is an average of five readings.

| | **Construction Site t=20 min** | | | | **Construction Site t=30 min** | | | | **Construction Site t=60 min** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hach 1 | Hach 2 | Lamotte | GW | Hach 1 | Hach 2 | Lamotte | GW | Hach 1 | Hach 2 | Lamotte | GW |
| Rep 1 | 408 | 406 | 290 | 297 | 2030 | 2059 | 1621 | 1430 | 1864 | 1854 | 1418 | 1289 |
| Rep 2 | 430 | 429 | 291 | 307 | 2022 | 2025 | 1643 | 1400 | 1850 | 1853 | 1366 | 1296 |
| Rep 3 | 427 | 423 | 298 | 307 | 2070 | 2074 | 1560 | 1436 | 1831 | 1834 | 1349 | 1307 |
| Rep 4 | 434 | 431 | 299 | 313 | 2071 | 2089 | 1607 | 1474 | 1852 | 1886 | 1377 | 1298 |
| Rep 5 | 426 | 426 | 292 | 312 | 2211 | 2201 | 1655 | 1511 | 1933 | 1942 | 1432 | 1340 |
| **AVG** | **425** | **423** | **294** | **307** | **2081** | **2090** | **1617** | **1450** | **1866** | **1874** | **1388** | **1306** |

| | **Construction Site t=150 min** | | | | **Hunnington Creek** | | | | **BG's Pond** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hach 1 | Hach 2 | Lamotte | GW | Hach 1 | Hach 2 | Lamotte | GW | Hach 1 | Hach 2 | Lamotte | GW |
| Rep 1 | 1001 | 1010 | 966 | 846 | 9.6 | 9.0 | 6.7 | 7.0 | 884 | 863 | 353 | 417 |
| Rep 2 | 1002 | 1006 | 974 | 849 | 9.6 | 9.4 | 6.8 | 6.7 | 879 | 859 | 352 | 417 |
| Rep 3 | 1043 | 1055 | 1052 | 866 | 9.0 | 8.6 | 6.5 | 6.2 | 898 | 874 | 356 | 433 |
| Rep 4 | 1079 | 1086 | 1053 | 898 | 9.2 | 9.2 | 7.1 | 6.4 | 879 | 871 | 352 | 448 |
| Rep 5 | 1161 | 1147 | 1053 | 955 | 8.6 | 8.9 | 6.4 | 6.6 | 887 | 875 | 359 | 444 |
| **AVG** | **1057** | **1061** | **1020** | **883** | **9.2** | **9.0** | **6.7** | **6.6** | **886** | **868** | **354** | **432** |

Table A.12. Experiment 4a, meter's standard deviation [NTU] for each field sample[15].

| | **Construction Site t=20 min** | **Construction Site t=30 min** | **Construction Site t=60 min** | **Construction Site t=150 min** | **Hunnington Creek** | **BG's Pond** |
|---|---|---|---|---|---|---|
| | Avg Rep [NTU] | Avg Rep [NTU] | Avg Rep [NTU] | Avg Rep [NTU] | Avg Rep [NTU] | Avg Rep [NTU] |
| Hach 1 | 425 | 2081 | 1866 | 1057 | 9.2 | 886 |
| Hach 2 | 423 | 2090 | 1874 | 1061 | 9.0 | 868 |
| LaMotte | 294 | 1617 | 1388 | 1020 | 6.7 | 354 |
| GW | 307 | 1450 | 1306 | 883 | 6.6 | 432 |
| Average | 362 | 1809 | 1608 | 1005 | 7.9 | 635 |
| **St. Dev** | **71.5** | **326** | **304** | **83.5** | **1.43** | **281** |

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[15] Averaged Rep NTU values obtained from averages calculated in Table A.11.

Table A.13. Experiment 4b, meters' averaged turbidity readings. Each replication, 'Rep', is an average of five readings[16].

| | **Construction Site t=20 min** | | | | **Construction Site t=30 min** | | | | **Construction Site t=60 min** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hach 1 | Hach 2 | Lamotte | GW | Hach 1 | Hach 2 | Lamotte | GW | Hach 1 | Hach 2 | Lamotte | GW |
| Rep 1 | 380 | 382 | 266 | 327 | 2049 | 2077 | 1397 | 1651 | 1798 | 1854 | 1397 | 1434 |
| Rep 2 | 387 | 390 | 274 | 344 | 2047 | 2072 | 1317 | 1604 | 1820 | 1859 | 1415 | 1485 |
| Rep 3 | | | | | 2055 | 2086 | 1649 | 1620 | 1838 | 1889 | 1367 | 1438 |
| Rep 4 | | | | | 2027 | 2061 | 1537 | 1618 | 1836 | 1870 | 1372 | 1446 |
| Rep 5 | | | | | 2130 | 2157 | 1696 | 1678 | 1958 | 1995 | 1502 | 1564 |
| **AVG** | **383** | **386** | **270** | **336** | **2062** | **2091** | **1519** | **1634** | **1850** | **1893** | **1411** | **1474** |

| | **Construction Site t=150 min** | | | | **Hunnington Creek** | | | | **BG's Pond** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hach 1 | Hach 2 | Lamotte | GW | Hach 1 | Hach 2 | Lamotte | GW | Hach 1 | Hach 2 | Lamotte | GW |
| Rep 1 | 1014 | 1013 | 984 | 992 | 12.1 | 12.1 | 10.7 | 9.3 | 828 | 845 | 390 | 443 |
| Rep 2 | 1002 | 1022 | 1004 | 995 | 11.1 | 10.8 | 8.2 | 7.9 | 861 | 870 | 392 | 449 |
| Rep 3 | 1014 | 1016 | 963 | 996 | 9.9 | 9.9 | 7.3 | 7.5 | 862 | 873 | 401 | 456 |
| Rep 4 | 1007 | 1010 | 988 | 974 | 9.2 | 9.6 | 7.0 | 7.5 | 871 | 871 | 411 | 460 |
| Rep 5 | 1003 | 1026 | 997 | 975 | 9.9 | 9.7 | 7.4 | 7.3 | 790 | 799 | 397 | 463 |
| **AVG** | **1008** | **1017** | **987** | **986** | **10.4** | **10.4** | **8.1** | **7.9** | **842** | **852** | **398** | **454** |

Table A.14. Experiment 4b, meter's standard deviation [NTU] for each field sample[17].

| | **Construction Site t=20 min** | **Construction Site t=30 min** | **Construction Site t=60 min** | **Construction Site t=150 min** | **Hunnington Creek** | **BG's Pond** |
|---|---|---|---|---|---|---|
| | Avg Rep [NTU] | Avg Rep [NTU] | Avg Rep [NTU] | Avg Rep [NTU] | Avg Rep [NTU] | Avg Rep [NTU] |
| Hach 1 | 383 | 2062 | 1850 | 1008 | 10.4 | 842 |
| Hach 2 | 386 | 2091 | 1893 | 1017 | 10.4 | 852 |
| LaMotte | 270 | 1519 | 1411 | 987 | 8.1 | 398 |
| GW | 336 | 1634 | 1474 | 986 | 7.9 | 454 |
| Average | 344 | 1826 | 1657 | 1000 | 9 | 637 |
| **St. Dev** | **54.2** | **292** | **250** | **15.4** | **1.40** | **244** |

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[16] Not enough sample was collected from 'Construction Site at t=20 min' to carry out five replications.

[17] Averaged Rep NTU values obtained from averages calculated in Table A.13.

# APPENDIX B.

## Soil properties of the selected South Carolina soils

Appendix B encompasses size distributions for each of the selected soil series based on soil's physiographic South Carolina region. Regions include the upstate Piedmont region, the mid-state Central region and the Coastal Plains region. The first table for each region compares the size distributions obtained from the aggregate size distribution (ASD) analysis and the primary particle size distributions (PSD) from the hydrometer analysis. Following this includes the tabular data from the ASD analysis.

Table B.1. Piedmont soils' ASD ('Measured') and primary PSD ('Hydrometer'). Values are percent finer [%]

| | Measured | | | | Hydrometer | | | |
|---|---|---|---|---|---|---|---|---|
| **Soil Series** | **Sand**[18] | **Silt**[19] | **Clay**[20] | **Silt+Clay** | **Sand** | **Silt** | **Clay** | **Silt+Clay** |
| **Georgeville Top** | 51.00 | 36.58 | 12.42 | 49.00 | 59.62 | 27.72 | 12.66 | 40.38 |
| **Herndon Top** | 65.00 | 28.58 | 6.42 | 35.00 | 56.54 | 31.58 | 11.88 | 43.46 |
| **Pacolet Top** | 91.00 | 7.48 | 1.52 | 9.00 | 65.98 | 18.22 | 15.81 | 34.02 |
| **Wilkes Top** | 88.50 | 10.06 | 1.44 | 11.50 | 72.90 | 14.50 | 12.59 | 27.10 |
| **Cataula Top** | 88.00 | 10.58 | 1.42 | 12.00 | 58.98 | 26.22 | 14.81 | 41.02 |
| **Appling Top** | 87.00 | 11.98 | 1.02 | 13.00 | 74.76 | 12.50 | 12.74 | 25.24 |
| **Cecil Top** | 91.00 | 8.13 | 0.87 | 9.00 | 69.40 | 15.72 | 14.88 | 30.60 |
| **Madison Top** | 91.00 | 8.23 | 0.77 | 9.00 | 68.62 | 18.43 | 12.95 | 31.38 |
| **Hiwassee Top** | 93.50 | 5.75 | 0.75 | 6.50 | 64.83 | 20.29 | 14.88 | 35.17 |
| **Wilkes Sub** | 76.50 | 15.19 | 8.31 | 23.50 | 74.98 | 12.29 | 12.74 | 25.02 |
| **Hiwassee Sub** | 80.50 | 13.76 | 5.74 | 19.50 | 73.26 | 12.00 | 14.74 | 26.74 |
| **Madison Sub** | 73.00 | 23.04 | 3.96 | 27.00 | 71.26 | 13.93 | 14.81 | 28.74 |
| **Cataula Sub** | 82.00 | 17.52 | 0.48 | 18.00 | 71.26 | 14.86 | 13.88 | 28.74 |
| **Cecil Sub** | 92.00 | 7.66 | 0.34 | 8.00 | 78.05 | 9.22 | 12.74 | 21.95 |
| **Appling Sub** | 88.50 | 11.35 | 0.15 | 11.50 | 75.83 | 11.36 | 12.81 | 24.17 |
| **Herndon Sub** | 67.00 | 32.91 | 0.09 | 33.00 | 63.19 | 23.86 | 12.95 | 36.81 |
| **Pacolet Sub** | 90.00 | 9.93 | 0.07 | 10.00 | 75.19 | 12.07 | 12.74 | 24.81 |
| **Georgeville Sub** | 46.00 | 53.97 | 0.03 | 54.00 | 54.98 | 27.22 | 17.81 | 45.02 |

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[18] For ASD analysis, Sand refers to aggregate and particle sizes ranging from 2 to 0.05 mm

[19] For ASD analysis, Silt refers to aggregate and particle sizes ranging from 0.05 to 0.002 mm

[20] For ASD analysis, Clay refers to aggregate and particle sizes less than 0.002 mm

Table B.2. Piedmont top soils’ ASD tabular data.

| | **Georgeville** | **Herndon** | **Pacolet** | **Wilkes** | **Cataula** | **Appling** | **Cecil** | **Madison** | **Hiwassee** |
|---|---|---|---|---|---|---|---|---|---|
| Particle Size [mm] | Percent finer [%] | | | | | | | | |
| 2.000 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 1.180 | 96.4 | 89.2 | 98.8 | 92.2 | 97.6 | 97.9 | 94.6 | 96.9 | 98.9 |
| 0.425 | 91.8 | 83.3 | 68.1 | 83.8 | 85.9 | 84.1 | 78.3 | 75.3 | 66.5 |
| 0.150 | 86.4 | 75.7 | 34.2 | 53.3 | 37.8 | 39.8 | 37.8 | 40.6 | 25.1 |
| 0.075 | 74.9 | 57.0 | 16.8 | 24.2 | 20.8 | 20.6 | 16.1 | 18.6 | 12.3 |
| 0.063 | 56.4 | 42.7 | 10.2 | 13.7 | 13.3 | 14.4 | 10.6 | 10.9 | 7.79 |
| 0.062 | 52.7 | 38.7 | 9.49 | 12.6 | 12.1 | 13.8 | 9.68 | 9.46 | 7.02 |
| 0.031 | 43.8 | 29.1 | 8.40 | 10.0 | 10.6 | 11.0 | 8.33 | 8.04 | 5.77 |
| 0.016 | 43.2 | 23.9 | 7.10 | 6.59 | 4.72 | 4.09 | 5.17 | 5.43 | 4.33 |
| 0.008 | 22.7 | 11.82 | 3.82 | 2.64 | 4.21 | 2.69 | 3.02 | 2.45 | 2.12 |
| 0.004 | 16.7 | 8.85 | 2.68 | 2.64 | 2.50 | 1.92 | 1.75 | 1.49 | 1.30 |
| 0.002 | 12.4 | 6.42 | 1.52 | 1.44 | 1.42 | 1.02 | 0.87 | 0.77 | 0.75 |

Table B.3. Piedmont subsoils’ ASD tabular data.

| | **Georgeville** | **Herndon** | **Pacolet** | **Wilkes** | **Cataula** | **Appling** | **Cecil** | **Madison** | **Hiwassee** |
|---|---|---|---|---|---|---|---|---|---|
| Particle Size [mm] | Percent finer [%] | | | | | | | | |
| 2.000 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 1.180 | 99.9 | 82.1 | 99.5 | 97.7 | 99.3 | 99.0 | 92.9 | 99.2 | 97.4 |
| 0.425 | 97.5 | 76.3 | 89.2 | 90.2 | 86.2 | 87.1 | 83.3 | 84.6 | 90.7 |
| 0.150 | 90.0 | 61.9 | 51.6 | 60.9 | 43.4 | 38.8 | 38.5 | 57.3 | 51.1 |
| 0.075 | 74.4 | 46.4 | 22.1 | 32.1 | 28.7 | 21.4 | 14.7 | 35.6 | 28.3 |
| 0.063 | 59.3 | 36.9 | 14.8 | 25.4 | 19.8 | 14.5 | 10.0 | 28.3 | 21.0 |
| 0.062 | 55.0 | 34.5 | 13.8 | 23.9 | 18.6 | 13.2 | 9.1 | 27.2 | 20.0 |
| 0.031 | 50.5 | 27.3 | 3.94 | 22.6 | 16.2 | 7.22 | 5.97 | 25.4 | 18.4 |
| 0.016 | 0.43 | 0.51 | 0.26 | 16.9 | 1.07 | 0.38 | 1.31 | 9.63 | 20.3 |
| 0.008 | 0.09 | 0.16 | 0.08 | 10.9 | 0.92 | 0.24 | 0.87 | 4.95 | 12.7 |
| 0.004 | 0.05 | 0.12 | 0.09 | 10.9 | 0.75 | 0.22 | 0.70 | 4.71 | 8.03 |
| 0.002 | 0.03 | 0.09 | 0.07 | 8.31 | 0.48 | 0.15 | 0.34 | 3.96 | 5.74 |

Table B.4. Central soils' ASD ('Measured') and primary PSD ('Hydrometer'). Values are percent finer [%]

| | **Measured** | | | | **Hydrometer** | | | |
|---|---|---|---|---|---|---|---|---|
| **Soil Series** | **Sand**[21] | **Silt**[22] | **Clay**[23] | **Silt+Clay** | **Sand** | **Silt** | **Clay** | **Silt+Clay** |
| **Ailey Top** | 88.00 | 10.38 | 1.62 | 12.00 | 71.05 | 14.36 | 14.59 | 28.95 |
| **Johnston Top** | 89.00 | 9.84 | 1.16 | 11.00 | 58.05 | 28.29 | 13.66 | 41.95 |
| **Lakeland Top** | 96.00 | 3.39 | 0.61 | 4.00 | 82.76 | 4.50 | 12.74 | 17.24 |
| **Dothan Top** | 93.00 | 6.50 | 0.50 | 7.00 | 75.47 | 10.58 | 13.95 | 24.53 |
| **Fuquay Top** | 98.00 | 1.56 | 0.44 | 2.00 | 85.05 | 2.22 | 12.74 | 14.95 |
| **Troup Top** | 96.00 | 3.68 | 0.32 | 4.00 | 81.40 | 6.72 | 11.88 | 18.60 |
| **Bonneau Top** | 92.50 | 7.24 | 0.26 | 7.50 | 62.83 | 24.22 | 12.95 | 37.17 |
| **Blanton Top** | 97.50 | 2.28 | 0.22 | 2.50 | 83.33 | 4.79 | 11.88 | 16.67 |
| **Vaucluse Top** | 97.00 | 2.85 | 0.15 | 3.00 | 81.40 | 5.72 | 12.88 | 18.60 |
| **Wagram Top** | 94.00 | 5.99 | 0.01 | 6.00 | 75.54 | 10.50 | 13.95 | 24.46 |
| **Dothan Sub** | 84.50 | 12.21 | 3.29 | 15.50 | 79.34 | 8.78 | 11.88 | 20.66 |
| **Bonneau Sub** | 80.50 | 16.94 | 2.56 | 19.50 | 63.26 | 23.86 | 12.88 | 36.74 |
| **Blanton Sub** | 94.00 | 4.49 | 1.51 | 6.00 | 85.05 | 2.22 | 12.74 | 14.95 |
| **Troup Sub** | 92.00 | 6.66 | 1.34 | 8.00 | 80.12 | 7.14 | 12.74 | 19.88 |
| **Vaucluse Sub** | 94.00 | 4.79 | 1.21 | 6.00 | 81.12 | 6.22 | 12.66 | 18.88 |
| **Wagram Sub** | 94.00 | 5.22 | 0.78 | 6.00 | 74.12 | 13.14 | 12.74 | 25.88 |
| **Fuquay Sub** | 97.00 | 2.40 | 0.60 | 3.00 | 86.05 | 3.22 | 10.74 | 13.95 |
| **Johnston Sub** | 89.50 | 10.27 | 0.23 | 10.50 | 81.12 | 6.14 | 12.74 | 18.88 |
| **Ailey Sub** | 88.00 | 11.80 | 0.20 | 12.00 | 79.05 | 8.22 | 12.74 | 20.95 |
| **Lakeland Sub** | 97.00 | 2.86 | 0.14 | 3.00 | 84.19 | 4.14 | 11.66 | 15.81 |

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[21] For ASD analysis, Sand refers to aggregate and particle sizes ranging from 2 to 0.05 mm

[22] For ASD analysis, Silt refers to aggregate and particle sizes ranging from 0.05 to 0.002 mm

[23] For ASD analysis, Clay refers to aggregate and particle sizes less than 0.002 mm

Table B.5. Central top soils' ASD tabular data.

| | **Ailey** | **Blanton** | **Bonneau** | **Dothan** | **Fuquay** | **Johnston** | **Lakeland** | **Troup** | **Vaucluse** | **Wagram** |
|---|---|---|---|---|---|---|---|---|---|---|
| Particle Size[mm] | Percent finer [%] | | | | | | | | | |
| 2.000 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 1.180 | 99.6 | 99.8 | 99.8 | 99.8 | 99.9 | 99.5 | 99.5 | 99.5 | 99.6 | 99.9 |
| 0.425 | 93.9 | 97.3 | 78.4 | 94.7 | 98.5 | 86.7 | 91.6 | 97.0 | 95.4 | 98.8 |
| 0.150 | 45.7 | 34.5 | 35.5 | 51.7 | 37.7 | 38.1 | 21.6 | 51.1 | 55.0 | 45.8 |
| 0.075 | 19.9 | 9.32 | 19.8 | 13.7 | 6.20 | 22.0 | 8.17 | 13.4 | 12.8 | 17.2 |
| 0.063 | 14.5 | 3.37 | 9.01 | 8.17 | 2.66 | 12.8 | 4.35 | 5.21 | 3.72 | 7.76 |
| 0.062 | 13.2 | 2.71 | 8.16 | 7.39 | 2.40 | 11.7 | 3.94 | 4.45 | 3.04 | 6.55 |
| 0.031 | 10.8 | 1.96 | 5.38 | 6.14 | 2.22 | 9.98 | 3.40 | 3.54 | 2.25 | 4.58 |
| 0.016 | 8.91 | 1.45 | 2.11 | 4.77 | 2.15 | 7.82 | 3.19 | 2.52 | 1.43 | 2.21 |
| 0.008 | 4.38 | 0.69 | 1.18 | 2.58 | 1.12 | 3.74 | 1.79 | 1.12 | 0.55 | 1.05 |
| 0.004 | 2.73 | 0.44 | 0.93 | 1.35 | 0.76 | 2.34 | 1.18 | 0.57 | 0.28 | 0.36 |
| 0.002 | 1.62 | 0.22 | 0.26 | 0.50 | 0.44 | 1.16 | 0.61 | 0.32 | 0.15 | 0.01 |

Table B.6. Central subsoils' ASD tabular data.

| | **Ailey** | **Blanton** | **Bonneau** | **Dothan** | **Fuquay** | **Johnston** | **Lakeland** | **Troup** | **Vaucluse** | **Wagram** |
|---|---|---|---|---|---|---|---|---|---|---|
| Particle Size[mm] | Percent finer [%] | | | | | | | | | |
| 2.000 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 1.180 | 97.5 | 99.9 | 99.8 | 97.3 | 99.9 | 98.9 | 99.3 | 99.3 | 99.1 | 99.93 |
| 0.425 | 89.7 | 97.6 | 98.6 | 92.6 | 98.4 | 89.9 | 93.5 | 97.7 | 95.7 | 99.20 |
| 0.150 | 26.7 | 44.5 | 62.4 | 40.9 | 56.3 | 30.4 | 31.5 | 66.1 | 55.7 | 71.34 |
| 0.075 | 16.6 | 12.0 | 29.3 | 21.9 | 7.13 | 15.4 | 7.78 | 18.2 | 17.5 | 26.60 |
| 0.063 | 12.6 | 7.04 | 21.7 | 16.6 | 3.45 | 11.6 | 3.78 | 9.04 | 7.31 | 16.25 |
| 0.062 | 11.9 | 6.41 | 20.4 | 15.7 | 3.23 | 11.1 | 3.39 | 8.18 | 6.68 | 15.01 |
| 0.031 | 10.5 | 5.68 | 17.68 | 14.6 | 2.91 | 8.71 | 2.61 | 7.13 | 5.80 | 11.45 |
| 0.016 | 0.75 | 6.22 | 12.95 | 14.8 | 2.64 | 1.02 | 0.97 | 6.99 | 5.62 | 8.71 |
| 0.008 | 0.33 | 3.19 | 8.29 | 8.1 | 1.49 | 0.45 | 0.41 | 3.86 | 3.47 | 4.37 |
| 0.004 | 0.26 | 2.34 | 4.93 | 5.2 | 1.08 | 0.36 | 0.25 | 2.24 | 1.83 | 2.35 |
| 0.002 | 0.20 | 1.51 | 2.56 | 3.29 | 0.60 | 0.23 | 0.14 | 1.34 | 1.21 | 0.78 |

Table B.7. Coastal soils' ASD ('Measured') and primary PSD ('Hydrometer'). Values are percent finer [%]

| | **Measured** | | | | **Hydrometer** | | | |
|---|---|---|---|---|---|---|---|---|
| **Soil Series** | **Sand**[24] | **Silt**[25] | **Clay**[26] | **Silt+Clay** | **Sand** | **Silt** | **Clay** | **Silt+Clay** |
| **Goldsboro Top** | 86.50 | 11.12 | 2.38 | 13.50 | 73.34 | 10.07 | 16.59 | 26.66 |
| **Lynchburg Top** | 77.50 | 20.51 | 1.99 | 22.50 | 64.76 | 21.36 | 13.88 | 35.24 |
| **Coxville Top** | 92.00 | 7.16 | 0.84 | 8.00 | 60.95 | 20.65 | 18.40 | 39.05 |
| **Norfolk Top** | 89.00 | 10.31 | 0.69 | 11.00 | 75.40 | 12.72 | 11.88 | 24.60 |
| **Rains Top** | 87.50 | 11.90 | 0.60 | 12.50 | 62.40 | 24.79 | 12.81 | 37.60 |
| **Noboco Top** | 93.00 | 6.79 | 0.21 | 7.00 | 66.62 | 20.50 | 12.88 | 33.38 |
| **Coxville Sub** | 64.50 | 27.83 | 7.67 | 35.50 | 71.34 | 14.00 | 14.66 | 28.66 |
| **Goldsboro Sub** | 82.00 | 13.85 | 4.15 | 18.00 | 65.26 | 24.86 | 9.88 | 34.74 |
| **Noboco Sub** | 76.50 | 21.53 | 1.97 | 23.50 | 67.19 | 18.93 | 13.88 | 32.81 |
| **Rains Sub** | 86.00 | 12.70 | 1.30 | 14.00 | 73.12 | 13.22 | 13.66 | 26.88 |
| **Lynchburg Sub** | 69.00 | 30.01 | 0.99 | 31.00 | 71.26 | 16.93 | 11.81 | 28.74 |
| **Norfolk Sub** | 83.00 | 16.12 | 0.88 | 17.00 | 79.05 | 10.22 | 10.74 | 20.95 |

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[24] For ASD analysis, Sand refers to aggregate and particle sizes ranging from 2 to 0.05 mm

[25] For ASD analysis, Silt refers to aggregate and particle sizes ranging from 0.05 to 0.002 mm

[26] For ASD analysis, Clay refers to aggregate and particle sizes less than 0.002 mm

Table B.8. Coastal top soils’ ASD tabular data.

| | **Coxville** | **Goldsboro** | **Lynchburg** | **Norfolk** | **Rains** |
|---|---|---|---|---|---|
| Particle Size [mm] | Percent finer [%] | | | | |
| 2.000 | 100 | 100 | 100 | 100 | 100 |
| 1.180 | 99.3 | 99.4 | 99.8 | 99.5 | 99.8 |
| 0.425 | 69.3 | 94.3 | 92.7 | 97.0 | 91.8 |
| 0.150 | 25.9 | 45.4 | 59.3 | 53.1 | 46.9 |
| 0.075 | 14.1 | 24.1 | 41.5 | 23.6 | 25.7 |
| 0.063 | 8.79 | 14.5 | 27.9 | 14.1 | 14.6 |
| 0.062 | 8.18 | 13.7 | 24.9 | 12.0 | 13.6 |
| 0.031 | 6.90 | 12.4 | 18.6 | 8.81 | 10.6 |
| 0.016 | 4.79 | 9.32 | 13.4 | 6.06 | 6.67 |
| 0.008 | 2.67 | 4.21 | 6.39 | 3.17 | 2.73 |
| 0.004 | 1.62 | 4.21 | 3.88 | 1.49 | 1.23 |
| 0.002 | 0.84 | 2.38 | 1.99 | 0.69 | 0.60 |

Table B.9. Coastal subsoils’ ASD tabular data.

| | **Coxville** | **Goldsboro** | **Lynchburg** | **Norfolk** | **Rains** |
|---|---|---|---|---|---|
| Particle Size [mm] | Percent finer [%] | | | | |
| 2.000 | 100 | 100 | 100 | 100 | 100 |
| 1.180 | 99.9 | 97.0 | 99.9 | 99.4 | 99.7 |
| 0.425 | 94.7 | 72.7 | 95.1 | 91.5 | 97.2 |
| 0.150 | 59.5 | 39.1 | 65.6 | 50.4 | 46.6 |
| 0.075 | 47.6 | 24.7 | 45.3 | 28.5 | 26.6 |
| 0.063 | 38.8 | 19.5 | 33.4 | 19.5 | 16.7 |
| 0.062 | 36.9 | 18.4 | 30.5 | 17.9 | 15.1 |
| 0.031 | 32.1 | 16.4 | 29.0 | 14.1 | 12.0 |
| 0.016 | 24.6 | 9.16 | 3.48 | 2.61 | 9.43 |
| 0.008 | 17.1 | 5.66 | 1.76 | 1.42 | 4.32 |
| 0.004 | 12.4 | 5.66 | 1.61 | 1.20 | 2.59 |
| 0.002 | 7.67 | 4.15 | 0.99 | 0.88 | 1.30 |

# APPENDIX C.

## Tabular data for selected soils’ turbidity as a function of suspended sediment concentration

Appendix C contains raw data used to establish relationships between turbidity and suspended sediment concentration. First, turbidity versus suspended sediment concentration is plotted for all top soils and subsoils. Next, soils are evaluated based on South Carolina physiographic region. Tables include all concentration and corresponding turbidity values for each region’s top soil and subsoils. This tabular data was used for subsequent figures that plot region’s top soil turbidity versus suspended sediment concentration and region’s subsoil turbidity versus suspended sediment concentration.

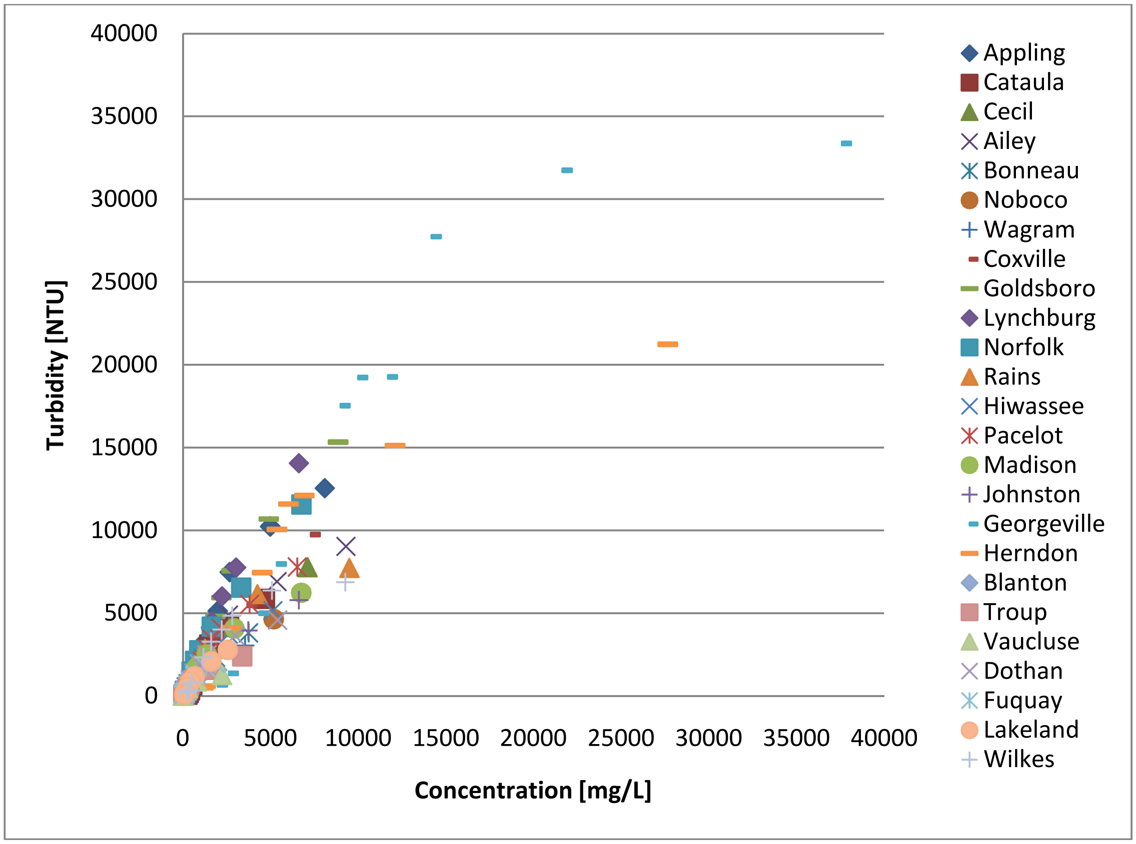

Figure C.1. Relationship of turbidity versus suspended sediment concentration for all top soils.

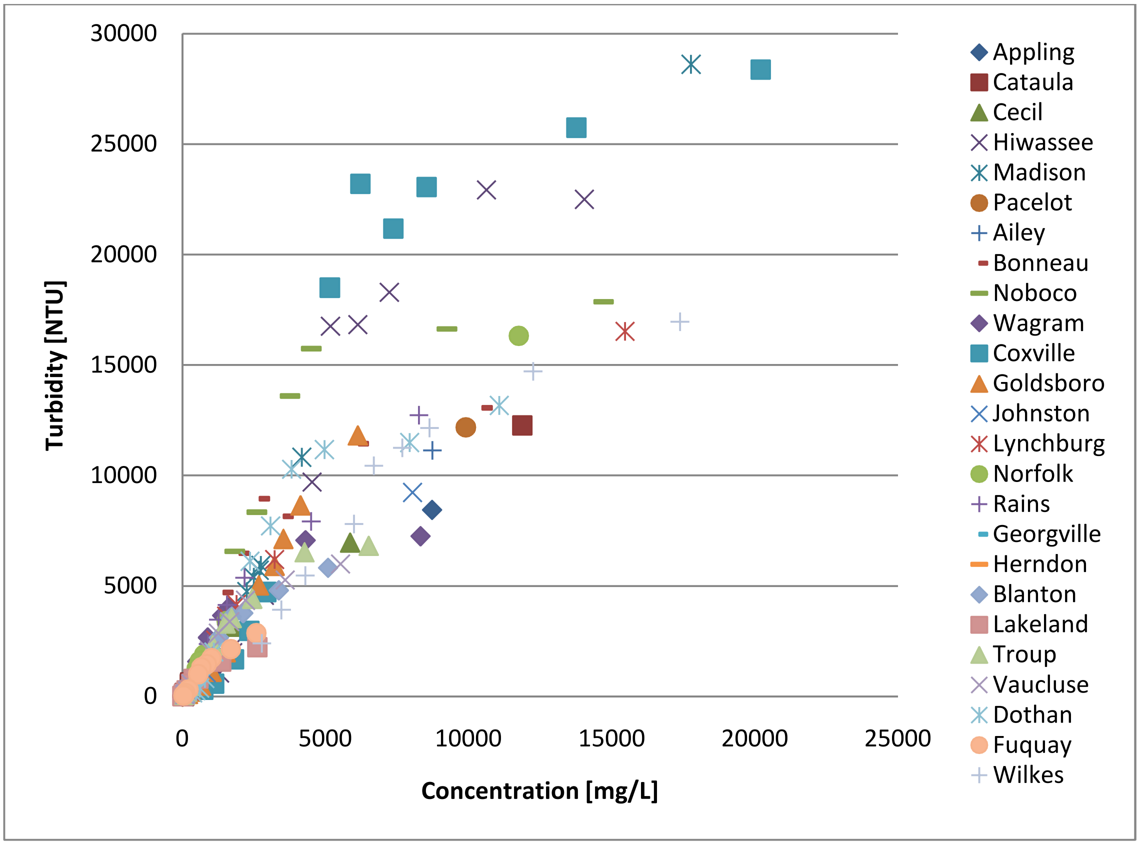

Figure C.2. Relationship of turbidity versus suspended sediment concentration for all subsoils.

Table C.1. Piedmont top soils[27]

| **Appling** | | **Cataula** | | **Cecil** | | **Georgeville** | | **Hiwassee** | |
|---|---|---|---|---|---|---|---|---|---|
| Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] |
| 8090 | 12548 | 4670 | 5864 | 7100 | 7780 | 37580 | 33370 | 5130 | 5158 |
| 4980 | 10244 | 2630 | 4214 | 2680 | 4178 | 21650 | 31740 | 2590 | 3718 |
| 2670 | 7480 | 1500 | 3094 | 1280 | 2542 | 14180 | 27740 | 1170 | 2278 |
| 1980 | 5132 | 1470 | 2937 | 910 | 2030 | 11680 | 19270 | 900 | 1735 |
| 1620 | 4084 | 1080 | 2224 | 600 | 1461 | 9990 | 19236 | 650 | 1403 |
| 1270 | 3315 | 910 | 1721 | 430 | 1028 | 8990 | 17532 | 480 | 1042 |
| 380 | 657 | 520 | 628 | 160 | 267 | 5350 | 7972 | 190 | 332 |
| 250 | 378 | 400 | 357 | 90 | 139 | 4350 | 4996 | 160 | 158 |
| 150 | 190 | 330 | 192 | 90 | 94.9 | 3110 | 2261 | 140 | 86.5 |
| 150 | 103 | 280 | 145 | 110 | 74.2 | 2610 | 1366 | 150 | 111 |
| 20 | 58.6 | 260 | 76.8 | 100 | 70.9 | 1980 | 673 | 130 | 82.4 |

| **Madison** | | **Pacolet** | | **Herndon** | | **Wilkes** | |
|---|---|---|---|---|---|---|---|
| Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] |
| 6750 | 6228 | 6520 | 7788 | 27660 | 21240 | 9260 | 16956 |
| 2940 | 4078 | 3800 | 5536 | 12100 | 15126 | 5080 | 14712 |
| 1360 | 2500 | 2180 | 4086 | 6920 | 12100 | 2810 | 12156 |
| 880 | 1826 | 1640 | 3430 | 6020 | 11596 | 2220 | 11252 |
| 710 | 1624 | 1400 | 2832 | 5360 | 10064 | 1610 | 10436 |
| 600 | 1191 | 1120 | 2099 | 4520 | 7456 | 1170 | 7808 |
| 270 | 419 | 450 | 725 | 2730 | 4118 | 490 | 5466 |
| 140 | 198 | 250 | 259 | 2230 | 2409 | 320 | 3917 |
| 110 | 93.4 | 170 | 158 | 1560 | 1272 | 220 | 2400 |
| 130 | 127 | 150 | 152 | 1290 | 594 | 160 | 1204 |
| 100 | 138 | 120 | 109 | 1170 | 503 | 70 | 417 |

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[27] Turbidity values are an average of five readings

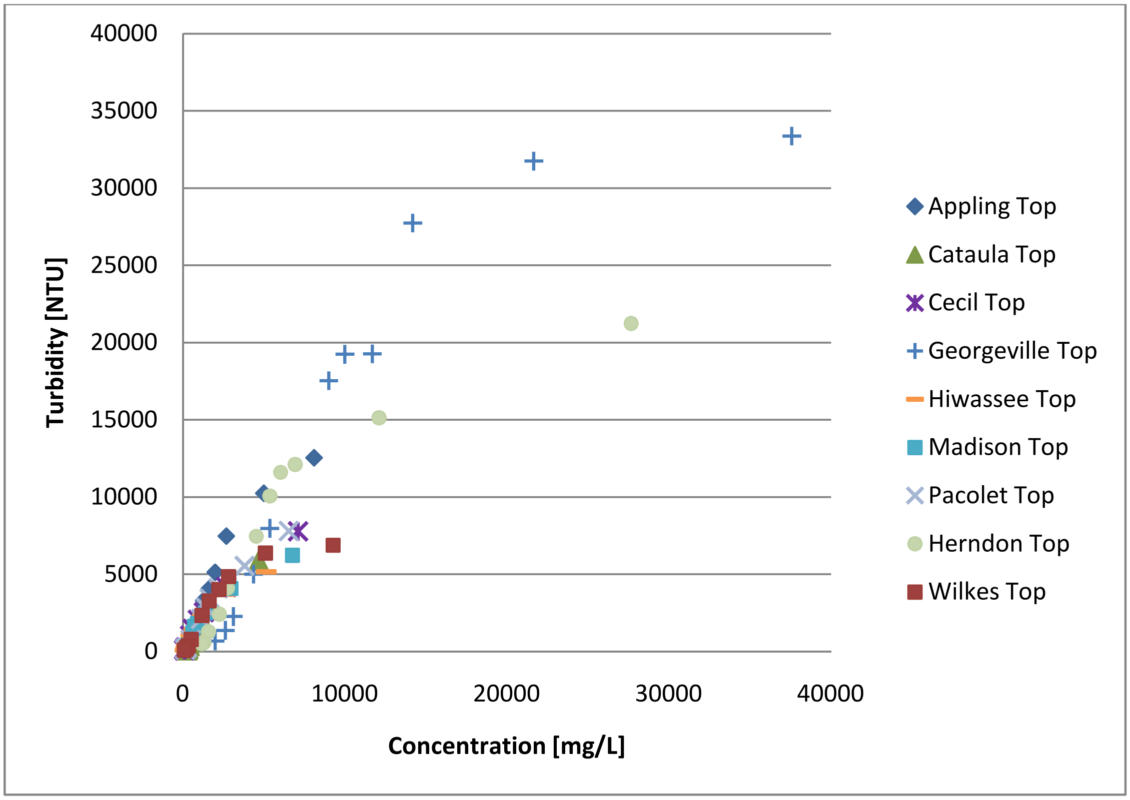

Figure C.3. Piedmont top soils' relationship of turbidity versus suspended sediment concentration.

Table C.2. Piedmont subsoils[28].

| **Appling** | | **Cataula** | | **Cecil** | | **Georgeville** | | **Hiwassee** | |
|---|---|---|---|---|---|---|---|---|---|
| Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] |
| 8720 | 8440 | 11870 | 12264 | 5860 | 6960 | 37400 | 37340 | 14040 | 22500 |
| 400 | 671 | 640 | 1301 | 1850 | 3156 | 150 | 1601 | 10620 | 22926 |
| 120 | 223 | 270 | 629 | 770 | 1744 | 40 | 32.8 | 7230 | 18294 |
| 90 | 208 | 270 | 597 | 650 | 1518 | 50 | 22.6 | 6130 | 16830 |
| 90 | 202 | 280 | 609 | 600 | 1290 | 40 | 15.1 | 5170 | 16758 |
| 90 | 153 | 260 | 555 | 350 | 931 | 40 | 11.4 | 4530 | 9704 |
| 0.001 | 31.6 | 80 | 147 | 130 | 354 | 10 | 7.27 | 2860 | 4570 |
| 0.001 | 19.0 | 60 | 112 | 160 | 321 | 0 | 5.31 | 2250 | 2882 |
| 20 | 9.12 | 60 | 45.6 | 30 | 75.5 | 0 | 2.71 | 1750 | 1974 |
| 0.001 | 4.41 | 50 | 31.8 | 10 | 37.1 | 0 | 0.76 | 1300 | 1051 |
| 0.001 | 1.85 | 50 | 20.0 | 30 | 47.5 | 0 | 2.88 | 910 | 334 |

| **Madison** | | **Pacolet** | | **Herndon** | | **Wilkes** | |
|---|---|---|---|---|---|---|---|
| Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] |
| 17770 | 28608 | 9900 | 12174 | 28410 | 20070 | 17380 | 16956 |
| 4170 | 10824 | 190 | 274 | 280 | 378 | 12250 | 14712 |
| 2740 | 5928 | 50 | 98.4 | 80 | 77.9 | 8630 | 12156 |
| 2680 | 5710 | 40 | 79.5 | 40 | 70.5 | 7680 | 11252 |
| 2490 | 5396 | 40 | 66.0 | 60 | 71.8 | 6690 | 10436 |
| 2250 | 4746 | 30 | 53.7 | 50 | 56.6 | 5990 | 7808 |
| 990 | 1781 | 0 | 10.36 | 20 | 17.9 | 4290 | 5466 |
| 600 | 1077 | 0 | 3.66 | 10 | 8.29 | 3460 | 3917 |
| 320 | 503.4 | 0 | 1.82 | 0 | 3.91 | 2770 | 2400 |
| 160 | 234.8 | 0 | 2.71 | 10 | 8.60 | 1670 | 1204 |
| 90 | 145.2 | 0 | 1.04 | 0 | 3.64 | 900 | 417 |

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[28] Turbidity values are an average of five readings

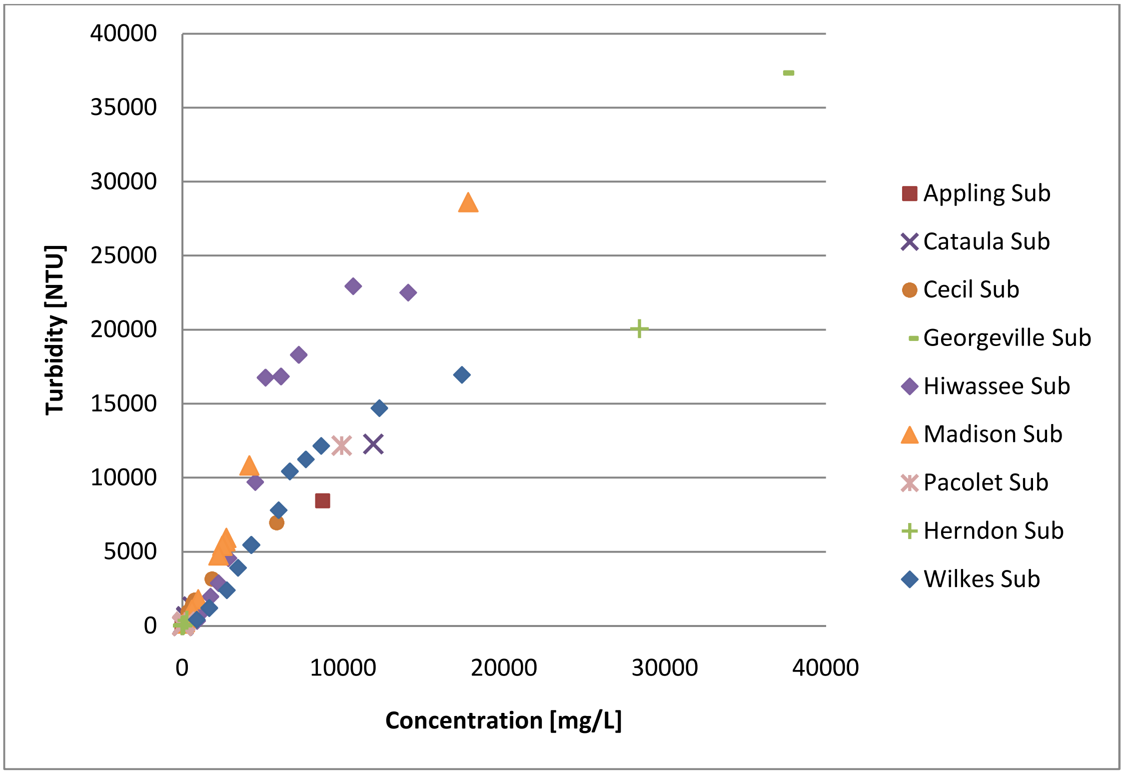

Figure C.4. Piedmont subsoils' relationship of turbidity versus suspended sediment concentration.

Table C.3. Central top soils[29].

| Ailey | | Bonneau | | Wagram | | Blanton | | Lakeland | |
|---|---|---|---|---|---|---|---|---|---|
| Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] |
| 9300 | 9032 | 3736 | 3810 | 3540 | 3042 | 1960 | 1555 | 2560 | 2788 |
| 5360 | 6916 | 1864 | 2330 | 1150 | 1454 | 880 | 1100 | 1620 | 2094 |
| 2590 | 4878 | 676 | 1297 | 470 | 774 | 490 | 933 | 680 | 1183 |
| 1970 | 3512 | 415 | 972 | 300 | 585 | 290 | 539 | 420 | 888 |
| 1620 | 2978 | 300 | 756 | 170 | 272 | 230 | 476 | 450 | 872 |
| 1320 | 2347 | 186 | 563 | 120 | 260 | 200 | 393 | 270 | 547 |
| 500 | 632 | 86 | 132 | 20 | 52 | 50 | 153 | 140 | 232 |
| 340 | 271 | 79 | 175 | 10 | 24 | 50 | 94 | 90 | 153 |
| 310 | 207 | 50 | 82 | 10 | 19 | 60 | 93 | 100 | 113 |
| 250 | 163 | 40 | 67 | 10 | 14 | 60 | 109 | 120 | 155 |
| 240 | 113 | 50 | 41 | 20 | 11 | 50 | 54 | 80 | 71 |

| Troup | | Vaucluse | | Dothan | | Fuquay | | Johnston | |
|---|---|---|---|---|---|---|---|---|---|
| Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] |
| 3380 | 2400 | 2220 | 1277 | 5400 | 4580 | 1840 | 1970 | 6620 | 5794 |
| 1470 | 1574 | 810 | 903 | 2970 | 3642 | 1320 | 1714 | 3730 | 3952 |
| 590 | 964 | 300 | 477 | 1370 | 2476 | 740 | 1306 | 960 | 1519 |
| 460 | 866 | 200 | 358 | 940 | 1946 | 660 | 1223 | 1020 | 1608 |
| 350 | 648 | 100 | 218 | 640 | 1392 | 420 | 862 | 700 | 1033 |
| 300 | 561 | 100 | 203 | 420 | 986 | 290 | 670 | 370 | 539 |
| 70 | 158 | 10 | 51 | 140 | 367 | 130 | 256 | 360 | 328 |
| 20 | 66 | 10 | 57 | 80 | 163 | 90 | 151 | 140 | 153 |
| 20 | 62 | 20 | 58 | 70 | 109 | 80 | 131 | 80 | 96 |
| 20 | 61 | 10 | 38 | 80 | 130 | 20 | 56 | 70 | 82 |
| 20 | 47 | 10 | 26 | 80 | 90 | 60 | 93 | 90 | 106 |

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[29] Turbidity values are an average of five readings

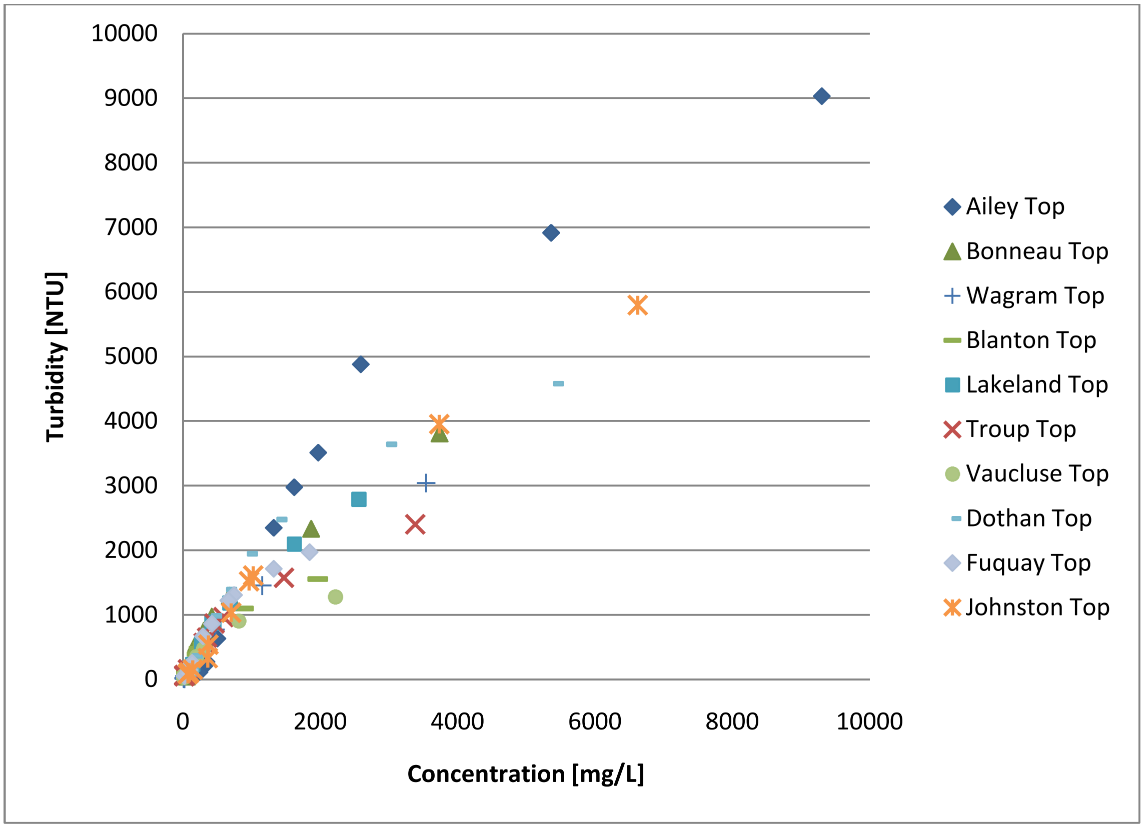

Figure C.5. Central top soils' relationship of turbidity versus suspended sediment concentration.

Table C.4. Central subsoils[30].

| **Ailey** | | **Bonneau** | | **Wagram** | | **Blanton** | | **Lakeland** | |
|---|---|---|---|---|---|---|---|---|---|
| Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] |
| 8730 | 11136 | 10480 | 13060 | 8320 | 7248 | 5090 | 5822 | 2620 | 2230 |
| 1140 | 1830 | 6160 | 11436 | 4300 | 7058 | 3370 | 4800 | 1350 | 1576 |
| 420 | 911 | 3530 | 8148 | 1620 | 4028 | 2120 | 3770 | 560 | 811 |
| 420 | 812 | 2700 | 8946 | 1390 | 3662 | 1720 | 3609 | 390 | 794 |
| 370 | 704 | 1990 | 6478 | 880 | 2669 | 1670 | 3551 | 320 | 575 |
| 320 | 521 | 1430 | 4706 | 510 | 1585 | 1270 | 2657 | 150 | 263 |
| 20 | 36 | 390 | 1038 | 100 | 266 | 630 | 1051 | 60 | 132 |
| 20 | 11 | 260 | 444 | 40 | 73 | 440 | 601 | 60 | 36 |
| 20 | 22 | 180 | 192 | 20 | 48 | 300 | 265 | 0 | 14 |
| 10 | 10 | 50 | 96 | 30 | 41 | 230 | 206 | 0 | 8 |
| 10 | 5 | 80 | 70 | 20 | 35 | 170 | 125 | 0 | 19 |

| **Troup** | | **Vaucluse** | | **Dothan** | | **Fuquay** | | **Johnston** | |
|---|---|---|---|---|---|---|---|---|---|
| Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] |
| 6510 | 6818 | 5520 | 5996 | 11070 | 13172 | 2580 | 2864 | 8040 | 9230 |
| 4270 | 6526 | 3590 | 5274 | 7940 | 11488 | 1690 | 2142 | 830 | 1078 |
| 2440 | 4420 | 2200 | 4352 | 4960 | 11172 | 1020 | 1738 | 260 | 349 |
| 1720 | 3544 | 1650 | 3382 | 3810 | 10284 | 850 | 1456 | 230 | 316 |
| 1510 | 3303 | 1250 | 2856 | 3080 | 7720 | 660 | 1311 | 220 | 299 |
| 1060 | 2310 | 940 | 2069 | 2360 | 6116 | 550 | 1004 | 150 | 252 |
| 280 | 478 | 290 | 573 | 1100 | 2009 | 210 | 320 | 50 | 75 |
| 170 | 216 | 180 | 251 | 780 | 810 | 100 | 161 | 30 | 16 |
| 100 | 135 | 110 | 126 | 600 | 383 | 50 | 70 | 30 | 15 |
| 90 | 102 | 100 | 105 | 470 | 257 | 50 | 42 | 10 | 6 |
| 80 | 70 | 80 | 72 | 360 | 165 | 40 | 43 | 40 | 3 |

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[30] Turbidity values are an average of five readings

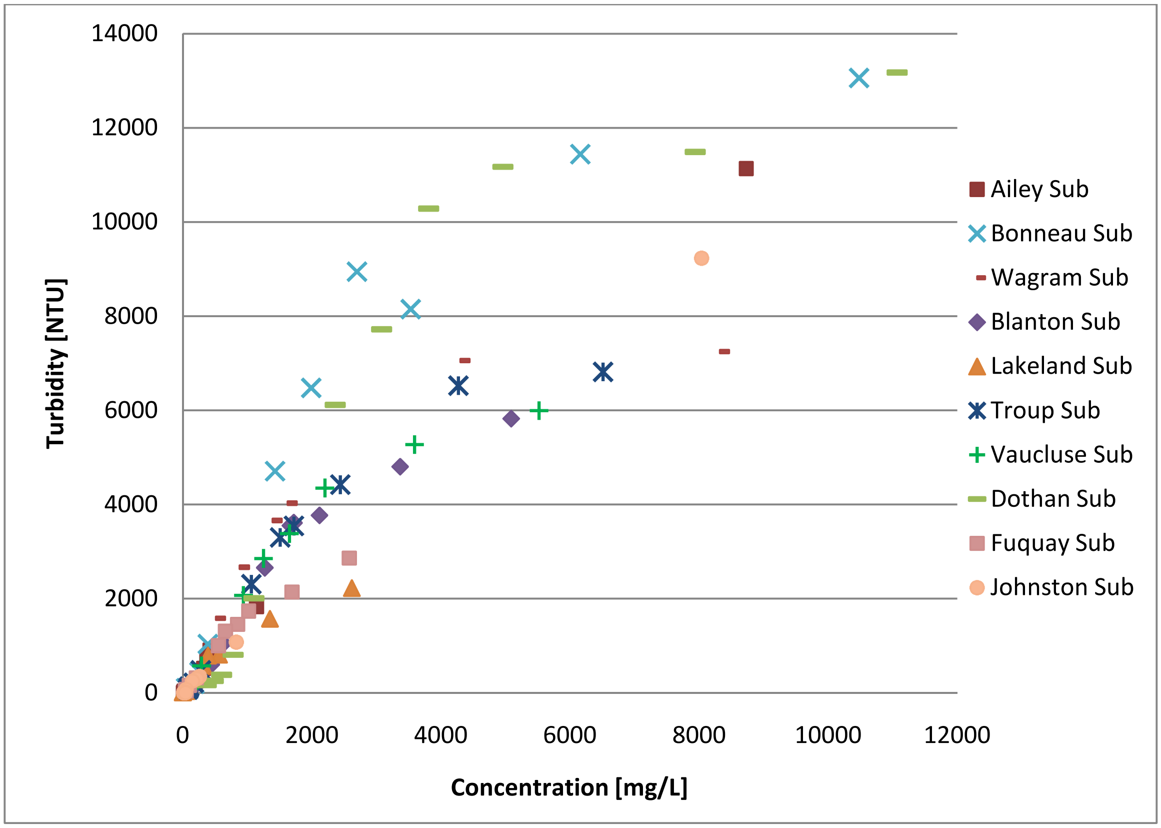

Figure C.6. Central subsoils' relationship of turbidity versus suspended sediment concentration.

Table C.5. Coastal top soils[31].

| **Coxville** | | **Goldsboro** | | **Lynchburg** | |
|---|---|---|---|---|---|
| Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] |
| 7290 | 9744 | 8850 | 15336 | 14890 | 11316 |
| 3670 | 5476 | 4900 | 10686 | 6610 | 14058 |
| 1760 | 3586 | 2780 | 7568 | 3030 | 7754 |
| 1340 | 2933 | 2190 | 5932 | 2230 | 6022 |
| 1020 | 2357 | 1850 | 4800 | 1650 | 4498 |
| 780 | 1802 | 1080 | 2970 | 1600 | 4126 |
| 360 | 621 | 510 | 1012 | 640 | 1248 |
| 220 | 292 | 360 | 520 | 460 | 529 |
| 140 | 147 | 170 | 189 | 320 | 260 |
| 130 | 99 | 140 | 139 | 200 | 175 |
| 120 | 63 | 150 | 107 | 190 | 129 |

| **Norfolk** | | **Rains** | | **Noboco** | |
|---|---|---|---|---|---|
| Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] |
| 6760 | 11568 | 9490 | 7740 | 5180 | 4644 |
| 3330 | 6548 | 4250 | 6156 | 1310 | 1712 |
| 1640 | 4192 | 1260 | 2850 | 530 | 931 |
| 940 | 2752 | 950 | 2464 | 340 | 747 |
| 700 | 2120 | 490 | 1226 | 180 | 421 |
| 500 | 1479 | 420 | 941 | 190 | 390 |
| 120 | 331 | 110 | 192 | 130 | 195 |
| 100 | 151 | 110 | 113 | 90 | 47 |
| 50 | 65 | 90 | 63 | 50 | 48 |
| 50 | 50 | 60 | 68 | 60 | 39 |
| 30 | 72 | 40 | 71 | 20 | 24 |

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[31] Turbidity values are an average of five readings

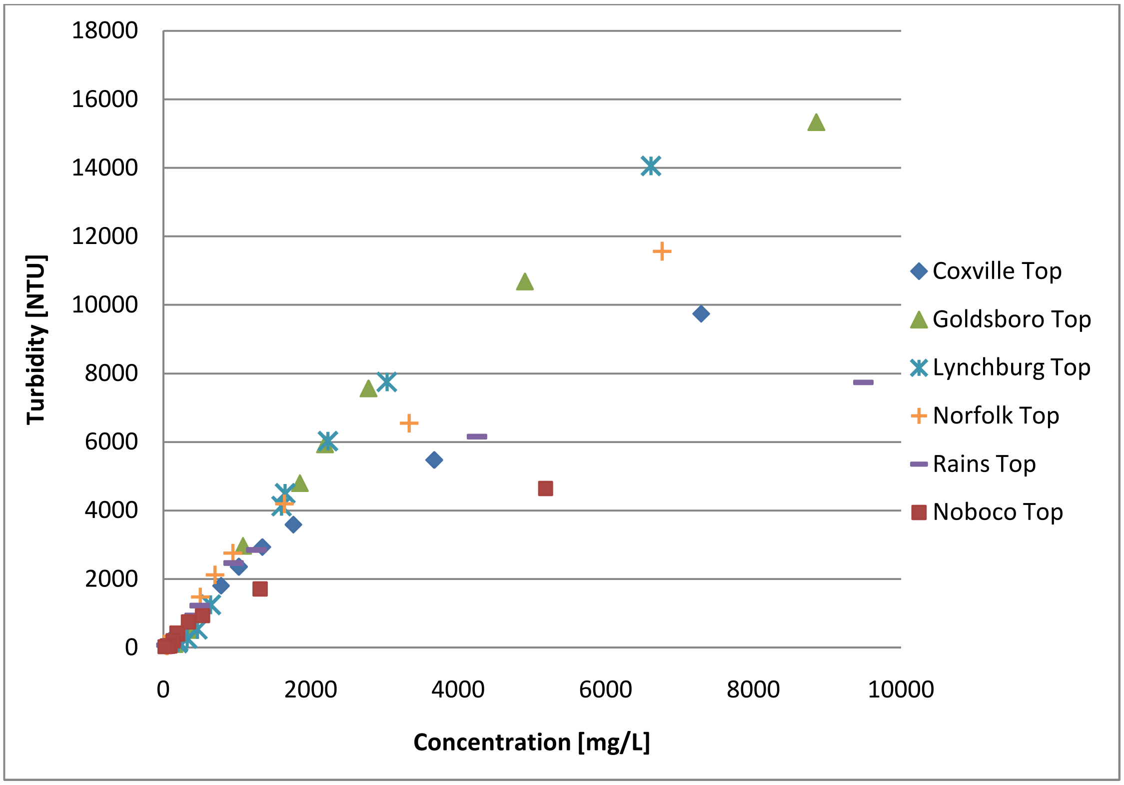

Figure C.7. Coastal top soils' relationship of turbidity versus suspended sediment concentration.

Table C.6. Coastal subsoils[32].

| **Coxville** | | **Goldsboro** | | **Lynchburg** | |
|---|---|---|---|---|---|
| Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] |
| 20200 | 28370 | 10410 | 10968 | 15460 | 16524 |
| 13760 | 25740 | 6130 | 11816 | 3220 | 6192 |
| 8530 | 23060 | 4130 | 8650 | 1890 | 4160 |
| 7370 | 21170 | 3530 | 7134 | 1540 | 3635 |
| 6220 | 23200 | 3220 | 5920 | 1330 | 1702 |
| 5150 | 18500 | 2670 | 5028 | 1160 | 2548 |
| 2930 | 4724 | 1510 | 2010 | 430 | 600 |
| 2340 | 2967 | 1020 | 1127 | 230 | 245 |
| 1800 | 1681 | 650 | 494 | 60 | 51 |
| 1110 | 577 | 300 | 228 | 50 | 46 |
| 730 | 309 | 190 | 122 | 10 | 26 |

| **Norfolk** | | **Rains** | | **Noboco** | |
|---|---|---|---|---|---|
| Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] | Conc. [mg/L] | Turbidity [NTU] |
| 11750 | 16324 | 8260 | 12732 | 14710 | 17862 |
| 1550 | 3416 | 4500 | 7920 | 9240 | 16632 |
| 760 | 1893 | 2170 | 5370 | 4500 | 15744 |
| 670 | 1637 | 1560 | 4134 | 3760 | 13596 |
| 610 | 1596 | 1260 | 3480 | 2600 | 8344 |
| 490 | 1247 | 900 | 2370 | 1830 | 6564 |
| 140 | 291 | 290 | 622 | 580 | 1595 |
| 110 | 177 | 200 | 284 | 360 | 647 |
| 160 | 53 | 100 | 133 | 260 | 361 |
| 10 | 48 | 50 | 83 | 170 | 166 |
| 10 | 38 | 70 | 62 | 150 | 101 |

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[32] Turbidity values are an average of five readings

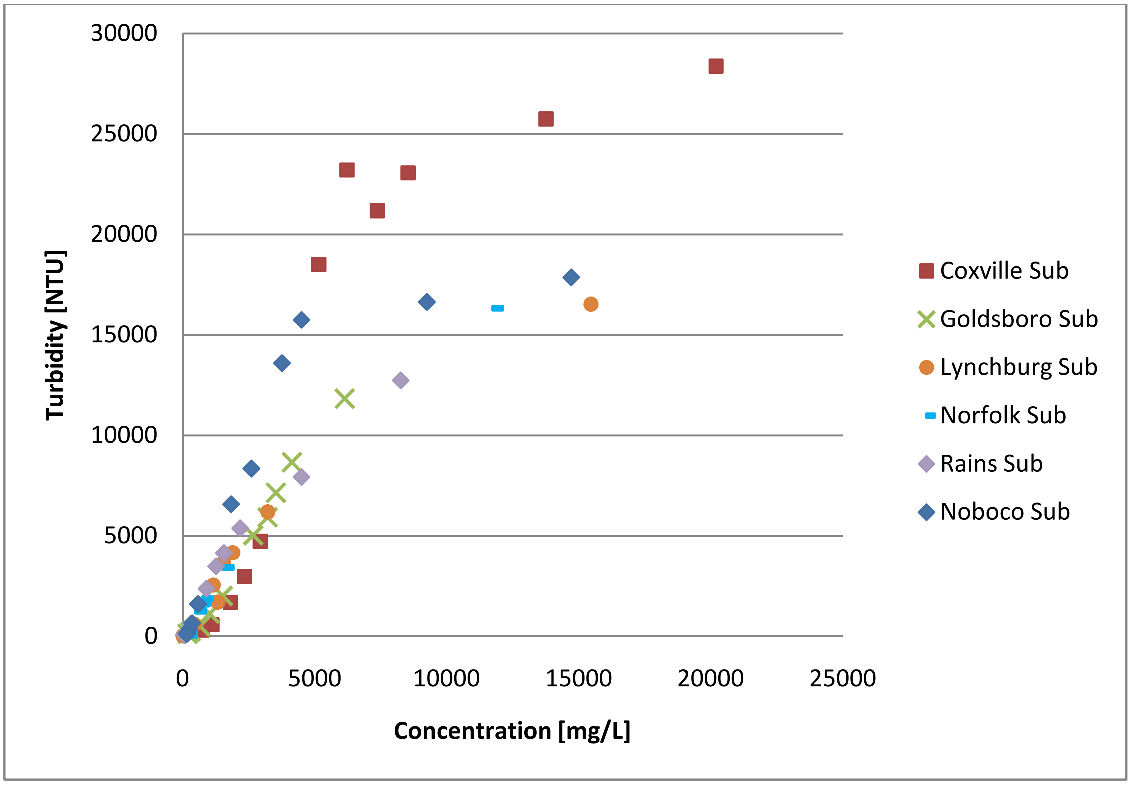

Figure C.8. Coast subsoils' relationship of turbidity versus suspended sediment concentration.

# APPENDIX D

## Tabular data for selected soils' turbidity as a function of sediment settling time

Appendix D contains raw data used to establish relationships between turbidity and sediment settling time. First, turbidity versus settling time is plotted for all top soils and subsoils. Next, soils are evaluated based on South Carolina physiographic region. Tables include all sample times and corresponding turbidity values for each region's top soil and subsoils. This tabular data was used for subsequent figures that plot region's top soil turbidity versus settling time and region's subsoil turbidity versus settling time.

Table D.1. Piedmont top soils.

| **Appling** | | **Cataula** | | **Cecil** | | **Georgeville** | | **Hiwassee** | |
|---|---|---|---|---|---|---|---|---|---|
| Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] |
| 0 | 12548 | 0 | 5864 | 0 | 7780 | 0 | 33370 | 0 | 5158 |
| 5 | 10244 | 5 | 4214 | 5 | 4178 | 5 | 31740 | 5 | 3718 |
| 30 | 7480 | 30 | 3094 | 30 | 2542 | 30 | 27740 | 30 | 2278 |
| 60 | 5132 | 60 | 2937 | 60 | 2030 | 60 | 19270 | 60 | 1735 |
| 120 | 4084 | 120 | 2224 | 120 | 1461 | 120 | 19236 | 120 | 1403 |
| 240 | 3315 | 240 | 1721 | 240 | 1028 | 240 | 17532 | 240 | 1042 |
| 1440 | 657 | 1440 | 628 | 1440 | 267 | 1440 | 7972 | 1440 | 332 |
| 2880 | 378 | 2880 | 357 | 2880 | 139 | 2880 | 4996 | 4320 | 158 |
| 5760 | 190 | 5760 | 192 | 5760 | 95 | 5760 | 2261 | 7200 | 87 |
| 11520 | 103 | 11520 | 145 | 10080 | 74 | 10080 | 1366 | 10080 | 111 |
| 23040 | 59 | 30240 | 77 | 20160 | 71 | 20160 | 673 | 20160 | 82 |

| **Madison** | | **Pacolet** | | **Herndon** | | **Wilkes** | |
|---|---|---|---|---|---|---|---|
| Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] |
| 0 | 6228 | 0 | 7788 | 0 | 21240 | 0 | 6876 |
| 5 | 4078 | 5 | 5536 | 5 | 15126 | 5 | 6374 |
| 30 | 2500 | 30 | 4086 | 30 | 12100 | 30 | 4846 |
| 60 | 1826 | 60 | 3430 | 60 | 11596 | 60 | 4004 |
| 120 | 1624 | 120 | 2832 | 120 | 10064 | 120 | 3276 |
| 240 | 1191 | 240 | 2099 | 240 | 7456 | 240 | 2326 |
| 1440 | 419 | 1440 | 725 | 1440 | 4118 | 1440 | 784 |
| 4320 | 198 | 4320 | 259 | 2880 | 2409 | 2880 | 361 |
| 7200 | 93 | 7200 | 158 | 5760 | 1272 | 5760 | 235 |
| 10080 | 127 | 10080 | 152 | 10080 | 594 | 10080 | 136 |
| 20160 | 138 | 20160 | 109 | 20160 | 503 | 20160 | 76 |

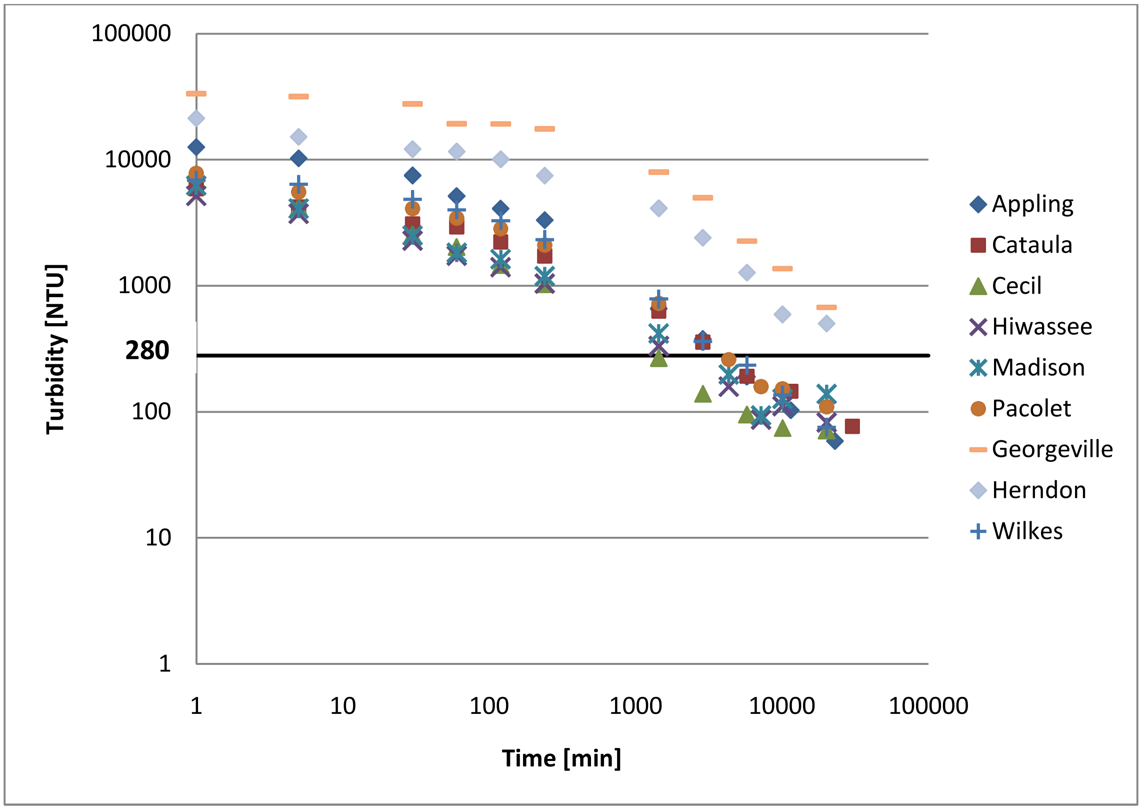

Figure D.1. Piedmont top soils’ relationship of turbidity and sediment settling time.

Table D.2. Piedmont subsoils.

| **Appling** | | **Cataula** | | **Cecil** | | **Georgeville** | | **Hiwassee** | |
|---|---|---|---|---|---|---|---|---|---|
| Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] |
| 1 | 8440 | 1 | 12264 | 1 | 6960 | 1 | 37340 | 1 | 22500 |
| 5 | 671 | 5 | 1301 | 5 | 3156 | 5 | 161 | 5 | 22926 |
| 30 | 223 | 30 | 629 | 30 | 1744 | 30 | 33 | 30 | 18294 |
| 60 | 208 | 60 | 597 | 60 | 1518 | 60 | 23 | 60 | 16830 |
| 120 | 202 | 120 | 609 | 120 | 1290 | 120 | 15 | 120 | 16758 |
| 240 | 153 | 240 | 555 | 240 | 931 | 240 | 11 | 240 | 9704 |
| 1440 | 32 | 1440 | 147 | 1440 | 354 | 1440 | 7 | 1440 | 4570 |
| 2880 | 19 | 2880 | 112 | 2880 | 321 | 2880 | 5 | 2880 | 2882 |
| 5760 | 9 | 5760 | 46 | 5760 | 75 | 5760 | 3 | 5760 | 1974 |
| 10080 | 4 | 10080 | 32 | 10080 | 37 | 10080 | 1 | 10080 | 1051 |
| 20160 | 2 | 30240 | 20 | 20160 | 48 | 20160 | 3 | 20160 | 334 |

| **Madison** | | **Pacolet** | | **Herndon** | | **Wilkes** | |
|---|---|---|---|---|---|---|---|
| Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] |
| 1 | 28608 | 1 | 12174 | 1 | 20070 | 1 | 16956 |
| 5 | 10824 | 5 | 274 | 5 | 378 | 5 | 14712 |
| 30 | 5928 | 30 | 98 | 30 | 78 | 30 | 12156 |
| 60 | 5710 | 60 | 80 | 60 | 70 | 60 | 11252 |
| 120 | 5396 | 120 | 66 | 120 | 72 | 120 | 10436 |
| 240 | 4746 | 240 | 54 | 240 | 57 | 240 | 7808 |
| 1440 | 1781 | 1440 | 10 | 1440 | 18 | 1440 | 5466 |
| 2880 | 1077 | 2880 | 4 | 2880 | 8 | 2880 | 3917 |
| 5760 | 503 | 5760 | 2 | 5760 | 4 | 5760 | 2400 |
| 10080 | 235 | 10080 | 3 | 10080 | 9 | 10080 | 1204 |
| 20160 | 145 | 20160 | 1 | 20160 | 4 | 20160 | 417 |

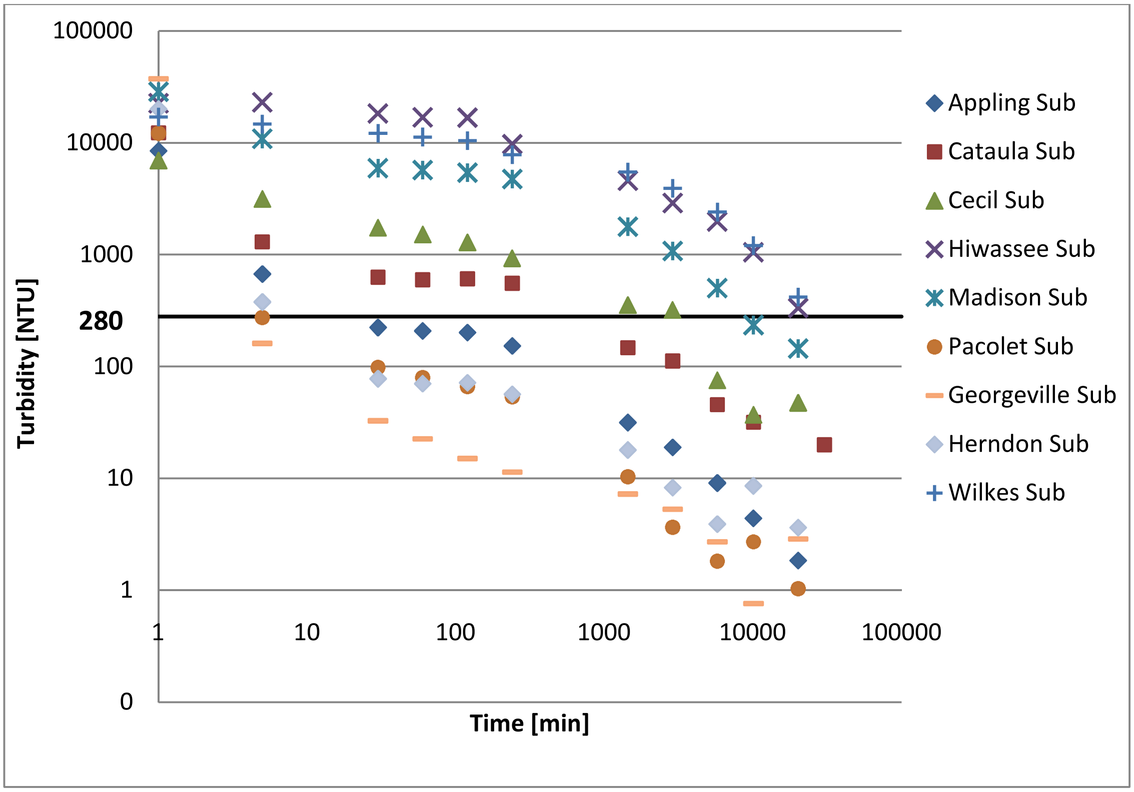

Figure D.2. Piedmont subsoils' relationship of turbidity and sediment settling time.

Table D.3. Central top soils.

| **Ailey** | | **Bonneau** | | **Wagram** | | **Blanton** | | **Lakeland** | |
|---|---|---|---|---|---|---|---|---|---|
| Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] |
| 1 | 9032 | 1 | 3810 | 1 | 3042 | 1 | 1555 | 1 | 2788 |
| 5 | 6916 | 5 | 2330 | 5 | 1454 | 5 | 1100 | 5 | 2094 |
| 30 | 4878 | 30 | 1297 | 30 | 774 | 30 | 933 | 30 | 1183 |
| 60 | 3512 | 60 | 972 | 60 | 585 | 60 | 539 | 60 | 888 |
| 120 | 2978 | 120 | 756 | 120 | 272 | 120 | 476 | 120 | 872 |
| 240 | 2347 | 240 | 563 | 240 | 260 | 240 | 393 | 240 | 547 |
| 1440 | 632 | 1440 | 132 | 1440 | 52 | 1440 | 153 | 1440 | 232 |
| 2880 | 271 | 2880 | 175 | 2880 | 24 | 2880 | 94 | 2880 | 153 |
| 5760 | 207 | 7200 | 82 | 5760 | 19 | 5760 | 93 | 7200 | 113 |
| 11520 | 163 | 10080 | 67 | 11520 | 14 | 10080 | 109 | 11520 | 155 |
| 21600 | 113 | 20160 | 41 | 23040 | 11 | 20160 | 54 | 21600 | 71 |

| **Troup** | | **Vaucluse** | | **Dothan** | | **Fuquay** | | **Johnston** | |
|---|---|---|---|---|---|---|---|---|---|
| Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] |
| 1 | 2400 | 1 | 1277 | 1 | 4580 | 1 | 1970 | 1 | 5794 |
| 5 | 1574 | 5 | 903 | 5 | 3642 | 5 | 1714 | 5 | 3952 |
| 30 | 964 | 30 | 477 | 30 | 2476 | 30 | 1306 | 30 | 1519 |
| 60 | 866 | 60 | 358 | 60 | 1946 | 60 | 1223 | 60 | 1608 |
| 120 | 648 | 120 | 218 | 120 | 1392 | 120 | 862 | 120 | 1033 |
| 240 | 561 | 240 | 203 | 240 | 986 | 240 | 670 | 240 | 539 |
| 1440 | 158 | 1440 | 51 | 1440 | 367 | 1440 | 256 | 1440 | 328 |
| 2880 | 66 | 2880 | 57 | 2880 | 163 | 2880 | 151 | 2880 | 153 |
| 5760 | 62 | 5760 | 58 | 5760 | 109 | 5760 | 131 | 7200 | 96 |
| 10080 | 61 | 10080 | 38 | 10080 | 130 | 10080 | 56 | 11520 | 82 |
| 20160 | 47 | 20160 | 26 | 20160 | 90 | 20160 | 93 | 20160 | 106 |

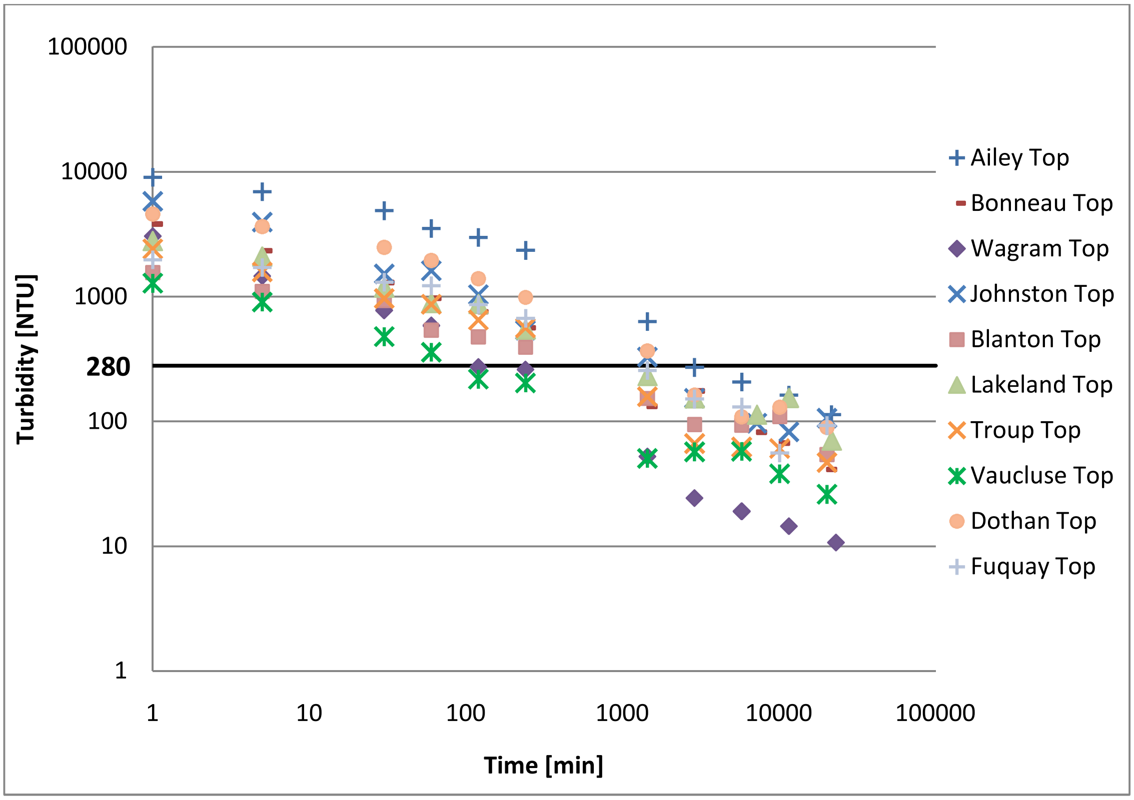

Figure D.3. Central top soils’ relationship of turbidity and sediment settling time.

Table D.4. Central subsoils.

| **Ailey** | | **Bonneau** | | **Wagram** | | **Blanton** | | **Lakeland** | |
|---|---|---|---|---|---|---|---|---|---|
| Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] |
| 1 | 11136 | 1 | 13060 | 1 | 7248 | 1 | 5822 | 1 | 2230 |
| 5 | 1830 | 5 | 11436 | 5 | 7058 | 5 | 4800 | 5 | 1576 |
| 30 | 911 | 30 | 8148 | 30 | 4028 | 30 | 3770 | 30 | 811 |
| 60 | 812 | 60 | 8946 | 60 | 3662 | 60 | 3609 | 60 | 794 |
| 120 | 704 | 120 | 6478 | 120 | 2669 | 120 | 3551 | 120 | 575 |
| 240 | 521 | 240 | 4706 | 240 | 1585 | 240 | 2657 | 240 | 263 |
| 1440 | 36 | 1440 | 1038 | 1440 | 266 | 1440 | 1051 | 1440 | 132 |
| 2880 | 11 | 2880 | 444 | 2880 | 73 | 2880 | 601 | 2880 | 36 |
| 5760 | 22 | 5760 | 192 | 5760 | 48 | 5760 | 265 | 5760 | 14 |
| 11520 | 10 | 11520 | 96 | 11520 | 41 | 10080 | 206 | 11520 | 8 |
| 21600 | 5 | 30240 | 70 | 23040 | 35 | 20160 | 125 | 20160 | 19 |

| **Troup** | | **Vaucluse** | | **Dothan** | | **Fuquay** | | **Johnston** | |
|---|---|---|---|---|---|---|---|---|---|
| Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] |
| 1 | 6818 | 1 | 5996 | 1 | 13172 | 1 | 2864 | 1 | 9230 |
| 5 | 6526 | 5 | 5274 | 5 | 11488 | 5 | 2142 | 5 | 1078 |
| 30 | 4420 | 30 | 4352 | 30 | 11172 | 30 | 1738 | 30 | 349 |
| 60 | 3544 | 60 | 3382 | 60 | 10284 | 60 | 1456 | 60 | 316 |
| 120 | 3303 | 120 | 2856 | 120 | 7720 | 120 | 1311 | 120 | 299 |
| 240 | 2310 | 240 | 2069 | 240 | 6116 | 240 | 1004 | 240 | 252 |
| 1440 | 478 | 1440 | 573 | 1440 | 2009 | 1440 | 320 | 1440 | 75 |
| 2880 | 216 | 2880 | 251 | 2880 | 810 | 2880 | 161 | 2880 | 16 |
| 5760 | 135 | 5760 | 126 | 5760 | 383 | 5760 | 70 | 7200 | 15 |
| 10080 | 102 | 10080 | 105 | 10080 | 257 | 10080 | 42 | 11520 | 6 |
| 20160 | 70 | 20160 | 72 | 20160 | 165 | 20160 | 43 | 20160 | 3 |

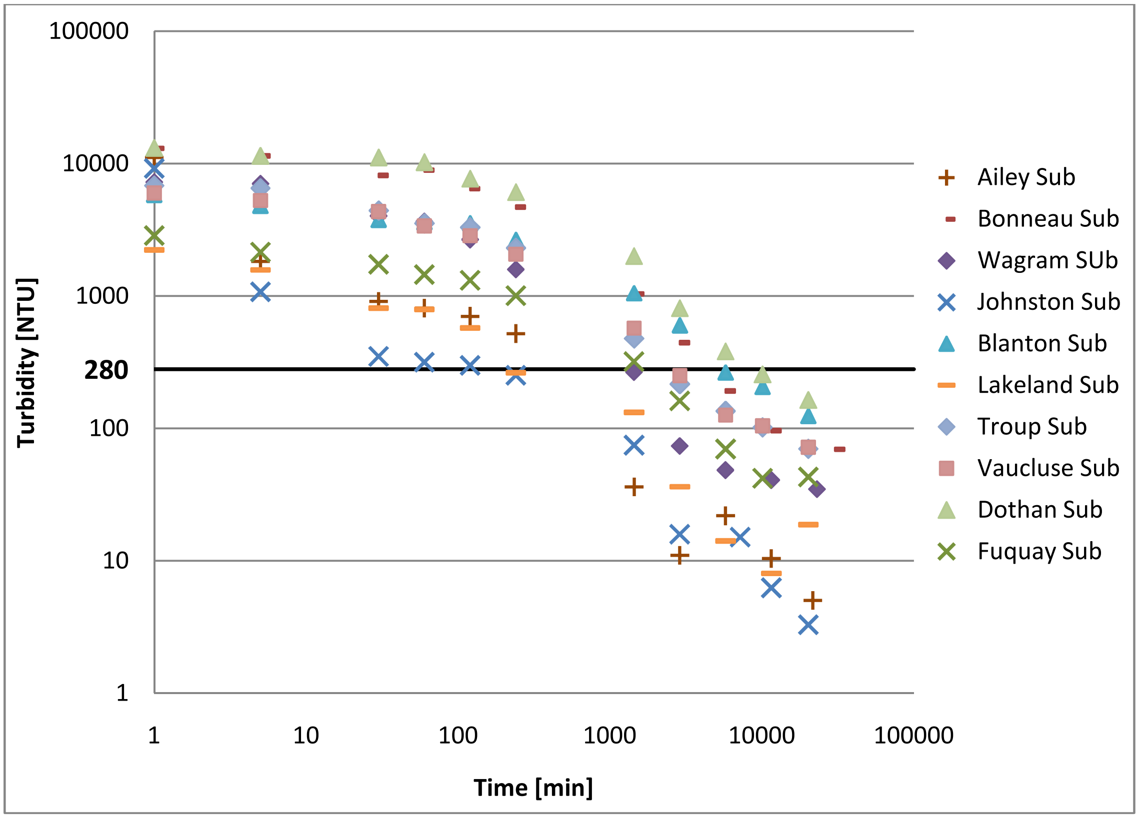

Figure D.4. Central subsoils' relationship of turbidity and sediment settling time.

Table D.5. Coastal top soils.

| **Coxville** | | **Goldsboro** | | **Lynchburg** | |
|---|---|---|---|---|---|
| Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] |
| 1 | 9744 | 1 | 15336 | 1 | 11316 |
| 5 | 5476 | 5 | 10686 | 5 | 14058 |
| 30 | 3586 | 30 | 7568 | 30 | 7754 |
| 60 | 2933 | 60 | 5932 | 60 | 6022 |
| 120 | 2357 | 120 | 4800 | 120 | 4498 |
| 240 | 1802 | 240 | 2970 | 240 | 4126 |
| 1440 | 621 | 1440 | 1012 | 1440 | 1248 |
| 2880 | 292 | 2880 | 520 | 2880 | 529 |
| 5760 | 147 | 5760 | 189 | 7200 | 260 |
| 11520 | 99 | 10080 | 139 | 10080 | 175 |
| 30240 | 63 | 20160 | 107 | 20160 | 129 |

| **Norfolk** | | **Rains** | | **Noboco** | |
|---|---|---|---|---|---|
| Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] |
| 1 | 11568 | 1 | 7740 | 1 | 4644 |
| 5 | 6548 | 5 | 6156 | 5 | 1712 |
| 30 | 4192 | 30 | 2850 | 30 | 931 |
| 60 | 2752 | 60 | 2464 | 60 | 747 |
| 120 | 2120 | 120 | 1226 | 120 | 421 |
| 240 | 1479 | 240 | 941 | 240 | 390 |
| 1440 | 331 | 1440 | 192 | 1440 | 195 |
| 2880 | 151 | 2880 | 113 | 2880 | 47 |
| 5760 | 65 | 7200 | 63 | 7200 | 48 |
| 10080 | 50 | 10080 | 68 | 10080 | 39 |
| 20160 | 72 | 20160 | 71 | 20160 | 24 |

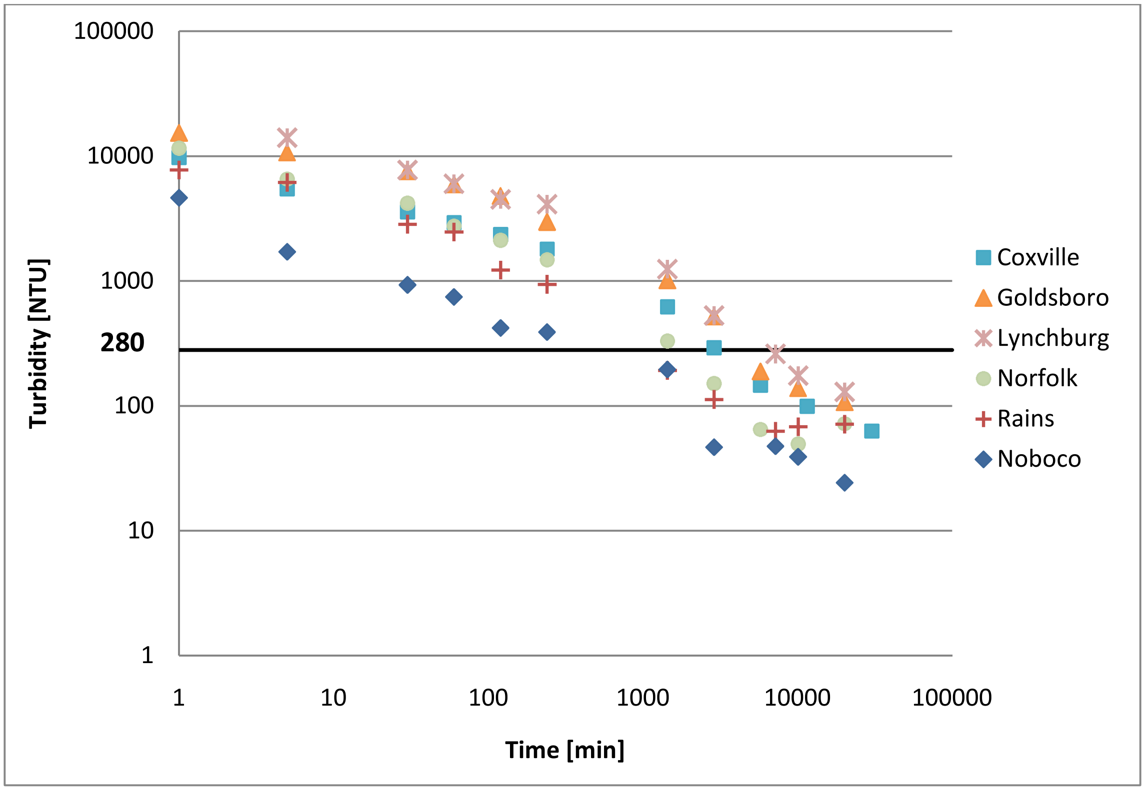

Figure D.5. Coastal top soils' relationship of turbidity and sediment settling time.

Table D.6. Coastal subsoils.

| **Coxville** | | **Goldsboro** | | **Lynchburg** | |
|---|---|---|---|---|---|
| Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] |
| 1 | 28370 | 1 | 10968 | 1 | 16524 |
| 5 | 25740 | 5 | 11816 | 5 | 6192 |
| 30 | 23060 | 30 | 8650 | 30 | 4160 |
| 60 | 21170 | 60 | 7134 | 60 | 3635 |
| 120 | 23200 | 120 | 5920 | 120 | 1702 |
| 240 | 18500 | 240 | 5028 | 240 | 2548 |
| 1440 | 4724 | 1440 | 2010 | 1440 | 600 |
| 2880 | 2967 | 2880 | 1127 | 2880 | 245 |
| 5760 | 1681 | 5760 | 494 | 7200 | 51 |
| 11520 | 577 | 11520 | 228 | 10080 | 46 |
| 30240 | 309 | 30240 | 122 | 20160 | 26 |

| **Norfolk** | | **Rains** | | **Noboco** | |
|---|---|---|---|---|---|
| Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] | Time [min] | Turbidity [NTU] |
| 1 | 16324 | 1 | 12732 | 1 | 17862 |
| 5 | 3416 | 5 | 7920 | 5 | 16632 |
| 30 | 1893 | 30 | 5370 | 30 | 15744 |
| 60 | 1637 | 60 | 4134 | 60 | 13596 |
| 120 | 1596 | 120 | 3480 | 120 | 8344 |
| 240 | 1247 | 240 | 2370 | 240 | 6564 |
| 1440 | 291 | 1440 | 622 | 1440 | 1595 |
| 2880 | 177 | 2880 | 284 | 2880 | 647 |
| 7200 | 53 | 7200 | 133 | 5760 | 361 |
| 10080 | 48 | 10080 | 83 | 10080 | 166 |
| 20160 | 38 | 20160 | 62 | 20160 | 101 |

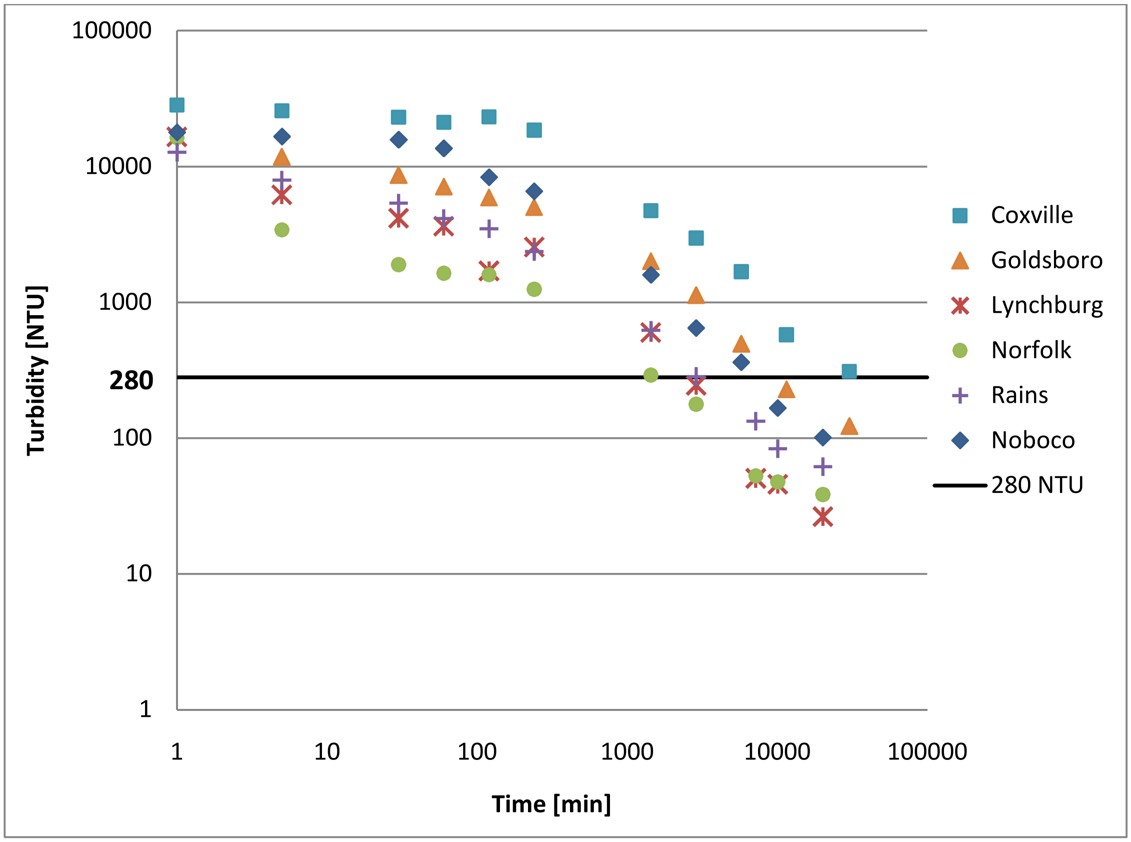

Figure D.6. Coastal subsoils' relationship of turbidity and sediment settling time.

# APPENDIX E

## Tabular data for selected soils' turbidity as a function of particle diameter

Appendix E contains raw data used to establish relationships between turbidity and aggregate/particle size. From applying Stoke's Law, particle diameters evaluated included 0.063, 0.014, 0.006, 0.004, 0.003, and 0.002 mm based on the previous sample times of 0 min, 5 min, 30 min, 1 hr, 2 hr and 4 hr. Particles sizes were compared to their corresponding turbidities and concentrations that were determined from previous procedures. Actual turbidity and concentration values were calculated using a subtraction method. Next, in order to compare all soils, the ratio of actual turbidity to concentration was calculated. All tabular data are reported in Appendix E tables for each region's top soil and subsoil. Lastly, subsequent figures plot region's top soil versus the ratio of turbidity to concentration and region's subsoil turbidity versus the ratio of turbidity to concentration.

Table E.1. Piedmont top soils.

| Soil Series | D [mm] | Conc. [mg/L] | Turbidity [NTU] | Actual Conc. [mg/L] | Actual Turbidity [NTU] | Turb./Conc. |
|---|---|---|---|---|---|---|
| Georgeville | 0.063 | 37580 | 33370 | 15930 | 1630 | 0.10 |
| | 0.014 | 21650 | 31740 | 7470 | 4000 | 0.54 |
| | 0.006 | 14180 | 27740 | 2500 | 8470 | 3.39 |
| | 0.004 | 11680 | 19270 | 1690 | 34 | 0.02 |
| | 0.003 | 9990 | 19236 | 1000 | 1704 | 1.70 |
| | 0.002 | 8990 | 17532 | 8990 | 17532 | 1.95 |
| Herndon | 0.063 | 27660 | 21240 | 15560 | 6114 | 0.39 |
| | 0.014 | 12100 | 15126 | 5180 | 3026 | 0.58 |
| | 0.006 | 6920 | 12100 | 900 | 504 | 0.56 |
| | 0.004 | 6020 | 11596 | 660 | 1532 | 2.32 |
| | 0.003 | 5360 | 10064 | 840 | 2608 | 3.10 |
| | 0.002 | 4520 | 7456 | 4520 | 7456 | 1.65 |
| Appling | 0.063 | 8090 | 12548 | 3110 | 2304 | 0.74 |
| | 0.014 | 4980 | 10244 | 2310 | 2764 | 1.20 |
| | 0.006 | 2670 | 7480 | 690 | 2348 | 3.40 |
| | 0.004 | 1980 | 5132 | 360 | 1048 | 2.91 |
| | 0.003 | 1620 | 4084 | 350 | 769 | 2.20 |
| | 0.002 | 1270 | 3315 | 1270 | 3315 | 2.61 |
| Cataula | 0.063 | 4670 | 5864 | 2040 | 1650 | 0.81 |
| | 0.014 | 2630 | 4214 | 1130 | 1120 | 0.99 |
| | 0.006 | 1500 | 3094 | 30 | 157 | 5.23 |
| | 0.004 | 1470 | 2937 | 390 | 713 | 1.83 |
| | 0.003 | 1080 | 2224 | 170 | 503 | 2.96 |
| | 0.002 | 910 | 1721 | 910 | 1721 | 1.89 |
| Cecil | 0.063 | 7100 | 7780 | 4420 | 3602 | 0.81 |
| | 0.014 | 2680 | 4178 | 1400 | 1636 | 1.17 |
| | 0.006 | 1280 | 2542 | 370 | 512 | 1.38 |
| | 0.004 | 910 | 2030 | 310 | 569 | 1.84 |
| | 0.003 | 600 | 1461 | 170 | 433 | 2.55 |
| | 0.002 | 430 | 1028 | 430 | 1028 | 2.39 |
| Hiwassee | 0.063 | 5130 | 5158 | 2540 | 1440 | 0.57 |
| | 0.014 | 2590 | 3718 | 1420 | 1440 | 1.01 |
| | 0.006 | 1170 | 2278 | 270 | 543 | 2.01 |
| | 0.004 | 900 | 1735 | 250 | 332 | 1.33 |
| | 0.003 | 650 | 1403 | 170 | 361 | 2.12 |
| | 0.002 | 480 | 1042 | 480 | 1042 | 2.17 |

| Soil Series | D [mm] | Conc. [mg/L] | Turbidity [NTU] | Actual Conc. [mg/L] | Actual Turbidity [NTU] | Turb./Conc. |
|---|---|---|---|---|---|---|
| Madison | 0.063 | 6750 | 6228 | 3810 | 2150 | 0.56 |
| | 0.014 | 2940 | 4078 | 1580 | 1578 | 1.00 |
| | 0.006 | 1360 | 2500 | 480 | 674 | 1.40 |
| | 0.004 | 880 | 1826 | 170 | 202 | 1.19 |
| | 0.003 | 710 | 1624 | 110 | 433 | 3.94 |
| | 0.002 | 600 | 1191 | 600 | 1191 | 1.99 |
| Pacelot | 0.063 | 6520 | 7788 | 2720 | 2252 | 0.83 |
| | 0.014 | 3800 | 5536 | 1620 | 1450 | 0.90 |
| | 0.006 | 2180 | 4086 | 540 | 656 | 1.21 |
| | 0.004 | 1640 | 3430 | 240 | 598 | 2.49 |
| | 0.003 | 1400 | 2832 | 280 | 733 | 2.62 |
| | 0.002 | 1120 | 2099 | 1120 | 2099 | 1.87 |
| Wilkes | 0.063 | 9260 | 6876 | 4180 | 502 | 0.12 |
| | 0.014 | 5080 | 6374 | 2270 | 1528 | 0.67 |
| | 0.006 | 2810 | 4846 | 590 | 842 | 1.43 |
| | 0.004 | 2220 | 4004 | 610 | 728 | 1.19 |
| | 0.003 | 1610 | 3276 | 440 | 950 | 2.16 |
| | 0.002 | 1170 | 2326 | 1170 | 2326 | 1.99 |

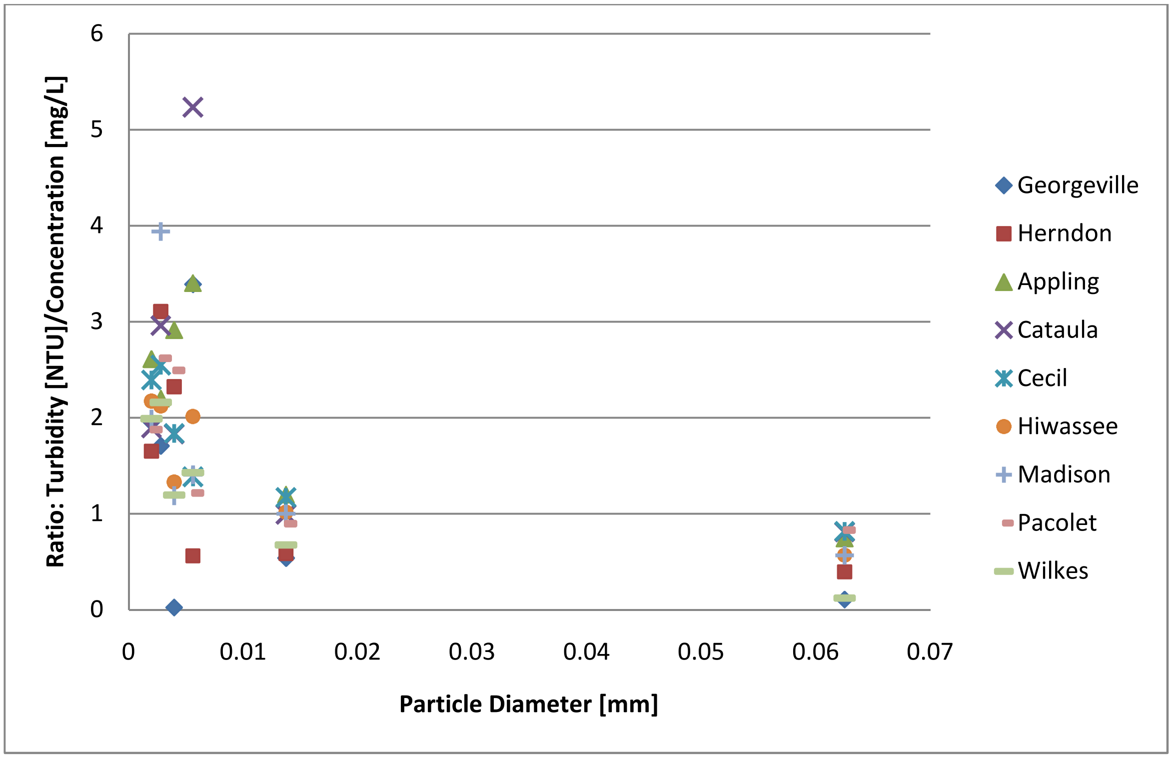

Figure E.1. Piedmont top soils' relationship of particle diameter and the ratio of turbidity to concentration.

Table E.2. Piedmont subsoils.

| Soil Series | D [mm] | Conc. [mg/L] | Turbidity [NTU] | Actual Conc. [mg/L] | Actual Turbidity [NTU] | Turb./Conc. |
|---|---|---|---|---|---|---|
| Hiwassee | 0.063 | 14040 | 22500 | 3420 | 0 | 0.00 |
| | 0.014 | 10620 | 22926 | 3390 | 4632 | 1.37 |
| | 0.006 | 7230 | 18294 | 1100 | 1464 | 1.33 |
| | 0.004 | 6130 | 16830 | 960 | 72 | 0.07 |
| | 0.003 | 5170 | 16758 | 640 | 7054 | 11.02 |
| | 0.002 | 4530 | 9704 | 4530 | 9704 | 2.14 |
| Madison | 0.063 | 17770 | 28608 | 13600 | 17784 | 1.31 |
| | 0.014 | 4170 | 10824 | 1430 | 4896 | 3.42 |
| | 0.006 | 2740 | 5928 | 60 | 218 | 3.63 |
| | 0.004 | 2680 | 5710 | 190 | 314 | 1.65 |
| | 0.003 | 2490 | 5396 | 240 | 650 | 2.71 |
| | 0.002 | 2250 | 4746 | 2250 | 4746 | 2.11 |
| Wilkes | 0.063 | 17380 | 16956 | 5130 | 2244 | 0.44 |
| | 0.014 | 12250 | 14712 | 3620 | 2556 | 0.71 |
| | 0.006 | 8630 | 12156 | 950 | 904 | 0.95 |
| | 0.004 | 7680 | 11252 | 990 | 816 | 0.82 |
| | 0.003 | 6690 | 10436 | 700 | 2628 | 3.75 |
| | 0.002 | 5990 | 7808 | 5990 | 7808 | 1.30 |
| Cataula | 0.063 | 11870 | 12264 | 11230 | 10963 | 0.98 |
| | 0.014 | 640 | 1301 | 360 | 672 | 1.87 |
| | 0.006 | 270 | 629 | 0 | 20 | 0.00 |
| | 0.004 | 270 | 597 | 0 | 0 | 0.00 |
| | 0.003 | 280 | 609 | 20 | 54 | 2.68 |
| | 0.002 | 260 | 555 | 260 | 555 | 2.14 |
| Cecil | 0.063 | 5860 | 6960 | 4010 | 3804 | 0.95 |
| | 0.014 | 1850 | 3156 | 1080 | 1412 | 1.31 |
| | 0.006 | 770 | 1744 | 120 | 226 | 1.88 |
| | 0.004 | 650 | 1518 | 50 | 228 | 4.56 |
| | 0.003 | 600 | 1290 | 250 | 359 | 1.44 |
| | 0.002 | 350 | 931 | 350 | 931 | 2.66 |
| Georgeville | 0.063 | 37400 | 37340 | 37250 | 37179 | 1.00 |
| | 0.014 | 150 | 161 | 100 | 128 | 1.28 |
| | 0.006 | 40 | 33 | 0 | 10 | 0.00 |
| | 0.004 | 50 | 23 | 10 | 8 | 0.75 |
| | 0.003 | 40 | 15 | 0 | 4 | 0.00 |
| | 0.002 | 40 | 11 | 40 | 11 | 0.28 |

| **Soil Series** | **D [mm]** | **Conc. [mg/L]** | **Turbidity [NTU]** | **Actual Conc. [mg/L]** | **Actual Turbidity [NTU]** | **Turb./Conc.** |
|---|---|---|---|---|---|---|
| Herndon | 0.063 | 28410 | 20070 | 9710 | 11900 | 1.23 |
| | 0.014 | 280 | 378 | 140 | 176 | 1.26 |
| | 0.006 | 80 | 78 | 10 | 19 | 1.89 |
| | 0.004 | 40 | 70 | 0 | 14 | 0.00 |
| | 0.003 | 60 | 72 | 10 | 15 | 1.52 |
| | 0.002 | 50 | 57 | 50 | 57 | 1.13 |
| Appling | 0.063 | 8720 | 8440 | 8320 | 7769 | 0.93 |
| | 0.014 | 400 | 671 | 280 | 447 | 1.60 |
| | 0.006 | 120 | 223 | 30 | 15 | 0.51 |
| | 0.004 | 90 | 208 | 0 | 6 | 0.00 |
| | 0.003 | 90 | 202 | 0 | 49 | 0.00 |
| | 0.002 | 90 | 153 | 90 | 153 | 1.70 |
| Pacelot | 0.063 | 9900 | 12174 | 9710 | 11900 | 1.23 |
| | 0.014 | 190 | 274 | 140 | 176 | 1.26 |
| | 0.006 | 50 | 98 | 10 | 19 | 1.89 |
| | 0.004 | 40 | 80 | 0 | 14 | 0.00 |
| | 0.003 | 40 | 66 | 10 | 12 | 1.23 |
| | 0.002 | 30 | 54 | 30 | 54 | 1.79 |

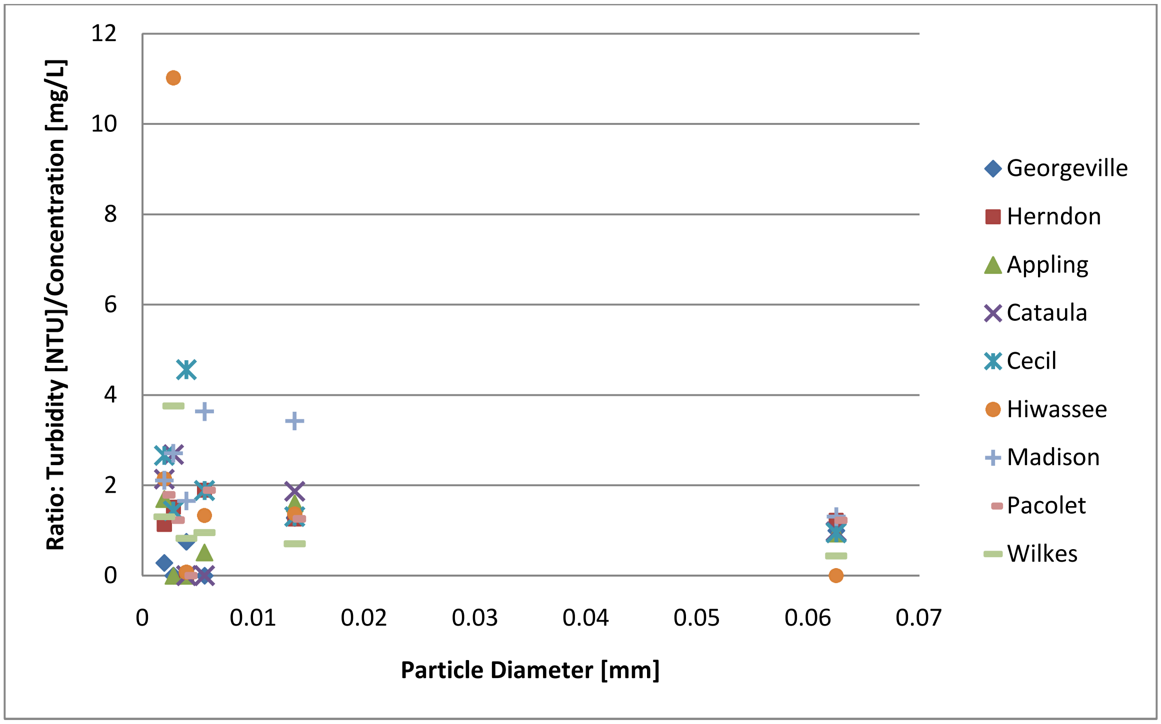

Figure E.2. Piedmont subsoils' relationship of particle diameter and the ratio of turbidity to concentration.

Table E.3. Central top soils.

| Soil Series | D [mm] | Conc. [mg/L] | Turbidity [NTU] | Actual Conc. [mg/L] | Actual Turbidity [NTU] | Turb./Conc. |
|---|---|---|---|---|---|---|
| Ailey | 0.063 | 9300 | 9032 | 3940 | 2116 | 0.54 |
| | 0.014 | 5360 | 6916 | 2770 | 2038 | 0.74 |
| | 0.006 | 2590 | 4878 | 620 | 1366 | 2.20 |
| | 0.004 | 1970 | 3512 | 350 | 534 | 1.53 |
| | 0.003 | 1620 | 2978 | 300 | 631 | 2.10 |
| | 0.002 | 1320 | 2347 | 1320 | 2347 | 1.78 |
| Johnston | 0.063 | 6620 | 5794 | 2890 | 1842 | 0.64 |
| | 0.014 | 3730 | 3952 | 2710 | 2344 | 0.86 |
| | 0.006 | 960 | 1519 | 0 | 0 | 0.00 |
| | 0.004 | 1020 | 1608 | 320 | 575 | 1.80 |
| | 0.003 | 700 | 1033 | 330 | 494 | 1.50 |
| | 0.002 | 370 | 539 | 370 | 539 | 1.46 |
| Bonneau | 0.063 | 3736 | 3810 | 1872 | 1480 | 0.79 |
| | 0.014 | 1864 | 2330 | 1188 | 1033 | 0.87 |
| | 0.006 | 676 | 1297 | 261 | 325 | 1.24 |
| | 0.004 | 415 | 972 | 115 | 217 | 1.88 |
| | 0.003 | 300 | 756 | 114 | 193 | 1.70 |
| | 0.002 | 186 | 563 | 186 | 563 | 3.02 |
| Wagram | 0.063 | 3540 | 3042 | 2390 | 1588 | 0.66 |
| | 0.014 | 1150 | 1454 | 680 | 680 | 1.00 |
| | 0.006 | 470 | 774 | 170 | 189 | 1.11 |
| | 0.004 | 300 | 585 | 130 | 313 | 2.40 |
| | 0.003 | 170 | 272 | 50 | 13 | 0.25 |
| | 0.002 | 120 | 260 | 120 | 260 | 2.16 |
| Blanton | 0.063 | 1960 | 1555 | 1080 | 455 | 0.42 |
| | 0.014 | 880 | 1100 | 390 | 168 | 0.43 |
| | 0.006 | 490 | 933 | 200 | 394 | 1.97 |
| | 0.004 | 290 | 539 | 60 | 63 | 1.05 |
| | 0.003 | 230 | 476 | 30 | 83 | 2.77 |
| | 0.002 | 200 | 393 | 200 | 393 | 1.96 |
| Lakeland | 0.063 | 2560 | 2788 | 940 | 694 | 0.74 |
| | 0.014 | 1620 | 2094 | 940 | 911 | 0.97 |
| | 0.006 | 680 | 1183 | 230 | 295 | 1.28 |
| | 0.004 | 420 | 888 | 0 | 16 | 0.00 |
| | 0.003 | 450 | 872 | 180 | 325 | 1.80 |
| | 0.002 | 270 | 547 | 270 | 547 | 2.03 |

| Soil Series | D [mm] | Conc. [mg/L] | Turbidity [NTU] | Actual Conc. [mg/L] | Actual Turbidity [NTU] | Turb./Conc. |
|---|---|---|---|---|---|---|
| Troup | 0.063 | 3380 | 2400 | 1910 | 826 | 0.43 |
| | 0.014 | 1470 | 1574 | 880 | 610 | 0.69 |
| | 0.006 | 590 | 964 | 130 | 98 | 0.76 |
| | 0.004 | 460 | 866 | 110 | 218 | 1.98 |
| | 0.003 | 350 | 648 | 50 | 87 | 1.73 |
| | 0.002 | 300 | 561 | 300 | 561 | 1.87 |
| Vaucluse | 0.063 | 2220 | 1277 | 1410 | 374 | 0.27 |
| | 0.014 | 810 | 903 | 510 | 426 | 0.83 |
| | 0.006 | 300 | 477 | 100 | 120 | 1.20 |
| | 0.004 | 200 | 358 | 100 | 140 | 1.40 |
| | 0.003 | 100 | 218 | 0 | 15 | 0.00 |
| | 0.002 | 100 | 203 | 100 | 203 | 2.03 |
| Dothan | 0.063 | 5400 | 4580 | 2430 | 938 | 0.39 |
| | 0.014 | 2970 | 3642 | 1600 | 1166 | 0.73 |
| | 0.006 | 1370 | 2476 | 430 | 530 | 1.23 |
| | 0.004 | 940 | 1946 | 300 | 554 | 1.85 |
| | 0.003 | 640 | 1392 | 220 | 406 | 1.85 |
| | 0.002 | 420 | 986 | 420 | 986 | 2.35 |
| Fuquay | 0.063 | 1840 | 1970 | 520 | 256 | 0.49 |
| | 0.014 | 1320 | 1714 | 580 | 408 | 0.70 |
| | 0.006 | 740 | 1306 | 80 | 83 | 1.04 |
| | 0.004 | 660 | 1223 | 240 | 361 | 1.50 |
| | 0.003 | 420 | 862 | 130 | 193 | 1.48 |
| | 0.002 | 290 | 670 | 290 | 670 | 2.31 |

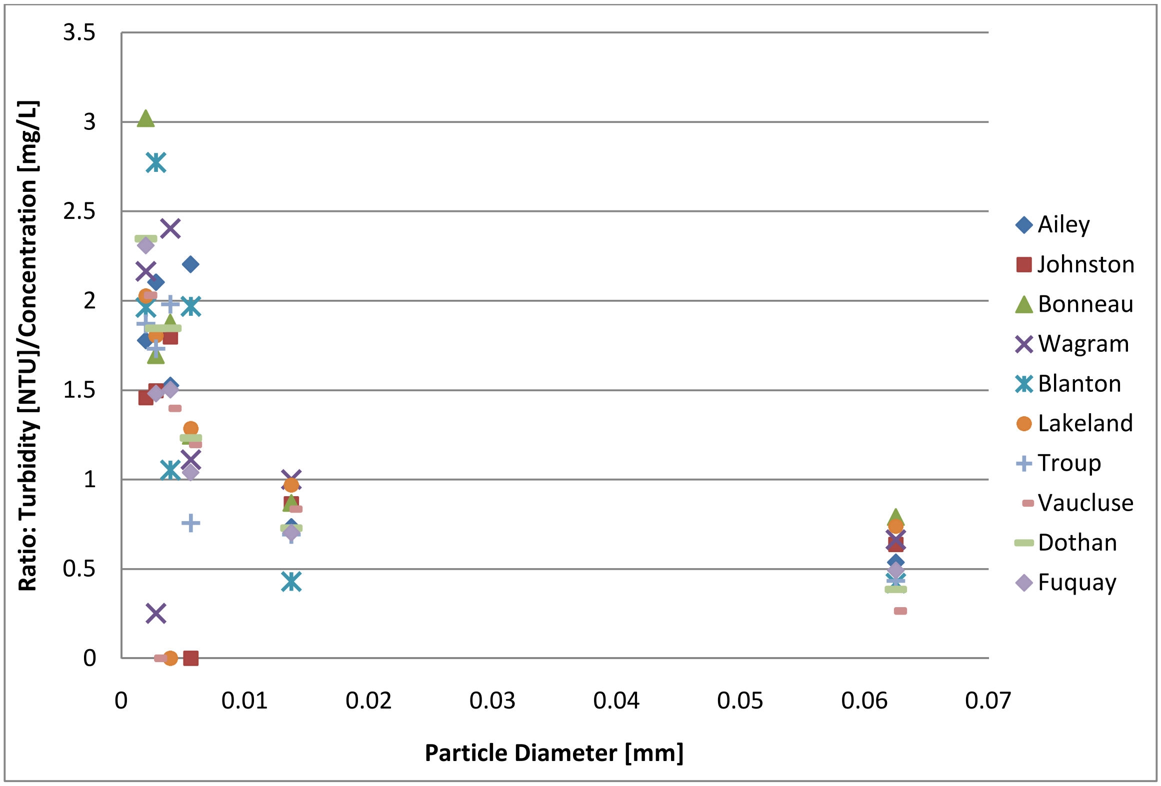

Figure E.3. Cental top soils' relationship of particle diameter and the ratio of turbidity to concentration.

Table E.4. Central subsoils.

| Soil Series | D [mm] | Conc. [mg/L] | Turbidity [NTU] | Actual Conc. [mg/L] | Actual Turbidity [NTU] | Turb./Conc. |
|---|---|---|---|---|---|---|
| Bonneau | 0.063 | 8320 | 7248 | 4020 | 190 | 0.05 |
| | 0.014 | 4300 | 7058 | 2680 | 3030 | 1.13 |
| | 0.006 | 1620 | 4028 | 230 | 366 | 1.59 |
| | 0.004 | 1390 | 3662 | 510 | 993 | 1.95 |
| | 0.003 | 880 | 2669 | 370 | 1084 | 2.93 |
| | 0.002 | 510 | 1585 | 510 | 1585 | 3.11 |
| Dothan | 0.063 | 2580 | 2864 | 890 | 722 | 0.81 |
| | 0.014 | 1690 | 2142 | 670 | 404 | 0.60 |
| | 0.006 | 1020 | 1738 | 170 | 282 | 1.66 |
| | 0.004 | 850 | 1456 | 190 | 145 | 0.76 |
| | 0.003 | 660 | 1311 | 110 | 307 | 2.79 |
| | 0.002 | 550 | 1004 | 550 | 1004 | 1.83 |
| Wagram | 0.063 | 5090 | 5822 | 1720 | 1022 | 0.59 |
| | 0.014 | 3370 | 4800 | 1250 | 1030 | 0.82 |
| | 0.006 | 2120 | 3770 | 400 | 161 | 0.40 |
| | 0.004 | 1720 | 3609 | 50 | 58 | 1.16 |
| | 0.003 | 1670 | 3551 | 400 | 894 | 2.24 |
| | 0.002 | 1270 | 2657 | 1270 | 2657 | 2.09 |
| Blanton | 0.063 | 2620 | 2230 | 1270 | 654 | 0.51 |
| | 0.014 | 1350 | 1576 | 790 | 765 | 0.97 |
| | 0.006 | 560 | 811 | 170 | 17 | 0.10 |
| | 0.004 | 390 | 794 | 70 | 219 | 3.13 |
| | 0.003 | 320 | 575 | 170 | 312 | 1.83 |
| | 0.002 | 150 | 263 | 150 | 263 | 1.76 |
| Troup | 0.063 | 5520 | 5996 | 1930 | 722 | 0.37 |
| | 0.014 | 3590 | 5274 | 1390 | 922 | 0.66 |
| | 0.006 | 2200 | 4352 | 550 | 970 | 1.76 |
| | 0.004 | 1650 | 3382 | 400 | 526 | 1.32 |
| | 0.003 | 1250 | 2856 | 310 | 787 | 2.54 |
| | 0.002 | 940 | 2069 | 940 | 2069 | 2.20 |
| Vaucluse | 0.063 | 11070 | 13172 | 3130 | 1684 | 0.54 |
| | 0.014 | 7940 | 11488 | 2980 | 316 | 0.11 |
| | 0.006 | 4960 | 11172 | 1150 | 888 | 0.77 |
| | 0.004 | 3810 | 10284 | 730 | 2564 | 3.51 |
| | 0.003 | 3080 | 7720 | 720 | 1604 | 2.23 |
| | 0.002 | 2360 | 6116 | 2360 | 6116 | 2.59 |

| Soil Series | D [mm] | Conc. [mg/L] | Turbidity [NTU] | Actual Conc. [mg/L] | Actual Turbidity [NTU] | Turb./Conc. |
|---|---|---|---|---|---|---|
| Ailey | 0.063 | 8730 | 11136 | 7590 | 9306 | 1.23 |
| | 0.014 | 1140 | 1830 | 720 | 919 | 1.28 |
| | 0.006 | 420 | 911 | 0 | 99 | 0.00 |
| | 0.004 | 420 | 812 | 50 | 109 | 2.17 |
| | 0.003 | 370 | 704 | 50 | 183 | 3.65 |
| | 0.002 | 320 | 521 | 320 | 521 | 1.63 |
| Johnston | 0.063 | 10480 | 13060 | 4320 | 1624 | 0.38 |
| | 0.014 | 6160 | 11436 | 2630 | 2490 | 0.95 |
| | 0.006 | 3530 | 8148 | 830 | 0 | 0.00 |
| | 0.004 | 2700 | 8946 | 710 | 2468 | 3.48 |
| | 0.003 | 1990 | 6478 | 560 | 1772 | 3.16 |
| | 0.002 | 1430 | 4706 | 1430 | 4706 | 3.29 |
| Lakeland | 0.063 | 6510 | 6818 | 2240 | 292 | 0.13 |
| | 0.014 | 4270 | 6526 | 1830 | 2106 | 1.15 |
| | 0.006 | 2440 | 4420 | 720 | 876 | 1.22 |
| | 0.004 | 1720 | 3544 | 210 | 241 | 1.15 |
| | 0.003 | 1510 | 3303 | 450 | 993 | 2.21 |
| | 0.002 | 1060 | 2310 | 1060 | 2310 | 2.18 |
| Fuquay | 0.063 | 8040 | 9230 | 7210 | 8152 | 1.13 |
| | 0.014 | 830 | 1078 | 570 | 729 | 1.28 |
| | 0.006 | 260 | 349 | 30 | 33 | 1.11 |
| | 0.004 | 230 | 316 | 10 | 17 | 1.70 |
| | 0.003 | 220 | 299 | 70 | 47 | 0.68 |
| | 0.002 | 150 | 252 | 150 | 252 | 1.68 |

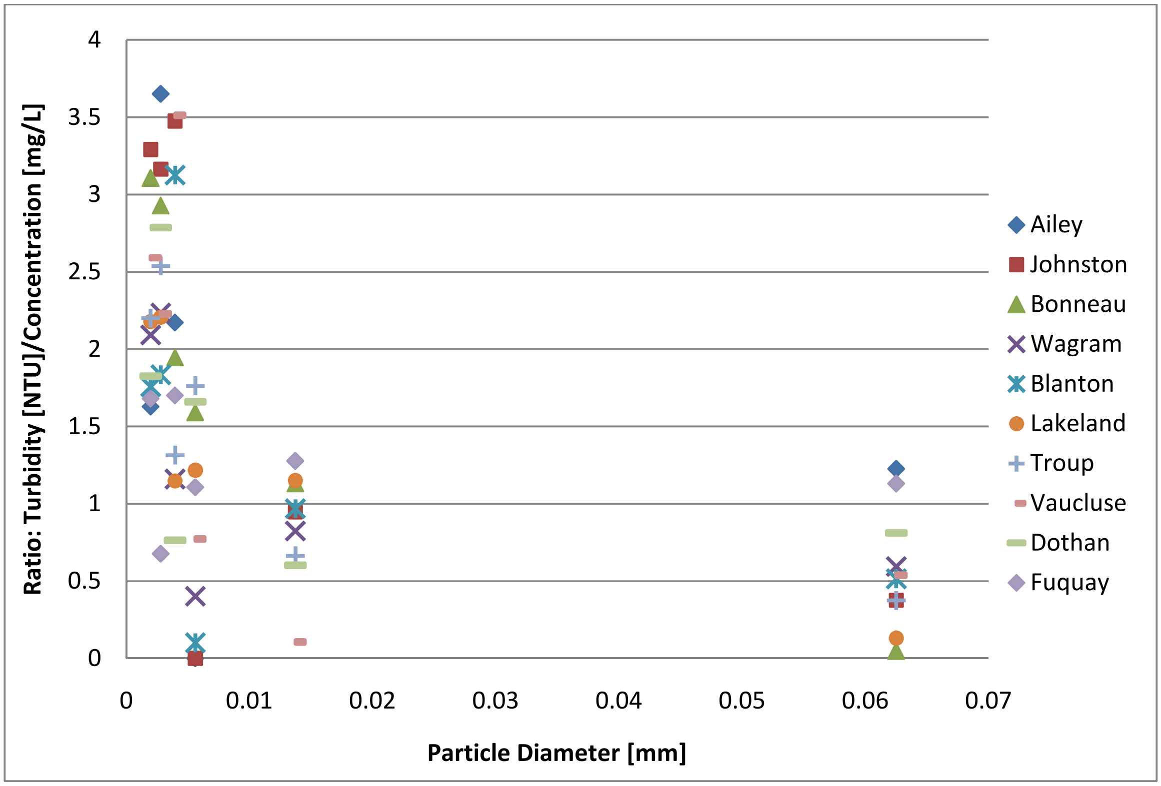

Figure E.4. Central subsoils' relationship of particle diameter and the ratio of turbidity to concentration.

Table E.5. Coastal top soils.

| Soil Series | D [mm] | Conc. [mg/L] | Turbidity [NTU] | Actual Conc. [mg/L] | Actual Turbidity [NTU] | Turb./Conc. |
|---|---|---|---|---|---|---|
| Goldsboro | 0.063 | 8850 | 15336 | 3950 | 4650 | 1.18 |
| | 0.014 | 4900 | 10686 | 2120 | 3118 | 1.47 |
| | 0.006 | 2780 | 7568 | 590 | 1636 | 2.77 |
| | 0.004 | 2190 | 5932 | 340 | 1132 | 3.33 |
| | 0.003 | 1850 | 4800 | 770 | 1830 | 2.38 |
| | 0.002 | 1080 | 2970 | 1080 | 2970 | 2.75 |
| Lynchburg | 0.063 | 14890 | 11316 | 8280 | 0 | 0.00 |
| | 0.014 | 6610 | 14058 | 3580 | 6304 | 1.76 |
| | 0.006 | 3030 | 7754 | 800 | 1732 | 2.17 |
| | 0.004 | 2230 | 6022 | 580 | 1524 | 2.63 |
| | 0.003 | 1650 | 4498 | 50 | 372 | 7.44 |
| | 0.002 | 1600 | 4126 | 1600 | 4126 | 2.58 |
| Coxville | 0.063 | 7290 | 9744 | 3620 | 4268 | 1.18 |
| | 0.014 | 3670 | 5476 | 1910 | 1890 | 0.99 |
| | 0.006 | 1760 | 3586 | 420 | 653 | 1.55 |
| | 0.004 | 1340 | 2933 | 320 | 576 | 1.80 |
| | 0.003 | 1020 | 2357 | 240 | 555 | 2.31 |
| | 0.002 | 780 | 1802 | 780 | 1802 | 2.31 |
| Norfolk | 0.063 | 6760 | 11568 | 3430 | 5020 | 1.46 |
| | 0.014 | 3330 | 6548 | 1690 | 2356 | 1.39 |
| | 0.006 | 1640 | 4192 | 700 | 1440 | 2.06 |
| | 0.004 | 940 | 2752 | 240 | 632 | 2.63 |
| | 0.003 | 700 | 2120 | 200 | 641 | 3.21 |
| | 0.002 | 500 | 1479 | 500 | 1479 | 2.96 |
| Noboco | 0.063 | 5180 | 4644 | 3870 | 2932 | 0.76 |
| | 0.014 | 1310 | 1712 | 780 | 781 | 1.00 |
| | 0.006 | 530 | 931 | 190 | 184 | 0.97 |
| | 0.004 | 340 | 747 | 150 | 326 | 2.17 |
| | 0.003 | 180 | 421 | 0 | 31 | 0.00 |
| | 0.002 | 190 | 390 | 190 | 390 | 2.05 |
| Rains | 0.063 | 9490 | 7740 | 5240 | 1584 | 0.30 |
| | 0.014 | 4250 | 6156 | 2990 | 3306 | 1.11 |
| | 0.006 | 1260 | 2850 | 310 | 386 | 1.25 |
| | 0.004 | 950 | 2464 | 460 | 1238 | 2.69 |
| | 0.003 | 490 | 1226 | 70 | 285 | 4.07 |
| | 0.002 | 420 | 941 | 420 | 941 | 2.24 |

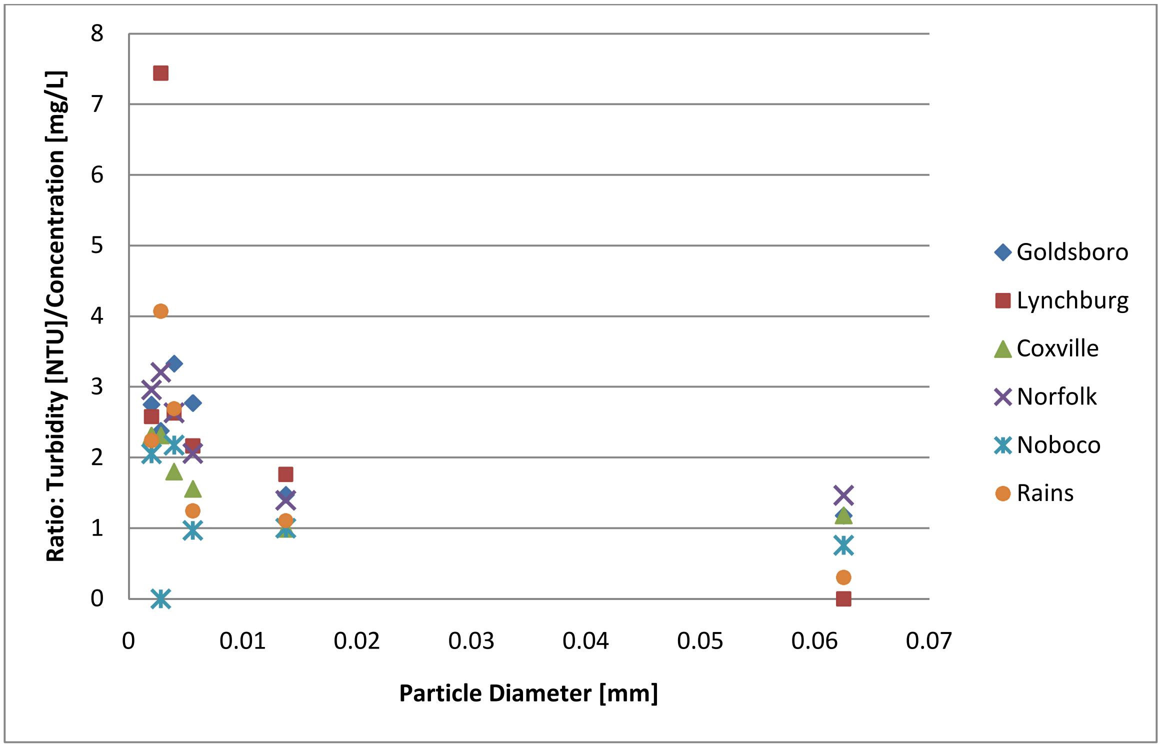

Figure E.5. Coastal top soils’ relationship of particle diameter and the ratio of turbidity to concentration.

Table E.6. Coastal subsoils.

| **Soil Series** | **D [mm]** | **Conc. [mg/L]** | **Turbidity [NTU]** | **Actual Conc. [mg/L]** | **Actual Turbidity [NTU]** | **Turb./Conc.** |
|---|---|---|---|---|---|---|
| Coxville | 0.063 | 20200 | 28370 | 6440 | 2630 | 0.41 |
| | 0.014 | 13760 | 25740 | 5230 | 2540 | 0.49 |
| | 0.006 | 8530 | 23060 | 1160 | 0 | 0.00 |
| | 0.004 | 7370 | 21170 | 1150 | 0 | 0.00 |
| | 0.003 | 6220 | 23200 | 1070 | 4700 | 4.39 |
| | 0.002 | 5150 | 18500 | 5150 | 18500 | 3.59 |
| Noboco | 0.063 | 14710 | 17862 | 5470 | 1230 | 0.22 |
| | 0.014 | 9240 | 16632 | 4740 | 888 | 0.19 |
| | 0.006 | 4500 | 15744 | 740 | 2148 | 2.90 |
| | 0.004 | 3760 | 13596 | 1160 | 5252 | 4.53 |
| | 0.003 | 2600 | 8344 | 770 | 1780 | 2.31 |
| | 0.002 | 1830 | 6564 | 1830 | 6564 | 3.59 |
| Goldsboro | 0.063 | 10410 | 10968 | 4280 | 0 | 0.00 |
| | 0.014 | 6130 | 11816 | 2000 | 3166 | 1.58 |
| | 0.006 | 4130 | 8650 | 600 | 1516 | 2.53 |
| | 0.004 | 3530 | 7134 | 310 | 1214 | 3.92 |
| | 0.003 | 3220 | 5920 | 550 | 892 | 1.62 |
| | 0.002 | 2670 | 5028 | 2670 | 5028 | 1.88 |
| Lynchburg | 0.063 | 15460 | 16524 | 12240 | 10332 | 0.84 |
| | 0.014 | 3220 | 6192 | 1330 | 2032 | 1.53 |
| | 0.006 | 1890 | 4160 | 350 | 525 | 1.50 |
| | 0.004 | 1540 | 3635 | 210 | 1087 | 5.18 |
| | 0.003 | 1330 | 1702 | 170 | 0 | 0.00 |
| | 0.002 | 1160 | 2548 | 1160 | 2548 | 2.20 |
| Norfolk | 0.063 | 11750 | 16324 | 10200 | 12908 | 1.27 |
| | 0.014 | 1550 | 3416 | 790 | 1523 | 1.93 |
| | 0.006 | 760 | 1893 | 90 | 256 | 2.84 |
| | 0.004 | 670 | 1637 | 60 | 41 | 0.68 |
| | 0.003 | 610 | 1596 | 120 | 349 | 2.91 |
| | 0.002 | 490 | 1247 | 490 | 1247 | 2.54 |
| Rains | 0.063 | 8260 | 12732 | 3760 | 4812 | 1.28 |
| | 0.014 | 4500 | 7920 | 2330 | 2550 | 1.09 |
| | 0.006 | 2170 | 5370 | 610 | 1236 | 2.03 |
| | 0.004 | 1560 | 4134 | 300 | 654 | 2.18 |
| | 0.003 | 1260 | 3480 | 360 | 1110 | 3.08 |
| | 0.002 | 900 | 2370 | 900 | 2370 | 2.63 |

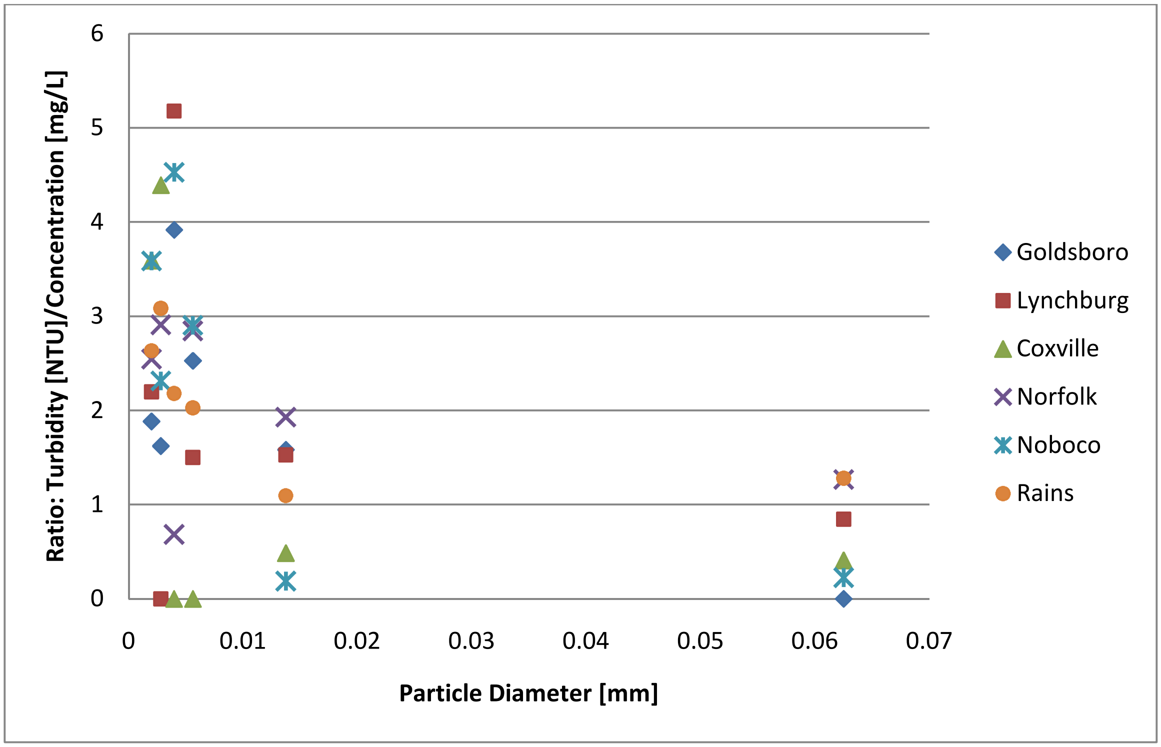

Figure E.6. Coastal subsoils' relationship of particle diameter and the ratio of turbidity to concentration.

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