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OPTIMIZATION OF BLOCK LAYOUT AND EVALUATION OF COLLECTION MAT MATERIALS FOR POLYACRYLAMIDE TREATMENT CHANNELS

by

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B.S.Env.E. University of Central Florida, 2012

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ABSTRACT

Construction sites are frequently cited as major sources of pollution that degrade the quality of surface water. The highly erodible topsoil is transported off site by stormwater runoff causing negative effects downstream. Research has shown that the small particles, which are the most susceptible to erosive forces, have more pollutants associated with them than larger soil particles. Currently, in the state of Florida, it is not permissible to discharge water to a receiving water body if the turbidity is more than 29 Nephelometric Turbidity Units (NTUs) above background or higher than background for an outstanding Florida water body. The removal of fine suspended sediment from water can be achieved by filtration, settling, and the use of chemical coagulants. Polyacrylamide (PAM), a coagulant, has been shown to be effective in removing fine suspended particles from water via coagulation and flocculation. The Stormwater Management Academy at the University of Central Florida has researched the use of PAM and collection mats in a treatment channel to meet state discharge requirements.

In this study, turbid water using sediment from typical Florida soils was simulated and passed through a channel. The channel contained polymer blocks in a configuration previously determined to be the most effective. An important component of the treatment system is the floc collection. This research examined three types of collection mats, namely jute, coconut fiber and polypropylene mix to collect the flocs. This thesis presents the results of this investigation.

The results for the sandy soil tests showed an average removal efficiency prior to the collection mat starting at 71% and decreasing to 44% at the end of the tests. The 20-foot coconut mat maintained an average removal efficiency of 90%. The turbidity due to silty-sandy soil was decreased with an average removal efficiency prior to the collection mat ranging from 50% to 65%. The average removal efficiency for the 20-foot coconut mat started at 85%and decreased to 60% during the tests. The turbidity due to crushed limestone showed an average removal efficiency prior to the collection mat ranging from 81% down to 69%

over time. The average results from the 20-foot coconut mat ranged from 65% to 80%. Turbidity was tested on the samples under two conditions, a 30 second settling time and completely mixed. Statistical results show a significant decrease (α=0.05) in turbidity between the mixed and settled samples.

Statistical analyses were performed on the collected data, which concluded that the capability of the mat to reduce turbidity can be repeated with a 95% confidence interval. The 20-foot length coconut mat had the highest turbidity removal efficiency for every soil type examined. Further statistical analysis showed that the achieved turbidity reduction was significantly different (α=0.05) for the various materials. It was observed that generally, each type of mat clogged during testing indicating that longer collection mats be used, possibly lining the entire channel. Recommendations from this study are to provide a settling area after the collection mats and line the entire length of the channel with the collection mat selected.

This thesis is dedicated to my parents

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1. INTRODUCTION

Problem Statement

Sediment and turbidity are among the most common pollutants affecting surface waters, resulting in reduced reservoir capacity, degradation of aquatic organism habitat, and decreased aesthetic value (R. A. K. McLaughlin, S. E.; Jennings, G. D. , 2009). Construction sites are one of the highest prone sources for these pollutants. Due to the fragile and pre-disturbed disposition, construction site soil can lead to severe stormwater runoff pollution causing negative effects to the ecosystem and the economy.

Areas disturbed for construction activity have soil erosion rates from 2 to 40,000 times greater than pre-construction conditions (Harbor, 1999). When stormwater hits a deforested, plowed, and milled construction site, a layer of nutrient rich top soil is removed and carried along with the runoff. Once the contaminated stormwater enters the ecosystem, it brings with it, nutrients and high turbidity that the system is not used to. The nutrients, such as nitrogen and phosphorous, may lead to issues such as algal blooms and lake eutrophication. Highly turbid water can prevent sunlight from traveling through the water because it acts as a deflector, preventing photosynthesis to occur as normal. Without photosynthesis, plant growth is halted and oxygen will not reach the organisms.

Contaminated stormwater can also negatively impact utilities provided for human life and lead to economic costs. For instance, when highly turbid water enters a storm sewer, the silt can clog the system leading to a need for dredging. For example, between 1980 and 1990, the Alemeda County Flood Control and Water Conservation District in California spent an estimated US$2.5 million per year for dredging, and it has been estimated that it would cost US$30 million per year to remove construction related sediment from San Francisco, CA area lakes and reservoirs (Harbor, 1999).

In order to limit these issues from occurring, stormwater contamination preventatives have been developed. Stormwater pollution prevention practices include permanent and temporary measures. Some of these methods include the use of silt fences, rock dams, permanent seeding, sediment ponds, polyacrylamide, collection mats, and riprap. This research focused on the effectiveness of polyacrylamide (PAM) in conjunction with collection mats. PAM is a water-soluble tool used for the removal of nutrients and particulates. It comes in the form of powder or solid blocks. This study focused on the capabilities and optimization of PAM blocks in a channel regarding turbidity removal on a construction site.

Research objective

The primary goal of this research was to develop a scientific method for optimizing the removal efficiency of turbidity removal through the use of PAM blocks and rolled erosion mats. A previous project at the University of Central Florida designed PAM configuration optimization turbidity removal. The current research method included testing PAM placed in the configuration previously established experimentally for the reduction of turbidity from runoff contaminated by three different soil types prevalent in Florida. In addition, various collection mats were placed at the downstream of the channel to capture the flocs formed by the PAM through the treatment process to evaluate the combined efficiency of the different mats. Collection mats at varied lengths and types in conjunction with the PAM were evaluated to discover the most proficient set. In addition to this work, an analysis of the exiting PAM concentration potential to the environment will also be discussed. The primary objectives for the research project are:

- Evaluation of the turbidity removal efficiency of three different collection mats combined with the established polyacrylamide block configuration
- Study the effect of collection mats on the additional removal of turbidity

Overview

Chapter one in this thesis includes the problem statement and the hypothesis and describes the intent of the project including environmental factors of stormwater runoff. The second chapter consists of the literature review of past or related projects as well as a description of the background. Chapter three discusses the methodology and approach used to determine the effectiveness of the PAM block formation. Chapter four includes the results of the tests, analyses and discussions of the findings. The fifth chapter presents the conclusions associated with the data collected including a summary and recommendations for the future.

2. LITERATURE REVIEW

Prior to starting research, a literature review was conducted on materials relating to laws and regulations, polyacrylamide (PAM), and collection mats. An overview of the information gathered is found in this section.

Current Laws and Regulations

Environmental Protection Agency Guidelines

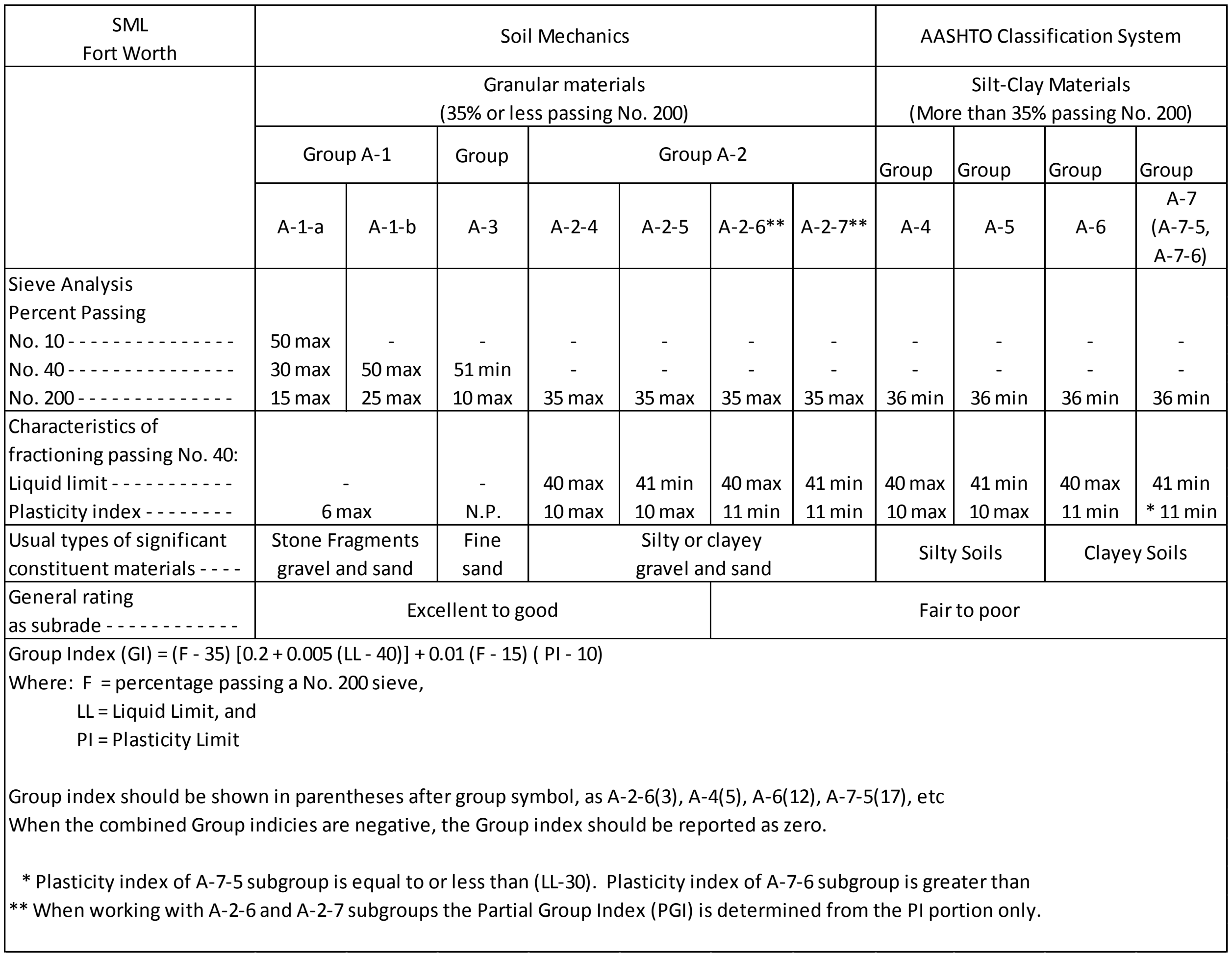
Sediment has been classified by the Environmental Protection Agency (EPA) as a major pollutant in United States streams and rivers (R. A. McLaughlin, 2004). In 2009 the EPA issued a final effluent guideline for limiting turbidity concentrations to 280 Nephelometric Turbidity Units (NTU) for construction sites when disturbing 20 or more acres at one time. However, in 2010 a litigation was filed by the Wisconsin Builders Association, Utility Water Action Group, and the National Association of Home Builders to revise the new standard and withdraw the numeric limitation for turbidity. An agreement was made to make actions by April 15th 2013 and propose a new rule by February 28th 2014. As of the beginning of 2014, the EPA numeric discharge standards for turbidity have been adjusted to 280 NTU while disturbing 10 or more acres of land ("Amendments to Effluent Limitations Guidelines and Standards for the Construction and Development Point Source Category," 2014).

FDEP Guidelines

The Florida Department of Environmental Protection (FDEP) has set discharge limits on treated stormwater based on background turbidity. The background measurement locations consist of the receiving water, upstream of the discharge point. In order to meet regulations, the discharge may not exceed 29NTUs above this background turbidity value (FDEP).

Soil Types

The American Association of State Highway and Transportation Officials (AASHTO) has a system used for soil classification based on particle distribution and Atterberg limits. Soil behavior is defined by the limits of water content. Particle distribution is determined by the particle size, shape, and gradation. These features describe a soils texture which include gravel, sand, silt, and clay ranging from >2mm to <0.01 mm. There are four states of a soil including viscous liquid state, plastic state, semi-solid state, and solid state in order from deepest to most shallow. AASHTO classification was developed by Hogentogler and Terzaghi in 1929 as the Public Roads Classification System. The classification of soils under the AASHTO standards include the sieve analysis percentage passing, characteristics of fraction passing No. 40 including Liquid Limit and plasticity index, the types of significant constituent materials, and general sub grade rating. General guidelines explain that A1-A3 soils are granular materials and A4-A7 are known as silt-clay materials("Engineering Classification of Soil AASHTO and USCS Das, Ch. 4," ; Staff, 1987)("Engineering Classification of Soil AASHTO and USCS Das, Ch. 4," ; Staff, 1987) . Figure 1 shows the properties used for soil classification.



SML Fort Worth	Soil Mechanics							AASHTO Classification System			
	Granular materials (35% or less passing No. 200)							Silt-Clay Materials (More than 35% passing No. 200)			
	Group A-1		Group	Group A-2				Group	Group	Group	Group
	A-1-a	A-1-b	A-3	A-2-4	A-2-5	A-2-6**	A-2-7**	A-4	A-5	A-6	A-7 (A-7-5, A-7-6)
Sieve Analysis											
Percent Passing											
No. 10 - - - - - - - - - - - - - - -	50 max	-	-	-	-	-	-	-	-	-	-
No. 40 - - - - - - - - - - - - - - -	30 max	50 max	51 min	-	-	-	-	-	-	-	-
No. 200 - - - - - - - - - - - - - -	15 max	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Characteristics of											
fractioning passing No. 40:											
Liquid limit - - - - - - - - - - -	-		-	40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min
Plasticity index - - - - - - - -	6 max		N.P.	10 max	10 max	11 min	11 min	10 max	10 max	11 min	* 11 min
Usual types of significant constituent materials - - - -	Stone Fragments gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty Soils		Clayey Soils	
General rating as subrade - - - - - - - - - - - -	Excellent to good					Fair to poor					

Group Index (GI) = (F - 35) [0.2 + 0.005 (LL - 40)] + 0.01 (F - 15) (PI - 10)

Where: F = percentage passing a No. 200 sieve,
LL = Liquid Limit, and
PI = Plasticity Limit

Group index should be shown in parentheses after group symbol, as A-2-6(3), A-4(5), A-6(12), A-7-5(17), etc
When the combined Group indicies are negative, the Group index should be reported as zero.

* Plasticity index of A-7-5 subgroup is equal to or less than (LL-30). Plasticity index of A-7-6 subgroup is greater than
** When working with A-2-6 and A-2-7 subgroups the Partial Group Index (PGI) is determined from the PI portion only.

Figure 1 AASHTO Flow Chart

Source: Soil Mechanics Level 1 – Module 2 AASHTO USDA Study Guide

ftp://ftp.wcc.nrcs.usda.gov/wntsc/H%26H/training/soilsOther/soil-AASHTO.pdf

Soil group A-3, commonly found in Central Florida, is within the granular materials section of the AASHTO flow chart, see Figure 1. Soils that fall into this section have properties of 35% or less passing the No. 200 sieve. Group A-3 consists of a fine sand material and has an excellent to good general rating as a subgrade. A-2-4 type soil, commonly found in North Florida, is also within the granular materials section of the AASHTO flow chart, see Figure 1 under Group A-2. Compared to A-3, this soil type consists of silty or clayey gravel and sand. This soil type is also consistent with an excellent to good general rating as a subgrade. Limestone is a sedimentary rock type and is frequently found in South Florida. The soil type chosen for this study consisted of a soil with a high percentage of limestone fines within it.

Polyacrylamide (PAM)

Polyacrylamide Structure

Polyacrylamide (PAM) a water soluble long-chain molecule formed by the polymerization of acrylamide (C_3H_5NO). The main industrial application of PAM has been linked with flocculating aqueous particle suspensions (Christian G. Daughton, 1988). Dry powder, logs, aqueous concentrations, or emulsion are the forms of PAM. As the molecular weight increases, the length of the polymer chain and viscosity of the PAM also increases. These characteristics lead to more effective use of the PAM (Scott, 2001). PAM can be manufactured to have three types of charges, namely cationic, anionic and nonionic (Hayes, 2003). Anionic PAM uses cationic bridging to bind with negatively charged soil through the use of divalent cations (Scott, 2001).

Polyacrylamide use on Construction Sites

PAM's use on construction sites range from increasing vegetation establishment, reduction of on and off-site water pollution, and decreased rilling. Research has shown that PAM reduces runoff by more than 30% on steep slopes and reduce sediment yield by more than 50% (Scott, 2001). There are many suggested techniques for optimum use of PAM logs on construction sites. For instance, it is important to prevent the PAM logs from drying out in between storm events (R. A. McLaughlin, 2004).

Environmental Effects of Polyacrylamide

PAM, at low doses is not toxic to humans. However, when manufactured with a cationic charge, PAM has been associated with the binding of fish gills (Hayes, 2003). Additionally, the acrylamide monomer is a possible carcinogen which is readily absorbed through the skin and becomes a neurotoxin (Hayes, 2003).

Erosion Control

Erosion control devices are an affordable method for meeting regulations. Conventional mulching and rolled erosion-control products (RECP) are the two most common engineered forms for reducing erosion on construction sites.

Conventional mulching

Within the sect of conventional mulching, there exists loose mulches, hydraulic mulches, and tackifiers. Loose mulches commonly consist of long strand straw and hay (between 10-20 centimeters in length) which are laid on the ground using a machine applied at a rate of 1.5-2.0 tons/acre (T. L. D. N. Austin, 1994). Once the mulch is laid, crimpers are used to anchor the loose material into the ground. Tackifiers are chosen when the slope increases. Tackifiers are a viscous material sprayed on the loose mulch instead of using the tackifiers to prevent flyways. In contrast to loose mulches, hydraulic mulches are approximately ½ inch in length and are composed of wood, paper pulp, newspaper, or cardboard fibers. The hydraulic mulch materials are sprayed on the ground combined with seed and soil. Due to the absorbing properties of these materials, hydraulic mulches are tackier than loose mulches and are able to stay in place when combined with water (T. L. D. N. Austin, 1994).

Rolled Erosion-Control Products

Rolled erosion-control products consist of mattings such as erosion-control nettings, open weave geotextile meshes, erosion control blankets, and geosynthetic mattings. Open-weave geotextile meshes are useful because its high strength and do not require an underlayer of loose mulch. Erosion control blankets commonly consist of coconut fiber, wood excelsior, or woven natural nettings (T. L. a. D. N. Austin, 1994). This type of matting is useful under gradual to steep slope conditions. Geosynthetic mattings are made from synthetics including polyethylene meshes. Compared to the degradable erosion control blankets, geosynthetics are designed for longer use.

Jute Mat

Jute is a biodegradable erosion control mat designed to keep soil intact to encourage plant growth and collect sediment in ditch check dams.. Jute is 100% natural, undyed, and unbleached and meets DOT specifications. Additionally, it is also used as a soil nutrient while holding seed and soil in place. The lifespan of jute is approximately 1 to 2 years .(Moore, 2011)

Synthetic Blanket

Synthetic blankets are a permanent soil reinforcement mat made of a polypropylene matrix. The mat is typically applied in situations requiring at least 3 years of reinforcement. The netting properties consist of two layers of UV stabilization netting. Typically, this mat is used to protect undergrowth from rain splash associated with runoff, protecting soil from hydraulically induced shear stresses, and encouraging the germination of seed and plant growth (ErosionTech).

Coconut Mat

Coconut blankets consist of a 100% mattress grade coir matrix. The mat is a Type 4-Extended Term erosion control blanket. The top and bottom net are made from heavy duty UV stabilized netting. This is for temporary application, lasting for approximately 36 months. The tight weave of composition leads to an effective method for stabilizing soil (Erosion).

Tested PAM Configuration Method Parameters

An optimized polyacrylamide block configuration was designed for turbidity removal. A hydraulic flume was utilized for the testing of polyacrylamide to optimize mixing energy (Chowdhury, 2011a). Two slopes were chosen on the flume, an 8H:1V and a 16H:1V. Three hydraulic flume configurations were tested for beneficial turbidity removal efficiencies. The Jump Configuration was designed to react with the PAM blocks immediately and settle before exposure to additional blocks. Figure 2 represents the Jump Configuration.

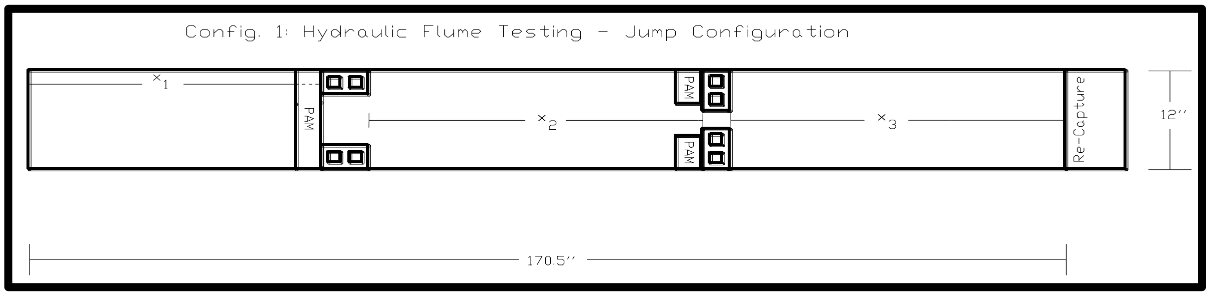


Figure 2 Jump Configuration

The configuration caused a decrease in cross sectional area causing a hike in velocity after the PAM blocks prior to the next phase of PAM blocks (Chowdhury, 2011a).

The Dispersion Configuration was designed to agitate the flow by causing diversions due to the obstructions along the channel.

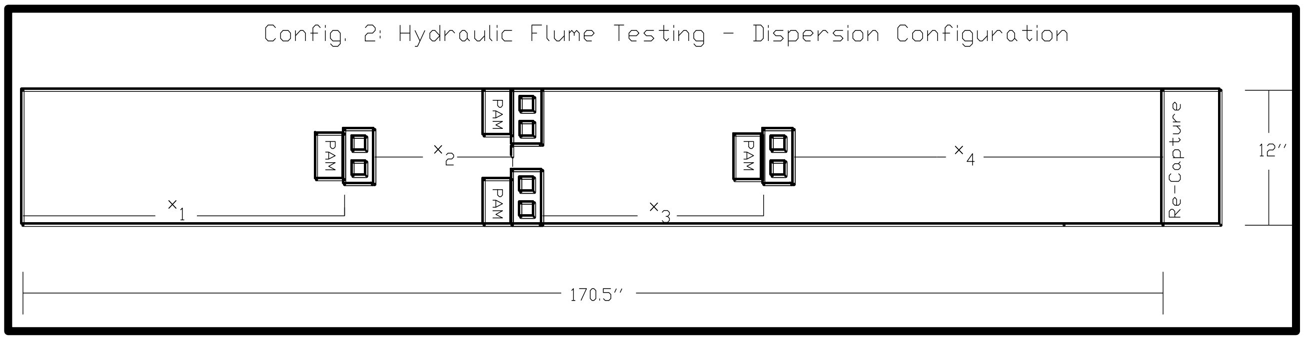


Figure 3 Dispersion Configuration

The result of this configuration caused a surge of flow through the space between the PAM blocks causing full water coverage over the PAM (Chowdhury, 2011a).

The final configuration tested was known as the Staggered Configuration. This configuration involved the use of PAM blocks staggering one another along the flume, shown in Figure 4.

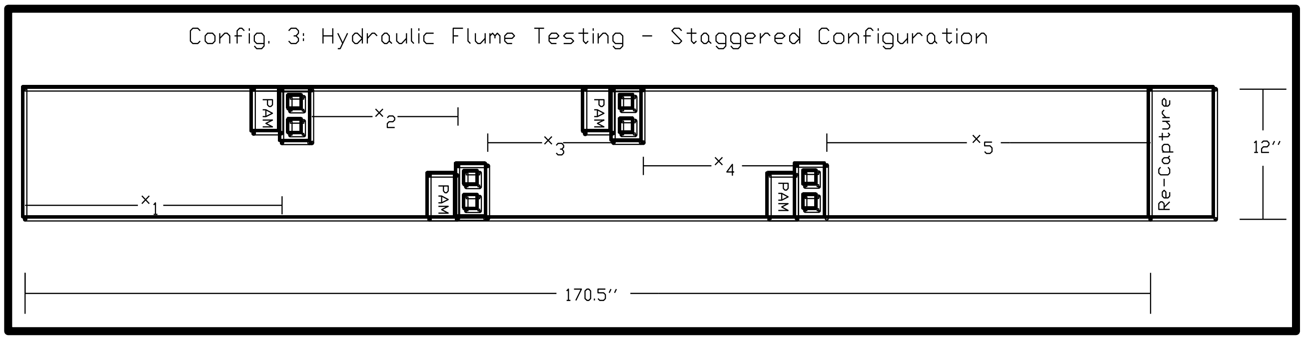


Figure 4 Staggered Configuration

The mixing zone for this configuration varies along the channel, where all of the obstructions are found. The downside of this configuration is the notice of dead zones behind the mason blocks requiring additional maintenance (Chowdhury, 2011a).

Based on the results from the flume study, a final recommendation was made for the use of a 16H:1V slope and the Dispersion Configuration to optimize removal efficiency.

3. METHODOLOGY

This section focuses on the methodology used to conduct research on the use of polyacrylamide (PAM) and collection mats down a channel to remove turbidity from soil laden water. Specifically, this section includes the toxicity consideration, soil sieve analysis, polyacrylamide laboratory scale testing, field scale testing, and post field testing.

Introduction

Research was conducted on the effectiveness of combining erosion control mats in conjunction with a predetermined PAM block configuration, the Dispersion Configuration, determined in 2011 (Chowdhury, 2011b). The testing procedure included three major phases, namely: laboratory-scale testing, field-scale testing, and designing a method to detect PAM concentrations in the effluent stream. Previous research concluded optimal mix speeds and doses for polyacrylamide (Chowdhury, 2011b). Jar tests were conducted using recommendations by Applied Polymers Inc. and confirmed by research. Field scale testing were conducted using PAM blocks in conjunction with three different rolled erosion mats with turbid water created using three soil types prevalent in Florida: sand, silty sand and crushed limestone for the evaluation of turbidity removal efficiency.

Toxicity consideration

In 2010 a 7-day chronic toxicity test, in accordance with EPA-821-R-02-13, and a 86-hour acute toxicity test, in accordance with EPA-821-R-012, were run on the APS 708X Floc Logs. Results from the chronic test indicated a LC25 (Lethal Concentration) was 97.47 ppm for water flea survival and the IC25 (Inhibition Concentration) was 6.3 ppm for water flea reproduction. When the chronic test was conducted with fathead minnows, the LC25 was 1710 ppm for survival and the IC25 was 2366 ppm (Dickens, 2010b). The results from the acute toxicity test on the water flea concluded the LC50 was >840 ppm for water flea survival and >3360 ppm for survival when tested on the rainbow trout (Dickens, 2010a). Since the PAM does have toxic properties in high does, discovering whether or not PAM was found in the channel's effluent seemed pertinent.

Sieve analysis

Prior to the laboratory and field scale testing, sieve analyses were conducted on the three soil types: AASHTO type A-3 and A-2-4, and crushed limestone. The purpose of the sieve analysis was to breakdown the size makeup of the aggregate particles from largest to smallest resulting in a gradation curve (WSDOT, 2013). Before the test began, the soil sample of approximately 500 g was oven dried in accordance with field operating procedures (FOP) to the nearest 0.1 percent of the total sample mass. The soil sample was weighed after it has been oven dried and recorded. The sieves were then each weighed separately and recorded. Next, each sieve was nested from greatest to smallest, with the soil sample placed in the first sieve (largest), starting with sieve number 4 (opening size 4.750 mm) down to sieve number 200 (opening size of 0.075 mm). The nested sieves were then placed in the mechanical shaker and shook for a minimum of 10 minutes. The sieves were then carefully separated and the mass of the sieve plus the retained soil was measured. Once the measurements were made, calculations were conducted to find the percent retained or the percent passing. Percent retained can be calculated via the following equation:

$$CPR = \frac{CMR}{M} * 100 \tag{3-1}$$

Where: CPR = Cumulative Percent Retained; M = Total Dry Sample mass before washing; IMR = Individual Mass Retained OR Adjusted Individual mass; CMR = Cumulative Mass Retained or Adjusted Individual mass.

Polyacrylamide Laboratory-Scale Testing

Applied Polymers and the Stormwater Management Academy laboratory at the University of Central Florida performed index testing on polymer dosage based on soil types and reaction times. In 2011 index testing was conducted at the Stormwater Management Academy to understand the how polymer dosage related to effectiveness dependent upon soil specificity, reaction time, and other variables (Chowdhury, 2011b). Through the use of jar testing, the optimal mixing speed was calculated to be 2.6 ft/s for a 30-second mixing time, which resulted in a removal efficiency of 85% to 90% (Chowdhury, 2011b). Additionally, the polymer APS 706b was concluded to be the most effective type to reduce turbidity in A-2-4 and A-3 soil. After a few months into testing, Applied Polymer Systems (APS) released new polymers which claimed to be more effective at reducing turbidity concentrations in the various soil types considered. The Stormwater Lab sent samples of ASHTOO type A-2-4, A-3, and crushed limestone to the APS laboratory. The results are shown in

Table 1 Applied Polymer Systems Polyacrylamide Types

Parameters	A-2-4 Soil	A-3	Crushed Limestone
pH	6.8	5.93	6.23
Hardness (PPM as CaCO3)	25	50	120
Polyacrylamide	APS 708x	APS 708x	APS 708x + APS 703d
Reaction Time (seconds)	30	30	30

Using the results from APS, adjustments were made in the research and APS 708x was used for A-2-4 and A-3 and APS 708x with 703d was used for the crushed limestone samples.

Hydraulic Principles for Channel Configuration

In 2011, the Stormwater Management Academy developed a spreadsheet in Microsoft Excel to quantify various parameters of open channel flow using the Manning Formula. Manning's formula is commonly used open channels with uniform flow for producing a flow rate in cubic feet per second, Q. The Manning formula is below.

$$Q\ (cfs) = \frac{1.486}{n} A R_h^{\frac{2}{3}} S_0^{\frac{1}{2}} \tag{3-2}$$

n = roughness coefficient; A = cross sectional area of the flowing fluid; R_h = Hydraulic radius = A wetted perimeter; S_0 = Slope

Additionally, the flow rate was based on Florida Department of Environmental Protection (FDEP) standards. When 10 or more acres of land are disturbed, the FDEP requires that there is a detention basin of at least 3,600 ft^3 on site. However, regulations also require the water be treated within 72 hours of containment. With a typical storm averaging 3 inches of water throughout the site, calculations were determined in previous work, as shown below.

$$1\ acre = 43{,}560\ ft.^2 \tag{3-3}$$

$$0.25\ ft.\, x \left(10\ acres\ x\ \frac{43{,}560\ ft.^2}{acre}\right) = 108{,}900\ ft.^3 \tag{3-4}$$

$$Q = \frac{108{,}900\ ft.^3}{72\ hours}\ x\ \frac{1\ hour}{3{,}600\ seconds} = \mathbf{0.42\ ft.^3/sec} \tag{3-5}$$

The resulting flow of 0.42 ft^3/s was used as a base to ensure the slope was calculated to optimize a mixing speed within the channel.

Field Scale Testing

Once the laboratory-scale testing was completed, the data collected was used to design and create a channel for field-scale testing. A test matrix was produced to organize the test schedule. Turbid water was created with these soil types: A-3, A-2-4, and crushed limestone due to their prevalence in Florida. The soil types and the PAM Dispersion Configuration were used as controls to analyze different types of matting and the mat lengths. Three rolled matting materials were chosen, jute mat, coconut fiber, and synthetic. The mat lengths analyzed were 10 and 20 feet. Figure 5 is a visual for the testing sequence.

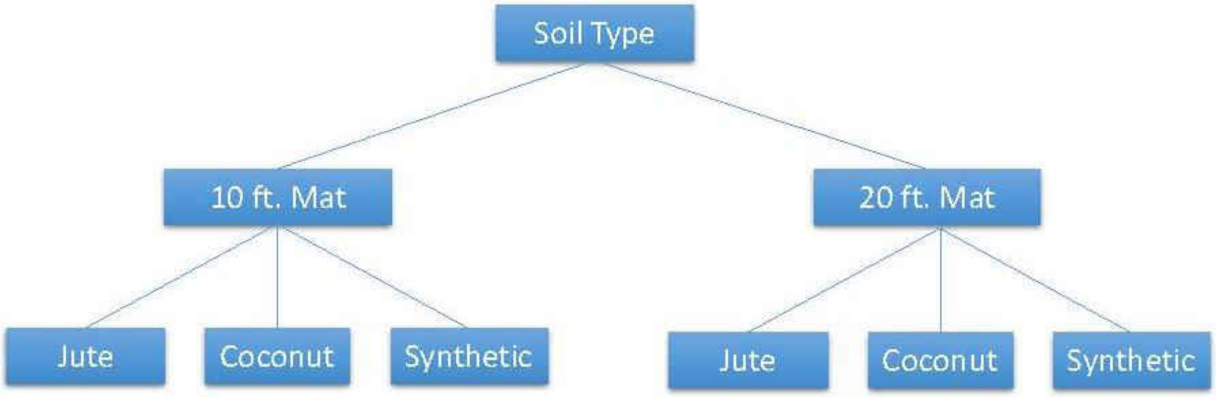


Figure 5 Field-Scale Testing Matrix

For each test, a soil type was chosen as well as a mat type and length. For example, a test would comprise an A-3 (sandy) soil, 10-foot. mat length and jute mat type. The test combination was repeated to have duplicate results to ensure consistency in testing procedure. Therefore, a total of 36 tests were conducted.

Channel setup

Previous research indicated that a slope of 16:1 was concluded to have the best results relating to flow and turbidity removal (Chowdhury, 2011b). A channel was created using this slope by dredging into the ground. The length of the channel was approximately 50 feet. Once the channel was constructed, two coverings were laid, a black mesh tarp and a clear Visquene tarp, as shown in Figure 6.

Figure 6 Channel Setup Prior to Smoothing Tarp

During the summer months, the Visquene tarp acted like a greenhouse causing undergrowth underneath of the tarp. To mitigate this problem, a black mesh tarp was laid prior to laying down the Visquene. Special care was taken to smooth out the tarps to prevent any folds, shown in Figure 6, or tears in the material. The tarps were secured by burying the ends into the soil and placing bricks on top to avoid erosion.

Setup Procedures

Before beginning a test, the weather forecast was initially checked to determine the feasibility of running the test. Once it was assured that it would not rain during a test, the test site was setup for testing. It was especially critical to inspect the Visquene for tears and the pumps inside the smaller testing cistern. Next, the water source (hose) was turned on to fill a 1,500-gallon cistern with water. As the cistern was filled, the channel was cleaned out with water and any large objects outside of the testing area were relocated away from the test site.

Nine PAM blocks and 9 five-gallon buckets were gathered. The PAM blocks were placed inside each of the five-gallon buckets which were then filled with water until the PAM blocks were fully submerged in the water in order to keep the PAM moist. The PAM blocks were submerged for 15 minutes or until the test began. The PAM blocks are shown soaking in Figure 7.

Figure 7 Soaking PAM Blocks

Next, the following apparatus were prepared for testing: turbidimeter, velocity probe, stopwatch, sampling sticks, extension cords, PAM testing folder, measurement-bridge, and sample bottle sets.

Two five-gallon buckets were used to fetch A-3, A-2-4, or crushed limestone and poured into the small cistern until the turbidity ranged between 300-500 NTU. The cinder blocks were placed in their designated spot, marked by a red dot on the channel bed(45 in. lengths).

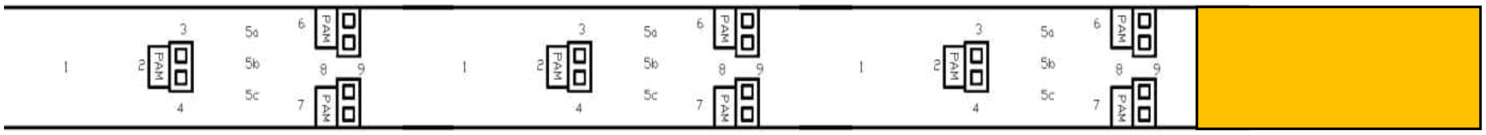


Figure 8 PAM and Cinder Block Configuration

The chosen erosion control mat was placed at the end of the channel, 45 in. after the last set of blocks and secured with 10 bricks to hold it in position. Lastly, the hydrated PAM blocks were placed in front of the cinder blocks, wrapping the excess rope around its representative cinder block and tucking its end under it.

Field Test Procedures

Before the field test was started, the testing responsibilities were reviewed to ensure all equipment and materials were properly working and prepared for testing. The stop watch was turned on and the water depth of the channel and velocity of the stream was measured as shown in Figure 9.

Figure 9 Measuring Water Depth of Channel and Velocity

At every two-minute time mark, starting from minute 0:00 the first grab samples were collected at minute 2:00 along the channel length and the last samples were collected at minute 16:00. Figure 10 shows the sampling process.

Figure 10 Sampling Procedure with Measurement Bridge

Velocity measurements and water samples were taken pre and post erosion control mat to analyze how the energy changed due to the mat’s roughness and to define the turbidity removal properties of the mats, respectively. Figure 11 Erosion Control Mat displays the sampling locations for the mats.

Figure 11 Erosion Control Mat

Post Field Testing

The purpose of this research was to develop a procedure that reduced the turbidity in effluent stormwater in order to meet regulatory requirement for construction site discharges. The turbidity tests measure the clarity of the water, caused by total suspended and dissolved solids. Therefore a procedure was developed to measure turbidity using a turbidimeter. Additionally, due to the concern relating to high concentrations of PAM causing toxicity, it was pertinent to determine whether or not it existed in the effluent water.

Turbidity Testing

Laboratory turbidity tests on the samples were conducted using the Nepholometry method, EPA Method 180.1. Temperature changes can affect the particles by possibly creating precipitates, therefore it was critical to take turbidity readings shortly after sampling (EPA, 1999). In order to avoid these errors, a standard operating procedure was set to ensure the turbidity was read within 48 hours of sampling. Three methods for running turbidity were established, a filtration method, a 30 second settled sample, and a grab sample.

Each test began by remixing the sample using a stir plate. The sample bottle was placed on a stir plate with a stir rod inside. The samples were mixed until mostly homogenous, which was found to take about 45 seconds. The first method included the use of a filter. While the sample was still on the mixer, 20 mL of the sample was ciphered and released onto a filter and was gravity pushed through. The filter was used to simulate a field collection mat in a lab setting. The resulting water was then ciphered into a turbidity sample bottle and read in the turbidimeter. The next method involved testing a grab sample of the mostly homogenous mixture. While the sample was still in the process of mixing, 10mL of the sample was ciphered and released into the turbidity sample bottles. The turbiditmeter tested the sample and the results were then recorded. The last method involved settling the homogenous mixture for 30 seconds prior to reading the turbidity. After testing the sample, the beaker is removed from the stir plate and laid to rest for a timed 30 seconds. After the sample rested, 10mL of sample is ciphered from the top half of the beaker, released into the turbidity sample bottle, and tested again using the turbiditmeter.

4. RESULTS

This section focuses on the results from the field scale testing. The results from the AASHTO A-3 type soil, AASHTO A-2-4 type soil, and the crushed limestone type soil were each separately analyzed in order to conclude optimal mat type and length combinations per soil type.

Rolled Erosion Control Devices

Three erosion control devices were chosen for this research, biodegradable Jute Erosion Control Matting (jute mat), ETPP-10 Class 5B permanent soil reinforcement mat (synthetic mat), and ETC-100 100% Coconut Class 4 (coconut mat). Jute mat is a loosely woven unbleached/undyed jute yarn. The synthetic mat is a permanent turf reinforcement mat consisting of a poly-propylene matrix. Coconut mat consists of tightly woven 100% mattress grade coir fiber. The detail sheets for the products can be found in the Appendix. These mats were cut at two different lengths, 10-foot and 20-foot and duplicates were run on them to ensure repeatability. The mats were placed 45 in. after the last set of PAM blocks in order to capture the flocs in the effluent prior to release into the environment.

Repeatable ANOVA tests and the Wilcoxon Rank Test ($\alpha=0.05$) were used to analyze the results of the data. Results showed that since the initial turbidity fluctuated between 300-500 NTUs the ANOVA results showed that the turbidity values could not be repeatable. However, when the ANOVA test analyzed the removal efficiency on the duplicated tests, the results showed that it the capability of the mat to reduce turbidity can be repeated. The Wilcoxon Rank Test resulted in similar results. The analysis showed that the turbidity on the effluent and influent were not the same and the effluent NTU ranked value was less than the influent ranked value.

AASHTO A-3 Type Soil

Polyacrylamide Influence

The first part of the analysis involved analyzing the average turbidity of the samples collected at the influent (A) and the end of the PAM configuration (D), shown in Figure 12.

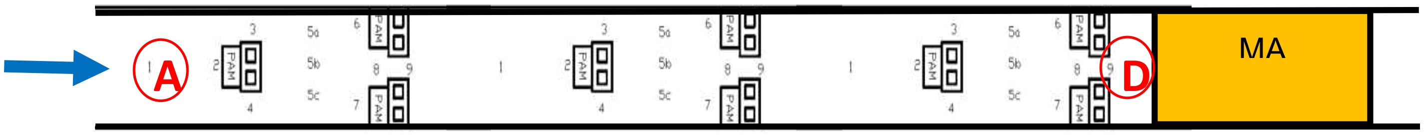


Figure 12 A-3 Soil Channel Configuration – PAM Sample Location

AASHTO A-3 type soil, granular fine sand, was coagulated using APS 708X PAM prior to mat treatment. The PAM configuration showed an average removal efficiency of 71% to 42.5% over 14 minutes of testing.. The results were analyzed using the initial turbidity NTU and the final NTU prior to the mat at location D, shown in Equation (4-1).

$$\frac{X_i - X_f}{X_f} * 100 = Removal\ Efficiency \qquad (4\text{-}1)$$

X_i = influent mat turbidity; X_f = effluent mat turbidity

Table 2 Average PAM Removal Efficiency with A-3 Soil

Time	Average Removal	Standard Deviation
2 min	71%	14%
4 min	54%	29%
6 min	51%	26%
8 min	48%	23%
10 min	48%	26%
12 min	46%	27%
14 min	44%	25%

The results indicate that the PAM blocks degrade over the course of time. Each PAM block was used for four tests. The results indicate that once the test is over and the PAM blocks are stored in plastic wrap the efficiency of its reuse is similar to its previous use. This would imply that during a long rainstorm the block may lose its effectiveness but before the next storm it should work at its original efficiency again.

The average turbidity results of the 30-second settled and the completely mixed samples were compared to one another. The settled samples showed a significant increase in removal efficiency compared to the completely mixed sample, shown in Figure 13.

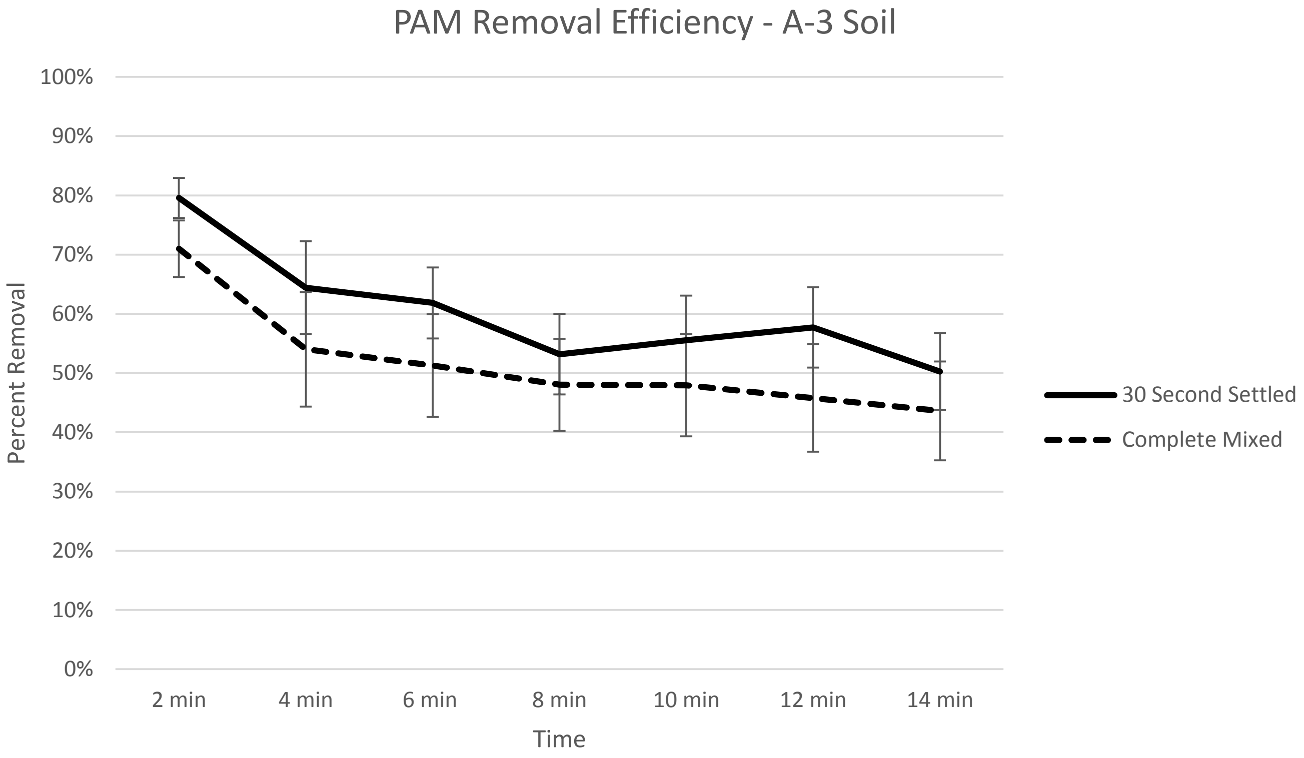


Figure 13 PAM Removal Efficiency A-3 Soil 30 Second Settle vs. Complete Mix

The results indicate that the use of a settling pond would be useful in removing additional turbidity. Additionally, these results also indicate that the standard deviation of the PAM samples before the collection mat may be high due to the quantity of particles that are still floating in the sample which could have been settled out due to a settling area.

Coconut Mat

After the PAM train, the coconut mat's influent and effluent water samples were analyzed for additional removal efficiency. The samples analyzed were at location (D) and location (E), shown in Figure 14.

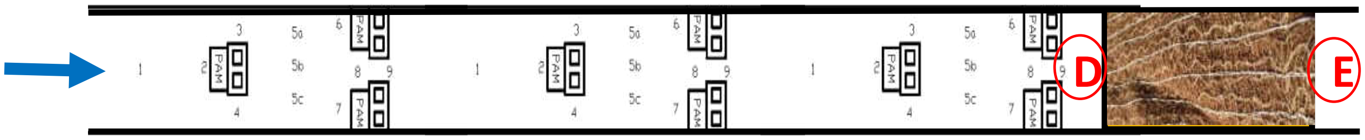


Figure 14 A-3 Soil Coconut Mat Sample Locations

Results from the tests show high removal efficiencies using 20 feet of coconut mat, a visual for the mat after the test can be shown in Figure 15.

Figure 15 A-3 Soil Coconut Mat

The wetted mat shows the flow of the water and where the sediment collected as it traveled downstream. A high volume of water was indicated on the upstream point where the water began to travel underneath the mat. This problem was mitigated by applying pressure and a small amount of hose water to the mat prior to the start of the test.

The results shown in Table 3 represent the average turbidity values gathered from the 10-foot coconut mat tests. The trend displayed shows a high removal efficiency from the PAM channel influent (A) to the PAM effluent (D). The turbidity continued to decrease once the mat was placed along the channel. However, it must be noted at the average turbidity removal began to decrease as the course of the test progressed.

Table 3 A-3 Soil Coconut 10-foot Mat Average Turbidity Results

Time	A (NTU)	D (NTU)	E (NTU)
2 min	521	147	87
4 min	408	262	91
6 min	391	210	83
8 min	354	237	102
10 min	327	200	130
12 min	264	189	113
14 min	268	188	125

Table 4 represents the average turbidity values gathered during the 20-foot coconut mat tests. These results show a trend of decreased turbidity over time and down the channel. The 20-foot mat showed a higher removal efficiency compared to the 10-foot mat, with average turbidity values averaging below 20 NTUs.

Table 4 A-3 Soil Coconut 20-foot Mat Average Turbidity Results

Time	A (NTU)	D (NTU)	E (NTU)
2 min	368	125	19
4 min	241	97	13
6 min	229	161	14
8 min	208	128	11
10 min	201	90	8
12 min	163	75	9
14 min	207	132	12

Unlike the other matting materials, the coconut fiber did not clog as quickly and resulted in a steady removal efficiency around 90%, as shown in Figure 16.

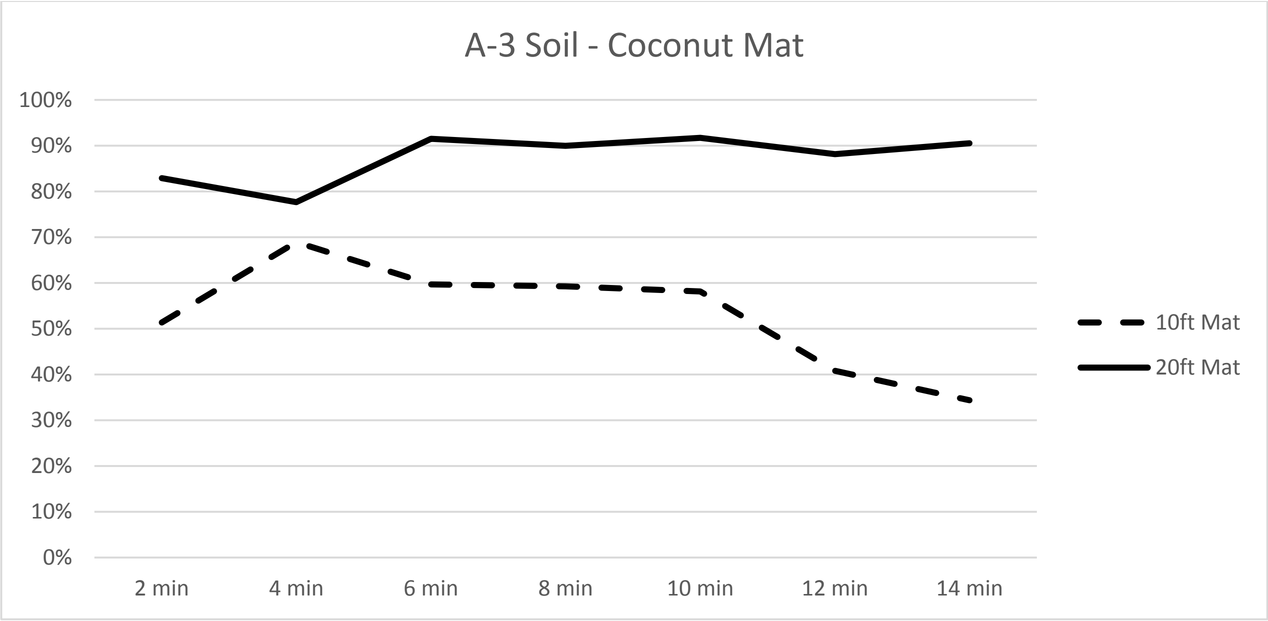


Figure 16 A-3 Soil – Coconut Mat Removal Efficiency

Figure 16 shows the removal efficiency trend of the coconut mat over time. The results show a lower removal efficiency using the 10-foot mat, the dotted line, which may be associated with clogging due to the shorter length. Fortunately the 20-foot mat, solid line, does not show signs of wear and tear as the test time progressed, however this does not mean that it will not clog.

Synthetic Mat

The synthetic mat showed inconsistent results compared to the coconut mat. Due to the plastic matrix of this material, the slippery coagulated soil did not bind as easily with this material. The samples analyzed were at location (D) and location (E), Figure 17.

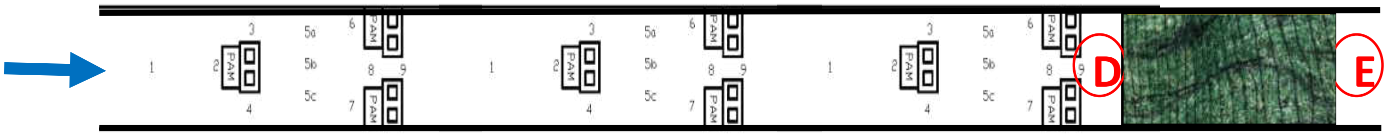


Figure 17 A-3 Soil Synthetic Mat Sample Locations

Results from the tests show lower removal efficiencies than the coconut mat, a visual for the 10-foot synthetic mat after the test can be shown in Figure 18.

Figure 18 A-3 Soil Synthetic Mat

In addition to the low friction make up of this mat, the material did not stay in place as easily and folds and creases formed in the mat during the test. Evidence does suggest that the synthetic mat does successfully remove turbidity, but not as effectively as the coconut mat system

The results shown in Table 5 represent the average turbidity values gathered from the 10-foot synthetic mat tests. The trend displayed shows a high removal efficiency from the PAM channel influent (A) to the PAM effluent (D). The turbidity continued to decrease once the mat was placed along the channel.

Table 5 A-3 Soil Synthetic 10-foot Mat Average Turbidity Results

Time	A (NTU)	D (NTU)	E (NTU)
2 min	577	149	94
4 min	320	161	75
6 min	315	173	97
8 min	311	175	93
10 min	311	186	98
12 min	305	185	96
14 min	299	180	94
16 min	289	201	109
18 min	275	187	96

Table 6 represents the average turbidity values gathered during the 20-foot synthetic mat tests. These results show a trend of decreased turbidity over time and down the channel. The 20-foot mat showed a higher removal efficiency compared to the 10-foot mat, however, these values varied more significantly than the 10-foot synthetic mat results.

Table 6 A-3 Soil Synthetic 20-foot Mat Average Turbidity Results

Time	A (NTU)	D (NTU)	E (NTU)
2 min	257	79	25
4 min	120	94	37
6 min	247	122	55
8 min	208	145	38
10 min	238	179	95
12 min	183	167	70
14 min	209	153	56
16 min	198	196	45
18 min	197	161	71

Figure 19 shows the results from Table 5 and Table 6 converted into a percent removal and graphed over time.

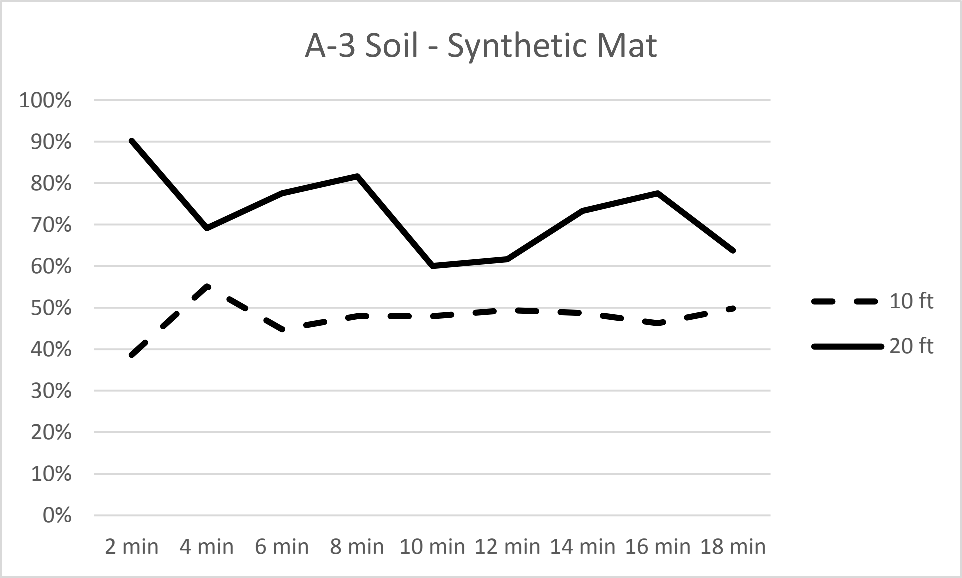


Figure 19 A-3 Soil – Synthetic Mat Removal Efficiency

Although the 10-foot mat, Figure 19, shows a consistent removal efficiency throughout the course of the test, the 20-foot mat, is less consistent. These results may be due to coagulated soil and PAM may have dislodged from the mat and ended up in the effluent stream.

Jute Mat

The jute mat showed inconsistent results compared to the coconut mat. Due to the loose weave of this material, the coagulated soil did not bind as easily with this material. The samples analyzed were at location (D) and location (E), shown in Figure 20.

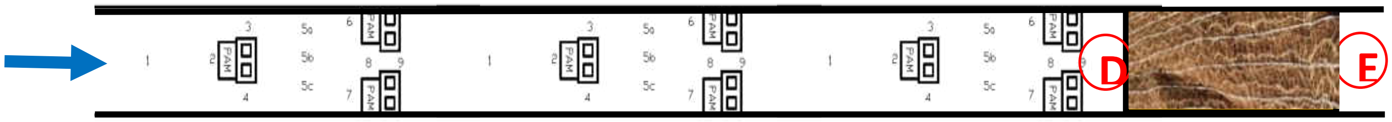


Figure 20 A-3 Soil Coconut Mat Sample Locations

Figure 21 shows the 10-foot jute mat prior to testing, and before the bricks were placed to secure it.

Figure 21 A-3 Soil - Jute Mat

The results shown in Table 7 and Table 5 represent the average turbidity values gathered from the 10-foot jute mat tests. The trend displayed shows a high removal efficiency from the PAM channel influent (A) to the PAM effluent (D). The turbidity continued to decrease once the mat was placed along the channel.

Table 7 A-3 Soil Jute 10-foot Mat Average Turbidity Results

Time	A (NTU)	D (NTU)	E (NTU)
2 min	281	48	32
4 min	261	89	50
6 min	265	50	29
8 min	252	68	14
10 min	213	94	28
12 min	227	127	69
14 min	232	63	36

Table 8 represents the average turbidity values gathered during the 20-foot jute mat tests. These results show a trend of decreased turbidity over time and down the channel. The 20-foot mat showed a higher removal efficiency compared to the 10-foot mat, although both results were very similar.

Table 8A-3 Soil Jute 20-foot Mat Average Turbidity Results

	A-3 Jute 20 -foot		
Time	**A (NTU)**	**D (NTU)**	**E (NTU)**
2 min	220	45	42
4 min	200	77	5
6 min	227	73	5
8 min	232	104	7
10 min	209	67	13
12 min	211	39	12
14 min	202	86	32

Results from the jute mat show consistent results compared to the other mats. Figure 22, showed a comparison between the 10-foot mat (dotted line) and the 20-foot mat (solid line).

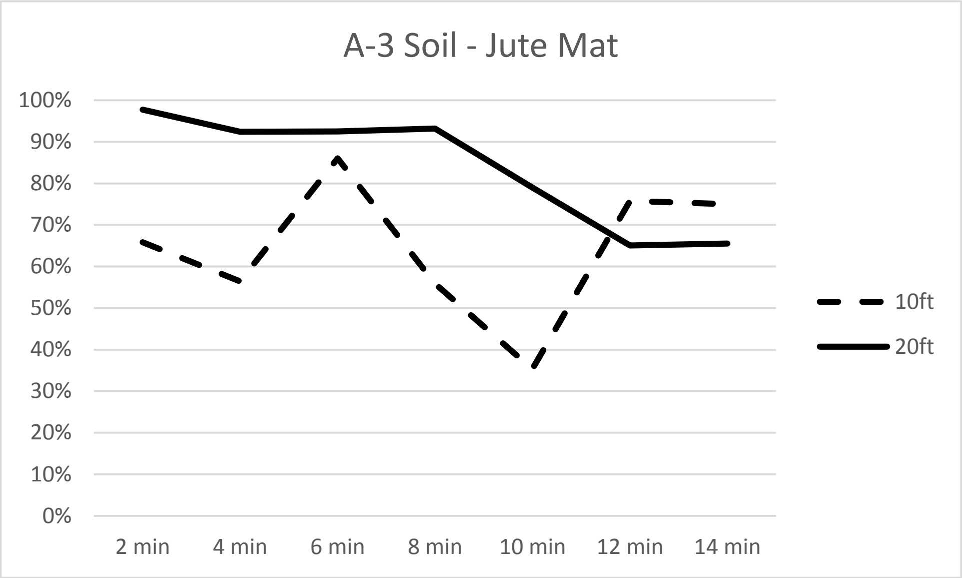


Figure 22 A-3 Soil – Jute Mat Removal Efficiency

20-foot mat results showed a consistent turbidity until half way through the test, when the removal efficiency dropped indicating the mat began to clog.. The 10-foot mat results, indicated mat clogging also. Although the final removal efficiency was around 70%, the dip after 8 minutes may be a warning that it may have already reached its carrying capacity.

Comparison

Each mat material length with the highest removal efficiency was compared to one another using Figure 23. The highest removal efficiency for A-3 soils was shown in each of the 20-foot mats.

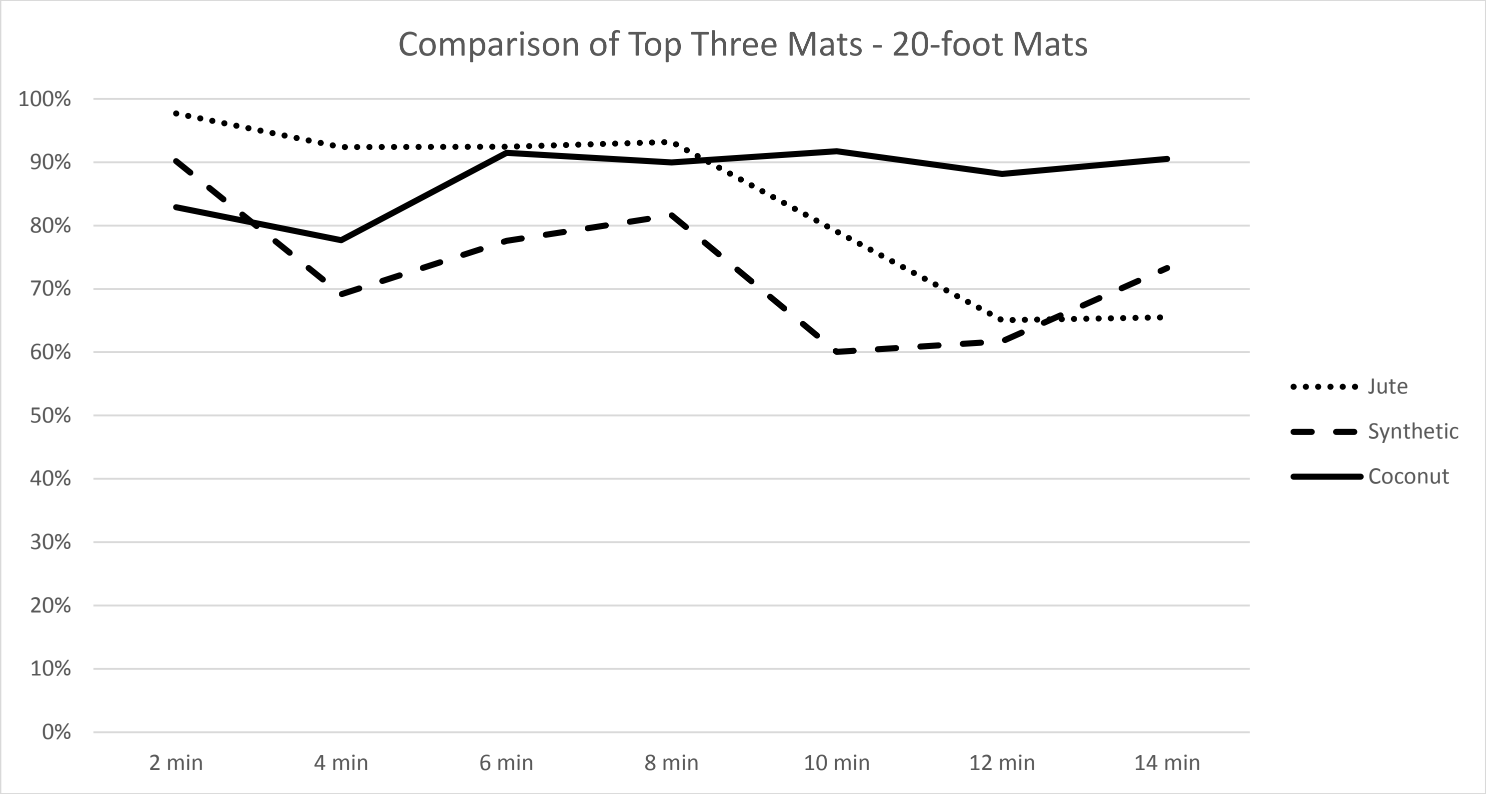


Figure 23 Comparison of Top Three Mats

Although the removal efficiency for the 20-foot coconut mat starts lower than the other two mats, it can be concluded that it would be the best choice due to its steady behavior has the tests progressed over time.

AASHTO A-2-4 Type Soil

Polyacrylamide Influence

The first part of the analysis involved analyzing the average turbidity of the samples collected at the influent (A) and the end of the PAM configuration (D), shown in Figure 24.

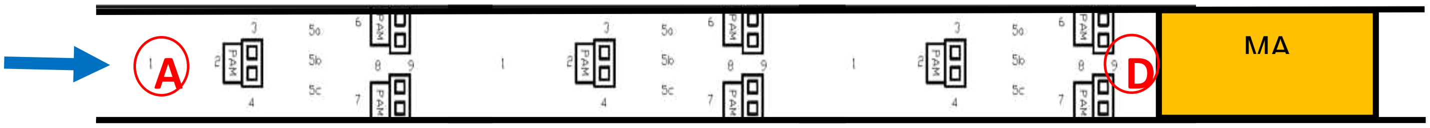


Figure 24 A-2-4 Soil Channel Configuration – PAM Sample Location

AASHTO A-2-4 a granular clayey sand was sieve tested to ensure soil type. While it had a clay content, there was no plastic limit. This soil was coagulated using APS 708x PAM prior to mat treatment. The PAM configuration showed an average removal efficiency of 65% to 50% over 14 minutes of testing. The results were taken using the initial turbidity NTU and the final NTU prior to the mat location at D, immediately before the mat.

Table 9 Average PAM Removal Efficiency with A-2-4 Soil

Time	**Average Removal**	**Standard Deviation**
2 min	65%	24%
4 min	50%	28%
6 min	55%	28%
8 min	50%	25%
10 min	49%	30%
12 min	49%	31%
14 min	50%	18%

The A-2-4 soil coagulates in large flocs causing lower mat efficiency than the A-3 type soil. Due to this reason, the highest average removal efficiency was around 60-70%. These results show that the mats may require a faster replacement time than when the A-3 type soil is applied.

The average turbidity results of the 30 second settled and the completely mixed samples were compared to one another. The settled samples did not show a significant increase in removal efficiency compared to the completely mixed sample, shown in Figure 25.

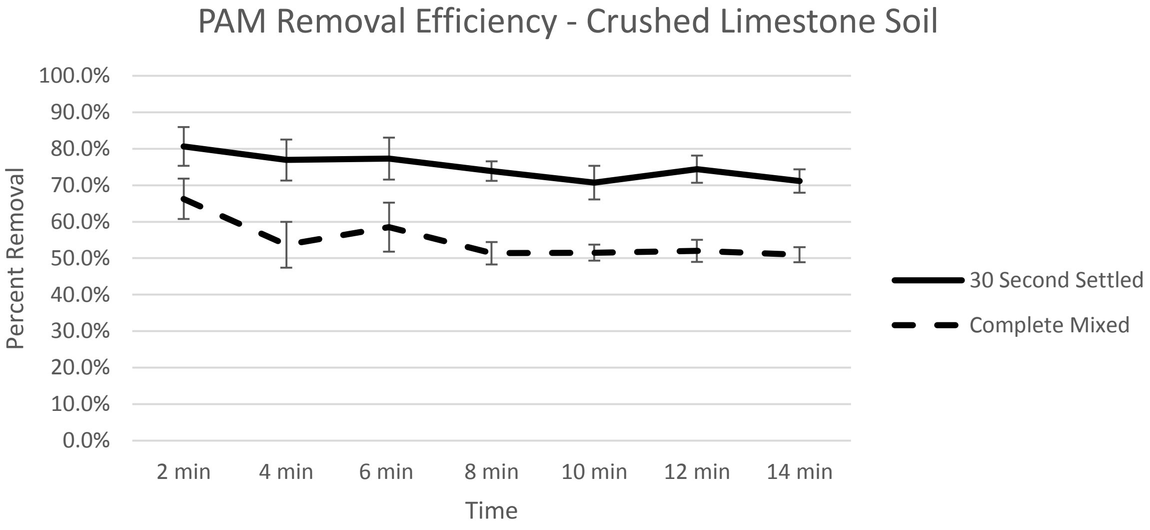


Figure 25 PAM Removal Efficiency A-2-4 Soil 30 Second Settle vs. Complete Mix

The data results indicate that the A-2-4 fines are so small that it would take longer for them to settle compared to the A-3 soil fines.

Coconut Mat

The coconut mat results were had a fairly consistent clogging trend over time. The samples analyzed were at location (D) and location (E), shown in Figure 26.

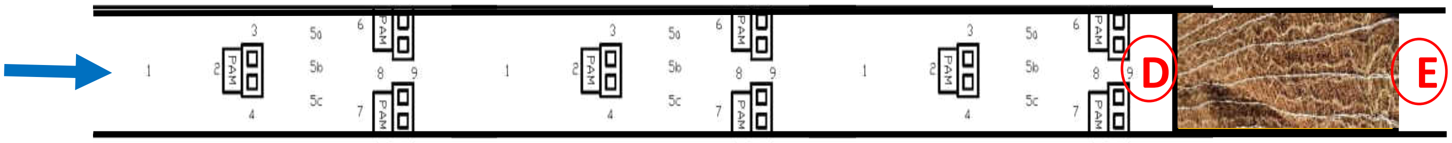


Figure 26 A-2-4 Soil Coconut Mat Sample Locations

Figure 27 shows the 20-foot coconut mat in use during a test. The flow sticks to a strict pattern over the mat which may be an indicator for future wear marks on the mat. Flipping the mat over may help to prevent uneven wear on the mats.

Figure 27 A-2-4 Coconut Mat

Due to the makeup of this mat, the tight mesh of fabric encouraged the A-2-4 fines to bond with the material. Table 10 and Table 11 present the raw averaged turbidity data compiled from the field tests.

Table 10 A-2-4 Coconut 10-foot Mat Average Turbidity Results

Time	A (NTU)	D (NTU)	E (NTU)
2 min	602	361	76
4 min	550	492	143
6 min	566	515	207
8 min	523	493	255
10 min	553	495	298
12 min	465	457	314
14 min	471	392	319

The results show that as time progresses the efficiency of the PAM blocks and the coconut mat decreases. This could be the result of mat clogging as the test progressed.

Table 11 A-2-4 Coconut 20-foot Mat Average Turbidity Results

Time	A (NTU)	D (NTU)	E (NTU)
2 min	528	202	33
4 min	506	334	53
6 min	505	413	97
8 min	490	541	117
10 min	487	378	127
12 min	455	332	198
14 min	413	360	162
16 min	413	318	138

The results show that the 20-foot mat successfully reduced turbidity in conjunction with the PAM. Similar to the 10-foot mat the removal efficiency drastically decreases over time. Figure 28, showed a very consistent clogging pattern of the two coconut mat lengths over time.

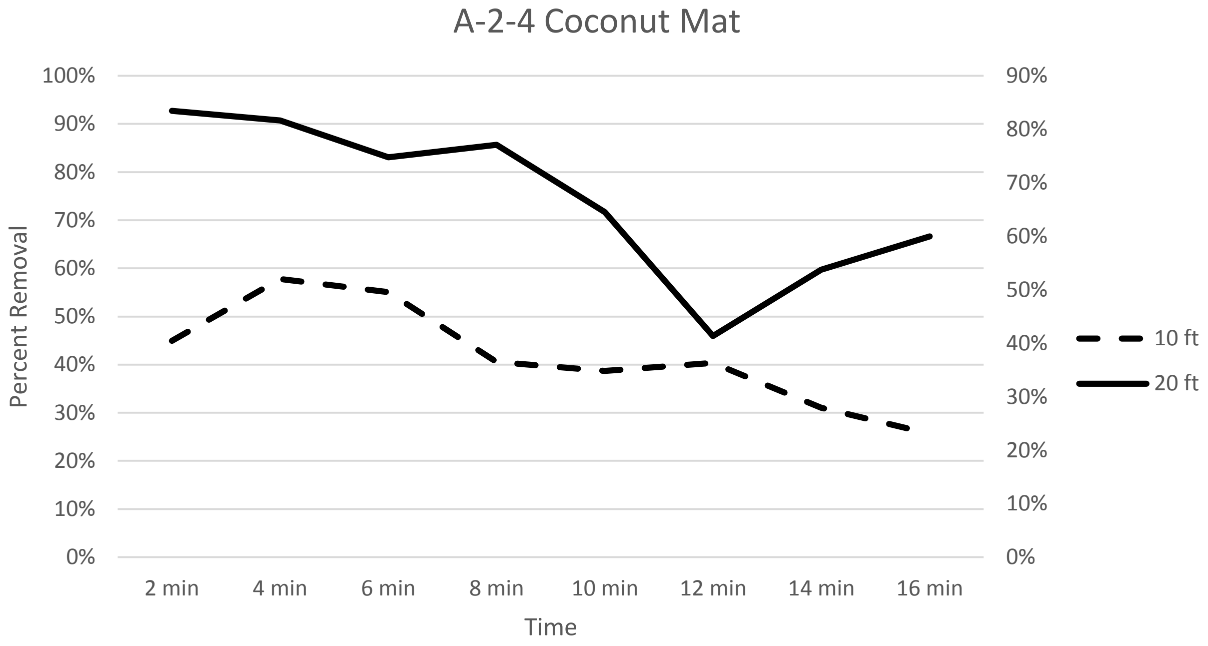


Figure 28 A-2-4 Soil – Coconut Mat Removal Efficiency

When the removal efficiency from the average turbidity of the mat influent and effluent were calculated, results showed that the 10-foot mat, the dotted line, did not efficiently remove the sediment. Since the removal efficiency began around 50% it can be assumed that the mat clogged very early in the test. The 20-foot coconut mat, the solid line, also clogged but at a slower rate. The dip at 8 minutes may mean that the mat has reached full capacity.

Synthetic Mat

The fabric of the synthetic material has not shown as successful removal efficiency results as the other materials. The samples analyzed were at location (D) and location (E), Figure 29.

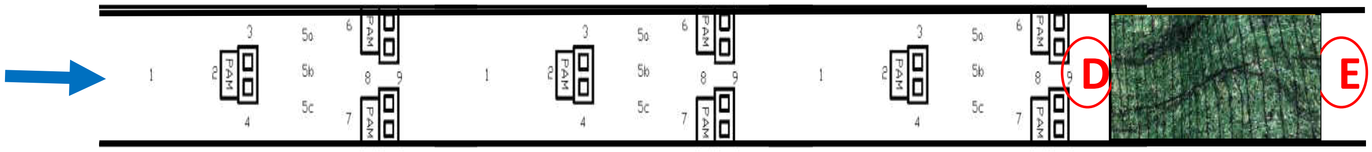


Figure 29 A-2-4 Soil Synthetic Mat Sample Locations

The advantages of this material is that it is more durable and can be cleaned and reused unlike the biodegradable materials. Figure 30 shows the 10- foot synthetic mat prior to testing.

Figure 30 A-2-4 Soil Synthetic Mat

Table 12The results present the averaged turbidity results from the sampled water taken every 2-minute interval during the course of the test. The samples analyzed included pre channel water (A), post PAM configuration (D) and after the mat (E).

Table 12 A-2-4 Synthetic 10-foot Mat Average Turbidity Results

Time	A (NTU)	D (NTU)	E (NTU)
2 min	335	114	39
6 min	293	158	58
8 min	282	155	67
10 min	268	160	72
12 min	271	120	55
14 min	242	139	60
16 min	241	134	82

The results noted very positive results compared to its use on A-3 soil. The final turbidity is low compared to the influent and the wear and tear is not as high as the coconut mat.

Table 13 Synthetic 20-foot Mat Average Turbidity Results

Time	A (NTU)	D (NTU)	E (NTU)
2 min	843	483	433
4 min	794	391	384
6 min	774	447	378
8 min	762	471	402
10 min	755	476	399
12 min	731	440	401
14 min	594	395	308
16 min	513	336	244

The synthetic mat results were lower than the results in the 10-foot mat, dotted line, opposed to the 20-foot mat, solid line, shown in Figure 31.

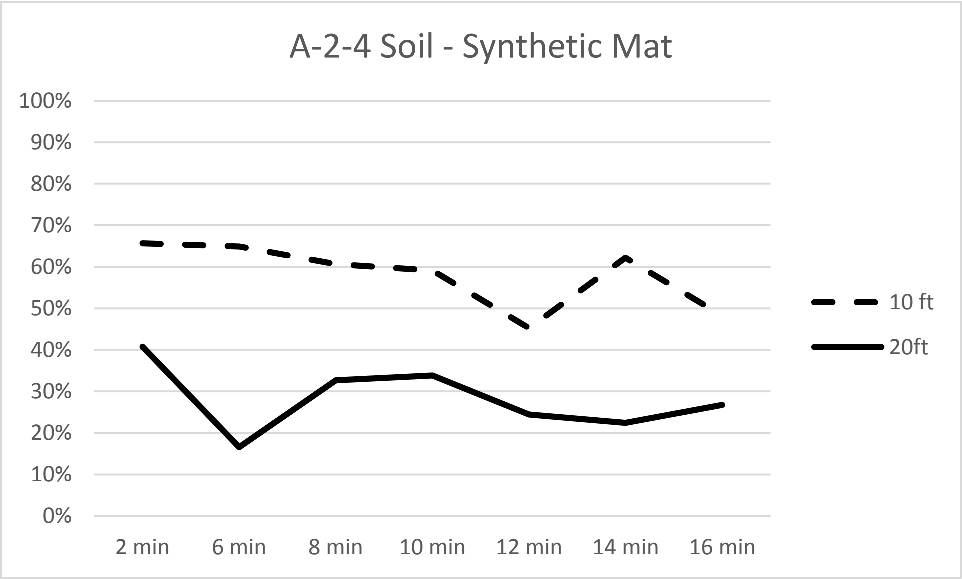


Figure 31 A-2-4 Soil – Synthetic Mat Removal Efficiency

The likelihood of this material working productively is not high may be due to the plastic consistency of the synthetic mat. Using this mat is not recommended due to the low removal efficiency. Additionally, insignificant data was gathered at the 2 minute mark concluding why this value was skipped on the graph.

Jute Mat

Similar to the results shown in the A-3 soil type, the jute mat showed signs of clogging very early in the tests. The samples analyzed were at location (D) and location (E), shown in Figure 32.

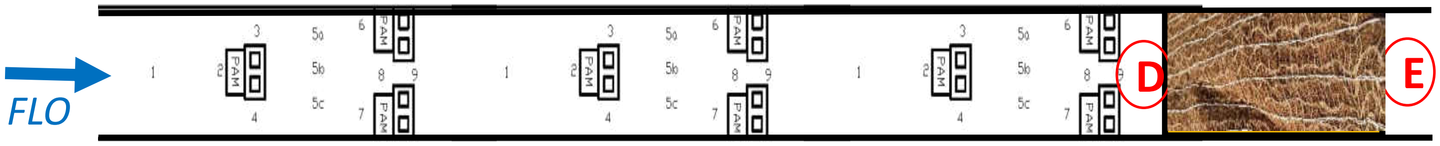


Figure 32 A-2-4 Soil Coconut Mat Sample Locations

Figure 33 shows a 20-foot jute mat during a test. There was a large volume on the mat during this time.

Figure 33 A-2-4 Soil Jute Mat

The friction on this mat caused buildup of the water during this test. This may help settle some of the heavier suspended solids. Table 14 and show the average of the raw data from the tests. “A” represents the channel influent, “D” represents the mat influent post PAM, and “E” represents the effluent.

Table 14 A-2-4 Jute 10-foot Mat Average Turbidity Results

Time	A (NTU)	D (NTU)	E (NTU)
2 min	618	423	250
4 min	579	457	314
6 min	577	469	336
8 min	538	421	345
10 min	509	404	332
12 min	481	397	324
14 min	432	329	300
16 min	387	293	230

The trend from this data shows a consistent decrease in turbidity relating to time. The PAM and the mat seem to lose their effectiveness as time passes. The short mat does not have the carrying capacity needed to for higher removal efficiency.

Table 15 A-2-4 Jute 20-foot Mat Average Turbidity Results

Time	A (NTU)	D (NTU)	E (NTU)
2 min	503	326	29.4
4 min	537	318	70.6
6 min	560	375	117
8 min	493	364	165
10 min	491	330	214
12 min	478	298	180
14 min	402	290	230
16 min	380	267	192

Similar to the 10-foot mat, the 20-foot mat shows decrease in turbidity as the water travels downstream. The longer mat has higher removal efficiency but decreases as time goes on. Results from the turbidity reduction efficiencies agree with this statement as the mat results show that the carrying capacity was met earlier in the experiment, shown in Figure 33. When the removal efficiency from D to E was plotted, a trend vs. time was visually identified.

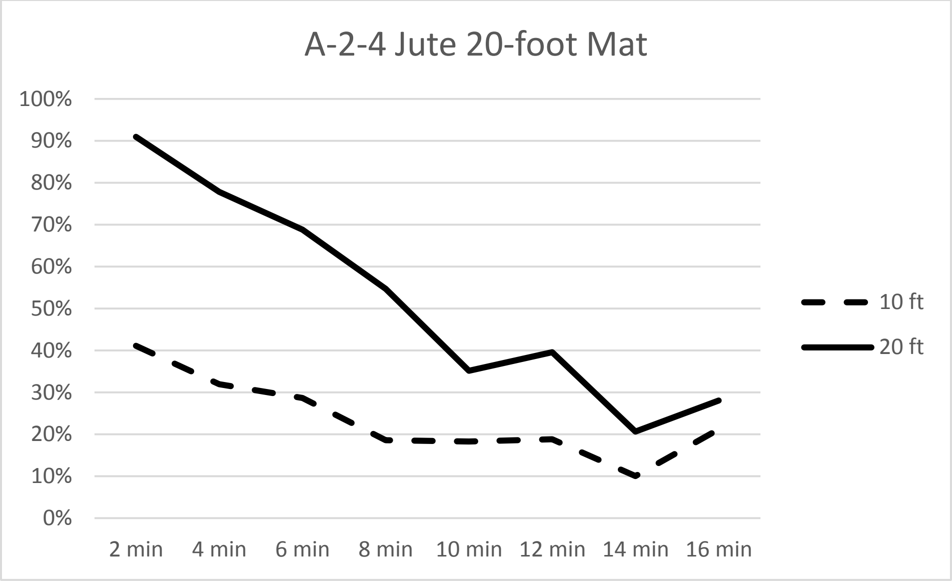


Figure 34 A-2-4 Soil Jute Mat Removal Efficiency

Although the 20-foot mat, the solid line, initially had high removal efficiency, it immediately began to fail and resulted in a final efficiency close to the 10-foot mat, the dotted line, shown in Figure 34.

Comparison

Each mat material length with the highest removal efficiency was compared to one another using Figure 35. The highest removal efficiency for A-2-4 soils were shown in the 20 -foot Jute and Coconut mats and the 10 -foot synthetic mat.

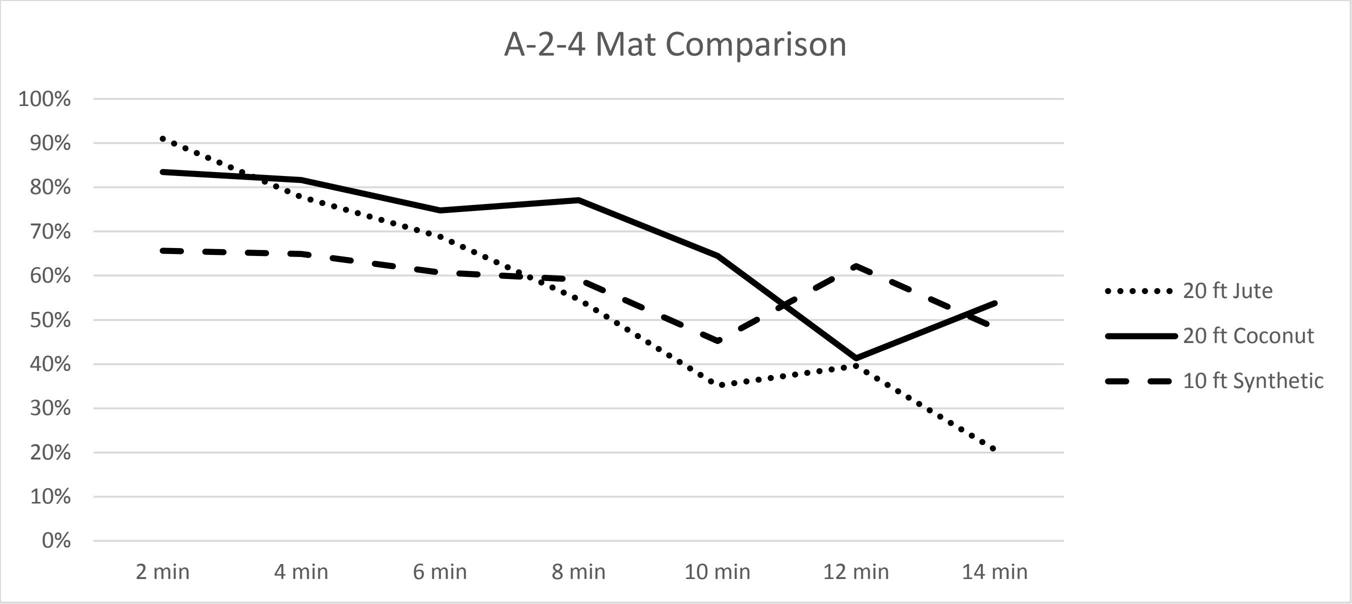


Figure 35 A-2-4 Mat Comparison

The 20 -foot coconut mat showed the best results over time compared to the other two mats. Although the 10 -foot synthetic mat ended at a higher efficiency, the coconut mat started higher suggesting a higher longevity over time.

Crushed Limestone Type Soil

Polyacrylamide Influence

The first part of the analysis involved analyzing the average turbidity of the samples collected at the influent (A) and the end of the PAM configuration (D), shown in Figure 24Figure 36.

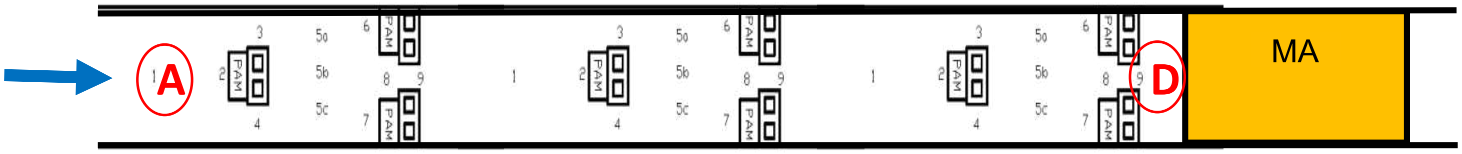


Figure 36 Crushed Limestone Soil Channel Configuration – PAM Sample Location

Crushed limestone was coagulated using APS 708x PAM and APS 703d PAM prior to mat treatment. The PAM configuration showed an average removal efficiency of 81% to 69% over 16 minutes of testing, shown in

Table 16. The results were taken using the initial turbidity NTU and the final NTU prior to the mat location at D.

Table 16 Average PAM Removal Efficiency with A-2-4 Soil

Time	Average Removal	Standard Deviation
2 min	81%	11%
4 min	78%	16%
6 min	79%	13%
8 min	76%	17%
10 min	75%	15%
12 min	75%	14%
14 min	75%	14%
16 min	69%	21%

Due to the properties of the crushed limestone, two PAM types: APS 708x (blue) and APS 703d (white), see in Figure 37, were required to coagulate the soil into large enough particles. The mats responded well to the flocculated particles and did not clog as quickly as the A-2-4 loads. The coconut mat showed the highest removal efficiencies at a consistent level over time.

Figure 37 Crushed Limestone PAM Configuration

The average turbidity results of the 30 second settled and the completely mixed samples were compared to one another. The settled samples showed a significant increase in removal efficiency compared to the completely mixed sample.

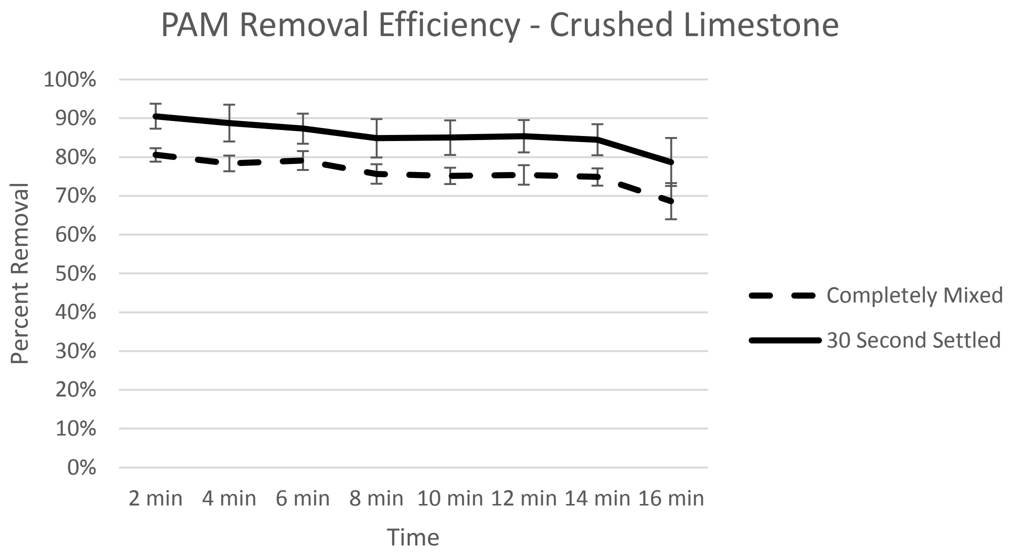


Figure 38 PAM Removal Efficiency Crushed Limestone Soil 30-second Settle vs. Complete Mix

The data results indicate that the use of a settling time showed a significant increase in removal efficiency when applied to the crushed limestone laden waters. Additionally, these results also indicate that the standard deviation of the PAM samples before the collection mat may be high due to the quantity of particles that are still floating in the sample which could have settled out in a settling area.

Coconut Mat

The coconut fiber was able to capture the soil without over loading and causing the flocs to end up in the effluent towards the end of the test. The samples analyzed were at location (D) and location (E), shown in Figure 39.

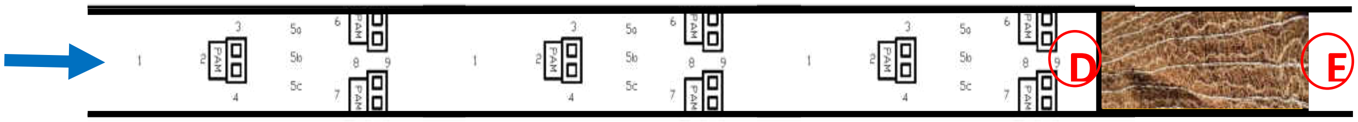


Figure 39 Crushed Limestone Soil Coconut Mat Sample Locations

Figure 40 shows a visual of the 20-foot coconut mat to remove sediments in limestone laden water.

Figure 40 Crushed Limestone Coconut Mat

The average influent for the 10-foot coconut mat tests began around 365 NTU. The PAM successfully removed approximately 75% of that overall turbidity before it reached the mat for further reduction. The 10-foot coconut mat successfully removed a significant quantity of the turbidity from the water resulting in an overall turbidity of around 65NTU. Table 17 visualizes these trends.

Table 17 Limestone Soil – 10-foot Coconut Mat

Time	A (NTU)	D (NTU)	E (NTU)
2 min	388	115	49
4 min	391	162	45
6 min	383	112	53
8 min	344	173	47
10min	377	179	68
12 min	343	176	58
14 min	358	160	55
16 min	338	158	78

The 20-foot coconut mat tests also showed an initial turbidity prior to the channel to be in the 300s, around 320 NTU. The PAM successfully reduced an average of approximately 75% of the total turbidity in the influent. After the PAM configuration, an additional reduction was shown in the effluent after the 20-foot coconut mat showing a final turbidity of approximately 44 NTU.

Table 18 Limestone Soil – 20-foot Coconut Mat

Time	A (NTU)	D (NTU)	E (NTU)
2 min	320	136	42
4 min	280	145	30
6 min	298	156	41
8 min	321	158	54
10min	354	185	50
12 min	368	176	32
14 min	356	182	65
16 min	256	181	36

Coconut mat showed high removal efficiencies and did not lead to a lower efficiency removal over time, shown in Figure 41. The average percent removal shown in the figure indicates that the mats did not fully clog during the course of the tests.

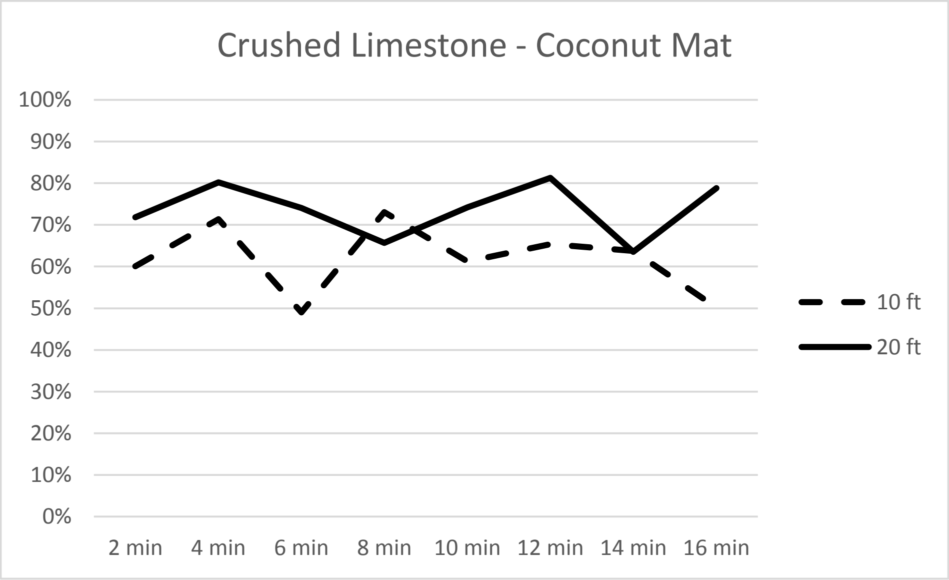


Figure 41 Limestone Soil – Coconut Mat

Synthetic Mat

The synthetic mat results showed that this material may not work effectively at longer lengths.

The samples analyzed were at location (D) and location (E), Figure 42.

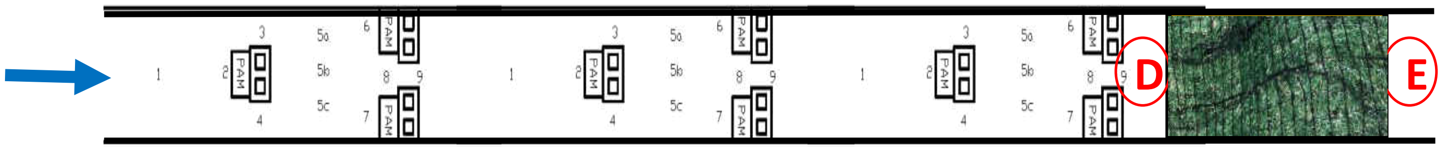


Figure 42 Crushed Limestone Soil Synthetic Mat Sample Locations

The clogs in the material may end up helping to minimize the holes in the fabric allowing for the particulates to hold inside the mat. Figure 43 shows a visual for the 10-foot synthetic mat prior to testing.

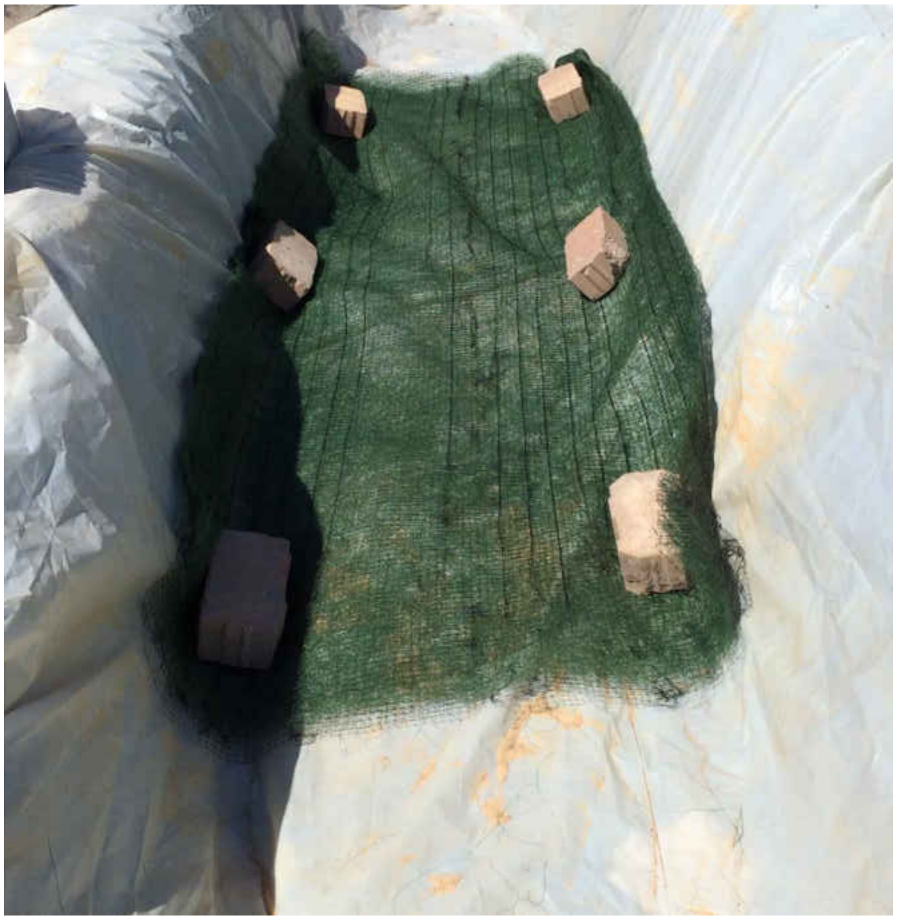


Figure 43 Crushed Limestone Synthetic Mat

The synthetic mat cut to 10-foot showed varying removal efficiency, ranging initially from 74 NTU and up to 118 NTU as the test proceeded, shown in Table 19. The PAM successfully reduced a large percentage of the turbidity initially before the water reached the mat. The addition of the mat did not remove as high of a percentage as the coconut mat.

Table 19 Limestone Soil – 10-foot Synthetic Mat

Time	A (NTU)	D (NTU)	E (NTU)
2 min	334	131	74
4 min	298	124	76
6 min	316	143	102
8 min	263	102	101
10min	259	134	98
12 min	315	152	112
14 min	307	173	118
16 min	319	157	103

Similarly, the 20-foot synthetic mat showed a varying concentration throughout the test. The PAM effectively removed a large portion of the turbidity but the mat did not result in a high reduction of turbidity, shown in Table 20.

Table 20 Limestone Soil – 20-foot Synthetic Mat

Time	A (NTU)	D (NTU)	E (NTU)
2 min	540	199	138
4 min	517	232	201
6 min	540	216	139
8 min	567	182	166
10min	514	227	152
12 min	556	222	119
14 min	558	249	148
16 min	244	191	206

The values of D and E displayed in Table 19 and Table 20 were converted into percent removal and presented in a graphical form shown in Figure 44.

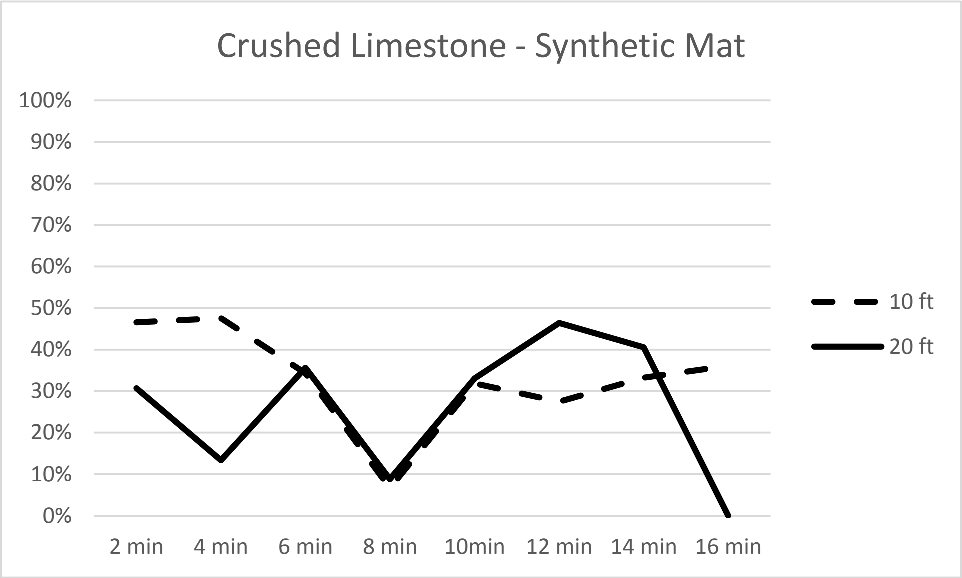


Figure 44 Limestone Soil – Synthetic Mat

The plot emphasizes the inconsistencies shown in the tabulated form of the tests. The 20-foot mat (solid line) shows complete clogging formed in the 14 minute mark leading to no removal efficiency by 16 minutes. These inconsistencies led to the conclusion weaves in the mats may lead to the flocs becoming dislodged from the mat.

Jute Mat

The jute mat showed moderate removal efficiencies when used with the crushed limestone. The samples analyzed were at location (D) and location (E), shown in Figure 45.

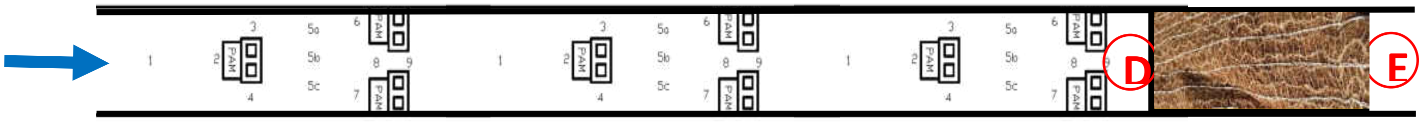


Figure 45 Crushed Limestone Soil Coconut Mat Sample Locations

Figure 47 shows the 10-foot coconut mat during a test with the crushed limestone laden water.

Figure 46 Crushed Limestone Jute Mat

Turbulence was shown at the beginning of each of the mats, and especially noticeable in the jute mats. This may be due to the flexible nature of the mat compared to the other two types.

The 10-foot jute mat successfully removed turbidity at the start of the test. However, as it progressed there were inconsistencies in the removal efficiency. Table 21 shows the average influent turbidity of the water was approximately 397 NTU in the influent and was successfully removed using the PAM to an average turbidity of 143 NTU. Additional removal was shown in E (after the mat), however the final turbidity value only averaged around 101 NTU.

Table 21 Limestone Soil – 10-foot Jute

Time	A (NTU)	D (NTU)	E (NTU)
2 min	408	136	79
4 min	372	181	73
6 min	409	160	79
8 min	401	168	63
10min	369	154	84
12 min	396	192	106
14 min	382	189	81
16 min	432	153	104

Table 22 shows the average results due to the 20-foot jute mat. The influent (A) turbidity was approximately 440 NTU and decreased to 207 NTU after the turbid water traveled through the PAM configuration. The final average turbidity was similar to the 10-foot mat even though the initial turbidity (A) and influent (D) turbidity were higher.

Table 22 Limestone Soil – 20-foot Jute

Limestone Soil - 20-foot Jute			
Time	**A (NTU)**	**D (NTU)**	**E (NTU)**
2 min	544	234	156
4 min	482	229	84
6 min	445	233	88
8 min	443	220	75
10min	423	216	84
12 min	417	184	140
14 min	402	174	69
16 min	365	166	150

The “D” and “E” turbidity values from Table 22 and Table 21 were converted into removal efficiency percentages and plotted, shown in Figure 47.

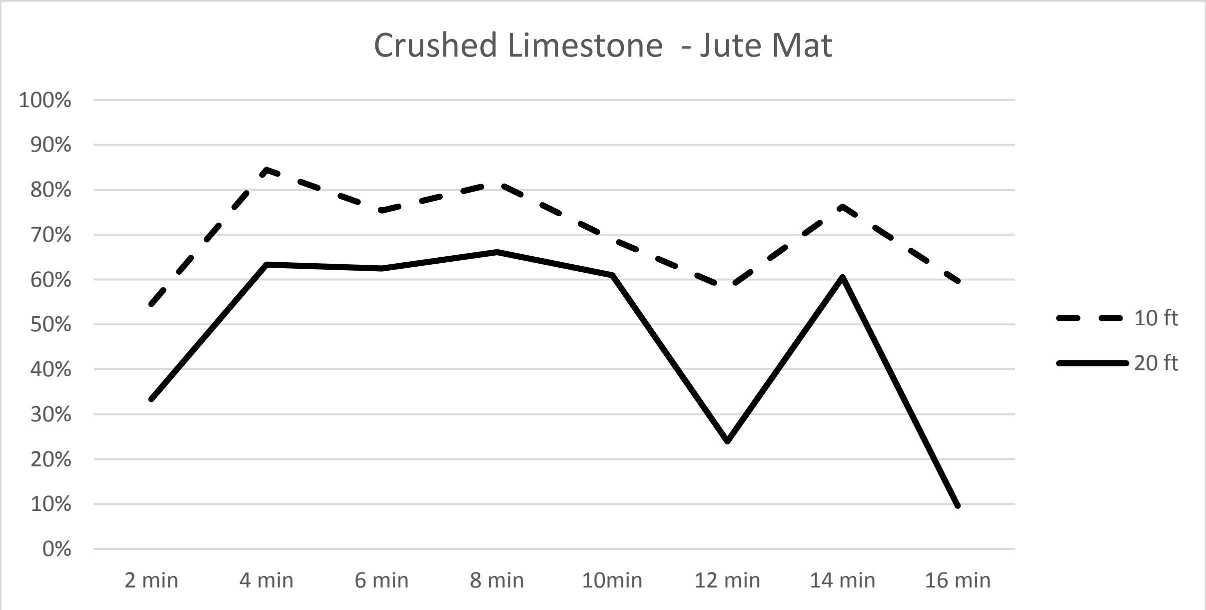


Figure 47 Limestone Soil – Jute Mat

The jute mat results showed decreased efficiency as the test progressed in time. The inconsistencies may have been due to dislodged particulates ending up in the effluent stream. Surprisingly the removal efficiency of the 10-foot mat showed high removal than the 20-foot mat which may indicate that the high initial turbidity at the beginning of the 20-foot test may have initially clogged the 20-foot jute mat preventing it from reaching a higher overall removal efficiency.

Comparison

Due to the inconsistent removal efficiency of the synthetic mat for the crushed limestone turbid water it was not used as a comparison for the final mat choice. Figure 48 presents a comparison between the average removal efficiencies of the 10-foot Jute mat and the 20-foot Coconut mat.

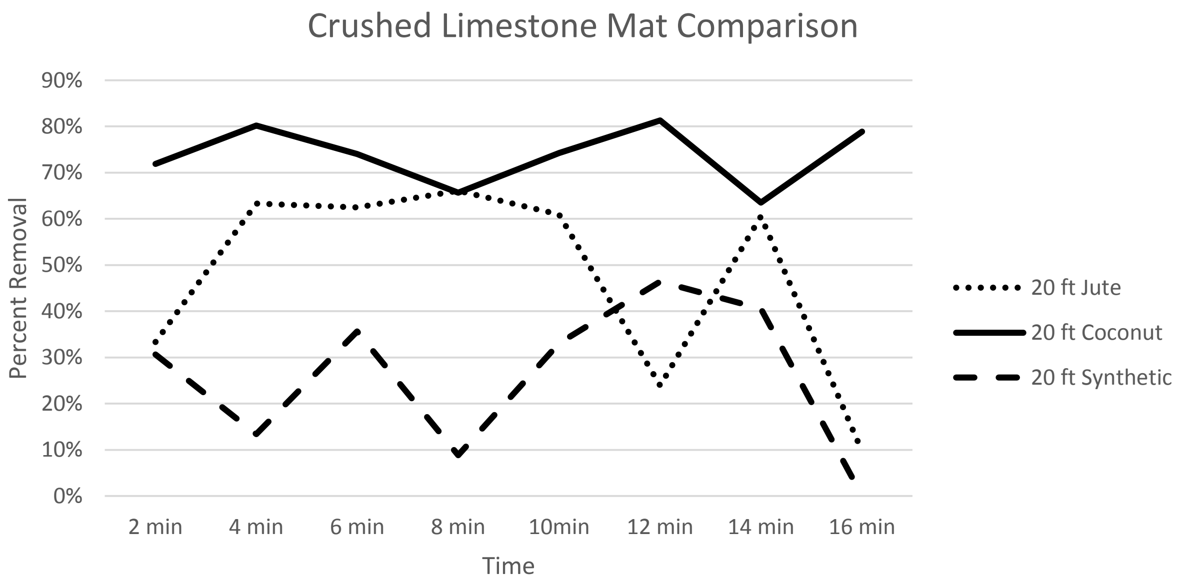


Figure 48 Crushed Limestone Mat Comparison

The results show many fluctuations between the two removal efficiencies. However, overall, the 20-foot coconut mat showed the highest removal trend, suggesting it would be the most efficient at removing turbidity.

Statistical Analysis

The samples collected from the test were non normal and nonparametric. For these reasons, Wilcoxon Signed Rank Test and ANOVA: Two-Factor without Replication Test using ranked results were used to statistically analyze the data. The statistical analysis results can be found in the Appendix.

Wilcoxon Signed Rank Test

The Wilcoxon signed rank test was designed to compare two population distributions for similarities. The one-tailed matched pairs test was chosen to test the influent and effluent samples and the effluent completely mixed and 30 second settled samples. D_1 and D_2 represented influent and effluent, and effluent completely mixed and 30 second settled samples respectively and the following hypothesis was tested:

$$H_o: D_1 and\ D_2 are\ identical \tag{4-2}$$

$$H_a: D_1 is\ shifted\ to\ the\ left\ of\ D_2 \tag{4-3}$$

Results from the Wilcoxon signed rank test showed that null hypothesis was rejected in both cases (α=0.05), ensuring that the influent samples were significantly larger than the effluent samples. Additionally, this also concluded that the use of a settling zone would result in a lower turbidity. Additionally the Wilcoxon signed rank test was used to compare the completely mixed and the coffee filter samples. The analysis showed the coffee filter results were significantly different (α=0.05) than the collection mat effluent samples. This would indicate that the coffee filter cannot be used accurately to mimic a mat on the field.

ANOVA Test

Analysis of variance (ANOVA) test is used to statistically determine whether or not two independent random samples differ from one another (Sinchich, 2997). The duplicate tests were compared with one another in various ways to ensure their similarities and to compare the influent and effluent sample results. ANOVA tests were run on the turbidity values on the duplicate tests concluding that the exact turbidity results could not be duplicated ($\alpha=0.05$) because each initial turbidity value varied between tests. However, when the percent removal values were statistically tested ($\alpha=0.05$), it was concluded that 80% of the results could be duplicated concluding that the mats percent removal could be duplicated.

5. CONCLUSIONS

The objective of the study was to research the use of polyacrylamide (PAM) and erosion control mats to mitigate environmental effects of highly erodible top soil entering waterways via stormwater runoff. An experimental setup was designed using a predetermined PAM configuration in conjunction with three types of collection mats, namely jute, coconut fiber, and polypropylene mix. Three turbidity test methods were used to test the efficiency of removing three common Florida soil types, sandy soil, silty-sandy, and crushed limestone fines, from stormwater discharged from a construction site.

The design stage of the research included three major phases, namely: laboratory-scale testing, field-scale testing, and designing a method to detect PAM in the effluent stream. Using the previous results from The Stormwater Laboratory at the University of Central Florida (UCF) and Applied Polymer Systems (APS) for mix speeds and doses for polyacrylamide, a field test was designed. It was concluded that APS 708x was the most effective PAM for removing turbidity from silty-sandy and sandy soil laden water and APS 708x in conjunction with APS 703d worked most effectively at removing turbidity from the limestone fine laden water.

The channel was developed using a 16:1 slope. Three sets of the Dispersion Configuration PAM blocks, using a total of nine blocks, were placed at vertical length of 45 in. apart. At the end of the PAM channel, a 10-foot or 20-foot collection mat was placed 45 in. after the last set of blocks. During the course of the test, samples were taken at the influent point, after every set of PAM blocks, and before and after the collection mats in 2 minute intervals. Additionally, height and velocity of flow measured along the test channel at 11 locations per set of PAM blocks.

Duplicate tests were run on the samples, totaling 36 tests in total. Repeatable ANOVA and Wilcoxon Signed Rank tests were used to statistically analyze the results to a confidence interval of 95%. It was concluded that the removal efficiency of that mats can be repeated (α=0.05). Additionally, the use of a 30-second settling time prior to turbidity testing also indicated a significant (α=0.05) decrease in the turbidity value. From the results, it was indicated that the 20-foot coconut mat showed the highest removal efficiency out of the mats for each of the soil types. The sandy soil tests showed that the test channel had an average removal efficiency starting at 71% and decreasing to 44% at the end of the tests. This decrease would imply that the PAM blocks lose their efficiency over time. However after they were cleaned and are reused the turbidity increased again resulting in similar trends. The 20-foot coconut mat kept a steady average removal efficiency of 90% throughout the tests. The silty-sandy soil tests showed that the test channel had an average removal efficiency ranging from 50% to 65% throughout the course of the tests. This would indicate that the silty-sandy soil did not lead to overuse by the end of the tests. However, it is still advised to wash the PAM blocks off after each rain event. The average removal efficiency for the 20-foot mat under the silty-sandy soil turbid water started around 85% and decreased to 60% in the last timed samples. The crushed limestone tests showed that the test channel had an average removal efficiency ranging from 81% down to 69% throughout the courses of the tests. Similar to the silty-sandy soil results, although the PAM blocks did not completely clog by the end of the test, it is still suggested that the blocks be cleaned after each rain event. The average turbidity removed via the 20-foot coconut mat under crushed limestone conditions showed removal efficiencies between 65% and 80%.

Suggestions for further study relating the impact of collection mats and PAM within a treatment channel are listed below.

Recommendations for Future Work:

1. Further research on length of the collection mat relating to the turbidity removal efficiencies
2. Toxicity testing of the effluent water treated with polyacrylamide

3. Introduction of PAM stabilization powder applied to the collection mats

General observations from the test showed that each type of mat completely clogged by the end of the tests indicating that longer collection mats be used, possibly lining the entire channel.

Operational Recommendations

1. Store the blocks in plastic wrap within a rectangular container to ensure a rectangular shape
2. Soak the PAM blocks prior to usage for at least 15 minutes
3. Tape tears in Visqueen as soon as they appear to avoid further damage

Polyacrylamide is a slippery yet sticky material when wet. Proper storage of this material will lead to a longer lifespan. It has been noted that when wrapped separately in plastic wrap, in a rectangular container, and under 85°F, the lifespan for polyacrylamide is much longer.

When placing the polyacrylamide blocks in front of the masonry blocks it is suggested to wrap them around using the rope attached to the PAM this ensures the PAM does not move around during the rain event.

APPENDIX A

SOIL SIEVE ANALYSIS

Table 23 Appendix Sieve Analysis A-3

Sieve Analysis

Description of soil A-3 Sample No. 2

Mass of oven dry sample, *W* 501.15 g

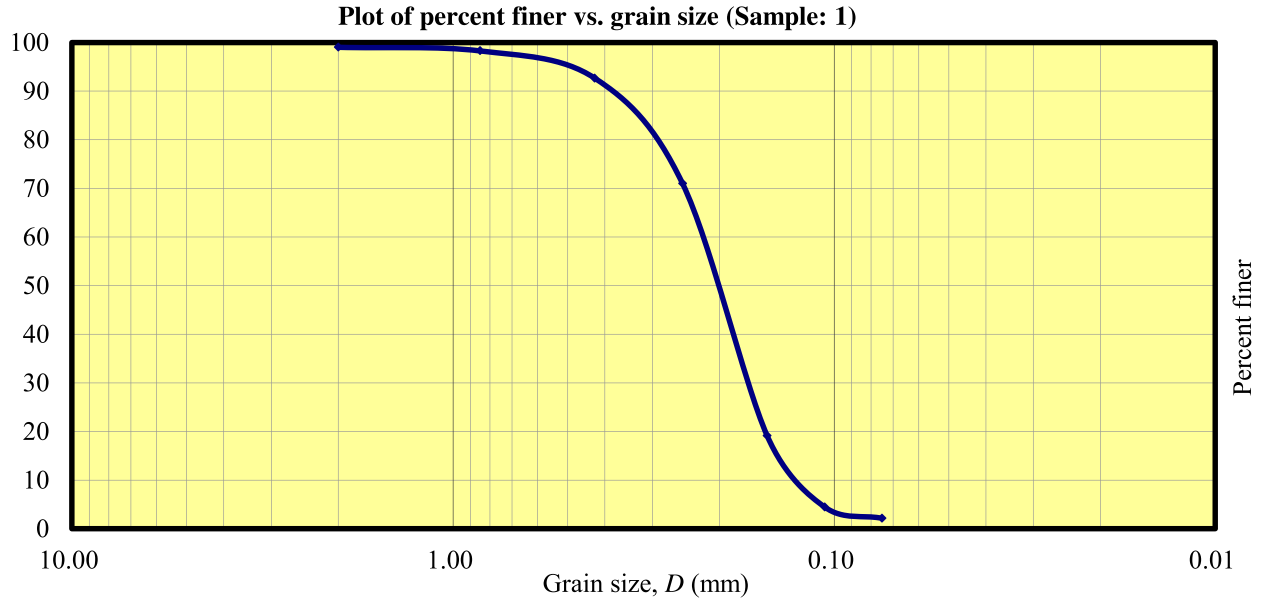
Location Pile for test bed

Tested by Zuzanna Wasowska Date July 25, 2013

Sieve No.	**Sieve opening (*mm*)**	**Mass of soil retained on each sieve, W_n (*g*)**	**Percent of mass retained on each sieve, R_n**	**Cumulative percent retained, $\sum R_n$**	**Percent finer, 100 - $\sum R_n$**
10	2.000	4.93	1.0	1.0	99.02
20	0.850	3.70	0.7	1.7	98.28
40	0.425	28.11	5.6	7.3	92.67
60	0.250	108.58	21.7	29.0	71.00
100	0.150	259.99	51.9	80.9	19.12
140	0.106	73.53	14.7	95.5	4.45
200	0.075	11.69	2.3	97.9	2.12
Pan	--	10.26	2.0		

$W_1 = \sum$ 500.8 g

Mass loss during sieve analysis = $[(W - W_1) \div W] \times 100 =$ 0.07 % (OK if less than 2%)



D60 =	0.31	(Determined from graph, corresponding to percents finer of 60%, 30%, and 10%)
D30 =	0.20	
D10 =	0.16	

Uniformity coefficient, $C_u = (D_{60} / D_{10}) =$	1.94
Coefficient of gradation, $C_c = [D^2_{30} \div (D_{60} \times D_{10})] =$	0.80

Effective size of soil sample, $D_{10} =$	0.16	***mm***

AASHTO Classification System:-	*A3 (Fine sand)*
Unified Classification System:-	*SP (Poorly graded sand)*

Table 24 Appendix A-2-4 Sieve Analysis

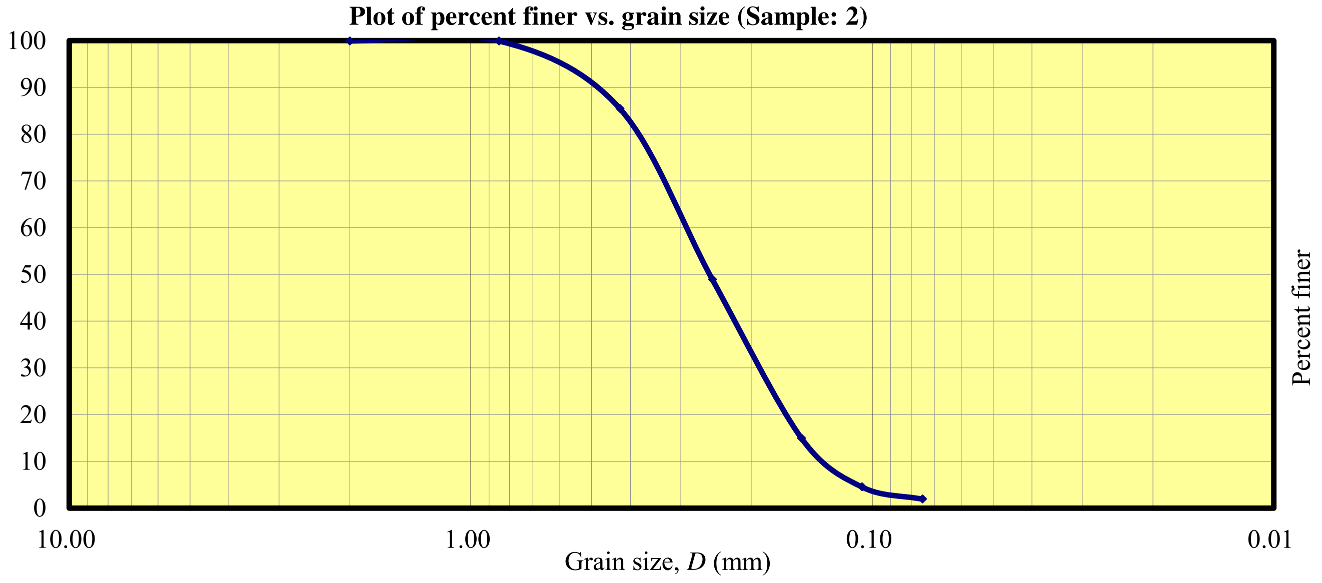
Sieve Analysis

Description of soil	Silty Sandy Soil (A-2-4)	Sample No.	1
		Mass of oven dry sample, *W*	499.98 g
Location	Bucky's Hauling		
Tested by	Marcus Geiger, Scotty Hickson	Date	October 29, 2012

Sieve No.	Sieve opening (*mm*)	Mass of soil retained on each sieve, W_n (*g*)	Percent of mass retained on each sieve, R_n	Cumulative percent retained, $\sum R_n$	Percent finer, $100 - \sum R_n$
10	2.000	0.47	0.1	0.1	99.91
20	0.850		0.0	0.1	99.91
40	0.425	72.23	14.4	14.5	85.46
60	0.250	182.75	36.6	51.1	48.91
100	0.150	169.78	34.0	85.0	14.95
140	0.106	52.22	10.4	95.5	4.51
200	0.075	13.02	2.6	98.1	1.90
Pan	--	7.60	1.5		

$W_1 = \sum$ 498.1 g

Mass loss during sieve analysis = $[(W - W_1) \div W] \times 100$ = 0.38 % (OK if less than 2%)



D_{60} =		(*Determined from graph, corresponding to percents finer of* 60%, 30%, *and* 10%)
D_{30} =		
D_{10} =		

Uniformity coefficient, $C_u = (D_{60} / D_{10})$ =	**#DIV/0!**
Coefficient of gradation, $C_c = [D^2_{30} \div (D_{60} \times D_{10})]$ =	**#DIV/0!**

Effective size of soil sample, D_{10} = *0.00* ***mm***

AASHTO Classification System:-

Unified Classification System:-

APPENDIX B

STATISTICAL ANALYSIS

Table 25 Appendix A-3 Soil 10-foot Coconut Mat Coffee Filter

Wilcoxon Signed-Rank Test

A-3 Soil
10ft Coconut Mat

Soil and Mat Type	*Rainfall Events (#)*	*Volume-Weighted Mean Turbidity*					
		Completely mixed post Mat	*Coffee Filter pre Mat*	*U - D*	*|U -D|*	*Rank of |U - D|*	*Signed Rank*
Effluent completely mixed vs. coffee filter 6/24/13 T1	2 min	8.48	20.9	-12	12	1	-1
	4 min	36.9	19.8	17	17	2	2
	6 min	62.1	28.6	34	34	4	4
	8 min	77.3	48	29	29	3	3
	10 min	90.8	37.6	53	53	5	5
	12 min	101	28.7	72	72	8	8
	14 min	112	55.3	57	57	7	7
	16 min	120	64.1	56	56	6	6

H_0: $\mu_U = \mu_D$ $(\mu_U - \mu_D) = 0$

H_1: $\mu_U > \mu_D$ $(\mu_U - \mu_D) > 0$

α: 0.05

w: w^-

W^+ =	35.0	W =	34.0
W^- =	1.0	N =	8
σ_W =	14.28	z =	2.42
α =	0.05	z crit =	1.64
μ_W =	0.00	p =	0.0086
W_{stat} =	1.0	W crit =	5.00
		Decision:	
		Decision:	Reject Ho

Table 26 Appendix – A-3 Soil 20-foot Coconut Mat Coffee Filter

Wilcoxon Signed-Rank Test

A-3 Soil 20ft Coconut Mat							
		Volume-Weighted Mean Turbidity					
Soil and Mat Type	***Rainfall Events (#)***	***Upstream***	***Downstream***	***U - D***	***|U -D|***	***Rank of |U - D|***	***Signed Rank***
Effluent completely mixed vs. coffee filter 7/12/13 T1	2 min	10.4	27	**-17**	**17**	**4**	**-4**
	4 min	11.5	14.9	**-3**	**3**	**2**	**-2**
	6 min	17.8	24.5	**-7**	**7**	**3**	**-3**
	8 min	10.4	27.1	**-17**	**17**	**5**	**-5**
	10 min	11	48.9	**-38**	**38**	**8**	**-8**
	12 min	15.1	18.1	**-3**	**3**	**1**	**-1**
	14 min	17.1	44.7	**-28**	**28**	**7**	**-7**
	16 min	19.5	44.5	**-25**	**25**	**6**	**-6**

H₀: $\mu_U = \mu_D$ $(\mu_U - \mu_D) = 0$

H₁: $\mu_U > \mu_D$ $(\mu_U - \mu_D) > 0$

α: 0.05

w: w^-

$W^+ =$	**0.0**	W =	**-36.0**
$W^- =$	**36.0**	N =	**8**
$\sigma_W =$	**14.28**	z =	**-2.49**
$\alpha =$	**0.05**	z crit =	**1.64**
$\mu_W =$	**0.00**	p =	**0.9941**
$W_{stat} =$	**0.0**	W crit =	**5.00**
		Decision:	
		Decision:	**Reject Ho**

Table 27 Appendix – A-3 Soil 10ft Synthetic Mat Coffee Filter

Wilcoxon Signed-Rank Test

A-3 Soil 10ft Synthetic Mat

Soil and Mat Type	*Rainfall Events (#)*	*Volume-Weighted Mean Turbidity*					
		Upstream	*Downstream*	*U - D*	*|U -D|*	*Rank of |U - D|*	*Signed Rank*
Effluent completely mixed vs. coffee filter 7/22/13 T1	2 min	57	35.7	21	21	5	5
	4 min	37.5	38.6	-1	1	1	-1
	6 min	68.6	42.1	27	27	7	7
	8 min	63.3	52.2	11	11	3	3
	10 min	74.3	40	34	34	8	8
	12 min	60.2	38.4	22	22	6	6
	14 min	64.6	45.7	19	19	4	4
	16 min	77.6	35.2	42	42	9	9
	18 min	51	53.1	-2	2	2	-2

H$_0$: $\mu_U = \mu_D$ $(\mu_U - \mu_D) = 0$

H$_1$: $\mu_U > \mu_D$ $(\mu_U - \mu_D) > 0$

α: 0.05

w: w^-

W^+ =	42.0	W =	39.0
W^- =	3.0	N =	9
σ_W =	16.88	z =	2.34
α =	0.05	z crit =	1.64
μ_W =	0.00	p =	0.0104
W_{stat} =	3.0	W crit =	8.00
		Decision:	
		Decision:	Reject Ho

Table 28 Appendix – 30 Second Settling vs Completely Mixed A-3 Coconut Mat

Wilcoxon Signed-Rank Test
A-3 Soil
10ft Coconut Mat

Soil and Mat Type	*Rainfall Events (#)*	*Volume-Weighted Mean Turbidity*					
		Downstream Completely Mixed	*Downstream 30sec settling*	*U - D*	*|U -D|*	*Rank of |U - D|*	*Signed Rank*
A-3 Soil 10ft Coconut Mat	2 min	178	123	55	55	5	5
	4 min	193	104	89	89	7	7
	6 min	145	131	14	14	1	1
	8 min	180	153	27	27	2	2
	10 min	255	215	40	40	4	4
	12 min	191	135	56	56	6	6
	14 min	199	167	32	32	3	3

H_0: $\mu_U = \mu_D$ $(\mu_U - \mu_D) = 0$
H_1: $\mu_U > \mu_D$ $(\mu_U - \mu_D) > 0$
α: 0.05
w: w^-

W^+ =	28.0	W =	28.0
W^- =	0.0	N =	7
σ_W =	11.83	z =	2.41
α =	0.05	z crit =	1.64
μ_W =	0.00	p =	0.0090
W_{stat} =	0.0	W crit =	3.00
		Decision:	
		Decision:	Reject Ho

Table 29 Appendix – 30 Second Settling vs Completely Mixed A-3 Synthetic Mat

Wilcoxon Signed-Rank Test

A-3 Soil 20ft Synthetic Mat

Soil and Mat Type	*Rainfall Events (#)*	*Volume-Weighted Mean Turbidity*					
		Downstream Completely Mixed	*Downstream 30sec settling*	*U - D*	*$\lvert U - D \rvert$*	*Rank of $\lvert U - D \rvert$*	*Signed Rank*
A-3 Soil 20ft Synthetic	2 min	25.3	20.9	4	4	2	2
	4 min	37	21	16	16	8	8
	6 min	55.4	49.4	6	6	5	5
	8 min	38.2	33.7	5	5	3	3
	10 min	95.1	78.2	17	17	9	9
	12 min	70.1	64.2	6	6	4	4
	14 min	55.8	47.7	8	8	6	6
	16 min	44.5	42.3	2	2	1	1
	18 min	71.4	61.4	10	10	7	7

		W^+ =	45.0	W =	45.0
H_0:	$\mu_U = \mu_D$	$(\mu_U - \mu_D) = 0$	W^- =	0.0	N =	9
H_1:	$\mu_U > \mu_D$	$(\mu_U - \mu_D) > 0$	σ_W =	16.88	z =	2.70
α:	0.05		α =	0.05	z crit =	1.64
w:	w^-		μ_W =	0.00	p =	0.0038
			W_{stat} =	0.0	W crit =	8.00
					Decision:	
					Decision:	Reject Ho

Table 30 Appendix - 30 Second Settling vs Completely Mixed A-3 Jute Mat

Wilcoxon Signed-Rank Test

A-3 Soil 20ft Jute Mat

Soil and Mat Type	*Rainfall Events (#)*	*Volume-Weighted Mean Turbidity*					
		Downstream Completely Mixed	*Downstream 30sec settling*	*U - D*	*|U -D|*	*Rank of |U - D|*	*Signed Rank*
A-3 Soil Jute 20 ft	2 min	1.47	1.45	0	0	1	1
	4 min	5.92	5.32	1	1	3	3
	6 min	7.03	7.19	0	0	2	-2
	8 min	8.94	5.38	4	4	5	5
	10 min	18.7	11.4	7	7	7	7
	12 min	15.9	7.78	8	8	8	8
	14 min	53.3	46.1	7	7	6	6
	16 min	25.1	16	9	9	9	9
	18 min	21.2	20.4	1	1	4	4

H_0: $\mu_U = \mu_D$ $(\mu_U - \mu_D) = 0$

H_1: $\mu_U > \mu_D$ $(\mu_U - \mu_D) > 0$

α: 0.05

w: w^-

W^+ =	43.0	W =	41.0
W^- =	2.0	N =	9
σ_W =	16.88	z =	2.46
α =	0.05	z crit =	1.64
μ_W =	0.00	p =	0.0076
W_{stat} =	2.0	W crit =	8.00
		Decision:	
		Decision:	Reject Ho

Table 31 Appendix - 30 Second Settling vs Completely Mixed A-2-4 Jute Mat

Wilcoxon Signed-Rank Test

A-2-4 10ft Jute Mat

Soil and Mat Type	*Rainfall Events (#)*	*Volume-Weighted Mean Turbidity*					
		Downstream Completely Mixed	*Downstream 30sec settling*	*U - D*	*$\lvert U - D \rvert$*	*Rank of $\lvert U - D \rvert$*	*Signed Rank*
A-2-4 Jute 20ft	2 min	29.4	15.2	**14**	**14**	**1**	**1**
	4 min	70.6	23.3	**47**	**47**	**2**	**2**
	6 min	117	55	**62**	**62**	**3**	**3**
	8 min	165	73	**92**	**92**	**4**	**4**
	10 min	214	64	**150**	**150**	**8**	**8**
	12 min	180	86	**94**	**94**	**5**	**5**
	14 min	230	115	**115**	**115**	**6**	**6**
	16 min	192	71	**121**	**121**	**7**	**7**

H_0: $\mu_U = \mu_D$ $(\mu_U - \mu_D) = 0$
H_1: $\mu_U > \mu_D$ $(\mu_U - \mu_D) > 0$
α: 0.05
w: w^-

W^+ =	**36.0**
W^- =	**0.0**
σ_W =	**14.28**
α =	**0.05**
μ_W =	**0.00**
W_{stat} =	**0.0**

W =	**36.0**
N =	**8**
z =	**2.56**
z crit =	**1.64**
p =	**0.0059**
W crit =	**5.00**
Decision:	
Decision:	**Reject Ho**

Table 32 Appendix - 30 Second Settling vs Completely Mixed A-2-4 Coconut Mat

Wilcoxon Signed-Rank Test

A-2-4 Soil 10ft Coconut Mat

Soil and Mat Type	*Rainfall Events (#)*	*Volume-Weighted Mean Turbidity*					
		Downstream Completely Mixed	*Downstream 30sec settling*	*U - D*	*|U -D|*	*Rank of |U - D|*	*Signed Rank*
A-2-4 Soil 10ft Coconut	2 min	25.9	19.2	**7**	**7**	**1**	**1**
	4 min	101	91	**10**	**10**	**3**	**3**
	6 min	174	165	**9**	**9**	**2**	**2**
	8 min	260	245	**15**	**15**	**4.5**	**4.5**
	10 min	328	304	**24**	**24**	**7**	**7**
	12 min	301	286	**15**	**15**	**4.5**	**4.5**
	14 min	293	273	**20**	**20**	**6**	**6**

H_0: $\mu_U = \mu_D$ $(\mu_U - \mu_D) = 0$

H_1: $\mu_U > \mu_D$ $(\mu_U - \mu_D) > 0$

α: 0.05

w: w^-

$W^+ =$	**28.0**
$W^- =$	**0.0**
$\sigma_W =$	**11.83**
α =	**0.05**
$\mu_W =$	**0.00**
$W_{stat} =$	**0.0**

W =	**28.0**
N =	**7**
z =	**2.41**
z crit =	**1.64**
p =	**0.0090**
W crit =	**3.00**
Decision:	
Decision:	**Reject Ho**

Table 33 Appendix - 30 Second Settling vs Completely Mixed A-2-4 Synthetic Mat

Wilcoxon Signed-Rank Test

A-2-4 Soil 10ft Synthetic Mat

Soil and Mat Type	*Rainfall Events (#)*	*Volume-Weighted Mean Turbidity*					
		Downstream Completely Mixed	*Downstream 30sec settling*	*U - D*	*|U -D|*	*Rank of |U - D|*	*Signed Rank*
A-2-4 Soil 10ft Synthetic	2 min	57.4	32.8	**25**	**25**	**4**	**4**
	4 min	52.6	38.4	**14**	**14**	**2**	**2**
	6 min	87.5	62.8	**25**	**25**	**5**	**5**
	8 min	106	71.9	**34**	**34**	**7**	**7**
	10 min	116	90	**26**	**26**	**6**	**6**
	12 min	83.2	69.9	**13**	**13**	**1**	**1**
	14 min	101	84.1	**17**	**17**	**3**	**3**
	16 min	142	119	**23**	**23**	**#N/A**	

H_0: $\mu_U = \mu_D$ $(\mu_U - \mu_D) = 0$

H_1: $\mu_U > \mu_D$ $(\mu_U - \mu_D) > 0$

α: 0.05

w: w^-

W^+ =	**28.0**	W =	**28.0**
W^- =	**0.0**	N =	**7**
σ_W =	**11.83**	z =	**2.41**
α =	**0.05**	z crit =	**1.64**
μ_W =	**0.00**	p =	**0.0090**
W_{stat} =	**0.0**	W crit =	**3.00**
		Decision:	
		Decision:	**Reject Ho**

Table 34 Appendix - 30 Second Settling vs Completely Mixed Limestone Jute Mat

Wilcoxon Signed-Rank Test

Crushed Limestone 10ft Jute Mat

Soil and Mat Type	*Rainfall Events (#)*	*Volume-Weighted Mean Turbidity*					
		Downstream Completely Mixed	*Downstream 30sec settling*	*U - D*	*|U -D|*	*Rank of |U - D|*	*Signed Rank*
Limestone 708X 10ft Jute	2 min	27	12	15	15	7	7
	4 min	13	6	7	7	5.5	5.5
	6 min	11	7	4	4	1	1
	8 min	17	12	5	5	3	3
	10 min	20	15	5	5	3	3
	12 min	42	15	27	27	8	8
	14 min	16	9	7	7	5.5	5.5
	16 min	36	31	5	5	3	3

H_0: $\mu_U = \mu_D$ $(\mu_U - \mu_D) = 0$

H_1: $\mu_U > \mu_D$ $(\mu_U - \mu_D) > 0$

α: 0.05

w: w^-

W^+ =	36.0	W =	36.0
W^- =	0.0	N =	8
σ_W =	14.28	z =	2.56
α =	0.05	z crit =	1.64
μ_W =	0.00	p =	0.0059
W_{stat} =	0.0	W crit =	5.00
		Decision:	
		Decision:	Reject Ho

Table 35 Appendix - 30 Second Settling vs Completely Mixed Limestone Coconut Mat

Wilcoxon Signed-Rank Test

Crushed Limestone 10ft Coconut Mat

Soil and Mat Type	*Rainfall Events (#)*	*Volume-Weighted Mean Turbidity*					
		Downstream Completely Mixed	*Downstream 30sec settling*	*U - D*	*|U -D|*	*Rank of |U - D|*	*Signed Rank*
Limestone 10ft Coconut	2 min	71.4	25.7	**46**	**46**	**8**	**8**
	4 min	69.5	42.8	**27**	**27**	**2.5**	**2.5**
	6 min	62.1	23.4	**39**	**39**	**5**	**5**
	8 min	38.3	28.1	**10**	**10**	**1**	**1**
	10 min	70	30.5	**40**	**40**	**6**	**6**
	12 min	81	37.7	**43**	**43**	**7**	**7**
	14 min	61.2	34.5	**27**	**27**	**2.5**	**2.5**
	16 min	79.3	51	**28**	**28**	**4**	**4**

H$_0$: $\mu_U = \mu_D$ $(\mu_U - \mu_D) = 0$
H$_1$: $\mu_U > \mu_D$ $(\mu_U - \mu_D) > 0$
α: 0.05
w: w^-

W^+ =	**36.0**	W =	**36.0**
W^- =	**0.0**	N =	**8**
σ_W =	**14.28**	z =	**2.56**
α =	**0.05**	z crit =	**1.64**
μ_W =	**0.00**	p =	**0.0059**
W_{stat} =	**0.0**	W crit =	**5.00**
		Decision:	
		Decision:	**Reject Ho**

Table 36 Appendix - 30 Second Settling vs Completely Mixed Limestone Synthetic Mat

Wilcoxon Signed-Rank Test

Crushed Limestone 10ft Synthetic Mat

Soil and Mat Type	*Rainfall Events (#)*	*Downstream Completely Mixed*	*Downstream 30sec settling*	*U - D*	*$\lvert U - D \rvert$*	*Rank of $\lvert U - D \rvert$*	*Signed Rank*
		Volume-Weighted Mean Turbidity					
Limestone 10ft Synthetic	2 min	15.2	12.6	3	3	1	1
	4 min	15.1	11.6	4	4	2	2
	6 min	30.6	20.2	10	10	6	6
	8 min	41.6	31.5	10	10	5	5
	10 min	23.9	18.4	6	6	3	3
	12 min	20.7	15	6	6	4	4
	14 min	39.6	26.9	13	13	8	8
	16 min	50	39.2	11	11	7	7

H_0: $\mu_U = \mu_D$ $(\mu_U - \mu_D) = 0$

H_1: $\mu_U > \mu_D$ $(\mu_U - \mu_D) > 0$

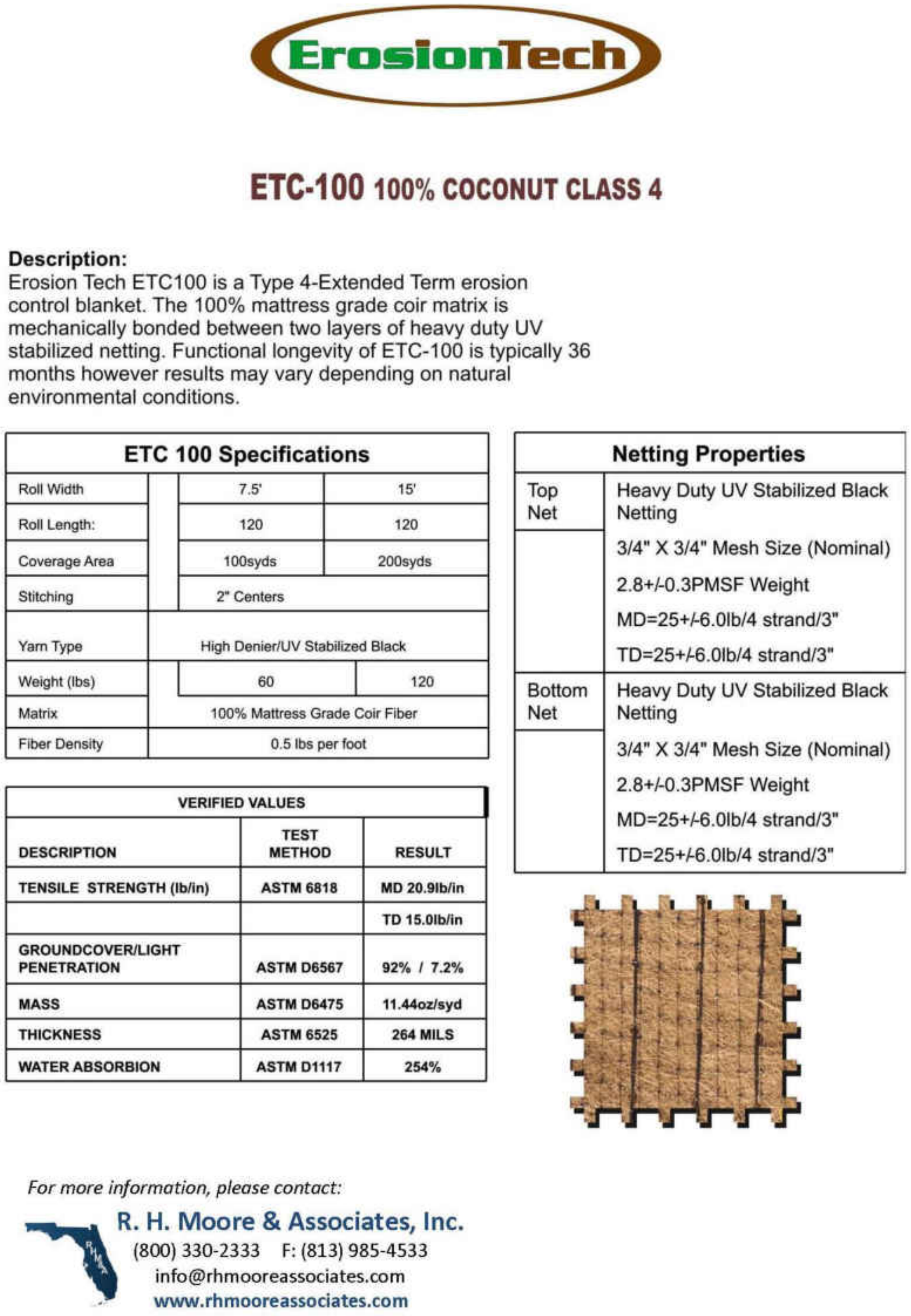
α: 0.05

w: w^-

W^+ =	36.0	W =	36.0
W^- =	0.0	N =	8
σ_W =	14.28	z =	2.56
α =	0.05	z crit =	1.64
μ_W =	0.00	p =	0.0059
W_{stat} =	0.0	W crit =	5.00
		Decision:	
		Decision:	Reject Ho

APPENDIX C

EROSION CONTROL MATS



ErosionTech

ETC-100 100% COCONUT CLASS 4

Description:
Erosion Tech ETC100 is a Type 4-Extended Term erosion control blanket. The 100% mattress grade coir matrix is mechanically bonded between two layers of heavy duty UV stabilized netting. Functional longevity of ETC-100 is typically 36 months however results may vary depending on natural environmental conditions.

ETC 100 Specifications

Roll Width	7.5'	15'
Roll Length:	120	120
Coverage Area	100syds	200syds
Stitching	2" Centers	
Yarn Type	High Denier/UV Stabilized Black	
Weight (lbs)	60	120
Matrix	100% Mattress Grade Coir Fiber	
Fiber Density	0.5 lbs per foot	

Netting Properties

Top Net	Heavy Duty UV Stabilized Black Netting
	3/4" X 3/4" Mesh Size (Nominal)
	2.8+/-0.3PMSF Weight
	MD=25+/-6.0lb/4 strand/3"
	TD=25+/-6.0lb/4 strand/3"
Bottom Net	Heavy Duty UV Stabilized Black Netting
	3/4" X 3/4" Mesh Size (Nominal)
	2.8+/-0.3PMSF Weight
	MD=25+/-6.0lb/4 strand/3"
	TD=25+/-6.0lb/4 strand/3"

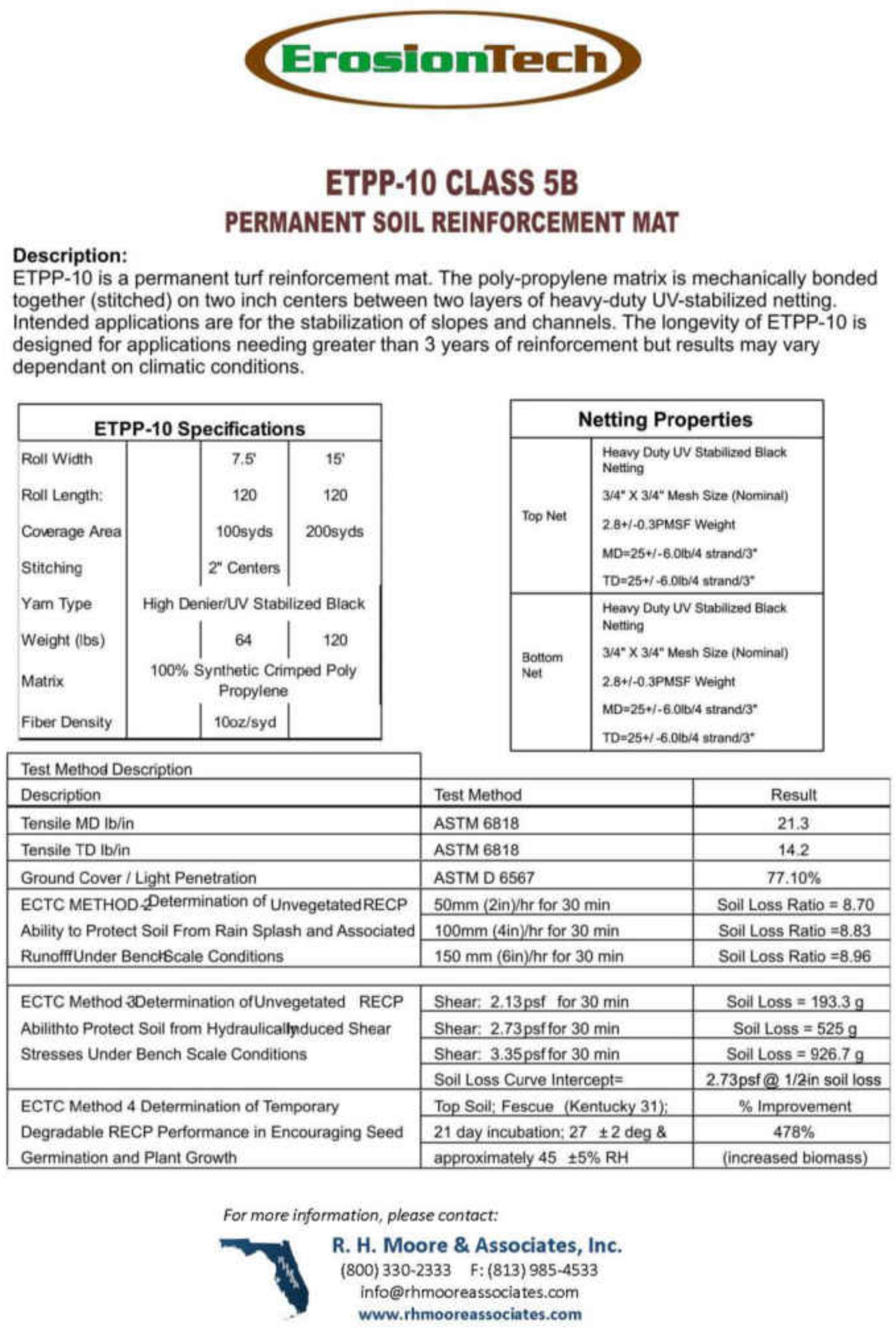
VERIFIED VALUES

DESCRIPTION	TEST METHOD	RESULT
TENSILE STRENGTH (lb/in)	ASTM 6818	MD 20.9lb/in
		TD 15.0lb/in
GROUNDCOVER/LIGHT PENETRATION	ASTM D6567	92% / 7.2%
MASS	ASTM D6475	11.44oz/syd
THICKNESS	ASTM 6525	264 MILS
WATER ABSORBION	ASTM D1117	254%

For more information, please contact:

R. H. Moore & Associates, Inc.
(800) 330-2333 F: (813) 985-4533
info@rhmooreassociates.com
www.rhmooreassociates.com

Figure 49 Appendix ETC 100 Coconut Mat



ErosionTech

ETPP-10 CLASS 5B

PERMANENT SOIL REINFORCEMENT MAT

Description:
ETPP-10 is a permanent turf reinforcement mat. The poly-propylene matrix is mechanically bonded together (stitched) on two inch centers between two layers of heavy-duty UV-stabilized netting. Intended applications are for the stabilization of slopes and channels. The longevity of ETPP-10 is designed for applications needing greater than 3 years of reinforcement but results may vary dependant on climatic conditions.

ETPP-10 Specifications

Roll Width		7.5'	15'
Roll Length:		120	120
Coverage Area		100syds	200syds
Stitching		2" Centers	
Yarn Type	High Denier/UV Stabilized Black		
Weight (lbs)		64	120
Matrix	100% Synthetic Crimped Poly Propylene		
Fiber Density		10oz/syd	

Netting Properties

Top Net	Heavy Duty UV Stabilized Black Netting
	3/4" X 3/4" Mesh Size (Nominal)
	2.8+/-0.3PMSF Weight
	MD=25+/-6.0lb/4 strand/3"
	TD=25+/ -6.0lb/4 strand/3"
Bottom Net	Heavy Duty UV Stabilized Black Netting
	3/4" X 3/4" Mesh Size (Nominal)
	2.8+/-0.3PMSF Weight
	MD=25+/-6.0lb/4 strand/3"
	TD=25+/ -6.0lb/4 strand/3"

Test Method Description

Description	Test Method	Result
Tensile MD lb/in	ASTM 6818	21.3
Tensile TD lb/in	ASTM 6818	14.2
Ground Cover / Light Penetration	ASTM D 6567	77.10%
ECTC METHOD 2 Determination of Unvegetated RECP Ability to Protect Soil From Rain Splash and Associated Runofff Under Bench Scale Conditions	50mm (2in)/hr for 30 min	Soil Loss Ratio = 8.70
	100mm (4in)/hr for 30 min	Soil Loss Ratio =8.83
	150 mm (6in)/hr for 30 min	Soil Loss Ratio =8.96
ECTC Method 3 Determination of Unvegetated RECP Abilithto Protect Soil from Hydraulically Induced Shear Stresses Under Bench Scale Conditions	Shear: 2.13psf for 30 min	Soil Loss = 193.3 g
	Shear: 2.73psf for 30 min	Soil Loss = 525 g
	Shear: 3.35psf for 30 min	Soil Loss = 926.7 g
	Soil Loss Curve Intercept=	2.73psf @ 1/2in soil loss
ECTC Method 4 Determination of Temporary Degradable RECP Performance in Encouraging Seed Germination and Plant Growth	Top Soil; Fescue (Kentucky 31);	% Improvement
	21 day incubation; 27 ±2 deg &	478%
	approximately 45 ±5% RH	(increased biomass)

For more information, please contact:

R. H. Moore & Associates, Inc.
(800) 330-2333 F: (813) 985-4533
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www.rhmooreassociates.com

Figure 50 Appendix – ETPP 10 Class 5B Synthetic Mat

Biodegradable

Jute Erosion Control Matting

Stop Erosion Damage Naturally

This coarse open mesh fabric keeps the soil in place until the plant material takes root.

Your #1 Solution to Meet the Challenges of Erosion Control

- Helps establish vegetation on steep slopes
- Holds seed and soil in place
- Excellent coverage in all types of terrain
- Meets most DOT specifications
- Easy to apply/reposition
- Conforms to difficult surfaces
- Biodegradable, 100% natural
- Acts as a soil nutrient
- Used to collect sediment in ditch check systems

Specifications - Jute Matting

Structure:	Woven
Yarn:	Jute, undyed, unbleached
Fabric Width:	48 inches
Fabric Length:	225 feet
Square Yards:	100
Weight:	.92 pounds per square yard
Roll Weight:	92 pounds
Yarn Count-Warp:	78 per width, minimum
Weft:	42 per linear yard, minimum
Absorption:	>450% of fabric weight
Open Area:	60 to 65%
Life:	1 to 2 years
Coverage:	50 rolls per acre (approximate)

Sod Staples also available

U-shaped, 500 per box, Usage: 200 staples per roll
Type: 10 inch, 11 gauge, 35 pounds per box
(other lengths available)

R. H. Moore & Associates
Soil Stabilization Erosion Control

7834 Depot Lane, Tampa, Florida 33637
Toll Free: (800) 330-2333 • Fax: (813) 985-4533
www.rhmooreassociates.com E-mail: info@rhmooreassociates.com

Figure 51 Appendix – Jute Erosion Control Matting

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