2011

Field Implementation Of Polyacrylamide For Runoff From Construction Sites

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FIELD IMPLEMENTATION OF POLYACRYLAMIDE FOR RUNOFF FROM CONSTRUCTION SITES

by

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B.S.C.E. University of Central Florida, 2009

A thesis submitted in partial fulfillment of the requirements
for the degree of Master of Science
in the Department of Civil, Environmental, and Construction Engineering
in the College of Engineering and Computer Science
at the University of Central Florida
Orlando, Florida

Summer Term
2011

ABSTRACT

Polyacrylamide (PAM) is often used a part of a treatment train for the treatment of stormwater to reduce its turbidity. This study investigated the application of PAM within various treatment systems for a construction site environment. The general concept is to introduce hydraulic principles when placing PAM blocks within an open channel in order to yield high mixing energies leading to high turbidity removal efficiency. The first part of the study observed energy variation using a hydraulic flume for three dissimilar configurations. The flume was ultimately used to determine which configuration would be most beneficial when transposed into field-scale conditions. Three different configurations were tested in the flume, namely, the Jump configuration, Dispersion configuration and the Staggered configuration.

The field-scale testing served as both justification of the findings within the controlled hydraulic flume and comprehension of the elements introduced within the field when attempting to reduce the turbidity of stormwater. As a result, the Dispersion configuration proved to be the most effective when removing turbidity and displayed a greater energy used for mixing within the open channel. Consequently, an analysis aid is developed based on calculations from the results of this study to better serve the sediment control industry when implementing PAM blocks within a treatment system.

Recommendations are made for modification and future applications of the research conducted. This innovative approach has great potential for expansion and future applications. Continued research on this topic can expand on key elements such as solubility of the PAM, toxicity of the configuration within the field, and additional configurations that may yield more advantageous energy throughout the open channel.

ACKNOWLEDGMENTS

I would first like to recognize my committee members: Dr. Manoj Chopra, Dr. Marty Wanielista, and Dr. Alain Kassab. Each of you has provided guidance that has structured not only the progression of my thesis, but my advancement as a respectable engineer and I am sincerely thankful for all of your efforts. I wish to extend a special thanks to Dr. Manoj Chopra who has not only served as my Committee Chair, but as a mentor throughout my college career. Many can teach, few can lead, but it takes a very unique role-model to positively change the character of a student that will last a lifetime. For that, I am forever grateful.

I also would like to thank Mike Hardin and Ikiensinma Gogo-Abite for their labor, guidance, and patience throughout the course of the research. Their support has been immeasurable and they have made every day a learning experience.

Thanks to the University of Central Florida, the Stormwater Management Academy, Seva Iwinski and Katie with Applied Polymer Systems, John Slupecki with American Excelsior, Jonathan Chang, Dan Smith, Kim Vazquez, Matthew Goolsby, Erik Stuart, Clayton Bender, Nicole Runnebaum, Jamie Capra, Jesus Ozuna, Rylee Hernandez, Daniel Hernandez, Lorena Jaramillo, Asaph Mauck, Scott Glancy, Travis Bates, Albert Rivera, Andrew Hood, Drew Rossi, Laura Holliman, Josh Sasser, Alex Parra, Jordan Yarnell, Juan Cruz, Yunus Salami, Zachary Haber and all the friends that have assisted with the research.

I am especially thankful for my family and all of the support they have shown. I could not have achieved this accomplishment without the consistent encouragement from my mother, brothers, and sister. Lastly, I would like to dedicate my thesis to my mother; the strongest women I have ever known. You have made me into the man I am.

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1 CHAPTER 1: INTRODUCTION

1.1 Problem Statement

Rivers, lakes, and streams across the United States are becoming more frequently damaged by sediment than any other pollutants (Hayes and McLaughlin 2005). According to the Environmental Protection Agency, nonpoint source pollution remains the nation's largest source of water quality problems. It's the main reason that approximately 40 percent of our surveyed rivers, lakes, and estuaries are not clean enough to meet basic uses such as fishing or swimming (USEPA 1996). Nonpoint source pollution occurs when rainfall, snowmelt, or irrigation runs over land or through the ground, picks up pollutants, and deposits them into rivers, lakes, and coastal waters or introduces them into ground water. Sediment mobilization impairs 13% of the assessed streams and contributes to 38% of the water quality problems (R. A. McLaughlin 2004). Disturbed, unprotected soils experience significant erosion compared to protected soils; be it from wind or due to stormwater runoff. More specifically, construction sites are among the most common areas to experience significant soil erosion due to the need to clear, grade and fully prepare a site for the commencement of construction. Construction sites have the capability of contributing significant loads of sediment to small areas in short periods of time (Kaufman 2000). Despite regulation, and due to the lack of effective enforcement, many modern construction sites suffer substantial sediment loss rates contributing to the degradation of neighboring environments such as wetlands, lakes, and rivers.

Uncontrolled erosion and sediment transport from land development activities also result in costly damage to aquatic areas and to both private and public lands (Livingston and McCarron 1988). As a fiscal matter, it is estimated that the annual cost to society for onsite loss of soil, nutrients, water and yield reduction due to soil erosion is over $27 billion per year (Faucette, et al. 2005). The Florida Department of Environmental Protection (FDEP) has set standards for the discharge of stormwater from an active construction site to a maximum turbidity of 29 Nephelometric Turbidity Units (NTU's) above background levels or not exceed background levels for outstanding Florida water bodies (FDEP, 1988). NTU's are basically units of clarity for water samples whereas a mixture of soil and water can achieve an NTU value in the thousands. This standard often requires the addition of chemical treatment to traditional BMPs to meet discharge requirements. Polyacrylamide (PAM) is water-soluble and used as a thickening or clarifying agent (Hydrosorb 2002). A primary focus of its development is to bring constituents together to coagulate or flocculate suspended solids in order to enhance the settlement and removal of these flocs from water and wastewater or to reduce soil movement. A practical, cost-effective system for dosing runoff with PAM is one of the key impediments to its extensive use (R. A. McLaughlin 2006). PAM comes in the form of powder or blocks. Blocks are typically used within a treatment system.

Currently, there is a lack of a scientific approach when utilizing PAM blocks within a treatment channel for turbidity removal. The industry is well aware of the capabilities of PAM regarding turbidity removal, yet much work is still needed to improve the feasibility and optimum configuration to place the blocks. PAM block placement is commonly a subjective choice and it is this very approach that may lead to overdosing a channel and less than anticipated turbidity removal efficiencies.

1.2 Research Objective

The primary goal of this research is to develop a scientifically sound design method based on experimental measurements and theoretical and empirical relationships for the use of PAM in a treatment channel to achieve turbidity removal in an effort to assist in meeting discharge requirements. Extensive experimental testing is conducted using a hydraulic flume and a full-scale field channel. Based on the findings, a scientific approach is used to derive equations for the placement of PAM blocks in a treatment channel that will result in optimal turbidity removal efficiency. These design equations will assist the scientific and construction community in the design of the treatment channel itself as well as the placement of baffles and PAM blocks.

The intent is to provide engineers and contractors with an easy to use technique for the design of PAM based treatment channels as opposed to the methods that currently exist. Both an under designed and over designed treatment system will not be cost effective. An under designed channel will continuously discharge turbid water while wasting the capacity of the PAM in use. An over designed channel will over dose the turbid water and can cause re-suspension of the excessive floc making the water turbid once again even after treatment. Such a system may also result in high levels of toxicity. This study will result in closer agreement between laboratory-scale results and observed full-scale results, improved performance of PAM blocks, reduce excess cost in materials and labor, and also reduce negative downstream effects from turbid stormwater discharges.

The research project aims to take some introductory steps in discovering a more strategic and scientific method of implementing PAM in combination with baffles within a treatment channel. The treatment channel consists of PAM blocks and masonry blocks to serve as baffles to provoke mixing. Masonry blocks have been chosen due to its accessibility on construction sites. Design equations are developed to provide a more encompassing approach to the configuration of PAM blocks and baffles in these treatment channels.

The primary objectives for the research project are:

1. *Evaluation of three different configurations of polyacrylamide blocks and baffle placement in a treatment channel using a hydraulic flume system in the laboratory*
2. *Derivation of design equations based on laboratory findings and empirical equations*
3. *Determination of turbidity removal efficiency in field-scale testing utilizing optimum configurations from objective 2 yielding the chosen mixing energy determined in the previously completed lab-scale testing*

1.3 Overview

Erosion is labeled as the process by which rainfall, wind, and water dislodges soil particles (Erosion & Sediment Control Designer & Reviewer Manual, June 2007). Sedimentation can destroy aquatic habitats, and high volumes of stormwater runoff can cause stream bank erosion (EPA, 2010). Consequently, stormwater runoff from construction activities has a significant influence on water quality. As runoff flows over disturbed soils, it can pick up pollutants like sediment, debris, and chemicals, and transports these to a nearby storm sewer system or directly to a river, lake, or coastal water (EPA, 2010).

PAM is a high molecular weight polymer and is widely used to control erosion in furrow irrigated agriculture. It functions by increasing cohesion, by strengthening soil particles, and by flocculating the suspended particles in the solution thereby creating larger aggregates and as a result decreases the transportability and helping particles to settle (Soupir, et al. 2004).

The increasing popularity of PAM within the industry forces the need for a more regulated implementation. By doing so, one can associate certain mixing durations and dosages to obtain a desired turbidity removal efficiency. The application of PAM also raises concerns of any implications it may have to the discharging environment. When any new chemical product, such as PAM, is introduced into the market, it is essential that it undergoes testing to reassure that it has no negative environmental effect.

The introduction of polyacrylamide (PAM) in the erosion control industry began in the 1990's (Soupir, 2004). It is used as a method of erosion control in various construction activities to clean discharge waters from the construction site before dispensing to receiving water bodies. PAM is a polymer that comes in various molecular weights and is widely used to control erosion in agriculture. It mainly functions by increasing cohesion, strengthening soil particles, and flocculating the suspended particles in the solution creating larger aggregates. As a result, this decreases the transportability of suspended particles and allows the particles to settle (Soupir, 2004). Flocculation is essentially an aggregation process assisted by organic electrolytes such as polymers. The main intent is to settle the suspended colloidal particles in water/wastewater quickly which typically settle slowly in normal conditions.

Despite PAM's introduction in the stormwater industry roughly two decades ago, there is not much research available on the application of polymers (McLaughlin, 2005 & Soupir, 2004). The industry has been using PAM for years, yet the applicability on site has been somewhat experimental. The approach has been to place a random dosage within a channel and allow the discharge water to contact the PAM, whereby the water clarity can be improved.

2 CHAPTER 2: LITERATURE REVIEW

2.1 What is Polyacrylamide?

Polyacrylamide is a synthetic, long-chain polymer designed to attract either positively charged particles or negatively charged particles. The long chain refers to the molecules basically repeating themselves many times for the manufacturing of the polymer. Commonly referred to as PAM, polyacrylamide is water-soluble and used as a thickening or clarifying agent (Hydrosorb 2002). A primary focus of its development is to bring constituents together to coagulate or flocculate suspended solids in order to remove them from water and wastewater or to reduce soil movement.

Pure PAM is a homopolymer of equal acrylamide units. PAM can be formulated with copolymers to give the specific charges. Both molecular weight and charge give PAM its various characteristics (Green and Stott 2001). Increasing the molecular weight increases the length of the polymer chain and the viscosity of the PAM solution. High molecular weight PAMs tend to be more effective than low molecular weight PAMs (Green and Stott 2001).

2.1.1 Types of Polyacrylamides

Three primary types of PAM currently exist; anionic, cationic, and non-ionic. The ionic charge properties of PAM play an integral role in its adsorption to the soil (Green and Stott 2001). Anionic polyacrylamide has molecules that carry a negative charge and pick up positively charged particles such as silty clayey sand and sand. It has no aquatic toxicity (Hydrosorb 2002). A highly anionic polymer would have an extended chain as the negative groups would repel each other. Anionic PAM, being negatively charged like silty clayey sand surfaces, would be expected to experience repulsion from the negatively charged silty clayey sand sites, however, it binds the negative sites through a process called cation bridging. Divalent cations are able to bridge the two negatively charged species together (Green and Stott 2001). Each positive charge of the divalent cation binds to one of the negative sites, either the silty clayey sand surface or the anionic PAM.

Conversely, cationic polyacrylamide has molecules that carry a positive charge. They attract negatively charged particles such as organic materials like carbon or human waste. Cationic polyacrylamide has very limited use due to the highly toxic potential to aquatic organisms (HydroDynamics and Stormwater Management Academy 2007). Cationic PAMs have shown significant toxicity issues to aquatic organisms and their use is commonly prohibited for most in-situ applications. Lastly, non-ionic polyacrylamide has molecules with no charge and is commonly used in mining applications. It has been suggested that nonionic polymers are too tightly coiled to induce beneficial soil interactions (Green and Stott 2001).

PAM is manufactured in three forms; block, powder, and liquid. Each has respective value when implementing into the field. The block form is typically introduced within treatment trains such as baffle boxes and open channels. Similar to soap on a rope, the block is formed with a rope anchored in the center for ease of positioning. The powder is commonly used for soil stabilization and enhancing vegetation. It is easily dispersed using a hydroseeding method. The liquid form dissolves more immediately, but it is more difficult to package and ship (Burridge 2005).

2.1.2 Processes using PAM

Past research has proven filtration alone is not enough to produce clear, clean water. Direct filtration is largely ineffective in removing all bacteria, viruses, soil particles and color, all of which contribute to turbidity. Two primary processes are used in water treatment within the industry, namely coagulation and flocculation

Coagulation is the process that causes the colloids to approach and adhere to each other to form larger particles, referred to as flocs (MWH 2005). Subsequently, flocculation turns the smaller particles of turbidity, color, and bacteria into larger flocs, either as precipitates or suspended particles making them more susceptible for removal (HydroDynamics and Stormwater Management Academy 2007). During coagulation, a positive ion is added to water to lessen the surface charge to the point where the particles are not resisted from each other. A coagulant is the chemical substance that is introduced into the water to accomplish this reaction. The most widely used coagulants in water treatment are aluminum sulfate and iron salts.

2.1.3 Water Clarity Alternatives

In addition to polymers such as polyacrylamides for turbidity removal efficiency are aluminum sulfate, referred to as alum, iron salts, and chitosan. Alum is employed more frequently than iron salts because it is usually cheaper. The principal factors affecting the coagulation and flocculation of water are turbidity, suspended solids, temperature, pH, cationic and anionic composition and concentration (Crittenden, et al. 2005). Similar to investigating soil specific polymers, it is vital to use laboratory or pilot plant coagulation studies, since a given source water may show optimum coagulation results for a particular coagulant. Due to the sequence of reactions that occur following the addition of alum or iron salts, it is not possible to predict the inferential performance of a coagulation process (MWH 2005).

Chitosan is a partially deacetylated polymer obtained from the alkaline deacetylation of chitin, biopolymer extracted from shellfish sources (Renault, et al. 2009). Deacetylation describes a reaction that removes an acetyl functional group from a chemical compound. This amino-biopolymer has received a great deal of attention in the last decades in water treatment processes for the removal of particulate and dissolved contaminants. In particular, the development of chitosan-based materials as useful coagulants and flocculants is an expanding field in the area of water and wastewater treatment. Their coagulation and flocculation properties can be used to eradicate particulate inorganic or organic suspensions, and also dissolved organic substances (Renault, et al. 2009).

2.2 Industrial Application of PAM

The coagulation and flocculation processes are used as a pretreatment prior to biological treatment in order to enhance biodegradability of the wastewater during the biological treatment. An essential feature of wastewater flocculation is the elimination of suspended solids (SS) and as much of the organic materials as possible. This process is commonly used for treatment in which compounds such as ferric chloride and/or polymer are added to wastewater in order to destabilize the colloidal materials and cause the small particles to accumulate into larger settleable flocs (Crittenden, et al. 2005). Several studies have reported the examination of this process for the treatment of industrial wastewater, especially with respect to performance optimization of coagulant/flocculant, determination of experimental conditions, assessment of pH and investigation of flocculant addition.

2.2.1 Beverage Industrial Wastewater Treatment

Amuda and Amoo, 2006 examined the effectiveness of the coagulation and flocculation processes using ferric chloride and polyelectrolyte, a non-ionic polymer, for the treatment of beverage industrial wastewater. The research revealed polyelectrolytes are advantageous over chemical coagulants because they are safer to handle and are easily biodegraded. Some of the raw materials used in the production of the beverages enhanced the organic load of the wastewater. The effects of dosages of ferric chloride and polyelectrolyte were also studied.

Samples of the wastewater were collected during the course of 9 months, three days a week. The organic matter analyzed for reduction was chemical oxygen demand (COD), total phosphorus (TP), and total suspended solids (TSS). The experiment examined the sole use of ferric chloride as well as in conjunction with the non-ionic PAM. Results verify that as the dosage of sole ferric chloride increases, as does the removals of COD, TP, and TSS, yet it is only linear until approximately 300 mg/L. It is stated that this may be caused by re-suspension of particles (Amuda and Amoo 2006).

When introducing the non-ionic PAM, the removal of COD reached 70% during the use of 100 mg/L ferric chloride and 5 mg/L polyelectrolyte (Amuda and Amoo 2006). Unlike the sole use of the chemical coagulant, when using polyelectrolyte, the TSS continuously increased when the dosage was increased. Although the removal percentages for the three organic matter analyzed did not achieve as high of a percent removal as the ferric chloride, the data reveals a linear increase with the use of PAM. The combined use of coagulant and PAM resulted in the production of sludge volume with reduction of 60% of the amount produced when coagulant was solely used for the treatment.

Dosage is a key factor when introducing PAM to the treatment process. The optimum dose of a coagulant or flocculant is defined as the value above which there is no significant difference in the increase in removal efficiency with a further addition of coagulant or flocculant (Amuda and Amoo 2006). This study concludes that the optimum doses of ferric chloride and polyelectrolyte that enhanced COD removal were 100 and 25 mg/L, respectively.

2.2.2 Pulp and Paper Mill Industry

In addition to the beverage production, the pulp and paper mill industry is a very water-intensive industry and constitutes a major source of aquatic pollution due to its high organic substances containing suspended solids, metals, fatty acids, etc. The effluent is toxic to aquatic organisms and exhibits strong impairments to neighboring ecosystems.

The flocculation performances of nine cationic and anionic polyacrylamides with different molecular weights and different charge densities in the treatment of pulp and paper mill wastewater have been observed. The experiments were conducted using jar tests. The dosages of the polyacrylamide ranged from 0.5 – 15 mg per liter (Wong, et al. 2006). An additional variable was the varying revolutions per minute. Rapid mixing at 200 rpm for 2 minutes followed by slow mixing at 40 rpm for 15 min and settling time of 30 minutes. The efficacy of the PAMs were measured based on the reduction of turbidity, the removal of total suspended solids (TSS) and the reduction of chemical oxygen demand (COD).

The PAM that was observed to work the best was the cationic Organopal 5415. This particular blend has a very high molecular weight and low charge density. It was stated to achieve a 95% turbidity removal efficiency and 98% of TSS removal. The outcome of the research suggests that a single-polymer system can be solely utilized in the coagulation-flocculation process due to the efficiency of the PAM to increase sedimentation due to gravity assuming a settling time of 30 minutes.

2.3 Field Testing Evaluation within Construction Environment

PAM has been proven effective in flocculating suspended sediment, but practical methods for introducing it into stormwater to reduce turbidity have limited its use for this purpose. The U.S. Environmental Protection Agency has documented that sediment is the major pollutant of streams and rivers in the United States (R. A. McLaughlin 2006).

Researchers at North Carolina State University have conducted many research projects enhancing the usage of PAM. More specifically, these studies have resulted in increased implementation of PAM blocks within a construction environment. In one particular study, a storage pond was used to provide gravity flows through 30 cm pipes to three sediment basins. Soil was then added to the flows in the pipes approximately 10 m from the discharge into the basins. The basins were all lined with geotextile to prevent scour and to allow sediment removal without altering the basin dimensions (R. A. McLaughlin 2004).

The inclusion of the PAM blocks always resulted in significant turbidity reduction. Generally, the longer the mixing time after the introduction of PAM, the better the flocculation is. It is stated that by placing the blocks at the end of the pipe revealed some evidence of increased turbidity, but was not deemed significant. Overall, the PAM blocks reduced turbidity significantly, although increasing the number of blocks did not improve the clarity of the water (R. A. McLaughlin 2006). Regardless of the outlet type used, the PAM treatment reduced turbidity more than any outlet effect. The research reveals that turbulent zones should try to be avoided. The creation of turbulent zones, induced by weirs in this project, is stated to may have contributed to the higher turbidity during those particular trials.

Additionally, McLaughlin (2006) has also observed temperature to influence the turbidity of water during his testing. It was found that the flocculation effect is greatly reduced under cold water conditions or when the blocks are allowed to dry between events, most likely due to increased water viscosity. Raising water temperature is usually not an option for managing runoff, but the PAM blocks should remain moist between treatments for most favorable results

(R. A. McLaughlin 2006). Experimentation under construction site conditions also indicated that PAM blocks need to be placed to avoid sediment or other material accumulations on the blocks, which tend to become coated and ineffective under those conditions.

Further research conducted by McLaughlin (2004) utilized different basin configurations. The optimal basin configuration for maximum turbidity reduction using PAM blocks included porous baffles made of a jute/coir material. The conclusion of the field tests ultimately revealed that the outlet type did not significantly change the turbidity of the reduction by PAM (R. A. McLaughlin 2004).

The implementation of sediment bags within the open channel was also examined to retain sediment and reduce turbidity, particularly in combination with PAM. These bags are commonly used as filters when sediment-laden water is pumped from excavated, construction sites (R. A. McLaughlin 2004). Several different types of materials were tested with and without adding PAM and measuring turbidity in the outflow. Ultimately, it was observed that the bags would always decrease the turbidity, but there was an apparent clogging problem (R. A. McLaughlin 2004).

2.4 Extending Retention Time

A vital interest when flocculation is occurring is settling time. One of many options is to extend retention times throughout the course of a containment area. Stormwater ponds designed to address water issues are only as sufficient as the time permitted to treat the water. They are infrequently considered ideal basins for water quality improvement. Generally, they are small and therefore the average retention time is much significantly smaller than the allotted 24 to 48 hours prescribed for quality ponds (Matthews, et al. 1997). This allows for little opportunity for the water to be treated.

In 1997, the objective of the Kingston Township Stormwater Pond Project was to retrofit the pond to improve its pollutant removal characteristics. The conception was that by increasing the effective retention time of the pond, the removal of waterborne pollutants through sedimentation should be increased. Directly connected to the pond is the Little Cataraqui Creek, which at the time the experimentation was conducted experienced an increase in runoff. This overload caused the pond to be hydraulically ineffective for the purposes originally anticipated. The baseflow levels during the summer months were approximately 0.03 m^3/sec.

Baffles, which are simply impermeable flow barriers, were installed within the stormwater pond to prevent short-circuiting of influent water and in-pond dead zones. This modification within the pond proved to increase mean residence time of the influent water which ultimately increased the effectiveness of the pond in removing pollutants through sedimentation (Matthews, et al. 1997).

Retention times in the retrofitted pond were determined using dye tracing readings. As explained by R.R. Matthews, et. al.(year?), a known mass of a fluorescent dye was injected at the inlet of the basin and the time series of dye concentrations was recorded at the outlet. These measurements were taken at various flows from mid-summer baseflow periods to higher post storm event flows. To measure the concentration of dye downstream in the pond effluent, water was pumped from the pond using a small bilge pump.

The installation of the baffles decreased the velocity and increased the amount of water retained throughout each trial as hypothesized. This translated into an increase in the time available for solids settling in the pond, and most likely an increased removal rate of influent suspended solids. Also, the avoidance of short-circuiting in the pond and the subsequent improvement in mixing ensures that stormwater does not flow through the pond without some enhancement of its quality by pollutant settling. It is stated that the improvements should especially be significant under slightly higher flows associated with small, frequent storms.

These measures taken for stormwater treatment are applicable to PAM treatment as well. The retention time baffles provide allow for the flocculated particles to settle and more easily be maintained. By introducing baffles, an open channel has the potential to create agitated mixing zones for PAM blocks and more effectively clean discharge water.

2.5 Soil Enhancement and Runoff Reduction

Part of the attractiveness of PAM is its versatility. It can be used for water clarity and pollution control, but it is also commonly used for soil stabilization such as steep slopes in construction, highway cuts, and other disturbed soils (Orts, et al. 2007).

William J. Orts et al., 2007 took full advantage of PAM's potential for soil stabilization for different applications. The first application was within runoff water. Low concentrations of anionic, high purity PAM eliminated sediment by more than 90% when added to irrigation water at 10 ppm (0.009988 grams/L). The second application was utilized at construction sites and road cuts at a rate of 49.6 lbs./ha^2. The testing for this application was conducted using simulated heavy rains and reduced sediment runoff by 60-85% (Orts, et al. 2007).

The remaining application was a mixture of polyacrylamide, aluminum chlorohydrate, and superabsorbent cross-linked PAM/acrylic acid copolymer referred to as "Tri-PAM". This was uniquely used to minimize the propagation of dust and soil during helicopter landings in arid soils such as that found in the Middle East. Ultimately, the PAM without the mixture had greater dust reduction at the helicopter pads, although the Tri-PAM was still very effective (Orts, et al. 2007).

Alongside reducing turbidity in discharge waters within a construction site, PAM also has a large capacity to reduce runoff. Both dry and liquid PAM has proven to reduce runoff, but only by a maximum of 5% (Soupir, et al. 2004). As the PAM is distributed amongst the landscape, any rain event will cause the soil specific polymer to adhere with the particles and create a mat effect retaining the soil. Improvements in aggregate stability achieved at low PAM application rates depend upon polymer charge density, soil moisture content, and type of exchangeable ion (Soupir, et al. 2004).

Additional research conducted by Yu, et al. (2002) also reveals evidence of soil augmentation. The general intent for this study was to increase infiltration rates on soils while reducing runoff and erosion using both gypsum and dry PAM. Seals are typically formed at the soil surface causing limited permeability and subsequently more runoff. It is suggested that PAM be distributed to the soil surface prior to the rainy season.

The experiments were conducted using a drip-type rainfall simulator. During each simulated rain event, the infiltration water was captured by a graduated cylinder every 4 minutes; water volume was recorded as a function time (Yu, et al. 2002).

Yu, et al., (2002) stated that the introduction of PAM on the upper 5 mm layer before exposing the soil to distilled water rain resulted in infiltration rates that correlated with control treatment. The combination of dry, granular PAM and gypsum significantly increased the infiltration rate on the silty loam soil. This is due to the characteristics of the gypsum. When rainwater comes in contact with the dry PAM and gypsum mixture, gypsum dissolves and increases the electrolyte concentration in the soil solution.

The introduction of PAM did not prevent seal formation, yet the mixture of PAM and gypsum had remarkable infiltration results with sandy silty clayey sand (Yu, et al. 2002).

Ultimately, PAM solely mixed with the soil did not seem to increase the infiltration rates through the soils, but PAM was very effective in reducing soil losses. Mixing dry PAM with soil was most effective in preventing erosion, because it increased inter-particle bonding due to the long polymer chains.

2.6 Wide Range of Usage of PAM in Conjunction with BMPs

Construction activities, including roadway projects, can be major contributors to sediment loading in streams and lakes. Polymers have also been used in conjunction with standard practice to enhance turbidity removal efficiency. A practical approach is simply to add a dosage to any existing erosion control or turbidity removal parameter, but experiments and application have proven this idea to be more scientific. A few categories the industry has coupled with polymers are fiber check dams, soil stabilization, armoring with matting, retrofits, and sediment retention barriers (HydroDynamics and Stormwater Management Academy 2007).

2.6.1 Fiber Check Dam Augmentation

Standard BMP's have been used alongside PAM and fiber check dams (FCDs) to provide sediment control. Significant reductions in turbidity and total suspended solids have been obtained using the FCDs, particularly those with PAM added (McLaughlin, et al. 2009). In McLaughlin et al.'s past study in 2009, two sites were used and both sites complied with standard best management practices. The sites consisted of small sediment traps followed by rock check dams. The PAM treatment contained approximately 100 grams of APS 705 lightly interspersed over the lower, center portion of each fiber check dam and over a small section down slope (McLaughlin, et al. 2009). PAM was reapplied after every major storm event, roughly twice a month. Runoff was collected by portable water samplers programmed for flow-weighted sampling.

The increase in turbidity with greater flows was suppressed substantially with the addition of polyacrylamide to the fiber check dams and remained well below 50 NTU. McLaughlin et al., 2009 also described a cost estimate comparison. The conservative results reveal that the fiber check dam system is comparable to cost with the standard practice of installing a shallow sediment trap beside a rock check dam. The fiber check dam system coupled with the granulated PAM resulted in turbidities of <10 NTU (McLaughlin, et al. 2009).

2.6.2 Polymer Enhanced Soil Stabilization

As previously mentioned, polymers have been used to stabilize soil on any slope condition. The granular polymer reacts with the soil, binding the mulch, seed, fertilizer, and other additives to the soil, holding it together until vegetation is established (Yu, et al. 2002). One method of doing so is through hydroseeding. A soil specific polymer can be added into the hydroseeding mix and disbursed over slopes. For example, on July 10, 2005 Hurricane Dennis raged through the Florida panhandle. Once the damage was completed, the Florida Department of Transportation needed to immediately implement a cost effective solution to maintain the shoulder erosion of US Highway 98. Soil specific APS 705 Silt Stop powder was introduced at a rate of 50 pounds per acre with open weave jute matting. Above that layer was then Bermuda grass sod (Systems 2006).

Over one year later, it is stated that the soft armoring technique is still performing well, requiring little maintenance and successfully mitigating coastal erosion. Over time, the jute mat has biodegraded and the sod vegetation has continued to establish root structure into the underlying topsoil. The shoulder areas along US Highway 98 are so well stabilized that they can now be used as access to the waterfront without fear of erosion (Systems 2006).

2.6.3 Polymer Enhanced Armoring with Matting

Polymer enhanced armoring with matting is the process by which soft flexible matting such as jute is placed onto the soil surface being treated. A soil specific polymer is then applied which reacts with the metals and silty clayey sands within the soil to bind it together. This complex attaches to the matting creating a highly erosion resistant surface that will support vegetation along with aiding in the attachment of fine particulate to the matting surface (HydroDynamics and Stormwater Management Academy 2007). Similar to the situation with the US Highway 98, it is common for all matting to be biodegradable.

2.6.4 Polymer Enhanced Retrofits

A retrofit is a device or structure placed in front of a permanent stormwater structure to serve as a temporary sediment filter and water removal device. Polymers blocks have been introduced upstream from retrofits reacting with metals and silty clayey sands within the soil to bind it together, allowing suspended sediment to be collected using jute or other organic matting downstream. In addition within this treatment option are check dams. These dams are installed upstream of the polymers in order to mitigate the sediment contact with the polymer blocks (HydroDynamics and Stormwater Management Academy 2007).

2.6.5 Sediment Retention Barriers

Sediment retention barriers are presented on graded sites to trap the fine sediment and silty clayey sands that flow through the silt fence barrier. The barrier is usually a double row of silt fence, standing about 4-6 feet apart filled with organic material such as straw or mulch.

Within the organic material, designers commonly blend soil specific polymer. The polymer within the organic material reacts with the suspended sediment, adjoining it into large particles that are trapped within the organics, clarifying the runoff (HydroDynamics and Stormwater Management Academy 2007).

Many other methods exist of coupling polymers to commonly exercised turbidity removal techniques. Strategically, polymers are placed serving as either a preliminary removal measure or a polishing step subsequent to the main application. In order to remain fiscally responsible when implementing polymers, it is vital to work in conjunction with professionals so overdosing does not occur. Limitations will arise and are common within construction sites, therefore, the proper enactment of polymer is a matter of not only the soil that is native to the site, but the basic environment surrounding where to place the application itself.

3 CHAPTER 3: BACKGROUND

3.1 Previous Work

Currently in the State of Florida, PAM is one accepted treatment standard as a best management practice (BMP) for erosion and sediment control within a treatment train. PAM can be applied to many different BMPs in order to help reduce the turbidity in the runoff from sites requiring turbidity and sediment control. However, there are several different manufactured forms of PAM, each possessing different qualities which make each one soil specific. Some studies have been conducted on the proper dosage and toxicity of PAM and are described in the next section.

3.1.1 Stormwater Management Academy Index Testing

Index testing on polymer dosage conducted at the Stormwater Management Academy laboratory at the University of Central Florida provides insight to its effectiveness, based on soil specificity, reaction time and other variables. The reaction time is a function of the flow rate and concentration of polymer (dosage) in turbid water. The study revealed evidence that high removal efficiency of PAM can be achieved in a laboratory setting, but it is important that the factors necessary for the efficiency be modeled in the field. As a follow-up to the index testing study, there is the need for the replication of PAM removal efficiency in practical (field-scale) applications, such as in discharge channels on construction sites.

This research focuses on the proper implementation of PAM blocks within a construction environment with particular attention to energy variation and water clarity. Field testing is essential to apply the findings of the index tests, and more directly, to develop scientific and standard implementation of PAM. This project is intended to assist engineers, researchers and contractors to be more fiscally responsible by optimizing PAM block application, as well as provide guidance to yield optimum performance of the PAM blocks required by developing the requisite mixing energy. The Stormwater Management Academy has extensive experience in PAM and aims to develop a systematic approach for its on-site application.

Jar testing was conducted to facilitate a more comprehensive understanding of polyacrylamides' reaction when introduced to a soil/water mix. The procedure for the turbidity reduction efficiency analysis is listed below and Figure 1 shows some of the equipment used within the laboratory:

1. *Prepare 45 grams of sediment. Crush all sediment clumps into a powder without degrading the particle size.*
2. *Pour sediment in with 1,260 mL of di-ionized water and shake for 2 minutes.*
3. *Let bottle settle for 60 seconds.*
4. *Carefully pour solution into second bottle being conscious of not allowing the settled particles to intrude into the second bottle. Allow the settled particles to remain on the bottom of the initial bottle.*
5. *Check initial turbidity of solution in second bottle.*
6. *Place stir bar in 100 mL beaker and put on stir plate. Tear 150 mg of polyacrylamide and place within beaker.*
7. *Turn on stir plate to 700 rpm and gently pour 60 mL of solution from second bottle. Allow mix for 30 seconds from time of contact of solution to polymer.*
8. *Remove beaker from stir plate and allow beaker to settle for 60 seconds to allow for immediate settlement of flocculated particles.*
9. *Lastly, check the turbidity of the solution within the beaker subsequent to the settling.*

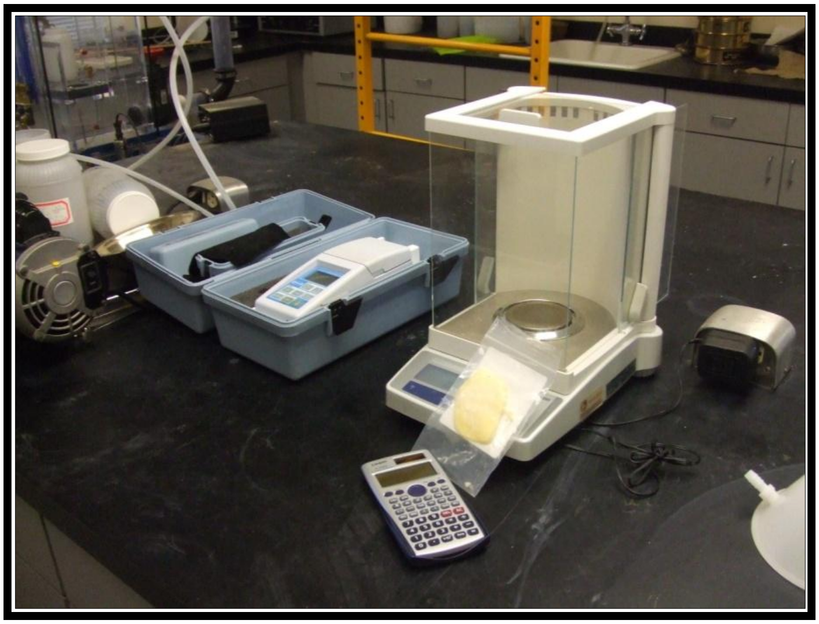

Figure 1: Turbidimeter, Scale, and PAM

This procedure was conducted on a wide range of PAM products provided by Applied Polymer Systems, Atlanta, GA. To further support the research conducted by the Stormwater Management Academy, below are charts and graphs resulting from examining one of the many polymers at different dosages, mixing speeds, and contact times. Table 1 is the turbidity removal efficiencies obtained in the laboratory at a concentration of 417 mg/L. Both Figure 2 and Figure 3 display the data in graphical form. Once approximately 60 seconds is achieved, there is an apparent plateau for the removal efficiencies obtained.

Table 1: PAM 745 @ 417 mg/L; Turbidity Removal Efficiencies Relative to Mixing Time and Speed

PAM 745: Efficiency with Time Speed							
Applied Polymer Concentration (mg/L)	*Mixing speed, ft/s*	1.4		2.6		3.8	
	Mixing Time, seconds	*w/o filter*	**filter*	*w/o filter*	**filter*	*w/o filter*	**filter*
417	30	59%	88%	91%	93%	96%	97.5%
	45	84%	91%	92%	95%	97%	97.8%
	60	96%	98%	96%	97%	98%	98.8%
	75	94%	97%	97%	98%	98%	98.5%
	90	93%	96%	97%	98%	99%	99.1%
	120	94%	96%	99%	99%	99.7%	99.7%

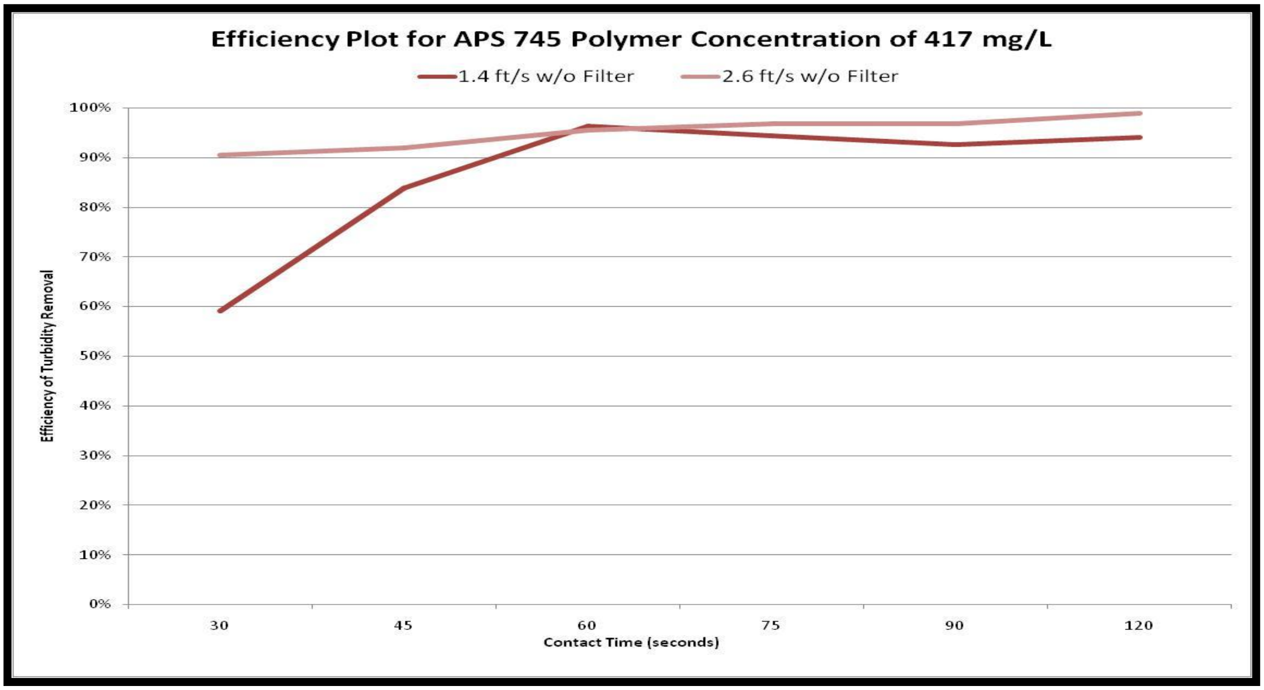

Figure 2: Plot of Efficiencies for APS 745 at 417 mg/L

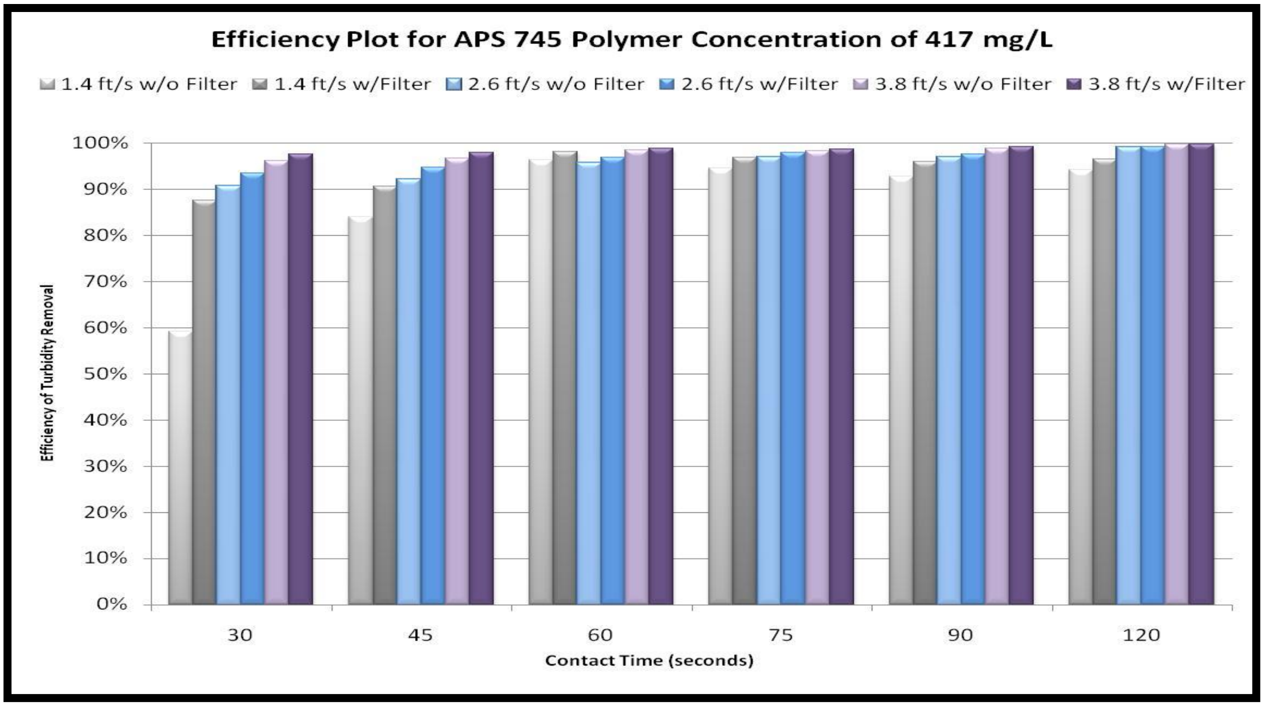

Figure 3: Bar Chart of Efficiencies for Polymer APS 745 at a concentration of 417 mg/L

Table 2 is the turbidity removal efficiencies for APS PAM 745 with double the concentration seen in Table 1. The graphical representation of the data can be observed in Figure 4 and Figure 5.

Table 2: PAM 745 @ 833 mg/L; Turbidity Removal Efficiencies Relative to Mixing Time and Speed

PAM 745: Efficiency with Time Speed							
Applied Polymer Concentration (mg/L)	*Mixing speed, ft/s*	1.4		2.6		3.8	
	Mixing Time, seconds	*w/o filter*	**filter*	*w/o filter*	**filter*	*w/o filter*	**filter*
833	30	74%	87%	84%	92%	90%	96%
	45	76%	87%	91%	95%	94%	96%
	60	89%	94%	92%	95%	96%	97%
	75	89%	95%	94%	96%	95%	97%
	90	92%	94%	93%	97%	95%	97%
	120	90%	94%	94%	96%		

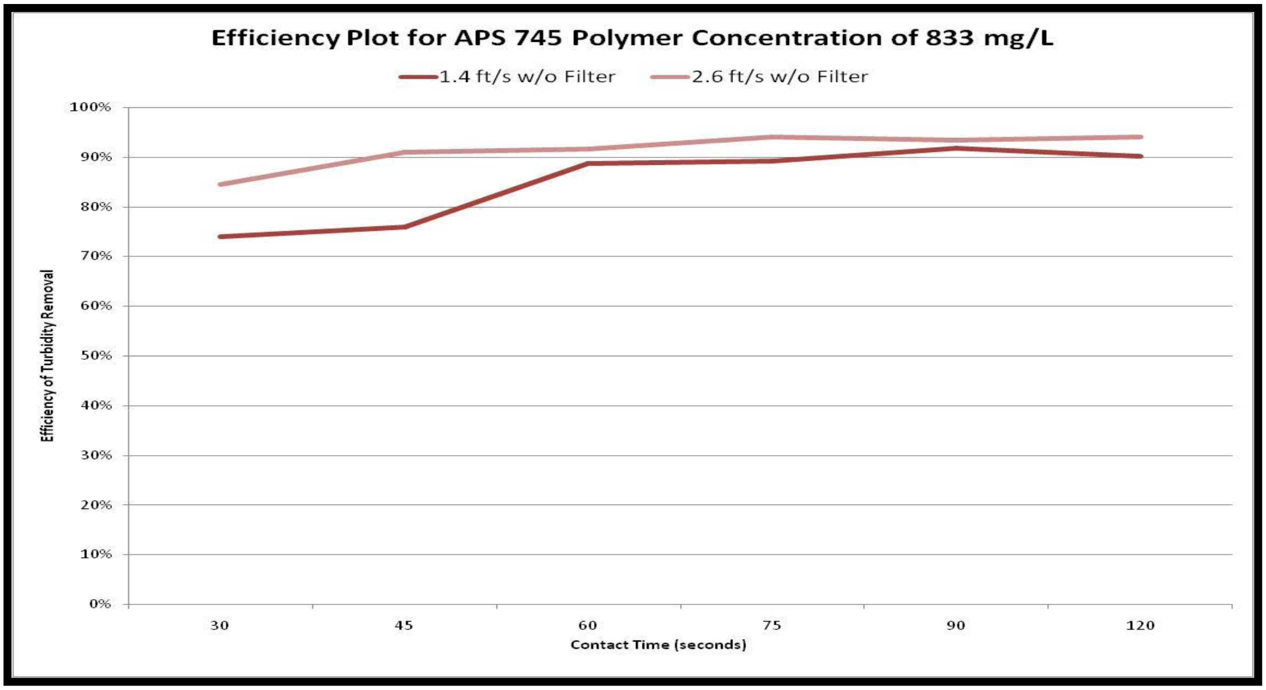

Figure 4: Plot of Efficiencies for APS 745 at 833 mg/L

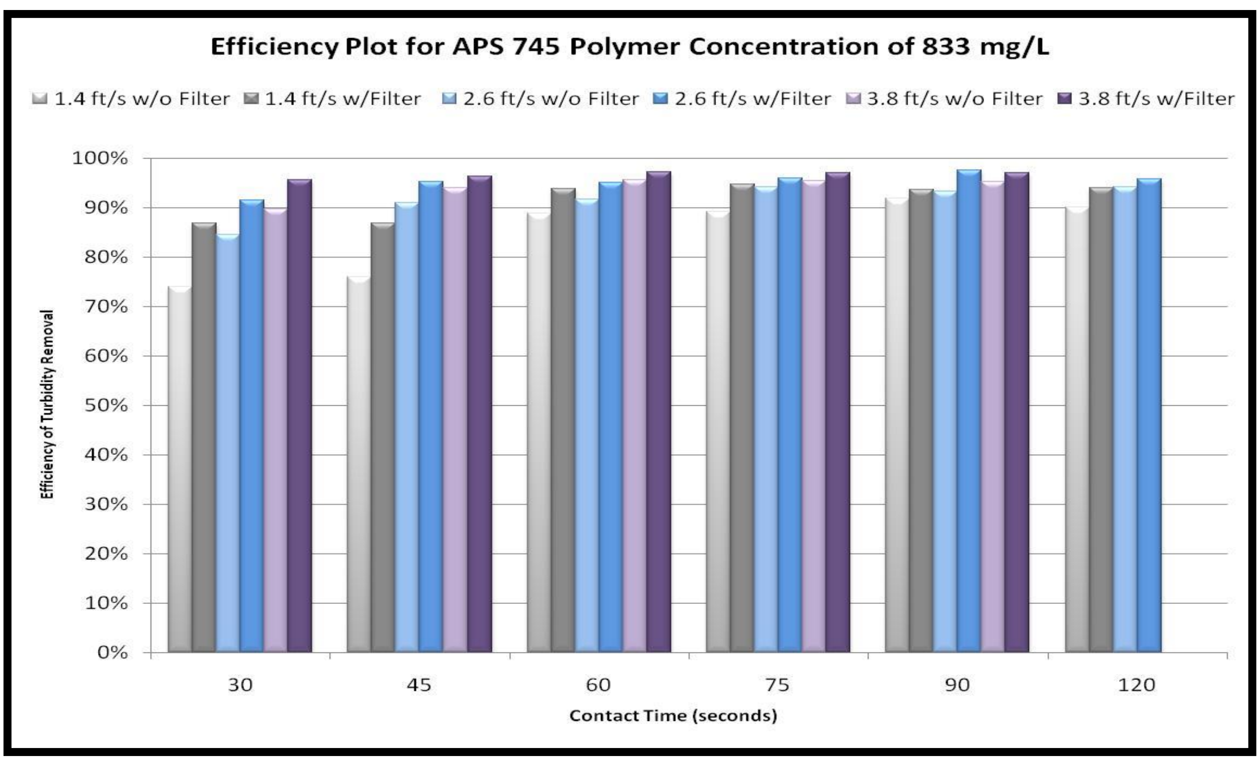

Figure 5: Bar Chart of Efficiencies for Polymer APS 745 at a Concentration of 833 mg/L

The conclusions from the previous jar testing clearly exhibit the effectiveness of polyacrylamide, whether in powder or block form. The dependence on duration and speed play a vital role in all incremental increases with the efficiency. As expected, as one increases mix speed as well as PAM dosage, the turbidity level decreases to improve clarity as shown in both Figure 3 and Figure 5. For instance, if one chooses to utilize a mixing speed of 1.4 ft/s with the APS 745 polymer, Figure 2 reveals that it is not until roughly 50 seconds of contact time that the efficiency level will comfortably plateau. Yet, if one chooses to use a mixing speed of 2.6 ft/s, high efficiency values can be achieved with minimal contact time involved. Even with a contact time of 30 seconds, the Figure above indicates that 85% to 90% efficiency of turbidity removal can be obtained. For instance, focusing on the efficiency line graph for APS 745 polymer concentration of 417 mg/L, it will take no more than 30 seconds of contact time to achieve an efficiency of at least 90% while it will take approximately 50 seconds if the mixing speed was lowered to 1.4 ft/s.

The reactions seen within the laboratory were obvious once the polyacrylamide was added to the turbid water. To serve as a better illustration of the effectiveness, Figure 6 is 60 ml of turbid water prior to mixing for 45 seconds where a stir bar can faintly been seen. Figure 7 is the same 60 ml of water after treatment. Floc particles can clearly be seen on the bottom of the beaker.

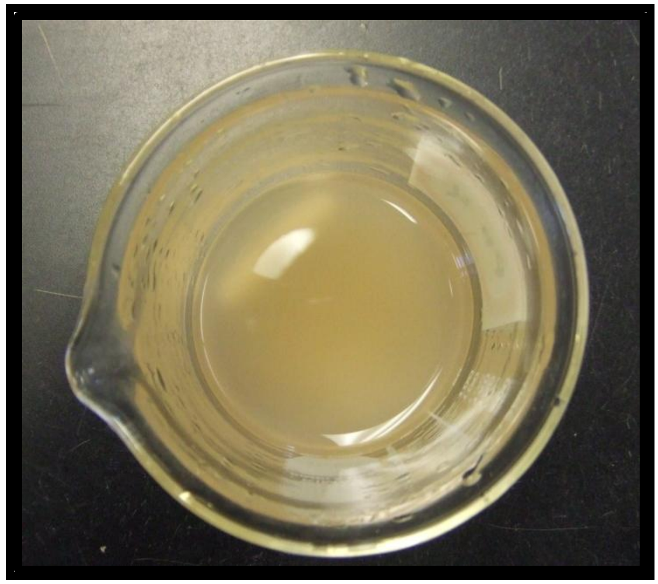

Figure 6: Water Sample Before Treatment

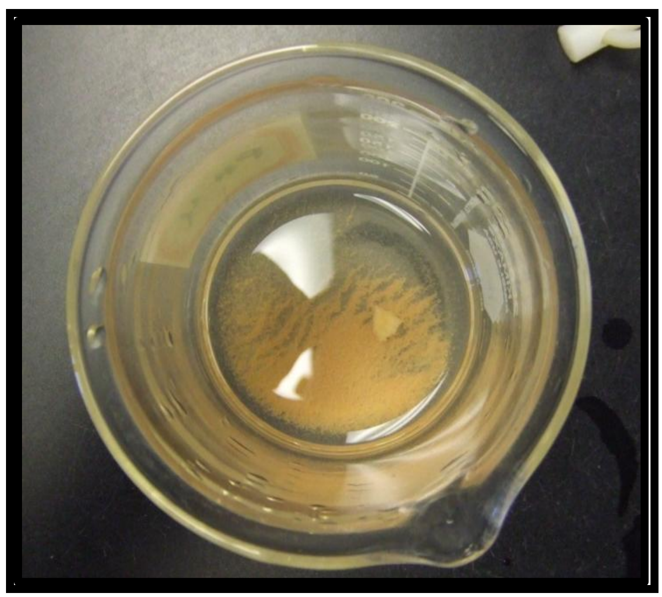

Figure 7: Water Sample After Treatment

All elements of the procedure greatly affect the outcome. There are many slight changes that may cause detectable differences although the dosages and speeds remain the same. For ideal results, it appeared as if the 1.4 ft/s speed was not sufficient. The research revealed much more volatility within the range of values at that speed. Ultimately, it is not needed to achieve the highest mixing speed and the greatest dosage to result in a high efficiency of turbidity removal. Examining these data, the different types of PAM tend to plateau where mixing speed and mixing time are variable. It is at that point that the efficiency of turbidity removal is static even as the variables increase. This awareness will greatly assist contractors and engineers to responsibly dose their discharge channels to achieve optimum turbidity removal efficiencies.

As the research progressed, potential causes for error were periodically noted. Some examples of potential sources of errors in the laboratory testing are moisture on fingers, different polymer block pieces possibly having different moisture contents, calibration of the turbidimeter, and also it sometimes would appear that immediate rotation once the polymer made contact to the solution did not always occur. A major concern, particularly with the polymer block, was the moisture of the polymer blocks. The blocks lose moisture constantly as they are exposed to the environment, which in turn affects their performance. The blocks in the field testing were kept in a wet condition to account for this limitation.

3.2 The Manning Formula and Hydraulic Principles

One of the most widely used formulas for uniform flow in open channels is that published by the Irish engineer Robert Manning. This formula produces a flow rate in cubic feet per second, Q. Manning had found from many tests that the value of *C* in the Chezy formula varied approximately as $R_h^{1/6}$, and others observed that the proportionality factor was very close to the reciprocal of n, the coefficient of roughness. In spite of the dimensional difficulties of the Manning's formula, which have overwhelmed those attempting to put all fluid mechanics on a rational dimensionless basis, it continues to be popular because it is simple to use and reasonably accurate. The Manning formula is below.

$$Q\ (cfs) = \frac{1.486}{n} A R_h^{2/3} S_0^{1/2} \quad \textbf{(1)}$$

n = roughness coefficient

A = cross sectional area of the flowing fluid

R_h = Hydraulic radius = A/wetted perimeter

S_0 = slope

Researchers encounter a number of different types of problems when using Manning's formula. For example, to find the normal depth of flow for a particular flow rate in a given channel, it is required to use a trial-and-error method because the initial height of water, y_0, is involved in A and R_h in complex ways (Finnemore and Franzini 2002).

3.3 Energy

The energy in open-channel flow is known to be the total energy in foot-pounds per pound. Ultimately, this yields a value of length. This relates to water in any streamline passing through a channel section and may be expressed as the total head in feet of water. This is equal to the sum of the elevation above the datum, the pressure head, and the velocity head which is a derivation from the prominent one-dimensional Euler Equation (Finnemore and Franzini 2002). For the case of an incompressible fluid such as water, the specific weight (γ) is constant. Integrating the Euler Equation, an energy per unit weight relationship can be derived for flow along a streamline.

$$\frac{p}{\gamma} + z + \frac{V^2}{2g} = constant\ (along\ a\ streamline) \quad \textbf{(2)}$$

This renowned equation is the Bernoulli's Theorem. When applying this equation, it is vital to recall the few basic assumptions that have been involved with the derivation of the Bernoulli Theorem:

- It assumes viscous (friction) effect are negligible;
- It assumes the flow is steady;
- The equation applies along a streamline
- It assumes the fluid to be incompressible; and
- It assumes no energy is added to or removed from the fluid along the streamline.

According to the principle of conservation of energy, the total energy head at the upstream section should be equal to the total energy head at the downstream section plus the loss of energy between the two sections (Chow 1959).

Specific energy in a channel section is defined as the energy per pound of water at any section of a channel, measured with respect to the channel bottom. The general equation becomes:

$$E = d\cos(\theta) + \alpha\frac{V^2}{2g} \tag{3}$$

Considering *d* to be the depth of the channel, α = 1.0, and the channel to have a small slope, the equation then becomes:

$$E = y + \frac{V^2}{2g} \tag{4}$$

This indicates that the specific energy is equal to the sum of the depth of water and the velocity head. It should be noted that flow conditions in open channels are complicated by the fact that the position of the free surface is likely to change with respect to time and space. The depth of flow, the discharge, and the slopes of the channel bottom are interdependent. Open-channel flow can be classified into many types and described in various ways (Chow 1959).

3.4 Brief Introduction to the Derivation Spreadsheet

The primary objective of this section is to understand the hydraulic principles behind the prospective open channel that will contain polyacrylamide blocks. A spreadsheet has been developed in Microsoft Excel that will quantify the various parameters of a trapezoidal or rectangular open channel using the Manning Formula. The following are the necessary input values for the derivation sheet: width of the discharge water, height of the discharge water, roughness coefficient, angle of the channel, and the side wall ratio (H: V) assuming the channel to be trapezoidal.

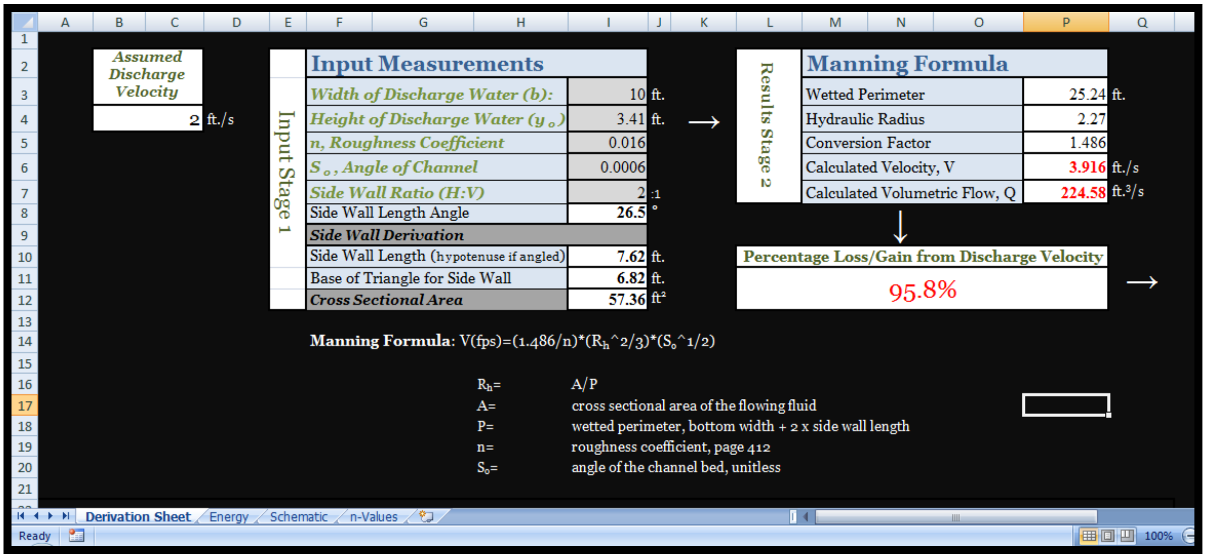

Figure 8: Screenshot of Derivation Spreadsheet

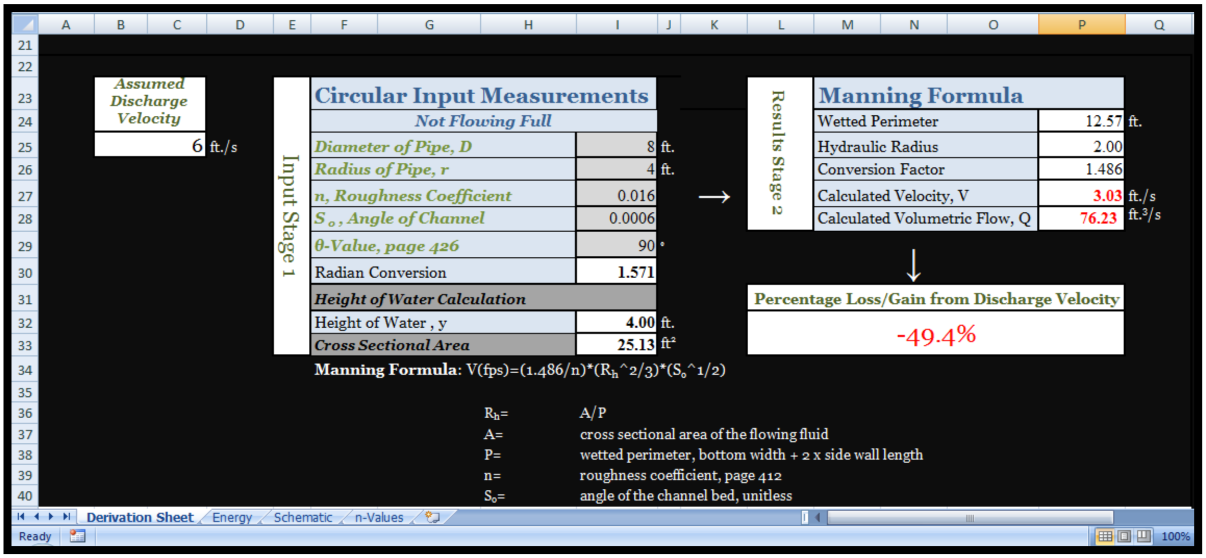

Figure 9: Screenshot of Input Values for Circular Input Measurements

3.5 Methodology of the Derivation Spreadsheet

The objective of the spreadsheet is to calculate the volumetric flow rate (ft.^{3}/sec) based on the given dimensions of the open channel. The design assumption for the channel is that the flow rate will be static and the critical depth calculations will be derived based on this assumption. Utilizing Manning's Equation, the velocity (ft./sec) for the desired cross section is then calculated. Once the velocity is found, Q (ft.^{3}/sec) = V (ft./sec) x A (ft.^{2}) is used to obtain the appropriate flow rate. The spreadsheet is used to calculate the flow rates for trapezoidal, triangular, rectangular, and circular cross sections.

An imperative, quantifiable measure of fluid flow is the specific energy created. For any cross-sectional shape, the specific energy, *E*, at a particular section is defined as the energy head referred to the channel bed as datum (Finnemore and Franzini 2002). The specific energy yields a comprehensive technique of characterizing the flow of any channel. One related parameter is critical depth. Critical depth is an important parameter in the analysis of varied flow in canals and natural streams (Swamee and Rathie 2005). The critical depth is the flow depth corresponding to the minimum specific energy. By formulating the specific energy of the theoretical cross-sectional flow, a relationship can be deduced by replicating the specific energy developed when the preliminary dosage for turbidity removal was calculated in the laboratory studies.

4 CHAPTER 4: EXPERIMENTAL SET-UP AND DESIGN

4.1 Introductory Remarks

This chapter describes the means and methods of conducting experimental testing using both the hydraulic flume in the laboratory and the field-scale channel. Although the results will be discussed in Chapter 5, this Chapter offers an elaborate comprehension of channel designs and the preparation for testing. All testing was conducted at the University of Central Florida, Orlando, Florida. The hydraulic flume testing was conducted within the Engineering Building II Hydraulics Laboratory and the Field-scale testing was completed at the Stormwater Management Academy Research and Testing (SMART) Field Laboratory.

4.2 Choice of Flow Rate to Analyze

The flow rate was obtained from educated assumptions paralleled by regulatory standards placed by the Florida Department of Environmental Protection. For a stormwater management system, it is practical to employ a predictive measure of the precipitation for the design process. The Florida Department of Environmental Protection (FDEP) requires a minimum of 3,600 $ft.^3$ of containment volume per acre when 10 acres or more of land is disturbed (HydroDynamics and Stormwater Management Academy 2007) for detention basins. It is also stated by the FDEP in Chapter 62-25.025: Regulations of Stormwater Discharge that detention basins shall provide the capacity for the specified treatment volume of stormwater within 72 hours. Therefore, the flow rate calculations are generated based on 72 hours of containment with the assumption of 3 inches of water throughout the watershed area needs to be treated and can be seen below. Although this is not directly related to a detention basin, the regulatory parameters were used for the calculation.

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

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

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

4.3 Preliminary Soil Specific Polymer (SSP) Analysis

Polyacrylamides are manufactured polymers that are soil specific. Within the industry, polyacrylamide vendors request that the client send a sample of the soil needed to be flocculated and controlled. Once received, many trials of turbidity removal efficiency testing are conducted with a variety of PAM types similar to that explained in section 3.1 Previous Work. The objective is to determine which polymer reacts best with the particular soil sent for investigation.

Likewise, soil specific polymer testing using various PAM types were chosen to test three Florida native soils. All tests were uniform in dosage, contact time, and mixing speed in attempt to lessen sources of error. The dosage chosen was 2,500 mg/L at a flow rate of 0.26 ft.^{3}/sec and contact time of 30 seconds for all tests conducted.

The analysis was conducted on four (4) polyacrylamide types given by Applied Polymer Systems in Atlanta, Georgia. Two soils chosen native to Florida are classified by AASHTO (American Association of State Highway and Transportation Officials) as A-3 and A-2-4. A third soil was also selected representing fine-grained lime rock which is common in the state as well. A sample analysis for A-2-4 is presented in Table 3. The dilution factor utilized for analysis was 5.

Table 3: Soil Specific Polymer (SSP) Analysis for A-2-4 Soil

		706b		**703d**	
		* 150 milligrams of PAM		* 150 milligrams of PAM	
		*Duration: 30 seconds		*Duration: 30 seconds	
		* Speed @ 700 rpm		* Speed @ 700 rpm	
Initial Turbidity					
Test 1	1020 NTU	Test 1	17 NTU	Test 1	72 NTU
Test 2	1005 NTU	Test 2	12 NTU	Test 2	51 NTU
Test 3	1080 NTU	Test 3	20 NTU	Test 3	69 NTU
Average Initial	**1035.0** NTU	Test 4	13 NTU	Test 4	56 NTU
		Test 5	15 NTU	Test 5	82 NTU
		Average	**15.4** NTU	Average	**66.0** NTU
		Stdev	3.2 NTU	Stdev	12.5 NTU
		Range	NTU	Range	NTU
		Removal Efficiency	98.51%	Removal Efficiency	93.62%
Initial Turbidity		**707a**		**703d#3**	
Test 1	820 NTU	* 150 milligrams of PAM		* 150 milligrams of PAM	
Test 2	835 NTU	*Duration: 30 seconds		*Duration: 30 seconds	
Test 3	795 NTU	* Speed @ 700 rpm		* Speed @ 700 rpm	
Average Initial	**816.7** NTU				
		Test 1	127 NTU	Test 1	63 NTU
		Test 2	154 NTU	Test 2	80 NTU
		Test 3	136 NTU	Test 3	70 NTU
		Test 4	109 NTU	Test 4	64 NTU
		Test 5	56 NTU	Test 5	53 NTU
		Average	**116.4** NTU	Average	**66.0** NTU
		Stdev	37.5 NTU	Stdev	9.9 NTU
		Range	NTU	Range	NTU
		Removal Efficiency	85.75%	Removal Efficiency	91.92%

As shown above, initial turbidity was taken for the source water mix prior to the PAM testing. Each PAM type was tested five times and averaged. The average was then used to calculate the turbidity removal efficiency against the initial turbidity as displayed in Equation 11.

$$\boldsymbol{Turbidity\ Removal\ Efficiency} = \left[\mathbf{1} - \left(\frac{\boldsymbol{Average\ Post\ Treated\ Turbidity}}{\boldsymbol{Initial\ Turbidity}}\right)\right] \boldsymbol{x}\ \mathbf{100} \tag{6}$$

The replication of specific energy was created based on the analysis with the chosen 100 mL beaker. The rpm value was converted into radians per minute and the diameter of the beaker was measured. The radians per minute were then multiplied by the radius to obtain the inches per minute. Following, the velocity calculated was then multiplied by the area to yield the volumetric flow. For example, at 700 rpm, the volumetric flow obtained is 0.26 ft.^{3}/sec and for

350 rpm 0.13 ft.^{3}/sec. A noted assumption for error is the fact that the solution within the beaker may not be flowing circularly at the same rate as the rpm gauge reads. At 700 rpm a vortex is formed within the center of the beaker while at 350 rpm the water is not as disordered. The likelihood of the water stirring at the same rate as the gauge indicates is more presumable as the rpm increase. A possible solution would be to use a stir bar closer to the diameter of the beaker. Table 4 shown below is a screenshot of the calculation for an rpm of 350.

Table 4: RPM Conversion to Volumetric Flow Rate, ft.^{3}/sec

rpm	350			1 rpm	6.2832	rad/min
rad/min	2199.12					
diameter	2.5	in				
radius	1.25	in				
in/min	2748.9					
ft/hr	13744.5					
ft/s	**3.82**					
Area	0.034088	ft^2				
	468.5289	*ft^3/hr*	**Volumetric Flow**			
	0.130147	*ft^3/sec*				

4.4 Hydraulic Flume Testing

The University of Central Florida Hydraulics Laboratory was utilized for hydraulic flume testing. The flume consisted of a plastic frame with dimensions of 15’ long x 1’ wide x 1.5’ tall. Figure 10 is an image of the full extent of the hydraulic flume.

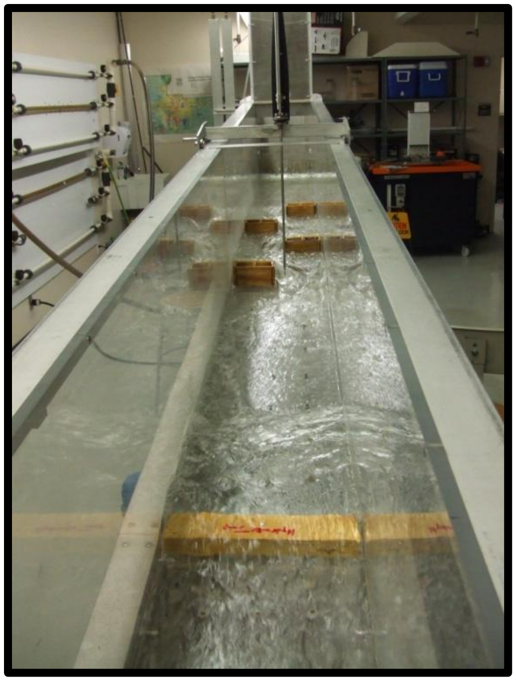

Figure 10: Image of Hydraulic Flume

It has two internal pumps above a large basin that continuously recycles water through the channel. If the flow rate desired is minimal, one pump could be completely shut off. The flume also has the capability of adjusting the slope of the channel which proved to be beneficial for translating the results to the future field-scale testing.

The channel bed width in the field was assumed to be three feet. This assessment was based on accommodating for the 15'' masonry blocks that would be placed laterally next to each other within the channel as shown later in the description of the various configurations. At that location, it is also necessary to allow a sufficient amount of water to pass through without introducing a large backwater depth.   Therefore, since the flume is one foot wide a scaling factor of 3:1 was employed during the hydraulic flume testing.

Since the water within the flume was continuously recycled, it was not permitted to place <u>actual</u> PAM products within the channel which may cause clogging of the flume. As a result, no turbidity removal efficiencies were calculated during the flume testing. Alternatively, the PAM blocks and masonry blocks intended to be used in the field were scaled by a 1/3 in all dimensions. In order to replicate the dimensions of the obstructions and not contaminate the water in any way, pressure treated wood was cut to the scaled size and screwed into place based on the respective configurations being analyzed at the time. Figure 11 is an image of the PAM block and masonry block combination used in the hydraulic flume.

Figure 11: Image of Wood Replication of Obstruction for Flume

The hydraulic flume testing was used to calculate energies throughout the channel and ultimately theorize which configurations would prove best within a field-scale study.

4.4.1 Testing Flow Chart

A flow chart of the hydraulic flume testing is shown in Figure 12. The two slopes chosen for the research are 8H:1V and 16H:1V. These two slopes were intended to provide perception of two significantly different angles within the range of acceptable channel slopes. The hydraulic flume configurations were originally tested with a 8H:1V slope. It was not until the most beneficial configuration was chosen that it was tested again with a 16H:1V slope. The flow rate was determined based on Manning's Equation.

Each configuration was tested five times. The distances between the obstructions were changed each of the five times to include multiplicity within the research. The objective was to find the most beneficial obstruction distance within each of the three configurations. The configurations are all explained in the next section. During the hydraulic flume testing, the distances x_2, x_3, and x_4 within the configuration were uniformly increased in order to observe if there was an enhancement within the flow pattern. Each test was completed with triplicates in attempt to average the values obtained. Therefore, a total of 45 tests were completed; i.e.*3 configurations x 5 altered distances of obstructions x 3 repeated tests for each trial = 45 total tests*.

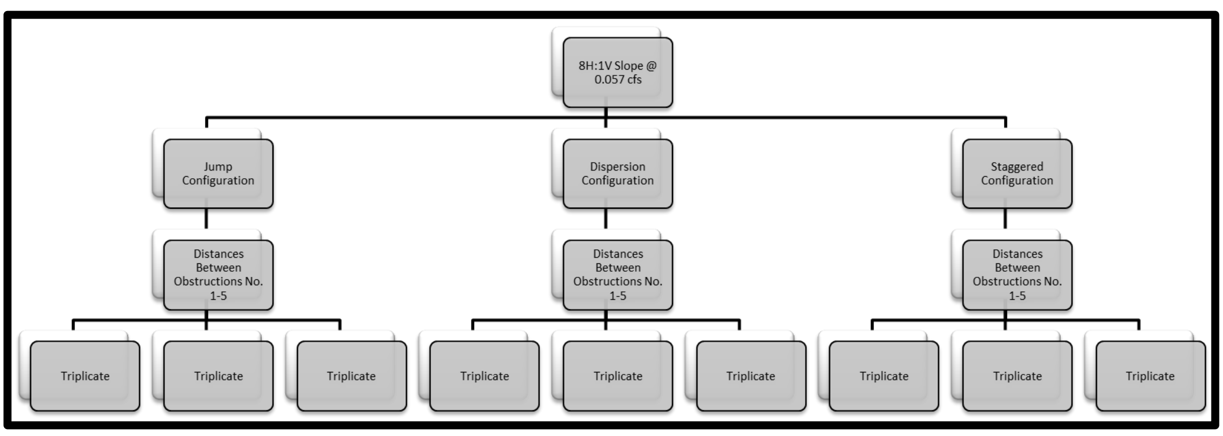

Figure 12: Hydraulic Flume Testing Flow Chart

4.4.2 Hydraulic Flume Configurations

Three configurations were chosen based on a variety of beneficial characteristics for the anticipated turbidity removal efficiency. Though countless arrangements could be selected, the three shown below all represent unique suggestions that will be analyzed. The analysis will monitor energy variation throughout the channel, dead zones, short circuits, and note all reactions at the obstructions. Each general configuration will be adjusted five times to choose the best distances necessary for the obstructions to perform ideally. By adjusting the space between the obstructions, adjustments will be made to the backwater depth, height of water, and many other characteristics that can be beneficial when considering the contact with the actual polyacrylamide within the future field study; all of which will be examined during the testing.

The Jump Configuration has been designed to instantly react with the first PAM block and settle within x_2 before being exposed to two more additional PAM blocks downstream. Figure 13 and Figure 14 are illustrations of the Jump Configuration.

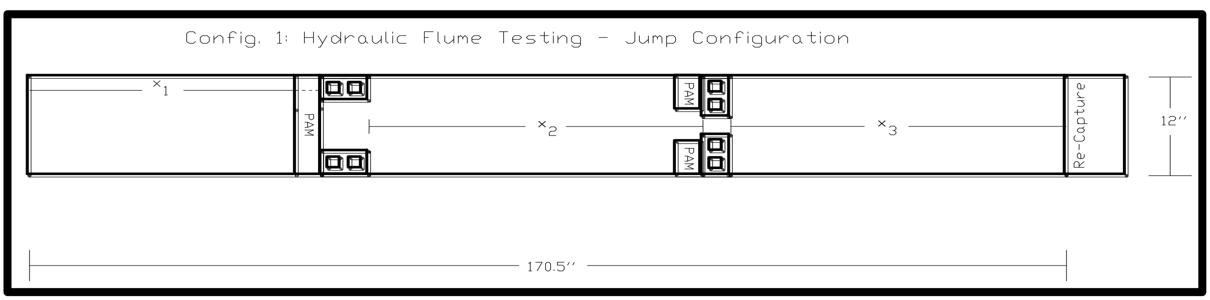

Figure 13: Hydraulic Flume - Jump Configuration

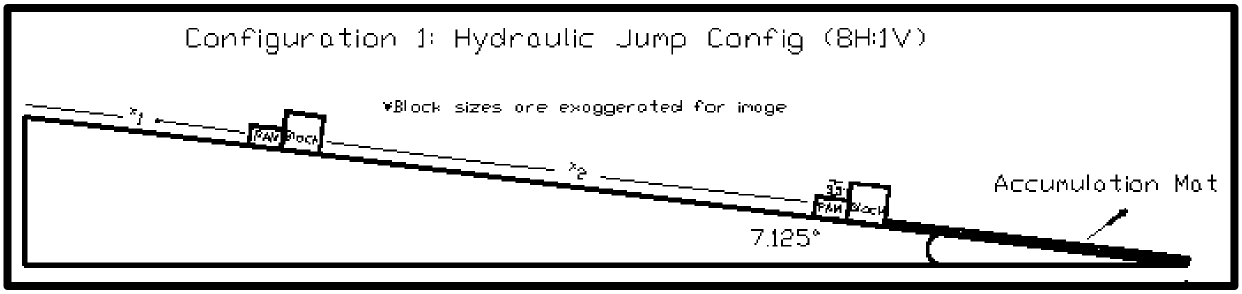

Figure 14: Hydraulic Flume - Jump Configuration Elevation

The generally impression is to create sub-critical flow with the hydraulic jump and force velocity of water to decrease allowing any flocs to settle with gravity within the x_2 section. As the flow increases in velocity downstream from the first obstruction, the second set of obstructions is placed laterally across from each other. Consequently, the cross sectional area is decreased causing a slight surge in velocity out of the center outlet after contact with the PAM blocks. Prior to the re-capture, the x_3 distance is predicted to allow residual settling for the remainder of flocs. The re-capture within the hydraulic flume is the ledge where the water is recycled back into the basin below the actual channel and pumped back in upstream.

The Dispersion Configuration is designed to agitate the flow more than the Jump Configuration. As the flow travels downstream it is split by a center obstruction forcing the water to flow against the walls of the channel. At that point, the water is exposed to two PAM block obstructions that are flush with the side walls. Figure 15 and Figure 16 are illustrations of the Dispersion Configuration.

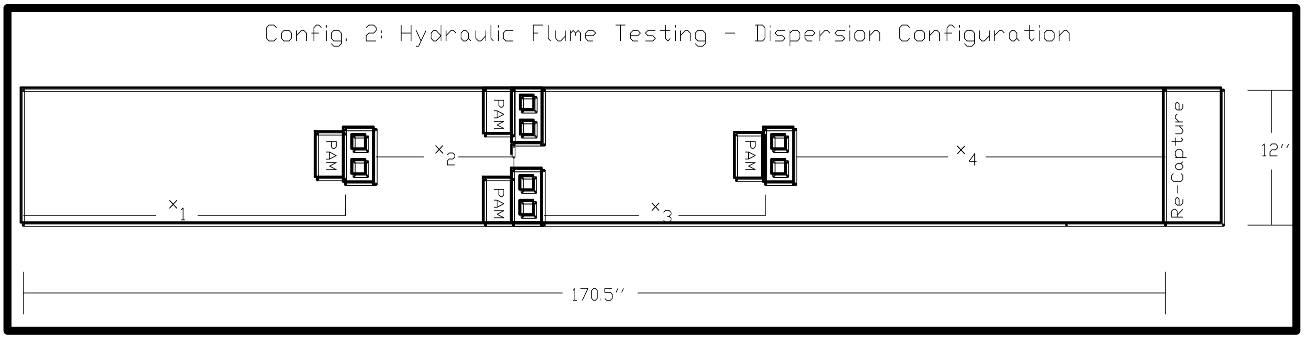

Figure 15: Hydraulic Flume - Dispersion Configuration

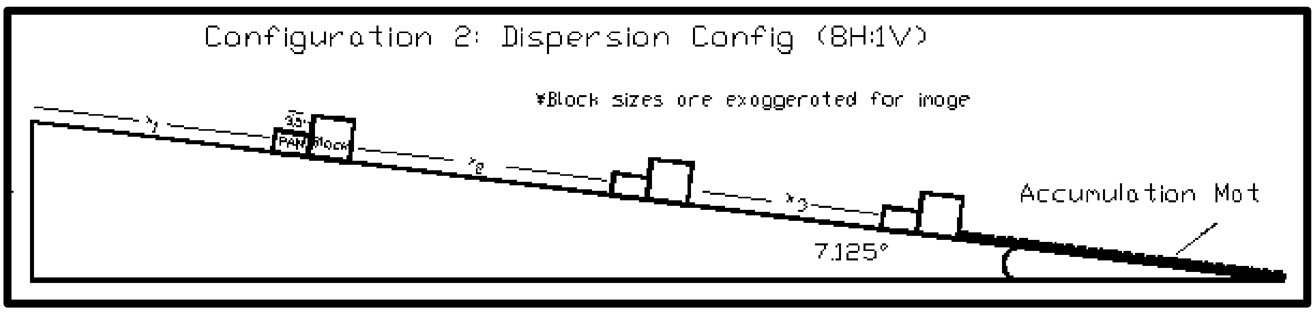

Figure 16: Hydraulic Flume - Dispersion Configuration Elevation

Similar to the Jump Configuration, the flow is surged through the outlet centered between the obstructions. Lastly, as a refining step, an additional single obstruction is placed in the center of the channel identical to the initial PAM block. Once the water splits again, adequate space will be left downstream within section x_4 to permit steady state flow as well as allow for flocs to settle along the way.

The third configuration is called the Staggered Configuration and is designed to integrate uniform agitation throughout the mixing zone. Figure 17 and Figure 18 are illustrations of the Staggered Configuration.

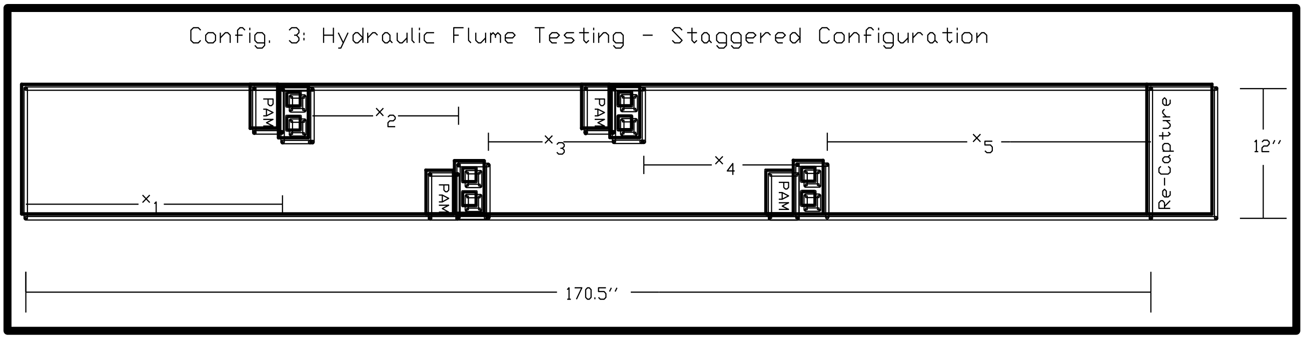

Figure 17: Hydraulic Flume - Staggered Configuration

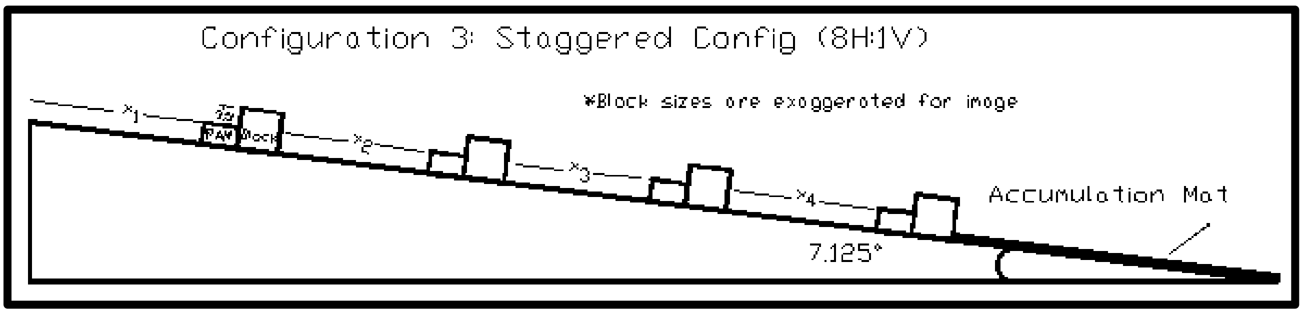

Figure 18: Hydraulic Flume - Staggered Configuration Elevation

The mixing zone is essentially the end of section x_1 through x_4 where all the obstructions are located. The premise of this design has been generated from that commonly seen within water treatment plants using baffles. The Staggered Configuration allows more contact time which consequently provides more settling time by forcing the water to twist around the four obstructions. There are concerns of dead zones directly behind the masonry blocks which would result in increased maintenance. If there is not enough flow to continuously force the source water downstream at these locations, there is an opportunity of flocs to consolidate. The velocities at these locations will be carefully evaluated. Results of the hydraulic flume testing are provided in the next chapter.

4.5 Field-Scale Testing

Full scale field-scale testing was conducted at the SMART field laboratory. This testing is the core of the research project. Unlike the hydraulic flume testing, field-scale testing is only conducted using two different chosen configurations on two separate slopes.

This testing is conducted after the hydraulic flume testing. The channel dimensions are constructed based on the findings of the hydraulic flume test. For instance, once the chosen configurations are set, the velocities are analyzed assuming a 30 second mixing time. The average velocity is then multiplied by the 30 second time frame to obtain the desired length of the channel.

Due to the controlled environment within the hydraulic flume testing, the field-scale testing reveals more of the complications seen in the field and as a result is more representative of the actual construction. Full size PAM blocks are utilized within the channel in front of actual masonry blocks. Sample bottles are used to gather source water at various positions within the channel both before and after the mixing zones to determine the turbidity removal efficiencies.

The chosen design of the channel is contingent upon the space provided within any field situation. It is vital that the channel be placed at a location near a pond. In attempt to mitigate maintenance efforts, all source water from the channel was discharged to a local pond adjacent to the SMART laboratory. Ultimately, the intent is to provide a scientifically developed design approach with PAM products for water clarity using hydraulic principles and evaluating the energy variation and turbidity removal efficiency.

4.6 Construction of the Field-Scale Channel

The feasibility of the entire field project is highly dependent on the construction of an adequate channel in the field. The scale of the channel is based on the hydraulic flume testing completed previously. It is important to note that various modifications were made due to length limitations and observations distinguished during the hydraulic flume testing and on the site conditions.

The original conception for the length of the channel was dictated by previous index laboratory testing. For instance, the testing conducted for the PAM/soil verification was mixed at 700 rpm. Using the diameter of the beaker utilized during testing, this converts to approximately 7.6 feet/sec and the PAM was mixed for 30 seconds. With these parameters for the mixing time, the length of the channel would need to be 228 feet. This length is clearly unreasonable and would be difficult to construct.

The next attempt to justify the length necessary for the field scale channel is to refer to the hydraulic flume testing. Focusing on the Staggered configuration, the velocities are averaged throughout all the data points taken. As expected, the velocities directly in front of the obstructions are relatively slow while the flow paths next to the obstructions are fast in comparison. Due to the symmetrical configuration of the obstructions, the average velocity seems to be appropriate. The average velocity of all the data points taken is 1.6 feet/sec. Once again referring to the index laboratory testing conducted at 30 second trials, the appropriate length of the channel would equate to 48 feet. Considering this distance to be suitable for the beginning straightway and the mixing zone, additional length needs to be measured for the implementation of the hydraulic jump downstream. During the hydraulic flume testing, the jump was placed 34 inches from the back of the last obstruction. Since the scale was reduced to 1/3, the hydraulic jump will be placed 8.5 feet away from the back of the final masonry block within the obstruction. Consequently, the channel lengthens to 56.5 feet.

Directly after the sloped channel is a plateau of 15 feet level with the surface. This is an additional polishing step being utilized to slow down the flow prior to discharging into a neighboring water body. The construction of this can be seen in the upper portion of Figure 19.

Figure 19: Construction of Hydraulic Jump and Plateau for Collection Mat

A collection mat called Curlex II is placed directly on top of 15 foot straightway. This product has been provided by American Excelsior Company of Arlington, Texas. Curlex II is an erosion control mat consisting of a specific cut 100% weed seed free Great Lakes Aspen curled wood excelsior with 80% six-inch fibers or greater fiber length (American Excelsior, pamphlet). This product is commonly used in substitute of jute mat or coconut fiber erosion control mats.

The product is held to the ground using masonry blocks, or other easily accessible materials on a construction site, along the side walls to force the flow to the center.

Two channel slopes are tested during this research. The first slope tested is 8H:1V. Therefore, the slope is approximately 7.13° or 12.5% grade. Thus, the height of the 8H:1V channel is 7.5 feet and the bottom length is 56' as shown in Figure 20. The second slope chosen for testing is 16H:1V. With modifications based on observations seen in the laboratory, the new length of the slope is 52 feet. Consequently, the height of the 16H:1V slope is 3.25 feet.

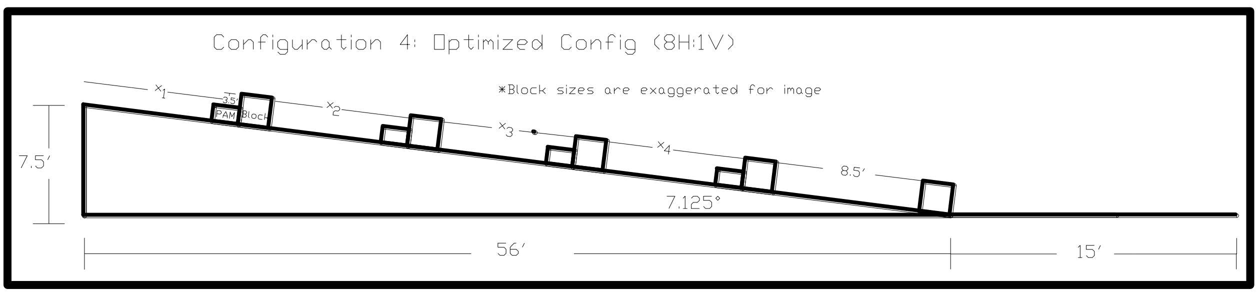

Figure 20: Slope Elevation

The landscaping, stockpiling, and much of the compaction for the channel are completed using a Bobcat Compact Track Loader. The soil that is being used for the channel is AASHTO classified A-3 which is commonly available at the SMART lab site. The soil is simply displaced using the track loader.

4.6.1 Slope Verification

The slope is consistently checked throughout the entire construction process using a Pro Shot ™ Digital laser level with a R7 Detector. This device is commonly used by concrete contractors. The device is placed level with the peak of the channel and the R7 Detector is attached to a ruler similar to those utilized for surveying. This peak point is used as a zero-point or datum to begin with. Leaving the laser level at its original location, the R7 Detector and ruler are then relocated at the center of the channel and again downstream from the peak. These tools verified the distances necessary to obtain both the 8H:1V initial slope and the 16H:1V secondary slope.

As a supplementary verification, a Skil® Digital Angle Finder is also utilized. String lines are posted from the peak of the channel to the bottom just prior to the 15 feet straightway. By doing so, it is clearly evident where it is necessary to cut and fill the soil to construct a more accurate slope. The angle finder is placed directly on the string line and held steady so a reading is observed while the bubble level is shown to be centered. Such measurements were taken throughout the channel every ten feet. This procedure gives clear indication where it is essential to level more soil and remove the excess.

Once the foundation of the channel was proven to be at the desired angle, the core of the channel needed to be dug out. No machinery was used to dig out the center. Shovels were used to remove the soil and in order to achieve the 2H:1V side walls, a plywood cut of the dimensions was sheered throughout the channel as shown in Figure 21. This permitted a more accurate development of the channel. Once again, string lines were used to give a constant depiction of the measurements projected for the channel.

Figure 21: Plywood Cut for 2H:1V Slope

At the conclusion of the channel formation, a single piece of 8 mil visqueen fabric was draped over the entire channel. The visqueen was pulled to be flush with the channel bed and the side walls in attempt to place a water proof barrier. The visqueen was then held in place using masonry blocks and brick pavers found at the SMART lab site along the outer banks of the channel and can be seen in Figure 22.

Figure 22: Visqueen Layer

4.6.2 Source Water Preparation

The appropriate sheet flow of the source water is a vital concern for the success of the experimentation. A 1,500 gallon cistern shown in Figure 23 is used to contain the soil and water mixture. This mixture is considered the source water. The cistern is placed within a flat, paved section next to the channel. Within the cistern are two submersible pumps. One pump discharges the water onto the channel through 2’’ diameter PVC pipes and the other pump is left within the cistern. The pump within the cistern is used to agitate and mix the source water. The average discharge of the agitating pump is 70 gallons per minute. This provides turbulent mixing for the large containment of water.

Figure 23: 1,500 Gallon Source Water Tank

It is important to provide a uniform flow for the channel from the 1,500 gallon cistern. A 2'' PVC pipe discharges water from the submersible pump within the cistern to the channel. In order to ensure uniform flow at the beginning of the channel, a chamber is created to provide a sheet flow effect. A 35 gallon plastic container, similar to a chamber, is used to provide the uniform flow. It is utilized as a storing cell for the source water. It allows the flow to elevate and release equally once the chamber is filled.

The pipes are connected to the chamber by cutting 2 inch circular holes and sealing PVC couplings. To guarantee that no water is released from the connection, metal washers are placed and sealed with silicon at the 2 inch circular cuts as presented in Figure 24 . This provides a simple, water tight insertion for the pipes.

Figure 24: Upstream Chamber for Source Water

A rectangular cut is also extended laterally across the opposite side of the incoming pipes to permit sheet flow directly out of the chamber. In order to accommodate for the substantial pressure forcing the plastic chamber to bulge outward, a ratchet strap is attached around the lower border. A plastic visqueen sheet is also sealed along the inside of the chamber using silicon and duct tape, then draped out the rectangular cut to flawlessly allow the source water to land directly on the channel bed.

4.6.3 Datum Device

A vital measurement for the calculation of energy is the height of water along the channel. A lateral device has been created to suitably obtain measurements of height across the channel bed. As shown in Figure 25 below, the datum device is essentially a ladder with plywood covering the bracings so one could walk across the channel. The dimensions of the device are 96’’ x 21.5’’ 4’’. ½ inch PVC pipes were placed strategically in the center of the device to be able to gather the height measurements at the chosen locations within the channel. The PVC pipes are held using aluminum conduit clamps commonly used for electrical wiring. Lastly, measuring tape was cut into three pieces long enough to reach the bottom of the channel bed and securely placed within each PVC pipe. Once the device is placed laterally across the channel, the premise is to place all measuring tape sections at the floor of the channel. Consequently, one would recognize the measurement at the surface of the PVC pipe to be the datum mark or “zero mark”. Once that has been established, one would simply elevate the measuring tape whereas the bottom of the tape skims the surface of the water. The difference in height from what was recorded as the datum mark will ultimately be the height of water at that particular location within the channel.

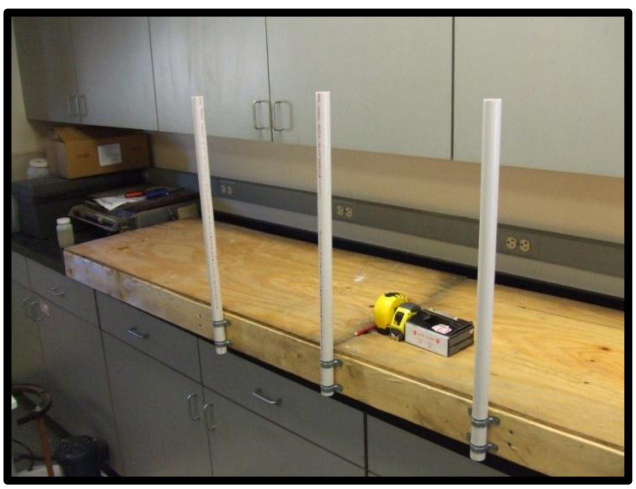

Figure 25: Construction of Datum Device

5 CHAPTER 5: RESULTS AND DISCUSSION

5.1 Introductory Remarks

Chapter five presents the results of the hydraulic flume and the field scale channel testing. Section 5.2 discusses the findings of the laboratory scale flume testing while section 5.3 discusses the results of the field channel tests. Some results are shown throughout the chapter, but all the data can be found in the Appendix.

5.2 Hydraulic Flume Testing

The objective of using the hydraulic flume was to verify which of the three chosen configurations would yield the most beneficial configuration to use in the field-scale testing. Some of the observed parameters forming the basis for the chosen configuration are energy variation, dead zones, short circuiting of the water path, velocity recovery downstream and backwater depth. Once again, no actual PAM blocks were used; therefore, the investigation was strictly hydraulics-related and no relation to turbidity removal efficiency.

Each of the three configurations was varied at least four times in order to obtain a broad range of the flow patterns. For example, the distance x_2 within the Jump Configuration was increased five times beginning with 31 inches. As the length in between the obstructions was reformed, the water fluctuation was as well. It was necessary to choose the configuration that would provide the most mixing without evading a single PAM block. After the length in between the obstructions was established, three trials were completed and averaged.

The hydraulic flume used for the testing is 170 inches long and 12 inches wide. There is a water re-capture 170 inches downstream from the beginning of the flume. The water is then recycled back upstream and continuously flows at the desired flow rate. Threaded holes are spread throughout the bed of the channel in order to screw in objects and keep them stationary. Many points along the channel were labeled for all three configurations and both velocity and height measurements were taken in order to enter these into the energy equation and obtain energy values.

The first configuration tested was the Jump Configuration (see Figure 13) . The hydraulic jump was screwed into the channel bed 45 7/8’’ from the beginning of the water outflow and the distance x_2 was 31 inches. For subsequent tests, x_2 was changed to 49’’, 67’’, 79’’ and 91’’. Once the obstructions were set on the channel bed, the slope of the flume was fixed at 12.5% or 8H:1V. The slope was verified using a level connected to the flume. Lastly, the velocity of the water needed to be adjusted to the scaled flow rate. In order to do so, the spreadsheet previously discussed in Chapter 3 was used.

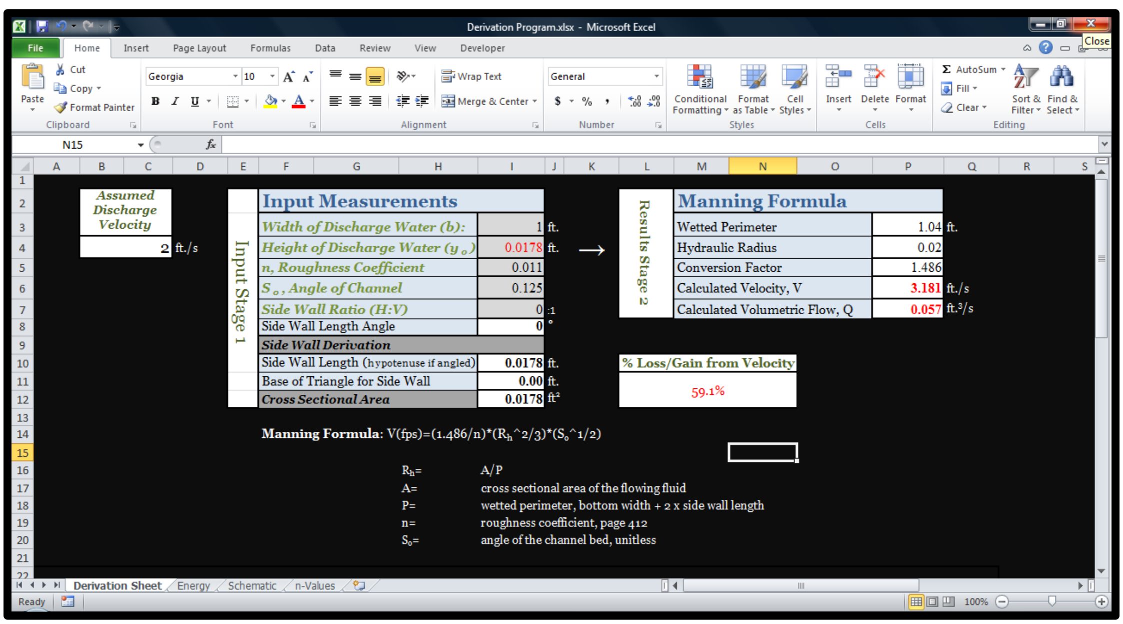

Figure 26: Snapshot of Derivation Spreadsheet for Flume Testing

The spreadsheet (see snapshot in Figure 26) uses the Manning Formula and an iterative approach to reach the desired flow rate. The known variable in this situation is the volumetric flow, Q. Using trial-and-error, different values are entered for the height of water, h. The height of the discharge water is directly related to the hydraulic radius, cross-sectional area of the water, and wetted perimeter. Based on the program, the height of water should be 0.0178 ft. or 0.2136 inches. The detailed calculation with the height of discharge water at 0.0178 ft. is presented below:

$$Area = 1' x\ 0.0178' = 0.0178\ ft.^2$$

$$Wetted\ Perimeter, P = 2(0.0178') + 1' = 1.0356'$$

$$Hydraulic\ Radius, R_h = \frac{A}{P} = \frac{0.0178\ ft.^2}{1.0356\ ft.} = 0.0172\ ft.$$

$$Constant: average\ roughness\ coefficient\ of\ glass, n, = 0.011$$

$$Constant: Slope, S_0 = 0.125$$

$$V = \frac{1.486}{(0.011)}\ x\ (0.0172)^{2/3}\ x\ (0.125)^{1/2} = \mathbf{3.181}\ {}^{\boldsymbol{ft.}}/_{\boldsymbol{sec}}$$

$$Q = VA = 3.181\ {}^{ft.}/_{sec}\ x\ 0.0178\ ft.^2 = \mathbf{0.057\ ft.^3}$$

All velocities including the initial, steady state velocity was confirmed using a Flow Watch-Water and Airspeed Measurement device. The device reveals values to the nearest tenth, therefore, the initial velocity value was taken as 3.2 fps. The device is shown in Figure 27 below.

Figure 27: Flow Watch-Water & Airspeed Measurement Device

5.2.1 Jump Configuration

Height and velocity measurements were taken at numerous positions throughout the channel. Figure 28 below shows the identification points for all the positions taken for the Jump Configuration. In addition to the measurements, all observations were noted during the course of each trial to supplement the data when choosing the best layout for each configuration.

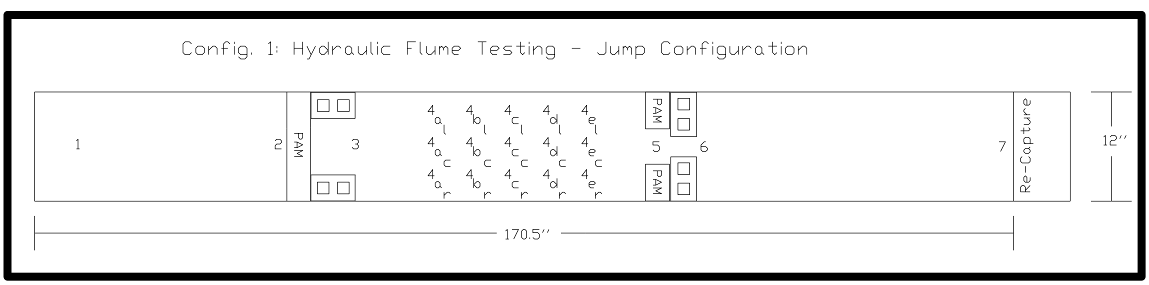

Figure 28: Jump Configuration Identification Points

Table 5: Jump Configuration Trial 1 Data Results @ 31'' between obstructions

11/4/2010
Full Size PAM
Set Up No. 6 **Slope (%)** **12.5**

Distance from incoming water to Masonry Block (Upstream side):	**45 7/8**	in.
Distance from back of the masonry block to Masonry Blocks (upstream side):	**30 3/4**	in.
Distance from back of second masonry blocks to water re-capture:	**85 7/8**	in.
Back water depth of hydraulic jump taken from masonry block (upstream):	**12 1/2**	in.
Back water depth of 2nd Obstruction:	**15**	in.

1 of 3

I.D.	*Length from H_2O Entrance (in.)*	*Height (mm)*	*Height (ft)*	*V (fps)*	*Energy (ft.)*
1	20.5	6.5	0.0213	3.2	0.1803
2	45.25	58.5	0.1919	1.25	0.2162
3	51	15.5	0.0509	2.8	0.1726
$4a_l$	53.75	7.5	0.0246	1.3	0.0508
$4a_c$	56.75	11.5	0.0377	3.1	0.1870
$4a_r$	56.75	5.5	0.0180	1.3	0.0443
$4b_l$	59.75	9	0.0295	2.7	0.1427
$4b_c$	59.75	9	0.0295	3.5	0.2197
$4b_r$	59.75	4	0.0131	1.5	0.0481
$4c_l$	62.75	7.5	0.0246	2.8	0.1463
$4c_c$	62.75	8.5	0.0279	3.3	0.1970
$4c_r$	62.75	4.5	0.0148	1.8	0.0651
$4d_l$	65.75	6	0.0197	3	0.1594
$4d_c$	65.75	7.5	0.0246	3.7	0.2372
$4d_r$	65.75	4.5	0.0148	2.5	0.1118
5	81.75	69	0.2264	1.5	0.2613
6	84.25	38	0.1247	3	0.2644
7	107.375	5.5	0.0180	3.2	0.1771

Table 6: Jump Configuration Trial 2 Data Results @ 31'' between obstructions

2 of 3

I.D.	***Length from H_2O Entrance (in.)***	***Height (mm)***	***Height (ft)***	***V (fps)***	***Energy (ft.)***
1	20.5	7	0.0230	3.2	0.1820
2	45.25	60	0.1969	1.2	0.2192
3	51	12	0.0394	2.85	0.1655
$4a_l$	53.75	8.5	0.0279	2.3	0.1100
$4a_c$	56.75	13	0.0427	3.2	0.2017
$4a_r$	56.75	7	0.0230	1.7	0.0678
$4b_l$	59.75	9	0.0295	2	0.0916
$4b_c$	59.75	8.5	0.0279	3.2	0.1869
$4b_r$	59.75	4	0.0131	2.1	0.0816
$4c_l$	62.75	6.5	0.0213	3	0.1611
$4c_c$	62.75	9	0.0295	3.6	0.2308
$4c_r$	62.75	4	0.0131	1.95	0.0722
$4d_l$	65.75	6	0.0197	3	0.1594
$4d_c$	65.75	8	0.0262	3.65	0.2331
$4d_r$	65.75	5	0.0164	2.4	0.1058
5	81.75	72	0.2362	1.55	0.2735
6	84.25	41	0.1345	3.1	0.2837
7	107.375	5	0.0164	3.2	0.1754

Table 7: Jump Configuration Trial 3 Data Results @ 31'' between obstructions

3 of 3

I.D.	***Length from H_2O Entrance (in.)***	***Height (mm)***	***Height (ft)***	***V (fps)***	***Energy (ft.)***
1	20.5	7	0.0230	3.3	0.1921
2	45.25	59.5	0.1952	1.3	0.2215
3	51	15	0.0492	2.8	0.1710
$4a_l$	53.75	9.5	0.0312	2.2	0.1063
$4a_c$	56.75	11	0.0361	3	0.1758
$4a_r$	56.75	6	0.0197	1.8	0.0700
$4b_l$	59.75	9	0.0295	2.5	0.1266
$4b_c$	59.75	10.5	0.0344	3.4	0.2140
$4b_r$	59.75	4	0.0131	1.7	0.0580
$4c_l$	62.75	6.5	0.0213	3.15	0.1754
$4c_c$	62.75	10	0.0328	3.6	0.2341
$4c_r$	62.75	4.5	0.0148	2	0.0769
$4d_l$	65.75	6	0.0197	3.1	0.1689
$4d_c$	65.75	8	0.0262	3.75	0.2446
$4d_r$	65.75	5	0.0164	2.6	0.1214
5	81.75	71	0.2329	1.6	0.2727
6	84.25	40.5	0.1329	3	0.2726
7	107.375	5.5	0.0180	3.2	0.1771

Table 8: Jump Configuration Data Results Average @ 31'' between obstructions

Average						
I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (mm)***	***Height (ft)***	***V (fps)***	***Energy (ft.)***
1	20.5	0.12	6.83	0.0224	3.23	0.1848
2	45.25	0.27	59.33	0.1947	1.25	0.2189
3	51	0.30	14.17	0.0465	2.82	0.1697
$4a_l$	56.75	0.33	8.50	0.0279	1.93	0.0859
$4a_c$	56.75	0.33	11.83	0.0388	3.10	0.1880
$4a_r$	56.75	0.33	6.17	0.0202	1.60	0.0600
$4b_l$	59.75	0.35	9.00	0.0295	2.40	0.1190
$4b_c$	59.75	0.35	9.33	0.0306	3.37	0.2066
$4b_r$	59.75	0.35	4.00	0.0131	1.77	0.0616
$4c_l$	62.75	0.37	6.83	0.0224	2.98	0.1606
$4c_c$	62.75	0.37	9.17	0.0301	3.50	0.2203
$4c_r$	62.75	0.37	4.33	0.0142	1.92	0.0713
$4d_l$	65.75	0.39	6.00	0.0197	3.03	0.1626
$4d_c$	65.75	0.39	7.83	0.0257	3.70	0.2383
$4d_r$	65.75	0.39	4.83	0.0159	2.50	0.1129
5	81.75	0.48	70.67	0.2318	1.55	0.2692
6	84.25	0.49	39.83	0.1307	3.03	0.2736
7	107.375	0.63	5.33	0.0175	3.20	0.1765

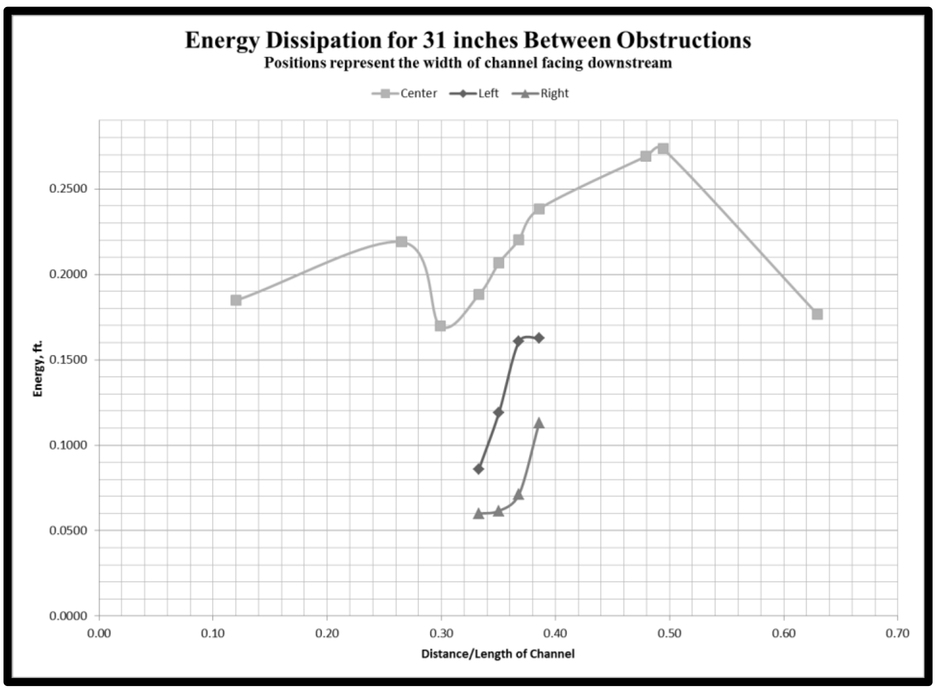

Figure 29: Jump Configuration Energy Variation @ 31 inches Between Obstructions

Table 5 shows the data results for the Jump Configuration when the distance between the obstructions was 31 inches. Triplicates were completed for each layout and trials 2 and 3 are shown in Table 6 and Table 7, respectively. 31 inches was the closest distance in between the obstructions. It is evident with this configuration that there is a disconnect between the left and right water paths as shown in Figure 29. In theory, since the flow is steady and the configuration is symmetrical, the original assumption was that the flow on the left and right sides would be close to identical. Additional testing with the hydraulic flume consistently demonstrated that the flow is in fact different on the left and right sides. Again, note that when referencing the directional flow, the “left” and “right” are labeled as if facing downstream.

The largest length in between the obstructions tested was 91 inches and those results are shown below. Table 9 is the results compiled from the first trial and the remaining two are shown in Table 10 and Table 11. At each individual point of the rectangular flume, the velocity and height measurements were used to calculate the respective energy and placed in the last column.

Table 9: Jump Configuration Trial 1 Data Results @ 91'' between obstructions

11/4/2010
Full Size PAM
Set Up No. 6 **Slope (%)** **12.5**

Distance from incoming water to Masonry Block (Upstream side):	**45 7/8**	in.
Distance from back of the masonry block to Masonry Blocks (upstream side):	**91**	in.
Distance from back of second masonry blocks to water re-capture:	**25 3/4**	in.
Back water depth of hydraulic jump taken from masonry block (upstream):	**12 1/4**	in.
Back water depth of 2nd Obstruction:	**14**	in.

1 of 3

I.D.	***Length from H_2O Entrance (in.)***	***Height (mm)***	***Height (ft)***	***V (fps)***	***Energy (ft.)***
1	20.5	9	0.0295	3.2	0.1885
2	44.5	65	0.2133	1.5	0.2482
3	51	19.5	0.0640	3.1	0.2132
$4a_l$	65.875	6	0.0197	3.55	0.2154
$4a_c$	65.875	8.5	0.0279	3.7	0.2405
$4a_r$	65.875	6.5	0.0213	3.85	0.2515
$4b_l$	80.875	9	0.0295	3.8	0.2538
$4b_c$	80.875	5.5	0.0180	3.35	0.1923
$4b_r$	80.875	8.5	0.0279	3.75	0.2462
$4c_l$	95.875	7	0.0230	4.5	0.3374
$4c_c$	95.875	8.5	0.0279	3.8	0.2521
$4c_r$	95.875	8	0.0262	3.9	0.2624
$4d_l$	110.875	6.5	0.0213	4.2	0.2952
$4d_c$	110.875	8.5	0.0279	4.1	0.2889
$4d_r$	110.875	8.5	0.0279	4.5	0.3423
$4e_l$	125.875	8.5	0.0279	4.4	0.3285
$4e_c$	125.875	8.5	0.0279	4.6	0.3565
$4e_r$	125.875	8.5	0.0279	4.7	0.3709
5	141.875	77.5	0.2543	1.7	0.2991
6	144.5	55	0.1804	3	0.3202
7	170.5	8	0.0262	2.25	0.1049

Table 10: Jump Configuration Trial 2 Data Results @ 91'' between obstructions

		2 of 3			
I.D.	***Length from H_2O Entrance (in.)***	***Height (mm)***	***Height (ft)***	***V (fps)***	***Energy (ft.)***
1	20.5	9	0.0295	3.1	0.1788
2	44.5	67.5	0.2215	1.4	0.2519
3	51	22	0.0722	3	0.2119
$4a_l$	65.875	7	0.0230	3.2	0.1820
$4a_c$	65.875	9.5	0.0312	4	0.2796
$4a_r$	65.875	7.5	0.0246	3.9	0.2608
$4b_l$	80.875	10.5	0.0344	4	0.2829
$4b_c$	80.875	5.5	0.0180	3.2	0.1771
$4b_r$	80.875	8	0.0262	4	0.2747
$4c_l$	95.875	8	0.0262	4.3	0.3134
$4c_c$	95.875	9.5	0.0312	3.7	0.2437
$4c_r$	95.875	7.75	0.0254	4.5	0.3399
$4d_l$	110.875	6	0.0197	4.1	0.2807
$4d_c$	110.875	8.5	0.0279	4.2	0.3018
$4d_r$	110.875	8	0.0262	4.4	0.3269
$4e_l$	125.875	8	0.0262	4.3	0.3134
$4e_c$	125.875	8.5	0.0279	4.5	0.3423
$4e_r$	125.875	7.75	0.0254	4.8	0.3832
5	141.875	72.5	0.2379	1.5	0.2728
6	144.5	56	0.1837	3	0.3235
7	170.5	8	0.0262	2.5	0.1233

Table 11: Jump Configuration Trial 3 Data Results @ 91'' between obstructions

		3 of 3			
I.D.	***Length from H_2O Entrance (in.)***	***Height (mm)***	***Height (ft)***	***V (fps)***	***Energy (ft.)***
1	20.5	9.5	0.0312	3.2	0.1902
2	44.5	66.5	0.2182	1.2	0.2405
3	51	21.5	0.0705	2.9	0.2011
$4a_l$	65.875	7	0.0230	3.7	0.2355
$4a_c$	65.875	9	0.0295	4	0.2780
$4a_r$	65.875	7.5	0.0246	3.9	0.2608
$4b_l$	80.875	8.5	0.0279	3.7	0.2405
$4b_c$	80.875	5	0.0164	3.5	0.2066
$4b_r$	80.875	7	0.0230	3.8	0.2472
$4c_l$	95.875	7	0.0230	4.5	0.3374
$4c_c$	95.875	7.5	0.0246	3.9	0.2608
$4c_r$	95.875	7.5	0.0246	4.15	0.2920
$4d_l$	110.875	6	0.0197	4.1	0.2807
$4d_c$	110.875	9	0.0295	3.9	0.2657
$4d_r$	110.875	8	0.0262	4.2	0.3002
$4e_l$	125.875	8.5	0.0279	4.3	0.3150
$4e_c$	125.875	8.5	0.0279	4.5	0.3423
$4e_r$	125.875	7.5	0.0246	4.55	0.3461
5	141.875	76.5	0.2510	1.6	0.2907
6	144.5	51.5	0.1690	3.1	0.3182
7	170.5	6	0.0197	2.6	0.1247

Table 12: Jump Configuration Data Results Average @ 91'' between obstructions

		Average				
I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (mm)***	***Height (ft)***	***V (fps)***	***Energy (ft.)***
1	20.5	0.12	9.17	0.0301	3.17	0.1858
2	44.5	0.26	66.33	0.2176	1.37	0.2466
3	51	0.30	21.00	0.0689	3.00	0.2086
$4a_l$	65.875	0.39	6.67	0.0219	3.48	0.2103
$4a_c$	65.875	0.39	9.00	0.0295	3.90	0.2657
$4a_r$	65.875	0.39	7.17	0.0235	3.88	0.2577
$4b_l$	80.875	0.47	9.33	0.0306	3.83	0.2588
$4b_c$	80.875	0.47	5.33	0.0175	3.35	0.1918
$4b_r$	80.875	0.47	7.83	0.0257	3.85	0.2559
$4c_l$	95.875	0.56	7.33	0.0241	4.43	0.3293
$4c_c$	95.875	0.56	8.50	0.0279	3.80	0.2521
$4c_r$	95.875	0.56	7.75	0.0254	4.18	0.2972
$4d_l$	110.875	0.65	6.17	0.0202	4.13	0.2855
$4d_c$	110.875	0.65	8.67	0.0284	4.07	0.2852
$4d_r$	110.875	0.65	8.17	0.0268	4.37	0.3229
$4e_l$	125.875	0.74	8.33	0.0273	4.33	0.3189
$4e_c$	125.875	0.74	8.50	0.0279	4.53	0.3470
$4e_r$	125.875	0.74	7.92	0.0260	4.68	0.3666
5	141.875	0.83	75.50	0.2477	1.60	0.2875
6	144.5	0.85	54.17	0.1777	3.03	0.3206
7	170.5	1.00	7.33	0.0241	2.45	0.1173

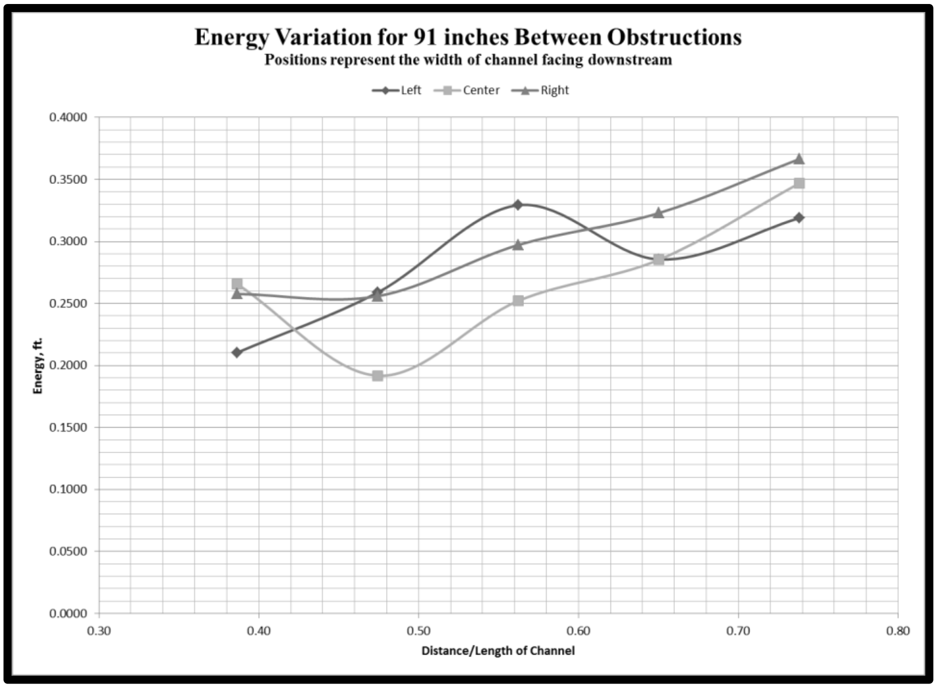

Figure 30: Jump Configuration Energy Variation @ 91 inches Between Obstructions

Ultimately, the Jump Configuration did not appear to be chosen for water fluctuation and mixing. The PAM blocks placed in the field scale testing need adequate mixing to occur and with this configuration, it is more a linear incline of energy than a clear oscillation. The Energy Variation graph for 91 inches between the obstruction sets shown above in Figure 30 visibly increase throughout the channel length. The water seemed to build up speed in between the obstruction sets, but not until roughly 34 inches from the jump. The hydraulic jump introduces a favorable time for settling although if a PAM block is causing the jump itself as depicted by this configuration, then that settling opportunity is essentially compromised and the only chance of settling is the area between the obstruction sets. Images of the hydraulic jump can be seen in Figure 31 and Figure 32. All additional test data for the Jump Configuration can be found in the Appendix.

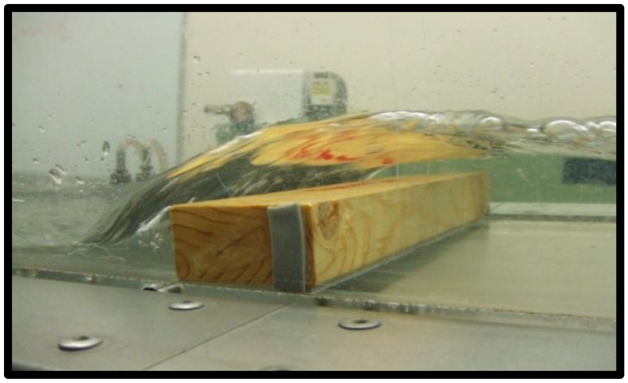

Figure 31: Hydraulic Jump within Flume

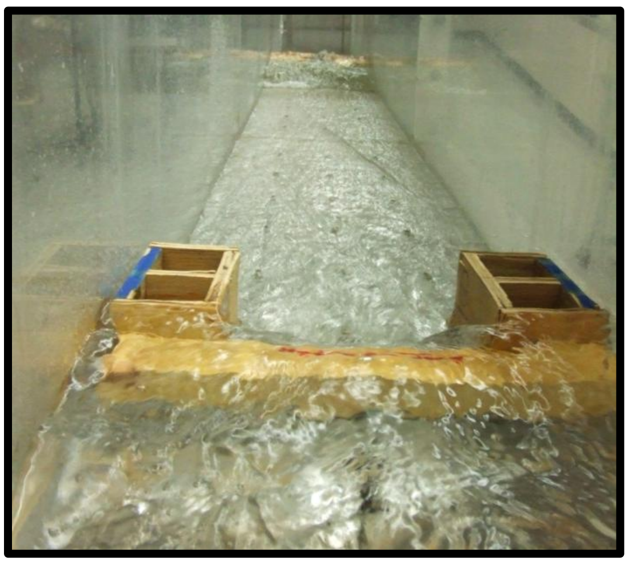

Figure 32: Jump Configuration facing downstream

5.2.2 Dispersion Configuration

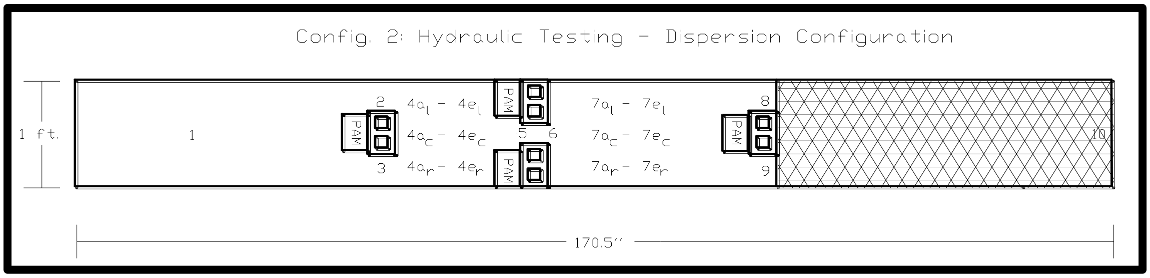

Figure 33: Dispersion Configuration Identification Points

The next configuration considered is the Dispersion Configuration. The intent of the Dispersion Configuration is to split the water flow forcing the paths to come into immediate contact with additional PAM blocks downstream. This illustration is shown above in Figure 33. The blocks were secured and the flume set-up for slope and flow rate was identical to that of the Jump Configuration. The distances altered for this configuration were x_2 and x_3 and as a result, x_4 (refer to Figure 15).

Table 13: Dispersion Configuration Trial 1 Data Results @ 27'' & 33'' between obstructions

11/15/2010
Full Size PAM
Set Up No. 2 **Slope (%)** **12.5**

X_1	**46**	in.
X_2	**27 1/4**	in.
X_3	**33 1/2**	
Distance from back of 3rd Obstruction to water re-capture:	**55 1/2**	in.
Back water depth of hydraulic jump taken from center obstruction:	**14 1/2**	in.

1 of 3

I.D.	*Length from H_2O Entrance (in.)*	*Distance/Length of Channel*	*Height (mm)*	*Height (ft)*	*V (fps)*	*Energy (ft.)*
1	21	0.12	7	0.0230	3.2	0.1820
2	47.5	0.28	19.5	0.0640	2	0.1261
3	47.5	0.28	19	0.0623	2.2	0.1375
$4a_l$	51.5	0.30	5	0.0164	1.6	0.0562
$4a_c$	51.5	0.30	3	0.0098	0.3	0.0112
$4a_r$	51.5	0.30	4	0.0131	1.7	0.0580
$4b_l$	55.5	0.33	8.5	0.0279	1.8	0.0782
$4b_c$	55.5	0.33	4	0.0131	0.5	0.0170
$4b_r$	55.5	0.33	9.5	0.0312	1.8	0.0815
$4c_l$	59.5	0.35	6	0.0197	2.9	0.1503
$4c_c$	59.5	0.35	13	0.0427	1.1	0.0614
$4c_r$	59.5	0.35	8	0.0262	3	0.1660
$4d_l$		0.00		0.0000		0.0000
$4d_c$		0.00		0.0000		0.0000
$4d_r$		0.00		0.0000		0.0000
$4e_l$		0.00		0.0000		0.0000
$4e_c$		0.00		0.0000		0.0000
$4e_r$		0.00		0.0000		0.0000
5	76.25	0.45	71.5	0.2346	1.9	0.2906
6	78.75	0.46	42	0.1378	2.9	0.2684
$7a_l$	84.65	0.50	7.5	0.0246	1.3	0.0508
$7a_c$	84.65	0.50	7	0.0230	3.3	0.1921
$7a_r$	84.65	0.50	6.5	0.0213	2.6	0.1263
$7b_l$	90.55	0.53	3.5	0.0115	0.7	0.0191
$7b_c$	90.55	0.53	3.5	0.0115	1.8	0.0618
$7b_r$	90.55	0.53	4	0.0131	2	0.0752
$7c_l$	96.45	0.57	7	0.0230	3.1	0.1722
$7c_c$	96.45	0.57	3	0.0098	1.1	0.0286
$7c_r$	96.45	0.57	4.5	0.0148	2.3	0.0969
$7d_l$	102.35	0.60	7	0.0230	3	0.1627
$7d_c$	102.35	0.60	3	0.0098	0.9	0.0224
$7d_r$	102.35	0.60	6.5	0.0213	3.3	0.1904
$7e_l$	108.25	0.63	6	0.0197	3.4	0.1992
$7e_c$	108.25	0.63	7	0.0230	0.8	0.0329
$7e_r$	108.25	0.63	6	0.0197	3	0.1594
8	112.25	0.66	22	0.0722	2.7	0.1854
9	112.25	0.66	19	0.0623	2.2	0.1375
10	170.5	1.00	5	0.0164	3	0.1562

Table 14: Dispersion Configuration Data Results Average @ 27'' & 33'' between obstructions

I.D.	Length from H_2O Entrance (in.)	Distance/Channel Length	Average Height (mm)	Height (ft)	Height S.D.	V (fps)	Velocity S.D.	Energy (ft.)
1	21	0.12	7.0	0.0230	0.00	3.2	0.00	0.1820
2	47.5	0.28	18.7	0.0612	0.76	1.9	0.06	0.1193
3	47.5	0.28	18.2	0.0596	0.76	2.3	0.06	0.1394
$4a_l$	51.5	0.30	5.2	0.0170	0.29	1.5	0.15	0.0504
$4a_c$	51.5	0.30	3.3	0.0109	0.29	0.2	0.10	0.0116
$4a_r$	51.5	0.30	4.0	0.0131	0.00	1.7	0.00	0.0580
$4b_l$	55.5	0.33	8.2	0.0268	0.29	2.2	0.32	0.0997
$4b_c$	55.5	0.33	4.2	0.0137	0.29	0.3	0.15	0.0154
$4b_r$	55.5	0.33	9.2	0.0301	0.29	1.6	0.20	0.0698
$4c_l$	59.5	0.35	5.8	0.0191	0.29	2.8	0.17	0.1409
$4c_c$	59.5	0.35	12.5	0.0410	0.50	1.0	0.23	0.0555
$4c_r$	59.5	0.35	7.8	0.0257	0.29	2.8	0.20	0.1474
$4d_l$								
$4d_c$								
$4d_r$								
$4e_l$								
$4e_c$								
$4e_r$								
5	76.25	0.45	70.8	0.2324	0.76	1.9	0.00	0.2884
6	78.75	0.46	41.7	0.1367	1.53	2.9	0.10	0.2673
$7a_l$	84.65	0.50	7.2	0.0235	0.29	1.3	0.06	0.0484
$7a_c$	84.65	0.50	7.0	0.0230	0.00	3.2	0.15	0.1787
$7a_r$	84.65	0.50	6.8	0.0224	0.29	2.5	0.15	0.1169
$7b_l$	90.55	0.53	3.7	0.0120	0.29	1.0	0.46	0.0265
$7b_c$	90.55	0.53	3.7	0.0120	0.29	1.9	0.12	0.0701
$7b_r$	90.55	0.53	4.0	0.0131	0.00	2.0	0.06	0.0773
$7c_l$	96.45	0.57	7.7	0.0252	0.58	3.1	0.06	0.1776
$7c_c$	96.45	0.57	3.0	0.0098	0.00	1.1	0.10	0.0286
$7c_r$	96.45	0.57	4.7	0.0153	0.29	2.3	0.25	0.0951
$7d_l$	102.35	0.60	7.2	0.0235	0.29	3.2	0.21	0.1858
$7d_c$	102.35	0.60	3.0	0.0098	0.00	0.8	0.12	0.0206
$7d_r$	102.35	0.60	6.8	0.0224	0.29	3.1	0.15	0.1749
$7e_l$	108.25	0.63	6.0	0.0197	0.50	3.4	0.06	0.1957
$7e_c$	108.25	0.63	7.0	0.0230	0.00	0.7	0.10	0.0306
$7e_r$	108.25	0.63	6.0	0.0197	0.00	3.1	0.15	0.1721
8	112.25	0.66	23.3	0.0766	1.53	2.3	0.35	0.1611
9	112.25	0.66	20.7	0.0678	1.53	2.3	0.06	0.1476
10	170.5	1.00	5.3	0.0175	0.58	2.9	0.21	0.1511

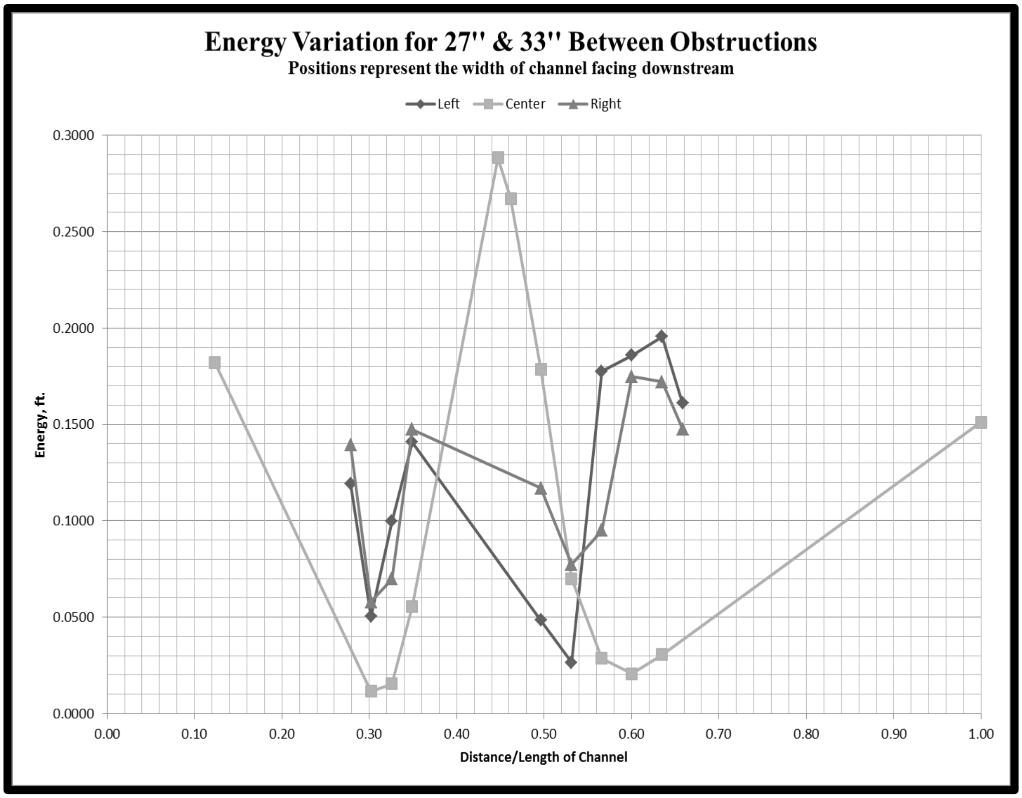

Figure 34: Dispersion Configuration Energy Variation @ 27'' & 33'' between obstructions

Table 15: Dispersion Configuration Trial 1 Data Results @ 57'' & 46'' between obstructions

11/15/2010
Full Size PAM
Set Up No. 2 **Slope (%)** **12.5**

X_1	**46**	in.
X_2	**57 1/2**	in.
X_3	**45 3/4**	in.
Distance from back of 3rd Obstruction to water re-capture:	**13 1/2**	in.
Back water depth of hydraulic jump taken from center obstruction:	**14 3/4**	in.

1 of 3

I.D.	*Length from H_2O Entrance (in.)*	*Distance/Length of Channel*	*Height (mm)*	*Height (ft)*	*V (fps)*	*Energy (ft.)*
1	21	0.12	7	0.0230	3.2	0.1820
2	47.5	0.28	14.5	0.0476	2.3	0.1297
3	47.5	0.28	24	0.0787	2.4	0.1682
$4a_l$	55.9	0.33	12.75	0.0418	1.9	0.0979
$4a_c$	55.9	0.33	6	0.0197	0.2	0.0203
$4a_r$	55.9	0.33	18	0.0591	1.5	0.0940
$4b_l$	64.3	0.38	12	0.0394	2.8	0.1611
$4b_c$	64.3	0.38	19	0.0623	2	0.1244
$4b_r$	64.3	0.38	7	0.0230	2.9	0.1536
$4c_l$	72.7	0.43	5	0.0164	2.1	0.0849
$4c_c$	72.7	0.43	11.75	0.0385	2.9	0.1691
$4c_r$	72.7	0.43	5	0.0164	2.6	0.1214
$4d_l$	81.1	0.48	7.5	0.0246	3.1	0.1738
$4d_c$	81.1	0.48	8	0.0262	3.6	0.2275
$4d_r$	81.1	0.48	7.5	0.0246	3.4	0.2041
$4e_l$	89.5	0.52	6.5	0.0213	3	0.1611
$4e_c$	89.5	0.52	6	0.0197	3.4	0.1992
$4e_r$	89.5	0.52	6	0.0197	3.7	0.2323
5	105.5	0.62	71	0.2329	1.7	0.2778
6	109	0.64	44	0.1444	2.8	0.2661
$7a_l$	117.5	0.69	9.5	0.0312	2.1	0.0996
$7a_c$	117.5	0.69	4.5	0.0148	2.7	0.1280
$7a_r$	117.5	0.69	4.5	0.0148	2.3	0.0969
$7b_l$	126	0.74	10	0.0328	2.3	0.1150
$7b_c$	126	0.74	3	0.0098	1	0.0254
$7b_r$	126	0.74	8.5	0.0279	2.5	0.1249
$7c_l$	134.5	0.79	8	0.0262	3.7	0.2388
$7c_c$	134.5	0.79	2.5	0.0082	0.5	0.0121
$7c_r$	134.5	0.79	7	0.0230	3.2	0.1820
$7d_l$	143	0.84	6.5	0.0213	3.2	0.1803
$7d_c$	143	0.84	9	0.0295	3	0.1693
$7d_r$	143	0.84	6	0.0197	3	0.1594
$7e_l$	151.5	0.89	5	0.0164	3.1	0.1656
$7e_c$	151.5	0.89	8	0.0262	3.2	0.1853
$7e_r$	151.5	0.89	5	0.0164	2.5	0.1135
8	156	0.91	19	0.0623	2	0.1244
9	156	0.91	16.5	0.0541	2	0.1162
10	170.5	1.00	15	0.0492	2.5	0.1463

Table 16: Dispersion Configuration Data Results Average @ 57'' & 46'' between obstructions

			Average					
I.D.	*Length from H_2O Entrance (in.)*	*Distance/Length of Channel*	*Height (mm)*	*Height (ft)*	*Height S.D.*	*V (fps)*	*Velocity S.D.*	*Energy (ft.)*
1	21	0.12	6.5	0.0213	0.50	3.2	0.00	0.1803
2	47.5	0.28	13.2	0.0432	1.26	2.1	0.17	0.1117
3	47.5	0.28	16.8	0.0552	6.33	2.4	0.15	0.1472
$4a_l$	55.9	0.33	10.3	0.0339	2.18	1.8	0.32	0.0824
$4a_c$	55.9	0.33	4.5	0.0148	1.32	0.3	0.06	0.0159
$4a_r$	55.9	0.33	11.0	0.0361	6.24	1.2	0.29	0.0572
$4b_l$	64.3	0.38	7.3	0.0241	4.04	2.8	0.10	0.1458
$4b_c$	64.3	0.38	16.2	0.0530	2.47	2.0	0.00	0.1152
$4b_r$	64.3	0.38	7.0	0.0230	0.00	2.9	0.10	0.1536
$4c_l$	72.7	0.43	4.3	0.0142	0.58	2.0	0.06	0.0784
$4c_c$	72.7	0.43	10.9	0.0358	0.88	2.9	0.15	0.1634
$4c_r$	72.7	0.43	4.8	0.0159	0.29	2.5	0.10	0.1129
$4d_l$	81.1	0.48	7.2	0.0235	0.29	3.0	0.12	0.1664
$4d_c$	81.1	0.48	8.0	0.0262	0.00	3.6	0.00	0.2275
$4d_r$	81.1	0.48	8.0	0.0262	0.50	3.4	0.20	0.2057
$4e_l$	89.5	0.52	6.5	0.0213	0.00	3.0	0.06	0.1580
$4e_c$	89.5	0.52	6.5	0.0213	0.50	3.4	0.15	0.2044
$4e_r$	89.5	0.52	6.7	0.0219	0.58	3.6	0.10	0.2231
5	105.5	0.62	71.3	0.2340	0.29	1.6	0.12	0.2755
6	109	0.64	42.0	0.1378	1.80	2.9	0.10	0.2684
$7a_l$	117.5	0.69	7.3	0.0241	1.89	2.0	0.06	0.0883
$7a_c$	117.5	0.69	4.5	0.0148	0.00	2.6	0.06	0.1224
$7a_r$	117.5	0.69	4.2	0.0137	0.58	2.2	0.15	0.0866
$7b_l$	126	0.74	8.8	0.0290	1.04	2.5	0.44	0.1260
$7b_c$	126	0.74	3.2	0.0104	0.29	1.0	0.00	0.0259
$7b_r$	126	0.74	5.8	0.0191	2.36	2.1	0.40	0.0855
$7c_l$	134.5	0.79	6.8	0.0224	1.04	3.6	0.26	0.2237
$7c_c$	134.5	0.79	3.3	0.0109	0.76	0.8	0.26	0.0209
$7c_r$	134.5	0.79	6.7	0.0219	0.58	3.0	0.21	0.1647
$7d_l$	143	0.84	5.7	0.0186	0.76	3.2	0.00	0.1776
$7d_c$	143	0.84	8.3	0.0273	0.58	2.9	0.17	0.1579
$7d_r$	143	0.84	5.2	0.0170	0.76	2.9	0.12	0.1506
$7e_l$	151.5	0.89	5.0	0.0164	0.00	3.0	0.15	0.1531
$7e_c$	151.5	0.89	7.8	0.0257	0.76	3.2	0.00	0.1847
$7e_r$	151.5	0.89	5.0	0.0164	0.00	2.6	0.21	0.1187
8	156	0.91	18.7	0.0612	0.58	2.1	0.15	0.1319
9	156	0.91	16.2	0.0530	1.04	2.1	0.12	0.1194
10	170.5	1.00	14.5	0.0476	0.87	2.4	0.06	0.1395

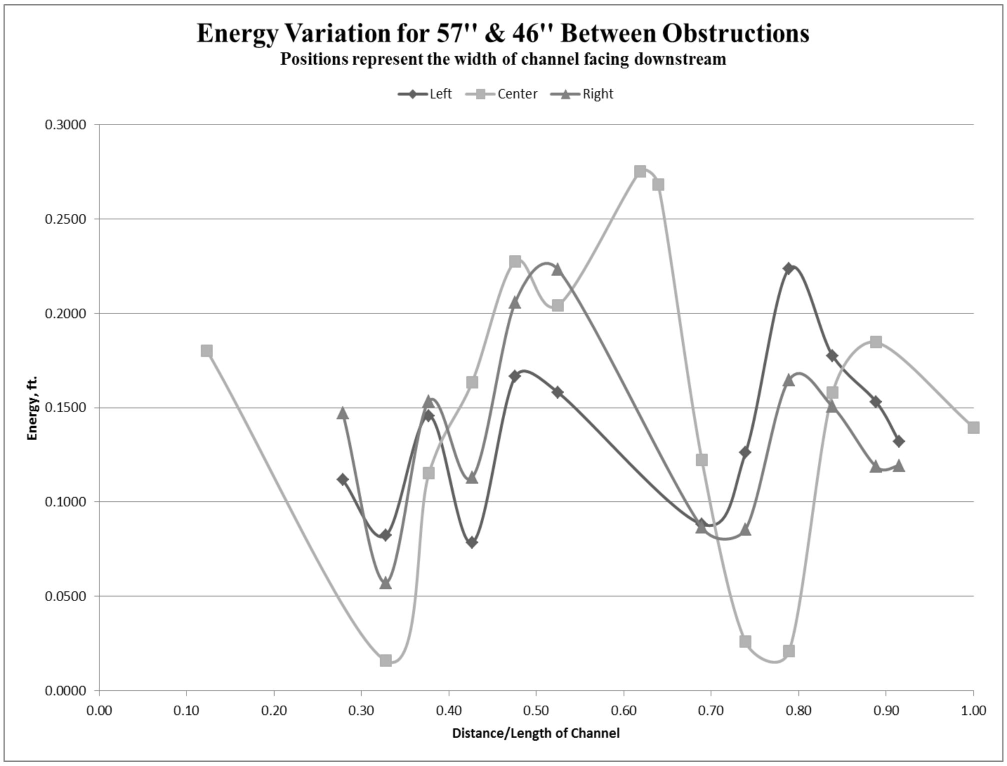

Figure 35: Dispersion Configuration Energy Variation@ 57'' & 46'' between obstructions

Table 13 is the data accumulation for trial 1 of the 27'' and 33'' between the obstructions. Additional measurements were taken with this configuration due to the more detailed behavior of the water throughout the channel. The section of Table 13 that does not have data entry is because sufficient space was not permitted with this layout; 27'' and 33'' between the obstructions was the closest layout investigated for the Dispersion Configuration. Table 14 is the average of the three trials the 27'' and 33'' layout and Figure 34 is the graph of the energy fluctuation.

The other distances chosen to test for x_2 and x_3 were 33'' and 40'', 45'' and 28'', and 45'' and 39'', respectively. As the distances were increased, more uniformity appeared within the energy variation. Similar to the Jump Configuration, the left and right water paths did not display identical energy variations. Table 15 is the data for trial 1 when the furthest distance between the obstructions, 57’’ and 46’’, was investigated for the Dispersion Configuration and Table 16 displays the average values amongst the three trials tested. The peak energy level for the first layout of 27’’ and 33’’ apart was 0.2884 ft. and the peak energy level for the furthest layout of 57’’ and 46’’ apart was 0.2755 ft. as seen in Figure 34 and Figure 35, respectively. This was caused by the jump induced by the two lateral obstructions.

It was observed that the backwater caused by the second obstruction set can be beneficial for the field-scale testing. This area can provide settling time for the flocs after contact to the initial PAM block. By keeping the flocs maintained to a confined area, maintenance for this configuration can be reduced and predictable.

The original intent of the final PAM block downstream was to serve as a polishing step prior to the collection mat. The issue observed from the flume testing validates that after the jump, the flow does not return to a steady state condition. For instance, the velocity range for the 27’’ and 33’’ layout begins with 2.0 fps and propels to 3.2 fps, but then immediately drops once again to 2.6 fps. The further the distance in between the obstructions are, the greater the chance of recovery to steady state. Unfortunately, field conditions dictate the configuration used and channel length is an important factor.

Preferably, the flow that comes in contact with the final PAM block needs to be forceful enough to achieve aggressive mixing at that location, but not too much to by-pass the opportunity and contact time for mixing. With the Dispersion Configuration, distance x_3 is a clear path for water flow to stabilize, but when space is limited, this is difficult to attain. The linear pathway for water to recover through the center of the channel occurs at points $7a_c$ – $7e_c$.

Figure 36 is a graph of the energy level of all five layouts from points $7a_c – 7e_c$. The figure displays that as the distance x_3 is reduced, less stabilization transpires within that section.

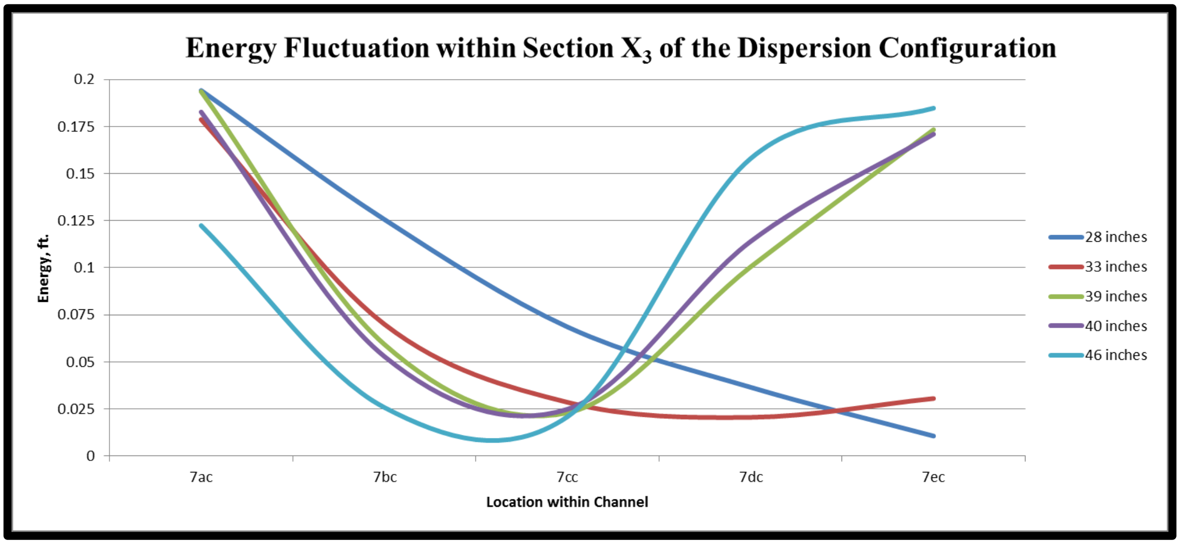

Figure 36: Energy Fluctuation for the Dispersion Configuration

Figure 36 is a verification of the finding that as the distance between the second obstruction set and the final PAM block downstream is increased, it is evident that stabilization follows. The 28 inch and 33inch lengths both show clear degradation without any sign of recovery back to the initial energy level. The remaining three distances all show signs of recovery and the furthest distance of 46 inches attempts to plateau towards the end of the section. Consequently, it is beneficial to place the final PAM block as a refining step the furthest possible distance the channel permits in order to allow the flow time to recover back to the steady state energy level. The steady state energy level when x_3 equals 46 inches was 0.1803 ft. and the energy level directly before the final PAM block for that particular layout was 0.1847 ft.

5.2.3 Staggered Configuration

The Staggered Configuration was selected to be studied as it is the most popular within the PAM industry. The masonry blocks serve as baffles and forces the water to maneuver around them. This results in additional treatment time and rigorous mixing throughout the course of the channel. Some of the major concerns observed with this investigation include the formation of dead zones, possible short circuiting of the water path and more extensive maintenance. With pockets of dead zones behind each individual masonry block, there is great potential for flocs to settle causing a cleaning effort behind all four blocks in additional to any accumulation of floc downstream towards the re-capture. Preferably, the floc should be contained within the fewest sections possible to reduce cost of cleaning and maintenance.

Four different layouts for this configuration were tested. The spacing in between all obstruction was uniform. More specifically, x_2, x_3 and x_4 were identical for each of the tests. The four lengths chosen for testing were 9 inches, 15 inches, 21.5 inches and 32.75 inches. Figure 37 displays the various locations in which velocity and height measurements were taken.

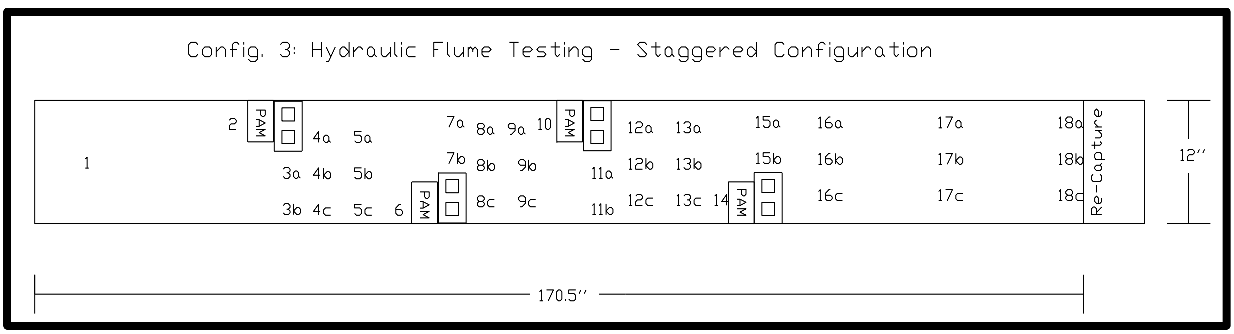

Figure 37: Staggered Configuration Identification Points

Table 17: Staggered Configuration Trial 1 Data Results @ 9'' between obstructions

11/17/2010
Full Size PAM
Set Up No. 2 **Slope (%)** **12.5**

X_1	**46**	in.
X_2	**9**	in.
X_3	**9**	in.
X_4	**9**	in.
Distance from back of 4th Obstruction to water re-capture:	**85 3/4**	in.

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I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (mm)***	***Height (ft)***	***V (fps)***	***Energy (ft.)***
1	21	0.12	7	0.0230	3.2	0.1820
2	44.25	0.26	57	0.1870	0.5	0.1909
3a	47.5	0.28	18	0.0591	2.2	0.1342
3b	47.5	0.28	20	0.0656	2.4	0.1551
4a	52.5	0.31	19.5	0.0640	0.3	0.0654
4b	52.5	0.31	18	0.0591	1.1	0.0778
4c	52.5	0.31	21.5	0.0705	1.6	0.1103
5a	54.5	0.32	24	0.0787	0.2	0.0794
5b	54.5	0.32	31	0.1017	1	0.1172
5c	54.5	0.32	39	0.1280	1	0.1435
6	57.25	0.34	62	0.2034	0.6	0.2090
7a	59.75	0.35	35	0.1148	1.9	0.1709
7b	59.75	0.35	8	0.0262	1.8	0.0766
8a	63	0.37	14	0.0459	1.1	0.0647
8b	63	0.37	15	0.0492	1	0.0647
8c	63	0.37	13.5	0.0443	0.2	0.0449
9a	65	0.38	36	0.1181	1.7	0.1630
9b	65	0.38	23	0.0755	0.3	0.0769
9c	65	0.38	24	0.0787	0.2	0.0794
10	68.25	0.40	71	0.2329	0.5	0.2368
11a	70.75	0.41	5	0.0164	1.2	0.0388
11b	70.75	0.41	32.5	0.1066	2	0.1687
12a	74	0.43	19.5	0.0640	0.2	0.0646
12b	74	0.43	21	0.0689	0.3	0.0703
12c	74	0.43	32	0.1050	1.1	0.1238
13a	76	0.45	25	0.0820	0.1	0.0822
13b	76	0.45	27	0.0886	0.3	0.0900
13c	76	0.45	46	0.1509	1.3	0.1772
14	79.25	0.46	70	0.2297	1	0.2452
15a	81.5	0.48	34.5	0.1132	2.2	0.1883
15b	81.5	0.48	8	0.0262	1.8	0.0766
16a	111	0.65	4.5	0.0148	2.5	0.1118
16b	111	0.65	4.5	0.0148	2.6	0.1197
16c	111	0.65	4	0.0131	1.8	0.0634
17a	139.75	0.82	4.5	0.0148	1.8	0.0651
17b	139.75	0.82	6	0.0197	3.2	0.1787
17c	139.75	0.82	6.5	0.0213	4	0.2698
18a	170.5	1.00	5	0.0164	2.6	0.1214
18b	170.5	1.00	5	0.0164	3.2	0.1754
18c	170.5	1.00	5.5	0.0180	3.7	0.2306

Table 18: Staggered Configuration Data Results Average @ 9'' between obstructions

			Average					
I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (mm)***	***Height S.D.***	***Height (ft)***	***V (fps)***	***Velocity S.D.***	***Energy (ft.)***
1	21	0.12	6.7	0.3	0.0219	3.2	0.0	**0.1809**
2	44.25	0.26	57.8	1.4	0.1897	0.4	0.1	**0.1918**
3a	47.5	0.28	18.3	0.6	0.0601	2.0	0.2	**0.1243**
3b	47.5	0.28	20.7	0.6	0.0678	2.5	0.2	**0.1649**
4a	52.5	0.31	19.7	0.3	0.0645	0.2	0.1	**0.0651**
4b	52.5	0.31	18.3	0.6	0.0601	1.1	0.1	**0.0778**
4c	52.5	0.31	23.5	1.8	0.0771	1.7	0.1	**0.1220**
5a	54.5	0.32	24.7	0.6	0.0809	0.1	0.1	**0.0812**
5b	54.5	0.32	31.3	0.6	0.1028	0.8	0.2	**0.1127**
5c	54.5	0.32	38.7	0.6	0.1269	1.1	0.1	**0.1456**
6	57.25	0.34	62.8	0.8	0.2061	0.5	0.1	**0.2106**
7a	59.75	0.35	34.0	1.0	0.1115	1.9	0.1	**0.1696**
7b	59.75	0.35	7.7	0.6	0.0252	1.6	0.2	**0.0633**
8a	63	0.37	14.0	1.0	0.0459	1.5	0.4	**0.0793**
8b	63	0.37	15.7	0.6	0.0514	1.0	0.1	**0.0680**
8c	63	0.37	14.8	1.3	0.0487	0.2	0.1	**0.0495**
9a	65	0.38	35.7	0.6	0.1170	1.5	0.3	**0.1520**
9b	65	0.38	24.0	1.0	0.0787	0.3	0.0	**0.0801**
9c	65	0.38	24.2	0.3	0.0793	0.2	0.1	**0.0797**
10	68.25	0.40	71.7	0.6	0.2351	0.5	0.1	**0.2385**
11a	70.75	0.41	5.0	0.0	0.0164	1.3	0.1	**0.0426**
11b	70.75	0.41	32.5	0.5	0.1066	2.0	0.0	**0.1687**
12a	74	0.43	20.2	0.8	0.0662	0.1	0.1	**0.0664**
12b	74	0.43	21.7	0.6	0.0711	0.3	0.1	**0.0725**
12c	74	0.43	31.0	1.0	0.1017	1.0	0.1	**0.1172**
13a	76	0.45	25.3	0.6	0.0831	0.1	0.0	**0.0833**
13b	76	0.45	27.5	0.5	0.0902	0.3	0.1	**0.0913**
13c	76	0.45	44.7	1.2	0.1465	1.2	0.3	**0.1702**
14	79.25	0.46	69.0	1.0	0.2264	1.1	0.1	**0.2452**
15a	81.5	0.48	34.7	0.3	0.1137	2.3	0.1	**0.1959**
15b	81.5	0.48	6.7	1.2	0.0219	1.9	0.1	**0.0799**
16a	111	0.65	4.7	0.3	0.0153	2.7	0.2	**0.1313**
16b	111	0.65	4.7	0.3	0.0153	2.5	0.1	**0.1150**
16c	111	0.65	4.3	0.3	0.0142	1.6	0.3	**0.0540**
17a	139.75	0.82	4.3	0.3	0.0142	1.8	0.1	**0.0627**
17b	139.75	0.82	6.0	0.0	0.0197	3.2	0.1	**0.1754**
17c	139.75	0.82	6.7	0.3	0.0219	4.0	0.0	**0.2703**
18a	170.5	1.00	5.0	0.0	0.0164	2.7	0.1	**0.1324**
18b	170.5	1.00	5.3	0.3	0.0175	3.2	0.1	**0.1798**
18c	170.5	1.00	5.5	0.0	0.0180	3.7	0.1	**0.2268**

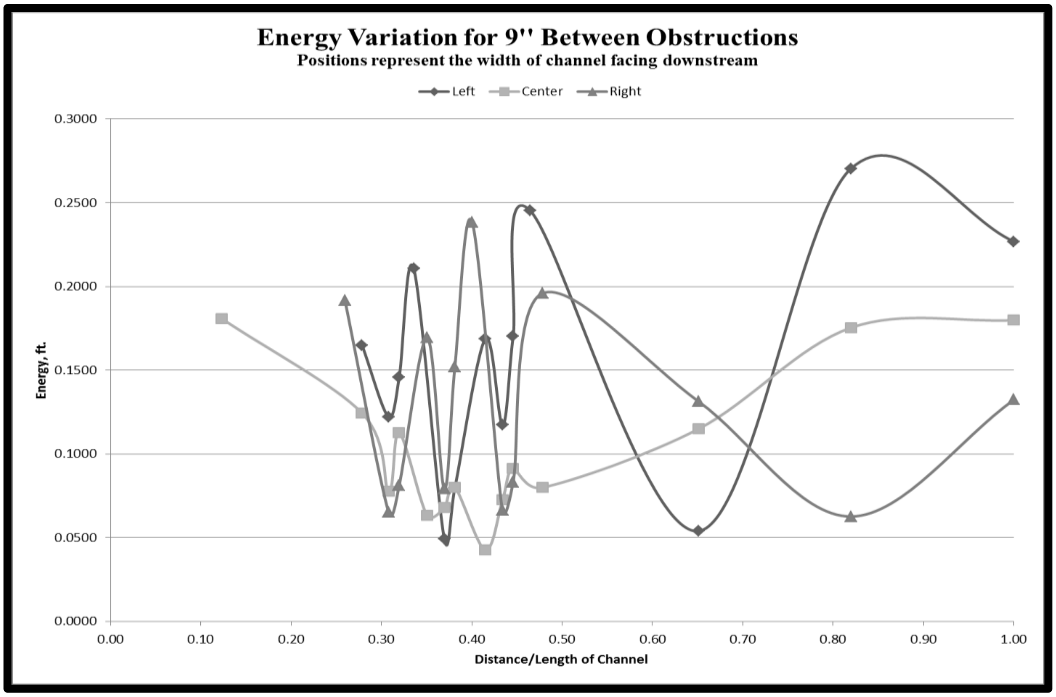


Figure 38: Staggered Configuration Energy Variation @ 9'' between obstructions

Table 17 is the resulting values obtained from the first trial of the Staggered Configuration with a uniform distance between the blocks set at 9 in. Table 18 is the average of all three trials tests for this layout. The 9 inch placement in between the obstructions did not yield favorable results. The distance was not found to be conducive for the purpose of this particular configuration as shown in Figure 38. The water appeared to pile over the obstructions, similar to a jump, as opposed to winding around them. As depicted by the energy Variation graph above, there does not appear to be much uniformity within the mixing zone. For this layout, the mixing zone is between 26 and 48 percent down the channel.

Table 19: Staggered Configuration Trial 1 Data Results @ 32.75'' between obstructions

11/17/2010
Full Size PAM
Set Up No. 2 **Slope (%)** **12.5**

X_1	**46**	in.
X_2	**32 3/4**	in.
X_3	**32 3/4**	in.
X_4	**32 3/4**	in.
Distance from back of 4th Obstruction to water re-capture:	**13 3/4**	in.

1 of 3

I.D.	*Length from H_2O Entrance (in.)*	*Distance/Length of Channel*	*Height (mm)*	*Height (ft)*	*V (fps)*	*Energy (ft.)*
1	21	0.12	6	0.0197	3.2	0.1787
2	44.25	0.26	61	0.2001	0.3	0.2015
3a	47.5	0.28	23	0.0755	2.3	0.1576
3b	47.5	0.28	27	0.0886	2.4	0.1780
4a	62.75	0.37	3.5	0.0115	0.3	0.0129
4b	62.75	0.37	9	0.0295	2.3	0.1117
4c	62.75	0.37	11	0.0361	3.5	0.2263
5a	75.75	0.44	5.5	0.0180	2.9	0.1486
5b	75.75	0.44	6	0.0197	4	0.2681
5c	75.75	0.44	6.5	0.0213	4	0.2698
6	79.75	0.47	66	0.2165	0.6	0.2221
7a	83.25	0.49	23.5	0.0771	2.5	0.1741
7b	83.25	0.49	28	0.0919	2.3	0.1740
8a	98	0.57	11	0.0361	3	0.1758
8b	98	0.57	7.5	0.0246	1.3	0.0508
8c	98	0.57	4	0.0131	0.2	0.0137
9a	111.5	0.65	6	0.0197	3.6	0.2209
9b	111.5	0.65	4.5	0.0148	2.8	0.1365
9c	111.5	0.65	4.5	0.0148	1.2	0.0371
10	115.5	0.68	61	0.2001	0.3	0.2015
11a	119.25	0.70	12	0.0394	2	0.1015
11b	119.25	0.70	30	0.0984	2.6	0.2034
12a	133.25	0.78	2.5	0.0082	0.1	0.0084
12b	133.25	0.78	8	0.0262	2	0.0884
12c	133.25	0.78	10	0.0328	3.6	0.2341
13a	147	0.86	5	0.0164	2.7	0.1296
13b	147	0.86	4.5	0.0148	3.5	0.2050
13c	147	0.86	6	0.0197	4	0.2681
14	151.5	0.89	63	0.2067	0.4	0.2092
15a	155.25	0.91	28.5	0.0935	2.3	0.1756
15b	155.25	0.91	23	0.0755	2.2	0.1506
16a	161.25	0.95	14	0.0459	2.3	0.1281
16b	161.25	0.95	3.5	0.0115	1	0.0270
16c	161.25	0.95	2	0.0066	0.1	0.0067
17a	165.75	0.97	17	0.0558	2.7	0.1690
17b	165.75	0.97	2.5	0.0082	0.3	0.0096
17c	165.75	0.97	2.5	0.0082	0.1	0.0084
18a	170.5	1.00	9	0.0295	3	0.1693
18b	170.5	1.00	9	0.0295	1.2	0.0519
18c	170.5	1.00	2	0.0066	0.2	0.0072

Table 20: Staggered Configuration Data Results Average @ 32.75'' between obstructions

		Average				
I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (mm)***	***Height (ft)***	***V (fps)***	***Energy (ft.)***
1	21	0.12	6.33	0.0208	3.2	0.1798
2	44.25	0.26	61.83	0.2029	0.4	0.2050
3a	47.5	0.28	24.50	0.0804	2.3	0.1602
3b	47.5	0.28	26.33	0.0864	2.5	0.1809
4a	62.75	0.37	3.33	0.0109	0.4	0.0130
4b	62.75	0.37	9.33	0.0306	2.2	0.1081
4c	62.75	0.37	10.50	0.0344	3.5	0.2247
5a	75.75	0.44	5.17	0.0170	3.0	0.1536
5b	75.75	0.44	6.17	0.0202	3.9	0.2605
5c	75.75	0.44	6.67	0.0219	4.0	0.2745
6	79.75	0.47	65.00	0.2133	0.4	0.2162
7a	83.25	0.49	22.83	0.0749	2.4	0.1669
7b	83.25	0.49	27.67	0.0908	2.2	0.1637
8a	98	0.57	10.67	0.0350	3.0	0.1717
8b	98	0.57	7.33	0.0241	1.3	0.0503
8c	98	0.57	3.50	0.0115	0.1	0.0118
9a	111.5	0.65	5.50	0.0180	3.5	0.2119
9b	111.5	0.65	4.17	0.0137	2.8	0.1325
9c	111.5	0.65	4.50	0.0148	1.5	0.0497
10	115.5	0.68	61.17	0.2007	0.4	0.2032
11a	119.25	0.70	14.33	0.0470	2.0	0.1091
11b	119.25	0.70	26.33	0.0864	2.6	0.1887
12a	133.25	0.78	2.43	0.0080	0.2	0.0086
12b	133.25	0.78	7.50	0.0246	2.1	0.0931
12c	133.25	0.78	10.83	0.0355	3.7	0.2443
13a	147	0.86	5.17	0.0170	2.8	0.1387
13b	147	0.86	4.83	0.0159	3.6	0.2171
13c	147	0.86	6.00	0.0197	4.0	0.2681
14	151.5	0.89	64.00	0.2100	0.5	0.2134
15a	155.25	0.91	29.17	0.0957	2.6	0.1980
15b	155.25	0.91	22.67	0.0744	2.1	0.1450
16a	161.25	0.95	12.67	0.0416	2.3	0.1261
16b	161.25	0.95	3.50	0.0115	1.0	0.0260
16c	161.25	0.95	2.00	0.0066	0.1	0.0067
17a	165.75	0.97	17.17	0.0563	2.8	0.1781
17b	165.75	0.97	2.83	0.0093	0.3	0.0104
17c	165.75	0.97	2.83	0.0093	0.1	0.0095
18a	170.5	1.00	9.33	0.0306	3.0	0.1704
18b	170.5	1.00	8.50	0.0279	1.2	0.0490
18c	170.5	1.00	2.83	0.0093	0.1	0.0096

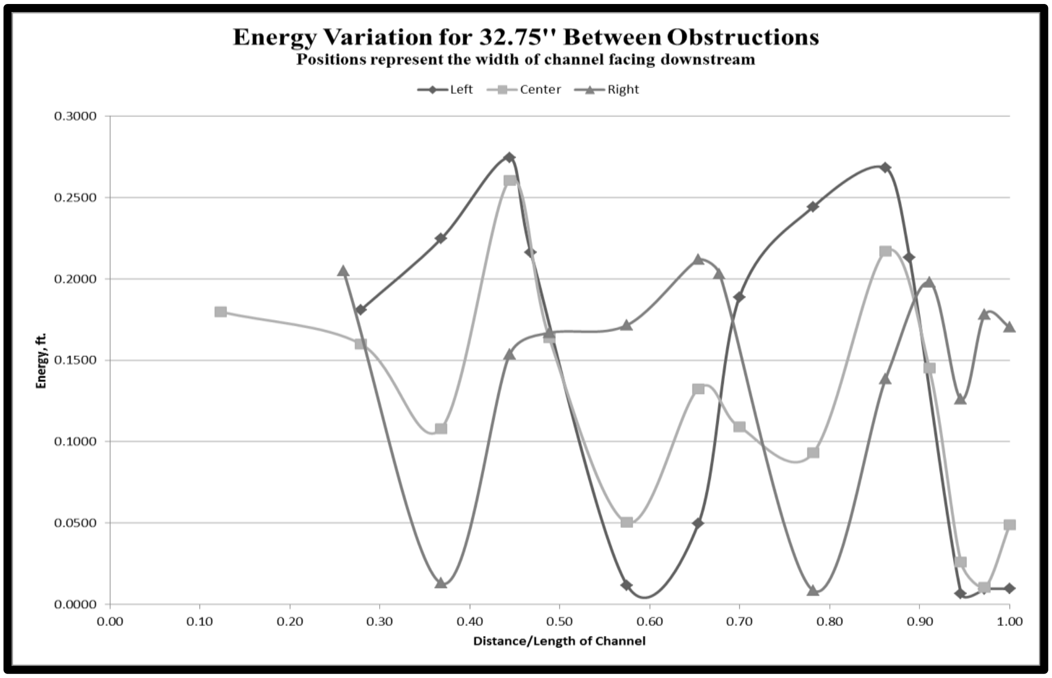


Figure 39: Staggered Configuration Energy Variation @ 32.75'' between obstructions

The furthest distance in between the obstructions tested for the Staggered configuration was 32.75’’. Table 19 displays the results for trial 1 and Table 20 is the average amongst the three trials tested or the 32.75’’ layout. Though much greater water flow throughout the channel was experienced than the 9 inch test, the variation was still not appealing. The right path does not appear to fluctuate as anticipated; there is a plateau between 50% and 65% down the channel as displayed in Figure 39. Most importantly, this layout demands an unreasonably long channel, especially if instituting a recovery section downstream of the mixing zone. Figure 40 is an image taking during the testing for the Staggered Configuration.

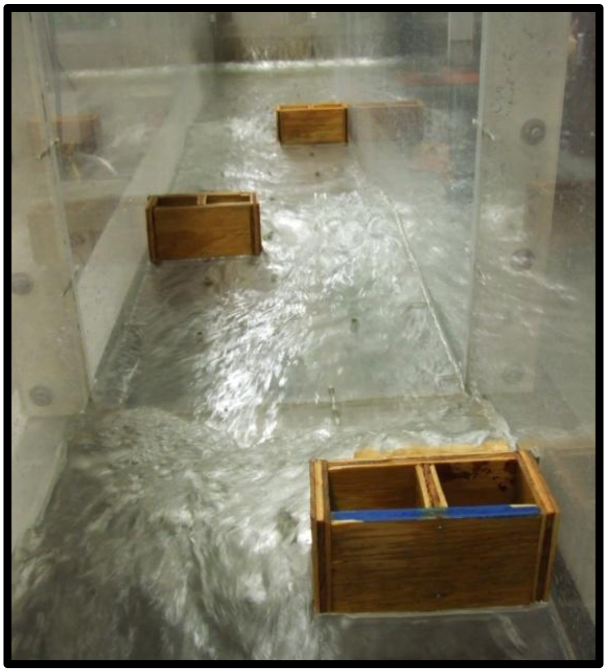


Figure 40: Flume Testing for Staggered Configuration

Table 21: Staggered Configuration Trial 1 Data Results @ 15'' between obstructions

11/17/2010
Full Size PAM
Set Up No. 2 **Slope (%)** **12.5**

X_1	**46**	in.
X_2	**15**	in.
X_3	**15**	in.
X_4	**15**	in.
Distance from back of 4th Obstruction to water re-capture:	**67 3/4**	in.

1 of 3

I.D.	*Length from H_2O Entrance (in.)*	*Distance/Length of Channel*	*Height (mm)*	*Height (ft)*	*V (fps)*	*Energy (ft.)*
1	21	0.12	6.5	0.0213	3.2	0.1803
2	43.75	0.26	63	0.2067	0.4	0.2092
3a	47.5	0.28	24	0.0787	2	0.1409
3b	47.5	0.28	24.5	0.0804	2.6	0.1853
4a	55	0.32	3	0.0098	0.2	0.0105
4b	55	0.32	5	0.0164	1.2	0.0388
4c	55	0.32	8	0.0262	2.3	0.1084
5a	59.5	0.35	13	0.0427	0.2	0.0433
5b	59.5	0.35	18	0.0591	0.5	0.0629
5c	59.5	0.35	16.5	0.0541	2.7	0.1673
6	63	0.37	74.5	0.2444	0.4	0.2469
7a	65.5	0.38	40	0.1312	1.7	0.1761
7b	65.5	0.38	22	0.0722	2.7	0.1854
8a	70.75	0.41	18.5	0.0607	2.5	0.1577
8b	70.75	0.41	3.5	0.0115	1	0.0270
8c	70.75	0.41	3	0.0098	0.1	0.0100
9a	75	0.44	13	0.0427	2.6	0.1476
9b	75	0.44	2	0.0066	0.3	0.0080
9c	75	0.44	5	0.0164	0.1	0.0166
10	79.5	0.47	77	0.2526	0.3	0.2540
11a	83.25	0.49	15	0.0492	2.2	0.1244
11b	83.25	0.49	27.5	0.0902	1.9	0.1463
12a	89.75	0.53	2	0.0066	0.1	0.0067
12b	89.75	0.53	3	0.0098	0.6	0.0154
12c	89.75	0.53	21	0.0689	2.5	0.1659
13a	93.75	0.55	11	0.0361	0.2	0.0367
13b	93.75	0.55	10	0.0328	0.4	0.0353
13c	93.75	0.55	13	0.0427	3	0.1824
14	99	0.58	74	0.2428	0.5	0.2467
15a	102.25	0.60	24	0.0787	1.6	0.1185
15b	102.25	0.60	22	0.0722	2.5	0.1692
16a	125.75	0.74	7	0.0230	3.6	0.2242
16b	125.75	0.74	5	0.0164	2.8	0.1381
16c	125.75	0.74	5	0.0164	1.3	0.0426
17a	148.75	0.87	5	0.0164	2.7	0.1296
17b	148.75	0.87	4.5	0.0148	2.5	0.1118
17c	148.75	0.87	9	0.0295	3.4	0.2090
18a	170.5	1.00	4	0.0131	2.3	0.0953
18b	170.5	1.00	6	0.0197	3.2	0.1787
18c	170.5	1.00	8	0.0262	4.2	0.3002

Table 22: Staggered Configuration Data Results Average @ 15'' between obstructions

			Average					
I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (mm)***	***Height S.D.***	***Height (ft)***	***V (fps)***	***Velocity S.D.***	***Energy (ft.)***
1	21	0.12	6.67	0.29	0.0219	3.2	0.0	0.1809
2	43.75	0.26	62.33	0.58	0.2045	0.4	0.1	0.2074
3a	47.5	0.28	24.17	0.29	0.0793	2.2	0.2	0.1544
3b	47.5	0.28	24.67	0.76	0.0809	2.6	0.1	0.1832
4a	55	0.32	3.17	0.29	0.0104	0.2	0.0	0.0110
4b	55	0.32	5.00	0.50	0.0164	1.6	0.3	0.0545
4c	55	0.32	8.50	0.50	0.0279	2.3	0.1	0.1124
5a	59.5	0.35	12.50	0.50	0.0410	0.2	0.1	0.0414
5b	59.5	0.35	18.33	1.53	0.0601	0.6	0.1	0.0651
5c	59.5	0.35	16.83	0.29	0.0552	2.7	0.1	0.1712
6	63	0.37	74.67	0.76	0.2450	0.4	0.1	0.2471
7a	65.5	0.38	38.50	1.32	0.1263	1.7	0.1	0.1730
7b	65.5	0.38	24.00	2.00	0.0787	2.7	0.0	0.1919
8a	70.75	0.41	20.50	3.04	0.0673	2.4	0.1	0.1592
8b	70.75	0.41	3.33	0.29	0.0109	1.0	0.1	0.0275
8c	70.75	0.41	2.83	0.29	0.0093	0.1	0.0	0.0095
9a	75	0.44	13.00	0.50	0.0427	2.7	0.1	0.1592
9b	75	0.44	2.17	0.29	0.0071	0.3	0.0	0.0275
9c	75	0.44	5.50	0.87	0.0180	0.1	0.1	0.0095
10	79.5	0.47	76.50	0.50	0.2510	0.4	0.1	0.2535
11a	83.25	0.49	15.33	1.53	0.0503	2.2	0.1	0.1255
11b	83.25	0.49	28.17	0.76	0.0924	1.9	0.1	0.1485
12a	89.75	0.53	2.00	0.00	0.0066	0.1	0.0	0.0067
12b	89.75	0.53	3.17	0.29	0.0104	0.9	0.2	0.0221
12c	89.75	0.53	23.17	2.02	0.0760	2.5	0.4	0.1757
13a	93.75	0.55	10.67	0.58	0.0350	0.1	0.1	0.0353
13b	93.75	0.55	11.67	1.53	0.0383	0.5	0.1	0.0417
13c	93.75	0.55	13.33	0.58	0.0437	3.0	0.0	0.1835
14	99	0.58	72.00	1.73	0.2362	0.4	0.1	0.2391
15a	102.25	0.60	23.67	1.53	0.0776	1.6	0.1	0.1191
15b	102.25	0.60	22.33	1.53	0.0733	2.5	0.1	0.1678
16a	125.75	0.74	6.83	0.29	0.0224	3.5	0.2	0.2163
16b	125.75	0.74	5.33	0.58	0.0175	2.5	0.4	0.1120
16c	125.75	0.74	4.83	0.29	0.0159	1.5	0.3	0.0524
17a	148.75	0.87	4.67	0.29	0.0153	2.8	0.1	0.1342
17b	148.75	0.87	4.83	0.29	0.0159	2.5	0.1	0.1103
17c	148.75	0.87	8.33	0.58	0.0273	3.5	0.1	0.2140
18a	170.5	1.00	4.17	0.29	0.0137	2.3	0.0	0.0958
18b	170.5	1.00	6.17	0.29	0.0202	3.3	0.1	0.1928
18c	170.5	1.00	7.50	0.50	0.0246	4.0	0.2	0.2772

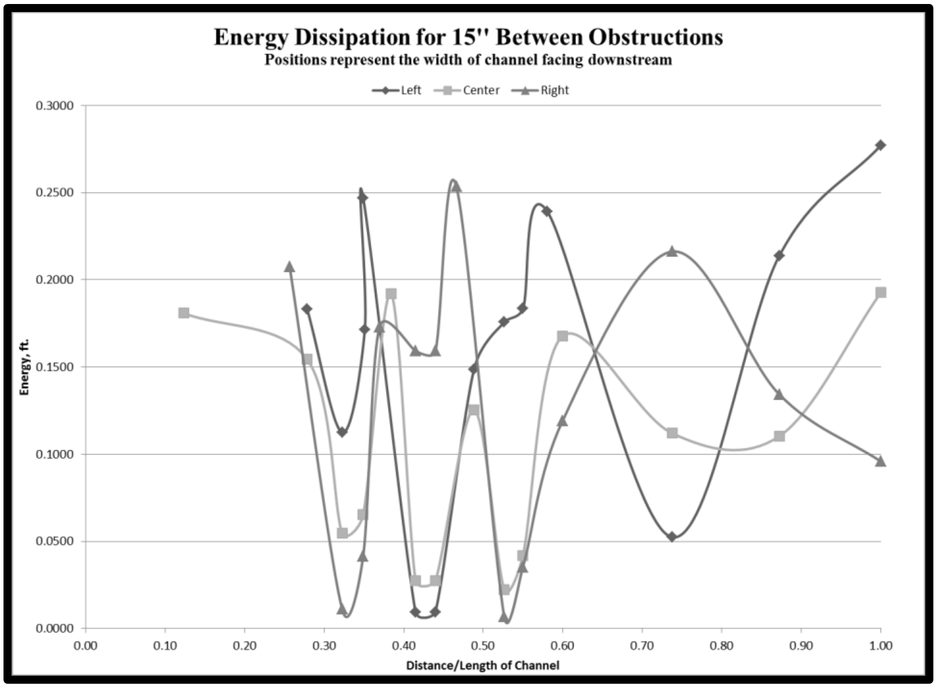


Figure 41: Staggered Configuration Energy Variation @ 15'' between obstructions

The 15 inches between the obstructions clearly displays uniform fluctuation. Table 21 displays the results taken from the first of three trials for the 15 in. layout and Table 22 shows the average measurements of the three trials. Both the left and right water paths follow a more steadied trend than the other distances tested as seen in Figure 41. Also, with the exception of the right path, the water attempts to stabilize once again downstream to the steady state. The major benefit of this layout is that the mixing zone does not intrude through most of the channel. Therefore, roughly 40% of the channel can be used to accumulate the floc created by the mixing zone. The water visibly routed around the obstructions and did not heighten over them as did with the 9 inch test. Due to the vast benefits, this distance was later chosen for the field-scale testing. All remaining results from the hydraulic flume testing not displayed in this chapter are presented within the Appendix.

5.2.4 Examination of Original Configurations

After the completion of the entire flume testing for the original configurations designed, careful attention was given to finding the one that would increase the performance of an open channel within a construction environment. Once again, a few areas of concern were uniform energy variation, limitation of dead zone possibility, and velocity recovery. The more predictable the results are, the more accurate the design can be, ultimately yielding high turbidity removal efficiencies. It is also imperative to keep floc deposits throughout the channel to a minimum; this will reduce the cleaning effort necessary for contractors or field engineers on the construction site.

The Jump Configuration did not seem to be appealing based on the findings of the flume test. The inventive notion for this configuration was to place a PAM block the full extent of the channel width. This would ensure contact with the incoming water, but as the backwater depth increases, the fluctuation at the PAM block is degraded and there does not appear to be enough contact at that location; the cost of the PAM block would greatly outweigh the benefit of having it induce a hydraulic jump. This configuration was not chosen to be carried over to the field-scale testing.

The Dispersion Configuration contained a collection of elements that when combined, appeared to be very advantageous for turbidity removal. The first obstruction forced the current of water to be disseminated along the walls of the channel, then immediately come into contact with a lateral obstruction set taking up 66% of the channel width. Even with the final PAM block downstream as a refining step, there still is sufficient room for the water to recover back to a steady state. In addition, there is distinct oscillation throughout this configuration.

The most beneficial layout for this configuration appeared to be when the obstructions were the furthest apart. Regardless of configuration, each test shows volatility amongst the left and right water paths, but this particular Dispersion configuration did not deviate considerably. The most extreme deviations between the left and right water paths were at the jump. At this point the fluctuation was very aggressive and both velocity and height measurements tend to be more subjective. The greatest percentage difference between the two paths for this dispersion layout was 38%. Table 23 below shows the percentage difference amongst the two water paths for the dispersion configuration with x_2 and x_3 equal to 57'' and 46'', respectively.

Table 23: Percentage Difference of Left and Right Water Paths for Dispersion Configuration

	I.D.	*Length from H_2O Entrance (in.)*	*Distance/Length of Channel*	*Energy (ft.)*	*% Difference*
Left Identification Points	2	47.5	0.28	0.1117	27%
	$4a_l$	55.9	0.33	0.0824	36%
	$4b_l$	64.3	0.38	0.1458	5%
	$4c_l$	72.7	0.43	0.0784	36%
	$4d_l$	81.1	0.48	0.1664	21%
	$4e_l$	89.5	0.52	0.1580	34%
	$7a_l$	117.5	0.69	0.0883	2%
	$7b_l$	126	0.74	0.1260	38%
	$7c_l$	134.5	0.79	0.2237	30%
	$7d_l$	143	0.84	0.1776	16%
	$7e_l$	151.5	0.89	0.1531	25%
	8	156	0.91	0.1319	10%
Right Identification Points	3	47.5	0.28	0.1472	27%
	$4a_r$	55.9	0.33	0.0572	36%
	$4b_r$	64.3	0.38	0.1536	5%
	$4c_r$	72.7	0.43	0.1129	36%
	$4d_r$	81.1	0.48	0.2057	21%
	$4e_r$	89.5	0.52	0.2231	34%
	$7a_r$	117.5	0.69	0.0866	2%
	$7b_r$	126	0.74	0.0855	38%
	$7c_r$	134.5	0.79	0.1647	30%
	$7d_r$	143	0.84	0.1506	16%
	$7e_r$	151.5	0.89	0.1187	25%
	9	156	0.91	0.1194	10%

Amongst the configurations tested, the most appealing appeared to be the Staggered Configuration. This configuration encompassed every element similar to the Dispersion Configuration, but the mixing zone occupies less space of the channel. More precisely, the mixing zone for the Dispersion Configuration occupies 66% of the channel whereas the Staggered Configuration occupies close to half of that at 34% of the channel.

As mentioned prior, the optimum length chose for the uniform distance in between the obstructions was15 inches. When focusing on the energy level directly in front of the PAM blocks, the 15’’ layout achieved the highest energy level amongst the other three layouts chosen. It is also noticed that the 15’’ layout energy levels slightly increase from the initial block and subsequently become relatively the same in front of each block as opposed to the 9’’ and 21.5’’ layouts. This can be observed in Figure 42 below.

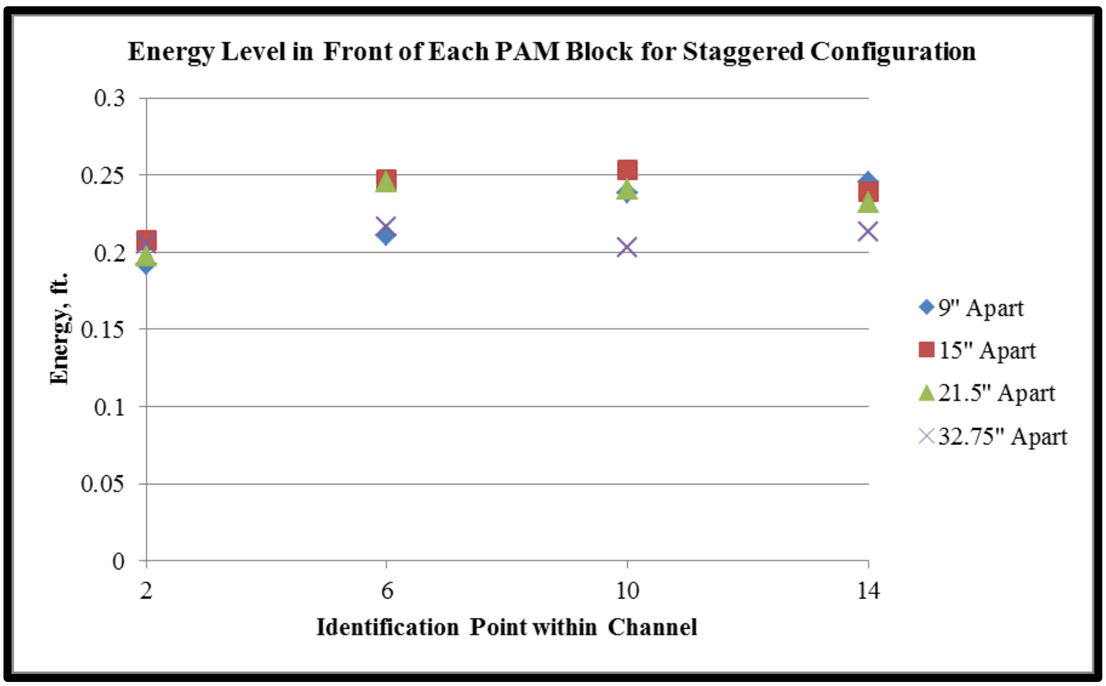


Figure 42: Staggered Configuration Energy Level in Front of PAM Blocks

5.2.5 Enhancement of Configurations

The Staggered Configuration and Dispersion Configuration discussed throughout the rest of the report is simply the Staggered Configuration *with the introduction of a hydraulic jump* *towards the end of the channel before the collection mat*. This addition was anticipated to slow the flow rate down prior to the collection mat being place downstream during the field-scale testing. The hydraulic jump would also present a collection area for the flocs formed from the mixing zone upstream directly in front of the jump within the backwater depth where the velocity is minimal. For purposes of observation, this configuration was also tested within the hydraulic flume prior to implementation on in the field.

The enhanced Staggered Configuration was tested at a slope of 16H:1V. Images of the hydraulic flume testing can be seen in Figure 45 and Figure 46. The flow rate utilized for this entire research project is fixed, therefore, the adjusted variable was the velocity. If all dimensions remain the same, as the slope is decreased the velocity is decreased in order to keep the flow rate static. The new steady state velocity needed to be achieved was approximately 2.6 fps. A major consideration caused by the slope in this scenario is the backwater depth and should be accounted for when implementing into the field.

In order to keep the number of tests at a reasonable level, only three layouts were tested for the enhanced Staggered Configuration; 9’’ apart, 15’’ apart and 21.5’’ apart. The most stabilized flow appeared to be at 15’’ apart. Table 24 shown below is the data values obtained from trial 1 of the Staggered Configuration testing. The notable difference between the Staggered and enhanced Staggered Configurations is the reduction in energy level downstream of the mixing zone. This degradation is estimated to be sufficient for settling of the flocs. The two figures (Figure 43 and Figure 44) below display the reduction of energy experienced downstream of the mixing zone with the Staggered configuration vs. the enhanced Staggered configuration. There appears to be a decrease of approximately 0.0450 feet of head with the enhanced Staggered Configuration.

The backwater depth was observed to be approximately 16 inches from the hydraulic jump.

Table 24: Staggered Configuration Trial 1 Data Results @ 15'' between obstructions

3/29/2011
Full Size PAM
Set Up No. 2 **Slope (%)** **6.25**

X_1	**46**	in.
X_2	**15**	in.
X_3	**15**	in.
X_4	**15**	in.
Distance from back of 4th Obstruction to hydraulic jump:	**34**	in.
Distance from back of hydraulic jump to water re-capture:	**36 1/4**	in.
Back Water Depth from Hydraulic Jump:	**15 7/8**	in.

I.D.	*Length from H_2O Entrance (in.)*	*Distance/Length of Channel*	Average *Height (mm)*	*Height (ft)*	*V (fps)*	*Energy (ft.)*
1	21	0.12	9	0.0295	2.6	0.1345
2	44	0.26	54	0.1772	1.1	0.1960
3a	47.5	0.28	29	0.0951	2.2	0.1703
3b	47.5	0.28	32	0.1050	1.6	0.1447
4a	51.5	0.30	16	0.0525	0.1	0.0526
4b	51.5	0.30	11	0.0361	2.5	0.1331
4c	51.5	0.30	25	0.0820	2	0.1441
5a	55.5	0.33	24	0.0787	0.3	0.0801
5b	55.5	0.33	25	0.0820	2.3	0.1642
5c	55.5	0.33	22	0.0722	2.3	0.1543
6	62.25	0.37	53	0.1739	0.8	0.1838
7a	65	0.38	42	0.1378	1.5	0.1727
7b	65	0.38	23	0.0755	2.3	0.1576
8a	69.75	0.41	36	0.1181	2.4	0.2076
8b	69.75	0.41	27	0.0886	0.4	0.0911
8c	69.75	0.41	25	0.0820	0.1	0.0822
9a	75	0.44	33	0.1083	2.4	0.1977
9b	75	0.44	32	0.1050	0.5	0.1089
9c	75	0.44	30	0.0984	0.4	0.1009
10	80.5	0.47	69	0.2264	1.4	0.2568
11a	83.5	0.49	13	0.0427	2.7	0.1558
11b	83.5	0.49	43	0.1411	1.7	0.1860
12a	89.75	0.53	22	0.0722	0.1	0.0723
12b	89.75	0.53	25	0.0820	0.3	0.0834
12c	89.75	0.53	30	0.0984	2.3	0.1806
13a	94.75	0.56	34	0.1115	0.2	0.1122
13b	94.75	0.56	33	0.1083	0.2	0.1089
13c	94.75	0.56	33	0.1083	2.5	0.2053
14	98.25	0.58	58	0.1903	1.6	0.2300
15a	101.25	0.59	45	0.1476	1.5	0.1826
15b	101.25	0.59	22	0.0722	3	0.2119
16a	107.5	0.63	34	0.1115	2.6	0.2165
16b	107.5	0.63	4	0.0131	1.6	0.0529
16c	107.5	0.63	3	0.0098	0.1	0.0100
17a	115	0.67	16	0.0525	3	0.1922
17b	115	0.67	15	0.0492	1.6	0.0890
17c	115	0.67	16	0.0525	0.2	0.0531
18a	123.25	0.72	11	0.0361	2.6	0.1411
18b	123.25	0.72	25	0.0820	2.8	0.2038
18c	123.25	0.72	27	0.0886	0.5	0.0925
19a	133.5	0.78	58	0.1903	1.2	0.2126
19b	133.5	0.78	61	0.2001	2.2	0.2753
19c	133.5	0.78	58	0.1903	0.7	0.1979
20a	138.5	0.81	10	0.0328	2.4	0.1222
20b	138.5	0.81	9	0.0295	2.5	0.1266
20c	138.5	0.81	13	0.0427	1.8	0.0930
21a	170.5	1.00	8	0.0262	2.7	0.1394
21b	170.5	1.00	8	0.0262	2.8	0.1480
21c	170.5	1.00	8	0.0262	3.1	0.1755

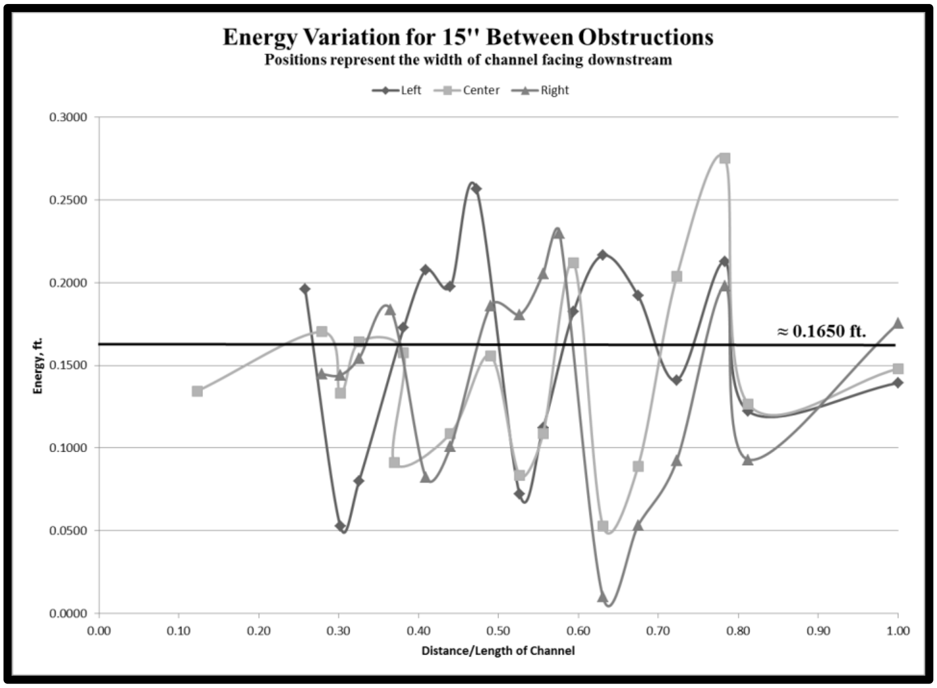


Figure 43: Enhanced Staggered Configuration Energy Variation @ 15'' between obstructions

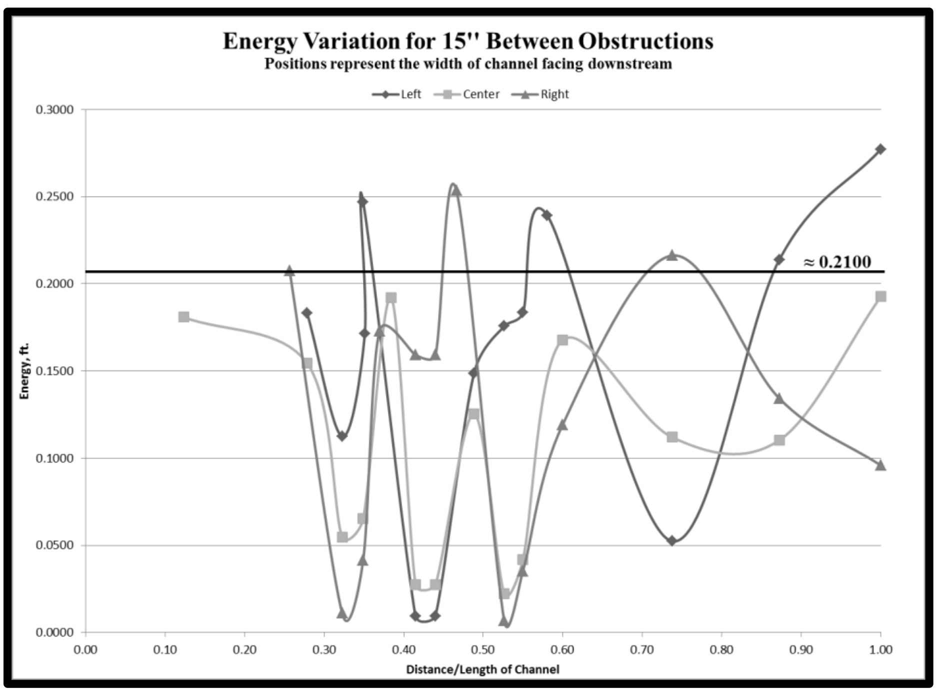


Figure 44: Staggered Configuration Energy Variation @ 15'' between obstructions

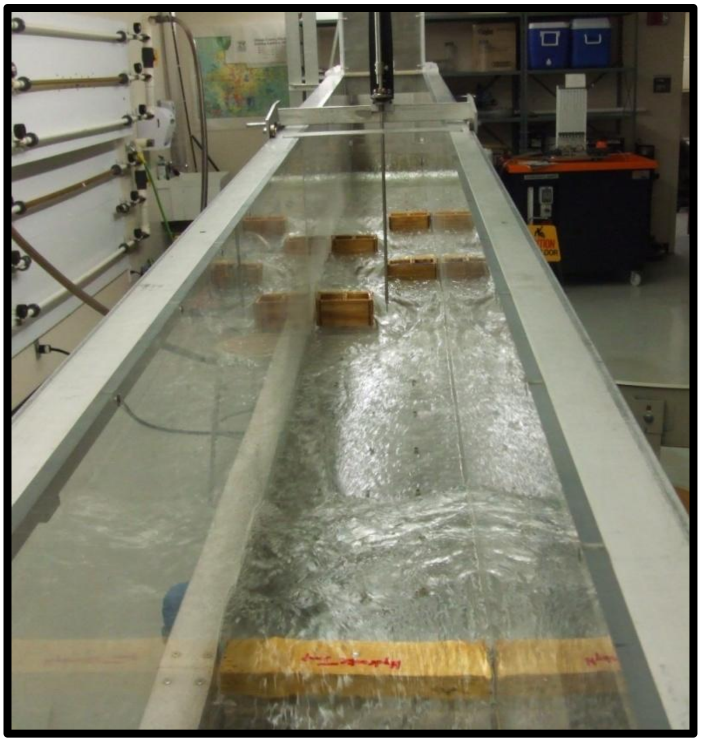


Figure 45: Staggered Flume Testing

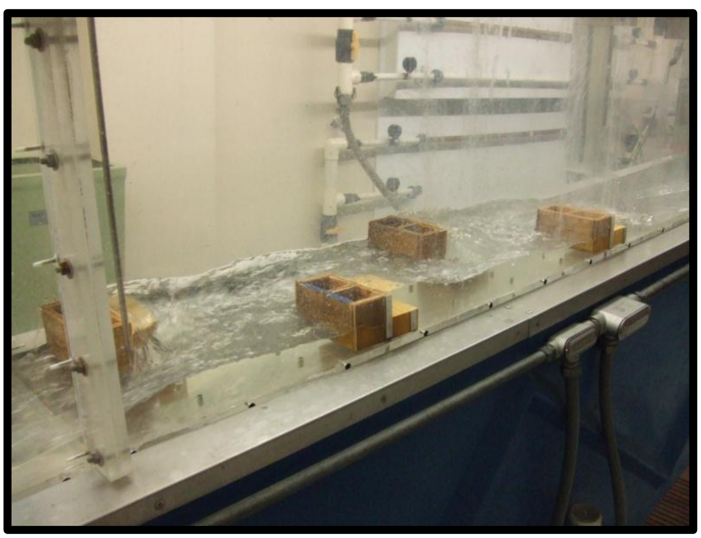


Figure 46: Water Flow with Staggered Configuration

After all observations and data collection amongst flume testing, the two configurations chosen for field-scale testing are the Staggered and the Dispersion. A hydraulic jump will be constructed downstream of the mixing zone in attempt to collect floc and normalize the flow as it comes in contact with the jute mat. The jump will be fixed and will not be removed when the Dispersion Configuration is being tested. As a result, it will serve both configurations downstream flow identically.

5.3 Field-Scale Testing

This section presents the results of the field scale channel testing. Three soil types were tested, namely, silty clayey sand, sand and crushed lime rock fines. The first soil tested was the silty clayey sand. In preparation for each test, certain parameters needed to be checked for operation. More specifically, prior to the discharge the 1,500 gallon tank needed to be filled with both potable water and enough soil to achieve a turbidity level above 400 NTUs. As previously discussed, a submersible pump was placed within the tank circulating the soil-water mix minutes prior to the testing. The pump was turned off immediately before the discharge pump was turned on to begin the actual testing. Essentially, the impression was to minimize any chance of re-suspension of particles that would typically settle in an actual field condition.

5.3.1 Testing Strategy

The static variables within each test were the incoming flow rate and the slope. The submersible pump made it challenging to obtain the exact flow rate desired of approximately 0.017 cfs for each test. As a result, additional bends were introduced to cause slight head loss. Although both pumps were connected to the chamber for the discharge water only one was used for the chosen flow rate. The velocity calculated for the steady state flow based on the channel dimensions was nearly 3.2 fps. This value was challenging to achieve in a steady manner.

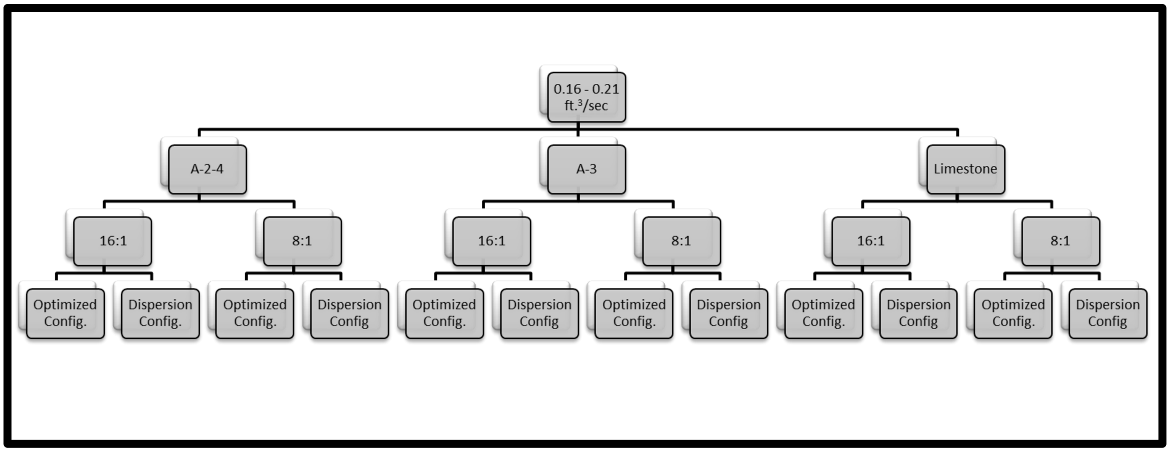


Figure 47: Flow Chart for Field-Scale Testing

For each soil, trials were conducted changing the slope and the obstruction configuration. Triplicates were completed for each scheme and a control test was conducted as well. The control tests were identical to the general testing with the exception of the PAM blocks. Consequently, there was a reduction of energy through the channel and virtually no turbidity removal.

Many tasks needed to be completed prior to each test. Below is a checklist that was used to verify that the necessary tasks were accomplished. The cleaning of the channel always took longer than the actual test. Each test lasted for approximately 20 minutes.

1. *Siphon excess water prior to hydraulic jump_____*
2. *Remove jute mat and use Wet-Vac to clean floc accumulation downstream_____*
3. *Place all PAM blocks in container and fill with water_____*
4. *Remove masonry blocks and scrub entire channel_____*
5. *Hose off any excess flocculants downstream from jump_____*
6. *Place new jute mat downstream of hydraulic jump_____*
7. *Place PAM blocks in front of masonry blocks respect to configuration being tested_____*
8. *Pour enough soil to create source water turbidity to be of detectible value; check from roughly 3 ft. below water surface level for NTU value_____*
9. *Print two identical Field Data Test Sheets and place them on clip boards_____*
10. *Prepare Velocity Meter (stored next to tensile machine)_____*
11. *Place U-bottles at blue chamber and D-bottles around the jump location_____*
12. *Place wood-datum device approximately 3 feet from discharge_____*

A suitable amount of samples sought to be collected for analysis; therefore, based on the amount of water provided by the cistern, samples were taken every two minutes. With the discharge rate set, the tank would take roughly 18 minutes to empty. Consequently, nine samples were collected from each of the three locations; upstream before the mixing zone, directly after the hydraulic jump and furthest downstream passed the Curlex II mat. The locations are clearly shown in Figure 48 below. It is understood that the samples are not truly representative when compared against the same time interval. For instance, the upstream sample taken after two minutes from the beginning of the trial is newly supplied to the channel whereas the water collected after two minutes at the D2 location is actually the water previously supplied to the channel seconds beforehand. Nonetheless, the purpose was to create a uniformity standard for the turbidity analysis.

Figure 48: Sample Location for Field-Scale Testing

5.3.2 Lessons Learnt from Initial Setup and Construction

Similar to any innovative procedure, some lessons are learnt from the testing. The first field-scale test revealed many flaws within the original plan for testing. Two PVC pipes were originally calculated to yield the optimum flow rate, yet this proved to be excessive. An additional major issue was the sealing of the channel. The visqueen was easily torn and needed to be observed closely for punctures. During the first test, the water intruded underneath the visqueen layer and eroded soil down the channel forcing vital modifications. One such change was that extra layers were added and all holes were covered with duct tape. Also, major ripples within the plastic visqueen were tightened and smoothed at the beginning of every test to ensure no unexpected water paths were introduced.

After a qualitative trial before actual testing it was clear that the original height of the hydraulic jump was not going to function as planned. The first hydraulic jump was only 6 inches from the channel bed. This did not provide much backwater depth nor was it effective when attempting to significantly reduce the velocity of the water. The height was increased before beginning actual testing to 13 inches.

Another critical change was the handling of the PAM blocks. Previous research states that PAM blocks need to be saturated prior to use. Before the first test, the PAM blocks were appropriately placed in respect to the Staggered Configuration and saturated using a hose for roughly two minutes per block. This did not prove to be effective. A more saturated approach was necessary. After every PAM test, each block was placed in a five gallon bucket filled with potable water until the next test. This assured that the PAM block was fully saturated and would perform optimally.

Table 25: 1/26/11 Staggered Configuration Turbidity Removal Efficiency Chart

STORMWATER MANAGEMENT ACADEMY				
Turbidity (NTU)				
Date:	26-Jan-11			
Slope:	8H:1V			
Polymer Type:	706b			
Configuration:	Optimized			
Identification	**Duration (min.)**	**Turbidity Removal Efficiency for D1 (%)**	**Turbidity Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0			
1	2	**18%**	**17%**	**19%**
2	4	**18%**	**22%**	**28%**
3	6	**13%**	**18%**	**22%**
4	8	**15%**	**20%**	**24%**
5	10	**17%**	**20%**	**23%**
6	12	**13%**	**21%**	**23%**
7	14	**10%**	**15%**	**18%**
8	16	**4%**	**15%**	**19%**
9	18	**9%**	**22%**	**27%**
AVERAGE	AVERAGE	**14%**	**19%**	**23%**

Table 26: 1/28/11 Staggered Configuration Turbidity Removal Efficiency Chart

STORMWATER MANAGEMENT ACADEMY				
Turbidity (NTU)				
Date:	28-Jan-11			
Slope:	8H:1V			
Polymer Type:	706b			
Configuration:	Optimized			
Identification	**Duration (min.)**	**Turbidity Removal Efficiency for D1 (%)**	**Turbidity Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0			
1	2	**97%**	**96%**	**98%**
2	4	**98%**	**98%**	**98%**
3	6	**96%**	**94%**	**98%**
4	8	**92%**	**95%**	**98%**
5	10	**89%**	**91%**	**96%**
6	12	**67%**	**85%**	**94%**
7	14	**57%**	**80%**	**94%**
8	16	**65%**	**73%**	**81%**
9	18	**48%**	**76%**	**87%**
AVERAGE	AVERAGE	**81%**	**89%**	**94%**

Table 25 and Table 26 are the first and second field-scale tests conducted, respectively. The test completed on 1/28/2011 used PAM blocks that were saturated by being placed in 5 gallon buckets. All PAM blocks were replaced at the same time regardless of individual function. The purpose was to limit sources of error and instill uniformity within the dosage. The PAM blocks were changed after every four tests; three trials and one control.

The first test on January 26, 2011 did not clearly display signs of flocculation nor was there much floc accumulated downstream once the test was completed. The results display that on average there is an increase of approximately 70% in turbidity removal efficiency between the two identical tests. Furthermore, as the PAM blocks were continuously placed within the 5 gallon buckets they would morph and take shape of the circumference of the bucket forcing the transition from the bucket to the channel to be very difficult. This would greatly affect the outcome once placed in the channel. In attempt to remedy this problem, the blocks were later placed in plastic containers where they could lay flat as they do on the channel bed. This solution is illustrated in Figure 49.

Figure 49: PAM Blocks within Container before Testing

The most significant modification made from the early tests was the dosage placed within the channel. During the few pilot tests conducted, it was observed that the three blocks previously assumed acceptable were in fact not enough for any significant turbidity removal. During the hydraulic flume testing only four blocks were tested for both the Staggered and Dispersion configurations, but after the first few trials the configurations were enhanced by adding two PAM blocks to provide more redundancy and greater turbidity removal efficiency within the channel. Though this modification used further channel space for the mixing zone, it was warranted by the field observations taken during the pilot tests.

Figure 50: Staggered Configuration after modifications

5.3.3 Staggered Configuration

Both configurations were influenced by the nature of the visqueen and the slight non-uniformities in slope of the channel. Although best attempts were made to construct a smooth slope and limit the ripples within the plastic visqueen, these incidents did occur out in the field and did appear to have some effect on the results. The first channel constructed was at slope 8H:1V and the silty clayey sand with the Staggered configuration were the first tests to be completed.

The water paths were analyzed similar to that of the hydraulic flume testing. As expected the energy levels fluctuated greatly in front of the PAM blocks relative to the steady state flow. Figure 51 below displays the fluctuation of energy for the Staggered Configuration in respect to the right side of the channel. The different lines represent each one of the triplicate trials completed. ANOVA analysis was used to verify if the triplicates were in fact similar for each test completed. Every ANOVA analysis concluded that there is no significant difference between any of the tests in respect to its directional flow; the energy level on the right side of the channel for each test shows relatively the same values, etc.

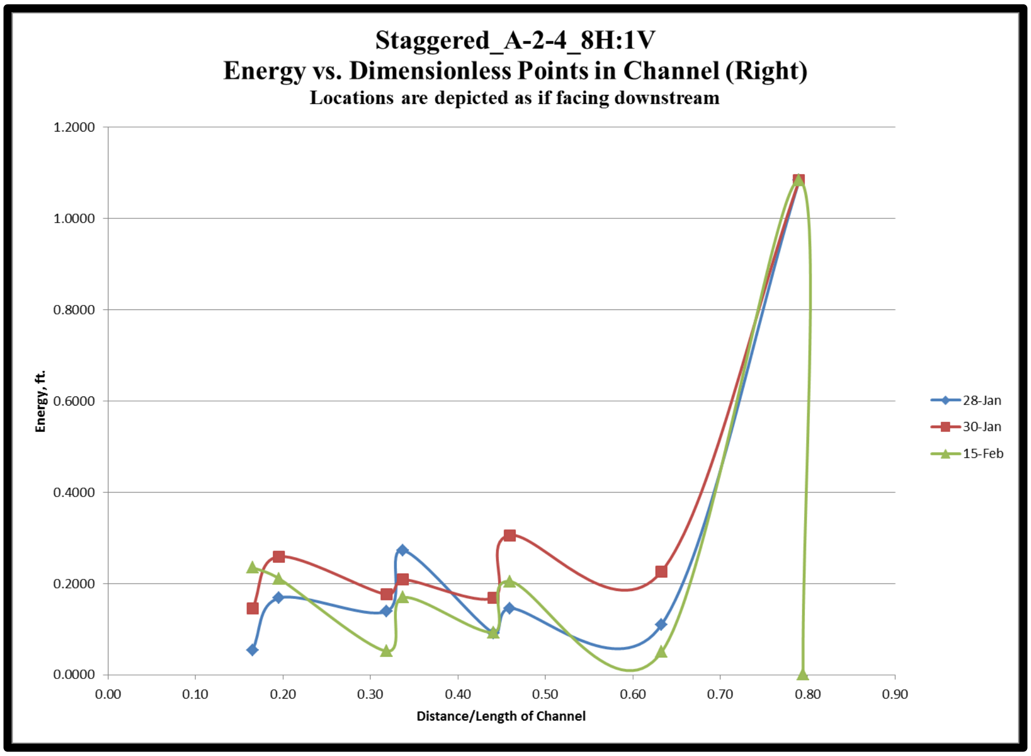


Figure 51: Energy Level of Water for Staggered Configuration

Figure 51 shows consistency amongst the points of the three trials. The large jump at 79% down the channel marks the hydraulic jump and the minor jumps at 15%, 34% and 46% are all points directly in front of the PAM blocks. With the hydraulic flume, the average energy directly before the PAM blocks obtained with the Staggered configuration was 0.2241 ft. All values were within two standard deviations. For the Staggered Configuration at an 8H:1V slope, the average fluctuation for the points directly in front of the PAM blocks was 0.1984 ft. Two outliers were removed that were not originally within two standard deviations and the average was conducted once again. Ultimately, it is viewed that a 12.2% degradation occurred when the PAM blocks were placed within the trapezoidal channel as opposed to a more controlled environment such as the flume.

5.3.4 Dispersion Configuration

Similar to the previous configuration, the Dispersion Configuration proved to be highly effective with a unique arrangement directing the water flow. Amongst the three designs tested using the hydraulic flume, this arrangement proved to be just as appealing as the Staggered in respect to mixing, energy levels, and limiting maintenance zones. Therefore, as a comparative channel, this was also tested out in the field after a few slight modifications made from the hydraulic flume testing.

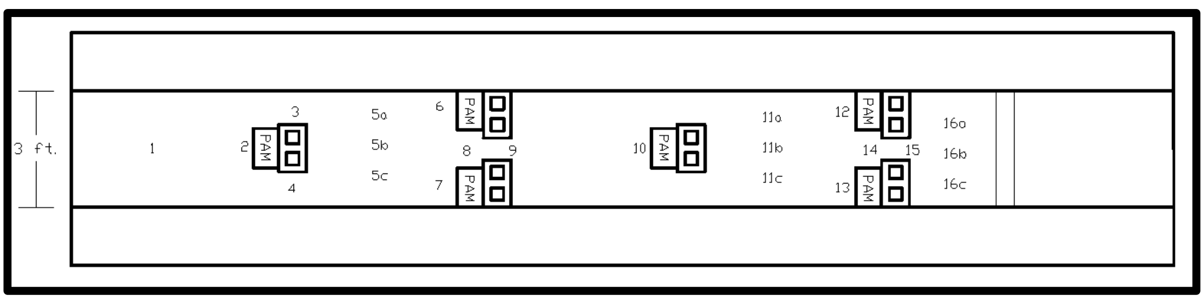


Figure 52: Field-Scale Dispersion Configuration and Identification Points

The flow introduces significant velocity reduction in three main areas; points 6 and 7, points 12 and 14, and the hydraulic jump which can be seen in Figure 53. On average the flow reduces to approximately 0.4 ft./sec directly in front of the lateral block sets across the width of the channel and closer to 0.1 ft./sec directly in front of the hydraulic jump. These areas provide an opportunity for the floc created to settle and. Initially, the attempt was to only introduce one mixing set with the three blocks. More specifically, points 2 through 9. After the first field test it was evident that more PAM would be needed to achieve acceptable turbidity removal efficiency. It was important to investigate where the best position would be within the channel to begin the second set.

Once again it was needed to reference the flume results to choose the appropriate length to allow for optimal fluctuation. The distances labeled for each layout are in reference to the x_2 and x_3 measurements, respectively. The 27''/33'' layout did not appear to be very uniform amongst its energy levels. The right water path loosely followed the trend of the left, but had greater energy levels. Backwater also appeared to be an issue; more depth was needed for x_2. The 33''/40'' proved to provide better room for the backwater. The peak energy level was very similar to that of the 27''/33'', but there was not much uniformity amongst the left and the right water paths. Also, there was a much greater decent in energy around 50% down the channel.

The 57''/46'' layout appeared to reveal similar energy peaks, but better uniformity and allowable space for backwater as shown in Figure 53. The trend appeared to match all 3 locations around 57''-46''. This was the furthest the obstructions were within the hydraulic flume testing. This fluctuation seems beneficial and short circuiting seems limited.

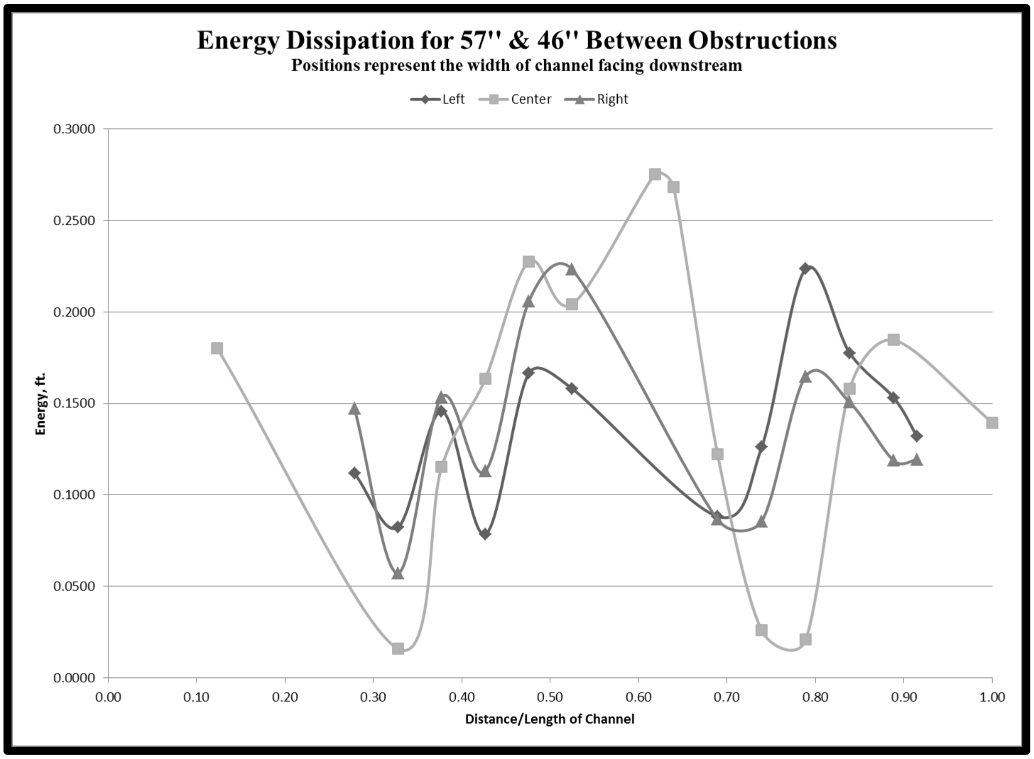


Figure 53: Chosen Layout for Dispersion Configuration

Table 27: Data Entry for Dispersion Configuration using A-2-4 Soil @ 8H:1V Slope

STORMWATER MANAGEMENT ACADEMY					
Researchers:	Rafiq, Scott, Ken, & Travis				
Date:	2/8/2011				
PAM Type	706b				
Soil Type:	A-2-4				
Configuration	Dispersion				
Slope	8H:1V				
X_1			**48**	in.	
X_2			**171**	in.	
X_3			**138**	in.	
X_4			**156**	in.	
Back Water Depth from Hydraulic Jump:			**110**	in.	
I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (ft.)***	***V (fps)***	***Energy_Rec (ft.)***
1	24	0.03	0.0365	1.7	0.0813
2	42	0.05	0.1250	0.4	0.1275
3	51.75	0.06	0.0625	2.8	0.1842
4	51.75	0.06	0.1094	3	0.2491
5a	141	0.16	0.0365	3.6	0.2377
5b	141	0.16	0.0313	1.2	0.0536
5c	141	0.16	0.0313	0.1	0.0314
6	220.5	0.26	0.1771	0.2	0.1777
7	220.5	0.26	0.1563	1	0.1718
8	223.5	0.26	0.1198	2.4	0.2092
9	234	0.27	0.0938	3	0.2335
10	366	0.43	0.1250	0.2	0.1256
11a	457.5	0.53	0.0260	3.4	0.2055
11b	457.5	0.53	0.0365	1.5	0.0714
11c	457.5	0.53	0.0313	3	0.1710
12	529.5	0.62	0.1823	1.2	0.2047
13	529.5	0.62	0.2188	1.3	0.2450
14	532.5	0.62	0.1771	2	0.2392
15	543	0.63	0.1406	3.3	0.3097
16a	610.5	0.71	0.5000	0.3	0.5014
16b	610.5	0.71	0.5313	0.8	0.5412
16c	610.5	0.71	0.5104	0.1	0.5106

Table 28: Turbidity Data for Turbidity Configuration using A-2-4 Soil @ 8H:1V Slope

STORMWATER MANAGEMENT ACADEMY				
Turbidity (NTU)				
Date:	8-Feb-11			
Slope:	8H:1V			
Polymer Type:	706b			
Configuration:	Dispersion			
Soil Type:	A-2-4			
Identification	**Duration (min.)**	**Turbidity Removal Efficiency for D1 (%)**	**Turbidity Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0			
1	2	**97%**	**97%**	**98%**
2	4	**98%**	**97%**	**99%**
3	6	**98%**	**98%**	**98%**
4	8	**98%**	**97%**	**99%**
5	10	**98%**	**98%**	**99%**
6	12	**96%**	**98%**	**98%**
7	14	**95%**	**97%**	**98%**
8	16	**96%**	**90%**	**99%**
9	18	**85%**	**92%**	**99%**
AVERAGE	AVERAGE	**96%**	**96%**	**99%**

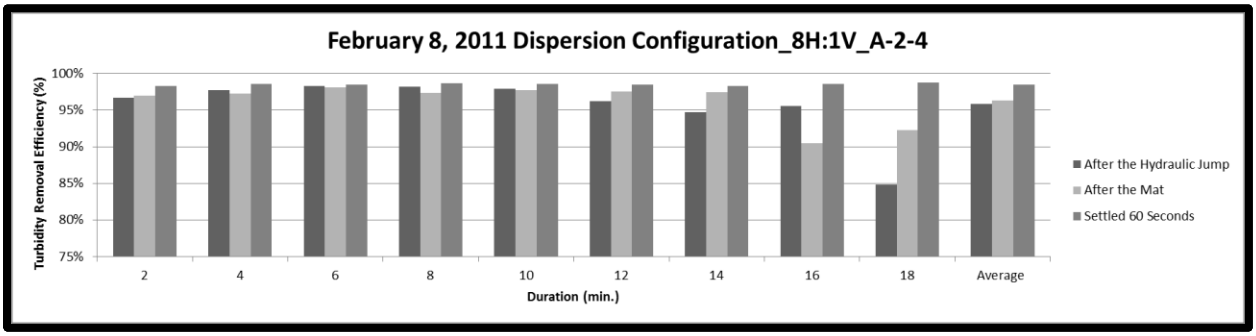


Figure 54: Dispersion Configuration Turbidity Removal Efficiency Graph for 8H:1V Slope

Table 29: Data Entry for Dispersion Configuration using A-3 Soil @ 8H:1V Slope

STORMWATER MANAGEMENT ACADEMY					
Researchers:	Rafiq, Ken, Travis, Scott				
Date:	2/24/2011				
PAM Type	706b				
Soil Type:	A-3				
Configuration	Dispersion				
Slope	8H:1V				
X_1			**48**	in.	
X_2			**171**	in.	
X_3			**138**	in.	
X_4			**156**	in.	
Back Water Depth from Hydraulic Jump:			**110**	in.	
I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (ft.)***	***V (fps)***	***Energy_Rec (ft.)***
1	24	0.03	0.0469	2.9	0.1775
2	42	0.05	0.0729	0.7	0.0805
3	51.75	0.06	0.1094	3.3	0.2785
4	51.75	0.06	0.0417	1.9	0.0977
5a	141	0.16	0.0208	1.7	0.0657
5b	141	0.16	0.0781	2	0.1402
5c	141	0.16	0.0469	1.7	0.0918
6	220.5	0.26	0.1927	0.4	0.1952
7	220.5	0.26	0.0729	1.8	0.1232
8	223.5	0.26	0.2396	1.6	0.2793
9	234	0.27	0.1458	3	0.2856
10	366	0.43	0.0833	1.7	0.1282
11a	457.5	0.53	0.0365	1.4	0.0669
11b	457.5	0.53	0.0781	1.9	0.1342
11c	457.5	0.53	0.0313	1	0.0468
12	529.5	0.62	0.3021	1.2	0.3244
13	529.5	0.62	0.2500	0.8	0.2599
14	532.5	0.62	0.2760	0.4	0.2785
15	543	0.63	0.3542	0.7	0.3618
16a	610.5	0.71	0.6250	0.2	0.6256
16b	610.5	0.71	0.7135	0.2	0.7142
16c	610.5	0.71	0.7083	0.1	0.7085

Table 30: Turbidity Data for Turbidity Configuration using A-3 Soil @ 8H:1V Slope

STORMWATER MANAGEMENT ACADEMY				
Turbidity (NTU)				
Date:	24-Feb-11			
Slope:	8H:1V			
Polymer Type:	706b			
Configuration:	Dispersion			
Soil Type:	A-3			
Identification	**Duration (min.)**	**Turbidity Removal Efficiency for D1 (%)**	**Turbidity Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0			
1	2	**84%**	**96%**	**96%**
2	4	**88%**	**97%**	**97%**
3	6	**84%**	**96%**	**97%**
4	8	**78%**	**95%**	**95%**
5	10	**78%**	**96%**	**97%**
6	12	**87%**	**96%**	**95%**
7	14	**78%**	**96%**	**96%**
8	16	**80%**	**95%**	**96%**
9	18	**79%**	**95%**	**96%**
AVERAGE	AVERAGE	**82%**	**96%**	**96%**

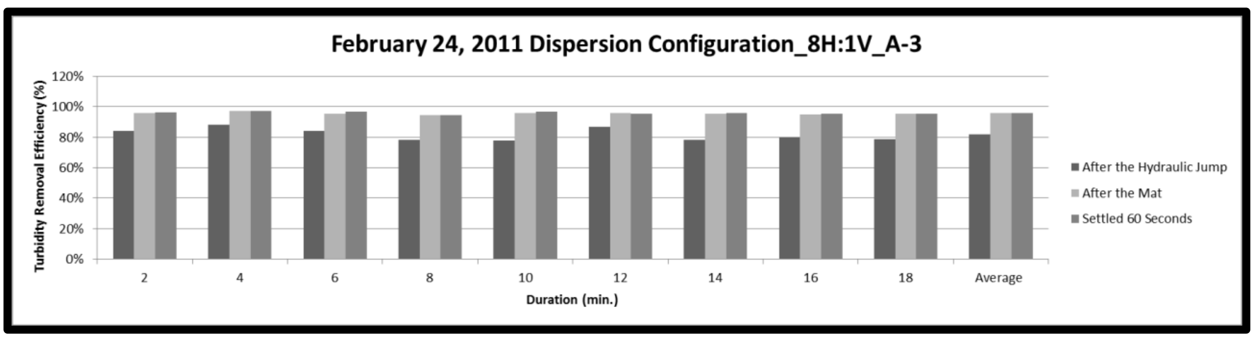


Figure 55: Dispersion Configuration Turbidity Removal Efficiency Graph for 8H:1V Slope

Table 31: Data Entry for Dispersion Configuration using Lime @ 16H:1V Slope

STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Nicole, Scott, Drew
Date:	5/17/2011 (2)
PAM Type	706b
Soil Type:	Limestone
Configuration	Dispersion
Slope	16H:1V

X_1	**48**	in.
X_2	**171**	in.
X_3	**138**	in.
X_4	**96**	in.
Back Water Depth from Hydraulic Jump:	**178**	in.

I.D.	*Length from H_2O Entrance (in.)*	*Distance/Length of Channel*	*Height (ft.)*	*V (fps)*	*Energy_Rec (ft.)*
1	24	0.03	0.0625	3.3	0.2316
2	42	0.06	0.2708	3.5	0.4611
3	51.75	0.07	0.0833	1.7	0.1282
4	51.75	0.07	0.0729	3.2	0.2319
5a	138	0.19	0.0208	1.6	0.0606
5b	138	0.19	0.0313	3.2	0.1903
5c	138	0.19	0.0677	3.1	0.2169
6	220.5	0.30	0.3438	0.7	0.3514
7	220.5	0.30	0.3750	0.3	0.3764
8	223.5	0.30	0.3333	0.3	0.3347
9	234	0.31	0.0521	1.7	0.0970
10	366	0.49	0.1354	1.4	0.1659
11a	424.5	0.57	0.0729	1.5	0.1079
11b	424.5	0.57	0.1250	2.9	0.2556
11c	424.5	0.57	0.0990	0.7	0.1066
12	469.5	0.63	0.3854	0.2	0.3860
13	469.5	0.63	0.3333	0.3	0.3347
14	472.5	0.64	0.3333	0.1	0.3335
15	483	0.65	0.2969	1.6	0.3366
16a	553.5	0.74	0.6667	0.5	0.6705
16b	553.5	0.74	0.7188	0.1	0.7189
16c	553.5	0.74	0.7552	0.3	0.7566

Table 32: Turbidity Data for Dispersion Configuration using Lime @ 16H:1V Slope

STORMWATER MANAGEMENT ACADEMY				
Turbidity (NTU)				
Date:	17-May-11			
Slope:	16H:1V			
Polymer Type:	706b			
Configuration:	Dispersion			
Soil Type:	Lime Rock			
Identification	**Duration (min.)**	**Turbidity Removal Efficiency for D1 (%)**	**Turbidity Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0			
1	2	**89%**	**92%**	**94%**
2	4	**90%**	**93%**	**94%**
3	6	**85%**	**83%**	**88%**
4	8	**85%**	**95%**	**96%**
5	10	**68%**	**90%**	**93%**
6	12	**88%**	**84%**	**85%**
7	14	**65%**	**90%**	**90%**
8	16	**56%**	**81%**	**86%**
9	18	**48%**	**72%**	**82%**
AVERAGE	AVERAGE	**80%**	**89%**	**92%**

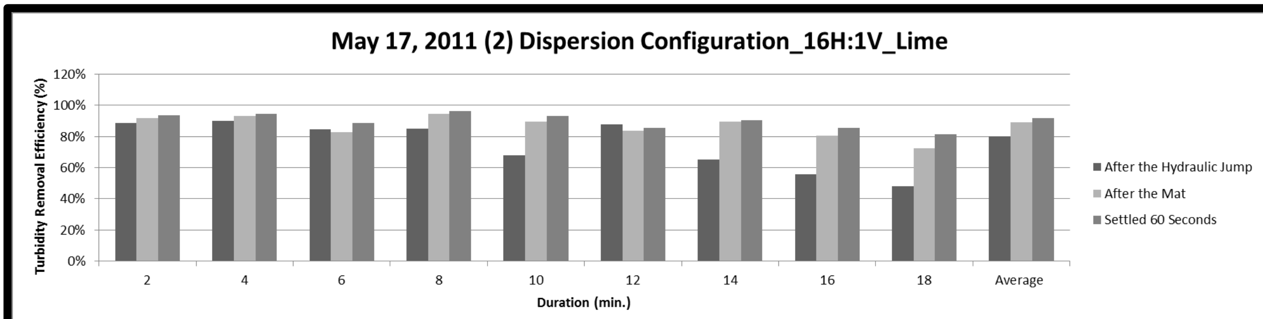


Figure 56: Dispersion Configuration Turbidity Removal Efficiency Graph for 16H:1V Slope

The data above has been provided to show the effective nature of the Dispersion Configuration. Each set of data is for a different soil type. Table 27 shows the results obtained from an A-2-4 trial using the Dispersion Configuration at a slope of 8H:1V and Table 29 has the same parameters with the exception of using A-3 soil. As expected since the same slope was used, the energies obtained from the two trials are relatively the same. The average percent difference amongst the energies of the two trials is 12.2%. Greater variability was noticed when taking the measurements at high fluctuation locations such as directly in front of the polymer blocks. Table 31 shows the measurements obtained during a Dispersion trial at a slope of 16H:1V.

Each test has achieved appreciable turbidity removal. Like the Staggered Configuration, the redundancy within the channel design offers model parameters for floc to form and settle. Table 28 is the removal efficiencies attained from the test indicated in Table 27. The following Figure 54 is a bar graph representation. As expected, the charts indicate that for each sample taken, the turbidity after the collection mat is generally greater than after the hydraulic jump. Table 30 and Figure 55 display the removal efficiencies for the Dispersion Configuration trial completed with A-3 soil and Table 32 and Figure 56 show the removal efficiencies using the crushed lime rock. A more detailed discussion in regard to the three soils tested can be found in section 5.4. All additional data can be found within the Appendix.

A key issue when beginning the testing was the placement of the final lateral obstruction set. The calculation was incorrect, and backwater did intrude very closely to the PAM blocks. This situation should be avoided because although the PAM block would be directly contacted to the water, virtually no fluctuation will be permitted to cause mixing. The blocks were later position further upstream in attempt to avoid this situation.

An issue attributed to this configuration was similar to the other. In few occasions the flow was more directed towards the right side of the channel due to ripples in the visqueen or slight depressions and the flow would not reach point 6. A unique issue with this arrangement was with the single, centered block behind points 2 and 10. It was observed that those masonry blocks would shift more as the PAM would seep underneath causing a slick surface. It is assumed that the shear force placed on the masonry blocks in the Staggered Configuration is enough to keep them stable. The centered block during testing is shown below in Figure 57

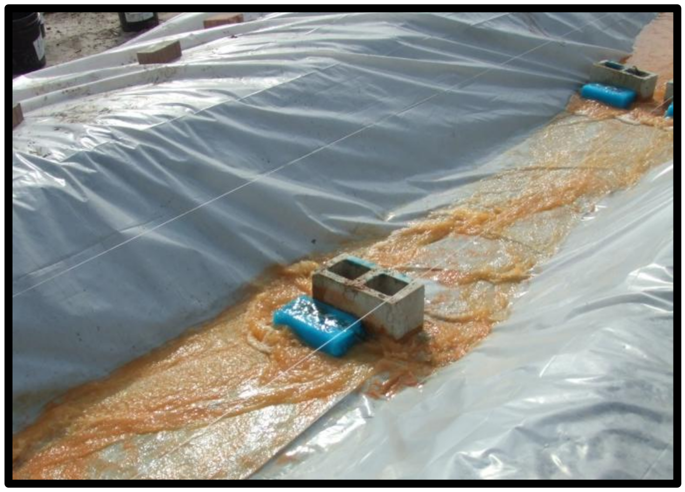


Figure 57: Centered Block for Dispersion Configuration

Contrary to the hypothesis, the Dispersion Configuration proved to be more operative. Largely, this arrangement generated better fluctuation at certain locations. When the flow was forced from the lateral obstruction set to the following individual block centered on the channel bed, the aggressive velocity ensured greater water heights and contact with the PAM. Further justification for endorsing the Dispersion Configuration can be found in the following section.

5.4 Observations of Soil Reactions to Treatment Channel

The soil chosen for the research project are representative of the south, central and northern parts of Florida. The purpose was to provide a more encompassing collection of data for the treatment channels tested. PAM is primarily utilized for the removal of fines and silt within source water, but has proven to also be effective with other soils such as sandy soils and even crushed lime rock. Larger particles, such as sand, are able to settle on their own accord in a relatively rapid manner and are not of primary concern when attempting to reduce turbidity. Expectedly, the trials conducted using silty clayey sand soil achieved the greatest turbidity removal efficiency. The percentage of fines and silt for the A-2-4 soil used was approximately 7 % whereas the A-3 soil consisted of 3.75% of fines and silt. When the A-2-4 soil was mixed into the source water, there were stretches of floc throughout the channel bed as seen in Figure 58.

Figure 58: Floc Throughout Channel

The A-3, or sandy soil, did not present similar results throughout the channel. There were large deposits of soil and floc directly in front of the PAM and masonry block obstruction set, but not throughout the channel. Also, it appeared that the A-3 trials did not provide large floc particles as did the A-2-4 silty clayey sand runs; more pellet flocs were accumulated downstream. Figure 59 shows the accumulation of floc and soil particles directly in front of a masonry block after a trial was conducted using A-3 soil. The PAM block was removed prior to taking the picture.

Figure 59: Floc Accumulation using A-3 Soil

The crushed lime rock was difficult to manage within the mixture of water due to the large aggregates of rock. When discharged from the cistern, the pump was stopped on a few instances because of blockage in the submersible pump. In addition, a submersible pump had to be replaced after the blockage permanently damaged the pump blade.

It is concluded that the primary reason the lime rock/water mix did not achieve appreciable turbidity removal is because calcium carbonate is easily soluble in water.

5.5 Effectiveness of Collection Mat

As previously prescribed, the final ten feet of the treatment channel was made up of matting. The matting was intended as a polishing step to collect the floc prior to discharging into the environment. During the 8H:1V slope tests, a 15 feet length of mat was used and once the second channel was constructed, it was decided that that amount was excessive and was reduced by 5 feet.

Curlex II matting provided by American Excelsior was used for the entire research project. A new 4’ x 10’ mat was placed downstream of the hydraulic jump each test for uniformity when analyzing. While waiting for the delivery of the Curlex II, testing trials were completed using the industry standard coconut fiber mat as shown in Figure 60.

Figure 60: Coconut Fiber Mat

It was quickly learned that this mat was not user friendly.   After the completion of the trials, it was very challenging to carry and dispose of the mat. When saturated with floc and water, the coconut fiber was not desirable to use. Also, the spacing between the weaves was very large and not uniform. The Curlex II mat proved to be very light and manageable in the field even after saturation. The cross section of the fibers was closer together and as a result the void spacing was smaller than that of the coconut fiber mat. The smaller void spacing captured more floc, yet clogging was a noticeable concern. It was observed that the first 5 feet of matting was significantly more populated with floc than the remaining 5 feet. It is recommended that testing be conducted investigating the capacity of floc that can be captured with the Curlex II as well as the time it takes for the mat to become clogged beyond operational value. Figure 61 is a close look at the Curlex II mat after a test using A-3 soil.

Figure 61: Curlex II Mat

ANOVA analyses were conducted to verify effectiveness of the matting as a necessary polishing step within the treatment channel. The turbidity values obtained directly after the hydraulic jump, D1, were compared to the turbidity values gathered for the samples collected after the mat, D2. The acceptable α value was set as 0.05. Amongst all of the completed trials, 27 out of 35 reveal that there is a significant difference in turbidity removal when the Curlex II mat is placed downstream of the hydraulic jump and are highlighted in Table 33 . Table 33 shows the p-value of every field-scale test when the D1 samples were compared to the D2 samples; the samples before the Curlex II mat vs. the samples post Curlex II mat.

Table 33: Comparison of Sample Location D1 and D2 using p-values

p -values for the Comparison of Sample Locations D1 and D2					
Configuration	**Soil**	***p* -value**	**Configuration**	**Soil**	***p* -value**
Optimized	A-2-4	0.216	Optimized	A-2-4	0.326
Optimized	A-2-4	0.930	Optimized	A-2-4	0.324
Optimized	A-2-4	0.062	Optimized	A-2-4	0.001
Dispersion	A-2-4	0.340	Dispersion	A-2-4	0.000
Dispersion	A-2-4	0.033	Dispersion	A-2-4	0.000
Dispersion	A-2-4	0.755	Dispersion	A-3	0.000
Optimized	A-3	0.000	Dispersion	A-3	0.000
Optimized	A-3	0.007	Dispersion	A-3	0.000
Optimized	A-3	0.001	Optimized	A-3	0.001
Dispersion	A-3	0.007	Optimized	A-3	0.000
Dispersion	A-3	0.000	Optimized	A-3	0.000
Dispersion	A-3	0.000	Optimized	Lime	0.038
Optimized	Lime	0.009	Optimized	Lime	0.018
Optimized	Lime	0.000	Optimized	Lime	0.001
Optimized	Lime	0.026	Dispersion	Lime	0.205
Dispersion	Lime	0.006	Dispersion	Lime	0.001
Dispersion	Lime	0.008	Dispersion	Lime	0.008
Dispersion	Lime	0.008			

Nearly all of the trials that did not prove to significantly reduce the turbidity of the water with the Curlex II mat was when using A-2-4 soil. Therefore, the data suggests that the treatment channel without the mat is sufficient for settling of the large floc particles created when A-2-4 soil was used.

5.6 Selection Process of the Chosen Field Configuration

The Dispersion Configuration was chosen as the optimal arrangement which disagrees with the original hypothesis. This conclusion was based on maintenance concerns, energy requirements, and ultimately the observed turbidity removal efficiency. The Dispersion Configuration is easily implemented in the field.

The configuration ensures direct contact of water and PAM with reduced areas of floc accumulation. With the Staggered Configuration, it was seen that there was an area of virtually no flow behind each masonry block that had a small accumulation of flocs. For maintenance purposes, it would be preferred that all floc accumulation be confined to few designated areas. The Dispersion Configuration has floc accumulation directly in front of the lateral obstruction set and again directly before the hydraulic jump.

It is investigated that for the best opportunity for flocculation to occur and turbidity to be removed within the treatment channel, the water path must permit the water to essentially restart the treatment process multiple times within the channel. More specifically, the configuration must allow water to go through a mixing zone set, return back to steady state and the process be repeated as if the water is being refined each time. The Staggered Configuration tested did not accomplish this goal. To achieve steady state between each intermediate section between the PAM blocks, an unreasonable channel distance would be needed. Figure 62 and Figure 63 are graphs of different configuration, but the trials were both completed at an 8H:1V slope using A-3 soil. As shown, the energy oscillation with the Staggered Configuration is more frequent with less percentage of the channel in between each peak. The Dispersion Configuration allows more time closer to the steady state energy subsequent to the peak caused by the PAM blocks. The main concern realized in the field, but not originally anticipated was the potential for floc re-suspension which is theoretically more prone to occur when there is no opportunity for adequate settling.

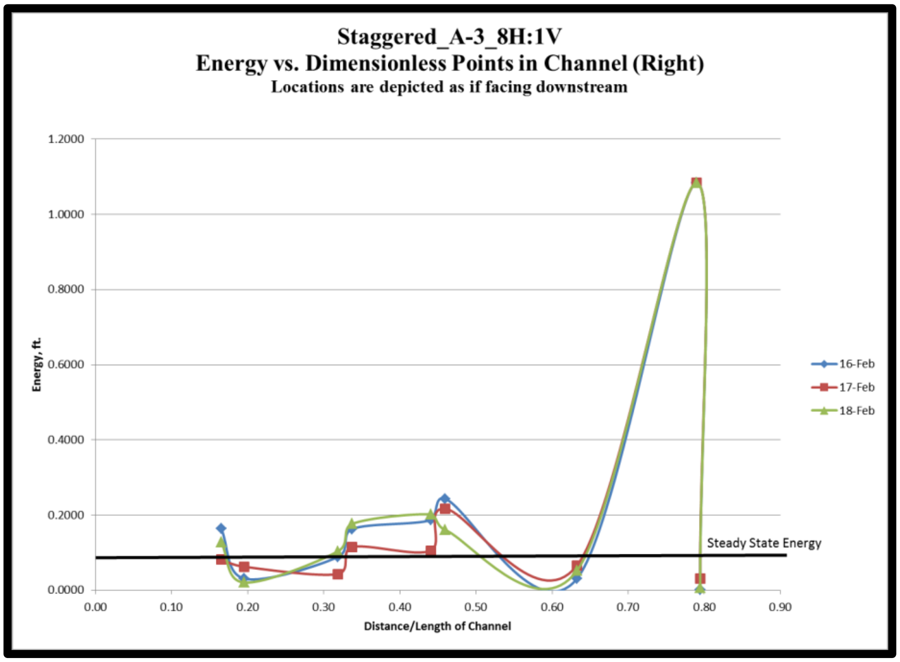


Figure 62: Staggered Configuration Energy Fluctuation with Steady State Energy Reference

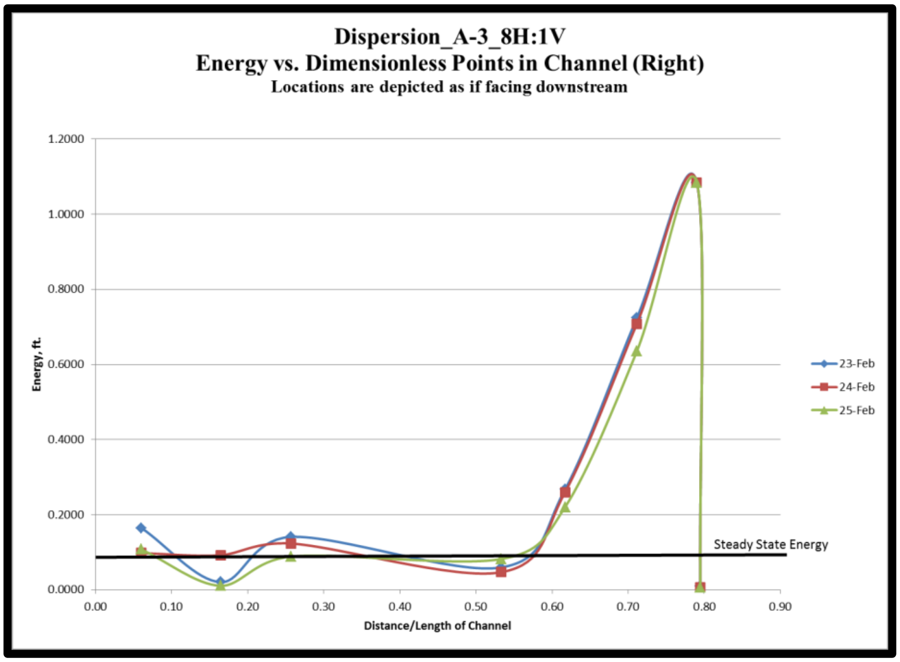


Figure 63: Dispersion Configuration Energy Fluctuation with Steady State Energy Reference

The critical factor when choosing the Dispersion Configuration was the turbidity removal efficiency achieved throughout the field-scale testing. Each slope and soil was tested by both configurations. Once again, ANOVA statistical analyses were used as verification. The procedure began with averaging the triplicates. The first step was to verify that the initial turbidity for all three trials were not significantly different from each other. Table 34 displays the ANOVA analysis completed for the three trials of Staggered Configuration at a slope of 8H:1V using silty clayey sand soil. The analysis shows that there is not a significant difference between the initial turbidity values amongst the three trials.

Table 34: Screenshot for Analysis of Chosen Configuration Step 1

8H:1V_A-2-4

Optimized Triplicate Analysis

Test 1-Initial (NTU)	Test 2-Initial (NTU)	Test 3-Initial (NTU)
852	893	947
882	879	954
853	879	922
850	869	925
859	881	902
836	880	924
828	854	901
795	796	901
685	629	828
561	504	748

Is there a significant difference between the initial turbidities of the same test?

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	10	8001	800.1	10074.32
Column 2	10	8064	806.4	17581.38
Column 3	10	8952	895.2	3874.844

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	56563.8	2	28281.9	2.690905	0.085969755	3.354131
Within Groups	283774.9	27	10510.18		NOT SIGNIFICANT	
Total	340338.7	29				

Optimized Triplicate Analysis

Test 1-Initial (NTU)	Test 2-Initial (NTU)	Test 3-Initial (NTU)	AVERAGE (NTU)
852	893	947	**897**
882	879	954	**905**
853	879	922	**885**
850	869	925	**881**
859	881	902	**881**
836	880	924	**880**
828	854	901	**861**
795	796	901	**831**
685	629	828	**714**

← **If not signifcantly different at a 90% confidence interval, average the the initial turbidity of the triplicates:**

The values were then averaged for the three tests as shown above in column E. As a result, it is then assumed that it is acceptable to use the average values for further analysis. More elaborately, Table 34 reveals that the initial turbidity values are not significantly different and therefore are averaged.

The same procedure was completed for all the turbidity values attained at the D2 location, which was after the full extent of the treatment channel including the Curlex II matting. Table 35 for the 8H:1V slope using A-2-4 displays that there is a significant difference amongst the values obtained from the triplicates. In this situation, the conservative approach was to use the trial with the highest turbidity values at location D2. For this example, the values in cells C32 through C40 are clearly the largest values. The larger the turbidity values for D2, the less the turbidity removal occurred for that particular trial. The final step was to calculate the turbidity removal efficiency using the averaged initial values and the test that yielded the highest turbidities out of the three trials. The turbidity removal efficiency calculation is shown below.

$$Turbidity\ Removal\ Efficiency\ (\%) = \left(1 - \frac{Post\ Treated\ Turbidity\ at\ Location\ D2\ (NTU)}{Initial\ Turbidity\ (NTU)}\right) x\ 100$$

This concludes the analysis of one configuration for a particular soil and slope combination.

Table 35: Analysis of Chosen Configuration Step 2

Optimized Triplicate Analysis

Duration	Test 1-After Curlex II (NTU)	Test 1-After Curlex II (NTU)	Test 1-After Curlex II (NTU)
2	32	187	30
4	19	225	32
6	55	247	46
8	43	177	27
10	75	460	26
12	126	469	32
14	161	463	38
16	182	412	47
18	134	326	94

Is there a significant difference between the D2 turbidities of the same test?

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	9	827	91.8889	3596.11
Column 2	9	2966	329.556	15302.5
Column 3	9	372	41.3333	447.75

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	426340	2	213170	33.0558	1.274E-07	3.40283
Within Groups	154771	24	6448.8		SIGNIFICANT	
Total	581111	26				

Since it is SIGNIFICANT, we will take the most conservative Test (highest turbidities) ←

Optimized Initial vs. Optimized D2 Values

Duration	Initial	D2 Values	Percent Reduction
2	905	187	**79%**
4	885	225	**75%**
6	881	247	**72%**
8	881	177	**80%**
10	880	460	**48%**
12	861	469	**46%**
14	831	463	**44%**
16	714	412	**42%**
18	604	326	**46%**

An identical procedure is then followed for the second configuration. Once the turbidity removal efficiency for the second configuration is obtained as it was calculated in Table 35, it is then compared to the previous configuration. If statements embedded into the cells display the configuration that generated higher turbidity removal efficiency. As shown in Table 36, the Dispersion Configuration consistently generated a greater turbidity removal efficiency for every duration for the 8H:1V slope using A-2-4 soil.

Table 36: Analysis of Chosen Configuration Final Step

Dispersion Initial vs. Dispersion D2 Values			
Duration	Initial	D2 Values	Percent Reduction
2	986	17	**98%**
4	993	16	**98%**
6	978	13	**99%**
8	983	16	**98%**
10	974	17	**98%**
12	966	25	**97%**
14	969	55	**94%**
16	938	79	**92%**
18	709	71	**90%**

Optimized vs. Dispersion Configuration			
Duration	Optimized % Reduction	Dispersion % Reduction	Ideal Configuration
2	79.3%	98.2%	**Dispersion**
4	74.6%	98.4%	**Dispersion**
6	72.0%	98.6%	**Dispersion**
8	79.9%	98.4%	**Dispersion**
10	47.7%	98.3%	**Dispersion**
12	45.5%	97.4%	**Dispersion**
14	44.3%	94.3%	**Dispersion**
16	42.3%	91.6%	**Dispersion**
18	46.1%	90.0%	**Dispersion**

This identical procedure was completed for the remaining slope/soil combinations. It was detected that although the Dispersion Configuration appeared to be the chosen configuration for the majority of the tests, the Staggered Configuration proved to be the better of the two for the lime source water. Specifically, it can be seen in Table 37 that during the early time intervals, the Dispersion Configuration is generally the chosen configuration while during the later durations the staggered arrangement seems to be more effective.

Table 37: Chosen Configuration Shown for Lime Soil

Lime			
8H:1V			
Optimized vs. Dispersion Configuration			
Duration	Optimized % Reduction	Dispersion % Reduction	Ideal Configuration
2	95.2%	93.2%	**Optimized**
4	84.2%	92.1%	**Dispersion**
6	85.1%	90.2%	**Dispersion**
8	89.5%	91.8%	**Dispersion**
10	89.8%	89.7%	**Optimized**
12	89.3%	85.9%	**Optimized**
14	88.1%	84.3%	**Optimized**
16	87.3%	85.5%	**Optimized**
18	88.4%	88.0%	**Optimized**
16H:1V			
Optimized vs. Dispersion Configuration			
Duration	Optimized % Reduction	Dispersion % Reduction	Ideal Configuration
2	93.2%	84.8%	**Optimized**
4	90.2%	90.4%	**Dispersion**
6	90.1%	87.0%	**Optimized**
8	92.2%	87.8%	**Optimized**
10	92.8%	87.3%	**Optimized**
12	89.6%	84.7%	**Optimized**
14	93.2%	86.6%	**Optimized**
16	88.4%	83.7%	**Optimized**
18	83.3%	83.8%	**Dispersion**

5.7 Additional Findings with Dispersion Configuration

The beginning 30% of each Dispersion Configuration trial was investigated in more detail against the steady state grade line. Most of the trials indicate that the energy between approximately 5% and 25% of the channel is relatively the same. Again, this is desired when attempting to revive the treatment process multiple times within the same channel. The 5% position is the beginning of the first, centered obstruction and 25% is where the lateral obstruction set begins. This is more clearly shown in Figure 64 and Figure 65 below.

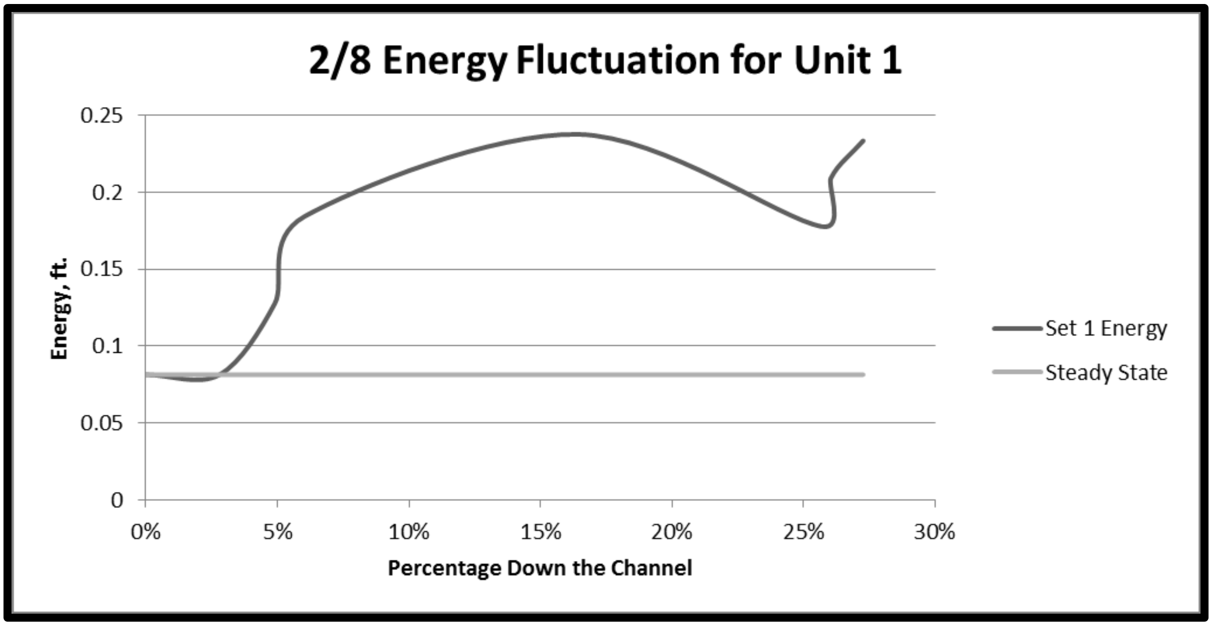


Figure 64: Energy Fluctuation for Initial 30% of Channel at Slope of 8H:1V using A-2-4 Soil

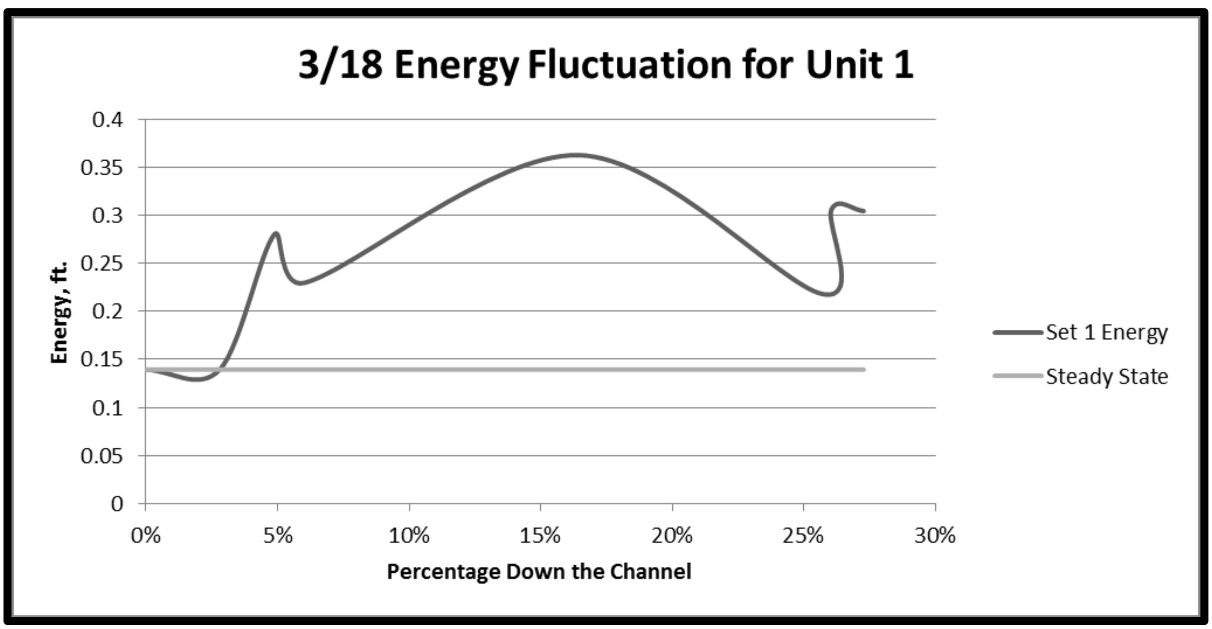


Figure 65: Energy Fluctuation for Initial 30% of Channel at Slope of 8H:1V using Lime Rock

Lastly, a thought-provoking observation was noted with regard to the cumulative energy attained throughout each Dispersion Configuration trial. It is understood that turbidity removal has a strong dependency on the velocity of water and contact time with the PAM, but the results obtained from the field-scale testing incline to contradict the initial proposition. After summing all the energy values obtained for each Dispersion Configuration trial, they were all ranked based on largest accumulated energy. It is shown in Figure 66 that the top four trials with the largest ranking actually have the lowest average turbidity removal efficiency when all samples were analyzed.

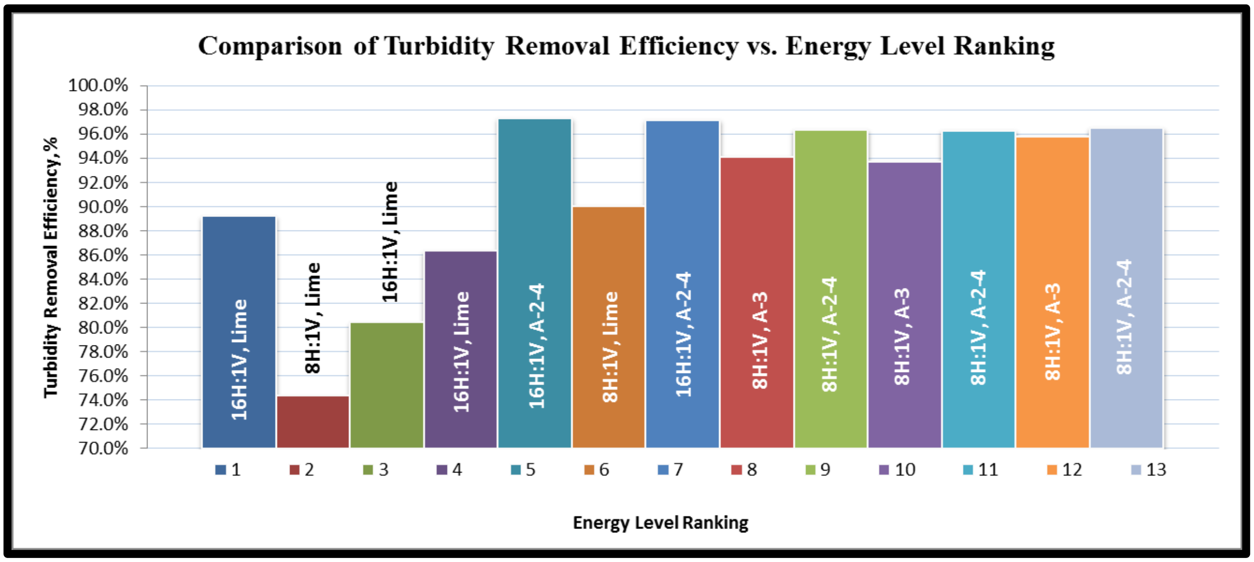


Figure 66: Comparison of Average Turbidity Removal Efficiency vs. Energy Accumulation

In addition, the change in energy through the flow path was investigated. Figure 66 below is a bar chart of average turbidity removal efficiency versus the cumulative change in energy from various points throughout the flow path of every Dispersion field test conducted. The chart does not display any conclusive evidence that greatest changes in the flow path yield higher turbidity removal efficiencies. Although, it is shown that the tests that resulted in the top four rankings of cumulative energy change are all relative to the 16H:1V slope. This may be due to the reduction in velocity experienced when the slope is lessened. The test with the highest turbidity removal efficiency is ranked second for cumulative change in energy.

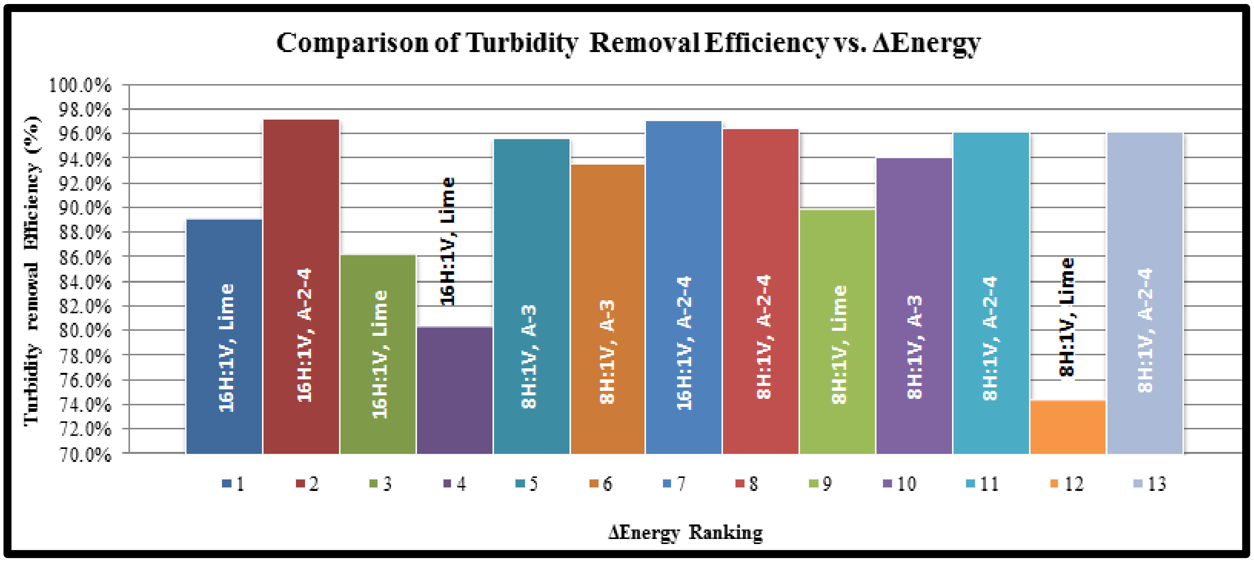


Figure 67: Comparison of Average Turbidity Removal Efficiency vs. Change in Energy Through Water Path

It is recommended that further investigation be done comparing energy accumulation and the respective turbidity removal efficiency. Ultimately, the data suggests that though a vital concern, it is not necessary to achieve the largest accumulations of energy to be able to yield high turbidity removal efficiencies.

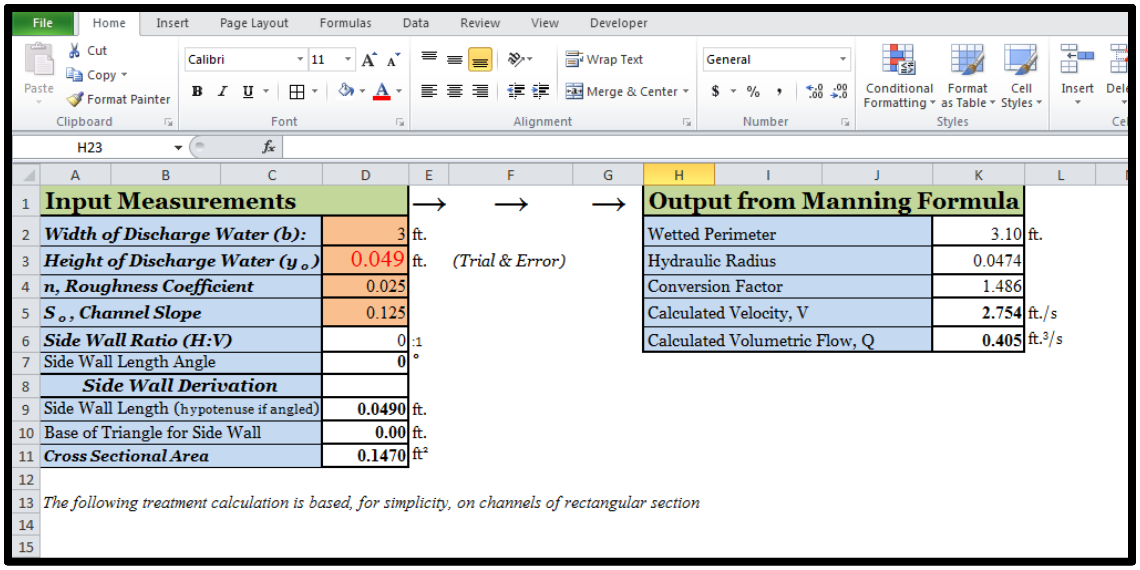
5.8 Treatment Channel Analysis Aid

Polymers have been utilized for decades in the sediment control industry, but there are few or no models or equations developed to support in the arrangement of blocks in order to yield high turbidity removal efficiencies. The staggered approach has been common, but even so, no design parameters have been generated that indicate optimal distances between the obstructions. A Treatment Channel Calculation and Analysis spreadsheet has been prepared in this study to provide the user an analysis aid in conjunction with creating a treatment channel in the field.

Among the two arrangements tested in the field, the Dispersion Configuration proved to be the most beneficial for various reasons discussed in the previous section. Therefore, the final Treatment Channel Calculation and Analysis spreadsheet is solely related to this arrangement. Microsoft Excel was used to derive the necessary distances between the masonry blocks within the treatment channel. The spreadsheet uses various observations, warranted assumptions, and hydraulic principles to calculate the optimal distances dependent on the volumetric flow rate coming from the inlet or water source. Due to the nominal amount of data used for the creation of the analysis aid, there is a recommended range of applicability that is discussed later.

The primary assumption is that the designer or contractor is aware of the volumetric flow rate that needs to be treated. The average volumetric flow rate used for the field testing for this research project was 0.40 $ft.^3/sec$ and was assumed to be static.

The first sheet in the Microsoft Excel file is titled “Height & Flow Rate”. It is here that a trial and error method is used to obtain the desired flow rate. It is essential to note that the treatment calculations are based, for simplicity, on channels of rectangular cross sections. It was shown in Chapter 5 that since the heights anticipated for the treatment channels are minimal, this is a safe assumption with no significant difference between the two methods of calculating; trapezoidal or rectangular. Figure 68 shows a screenshot of the Height & Flow Rate sheet using a height of 0.049 ft. to derive a flow rate of 0.405 $ft.^3/sec$.



	Input Measurements			→	→	→	Output from Manning Formula	
2	*Width of Discharge Water (b):*	3	ft.				Wetted Perimeter	3.10 ft.
3	*Height of Discharge Water (y_o)*	0.049	ft.	(Trial & Error)			Hydraulic Radius	0.0474
4	*n, Roughness Coefficient*	0.025					Conversion Factor	1.486
5	*S_o, Channel Slope*	0.125					Calculated Velocity, V	2.754 ft./s
6	*Side Wall Ratio (H:V)*	0	:1				Calculated Volumetric Flow, Q	0.405 ft.³/s
7	Side Wall Length Angle	0	°					
8	*Side Wall Derivation*							
9	Side Wall Length (hypotenuse if angled)	0.0490	ft.					
10	Base of Triangle for Side Wall	0.00	ft.					
11	*Cross Sectional Area*	0.1470	ft²					
12								
13	*The following treatment calculation is based, for simplicity, on channels of rectangular section*							

Figure 68: Screenshot of Height & Flow Rate Sheet

Next, the Manning Formula is used to calculate the resulting velocity and height of water based on the desired volumetric flow rate, Q. It is mandatory that the user enter all the values in the tan colored input cells. More importantly, cell D3 needs to be continuously altered until the "Calculated Volumetric Flow, Q" on the output side yields the correct flow rate in this iterative solution. Also, it is recommended that the channel remain three feet wide. The Dispersion configuration is tested with this measurement assumed to be static and any shorter would not effectively fit the masonry blocks laterally as intended. Once the preferred values are entered and Q is achieved, the user must not change anything in this sheet as the subsequent sheets will reference the "Height & Flow Rate" values.

The "Reach Calculation" sheet is used to calculate the backwater, or reach, caused by the lateral obstruction set. It is assumed that the masonry blocks are extended throughout the entire width of the channel which provides a conservative backwater distance. This will cause backwater based on the flow rate and height of the obstruction. For this design, a basic masonry block which is typically 7.5 inches high is used for the calculation.

An analysis for the reach is conducted using the change in energy, the slope and the energy gradient, S. Picturing the water build up as a right triangle, the dimensions and velocities on both ends will be used to derive the reach. The upstream end of the triangle is assumed to be at steady state and the downstream end will be the height of the obstruction; or in this case, the height of the masonry block. The height of a typical masonry block is 0.625 ft. Figure 69 is a general diagram of the reach from Point 1 to Point 2.

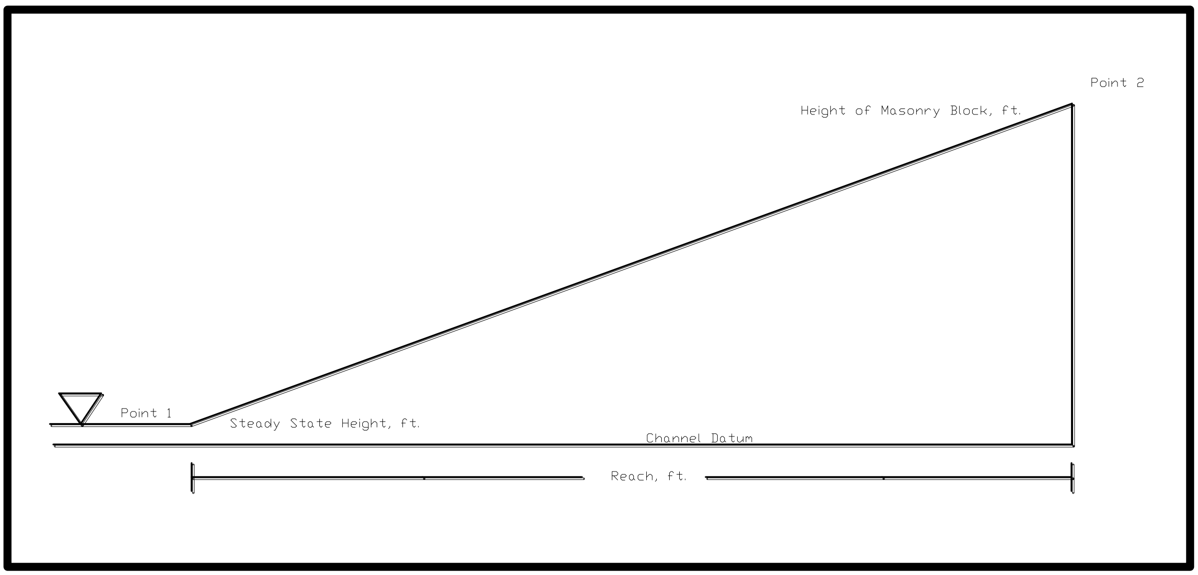


Figure 69: Schematic of Reach Calculation, Δx

The equation for Δx or reach is shown below. Greater accuracy results from smaller depth variations in each reach. The basic execution of the equation is the difference of energy from Point 1 to Point 2 divided by the difference of the energy gradient and the slope of the channel (Finnemore and Franzini 2002).

$$\Delta \mathrm{x} = \frac{\left(y_1+\frac{V_1^2}{2g}\right)-\left(y_2+\frac{V_2^2}{2g}\right)}{S-S_0} = \frac{E_1-E_2}{S-S_0} \qquad (7)$$

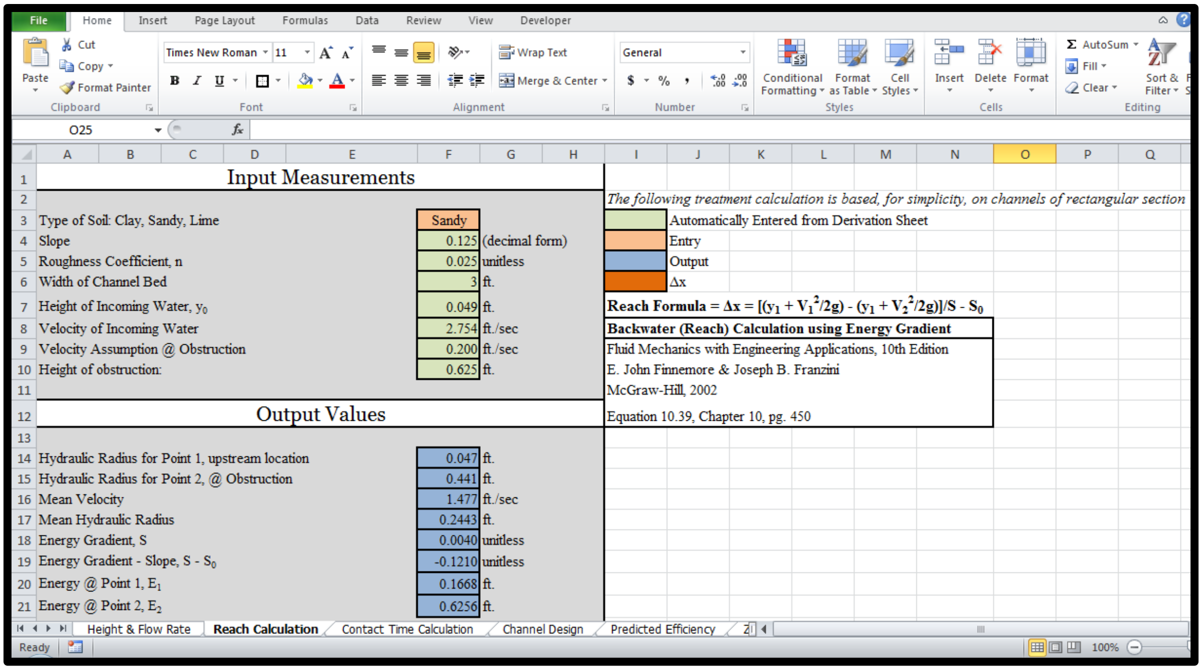


Figure 70: Screenshot of Reach Calculation sheet

As indicated by the color coded legend in column I of Figure 70, the only input value necessary for this spreadsheet is the type of soil being used. The only three soils able to be placed in cell F3 are Silty clayey sand, Sandy, or Lime.

The output values shown are simply each value necessary for the calculation of the reach. A similar approach will be used later for the backwater calculation caused by the hydraulic jump downstream. One of the output values is the energy gradient, S. The energy gradient calculation is shown below.

$$S = \left(\frac{n\bar{V}}{1.486\bar{R}_h^{2/3}}\right)^2 \tag{8}$$

The bars over the velocity and hydraulic radius indicate these values are the means of the respective values at the two ends of the reach. The remaining portion of the Reach Calculation sheet is the ending results for the reach, the length in between the obstructions and the L-value that will be used further in the process which is displayed in Figure 71.

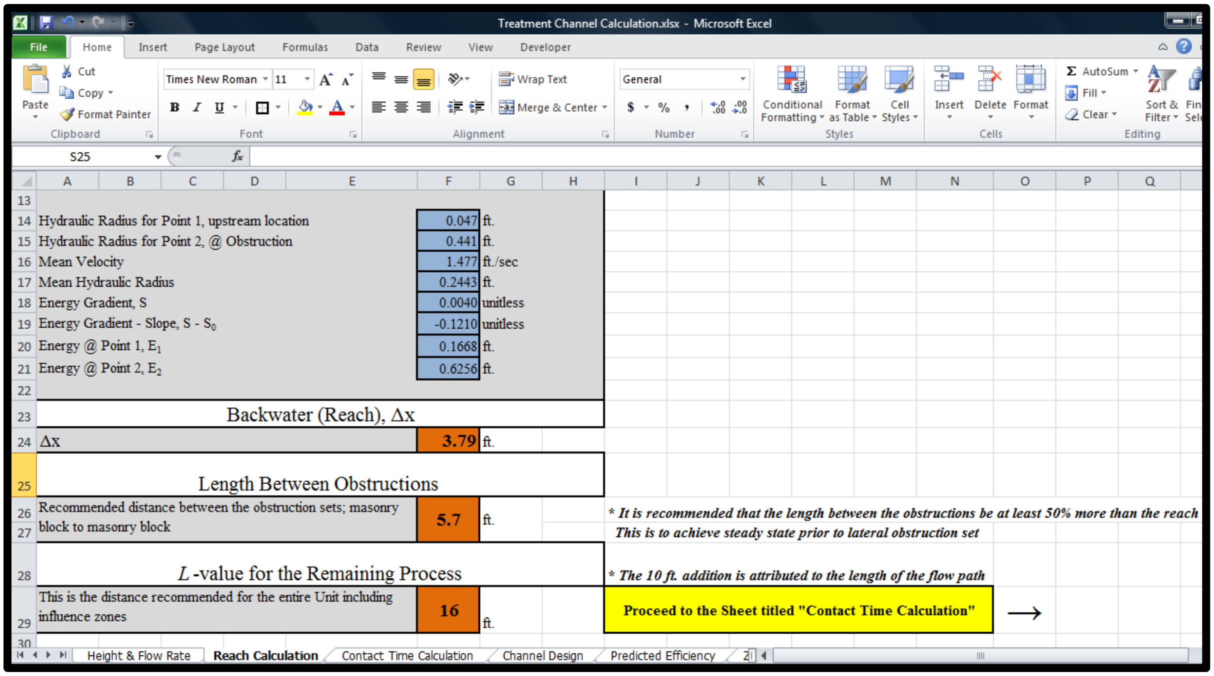


Figure 71: Reach Calculation Output

The calculation for reach is shown below using the values previously shown from the Height & Flow Rate sheet. It was consistently observed that the velocity directly in front of the hydraulic jump downstream was 0.1 ft./sec and this value will be used for the theoretical jump caused by the masonry blocks.

$$E_1 = 0.049\ ft. + \frac{(2.754\ ft./sec)^2}{64.4\ ft./sec^2} = 0.1668\ ft.$$

$$E_2 = 0.625\ ft. + \frac{(0.1\ ft./sec)^2}{64.4\ ft./sec^2} = 0.6256\ ft.$$

$$S = \left(\frac{0.025\ x\ \left(\frac{2.754 + 0.1}{2}\right)}{1.486\ x\ \left(\frac{0.047 + 0.441}{2}\right)^{\frac{2}{3}}} \right)^2 = 0.004$$

$$S_0 = 0.125$$

$$\Delta x = \frac{0.1668\ ft. - 0.6256\ ft.}{0.004 - 0.125} = \mathbf{3.79\ ft.}$$

This value matches that shown in Figure 71. This value is then increased by 50% to allow a distance to allow the flow to achieve a steady state condition prior to being affected by the backwater. Again, a conservative assumption had already been made in calculating the backwater by assuming that the masonry blocks extended throughout the entire width of the channel. Lastly, the L-value is derived. This distance is the length attributed to the actual flow path of the water. The 50% increased distance is the linear length from the back of the first masonry block to the front of the blocks being used for the lateral obstruction set. This does not account for the travel amongst the PAM and masonry blocks. Figure 72 below shows arrows of the anticipated path which provides the additional lengths necessary for calculating the contact time through one unit. A unit is basically the combination of the first block and the two blocks used for the lateral obstruction

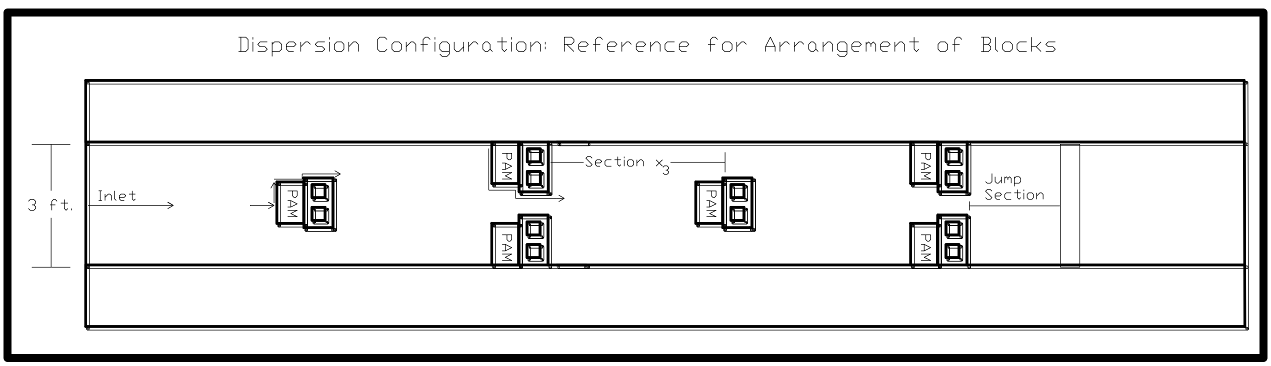


Figure 72: Dispersion Configuration Flow Path

The “Contact Time Calculation” sheet uses a step by step method to achieve the theoretical contact time . Respective zones were created for ease of calculation and can be seen in Figure 70. Each zone has a different formula for velocity depending on the values obtained during the field-scale testing or have been assigned a velocity based on the consistently observed values of velocities seen at that particular location. The zones are displayed in Figure 73.

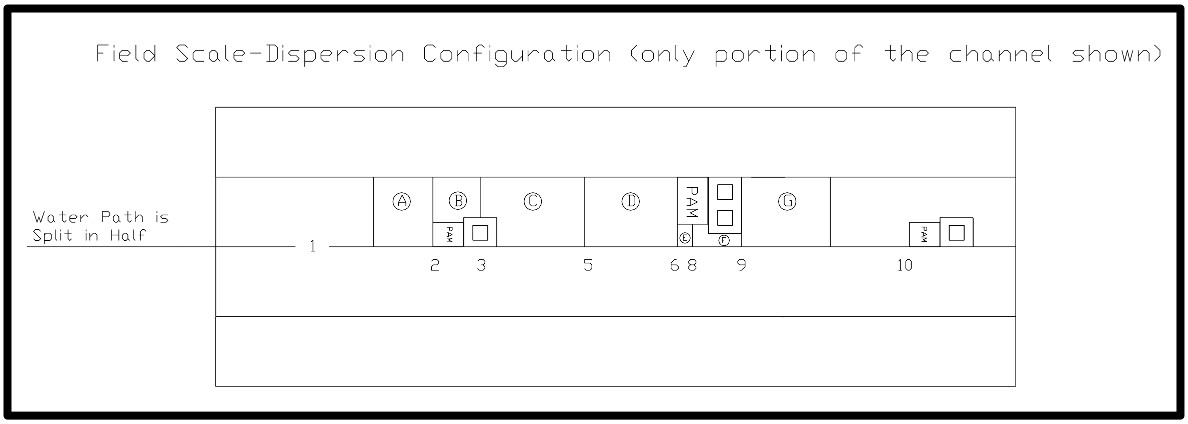


Figure 73: Zone Identification

Zone A is set as 9 inches before the PAM block. The velocity for this section is assumed to be the incoming, steady state velocity calculated in the Height & Flow Rate sheet.

Zone A Length = 0.75 ft.

Zone A Velocity = *steady state velocity from inlet*

Zone B is 1.46 feet and this length takes into account the flow path coming into contact with the center of the PAM and around the masonry block through the center of the masonry block as shown above. This velocity is set as 1.1 ft./sec. This was seen to be the average amongst all the Dispersion tests after one outlier was taken out. All remaining values prior to the average calculation were within two standard deviations and can be seen in Table 38.

Table 38: Average Velocity for Zone B and Zone E

	Zone B Velocity	Outlier?	Zone E Velocity	Outlier?
	1.1	Not Outlier	0.7	Not Outlier
	1.1	Not Outlier	0.7	Not Outlier
	0.4	Not Outlier	0.2	Not Outlier
	0.3	Not Outlier	0.4	Not Outlier
	0.7	Not Outlier	0.4	Not Outlier
	0.3	Not Outlier	0.2	Not Outlier
	2	Not Outlier	0.5	Not Outlier
	0.2	Not Outlier	0.5	Not Outlier
	0.2	Not Outlier	0.5	Not Outlier
	2	Not Outlier	0.8	Not Outlier
	1.2	Not Outlier	0.6	Not Outlier
	0.5	Not Outlier	0.5	Not Outlier
	0.5	Not Outlier	0.4	Not Outlier
	2.7	Not Outlier	0.7	Not Outlier
	3.5	Not Outlier	0.7	Not Outlier
AVERAGE	**1.113**	**ft./sec**	**0.520**	**ft./sec**

Zone B Length = 1.46 ft.

Zone B Velocity = 1.1 ft./sec

Zone C extends from the center of the first masonry block through half of the L-value previously calculated. For the field-scale testing this was seen to be 7.44 feet. The velocity for Zone C is derived from the values seen during this research project. All velocities detected at location 3 for both slopes were averaged and graphed as shown in Table 39 and Figure 74

Table 39: Average Velocity for Point 3

What are the average velocity values obtained for Point 3 respect to the slope?	
Slope	Velocity, fps
0.0625	1.78
0.1250	2.72

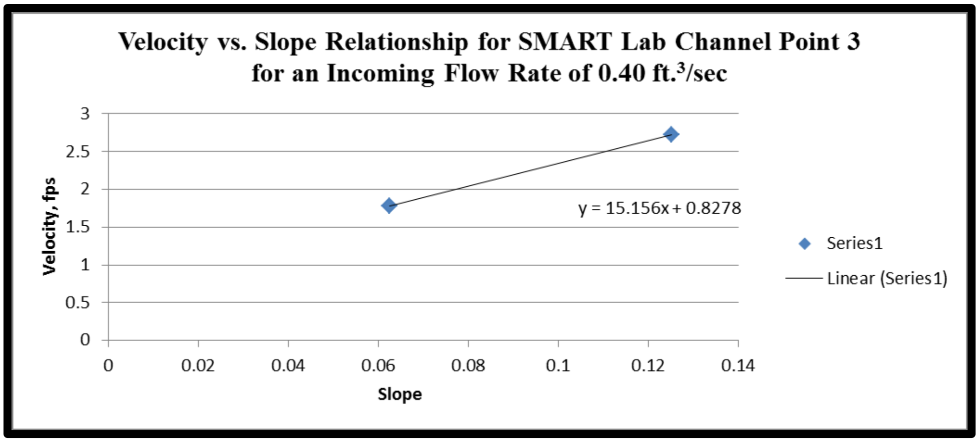


Figure 74: Regression Equation for Point 3

As shown, the graph indicates the regression equation created from the velocity vs. slope chart is $y = 15.156x + 0.8278$. This equation is embedded in cell F15 as shown in Figure 75. For greater accuracy, it is recommended that the slopes used for the equation remain between 8H:1V and 16H:1V.

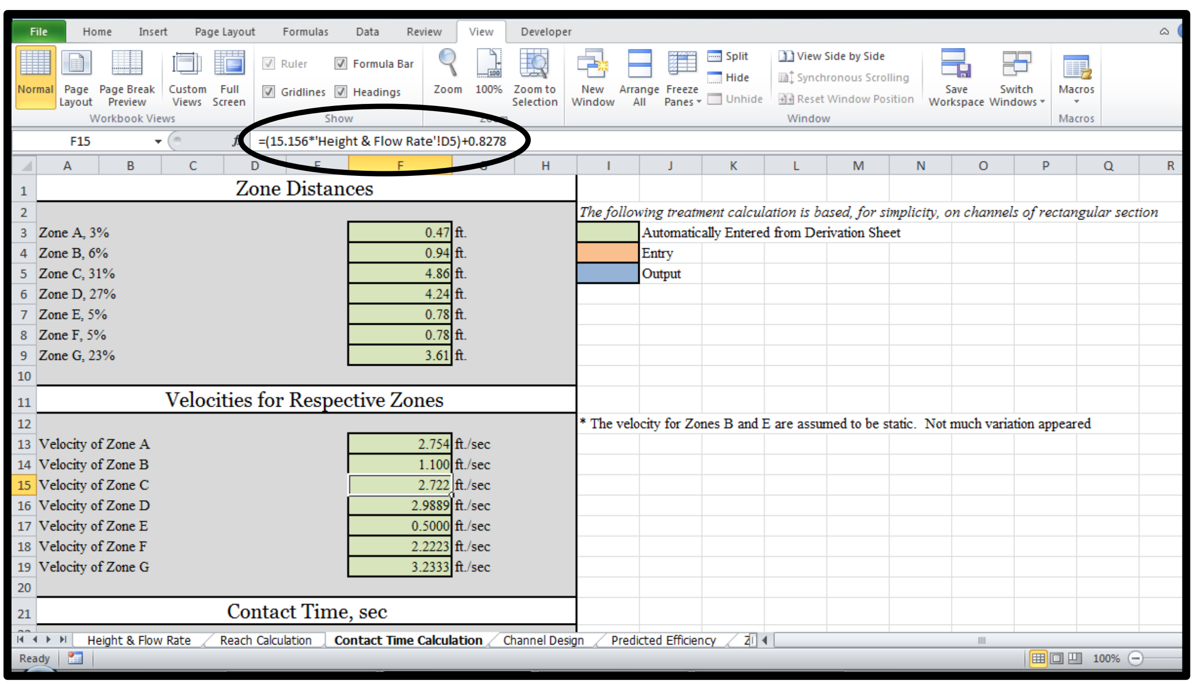


Figure 75: Zone C Embedded Equation for Velocity

Zone C Length = 7.44 ft.

Zone C Velocity = 15.156x + 0.8278

x = channel slope (decimal form)

Zone D ranges from half of the length in between the obstructions to the second PAM block. In the field this was measured as 6.63 feet. The velocity was calculated in the same fashion as Zone C and can be seen in Table 40and Figure 76 below. The average velocity values and respective graph are shown below. The embedded equation for Zone D is $y = 16.422x + 0.9361$.

Table 40: Average Velocity for Point 5a

What are the average velocity values obtained for Point 5a respect to the slope?	
Slope	Velocity, fps
0.0625	1.96
0.1250	2.99

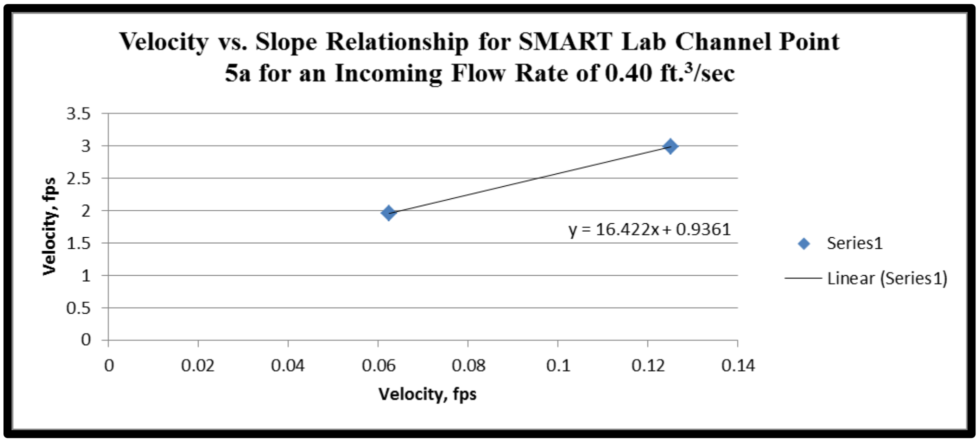


Figure 76: Regression Equation for Point 5a

Zone D Length = 6.63 ft.

Zone D Velocity = 16.422x +0.9361

x = channel slope (decimal form)

Zone E is calculated similar to Zone B. The length was seen to be 1.25 feet during the field testing and the velocity is set as 0.5 ft./sec. Table 38 displays all the velocity values for Zone E and the respective average.

Zone E Length = 1.25 ft.

Zone E Velocity = 0.5 ft./sec

Zone F is the slight distance from the center of the PAM block of the lateral obstruction set through the downstream end of the masonry block. The distance was 1.17 feet and the embedded velocity equation is $y = 16.956 + 0.1028$ resulting from Table 41 and Figure 77 .

Table 41: Average Velocity for Point 8

What are the average velocity values obtained for Point 8 respect to the slope?

Slope	Velocity, fps
0.0625	1.16
0.1250	2.22

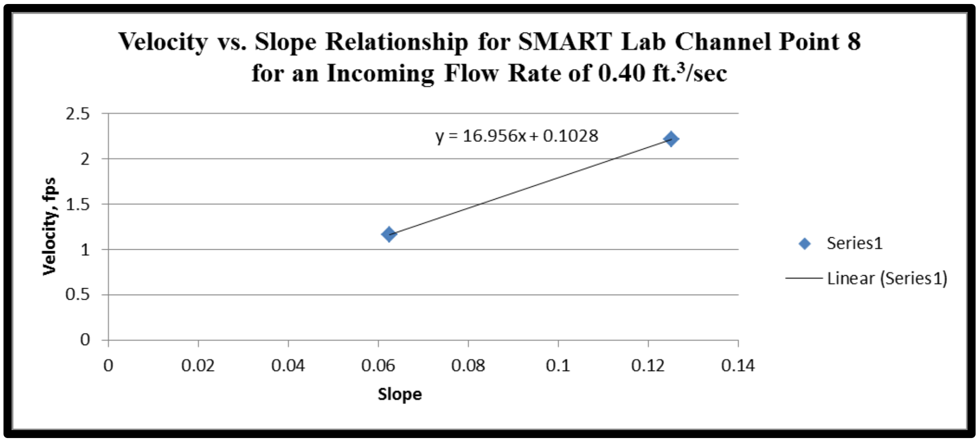


Figure 77: Regression Equation for Point 8

Zone F Length = 1.17 ft.

Zone F Velocity = 16.956x + 0.1028

x = channel slope (decimal form)

The final zone is Zone G and extends from the tip of the masonry block of the lateral obstruction set through an arbitrarily distance of 66 inches. The Zone G embedded equation is $y = 25.933x - 0.0083$.

Table 42: Average Velocity for Point 9

What are the average velocity values obtained for Point 9 respect to the slope?	
Slope	Velocity, fps
0.0625	1.61
0.1250	3.23

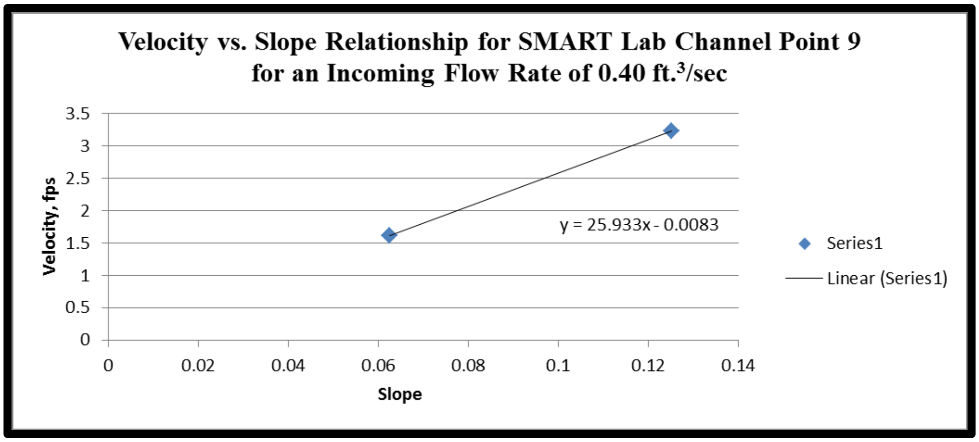


Figure 78: Regression Equation for Point 9

Zone G Length = 5.5 ft.

Zone G Velocity = 25.933x – 0.0083

x = channel slope (decimal form)

Using the layout from the field-scale testing, ratios were assigned for each zone in respect to the L-value. The total length amongst all zones for the Dispersion Configuration testing was 24.19 feet. Each zone length was divided by this amount and resulting percentages for each zone was achieved. These percentages are used to calculate any zone length based on the L-value derived. For example, Zone G is 5.5 ft./24.19 ft. or 22.7% of the entire flow path length.

Once the lengths and the velocities are found, the spreadsheet then divides each zone's length by its velocity to obtain the contact time for that particular zone. These times are then added and considered to be the entire contact time in seconds through one Unit. A Unit is basically the combination of the first block and the two blocks used for the lateral obstruction. Lastly, the sheet indicates whether or not more than one Unit is needed. The minimum amount of contact time set for any practicable turbidity removal is 20 seconds. Though this is arbitrary, this time was seen to be the minimum required to obtain high turbidity removal efficiency amongst many of the field-scale tests. Decision statements are then used to decide the number of Units and then cell F35 reveals the contact time associated to that precise design. This is shown in Figure 79.

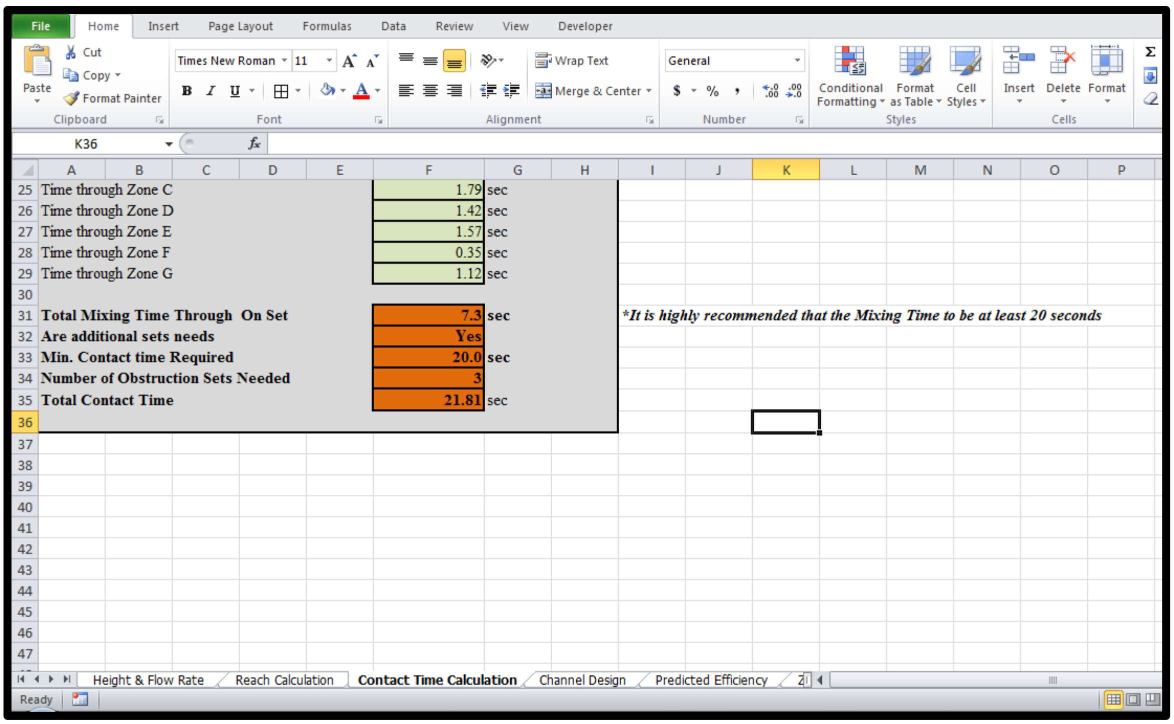


Figure 79: Contact Time Calculation

The "Channel Design" sheet is considered to be the most beneficial for designers and contractors. This sheet calculates the necessary distances for the entire treatment channel. The step by step approach is intended to be user friendly and easily identifiably in conjunction with Figure 72 shown above.

At this point, the only remaining distance needed to be derived is the distance for the Jump Section. This is the distance necessary in between the last obstruction set and the hydraulic jump. It is calculated using the previous reach equation. The user simply needs to place the desired height for the jump as shown in Figure 80 and the sheet computes the projected backwater length.

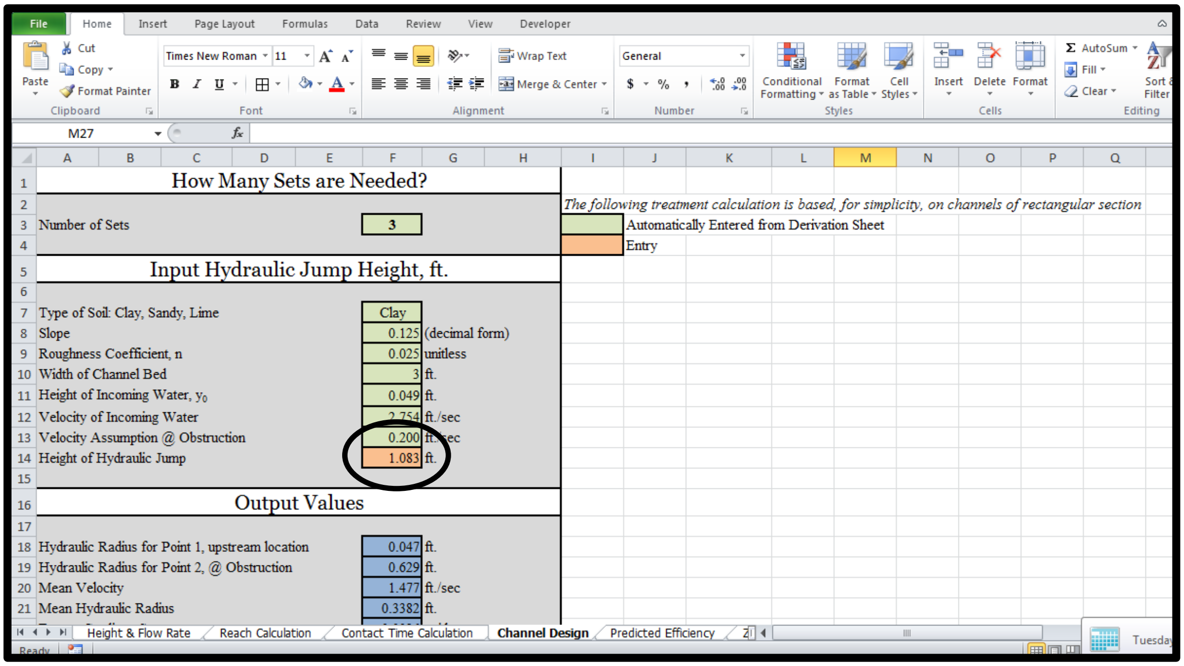


Figure 80: Screenshot of Channel Design Sheet

Beginning at row 29, the highlighted values in red display the recommended distances for the treatment channel. This can be seen in Figure 81. The placement of the first masonry block will always be 4 feet from the inlet or incoming water. The first lateral obstruction set is then placed at the distance previously derived in the Reach Calculation sheet that was enhanced by 50% which completes the Unit 1. The beginning of the next Unit will be 11 feet from the previous masonry block as shown within Section x_3. The steps need to be repeated until the required number of Units is achieved. Lastly, the Jump Section is at least the distance calculated as the reach for the hydraulic jump.

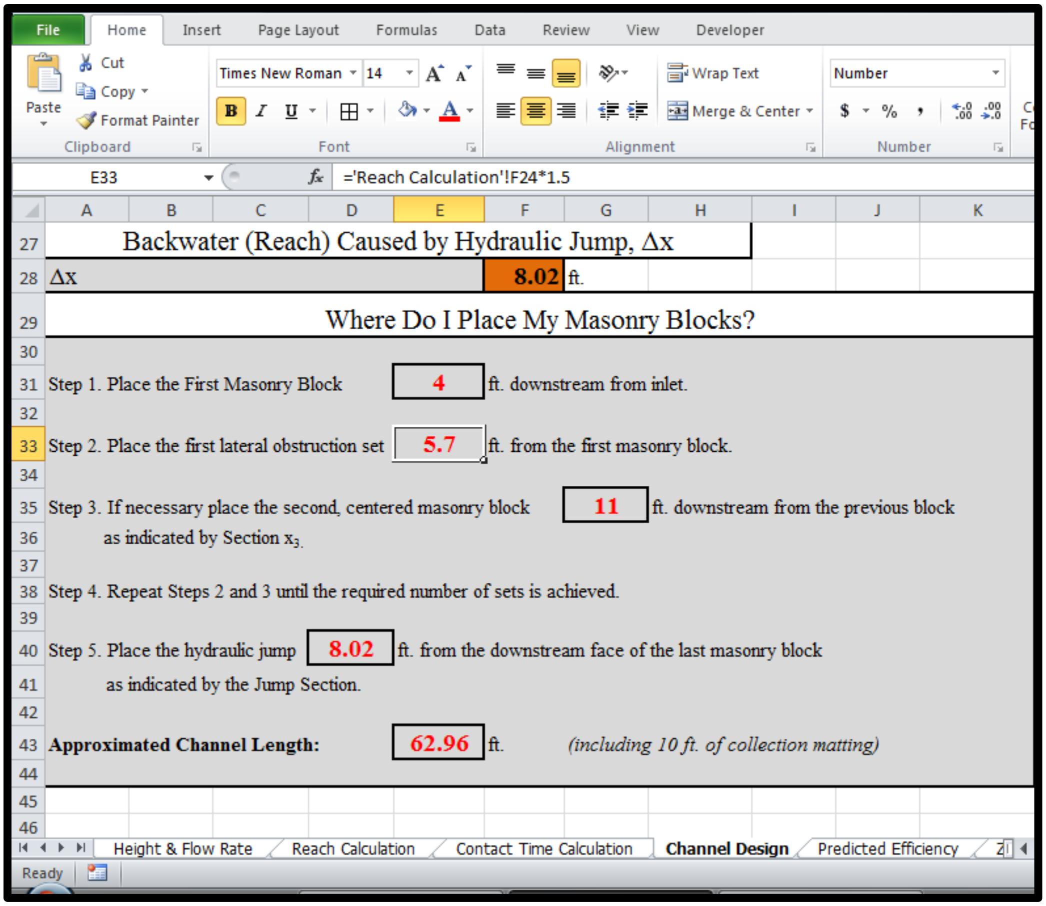


Figure 81: Recommended Channel Design Output

The final sheet, Predicted Efficiency, is then used as a conventional estimate of the turbidity removal efficiency. Linear equations were derived for each individual soil tested during the field-scale testing at the Stormwater Management Academy. A table was developed associating the slope and contact time calculated with the resulting turbidity removal efficiency achieved for that particular test in the field.

The derivation of each equation was aided by the regression analysis function within the spreadsheet program. The independent variables for the analysis are the slopes and the contact time. The dependent variable is the turbidity removal efficiency. The output from the regression analysis is shown in Figure 82. The main focus on the regression output is placed on the intercept and variables.

Dispersion-Clay

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.742568215
R Square	0.551407553
Adjusted R Square	0.401876738
Standard Error	0.179320303
Observations	9

ANOVA

	df	SS	MS	F	Significance F
Regression	2	0.237154262	0.118577131	3.687584737	0.090272583
Residual	6	0.192934627	0.032155771		
Total	8	0.430088889			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%
Intercept	0.365234814	0.257622117	1.417715289	0.206054055	-0.265143797	0.995613425	-0.265143797
X Variable 1	1.687675588	1.988970505	0.848517152	0.428697163	-3.179159913	6.554511089	-3.179159913
X Variable 2	0.010240889	0.003778405	2.710373927	0.035088632	0.000995466	0.019486312	0.000995466

RESIDUAL OUTPUT

Observation	Predicted Y	Residuals	Standard Residuals
1	1.13944317	-0.16944317	-1.091098532
2	0.678603155	-0.238603155	-1.536441698
3	0.782761862	0.177238138	1.141292813
4	0.782761862	0.177238138	1.141292813
5	0.906429951	0.053570049	0.344954604
6	0.884890099	0.085109901	0.548049754
7	0.858023024	0.111976976	0.721055406
8	1.033963446	-0.063963446	-0.411880997
9	0.573123431	-0.133123431	-0.857224163

Equation for Clay: $y = 1.69S_0+0.0102c_t+0.365$

y = Turbidity Removal Efficiency
S_0 = channel slope (input as a decimal)
c_t = contact time, sec

Figure 82: Regression Summary Output for Silty clayey sand

The procedure was repeated for sandy soils and lime and the respective equations were placed within the Predicted Efficiency sheet. It is important to note that the range of applicability is between 20 – 40 seconds. It was witnessed that with 40 seconds of contact time, high turbidity removal efficiencies can be attained. Due to the nominal amount of trials tested, there is an apparent degradation of accuracy when input values skew too far from this range. The range of slopes is preferred to be between 0.125 and 0.0625 also due to the limited data accumulation. It is recommended that further testing should be completed to enhance the database and obtain more encompassing equations for the purposes of science and the sediment control industry.

Table 43: Equation Verification for Predicted Removal Efficiency

Dates of Test	Soil Type	Slope	Est. Time of Travel thru Mixing Zone, sec	Normalized Average Turbidity Removal Efficiency	Equation Utilized	Turbidity Removal Efficiency Calculated	Actual Average Turbidity Removal Efficiency
Correction Value	Clay	0.125	55	0.96	$y = 1.64S_0+0.0102c_t+0.365$	1.13	0.96
Correction Value	Clay	0.125	10.0	0.44	$y = 1.64S_0+0.0102c_t+0.365$	0.67	0.40
2.1	Clay	0.125	20.2	0.96	$y = 1.64S_0+0.0102c_t+0.365$	0.78	0.96
2.3	Clay	0.125	20.2	0.96	$y = 1.64S_0+0.0102c_t+0.365$	0.78	0.96
2.8	Clay	0.125	32.2	0.96	$y = 1.64S_0+0.0102c_t+0.365$	0.90	0.96
4.21	Clay	0.0625	40.4	0.97	$y = 1.64S_0+0.0102c_t+0.365$	0.88	0.97
4.22	Clay	0.0625	37.8	0.97	$y = 1.64S_0+0.0102c_t+0.365$	0.85	0.97
Correction Value	Clay	0.0625	55.0	0.97	$y = 1.64S_0+0.0102c_t+0.365$	1.03	0.97
Correction Value	Clay	0.0625	10.0	0.44	$y = 1.64S_0+0.0102c_t+0.365$	0.57	0.40
Correction Value	A3	0.125	45.0	0.86	$y = -1.11S_0+0.0149c_t+0.460$	0.99	0.86
Correction Value	A3	0.125	20.0	0.44	$y = -1.11S_0+0.0149c_t+0.460$	0.62	0.40
2.23	A3	0.125	75.7	0.96	$y = -1.11S_0+0.0149c_t+0.460$	1.45	0.94
2.24	A3	0.125	32.6	0.65	$y = -1.11S_0+0.0149c_t+0.460$	0.81	0.96
2.25	A3	0.125	36.1	0.83	$y = -1.11S_0+0.0149c_t+0.460$	0.86	0.92
4.27	A3	0.0625	40.3	0.88	$y = -1.11S_0+0.0149c_t+0.460$	0.99	0.83
4.28 (1)	A3	0.0625	43.4	0.92	$y = -1.11S_0+0.0149c_t+0.460$	1.04	0.65
4.28 (2)	A3	0.0625	54.9	0.94	$y = -1.11S_0+0.0149c_t+0.460$	1.21	0.88
Correction Value	A3	0.0625	45.0	0.96	$y = -1.11S_0+0.0149c_t+0.460$	1.06	0.96
Correction Value	A3	0.0625	20.0	0.44	$y = -1.11S_0+0.0149c_t+0.460$	0.69	0.40
Correction Value	Lime	0.125	55.0	0.9	$y = -0.0247S_0+0.0095c_t+0.363$	0.88	0.9
Correction Value	Lime	0.125	10.0	0.44	$y = -0.0247S_0+0.0095c_t+0.363$	0.45	0.40
3.18	Lime	0.125	17.4	0.44	$y = -0.0247S_0+0.0095c_t+0.363$	0.53	0.90
3.23	Lime	0.125	43.1	0.74	$y = -0.0247S_0+0.0095c_t+0.363$	0.77	0.74
3.23 (2)	Lime	0.125	43.5	0.74	$y = -0.0247S_0+0.0095c_t+0.363$	0.77	0.74
5.16	Lime	0.0625	67.1	0.90	$y = -0.0247S_0+0.0095c_t+0.363$	1.00	0.86
5.17 (1)	Lime	0.0625	54.1	0.86	$y = -0.0247S_0+0.0095c_t+0.363$	0.88	0.80
5.17 (2)	Lime	0.0625	49.1	0.80	$y = -0.0247S_0+0.0095c_t+0.363$	0.83	0.89
Correction Value	Lime	0.0625	55.0	0.90	$y = -0.0247S_0+0.0095c_t+0.363$	0.88	0.90
Correction Value	Lime	0.0625	10	0.44	$y = -0.0247S_0+0.0095c_t+0.363$	0.46	0.44

As shown above in Table 43, correction values were added to each soil category to assist the regression analysis for the upper and lower bounds. For example, a correction value for silty clayey sand assuming a 10 second contact time will theoretically yield a 44% turbidity removal efficiency. These values are used to expand the equations more appropriately throughout the recommended range of 20 – 40 seconds of contact time.

Turbidity Removal Efficiency Prediction Equation for Silty clayey sand:

$$\mathbf{y = 1.64S_0+0.0102c_t+0.365}$$

S_0 = channel slope (decimal form)

c_t = contact time

Turbidity Removal Efficiency Prediction Equation for Sandy Soil:

$$\mathbf{y = -1.11S_0+0.0149c_t+0.460}$$

S_0 = channel slope (decimal form)

c_t = contact time

Turbidity Removal Efficiency Prediction Equation for Lime Rock:

y = -0.0247S0+0.0095ct+0.363

S_0 = channel slope (decimal form)

c_t = contact time

Figure 83 is a screenshot of the Predicted Efficiency sheet. The linear equations derived from the regression analyses are not only embedded within the cells, but also displayed in bold.

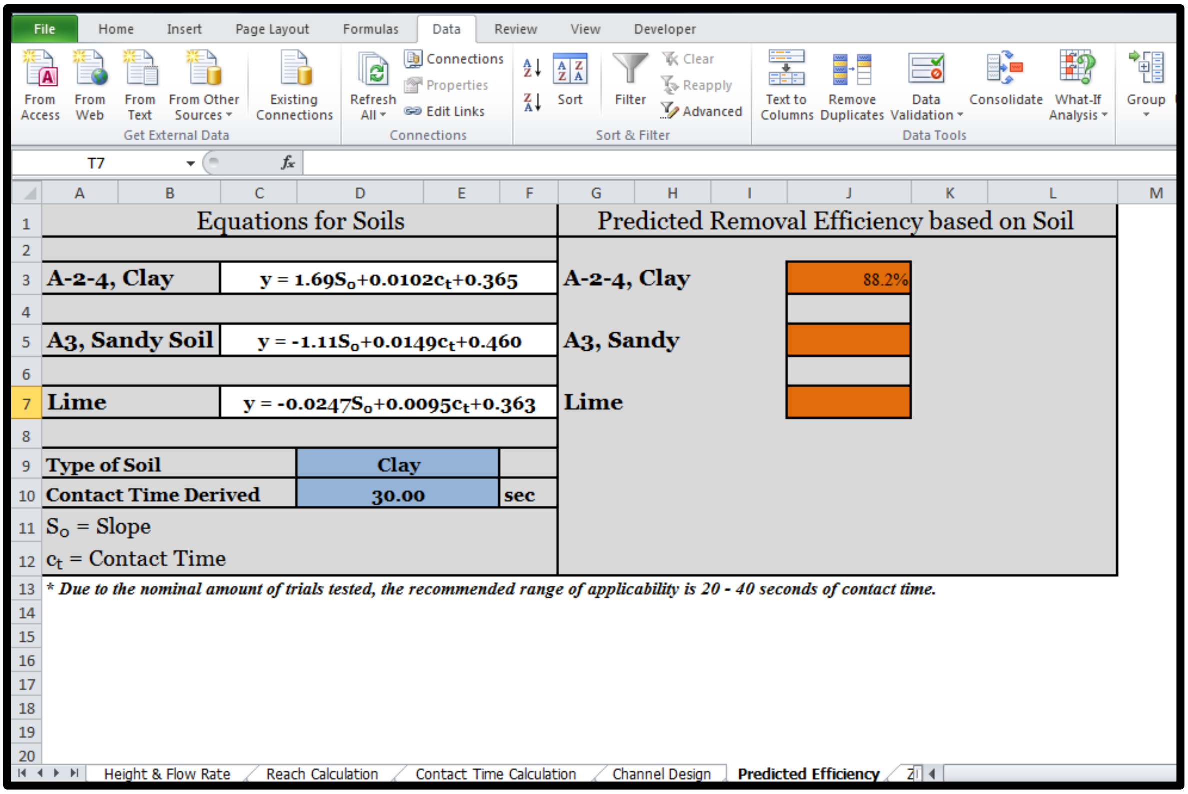


Figure 83: Screenshot of Predicted Efficiency Sheet

No input is necessary for the Predicted Efficiency sheet. The type of soil is referenced from the *Reach Calculation* sheet and the contact time is drawn from the *Contact Time Calculation* sheet. The sheet only displays the estimated turbidity removal efficiency of the soil indicated. To verify the equations, each calculated efficiency was tested against the actual removal efficiency seen in the field and ANOVA analyses were completed to check whether there was a significant difference between the calculated and actual turbidity removal efficiency. Although no significant difference was shown between the calculated turbidity removal efficiency and the actual value for any soil, the p-value for the sandy soil indicates that it is not as accurate as the equations for silty clayey sand and lime. The closer the p-values are to 1, the closer the values being compared actually are. The p-values for silty clayey sand, sandy soil and lime are 0.97, 0.08 and 0.89, respectively.

Clay: Is there a significant difference between the Removal Efficiency Obtained and the Removal Efficiency Calculated?
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	9	7.584686728	0.84274297	0.029380827
Column 2	9	7.55	0.838888889	0.061936111

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6.68427E-05	1	6.68427E-05	0.001463972	0.969952216	4.493998478
Within Groups	0.730535504	16	0.045658469			
Total	0.730602347	17				

Using a Confidence Interval of 95%, there is not a significant difference between the two turbidity removal efficiency values.

Sandy: Is there a significant difference between the Removal Efficiency Obtained and the Removal Efficiency Calculated?
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	10	9.71183307	0.971183307	0.060073183
Column 2	10	7.8	0.78	0.048288889

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.182755284	1	0.182755284	3.373048927	0.082842546	4.413873419
Within Groups	0.975258643	18	0.054181036			
Total	1.158013928	19				

Using a Confidence Interval of 95%, there is not a significant difference between the two turbidity removal efficiency values.

Lime: Is there a significant difference between the Removal Efficiency Obtained and the Removal Efficiency Calculated?
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	10	7.447968695	0.74479687	0.038184548
Column 2	10	7.57	0.757	0.035556667

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.000744582	1	0.000744582	0.020194459	0.888573838	4.413873419
Within Groups	0.663670933	18	0.036870607			
Total	0.664415515	19				

Using a Confidence Interval of 95%, there is not a significant difference between the two turbidity removal efficiency values.

5.8.1 Analysis Aid Example 1

A large construction site is being excavated to build the headquarters for ACME, Inc. in central Florida. As part of the erosion and sediment control requirements, it is mandated that the contractor clean the site water prior to discharge within neighboring retention ponds. The anticipated flow rate is 0.30 $ft.^3$/sec and the primary soil being removed from the water is sandy soil. There is an embankment area near a retention pond that has a considerable length at a steady slope of 12H:1V. Visqueen will be laid to line the treatment channel and the hydraulic jump down the channel will be 15'' high. How many Units of baffles are needed? How long is the entire channel? What is the estimated turbidity removal efficiency?

As previously indicated, it is highly recommended that the width be 3 feet. This will provide just enough space for the lateral obstruction set and the water to flow causing fluctuations in energy. The first step is to define the parameters in the Height & Flow Rate.

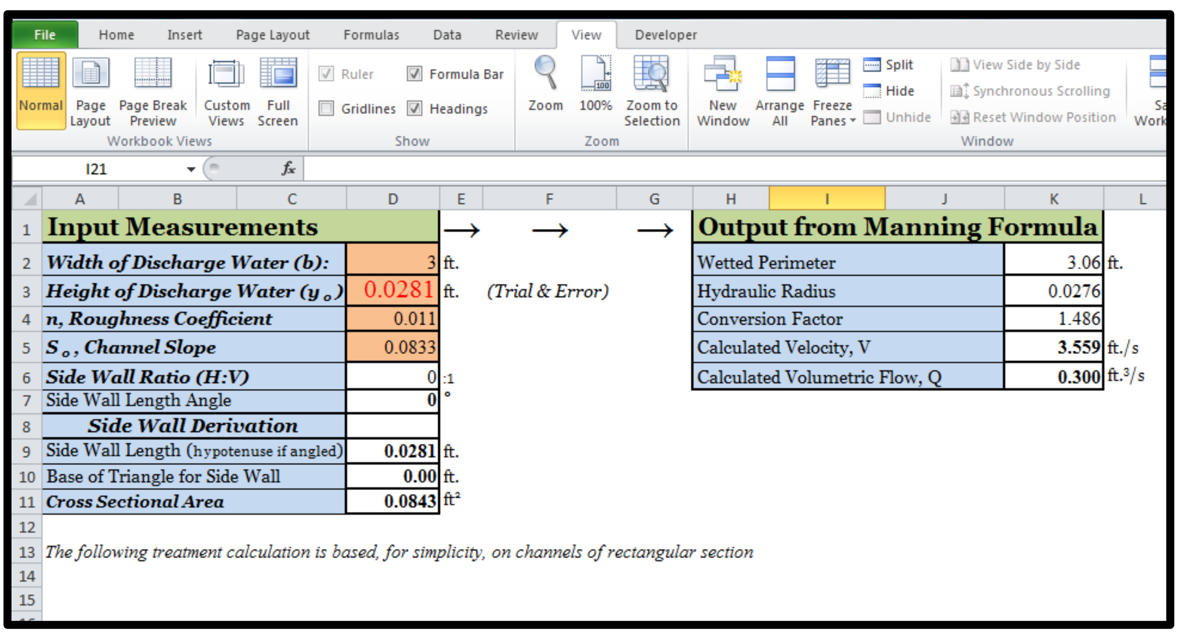


Figure 84: Screenshot for Example 1 Height & Flow Rate

As shown in Figure 84, the resulting height from a volumetric flow of 0.30 ft.^{3}/sec is 0.0281 ft. The resulting reach is calculated as 4.89 ft. and the length in between the obstructions for one unit is 7.3 ft.

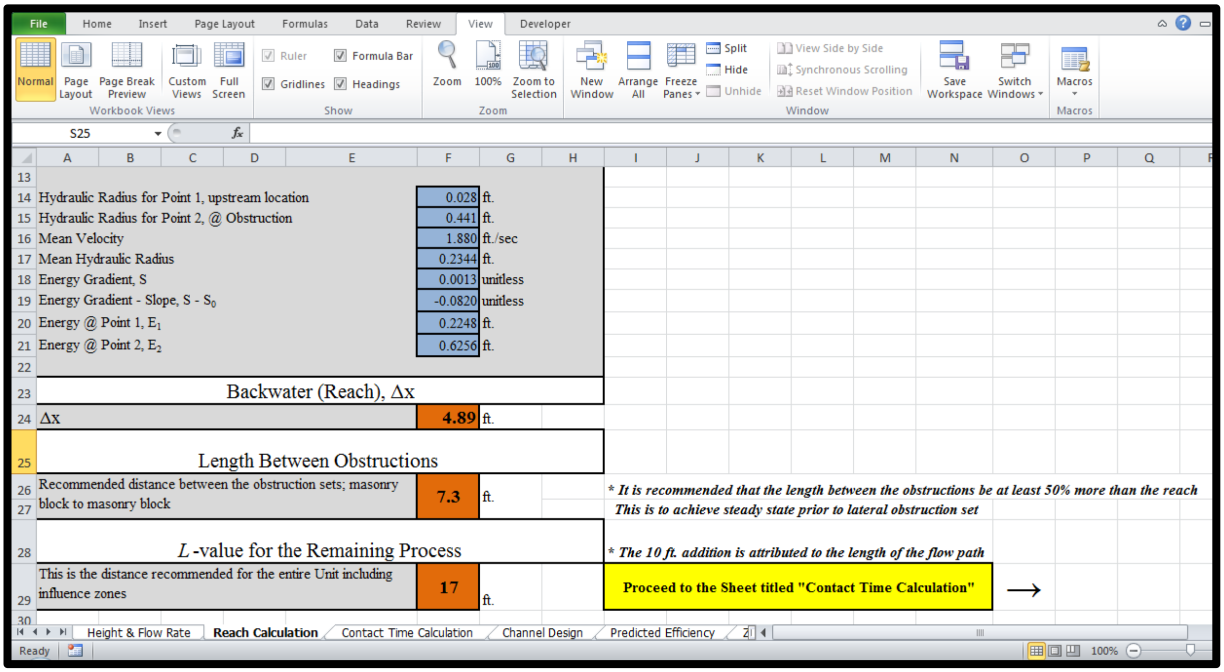


Figure 85: Screenshot for Example 1 Reach Calculation

The Contact Time Calculation sheet indicates that based on the flow, three units are needed. The entire contact time calculated is 29.56 seconds which is within the range of applicability.

The hydraulic jump is 15'', or 1.25 ft. The reach, or backwater, is then calculated using the Channel Design sheet. The only input value needed for this sheet is the height of the anticipated hydraulic jump. As indicated by Figure 86 the reach calculated for this design caused by the 15'' jump is 13.30 ft.

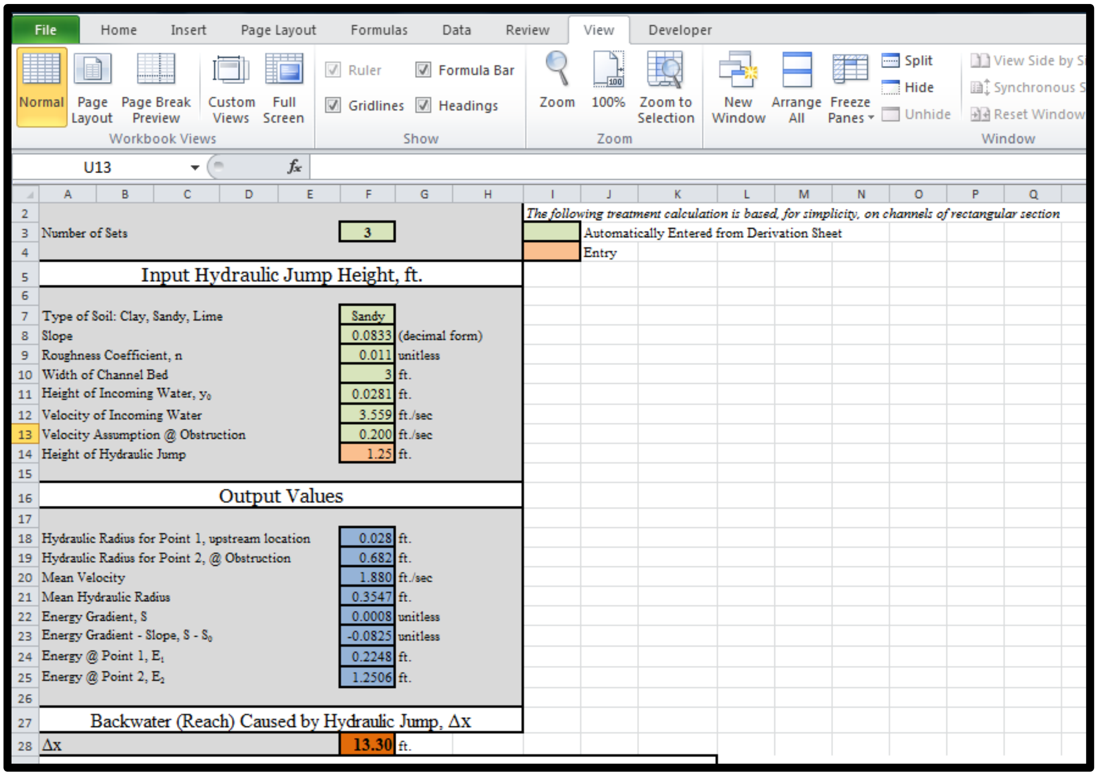


Figure 86: Example 1 Hydraulic Jump Reach

The entire channel including the 10 foot spacing allowance for collection matting such as Curlex II is calculated to be 60 feet. The output provided by Figure 87 provides the contractor with the recommended treatment channel arrangement.

Where Do I Place My Masonry Blocks?		
Step 1. Place the First Masonry Block	4	ft. downstream from inlet.
Step 2. Place the first lateral obstruction set	7.3	ft. from the first masonry block.
Step 3. If necessary place the second, centered masonry block as indicated by Section x_3.	11	ft. downstream from the previous block
Step 4. Repeat Steps 2 and 3 until the required number of sets are achieved.		
Step 5. Place the hydraulic jump as indicated by the Jump Section.	13.30	ft. from the downstream face of the last masonry block
Approximated Channel Length:	73.18	ft. *(including 10 ft. of collection matting)*

Figure 87: Example 1 Recommended Treatment Design

Lastly, the predicted turbidity removal efficiency is displayed in the design aid. For this particular scenario, a turbidity removal efficiency of 81% can be expected as shown below in Figure 88.

Equations for Soils			Predicted Removal Efficiency based on Soil	
A-2-4, Clay	**$y = 1.69S_o+0.0102c_t+0.365$**		**A-2-4, Clay**	
A3, Sandy Soil	**$y = -1.11S_o+0.0149c_t+0.460$**		**A3, Sandy**	80.8%
Lime	**$y = -0.0247S_o+0.0095c_t+0.363$**		**Lime**	
Type of Soil	**Sandy**			
Contact Time Derived	**29.56**	**sec**		
S_o = Slope				
c_t = Contact Time				

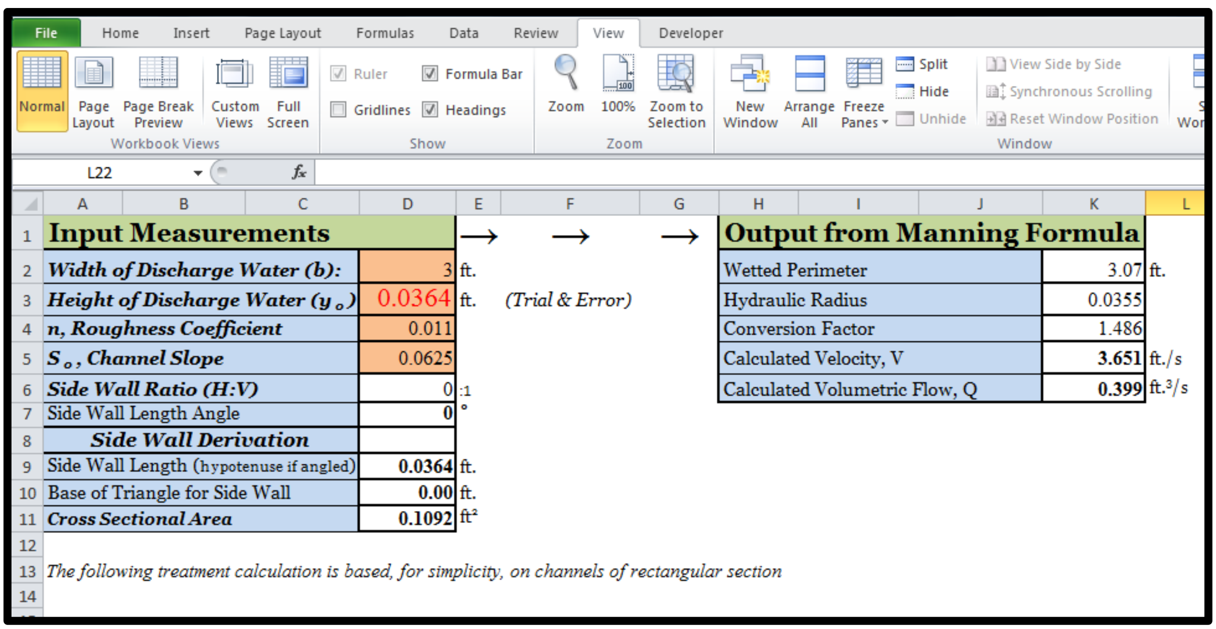
**** Due to the nominal amount of trials tested, the recommended range of applicability is 20 - 40 seconds of contact time.***

Figure 88: Example 1 Screenshot of Predicted Removal Efficiency

5.8.2 Analysis Aid Example 2

The Stormwater Management Academy would like to verify the treatment channel calculation and analysis aid. The anticipated flow rate is 0.40 ft.^{3}/sec and the primary soil being removed from the water is silty clayey sand. The 16H:1V channel is still in operation at the field site and is layered with visqueen. The hydraulic jump will be 1.083 ft. high. How many Units of baffles are needed? How long is the entire channel? What is the estimated turbidity removal efficiency? Does this appear to be the same or similar to the removal efficiency attained during field-scale testing?

Once again, the first step is to define the parameters in the Height & Flow Rate as shown in.

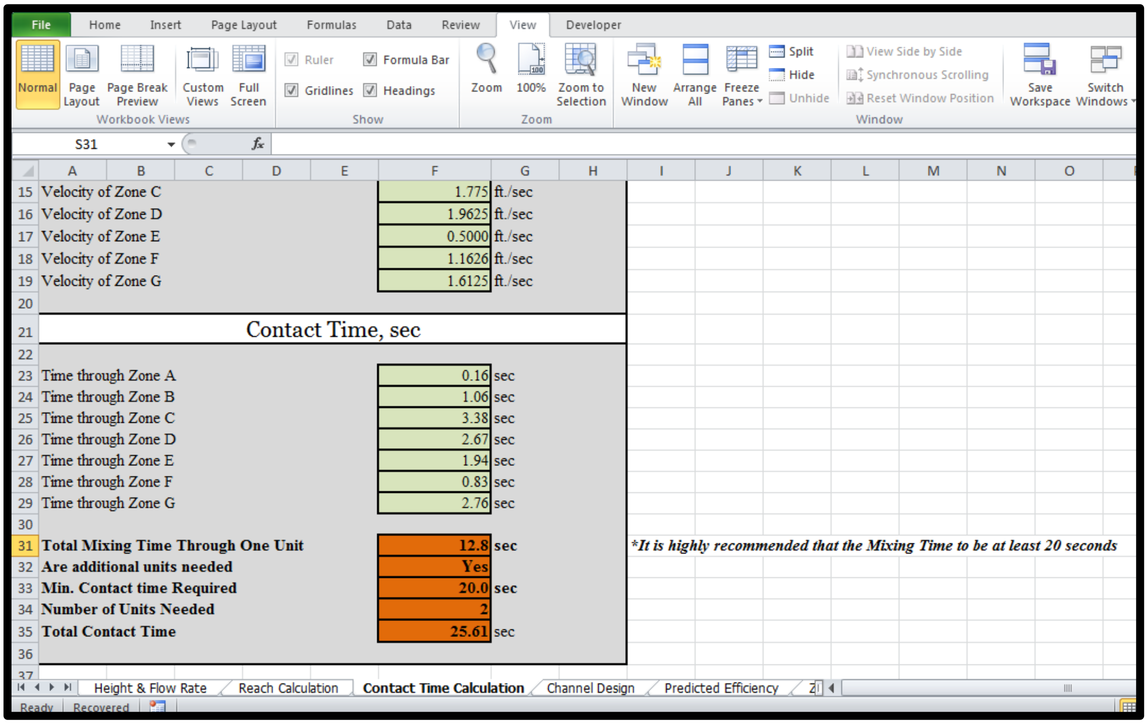


Input Measurements				Output from Manning Formula		
Width of Discharge Water (b):	3	ft.		Wetted Perimeter	3.07	ft.
Height of Discharge Water (y_o)	0.0364	ft.	*(Trial & Error)*	Hydraulic Radius	0.0355	
n, Roughness Coefficient	0.011			Conversion Factor	1.486	
S_o, Channel Slope	0.0625			Calculated Velocity, V	**3.651**	ft./s
Side Wall Ratio (H:V)	0	:1		Calculated Volumetric Flow, Q	**0.399**	ft.^{3}/s
Side Wall Length Angle	**0**	°				
Side Wall Derivation						
Side Wall Length (hypotenuse if angled)	**0.0364**	ft.				
Base of Triangle for Side Wall	**0.00**	ft.				
Cross Sectional Area	**0.1092**	ft²				

The following treatment calculation is based, for simplicity, on channels of rectangular section

Figure 89: Example 2 Height & Flow Rate

As shown in Figure 89, the resulting height from a volumetric flow of 0.40 ft.^{3}/sec is 0.0364 ft. The resulting reach is calculated as 6.25 ft. and the length in between the obstructions for one unit is 9.4 ft. It is shown in Figure 90 that two units are necessary and the total contact time is 25.61 seconds.



15	Velocity of Zone C	1.775	ft./sec
16	Velocity of Zone D	1.9625	ft./sec
17	Velocity of Zone E	0.5000	ft./sec
18	Velocity of Zone F	1.1626	ft./sec
19	Velocity of Zone G	1.6125	ft./sec
20			
21	Contact Time, sec		
22			
23	Time through Zone A	0.16	sec
24	Time through Zone B	1.06	sec
25	Time through Zone C	3.38	sec
26	Time through Zone D	2.67	sec
27	Time through Zone E	1.94	sec
28	Time through Zone F	0.83	sec
29	Time through Zone G	2.76	sec
30			
31	**Total Mixing Time Through One Unit**	**12.8**	**sec**
32	**Are additional units needed**	**Yes**	
33	**Min. Contact time Required**	**20.0**	**sec**
34	**Number of Units Needed**	**2**	
35	**Total Contact Time**	**25.61**	sec

**It is highly recommended that the Mixing Time to be at least 20 seconds*

Figure 90: Contact Time for Example 2

The hydraulic jump is 1.083 ft. and causes a reach of 17.47 ft. The Channel Design sheet indicates that the approximated channel length is 62.48 ft. This is shown below.

Where Do I Place My Masonry Blocks?		
Step 1. Place the First Masonry Block	4	ft. downstream from inlet.
Step 2. Place the first lateral obstruction set	9.4	ft. from the first masonry block.
Step 3. If necessary place the second, centered masonry block as indicated by Section x_3.	11	ft. downstream from the previous block
Step 4. Repeat Steps 2 and 3 until the required number of sets are achieved.		
Step 5. Place the hydraulic jump as indicated by the Jump Section.	17.47	ft. from the downstream face of the last masonry block
Approximated Channel Length:	62.48	ft. *(including 10 ft. of collection matting)*

Figure 91: Example 2 Recommended Treatment Design

The predicted turbidity removal efficiency shown in Figure 92 is approximately 74%. Conclusively, if a treatment channel of length 63 feet with a hydraulic jump and two units was implemented, it is estimated that the turbidity of the silty clayey sand source water would be reduced by 74%.

Equations for Soils			Predicted Removal Efficiency based on Soil	
A-2-4, Clay	**$y = 1.69S_o+0.0102c_t+0.365$**		**A-2-4, Clay**	73.6%
A3, Sandy Soil	**$y = -1.11S_o+0.0149c_t+0.460$**		**A3, Sandy**	
Lime	**$y = -0.0247S_o+0.0095c_t+0.363$**		**Lime**	
Type of Soil	**clay**			
Contact Time Derived	**26.00**	**sec**		
S_o = Slope				
c_t = Contact Time				

** Due to the nominal amount of trials tested, the recommended range of applicability is 20 - 40 seconds of contact time.*

Figure 92: Example 2 Predicted Removal Efficiency

This conservative value does lie in an acceptable range based on values attained during field-scale testing. Due to the amount of fines and silt within the soil, it is expected that high turbidity removal efficiences can be achieved when the soil causing the majority of the turbidity is silty clayey sand. It should be noted that every field-scale test completed achieved at least a 96% removal efficiency when the source water contained primarily silty clayey sand. In summary, polymer treatment is most effective for fine grained soils and may not be very effective for coarse grained soils.

6 CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The objective of this research was to design and conduct experimentation with a field-scale treatment channels using masonry blocks and polyacrylamide for turbidity removal followed by modeling the results. A analysis aid was created based on the results of the experimental work. The motivation for this research study was initiated from an earlier laboratory-scale polyacrylamide examination conducted at the University of Central Florida Stormwater Management Academy field laboratory. The design phase of this research included the investigation of three configurations based on general hydraulic principles using a laboratory hydraulic flume. Based on the variations in the energy and anticipated maintenance concerns, the chosen configuration assumed for the field-scale study was the Staggered Configuration. As a comparative measure, the second most appealing configuration was chosen to be implemented within the field as well; namely, the Dispersion Configuration.

The uniform spacing in between the masonry blocks for the field-scale testing was 45 in. The spacing for the Dispersion Configuration was 48 in., 171 in., 138 in. and 156 in. respective to sections x_1, x_2, x_3 and x_4. The x_4 distance was altered due to the backwater of the hydraulic jump when the 16H:1V slope was being used. The alternating parameters for the field-scale testing were configuration, slope and soil for the source water. The incoming volumetric flow rate was assumed to be static. While the initial hypothesis following the laboratory work was that the Staggered Configuration would perform the best, the field-testing resulted in the conclusion Dispersion Configuration is the chosen configuration.

Although both configurations demonstrated high effectiveness in reducing turbidity, the Dispersion Configuration produced better results with respect to the energy generated, contact time, zone of steady flow for floc settlement and lower maintenance requirements. Ultimately, the turbidity removal efficiency for each trial with the Dispersion Configuration was also the highest observed. The largest average turbidity removal efficiency attained in the field using the Dispersion Configuration was 97.0%. This occurred during a test run with a 16H:1V slope using A-2-4 soil. The lowest average turbidity removal efficiency was 64.8% which occurred at a 16H:1V slope using A-3 soil.

Lastly, an analysis aid was created using all the data for the chosen configuration to assist contractors and engineers when building a treatment channel with respect to floc log and baffle placement. Based on the volumetric flow rate and the slope desired, the aid employs the dimensions and soil desired for removal and provides guidance for a recommended treatment channel design. It is noted that due to the limited amount of data used in the creation of the analysis aid, there is a limitation on the recommended range of applicability. The analysis aid can also provide a predicted turbidity removal efficiency based upon the computed contact time, the primary soil type in solution that is being removed from the source water and the slope of the channel. Calculated removal efficiencies were compared to actual efficiencies attained during the field-scale testing. At a 95% confidence interval, there proved to be no significant difference between these two sets of values leading to the conclusion that the analysis aid was an effective and reliable predictor of treatment efficiencies within the given the range of applicability.

6.2 Recommendations

Suggestions for further study related to the behavior of polyacrylamide blocks within treatment channels are listed below.

Recommendations for Future Work

1.) More detailed dosage modeling should be conducted based on desired volumetric flow rate,
2.) Further research on the capacity of the collection mats to accumulate post-treatment floc should be conducted,
3.) The settling times for various floc particles should be studied using Stokes' law,
4.) Further studies on parameter variability to augment the analysis aid,
5.) The Dispersion Configuration should be tested for additional slopes and soil types,
6.) Toxicity testing of the water subsequent to polymer treatment should be conducted, and
7.) The solubility results for the APS 706b PAM block should be investigated. This will prove to be informative for passive situations when the PAM block is not being used for treatment, but fully saturated within its respective container.

Operational Recommendations

1.) Use a trapezoidal flume when modeling the configuration,
2.) Store blocks in a rectangular container that takes shape of block,
3.) Keep blocks inside when outside temperature is considerably hot,
4.) Use the water within the container as additional polymer for channel,
5.) Make a depression within the channel bed in attempt to provide resistive strength and seat the polymer, and
6.) Safety should be taken very seriously when implementing polyacrylamide blocks within a treatment channel. The surface is considerably slippery and falling accidents are prone to happen.

APPENDIX A
SOIL SIEVE ANALYSIS

Sieve Analysis

Description of soil: Poorly graded fine SAND (A3)

Sample No. 1

Mass of oven dry sample, *W* 684.37 g

Location: PAM Field Test

Tested by: Rafiq & Scott

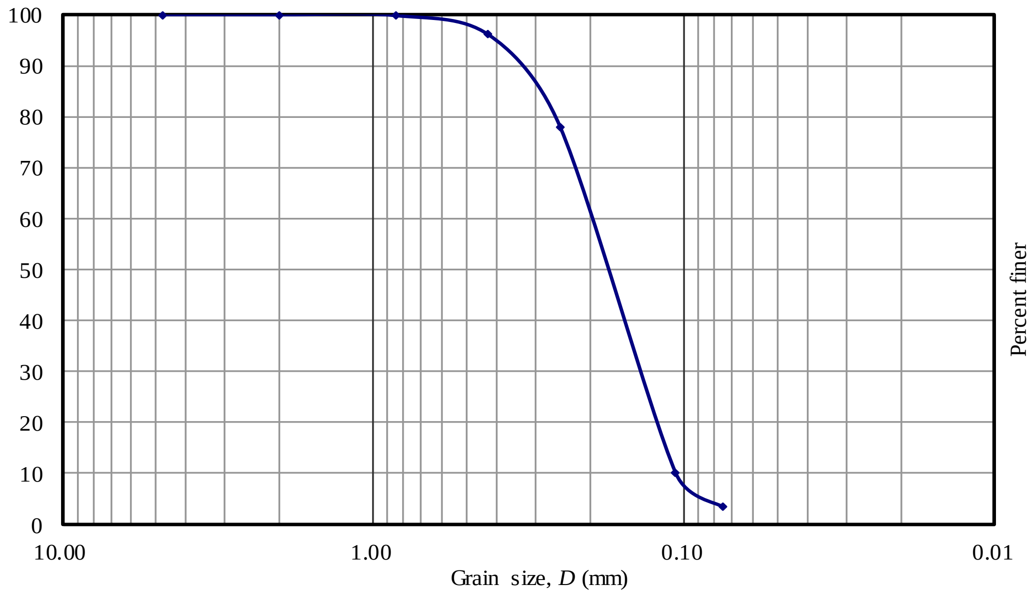
Date: January 28, 2011

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, $100 - \sum R_n$
4	4.750	0.1	0.0	0.0	100.0
10	2.000	0.1	0.0	0.0	100.0
20	0.850	1.1	0.2	0.2	99.8
40	0.425	25.9	3.8	4.0	96.0
60	0.250	123.7	18.1	22.0	78.0
140	0.106	465.0	67.9	90.0	10.0
200	0.075	44.7	6.5	96.5	3.5
Pan	--	23.8	3.479112176		

$W_1 = \sum$ 684.3 g

Mass loss during sieve analysis = $[(W - W_1) \div W] \times 100 =$ 0.01 % (OK if less than 2%)

Plot of percent finer vs. grain size (Sample: 1)



Determination of Particle Passing Sieve 200

Description of soil A-3 Sample No. 1

Location

Tested by Rafiqul Chowdhury Date January 28, 2011

Item	Test No. 1	Test No. 2	Test No. 3
Can No.	SW 10	SW 33	
Mass of can, W_1 (g)	49.61	50.25	
Mass of can + wet soil, W_2 (g)	100.05	101.65	
Mass of can + dry soil, W_3 (g)	96.78	98.32	
Mass of moisture, W_2 - W_3 (g)	3.27	3.33	
Mass of dry soil, W_3 - W_1 (g)	47.17	48.07	
Moisture content, w(%)	6.93	6.93	
Mass of can + washed soil, W_4 (g)	95.5	97.0	
Mass of washed soil, W_5 (g)	45.9	46.8	
Passing Sieve 200 (%)	2.8	2.7	
Average Passing Sieve 200 (%)	2.8		

Sieve Analysis

Description of soil A-2-4 (North Florida) Sample No. 1

Mass of oven dry sample, W 793.59 g

Location Stormwater Management Academy

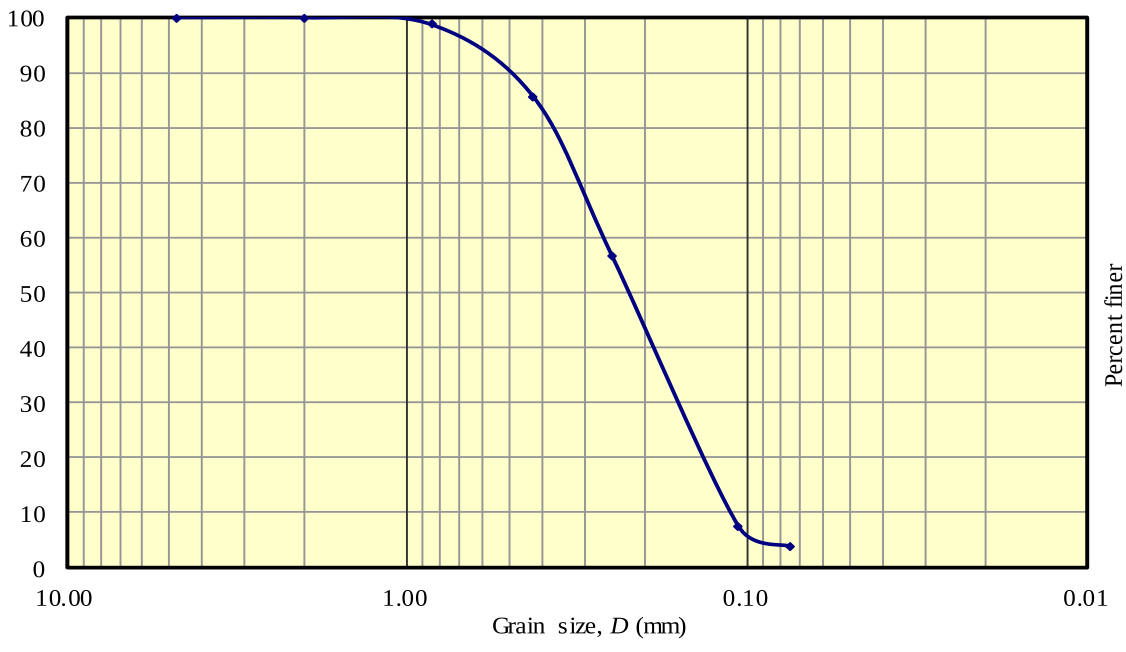
Tested by Rafiq Chowdhury Date January 28, 2011

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, $100 - \sum R_n$**
4	4.750	0.0	0.0	0.0	100.0
10	2.000	0.3	0.0	0.0	100.0
20	0.850	9.8	1.2	1.3	98.7
40	0.425	104.6	13.2	14.5	85.5
60	0.250	228.7	28.8	43.3	56.7
140	0.106	390.8	49.2	92.5	7.5
200	0.075	28.5	3.6	96.1	3.9
Pan	--	28.0	3.527010169		

$W_1 = \sum$ 790.7 g

Mass loss during sieve analysis = $[(W - W_1) \div W] \times 100 =$ 0.36 % (OK if less than 2%)

Plot of percent finer vs. grain size (Sample: 1)



Determination of Particle Passing Sieve 200

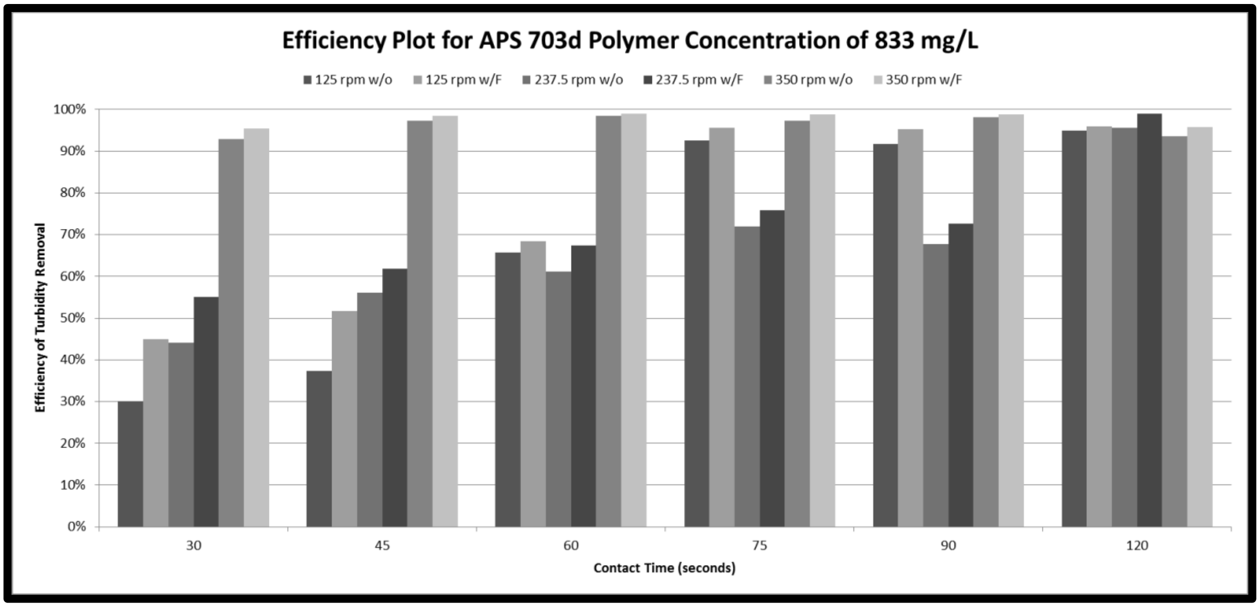
Description of soil: A-2-4 Sample No. 1

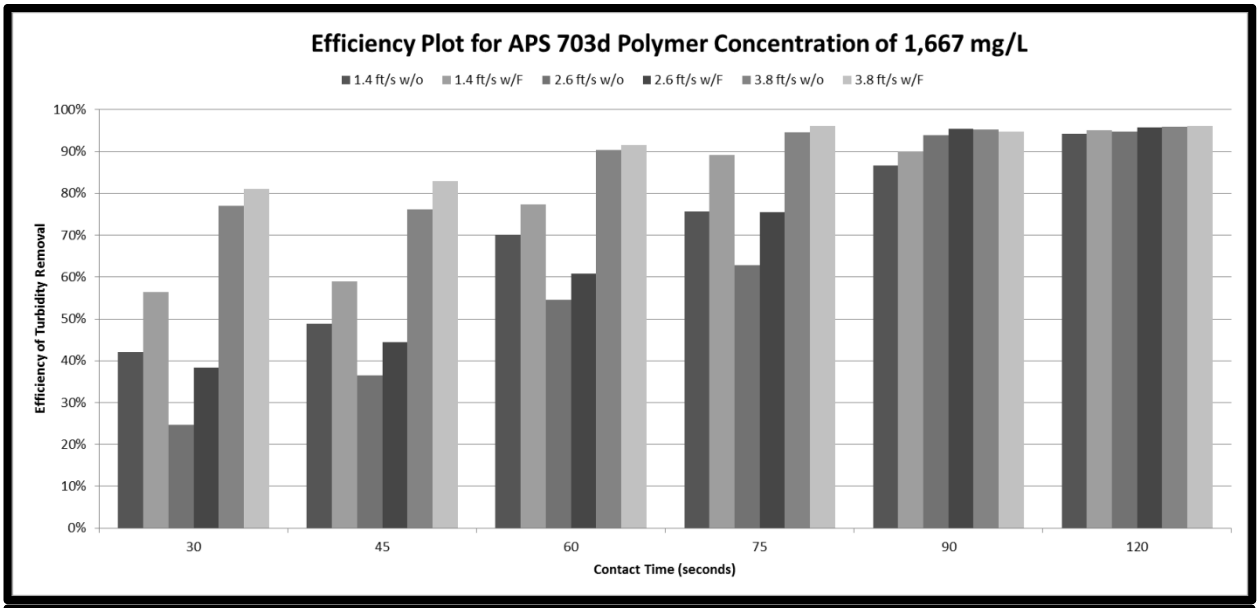
Location:

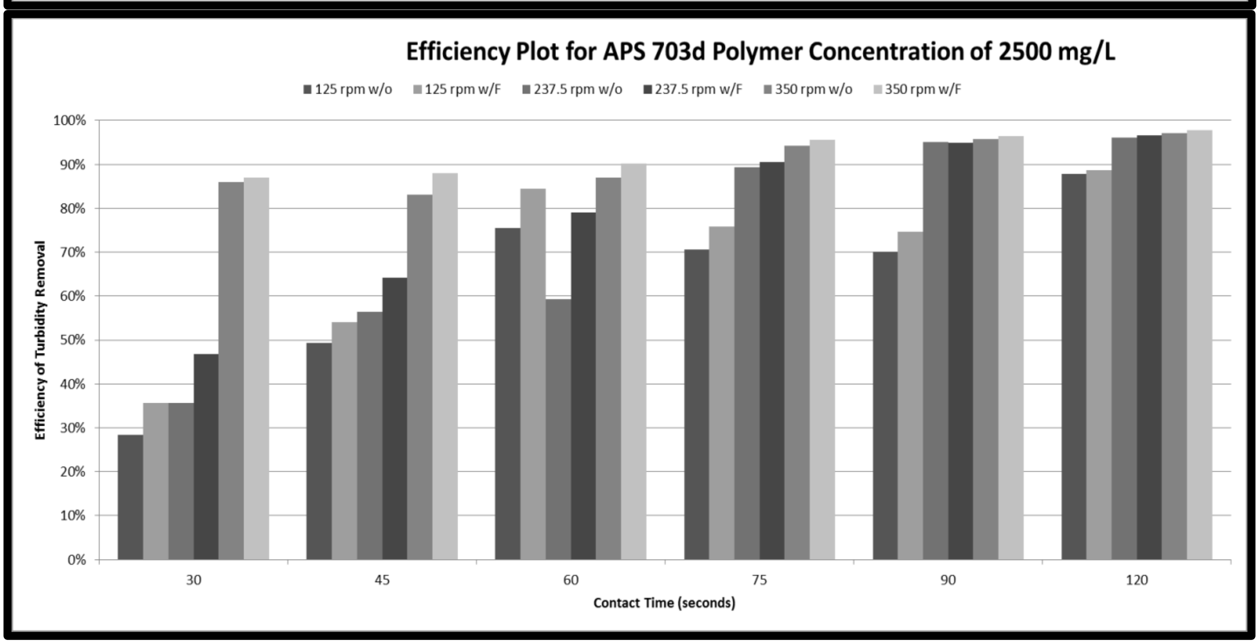
Tested by: Rafiq & Scott Date: January 28, 2011

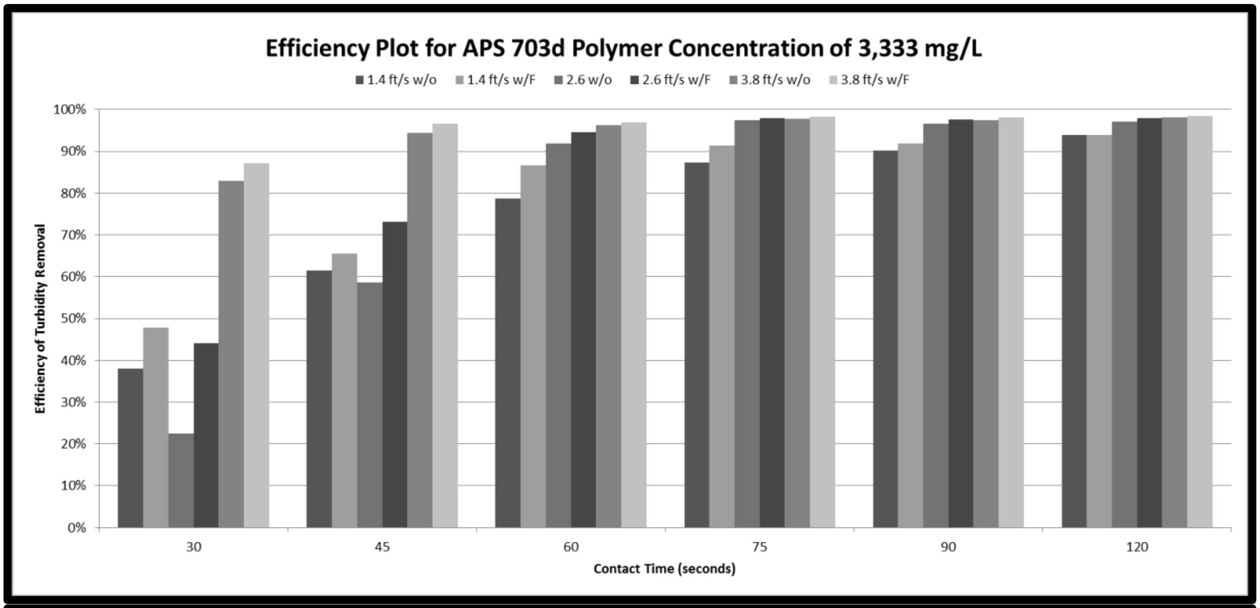
Item	Test No. 1	Test No. 2	Test No. 3
Can No.	SW 30	SW 35	
Mass of can, W_1 (g)	50.51	50.47	
Mass of can + wet soil, W_2 (g)	235.93	231.78	
Mass of can + dry soil, W_3 (g)	213.09	209.37	
Mass of moisture, W_2 - W_3 (g)	22.84	22.41	
Mass of dry soil, W_3 - W_1 (g)	162.58	158.9	
Moisture content, w(%)	14.05	14.10	
Mass of can + washed soil, W_4 (g)	184.9	183.5	
Mass of washed soil, W_5 (g)	134.4	133.0	
Passing Sieve 200 (%)	17.4	16.3	
Average Passing Sieve 200 (%)	16.8		

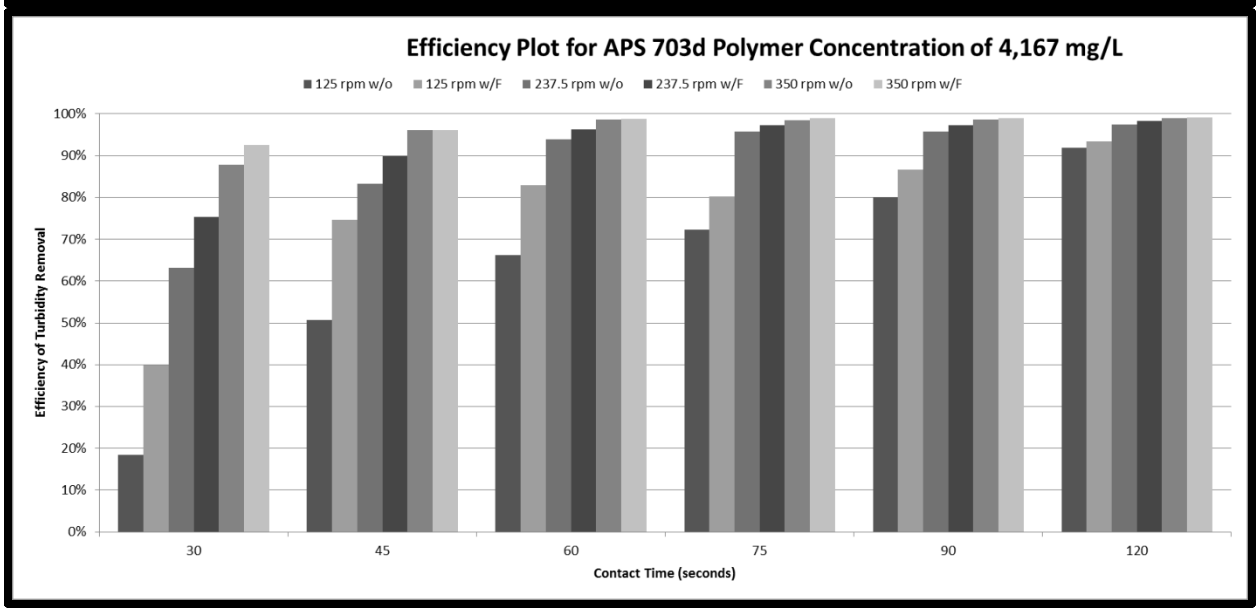
APPENDIX B
STORMWATER MANAGEMENT ACADEMY INDEX LABORATORY TESTING FOR POLYACRYLAMIDE

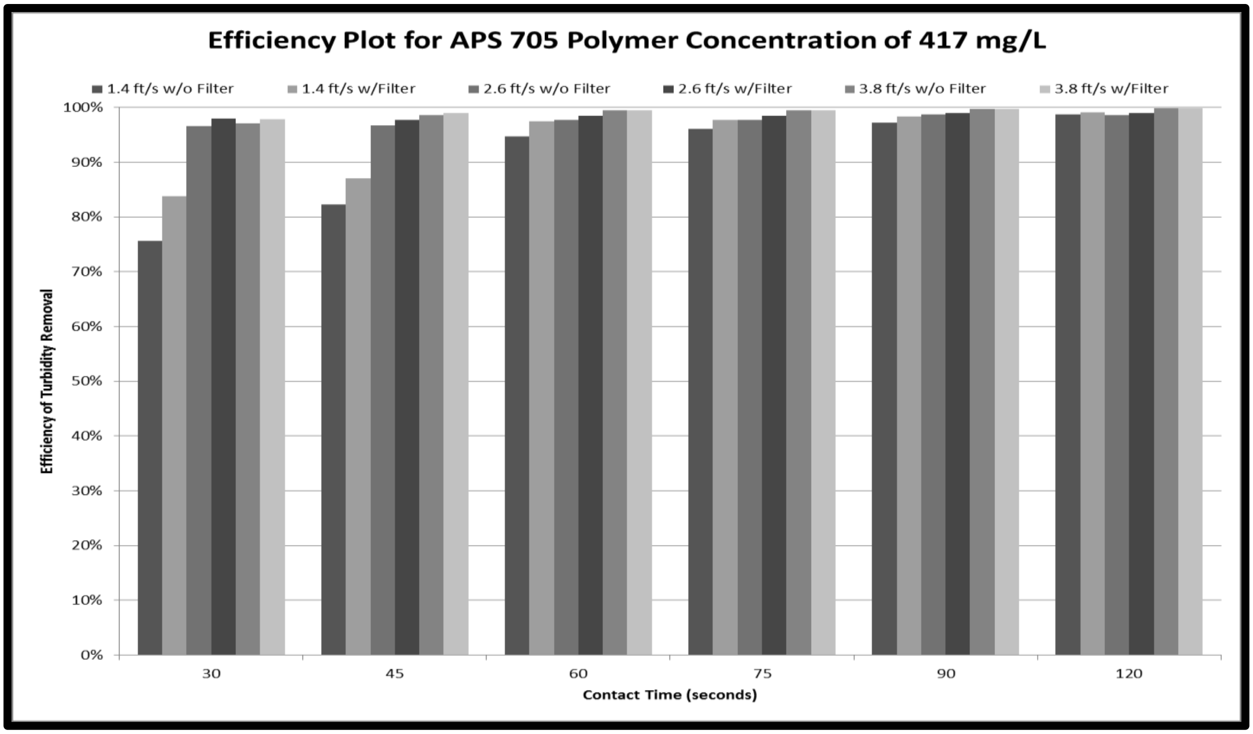

Efficiency Plot for APS 703d Polymer Concentration of 833 mg/L
125 rpm w/o
125 rpm w/F
237.5 rpm w/o
237.5 rpm w/F
350 rpm w/o
350 rpm w/F
Efficiency of Turbidity Removal
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
30
45
60
75
90
120
Contact Time (seconds)

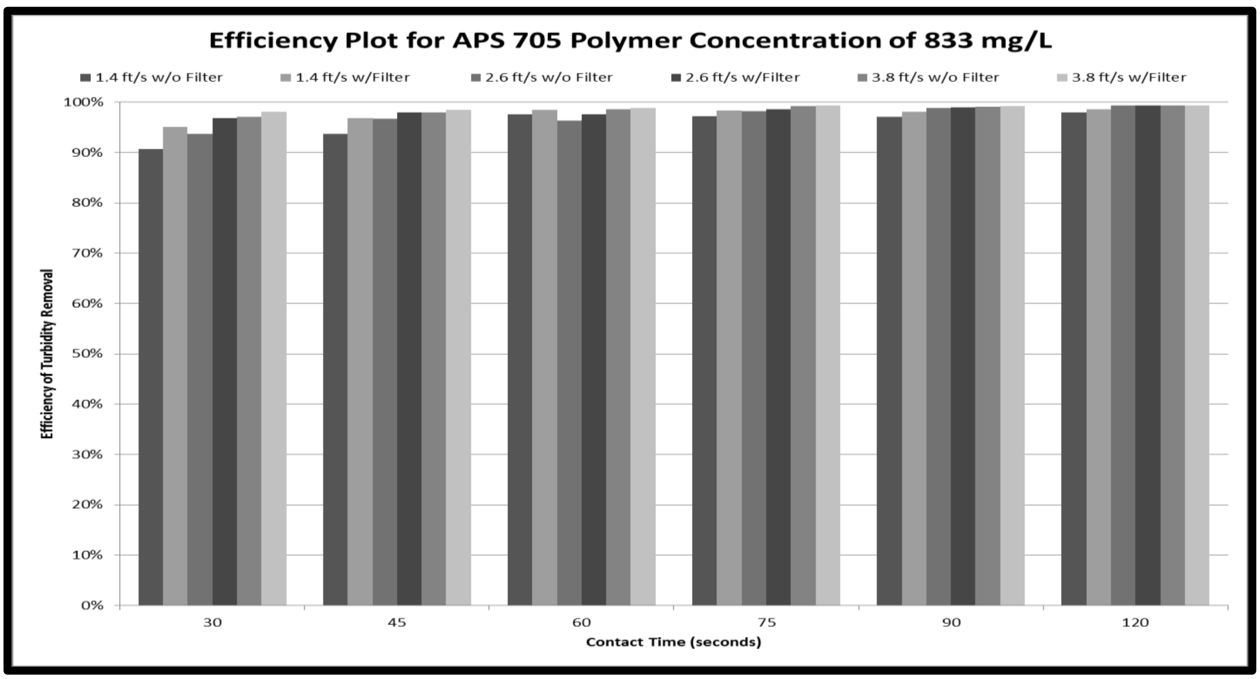

Efficiency Plot for APS 703d Polymer Concentration of 1,667 mg/L
1.4 ft/s w/o
1.4 ft/s w/F
2.6 ft/s w/o
2.6 ft/s w/F
3.8 ft/s w/o
3.8 ft/s w/F
Efficiency of Turbidity Removal
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
30
45
60
75
90
120
Contact Time (seconds)


Efficiency Plot for APS 703d Polymer Concentration of 2500 mg/L
125 rpm w/o
125 rpm w/F
237.5 rpm w/o
237.5 rpm w/F
350 rpm w/o
350 rpm w/F
Efficiency of Turbidity Removal
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
30
45
60
75
90
120
Contact Time (seconds)


Efficiency Plot for APS 703d Polymer Concentration of 3,333 mg/L
1.4 ft/s w/o
1.4 ft/s w/F
2.6 w/o
2.6 ft/s w/F
3.8 ft/s w/o
3.8 ft/s w/F
Efficiency of Turbidity Removal
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
30
45
60
75
90
120
Contact Time (seconds)


Efficiency Plot for APS 703d Polymer Concentration of 4,167 mg/L
125 rpm w/o
125 rpm w/F
237.5 rpm w/o
237.5 rpm w/F
350 rpm w/o
350 rpm w/F
Efficiency of Turbidity Removal
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
30
45
60
75
90
120
Contact Time (seconds)


Efficiency Plot for APS 705 Polymer Concentration of 417 mg/L
1.4 ft/s w/o Filter
1.4 ft/s w/Filter
2.6 ft/s w/o Filter
2.6 ft/s w/Filter
3.8 ft/s w/o Filter
3.8 ft/s w/Filter
Efficiency of Turbidity Removal
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
30
45
60
75
90
120
Contact Time (seconds)


Efficiency Plot for APS 705 Polymer Concentration of 833 mg/L
1.4 ft/s w/o Filter
1.4 ft/s w/Filter
2.6 ft/s w/o Filter
2.6 ft/s w/Filter
3.8 ft/s w/o Filter
3.8 ft/s w/Filter
Efficiency of Turbidity Removal
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
30
45
60
75
90
120
Contact Time (seconds)

APPENDIX C
HYDRAULIC FLUME DATA

JUMP CONFIGURATION

11/4/2010
Full Size PAM
Set Up No. 6 **Slope (%)** **12.5**

Distance from incoming water to Masonry Block (Upstream side):	**45 7/8**	in.
Distance from back of the masonry block to Masonry Blocks (upstream side):	**30 3/4**	in.
Distance from back of second masonry blocks to water re-capture:	**85 7/8**	in.
Back water depth of hydraulic jump taken from masonry block (upstream):	**12 1/2**	in.
Back water depth of 2nd Obstruction:	**15**	in.

I.D.	***Length from H_2O Entrance (in.)***	Average ***Distance/Length of Channel***	***Height (mm)***	***Height (ft)***	***V (fps)***	***Energy (ft.)***
1	20.5	0.12	6.83	0.0224	3.23	0.1848
2	45.25	0.27	59.33	0.1947	1.25	0.2189
3	51	0.30	14.17	0.0465	2.82	0.1697
$4a_l$	56.75	0.33	8.50	0.0279	1.93	0.0859
$4a_c$	56.75	0.33	11.83	0.0388	3.10	0.1880
$4a_r$	56.75	0.33	6.17	0.0202	1.60	0.0600
$4b_l$	59.75	0.35	9.00	0.0295	2.40	0.1190
$4b_c$	59.75	0.35	9.33	0.0306	3.37	0.2066
$4b_r$	59.75	0.35	4.00	0.0131	1.77	0.0616
$4c_l$	62.75	0.37	6.83	0.0224	2.98	0.1606
$4c_c$	62.75	0.37	9.17	0.0301	3.50	0.2203
$4c_r$	62.75	0.37	4.33	0.0142	1.92	0.0713
$4d_l$	65.75	0.39	6.00	0.0197	3.03	0.1626
$4d_c$	65.75	0.39	7.83	0.0257	3.70	0.2383
$4d_r$	65.75	0.39	4.83	0.0159	2.50	0.1129
5	81.75	0.48	70.67	0.2318	1.55	0.2692
6	84.25	0.49	39.83	0.1307	3.03	0.2736
7	107.375	0.63	5.33	0.0175	3.20	0.1765

11/3/2010
Full Size PAM
Set Up No. 5 **Slope (%)** **12.5**

Distance from incoming water to Masonry Block (Upstream side):	**45 7/8**	in.
Distance from back of the masonry block to Masonry Blocks (upstream side):	**48 7/8**	in.
Distance from back of second masonry blocks to water re-capture:	**67 7/8**	in.
Back water depth of hydraulic jump taken from masonry block (upstream):	**12 1/2**	in.
Back water depth of 2nd Obstruction:	**14 1/4**	in.

Average

I.D.	*Length from H_2O Entrance (in.)*	*Distance/Length of Channel*	*Height (mm)*	*Height (ft)*	*V (fps)*	*Energy (ft.)*
1	20.5	0.12	6.50	0.0213	3.13	0.1738
2	44	0.26	58.83	0.1930	1.22	0.2160
3	51.25	0.30	13.17	0.0432	2.77	0.1621
$4a_l$	56.5	0.33	7.50	0.0246	2.47	0.1191
$4a_c$	56.5	0.33	7.67	0.0252	3.30	0.1943
$4a_r$	56.5	0.33	4.33	0.0142	1.60	0.0540
$4b_l$	62.5	0.37	5.58	0.0183	3.10	0.1675
$4b_c$	62.5	0.37	7.00	0.0230	3.67	0.2317
$4b_r$	62.5	0.37	4.67	0.0153	2.07	0.0816
$4c_l$	68.5	0.40	4.83	0.0159	2.87	0.1435
$4c_c$	68.5	0.40	6.17	0.0202	3.63	0.2252
$4c_r$	68.5	0.40	4.50	0.0148	2.73	0.1308
$4d_l$	74.5	0.44	5.33	0.0175	2.70	0.1307
$4d_c$	74.5	0.44	5.50	0.0180	3.07	0.1641
$4d_r$	74.5	0.44	4.67	0.0153	2.60	0.1203
$4e_l$	80.5	0.47	7.00	0.0230	3.53	0.2168
$4e_c$	80.5	0.47	5.08	0.0167	2.57	0.1190
$4e_r$	80.5	0.47	5.00	0.0164	2.60	0.1214
5	100	0.59	73.17	0.2400	1.10	0.2588
6	102.5	0.60	39.83	0.1307	3.00	0.2704
7	170.5	1.00	5.50	0.0180	3.15	0.1721

11/5/2010
Full Size PAM
Set Up No. 5 **Slope (%)** **12.5**

Distance from incoming water to Masonry Block (Upstream side):	**45 7/8**	in.
Distance from back of the masonry block to Masonry Blocks (upstream side):	**67**	in.
Distance from back of second masonry blocks to water re-capture:	**49 7/8**	in.
Back water depth of hydraulic jump taken from masonry block (upstream):	**12 1/2**	in.
Back water depth of 2nd Obstruction:	**13 7/8**	in.

I.D.	*Length from H_2O Entrance (in.)*	Average *Distance/Length of Channel*	*Height (mm)*	*Height (ft)*	*V (fps)*	*Energy (ft.)*
1	20.5	0.12	6.50	0.0213	3.08	0.1689
2	44	0.26	59.00	0.1936	1.13	0.2135
3	51.25	0.30	12.00	0.0394	2.72	0.1540
$4a_l$	59.75	0.35	6.33	0.0208	2.98	0.1590
$4a_c$	59.75	0.35	8.33	0.0273	3.55	0.2230
$4a_r$	59.75	0.35	4.83	0.0159	1.85	0.0690
$4b_l$	68.75	0.40	4.17	0.0137	2.55	0.1146
$4b_c$	68.75	0.40	6.33	0.0208	3.60	0.2220
$4b_r$	68.75	0.40	5.00	0.0164	2.92	0.1485
$4c_l$	77.75	0.46	7.33	0.0241	3.40	0.2036
$4c_c$	77.75	0.46	5.00	0.0164	2.72	0.1310
$4c_r$	77.75	0.46	4.67	0.0153	2.70	0.1285
$4d_l$	85.875	0.50	6.83	0.0224	3.57	0.2200
$4d_c$	85.875	0.50	4.50	0.0148	2.20	0.0899
$4d_r$	85.875	0.50	6.00	0.0197	2.93	0.1533
$4e_l$	98.6875	0.58	6.00	0.0197	3.42	0.2010
$4e_c$	98.6875	0.58	5.83	0.0191	2.93	0.1527
$4e_r$	98.6875	0.58	5.33	0.0175	3.08	0.1651
5	117.75	0.69	72.00	0.2362	1.55	0.2735
6	120.25	0.71	39.00	0.1280	2.95	0.2631
7	170.5	1.00	6.83	0.0224	3.37	0.1984

11/4/2010
Full Size PAM
Set Up No. 6 **Slope (%)** **12.5**

Distance from incoming water to Masonry Block (Upstream side):	**45 7/8**	in.
Distance from back of the masonry block to Masonry Blocks (upstream side):	**79**	in.
Distance from back of second masonry blocks to water re-capture:	**37 7/8**	in.
Back water depth of hydraulic jump taken from masonry block (upstream):	**12 3/8**	in.
Back water depth of 2nd Obstruction:	**14 1/4**	in.

1 of 1

I.D.	*Length from H_2O Entrance (in.)*	*Distance/Length of Channel*	*Height (mm)*	*Height (ft)*	*V (fps)*	*Energy (ft.)*
1	20.5	0.12	6	0.0197	3.2	0.17869
2	44.5	0.26	59	0.1936	1.3	0.21981
3	51	0.30	12.5	0.0410	2.9	0.17160
$4a_l$	56.875	0.33	6	0.0197	1.4	0.05012
$4a_c$	56.875	0.33	10	0.0328	3.3	0.20191
$4a_r$	56.875	0.33	4	0.0131	0.8	0.02306
$4b_l$	68.875	0.40	9	0.0295	3	0.16928
$4b_c$	68.875	0.40	6.5	0.0213	3.6	0.22257
$4b_r$	68.875	0.40	6.75	0.0221	2.6	0.12711
$4c_l$	80.875	0.47	6	0.0197	3.5	0.20990
$4c_c$	80.875	0.47	5	0.0164	2.5	0.11345
$4c_r$	80.875	0.47	9	0.0295	3.3	0.19863
$4d_l$	92.875	0.54	5.5	0.0180	3.4	0.19755
$4d_c$	92.875	0.54	5.5	0.0180	2.9	0.14863
$4d_r$	92.875	0.54	7.5	0.0246	3.4	0.20411
$4e_l$	104.875	0.62	5.5	0.0180	3.3	0.18714
$4e_c$	104.875	0.62	7.5	0.0246	3.4	0.20411
$4e_r$	104.875	0.62	6.5	0.0213	2.8	0.14306
5	130	0.76	73.5	0.2411	1.4	0.27158
6	132.5	0.78	47	0.1542	2.8	0.27594
7	170.5	1.00	7	0.0230	2.9	0.15356

DISPERSION CONFIGURATION

11/15/2010
Full Size PAM
Set Up No. : **Slope (%)** **12.5**

X_1	**46**	in.
X_2	**27 1/4**	in.
X_3	**33 1/2**	
Distance from back of 3rd Obstruction to water re-capture:	**55 1/2**	in.
Back water depth of hydraulic jump taken from center obstruction:	**14 1/2**	in.

I.D.	*Length from H_2O Entrance (in.)*	*Distance/Channel Length*	Average *Height (mm)*	*Height (ft)*	*Height S.D.*	*V (fps)*	*Velocity S.D.*	*Energy (ft.)*
1	21	0.12	7.0	0.0230	0.00	3.2	0.00	0.1820
2	47.5	0.28	18.7	0.0612	0.76	1.9	0.06	0.1193
3	47.5	0.28	18.2	0.0596	0.76	2.3	0.06	0.1394
$4a_l$	51.5	0.30	5.2	0.0170	0.29	1.5	0.15	0.0504
$4a_c$	51.5	0.30	3.3	0.0109	0.29	0.2	0.10	0.0116
$4a_r$	51.5	0.30	4.0	0.0131	0.00	1.7	0.00	0.0580
$4b_l$	55.5	0.33	8.2	0.0268	0.29	2.2	0.32	0.0997
$4b_c$	55.5	0.33	4.2	0.0137	0.29	0.3	0.15	0.0154
$4b_r$	55.5	0.33	9.2	0.0301	0.29	1.6	0.20	0.0698
$4c_l$	59.5	0.35	5.8	0.0191	0.29	2.8	0.17	0.1409
$4c_c$	59.5	0.35	12.5	0.0410	0.50	1.0	0.23	0.0555
$4c_r$	59.5	0.35	7.8	0.0257	0.29	2.8	0.20	0.1474
$4d_l$								
$4d_c$								
$4d_r$								
$4e_l$								
$4e_c$								
$4e_r$								
5	76.25	0.45	70.8	0.2324	0.76	1.9	0.00	0.2884
6	78.75	0.46	41.7	0.1367	1.53	2.9	0.10	0.2673
$7a_l$	84.65	0.50	7.2	0.0235	0.29	1.3	0.06	0.0484
$7a_c$	84.65	0.50	7.0	0.0230	0.00	3.2	0.15	0.1787
$7a_r$	84.65	0.50	6.8	0.0224	0.29	2.5	0.15	0.1169
$7b_l$	90.55	0.53	3.7	0.0120	0.29	1.0	0.46	0.0265
$7b_c$	90.55	0.53	3.7	0.0120	0.29	1.9	0.12	0.0701
$7b_r$	90.55	0.53	4.0	0.0131	0.00	2.0	0.06	0.0773
$7c_l$	96.45	0.57	7.7	0.0252	0.58	3.1	0.06	0.1776
$7c_c$	96.45	0.57	3.0	0.0098	0.00	1.1	0.10	0.0286
$7c_r$	96.45	0.57	4.7	0.0153	0.29	2.3	0.25	0.0951
$7d_l$	102.35	0.60	7.2	0.0235	0.29	3.2	0.21	0.1858
$7d_c$	102.35	0.60	3.0	0.0098	0.00	0.8	0.12	0.0206
$7d_r$	102.35	0.60	6.8	0.0224	0.29	3.1	0.15	0.1749
$7e_l$	108.25	0.63	6.0	0.0197	0.50	3.4	0.06	0.1957
$7e_c$	108.25	0.63	7.0	0.0230	0.00	0.7	0.10	0.0306
$7e_r$	108.25	0.63	6.0	0.0197	0.00	3.1	0.15	0.1721
8	112.25	0.66	23.3	0.0766	1.53	2.3	0.35	0.1611
9	112.25	0.66	20.7	0.0678	1.53	2.3	0.06	0.1476
10	170.5	1.00	5.3	0.0175	0.58	2.9	0.21	0.1511

11/15/2010
Full Size PAM
Set Up No. 2 **Slope (%)** **12.5**

X_1	**46**	in.
X_2	**33 1/2**	in.
X_3	**39 3/4**	in.
Distance from back of 3rd Obstruction to water re-capture:	**43 1/2**	in.
Back water depth of hydraulic jump taken from center obstruction:	**14 3/4**	in.

I.D.	*Length from H_2O Entrance (in.)*	*Distance/Channel Length*	Average *Height (mm)*	*Height (ft)*	*Height S.D.*	*V (fps)*	*Velocity S.D.*	*Energy (ft.)*
1	21	0.12	6.58	0.0216	0.14	3.2	0.00	0.1806
2	47.5	0.28	16.33	0.0536	2.08	2.0	0.06	0.1136
3	47.5	0.28	16.83	0.0552	2.02	2.4	0.21	0.1422
$4a_l$	51.2	0.30	9.83	0.0323	0.76	1.4	0.15	0.0613
$4a_c$	51.2	0.30	3.00	0.0098	0.00	0.2	0.06	0.0103
$4a_r$	51.2	0.30	7.50	0.0246	4.77	1.4	0.06	0.0565
$4b_l$	54.9	0.32	10.00	0.0328	0.50	2.0	0.42	0.0970
$4b_c$	54.9	0.32	4.33	0.0142	0.58	0.4	0.12	0.0163
$4b_r$	54.9	0.32	9.17	0.0301	4.07	1.7	0.06	0.0732
$4c_l$	58.6	0.34	7.17	0.0235	0.29	3.3	0.06	0.1892
$4c_c$	58.6	0.34	10.00	0.0328	1.00	0.6	0.06	0.0378
$4c_r$	58.6	0.34	9.00	0.0295	0.00	2.2	0.10	0.1047
$4d_l$	62.3	0.37	6.50	0.0213	0.50	3.0	0.10	0.1611
$4d_c$	62.3	0.37	13.33	0.0437	2.08	2.0	0.00	0.1059
$4d_r$	62.3	0.37	7.00	0.0230	0.87	3.0	0.06	0.1658
$4e_l$	66	0.39	4.67	0.0153	0.29	2.7	0.10	0.1285
$4e_c$	66	0.39	13.33	0.0437	0.29	2.5	0.10	0.1408
$4e_r$	66	0.39	5.83	0.0191	0.29	3.1	0.15	0.1716
5	82.25	0.48	70.17	0.2302	1.26	2.0	0.10	0.2923
6	84.75	0.50	48.83	0.1602	0.29	2.9	0.10	0.2908
$7a_l$	92.05	0.54	4.67	0.0153	0.29	0.4	0.12	0.0182
$7a_c$	92.05	0.54	5.17	0.0170	0.29	3.3	0.12	0.1827
$7a_r$	92.05	0.54	4.67	0.0153	0.58	2.9	0.17	0.1459
$7b_l$	99.35	0.58	4.17	0.0137	0.76	1.2	0.12	0.0373
$7b_c$	99.35	0.58	3.00	0.0098	0.00	1.7	0.15	0.0530
$7b_r$	99.35	0.58	3.50	0.0115	0.50	1.7	0.12	0.0581
$7c_l$	106.65	0.63	8.33	0.0273	0.58	3.3	0.06	0.1999
$7c_c$	106.65	0.63	3.17	0.0104	0.29	1.0	0.06	0.0249
$7c_r$	106.65	0.63	7.83	0.0257	0.29	2.9	0.15	0.1593
$7d_l$	113.95	0.67	6.33	0.0208	0.58	3.3	0.12	0.1933
$7d_c$	113.95	0.67	9.67	0.0317	0.58	2.3	0.00	0.1139
$7d_r$	113.95	0.67	6.33	0.0208	0.29	3.3	0.06	0.1933
$7e_l$	121.25	0.71	6.00	0.0197	0.50	3.2	0.00	0.1787
$7e_c$	121.25	0.71	9.50	0.0312	1.32	3.0	0.00	0.1709
$7e_r$	121.25	0.71	5.67	0.0186	0.58	3.0	0.00	0.1583
8	125.5	0.74	16.00	0.0525	1.00	2.2	0.12	0.1254
9	125.5	0.74	19.83	0.0651	0.76	2.2	0.06	0.1425
10	170.5	1.00	6.17	0.0202	0.29	3.2	0.10	0.1792

11/15/2010
Full Size PAM
Set Up No. 2 **Slope (%)** **12.5**

X_1	**46**	in.
X_2	**45 1/4**	in.
X_3	**27 3/4**	in.
Distance from back of 3rd Obstruction to water re-capture:	**43 1/2**	in.
Back water depth of hydraulic jump taken from center obstruction:	**14 3/4**	in.

I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Average Height (mm)***	***Height (ft)***	***Height S.D.***	***V (fps)***	***Velocity S.D.***	***Energy (ft.)***
1	21	0.12	6.33	0.0208	0.29	3.2	0.00	0.1798
2	47.5	0.28	18.67	0.0612	0.58	2.0	0.00	0.1234
3	47.5	0.28	20.50	0.0673	0.50	2.3	0.06	0.1518
$4a_l$	53.7	0.31	6.83	0.0224	0.76	1.6	0.15	0.0605
$4a_c$	53.7	0.31	4.50	0.0148	0.50	0.3	0.06	0.0159
$4a_r$	53.7	0.31	10.50	0.0344	1.32	1.9	0.30	0.0905
$4b_l$	59.9	0.35	6.50	0.0213	0.50	3.2	0.10	0.0605
$4b_c$	59.9	0.35	13.83	0.0454	1.04	1.5	0.25	0.0819
$4b_r$	59.9	0.35	8.33	0.0273	0.58	2.8	0.21	0.1462
$4c_l$	66.1	0.39	4.67	0.0153	0.29	2.5	0.06	0.1150
$4c_c$	66.1	0.39	13.17	0.0432	0.29	2.6	0.10	0.1482
$4c_r$	66.1	0.39	6.00	0.0197	0.00	3.0	0.06	0.1626
$4d_l$	72.3	0.42	4.83	0.0159	0.76	2.0	0.06	0.0759
$4d_c$	72.3	0.42	10.50	0.0344	0.50	3.2	0.10	0.1935
$4d_r$	72.3	0.42	5.50	0.0180	0.50	2.7	0.06	0.1341
$4e_l$	84.7	0.50	8.33	0.0273	1.53	3.0	0.10	0.1671
$4e_c$	84.7	0.50	8.00	0.0262	0.50	3.7	0.06	0.2427
$4e_r$	84.7	0.50	7.83	0.0257	0.29	3.1	0.59	0.1717
5	94.25	0.55	74.17	0.2433	1.04	1.8	0.15	0.2955
6	96.75	0.57	52.00	0.1706	1.00	2.9	0.06	0.3042
$7a_l$	101.15	0.59	13.00	0.0427	1.32	1.1	0.23	0.0626
$7a_c$	101.15	0.59	9.67	0.0317	0.29	3.2	0.21	0.1941
$7a_r$	101.15	0.59	7.00	0.0230	0.50	2.6	0.26	0.1279
$7b_l$	105.55	0.62	9.33	0.0306	3.21	1.1	0.06	0.0483
$7b_c$	105.55	0.62	4.67	0.0153	0.29	2.7	0.06	0.1257
$7b_r$	105.55	0.62	4.33	0.0142	0.29	2.4	0.06	0.1062
$7c_l$	109.95	0.64	4.33	0.0142	0.58	1.5	0.00	0.0492
$7c_c$	109.95	0.64	3.83	0.0126	0.29	1.9	0.10	0.0686
$7c_r$	109.95	0.64	3.33	0.0109	0.29	1.8	0.06	0.0631
$7d_l$	114.35	0.67	9.67	0.0317	0.58	1.8	0.25	0.0839
$7d_c$	114.35	0.67	3.17	0.0104	0.29	1.3	0.10	0.0366
$7d_r$	114.35	0.67	8.33	0.0273	0.58	2.2	0.29	0.1048
$7e_l$	118.75	0.70	7.17	0.0235	0.29	3.4	0.10	0.2030
$7e_c$	118.75	0.70	3.00	0.0098	0.00	0.2	0.06	0.0107
$7e_r$	118.75	0.70	7.83	0.0257	0.29	2.9	0.32	0.1533
8	125.25	0.73	19.25	0.0632	0.66	2.9	0.10	0.1937
9	125.25	0.73	18.50	0.0607	0.50	2.8	0.06	0.1854
10	170.5	1.00	6.67	0.0219	0.29	3.6	0.25	0.2194

11/12/2010
Full Size PAM
Set Up No. 1 **Slope (%)** **12.5**

X_1	**46**	in.
X_2	**45 1/4**	in.
X_3	**39 1/4**	
Distance from back of 3rd Obstruction to water re-capture:	**31 3/4**	in.
Back water depth of hydraulic jump taken from center obstruction:	**14 1/2**	in.

I.D.	*Length from H_2O Entrance (in.)*	*Distance/Channel Length*	Average *Height (mm)*	*Height (ft)*	*Height S.D.*	*V (fps)*	*Velocity S.D.*	*Energy (ft.)*
1	21	0.12	6.5	0.0213	0.50	3.2	0.00	0.1803
2	47.5	0.28	18.7	0.0612	4.16	2.4	0.21	0.1507
3	47.5	0.28	18.5	0.0607	2.78	2.2	0.07	0.1336
$4a_l$	54	0.32	9.3	0.0306	4.25	1.3	0.28	0.0569
$4a_c$	54	0.32	2.7	0.0087	0.76	0.1	0.07	0.0090
$4a_r$	54	0.32	8.0	0.0262	4.00	1.6	0.07	0.0660
$4b_l$	60	0.35	5.3	0.0175	0.58	3.0	0.07	0.1604
$4b_c$	60	0.35	10.3	0.0339	4.51	0.9	0.00	0.0474
$4b_r$	60	0.35	7.7	0.0252	0.76	2.3	0.14	0.1049
$4c_l$	66	0.39	4.2	0.0137	0.76	2.3	0.07	0.0958
$4c_c$	66	0.39	11.2	0.0366	0.29	2.4	0.00	0.1261
$4c_r$	66	0.39	4.5	0.0148	0.50	3.1	0.21	0.1640
$4d_l$	72	0.42	4.7	0.0153	1.61	2.0	0.07	0.0774
$4d_c$	72	0.42	9.0	0.0295	0.50	3.0	0.00	0.1724
$4d_r$	72	0.42	4.7	0.0153	0.58	2.6	0.28	0.1203
$4e_l$	78	0.46	5.5	0.0180	1.00	2.3	0.64	0.1002
$4e_c$	78	0.46	8.3	0.0273	0.58	3.6	0.00	0.2323
$4e_r$	78	0.46	7.3	0.0241	0.29	2.8	0.14	0.1458
5	94.25	0.55	76.5	0.2510	1.32	1.7	0.00	0.2941
6	97.25	0.57	46.8	0.1537	0.29	2.8	0.00	0.2783
$7a_l$	103.4	0.61	3.8	0.0126	1.44	0.4	0.28	0.0147
$7a_c$	103.4	0.61	5.3	0.0175	0.58	3.4	0.14	0.1935
$7a_r$	103.4	0.61	3.2	0.0104	0.76	2.3	0.00	0.0949
$7b_l$	110.55	0.65	2.8	0.0093	1.04	1.2	0.07	0.0317
$7b_c$	110.55	0.65	3.3	0.0109	1.04	1.8	0.21	0.0594
$7b_r$	110.55	0.65	2.3	0.0077	0.76	1.8	0.07	0.0561
$7c_l$	117.7	0.69	6.5	0.0213	0.00	3.4	0.14	0.2008
$7c_c$	117.7	0.69	3.2	0.0104	0.29	0.9	0.00	0.0230
$7c_r$	117.7	0.69	6.2	0.0202	0.29	3.1	0.00	0.1663
$7d_l$	124.85	0.73	6.2	0.0202	0.29	3.2	0.07	0.1759
$7d_c$	124.85	0.73	7.0	0.0230	1.00	2.2	0.00	0.1004
$7d_r$	124.85	0.73	5.2	0.0170	0.76	3.1	0.14	0.1662
$7e_l$	132	0.77	5.5	0.0180	0.50	3.0	0.00	0.1578
$7e_c$	132	0.77	7.3	0.0241	1.04	3.1	0.07	0.1733
$7e_r$	132	0.77	4.2	0.0137	0.29	3.0	0.07	0.1565
8	138	0.81	14.3	0.0470	0.58	2.0	0.07	0.1112
9	138	0.81	15.3	0.0503	0.29	2.0	0.14	0.1145
10	170.5	1.00	6.7	0.0219	0.29	3.7	0.04	0.2287

11/15/2010
Full Size PAM
Set Up No. 2 **Slope (%)** **12.5**

X_1	**46**	in.
X_2	**57 1/2**	in.
X_3	**45 3/4**	in.
Distance from back of 3rd Obstruction to water re-capture:	**13 1/2**	in.
Back water depth of hydraulic jump taken from center obstruction:	**14 3/4**	in.

I.D.	*Length from H_2O Entrance (in.)*	*Distance/Length of Channel*	Average *Height (mm)*	*Height (ft)*	*Height S.D.*	*V (fps)*	*Velocity S.D.*	*Energy (ft.)*
1	21	0.12	6.5	0.0213	0.50	3.2	0.00	0.1803
2	47.5	0.28	13.2	0.0432	1.26	2.1	0.17	0.1117
3	47.5	0.28	16.8	0.0552	6.33	2.4	0.15	0.1472
$4a_l$	55.9	0.33	10.3	0.0339	2.18	1.8	0.32	0.0824
$4a_c$	55.9	0.33	4.5	0.0148	1.32	0.3	0.06	0.0159
$4a_r$	55.9	0.33	11.0	0.0361	6.24	1.2	0.29	0.0572
$4b_l$	64.3	0.38	7.3	0.0241	4.04	2.8	0.10	0.1458
$4b_c$	64.3	0.38	16.2	0.0530	2.47	2.0	0.00	0.1152
$4b_r$	64.3	0.38	7.0	0.0230	0.00	2.9	0.10	0.1536
$4c_l$	72.7	0.43	4.3	0.0142	0.58	2.0	0.06	0.0784
$4c_c$	72.7	0.43	10.9	0.0358	0.88	2.9	0.15	0.1634
$4c_r$	72.7	0.43	4.8	0.0159	0.29	2.5	0.10	0.1129
$4d_l$	81.1	0.48	7.2	0.0235	0.29	3.0	0.12	0.1664
$4d_c$	81.1	0.48	8.0	0.0262	0.00	3.6	0.00	0.2275
$4d_r$	81.1	0.48	8.0	0.0262	0.50	3.4	0.20	0.2057
$4e_l$	89.5	0.52	6.5	0.0213	0.00	3.0	0.06	0.1580
$4e_c$	89.5	0.52	6.5	0.0213	0.50	3.4	0.15	0.2044
$4e_r$	89.5	0.52	6.7	0.0219	0.58	3.6	0.10	0.2231
5	105.5	0.62	71.3	0.2340	0.29	1.6	0.12	0.2755
6	109	0.64	42.0	0.1378	1.80	2.9	0.10	0.2684
$7a_l$	117.5	0.69	7.3	0.0241	1.89	2.0	0.06	0.0883
$7a_c$	117.5	0.69	4.5	0.0148	0.00	2.6	0.06	0.1224
$7a_r$	117.5	0.69	4.2	0.0137	0.58	2.2	0.15	0.0866
$7b_l$	126	0.74	8.8	0.0290	1.04	2.5	0.44	0.1260
$7b_c$	126	0.74	3.2	0.0104	0.29	1.0	0.00	0.0259
$7b_r$	126	0.74	5.8	0.0191	2.36	2.1	0.40	0.0855
$7c_l$	134.5	0.79	6.8	0.0224	1.04	3.6	0.26	0.2237
$7c_c$	134.5	0.79	3.3	0.0109	0.76	0.8	0.26	0.0209
$7c_r$	134.5	0.79	6.7	0.0219	0.58	3.0	0.21	0.1647
$7d_l$	143	0.84	5.7	0.0186	0.76	3.2	0.00	0.1776
$7d_c$	143	0.84	8.3	0.0273	0.58	2.9	0.17	0.1579
$7d_r$	143	0.84	5.2	0.0170	0.76	2.9	0.12	0.1506
$7e_l$	151.5	0.89	5.0	0.0164	0.00	3.0	0.15	0.1531
$7e_c$	151.5	0.89	7.8	0.0257	0.76	3.2	0.00	0.1847
$7e_r$	151.5	0.89	5.0	0.0164	0.00	2.6	0.21	0.1187
8	156	0.91	18.7	0.0612	0.58	2.1	0.15	0.1319
9	156	0.91	16.2	0.0530	1.04	2.1	0.12	0.1194
10	170.5	1.00	14.5	0.0476	0.87	2.4	0.06	0.1395

STAGGERED CONFIGURATION

11/17/2010
Full Size PAM
Set Up No. 2 **Slope (%)** **12.5**

X_1	**46**	in.
X_2	**9**	in.
X_3	**9**	in.
X_4	**9**	in.
Distance from back of 4th Obstruction to water re-capture:	**85 3/4**	in.

I.D.	*Length from H_2O Entrance (in.)*	*Distance/Length of Channel*	Average *Height (mm)*	*Height S.D.*	*Height (ft)*	*V (fps)*	*Velocity S.D.*	*Energy (ft.)*
1	21	0.12	6.7	0.3	0.0219	3.2	0.0	**0.1809**
2	44.25	0.26	57.8	1.4	0.1897	0.4	0.1	**0.1918**
3a	47.5	0.28	18.3	0.6	0.0601	2.0	0.2	**0.1243**
3b	47.5	0.28	20.7	0.6	0.0678	2.5	0.2	**0.1649**
4a	52.5	0.31	19.7	0.3	0.0645	0.2	0.1	**0.0651**
4b	52.5	0.31	18.3	0.6	0.0601	1.1	0.1	**0.0778**
4c	52.5	0.31	23.5	1.8	0.0771	1.7	0.1	**0.1220**
5a	54.5	0.32	24.7	0.6	0.0809	0.1	0.1	**0.0812**
5b	54.5	0.32	31.3	0.6	0.1028	0.8	0.2	**0.1127**
5c	54.5	0.32	38.7	0.6	0.1269	1.1	0.1	**0.1456**
6	57.25	0.34	62.8	0.8	0.2061	0.5	0.1	**0.2106**
7a	59.75	0.35	34.0	1.0	0.1115	1.9	0.1	**0.1696**
7b	59.75	0.35	7.7	0.6	0.0252	1.6	0.2	**0.0633**
8a	63	0.37	14.0	1.0	0.0459	1.5	0.4	**0.0793**
8b	63	0.37	15.7	0.6	0.0514	1.0	0.1	**0.0680**
8c	63	0.37	14.8	1.3	0.0487	0.2	0.1	**0.0495**
9a	65	0.38	35.7	0.6	0.1170	1.5	0.3	**0.1520**
9b	65	0.38	24.0	1.0	0.0787	0.3	0.0	**0.0801**
9c	65	0.38	24.2	0.3	0.0793	0.2	0.1	**0.0797**
10	68.25	0.40	71.7	0.6	0.2351	0.5	0.1	**0.2385**
11a	70.75	0.41	5.0	0.0	0.0164	1.3	0.1	**0.0426**
11b	70.75	0.41	32.5	0.5	0.1066	2.0	0.0	**0.1687**
12a	74	0.43	20.2	0.8	0.0662	0.1	0.1	**0.0664**
12b	74	0.43	21.7	0.6	0.0711	0.3	0.1	**0.0725**
12c	74	0.43	31.0	1.0	0.1017	1.0	0.1	**0.1172**
13a	76	0.45	25.3	0.6	0.0831	0.1	0.0	**0.0833**
13b	76	0.45	27.5	0.5	0.0902	0.3	0.1	**0.0913**
13c	76	0.45	44.7	1.2	0.1465	1.2	0.3	**0.1702**
14	79.25	0.46	69.0	1.0	0.2264	1.1	0.1	**0.2452**
15a	81.5	0.48	34.7	0.3	0.1137	2.3	0.1	**0.1959**
15b	81.5	0.48	6.7	1.2	0.0219	1.9	0.1	**0.0799**
16a	111	0.65	4.7	0.3	0.0153	2.7	0.2	**0.1313**
16b	111	0.65	4.7	0.3	0.0153	2.5	0.1	**0.1150**
16c	111	0.65	4.3	0.3	0.0142	1.6	0.3	**0.0540**
17a	139.75	0.82	4.3	0.3	0.0142	1.8	0.1	**0.0627**
17b	139.75	0.82	6.0	0.0	0.0197	3.2	0.1	**0.1754**
17c	139.75	0.82	6.7	0.3	0.0219	4.0	0.0	**0.2703**
18a	170.5	1.00	5.0	0.0	0.0164	2.7	0.1	**0.1324**
18b	170.5	1.00	5.3	0.3	0.0175	3.2	0.1	**0.1798**
18c	170.5	1.00	5.5	0.0	0.0180	3.7	0.1	**0.2268**

Set Up No. 2 **Slope (%)** **12.5**

X_1	**46**	in.
X_2	**15**	in.
X_3	**15**	in.
X_4	**15**	in.
Distance from back of 4th Obstruction to water re-capture:	**67 3/4**	in.

I.D.	*Length from H_2O Entrance (in.)*	*Distance/Length of Channel*	Average *Height (mm)*	*Height S.D.*	*Height (ft)*	*V (fps)*	*Velocity S.D.*	*Energy (ft.)*
1	21	0.12	6.67	0.29	0.0219	3.2	0.0	0.1809
2	43.75	0.26	62.33	0.58	0.2045	0.4	0.1	0.2074
3a	47.5	0.28	24.17	0.29	0.0793	2.2	0.2	0.1544
3b	47.5	0.28	24.67	0.76	0.0809	2.6	0.1	0.1832
4a	55	0.32	3.17	0.29	0.0104	0.2	0.0	0.0110
4b	55	0.32	5.00	0.50	0.0164	1.6	0.3	0.0545
4c	55	0.32	8.50	0.50	0.0279	2.3	0.1	0.1124
5a	59.5	0.35	12.50	0.50	0.0410	0.2	0.1	0.0414
5b	59.5	0.35	18.33	1.53	0.0601	0.6	0.1	0.0651
5c	59.5	0.35	16.83	0.29	0.0552	2.7	0.1	0.1712
6	63	0.37	74.67	0.76	0.2450	0.4	0.1	0.2471
7a	65.5	0.38	38.50	1.32	0.1263	1.7	0.1	0.1730
7b	65.5	0.38	24.00	2.00	0.0787	2.7	0.0	0.1919
8a	70.75	0.41	20.50	3.04	0.0673	2.4	0.1	0.1592
8b	70.75	0.41	3.33	0.29	0.0109	1.0	0.1	0.0275
8c	70.75	0.41	2.83	0.29	0.0093	0.1	0.0	0.0095
9a	75	0.44	13.00	0.50	0.0427	2.7	0.1	0.1592
9b	75	0.44	2.17	0.29	0.0071	0.3	0.0	0.0275
9c	75	0.44	5.50	0.87	0.0180	0.1	0.1	0.0095
10	79.5	0.47	76.50	0.50	0.2510	0.4	0.1	0.2535
11a	83.25	0.49	15.33	1.53	0.0503	2.2	0.1	0.1255
11b	83.25	0.49	28.17	0.76	0.0924	1.9	0.1	0.1485
12a	89.75	0.53	2.00	0.00	0.0066	0.1	0.0	0.0067
12b	89.75	0.53	3.17	0.29	0.0104	0.9	0.2	0.0221
12c	89.75	0.53	23.17	2.02	0.0760	2.5	0.4	0.1757
13a	93.75	0.55	10.67	0.58	0.0350	0.1	0.1	0.0353
13b	93.75	0.55	11.67	1.53	0.0383	0.5	0.1	0.0417
13c	93.75	0.55	13.33	0.58	0.0437	3.0	0.0	0.1835
14	99	0.58	72.00	1.73	0.2362	0.4	0.1	0.2391
15a	102.25	0.60	23.67	1.53	0.0776	1.6	0.1	0.1191
15b	102.25	0.60	22.33	1.53	0.0733	2.5	0.1	0.1678
16a	125.75	0.74	6.83	0.29	0.0224	3.5	0.2	0.2163
16b	125.75	0.74	5.33	0.58	0.0175	2.5	0.4	0.1120
16c	125.75	0.74	4.83	0.29	0.0159	1.5	0.3	0.0524
17a	148.75	0.87	4.67	0.29	0.0153	2.8	0.1	0.1342
17b	148.75	0.87	4.83	0.29	0.0159	2.5	0.1	0.1103
17c	148.75	0.87	8.33	0.58	0.0273	3.5	0.1	0.2140
18a	170.5	1.00	4.17	0.29	0.0137	2.3	0.0	0.0958
18b	170.5	1.00	6.17	0.29	0.0202	3.3	0.1	0.1928
18c	170.5	1.00	7.50	0.50	0.0246	4.0	0.2	0.2772

11/17/2010
Full Size PAM
Set Up No. Slope 12.5

X_1	**46**	in.
X_2	**21 1/2**	in.
X_3	**21 1/2**	in.
X_4	**21 1/2**	in.
Distance from back of 4th Obstruction to water re-capture:	**50 1/4**	in.

I.D.	*Length from H_2O Entrance (in.)*	*Distance/Length of Channel*	Average *Height (mm)*	*Height S.D.*	*Height (ft)*	*V (fps)*	*Velocity S.D.*	*Energy (ft.)*
1	21	0.12	6.17	0.29	0.0202	3.2	0.0	0.1792
2	44.25	0.26	59.67	2.31	0.1958	0.3	0.1	0.1975
3a	47.5	0.28	20.67	1.53	0.0678	2.3	0.1	0.1476
3b	47.5	0.28	20.33	1.15	0.0667	2.7	0.1	0.1771
4a	58.25	0.34	2.00	0.00	0.0066	0.4	0.1	0.0086
4b	58.25	0.34	3.00	0.00	0.0098	1.2	0.1	0.0335
4c	58.25	0.34	14.67	1.15	0.0481	2.8	0.1	0.1728
5a	65.25	0.38	7.00	0.00	0.0230	0.3	0.1	0.0247
5b	65.25	0.38	6.50	0.50	0.0213	2.7	0.1	0.1317
5c	65.25	0.38	11.50	0.50	0.0377	3.6	0.0	0.2390
6	69.5	0.41	73.67	0.58	0.2417	0.5	0.1	0.2456
7a	71.25	0.42	28.33	0.58	0.0930	1.9	0.0	0.1490
7b	71.25	0.42	24.17	0.29	0.0793	2.5	0.1	0.1763
8a	80	0.47	15.50	2.18	0.0509	2.7	0.1	0.1669
8b	80	0.47	2.67	0.29	0.0087	0.7	0.2	0.0157
8c	80	0.47	3.17	0.29	0.0104	0.2	0.1	0.0110
9a	88.25	0.52	9.83	0.29	0.0323	3.0	0.1	0.1751
9b	88.25	0.52	6.33	0.29	0.0208	1.6	0.4	0.0605
9c	88.25	0.52	5.67	0.29	0.0186	0.5	0.1	0.0230
10	92	0.54	72.33	0.58	0.2373	0.5	0.1	0.2407
11a	95.25	0.56	20.00	1.00	0.0656	2.4	0.0	0.1551
11b	95.25	0.56	29.83	1.04	0.0979	2.0	0.1	0.1621
12a	103	0.60	2.17	0.29	0.0071	0.3	0.1	0.0082
12b	103	0.60	2.83	0.29	0.0093	0.5	0.1	0.0127
12c	103	0.60	15.83	0.29	0.0519	2.8	0.1	0.1737
13a	111.5	0.65	7.33	0.58	0.0241	1.1	0.2	0.0417
13b	111.5	0.65	6.33	0.29	0.0208	3.1	0.1	0.1668
13c	111.5	0.65	8.17	0.29	0.0268	3.7	0.1	0.2356
14	115.75	0.68	70.00	1.00	0.2297	0.4	0.1	0.2317
15a	119	0.70	34.33	0.76	0.1126	2.1	0.0	0.1811
15b	119	0.70	22.33	0.58	0.0733	2.1	0.1	0.1418
16a	137	0.80	8.17	0.29	0.0268	2.6	0.1	0.1345
16b	137	0.80	6.67	0.29	0.0219	1.8	0.2	0.0722
16c	137	0.80	4.83	0.29	0.0159	0.5	0.1	0.0192
17a	153.5	0.90	5.00	0.00	0.0164	3.2	0.2	0.1721
17b	153.5	0.90	4.33	0.58	0.0142	3.0	0.1	0.1571
17c	153.5	0.90	4.67	0.29	0.0153	1.6	0.6	0.0567
18a	170.5	1.00	4.83	0.29	0.0159	2.4	0.1	0.1078
18b	170.5	1.00	4.33	0.58	0.0142	2.2	0.2	0.0894
18c	170.5	1.00	7.50	0.50	0.0246	3.8	0.1	0.2449

11/17/2010
Full Size PAM
Set Up No. 2 **Slope (%)** **12.5**

X_1	**46**	in.
X_2	**32 3/4**	in.
X_3	**32 3/4**	in.
X_4	**32 3/4**	in.
Distance from back of 4th Obstruction to water re-capture:	**13 3/4**	in.

I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	Average ***Height (mm)***	***Height (ft)***	***V (fps)***	***Energy (ft.)***
1	21	0.12	6.33	0.0208	3.2	0.1798
2	44.25	0.26	61.83	0.2029	0.4	0.2050
3a	47.5	0.28	24.50	0.0804	2.3	0.1602
3b	47.5	0.28	26.33	0.0864	2.5	0.1809
4a	62.75	0.37	3.33	0.0109	0.4	0.0130
4b	62.75	0.37	9.33	0.0306	2.2	0.1081
4c	62.75	0.37	10.50	0.0344	3.5	0.2247
5a	75.75	0.44	5.17	0.0170	3.0	0.1536
5b	75.75	0.44	6.17	0.0202	3.9	0.2605
5c	75.75	0.44	6.67	0.0219	4.0	0.2745
6	79.75	0.47	65.00	0.2133	0.4	0.2162
7a	83.25	0.49	22.83	0.0749	2.4	0.1669
7b	83.25	0.49	27.67	0.0908	2.2	0.1637
8a	98	0.57	10.67	0.0350	3.0	0.1717
8b	98	0.57	7.33	0.0241	1.3	0.0503
8c	98	0.57	3.50	0.0115	0.1	0.0118
9a	111.5	0.65	5.50	0.0180	3.5	0.2119
9b	111.5	0.65	4.17	0.0137	2.8	0.1325
9c	111.5	0.65	4.50	0.0148	1.5	0.0497
10	115.5	0.68	61.17	0.2007	0.4	0.2032
11a	119.25	0.70	14.33	0.0470	2.0	0.1091
11b	119.25	0.70	26.33	0.0864	2.6	0.1887
12a	133.25	0.78	2.43	0.0080	0.2	0.0086
12b	133.25	0.78	7.50	0.0246	2.1	0.0931
12c	133.25	0.78	10.83	0.0355	3.7	0.2443
13a	147	0.86	5.17	0.0170	2.8	0.1387
13b	147	0.86	4.83	0.0159	3.6	0.2171
13c	147	0.86	6.00	0.0197	4.0	0.2681
14	151.5	0.89	64.00	0.2100	0.5	0.2134
15a	155.25	0.91	29.17	0.0957	2.6	0.1980
15b	155.25	0.91	22.67	0.0744	2.1	0.1450
16a	161.25	0.95	12.67	0.0416	2.3	0.1261
16b	161.25	0.95	3.50	0.0115	1.0	0.0260
16c	161.25	0.95	2.00	0.0066	0.1	0.0067
17a	165.75	0.97	17.17	0.0563	2.8	0.1781
17b	165.75	0.97	2.83	0.0093	0.3	0.0104
17c	165.75	0.97	2.83	0.0093	0.1	0.0095
18a	170.5	1.00	9.33	0.0306	3.0	0.1704
18b	170.5	1.00	8.50	0.0279	1.2	0.0490
18c	170.5	1.00	2.83	0.0093	0.1	0.0096

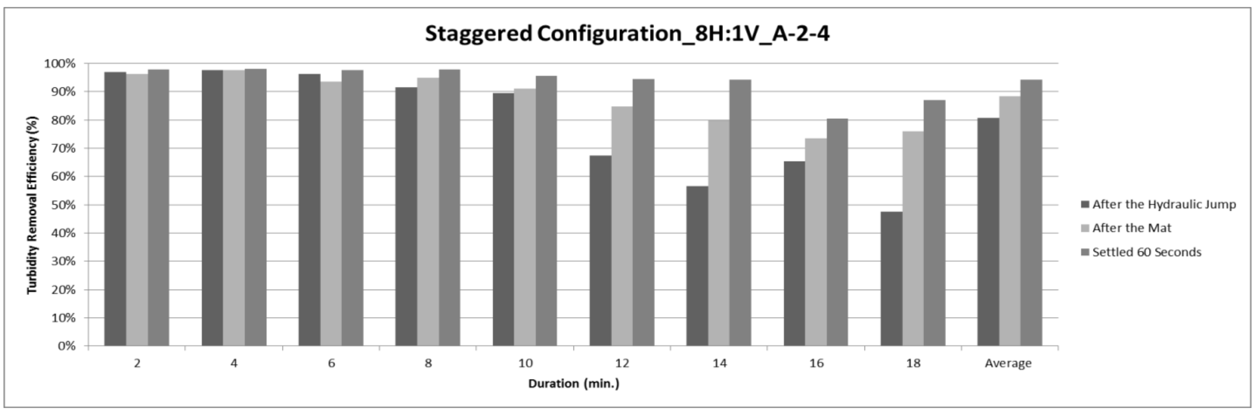
APPENDIX D
FIELD-SCALE TESTING DATA

STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Scott, Ken
Date:	1/28/2011
PAM Type	706b
Soil Type:	A-2-4
Configuration	Optimized
Slope	8H:1V

X_1	**138**	in.
X_2	**45**	in.
X_3	**45**	in.
X_4	**45**	in.
Back Water Depth from Hydraulic Jump:	**13**	in.

I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (ft.)***	***V (fps)***	***Energy_Rec (ft.)***
1	24	0.03	0.0417	3.8	0.2659
2	132	0.15	0.1875	2	0.2496
3a	141.75	0.17	0.0469	0.8	0.0568
3b	141.75	0.17	0.0469	0.7	0.0545
4a	168	0.20	0.0365	3.7	0.2490
4b	168	0.20	0.0156	2.3	0.0978
4c	168	0.20	0.0469	2.8	0.1686
5	237	0.28	0.0938	0.1	0.0939
6a	273	0.32	0.0104	0.5	0.0143
6b	273	0.32	0.0417	3.2	0.2007
6c	273	0.32	0.0417	2.5	0.1387
7	289.5	0.34	0.1510	2.8	0.2728
8a	299.25	0.35	0.0260	0.1	0.0262
8b	299.25	0.35	0.0365	2.5	0.1335
9a	378	0.44	0.0417	2	0.1038
9b	378	0.44	0.0260	1.2	0.0484
9c	378	0.44	0.0417	1.8	0.0920
10	394.5	0.46	0.1458	0.1	0.1460
11a	404.25	0.47	0.0625	4	0.3109
11b	404.25	0.47	0.0260	1	0.0416
12a	543	0.63	0.0469	2.7	0.1601
12b	543	0.63	0.0156	0.4	0.0181
12c	543	0.63	0.0417	2.1	0.1101
13a	678	0.79	1.0833	0.1	1.0835
13b	678	0.79	1.0833	0.2	1.0840
13c	678	0.79	1.0833	0.1	1.0835

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Rafiq Chowdhury							
Date:	28-Jan-11							
Date Completed:	30-Jan-11							
Slope:	8H:1V							
Polymer Type:	706b							
Configuration:	Optimized							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Turbidity Removal Efficiency for D1 (%)**	**Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	852						
1	2	882	26	32	18	**97%**	**96%**	**98%**
2	4	853	20	19	16	**98%**	**98%**	**98%**
3	6	850	31	55	20	**96%**	**94%**	**98%**
4	8	859	72	43	19	**92%**	**95%**	**98%**
5	10	836	88	75	36	**89%**	**91%**	**96%**
6	12	828	270	126	46	**67%**	**85%**	**94%**
7	14	795	345	161	45	**57%**	**80%**	**94%**
8	16	685	237	182	133	**65%**	**73%**	**81%**
9	18	561	294	134	73	**48%**	**76%**	**87%**
AVERAGE	Average	**800.10**	**153.67**	**91.89**	**45.11**	**81%**	**89%**	**94%**

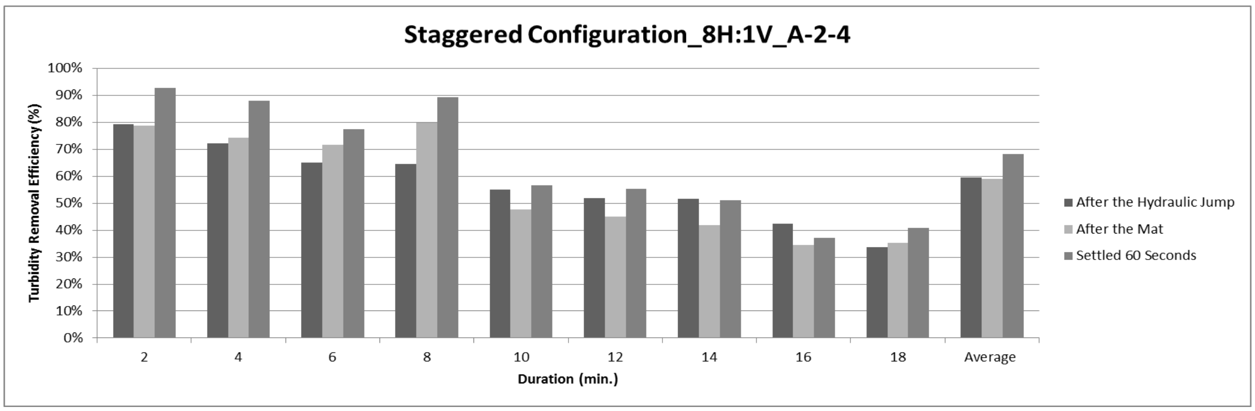


STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Scott, Rylee, Daniel & Matt
Date:	1/30/2011
PAM Type	706b
Soil Type:	A-2-4
Configuration	Optimized
Slope	8H:1V

X_1	**138**	in.
X_2	**45**	in.
X_3	**45**	in.
X_4	**45**	in.
Back Water Depth from Hydraulic Jump:	**13**	in.

I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (ft.)***	***V (fps)***	***Energy_Rec (ft.)***
1	24	0.03	0.0677	3	0.2075
2	132	0.15	0.2500	1	0.2655
3a	141.75	0.17	0.0365	2	0.0986
3b	141.75	0.17	0.0833	2	0.1454
4a	168	0.20	0.0365	2	0.0986
4b	168	0.20	0.0156	2.3	0.0978
4c	168	0.20	0.0469	3.7	0.2595
5	237	0.28	0.1823	0.7	0.1899
6a	273	0.32	0.0208	1	0.0364
6b	273	0.32	0.0260	2.5	0.1231
6c	273	0.32	0.0365	3	0.1762
7	289.5	0.34	0.1042	2.6	0.2091
8a	299.25	0.35	0.0104	0.5	0.0143
8b	299.25	0.35	0.0573	3.1	0.2065
9a	378	0.44	0.0208	4	0.2693
9b	378	0.44	0.0417	1.5	0.0766
9c	378	0.44	0.0469	2.8	0.1686
10	394.5	0.46	0.1927	2.7	0.3059
11a	404.25	0.47	0.0521	3.4	0.2316
11b	404.25	0.47	0.0365	2.7	0.1497
12a	543	0.63	0.0260	4.1	0.2871
12b	543	0.63	0.0156	3	0.1554
12c	543	0.63	0.0365	3.5	0.2267
13a	678	0.79	1.0833	0.1	1.0835
13b	678	0.79	1.0833	0.2	1.0840
13c	678	0.79	1.0833	0.1	1.0835

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Rafiq Chowdhury							
Date:	30-Jan-11							
Date Completed:	31-Jan-11							
Slope:	8H:1V							
Polymer Type:	706b							
Configuration:	Optimized							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Removal Efficiency for D1 (%)**	**Turbidity Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	893						
1	2	879	182	187	64	**79%**	**79%**	**93%**
2	4	879	243	225	105	**72%**	**74%**	**88%**
3	6	869	304	247	195	**65%**	**72%**	**78%**
4	8	881	311	177	93	**65%**	**80%**	**89%**
5	10	880	396	460	381	**55%**	**48%**	**57%**
6	12	854	410	469	381	**52%**	**45%**	**55%**
7	14	796	385	463	390	**52%**	**42%**	**51%**
8	16	629	362	412	395	**42%**	**34%**	**37%**
9	18	504	334	326	298	**34%**	**35%**	**41%**
AVERAGE	Average	**806.40**	**325.22**	**329.56**	**255.78**	**60%**	**59%**	**68%**

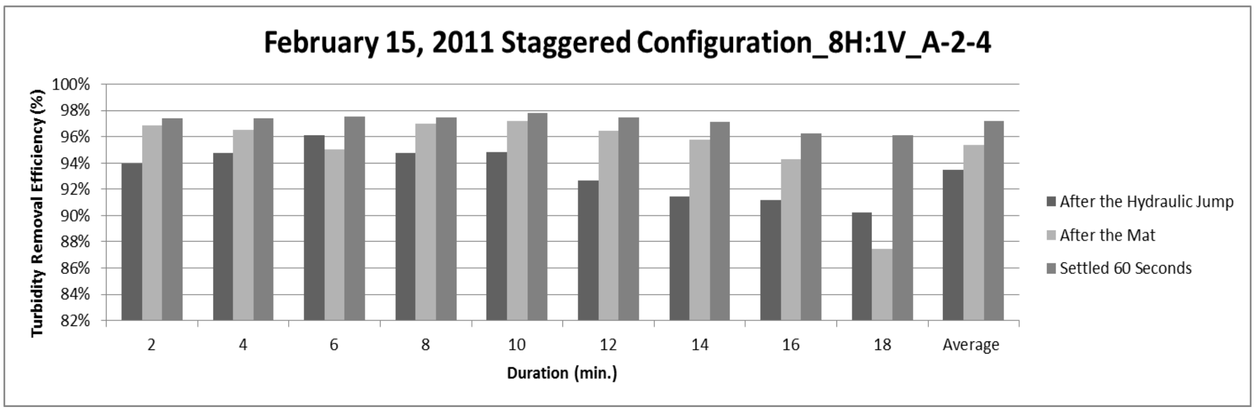


STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Ken, Scott, Travis
Date:	2/15/2011
PAM Type	706b
Soil Type:	A-2-4
Configuration	Optimized
Slope	8H:1V

X_1	**138**	in.
X_2	**45**	in.
X_3	**45**	in.
X_4	**45**	in.
Back Water Depth from Hydraulic Jump:	**111**	in.

I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (ft.)***	***V (fps)***	***Energy_Rec (ft.)***
1	24	0.03	0.0313	2	0.0934
2	132	0.15	0.2760	1	0.2916
3a	141.75	0.17	0.0365	0.7	0.0441
3b	141.75	0.17	0.1302	2.6	0.2352
4a	168	0.20	0.0104	0.1	0.0106
4b	168	0.20	0.0313	0.8	0.0412
4c	168	0.20	0.0417	3.3	0.2108
5	237	0.28	0.2031	2.1	0.2716
6a	273	0.32	0.0469	0.1	0.0470
6b	273	0.32	0.0625	2.1	0.1310
6c	273	0.32	0.0260	1.3	0.0523
7	289.5	0.34	0.1510	1.1	0.1698
8a	299.25	0.35	0.0677	2.2	0.1429
8b	299.25	0.35	0.0208	1.8	0.0711
9a	378	0.44	0.0208	0.1	0.0210
9b	378	0.44	0.0260	1.3	0.0523
9c	378	0.44	0.0313	2	0.0934
10	394.5	0.46	0.1823	1.2	0.2047
11a	404.25	0.47	0.0677	2.1	0.1362
11b	404.25	0.47	0.0260	0.2	0.0267
12a	543	0.63	0.0469	3.2	0.2059
12b	543	0.63	0.0313	1.5	0.0662
12c	543	0.63	0.0104	1.6	0.0502
13a	678	0.79	1.0833	0.1	1.0835
13b	678	0.79	1.0833	0.1	1.0835
13c	678	0.79	1.0833	0.1	1.0835

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Rafiq Chowdhury							
Date:	15-Feb-11							
Date Completed:	16-Feb-11							
Slope:	8H:1V							
Polymer Type:	706b							
Configuration:	Staggered							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Turbidity Removal Efficiency for D1 (%)**	**Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	947						
1	2	954	74	30	25	**94%**	**97%**	**97%**
2	4	922	58	32	24	**95%**	**97%**	**97%**
3	6	925	48	46	23	**96%**	**95%**	**98%**
4	8	902	36	27	23	**95%**	**97%**	**97%**
5	10	924	47	26	20	**95%**	**97%**	**98%**
6	12	901	48	32	23	**93%**	**96%**	**97%**
7	14	901	66	38	26	**91%**	**96%**	**97%**
8	16	828	77	47	31	**91%**	**94%**	**96%**
9	18	748	73	94	29	**90%**	**87%**	**96%**
AVERAGE	Average	**895.20**	**58.56**	**41.33**	**24.89**	**93%**	**95%**	**97%**

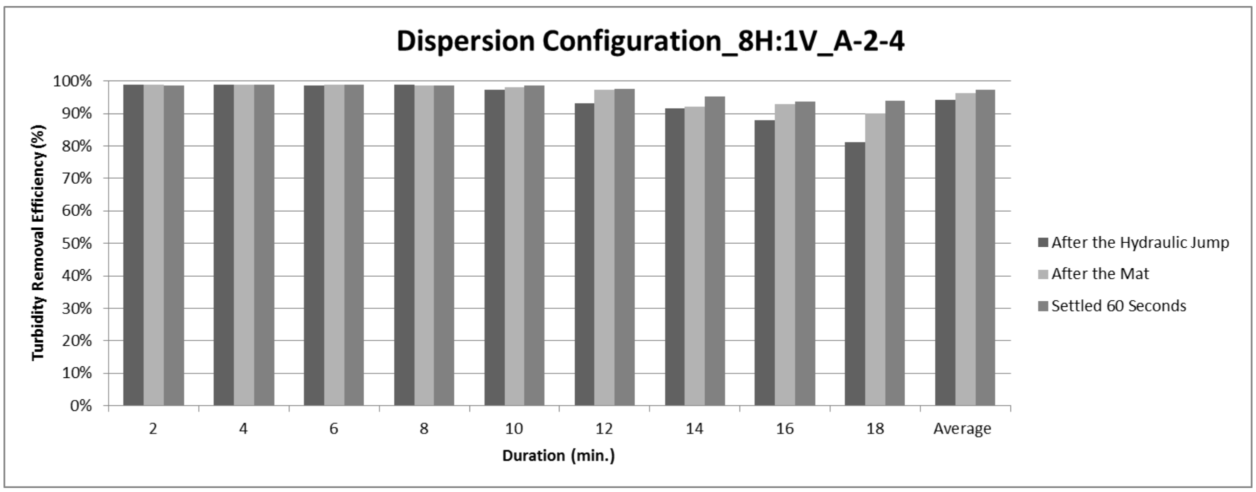


STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Scott, Mike, Rylee, & Ken
Date:	2/1/2011
PAM Type	706b
Soil Type:	A-2-4
Configuration	Dispersion
Slope	8H:1V

X_1	**48**	in.
X_2	**171**	in.
X_3	**138**	in.
X_4	**156**	in.
Back Water Depth from Hydraulic Jump:	**112**	in.

I.D.	*Length from H_2O Entrance (in.)*	*Distance/Length of Channel*	*Height (ft.)*	*V (fps)*	*Energy_Rec (ft.)*
1	24	0.03	0.0365	3	0.1762
2	42	0.05	0.1250	1.1	0.1438
3	51.75	0.06	0.0573	3.1	0.2065
4	51.75	0.06	0.1458	3.6	0.3471
5a	141	0.16	0.0833	3.1	0.2326
5b	141	0.16	0.0625	2	0.1246
5c	141	0.16	0.0000	1.1	0.0188
6	220.5	0.26	0.1667	0.7	0.1743
7	220.5	0.26	0.0833	0.3	0.0847
8	223.5	0.26	0.1615	3	0.3012
9	234	0.27	0.0990	3.6	0.3002
10	366	0.43	0.1719	1	0.1874
11a	457.5	0.53	0.0208	1.5	0.0558
11b	457.5	0.53	0.0521	2.9	0.1827
11c	457.5	0.53	0.0365	1.7	0.0813
12	529.5	0.62	0.1979	0.9	0.2105
13	529.5	0.62	0.2344	1.7	0.2793
14	532.5	0.62	0.1146	2.5	0.2116
15	543	0.63	0.1250	3.3	0.2941
16a	610.5	0.71	0.4948	0.3	0.4962
16b	610.5	0.71	0.5156	0.1	0.5158
16c	610.5	0.71	0.5365	0.1	0.5366
17a	678	0.79	1.0833	0.1	1.0835
17b	678	0.79	1.0833	0	1.0833
17c	678	0.79	1.0833	0.1	1.0835

STORMWATER MANAGEMENT ACADEMY									
Turbidity (NTU)									
Researcher(s)	Scott Glancy								
Date:	1-Feb-11								
Date Completed:	3-Feb-11								
Slope:	8H:1V								
Polymer Type:	706b								
Configuration:	Dispersion								
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Diffence Between U & D2**	**Removal Efficiency for D1 (%)**	**Removal Efficiency for D2 (%)**	**Removal Efficiency for D2-Settled (%)**
Initial	0	823							
1	2	1005	12	12	13	993	**99%**	**99%**	**99%**
2	4	1020	12	11	11	1009	**99%**	**99%**	**99%**
3	6	980	13	11	11	969	**99%**	**99%**	**99%**
4	8	965	12	13	13	952	**99%**	**99%**	**99%**
5	10	960	27	18	13	942	**97%**	**98%**	**99%**
6	12	1000	68	26	24	974	**93%**	**97%**	**98%**
7	14	975	83	77	46	898	**91%**	**92%**	**95%**
8	16	1035	125	73	65	962	**88%**	**93%**	**94%**
9	18	736	138	74	44	662	**81%**	**90%**	**94%**
AVERAGE	Average	**949.90**	**54.44**	**35.00**	**26.67**	**929.00**	**94%**	**96%**	**97%**

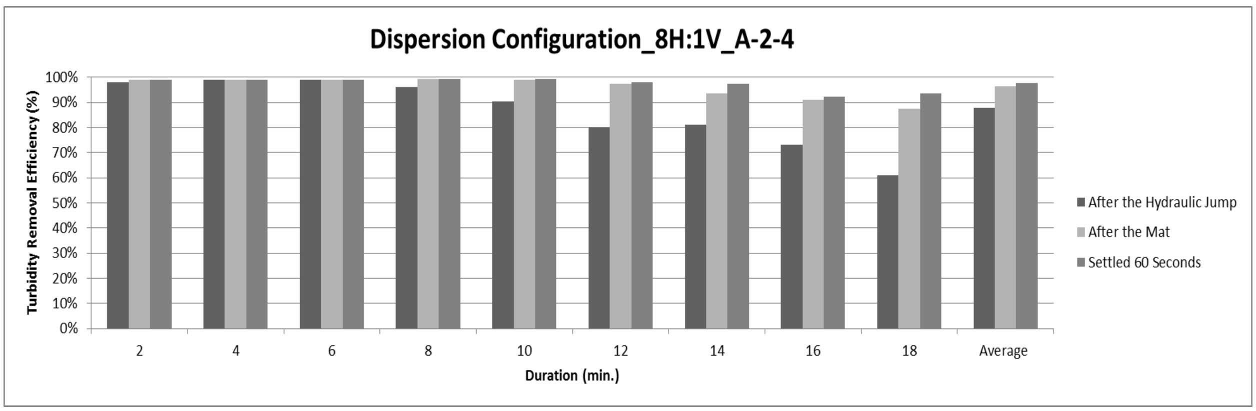


STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Scott, Ken, Drew Rossi, & Josh Sasser
Date:	2/3/2011
PAM Type	706b
Soil Type:	A-2-4
Configuration	Dispersion
Slope	8H:1V

X_1	**48**	in.
X_2	**171**	in.
X_3	**138**	in.
X_4	**156**	in.
Back Water Depth from Hydraulic Jump:	**112**	in.

I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (ft.)***	***V (fps)***	***Energy_Rec (ft.)***
1	24	0.03	0.0625	3	0.2023
2	42	0.05	0.0885	1.1	0.1073
3	51.75	0.06	0.0729	3.1	0.2221
4	51.75	0.06	0.0781	3.6	0.2794
5a	141	0.16	0.0573	3.1	0.2065
5b	141	0.16	0.0365	2	0.0986
5c	141	0.16	0.0052	1.1	0.0240
6	220.5	0.26	0.0677	0.7	0.0753
7	220.5	0.26	0.0365	0.3	0.0379
8	223.5	0.26	0.0781	3	0.2179
9	234	0.27	0.0781	3.6	0.2794
10	366	0.43	0.1589	1	0.1744
11a	457.5	0.53	0.0208	1.5	0.0558
11b	457.5	0.53	0.0313	2.9	0.1618
11c	457.5	0.53	0.0260	1.9	0.0821
12	529.5	0.62	0.1563	0.9	0.1688
13	529.5	0.62	0.1510	1.5	0.1860
14	532.5	0.62	0.1042	2.5	0.2012
15	543	0.63	0.1042	3	0.2439
16a	610.5	0.71	0.5156	0.3	0.5170
16b	610.5	0.71	0.5469	0.1	0.5470
16c	610.5	0.71	0.5000	0.1	0.5002
17a	678	0.79	1.0833	0.1	1.0835
17b	678	0.79	1.0833	0	1.0833
17c	678	0.79	1.0833	0.1	1.0835

STORMWATER MANAGEMENT ACADEMY									
Turbidity (NTU)									
Researcher(s)	Rafiq Chowdhury, Scott Glancy, & Travis								
Date:	3-Feb-11								
Date Completed:	8-Feb-11								
Slope:	8H:1V								
Polymer Type:	706b								
Configuration:	Dispersion								
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Diffence Between U & D2**	**Turbidity Removal Efficiency for D1 (%)**	**Turbidity Removal Efficiency for D2 (%)**	**Removal Efficiency for D2-Settled (%)**
Initial	0	992							
1	2	962	20	10	10	952	**98%**	**99%**	**99%**
2	4	982	11	10	10	972	**99%**	**99%**	**99%**
3	6	978	10	10	10	968	**99%**	**99%**	**99%**
4	8	991	38	8	8	983	**96%**	**99%**	**99%**
5	10	990	97	10	6	980	**90%**	**99%**	**99%**
6	12	933	184	24	18	909	**80%**	**97%**	**98%**
7	14	980	185	65	27	915	**81%**	**93%**	**97%**
8	16	894	239	80	68	814	**73%**	**91%**	**92%**
9	18	651	253	81	42	570	**61%**	**88%**	**94%**
AVERAGE	Average	**935.30**	**115.22**	**33.11**	**22.11**	**895.89**	**88%**	**96%**	**98%**

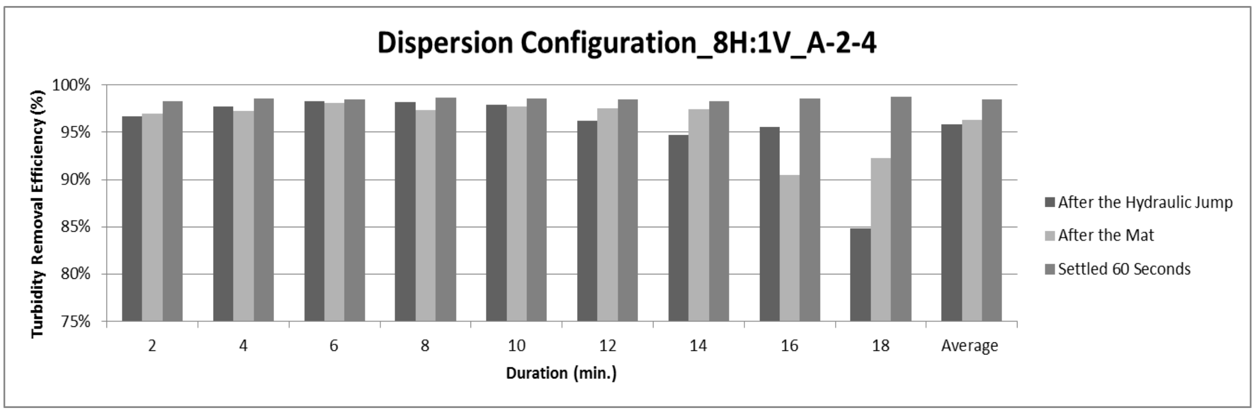


STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Scott, Ken, & Travis
Date:	2/8/2011
PAM Type	706b
Soil Type:	A-2-4
Configuration	Dispersion
Slope	8H:1V

X_1	**48**	in.
X_2	**171**	in.
X_3	**138**	in.
X_4	**156**	in.
Back Water Depth from Hydraulic Jump:	**110**	in.

I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (ft.)***	***V (fps)***	***Energy_Rec (ft.)***
1	24	0.03	0.0365	1.7	0.0813
2	42	0.05	0.1250	0.4	0.1275
3	51.75	0.06	0.0625	2.8	0.1842
4	51.75	0.06	0.1094	3	0.2491
5a	141	0.16	0.0365	3.6	0.2377
5b	141	0.16	0.0313	1.2	0.0536
5c	141	0.16	0.0313	0.1	0.0314
6	220.5	0.26	0.1771	0.2	0.1777
7	220.5	0.26	0.1563	1	0.1718
8	223.5	0.26	0.1198	2.4	0.2092
9	234	0.27	0.0938	3	0.2335
10	366	0.43	0.1250	0.2	0.1256
11a	457.5	0.53	0.0260	3.4	0.2055
11b	457.5	0.53	0.0365	1.5	0.0714
11c	457.5	0.53	0.0313	3	0.1710
12	529.5	0.62	0.1823	1.2	0.2047
13	529.5	0.62	0.2188	1.3	0.2450
14	532.5	0.62	0.1771	2	0.2392
15	543	0.63	0.1406	3.3	0.3097
16a	610.5	0.71	0.5000	0.3	0.5014
16b	610.5	0.71	0.5313	0.8	0.5412
16c	610.5	0.71	0.5104	0.1	0.5106
17a	678	0.79	1.0833	0.2	1.0840
17b	678	0.79	1.0833	0	1.0833
17c	678	0.79	1.0833	0.1	1.0835

STORMWATER MANAGEMENT ACADEMY									
Turbidity (NTU)									
Researcher(s)	Rafiq Chowdhury, Scott Glancy								
Date:	8-Feb-11								
Date Completed:	9-Feb-11								
Slope:	8H:1V								
Polymer Type:	706b								
Configuration:	Dispersion								
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Diffence Between U & D2**	**Turbidity Removal Efficiency for D1 (%)**	**Turbidity Removal Efficiency for D2 (%)**	**Removal Efficiency for D2-Settled (%)**
Initial	0	890							
1	2	990	33	30	17	960	**97%**	**97%**	**98%**
2	4	978	22	27	14	951	**98%**	**97%**	**99%**
3	6	976	17	19	15	957	**98%**	**98%**	**98%**
4	8	992	18	26	13	966	**98%**	**97%**	**99%**
5	10	972	20	22	14	950	**98%**	**98%**	**99%**
6	12	966	37	24	15	942	**96%**	**98%**	**98%**
7	14	951	50	24	16	927	**95%**	**97%**	**98%**
8	16	884	39	84	13	800	**96%**	**90%**	**99%**
9	18	740	112	57	9	683	**85%**	**92%**	**99%**
AVERAGE	Average	**933.90**	**38.67**	**34.78**	**14.00**	**904.00**	**96%**	**96%**	**99%**



Graphable Data Frame			
ID	Trial 1 - Left	Trial 2 - Left	Trial 3 - Left
3	0.206515269	0.222140269	0.18423913
5a	0.232556936	0.206515269	0.237700569
6	0.174275362	0.075317029	0.177704451
11a	0.055771222	0.055771222	0.205544772
12	0.210494306	0.16882764	0.204651915
16a	0.496189182	0.517022516	0.501397516
17a	1.083488613	1.083488613	1.083954451
18a	0	0.026242236	0.003881988

Is There a Significant Difference Between the Energy Values on the Left Side of the Channel Amongst the 3-Tr

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	8	2.45929089	0.307411361	0.119808
Column 2	8	2.355324793	0.294415599	0.125398
Column 3	8	2.599074793	0.324884349	0.11259

ANOVA

ce of Varic	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between (	0.003740106	2	0.001870053	0.01568	0.984454032	3.4668
Within Gr(	2.504572268	21	0.119265346		NOT SIGNIFICANT	
Total	2.508312374	23				

Graphable Data Frame			
ID	Trial 1 - Right	Trial 2 - Right	Trial 3 - Right
4	0.347075569	0.279367236	0.249126553
5c	0.01878882	0.023997153	0.03140528
7	0.084730849	0.037855849	0.17177795
11c	0.08133411	0.070917443	0.171001553
13	0.279250776	0.195917443	0.244992236
16c	0.536613613	0.50015528	0.510571946
17c	1.083488613	1.083488613	1.083488613
18c	0	0.01878882	0.009937888

Is There a Significant Difference Between the Energy Values on the Right Side of the Channel Amongst the 3-Trials?

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	8	2.43128235	0.303910294	0.133657
Column 2	8	2.210487836	0.27631098	0.133877
Column 3	8	2.472302019	0.309037752	0.121788

ANOVA

ce of Varic	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between (	0.004957479	2	0.00247874	0.0191	0.981097875	3.4668
Within Gr(	2.72525789	21	0.129774185		NOT SIGNIFICANT	
Total	2.730215369	23				

Graphable Data Frame			
ID	Trial 1 - Center	Trial 2 - Center	Trial 3 - Center
1	0.176209886	0.202251553	0.08133411
2	0.14378882	0.107330487	0.127484472
5b	0.124611801	0.098570135	0.053610248
8	0.301209886	0.217876553	0.20923266
9	0.300200569	0.279367236	0.233501553
10	0.18740295	0.174382117	0.125621118
11b	0.182673395	0.161840062	0.071396222
14	0.211633023	0.201216356	0.239195135
15	0.294099379	0.273266046	0.309724379
16b	0.51578028	0.54703028	0.541187888
17b	1.083333333	1.083333333	1.083333333
18b	0	0.01552795	0.050310559

Is There a Significant Difference Between the Energy Values on the Center of the Channel Amongst the 3-Trials?

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	12	3.520943323	0.293411944	0.077675
Column 2	12	3.361992107	0.280166009	0.080964
Column 3	12	3.125931677	0.260494306	0.086619

ANOVA

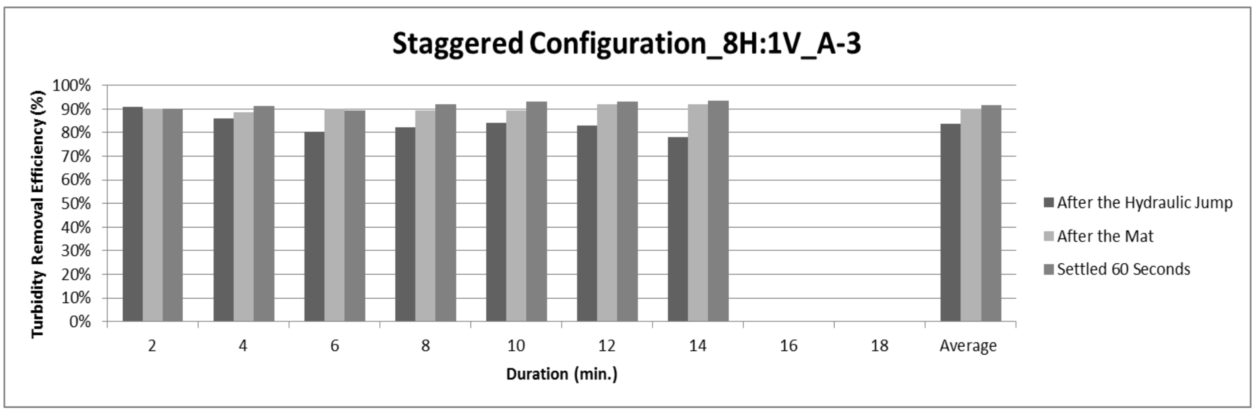
ce of Varic	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between (	0.006584006	2	0.003292003	0.040268	0.960579156	3.284918
Within Gr(	2.697830641	33	0.081752444		NOT SIGNIFICANT	
Total	2.704414647	35				

STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Ken, Asaph, Alicia
Date:	2/16/2011
PAM Type	706b
Soil Type:	A-3
Configuration	Optimized
Slope	8H:1V

X_1	**138**	in.
X_2	**45**	in.
X_3	**45**	in.
X_4	**45**	in.
Back Water Depth from Hydraulic Jump:		in.

I.D.	*Length from H_2O Entrance (in.)*	*Distance/Length of Channel*	*Height (ft.)*	*V (fps)*	*Energy_Rec (ft.)*
1	24	0.03	0.0573	1.6	0.0970
2	132	0.15	0.2396	1.5	0.2745
3a	141.75	0.17	0.0313	2.1	0.0997
3b	141.75	0.17	0.0885	2.2	0.1637
4a	168	0.20	0.0052	0.7	0.0128
4b	168	0.20	0.0573	2.5	0.1543
4c	168	0.20	0.0208	0.8	0.0308
5	237	0.28	0.1875	1	0.2030
6a	273	0.32	0.0156	0.4	0.0181
6b	273	0.32	0.0260	0.5	0.0299
6c	273	0.32	0.0260	2	0.0882
7	289.5	0.34	0.1406	1.2	0.1630
8a	299.25	0.35	0.1198	2	0.1819
8b	299.25	0.35	0.0156	1	0.0312
9a	378	0.44	0.0104	1.6	0.0502
9b	378	0.44	0.0208	0.8	0.0308
9c	378	0.44	0.0469	3	0.1866
10	394.5	0.46	0.2083	1.5	0.2433
11a	404.25	0.47	0.0677	2.4	0.1571
11b	404.25	0.47	0.0729	0.5	0.0768
12a	543	0.63	0.0104	1.2	0.0328
12b	543	0.63	0.0313	0.1	0.0314
12c	543	0.63	0.0156	1	0.0312
13a	678	0.79	1.0833	0.2	1.0840
13b	678	0.79	1.0833	0.1	1.0835
13c	678	0.79	1.0833	0.1	1.0835

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Rafiq Chowdhury							
Date:	16-Feb-11							
Date Completed:	17-Feb-11							
Slope:	8H:1V							
Polymer Type:	706b							
Configuration:	Staggered							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Turbidity Removal Efficiency for D1 (%)**	**Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	401						
1	2	513	47	50	50	**91%**	**90%**	**90%**
2	4	418	59	48	37	**86%**	**89%**	**91%**
3	6	384	75	38	41	**80%**	**90%**	**89%**
4	8	398	71	42	32	**82%**	**89%**	**92%**
5	10	417	66	45	28	**84%**	**89%**	**93%**
6	12	395	67	31	27	**83%**	**92%**	**93%**
7	14	394	87	32	25	**78%**	**92%**	**94%**
8	16	N/A	N/A	N/A	N/A			
9	18	N/A	N/A	N/A	N/A			
AVERAGE	Average	**415.00**	**67.43**	**40.86**	**34.29**	**84%**	**90%**	**92%**

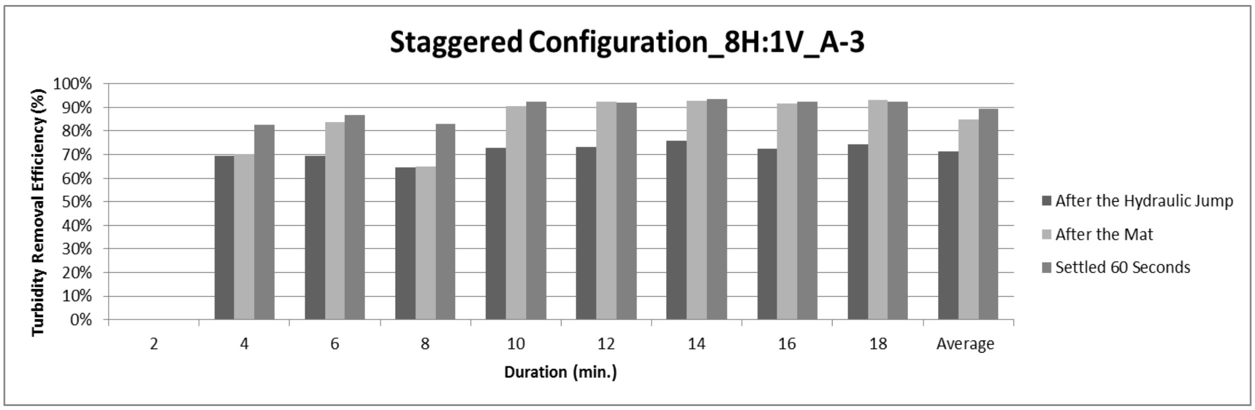


STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Ken, Jesus, Scott, and Travis
Date:	2/17/2011
PAM Type	706b
Soil Type:	A-3
Configuration	Staggered
Slope	8H:1V

X_1	**138**	in.
X_2	**45**	in.
X_3	**45**	in.
X_4	**45**	in.
Back Water Depth from Hydraulic Jump:		in.

I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (ft.)***	***V (fps)***	***Energy_Rec (ft.)***
1	24	0.03	0.0313	2.2	0.1064
2	132	0.15	0.2031	0.1	0.2033
3a	141.75	0.17	0.0260	1.9	0.0821
3b	141.75	0.17	0.0417	1.6	0.0814
4a	168	0.20	0.0104	0.4	0.0129
4b	168	0.20	0.0573	0.7	0.0649
4c	168	0.20	0.0469	1	0.0624
5	237	0.28	0.0833	0.5	0.0872
6a	273	0.32	0.0260	0.1	0.0262
6b	273	0.32	0.0365	0.3	0.0379
6c	273	0.32	0.0208	1.2	0.0432
7	289.5	0.34	0.0885	1.3	0.1148
8a	299.25	0.35	0.0729	2	0.1350
8b	299.25	0.35	0.0156	1.8	0.0659
9a	378	0.44	0.0156	0.8	0.0256
9b	378	0.44	0.0208	0.5	0.0247
9c	378	0.44	0.0365	2.1	0.1049
10	394.5	0.46	0.1719	1.7	0.2168
11a	404.25	0.47	0.0208	0.8	0.0308
11b	404.25	0.47	0.0990	1	0.1145
12a	543	0.63	0.0104	0.8	0.0204
12b	543	0.63	0.0313	0.5	0.0351
12c	543	0.63	0.0313	1.5	0.0662
13a	678	0.79	1.0833	0.1	1.0835
13b	678	0.79	1.0833	0.1	1.0835
13c	678	0.79	1.0833	0.1	1.0835

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Rafiq Chowdhury							
Date:	17-Feb-11							
Date Completed:	18-Feb-11							
Slope:	8H:1V							
Polymer Type:	706b							
Configuration:	Staggered							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Turbidity Removal Efficiency for D1 (%)**	**Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	355						
1	2	345	N/A	N/A	N/A			
2	4	361	110	108	63	**70%**	**70%**	**83%**
3	6	352	107	58	47	**70%**	**84%**	**87%**
4	8	354	125	124	60	**65%**	**65%**	**83%**
5	10	361	98	35	27	**73%**	**90%**	**93%**
6	12	366	98	28	30	**73%**	**92%**	**92%**
7	14	354	85	26	23	**76%**	**93%**	**94%**
8	16	324	95	27	25	**73%**	**92%**	**92%**
9	18	347	89	24	26	**74%**	**93%**	**93%**
AVERAGE	Average	**351.90**	**100.88**	**53.75**	**37.63**	**71%**	**85%**	**89%**

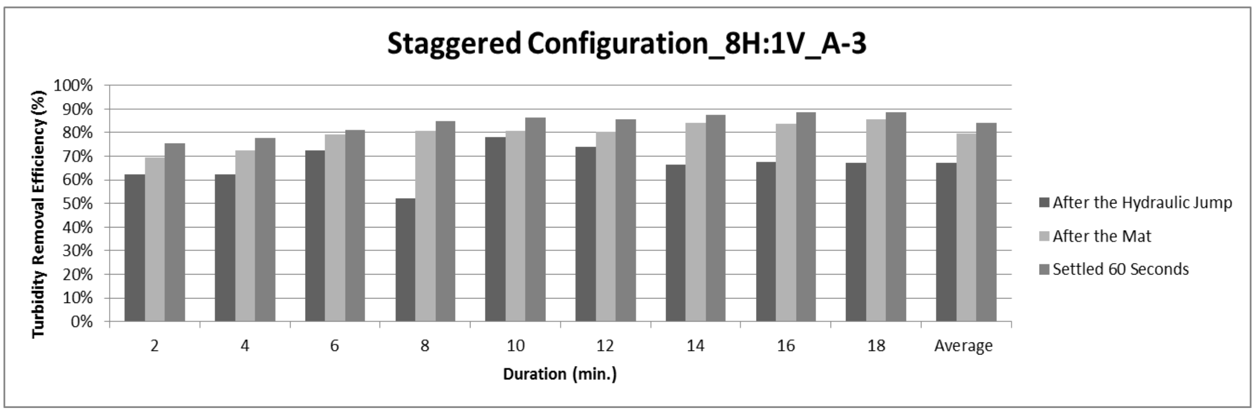


STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Scott, Travis
Date:	2/18/2011
PAM Type	706b
Soil Type:	A-3
Configuration	Staggered
Slope	8H:1V

X_1	**138**	in.
X_2	**45**	in.
X_3	**45**	in.
X_4	**45**	in.
Back Water Depth from Hydraulic Jump:		in.

I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (ft.)***	***V (fps)***	***Energy_Rec (ft.)***
1	24	0.03	0.0417	2.7	0.1549
2	132	0.15	0.2396	0.9	0.2522
3a	141.75	0.17	0.0469	2.4	0.1363
3b	141.75	0.17	0.0521	2.2	0.1272
4a	168	0.20	0.0052	0.1	0.0054
4b	168	0.20	0.0469	2.3	0.1290
4c	168	0.20	0.0104	0.8	0.0204
5	237	0.28	0.1458	0.7	0.1534
6a	273	0.32	0.0052	0.1	0.0054
6b	273	0.32	0.0365	1.1	0.0552
6c	273	0.32	0.0208	2.3	0.1030
7	289.5	0.34	0.1667	0.8	0.1766
8a	299.25	0.35	0.0729	2.1	0.1414
8b	299.25	0.35	0.0208	1.4	0.0513
9a	378	0.44	0.0052	1.2	0.0276
9b	378	0.44	0.0156	1.3	0.0419
9c	378	0.44	0.0885	2.7	0.2017
10	394.5	0.46	0.1563	0.5	0.1601
11a	404.25	0.47	0.1458	2.2	0.2210
11b	404.25	0.47	0.0365	0.9	0.0490
12a	543	0.63	0.0833	0.8	0.0933
12b	543	0.63	0.0260	1.3	0.0523
12c	543	0.63	0.0469	0.6	0.0525
13a	678	0.79	1.0833	0.1	1.0835
13b	678	0.79	1.0833	0.1	1.0835
13c	678	0.79	1.0833	0.1	1.0835

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Rafiq Chowdhury							
Date:	18-Feb-11							
Date Completed:	18-Feb-11							
Slope:	8H:1V							
Polymer Type:	706b							
Configuration:	Staggered, A-3							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Removal Efficiency for D1 (%)**	**Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	347						
1	2	311	117	95	76	**62%**	**69%**	**76%**
2	4	320	121	88	71	**62%**	**73%**	**78%**
3	6	310	86	64	59	**72%**	**79%**	**81%**
4	8	329	158	64	50	**52%**	**81%**	**85%**
5	10	309	68	60	42	**78%**	**81%**	**86%**
6	12	347	91	68	50	**74%**	**80%**	**86%**
7	14	302	101	48	38	**67%**	**84%**	**87%**
8	16	308	105	50	35	**68%**	**84%**	**89%**
9	18	305	100	44	35	**67%**	**86%**	**89%**
AVERAGE	Average	**318.80**	**105.22**	**64.56**	**50.67**	**67%**	**80%**	**84%**

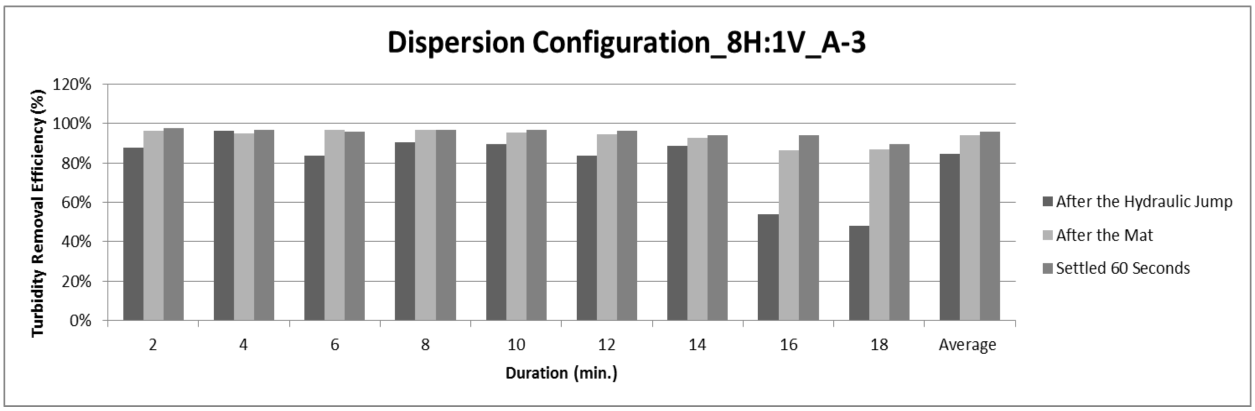


STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Asaph, Travis, Ken
Date:	2/23/2011
PAM Type	706b
Soil Type:	A-3
Configuration	Dispersion
Slope	8H:1V

X_1	**48**	in.
X_2	**171**	in.
X_3	**138**	in.
X_4	**156**	in.
Back Water Depth from Hydraulic Jump:	**109**	in.

I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (ft.)***	***V (fps)***	***Energy_Rec (ft.)***
1	24	0.03	0.0625	3.2	0.2215
2	42	0.05	0.2083	0.3	0.2097
3	51.75	0.06	0.1719	2.3	0.2540
4	51.75	0.06	0.0677	2.5	0.1648
5a	141	0.16	0.0365	1.8	0.0868
5b	141	0.16	0.0521	4.1	0.3131
5c	141	0.16	0.0104	0.8	0.0204
6	220.5	0.26	0.1875	0.4	0.1900
7	220.5	0.26	0.1406	0.1	0.1408
8	223.5	0.26	0.2344	1.1	0.2532
9	234	0.27	0.1198	2.8	0.2415
10	366	0.43	0.1042	0.1	0.1043
11a	457.5	0.53	0.0260	1.8	0.0764
11b	457.5	0.53	0.0417	1	0.0572
11c	457.5	0.53	0.0469	0.9	0.0595
12	529.5	0.62	0.2708	0.2	0.2715
13	529.5	0.62	0.2667	0.2	0.2673
14	532.5	0.62	0.3646	0.4	0.3671
15	543	0.63	0.4833	0.2	0.4840
16a	610.5	0.71	0.6875	0.1	0.6877
16b	610.5	0.71	0.7240	0.1	0.7241
16c	610.5	0.71	0.7240	0.1	0.7241
17a	678	0.79	1.0833	0.1	1.0835
17b	678	0.79	1.0833	0.1	1.0835
17c	678	0.79	1.0833	0.1	1.0835

STORMWATER MANAGEMENT ACADEMY									
Turbidity (NTU)									
Researcher(s)	Rafiq Chowdhury								
Date:	23-Feb-11								
Date Completed:	28-Feb-11								
Slope:	8H:1V								
Polymer Type:	706b								
Configuration:	Dispersion, A-3								
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Diffence Between U & D2**	**Turbidity Removal Efficiency for D1 (%)**	**Turbidity Removal Efficiency for D2 (%)**	**Removal Efficiency for D2-Settled (%)**
Initial	0	282							
1	2	282	34	10	7	272	**88%**	**96%**	**98%**
2	4	289	11	15	9	274	**96%**	**95%**	**97%**
3	6	202	33	6	8	196	**84%**	**97%**	**96%**
4	8	267	25	9	9	258	**91%**	**97%**	**97%**
5	10	274	28	12	9	262	**90%**	**96%**	**97%**
6	12	287	46	15	11	272	**84%**	**95%**	**96%**
7	14	218	25	16	13	202	**89%**	**93%**	**94%**
8	16	187	47	25	11	162	**54%**	**87%**	**94%**
9	18	166	86	22	17	144	**48%**	**87%**	**90%**
AVERAGE	Average	**245.40**	**37.22**	**14.44**	**10.44**	**226.89**	**85%**	**94%**	**96%**

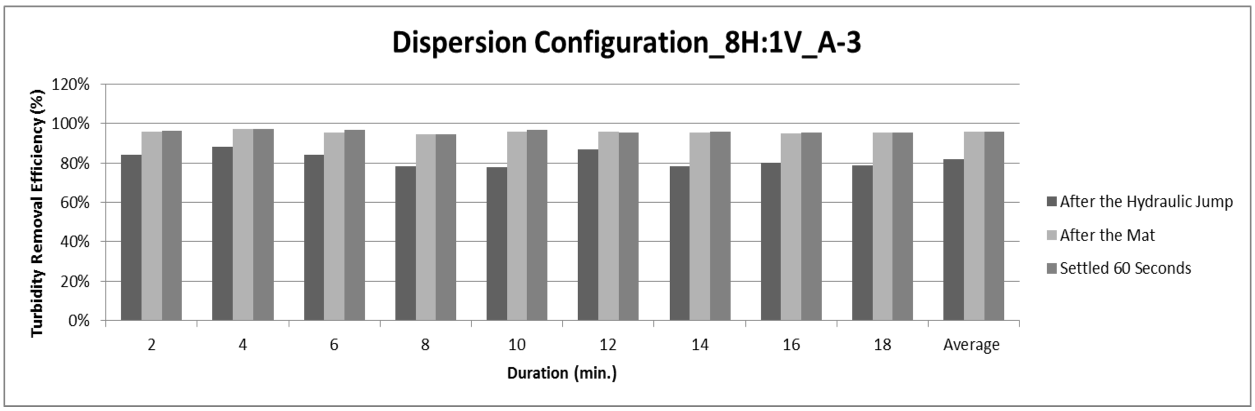


STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Ken, Travis, Scott
Date:	2/24/2011
PAM Type	706b
Soil Type:	A-3
Configuration	Dispersion
Slope	8H:1V

X_1	**48**	in.
X_2	**171**	in.
X_3	**138**	in.
X_4	**156**	in.
Back Water Depth from Hydraulic Jump:	**110**	in.

I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (ft.)***	***V (fps)***	***Energy_Rec (ft.)***
1	24	0.03	0.0469	2.9	0.1775
2	42	0.05	0.0729	0.7	0.0805
3	51.75	0.06	0.1094	3.3	0.2785
4	51.75	0.06	0.0417	1.9	0.0977
5a	141	0.16	0.0208	1.7	0.0657
5b	141	0.16	0.0781	2	0.1402
5c	141	0.16	0.0469	1.7	0.0918
6	220.5	0.26	0.1927	0.4	0.1952
7	220.5	0.26	0.0729	1.8	0.1232
8	223.5	0.26	0.2396	1.6	0.2793
9	234	0.27	0.1458	3	0.2856
10	366	0.43	0.0833	1.7	0.1282
11a	457.5	0.53	0.0365	1.4	0.0669
11b	457.5	0.53	0.0781	1.9	0.1342
11c	457.5	0.53	0.0313	1	0.0468
12	529.5	0.62	0.3021	1.2	0.3244
13	529.5	0.62	0.2500	0.8	0.2599
14	532.5	0.62	0.2760	0.4	0.2785
15	543	0.63	0.3542	0.7	0.3618
16a	610.5	0.71	0.6250	0.2	0.6256
16b	610.5	0.71	0.7135	0.2	0.7142
16c	610.5	0.71	0.7083	0.1	0.7085
17a	678	0.79	1.0833	0.1	1.0835
17b	678	0.79	1.0833	0.1	1.0835
17c	678	0.79	1.0833	0.1	1.0835

STORMWATER MANAGEMENT ACADEMY									
Turbidity (NTU)									
Researcher(s)	Rafiq Chowdhury								
Date:	24-Feb-11								
Date Completed:	28-Feb-11								
Slope:	8H:1V								
Polymer Type:	706b								
Configuration:	Dispersion, A-3								
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Diffence Between U & D2**	**Turbidity Removal Efficiency for D1 (%)**	**Turbidity Removal Efficiency for D2 (%)**	**Removal Efficiency for D2-Settled (%)**
Initial	0	325							
1	2	321	50	13	12	308	**84%**	**96%**	**96%**
2	4	313	37	9	8	304	**88%**	**97%**	**97%**
3	6	314	49	14	10	300	**84%**	**96%**	**97%**
4	8	257	56	14	14	243	**78%**	**95%**	**95%**
5	10	305	68	12	10	293	**78%**	**96%**	**97%**
6	12	306	40	12	14	294	**87%**	**96%**	**95%**
7	14	297	65	13	12	284	**78%**	**96%**	**96%**
8	16	290	70	14	13	276	**80%**	**95%**	**96%**
9	18	276	58	13	12	263	**79%**	**95%**	**96%**
AVERAGE	Average	**300.40**	**54.78**	**12.67**	**11.67**	**285.00**	**82%**	**96%**	**96%**

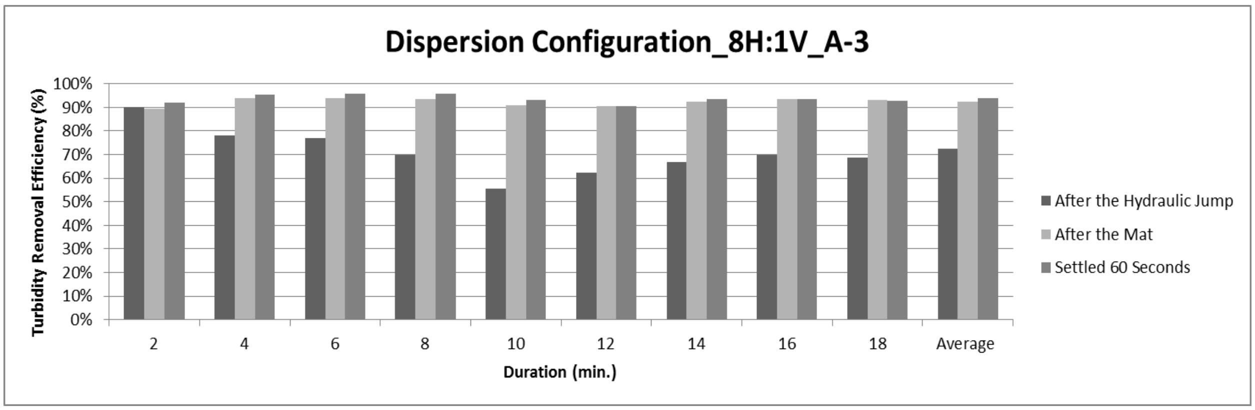


STORMWATER MANAGEMENT ACADEMY	
Researchers:	Scott, Ken, Travis, Mike
Date:	2/25/2011
PAM Type	706b
Soil Type:	A-3
Configuration	Dispersion
Slope	8H:1V

X_1	**48**	in.
X_2	**171**	in.
X_3	**138**	in.
X_4	**156**	in.
Back Water Depth from Hydraulic Jump:	**110**	in.

I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (ft.)***	***V (fps)***	***Energy_Rec (ft.)***
1	24	0.03	0.0313	1.6	0.0710
2	42	0.05	0.1875	0.3	0.1889
3	51.75	0.06	0.1719	3.3	0.3410
4	51.75	0.06	0.0625	1.7	0.1074
5a	141	0.16	0.0990	1.6	0.1387
5b	141	0.16	0.0938	1.2	0.1161
5c	141	0.16	0.0104	0.1	0.0106
6	220.5	0.26	0.2708	0.2	0.2715
7	220.5	0.26	0.0885	0.1	0.0887
8	223.5	0.26	0.2448	1.2	0.2672
9	234	0.27	0.1510	3	0.2908
10	366	0.43	0.0833	1	0.0989
11a	457.5	0.53	0.0260	2.5	0.1231
11b	457.5	0.53	0.0990	1.8	0.1493
11c	457.5	0.53	0.0781	0.5	0.0820
12	529.5	0.62	0.1667	1.2	0.1890
13	529.5	0.62	0.2188	0.3	0.2201
14	532.5	0.62	0.3125	0.9	0.3251
15	543	0.63	0.3646	0.8	0.3745
16a	610.5	0.71	0.4792	0.1	0.4793
16b	610.5	0.71	0.6146	0.3	0.6160
16c	610.5	0.71	0.6354	0.1	0.6356
17a	678	0.79	1.0833	0.1	1.0835
17b	678	0.79	1.0833	0.1	1.0835
17c	678	0.79	1.0833	0.1	1.0835

STORMWATER MANAGEMENT ACADEMY									
Turbidity (NTU)									
Researcher(s)	Scott Glancy and Travis Bates								
Date:	25-Feb-11								
Date Completed:	25-Feb-11								
Slope:	8H:1V								
Polymer Type:	706b								
Configuration:	Dispersion, A-3								
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Diffence Between U & D2**	**Turbidity Removal Efficiency for D1 (%)**	**Turbidity Removal Efficiency for D2 (%)**	**Removal Efficiency for D2-Settled (%)**
Initial	0	261							
1	2	245	24	26	20	219	**90%**	**89%**	**92%**
2	4	228	50	14	11	214	**78%**	**94%**	**95%**
3	6	229	53	14	10	215	**77%**	**94%**	**96%**
4	8	219	66	14	9	205	**70%**	**94%**	**96%**
5	10	218	97	20	15	198	**56%**	**91%**	**93%**
6	12	210	79	20	20	190	**62%**	**90%**	**90%**
7	14	201	67	15	13	186	**67%**	**93%**	**94%**
8	16	214	51	14	14	200	**70%**	**93%**	**93%**
9	18	207	65	14	15	193	**69%**	**93%**	**93%**
AVERAGE	Average	**223.20**	**61.33**	**16.78**	**14.11**	**202.22**	**73%**	**92%**	**94%**



Graphable Data Frame			
ID	Trial 1 - Left	Trial 2 - Left	Trial 3 - Left
3	0.254017857	0.278474379	0.340974379
5a	0.086768892	0.06570911	0.138709886
6	0.189984472	0.195192805	0.271454451
11a	0.076352226	0.066893116	0.123091356
12	0.271454451	0.324443582	0.189026915
16a	0.68765528	0.625621118	0.479321946
17a	1.083488613	1.083488613	1.083488613
18a	0.022360248	0.026242236	0.009937888

Is There a Significant Difference Between the Energy Values on the Left Side of the Channel Amongst the 3-Trials?

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	8	2.672082039	0.334010255	0.13464
Column 2	8	2.666064959	0.33325812	0.129608
Column 3	8	2.636005435	0.329500679	0.113615

ANOVA

rce of Varia	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between (	9.33876E-05	2	4.66938E-05	0.000371	0.999629355	3.4668
Within Gr(	2.645038588	21	0.125954218		NOT SIGNIFICANT	
Total	2.645131976	23				

Graphable Data Frame			
ID	Trial 1 - Right	Trial 2 - Right	Trial 3 - Right
4	0.164758023	0.097722567	0.107375776
5c	0.020354555	0.091750776	0.010571946
7	0.14078028	0.123227226	0.088696946
11c	0.05945264	0.04677795	0.082006988
13	0.267287785	0.259937888	0.220147516
16c	0.724113613	0.708488613	0.635571946
17c	1.083488613	1.083488613	1.083488613
18c	0.009937888	0.005590062	0.005590062

Is There a Significant Difference Between the Energy Values on the Right Side of the Channel Amongst the 3-Trials?

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	8	2.470173395	0.308771674	0.151146
Column 2	8	2.416983696	0.302122962	0.149802
Column 3	8	2.233449793	0.279181224	0.147013

ANOVA

ce of Varic	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between (	0.003856329	2	0.001928165	0.012913	0.987177928	3.4668
Within Gr(	3.135732484	21	0.149320594		NOT SIGNIFICANT	
Total	3.139588813	23				

Graphable Data Frame			
ID	Trial 1 - Center	Trial 2 - Center	Trial 3 - Center
1	0.221506211	0.177465062	0.071001553
2	0.209730849	0.080525362	0.188897516
5b	0.313108178	0.140236801	0.116110248
8	0.25316382	0.279334886	0.267151915
9	0.241530797	0.285584886	0.290793219
10	0.104321946	0.12820911	0.098861284
11b	0.057194617	0.134180901	0.149268892
14	0.367067805	0.278526139	0.32507764
15	0.483954451	0.361775362	0.374521222
16b	0.724113613	0.714162785	0.615980849
17b	1.083488613	1.083488613	1.083488613
18b	0.001397516	0.039751553	0.001397516

Is There a Significant Difference Between the Energy Values on the Center of the Channel Amongst the 3-Trials?

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	12	4.060578416	0.338381535	0.092808
Column 2	12	3.70324146	0.308603455	0.091169
Column 3	12	3.582550466	0.298545872	0.08836

ANOVA

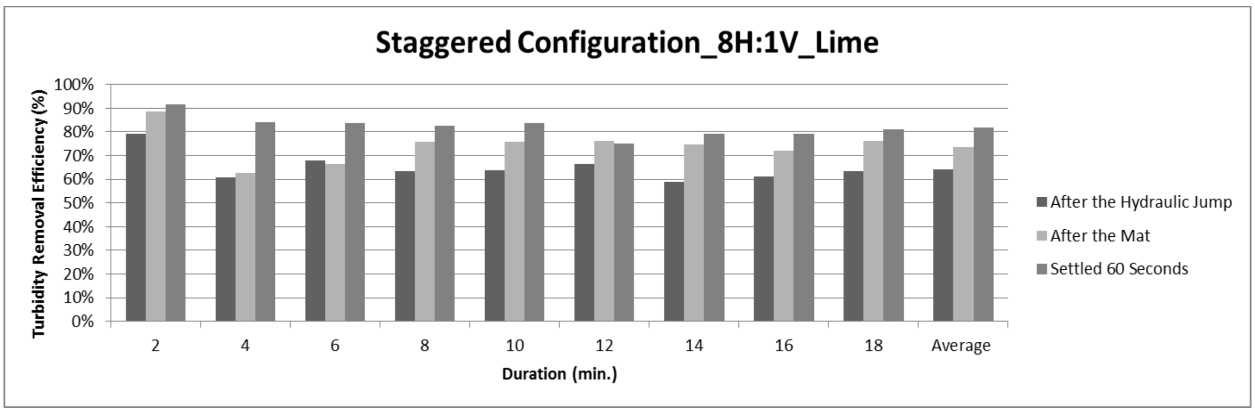
ce of Varic	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between (	0.010299076	2	0.005149538	0.056726	0.944944662	3.284918
Within Gr(	2.995701352	33	0.090778829		NOT SIGNIFICANT	

Researchers:	Rafiq, Ken, Travis, Scott
Date:	3/15/2011
PAM Type	706b
Soil Type:	Lime
Configuration	Optimized
Slope	8H:1V

X_1	**138**	in.
X_2	**45**	in.
X_3	**45**	in.
X_4	**45**	in.
Back Water Depth from Hydraulic Jump:		

I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (ft.)***	***V (fps)***	***Energy_Rec (ft.)***
1	24	0.03	0.0521	2	0.1142
2	132	0.15	0.2344	3.7	0.4470
3a	141.75	0.17	0.0469	2.2	0.1220
3b	141.75	0.17	0.0677	0.8	0.0776
4a	168	0.20	0.0156	0.6	0.0212
4b	168	0.20	0.0260	3	0.1658
4c	168	0.20	0.0313	1.6	0.0710
5	237	0.28	0.2396	0.9	0.2522
6a	273	0.32	0.0417	0.9	0.0542
6b	273	0.32	0.0365	2.1	0.1049
6c	273	0.32	0.0417	1.8	0.0920
7	289.5	0.34	0.1458	2.2	0.2210
8a	299.25	0.35	0.0208	1.6	0.0606
8b	299.25	0.35	0.0469	2	0.1090
9a	378	0.44	0.0052	1.1	0.0240
9b	378	0.44	0.0365	1.6	0.0762
9c	378	0.44	0.0208	1.7	0.0657
10	394.5	0.46	0.1042	1.1	0.1230
11a	404.25	0.47	0.0885	1.3	0.1148
11b	404.25	0.47	0.0208	1.3	0.0471
12a	543	0.63	0.0260	0.3	0.0274
12b	543	0.63	0.0208	1.6	0.0606
12c	543	0.63	0.0313	1.9	0.0873
13a	678	0.79	1.0833	0.1	1.0835
13b	678	0.79	1.0833	0.1	1.0835
13c	678	0.79	1.0833	0.1	1.0835

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Rafiq Chowdhury							
Date:	15-Mar-11							
Date Completed:	31-Mar-11							
Slope:	8H:1V							
Polymer Type:	706b							
Configuration:	Optimized, Lime							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Removal Efficiency for D1 (%)**	**Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	219						
1	2	300	62.1	34.1	25.1	**79%**	**89%**	**92%**
2	4	292	115	109	46	**61%**	**63%**	**84%**
3	6	307	98.1	103	50.6	**68%**	**66%**	**84%**
4	8	305	112	73.9	53.7	**63%**	**76%**	**82%**
5	10	299	108	71.9	49	**64%**	**76%**	**84%**
6	12	311	104	74.3	77.4	**67%**	**76%**	**75%**
7	14	303	124	77.2	63.6	**59%**	**75%**	**79%**
8	16	295	111	82.7	61.3	**61%**	**72%**	**79%**
9	18	314	115	75.2	59.1	**63%**	**76%**	**81%**
AVERAGE	Average	**294.50**	**105.47**	**77.92**	**53.98**	**64%**	**74%**	**82%**

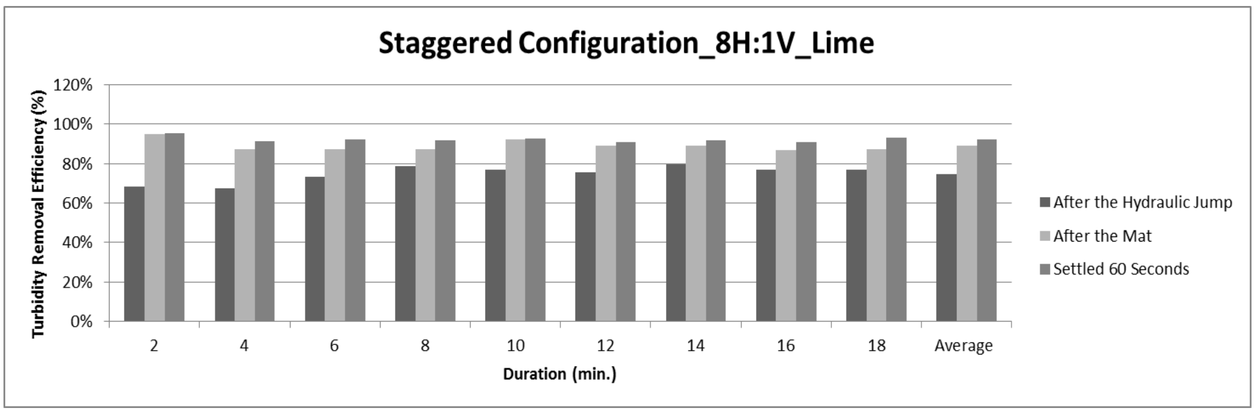


STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Ken, Travis, Asaph
Date:	3/16/2011
PAM Type	706b
Soil Type:	Lime
Configuration	Optimized
Slope	8H:1V

X_1	**138**	in.
X_2	**45**	in.
X_3	**45**	in.
X_4	**45**	in.
Back Water Depth from Hydraulic Jump:		in.

I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (ft.)***	***V (fps)***	***Energy_Rec (ft.)***
1	24	0.03	0.0521	2.4	0.1415
2	132	0.15	0.2344	0.3	0.2358
3a	141.75	0.17	0.0365	2.2	0.1116
3b	141.75	0.17	0.0469	0.3	0.0483
4a	168	0.20	0.0677	1.1	0.0865
4b	168	0.20	0.0469	2	0.1090
4c	168	0.20	0.0313	2.2	0.1064
5	237	0.28	0.2708	1.2	0.2932
6a	273	0.32	0.0104	0.3	0.0118
6b	273	0.32	0.0625	1.6	0.1023
6c	273	0.32	0.0313	2.6	0.1362
7	289.5	0.34	0.0833	0.5	0.0872
8a	299.25	0.35	0.1458	0.3	0.1472
8b	299.25	0.35	0.0990	2.1	0.1674
9a	378	0.44	0.0677	0.9	0.0803
9b	378	0.44	0.0573	2	0.1194
9c	378	0.44	0.0208	1.7	0.0657
10	394.5	0.46	0.1250	0.2	0.1256
11a	404.25	0.47	0.0990	2	0.1611
11b	404.25	0.47	0.0156	1	0.0312
12a	543	0.63	0.0573	2.3	0.1394
12b	543	0.63	0.0625	1	0.0780
12c	543	0.63	0.0104	0.6	0.0160
13a	678	0.79	1.0833	0.1	1.0835
13b	678	0.79	1.0833	0.1	1.0835
13c	678	0.79	1.0833	0.1	1.0835

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Scott Glancy & Travis Bates							
Date:	16-Mar-11							
Date Completed:	31-Mar-11							
Slope:	8H:1V							
Polymer Type:	706b							
Configuration:	Optimized, Lime							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Removal Efficiency for D1 (%)**	**Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	564						
1	2	707	223	33.6	33	**68%**	**95%**	**95%**
2	4	690	223	87.4	59.5	**68%**	**87%**	**91%**
3	6	692	184	86.2	54	**73%**	**88%**	**92%**
4	8	707	151	89	57.3	**79%**	**87%**	**92%**
5	10	703	163	53	49.5	**77%**	**92%**	**93%**
6	12	692	169	73.9	61	**76%**	**89%**	**91%**
7	14	647	131	70.5	53.1	**80%**	**89%**	**92%**
8	16	649	120	84.7	59	**77%**	**87%**	**91%**
9	18	648	149	83.3	44.5	**77%**	**87%**	**93%**
AVERAGE	Average	**669.90**	**168.11**	**73.51**	**52.32**	**75%**	**89%**	**92%**

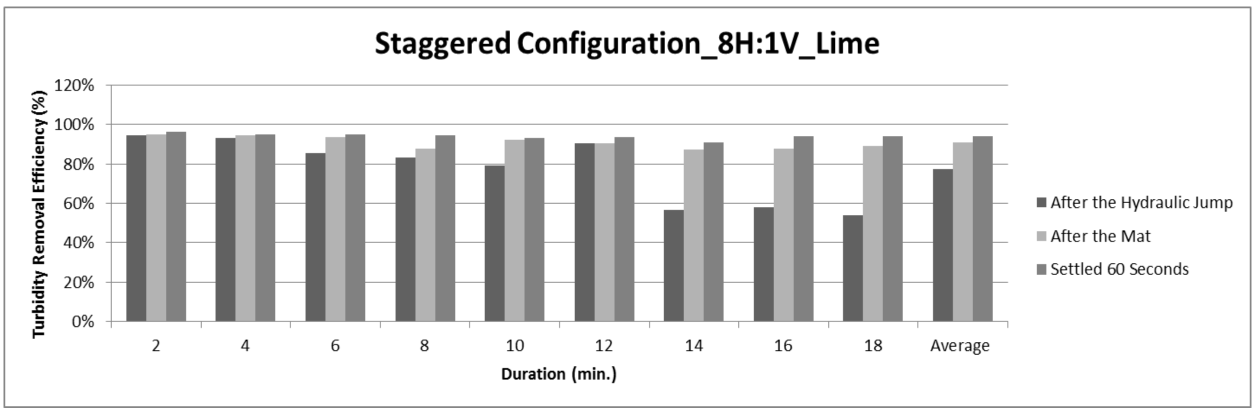


STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Ken, Travis, Asaph
Date:	3/17/2011
PAM Type	706b
Soil Type:	Lime
Configuration	Optimized
Slope	8H:1V

X_1	**138**	in.
X_2	**45**	in.
X_3	**45**	in.
X_4	**45**	in.
Back Water Depth from Hydraulic Jump:		in.

I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (ft.)***	***V (fps)***	***Energy_Rec (ft.)***
1	24	0.03	0.0521	1.4	0.0825
2	132	0.15	0.1875	0.3	0.1889
3a	141.75	0.17	0.0208	0.3	0.0222
3b	141.75	0.17	0.0625	2.3	0.1446
4a	168	0.20	0.0208	0.2	0.0215
4b	168	0.20	0.0625	2.8	0.1842
4c	168	0.20	0.0208	1.3	0.0471
5	237	0.28	0.2865	2.3	0.3686
6a	273	0.32	0.0208	1.6	0.0606
6b	273	0.32	0.0573	2.2	0.1324
6c	273	0.32	0.0052	1	0.0207
7	289.5	0.34	0.1406	1.3	0.1669
8a	299.25	0.35	0.0365	1.4	0.0669
8b	299.25	0.35	0.0625	1.7	0.1074
9a	378	0.44	0.0052	1	0.0207
9b	378	0.44	0.0625	2.3	0.1446
9c	378	0.44	0.0260	2.2	0.1012
10	394.5	0.46	0.1302	0.5	0.1341
11a	404.25	0.47	0.0781	2.3	0.1603
11b	404.25	0.47	0.0260	1	0.0416
12a	543	0.63	0.0104	2.9	0.1410
12b	543	0.63	0.1146	1.2	0.1369
12c	543	0.63	0.0156	0.8	0.0256
13a	678	0.79	1.0833	0.1	1.0835
13b	678	0.79	1.0833	0.1	1.0835
13c	678	0.79	1.0833	0.1	1.0835

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Scott Glancy & Travis Bates							
Date:	17-Mar-11							
Date Completed:	21-Mar-11							
Slope:	8H:1V							
Polymer Type:	706b							
Configuration:	Optimized, Lime							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Turbidity Removal Efficiency for D1 (%)**	**Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	261						
1	2	287	16	14	11	**94%**	**95%**	**96%**
2	4	247	17	13	12	**93%**	**95%**	**95%**
3	6	268	39	17	13	**85%**	**94%**	**95%**
4	8	279	47	34	15	**83%**	**88%**	**95%**
5	10	263	55	20	18	**79%**	**92%**	**93%**
6	12	290	28	28	18	**90%**	**90%**	**94%**
7	14	281	122	36	26	**57%**	**87%**	**91%**
8	16	282	111	34	17	**58%**	**88%**	**94%**
9	18	257	118	28	15	**54%**	**89%**	**94%**
AVERAGE	Average	**271.50**	**61.44**	**24.89**	**16.11**	**77%**	**91%**	**94%**

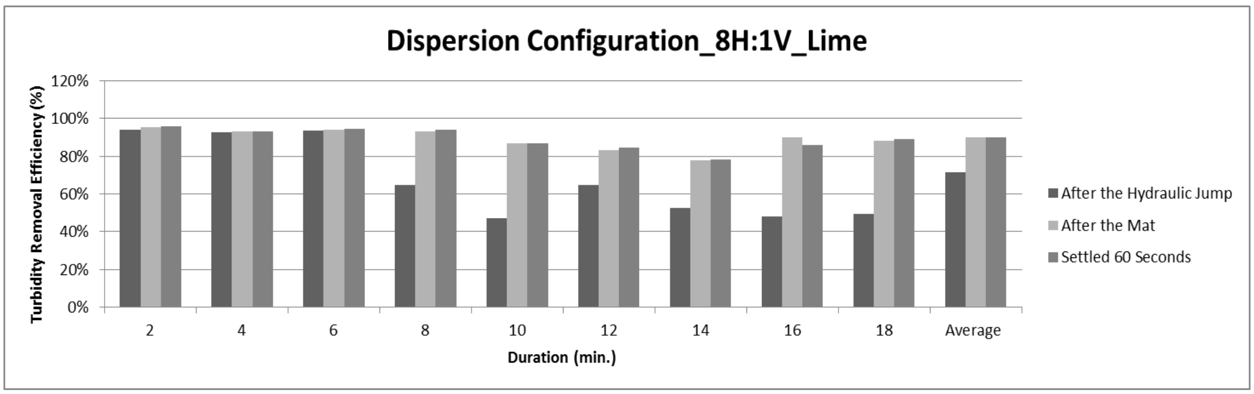


STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Ken, Scott, Travis
Date:	3/18/2011
PAM Type	706b
Soil Type:	Lime
Configuration	Dispersion
Slope	8H:1V

X_1	**48**	in.
X_2	**171**	in.
X_3	**138**	in.
X_4	**156**	in.
Back Water Depth from Hydraulic Jump:	**109**	in.

I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (ft.)***	***V (fps)***	***Energy_Rec (ft.)***
1	24	0.03	0.0573	2.3	0.1394
2	42	0.05	0.2188	2	0.2809
3	51.75	0.06	0.1250	2.6	0.2300
4	51.75	0.06	0.0938	2.3	0.1759
5a	141	0.16	0.0625	4.4	0.3631
5b	141	0.16	0.0260	1.6	0.0658
5c	141	0.16	0.0052	0.1	0.0054
6	220.5	0.26	0.1563	2	0.2184
7	220.5	0.26	0.1146	0.2	0.1152
8	223.5	0.26	0.1667	3	0.3064
9	234	0.27	0.1146	3.5	0.3048
10	366	0.43	0.2083	1.5	0.2433
11a	457.5	0.53	0.0573	1.6	0.0970
11b	457.5	0.53	0.0625	1.7	0.1074
11c	457.5	0.53	0.0156	0.1	0.0158
12	529.5	0.62	0.2969	2.1	0.3654
13	529.5	0.62	0.1719	0.3	0.1733
14	532.5	0.62	0.1771	2.4	0.2665
15	543	0.63	0.1667	3	0.3064
16a	610.5	0.71	0.5156	0.2	0.5162
16b	610.5	0.71	0.5625	0.3	0.5639
16c	610.5	0.71	0.5000	0.1	0.5002
17a	678	0.79	1.0833	0.1	1.0835
17b	678	0.79	1.0833	0.1	1.0835
17c	678	0.79	1.0833	0.1	1.0835

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Scott Glancy & Travis Bates							
Date:	18-Mar-11							
Date Completed:	21-Mar-11							
Slope:	8H:1V							
Polymer Type:	706b							
Configuration:	Dispersion, Lime							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Removal Efficiency for D1 (%)**	**Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	470						
1	2	434	25	19	17	**94%**	**96%**	**96%**
2	4	336	25	22	22	**93%**	**93%**	**93%**
3	6	384	25	22	20	**93%**	**94%**	**95%**
4	8	380	134	26	23	**65%**	**93%**	**94%**
5	10	341	180	45	45	**47%**	**87%**	**87%**
6	12	331	117	56	51	**65%**	**83%**	**85%**
7	14	303	143	67	65	**53%**	**78%**	**79%**
8	16	276	120	28	38	**48%**	**90%**	**86%**
9	18	284	143	33	31	**50%**	**88%**	**89%**
AVERAGE	Average	**353.90**	**101.33**	**35.33**	**34.67**	**71%**	**90%**	**90%**

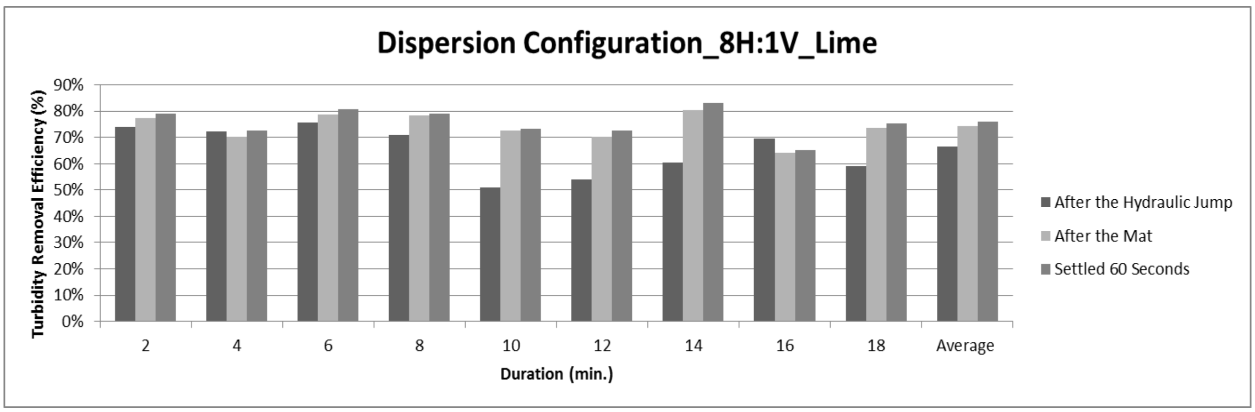


STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Ken, Nicole, Daniel, Rylee
Date:	3/23/2011
PAM Type	706b
Soil Type:	Lime
Configuration	Dispersion
Slope	8H:1V

X_1	**48**	in.
X_2	**171**	in.
X_3	**138**	in.
X_4	**156**	in.
Back Water Depth from Hydraulic Jump:	**109**	in.

I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (ft.)***	***V (fps)***	***Energy_Rec (ft.)***
1	24	0.03	0.0625	2.6	0.1675
2	42	0.05	0.1719	0.2	0.1725
3	51.75	0.06	0.0938	2	0.1559
4	51.75	0.06	0.0990	3.3	0.2681
5a	141	0.16	0.0625	3.8	0.2867
5b	141	0.16	0.0573	3.5	0.2475
5c	141	0.16	0.0052	0.1	0.0054
6	220.5	0.26	0.2240	0.5	0.2278
7	220.5	0.26	0.1823	0.6	0.1879
8	223.5	0.26	0.1198	2.4	0.2092
9	234	0.27	0.0990	3.4	0.2785
10	366	0.43	0.0990	0.8	0.1089
11a	457.5	0.53	0.0729	2.6	0.1779
11b	457.5	0.53	0.0833	3	0.2231
11c	457.5	0.53	0.0417	2.6	0.1466
12	529.5	0.62	0.2604	0.1	0.2606
13	529.5	0.62	0.3333	0.1	0.3335
14	532.5	0.62	0.3750	0.8	0.3849
15	543	0.63	0.5000	1.5	0.5349
16a	610.5	0.71	0.6563	0.1	0.6564
16b	610.5	0.71	0.6510	0.5	0.6549
16c	610.5	0.71	0.6667	0.1	0.6668
17a	678	0.79	1.0833	0.1	1.0835
17b	678	0.79	1.0833	0.1	1.0835
17c	678	0.79	1.0833	0.1	1.0835

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Rafiq Chowdhury							
Date:	23-Mar-11							
Date Completed:	24-Mar-11							
Slope:	8H:1V							
Polymer Type:	706b							
Configuration:	Dispersion, Lime							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Turbidity Removal Efficiency for D1 (%)**	**Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	156						
1	2	199	52	45	42	**74%**	**77%**	**79%**
2	4	158	44	47	43	**72%**	**70%**	**73%**
3	6	206	50	44	40	**76%**	**79%**	**81%**
4	8	172	50	37	36	**71%**	**78%**	**79%**
5	10	120	59	33	32	**51%**	**73%**	**73%**
6	12	135	62	40	37	**54%**	**70%**	**73%**
7	14	189	75	37	32	**60%**	**80%**	**83%**
8	16	167	48	60	58	**69%**	**64%**	**65%**
9	18	125	51	33	31	**59%**	**74%**	**75%**
AVERAGE	Average	**162.70**	**54.56**	**41.78**	**39.00**	**66%**	**74%**	**76%**

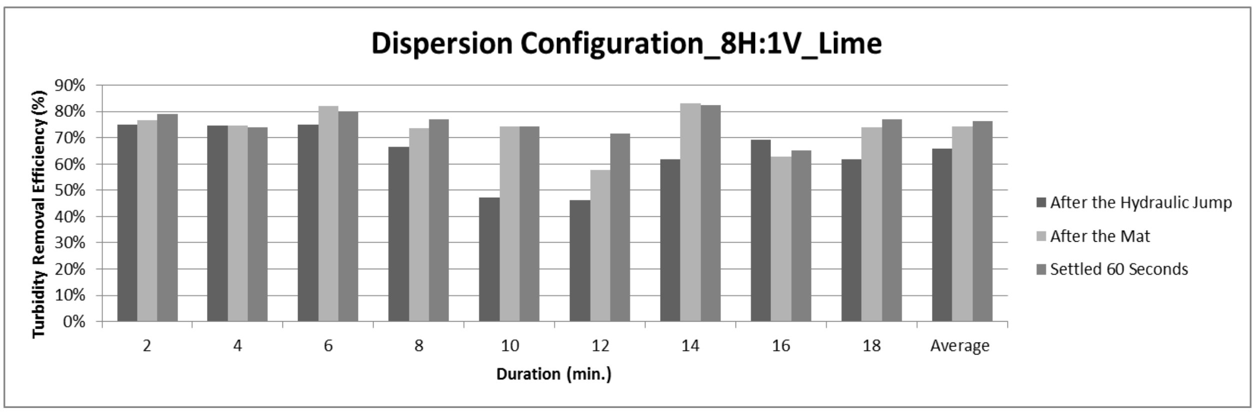


STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Ken, Nicole, Daniel, Rylee
Date:	3/23/2011
PAM Type	706b
Soil Type:	Lime
Configuration	Dispersion
Slope	8H:1V

X_1	**48**	in.
X_2	**171**	in.
X_3	**138**	in.
X_4	**156**	in.
Back Water Depth from Hydraulic Jump:	**109**	in.

I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (ft.)***	***V (fps)***	***Energy_Rec (ft.)***
1	24	0.03	0.0573	2.6	0.1623
2	42	0.05	0.1667	0.2	0.1673
3	51.75	0.06	0.0938	2	0.1559
4	51.75	0.06	0.0990	3.3	0.2681
5a	141	0.16	0.0625	3.8	0.2867
5b	141	0.16	0.0625	3.5	0.2527
5c	141	0.16	0.0052	0.1	0.0054
6	220.5	0.26	0.2240	0.5	0.2278
7	220.5	0.26	0.1823	0.6	0.1879
8	223.5	0.26	0.1198	2.3	0.2019
9	234	0.27	0.0990	3.2	0.2580
10	366	0.43	0.0938	0.6	0.0993
11a	457.5	0.53	0.0729	2.2	0.1481
11b	457.5	0.53	0.0833	3	0.2231
11c	457.5	0.53	0.0417	2.6	0.1466
12	529.5	0.62	0.2604	0.1	0.2606
13	529.5	0.62	0.3333	0.1	0.3335
14	532.5	0.62	0.3750	1.1	0.3938
15	543	0.63	0.4896	1.6	0.5293
16a	610.5	0.71	0.6563	0.1	0.6564
16b	610.5	0.71	0.6510	0.5	0.6549
16c	610.5	0.71	0.6667	0.1	0.6668
17a	678	0.79	1.0833	0.1	1.0835
17b	678	0.79	1.0833	0.1	1.0835
17c	678	0.79	1.0833	0.1	1.0835

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Rafiq Chowdhury							
Date:	23-Mar-11							
Date Completed:	24-Mar-11							
Slope:	8H:1V							
Polymer Type:	706b							
Configuration:	Dispersion, Lime							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Removal Efficiency for D1 (%)**	**Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	177						
1	2	201	50	47	42	**75%**	**77%**	**79%**
2	4	166	42	42	43	**75%**	**75%**	**74%**
3	6	201	50	36	40	**75%**	**82%**	**80%**
4	8	156	52	41	36	**67%**	**74%**	**77%**
5	10	125	66	32	32	**47%**	**74%**	**74%**
6	12	130	70	55	37	**46%**	**58%**	**72%**
7	14	183	70	31	32	**62%**	**83%**	**83%**
8	16	166	51	62	58	**69%**	**63%**	**65%**
9	18	134	51	35	31	**62%**	**74%**	**77%**
AVERAGE	Average	**163.90**	**55.78**	**42.33**	**39.00**	**66%**	**74%**	**76%**



Graphable Data Frame			
ID	Trial 1 - Left	Trial 2 - Left	Trial 3 - Left
3	0.229968944	0.155861801	
5a	0.363121118	0.286723602	
6	0.218361801	0.227840321	
11a	0.097043219	0.177885611	
12	0.365353261	0.260571946	
16a	0.516246118	0.65640528	
17a	1.083488613	1.083488613	
18a	0.026242236	0.12173913	

Is There a Significant Difference Between the Energy Values on the Left Side of the Channel Amongst the 3-Trials?

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	8	2.899825311	0.362478164	0.109335
Column 2	8	2.970516304	0.371314538	0.110657

ANOVA

ce of Varic	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between (	0.000312326	1	0.000312326	0.002839	0.958256684	4.60011
Within Gr(	1.539943417	14	0.109995958		NOT SIGNIFICANT	
Total	1.540255744	15				

Graphable Data Frame			
ID	Trial 1 - Right	Trial 2 - Right	Trial 3 - Right
4	0.175892857	0.268057712	
5c	0.005363613	0.005363613	
7	0.115204451	0.187881729	
11c	0.01578028	0.146635611	
13	0.173272516	0.333488613	
16c	0.50015528	0.666821946	
17c	1.083488613	1.083488613	
18c	0.034937888	0.005590062	

Is There a Significant Difference Between the Energy Values on the Right Side of the Channel Amongst the 3-Trials?

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	8	2.104095497	0.263011937	0.135205
Column 2	8	2.697327899	0.337165987	0.135583

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.021995293	1	0.021995293	0.162454	0.692995044	4.60011
Within Groups	1.895515828	14	0.135393988		NOT SIGNIFICANT	
Total	1.91751112	15				

Graphable Data Frame			
ID	Trial 1 - Center	Trial 2 - Center	Trial 3 - Center
1	0.139434524	0.167468944	
2	0.280861801	0.172496118	
5b	0.065793219	0.247509058	
8	0.306418219	0.20923266	
9	0.304800725	0.278461439	
10	0.243271222	0.108896222	
11b	0.107375776	0.223084886	
14	0.266524327	0.384937888	
15	0.306418219	0.534937888	
16b	0.563897516	0.654923654	
17b	1.083488613	1.083488613	
18b	0.026242236	0.07515528	

Is There a Significant Difference Between the Energy Values on the Center of the Channel Amongst the 3-Trials?

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	12	3.694526398	0.3078772	0.080022
Column 2	12	4.14059265	0.345049388	0.083287

ANOVA

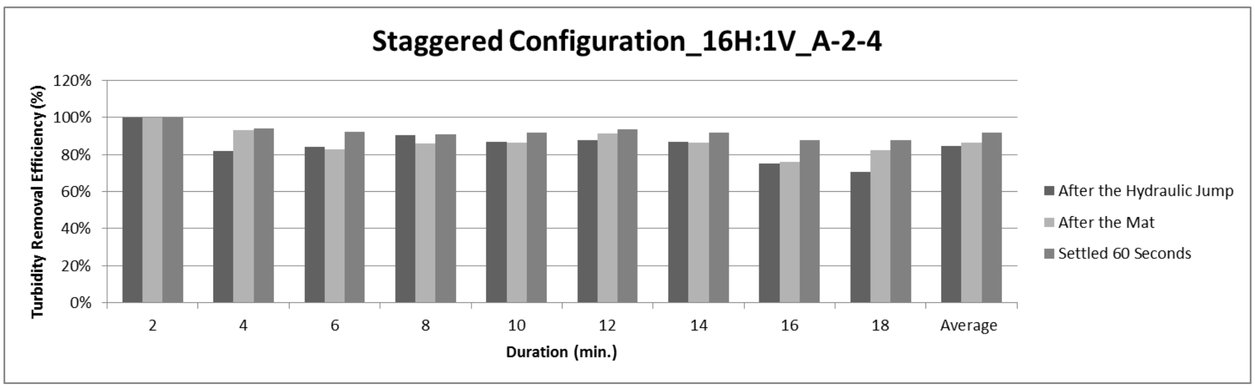
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.008290629	1	0.008290629	0.101533	0.753002919	4.30095
Within Groups	1.796397146	22	0.081654416		NOT SIGNIFICANT	
Total	1.804687775	23				

STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Scott, Travis, Ken
Date:	4/14/2011
PAM Type	706b
Soil Type:	A-2-4
Configuration	Optimized
Slope	16H:1V

X_1	**96**	in.
X_2	**64 1/2**	in.
X_3	**64 1/2**	in.
X_4	**64 1/2**	in.
Back Water Depth from Hydraulic Jump:		in.

I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (ft.)***	***V (fps)***	***Energy_Rec (ft.)***
1	24	0.03	0.0260	2.4	0.1155
2	90	0.12	0.1458	0.1	0.1460
3a	99.75	0.13	0.0573	2.6	0.1623
3b	99.75	0.13	0.0885	3.1	0.2378
4a	135.75	0.18	0.0000	0	0.0000
4b	135.75	0.18	0.0677	3	0.2075
4c	135.75	0.18	0.0417	2.9	0.1723
5	234	0.31	0.2500	1.1	0.2688
6a	279.75	0.38	0.0313	0.7	0.0389
6b	279.75	0.38	0.0417	2.8	0.1634
6c	279.75	0.38	0.0000	1.6	0.0398
7	306	0.41	0.1250	0.7	0.1326
8a	315.75	0.42	0.0573	0.9	0.0699
8b	315.75	0.42	0.0625	2.6	0.1675
9a	423.75	0.57	0.0260	0.9	0.0386
9b	423.75	0.57	0.0677	2.3	0.1499
9c	423.75	0.57	0.0313	1.3	0.0575
10	450	0.60	0.1979	0.1	0.1981
11a	459.75	0.62	0.2135	0.1	0.2137
11b	459.75	0.62	0.3646	0.1	0.3647
12a	543.75	0.73	0.5938	0.1	0.5939
12b	543.75	0.73	0.6094	0.1	0.6095
12c	543.75	0.73	0.6250	0.1	0.6252
13a	624	0.84	1.0000	0.3	1.0014
13b	624	0.84	1.0000	0.3	1.0014
13c	624	0.84	1.0000	0.1	1.0002

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Rafiq Chowdhury							
Date:	14-Apr-11							
Date Completed:	15-Apr-11							
Slope:	16H:1V							
Polymer Type:	706b							
Configuration:	Staggered, A-2-4							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Turbidity Removal Efficiency for D1 (%)**	**Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	328						
1	2	357				**100%**	**100%**	**100%**
2	4	351	64	24	20	**82%**	**93%**	**94%**
3	6	320	50	55	24	**84%**	**83%**	**93%**
4	8	328	31	46	29	**91%**	**86%**	**91%**
5	10	349	45	47	28	**87%**	**87%**	**92%**
6	12	334	40	28	21	**88%**	**92%**	**94%**
7	14	278	37	38	23	**87%**	**86%**	**92%**
8	16	241	53	58	29	**75%**	**76%**	**88%**
9	18	206	60	36	25	**71%**	**83%**	**88%**
AVERAGE	Average	**309.20**	**47.50**	**41.50**	**24.88**	**85%**	**87%**	**92%**

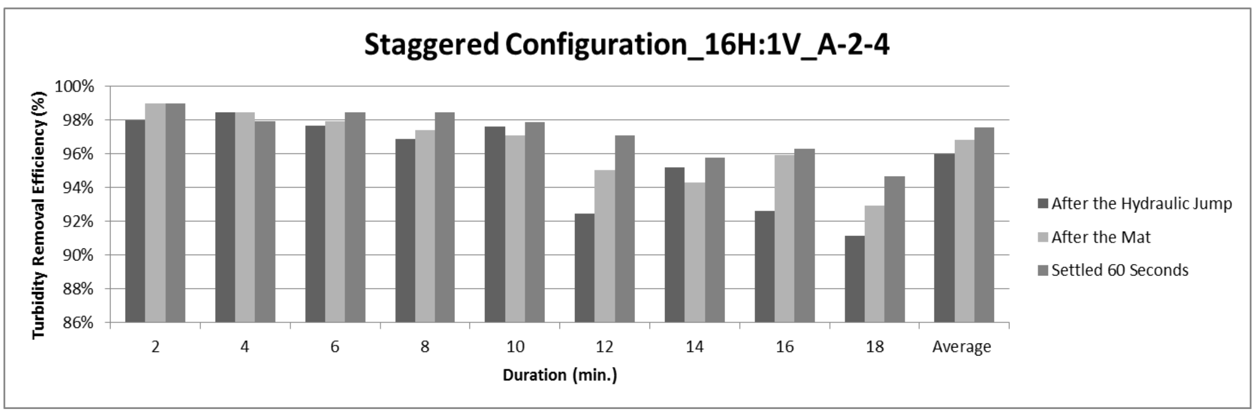


STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Scott, Travis, Mike
Date:	4/15/2011
PAM Type	706b
Soil Type:	A-2-4
Configuration	Optimized
Slope	16H:1V

X_1	**96**	in.
X_2	**64 1/2**	in.
X_3	**64 1/2**	in.
X_4	**64 1/2**	in.
Back Water Depth from Hydraulic Jump:		in.

I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (ft.)***	***V (fps)***	***Energy_Rec (ft.)***
1	24	0.03	0.0469	2.8	0.1686
2	90	0.12	0.2656	0.6	0.2712
3a	99.75	0.13	0.0625	2.2	0.1377
3b	99.75	0.13	0.0677	3.3	0.2368
4a	135.75	0.18	0.0000	0	0.0000
4b	135.75	0.18	0.0677	3	0.2075
4c	135.75	0.18	0.0156	3.3	0.1847
5	234	0.31	0.2031	0.2	0.2037
6a	279.75	0.38	0.0313	1.1	0.0500
6b	279.75	0.38	0.0573	2.7	0.1705
6c	279.75	0.38	0.0156	1.8	0.0659
7	306	0.41	0.0521	1.5	0.0870
8a	315.75	0.42	0.0365	1.6	0.0762
8b	315.75	0.42	0.0625	3	0.2023
9a	423.75	0.57	0.1563	0.3	0.1576
9b	423.75	0.57	0.1771	1	0.1926
9c	423.75	0.57	0.1042	1.5	0.1391
10	450	0.60	0.2240	0.1	0.2241
11a	459.75	0.62	0.2865	0.5	0.2903
11b	459.75	0.62	0.2865	0.2	0.2871
12a	543.75	0.73	0.6823	0.3	0.6837
12b	543.75	0.73	0.6823	0.1	0.6824
12c	543.75	0.73	0.6823	0.1	0.6824
13a	624	0.84	1.0000	0.1	1.0002
13b	624	0.84	1.0000	0.1	1.0002
13c	624	0.84	1.0000	0.1	1.0002

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Scott Glancy							
Date:	15-Apr-11							
Date Completed:	18-Apr-11							
Slope:	16H:1V							
Polymer Type:	706b							
Configuration:	Staggered, A-2-4							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Removal Efficiency for D1 (%)**	**Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	443						
1	2	392	8	4	4	**98%**	**99%**	**99%**
2	4	391	6	6	8	**98%**	**98%**	**98%**
3	6	388	9	8	6	**98%**	**98%**	**98%**
4	8	384	12	10	6	**97%**	**97%**	**98%**
5	10	376	9	11	8	**98%**	**97%**	**98%**
6	12	344	26	17	10	**92%**	**95%**	**97%**
7	14	332	16	19	14	**95%**	**94%**	**96%**
8	16	270	23	11	10	**93%**	**96%**	**96%**
9	18	226	20	16	12	**91%**	**93%**	**95%**
AVERAGE	Average	**354.60**	**14.33**	**11.33**	**8.67**	**96%**	**97%**	**98%**

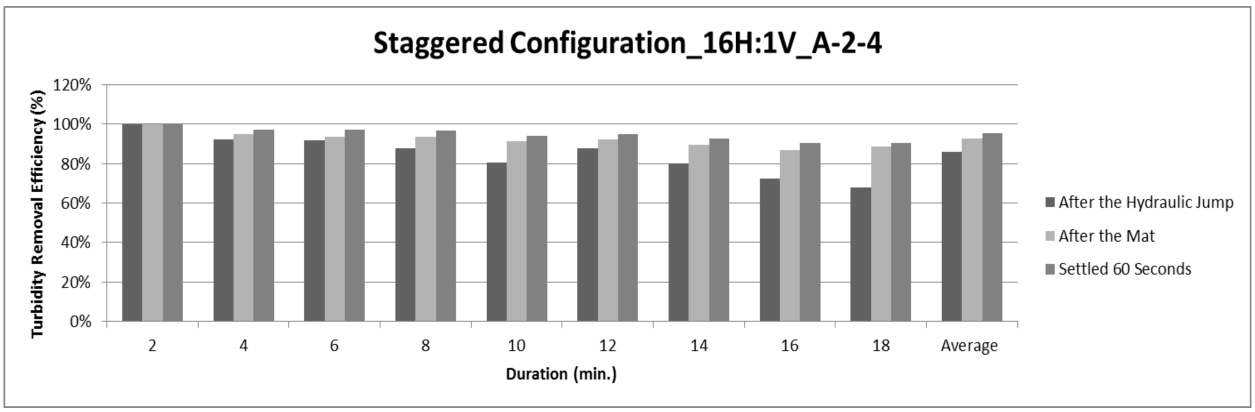


STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Daniel, Scott, Travis
Date:	4/16/2011
PAM Type	706b
Soil Type:	A-2-4
Configuration	Optimized
Slope	16H:1V

X_1	**96**	in.
X_2	**64 1/2**	in.
X_3	**64 1/2**	in.
X_4	**64 1/2**	in.
Back Water Depth from Hydraulic Jump:		in.

I.D.	*Length from H_2O Entrance (in.)*	*Distance/Length of Channel*	*Height (ft.)*	*V (fps)*	*Energy_Rec (ft.)*
1	24	0.03	0.0469	2.4	0.1363
2	90	0.12	0.1250	0.1	0.1252
3a	99.75	0.13	0.1042	2.8	0.2259
3b	99.75	0.13	0.0625	3.4	0.2420
4a	135.75	0.18	0.0000	0	0.0000
4b	135.75	0.18	0.0885	2.6	0.1935
4c	135.75	0.18	0.0365	3.5	0.2267
5	234	0.31	0.1823	0.4	0.1848
6a	279.75	0.38	0.0313	2	0.0934
6b	279.75	0.38	0.0260	3	0.1658
6c	279.75	0.38	0.0260	2.7	0.1392
7	306	0.41	0.0781	0.1	0.0783
8a	315.75	0.42	0.0104	2.2	0.0856
8b	315.75	0.42	0.0938	2.9	0.2243
9a	423.75	0.57	0.1198	0.1	0.1199
9b	423.75	0.57	0.1667	1.4	0.1971
9c	423.75	0.57	0.1042	1.3	0.1304
10	450	0.60	0.2396	0.2	0.2402
11a	459.75	0.62	0.2604	0.2	0.2610
11b	459.75	0.62	0.3438	0.5	0.3476
12a	543.75	0.73	0.6250	0.3	0.6264
12b	543.75	0.73	0.6250	0.4	0.6275
12c	543.75	0.73	0.5990	0.1	0.5991
13a	624	0.84	1.0000	0.1	1.0002
13b	624	0.84	1.0000	0.1	1.0002
13c	624	0.84	1.0000	0.1	1.0002

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Scott Glancy							
Date:	16-Apr-11							
Date Completed:	18-Apr-11							
Slope:	16H:1V							
Polymer Type:	706b							
Configuration:	Staggered, A-2-4							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Turbidity Removal Efficiency for D1 (%)**	**Turbidity Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	597						
1	2	427				**100%**	**100%**	**100%**
2	4	416	31	21	11	**93%**	**95%**	**97%**
3	6	379	30	24	11	**92%**	**94%**	**97%**
4	8	377	46	23	12	**88%**	**94%**	**97%**
5	10	347	68	30	20	**80%**	**91%**	**94%**
6	12	332	41	25	17	**88%**	**92%**	**95%**
7	14	276	55	29	20	**80%**	**89%**	**93%**
8	16	249	67	33	24	**72%**	**87%**	**90%**
9	18	215	69	24	20	**68%**	**89%**	**91%**
AVERAGE	Average	**361.50**	**50.88**	**26.13**	**16.88**	**86%**	**93%**	**95%**



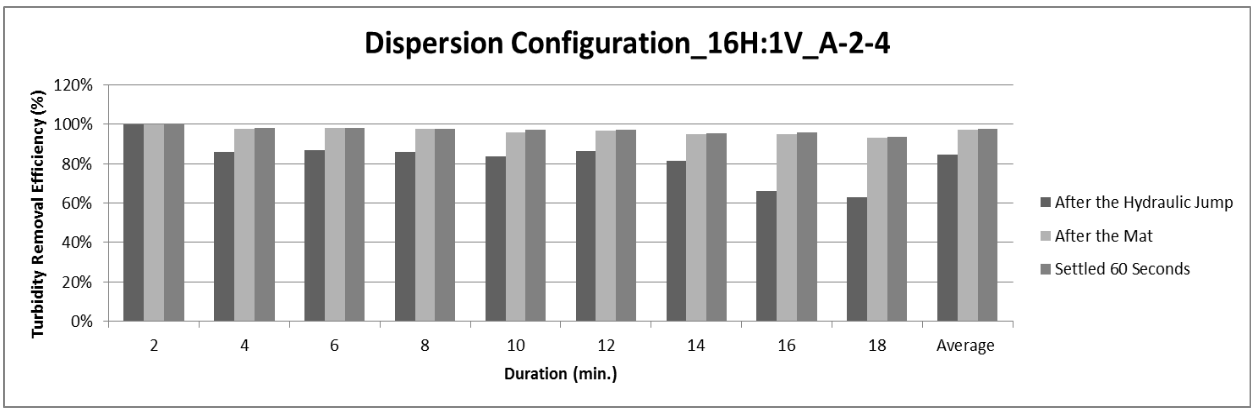
STORMWATER MANAGEMENT ACADEMY

Researchers:	Rafiq, Mike, Ken, Daniel, Travis
Date:	4/21/2011
PAM Type	706b
Soil Type:	A-2-4
Configuration	Dispersion
Slope	16H:1V

X_1	**48**	in.
X_2	**171**	in.
X_3	**138**	in.
X_4	**96**	in.
Back Water Depth from Hydraulic Jump:	**177**	in.

I.D.	*Length from H_2O Entrance (in.)*	*Distance/Length of Channel*	*Height (ft.)*	*V (fps)*	*Energy_Rec (ft.)*
1	24	0.03	0.0729	2.4	0.1624
2	42	0.06	0.1198	2.8	0.2415
3	51.75	0.07	0.0729	2.4	0.1624
4	51.75	0.07	0.0781	2.4	0.1676
5a	138	0.19	0.0365	1.2	0.0588
5b	138	0.19	0.0573	3	0.1970
5c	138	0.19	0.0260	3.3	0.1951
6	220.5	0.30	0.1615	0.1	0.1616
7	220.5	0.30	0.1458	0.4	0.1483
8	223.5	0.30	0.1771	2.8	0.2988
9	234	0.31	0.0625	2.7	0.1757
10	366	0.49	0.1458	0.7	0.1534
11a	424.5	0.57	0.0313	1.5	0.0662
11b	424.5	0.57	0.0729	1.5	0.1079
11c	424.5	0.57	0.0417	2.2	0.1168
12	469.5	0.63	0.2708	0.4	0.2733
13	469.5	0.63	0.3229	0.2	0.3235
14	472.5	0.64	0.3177	1.2	0.3401
15	483	0.65	0.3646	1.6	0.4043
16a	553.5	0.74	0.7083	2.7	0.8215
16b	553.5	0.74	0.7917	2.5	0.8887
16c	553.5	0.74	0.7083	2.9	0.8389
17a	624	0.84	1.0000	0.1	1.0002
17b	624	0.84	1.0000	0.1	1.0002
17c	624	0.84	1.0000	0.1	1.0002

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Rafiq Chowdhury							
Date:	21-Apr-11							
Date Completed:	26-Apr-11							
Slope:	16H:1V							
Polymer Type:	706b							
Configuration:	Dispersion, A-2-4							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Removal Efficiency for D1 (%)**	**Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	589						
1	2	414				**100%**	**100%**	**100%**
2	4	383	53	9	7	**86%**	**98%**	**98%**
3	6	358	47	7	6	**87%**	**98%**	**98%**
4	8	333	46	7	7	**86%**	**98%**	**98%**
5	10	257	42	10	7	**84%**	**96%**	**97%**
6	12	255	34	8	7	**87%**	**97%**	**97%**
7	14	213	39	11	10	**82%**	**95%**	**95%**
8	16	178	63	9	7	**66%**	**95%**	**96%**
9	18	163	60	11	10	**63%**	**93%**	**94%**
AVERAGE	Average	**314.30**	**48.00**	**9.00**	**7.63**	**85%**	**97%**	**98%**

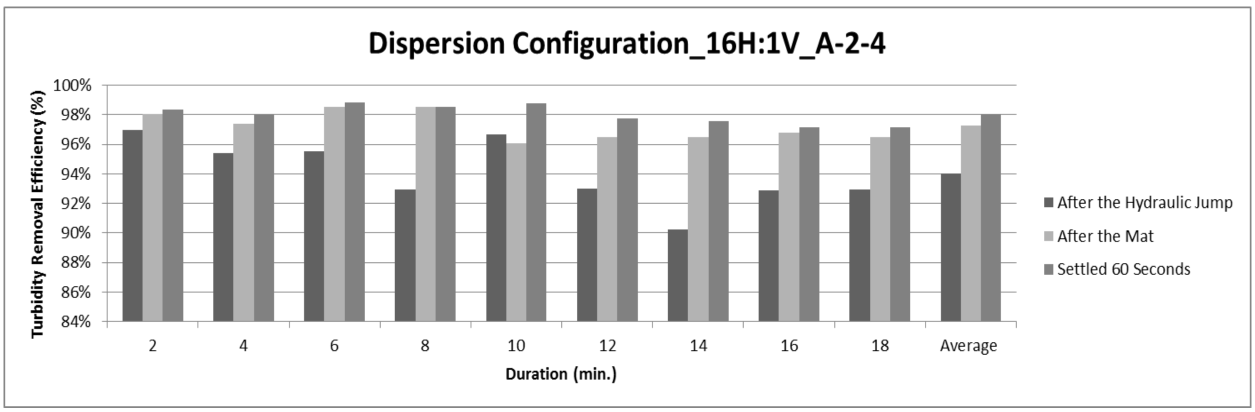


STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Mike, Travis, Ken
Date:	4/22/2011
PAM Type	706b
Soil Type:	A-2-4
Configuration	Dispersion
Slope	16H:1V

X_1	**48**	in.
X_2	**171**	in.
X_3	**138**	in.
X_4	**96**	in.
Back Water Depth from Hydraulic Jump:	**177**	in.

I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (ft.)***	***V (fps)***	***Energy_Rec (ft.)***
1	24	0.03	0.0573	2.1	0.1258
2	42	0.06	0.1146	2	0.1767
3	51.75	0.07	0.0833	3.1	0.2326
4	51.75	0.07	0.0885	2.8	0.2103
5a	138	0.19	0.0208	2	0.0829
5b	138	0.19	0.0156	1.5	0.0506
5c	138	0.19	0.0573	2.2	0.1324
6	220.5	0.30	0.3125	0.5	0.3164
7	220.5	0.30	0.3125	0.5	0.3164
8	223.5	0.30	0.3021	3.6	0.5033
9	234	0.31	0.1042	1.8	0.1545
10	366	0.49	0.1354	1.5	0.1704
11a	424.5	0.57	0.0156	2	0.0777
11b	424.5	0.57	0.0469	2.2	0.1220
11c	424.5	0.57	0.0260	0.7	0.0337
12	469.5	0.63	0.2813	0.1	0.2814
13	469.5	0.63	0.2917	0.1	0.2918
14	472.5	0.64	0.3125	1	0.3280
15	483	0.65	0.3594	1.6	0.3991
16a	553.5	0.74	0.6667	0.2	0.6673
16b	553.5	0.74	0.7865	0.1	0.7866
16c	553.5	0.74	0.6615	0.1	0.6616
17a	624	0.84	1.0000	0.1	1.0002
17b	624	0.84	1.0000	0.1	1.0002
17c	624	0.84	1.0000	0.2	1.0006

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Rafiq Chowdhury							
Date:	22-Apr-11							
Date Completed:	27-Apr-11							
Slope:	16H:1V							
Polymer Type:	706b							
Configuration:	Dispersion, A-2-4							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Turbidity Removal Efficiency for D1 (%)**	**Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	348						
1	2	360	11	7	6	**97%**	**98%**	**98%**
2	4	347	16	9	7	**95%**	**97%**	**98%**
3	6	337	15	5	4	**96%**	**99%**	**99%**
4	8	341	24	5	5	**93%**	**99%**	**99%**
5	10	332	11	13	4	**97%**	**96%**	**99%**
6	12	315	22	11	7	**93%**	**97%**	**98%**
7	14	287	28	10	7	**90%**	**97%**	**98%**
8	16	282	26	9	8	**93%**	**97%**	**97%**
9	18	283	20	10	8	**93%**	**96%**	**97%**
AVERAGE	Average	**323.20**	**19.22**	**8.78**	**6.22**	**94%**	**97%**	**98%**



Graphable Data Frame			
ID	Trial 1 - Left	Trial 2 - Left	Trial 3 - Left
3	0.16235766	0.232556936	0.123479555
5a	0.058818582	0.082945135	0.071680901
6	0.161613613	0.316381988	0.010798395
11a	0.066187888	0.077736801	0.088153468
12	0.273317805	0.28140528	0.283650362
16a	0.821532091	0.667287785	0.708488613
17a	1.00015528	1.00015528	1.00015528
18a	0.12173913	0.062111801	0.056055901

Is There a Significant Difference Between the Energy Values on the Left Side of the Channel Amongst the 3-Trials?

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	8	2.66572205	0.333215256	0.13383
Column 2	8	2.720581004	0.340072626	0.110077
Column 3	8	2.342462474	0.292807809	0.132607

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.010436662	2	0.005218331	0.041579	0.959352488	3.4668
Within Groups	2.635595399	21	0.125504543		NOT SIGNIFICANT	
Total	2.646032061	23				

Graphable Data Frame			
ID	Trial 1 - Right	Trial 2 - Right	Trial 3 - Right
4	0.167565994	0.210280797	0.180383023
5c	0.195141046	0.132446946	0.120593944
7	0.148317805	0.316381988	0.036840062
11c	0.116821946	0.033650362	0.092514234
13	0.323537785	0.291821946	0.226442805
16c	0.838923395	0.661613613	0.59390528
17c	1.00015528	1.000621118	1.00015528
18c	0.261024845	0.01257764	0.056055901

Is There a Significant Difference Between the Energy Values on the Right Side of the Channel Amongst the 3-Trials?

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	8	3.051488095	0.381436012	0.116396
Column 2	8	2.65939441	0.332424301	0.114748
Column 3	8	2.306890528	0.288361316	0.114176

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.034684249	2	0.017342125	0.150661	0.86106026	3.4668
Within Groups	2.417238112	21	0.115106577		NOT SIGNIFICANT	
Total	2.451922362	23				

Graphable Data Frame			
ID	Trial 1 - Center	Trial 2 - Center	Trial 3 - Center
1	0.16235766	0.125769928	0.041569617
2	0.241530797	0.176695135	0.110772516
5b	0.197043219	0.050562888	0.104936594
8	0.298822464	0.503325569	0.220697464
9	0.175698758	0.154477226	0.273253106
10	0.153442029	0.170354555	0.183190994
11b	0.107854555	0.12203028	0.162260611
14	0.340068582	0.32802795	0.375621118
15	0.404334886	0.359996118	0.418064182
16b	0.888716356	0.786613613	0.755363613
17b	1.00015528	1.00015528	1.00015528
18b	0.089440994	0.026242236	0.026242236

Is There a Significant Difference Between the Energy Values on the Center of the Channel Amongst the 3-Trials?

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	12	4.05946558	0.338288798	0.08935
Column 2	12	3.804250776	0.317020898	0.092876
Column 3	12	3.672127329	0.306010611	0.088364

ANOVA

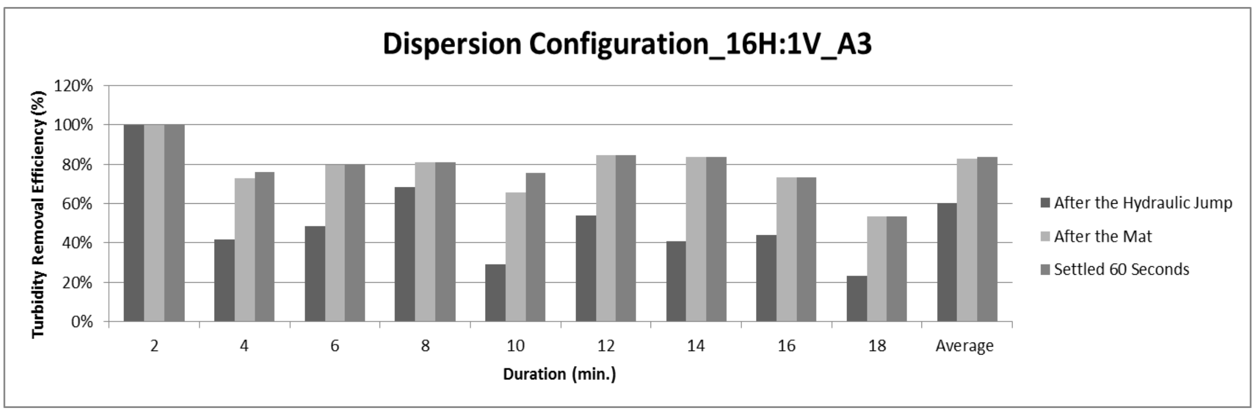
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.006461726	2	0.003230863	0.03582	0.964851314	3.284918
Within Groups	2.976499036	33	0.09019694		NOT SIGNIFICANT	
Total	2.982960761	35				

STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Travis, Nicole, Drew
Date:	4/27/2011
PAM Type	706b
Soil Type:	A3
Configuration	Dispersion
Slope	16H:1V

X_1	**48**	in.
X_2	**171**	in.
X_3	**138**	in.
X_4	**96**	in.
Back Water Depth from Hydraulic Jump:	**178**	in.

I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (ft.)***	***V (fps)***	***Energy_Rec (ft.)***
1	24	0.03	0.0313	2.4	0.1207
2	42	0.06	0.1510	1.2	0.1734
3	51.75	0.07	0.0990	1.7	0.1438
4	51.75	0.07	0.0781	2	0.1402
5a	138	0.19	0.0260	1	0.0416
5b	138	0.19	0.0208	2	0.0829
5c	138	0.19	0.0260	3.4	0.2055
6	220.5	0.30	0.1563	0.8	0.1662
7	220.5	0.30	0.1406	0.3	0.1420
8	223.5	0.30	0.0365	0.7	0.0441
9	234	0.31	0.0313	1	0.0468
10	366	0.49	0.1094	2.1	0.1779
11a	424.5	0.57	0.0469	2.3	0.1290
11b	424.5	0.57	0.0469	2.6	0.1518
11c	424.5	0.57	0.0260	1.6	0.0658
12	469.5	0.63	0.1458	0.4	0.1483
13	469.5	0.63	0.1667	0.4	0.1692
14	472.5	0.64	0.4167	0.8	0.4266
15	483	0.65	0.4271	1.4	0.4575
16a	553.5	0.74	0.4948	0.1	0.4949
16b	553.5	0.74	0.7083	0.1	0.7085
16c	553.5	0.74	0.7292	0.1	0.7293
17a	624	0.84	1.0000	0.1	1.0002
17b	624	0.84	1.0000	0.1	1.0002
17c	624	0.84	1.0000	0.1	1.0002

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Rafiq Chowdhury							
Date:	27-Apr-11							
Date Completed:	28-Apr-11							
Slope:	16H:1V							
Polymer Type:	706b							
Configuration:	Dispersion, A3							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Removal Efficiency for D1 (%)**	**Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	251						
1	2	49				**100%**	**100%**	**100%**
2	4	67	39	18	16	**42%**	**73%**	**76%**
3	6	64	33	13	13	**48%**	**80%**	**80%**
4	8	63	20	12	12	**68%**	**81%**	**81%**
5	10	41	29	14	10	**29%**	**66%**	**76%**
6	12	65	30	10	10	**54%**	**85%**	**85%**
7	14	56	33	9	9	**41%**	**84%**	**84%**
8	16	41	25	11	11	**44%**	**73%**	**73%**
9	18	30	23	14	14	**23%**	**53%**	**53%**
AVERAGE	Average	**72.70**	**29.00**	**12.63**	**11.88**	**60%**	**83%**	**84%**

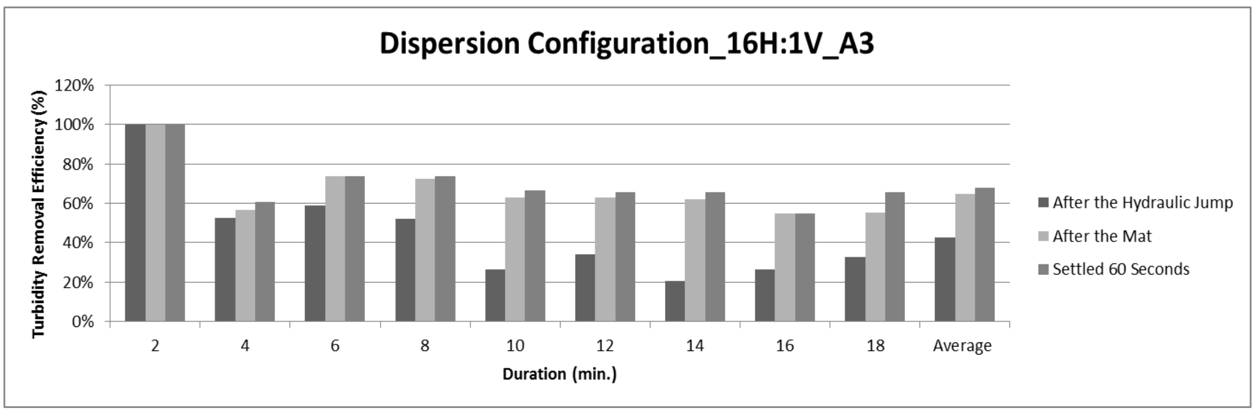


STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Travis, Drew H., Nicole
Date:	4/28/2011 (1)
PAM Type	706b
Soil Type:	A3
Configuration	Dispersion
Slope	16H:1V

X_1	**48**	in.
X_2	**171**	in.
X_3	**138**	in.
X_4	**96**	in.
Back Water Depth from Hydraulic Jump:	**178**	in.

I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (ft.)***	***V (fps)***	***Energy_Rec (ft.)***
1	24	0.03	0.0260	2.2	0.1012
2	42	0.06	0.1667	0.5	0.1705
3	51.75	0.07	0.1250	1.8	0.1753
4	51.75	0.07	0.0833	3.2	0.2423
5a	138	0.19	0.0677	2.3	0.1499
5b	138	0.19	0.0365	2	0.0986
5c	138	0.19	0.0729	2.7	0.1861
6	220.5	0.30	0.2708	0.6	0.2764
7	220.5	0.30	0.2656	0.1	0.2658
8	223.5	0.30	0.0469	0.4	0.0494
9	234	0.31	0.0417	1.3	0.0679
10	366	0.49	0.1875	0.8	0.1974
11a	424.5	0.57	0.0208	2.5	0.1179
11b	424.5	0.57	0.0469	2.3	0.1290
11c	424.5	0.57	0.0833	1.4	0.1138
12	469.5	0.63	0.1771	0.3	0.1785
13	469.5	0.63	0.1719	0.3	0.1733
14	472.5	0.64	0.3750	0.2	0.3756
15	483	0.65	0.4167	1.5	0.4516
16a	553.5	0.74	0.7083	0.1	0.7085
16b	553.5	0.74	0.7083	0.2	0.7090
16c	553.5	0.74	0.7083	0.1	0.7085
17a	624	0.84	1.0000	0.1	1.0002
17b	624	0.84	1.0000	0.1	1.0002
17c	624	0.84	1.0000	0.1	1.0002

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Travis Bates							
Date:	28-Apr-11							
Date Completed:	28-Apr-11							
Slope:	16H:1V							
Polymer Type:	706b							
Configuration:	Dispersion, A3							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Removal Efficiency for D1 (%)**	**Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	88						
1	2	72				**100%**	**100%**	**100%**
2	4	74	35	32	29	**53%**	**57%**	**61%**
3	6	73	30	19	19	**59%**	**74%**	**74%**
4	8	69	33	19	18	**52%**	**72%**	**74%**
5	10	57	42	21	19	**26%**	**63%**	**67%**
6	12	70	46	26	24	**34%**	**63%**	**66%**
7	14	58	46	22	20	**21%**	**62%**	**66%**
8	16	53	38	24	24	**26%**	**55%**	**55%**
9	18	58	39	26	20	**33%**	**55%**	**66%**
AVERAGE	Average	**67.20**	**38.63**	**23.63**	**21.63**	**43%**	**65%**	**68%**

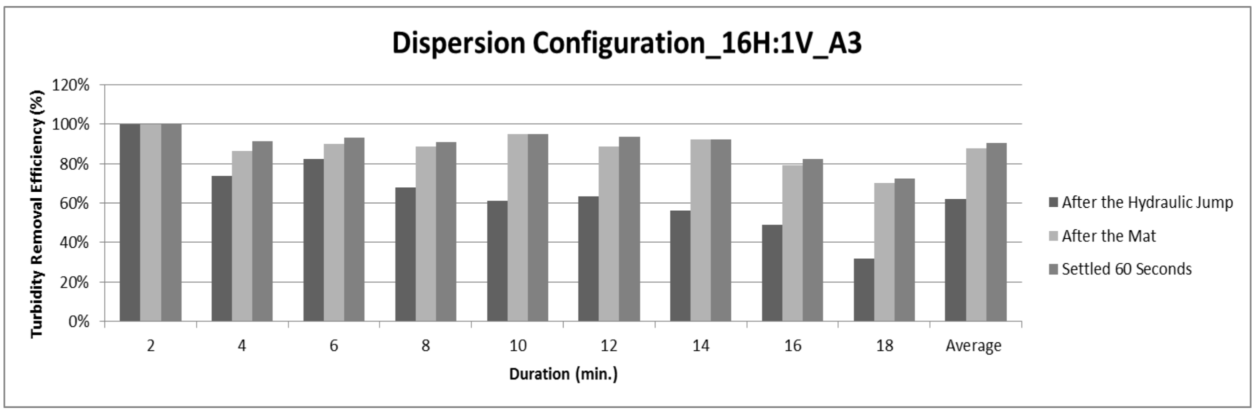


STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Travis, Drew H., Nicole
Date:	4/28/2011 (2)
PAM Type	706b
Soil Type:	A3
Configuration	Dispersion
Slope	16H:1V

X_1	**48**	in.
X_2	**171**	in.
X_3	**138**	in.
X_4	**96**	in.
Back Water Depth from Hydraulic Jump:	**177**	in.

I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (ft.)***	***V (fps)***	***Energy_Rec (ft.)***
1	24	0.03	0.0365	2.2	0.1116
2	42	0.06	0.1354	0.5	0.1393
3	51.75	0.07	0.0677	2.1	0.1362
4	51.75	0.07	0.0625	3	0.2023
5a	138	0.19	0.0521	2.6	0.1571
5b	138	0.19	0.0156	2.7	0.1288
5c	138	0.19	0.0365	2.6	0.1414
6	220.5	0.30	0.3073	0.5	0.3112
7	220.5	0.30	0.2656	0.3	0.2670
8	223.5	0.30	0.0625	0.2	0.0631
9	234	0.31	0.0521	1.1	0.0709
10	366	0.49	0.1146	1.3	0.1408
11a	424.5	0.57	0.0260	2.3	0.1082
11b	424.5	0.57	0.0417	3	0.1814
11c	424.5	0.57	0.0469	2.2	0.1220
12	469.5	0.63	0.1771	0.1	0.1772
13	469.5	0.63	0.3229	0.5	0.3268
14	472.5	0.64	0.4063	0.2	0.4069
15	483	0.65	0.4271	1.7	0.4720
16a	553.5	0.74	0.7083	0.1	0.7085
16b	553.5	0.74	0.7813	0.1	0.7814
16c	553.5	0.74	0.7917	0.1	0.7918
17a	624	0.84	1.0000	0.3	1.0014
17b	624	0.84	1.0000	0.2	1.0006
17c	624	0.84	1.0000	0.5	1.0039

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Rafiq Chowdhury							
Date:	28-Apr-11							
Date Completed:	2-May-11							
Slope:	16H:1V							
Polymer Type:	706b							
Configuration:	Dispersion, A3							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Removal Efficiency for D1 (%)**	**Turbidity Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	85						
1	2	78				**100%**	**100%**	**100%**
2	4	95	25	13	8	**74%**	**86%**	**92%**
3	6	102	18	10	7	**82%**	**90%**	**93%**
4	8	90	29	10	8	**68%**	**89%**	**91%**
5	10	82	32	4	4	**61%**	**95%**	**95%**
6	12	96	35	11	6	**64%**	**89%**	**94%**
7	14	91	40	7	7	**56%**	**92%**	**92%**
8	16	63	40	13	11	**49%**	**79%**	**83%**
9	18	47	32	14	13	**32%**	**70%**	**72%**
AVERAGE	Average	**82.90**	**31.38**	**10.25**	**8.00**	**62%**	**88%**	**90%**



Graphable Data Frame			
ID	Trial 1 - Left	Trial 2 - Left	Trial 3 - Left
3	0.14383411	0.175310559	0.136186594
5a	0.041569617	0.14985119	0.157052277
6	0.166187888	0.276423395	0.311173654
11a	0.129017857	0.117883023	0.108184524
12	0.148317805	0.178480849	0.177238613
16a	0.494946946	0.708488613	0.708488613
17a	1.00015528	1.00015528	1.001397516
18a	0.001397516	0.00015528	0.000621118

Is There a Significant Difference Between the Energy Values on the Left Side of the Channel Amongst the 3-Trials?

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	8	2.125427019	0.265678377	0.109898
Column 2	8	2.606748188	0.325843524	0.118318
Column 3	8	2.600342909	0.325042864	0.120384

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.019052342	2	0.009526171	0.081981	0.921582952	3.4668
Within Groups	2.440198329	21	0.11619992		NOT SIGNIFICANT	
Total	2.459250671	23				

Graphable Data Frame			
ID	Trial 1 - Right	Trial 2 - Right	Trial 3 - Right
4	0.140236801	0.242339545	0.202251553
5c	0.205544772	0.186115424	0.141427277
7	0.142022516	0.26578028	0.267022516
11c	0.065793219	0.113768116	0.12203028
13	0.169151139	0.173272516	0.326798654
16c	0.729321946	0.708488613	0.791821946
17c	1.00015528	1.00015528	1.003881988
18c	0.00015528	0.002484472	0.000621118

Is There a Significant Difference Between the Energy Values on the Right Side of the Channel Amongst the 3-Trials?

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	8	2.452380952	0.306547619	0.127925
Column 2	8	2.692404244	0.336550531	0.114731
Column 3	8	2.855855331	0.356981916	0.124167

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.010296626	2	0.005148313	0.042105	0.958850216	3.4668
Within Groups	2.567761591	21	0.122274361		NOT SIGNIFICANT	
Total	2.578058216	23				

Graphable Data Frame			
ID	Trial 1 - Center	Trial 2 - Center	Trial 3 - Center
1	0.120690994	0.101196946	0.111613613
2	0.173401915	0.170548654	0.139298654
5b	0.082945135	0.098570135	0.128823758
8	0.044067029	0.049359472	0.063121118
9	0.04677795	0.067908903	0.070872153
10	0.177853261	0.197437888	0.140825569
11b	0.151843944	0.129017857	0.181418219
14	0.426604555	0.375621118	0.406871118
15	0.427704451	0.416821946	0.427238613
16b	0.708488613	0.708954451	0.78140528
17b	1.00015528	1.00015528	1.000621118
18b	0.050310559	0.000621118	0.001397516

Is There a Significant Difference Between the Energy Values on the Center of the Channel Amongst the 3-Trials?

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	12	3.410843685	0.284236974	0.09187
Column 2	12	3.316213768	0.276351147	0.092094
Column 3	12	3.453506729	0.287792227	0.097839

ANOVA

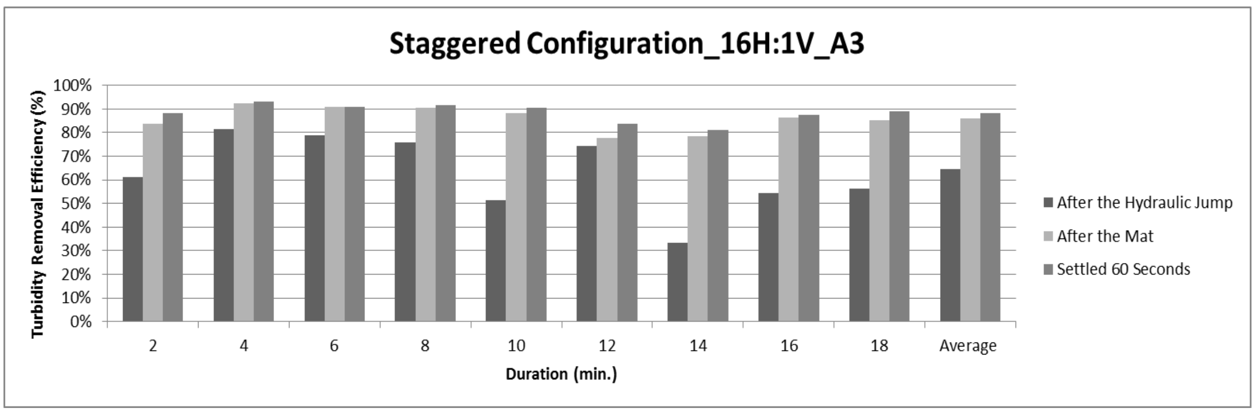
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.000822898	2	0.000411449	0.00438	0.995629987	3.284918
Within Groups	3.099836245	33	0.093934432		NOT SIGNIFICANT	
Total	3.100659142	35				

STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Matt, Mike, Drew H.
Date:	5/2/2011
PAM Type	706b
Soil Type:	A3
Configuration	Staggered
Slope	16H:1V

X_1	96	in.
X_2	64 1/2	in.
X_3	64 1/2	in.
X_4	64 1/2	in.

I.D.	*Length from H_2O Entrance (in.)*	*Distance/Length of Channel*	*Height (ft.)*	*V (fps)*	*Energy_Rec (ft.)*
1	24	0.03	0.0625	2.4	0.1519
2	90	0.12	*0.1250*	0.1	0.1252
3a	99.75	0.13	0.1406	3	0.2804
3b	99.75	0.13	0.1042	1.6	0.1439
4a	135.75	0.18	0.0052	0.1	0.0054
4b	135.75	0.18	0.0729	3	0.2127
4c	135.75	0.18	0.0833	2.1	0.1518
5	234	0.31	*0.0625*	0.1	0.0627
6a	279.75	0.38	0.0208	0.6	0.0264
6b	279.75	0.38	0.0365	1.7	0.0813
6c	279.75	0.38	0.0469	3.2	0.2059
7	306	0.41	*0.1042*	0.1	0.1043
8a	315.75	0.42	0.0469	1.4	0.0773
8b	315.75	0.42	0.0625	3	0.2023
9a	423.75	0.57	0.0104	0.1	0.0106
9b	423.75	0.57	0.0625	2.5	0.1595
9c	423.75	0.57	0.0313	3.5	0.2215
10	450	0.60	*0.1146*	0.6	0.1202
11a	459.75	0.62	0.1719	1.8	0.2222
11b	459.75	0.62	0.1667	0.1	0.1668
12a	543.75	0.73	0.6042	0.4	0.6067
12b	543.75	0.73	0.6667	0.1	0.6668
12c	543.75	0.73	0.6250	0.1	0.6252
13a	624	0.84	1.0000	0.1	1.0002
13b	624	0.84	1.0000	0.1	1.0002
13c	624	0.84	1.0000	0.1	1.0002

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Rafiq Chowdhury							
Date:	2-May-11							
Date Completed:	3-May-11							
Slope:	16H:1V							
Polymer Type:	706b							
Configuration:	Staggered, A3							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Removal Efficiency for D1 (%)**	**Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	84						
1	2	67	26	11	8	**61%**	**84%**	**88%**
2	4	103	19	8	7	**82%**	**92%**	**93%**
3	6	100	21	9	9	**79%**	**91%**	**91%**
4	8	107	26	10	9	**76%**	**91%**	**92%**
5	10	103	50	12	10	**51%**	**88%**	**90%**
6	12	98	25	22	16	**74%**	**78%**	**84%**
7	14	84	56	18	16	**33%**	**79%**	**81%**
8	16	103	34	14	13	**54%**	**86%**	**87%**
9	18	107	47	16	12	**56%**	**85%**	**89%**
AVERAGE	Average	**95.60**	**33.78**	**13.33**	**11.11**	**65%**	**86%**	**88%**

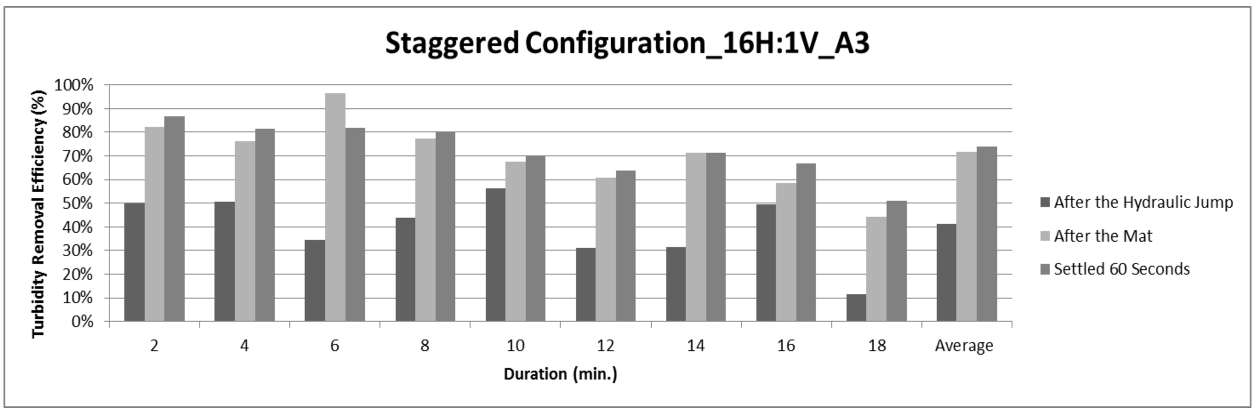


STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Drew H., Mike
Date:	5/3/2011
PAM Type	706b
Soil Type:	A3
Configuration	Optimized
Slope	16H:1V

X_1	**96**	in.
X_2	**64 1/2**	in.
X_3	**64 1/2**	in.
X_4	**64 1/2**	in.
Back Water Depth from Hydraulic Jump:		in.

I.D.	*Length from H_2O Entrance (in.)*	*Distance/Length of Channel*	*Height (ft.)*	*V (fps)*	*Energy_Rec (ft.)*
1	24	0.03	0.0625	1.8	0.1128
2	90	0.12	0.1042	0.5	0.1080
3a	99.75	0.13	0.1302	3.1	0.2794
3b	99.75	0.13	0.0990	1.8	0.1493
4a	135.75	0.18	0.0052	0.5	0.0091
4b	135.75	0.18	0.0104	0.1	0.0106
4c	135.75	0.18	0.0208	3.3	0.1899
5	234	0.31	0.0833	0.1	0.0835
6a	279.75	0.38	0.0313	0.4	0.0337
6b	279.75	0.38	0.0625	1.2	0.0849
6c	279.75	0.38	0.0833	3.2	0.2423
7	306	0.41	0.1146	0.1	0.1147
8a	315.75	0.42	0.0938	0.8	0.1037
8b	315.75	0.42	0.1146	2.9	0.2452
9a	423.75	0.57	0.0313	0.9	0.0438
9b	423.75	0.57	0.0365	3	0.1762
9c	423.75	0.57	0.0208	2.5	0.1179
10	450	0.60	0.0885	0.8	0.0985
11a	459.75	0.62	0.1302	0.2	0.1308
11b	459.75	0.62	0.1406	1.5	0.1756
12a	543.75	0.73	0.6823	0.1	0.6824
12b	543.75	0.73	0.7292	0.1	0.7293
12c	543.75	0.73	0.6771	0.4	0.6796
13a	624	0.84	1.0000	0.1	1.0002
13b	624	0.84	1.0000	0.1	1.0002
13c	624	0.84	1.0000	0.1	1.0002

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Rafiq Chowdhury							
Date:	3-May-11							
Date Completed:	4-May-11							
Slope:	16H:1V							
Polymer Type:	706b							
Configuration:	Staggered, A3							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Removal Efficiency for D1 (%)**	**Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	76						
1	2	90	45	16	12	**50%**	**82%**	**87%**
2	4	75	37	18	14	**51%**	**76%**	**81%**
3	6	55	36	2	10	**35%**	**96%**	**82%**
4	8	75	42	17	15	**44%**	**77%**	**80%**
5	10	80	35	26	24	**56%**	**68%**	**70%**
6	12	61	42	24	22	**31%**	**61%**	**64%**
7	14	73	50	21	21	**32%**	**71%**	**71%**
8	16	75	46	31	25	**49%**	**59%**	**67%**
9	18	43	38	24	21	**12%**	**44%**	**51%**
AVERAGE	Average	**70.30**	**41.22**	**19.89**	**18.22**	**41%**	**72%**	**74%**

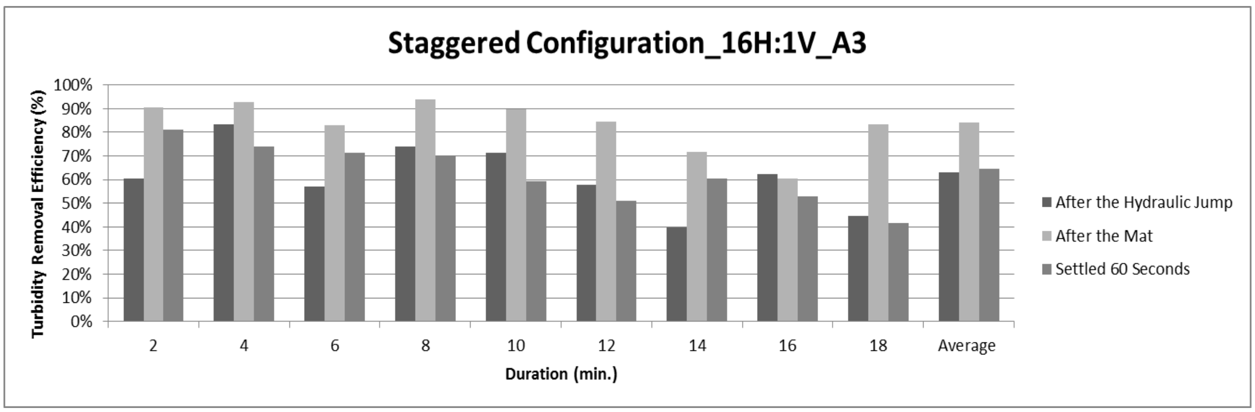


STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Drew H., Mike
Date:	5/4/2011
PAM Type	706b
Soil Type:	A3
Configuration	Optimized
Slope	16H:1V

X_1	**96**	in.
X_2	**64 1/2**	in.
X_3	**64 1/2**	in.
X_4	**64 1/2**	in.
Back Water Depth from Hydraulic Jump:		in.

I.D.	*Length from H_2O Entrance (in.)*	*Distance/Length of Channel*	*Height (ft.)*	*V (fps)*	*Energy_Rec (ft.)*
1	24	0.03	0.0313	2.6	0.1362
2	90	0.12	0.1354	0.8	0.1454
3a	99.75	0.13	0.1354	1.3	0.1617
3b	99.75	0.13	0.0625	1	0.0780
4a	135.75	0.18	0.0052	0.1	0.0054
4b	135.75	0.18	0.0521	3.2	0.2111
4c	135.75	0.18	0.0625	3.7	0.2751
5	234	0.31	0.0885	0.3	0.0899
6a	279.75	0.38	0.0156	0.3	0.0170
6b	279.75	0.38	0.0313	1	0.0468
6c	279.75	0.38	0.1302	2.4	0.2196
7	306	0.41	0.1354	0.4	0.1379
8a	315.75	0.42	0.0521	1.9	0.1081
8b	315.75	0.42	0.0781	2.8	0.1999
9a	423.75	0.57	0.0104	2	0.0725
9b	423.75	0.57	0.0677	2.9	0.1983
9c	423.75	0.57	0.0885	2.8	0.2103
10	450	0.60	0.1250	1.7	0.1699
11a	459.75	0.62	0.1302	0.8	0.1401
11b	459.75	0.62	0.1458	1.4	0.1763
12a	543.75	0.73	0.6667	0.3	0.6681
12b	543.75	0.73	0.6875	0.4	0.6900
12c	543.75	0.73	0.6615	0.1	0.6616
13a	624	0.84	1.0000	0.1	1.0002
13b	624	0.84	1.0000	0.1	1.0002
13c	624	0.84	1.0000	0.1	1.0002

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Rafiq Chowdhury							
Date:	4-May-11							
Date Completed:	10-May-11							
Slope:	16H:1V							
Polymer Type:	706b							
Configuration:	Staggered, A3							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Removal Efficiency for D1 (%)**	**Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	64						
1	2	63	25	6	12	**60%**	**90%**	**81%**
2	4	54	9	4	14	**83%**	**93%**	**74%**
3	6	35	15	6	10	**57%**	**83%**	**71%**
4	8	50	13	3	15	**74%**	**94%**	**70%**
5	10	59	17	6	24	**71%**	**90%**	**59%**
6	12	45	19	7	22	**58%**	**84%**	**51%**
7	14	53	32	15	21	**40%**	**72%**	**60%**
8	16	53	20	21	25	**62%**	**60%**	**53%**
9	18	36	20	6	21	**44%**	**83%**	**42%**
AVERAGE	Average	**51.20**	**18.89**	**8.22**	**18.22**	**63%**	**84%**	**64%**

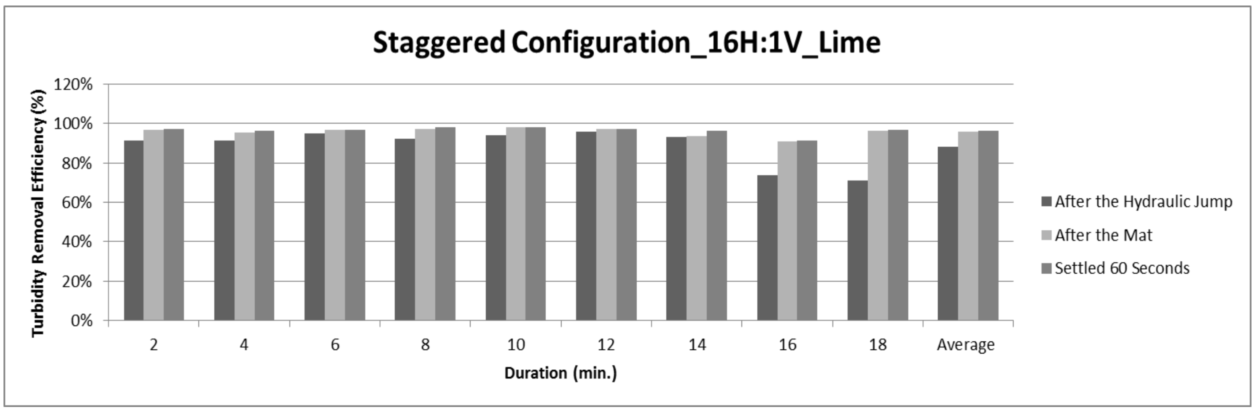


STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Drew H., Rylee, Daniel
Date:	5/5/2011
PAM Type	706b
Soil Type:	Limestone
Configuration	Staggered
Slope	16H:1V

X_1	**96**	in.
X_2	**64 1/2**	in.
X_3	**64 1/2**	in.
X_4	**64 1/2**	in.
Back Water Depth from Hydraulic Jump:		in.

I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (ft.)***	***V (fps)***	***Energy_Rec (ft.)***
1	24	0.03	0.0573	2.8	0.1790
2	90	0.12	0.1510	2.3	0.2332
3a	99.75	0.13	0.1042	3.3	0.2733
3b	99.75	0.13	0.0938	1.9	0.1498
4a	135.75	0.18	0.0052	2.5	0.1023
4b	135.75	0.18	0.0417	2.8	0.1634
4c	135.75	0.18	0.0365	3.2	0.1955
5	234	0.31	0.0417	0.2	0.0423
6a	279.75	0.38	0.0104	1.3	0.0367
6b	279.75	0.38	0.0677	2.2	0.1429
6c	279.75	0.38	0.0729	3.6	0.2742
7	306	0.41	0.1510	2.3	0.2332
8a	315.75	0.42	0.0677	2.4	0.1571
8b	315.75	0.42	0.0781	2.8	0.1999
9a	423.75	0.57	0.0625	1.6	0.1023
9b	423.75	0.57	0.0521	2.3	0.1342
9c	423.75	0.57	0.0625	3.5	0.2527
10	450	0.60	0.1198	2	0.1819
11a	459.75	0.62	0.0521	2.2	0.1272
11b	459.75	0.62	0.0729	2.4	0.1624
12a	543.75	0.73	0.6875	1.1	0.7063
12b	543.75	0.73	0.7500	0.1	0.7502
12c	543.75	0.73	0.6667	0.1	0.6668
13a	624	0.84	1.0000	0.1	1.0002
13b	624	0.84	1.0000	0.1	1.0002
13c	624	0.84	1.0000	0.1	1.0002

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Rafiq Chowdhury							
Date:	5-May-11							
Date Completed:	11-May-11							
Slope:	16H:1V							
Polymer Type:	706b							
Configuration:	Staggered, Limestone							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Turbidity Removal Efficiency for D1 (%)**	**Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	279						
1	2	259	22	8	7	**92%**	**97%**	**97%**
2	4	281	24	13	10	**91%**	**95%**	**96%**
3	6	293	15	9	9	**95%**	**97%**	**97%**
4	8	312	24	8	6	**92%**	**97%**	**98%**
5	10	310	18	6	6	**94%**	**98%**	**98%**
6	12	290	12	8	8	**96%**	**97%**	**97%**
7	14	264	18	17	10	**93%**	**94%**	**96%**
8	16	261	90	24	22	**74%**	**91%**	**92%**
9	18	234	68	8	7	**71%**	**97%**	**97%**
AVERAGE	Average	**278.30**	**32.33**	**11.22**	**9.44**	**88%**	**96%**	**97%**

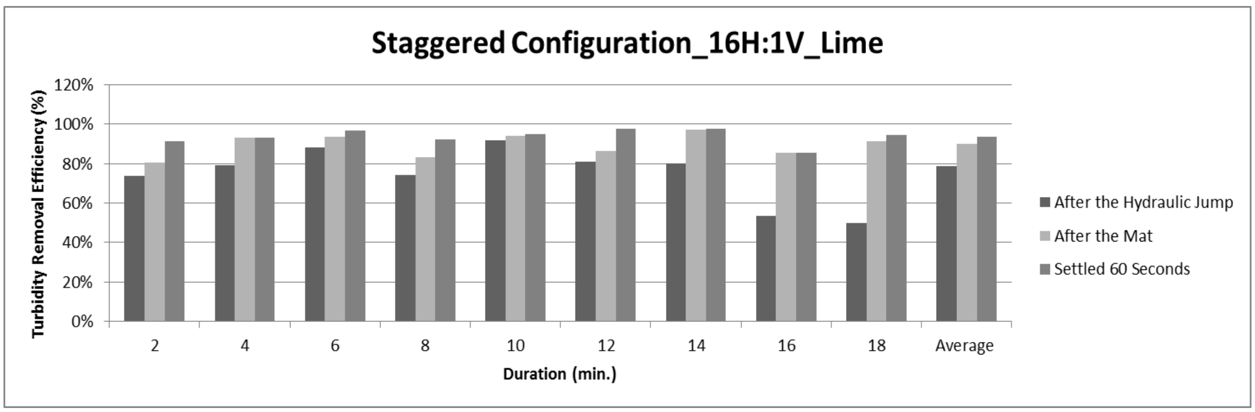


STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Rylee, Daniel, Mike
Date:	5/10/2011
PAM Type	706b
Soil Type:	Limestone
Configuration	Staggered
Slope	16H:1V

X_1	**96**	in.
X_2	**64 1/2**	in.
X_3	**64 1/2**	in.
X_4	**64 1/2**	in.
Back Water Depth from Hydraulic Jump:		in.

I.D.	*Length from H_2O Entrance (in.)*	*Distance/Length of Channel*	*Height (ft.)*	*V (fps)*	*Energy_Rec (ft.)*
1	24	0.03	0.0990	2.8	0.2207
2	90	0.12	0.1094	3.2	0.2684
3a	99.75	0.13	0.1406	3	0.2804
3b	99.75	0.13	0.1146	2.9	0.2452
4a	135.75	0.18	0.0052	1.8	0.0555
4b	135.75	0.18	0.0521	3.5	0.2423
4c	135.75	0.18	0.0521	2.9	0.1827
5	234	0.31	0.1042	0.6	0.1098
6a	279.75	0.38	0.0052	1.1	0.0240
6b	279.75	0.38	0.0938	2.4	0.1832
6c	279.75	0.38	0.0729	3.2	0.2319
7	306	0.41	0.1510	0.8	0.1610
8a	315.75	0.42	0.0677	2.4	0.1571
8b	315.75	0.42	0.0677	3.1	0.2169
9a	423.75	0.57	0.0417	1.9	0.0977
9b	423.75	0.57	0.0365	2.5	0.1335
9c	423.75	0.57	0.0365	0.5	0.0403
10	450	0.60	0.1302	2.2	0.2054
11a	459.75	0.62	0.0521	2.4	0.1415
11b	459.75	0.62	0.1094	2.2	0.1845
12a	543.75	0.73	0.6510	1	0.6666
12b	543.75	0.73	0.6667	0.1	0.6668
12c	543.75	0.73	0.7292	0.1	0.7293
13a	624	0.84	1.0000	0.1	1.0002
13b	624	0.84	1.0000	0.1	1.0002
13c	624	0.84	1.0000	0.1	1.0002

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Rafiq Chowdhury							
Date:	10-May-11							
Date Completed:	13-May-11							
Slope:	16H:1V							
Polymer Type:	706b							
Configuration:	Staggered, Lime rock							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Removal Efficiency for D1 (%)**	**Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	185						
1	2	149	39	29	13	**74%**	**81%**	**91%**
2	4	134	28	9	9	**79%**	**93%**	**93%**
3	6	214	25	14	7	**88%**	**93%**	**97%**
4	8	184	47	31	14	**74%**	**83%**	**92%**
5	10	251	20	15	13	**92%**	**94%**	**95%**
6	12	127	24	17	3	**81%**	**87%**	**98%**
7	14	176	35	5	4	**80%**	**97%**	**98%**
8	16	192	36	28	28	**54%**	**85%**	**85%**
9	18	178	89	15	10	**50%**	**92%**	**94%**
AVERAGE	Average	**179.00**	**38.11**	**18.11**	**11.22**	**79%**	**90%**	**94%**

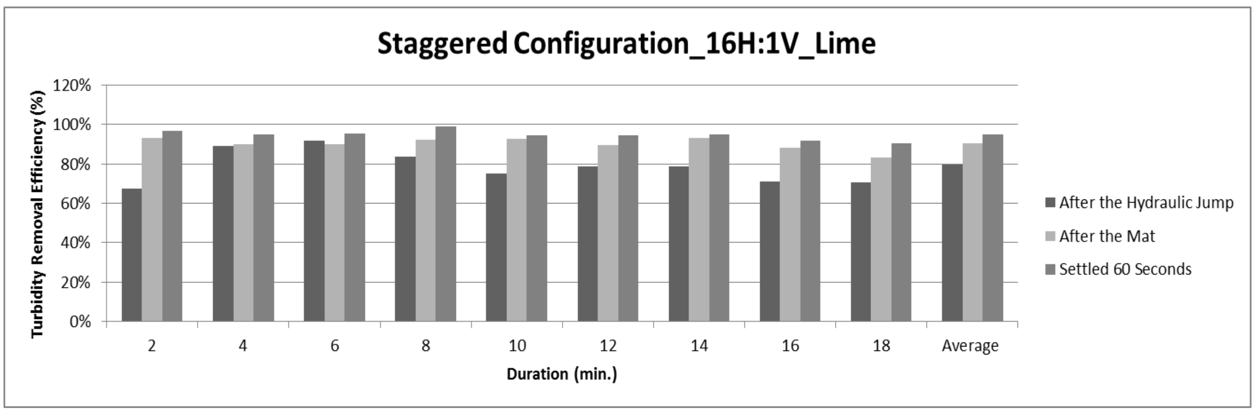


STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Albert, Daniel, Ken
Date:	5/11/2011
PAM Type	706b
Soil Type:	Limestone
Configuration	Staggered
Slope	16H:1V

X_1	**96**	in.
X_2	**64 1/2**	in.
X_3	**64 1/2**	in.
X_4	**64 1/2**	in.
Back Water Depth from Hydraulic Jump:		in.

I.D.	*Length from H_2O Entrance (in.)*	*Distance/Length of Channel*	*Height (ft.)*	*V (fps)*	*Energy_Rec (ft.)*
1	24	0.03	0.0417	3	0.1814
2	90	0.12	0.1927	2.9	0.3233
3a	99.75	0.13	0.0625	2.8	0.1842
3b	99.75	0.13	0.0573	2.6	0.1623
4a	135.75	0.18	0.0052	2.5	0.1023
4b	135.75	0.18	0.0365	2.6	0.1414
4c	135.75	0.18	0.0625	3.3	0.2316
5	234	0.31	0.1094	0.9	0.1220
6a	279.75	0.38	0.0260	1.2	0.0484
6b	279.75	0.38	0.0729	2.7	0.1861
6c	279.75	0.38	0.0781	2	0.1402
7	306	0.41	0.1094	1.8	0.1597
8a	315.75	0.42	0.0469	2.2	0.1220
8b	315.75	0.42	0.0833	3	0.2231
9a	423.75	0.57	0.0313	1	0.0468
9b	423.75	0.57	0.0417	2.6	0.1466
9c	423.75	0.57	0.0573	3.2	0.2163
10	450	0.60	0.1302	2.3	0.2124
11a	459.75	0.62	0.1615	1.1	0.1802
11b	459.75	0.62	0.1875	0.1	0.1877
12a	543.75	0.73	0.6354	0.9	0.6480
12b	543.75	0.73	0.6667	0.1	0.6668
12c	543.75	0.73	0.7083	0.1	0.7085
13a	624	0.84	1.0000	0.1	1.0002
13b	624	0.84	1.0000	0.1	1.0002
13c	624	0.84	1.0000	0.1	1.0002

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Rafiq Chowdhury							
Date:	11-May-11							
Date Completed:	16-May-11							
Slope:	16H:1V							
Polymer Type:	706b							
Configuration:	Staggered, Lime Rock							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Turbidity Removal Efficiency for D1 (%)**	**Turbidity Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	452						
1	2	385	125	26	13	**68%**	**93%**	**97%**
2	4	387	42	38	20	**89%**	**90%**	**95%**
3	6	413	34	41	18	**92%**	**90%**	**96%**
4	8	387	63	30	3	**84%**	**92%**	**99%**
5	10	377	94	27	20	**75%**	**93%**	**95%**
6	12	374	80	39	20	**79%**	**90%**	**95%**
7	14	355	75	24	17	**79%**	**93%**	**95%**
8	16	346	86	40	28	**71%**	**88%**	**92%**
9	18	342	100	57	33	**71%**	**83%**	**90%**
AVERAGE	Average	**381.80**	**77.67**	**35.78**	**19.11**	**80%**	**91%**	**95%**

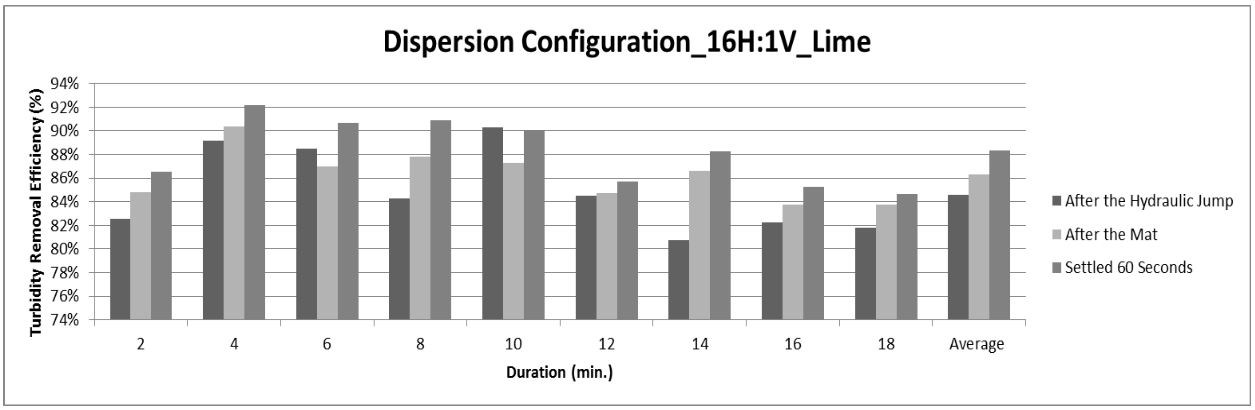


STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Scott, Matt, Lorena
Date:	5/16/2011
PAM Type	706b
Soil Type:	Limestone
Configuration	Dispersion
Slope	16H:1V

X_1	**48**	in.
X_2	**171**	in.
X_3	**138**	in.
X_4	**96**	in.
Back Water Depth from Hydraulic Jump:	**177**	in.

I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (ft.)***	***V (fps)***	***Energy_Rec (ft.)***
1	24	0.03	0.0625	3.9	0.2987
2	42	0.06	0.1823	3.8	0.4065
3	51.75	0.07	0.1042	0.8	0.1141
4	51.75	0.07	0.0625	2.6	0.1675
5a	138	0.19	0.0313	2	0.0934
5b	138	0.19	0.0313	2.5	0.1283
5c	138	0.19	0.0417	1.1	0.0605
6	220.5	0.30	0.3125	0.4	0.3150
7	220.5	0.30	0.3333	0.3	0.3347
8	223.5	0.30	0.3333	0.2	0.3340
9	234	0.31	0.0521	1.6	0.0918
10	366	0.49	0.1875	1.9	0.2436
11a	424.5	0.57	0.0469	0.3	0.0483
11b	424.5	0.57	0.0938	1.2	0.1161
11c	424.5	0.57	0.0833	0.2	0.0840
12	469.5	0.63	0.4063	0.3	0.4076
13	469.5	0.63	0.3177	0.2	0.3183
14	472.5	0.64	0.3333	0.1	0.3335
15	483	0.65	0.3177	1.4	0.3481
16a	553.5	0.74	0.5625	0.1	0.5627
16b	553.5	0.74	0.6563	0.1	0.6564
16c	553.5	0.74	0.7083	0.1	0.7085
17a	624	0.84	1.0000	0.1	1.0002
17b	624	0.84	1.0000	0.1	1.0002
17c	624	0.84	1.0000	0.1	1.0002

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Jamie Capra							
Date:	16-May-11							
Date Completed:	17-May-11							
Slope:	16H:1V							
Polymer Type:	706b							
Configuration:	Dispersion. Limestone							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Turbidity Removal Efficiency for D1 (%)**	**Turbidity Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	786						
1	2	848	148	129	114	**83%**	**85%**	**87%**
2	4	840	91	81	66	**89%**	**90%**	**92%**
3	6	860	99	112	80	**88%**	**87%**	**91%**
4	8	822	129	100	75	**84%**	**88%**	**91%**
5	10	826	80	105	82	**90%**	**87%**	**90%**
6	12	805	125	123	115	**84%**	**85%**	**86%**
7	14	748	144	100	88	**81%**	**87%**	**88%**
8	16	725	161	118	107	**82%**	**84%**	**85%**
9	18	709	129	115	109	**82%**	**84%**	**85%**
AVERAGE	Average	**796.90**	**122.89**	**109.22**	**92.89**	**85%**	**86%**	**88%**

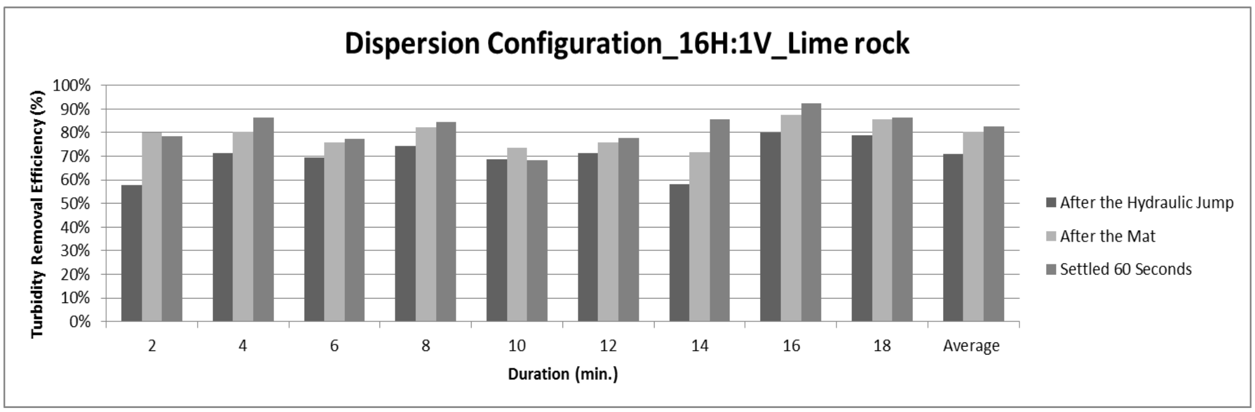


STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Scott, Mike, Nicole
Date:	5/17/2011
PAM Type	706b
Soil Type:	Limestone
Configuration	Dispersion
Slope	16H:1V

X_1	**48**	in.
X_2	**171**	in.
X_3	**138**	in.
X_4	**96**	in.
Back Water Depth from Hydraulic Jump:	**178**	in.

I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (ft.)***	***V (fps)***	***Energy_Rec (ft.)***
1	24	0.03	0.0365	3.6	0.2377
2	42	0.06	0.1875	2.7	0.3007
3	51.75	0.07	0.1042	0.6	0.1098
4	51.75	0.07	0.1250	2.6	0.2300
5a	138	0.19	0.0313	3	0.1710
5b	138	0.19	0.0208	2.7	0.1340
5c	138	0.19	0.0833	1.8	0.1336
6	220.5	0.30	0.2344	0.7	0.2420
7	220.5	0.30	0.2396	0.3	0.2410
8	223.5	0.30	0.3333	1.1	0.3521
9	234	0.31	0.0260	1.7	0.0709
10	366	0.49	0.1250	0.6	0.1306
11a	424.5	0.57	0.0990	1.9	0.1550
11b	424.5	0.57	0.1667	2.4	0.2561
11c	424.5	0.57	0.1667	1.5	0.2016
12	469.5	0.63	0.3906	0.5	0.3945
13	469.5	0.63	0.3698	0.2	0.3704
14	472.5	0.64	0.3333	0.1	0.3335
15	483	0.65	0.3438	1.6	0.3835
16a	553.5	0.74	0.5833	0.1	0.5835
16b	553.5	0.74	0.7292	0.1	0.7293
16c	553.5	0.74	0.7292	0.1	0.7293
17a	624	0.84	1.0000	0.1	1.0002
17b	624	0.84	1.0000	0.1	1.0002
17c	624	0.84	1.0000	0.1	1.0002

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Scott Glancy							
Date:	17-May-11							
Date Completed:	17-May-11							
Slope:	16H:1V							
Polymer Type:	706b							
Configuration:	Dispersion. Limestone							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Turbidity Removal Efficiency for D1 (%)**	**Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	372						
1	2	254	107	51	55	**58%**	**80%**	**78%**
2	4	333	95	65	46	**71%**	**80%**	**86%**
3	6	301	92	73	68	**69%**	**76%**	**77%**
4	8	294	76	52	46	**74%**	**82%**	**84%**
5	10	231	72	61	73	**69%**	**74%**	**68%**
6	12	257	74	62	57	**71%**	**76%**	**78%**
7	14	181	76	51	26	**58%**	**72%**	**86%**
8	16	276	74	35	21	**80%**	**87%**	**92%**
9	18	260	55	37	36	**79%**	**86%**	**86%**
AVERAGE	Average	**275.90**	**80.11**	**54.11**	**47.56**	**71%**	**80%**	**83%**

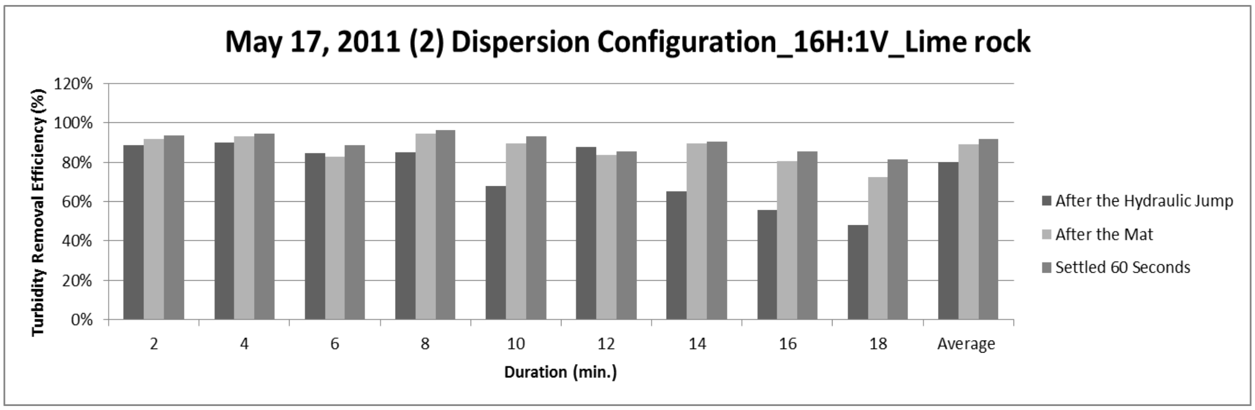


STORMWATER MANAGEMENT ACADEMY	
Researchers:	Rafiq, Nicole, Scott, Drew
Date:	5/17/2011 (2)
PAM Type	706b
Soil Type:	Limestone
Configuration	Dispersion
Slope	16H:1V

X_1	**48**	in.
X_2	**171**	in.
X_3	**138**	in.
X_4	**96**	in.
Back Water Depth from Hydraulic Jump:	**178**	in.

I.D.	***Length from H_2O Entrance (in.)***	***Distance/Length of Channel***	***Height (ft.)***	***V (fps)***	***Energy_Rec (ft.)***
1	24	0.03	0.0625	3.3	0.2316
2	42	0.06	0.2708	3.5	0.4611
3	51.75	0.07	0.0833	1.7	0.1282
4	51.75	0.07	0.0729	3.2	0.2319
5a	138	0.19	0.0208	1.6	0.0606
5b	138	0.19	0.0313	3.2	0.1903
5c	138	0.19	0.0677	3.1	0.2169
6	220.5	0.30	0.3438	0.7	0.3514
7	220.5	0.30	0.3750	0.3	0.3764
8	223.5	0.30	0.3333	0.3	0.3347
9	234	0.31	0.0521	1.7	0.0970
10	366	0.49	0.1354	1.4	0.1659
11a	424.5	0.57	0.0729	1.5	0.1079
11b	424.5	0.57	0.1250	2.9	0.2556
11c	424.5	0.57	0.0990	0.7	0.1066
12	469.5	0.63	0.3854	0.2	0.3860
13	469.5	0.63	0.3333	0.3	0.3347
14	472.5	0.64	0.3333	0.1	0.3335
15	483	0.65	0.2969	1.6	0.3366
16a	553.5	0.74	0.6667	0.5	0.6705
16b	553.5	0.74	0.7188	0.1	0.7189
16c	553.5	0.74	0.7552	0.3	0.7566
17a	624	0.84	1.0000	0.1	1.0002
17b	624	0.84	1.0000	0.2	1.0006
17c	624	0.84	1.0000	0.1	1.0002

STORMWATER MANAGEMENT ACADEMY								
Turbidity (NTU)								
Researcher(s)	Rafiq Chowdhury							
Date:	17-May-11							
Date Completed:	19-May-11							
Slope:	16H:1V							
Polymer Type:	706b							
Configuration:	Dispersion. Lime rock							
Identification	**Duration (min.)**	**Upstream 1 (Cistern)**	**Downstream 1 (After Jump)**	**Downstream 2 (After Mat)**	**Downstream 2 (Settled for 60 sec)**	**Turbidity Removal Efficiency for D1 (%)**	**Removal Efficiency for D2 (%)**	**Turbidity Removal Efficiency for D2-Settled (%)**
Initial	0	632						
1	2	498	57	40	32	**89%**	**92%**	**94%**
2	4	501	50	35	28	**90%**	**93%**	**94%**
3	6	252	39	43	29	**85%**	**83%**	**88%**
4	8	513	76	28	18	**85%**	**95%**	**96%**
5	10	306	98	32	21	**68%**	**90%**	**93%**
6	12	266	33	43	39	**88%**	**84%**	**85%**
7	14	344	119	36	33	**65%**	**90%**	**90%**
8	16	263	89	51	38	**56%**	**81%**	**86%**
9	18	224	116	62	41	**48%**	**72%**	**82%**
AVERAGE	Average	**379.90**	**75.22**	**41.11**	**31.00**	**80%**	**89%**	**92%**



Graphable Data Frame			
ID	Trial 1 - Left	Trial 2 - Left	Trial 3 - Left
3	0.114104555	0.109756729	0.12820911
5a	0.093361801	0.171001553	0.060584886
6	0.314984472	0.241983696	0.351358696
11a	0.048272516	0.155014234	0.107854555
12	0.407647516	0.394506988	0.386037785
16a	0.56265528	0.583488613	0.670548654
17a	1.00015528	1.00015528	1.00015528
18a	0.002484472	0.000621118	0.00015528

Is There a Significant Difference Between the Energy Values on the Left Side of the Channel Amongst the 3-Trials?

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	8	2.54366589	0.317958236	0.113939
Column 2	8	2.656528209	0.332066026	0.105448
Column 3	8	2.704904244	0.338113031	0.119943

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.001711498	2	0.000855749	0.007566	0.99246563	3.4668
Within Groups	2.375314492	21	0.113110214		NOT SIGNIFICANT	
Total	2.37702599	23				

Graphable Data Frame			
ID	Trial 1 - Right	Trial 2 - Right	Trial 3 - Right
4	0.167468944	0.229968944	0.231922878
5c	0.060455487	0.133643892	0.216931936
7	0.334730849	0.240980849	0.376397516
11c	0.083954451	0.201604555	0.106567029
13	0.318329451	0.370412785	0.334730849
16c	0.708488613	0.729321946	0.756605849
17c	1.00015528	1.00015528	1.00015528
18c	0.005590062	0.009937888	0.00015528

Is There a Significant Difference Between the Energy Values on the Right Side of the Channel Amongst the 3-Trials?

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	8	2.679173137	0.334896642	0.122454
Column 2	8	2.916026139	0.364503267	0.11087
Column 3	8	3.023466615	0.377933327	0.113717

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.007757533	2	0.003878767	0.03353	0.967077488	3.4668
Within Groups	2.429284566	21	0.115680217		NOT SIGNIFICANT	
Total	2.437042099	23				

Graphable Data Frame			
ID	Trial 1 - Center	Trial 2 - Center	Trial 3 - Center
1	0.298680124	0.237700569	0.231599379
2	0.406515269	0.300698758	0.461050725
5b	0.128299689	0.134032091	0.190256211
8	0.333954451	0.352122153	0.334730849
9	0.052238613	0.033650362	0.054567805
10	0.243555901	0.130590062	0.165851449
11b	0.116110248	0.25610766	0.255590062
14	0.333488613	0.333488613	0.333488613
15	0.317863613	0.34390528	0.29703028
16b	0.65640528	0.729321946	0.71890528
17b	1.00015528	1.00015528	1.000621118
18b	0.001397516	0.002484472	0.000621118

Is There a Significant Difference Between the Energy Values on the Center of the Channel Amongst the 3-Trials?

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	12	3.888664596	0.324055383	0.076479
Column 2	12	3.854257246	0.321188104	0.081493
Column 3	12	4.044312888	0.337026074	0.078612

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.001709206	2	0.000854603	0.010837	0.989225247	3.284918
Within Groups	2.6024242	33	0.078861339		NOT SIGNIFICANT	
Total	2.604133406	35				

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