Improvements in the Design and Application of Erosion and Sediment Control Technologies for the Construction Industry

by

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A dissertation submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Doctor of Philosophy

Auburn, Alabama
December 10, 2016

Keywords: sediment basin, NPDES, SEDspread,
construction stormwater, unmanned aerial vehicles

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ABSTRACT

Erosion and sediment controls (ESCs) have become essential components of construction related activities. Stormwater pollution prevention regulations are the principal catalysts driving the development of new ESC practices and products to ensure regulatory compliance for the construction industry. Federal, state, and local environmental protection regulations require construction generated pollution to be controlled on-site prior to discharge to avoid impairment of receiving waterbodies. Regulations include provisions on the design, implementation, inspection and maintenance, of ESC practices.

This dissertation explores improvements made in the design and application of ESC technologies through the development of a sediment basin design tool, large-scale testing of sediment basin practices, the use of unmanned aerial vehicles for inspection purposes, and the transfer of innovative ESC technology to the construction industry.

Sediment basins are stormwater detention practices commonly used to capture and treat sediment-laden runoff prior to discharging from a construction site. However design and implementation of basins in the field often deviate significantly from regulatory design guidance. A spreadsheet based tool, SEDspread, was developed to provide designers a user-friendly platform to assist in the sediment basin design process. The tool provides designers the ability to implement hydrologic based designs to allow for appropriately sized and configured sediment basins on construction sites based upon the regionally specific design criteria [i.e., 1,800 or 3,600 ft^3/ac (125 or 250 m^3/ha) volume sizing factor, 2-yr, 24-hr rainfall event, or manual input].

Further research is necessary to understand sediment basin performance under various design conditions using large-scale testing techniques. This dissertation details the design, construction, methodology, and testing performed on a 2,790 ft^3 (79.0m^3), large-scale sediment basin at the Auburn University - Erosion and Sediment Control Testing Facility (AU-ESCTF). Testing was performed on various sediment basin design configurations and high-rate lamella plate settler technology within the basin. Data collection efforts included: water quality, flow rates, basin stage levels, sediment deposition volumes, and sediment sampling for particle characterization. Data was used to evaluate the performance of various basin design configurations.

Testing results indicated that the use of an excavated sump in the forebay of the sediment basin inflow channel and the use of a modified first baffle system provided no improvements to the performance of the basin. Testing did show that high-rate lamella settlers oriented in upward and parallel configurations were 18.2% and 29.0% more effective at reducing turbidity between Bay 1 and Bay 4 when compared to the Alabama Department of Transportation (ALDOT) standard configuration, respectively.

Remote sensing with unmanned aerial vehicles (UAVs) has the potential to provide high quality aerial imagery and data that can assist Qualified Credential Inspectors (QCIs) in performing focused, strategic site inspections in an efficient and effective manner. Research performed on an active construction site showed that UAVs have the potential to assist inspectors in performing thorough site inspections efficiently and more strategically. By providing a complete aerial view of the site at the onset of an inspection, the inspector has the ability to quickly identify problem areas, discharge points of concern, and determine whether further detailed investigations are warranted. Furthermore, photogrammetric techniques were used to provide analyses on the collected aerial data through the creation of digital elevation models (DEMs).

Through the results of recent AU-ESCTF research efforts, ESC designs are transitioning towards hydraulic and hydrologic based designs to better cater to site parameters and improve the performance of practices. While educational and research resources for ESC designs have increased in availability, a need still exists to fill the gaps between the knowledge base developed through research and the needs of practitioners. The ESC Technology Transfer programs developed and disseminated at the AU-ESCTF provide the platform to distribute knowledge, practice, and techniques with industry professionals. The AU-ESCTF has provided several successful training opportunities geared at specific target audiences within the ESC industry.

ACKNOWLEDGEMENTS

I would like to extend my gratitude to Dr. Wesley C. Zech for his unconditional support, devoted mentorship, and academic guidance throughout the course of this journey. Dr. Zech enlisted an aspiration to succeeded in my graduate endeavors and has never showed any hesitation to trust in my abilities. Additionally, I would like to thank Dr. Xing Fang, and Dr. Jose G. Vasconcelos, Dr. Mark Dougherty, Dr. Eve Brantley, Dr. Rod E. Turochy, and Dr. Jeffrey J. LaMondia, for their time and guidance throughout this research effort. I also deeply grateful for the mentorship and support provided from Mr. Barry Fagan, Mr. Wade Henry, Mr. Earl Norton, Mr. Perry Oakes, and Mr. John Slupecki.

This work would not have been possible without the support from the Alabama Department of Transportation, Auburn University Highway Research Center, Alabama Technology Transfer Center, Auburn University Civil Engineering Department, and Samuel Ginn College of Engineering. I would also like to thank the National Center for Asphalt Technology Pavement Test Track staff for their assistance; Mr. Guy Savage for testing support and coordination at the Auburn University - Erosion and Sediment Control Testing Facility; and to the numerous undergraduate research assistants who put in countless hours of sweat and hard manual labor to help make the laboratory testing efforts timely and successful.

My time in Auburn has been blessed by special friendships. I would like to thank Veronica Ramirez, Dr. Wesley Donald, Dr. Dave Mante, Blake Whitman, Sarah Gustitus, Michael Giudici, and Austin Harmon. I'm thankful for being blessed with having a family away from home; Dr.

Zech, April, Watson, Winter, Wade, Marianne “Mama Zech”, the late Carl Zech, whom have spoiled me over the last several years with innumerable hours of laughter, entertainment, fellowship, and love.

I’m most of all grateful to my immediate family for their love and unending support throughout my graduate studies. I’m grateful for the hard work and persistence instilled in me by my parents and for their belief in my abilities. This work is a direct outcome of their encouragement, hard work, sacrifice, and most importantly, their unconditional love.

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CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND

Mankind has spent the majority of its existence manipulating the natural environment to better suit its needs. The construction of buildings, bridges, and roads, plays a major role in our daily lives. The annual value of U.S. construction is worth $1.12 trillion with linear transportation projects accounting for $135 billion *(U.S. Census Bureau 2016)*. Construction activities can create a major source of pollution. Several pollutants of concern associated with land development include: sediment, pesticides, fertilizers, petrochemicals, construction chemicals, wash water, paper, garbage, and sanitary waste. Construction activities involve heavy earthmoving activities that typically disturb several acres of land. Due to the nature of construction activity, sediment is the predominant pollutant of concern during the clearing and grading stages, which typically exposes large un-vegetated and un-stabilized land areas to erosive elements *(USEPA 2005)*. The lack of ground cover during construction results in land areas being susceptible to increased rates of soil erosion. As stormwater runoff flows over unprotected areas on construction sites, it can suspend and transport pollutants causing significant physical, chemical, and biological water quality impacts and impairments to nearby receiving waters *(Maxted and Shaver 1998)*. Furthermore, polluted surface waters can affect operations at water treatment plants, power stations, and other water-handling facilities. Sediment runoff rates from construction sites can be 10 to 20 times higher than those of agricultural lands and 1,000 to 2,000 times greater than those of forested lands *(USEPA 2009)*. Construction sites have measured erosion rates of approximately 20 to 200 tons per acre (45 to 450 metric tons per ha) per year *(Pitt et al. 2007)*. Further construction development creates impervious surfaces (i.e., driveways, sidewalks, parking lots, and roads) and creates more efficient drainage paths, which reduce infiltration of rainfall and stormwater runoff. A decrease in permeable surfaces increases runoff quantity and peak discharge rates, which increases the vulnerability of on-site erosion *(Clark and Pitt 1999)*. Sediment emanating from slope and channel erosion are transported into existing stormwater conveyance systems. Other pollutants stemming from construction activities can also be introduced to the local environment through the improper use and disposal of chemicals and hydrocarbons. Erosion and the resulting sedimentation in waterways have become one of the nation's largest water pollution problems. The USEPA identifies sediment along with nutrients and heavy metals, which typically sorb to soil particles, as the most widespread pollutants affecting the beneficial uses of the Nation's rivers and streams *(USEPA 1998; 2016)*.

Stormwater is typically conveyed into receiving water systems, which can lead to a direct input source of sediment and pollutants into water ways. Polluted stormwater can result in highly turbid suspended sediment plumes affecting aquatic habitat and species. Water quality in impacted water bodies and wetlands becomes extremely vulnerable to harm and degradation through the process of sedimentation. Turbidity and suspended solids reduce the light available beneath the water surface that may affect wetland and lake integrity by damaging the health of submerged vegetation. When suspended solids settle by means of sedimentation, the nature of the streambed is changed that can result in a reduction of aquatic seedling emergence and can deprive organisms of oxygen supply. Sediment impairs the process of photosynthesis, respiration, and can layer aquatic nesting areas with deposition *(Gleason et al. 2003)*. Silts and sediments that settle in these ecosystems can have a detrimental effect on the native biota impacting necessary life functions of the aquatic habitat and species (i.e., photosynthesis, respiration, growth, and reproduction) *(Gleason et al. 2003)*.

In addition to environmental implications, sedimentation can cause vast economic problems. The loss of aquatic habitat and diminished water quality is often difficult to quantify, however some impacts (i.e., the cost of dredging and disposing of accumulated sediment) are easier to assess. Furthermore, the cost of eroded soil replacement comes at a high price. Eroded sediments may include the loss of soil nutrients necessary for plant growth. This nutrient loss can lead to topsoil replacement actions to satisfy proper vegetative growth *(Goldman et al. 1986)*. The creation of soil is a slow process, therefore better methods and practices for controlling erosion, sedimentation, and other pollutants from construction sites are needed to forestall these problems and meet the demands of increasing growth and development.

The urgency for soil conservation was sparked by the Dust Bowl of the 1930's, which resulted in the formation of the Soil Erosion Service in 1933 by President Franklin D. Roosevelt *(Helms 1985)*. The Clean Water Act of 1972 established the National Pollutant Discharge Elimination System (NPDES), which triggered federal, state, and local stormwater regulations *(USEPA 2010)*. The NPDES Construction General Permit (CGP) requires operators to develop a detailed Stormwater Pollution Prevention Plan (SWPPP) and obtain a permit prior to beginning construction. The SWPPP is a comprehensive plan used to mitigate problems associated with sediment migration from construction sites to receiving waterways by incorporating proper erosion and sediment control (ESC) practices during land disturbing phases. These federal regulations and stormwater permits are intended to avoid further degradation and impairment of receiving waterways. Enforcement requires construction sites to implement ESC practices throughout all phases of land disturbing activities. In some cases, numerical discharge effluent limitations are imposed to provide maximum allowable pollutant discharge concentrations from disturbed sites. Permitting agencies stipulate that ESC practices shall be designed and maintained to minimize erosion and maximize sediment removal resulting from a 2-yr, 24-hr storm event as defined by the National Weather Service and Technical Paper No. 40 *(Alabama Department of Environmental Management [ADEM] 2011; USEPA 2012).*

Construction stormwater pollution is a global problem, however the southeastern United States is especially vulnerable due to its heavy rainfall and highly erodible colloidal soils *(Pitt et al. 2007)*. The Alabama Department of Transportation (ALDOT) is one of the largest facilitators of construction activities in the State of Alabama, responsible for the construction and maintenance of the 11,800 mi (18,990 km) network of state roadways. In the 2015 fiscal year, the ALDOT construction bureau reported 455 active construction projects totaling $1.7 billion. As such, ALDOT not only has regulatory requirements and commitments, but also carries an obligation to utilize practices that reflect the state-of-the-practice for effective management of construction stormwater. ALDOT construction runoff is regulated by a statewide NPDES general permit for construction discharge, and is regulated in urban areas by an ALDOT individual permit for Municipal Separate Storm Sewer System (MS4) discharges. ALDOT has established standard specifications that demonstrate proven practices for implementing, installing, and maintaining ESC practices on construction projects *(ALDOT 2015)*. Although ALDOT has developed standard drawings and specifications for ESC practices, the performance of these practices needs to be evaluated to understand their overall effectiveness. Performance data can be used by ALDOT to continuously improve and strengthen the stormwater program where deficiencies in ESC practices are found. It is becoming increasingly critical for designers and contractors to have an understanding of ESC practice effectiveness to ensure they are being properly implemented and maintained to meet current and expected increasingly stringent stormwater effluent compliance regulations.

1.2 EROSION AND SEDIMENT CONTROL

Erosion controls are practices implemented to reduce the detachment and transport of soil particles principally generated by the kinetic energy resulting from rainfall impact, stormwater runoff, and wind. The primary functions of erosion controls are to reduce the energy of erosive forces imposed on the underlying soil by providing soil cover or by reducing stormwater runoff velocities. Typical temporary erosion control practices used on construction sites include: ditch checks, erosion control blankets, slope drains, slope interrupters, surface mulches, and turf reinforcement matting, amongst others. Sediment controls are implemented in conjunction with erosion controls to mitigate the transport of eroded soil and prevent soil from leaving a construction site. These practices are aimed at capturing soil particles entrained in stormwater runoff, primarily through the process of sedimentation. Typical sediment control practices include: flocculants, inlet protection, perimeter controls, sediment basins, and surface water skimmers.

The benefits of efficient ESC practices can be applied to the triple bottom line approach. This method accounts for the dynamic relationships between environmental impacts, social justice, and sustainable economic development outcomes in construction and infrastructure improvement projects. The use of efficient controls can help meet this sustainable approach by:

(1) reducing environmental impacts – pollutant loads on receiving waterways, improving water clarity and quality, minimizing detrimental impact to aquatic life, etc.,

(2) social justice – the action of not endangering waterways with pollutants that may cause harm to aquatic life and humans, and,

(3) economics – not only will increased upfront investments on erosion and sediment controls provide life cycle cost reductions in mitigating damages that may have resulted from erosion and sedimentation, but proper controls may provide economic benefit to the seafood industry that may have been impacted due to pollution.

1.2.1 GOVERNING REGULATIONS

Increased public awareness and enactment of state and federal regulations have come as a response to nonpoint source pollution such as stormwater runoff from construction sites. The Federal Water Pollution Control Act of 1972 (Clean Water Act or CWA), passed by congress is the primary legislation governing the protection and improvement of water quality in the U.S. The U.S. Environmental Protection Agency (USEPA) is authorized under the CWA to issue National Pollutant Discharge Elimination System (NPDES) permits for point and non-point source pollutant discharges. The NPDES requires project operators, the parties responsible for control over construction plans and specifications and day-to-day of construction activities, to obtain coverage under the Construction General Permit (CGP), which regulates stormwater runoff as a pollutant. A CGP is required for land disturbing projects that disturb an area of 1 acre (0.4 ha) or greater. The permit enforces that operators design, install, and maintain erosion and sediment controls that minimize the discharge of pollutants from earth-disturbing activities. Minimal disturbance areas, timely control implementation, and proper maintenance requirements are part of CGP compliance.

Compliance with the CGP includes meeting USEPA's construction and development (C&D) effluent limitations. These effluent limitations were promulgated in 2009 through the NPDES Phase II permitting as non-numeric requirements for all sites, and numeric limits for turbidity for larger construction sites. The non-numeric limitations are specific control requirements that include: the provision of buffers near surface waters, the use of perimeter controls, use of sediment track-out practices, control of discharge from stockpiles, managing dust pollution, minimizing disturbance to steep slopes, preserving topsoil, limiting soil compaction, and protecting storm drain inlets. The numeric limitation on turbidity applies to sites that disturb 10 ac or more (4.0 ha) at a time. The limit sets the daily maximum turbidity value to be no greater than 280 nephelometric turbidity units (NTUs). The effluent limitation does not apply for days where storms larger than the local 2-yr, 24-hr storm event are recorded (i.e. upset conditions).

Since the proposal of the numeric limit in 2009, the USEPA discovered that the data used to calculate the numeric limit for turbidity was misinterpreted and that there was insufficient data to support the established effluent limit of 280 NTU. The numeric limit was stayed indefinitely until the EPA gathers and collects data to support the recalculation of the turbidity limit, however the non-numeric effluent guidelines are still part of the latest CGP *(USEPA 2012)*.

The NPDES CGP also includes specific monitoring requirements for sites that discharge stormwater to sediment or nutrient-impaired waters. These waterways have been identified by the USEPA and state agencies in 303(d) lists as sensitive waters that are too polluted or otherwise degraded to meet water quality standards. These impaired waters have been assigned a total maximum daily load (TMDL), or a maximum amount of a pollutant that a water body can receive. Construction activities under the CGP that discharge stormwater to listed impaired waterways may be subject to additional water quality-based limitations on a site-specific basis that need to be considered and satisfied.

The USEPA has authorized 46 states to issue NPDES permitting. These state permits meet the federal permit requirements and in many cases are more stringent than their federal counterpart. For example, the New Jersey Department of Environmental Protection (NJDEP) requires an 80% totals suspended solids (TSS) removal from construction site runoff *(NJDEP 2004)*.

The Alabama Department of Environmental Management (ADEM) manages the NPDES permitting process for the state. The permit requires operators to develop a detailed stormwater pollution prevention plan (SWPPP) or construction best management practices plan (CBMPP) prior to submitting a notice of intent for a CGP. The CBMPP is a comprehensive site plan of action to prevent the pollution of the environment surrounding a project area through the use of temporary erosion and sediment control measures and best management practices (BMPs). The CBMPP is used to confront the problems associated with sediment migration from construction sites to receiving waterways, by incorporating proper erosion and sediment control measures into construction projects during land disturbing phases. Similar to the USEPA, ADEM enforces increased compliance regulations for sediment or nutrient impaired waterways. ADEM limits turbidity of effluent discharged from a construction site to a 50 NTUs increase above background levels *(ADEM 2013)*.

1.2.2 BEST MANAGEMENT PRACTICES

BMPs are practices and procedures selected by designers and implemented by contractors that control or abate the discharge of pollutants from construction sites. BMPs include appropriate ESC program oversight, construction site planning and management, proper site housekeeping and materials management, ESC implementation and maintenance, and pollution prevention. ADEM stipulates that BMPs shall be designed and maintained to minimize erosion and maximize sediment removal resulting from a 2-yr, 24-hr storm event as defined by the National Weather Service and Technical Paper No. 40, *"Rainfall Frequency Atlas of the U.S." (ADEM 2011)*.

As the largest manager of state highway construction and maintenance projects in the state of Alabama, ALDOT has established a CBMPP to guide designers, inspectors, and contractors in environmental and stormwater compliance. An ALDOT CBMPP includes a design and operational component that is created and maintained for every ALDOT construction project requiring an ADEM CGP. The ALDOT CBMPP standard specifications and general applications include a set of special drawings that demonstrate the ALDOT established standard practices for stormwater runoff BMPs, including: temporary slope drains, sediment barriers, erosion control practices, ditch checks, inlet protection practices (IPPs), sediment basins, and various other common erosion and sediment control practices.

Although ALDOT has developed standard drawings and specifications for BMPs, the performance of these practices needs to be evaluated to understand their overall effectiveness. By having knowledge of performance, ALDOT can help improve and strengthen the stormwater program where BMP deficiencies are found. The understanding of BMP effectiveness is becoming increasingly critical for designers and contractors to ensure proper implementation and maintenance of practices to meet current and expected increasingly stringent stormwater effluent compliance regulations and regulatory compliance inspections.

1.3 RESEARCH OBJECTIVES

This research was divided into four predominate components associated with the design, improvement, inspection, and technology transfer of ESC practices, with specific emphasize on sediment basins.

The specific objectives of this research are as follows:

(1) Provide a user-friendly tool to allow designers to adequately size sediment basins based on local hydrologic conditions,

(2) Develop a large-scale testing methodology, protocols, testing apparatus, and perform replicable tests on a sediment basin to assess the effectiveness of various treatments,

(3) Identify applications where unmanned aerial vehicles (UAVs) can be used to facilitate the inspection process of ESCs on construction sites, and

(4) Provide technology transfer between research outcomes and industry practitioners.

The project was divided into the following seven tasks to satisfy the defined research objectives as follows:

(1) Identify, describe, evaluate, and critically assess pertinent literature on the state-of-the-practice regarding sediment basins used by state agencies,

(2) Develop a spreadsheet based tool to allow users nationwide to adequately and seamlessly design sediment basins based on local hydrologic conditions,

(3) Design and construct a large-scale sediment basin to provide for testing of various treatments.

(4) Develop an applicable methodology and testing apparatus for large-scale performance-based testing of sediment basins based upon Alabama runoff conditions, and current testing methods and technology,

(5) Analyze collected water quality and sediment data for evaluating the effectiveness of sediment basin treatments,

(6) Conduct a proof-of-principle study on the use of UAVs for the inspection of ESC practices on construction sites,

(7) Develop and conduct classroom and field training for practitioners (i.e., designers, inspectors, and contractors) in the proper selection, installation, and maintenance of ESC practices.

1.4 EXPECTED OUTCOMES

The outcomes of the study are to provide the ESC industry knowledge, resources, and educational outreach opportunities required to conform to growing regulations through the use of improved technology. By providing scientific results from this study, improved guidelines for properly implementing and installing sediment basins and in providing effective inspections will provide practitioners the required platform to guide and govern designers, inspectors, and contractors. This research will provide a deeper understanding and knowledge on sediment basins and their efficiency, as well as the potential for use of UAVs for inspection of ESC practices. Additional research efforts should emanate from this project allowing further opportunities for increasing knowledge and technology transfer in the ESC industry.

1.5 ORGANIZATION OF DISSERTATION

This dissertation is divided into seven chapters that organize, illustrate, and describe the steps taken to meet the defined research objectives. Following this chapter, Chapter Two: *Sediment Basin Literature Review*, provides an overview of the current technology and research performed on sediment basins. Chapter Three: *Sediment Basin Design Tool: SEDspread*, details the development of a design tool used to adequately size and configure sediment basins and supporting practices (i.e. baffles, surface skimmer, auxiliary spillway). Chapter Four: *Large-Scale Performance Evaluations of Sediment Basin Configuration and High-Rate Lamella Settlers*, outlines the design, apparatus, methods, and procedures developed for preparing and performing large-scale sediment experiments as well as research results. Chapter Five: *UAV for Inspection Applications*, is a study on using unmanned aerial vehicles for performing construction inspections of ESC practices. Chapter Six: *Training and Outreach*, describes technology transfer efforts at the Auburn University - Erosion and Sediment Control Testing Facility (AU-ESCTF), geared at disseminating research results to industry practitioners. Chapter Seven: *Conclusions and Recommendations*, provides a summary of the tasks accomplished and identifies research that can be conducted to further advance this research effort.

CHAPTER TWO:
SEDIMENT BASIN LITERATURE REVIEW

2.1 DEFINITION AND PURPOSE OF SEDIMENT BASINS

Sediment basins are sediment control practices installed near discharge points on construction sites intended to temporarily detain and treat sediment-laden stormwater prior to discharging offsite. Sediment basins are designed to provide storage and detention time to allow for suspended sediment to settle through gravity. Standardized guidance on sediment basin design typically implement common features within basins intended to facilitate the retention of sediments. Design features include volume sizing factors (*VSFs*), typical sizing geometries, use of energy dissipaters in the form of baffles, dewatering mechanisms, and often times the use of chemical treatment *(ALDOT 2010; ALDOT 2012; USEPA 1986).* However, a one-size fits all approach is not applicable across all construction sites, as local hydrologic (rainfall) and soil conditions influence the proper design of basins *(Fifield 2015).*

2.2 STORAGE AND GEOMETRY

Inflow hydrographs, sediment pollutographs, and source soil composition directly correlate to the effluent grain size distribution from a sediment basin. The geometry of a sediment basin is the primary characteristic that most influences trapping efficiency by affecting flow paths and residence times *(Thaxton et al. 2004).* Volume considerations are necessary to provide sufficient storage to detain total runoff volumes from rainfall events and to prevent overtopping conditions, which drastically reduce the performance of sediment basins. Additional dead storage within the basin is also required to provide volume for deposited sediment. To provide adequate storage, design guidance is developed by relying on either standard *VSF*s or design rainfall events.

Early design guidance called for volumes to store the local 10-yr, 24-hr rainfall event *(USEPA 1976)*. In an effort to simplify hydrologic design calculations, a *VSF* of 1,800 ft^3/acre (125 m^3/ha) of contributing drainage area was adopted by several state agencies *(North Carolina Department of Transportation 2012)*. The USEPA implemented a *VSF* in 1992 by selecting a 3.0 in. (7.62 cm) rainfall to represent a 2-yr, 24-hr rainfall event in a number of locations. The agency assumed that the event would generate 1.0 in. (2.54 cm) of runoff, which is approximately 3,600 ft^3/ac (250 m^3/ha) of contributing land area. The USEPA has identified this *VSF* as capable of storing 90% of the rainfall events occurring each year *(USEPA 1991; USEPA 1992)*. This guidance has been criticized for not providing sufficient storage to provide full runoff capture of the 2-yr, 24-hr rainfall event in the majority of the U.S., as the one size fits all approach does not consider local hydrologic factors *(Fifield 2015)*. Recognizing this shortcoming, in 2008 the USEPA adjusted their standards, recommending that sediment basins contain sufficient storage for the runoff volume generated from the local 2-yr, 24-hr rainfall event, or the volume of 3,600 ft^3/ac (250 m^3/ha) *(USEPA 1998)*. Depending on local climate, the two sizing factors result in drastically different volumes of storage. SHAs, such as ALDOT, are transitioning into requiring the sediment basin designs to contain runoff from the local 2-yr, 24-hr rainfall event, requiring a detailed hydrologic analysis to be performed for proper sizing *(ALDOT 2010)*.

Guidance is also provided for the maximum contributing drainage area that should be routed to a sediment basin. Design requirements vary greatly throughout the country. The State of Alabama Soil and Water Conservation Committee (AL-SWCC) recommends that the maximum drainage area per sediment basin be no more than 10 ac (4.0 ha), with the absolute maximum being 100 ac (405 ha) *(AL-SWCC 2014)*. To optimize pond performance, it is generally recommended that sediment basins should be long and narrow; with a minimum length to width ratio (*L:W)* of 2:1 *(AL-SWCC 2014; Barfield et al. 1983; Chen 1975; Griffin et al. 1985; North Carolina Department of Environmental and Natural Resources [NC-DENR] 2013)*. However, maximum settling efficiency can be expected from a sediment pond with a length-to-width ratio of about 5:1 *(USEPA 1976)*.

Basin surface area sizing is often derived through the concept of Stokes law, which describes the drag force acting on a spherical object at a low Reynolds number (i.e., laminar flow conditions). Stokes law shows that terminal velocity of a spherical particle is proportional to the diameter and mass of the object. Stokes law allows designers to select a basin surface area that will provide a flow length sufficient to provide enough time for the design soil particle size to fall out of suspension and be captured. Stokes law for spherical objects is shown below in Eq. 2.1 *(Cimbala and Cengel 2008; Fifield 2011)*:

$$V_s = \frac{g * (s-1) * d^2}{18 * \mu} \quad \text{(Eq. 2.1)}$$

Where,

V_s = terminal velocity, ft/s (m/s)

g = acceleration of gravity, 32.2 ft/s^2 (9.81 m/s^2)

s = specific gravity of suspended particle

d = diameter of suspended particle, ft (m)

μ = kinematic viscosity of fluid, ft^2/s (m^2/s)

This relation shows that terminal velocity of a spherical particle is proportional to the diameter and mass of the object. The velocity is also affected by the viscosity of the water, therefore warmer temperature water will provide faster settling times. This equation allows designers to select a basin surface area that will provide a flow length sufficient to provide enough time for the design soil particle size to fall out of suspension. Stoke's law does however have limitations; assumption of a single perfectly spherical particle, ideal and unhindered settling conditions, and no interaction between intermolecular and electromagnetic forces.

2.3 ENERGY DISSIPATION

Turbulent flow conditions within a sediment basin are undesirable in that they cause re-suspension of sediment. To provide sediment particles an increased opportunity to settle, energy dissipaters are commonly employed in sediment basins. Baffles help reduce turbulence and provide lower-velocity flow conditions. Flow energy is dissipated when baffles are used as they allow water to flow across the width of the basin at uniform velocity *(Chen 1975)*. Turbulent flows are undesirable in basins as they contribute to prolonged suspension *(Goldman et al. 1986)*. In addition, studies conducted using steady-state tracer evaluations have shown that the use of barriers reduce short-circuiting by preventing inflow from moving directly to the outlet *(Millen et al. 1997)*. Another advantage of baffles is that they provide an increase in the effective width of the basin.

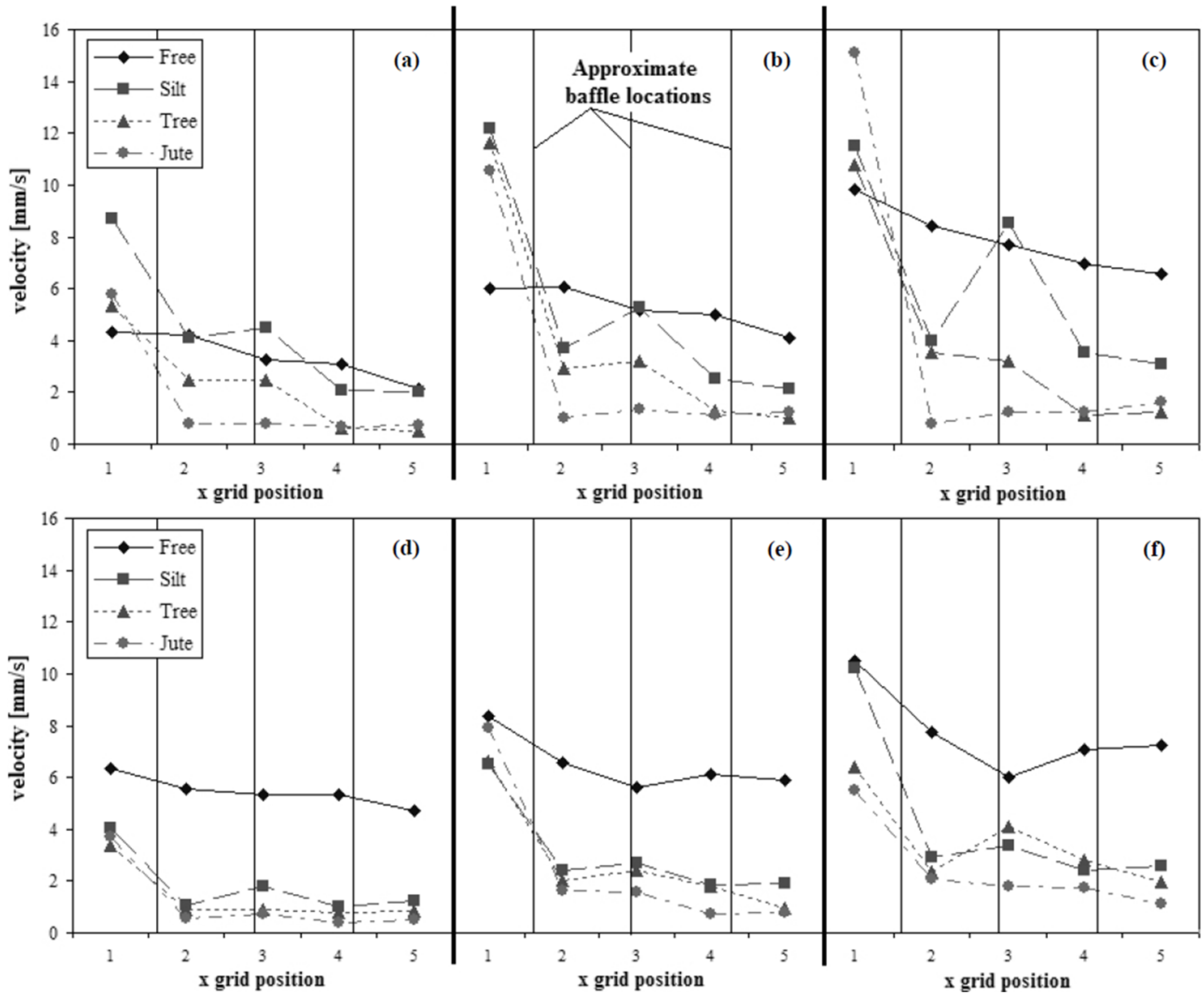
Millen et al. conducted baffle treatment experiments on a 5,500 ft^3 (155 m^3) sediment basin and concluded that baffles constructed of filter fabric with weirs cut along the top of the baffle were statistically significant at improving the sediment retention of a perforated riser sediment basin system by 1.3%. The inclusion a floating skimmer in lieu of the perforated riser in the same baffle system reduced sediment retention by 0.3% *(Millen et al. 1997)*. Three rows of coir baffle dissipaters installed perpendicular to the direction of inflow are considered common practice in the design of sediment basins *(ALDOT 2012; AL-SWCC 2014; NC-DENR 2013)*. Figure 2.1(a) shows a sample of coconut coir typically used as a sediment basin baffle. Figure 2.1(b) shows a series of baffles installed in a sediment basin.

(a) coconut coir (b) baffle installed in basin

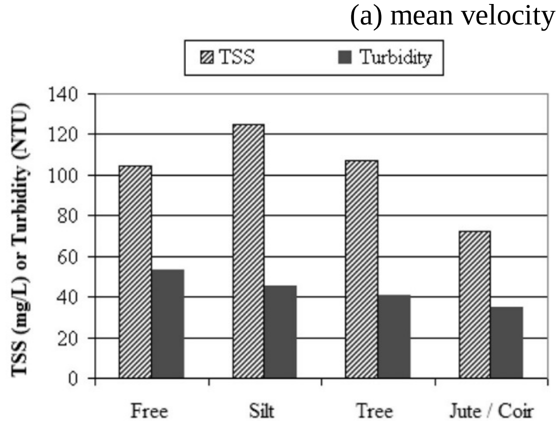
Figure 2.1 Sediment Basin Baffles.

Thaxton et al. *(2004)* conducted experiments on various baffle materials installed in a 2:1 rectangular 812 ft^3 (23 m^3) sediment basin at the Sediment and Erosion Control Research and Education Facility (SECREF) on the North Carolina State University Lake Wheeler Field Laboratory in Raleigh, North Carolina. Experiments were performed with baffles made up of three different types of materials: woven polypropylene silt fence with 204 threads/ft, polyethylene tree-protection fence with openings of 2.0 by 4.0 in. (5.1 by 10.2 cm), and jute/coir combination composed of a standard jute mesh backed by a woven coir erosion control blanket. Baffles were installed in three parallel rows spaced at 3.0 ft (91.4 cm), perpendicular to the direction of flow. The silt fence installation included weirs placed at staggered locations to route flow around the baffles rather than through the material.

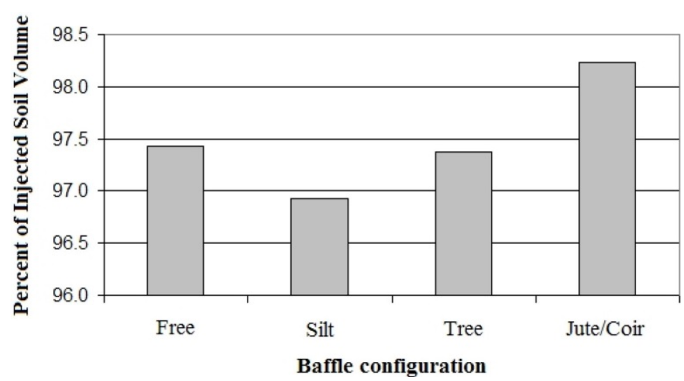
The baffles were evaluated for their capability to decrease the velocity between each row. The study concluded that the use of baffles substantially reduced mean flow velocities and velocity fluctuations compared to an open basin. The jute/coir baffles outperformed both the tree-protection baffles and the silt fence baffles. The jute/coir baffle reduced mean flow velocity by 75%, indicating superior absorption of inflow momentum as shown in the plot in Figure 2.2(a), which shows velocity measurements across the sediment basin at various grid positions. The study further indicated that the jute/coir baffles more effectively diffused the incoming energy such that more of the pond volume participated in the sediment settling process. The result was lower turbidity and TSS at the basin outlet as well as the highest sediment capture effectiveness with the jute/coir baffle system installed as shown in Figure 2.2(b) and (c). It was also found that the first baffle provided the greatest benefit, providing velocity reduction ranging between 69.4 to 75.4% of upstream velocities. Subsequent baffles provided marginal reduction in velocities and turbulence. The researchers concluded that an optimal baffle open space fraction between 5 to 10% may exist. *(Thaxton et al. 2004).*



(a) mean velocity magnitude along basin length



(b) TSS and turbidity at basin outlet



(c) percent of introduced soil captured in basin

Figure 2.2 Baffle System Results ***(Thaxton and McLaughlin 2004; 2005)***

2.4 CHEMICAL TREATMENT

Very fine suspended soil particles (i.e., clay and silt) require long detention times that exceed typical sediment basin treatment conditions. Chemical treatment using coagulants can promote the process of soil particle binding, providing for flocculation. Several types of chemical treatments (Table 2.1) have been used in stormwater treatment including: aluminum sulfate *(Harper 1990)*, calcium sulfate *(Przepiora et al. 1997; Przepiora et al. 1998)*, and polyacrylamide *(Bhardwaj and McLaughlin 2008)* among others. Coagulant chemicals work by neutralizing the electrical charges of the soil particles in the water, allowing the fine material to agglomerate and form large clumps or flocs. Flocs settle out of suspension through gravity. Chemicals that function primarily by charge neutralization are considered to be coagulants, whereas chemicals that remove particulates by both charge neutralization and bridging are considered flocculants. These chemicals are commonly used to treat stormwater. In sediment basins, coagulants and flocculants can be used as an active treatment approach to promote settlement of the finely suspended soil particles.

These chemical agents use electrical charges to attract sediment particles to coagulate. Charges can be cationic (positive), anionic (negative), nonionic (neutral), or amphoteric (changeable, depending on pH of water). When used in excess, cationic treatments have been shown to be toxic to fish as the positively charged particles are attracted to the negatively charged hemoglobin in the gills *(USEPA 2005)*.

Table 2.1 Chemicals Typically used for Treating Turbidity [A]

Chemical	Make-up	Charge	Composition	Drawbacks
Chitosan	polymer	cationic	chiten: derived from crab, shrimp, and other crustacean shells	costly, toxic if overdosed
Polyacrylamide	synthetic polymer	anionic cationic nonionic	wide variety of acrylamide chemicals	cationic form is toxic to fish
Diallyldimethyl Ammonium Chloride (DADMAC)	monomer	cationic	-	strong aquatic toxicity if overdosed
Calcium Sulfate (Gypsum)	inorganic	-	naturally occurring mineral	
Aluminum Sulfate (Alum)	inorganic	-	-	can increase acidify water if overdosed
Aluminum Chlorhydroxide [$Al_2Cl(OH)_5$]		cationic	-	toxic if overdosed
Mimosa Bark	-	-	-	toxic if overdosed

Notes: [A] *(McLaughlin and Zimmerman 2009; ProTech General Contracting Services 2004)*

2.4.1 POLYACRYLAMIDE

Polyacrylamide (PAM) is a high molecular weight synthetic polymer that can be manufactured to have a variety of chain lengths and to be anionic, cationic, or nonionic in net charge. PAM can be used both to reduce erosion and to control sediment contained in runoff. The polymers are predominantly used on agricultural applications to control erosion and promote infiltration on irrigated lands *(Lentz and Sojka 1994)*. When applied to soils, PAM binds to soil particles and forms a gel that decreases soil bulk density, absorbs water, and binds fine-grained soil particles *(USEPA 2005)*. PAM reaction with suspended soil particles is rapid and irreversible, with little free PAM remaining after treatment *(Sojka et al. 2007)*.

Anionic PAM is preferred for environmental applications as it has not been proven to be toxic to aquatic fauna or plant species *(J. W. Qian et al. 2004; Peng and Di 1994; Sojka et al. 2007; USEPA 2005)*. The polymer molecule is too large to cross cellular membranes, and is not absorbed by the gastrointestinal tract, is not metabolized, and does not bio-accumulate in living tissue *(USEPA 2005)*. Concern for PAM toxicity has arisen *(McLaughlin 2003)* from the acrylamide monomer associated as a contaminant of the PAM manufacturing process. Acrylamide has been shown to be both a neurotoxin and carcinogen. Regulations require that acrylamides make up no more than 0.05 percent of PAM *(USEPA 2005)*.

PAM is available in several forms including: aqueous concentrate, powder, blocks/cubes, and emulsions. These forms allow for various dosing methods. Prior to the availability of PAM blocks, a practical, cost-effective system for dosing runoff was lacking and thus limited its use *(McLaughlin 2006)*. PAM blocks are designed to be placed in runoff flows. The intention is to have the PAM dissolve as the water passes over the block, with agitation, coagulation, and flocculation provided downstream of the introduction area.

Bhardwaj and McLaughlin *(2008)* conducted controlled experiments on a small-scale stilling basin to determine the effectiveness of two PAM dosing systems to flocculate suspended sediments. Stilling basins were used to detain turbid water pumped from borrow pits or other excavations on constructions sites. Experiments were performed in a 777 ft^3 (22.0 m^3) stilling basin at the SECREF. Turbid water was prepared by introducing 1,543 lbs (700 kg) of sandy clay loam textured soil with a flow of 0.14 ft^3/s (0.004 m^3/s) over 30 minutes. The mixture produced turbidity in the range of 150 to 400 NTU. Turbid flows were collected in a mixing pond and allowed to settle for five minutes prior to pumping into the stilling basin. Pumping into the stilling basin was conducted for 130 minutes, 40 minutes of which overtopped through the exit spillway. A passive system using PAM blocks was compared to an active approach using PAM solution injection at 4 mg/L. The research concluded that both the active and passive systems provided significant turbidity decreases by 66% to 88%, respectively. Active PAM treatment provided TSS reductions up to 80%. The passive system reduced TSS by 45% to 65%, which was found to be insignificant compared to control tests without PAM application. The study further concluded that the use of porous baffles had little effect compared to PAM treatment in water quality improvements *(Bhardwaj and McLaughlin 2008).*

(a) blocks (b) granular (c) emulsion

Figure 2.3 PAM Types *(Applied Polymer Systems Inc. 2016)*.

2.5 DEWATERING

Dewatering is the controlled discharge of water from a sediment basin. The time required to dewater, or the detention time, should correlate with the time required for sediment to settle out of suspension, while also regenerating storage to contain runoff from subsequent rainfall events. Sediment basins are typically designed to detain water for periods ranging between 24 to 72 hours. Research studies have shown that increasing detention times will enhance sediment capture, as time is made available for smaller sediment particles to be removed by settling *(Albert 2001; Millen et al. 1997; Vaughan and Jarrett 2001).*

Dewatering of basins is typically controlled by a principal spillway. Effluent discharge has traditionally been achieved through the use of perforated steel pipe or plywood riser structures. However recent technology has incorporated the use of floating surface skimmers to achieve higher quality discharge that contains a lower concentration of suspended solids. Skimmers function by floating at or near the water surface of the basin allowing dewatering to occur through one or several orifices. The mechanism is attached to a discharge pipe that is connected to the basin's outlet. In contrast to riser structures, skimmers always dewater from the top of the basin, which is typically characterized by higher quality water, as soil particles settle below the skimmer orifice(s). In practice, sediment basins are typically designed to detain water for periods ranging between two to five days, and thus proper sizing of surface skimmers is necessary to achieve desired detention times.

As the detention period is increased, smaller sediment particles will be removed by gravitational settling. Research has shown that extended detention times provide enhanced sediment capture. Sediment loss (outflow) from basins with a six hour dewatering time was 2.7 times greater than the sediment loss when a 24 hr dewatering time was used (Albert 2001).

Auxiliary or emergency spillways are also incorporated into dewatering designs to allow for passage of stormwater that exceeds the designed capacity of the basin.

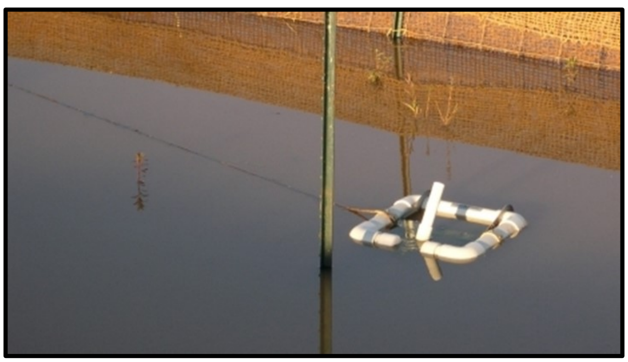
2.5.1 RISER STRUCTURE

Traditional sediment basin designs used a perforated riser structure to provide for dewatering. These primary spillway structures are typically manufactured of corrugated aluminum pipe or plywood box. The structure consists of one or more columns of holes drilled into the device that allows water to pass through. The device is typically wrapped in a geotextile and backfilled with aggregate to provide a filtering mechanism. These passive flow systems control the basin dewatering time and withdraw effluent form several vertically distributed openings within the water column. However, poor principal spillway design often leads to rapid dewatering and inefficient sediment removal *(Millen et al. 1997)*. Discharge through perforated risers varies depending on the hydrostatic head above the openings. Higher flow rates occur during conditions where the basin is full compared to when the basin is relatively empty. From a sediment discharge standpoint, this is undesirable as the basin tends to be at its greatest depth (and greatest suspended sediment concentration) immediately following storm events, allowing for high flow at depths with the highest sediment concentrations. Appropriately designed perforated riser structures have been shown to have sediment capture effectiveness of 88% or higher *(Edwards et al. 1999; Fennessey and Jarrett 1997; Ward et al. 1979)*. Figure 2.4 depicts a riser installed in an ALDOT sediment basin.

Figure 2.4 Perforated Riser Structure in ALDOT Sediment Basin.

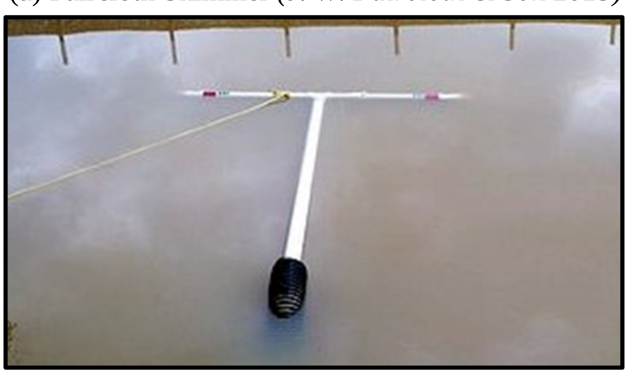
2.5.2 SURFACE SKIMMER

Surface skimmers have been introduced as a standard practice for dewatering sediment basins and have been adopted by many state environmental regulatory agencies as the principal dewatering mechanism, replacing riser pipes. Skimmers function by floating at or near the water surface of the basin allowing dewatering to occur through one or several orifices. The floating mechanism is attached to a pipe connected to the basin's outlet (Figure 2.5). These surface skimmers typically have lower outflow rates in comparison to riser structures. Longer dewatering times are desirable as researchers have determined that the majority of sediment loss from a basin with a skimmer occurred in the first five to nine hours after the start of the storm event *(Millen et al. 1997; Vaughan and Jarrett 2001)*. Skimmers come in a variety of styles and sizes (Figure 2.5), and are selected to match designed stormwater detention times. Albert *(2001)* showed that sediment loss from a basin equipped with a perforated riser principal spillway was 1.8 times greater than when a skimmer principal spillway was used. Further research performed on the Faircloth Skimmer, pictured in Figure 2.5(a), has shown to provide for only a 2.6% difference between the two systems (96.8% capture of fine sediments using skimmer, compared to 94.2% capture rates of perforated-riser dewatering devices) *(Millen et al. 1997).* Experiments have shown that skimmers equipped with orifices at the top of the arm provide for enhanced capture of sediments in the basin when compared to skimmers with orifices at the base of the device *(Vaughan and Jarrett 2001).* Some skimmer styles have orifices that can be custom cut to match a specific application (required outflow rate or detention time). When there are a large percent of fine sediments existing in the water column of a sediment basin, the sediment removal efficiency of surface skimmers is not significantly better than traditional perforated-riser dewatering devices.



(a) Faircloth Skimmer *(J. W. Faircloth & Son 2015)*

(b) ESC Skimmer



(c) IAS Skimmer *(Innovative Applied Sol. 2014)*

(d) Marlee Skimmer *(McCutchen 2015)*

Figure 2.5 Common Surface Skimmers.

2.5.3 INFILTRATION

The most effective method to capture 100% of sediment entering a basin is to provide for full stormwater capture and to detain the runoff until it is removed via evaporation and infiltration. Double-ring infiltrometer testing on ten sediment basins in Pennsylvania showed that basin infiltration rates vary significantly (0.016 to 0.854 in/hr). The researchers concluded through a series of experiments that delaying dewatering from a skimmer (e.g. using a valve to stop the outflow from the skimmer) allowed for significant increase in the amount of sediment captured by sediment basin's ability to infiltrate stormwater. A 98% sediment capture was reported for a basin, which was delayed seven days in dewatering *(Bidelspach et al. 2004)*. For the sediment basin with a low infiltration capacity and for areas with more frequent storm events (shorter inter-event dry periods), delayed dewatering increases the risk of overflow of high-sediment-concentration runoff through the emergency spillway, reducing long-term performance of the sediment basin.

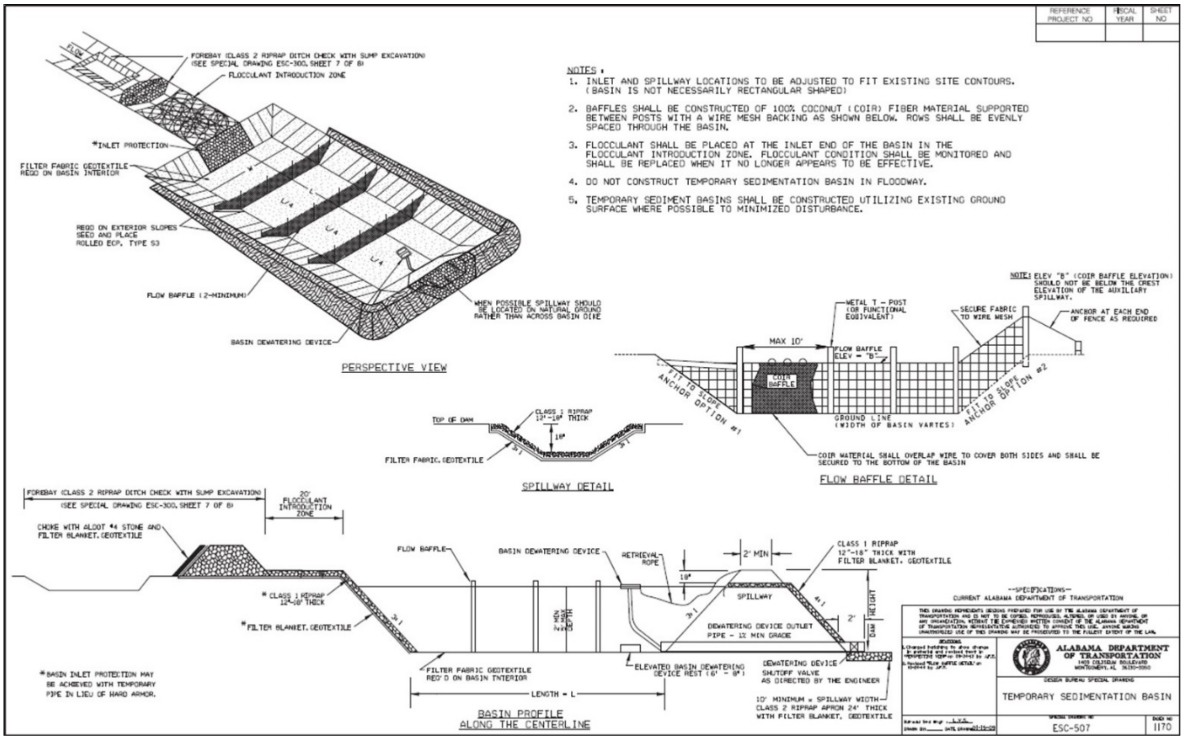
2.5.3.1 Auxiliary Spillway

The auxiliary or emergency spillway is a feature implemented in sediment basin design and construction to provide for stormwater to bypass when flow conditions exceed the designed detention volume. Spillways are commonly designed as rectangular weirs along the embankment of the basin. While sediment basins are typically designed to detain runoff emanating from a 2-yr, 24-hr storm event, the spillway is sized to pass the peak flow rate from a larger event (i.e. 10-yr, 24-hr or 25-yr, 24-hr design storm). The spillway is lined with a turf reinforcement mat or riprap to provide protection from high velocity flow *(Virginia Department of Environmental Quality 1992)*.

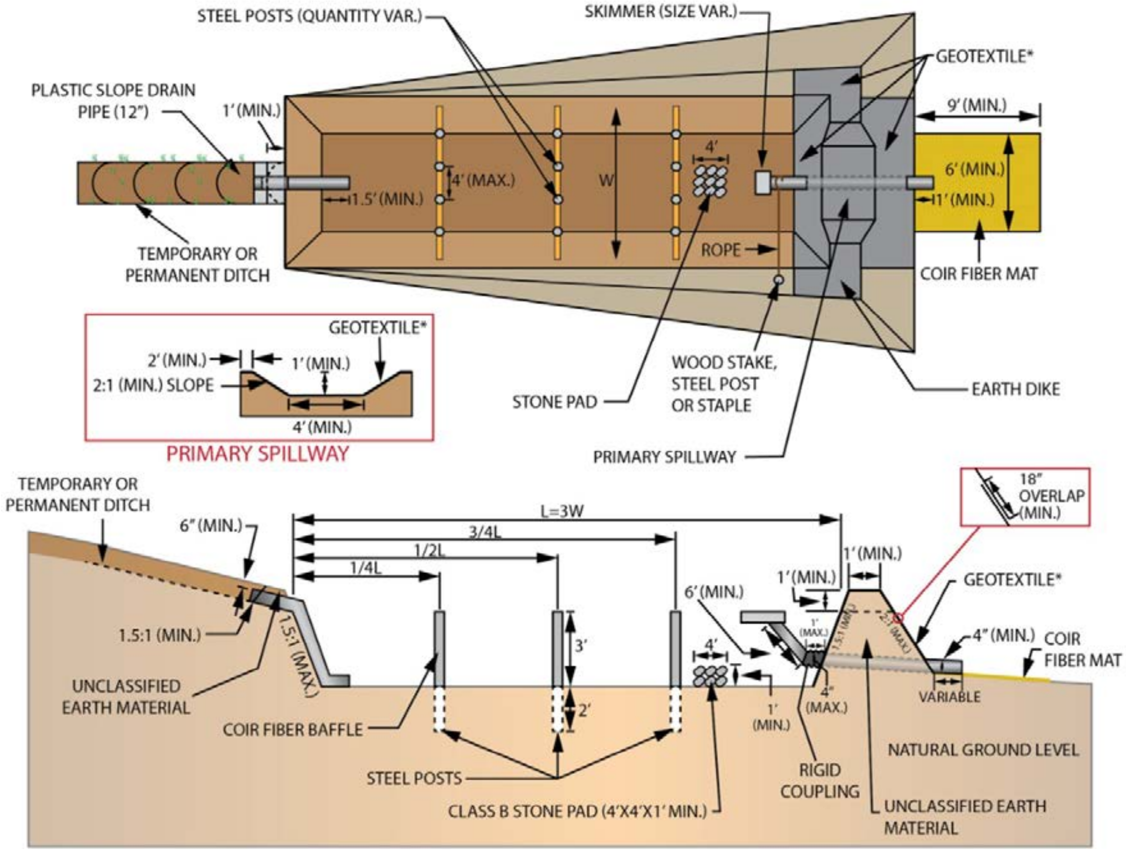
2.6 SEDIMENT BASIN DESIGN AND CONSTRUCTION

Design features presented above have been incorporated into environmental and SHAs' standardized sediment basin details. Examples of such specifications are provided in Figure 2.6. ALDOT and the North Carolina Department of Transportation (NCDOT) updated their standard sediment basin specifications in 2012 and 2015, respectively. The designs incorporate similar components including: four equivalent sized bays within the basin separated by equally spaced baffles, a dewatering skimmer, and an auxiliary spillway. Both designs have moved away from using a traditional riser structure. The ALDOT design, Figure 2.6(a), includes unique components such as: a forebay (sump excavation between two riprap ditch checks) and a flocculent introduction zone *(NCDOT 2015)*. The NCDOT standard detail, Figure 2.6(b), differs primarily in that it requires the *L:W* to be a minimum of 3:1 versus ALDOT's minimum ratio of 2:1.

These drawings are intended to provide designers and contractors with specifications on how to properly implement a sediment basin on construction sites. While there is slight variance between preferences between states and agencies, the basic principle components of sediment basins contain common features throughout standards.



(a) ALDOT standard specifications *(ALDOT 2015)*

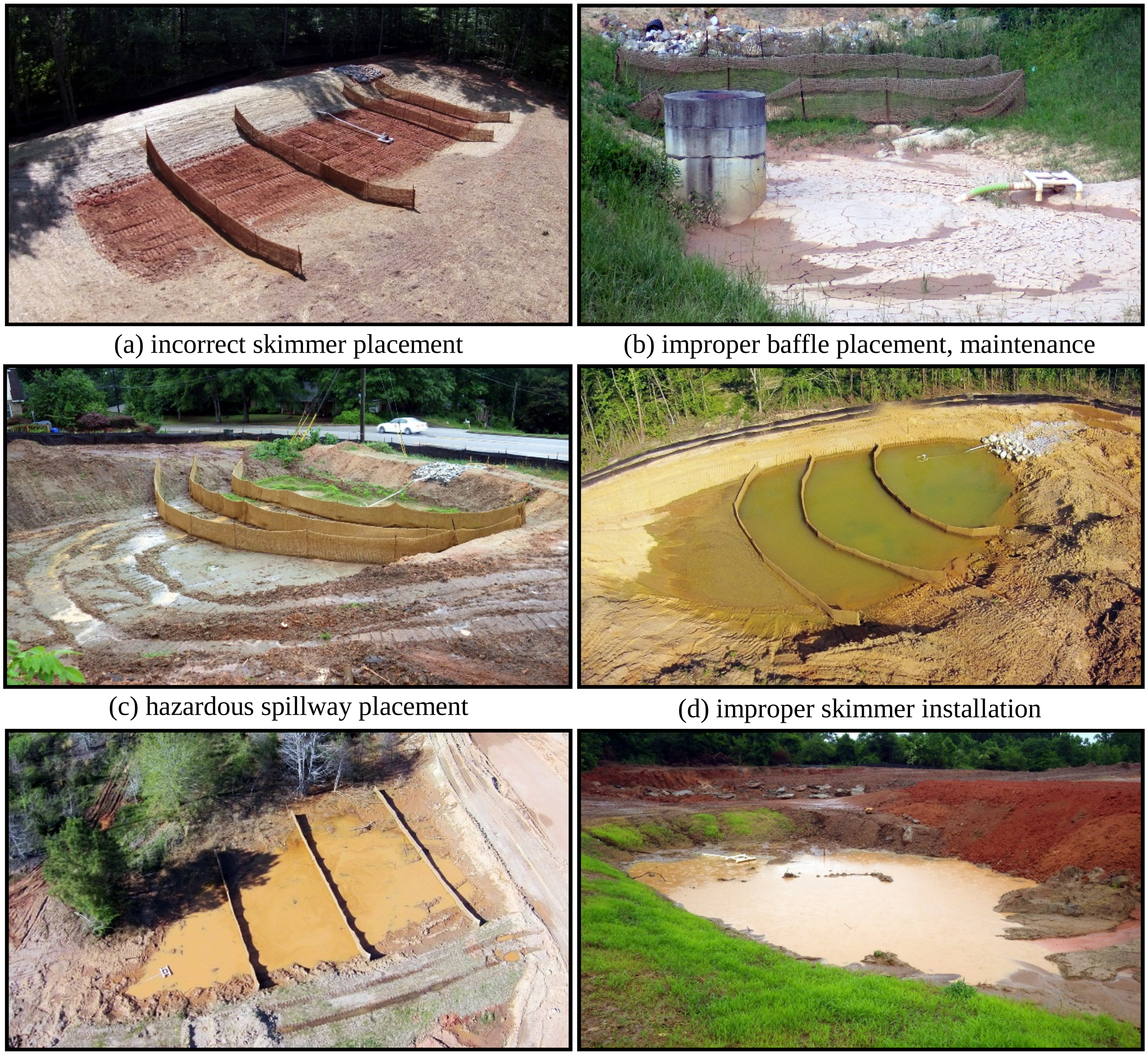


(b) NCDOT standard specifications *(NCDOT 2015)*

Figure 2.6 ALDOT and NCDOT Sediment Basin Design Guidance.

2.6.1 COMMON SEDIMENT BASIN IMPLEMENTATION ISSUES

Although standard specifications are available to guide designers in appropriate basin designs, it is common to find constructed practices that fail to meet specifications. Figure 2.7 depicts several examples of poorly designed and constructed sediment basins on construction sites. These photographs provide examples of common deficiencies found in constructed basins. Figure 2.7(a) shows a skimmer designed for placement in the center bay of a basin. This is undesirable as surface skimmers are typically placed in the final bay of the basin to provide the longest possible flow path, increasing the amount of time sediment has to settle out of suspension prior to offsite stormwater discharge. Figure 2.7(b) shows a basin with poorly maintained baffles placed only at the entrance of the basin, creating bays that are unevenly spaced and thus increasing the risk of turbulent flows and sediment re-suspension. The photograph also shows deposited sediment restraining the surface skimmer from floating freely, emphasizing the need for regular sediment basin maintenance. Figure 2.7(c) depicts a spillway constructed directly next to a roadway, creating a dangerous flood hazard if overtopping conditions are encountered. Figure 2.7(c) and (d) show basins with skimmers installed through the auxiliary spillway, which will cause the basin to retain a large volume of dead storage, leading to an increased risk of overtopping conditions during subsequent rainfall events. Figure 2.7(e) shows a sediment basin that has not been adequately excavated to contain runoff within a defined geometry, leading to the hazard of flow bypassing the basin during large rainfall events. Figure 2.7(f) shows a basin without baffles installed to dissipate incoming flow energy. A common observation with these presented examples are lack of basin stabilization, which is critical to minimize erosion and re-suspension of sediment. Erosion and re-suspension within the basin has been shown to account for up to 50% of the sediment loss from the system *(Fennessey and Jarrett 1997; Millen et al. 1997).*



(a) incorrect skimmer placement
(b) improper baffle placement, maintenance
(c) hazardous spillway placement
(d) improper skimmer installation
(e) undefined geometry
(f) lack of baffles

Figure 2.7 Poorly Designed and Constructed Sediment Basins.

2.7 WATER QUALITY PARAMETERS

Various parameters are used to assess the quality of water and the effectiveness of a treatment system. The principle methods for measuring the performance of particle removal process in water treatment systems are turbidity and particle counting via weight. Both techniques have limitations, thus a single method may not provide all the information needed to determine performance. Furthermore, flows and concentrations in channelized flow cross sections are usually unsteady, consequently, samples represent conditions only at the time and location of sample collection.

2.7.1 TURBIDITY

Turbidity is a measurement of the relative clarity of water and serves as an indicator to assess the environmental health of a water body. Measurements of turbidity were first used to maintain the aesthetic quality of treated drinking water. Turbidity is measured using an instrument called a turbidimeter that detects the intensity of light scattered at one or more angles to an incident beam of light. Turbidity is typically reported in nephelometric turbidity units (NTU). High turbidity values indicate the presence of suspended and dissolved matter. It is one of the most commonly used parameters to indirectly assess the amount of sediment in water as it can be easily measured in the field using a hand-held portable device. Figure 2.8 depicts a range of turbidity for the soil used in the laboratory testing component of this research. Turbidity is an optical property and is not a direct measure of the concentration of sediment in the sample *(American Water Works Association 1999; ASTM Standard D3977-97(13) 2013).*

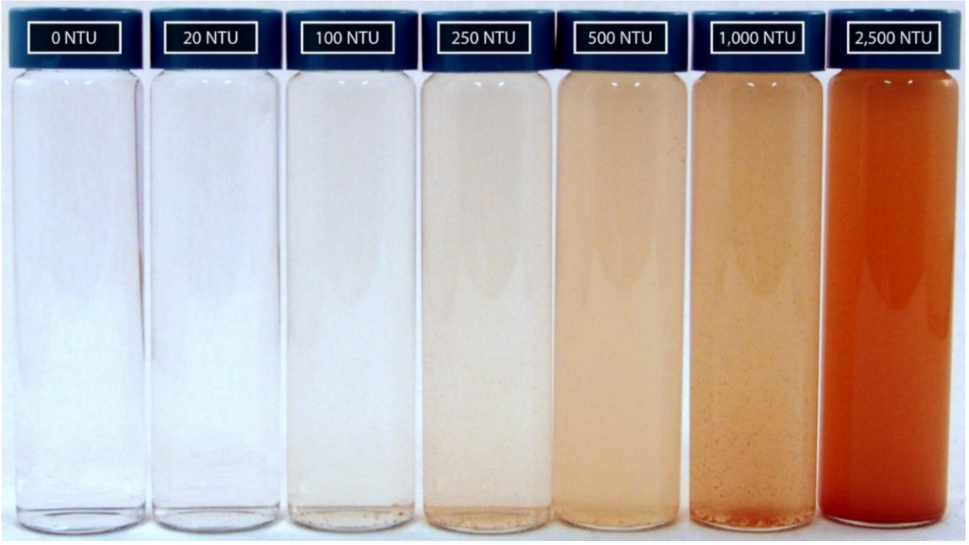


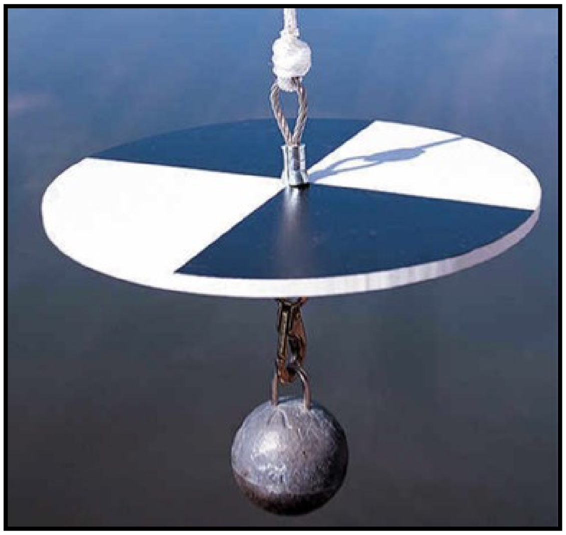
Figure 2.8 Turbidity Samples.

Secchi disks are commonly used in water bodies to provide an indication of water clarity. Secchi disks operate by placing a black and white painted disk into the water at the surface and slowly lowering the disk until it is at the maximum depth where it is still visible to the operator. This method has several limitations due to the variability in sunlight glare and differences in operator eyesight. A secchi disk is shown in Figure 2.9(c).

A turbidity tube, shown in Figure 2.9(d), is used as a visual method to determine the clarity of a water sample. The method provides for a measure of turbidity without the use of a turbidimeter. Due to its relatively low cost, the turbidity tube is commonly used in developing countries to assess water quality. The turbidity tube works by observing a viewing disk in a sample of water through a clear tube. The base of the tube holds the painted viewing disk. Turbidity is determined by correlating the measured depth of water in the apparatus at which the viewing disk is no longer visible from the top of the open tube. Similar to the secchi disk, the method has limitations due to variability in lighting conditions and operator eyesight.

(a) Hach® turbidimeter *(Hach 2015)*

(b) Hach® portable turbidimeter *(Hach 2015)*



(c) secchi disk *(Forestry Suppliers 2016)*

(d) turbidity tube *(Forestry Suppliers 2016)*

Figure 2.9 Turbidity Measuring Apparatus.

2.7.2 Total Suspended Solids

TSS are nonfilterable solids in a given volume of water. TSS is determined by filtering a well-mixed sample through a pre-weighed standard 2 μm glass fiber filter. The filter is dried at 221ºF (105ºC) and weighed to determine the mass of the nonfilterable mass captured on the filter *(ASTM Standard D5907-13 2013)*. One of the major limitations of the TSS analytical method is that the process involves removing a subsample of the collected water sample. According to the U.S. Geological Survey (USGS), the TSS analytical method to determine concentrations of suspended material in open channel-flow can result in unacceptably large errors and is fundamentally unreliable. For example, if a sample contains a significant percentage of sand-size material, then stirring, shaking, or otherwise agitating the sample before obtaining a subsample will rarely produce an aliquot representative of the sediment concentration and particle-size distribution of the original sample. Aliquots obtained by pipette might be withdrawn from the lower part of the sample where the sand concentration tends to be enriched immediately after agitation, or from a higher part of the sample where the sand concentration is rapidly depleted *(Glysson et al. 2000).*

2.7.3 Total Dissolved Solids

Total dissolved solids (TDS) is the total weight of all soluble solids dissolved (i.e., passing through a filter) in a given volume of water. The test is conducted by first passing a sample of water through a 2 μm filter. The substrate is then heated to 356ºF (180ºC), allowing the liquid media to evaporate. The remaining solids are weighed in a tared vessel to determine the TDS. Results are reported as a mass of solids over a unit volume of water (mg/L) or parts per million (PPM). TDS and TSS tests are typically conducted at the same time since TDS can be determined from TSS test substrate. TDS is used predominantly for drinking water analysis and the environmental assessment of salinity, where an indicator of cations and anions is desired. Meters and probes are also available that determine TDS by measuring conductivity and applying a conversion factor *(ASTM Standard D5907-13 2013).*

2.7.4 Suspended Sediment Concentration (SSC)

Suspended sediment concentration (SSC) is the measure of the entire sediment mass in a collected water sample and is used predominantly for analysis of water samples collected from lakes, reservoirs, ponds, streams, and other water bodies. SSC analysis follows ASTM Standard D3977, which provides three methods for determining sediment concentration: (1) evaporation, (2) filtration, and (3) wet-sieving-filtration. The evaporation method is used on samples that contain sediment that settle out of suspension within an allotted storage time. The filtration method can only be used on samples containing sand concentrations less than about 10,000 ppm and clay concentrations less than about 200 ppm. The wet-sieving filtration method is used if two concentration values are required: one for sand particles and one for silt and clay particles *(ASTM Standard D3977-97(13) 2013)*.

The terms SSC and TSS are often used interchangeably to describe the concentration of suspended solid material in a water samples, however, the analytical procedures for SSC and TSS differ and at times can produce considerably different results. The SSC analytical method uses the entire water-sediment mixture to calculate SSC values. In contrast, TSS analysis entails the withdrawal of an aliquot of the original sample analysis. The USGS uses ASTM method D3977 as the standard for determining suspended material concentration in surface water samples as it is accepted to be a more reliable measure of sediment concentration than TSS and TDS.

TSS, turbidity, and data obtained from optical backscatter instruments are used as surrogates for suspended sediment and are often less expensive to collect and/or analyze and some may be collected on a near-continuous basis. However, proper use of these surrogate measurements of suspended material requires that a relationship between SSC and the surrogate be defined and documented for each site at which the data are collected *(Glysson et al. 2000)*.

2.7.5 SUMMARY

Several research studies have been performed on both active construction site and dedicated experimental sediment basins. This chapter provided a summary of relevant sediment basin research including investigations into the overall sediment capture effectiveness, performance of various energy dissipating baffle materials, and differences between commonly used spillway devices. A summary of the presented literature relevant to the design and testing methodology of the AU-ESCTF sediment basin is presented in Table 2.2.

Table 2.2 Literature Review Summary

Study	Tested Parameters	Flow / Sediment Introduction	Data Collection Summary	Major Findings
Bhardwaj and McLaughlin 2008	physical and chemical treatments to control turbidity (i.e. baffles, active and passive PAM treatment), 777 ft^3 (22 m^3) sediment basin	0.14 ft^3/s (0.004 m^3/s) for 130 min, 1,543 lbs. (700 kg) of sediment (settlement prior to introducing to test basin) 150 to 400 NTU	6 samplers @ 5 min. for NTU / TSS, bubbler mod. for spillway	active & passive PAM treatment reduced turbidity by 88%, active PAM treatment more effective at reducing TSS
Bhardwaj et al. 2008	777 ft^3 (22 m^3) sediment basin: coir baffles, bottom inlet level spreader, PAM dosing	0.14 ft^3/s (0.004 m^3/s) for 130 min, 1,543 lbs. (700 kg) of sediment (settlement prior to introducing to test basin)	7 samplers @ 5 min. for NTU / TSS, bubbler mod. for spillway, clay mineralogy (x-ray diff. analysis), particle size dist. (hydrometer), baffle capture weights	reduced TSS by 45% to 65%
Bidelspach et al. 2004	sediment retention efficiency of delayed dewatering times on controlled sediment basin 5,000 ft^3 (142 m^3)	3,531 ft^3 (100 m^3) inflow hydrograph, 1000 lbs. (454 kg) of sediment	automated sampler at dewatering	sediment retention efficiencies for delayed dewatering of 0, 12, and 168 hrs resulted in 92, 94, and 98% capture effectiveness resp., infiltration contributed to dewatering
Engle and Jarrett 1995	sediment retention efficiency of filtered perforate riser outlets, lab scale basin 46.6 ft^3 (1.3 m^3)	121 lbs. (55 kg) of sediment	dewatering rates, sediment concentrations, sediment discharge rates, sediment retention efficiencies	no filter = 60-71% sediment retention, expanded polystyrene chips + 2-B gravel filter = 23-25% more effective
Griffin et al. 1985	dead storage characteristics of laboratory model using dye tracer tests	N/A	N/A	length to width ratios of 2:1 recommended for sediment basin design
Line and White 2001	trapping efficiency of sediment traps on construction sites in NC	natural storm events	water quality (total phosphorus, TSS, turbidity), sediment vol. via surveying, sediment analysis (hydrometer)	trapping efficiency ranged between 59 to 69%.

Table 2.2 (Continued): Literature Review Summary

Study	Tested Parameters	Flow / Sediment Introduction	Data Collection Summary	Major Findings
Logan 2012	trapping efficiency of sediment basin on construction site monitoring, 9.21 ac (3.73 ha) drainage basin @ 1,800 ft^3/ac (126 m^3/ha)	natural storm events	5 samplers, bubbler mod. for inflow, area velocity mod. for outflow, retained sediment analysis, baffle capture weights	correct selection of PAM critical to effective performance, resuspension evident after multiple events, basin volume should be increased to 3,600 ft^3/ac (250 m^3/ha)
McLaughlin et al. 2009	comparison of various design parameters (forebays, baffles, ditch stabilization, PAM, skimmers) on construction site sediment basins, 530 ft^3 (15 m^3)	natural storm events	15 min. interval sampling for turbidity / TSS	water quality improvements by simple modifications, traps and skimmer did not contribute to improvement
Przepiora et al. 1997	compared efficiency of several calcium sulfate sources in reducing NTU of water samples collected from construction site sediment basins in NC	laboratory, bench-scale experiments	turbidity, pH, conductivity, and dissolved Ca	calcium sulfate applied at the rate of 350 to 700 mg/L reduced fine-grained suspended sediment in basins within 3 hours
Przepiora et al. 1998	evaluated the efficiency of calcium sulfate as a chemical flocculent in three construction site basins, 1,590 to 5,830 ft^3 (45 to 165 m^3) equipped with skimmer	natural storm events	100 mL (3.4 oz.) grab samples from outlet	surface application of molding plaster significantly reduced both turbidity and the cumulative amount of suspended solids discharged
Thaxton and McLaughlin 2005	sediment basin, 812 ft^3 (23 m^3): vel. reduction by baffle type	0.50, 1.00, 1.50 ft^3/s	velocity at 50 points, bubbler mod. for flow rates	jute/coir and tree baffles most effectively diffuse inflow momentum

CHAPTER THREE:
SEDIMENT BASIN DESIGN TOOL: SEDSPREAD

3.1 RESEARCH OBJECTIVES

The objective of this study was to develop SEDspread, a spreadsheet-based tool to assist in the sediment basin design process. The goal for the tool is to provide designers the ability to easily implement hydrologic based designs to allow for appropriately sized and configured sediment basins on construction sites based upon the regionally specific design criteria (i.e., 1,800 or 3,600 ft^3/ac [125 or 250 m^3/ha] volume sizing factor (*VSF)*, 2-yr, 24-hr rainfall event, or manual input). The tool was designed with the intent of applicability to any construction site in the U.S.

3.2 SEDSPREAD DEVELOPMENT

A spreadsheet workbook was developed with eight worksheets to allow users to design sediment basin geometry and volumes, surface skimmer sizing, size of an auxiliary spillway, and baffle configurations. In addition, a stage-storage relationship plot and the selected dewatering schedule of the designed basin are included in the output. The developed workbook is available for free download online at: www.eng.auburn.edu/research/centers/auesctf/tools/sedspread.html. The individual worksheets listed in order are:

(1) Basin Design,

(2) Cut Sheet,

(3) Stage-Storage Relationship Chart,

(4) *Dewatering Schedule Chart*

(5) *Basin Stage-Storage Relationship*

(6) *Computation of Dewatering Rate*

(7) *Regulatory Guidance, and*

(8) *GIS Referenced 2-yr, 24-hr Rainfall and Soil CN Data for U.S.*,

Sheets one through four are the primary design and output worksheets, while sheets five through eight supplement the calculations within the first four sheets.

3.2.1 BASIN SIZING

The developed SEDspread workbook is compatible with both U.S. customary and International System of Units (SI). The first worksheet, *Basin Design*, includes all user defined inputs that are required to design the basin. The *Basin Design* worksheet is divided into two primary sections: user provided inputs and regulatory design guidance. User inputs are divided into six sections: site parameters, site geometry constraints, surface skimmer design, basin configuration, basin capacity, auxiliary spillway design, and baffle design. The user input section of the worksheet is used to compare design parameters with the selected regulatory design guidance. Regulatory design guidance can be selected from a drop down menu, which lists available guidance references. Regulatory parameters are mined from data in the seventh worksheet: *Regulatory Guidance*. When designed parameters fail to meet the regulatory design guidance, prompts indicate where sizing adjustments are required.

Table 3.1 below provides a summary of the notation used throughout the equations and relationships developed for the workbook.

Table 3.1 Notations and Summary of Variables

Notation	Description	Units	
C_d	coefficient of discharge of skimmer orifice	-	-
CN	curve number for runoff (TR-55)	-	-
D_{DS}	depth of dead storage	ft	m
D_{FB}	depth of freeboard	ft	m
D_{LS}	depth of live storage	ft	m
D_{post}	depth of baffle post staking	ft	m
D_{total}	depth of total basin (D_{DS}+D_{FB})	ft	m
D_{TS}	depth of total storage (D_{DS}+D_{LS})	ft	m
E_{SW}	elevation of spillway flow depth	ft	m
H_{baf}	height of baffle material	ft	m
H_{SW}	height of spillway	ft	m
$H{:}V$	horizontal to vertical side slopes	ft/ft	m/m
L_{bay}	length of bays	ft	m
L_{BOT}	length of basin bottom	ft	m
L_{post}	length of baffle posts	ft	m
L_{SW}	length of spillway	ft	m
L_{TOP}	length of basin top	ft	m
$L{:}W$	length to width ratio	ft/ft	m/m
n	spillway constant, 1.866 (SI) or 3.367 (US)	-	-
N_{bay}	number of bays within basin	-	-
N_{post}	number of posts required	-	-
P	depth of 2-yr, 24-hr rainfall event	in.	cm
$Ø_{skim}$	diameter of surface skimmer orifice	in.	cm
Q_{skim}	flow rate of surface skimmer	ft^3/hr	m^3/hr
Q_{SW}	flow rate spillway design	ft^3/s	m^3/s
SA	basin footprint surface area	ft^2	m^2
S_{post}	spacing baffle post	ft	m
T_{skim}	time of dewatering of V_{LS}	hrs	hrs
V_{DS}	volume of dead storage	ft^3	m^3
V_{LS}	volume of live storage	ft^3	m^3
V_{SW+FB}	volume of spillway and freeboard	ft^3	m^3
V_{total}	volume of total basin (V_{TS}+V_{SW+FB})	ft^3	m^3
V_{TS}	volume of total storage (V_D+V_L)	ft^3	m^3
VSF	volume sizing factor	ft^3/ac	m^3/ha
W_{BOT}	width of basin bottom	ft	m
W_{TOP}	width of basin top	ft	m

The site parameters require a user to select one of three sizing methods from a drop down list: manual input; regulatory guidance; or 2-yr, 24-hr design rainfall event. When the manual sizing method is selected, the user is prompted to input the designed rainfall event runoff volume, which should be equal to the design sediment basin live storage volume, and the corresponding *VSF* is calculated by dividing the design storm volume over the contributory drainage area. Selecting the regulatory sizing method, prompts a *VSF* based on the minimum regulatory guidance. The current version of SEDspread provides regulatory guidance from ALDOT, NCDOT, and AL-SWCC; more guidance will be added in the future when it becomes available. The 2-yr, 24-hr design rainfall event sizing option prompts for a site soil curve number (*CN*) value and the 2-yr, 24-hr rainfall depth, *P* (in., cm). The *CN* and *P* are used to compute a *VSF* indicative of the selected parameters. The *CN* and *P* values can be input manually, if known, or by inputting the U.S. Zone Improvement Plan (ZIP) code of the project location. Providing the ZIP code will prompt a predetermined *CN* as well as the specific 2-yr, 24-hr rainfall event depth for that area. Other design parameter inputs needed include: the contributory drainage area (ac, ha) that provide runoff flows into the basin, auxiliary spillway design flow rate, Q_{SW} (ft^3/s, m^3/s), and a live storage safety factor. The safety factor is a multiple applied to the design to increase the live storage volume (V_{LS}) of the basin.

Basin configuration inputs include: *L:W*, horizontal to vertical (*H:V*) side slopes, dead storage depth (D_{DS}) (ft, m), and live storage depth (D_{LS}) (ft, m). ALDOT suggests D_{DS} to be between 6.0 and 12 in. (15.2 to 30.5 cm). Optional site geometry constraints allow for the user to input the maximum length, width, and depth constraints on the planned location of the basin. These parameters are useful for prompting the user if the current design exceeds site restrictions.

To calculate the geometry of the auxiliary weir, the user is required to input the design spillway flow rate, Q_{SW} (ft^3/s or m^3/s), and length of the spillway, L_{SW} (ft or m). Using these inputs, the worksheet applies the broad crested weir equation *(Sturm 2010)* to determine the flow depth over the weir (coefficient of discharge assumed to be 1.0), given by,

$$D_{SW} = \left[\frac{Q_{SW}}{(2/3)^{\frac{3}{2}} g^{\frac{1}{2}} L_{SW}}\right]^{\frac{2}{3}} \quad \text{(Eq. 3.1)}$$

The freeboard depth above the crown of flow (D_{FB}) is a user input required for sizing the freeboard portion of the basin.

Remaining geometric basin properties are appropriately sized based on the configuration inputs provided. Using geometric relationships for a trapezoidal prism, the following equations were developed to determine the basin's: top width (W_{TOP}), bottom width (W_{BOT}), bottom length (L_{BOT}), dead storage volume (V_{DS}), live storage volume (V_{LS}), spillway and freeboard volume (V_{FB}), total basin volume (V_{Total}), and total basin surface area (SA),

$$W_{TOP} = \frac{L_{TOP}}{L{:}W} \quad \text{(Eq. 3.2)}$$

$$W_{BOT} = W_{TOP} - 2D_{total}(H{:}V) \quad \text{(Eq. 3.3)}$$

$$L_{BOT} = L_{TOP} - 2D_{total}(H{:}V) \quad \text{(Eq. 3.4)}$$

$$V_{DS} = \frac{D_{DS}}{6}[(W_{BOT} + 2D_{DS}H{:}V)(L_{BOT} + 2D_{DS}H{:}V) + 4(L_{BOT} + D_{DS}H{:}V)(W_{BOT} + D_{DS}H{:}V) + L_{BOT}W_{BOT}] \quad \text{(Eq. 3.5)}$$

$$V_{LS} = \frac{D_{LS}}{6}[(L_{BOT} + 2D_{TS}H{:}V)(W_{BOT} + 2D_{TS}H{:}V) + 4(L_{BOT} + D_{TS}H{:}V + D_{DS}H{:}V)(W_{BOT} + D_{TS}H{:}V + D_{DS}H{:}V) + (L_{BOT} + 2D_{DS}H{:}V)(W_{BOT} + 2D_{DS}H{:}V)] \quad \text{(Eq. 3.6)}$$

$$V_{SW+FB} = \frac{D_{total} - D_{TS}}{6}[L_{TOP}W_{TOP} + 4(L_{TOP} + D_{TS}H{:}V)(W_{TOP} + D_{TS}H{:}V) + (L_{BOT} + 2D_{TS}H{:}V)((W_{BOT} + 2D_{TS}H{:}V)] \quad \text{(Eq. 3.7)}$$

$$V_{total} = \frac{D_T}{6}[L_{TOP}W_{TOP} + (L_{TOP} + L_{BOT})(W_{TOP} + W_{BOT}) + L_{BOT}W_{BOT}] \quad \text{(Eq. 3.8)}$$

$$SA = [L_{BOT} + 2D_T(H{:}V)][W_{BOT} + 2D_T(H{:}V)] \quad \text{(Eq. 3.9)}$$

Based on the performed calculations of the V_{LS} and the input basin configuration parameters, the user can then click the VBA encoded button "CLICK WHEN RED TO SIZE SEDIMENT

BASIN". When clicked the button color changes to green indicating that the code solved for design parameters. The VBA code functions by using Excel's solver tool to determine a L_{TOP} that results in the calculated live storage volume equal to the design sediment basin volume. When making adjustments to input parameters that affect the previously calculated outputs, the sizing volume button highlights in the color red to notify the user that recalculation is required.

3.2.2 GIS Based CN and P Determination

The *CN* contributes to the runoff modeling by characterizing the runoff-potential of land covers and land uses (i.e., soils, plants, impervious area, interception, and surface storage) that are assigned to areas based on cover type. *CNs* range from 0 to 100; the higher the value, the greater the runoff potential of the soil, while lower *CN* values indicate higher soil permeability. Soils are also divided into four hydrologic soil groups (HSGs) (i.e. A, B, C, and D) according to their minimum infiltration rate. The HSGs further serve as an indication of the transmission rate of the soil *(Perez et al. 2014; 2016)*. HSG data were mined from CONUS-Soil datasets that characterizes soils into individual map units *(Miller and White 1998)*. Each map unit is associated with the percent occurrence of HSGs. To compute a weighted average *CN* for a construction site in a given area, the land use for each soil classification was first assigned as "*Developing Urban Areas with Newly Graded Areas (pervious only, no vegetation)*" and then corresponding *CNs* were specified to the soil classes (*CNs* are 77, 86, 91, and 94 for HSG A, B, C, and D, respectively) *(USDA 1986)*. Using the percent occurrence of each soil classification per map unit, the resulting weighted average was a composite *CN* for each map unit considered to be under construction. This data was organized into a GIS raster layer that was attributed by ZIP code to determine the highest occurring *CN* per each boundary.

Rainfall values indicate the depth of rainfall that is associated with a design rainfall event and is dependent on regional and climatic characteristics. Precipitation depth (*P*) for the 2-yr, 24-hr design rainfall event was mined from the National Oceanic and Atmospheric Administrations' (NOAA) Atlas 14 Precipitation Frequency Data Server (PFDS) *(National Oceanic and Atmospheric Administration's National Weather Service 2014)*. Similar to *CN* values, *P* values were summarized by the maximum occurrence per ZIP code for the entire U.S. Collectively the *CN* and *P* data were incorporated into the eighth worksheet of the design tool, *GIS Referenced 2-yr, 24-hr Rainfall and Soil CN Data*. The 2-yr, 24-hr volume design option calls the prepared *CN* and *P* values for the respective ZIP code boundary, which is then used to calculate the *VSF*.

3.2.3 VOLUME SIZING FACTOR DETERMINATION

A *VSF* is used to determine the live storage volume when multiplied against the contributing drainage area. Using the 2-yr, 24-hr basin sizing method recommended by USEPA, the developed tool determines an appropriate volume factor based on the input *CN* and *P*. The *VSF* in ft^3/ac (m^3/ha) is the total direct runoff volume for one acre (hectare) of drainage area. The time of concentration of the drainage area and rainfall distribution only affect the runoff hydrograph shape, therefore their variance does not affect the total runoff volume. Thus, expected runoff per unit area can be determined with a given *CN* and *P* using the Natural Resources Conservation Service (NRCS) *CN* method *(United States Department of Agriculture 1986),*

$$VSF = \frac{\left[P - 0.2\left(\frac{1000}{CN} - 10\right)\right]^2}{P + 0.8\left(\frac{1000}{CN} - 10\right)} * \frac{43{,}560}{12} \qquad \text{(Eq. 3.10)}$$

A plot of the *VSF* relationships is shown in Figure 3.1 for *CNs* of 77, 86, 91, and 94, representing newly graded area HSG's A, B, C, and D, respectively.

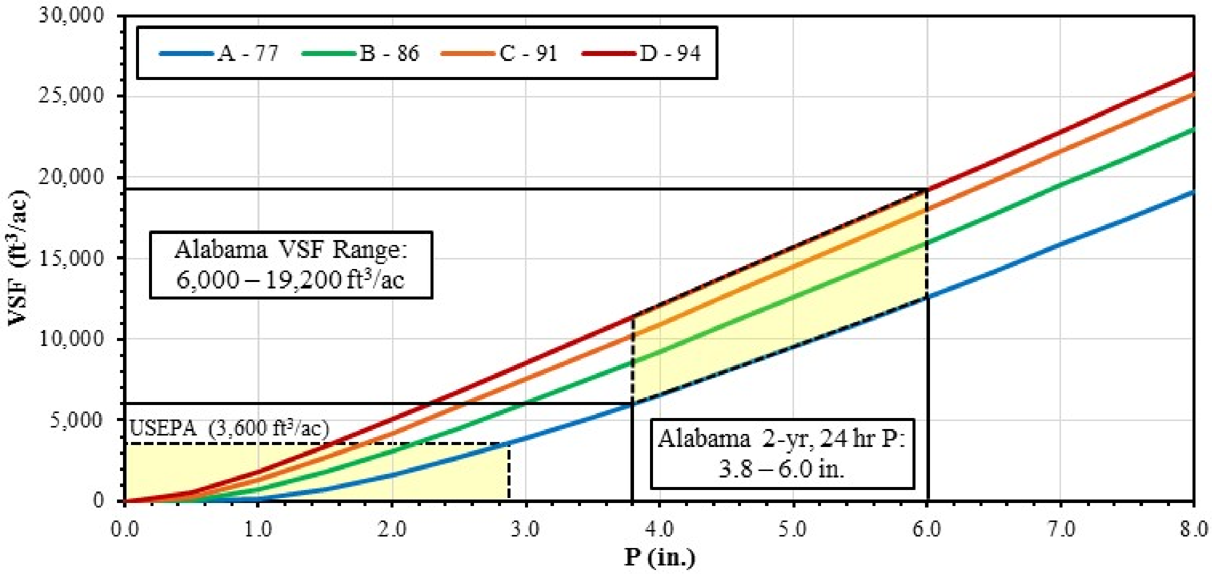


Figure 3.1 VSF Determination Based on CN and P.

The depicted chart validates Fifield's *(2015)* findings, where the current design guidance of 3,600 ft^3/ac (250 m^3/ha) correlates approximately to a 2.9, 2.2, 1.8, and 1.6 in. (7.4, 5.6, 4.6, and 4.1 cm) rainfall event for Type A, B, C, and D soils, respectively. Due to these limited ranges of *P*, the 3,600 ft^3/ac (250 m^3/ha) sizing guidance is not necessarily applicable to 2-yr, 24-hr rainfall quantities across the entire U.S.

3.2.4 SURFACE SKIMMER SIZING

Another important sediment design consideration is in the appropriate sizing of the floating surface skimmer to achieve dewatering within the desired period. The worksheet calculates the required dewatering rate, Q_{skim} (ft^3/hr or m^3/hr), by dividing the calculated live storage volume (V_{LS}) of the basin by the user defined desired dewatering time (T_{skim}). This calculation is used to recommend a surface skimmer orifice diameter derived from the following equation *(Wanielista et al. 1997)*,

$$Q = C_d \left(\frac{1}{4}d^2\right)\sqrt{2gh} \qquad \text{(Eq. 3.11)}$$

where Q is the discharge rate (ft^3/s or m^3/s), C_d is the coefficient of discharge, d is the orifice diameter (ft or m), g is acceleration due to gravity (32.2 ft/s^2 or 9.81 m/s^2), and h is the head acting on the orifice (ft or m). A C_d of 0.6 was selected for sharp orifices, and the assumption was made that the center of the skimmer orifice floats at a depth below the surface where h is approximately equal to $2d$. Based on these parameters, the skimmer orifice diameter $Ø_{skim}$ (in. or cm) can be expressed by the relationship,

$$\emptyset_{skim} = xQ_{skim}^{\frac{2}{5}} \tag{Eq. 3.12}$$

where $x = 0.2665$, or $x = 2.8163$ when using U.S. customary or SI units, respectively. This equation was incorporated into the worksheet to provide an orifice diameter recommendation for selecting an appropriately sized surface skimmer. However, the designer should verify with the specified skimmer manufacturer to ensure the skimmer is correctly sized for the designed discharge.

While infiltration and evaporation certainly lead to sediment basin dewatering, these factors were abstained from the calculation. These rates can be difficult to predict due to variable sunlight and shading conditions altering evaporation capabilities, while deposited sediment along the basin floor and elevated ground water tables can alter infiltration and evaporation rates. Furthermore, evaporation and infiltration provide benefits and enhance the sediment basin's performance as it dewaters without discharging into the receiving waterbody, therefore, making the SEDspread design conservative.

3.2.5 Baffle Design

The *Basin Design* worksheet includes a baffle design calculation to appropriately determine installation parameters. A user defines the number of bays, N_{bay}, desired within the basin, post spacing, S_{post} (ft, m), and post staking depth, D_{post} (ft, m). Based on these inputs and the computed geometry of the sediment basin, calculations are performed to determine the length of each bay,

L_{bay} (ft, m), number of posts required, N_{post}, for the installation, length of posts required, L_{post} (ft, m), height of baffle material, H_{baf} (ft, m), and the total length of baffle material required, L_{baf} (ft, m). These outputs are useful for an installer to know the correct quantities of materials required and ensuring proper installation height. The following equations are used to solve for the output parameters,

$$L_{bay} = \frac{L_{bot}}{N_{bay}} \quad \text{(Eq. 3.13)}$$

$$N_{post} = (N_{bay} - 1)(W_{bot} + \frac{2E_{SW}H:V}{S_{post}} + 1) \quad \text{(Eq. 3.14)}$$

$$L_{post} = D_{post} + E_{SW} + u \quad \text{(Eq. 3.15)}$$

$$H_{baf} = E_{SW} \quad \text{(Eq. 3.16)}$$

$$L_{baf} = 2(N_{bay} - 1)(W_{bot} + 2E_{SW}H:V) \quad \text{(Eq. 3.17)}$$

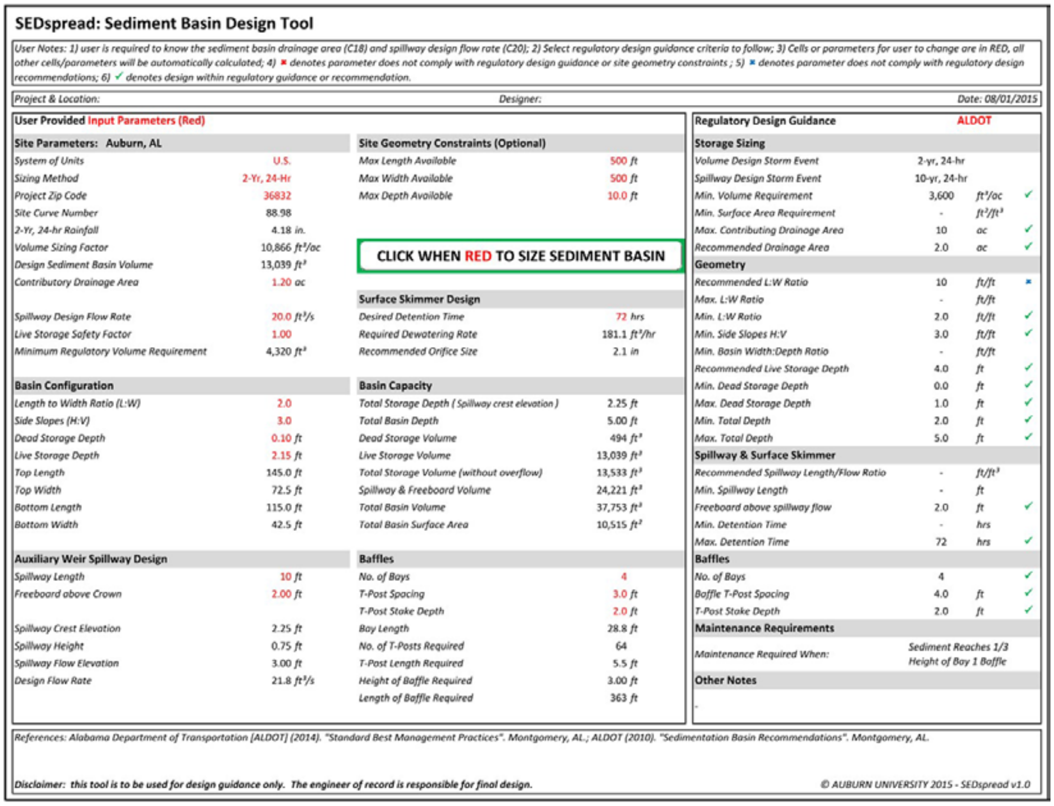
where u = 0.5 ft or 0.15 m, depending on system of units, to ensure enough of the post remains exposed above the baffle height to provide proper anchoring. H_{baf} is equal to the E_{SW} to ensure that flow is treated through the energy dissipaters even during overtopping conditions based on the recommendation from a previous study *(Fang et al. 2015)*. Calculation of L_{baf} assumes that both faces of the baffle are being covered with material, however, the value should be halved if the acquired baffle material width is > $2H_{baf}$.

3.2.6 DESIGN OUTPUTS

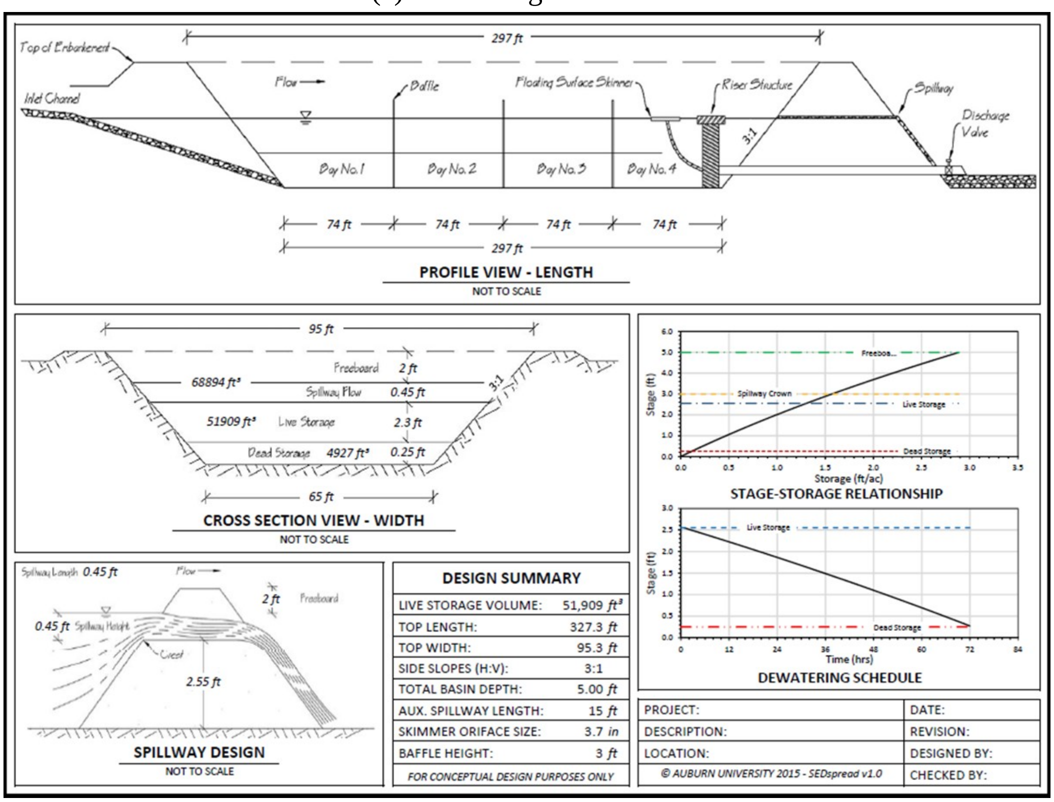
Calculated design parameters are provided in the *Basin Design* worksheet, shown in Figure 3.2(a), however key parameters are also summarized in the *Cut Sheet*, shown in Figure 3.2(b). The *Cut Sheet* worksheet is separated into seven sections providing an overall synopsis of the designed basin. The intent of this sheet is to depict a summary of the designed configuration of the basin on a typical drawing. A computer-aided design (CAD) of a sediment basin profile view, cross section, and of a broad crested spillway are included as details. Overlaid on these not to scale CAD drawings are dimensions, which are linked to those in the *Basin Design* worksheet. A design summary table provides key outputs including: V_{LS}, L_{TOP}, W_{TOP}, $H{:}V$, D_T, L_{SW}, $Ø_{skim}$, and H_{baf}. Two plots depicting the stage-storage relationship and dewatering schedule are also included in the *Cut Sheet*.

The stage-storage relationship is also plotted in the *Stage-Storage Relationship Chart* worksheet. This chart is a summary showing the volume or storage (ft/ac, m/ha) versus the stage (ft or m) in the designed basin. Calculations for the relationship are performed in the *Basin Stage-Storage Relationship* worksheet. The sheet determines the surface area at 100 increments along the depth of the basin by multiplying the respective length and width at a given stage. Incremental volumes are determined and summed to produce cumulative volumes across the entire depth of the basin. These values are then plotted on the *Basin Stage-Storage Relationship* worksheet.

The *Dewatering Schedule Chart*, shows a plot of the calculated live storage stage of the basin (ft or m) over the course of the designed dewatering period. Similarly, these values are calculated on the *Computation of Dewatering Rate* worksheet. The worksheet is separated into 100 increments along the live storage depth of the basin and the incremental and cumulative volumes across the stages are calculated. The sheet then applies the selected dewatering rate and cumulatively subtracts the values across the stage segments. The columns containing the basin stage (ft or m), and cumulative dewatering time (hr) are used to produce the *Dewatering Schedule Chart*. The dewatering time calculated by SEDspread is limited to the V_{LS} and does not account for the overtopping period, if flow were to pass through the spillway.



(a) basin design worksheet

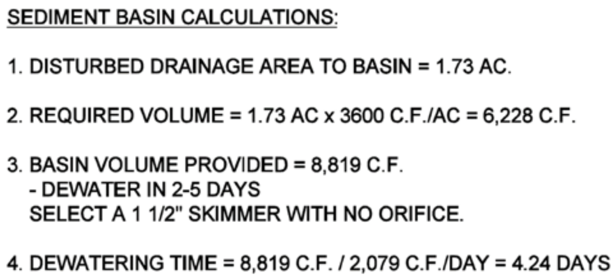


(b) cut sheet worksheet

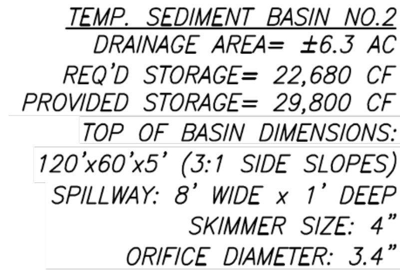
Figure 3.2 SEDspread Worksheets.

3.3 CASE STUDY

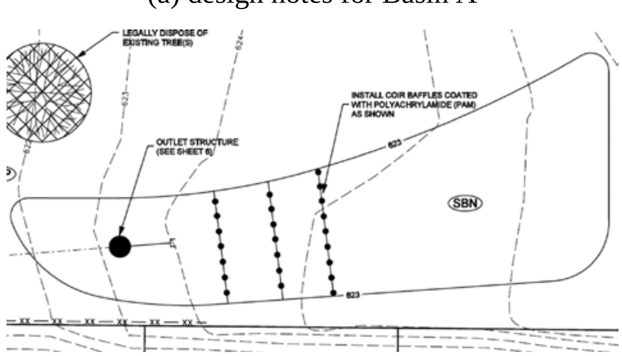
Although significant guidance and research literature are available in proper sediment basin design and plans are approved by local and state compliance agencies, it is not uncommon in current practice to see poorly designed and/or constructed basins. A contributor of poor implementation is the lack of design details provided on construction plans to appropriately depict to contractors and installers the desired configuration for the basin to perform as expected. To demonstrate the applicability of the developed design tool in improving current design practices, a case study was performed to provide an appropriate design of two sediment basins on a local commercial development (Basin A) and residential subdivision (Basin B) construction projects in Auburn, AL. Design calculations, construction details, and as-built photos of the basins, are shown in Figure 3.3.



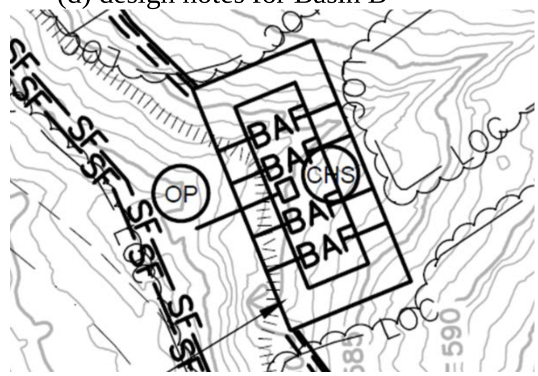
(a) design notes for Basin A



(d) design notes for Basin B



(b) construction details for Basin A



(e) construction details for Basin B

(c) Basin A as-built

(f) Basin B as-built

Figure 3.3 Case Study Sediment Basin Designs and Details.

Each of the two basins exhibits examples of improper design and construction of the sediment basins. From the designer's details, Figure 3.3(a) and (d), it is evident that there is poor implementation of necessary parameters for the sediment basins to function as intended. Dedicated inflow channels to convey stormwater to the basin have not been provided in either basin. Channels play a critical role in the function and performance of a sediment basin by collecting runoff from the site and introducing flow into the first bay of the system. This allows the baffles placed between bays to slow inflow velocities and distribute flow evenly across the width of the basin. Turbulence in subsequent bays should be minimized, allowing suspended sediment to settle through gravity. By not providing a dedicated inflow channel, these two basins collect sheet or shallow concentrated flow across all faces of the basin. A result of this is evident in Figure 3.3(c), where inflow has eroded the embankment directly in front of the surface skimmer, not only producing turbulent conditions within the dewatering bay, but also contributing to sediment re-suspension and increased turbidity. The design detail for Basin B, Figure 3.3(e), calls for the placement of the surface skimmer in the middle of the basin (i.e., bay 3 of 5), limiting the flow length. Furthermore, the orientation of Basin B is situated to where flow enters primarily parallel to the desired treatment direction, bypassing the effect of the baffles. In addition, the design and construction of Basin A does not include a dedicated auxiliary spillway, posing a flooding hazard to neighboring property and motorists.

From the provided calculations shown in Figure 3.3(a) and (d), it is evident that the designers implemented the 3,600 ft^3/ac (250 m^3/ha) guidance, and that additional storage was provided for both basins. To demonstrate the applicability of the sediment basin design tool, the two basins were redesigned using the 2-yr, 24-hr design option as shown in Table 3.2.

Table 3.2 Design Summary for Basin A and Basin B using SEDspread

Parameter	Basin A	Basin B
ZIP Code	36830	36832
CN	92.9	89.0
2-yr, 24-hr *P*, in. (cm)	4.18 (10.61)	4.18 (10.61)
Calculated *VSF*, ft^3/ac (m^3/ha)	12,148 (850.0)	10,724 (750.4)
Contributory Drainage Basin, ac (ha)	1.73 (0.70)	6.3 (2.55)
Calculated Volume, ft^3 (m^3)	22,669 (641.9)	74,148 (2099.6)
As-Designed Volume, ft^3 (m^3)	6,228 (176.4)	22,680 (642.3)
Factor of Difference	3.6	3.3

Comparing the input parameters, we see that although the projects are located in the same city, *CN* values differ, resulting in a *VSF* difference of 12% between the two sites. The calculated storage volumes for Basin A is 22,669 ft^3 (642 m^3), which is 3.6 times larger than the originally designed containment volume of 6,228 ft^3 (176.4 m^3). Similarly, Basin B was under designed to the 2-yr, 24-hr rainfall event by a factor of 3.3.

3.4 CONCLUSIONS

This study developed SEDspread, a hydrologic based design tool that allows for the appropriate sizing and configuration of sediment basins on construction sites. The developed workbook contains three sizing options, allowing users to input site parameters and constraints to determine the required basin capacity and configuration, surface skimmer selection, size of the auxiliary spillway, and baffle configuration.

SEDspread includes geospatially derived data that allows for the automated selection of design hydrologic and soil conditions through the input of a U.S. ZIP code for project location, or manual input as required. A hydrologic analysis was performed to relate input hydrologic parameters to appropriate 2-yr, 24-hr design *VSFs*. The workbook includes a summary sheet that provides users with schematics of the designed basin, available as a supplement to facilitate effective communication between the designer and contractor.

To showcase the capabilities of the developed workbook, a case study was performed to compare the actual designs of two sediment basins from local construction sites to the designs generated through SEDspread using the 2 yr, 24 hr rainfall event. The case study resulted in a volumetric difference factor of 3.6 and 3.3, indicating the basins were severely under designed for the local 2-yr, 24-hr rainfall event.

This tool should allow designers to efficiently and effectively design sediment basins using local hydrologic and soil conditions. Furthermore, the tool can be used to supplement communication between designers and construction personnel to ensure basins are constructed as designed.

CHAPTER FOUR:
LARGE-SCALE PERFORMANCE EVALUATIONS OF SEDIMENT BASIN CONFIGURATION AND HIGH-RATE LAMELLA SETTLERS

4.1 INTRODUCTION

Sediment basins are commonly used on construction sites to treat stormwater prior to discharge. The performance of these basins have been investigated by researchers, however controlled experiments in a large-scale sediment basin have not been widely performed. Standardized testing methods in a controlled environment allow researchers to better quantify the performance of current standard sediment basin designs, while also providing efficiency and performance improvements.

4.2 RESEARCH OBJECTIVES

The objectives of the study were to: (1) design and construct a sediment basin testing apparatus at the AU-ESCTF, (2) develop a testing methodology to produce repeatable large-scale sediment basin tests, and (3) perform large-scale testing to evaluate the performance of sediment basin configurations and the use of high-rate lamella plate settlers.

4.3 AU-ESCTF FACILITY OVERVIEW

The AU-ESCTF was designed and constructed in 2009 as part of a research collaboration with Auburn University and ALDOT. The facility is located at the National Center for Asphalt Technology (NCAT) Pavement Test Track in Opelika, AL. The facility has the capability of assisting ALDOT, other state highway agencies, and municipalities with research, product evaluation, and training associated with ESC practices commonly used in construction. The AU-ESTCF operates on 2.5 acres (1 ha) dedicated to the large-scale testing of ditch check, inlet protection practices, sediment basins, and sediment barriers.

The mission of the AU-ESCTF focuses on three primary components: (1) research and development (R&D), (2) product evaluation, and (3) training. R&D consists of providing a scientific understanding of ESC practices used in construction to minimize impacts to the surrounding environment through performance based, large-scale testing. The purpose of R&D is to improve the effectiveness of current ESCs typically implemented in the field. Product evaluation provides independent, third-party, standardized testing of manufactured ESC practices seeking ALDOT approval to be included on their list of qualified materials, sources, and devices requiring special acceptance. Overall product performance is compared against conventional practices to evaluate whether a product provides a substantial improvement in either preventing erosion or promoting sedimentation on-site. The focus of training is on using knowledge learned through R&D and product evaluation testing, and transferring that knowledge to designers, contractor personnel, inspectors, and regulators to highlight improved ways of installing, maintaining, and inspecting various ESC practices on-site.

(a) AU-ESCTF (west view) (b) AU-ESCTF (east view)

(c) aerial photograph during an active sediment basin demonstration

Figure 4.1 AU-ESCTF and Sediment Basin.

4.4 SEDIMENT BASIN DESIGN

The AU-ESCTF sediment basin was designed and constructed to be a large-scale sediment basin typical of ALDOT design standards. Based upon available land at the facility, a general basin detail drawing was developed, shown in Figure 4.3(a), to aid in the construction effort. A detailed as-built survey was conducted using a robotic total station to provide existing topographical conditions of the basin once constructed. Data analyses performed shows the topography in and around the surrounding area of the sediment basin, Figure 4.1(b). The constructed sediment basin measures 44 by 16 ft (13.4 by 4.9 m) along the bottom, with a total excavated footprint of 56 by 28 ft (17.1 by 8.5 m). The depth of the basin is approximately 3.5 ft (1.07 m). The completed basin, along with installed testing apparatus is shown in Figure 4.1(c).

The basin is comprised of several features intended to facilitate sediment settling in stormwater. Following ALDOT standard details and specifications *(ALDOT 2010; ALDOT 2012)*, three rows of wire backed coir baffles were installed in the basin to provide for four separate bays (i.e., Bays 1-4), 11 ft (3.4 m) in length, and 16 ft (4.9 m) in width. Steel studded t-posts were spaced 4.0 ft (1.2 m) apart and inserted 2.0 ft (0.61 m) into the ground. Wire backing was attached to the t-posts and extended along the width of the basin, up the side slopes. Coir netting was placed on both sides of the wire mesh and secured along the bottom of the basin and along the side slopes using 6.0 in. (15 cm) steel U-shaped sod staples. The height of the baffles were set at the same elevation as the maximum water depth (freeboard), i.e., the invert of the spillway, which followed recommendations from the AL-SWCC and from a previous ALDOT study *(AL-SWCC 2014; Fang et al. 2012)*.

Basin dewatering is provided by a 1.5 in. (3.8 cm) skimmer connected to a 4.0 in. (10 cm) polyvinyl chloride (PVC) outlet pipe. The pipe was equipped with a gate valve to prevent discharge and completely contain water in the basin when desired. The skimmer was installed in Bay 4 of the basin and discharged through the side of the basin into the facility's water/sediment storage basin.

Inflow is directed into the sediment basin via a 90 ft (27.4 m) Flexamat® tied concrete block mat armored channel with a longitudinal slope of 5% and the total channel depth of 4 ft (1.2 m) (Figure 4.3). The inflow channel was designed for a bottom width of 4 ft, side slope of 2:1 (H:V), and top width of 20 ft (1.2 m) (Figure 4.3). The most upstream portion of the inflow channel was designed to have a water and sediment introduction system, which is supported by an 8 by 10 ft

(2.4 by 3.0 m) concrete pad. Figure 4.2 is an architectural rendering of the sediment basin produced on Google SketchUp™ software.

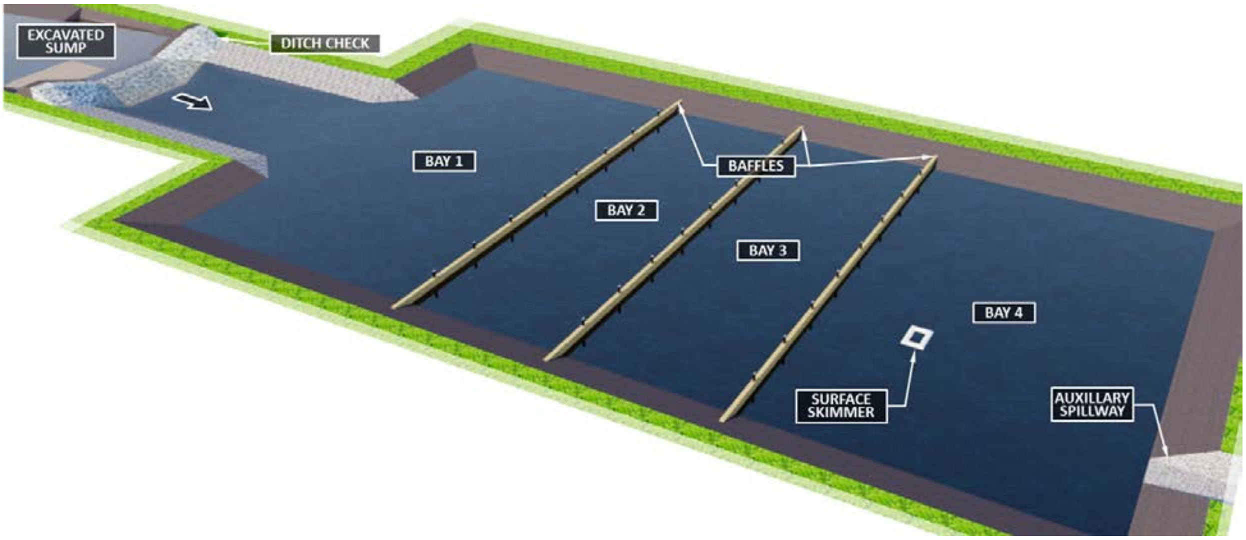
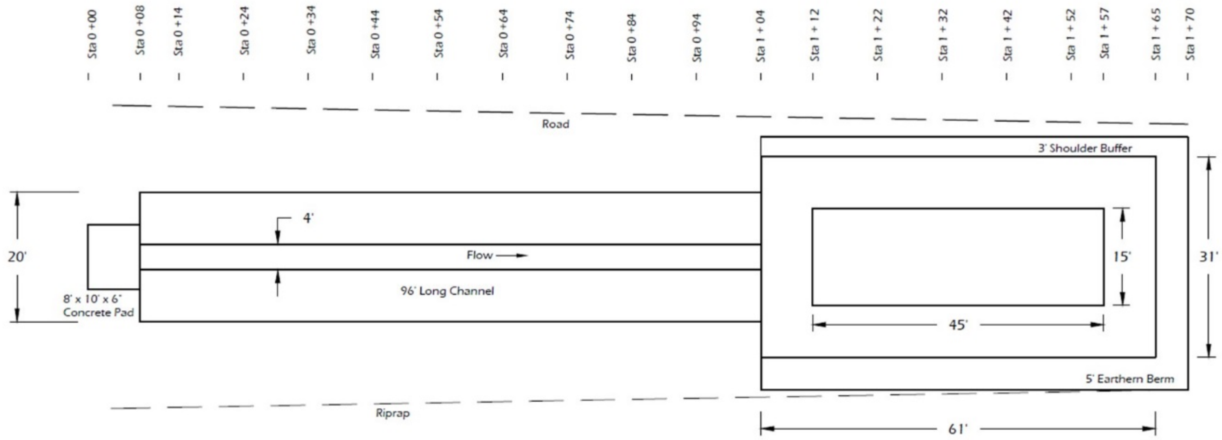
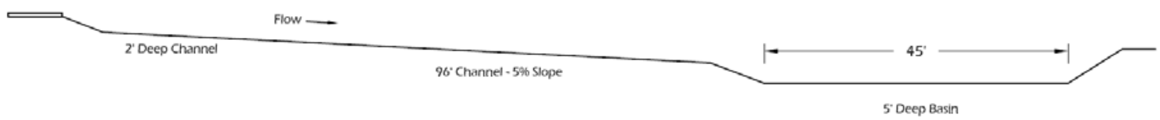


Figure 4.2 Rendering of Sediment Basin.

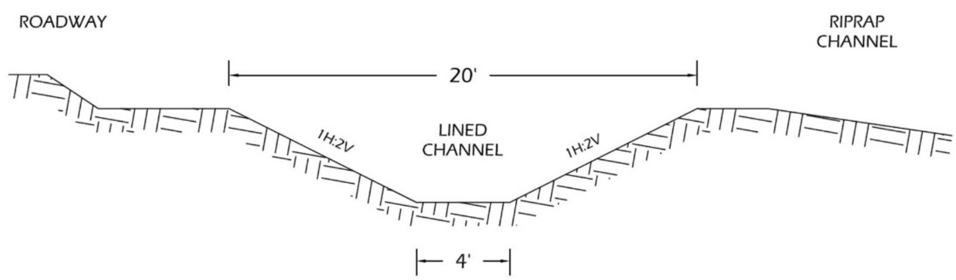
Figure 4.3 is a CAD detail of the sediment basin design, including plan, profile, and channel and basin cross sectional views.



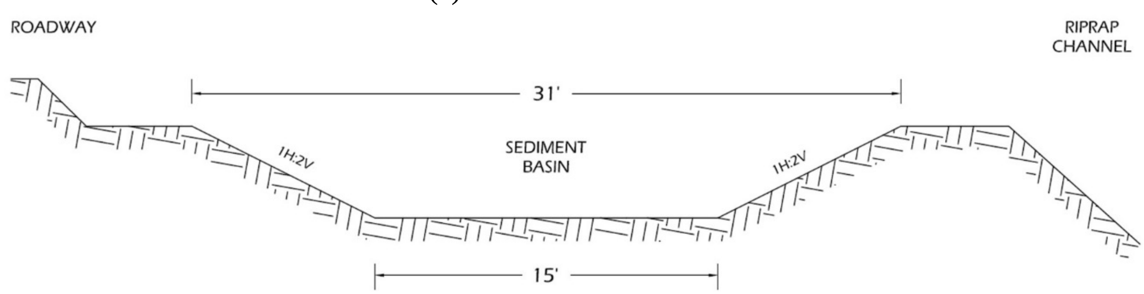
(a) plan view



(b) profile view



(c) channel section view



(d) sediment basin section view

Figure 4.3 Design of the AU-ESCTF Sediment Basin Including Inflow Channel.

As per ALDOT design standards, an enhanced rip-rap ditch check was installed in the inflow channel approximately 20 ft (6.1 m) upstream of the sediment basin *(ALDOT 2015)*. This feature is intended to facilitate the capture of rapidly settable solids prior to reaching the basin.

From a GIS analysis of the topographical survey, it was determined that the dead storage, or volume below the basin's discharge pipe, was at an elevation of 4.8 in. (12.2 cm) above the basin floor, providing for 43 ft^3 (1.2 m^3). The auxiliary spillway becomes active when the stage in the basin exceeds 3.5 ft (1.1 m). The total storage of the basin, as-built, is 2,790 ft^3 (79.0 m^3). To maximize the water storage capability, no dead storage or freeboard were considered in the geometry of the basin.

Table 4.1 provides comparisons between the Alabama Handbook, ALDOT sediment basin design standards, NCDOT design standards, and the constructed test sediment basin at the AU-ESCTF.

Table 4.1 Sediment Basin Comparison to Standard Detail

Parameters	AL Handbook	ALDOT	NCDOT	AU-ESCTF
Upstream Sump	-	✓	×	✓
Upstream Ditch Check	-	✓	×	✓
Dewatering Skimmer	✓	✓	✓	✓
Auxiliary Spillway Design	10 yr, 24 hr	10 yr, 24 hr	10 yr, 24 hr	-
Maximum Drainage Area, ac (ha)	10 (4.0)	10 (4.0)	100 (405)	-
Minimum Volume, ft^3/ac (m^3/ha)	3,600 (252)	3,600 (252)	1,800 (126)	-
Design Detention Time, hrs	48 - 120	72	48	56 [A]
Coir Baffles / Bays	3 / 4	3 / 4	3 / 4	3 / 4
Baffle Material Specs., oz/yd^2 (g/m^2)	20.6 - 26.5 (700 - 900)	≥ 23.0 (780) [B]	≥ 20 (678)	-
Baffle Open Space Fraction	-	0.50	0.50	-
Baffle Post Spacing, ft (m)	4 (1.2)	4 (1.2)	4 (1.2)	4 (1.2)
Min. Freeboard, ft (m)	1.0 (0.30)	1.5 (0.46)	-	0.0
Dead Storage, in. (m)	-	6 - 12 (0.15 - 0.30)	12 (0.30)	5 (0.13)
Basin Depth (ft)	≥ 2.0 (0.61)	2.0 - 5.0 (0.61 - 1.52)[C]	3.0 - 5.0 (0.91 - 1.52)	2.6 - 3.4 (0.79 – 1.04)[D]
Min. Length : Width Ratio	2:1	2:1 [E]	3:1 [F]	2:1

Notes: [A] estimated
[B] 20 oz/yd^2 (678 g/m^2) min. *(ALDOT 2012)*
[C] 3.0 ft (0.91 m) preferred
[D] basin bottom elevation varies
[E] 10:1 preferred
[F] 2:1 *(NCSCC 2013)*

4.5 SEDIMENT BASIN CONSTRUCTION

Prior to excavation of the sediment basin, the cut and fill geometry of the basin and channel was staked out using a robotic total station, see Figure 4.4(a). Two mini excavators and a skid steer were used during the excavation process, Figure 4.4(b), which took the three operators two days to complete. Excavation started with the channel and worked into the basin. The channel was finalized to grade with the use of a mini skid steer and compacted with a vibratory plate compactor Figure 4.4(c). To stabilize the channel and disturbed area around the basin, hydro-seeding was applied, Figure 4.4(d). The hydro-seeding was allowed to cure prior to the installation of the concrete lined block system in the channel Figure 4.4(e) and (f).

(a) pre-construction layout

(b) sediment basin excavation

(c) channel compaction

(d) hydro-seeding

(e) Flexamat installation

(f) established vegetation

Figure 4.4 Construction and Stabilization of Sediment Basin

Video 4.1 shows a time lapse of the hydro-seeding process used to establish vegetation along the sediment basin inflow channel.

Video 4.1 Hydro-Seeding Sediment Basin Channel.

Video 4.2 shows a time lapse of the installation of the Flexamat tied concrete block system being installed along the inflow channel of the basin.

Video 4.2 Installation of Flexamat Channel Lining.

4.5.1 Infiltration Modifications

During construction, rocky soils were found on the south end of the sediment basin. The soils were indicative of high infiltration capacity, which was undesirable for the functionality of experimentally testing the sediment basin. In an attempt to prevent seepage, a plastic liner was installed along the south wall of the basin prior to the placement of 3.5 oz/yd^2 (120 g/m^2) of unwoven filter fabric geotextile material. The installation of the liner and filter fabric is shown in Figure 4.5

(a) Plastic Membrane (b) Geotextile Lining

(c) installation of bentonite layer

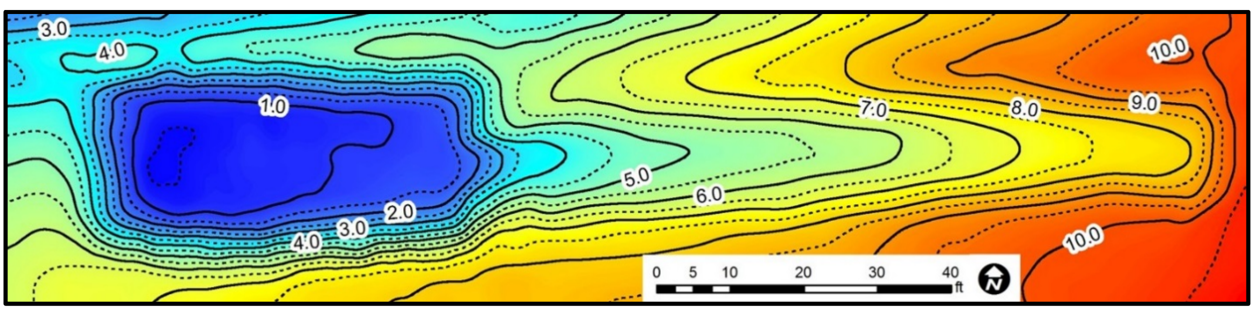
Figure 4.5 Installation of Basin's Lining.

During early stages of testing, it became evident that the plastic liner was insufficient in reducing the infiltration rate and further modifications would be needed. Several lining options were investigated including: sealing with shotcrete, lining with concrete cloth material, lining with geo-membrane, and lining with bentonite sealer. Ultimately the most feasible option resulted in using a bentonite pond liner. Installation of the liner required excavation of 12 in. (0.30 m) below the sediment basin. Once installed, the liner was backfilled and compacted with approximately 6 in. (0.15 m) of soil, as shown in Figure 4.5(c).

To minimize the effects from natural storm events impacting testing, a reclaimed asphalt pavement (RAP) berm was constructed along the south face of the basin. This berm directs stormwater away from the test basin and towards the facility's lower retention pond. Storm event influences are limited to direct rainfall and runoff occurring in the immediate local upstream vicinity of the test basin.

4.5.2 AS-BUILT

A detailed as-built survey was conducted on June 17, 2014 using a Trimble S6 robotic total station. The survey provides existing topographical conditions of the basin. Data analyses were conducted using esri® ArcGIS™. Figure 4.6 shows the topography in and around the surrounding area of the sediment basin. The survey was updated on December 12, 2014 after re-grading and compacting the basin floor.



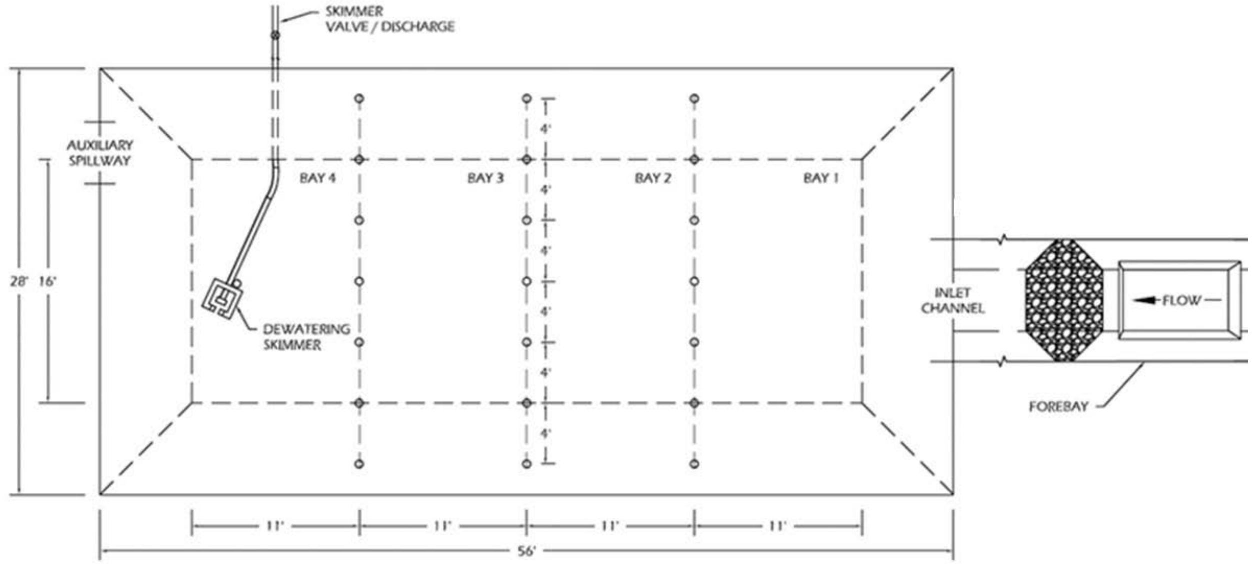
Note: dashed contour lines are ½ ft elevation increments from solid contour lines.

Figure 4.6 Sediment Basin Topography

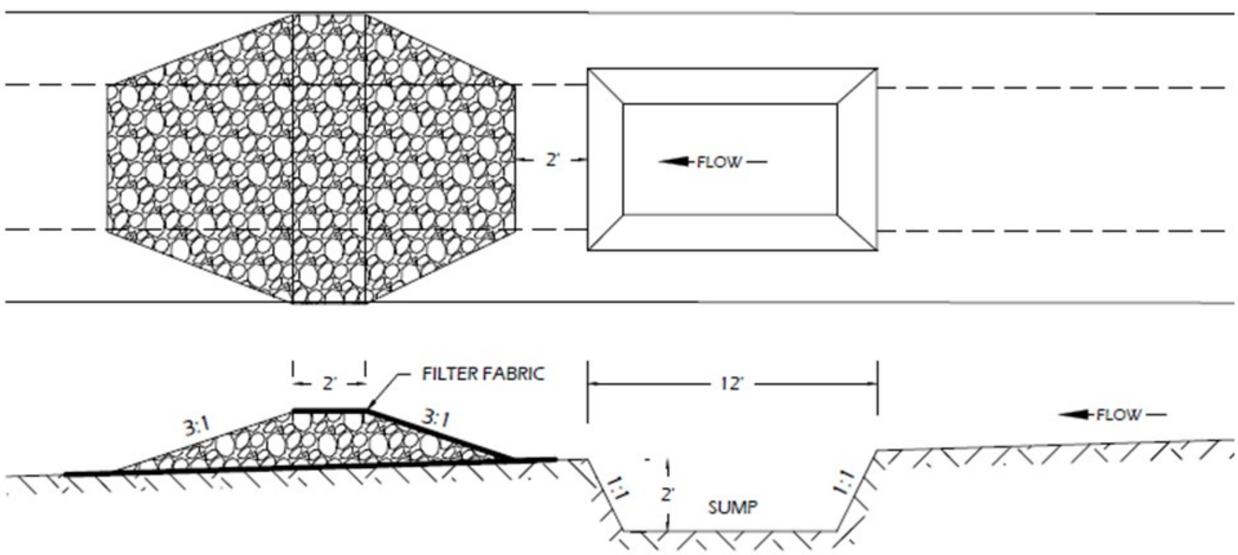
Using the topographical survey, a general basin detail drawing was created on AutoCAD, shown in Figure 4.7(a). The constructed sediment basin measures 44 by 16 ft (13.4 by 4.9 m) along the bottom, with a total excavated footprint of 56 by 28 ft (17.1 by 8.5 m).

As an installation iteration, a forebay was constructed and prepared for testing. The design followed ALDOT standards and was constructed upstream of the sediment basin along the Flexamat channel. The forebay consisted of an excavated sump positioned between two standard rip-rap ditch checks with an 8 oz./yd^2 (271 g/m^2) filter fabric choker. The forebay was installed approximately 20 ft (6.1 m) upstream of the sediment basin entrance. This feature is intended to facilitate the capture of rapidly settable solids from sediment-laden inflow (runoff).

The design of the forebay is included in Figure 4.7(b). The forebay consists of a riprap ditch check approximately 20 ft (6.1 m) upstream of the basin entrance. For evaluations that called for its inclusion, an excavated sump was added directly upstream of the ditch check. The sump measured 4 ft (1.2 m) wide, 12 ft (3.7 m) in length, and 2 ft (0.61 m) deep.



(a) sediment basin plan detail



(b) forebay plan and profile details

Figure 4.7 Sediment Basin and Forebay Detail.

4.5.3 BASIN STORAGE

From a GIS analysis of the topographical survey, it was determined that the basin has a bottom elevation of 632.4 ft (193.8 m). The dead storage without outflow from skimmer is 0.4 ft (0.12 m) and 43 ft^3 (1.2 m^3). The auxiliary spillway is situated at 635.9 ft (193.8 m) of elevation and is activated when the stage level in the basin exceeds 3.5 ft (1.07 m), slightly less than the original design depth of 4.0 ft (1.22 m),. The total storage of the basin is 2,790 ft^3 (79.0 m^3). To maximize the water storage capability, no dead storage or freeboard was considered in the geometry of the basin. Volumetrically, the basin is 70% full when the stage is at 2.55 ft (0.78 m) which corresponds to a volume of 1,691 ft^3 (47.9 m^3). A detailed stage-storage relationship has been provided in Table 4.2 and a graphical representation of the live storage volume is shown in Figure 4.8.

Table 4.2 Sediment Basin Stage-Storage Relationship

Zone	Elevation		Stage		Area		Storage	
	ft	m	ft	m	ft^2	m^2	ft^3	m^3
Dead Storage 43 ft^3 (1.2 m^3)	632.4	192.76	0.0	0.00	0.6	0.1	0.0	0.0
	632.6	192.82	0.2	0.06	93.6	8.7	7.7	0.2
	632.8	192.88	0.4	0.12	268.3	24.9	43.1	1.2
Live Storage 2,373 ft^3 (67.2 m^3)	633.0	192.94	0.6	0.18	425.1	39.5	114.5	3.2
	633.2	193.00	0.8	0.24	560.3	52.1	213.6	6.0
	633.4	193.06	1.0	0.30	667.1	62.0	337.2	9.5
	633.6	193.12	1.2	0.37	735.6	68.3	477.8	13.5
	633.8	193.18	1.4	0.43	789.9	73.4	630.5	17.9
	634.0	193.24	1.6	0.49	838.3	77.9	793.3	22.5
	634.2	193.30	1.8	0.55	883.5	82.1	965.5	27.3
	634.4	193.37	2.0	0.61	926.6	86.1	1146.6	32.5
	634.6	193.43	2.2	0.67	968.1	89.9	1336.1	37.8
	634.8	193.49	2.4	0.73	1010.6	93.9	1533.9	43.4
	635.0	193.55	2.6	0.79	1055.4	98.0	1740.5	49.3
	635.2	193.61	2.8	0.85	1102.3	102.4	1956.3	55.4
	635.4	193.67	3.0	0.91	1148.8	106.7	2181.4	61.8
Freeboard 373 ft^3 (10.6 m^3)	635.6	193.73	3.2	0.98	1197.6	111.3	2415.9	68.4
	635.8	193.79	3.4	1.04	1259.5	117.0	2661.1	75.4
	635.9 [A]	193.83	3.5	1.07	1292.9	120.1	2789.0	79.0

Notes: [A] spillway elevation`

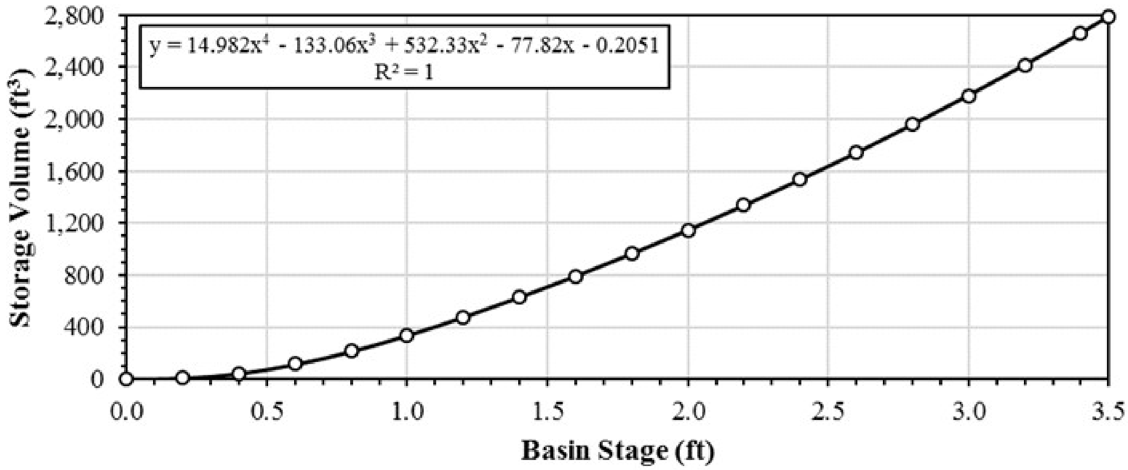


Figure 4.8 Live Storage Stage-Storage Graphical Relationship.

Video 4.3 shows an overview of the installed sediment basin following a lamella settler experiment.

Video 4.3 Overview of Sediment Basin System with Lamella Settlers Installed.

4.6 METHODOLOGY

This section describes the development of apparatus as well as the methods, procedures, and testing regime that were used to perform standardized tests in the sediment basin under various treatments.

4.6.1 WATER INTRODUCTION SYSTEM

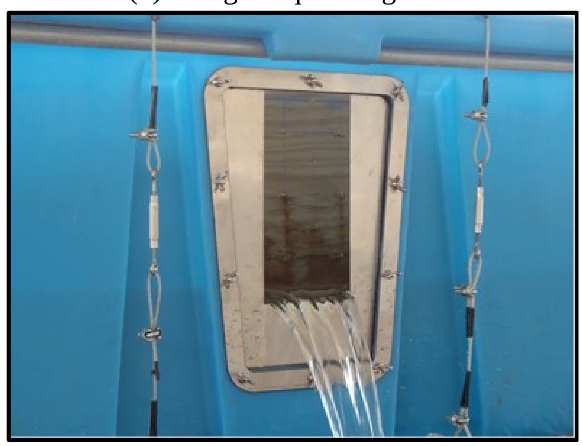
The introduction of water into the basin was designed in a fashion that would allow for accurate flow rate monitoring and ease of use. To achieve the desired flow control necessary for testing, a four-stage water introduction process was developed. This setup consists of a pump system, a tank for equalizing and staging flows, shown in Figure 4.9(b) and (c), a discharge weir for controlling flow rates introduced into the channel, pictured in Figure 4.9(d), and a soil-water mixing trough for creating sediment-laden flow.

The pumping system used consisted of three semi-trash pumps. Two of these pumps were equipped with 4 in. (10.2 cm) outflow ports (NorthStar driven with a Honda GX 270 engine, 0.86 ft^3/s [0.024 m^3/s] capacity) and the third was a 3 in. (7.62 cm) outflow port (NorthStar driven with a Honda GX160 engine, 0.59 ft^3/s [0.017 m^3/s] capacity). These pumps transported water from the AU-ESCTF upper storage supply pond into the equalizing tank located upstream the basin inflow channel. This 300 gal (1,136 L) capacity tank was customized with three inlets and four outlets. The inlets are located on the back side of the tank and are connected directly to the pumps via 3 and 4 in. (7.62 and 10.2 cm) flexible hosing and plumbing fittings. The 4 in. (10.2 cm) outlets, located directly beneath the tank, are controlled by individual gate valves, shown in Figure 4.9(a). These outlets are used to prevent overflows leaving the tank by returning water to the supply pond via 5 in. (12.7 cm) flexible hosing. By having all outlet valves open, the system allows for pumps to be primed and pressurized prior to commencing a test. Valves are adjusted to introduce water into the test channel at a desired flow rate by maintaining constant water level in the tank. Images of all water introduction components are shown in Figure 4.9.

(a) gate valves

(b) 300-gal. equalizing tank

(c) manufactured trough baffle



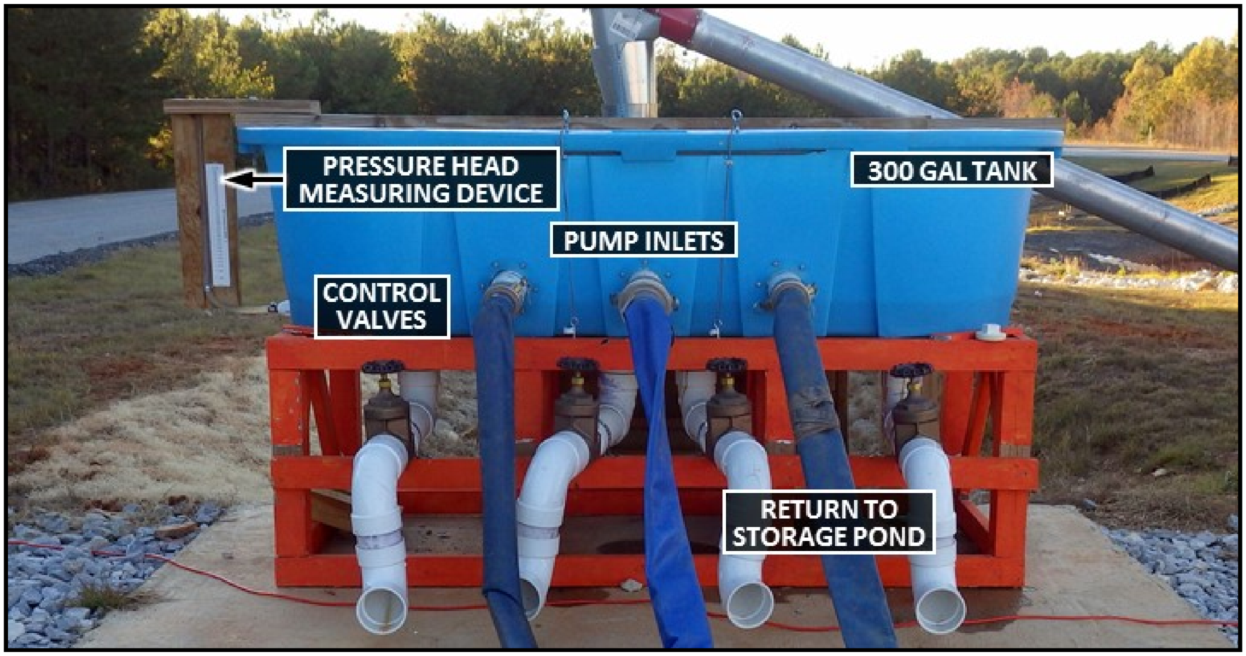
(d) installed weir plate

Figure 4.9 Water Introduction System.

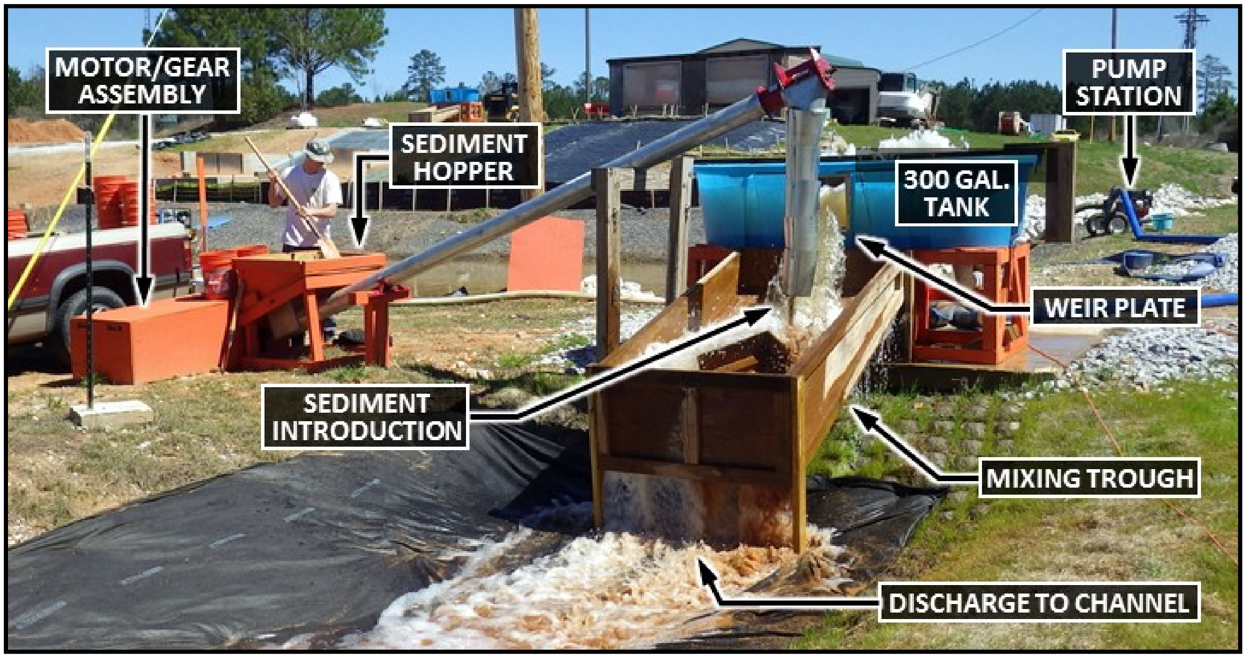
Water flowing into the test channel was measured through a fabricated rectangular weir plate attached to an opening cut on the channel face of the equalizing tank, Figure 4.9(d). The weir was constructed to allow for different weir plates to be easily interchanged for controlling varying flow ranges. This interchangeable system allowed for any opening to be cut into an approximate 16 in. (40.6 cm) high by 10 in. (25.4 cm) blank sheet metal plate which fit into the designed opening. The weir plate was secured to the polyethylene tank by bolts and butterfly nuts to a manufactured washer plate located on the inside of the equalizing tank. Between the tank and washer plate, a rubber gasket was fitted to provide a water tight seal.

4.6.2 SEDIMENT INTRODUCTION SYSTEM

The sediment introduction system (Figure 4.10) was designed using a 6 in. (15.2 cm) diameter, 16 ft (4.9 m) long auger that allows sediment to be introduced into the water/sediment mixing trough at a controlled rate. The motor, gear box, and sprocket system, were designed for the desired sediment introduction rate. A 1,740 rpm, 3.0 hp (2.2 kW) single phase motor (North American Electric, Inc.) was installed with a gear box reducer with ratio of 15:1 (WorldWide Electric Corp.). The gear box turned a 3.30 in. (8.4 cm) sprocket which was connected to a 1 in. (2.54 cm) diameter train shaft. This train shaft turned two sprockets. A 7.93 in. (20.1 cm) sprocket connected to the gearbox sprocket, and a 2.97 in. (7.54 cm) sprocket connected to the auger drive shaft. The auger drive shaft had a 7.61 in. (19.33 cm) sprocket. All sprockets were connected using a No. 40 roller chain. This gear ratio system reduced the auger drive shaft speed to approximately 18.8 RPM. The motor was equipped with a thermal protection switch and powered via single phase, 220 V electricity. To further protect the motor from overheating, 15 amp fuses were installed in the electrical circuit. A hopper was fabricated to allow the system to be loaded with sediment during an experiment. Figure 4.10(b) illustrates the complete sediment introduction assembly. The flow and sediment introduction system is demonstrated in Video 4.4.



(a) flow regulation system



(b) sediment introduction

Figure 4.10 Water and Sediment Introduction System During Testing.

Video 4.4 Flow and Sediment Introduction System.

4.6.3 Sediment Basin Dewatering

Dewatering is achieved using 1.5 in. (3.81 cm) Faircloth Skimmer® which dewaters from the top of the water column. The skimmer is connected to a 1.5 in. (3.81 cm) section of schedule 40 polyvinyl chloride (PVC) pipe and a flexible hose connection. The flexible hose connects to a 4 in. (10.2 cm) discharge PVC routed to the facility's sediment basin. A gate valve installed on the discharge line allows the flow to be shut if desired. Based on Faircloth sizing calculations, a 0.9 in. (2.29 cm) diameter orifice was cut to dewater the basin within approximately 56 hours.

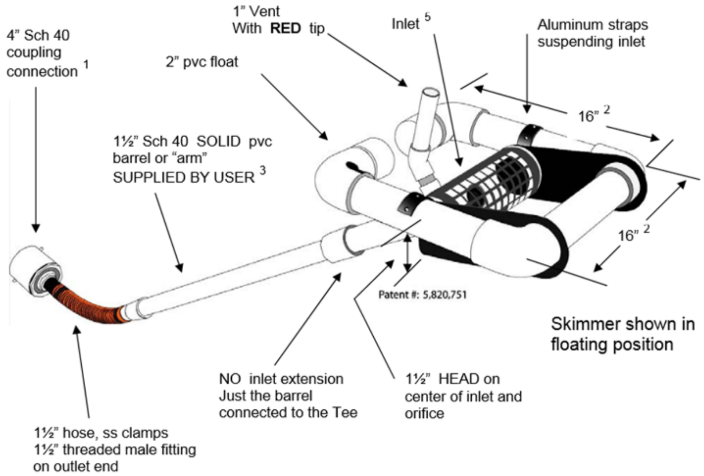


Figure 4.11 1.5 in. (3.81 cm) Faircloth Skimmer *(J. W. Faircloth & Son 2007)*.

While the skimmer was the primary dewatering mechanism, infiltration and evaporation still contributed in the removal of water from the basin. An infiltration test was performed by filling the basin with water and closing the skimmer valve to evaluate the rate of water removal from the basin. Results from the first 24 hrs of the infiltration test indicated that the basin infiltrated at an average rate of 0.86 in/hr (2.2 cm/hr). Based on the stage-storage relationship of the basin, the approximate infiltration rate is 96 ft^3/hr (2.7 m^3/hr). Figure 4.12 shows the dewatering rate and stage of the basin over time during the infiltration test.

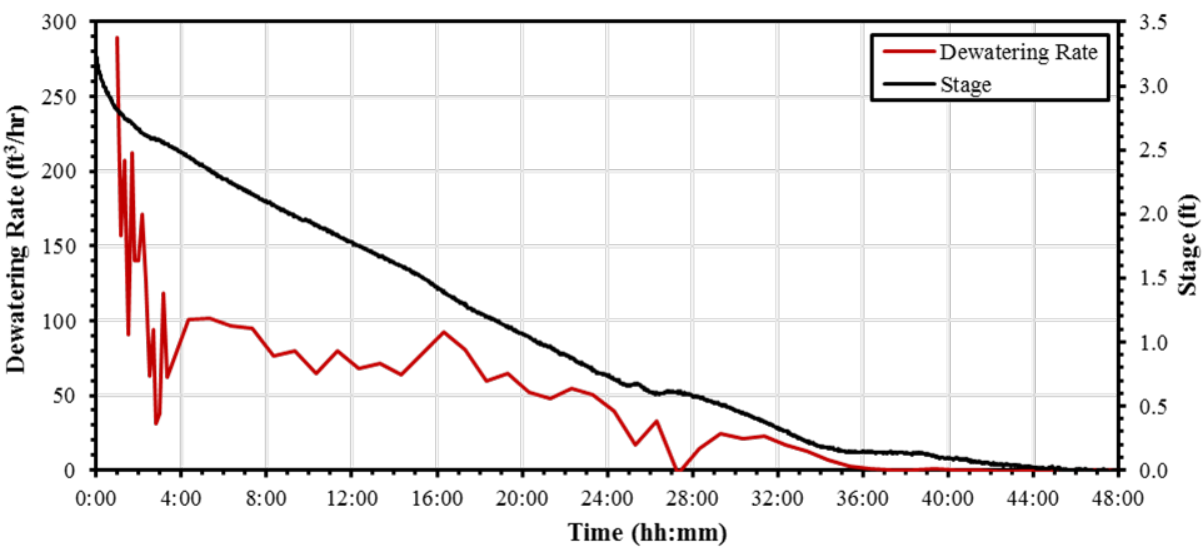


Figure 4.12 Sediment Basin Infiltration Test.

4.6.4 Auxiliary Spillway

An auxiliary or emergency spillway (Figure 4.13) was provided to allow excessive water to overtop at a designated and protected channel. The crest of the spillway is situated 0.4 ft (0.12 m) above the live storage section of the basin. The spillway was constructed by creating a depression on the northwest corner of the basin. Breached flows are routed towards the facility's existing riprap channel and lower retention pond. The spillway is lined with Flexamat tied concrete block matting to protect from scouring during overtopping conditions.

(a) spillway (b) spillway during flow

Figure 4.13 Auxiliary Spillway

4.6.5 Experimental Design and Testing Regime

To evaluate the performance of various sediment basin configurations and technology, an experimental design and testing regime was developed to mimic conditions to be expected on construction sites. Flow and sediment introduction rates were selected to mimic expected conditions from a local 2-yr, 24-hr design rainfall event. Additionally, a testing regime was designed to create a replicable experiment used to efficiently access and compare performance between various basin configurations and innovative sediment basin technology.

4.6.5.1 Flow Rate

Sediment basins are sized based on the contributory drainage area of the site. Two sizing options for the design of a sediment basin are commonly used by ALDOT. The first method provides 3,600 ft^3 of storage per acre (250 m^3/ha) of contributory area, thereby providing storage for the first 1.0 in. (2.5 cm) of runoff. To mimic expected flow conditions based on the constructed size of the basin, back calculation procedures were performed in Bentley® PondPack® V8i hydrologic modeling software using the average 2-yr, 24-hr Type III rainfall event for the state of Alabama, of 4.43 in. (11.3 cm) *(Perez et al. 2016)*. Using the 3,600 ft^3/ac (250 m^3/ha) design criteria, the constructed basin will provide detention for runoff emanating from a contributory drainage area of 0.775 ac (0.314 ha) since the storage of the basin is 2,790 ft^3 (78.9 m^3). Due to the small size of the drainage area, the time of concentration was set to 0.083 hrs. This drainage area results in a storm hydrograph volume of 8,938 ft^3 (253 m^3) with a peak flow rate of 2.47 ft^3/s (0.070 m^3/s).

The second sizing method considers the complete detention of runoff volume generated from a 2-yr, 24-hr event over the contributory area *(ALDOT 2010)*. Following TR-55 methodology, a curve number (CN) of 88.5 was applied to the entire contributory area *(Perez et al. 2014)*. It was also assumed that the time of concentration for the event would be 0.083 hour (5 min.), based on a relatively small contributory area. Using these parameters, an iterative hydrologic analysis was performed using a 2-yr, 24-hr soil conservation service (SCS) Type III rainfall distribution with a state-wide rainfall of 4.43 in. (11.3 cm), which resulted in a contributory area of 0.242 ac (0.098 ha) *(USDA 1986)*. The resulting stormwater runoff volume was 2,790 ft^3 (79.0 m^3) with a peak flow rate of 0.77 ft^3/s (0.022 m^3) occurring at 12.1 hours.

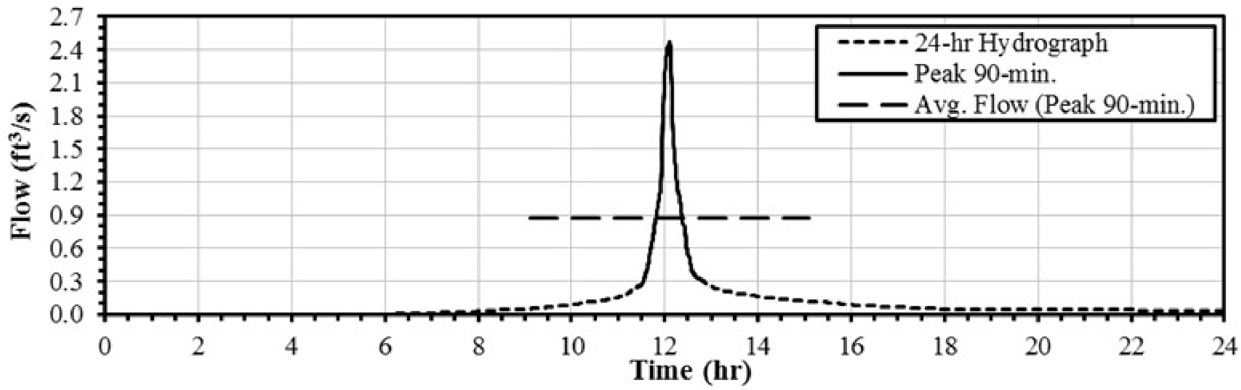
The intent of flow introduction was to provide the sediment basin with the total volume of runoff produced by a 2-yr, 24-hr rainfall event over the course of 30 minutes, while also mimicking the expected peak flow rate. Information obtained from hydrographs for the 2-yr, 24-hr design storm events are summarized in Table 4.3 for both the 0.775 ac (0.314 ha) and 0.242 ac (0.098 ha) hypothetical drainage areas derived from the two sizing methods. Figure 4.14 is a plot showing the hydrographs for the resulting 2-yr, 24-hr rainfall events.

Table 4.3 Basin Storage Parameters

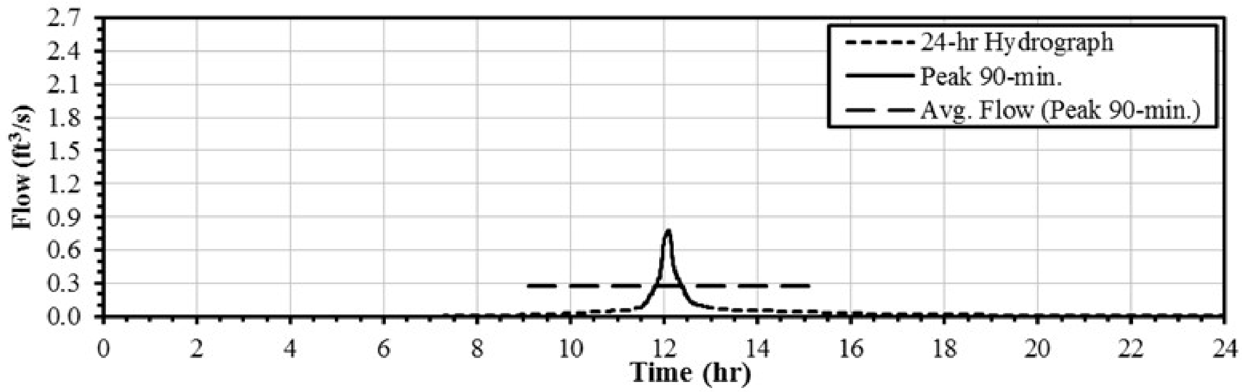
Sizing Parameter	Contributory Area [A]		Storm Volume [B], ft^3 (m^3)	Peak Flow, ft^3/s (m^3/s)	Avg. Testing Flow Rate, ft^3/s (m^3/s)		
	ac (ha)	ft^2 (m^2)			30 min	45 min	60 min
1,800 ft^3/ac (125 m^3/ha)	1.549 (0.627)	67,474 (6,268)	17,864 (505.9)	4.93 (0.140)	9.92 (0.281)	6.62 (0.187)	4.96 (0.140)
3,600 ft^3/ac (250 m^3/ha)	0.775 (0.314)	33,747 (3,135)	8,938 (253.1)	2.47 (0.070)	4.97 (0.141)	3.31 (0.094)	2.48 (0.070)
2-yr, 24-hr event	0.242 (0.098)	10,541 (979.3)	2,793 (79.1)	0.77 (0.022)	1.55 (0.044)	1.03 (0.029)	0.78 (0.022)

Notes: [A] based on design or sizing parameter
[B] simulated runoff volume for SCS Type III 2-yr, 24 hr rainfall event, and available storage in AU-ESCTF sediment basin is 2,790 ft^3 (79.0 m^3)

To investigate various contributory drainage areas, corresponding stormwater volumes, and peak flow rates for the SCS Type III local 2-yr, 24-hr storm event, several iterations were analyzed. Based on the basin sizing analysis and preliminary sediment basin filling test runs, the targeted flow introduction rate of 1.50 ft^3/s (0.042 m^3/s) for a 30 minute water introduction duration was selected. This rate maximizes the storage capability of the basin, filling the entire volume during a 30 minute test. This targeted test flow rate produces 2,700 ft^3 (76.5 m^3), and is nearly double the peak flow rate of the selected design rainfall event, exceeding the peak by 0.73 ft^3/s (0.021 m^3/s) for 0.242 ac (0.098 ha) drainage area.



(a) 0.775 acre basin



(b) 0.242 acre basin

Figure 4.14 2-yr, 24-hr Rainfall Event Hydrographs.

The selected flow introduction rate of 1.50 ft^3/s (0.042 m^3/s) is also representative to the average flow rate over the peak 30 minute (1.66 ft^3/s [0.047 m^3/s]) for 0.775 ac (0.314 ha) drainage area, which is designed under the 3,600 ft^3/ac (250 m^3/ha) criteria. In addition, the test flow rate of 1.50 ft^3/s (0.042 m^3/s) is similar to the 30 minute average testing flow rate (1.55 ft^3/s [0.044 m^3/s]) for 0.242 ac (0.098 ha) drainage area, designed for the average 2-yr, 24 hr rainfall event in Alabama.

4.6.6 SEDIMENT INTRODUCTION RATE

To mimic expected sediment transport, the sediment introduction rate was computed using the modified universal soil loss equation (MUSLE), which estimates sediment yields based on individual storm events *(Williams 1975)*. MUSLE uses runoff variables to estimate soil loss on the basis that runoff is a better indicator of sediment yield rather than rainfall amount. The MUSLE is given by the equation: $S = 95(Qp_p)^{0.56}KLSCP$, where: S is sediment yield (tons), Q is the 2-yr, 24-hr storm runoff volume (acre-ft), p_p is the event peak discharge (ft^3/s), and K, LS, C, P are MUSLE parameters.

Based upon experimental flow calculations conducted for the state of Alabama, the MUSLE equation was applied to the peak 30 minutes of the design storm, which produces of 935 ft^3 (26.5 m^3) with a peak discharge of 0.77 ft^3/s (0.022 m^3/s). A soil erodibility factor (*K*) of 0.085 was selected and a slope-length and steepness factor (*LS*) was determined to be 0.83, representative of 16% slopes at 20 ft (6.1 m) lengths for conditions of high rill to interrill erosion ratios *(Pitt et al. 2007)*. Although erosion control practices (i.e., mulching, temporary seeding, etc.) would be implemented alongside sediment controls, the worst-case design scenario for a vegetative cover practice factor (*C*) of 1.0 was chosen for bare soil conditions. Similarly, the ponding or erosion control practice factor (*P*) was selected to be 1.0. This situation may be encountered where sediment basins are constructed prior to final site grading and the installation of erosion controls and/or vegetative establishment. Using the aforementioned variables, total sediment yield was computed for an output of 1,348 lbs (611 kg). The sediment load targeted metering rate is 44.9 lbs/min (20.4 kg/min) over the 30 minute test duration. Calibration of the sediment introduction system revealed a soil introduction rate of 45.2 lb/min (20.5 kg/min). Based upon this rate, the sediment introduction concentration is 8,044 mg/L (1,356 lbs / 2,700 ft^3) if all introduced sediment would flow into the basin. However a certain amount of sediment is deposited in the inflow channel.

4.6.7 SOIL PARAMETERS

For sediment-laden tests to be replicable, a stockpile of soil, native to the state of Alabama, was used for all tests. The soil used for sediment introduction was acquired from a source local to Opelika, AL. The soil stock was sieved through a 0.5 in. (1.3 cm) screen to remove large aggregate and organic debris prior to use in the testing apparatus. A particle size analysis as well as a compaction test was conducted in the geotechnical laboratory to characterize the soil properties. The average particle size distribution of the three analysis performed is shown in Figure 4.15.

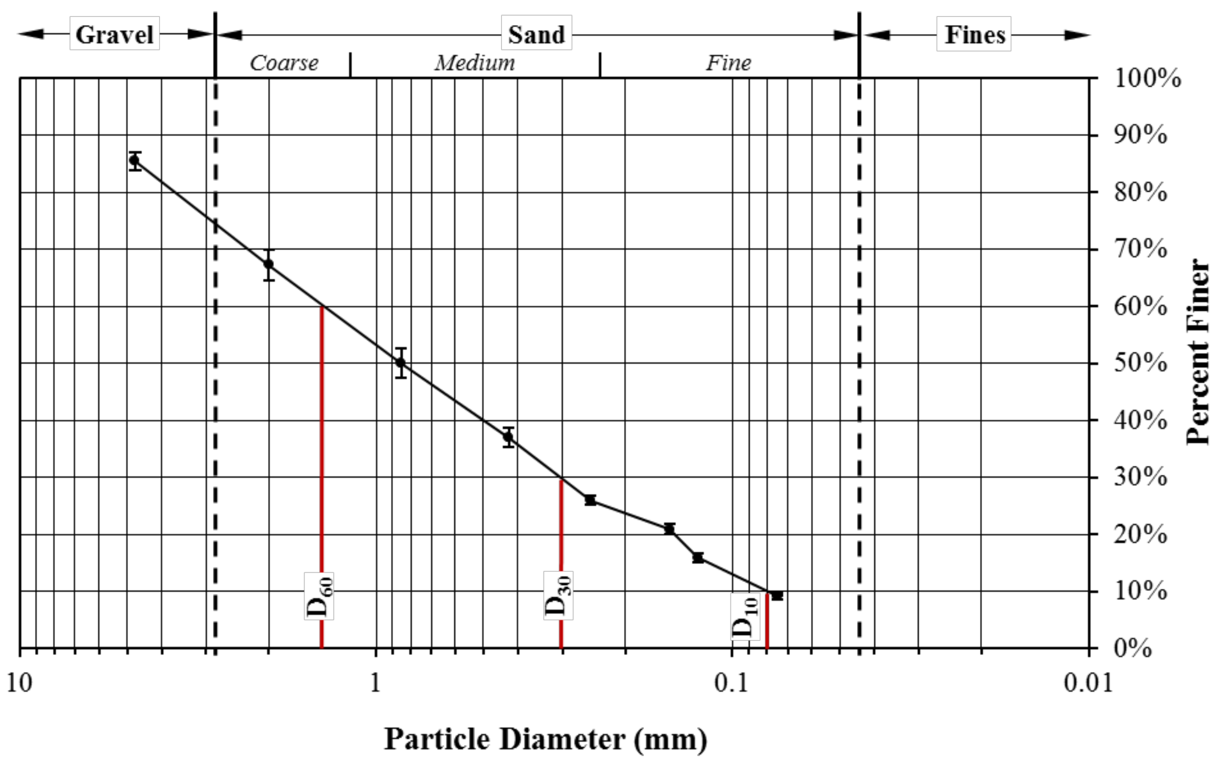


Figure 4.15 Particle Size Distribution for Sediment.

Table 4.4 displays a summary of the sieve analysis of the soil performed under ASTM standardized methods *(ASTM Standard D422-63(07) 2007)*. Under the Unified Soil Classification System (USCS), the soil is categorized as a poorly graded sand with silt *(ASTM Standard D2487-11 2011)*.

Table 4.4 Sieve Analysis of Sediment

Sieve	Apparent Opening Size (mm)	Percent Finer (%)				
		Sample No. 1	**Sample No. 2**	**Sample No. 3**	**Avg.**	**Std. Dev.**
#4	4.750	89.4%	87.6%	87.6%	87.5%	1.6%
#10	2.000	73.9%	69.5%	69.5%	70.2%	2.8%
#20	0.850	56.0%	51.3%	51.3%	52.4%	2.6%
#40	0.425	40.5%	37.0%	37.0%	38.1%	1.7%
#60	0.250	26.6%	24.7%	24.7%	25.8%	0.8%
#100	0.150	21.3%	19.3%	19.3%	20.5%	0.9%
#120	0.125	14.7%	13.8%	13.8%	14.8%	0.9%
#200	0.075	8.4%	8.0%	8.0%	8.5%	0.5%
Pan	0.000	0.0%	0.0%	0.0%	0.0%	0.0%
D_{60} = 0.055 in. (1.40 mm)		D_{30} = 0.008 in. (0.20mm)			D_{10} = 0.003 in. (0.08 mm)	
C_u = 17.7		C_c = 0.81			% Gravel = 12.5	
USCS classification: SP-SM, poorly graded sand with silt						

Notes:
USCS: Unified Soil Classification System
D_{60}, D_{30}, D_{10} = soil particle diameter at which 60%, 30%, or 10% of the mass of a soil sample is finer
C_u = coefficient of uniformity
C_c = coefficient of curvature

The soil was also analyzed for the maximum practically achievable density. A standard proctor test *(ASTM Standard D698-12 2012)* was performed on the soil to determine the maximum dry density (ρ_{dmax}) and the optimum moisture content (OMC) for the soil. The ρ_{dmax} was determined to be 108.1 lbs/ft^3 (1,732 kg/m^3) at an OMC of 15.5%. The developed proctor curve is shown in Figure 4.16.

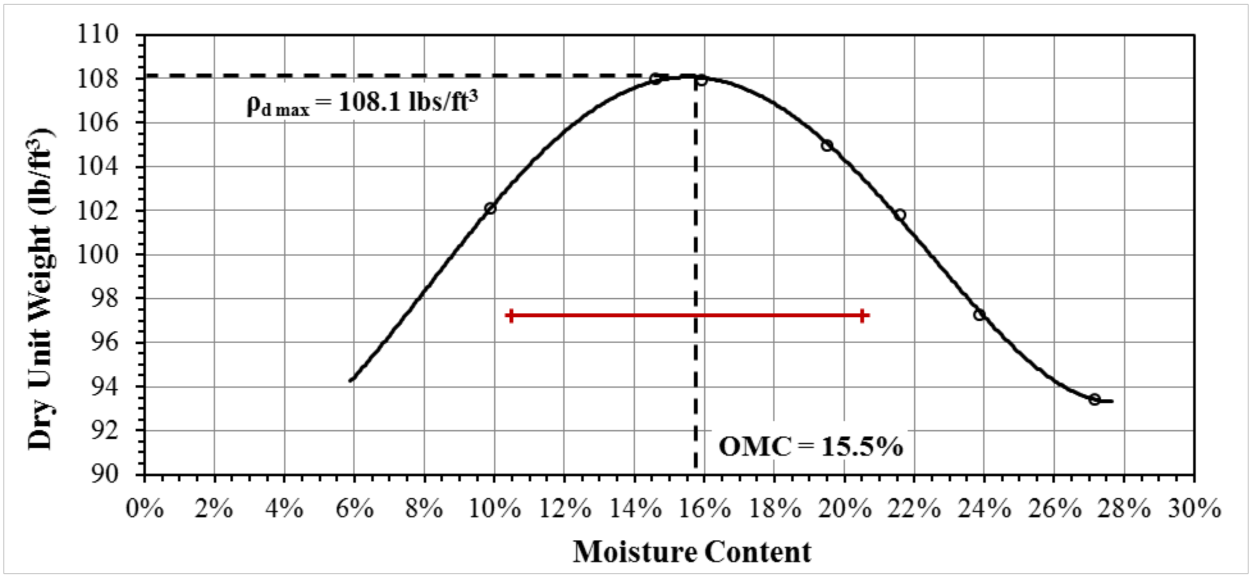


Figure 4.16 Soil Geotechnical Report.

As indicated in Figure 4.16 with a red solid line, the dry unit weight for 90% compaction was calculated to be 97.3 lbs/ft^3 (1,559 kg/m^3) with a moisture content ranging between 10.5 to 20.5%.

In addition to analysis performed in the geotechnical laboratory, a soil sample was submitted for testing to the Auburn University Soil Testing Laboratory which returned a report indicating the sample composition was of 46.9% sand, 28.1% silt, and 25% clay. This analysis corresponds to a loam soil type on the USDA soil texture triangle *(USDA 1987)*.

4.6.8 SEDIMENT BASIN TREATMENTS

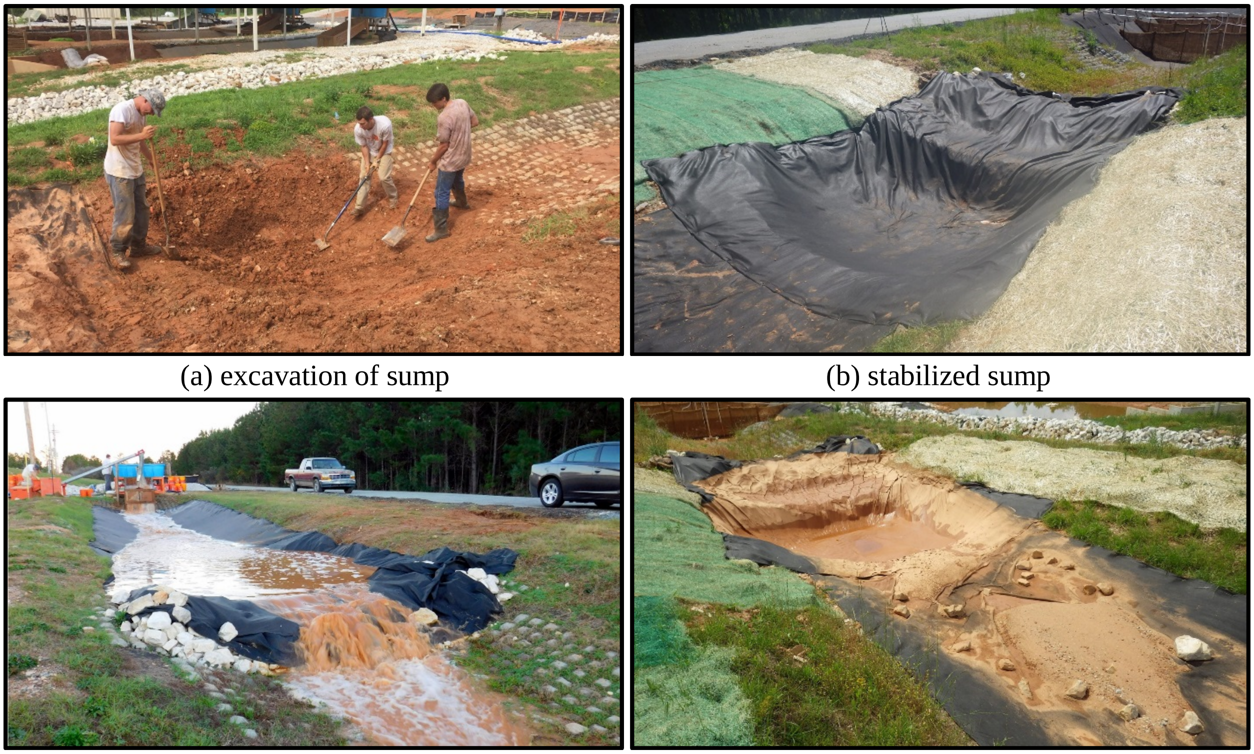
The testing regime was divided into two phases. The first phase evaluated the performance of an excavated sump placed within the inflow channel, and the use of a modified coir baffle between the first and second bay.

4.6.8.1 ALDOT Standard Configuration

ALDOT maintains a set of standards in the design and construction of sediment basins used on their projects *(ALDOT 2010; ALDOT 2015)*. This configuration was evaluated in the sediment basin and was considered to be the control.

4.6.8.2 Excavated Sump

A sump is an excavated portion within the inflow channel upstream of a ditch check intended to facilitate the capture of larger, rapidly settable particles, prior to reaching the sediment basin *(ALDOT 2015)*. The sump provides a dedicated collection area that is easier for an operator to access and maintain when routine dredging of collected material is warranted. ALDOT standards include details for the use of an excavated sump upstream of the sediment basin in the inflow channel, however its use is optional. Therefore, tests were performed with the inclusion of an excavated sump to determine if its inclusion is beneficial when compared to the standard installation without the sump. Figure 4.17 shows the condition with the excavated sump included in testing.



(a) excavation of sump

(b) stabilized sump

(c) sump during testing

(d) post-test deposition

Figure 4.17 Excavated Sump Treatment.

4.6.8.3 Modified First Baffle

Investigations performed by researchers have demonstrated that baffles have the ability to improve flow uniformity and decrease turbulence. It has also been reported that the first baffle within a sediment basin provides the most benefit *(Christopher et al. 2003; Thaxton et al. 2004; Thaxton and McLaughlin 2005)*. To optimize the first baffle, evaluations were performed to provide comparisons between the standard ALDOT baffle configuration and a modified baffle with a smaller percent open area. A combination of photo editing and CAD software was used to determine the percent open area from a scanned sample of coir baffle. Figure 4.18 shows the various steps involved in analyzing the coir baffle (scanned image on left, CAD vector on right). Using this technique, it was determined that the percent open area was 43.4% per layer.

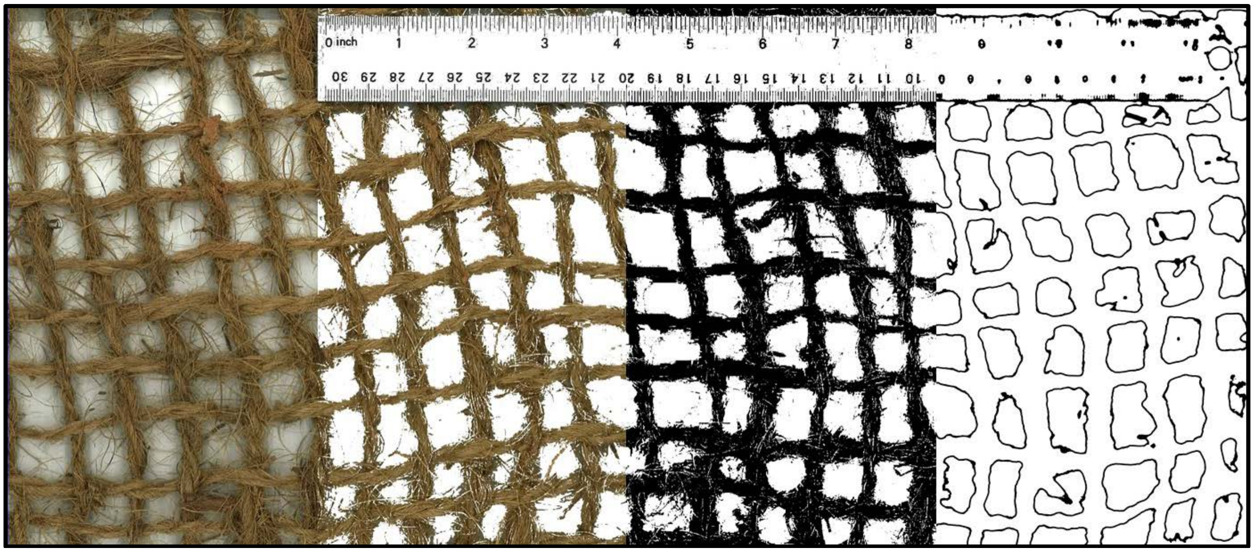


Figure 4.18 Percent Open Area Analysis.

The ALDOT standard installation requires a layer of coir material on each side of the baffle resulting in an effective percent open area of 21.7%. The first baffle was modified by doubling the coir mesh to reduce the apparent opening size, with the goal of trapping more sediment within the first bay of the basin. Using this installation, the percent open area was reduced to 10.9%. The baffle systems are shown in Figure 4.19 installed in the sediment basin prior to testing.

(a) standard baffle

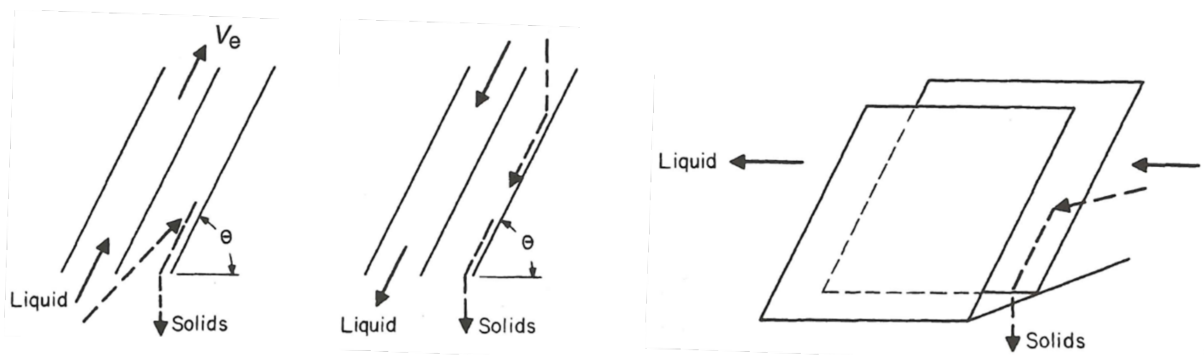
(b) modified baffle

(c) modified first baffle vs. standard second and third baffles

Figure 4.19 Comparison of Standard and Modified First Baffle System.

4.6.8.4 High-Rate Lamella Settlers

Lamella clarifiers are comprised of a series of inclined parallel plates traditionally used in water purification and wastewater treatment to create conditions more favorable for particle settling *(Crittenden et al. 2005; Montgomery 1985)*. The settling efficiency of solids suspended in liquid is improved by increasing surface area available for particles to settle. Residential and industrial wastewater treatment facilities have used high rate lamella settlers to provide for more efficient particle settling. However, their use within a construction site sediment basin has not previously been evaluated. The principle of high rate settling is to increase the available settling surfaces in a sedimentation process. Inclined plates are used to decrease the vertical distance a particle travels before settling onto a surface. Planar surfaces, referred to as lamellas, are positioned at an angle to facilitate the sliding of these particles from the plate to the bottom of the basin. Inclined settling systems are used in one of three flow directions: countercurrent (upward flow), concurrent (downward flow), and cross-flow (parallel flow) as shown in Figure 4.20(a) through (c).



(a) countercurrent (b) concurrent (c) cross

Figure 4.20 Lamella Settler Flow Geometries *(American Water Works Association 1999)*.

Lamella settlers function best when the Reynolds number is below 800 when calculated using the mean velocity between the inclined surfaces. The time required for a particle to settle the vertical distance between two plate surfaces is calculated using eq 4.1 *(American Water Works Association 1999)*:

$$t = \frac{w}{v \cos \theta} \qquad \text{(Eq. 4.1)}$$

Where,

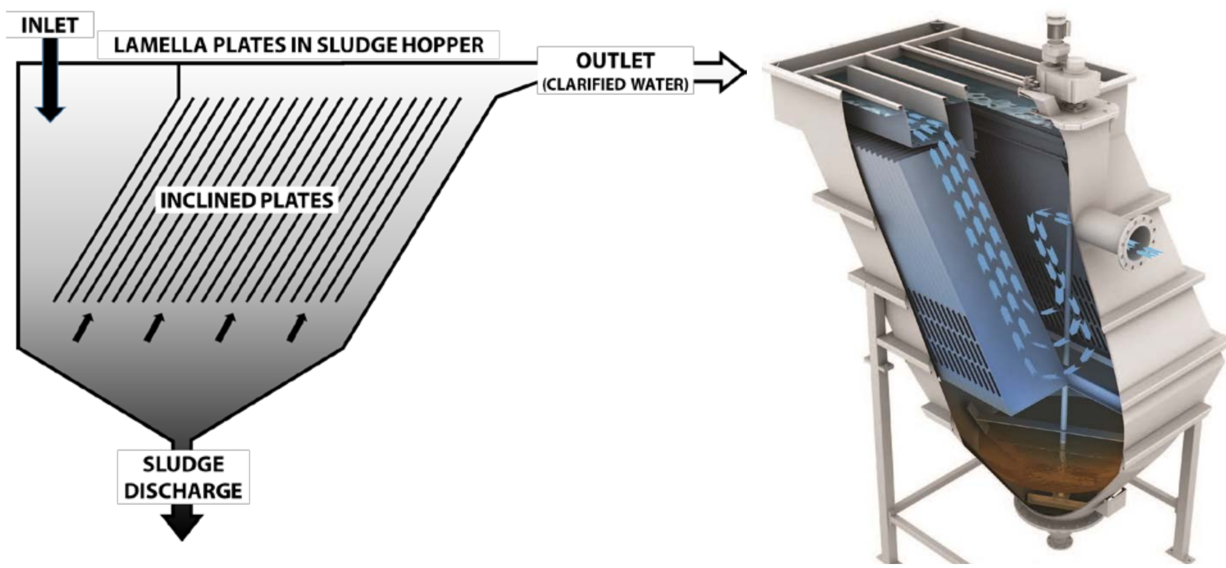
t = time,

w = perpendicular distance between surfaces,

v = settling velocity, and

θ = angle of surface inclination from horizontal.

A typical lamella plate settler system installed in a clarifier tank is shown in Figure 4.21. Flow is directed up the inclined plates in countercurrent flow configuration. As particles settle, sludge is formed which is directed towards the bottom of the clarifier tank and discharged from the system.



(a) settler schematic (b) settler system *(Hydro Int. 2016)*

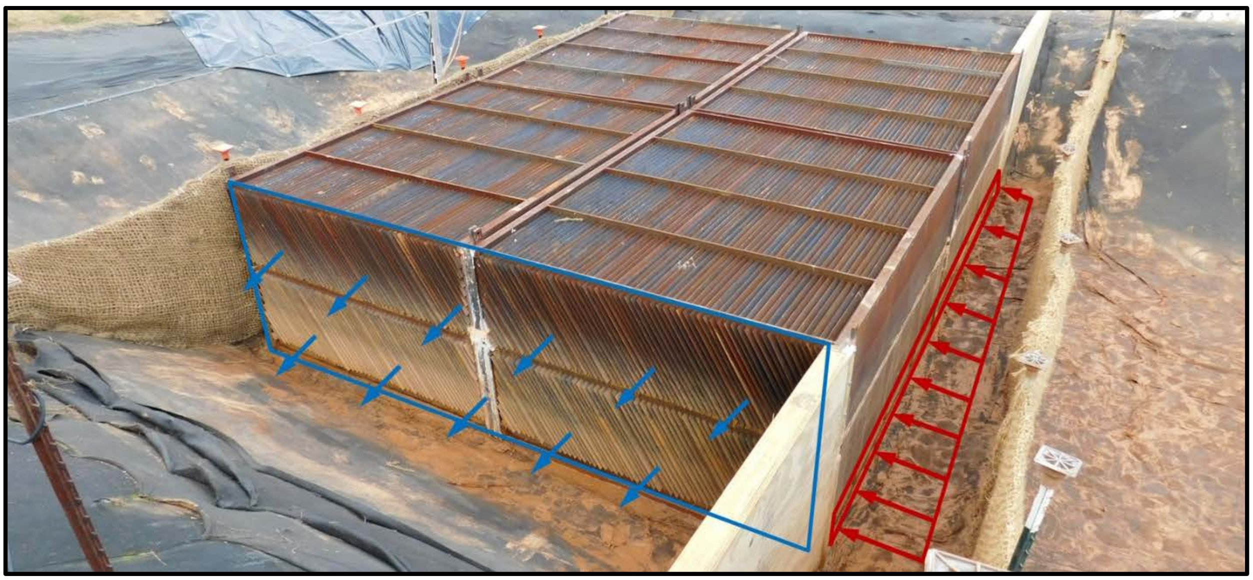
Figure 4.21 Typical Lamella Settler Configuration.

For the purpose of this research, a high-rate lamella settler system consisting of eight individual units was developed that would allow for evaluations under upward and parallel flow conditions. The units were constructed of steel and were fabricated by Davis Machine Works, Opelika, AL. Figure 4.22 shows a fabricated unit without the steel plates installed.

Figure 4.22 Lamella Settler Unit without Plates.

The first Lamella tests were performed in the upward flow condition. Eight individual units were installed to create a system of four tanks stacked two rows in height. Wing walls were constructed out of lumber and installed in the upstream face to force water through the opening at the bottom of the Lamella system (red arrows in Figure 4.23 [b]). Flow was directed up the plates and out the sides of the tanks along the openings (blue arrows in Figure 4.23 [b]). Gaps between the individual tanks along the front, sides, and back, were sealed using strips of sheet metal, caulk, and insulating foam spray.

(a) installation of settler units



(b) completed installation with wing walls

Figure 4.23 Lamella Settler Units in Upward Flow Configuration.

The seconds set of Lamella tests were performed in the parallel flow condition. The eight units were removed from the basin and rotated 90 degrees to allow flow to travel in the cross-current direction. Gaps between tanks were sealed and the wing wall system was modified to fit the parallel flow orientation.

(a) installation of settler units

(b) completed installation with wing walls

Figure 4.24 Lamella Settler Units in Parallel Flow Configuration.

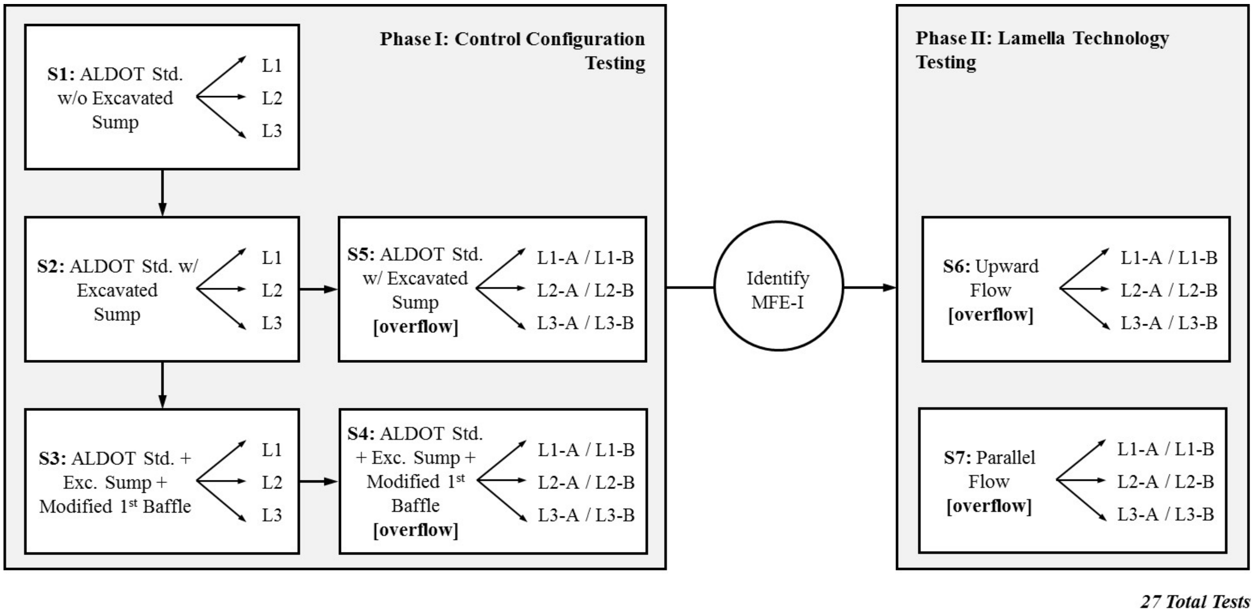
Video 4.5 shows a time-lapse of the process of removing the lamella tanks from the basin, removing captured sediment from the floor of the basin, and re-installing the plates in the parallel flow configuration.

Video 4.5 Removal and Re-Installation of Lamella Plates in Parallel Flow Configuration.

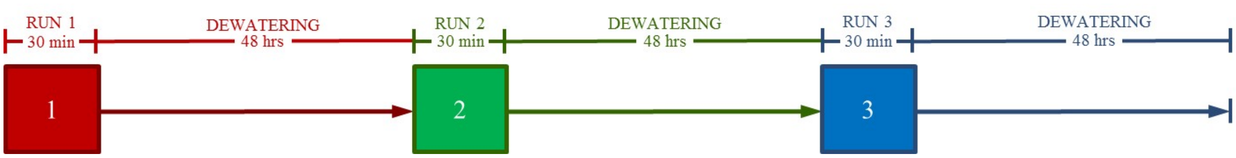
4.6.9 TESTING REGIME

To assess the performance of the sediment basin under various configurations and with the use of lamella settling technology, a staged experimental testing regime was developed. As data was analyzed following initial tests, modifications to the regime were made throughout testing to provide the most effective means of evaluating treatments. The developed regime, shown in Figure 4.25, is comprised of seven series of evaluations (S1 through S7) with a total of 27 tests.

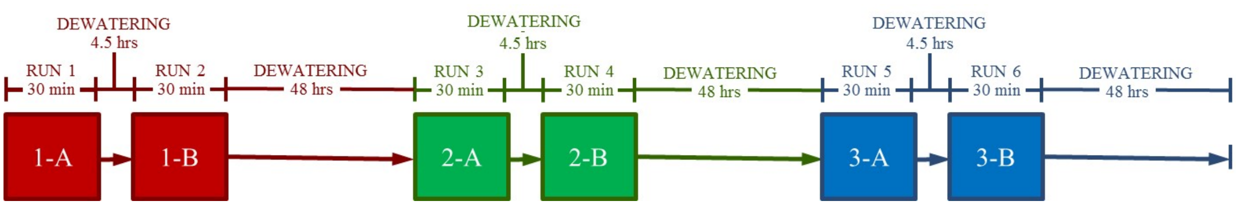
The first test within each series, L1, started with a clean and empty basin, free of sediment. Subsequent tests (i.e., L2 and L3) were conducted once the basin had completely dewatered, however sediment contained from preceding tests was not removed from the basin. Performance was evaluated based upon the exposure of the three tests, which mimics the installation of a new sediment basin at a construction site that is not maintained (i.e., dredged of sediment) between subsequent storm events. To gain a better understanding of basin performance under the condition where a storm event occurs while the basin is partially full from a preceding event, overtopping tests were incorporated into the testing regime. These overtopping tests (i.e., S4-S7), were comprised of a set of three replicate fill, partially empty, and overtop cycles (L1-A through L3-B), totaling six tests per evaluation. Part A of each of these evaluations filled the basin completely without overtopping. Part B began once 30% of the volume within the basin had dewatered, resulting in 70% of the test inflow passing through the auxiliary spillway. Volumetrically, the basin is 70% full when the stage is at 2.55 ft (0.77 m), which corresponds to a volume of 1,691 ft^3 (47.9 m^3). All tests, regardless of series type, were conducted with a 1.50 ft^3/s (0.042 m^3/s) flow rate and 45.2 lb/min (20.5 kg/min) sediment introduction rate for a 30 minute duration.



(a) testing regime



(b) empty condition test series sequence



(c) overflow condition test series sequence

Figure 4.25 Developed Sediment Basin Testing Regime and Test Series Sequence.

Test series S1 and S2 were conducted to provide sediment basin performance comparisons when an excavated sump is included in the forebay. The inclusion of the sump in subsequent testing (S3 through S7) was determined from performance data comparisons. Once the use of an excavated sump was assessed, the next series of tests (S3) evaluated a modified first baffle system installed between the first and second bay. Both the treatments with the excavated sump and modified first baffle were evaluated under the overtopping testing condition (S4 and S5). Between the treatments using a sump and modified first baffle, the most feasible and effective installation (MFE-I) was selected to proceed with further testing. The MFE-I was then evaluated under the overtopping test condition (S4).

The second phase of testing focused on deploying high-rate lamella settling technology within the third and fourth bays of the basin. Two separate configurations of the technology were tested within the basin (i.e., upward and longitudinal flow geometry) and each will be evaluated under an overtopping series of tests (S5 through S7). The designed testing regime allowed for direct comparisons between the MFE-I and the use of the high-rate settlers in both tested configurations.

4.6.10 DATA COLLECTION

Data collected during testing provides comparative means of performance with the varying tested basin configurations and treatments. Water quality, flow rates, basin stage levels, sediment deposition volumes, and sediment sampling for particle characterization, were collected during and after tests. Turbidity results were obtained from automated probes. Physical grab sampling was also conducted during initial tests to determine relationships between TSS and turbidity. Figure 4.26 provides an overview of the data collection instrumentation layout within the sediment basin.

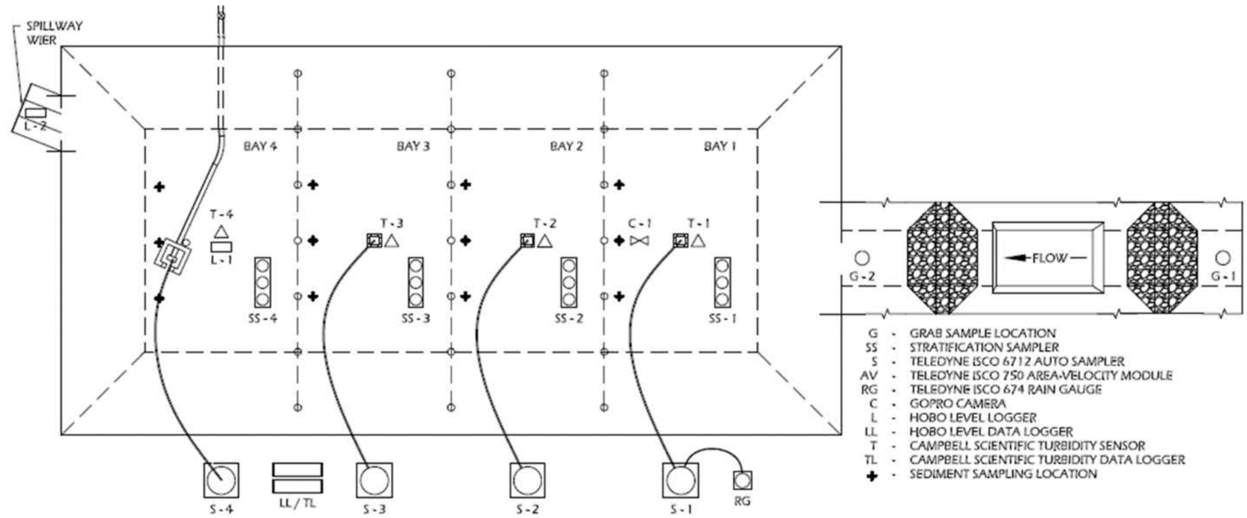


Figure 4.26 Data Collection Instrumentation Layout.

4.6.10.1 Turbidity Probes

Three Campbell Scientific OBS3+ turbidity sensors with logging capabilities were used during testing. The sensors were placed Bays 1, 2, and 4. The sensors have the capability of measuring up to 4,000 NTU. A Campbell Scientific CR850 data logger was mounted near the sensors and was powered by a 12V deep cycle marine battery.

4.6.10.2 ADV Sensor

A SonTek Argonaut® multi-cell doppler current profiler was installed in Bay 1 at the mouth of the sediment basin to analyze flow within the entrance of the basin. This probe monitored three dimensional flow velocities. The sensor was powered by a 12V deep cycle marine battery.

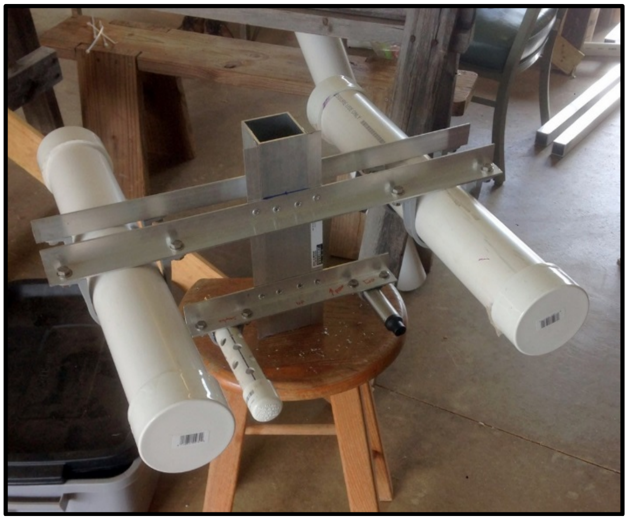
4.6.10.3 Level Loggers

Three Onset HOBO water level pressure transducers (U20-001-04) were used during testing to accurately monitor the stage of the basin throughout the duration of the experiments. Two loggers were used within Bay 4 and the third was placed in the auxiliary spillway weir box (Figure 4.27) during overflow experiments. Of the loggers placed in Bay 4, one was installed near the basin floor, and the second was installed above the high water mark, with the purpose of recording atmospheric pressure and temperature. A perforated 1.5 in. (3.8 cm) PVC tube was used as a monitoring cylinder to protect the level loggers from direct sunlight. The level loggers placed inside the basin were programed to take measurements at one minute intervals, while the level logger placed in the auxiliary spillway weir box, took readings at 10 second intervals.

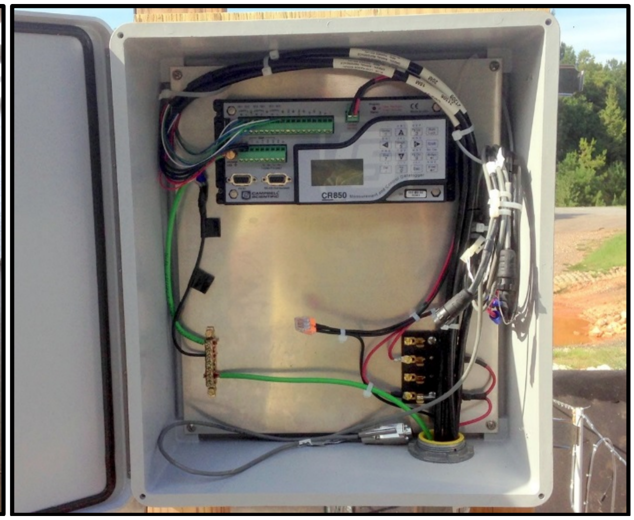
Figure 4.27 Auxiliary Spillway Weir Box.

4.6.10.4 Water Sampling

Water sampling was only conducted during initial tests and was used to validate turbidity probe results and to determine turbidity and TSS relationships. For grab sampling, five automated Teledyne Isco 6712 full-size portable samplers were deployed, one per each of the four bays within the basin and an additional sampler near the bottom of Bay 2. Suction tubing was routed to a suction head mounted to custom built floating skimmers in the center of each of the first three bays, and on the outlet skimmer in the fourth bay. Sample collection begin once the stage in the basin reached the height of the floating skimmers.



(a) floating sampling apparatus



(b) turbidity data logger

(c) level logger (Onset 2016)

(d) ADV sensor *(SonTek / Xylem Inc. 2016)*

(e) automated sampler

(f) rain gauge *(Teledyne Technologies Inc. 2013)*

Figure 4.28 Data Collection Equipment.

To minimize the turbulence caused by the automated sampling, the 0.375 in. (0.953 cm) suction tubing was routed to direct purge and rinse volumes from reentering the basin. Figure 4.29

depicts the setup that used a tee connection to split sampler line to a collection point and discharge point. One-way check valves directed flows in the desired flow path. The suction line was attached to a taught steel wire angled down gradient across the basin. Since the sampler was programmed to suction the length of line between the collection point and sampler, the slope allows the drain line section between the check valve and discharge point to drain without the need of additional pumping. This setup however was abandoned after valve clogging became an issue causing air to bleed through the valves. A single purge cycle replaced the one-way valve mechanisms.

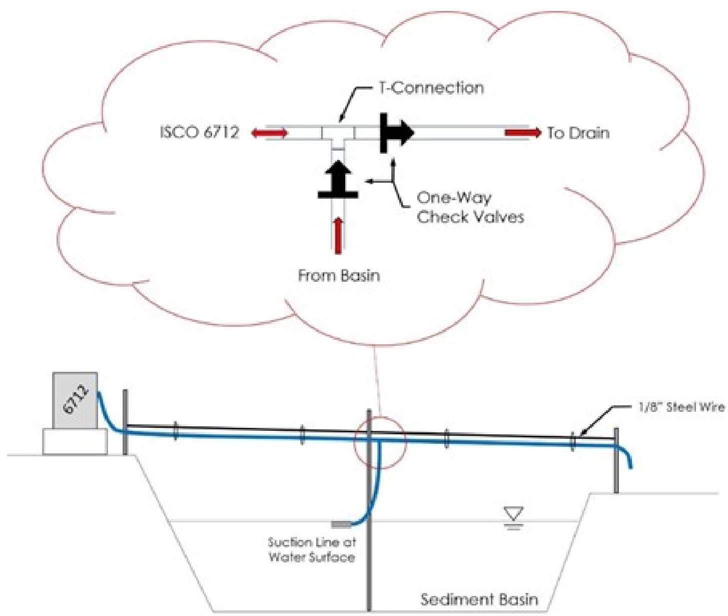


Figure 4.29 Sampler Suction and Discharge Line Routing.

Automated samplers were programed to collect 13.5 oz. (400 mL) samples through two separate collection cycles using a non-uniform time paced sampling program. The first cycle of the program collected samples every five minutes for the first 60 minutes of sampling. Thereafter, a second cycle collected one sample every 120 minutes for a period of 23 hours. A total of 24 water samples per sampler were collected, totaling approximately 96 total automated samples per test. During overtopping experiments, an additional sampler was located at the auxiliary spillway to collect samples at three minute intervals. TSS and turbidity analysis methods followed EPA standard testing specifications *(USEPA 1999; 2003)*.

During the duration of the flow introduction period (30 minutes), grab samples were taken in two locations along the inflow channel. The first point was directly downstream of the mixing trough, and the second point was at the sediment basin entrance. Samples were taken at five minute intervals. All manual grab samples commenced once flows reached the sampling location and ended once all flow has subsided (i.e., reached the sediment basin). Typically, six samples were taken at the upstream point, and up to twelve samples at the downstream location due to the delayed dewatering of the forebay. Table 4.5 summarizes the water sampling regime.

Table 4.5 Water Sample Collection

Sample Type	Location	Sample Interval	Samples	Total Samples
Grab Samples	Introduction Zone	5 min.	6	18
	Basin Entrance		12	
Automated Surface Samples	Bay 1	5 min (0-60 min) / 120 min (1-24 hr)	24	96
	Bay 2		24	
	Bay 3		24	
	Bay 4		24	
Automated Bottom Sampler	Bay 2	5 min (0-60 min) / 120 min (1-24 hr)	24	24
			Total Samples:	138

4.6.10.5 Rain Gauge

To account for any precipitation occurring during testing and dewatering durations, a Teledyne Isco 674 rain gauge was used with the sampler located in Bay No. 4. The gauge, Figure 4.28(f) detailed the start time of rain events, duration, and intensity.

4.7 PHASE I: CONTROL CONFIGURATION TESTING RESULTS

This section describes the data and results collected and analyzed for the control treatments tested in the sediment basin to determine the MFE-I. The evaluated treatments included:

S1: ALDOT standard configuration,

S2: ALDOT standard configuration with excavated sump in forebay + standard first baffle,

S3: ALDOT standard configuration with excavated sump + modified first baffle,

S4: ALDOT standard configuration with excavated sump + standard first baffle (overflow),

S5: ALDOT standard configuration with excavated sump + modified first baffle (overflow).

4.7.1 ALDOT STANDARD CONFIGURATION

The first series of tests (S1) conducted in the sediment basin was the ALDOT standard configuration without the inclusion of an excavated sump in the inflow channel. The configuration was evaluated under a series of three tests. Overflow evaluations were not performed on this configuration.

The average turbidity results of the three runs (i.e. S1-L1, S1-L2, S1-L3) were obtained from the probes used in bays 1, 2, and 4 and are plotted on Figure 4.30. From the plot, there are three evident trends discernable from the slope of the turbidity. The first 30 minutes is referred to as the filling period where turbidity is consistent with an average of 767 NTU in Bay 1. Initial turbidity in Bay 2 and Bay 4 are as high as in Bay 1, however sharply decrease to 314 and 306 NTU, respectively at the conclusion of the filling period. This indicates that baffle between Bay 1 and Bay 2 is effective in isolating the highly turbid inflow turbidity to Bay 1. After the filling period concludes, there is a sharp decrease in turbidity values as the water in the basin is stilled, allowing for particles to settle without any turbulence. The rapid settling period is approximately the duration extending from 45 to 60 min. During this time frame turbidity values decrease to 243, 217, and 268 NTU in Bay 1, Bay 2, and Bay 3, respectively. The sharp decrease in turbidity within Bay 1 indicates that the turbulent inflow is the predominant factor resulting in elevated turbidity levels during the first 30 min of the test duration when water is being introduced. Beyond the 1 hr period, turbidity values continue to decay at a very slow rate. This period is referred to as the polishing period. At the 12 hr time frame, turbidity values are essentially identical within the three measured bays with an average value of 113 NTU.

Interestingly, there is little difference in turbidity between the three bays after the filling period. Bay 2 also had the lowest turbidity values after the rapid settling period. This may indicate that the baffles may only be critical in reducing turbidity during the time where stormwater is entering or moving through the basin.

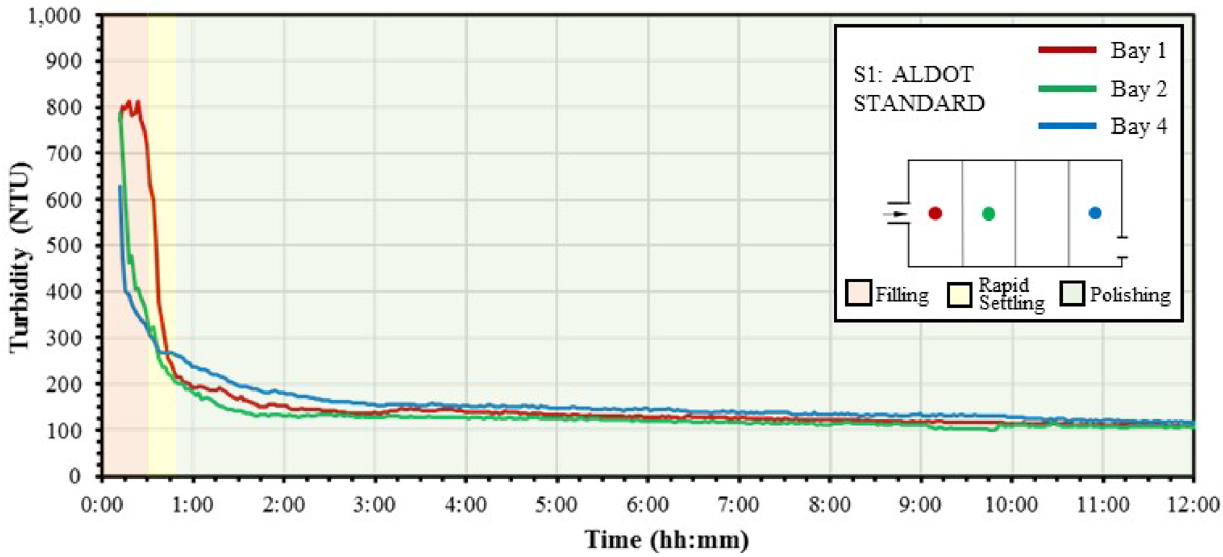


Figure 4.30 S1 ALDOT Standard Configuration Turbidity.

4.7.2 EXCAVATED SUMP

The second treatment tested was the addition of an excavated sump in the forebay of the inflow channel (S2). Turbidity is plotted in Figure 4.31. The turbidity results are similar to that of the ALDOT standard configuration (S1), with the same filling, rapid settling, and polishing periods discernable. The initial turbidity in Bay 1 was slightly lower than in S1, averaging 698

NTU during the 30 min. filling period. After 12 hrs of settling, the average turbidity in the basin was 137 NTU across the three bays, slightly higher than values seen in S1.

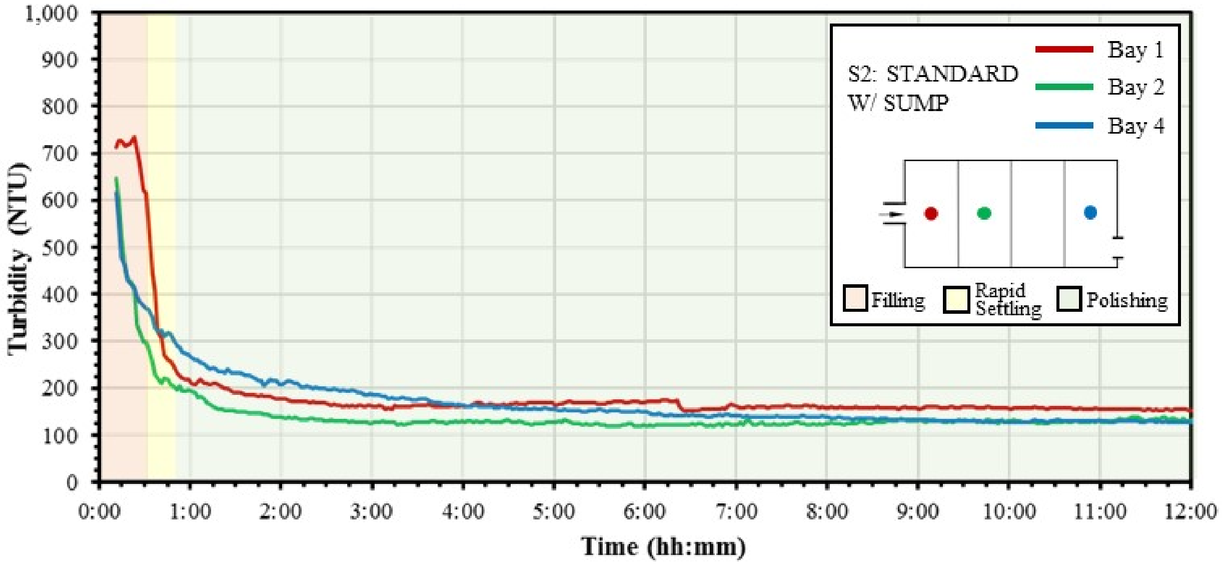


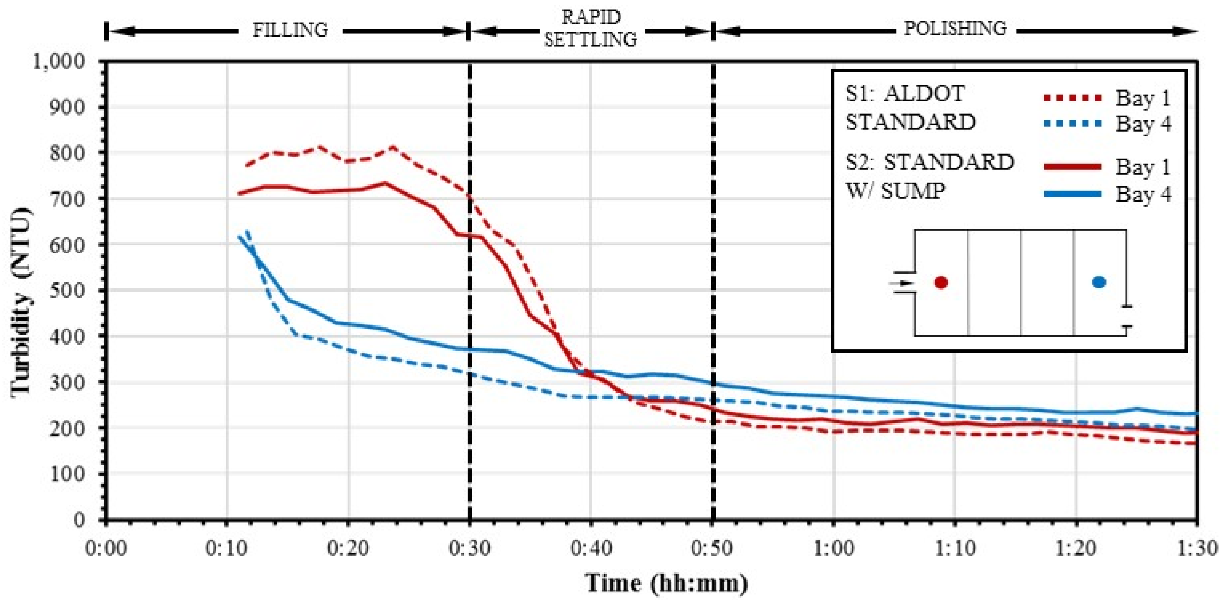
Figure 4.31 S2 ALDOT Standard with Excavated Sump Turbidity.

Figure 4.32(a) and (b) show the comparison of sediment deposition along the forebay section of the channel. As can be seen in the photographs, a significant amount of sediment was captured for both treatments. Sediment containment for the excavated sump treatment (S2) extended beyond the sump as a significant amount of deposition occurred at the hydraulic jump, or transition between supercritical and subcritical flow in the channel.

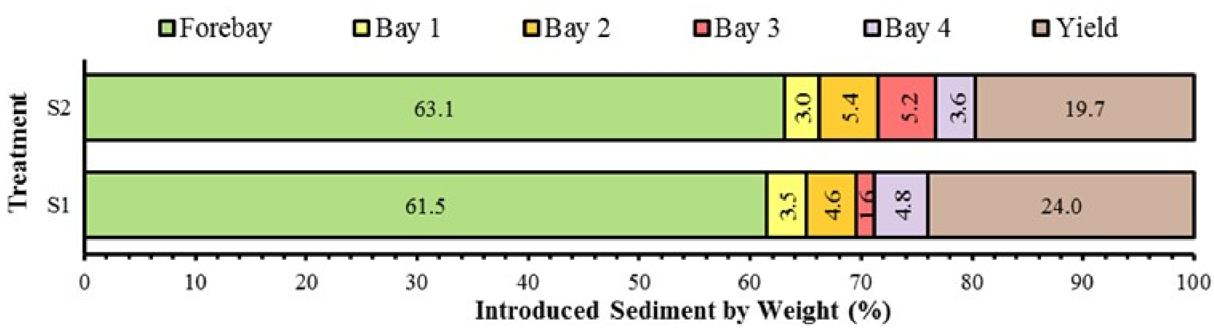
A comparison of the differences within the first 90 min. of testing between S1 and S2 treatments is shown in Figure 4.32(c). From the plot, it is evident that the S2 treatment had slightly lower turbidity in Bay 1 during the filling period, however turbidity in Bay 4 during the same period was slightly higher than it was during the treatment without the excavated sump, S1. After the filling period, the turbidity for both treatments acts similarly.

(a) inflow channel without excavated sump (S1)

(b) inflow channel with excavated sump (S2)



(c) turbidity comparison



(d) sediment capture comparison

Figure 4.32 Comparison of S2 and S1 Treatments.

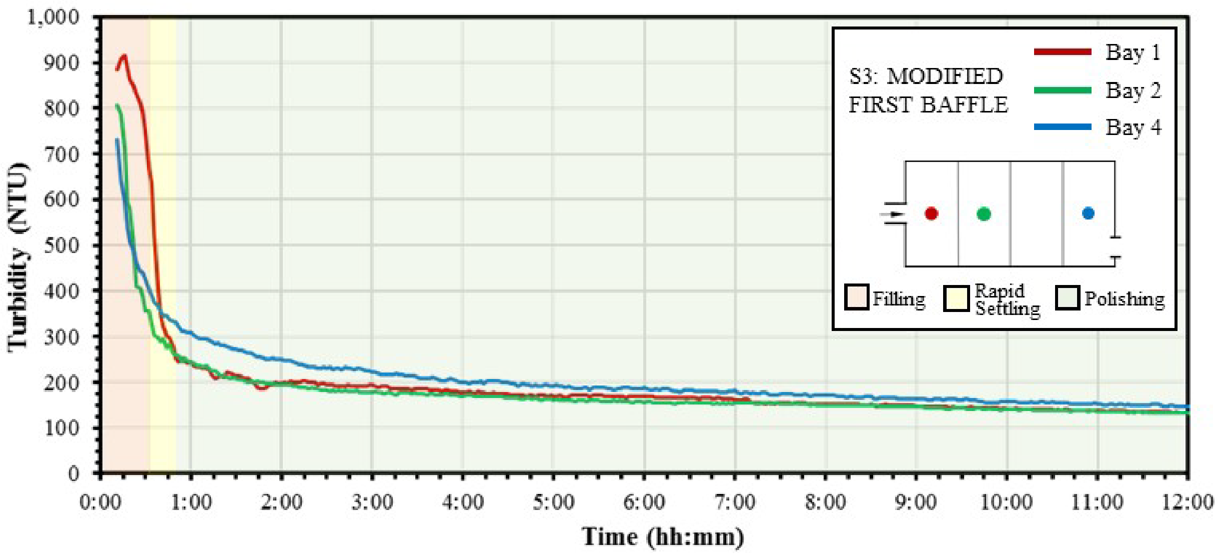
A comparison of the sediment captured in the basin is provided in Figure 4.32(d). As can be seen in the plot, the S2 excavated sump treatment captured approximately 1.6% more sediment than the S1 standard configuration. Furthermore, an additional 3.3% of sediment was captured within Bays 1 through 4. These small difference in capture effectiveness, would be difficult to correlate to the addition of the sump\ without additional replicate tests for statistical comparison.

The inclusion of the excavated sump was observed to have no significant difference in the performance of the sediment basin from a water quality and sediment retention standpoint. Therefore, the excavated sump was left in place for subsequent tests. It was observed that sediment captured within the forebay became resuspended during subsequent tests. This is evident in Video 4.6.

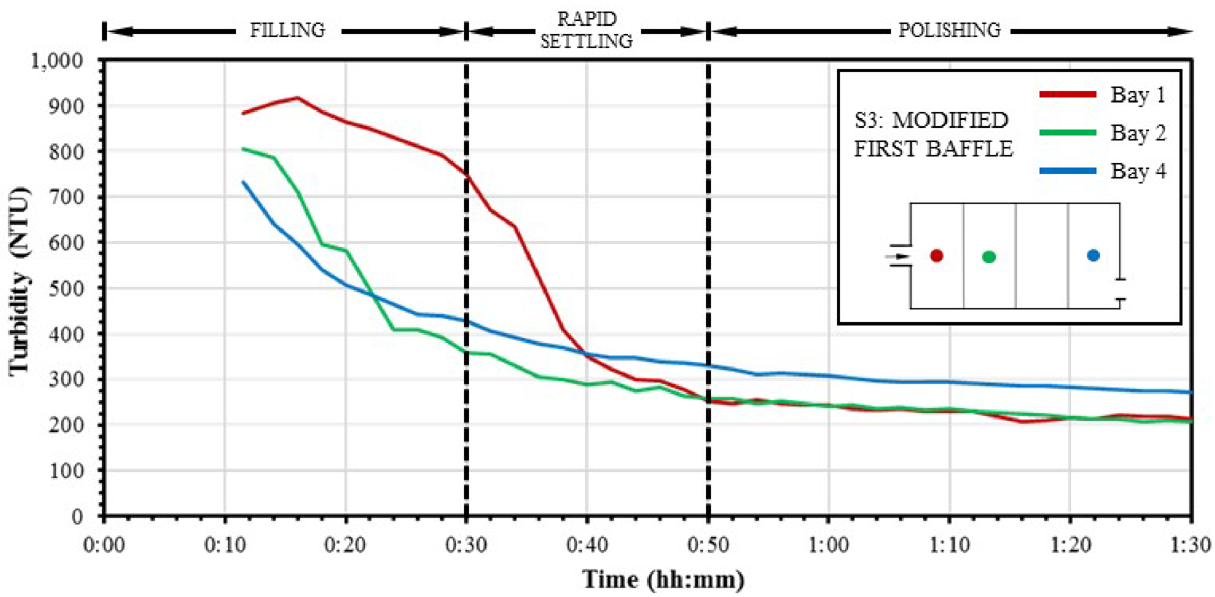
Video 4.6 Resuspension of Captured Sediment in Forebay.

4.7.3 Modified First Baffle

The third series of testing was the treatment with the modified first baffle. The treatment was subjected to three back-to-back 30-minute events. Results from the modified baffle treatment (S3) were compared to the standard baffle treatment (S2). Both treatments were performed with the excavated sump in the forebay. Turbidity results from the modified first baffle treatment are shown in Figure 4.33.



(a) turbidity (0 to 12 hrs.)

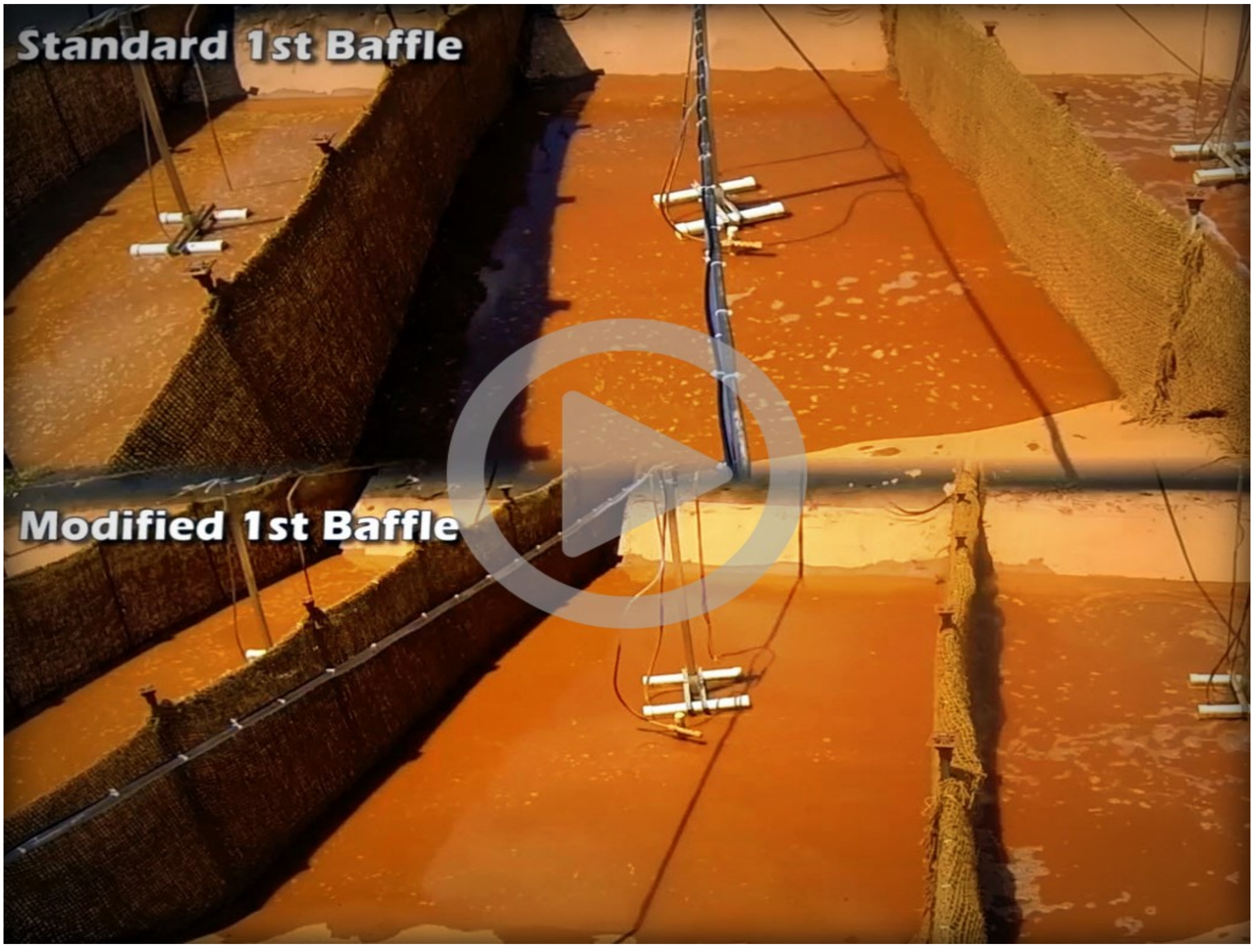


(b) turbidity (0 to 1.5 hrs.)

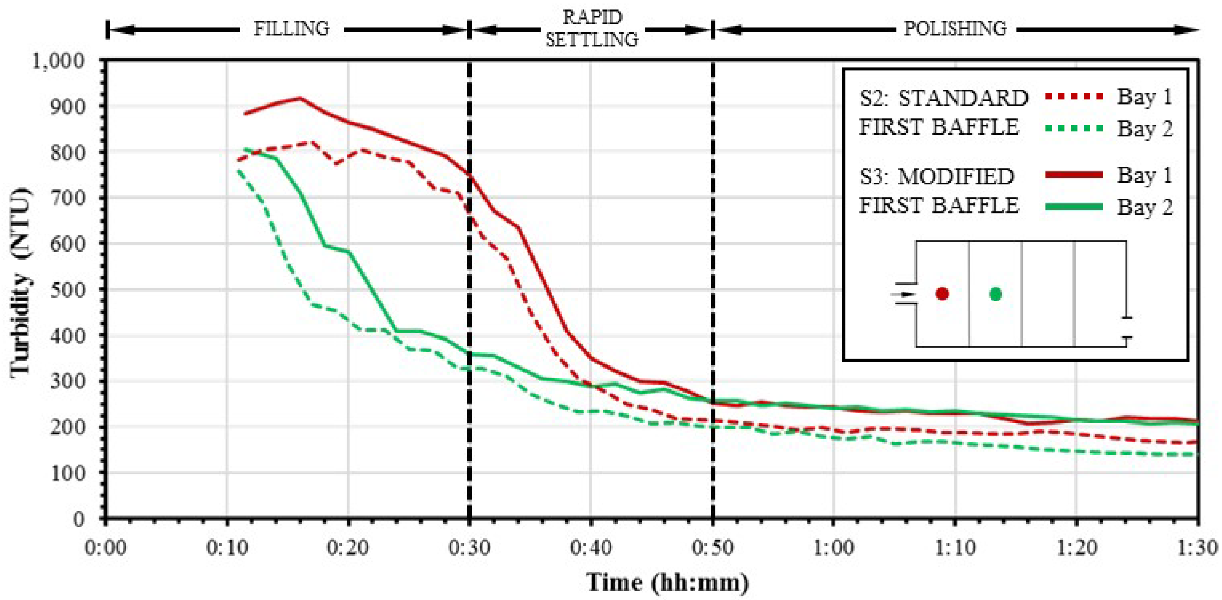
Figure 4.33 S3 Modified First Baffle Treatment.

Visual observations during testing showed that use of the modified first baffle resulted in less turbulence in Bay 2 and Bay 3 when compared to treatments using the standard first baffle, Video 4.7. Turbidity results obtained from the probes were compared between Bay 1 and Bay 2, Figure 4.35(a). These results indicate that turbidity during the modified baffle treatment (S3) was slightly higher (approximately 100 NTU) in both Bay 1 and Bay 2 during the filling and rapid settling period than the treatment with the standard baffle (S2). The results also show that during the polishing period, the turbidity was relatively unchanged between Bay 1 and Bay 2, which was a different behavior than what was observed with the standard baffle treatment (S2).

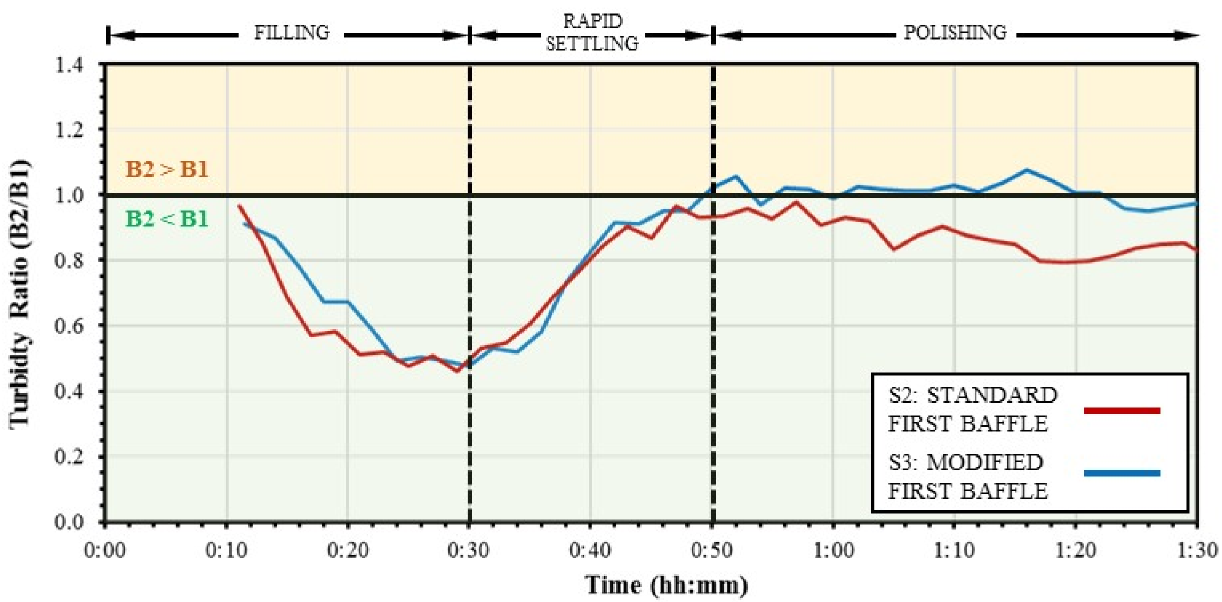
To further compare turbidity results, Bay 2 turbidity was divided by Bay 1 turbidity for each sample, to determine the efficiency in turbidity reduction between the two bays. Figure 4.35(b) shows a plot of this efficiency comparison. Points below 1.0 (shaded in green) indicate that there was a reduction in turbidity between the two bays, while points above 1.0 (shaded in orange) indicate there was an increase in turbidity between the bays. Results from this comparison show that the treatment with standard first baffle (S2) outperformed the modified first baffle treatment (S3).



Video 4.7 Comparison of Standard and Modified First Baffle.



(a) turbidity comparison



(b) treatment efficiency

Figure 4.34 Turbidity Comparison of S3 and S2 Treatments.

Sediment retained in each bay was compared to the standard baffle (S2) treatment, Figure 4.35(a). Figure 4.35(b) shows the sediment retention effectiveness within the four bays of the basin. Comparing the two treatments, there was 4.5% more sediment captured in Bay 1 during the modified first baffle treatment (S3) than was captured in Bay 1 during the standard first baffle treatment when comparing sediment captured within the four bays of the basin.

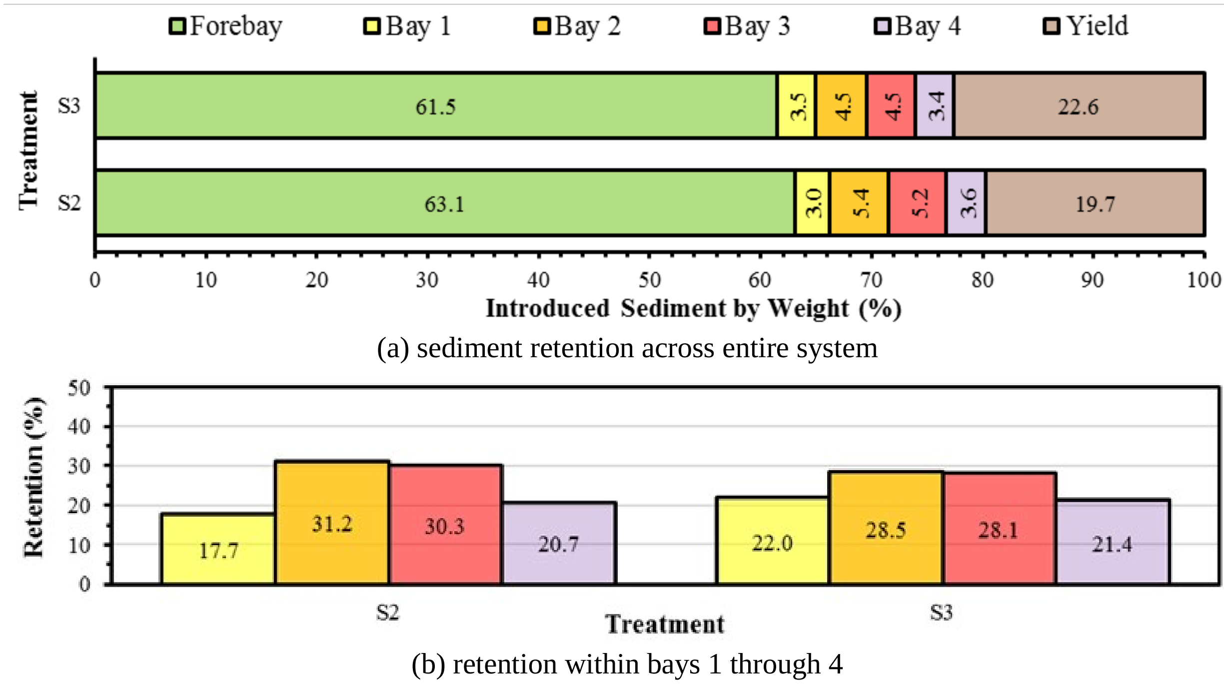
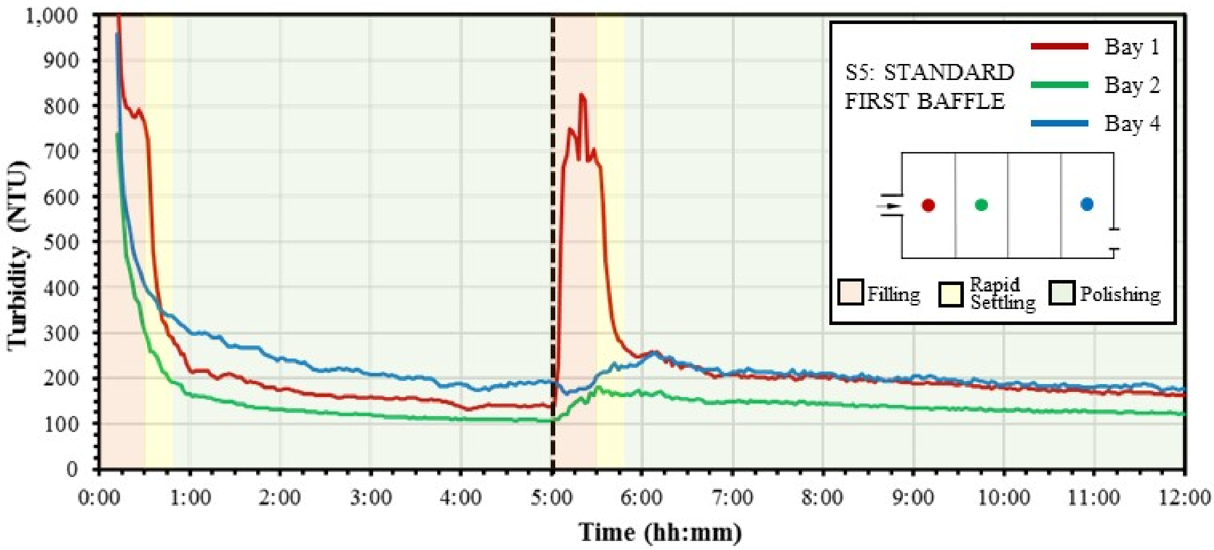


Figure 4.35 Sediment Retention Comparison of S3 and S2 Treatments.

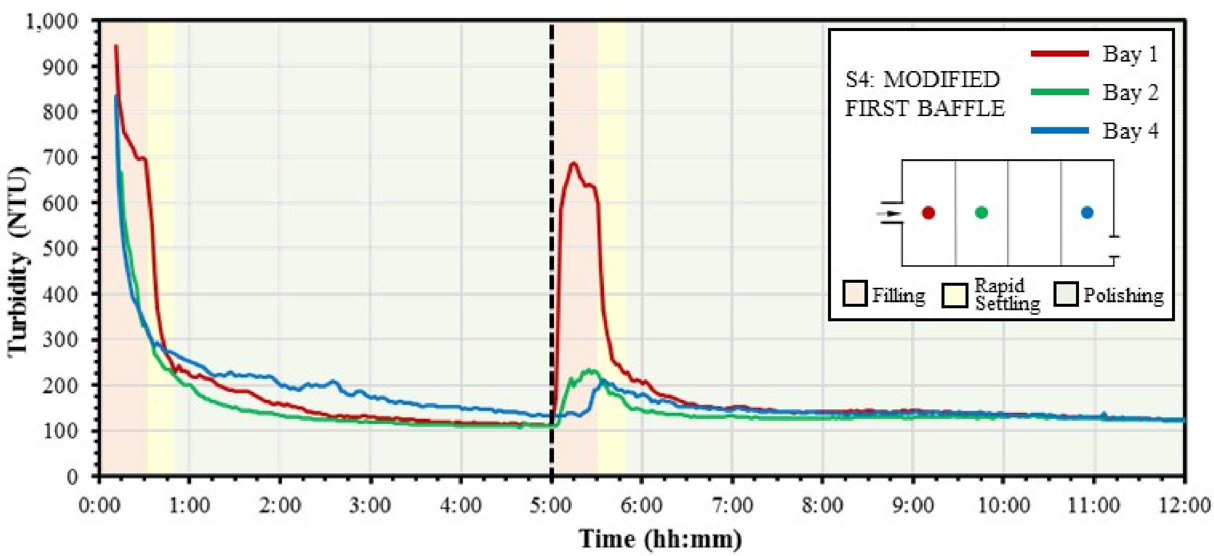
While sediment retention was slightly improved using modified first baffle treatment (S3), the turbidity results from this comparison indicated that the modified first baffle was not advantageous.

4.7.4 Overflow Tests

Overflow tests were conducted on both the standard first baffle (S5) and modified first baffle (S4) installation configurations. The purpose of these tests were to evaluate how the baffles influenced the performance of the basin during conditions that force water to flow through the auxiliary spillway. Turbidity data for the two treatments is shown in Figure 4.36. The data follows the same pattern that was observed in the single test series (S2 and S3), where the turbidity between Bay 1 and Bay 2 is relatively unchanged for the modified first baffle treatment (S4). In contrast, there is a discernable difference between turbidity in Bay 1 and Bay 4 with the standard first baffle treatment (S5). During the second fill cycle (i.e. 5:00 to 5:30), the turbidity in Bay 1 increases dramatically. However, turbidity in Bay 2 and Bay 4 only experiences a gradual increase in turbidity rather than the spike that is observed in Bay 1. This indicates that Bay 1 has the most influence in absorbing the turbidity impact from a subsequent runoff event. This further illustrates how the first baffle system is the most important in retaining turbidity in Bay 1.



(a) standard first baffle, S5, turbidity



(b) modified first baffle, S4, turbidity

Figure 4.36 Turbidity Comparison of S5 and S4 Treatments.

The ratio between Bay 2 and Bay 1 turbidity was compared for the two treatments, each normalized by dividing by Bay 1 turbidity, Figure 4.37. Results from the comparison show that the standard first baffle treatment (S5) outperformed the modified first baffle treatment (S4), further validating results from the single fill experiments, S2 and S3. During the filling period (i.e. 00:00 to 00:30 and 5:00 to 5:30) and the polishing periods (i.e., 00:50 to 5:00 and 5:50 to 12:00), the average performance difference between the treatments show that the standard first baffle is 26.5% and 19.5% more effective at reducing turbidity between Bay 1 and Bay 2, respectively. These results corroborate past research studies *(Christopher et al. 2003; Thaxton et al. 2004; Thaxton and McLaughlin 2004)* that have identified diminishing returns with smaller percent opening size.

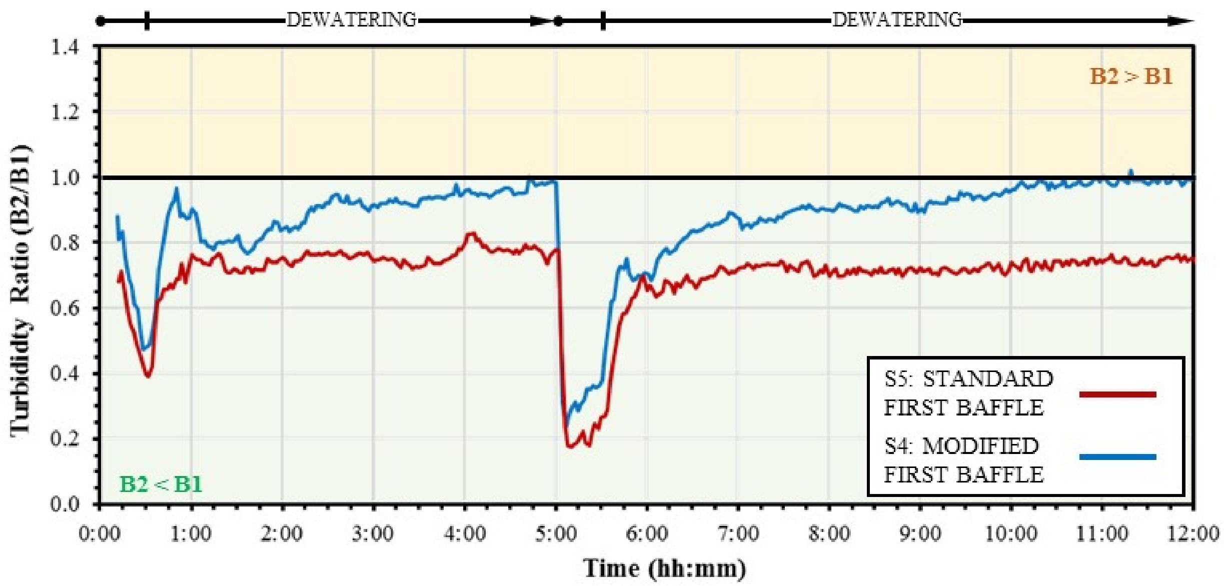


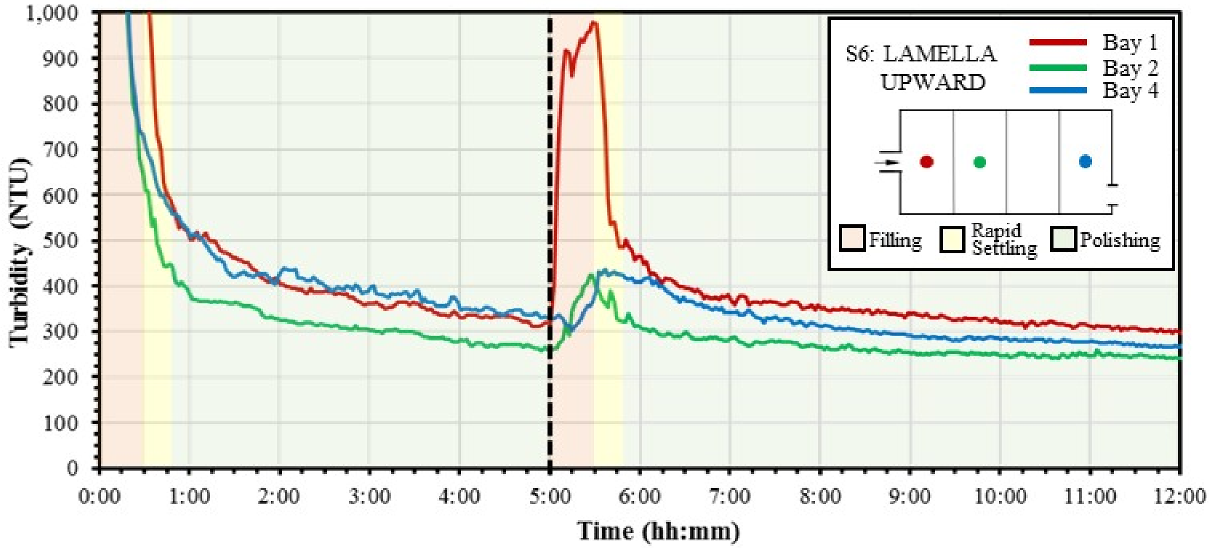
Figure 4.37 Turbidity Ratio Comparison of S5 and S4 Treatments.

4.8 PHASE II: LAMELLA TECHNOLOGY TESTING RESULTS

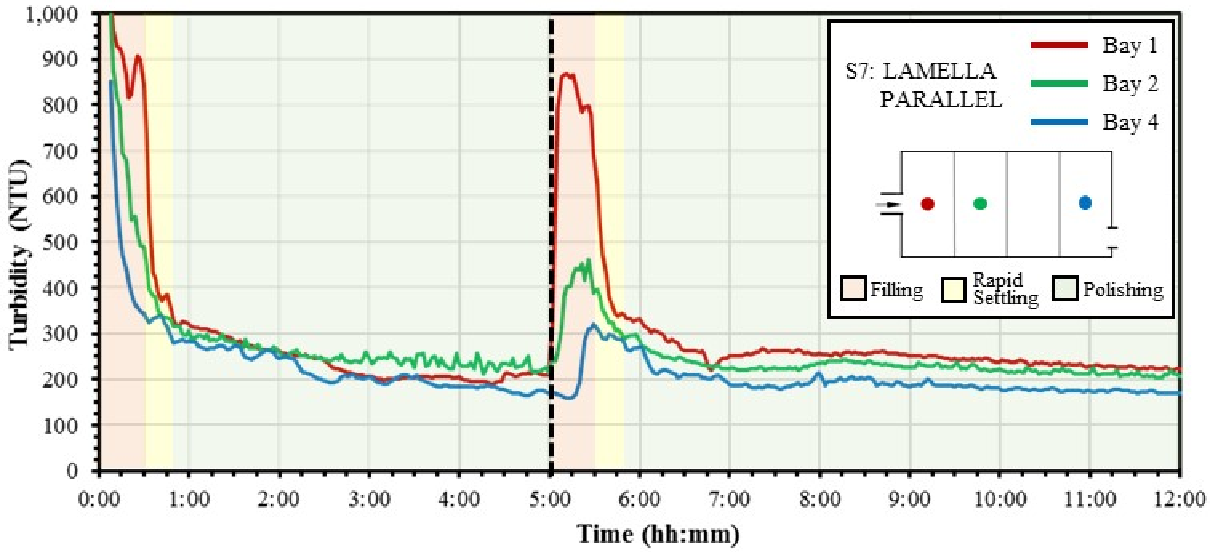
Due to the results from the control configuration testing (Phase 1), it was determined that the ALDOT standard sediment basin configuration with the excavated sump in the forebay was the MFE-I. This configuration was used for testing the lamella settlers in the two configuration (i.e. upward flow and parallel flow). Furthermore, it was determined that the data obtained from the overflow configuration tests provided more comparative data than did the tests performed with the single fill condition. Therefore, only overflow type tests were performed for Phase II tests.

A series of overtopping tests were run on the lamella system installed in the upward and parallel flow configurations. Video 4.8 shows a time-lapse of an overflow test on the upward oriented lamella configuration. Figure 4.38 shows the turbidity plots for the two installation treatments.

Video 4.8 Upward Flow Lamella Settler Experiment.



(a) lamella settlers in upward flow configuration



(b) lamella settlers in parallel flow configuration

Figure 4.38 Turbidity Comparison of S6 and S7 Treatments.

The lamella system had little effect on the water quality behavior of the sediment basin in either configuration. Interestingly, the turbidity for both configurations was significantly higher than turbidity observed in Phase I testing. This difference may be attributed to temperature influences that are described further in the next section. To evaluate the efficiency of the system in reducing turbidity across the basin, a ratio of Bay 4 turbidity to Bay 1 turbidity is plotted in Figure 4.39 for the MFE-I (S5) and the two lamella treatments (S6 and S7).

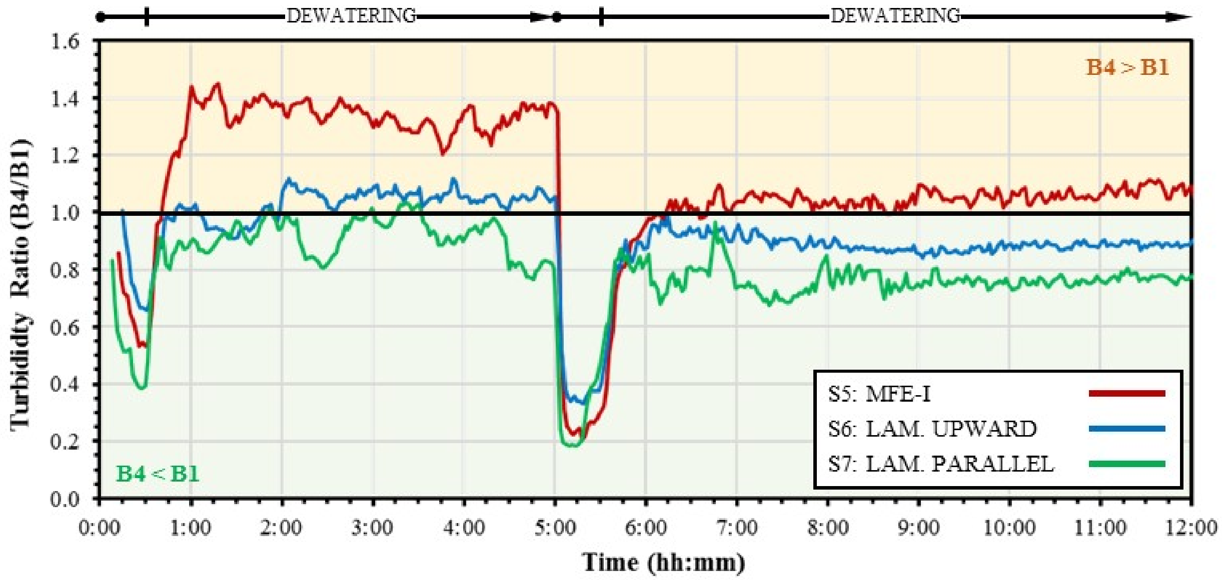


Figure 4.39 Turbidity Ratio Comparison of S5, S6, and S7 Treatments.

When comparing turbidity ratios between Bay 1 and Bay 4, it is evident that the lamella parallel flow configuration outperformed the lamella upward flow configuration and the MFE-I treatment. The lamella upward treatment performed better than the MFE-I only during dewatering periods (i.e. 00:30 to 5:00 and 5:30 to 12:00). Turbidity in Bay 4 was actually higher throughout the dewatering periods for the MFE-I configuration and reduction between Bay 4 and Bay 1 was only observed during the dewatering period when the lamella plates were added to the sediment basin. During the filling periods (i.e. 00:00 to 00:30 and 5:00 to 5:30), the lamella system in upward flow configuration (S6) compared to the MFE-I (S5) had a decrease in performance of 36.6%. During the polishing periods (i.e. 00:50 to 05:00 and 05:50 to 12:00), the lamella system in upward flow configuration (S6) outperformed the MFE-I (S5) by 18.2%. The average increase in performance for the lamella system in parallel flow configuration (S7) compared to the MFE-I

(S5) was 6.5% during the filling periods (i.e. 00:00 to 00:30 and 5:00 to 5:30) and 29.0% during the polishing periods (i.e. 00:50 to 05:00 and 05:50 to 12:00).

4.9 DISCUSSION

The following section provides discussion on temperature variability and TSS analysis performed during the sediment basin experiments.

4.9.1 TEMPERATURE INFLUENCE

Water quality results showed significant discrepancies between turbidity levels throughout the duration of the experiments. This is exemplified by Figure 4.40 where the turbidity in Bay 1 and Bay 4 is plotted for the MFE-I (S5) treatment and the lamella in upward flow configuration (S6).

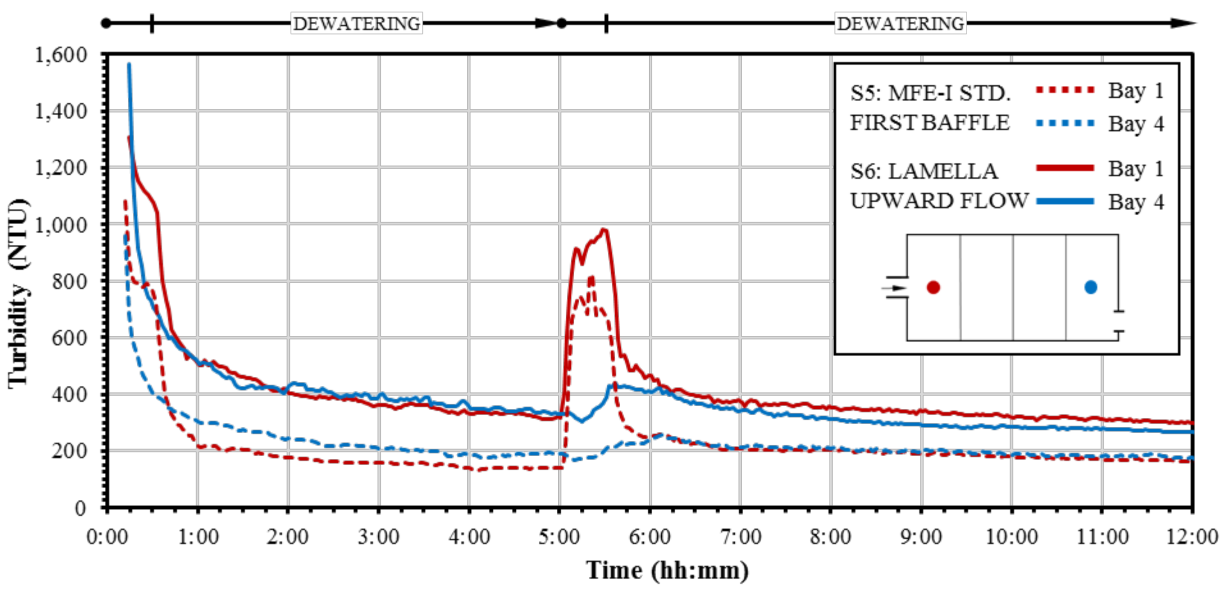


Figure 4.40 Turbidity Discrepancy Between Treatments.

The testing methodology developed for these experiments ensured variables remained consistent from test to test. The only variables that were not controllable were those attributed to weather. Testing was not conducted during rainfall events, and wind likely had no noticeable effect on mixing within the basin. Temperature however did fluctuate throughout the year and was the likely culprit in these observed turbidity differences. Table 4.6 shows a summary of all tests performed in the sediment basin and the corresponding average water temperature for the tests. Temperatures were obtained from the level loggers used to monitor water depth over the course of tests. Water temperatures ranged between 54.0 to 88.3 ºF (12.2 to 31.2 ºC).

Table 4.6 Avg. Water Temperature for Tests Performed in Sediment Basin.

Treatment	Segment	Date	Avg. Water Temp., ºF (ºC)
S1: ALDOT Standard w/o Excavated Sump	L-1	3/16/2015	61.0 (16.1)
	L-2	3/18/2015	64.3 (17.9)
	L-3	3/30/2015	62.9 (17.2)
S2: ALDOT Standard + Excavated Sump	L-1	5/1/2015	69.7 (20.9)
	L-2	5/8/2015	80.9 (27.2)
	L-3	5/12/2015	82.1 (27.8)
S3: ALDOT Standard + Excavated Sump + Modified First Baffle	L-1	5/29/2015	80.4 (26.9)
	L-2	6/1/2015	83.0 (28.3)
	L-3	6/5/2015	84.4 (29.1)
S4: ALDOT Standard + Excavated Sump + Modified First Baffle [overflow]	L-1	7/10/2015	86.2 (30.1)
	L-2	7/14/2015	88.3 (31.2)
	L-3	7/17/2015	86.0 (30.0)
S5: ALDOT Standard + Excavated Sump [overflow]	L-1	9/21/2015	79.2 (26.2)
	L-2	9/25/2015	73.8 (23.2)
	L-3	9/30/2015	76.1 (24.5)
S6: Lamella Upward Flow [overflow]	L-1	12/10/2015	54.9 (12.7)
	L-2	12/15/2015	58.7 (14.8)
	L-3	12/18/2015	54.0 (12.2)
S7: Lamella Parallel Flow [overflow]	L-1	4/29/2016	79.7 (26.5)
	L-2	5/2/2016	80.0 (26.7)
	L-3	5/5/2016	73.4 (23.0)

Figure 4.41 shows a plot of the average water temperature of the tests performed and the plot of the average daily temperature for the weather station located at the Auburn University Regional Airport (KAUO) *(Weather Underground 2016).*

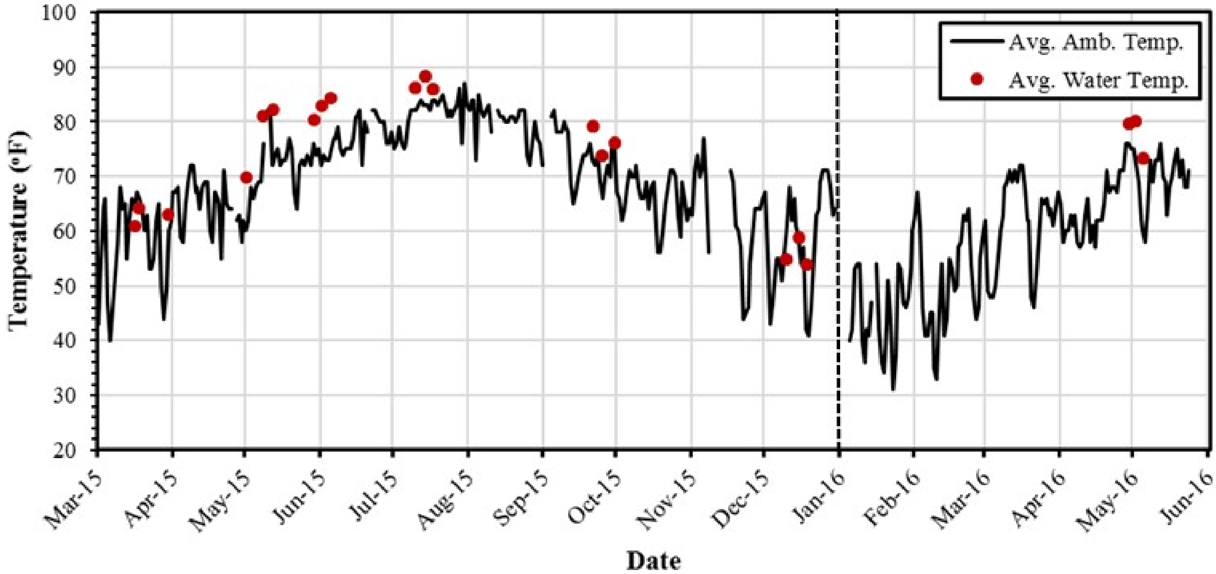
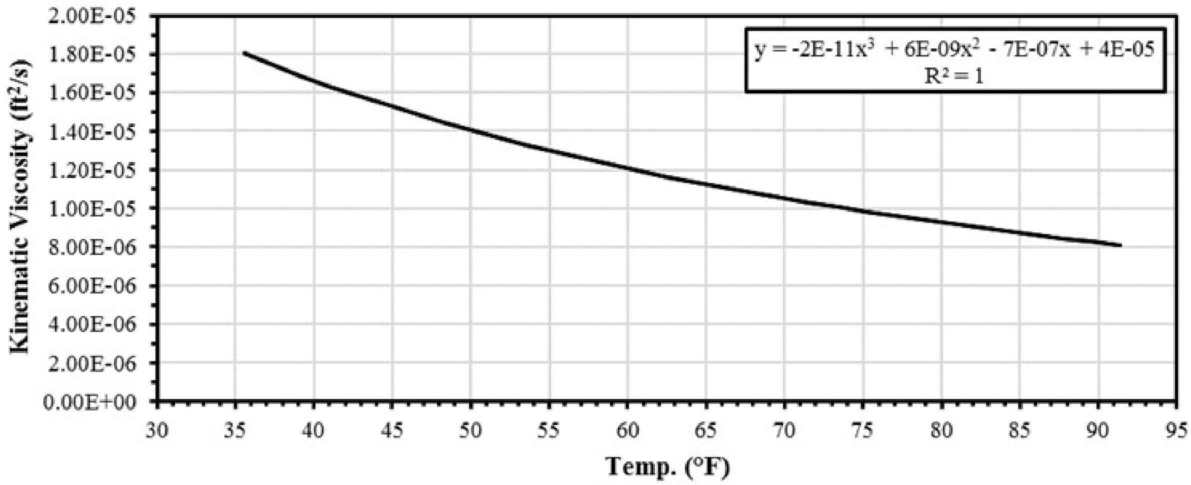


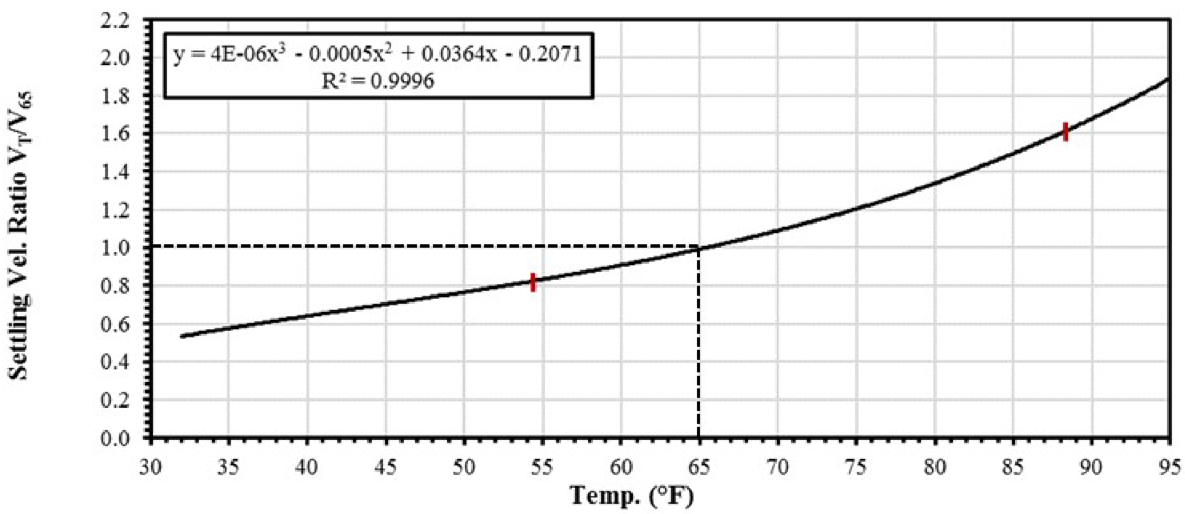
Figure 4.41 Temperatures for Tests Performed in Sediment Basin.

Through Stokes law, settling velocity is dependent on acceleration due to gravity, specific gravity of a suspended particle, diameter of spherical particle, and the kinematic viscosity of the fluid. The only variable that changes between tests is the kinematic viscosity which is a direct function of water temperature. Viscosity and settling velocity are inversely proportional, as the viscosity increases, the settling velocity decreases. The kinematic viscosity of water is directly proportional to water temperature, as temperature increases, the viscosity decreases. Therefore, the settling velocity of a spherical particle under Stokes law increases as the temperature of water increases.

To determine the effect of temperature on the tests conducted, a plot was created to develop a ratio of settling velocities at varying temperatures. Kinematic viscosity was plotted against temperature for 47 known temperature points. This data set was fitted to a polynomial regression curve to develop a relationship for the points, Figure 4.42(a). The settling velocity for a theoretical particle of 3.9×10^{-4} in. (0.01 mm) was then calculated for 37 data points (i.e. 32 to 96.8 ºF [0 to 36 ºC]) using Stokes law and the developed regression equation for viscosity. The settling velocity for those points was divided by the settling velocity at 65 ºF (18.3ºC) (average annual water temperature in the state of Alabama) to develop a ratio, Figure 4.42(b). With the range of water temperatures experienced during testing, the settling velocity can vary as much as 200%.



(a) temperature and kinematic viscosity relationship



(b) developed settling velocity ratio

Figure 4.42 Temperature Effect on Settling Velocity.

While there are no existing studies correlating turbidity to viscosity or settling velocity, this settling velocity ratio relationship was developed to transform turbidity curves to a baseline temperature, 65 ºF (18.3ºC). By applying this correction, turbidity curves for tests performed at temperatures above the baseline are shifted down, while data for tests performed at temperatures lower than the baseline are shifted up. Applying this technique provided a normalization to the data that can be shown in Figure 4.43

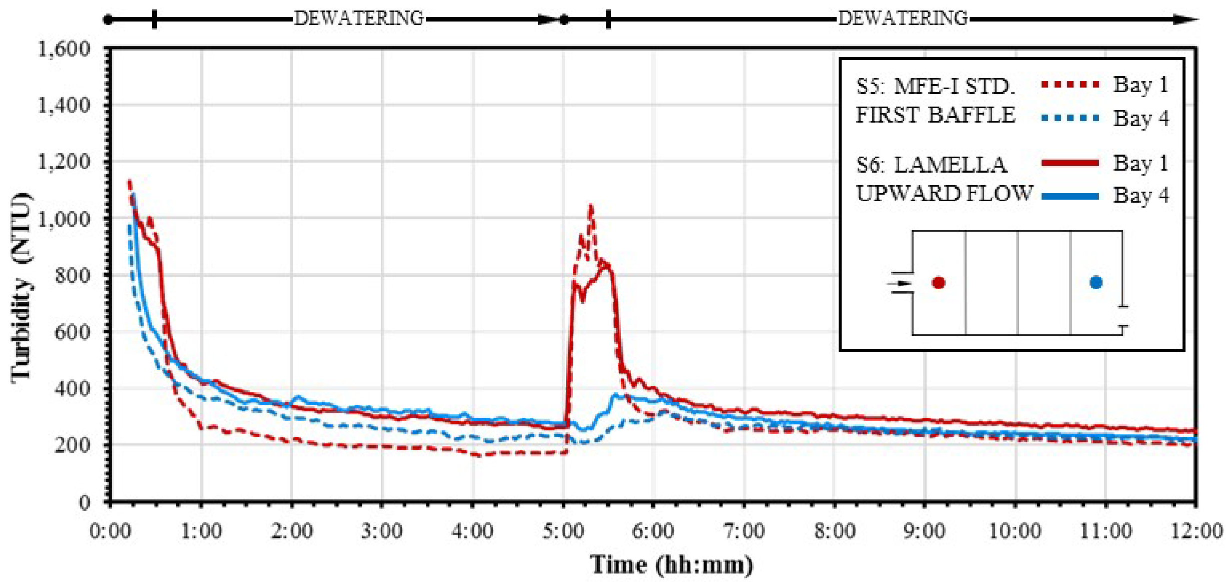
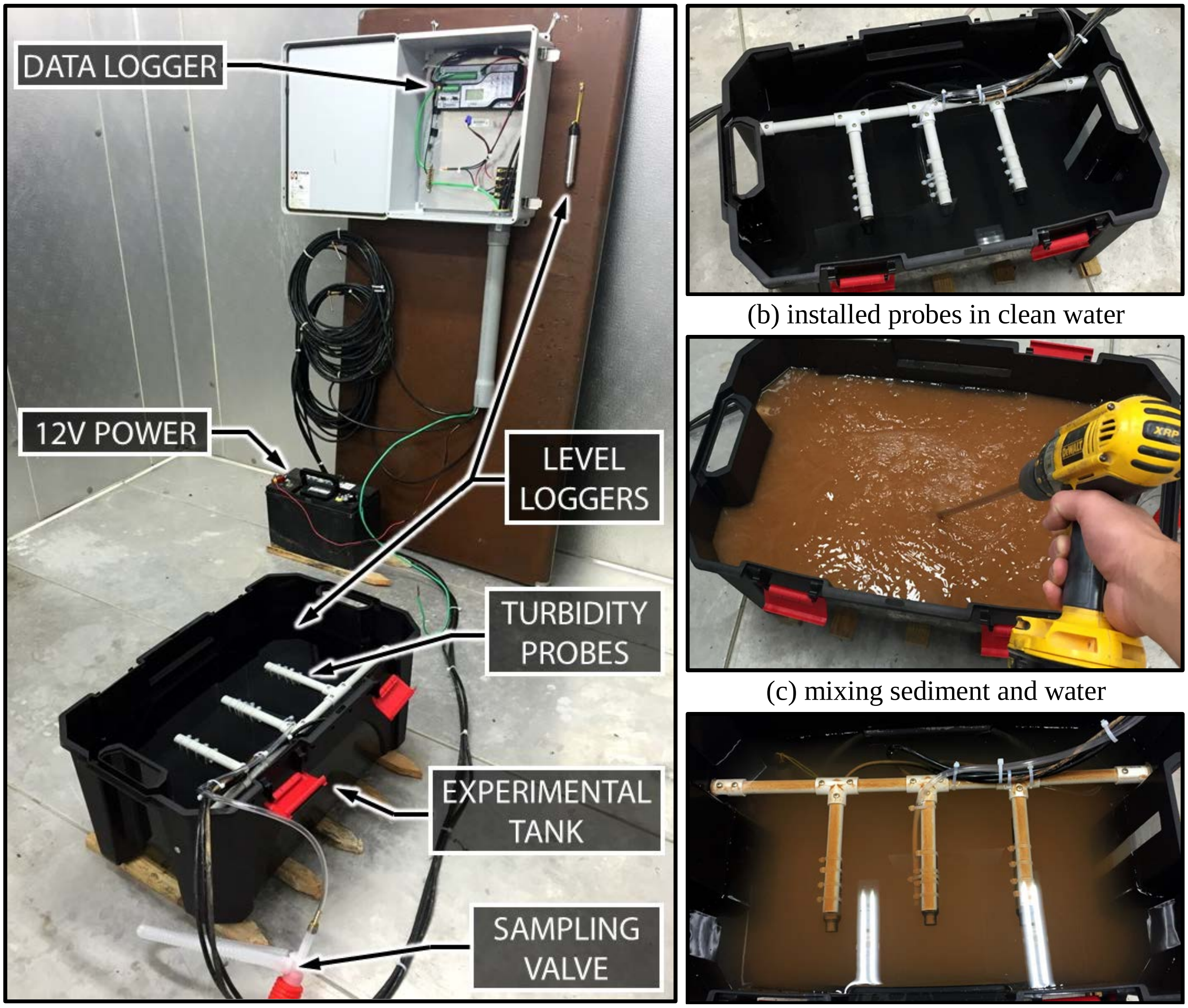


Figure 4.43 Temperature Normalization for S5 and S6 Turbidity Data.

An empirical approach was conducted in a Nor-lake, Inc.® Enviro-Line walk-in environmental chamber under controlled conditions to provide testing data to the developed temperature normalization approach. Experiments were conducted in a plastic tank filled with 15 gallons (56.7 L) of tap water. Approximately 7.1 oz (200 g) of soil sieved to the No. 200 (0.074 mm) sieve was added to the tank and agitated with a power drill paint mixer. The three Campbell Scientific OBS3+ turbidity probes were installed at the surface of the tank and continuously monitored water quality over the duration of the experiment. Ambient temperatures in the chamber were increased at 10 ºF (5.5 ºC) intervals ranging from target temperatures of 45 to 95 ºF (7.2 to 35 ºC), Figure 4.45(a). Temperatures in the chamber and tank were monitored using a standard alcohol thermometer and two Hobo level loggers. Once equilibrium conditions were reached in the tank, mixing was conducted to resuspend sediment in the water. The tank was then allowed to sit undisturbed to allow for settling to occur.



(b) installed probes in clean water

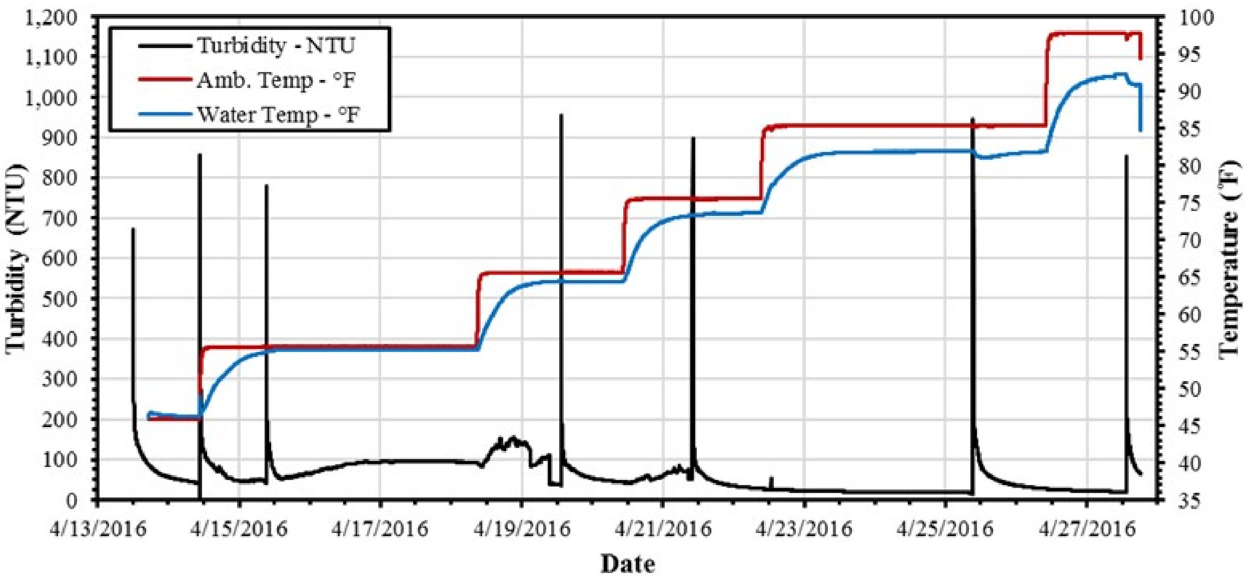
(c) mixing sediment and water

(a) apparatus in environmental chamber

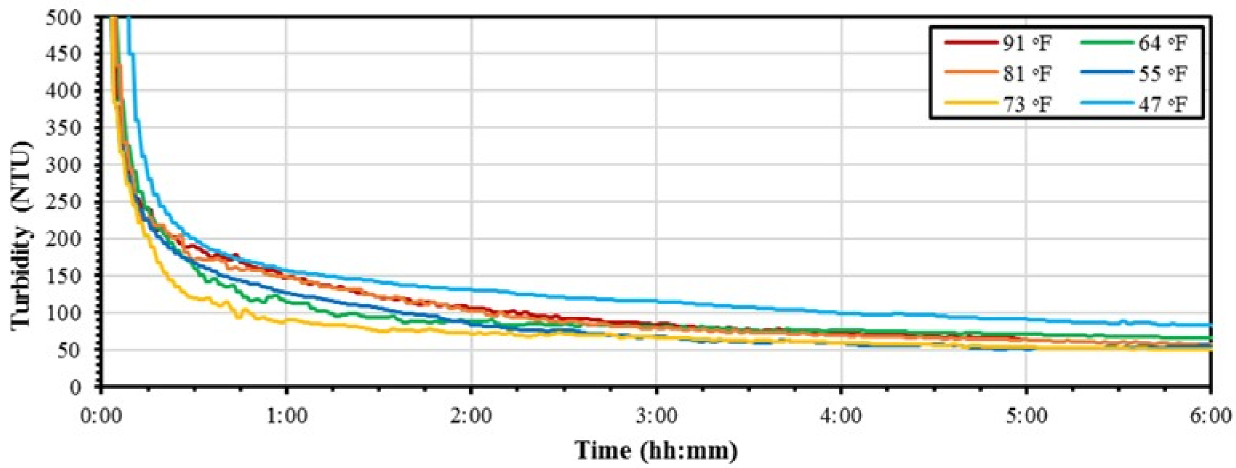
(d) tank after settling period

Figure 4.44 Environmental Chamber Temperature Adjustment Testing.

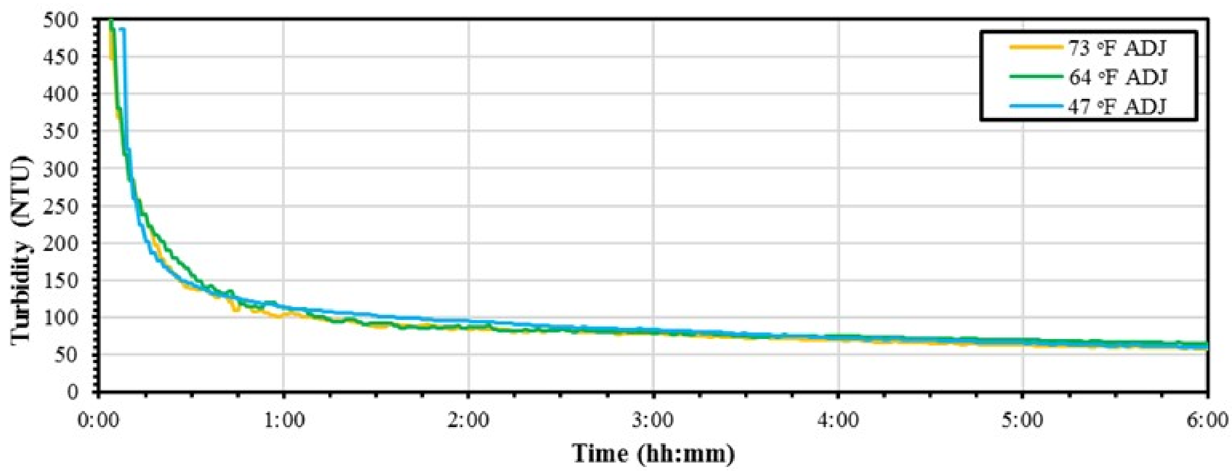
Differences in the turbidity decay rate were observed through the turbidity probes and are plotted in Figure 4.45(b). Of the six temperature ranges tested, three followed the trend of increasing turbidity decay rate with increased temperature: 47 ºF, 64 ºF, and 73 ºF (8.3 ºC, 17.8 ºC, and 22.8 ºC). The turbidity standard deviation between these three temperatures averaged 23.3 NTU throughout the first six hours of the experiment. The temperature adjustment factor was applied to these three temperature experiments to normalize the data to 65 ºF (18.3ºC). This adjustment is shown in Figure 4.45(c). The adjusted turbidity standard deviation between these three temperatures averaged 4.8 NTU throughout the first six hours of the experiment. The applied adjustment increased the correlation of the three data series by a factor of 4.9.



(a) turbidity and temperature data summary for all experiments



(b) turbidity results for tested temperatures



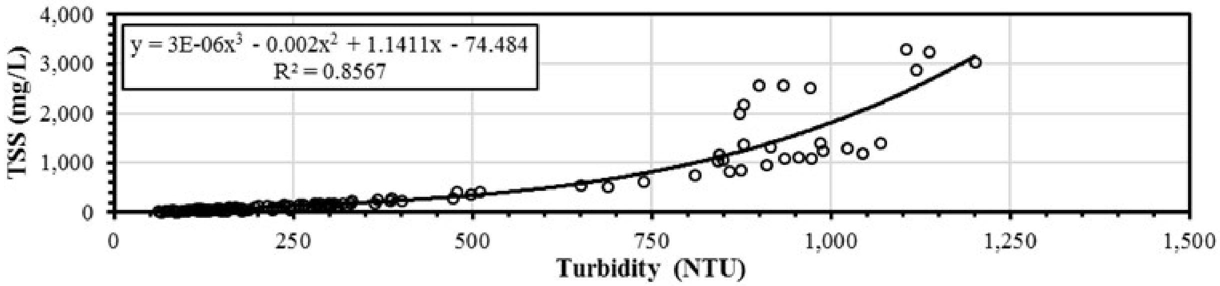
(c) adjusted turbidity based on temperature for select experiments

Figure 4.45 Temperature Adjustment Experimental Results.

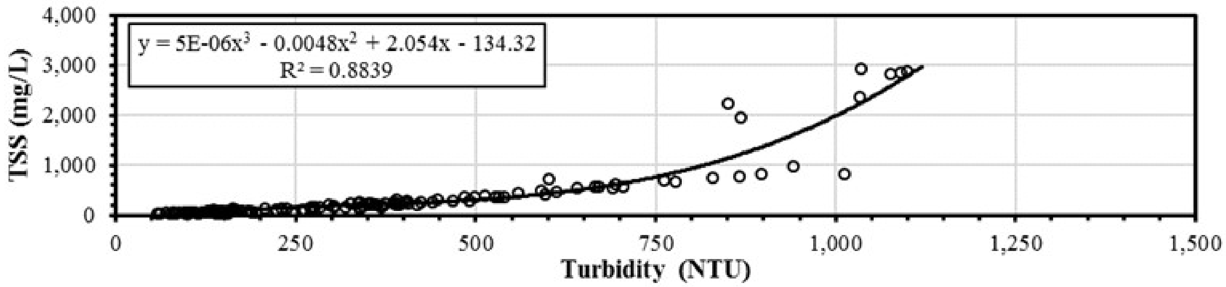
While further replications would be required to verify this proposed temperature adjustment factor, preliminary data supports the hypothesis that the decay rate of turbidity follows the same pattern as the ratio of settling velocity at different temperatures.

4.9.2 TSS Relationship

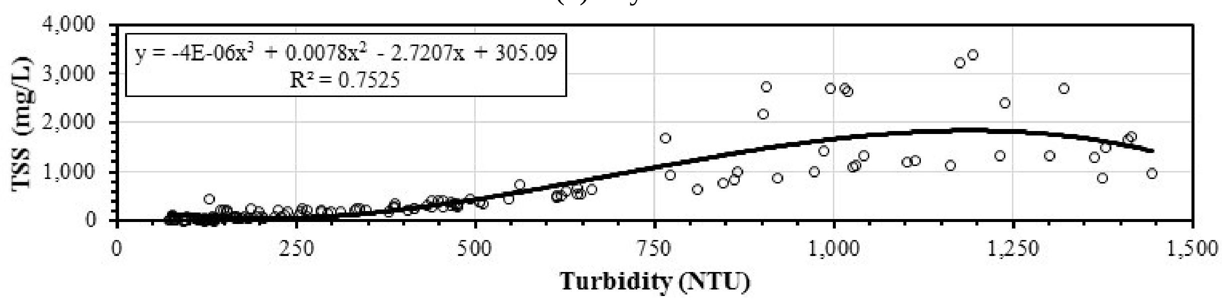
The primary means of evaluating the performance of the treatments tested in the sediment basin was through the turbidity data that was read by the probes installed in Bays 1, 2, and 4. However, grab samples were also obtained from initial tests (i.e. S1 and S2) using automated samplers in Bay 1, Bay 2, Bay 2 bottom, Bay 3, and Bay 4. These samples were analyzed for turbidity and TSS using laboratory methods. The purpose of these samples was to determine the relationship between turbidity and TSS to correlate measurements taken by the probes. The TSS vs. turbidity results were separated by bay and plotted to determine the best fit polynomial relationship as shown in Figure 4.46. The plotted relationships show a relatively strong relationship between TSS and turbidity with R^2 values ranging between 0.75 and 0.93.



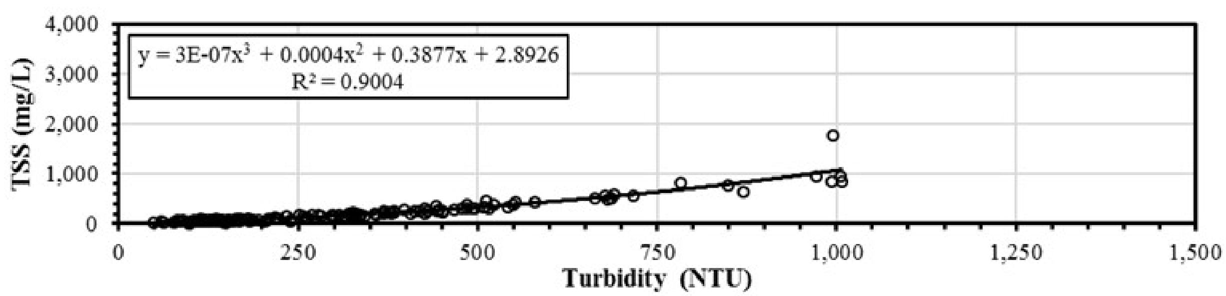
(a) Bay 1



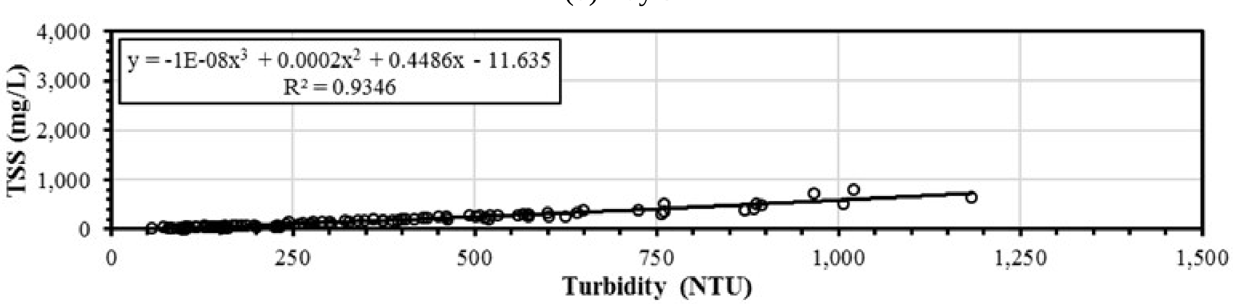
(b) Bay 2



(c) Bay 2 Bottom



(d) Bay 3



(e) Bay 4

Figure 4.46 TSS vs. Turbidity Relationship.

4.10 CONCLUSION

This study has shown the need for large-scale, reproducible sediment basin testing techniques to improve current practices and to achieve greater in-field performance. The study included the design and construction of a large-scale sediment basin at the AU-ESCTF intended to test several sediment basin design configurations to understand the performance of the current standard design and for improving the efficiency and performance of various basin treatments. The developed apparatus lends to dedicated and controlled testing where researchers are not at the mercy of unpredictable runoff and erosion contributions on active construction sites. The constructed sediment basin testing apparatus and presented methodology providing researchers with a method in which to test basin configurations and treatment technology in a controlled scenario replicating field conditions and allowing for better understanding of sediment basin design practices. Results of standardized performance based testing will lead to improved design guidance that practitioners can refer to when incorporating sediment basins as an element of the SWPPP for construction sites.

The constructed sediment basin has a total storage of 2,790 ft^3 (79.0 m^3). The metered water and sediment introduction apparatus were developed to allow researchers to control the inflow of material into the basin. Hydrological analyses were used to determine applicable flow and sediment rates for testing, which lends to a uniformed testing procedure that can be applied in various geographical areas based on local rainfall and soil hydrology characteristics. A phased testing regime was developed that allows for evaluating sumps, modified baffles, and high-rate lamella settling technology. Under the developed regime, the basin was subjected to 27 tests in eight series to evaluate treatments under replicated events and overtopping conditions. Data collection included: water quality, flow rates, basin stage levels, sediment deposition volumes, and sediment sampling for particle characterization, and were subsequently used to evaluate the performance of various tested practices in the basin. The developed methodology allowed AU-ESCTF researchers to provide testing guidance for the evaluation of sediment basin technology.

Observed results showed that the use of an excavated sump in the forebay had no significant effect on water quality treatment in the basin. Furthermore, the use of a modified coir first baffle with 10.9% percent open area was shown to be less effective in treating turbidity than the standard ALDOT baffle configuration. The MFE-I was determined to be the ALDOT standard configuration with excavated sump in the forebay. The MFE-I was used for Phase II testing of the high-rate lamella settlers in the upward and parallel flow configurations. Both high-rate settler configurations treated stormwater more effectively than the MFE-I system without the settlers. The parallel flow configuration outperformed the upward flow and MFE-I configuration by 18.2 and 29.0%, respectively. During all overflow tests performed, the sediment basin had a higher efficiency during the overtopping event then did during the empty fill condition. This indicates that having dead storage in the basin is important to provide dilution to highly turbid receiving flows, and to dissipate the energy, reducing resuspension of settled particles.

Future research efforts should emanate from this project, allowing for further improvements to enhance the performance of sediment basins used in the field while also lending to educational outreach that will continue to increase the general knowledge in the ESC industry.

CHAPTER FIVE:
UAV FOR INSPECTION APPLICATIONS

5.1 LITERATURE REVIEW

The USEPA NPDES CGP requires formal site inspections be performed on a weekly basis or within 24 hours of the occurrence of a storm event producing 0.25 in. (0.64 cm) of rainfall or greater *(USEPA 2012)*. State departments of transportation maintain best management plans to help ensure stormwater compliance, which at times are required to follow state and local environmental requirements for NPDES CGP. For example, ADEM requires that a certified Qualified Credentialed Inspector (QCI) be assigned to each permitted construction project and perform regular site inspection of ESC practices. Daily observation of discharge points and areas of the project where the ground is disturbed are required, and formal inspections are required on a weekly basis or after the accumulation of 0.75 in. (1.91 cm) of rainfall within 24 hours *(ADEM 2011)*. The project Qualified Credential Professional (QCP) shall perform a site evaluation every six months or more frequently if necessary *(ADEM 2011)*. QCI's conduct regular inspections of regulated construction activities to ensure effective ESCs are properly installed and are being maintained regularly. Inspection reports are to be retained for at least three years from the date that permit coverage expires.

Site inspections on large project sites can become a time-consuming, arduous task, requiring QCIs to conduct complete site walkthrough to inspect all discharge points and site ESC practices. In an effort to expedite the process for inspection personnel, unmanned aerial vehicles (UAVs) could assist in identifying and documenting areas on a site that is deficient and requires immediate attention by the controlling contractor.

5.2 UNMANNED AERIAL VEHICLES

UAVs are an emerging remote sensing tool capable of acquiring high resolution spatial and sensing data. Remote sensing with UAVs has the potential to provide high quality aerial imagery and data that can assist QCIs to perform focused, strategic site inspections in an efficient and effective manner. UAVs are economical and flexible in acquiring aerial data (i.e. photographs, videos, and elevation data) and can be pre-programmed with flight patterns to objectively repetitively capture data over construction areas being inspected. UAV based remote sensing enables user-controlled image acquisition and bridges the gap in scale and resolution between ground observation and imagery acquired from conventional manned aircraft and satellites. UAVs present a cost-effective method that can adapt image characteristics to the size of observed objects, and monitor the processes of change within a landscape *(d'Oleire-Oltmanns et al. 2012)*.

UAVs have the potential to assist inspectors perform thorough site inspections efficiently and strategically. By providing a complete detailed aerial view of the site at the onset of an inspection, the inspector has the ability to quickly identify problem areas, discharge points of concern, and determine whether further detailed investigations are warranted. Photogrammetric techniques can also be used to provide analyses using the collected aerial data through the creation of digital elevation models (DEMs).

Historically, aerial imagery has been captured through the use of satellites and manned aircraft. Although efficient, these methods provide resolution details in the range of 7.9 to 19.7 in./pixel (20 to 50 cm/pixel). Furthermore, the cost, resources, and time to operate these systems are much higher than the operation of a UAV. UAVs are capable of taking off and landing from rugged terrain, and operate at much lower altitudes in comparison to other flight systems. Thus, UAV systems can provide much greater resolution data, as detailed as 0.40 in./pixel (1 cm/pixel) *(Turner et al. 2012)*. By increasing pixel density, higher resolution data can be collected and used to create more accurate photogrammetric data. Photogrammetry is the mathematical process by which triangulation is constructed from photographs to create three-dimensional representations from two dimensional photography. The use of photogrammetry techniques in aerial and satellite imagery sciences can be applied to create highly detailed aerial mosaics of surveyed areas. UAV photogrammetry is applied to derive point clouds from imagery to describe a surface. These point clouds are converted into DEMs that provide topographic data (i.e., x, y, and z coordinates) of a surface. High resolution aerial images can be geo-referenced using ground control points identified via traditional surveying methods. Commercially available computer software has the capability of converting aerial images to DEMs *(Michel Kasser and Egels 2002)*.

A literature review was conducted to identify specific applications in which UAV technology can potentially be used as a tool for performing construction site inspections and monitoring project progression. The following six applications were identified: (1) construction documentation, (2) site inspections of ESC practices, (3) soil erosion quantifications, (4) erosivity risk and prediction, (5) stockpile and basin storage volumes, and (6) assessing vegetative establishment and site stabilization. Each aforementioned application is presented in the following sections.

5.2.1 CONSTRUCTION DOCUMENTATION

Proper construction documentation is a key component in the modern construction industry, which has become increasingly burdened with legal disputes *(Kangari 1995)*. One of the most critical project documentations is an assessment of pre-development conditions. Preliminary site assessments collect information about a site and its surrounding areas prior to breaking ground and the initiation of construction. These preliminary site surveys can be a useful tool to identify natural resources that may need to be avoided, coordinated, or addressed prior to site selection; property and right-of-way procurement; or design. These preliminary site assessments make a critical contribution to initial project documentation. Having high resolution aerial photographic documentation would become particularly useful in the event of environmental complaints or litigation. Aerial photography interpretation can be used in conjunction with geographic information systems (GIS) to develop exhibits recreating predevelopment site conditions.

Recording project progression throughout the life of a project is another important documentation component. Detailed aerial image mosaics can be used to document overall project progression and status throughout the course of investigations and the project timeline. This information can be compiled after each site visit and used to evaluate contractor progress, claims or disputes, and whether corrective actions have been taken to mitigate ESC deficiencies identified during previous site inspections. Further beneficial uses can emanate from UAV inspections including: material management, measurement of pavement sub-base volumes, and project progress dispute resolutions. Aerial photographs can be further used for public meetings and to provide designers with visual project updates on progress made to date.

5.2.2 SITE INSPECTIONS OF ESC PRACTICES

Aerial inspections can assist inspectors in identifying on- and off-site problem areas associated with employed ESC practices. This will also allow for direct comparison between past UAV inspections to ensure continued environmental compliance by contractors. Aerial images can be used to quickly identify problem areas and discharge concerns within the site leading the inspector to conduct further investigation on-foot, as needed. Damaged perimeter controls, sediment plumes, rogue runoff paths, and sediment accumulation on- or off-site will be evident from high resolution aerial photos and videos. Further examples include observing various ESC practices for improper installations or failures requiring corrective action by the contractor.

5.2.3 Soil Erosion Quantification

Traditional surveying methods have been used to produce DEMs for the purpose of quantifying soil erosion and sediment yields from construction sites. UAVs can be used to capture low altitude aerial photographs capable of producing highly detailed and accurate DEMs through photogrammetric processing *(Colomina and Molina 2014)*. High resolution DEMs can be used to compare surface elevation changes within the site over the course of several inspection or rain events *(Martinez-Casasnovas et al. 2002)*. DEMs can be compared to subsequent aerial surveys to calculate soil loss or soil accumulations within a construction area. This tool can be used to identify highly erosive areas and offsite sediment migration to quantify sediment yields from areas of concern.

5.2.4 Erosivity Risks and Predictions

Watershed simulation models are widely used in evaluating hydrological responses from various land use and land management practices. DEM's can be used to characterize topographic features that will be conducive to conveying runoff. GIS hydrology tools can be applied to delineate sub-basins and runoff flow reaches and paths. Furthermore, likelihood indicator models can be used to produce probabilistic surfaces that indicate the risk of excessive runoff accumulation *(Leh and Chaubey 2009)*. The use of these tools with an accurate DEM representation, can provide designers guidance on which ESC practices to specify for various site characteristics based on expected stormwater runoff conditions on the current site topography.

5.2.5 STOCKPILE AND BASIN STORAGE VOLUMES

Traditionally stockpile volumes have been determined using survey characteristic break lines or planimetry methods, where the volume is calculated by interpolating and summing cross sections or profiles along an axis. As mentioned above, UAVs can be used to capture high resolution photographs to create DEMs. GIS analysis can compute volumetric differences between the stockpile and a reference plane. The quantification of stockpile volumes can be a useful tool for contractors to determine the quantity of stocked material needed for a project. Excessive, or unneeded quantities can be relocated or protected from exposure to limit the risk of erosion.

UAV derived DEMs can similarly provide detailed volumetric quantification of available storage within sediment basins constructed on-site. This tool will assist inspectors in ensuring basin construction follows the design of the intended structure. Furthermore, it will allow contractors and inspectors to identify when maintenance is required to remove sediment from the basin to maintain overall capture efficiency.

5.2.6 ASSESSING VEGETATIVE ESTABLISHMENT AND SITE STABILIZATION

Temporary and permanent vegetation establishment are critical elements in providing effective on-site erosion control and stabilizing a construction site. Disturbed areas exposed for extended periods without any activity must be stabilized with mulches, temporary vegetation, permanent vegetation, or by other equivalent controls *(Pitt et al. 2007).* The initiation of stabilization within 14 days is required whenever earth-disturbing activities have permanently or temporarily ceased on any portion of a site. Additionally, the NPDES CGP requires that operators provide evenly distributed and uniform vegetation that provides 70 percent or more of the coverage density that existed prior to commencing earth-disturbing activities *(USEPA 2012).*

Determining percent ground cover, or the percentage of the surface occupied by vegetation, can become a difficult, subjective characteristic to measure, and is typically visually estimated. Aerial infrared photographs can be used to calculate percent vegetation cover and density achieved. Methods for determining vegetation indices, particularly the normalized difference vegetation index (NDVI) have been applied to a wide variety of remote sensing vegetation studies. Indices are recorded by measuring infrared reflectance of vegetation, which can signal vegetative species, and even plant health and stress based on measured reflectance bands *(Shank 2008)*. Vegetative indices, which have historically been acquired from satellite or airplane based sensors, can be captured using UAVs operating at low altitudes. Vegetative establishment indices will help identify areas in a construction site that are exposed and in need of reseeding or nourishing to minimize the risk of erosion.

5.3 RESEARCH OBJECTIVES

The purpose of this study was to identify and evaluate the potential applications where the use of UAV systems can enhance site inspections of ESC practices and monitor project progression over time. A literature review is discussed and a case study is presented in which a UAV system was used to capture data from an active residential land development construction site over a period of four months.

5.4 METHODOLOGY

A proof of principle study was conducted to investigate the potential applications of UAV technology. A 25 acre (10.1 ha) residential development construction site located in Auburn, Alabama was selected as the study site. Observations spanned the majority of the land grading phase of construction. This construction site was selected for analysis because its topographic characteristics are similar to roadway construction sites, and due to the site's proximity to environmentally sensitive areas. The site discharges into an unnamed tributary along the southern edge of the development. Approximately 50 to 75% of the project area was disturbed throughout the duration of the study. A low to moderate level of poorly implemented and maintained ESC practices were applied to the site.

5.4.1 UNMANNED AERIAL VEHICLE

To investigate the capability of employing UAV technology in evaluating ESC practices, a DJI Phantom 2 Vision^{TM} was acquired for the study. While a multitude of UAVs are commercially available, the DJI Phantom 2 Vision is a low cost consumer grade quadcopter designed for amateur photographers. This particular UAV uses global positioning systems (GPS) to assist the operator in flying. This system creates a user-friendly flight operation that is easy and quick to learn. In addition, the GPS navigation allows the UAV to return to its take-off location and automatically land when remote control connection is lost, or when the batteries are depleted. A downloadable application allows the quadcopter to be controlled with the aid of a digital device (i.e., smartphone or tablet). In addition, a flight plan using pre-programed waypoints for the UAV to autonomously follow can be set using the available application. Video 5.1 demonstrates a UAV following established waypoints and capturing images for post-processing.

Video 5.1 UAV following Waypoint Flight Plan.

The UAV has a built in GPS enabled camera capable of taking high resolution photographs and videos, streaming live field of view footage, location, and battery life to the digital device wirelessly during flight. Note that there are numerous UAV options available. The DJI Phantom 2 Vision was selected for this research to demonstrate the utility of the technology and does not imply a product endorsement by Auburn University or the Transportation Research Board. The complete technical specifications for the DJI Phantom 2 Vision are listed in Table 5.1.

Table 5.1 Phantom Vision 2 Technical Specifications *(DJI Innovations 2014)*

MSRP	$1,019	**Max Flight Speed**	33.6 mi/hr (15 m/s)
Load Capacity	3.09 lb (1.40 kg)	**Max Vertical Speed**	13.4 mi/hr (6 m/s)
Weight	2.56 lb (1.16 kg)	**Engines**	4 brushless
Diagonal Length	13.8 in (350 mm)	**Camera Resolution**	14 MP
Operation Range	984 ft (300 m)	**Video Resolution**	1080/30p or 1080/60i
Flight Plan Input	Digital Device App.	**Gimbal Tilt Range**	0-60 deg.
Flight Range	25 min	**Battery**	5,200 mAh LiPo

The DJI Phantom Vision 2 quadcopter was used to conduct a proof-of-principle study over an active residential construction site. Six total flights were conducted over the course of four months. Flights typically followed a period of major rainfall events. High resolution images were captured using the UAV's built in 14 megapixel camera. The quadcopter was flown at an elevation of approximately 150 ft (45.7 m) during all flights. The elevation was maintained by providing manual adjustments from the operator. Images were captured with approximately 70% overlap. UAV operation was limited within unregulated Federal Aviation Administration (FAA) Class G airspace at all times to conform to governing regulations. All flights were performed during daylight hours, with favorable weather and wind conditions, and in an environment closed to the general public. Special consideration was taken to steer clear of all overhead obstructions, manned aircrafts, individuals, and wildlife. Table 5.2 provides a precipitation log for major storm events occurring in Auburn, AL during the duration of the study.

Table 5.2 Auburn, AL Major [A] Precipitation Events and UAV Flights

Date	Precipitation	Date	Precipitation
3/8/14 - Flight #1		4/29/14	1.12 in. (2.84 cm)
3/11/14	0.38 in. (0.96 cm)	**5/01/14 - Flight #5**	
3/16/14	2.33 in. (5.92 cm)	5/09/14	0.59 in. (1.50 cm)
3/23/14	0.29in. (0.74 cm)	5/10/14	0.30 in. (0.76 cm)
3/30/14 - Flight #2		5/14/14	1.53 in. (3.89 cm)
4/06/14	2.01 in. (5.11 cm)	5/28/14	0.28 in. (0.71 cm)
4/07/14	2.64 in. (6.71 cm)	6/06/14	0.44 in. (1.12 cm)
4/10/14 - Flight #3		6/10/14	0.31 in. (0.79 cm)
4/14/14	1.48 in. (3.76 cm)	6/11/14	0.91 in. (2.31 cm)
4/15/14	0.25 in. (0.64 cm)	6/23/14	0.33 in. (0.84 cm)
4/18/14	2.51 in. (6.38 cm)	6/30/14	0.59 in. (1.42 cm)
4/20/14 - Flight #4		**6/30/14 - Flight #6**	
total precipitation [B] within study period: 21.78 in. (55.32 cm)			

Notes [A] storm events exceeding 0.25 in. (0.64 cm)
[B] between 3/11/14 through 6/30/14, including all minor rain events not tabulated

The UAV flights were followed by conventional site inspections on-foot and additional photographs were taken providing a ground perspective of various site areas investigated. The aerial photos taken through the proof-of-principle analyses were post-processed using Agisoft PhotoScan Pro™ software, which allowed for a detailed photogrammetric analysis.

5.4.2 GROUND CONTROL POINTS

Ground control points were established on-site to create visual points to tie into the photogrammetric process. Ground control points are object points that are represented in aerial imagery from which three-dimensional object coordinates (i.e., x, y, and z) are known *(Linder 2009)*. Control points included sewer and stormwater manhole covers, water main valve covers, and visual reference aids flagged onsite. A total of 42 ground control points spread throughout the site were recorded with the use of a robotic total station. Existing reference points created by land surveyors were used to determine true control point coordinates within the 1983 Alabama State Plane East geographic coordinate system.

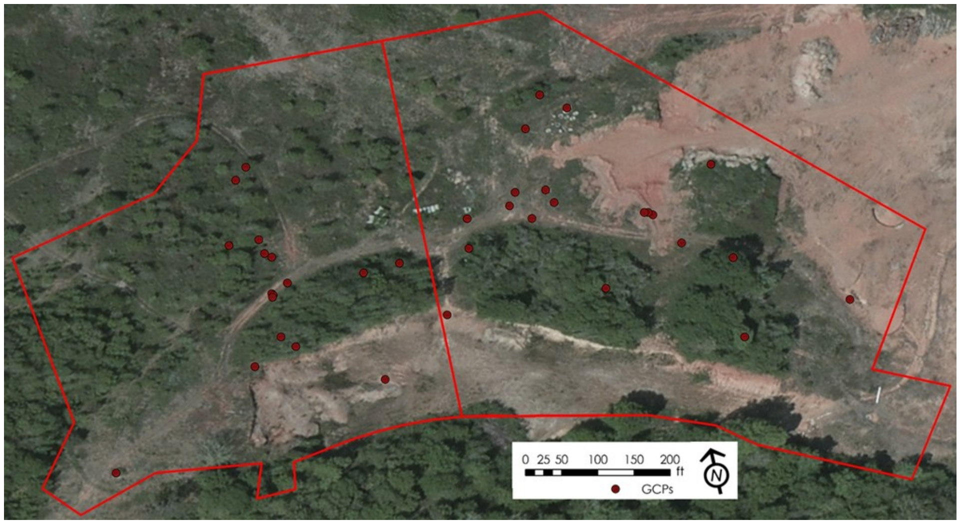
5.5 RESULTS

The results of this study have been categorized into the following sections: (1) construction stormwater site inspections, (2) tracking project progression, and (3) digital elevation models. The following sections will discuss our findings and the applicability of a UAV in enhancing both construction site stormwater inspections and the monitoring of construction progress over the course of a project's construction timeline.

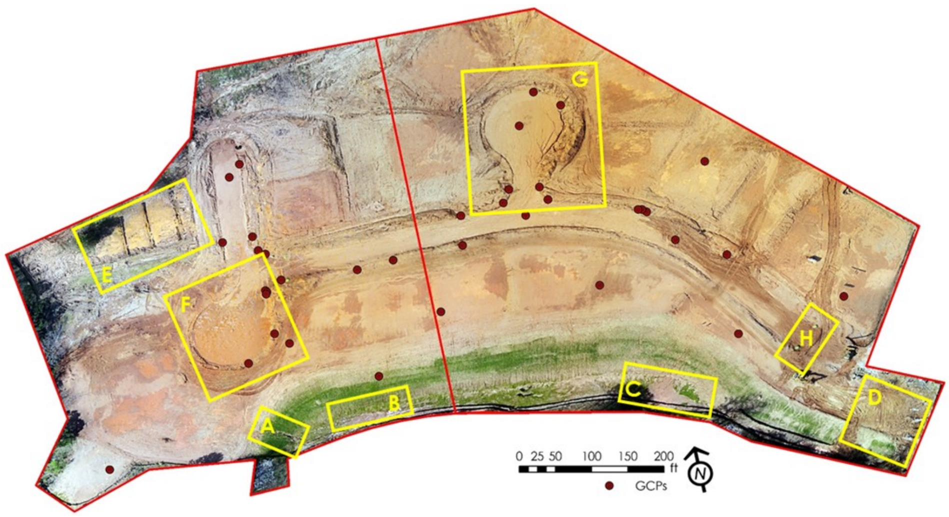
5.5.1 CONSTRUCTION SITE STORMWATER INSPECTIONS

One major advantage of using aerial imagery to supplement inspections, is the unique synoptic perspective that is generated. Figure 5.1(a) through (c) provide aerial images of the site under the following site conditions: predevelopment, partial development, and post development. Figure 5.1(a) provides a satellite aerial image obtained from Microsoft Bing™ illustrating predevelopment conditions prior to the onset of major land grading activities. The red points overlaid on Figure 5.1 (a) through (c) are the established ground control points providing exact x, y, and z coordinates. Figure 5.1(b) provides a project site mosaic created using photogrammetry software to mesh 69 aerial images taken during a UAV site inspection conducted on April 10, 2014. From Figure 5.1(b), it is easily apparent as to which areas are in need of further investigation and corrective action. A large gully is discernable on a steep slope in Region A. Region B highlights an area of sedimentation and Region C identifies a large amount of sediment deposited in a downslope area adjacent to site perimeter controls that require corrective action (i.e. maintenance) by the contractor. The high resolution mosaic photo also depicts hundreds of rills along the southern embankment resulting in large sediment yields. An advantage noted in this study was the ability for an inspector to identify the locations where runoff concentrates to the mouth of the rill formations. An inspector using UAV imagery can pinpoint problem locations and recommend to the contractor to install an appropriate slope drain, diversion, or interception practice to prevent further erosion along the slope. Other site features identified in the mosaic illustrated in Figure 5.1(b) include the site construction entrance (Region D), sediment basin (Region E), cul-de-sacs (Region F and G), and two storm drain inlets (Figure H). Video 5.2 captures a summary construction site, highlighting key elements and features identified in aerial imagery.

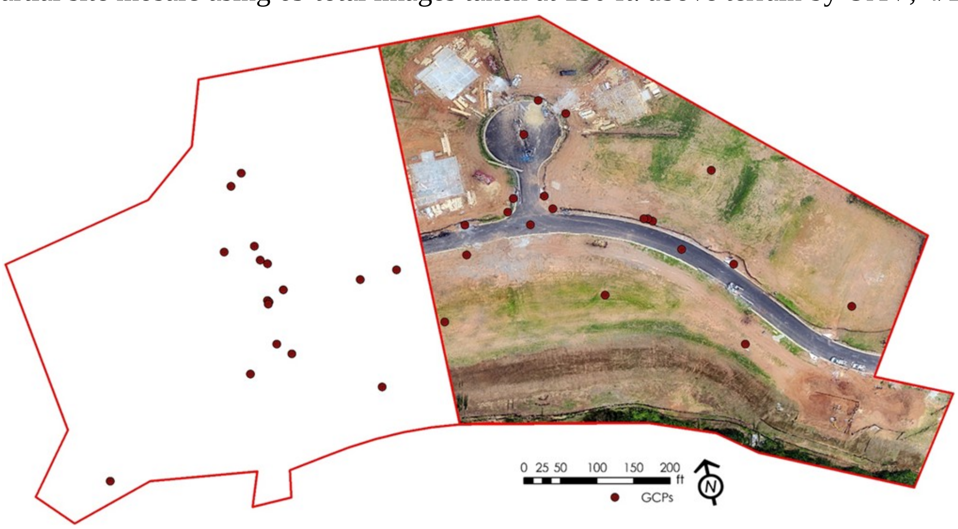
Video 5.2 Inspection of Construction Site Activities.



(a) satellite imagery of pre-development site condition *(Microsoft Bing Satelite Imagery 2010)*



(b) partial site mosaic using 69 total images taken at 150 ft. above terrain by UAV, 4/10/14



(c) partial site mosaic using 45 total images taken at 150 ft. above terrain by UAV, 6/30/14

Figure 5.1 Developed Aerial Project Site Mosaics.

These mosaics convey a true and scaled representation of the entire project site. All major features of the site are available on one image that allows a user to easily point out components or areas of concern. The scaled mosaic allows for length and area measurements to quantify various parameters (i.e. rill and gully lengths, project perimeter lengths, stabilized vs. unstabilized areas, etc.). These measurements can be used to determine material quantities required to protect or stabilize an area (i.e. seed and mulch quantities, perimeter control lengths, etc.) to remain in environmental compliance.

Upon completion of the aerial inspection, the researchers proceeded in performing a traditional inspection by walking the entire site and taking ground level photographs with a digital camera. Figure 5.2 provides a comparison of the aerial vantage point and conventional ground inspection vantage point on several problem areas identified within the study area.

Advantages in aerial photographs are apparent in the perspective comparisons. The aerial photographs shown in Figure 5.2(a), (c), and (e) were taken at the beginning of the site inspection process. It was easy for the researchers to quickly identify problem areas onsite since the large gully, all the rills on the hill slope, and the plumes of sedimentation were readily apparent from the aerial photographs. Detailed inspections of these onsite areas were conducted on-foot and the ground perspective pictures, coupled with the aerial images further detail the magnitude of the identified problems. Figure 5.2(a) is an aerial photograph taken of a large gully formation on a steep embankment. Compared to the photo taken from the ground perspective, Figure 5.2(b), where only the base of the gully is depicted, the aerial photograph shows the entire formation allowing an inspector to identify both the source of the gully and the location of eroded material deposited downstream. Similarly, Figure 5.2(c) and (e) of the sedimentation areas shows the upstream runoff source and rill formations that are the source of the deposition. These features are not evident in the ground perspective photographs Figure 5.2(d) and (f).


(a) aerial view of large gully (Region A)


(b) ground view of large gully (Region A)


(c) aerial view of sediment deposition (Region B)


(d) ground view of deposition (Region B)


(e) aerial view of rills and sediment (Region C)


(f) ground view of rills and sediment (Region C)

Note: indicates vantage point location & direction for corresponding ground perspective photograph.

Figure 5.2 Comparison of Perspectives from Site Inspection Performed on 4/10/2014.

By holding a pre-established flight path at a constant elevation, photos taken during subsequent inspections can be easily compared to determine if corrective actions have been taken by the contractor. Figure 5.3(a) and (b) show attempts made by the contractor to mitigate deficiencies in ESC practices located in the southeastern corner of the site, Region D of Figure 5.1(b). Silt fence and hay bale ditch checks were added along a discharge channel as seen in Figure 5.3(b). The photos also show that mulching was applied to the surface of the embankment to help stabilize areas tracked by equipment. The addition of a slope drain is also evident, thereby minimizing stormwater runoff from flowing over the slope. Figure 5.3(c) and (d) depict similar silt fence and hay bale repairs made by the contractor to a large gully along the southwest edge of the site, Region A of Figure 5.1(b).

(a) offsite runoff issues (Region D), 4/10/14

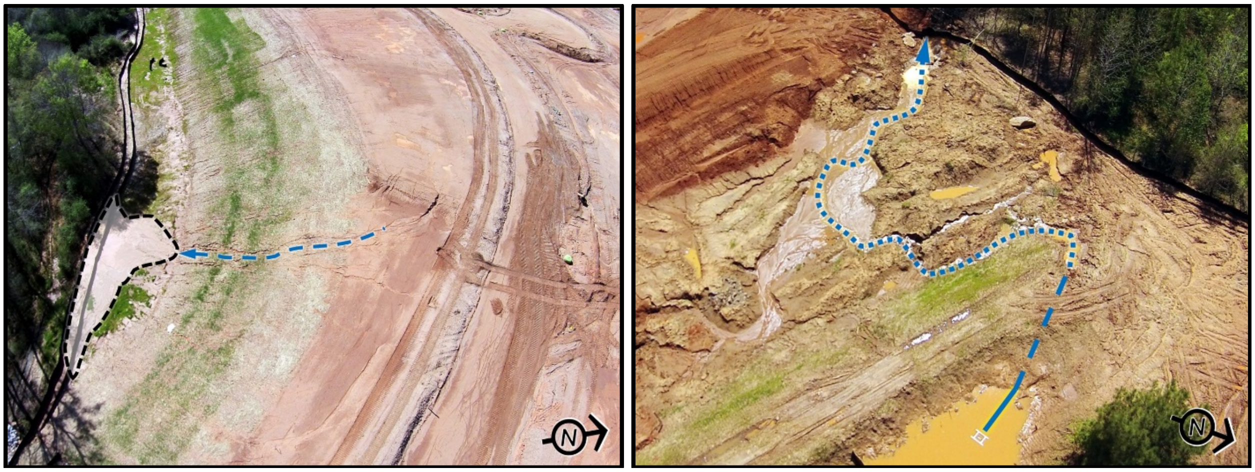
(b) corrective actions taken by contractor, 4/20/14

(c) gully formation (Region A), 4/10/14

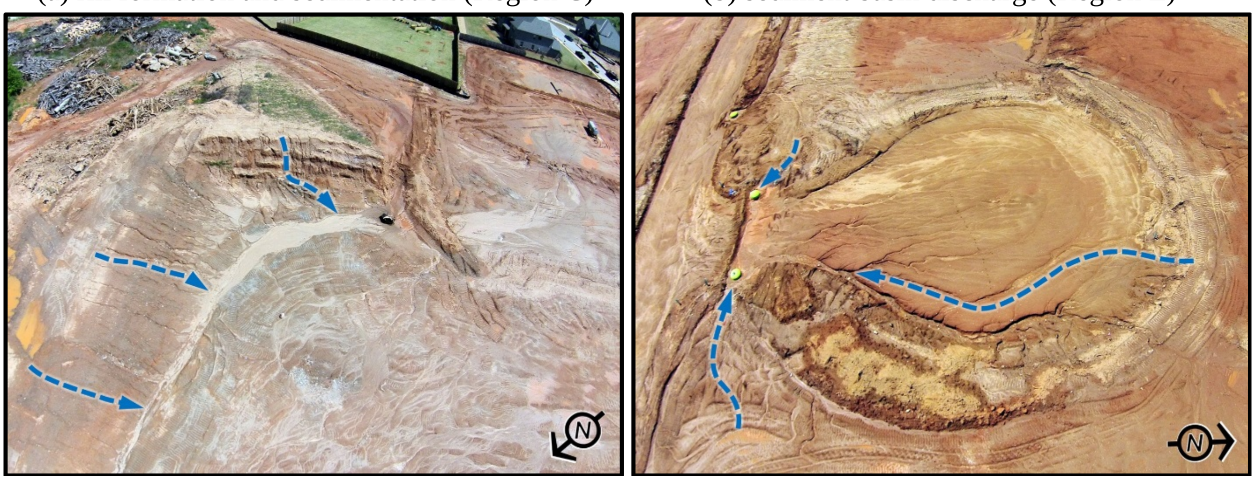
(d) corrective actions taken by contractor, 4/20/14

Figure 5.3 Aerial Comparison of Two Flight Dates.

Another advantage of using aerial imagery for inspections identified through the proof-of-principle study is the identification of stormwater flow paths that can be easily seen carved into the terrain. Figure 5.4(a) through (d) show various areas of the project with major, eroded flow paths illustrated. Figure 5.4(a) shows the conveyance of stormwater onsite, corresponding to Region C of Figure 5.1(b), which caused a rill to form in the slope. The rill resulted in a large amount of sedimentation accumulating against the installed silt fence perimeter control at the toe of the slope. Figure 5.4(b) illustrates the routing of the discharge path from the outlet of a sediment basin skimmer, which corresponds to Region E depicted in Figure 5.1(b). From this aerial vantage point, the inspector can clearly identify that the design has been poorly implemented by the contractor, forcing discharged water from the sediment basin back on-site through un-stabilized terrain, and forcing discharge through a perimeter silt fence. Figure 5.4(c) and (d) depict how simply flow paths are identified along steep slopes, and near drop inlets.



(a) rill formation and sedimentation (Region C) (b) sediment basin discharge (Region E)



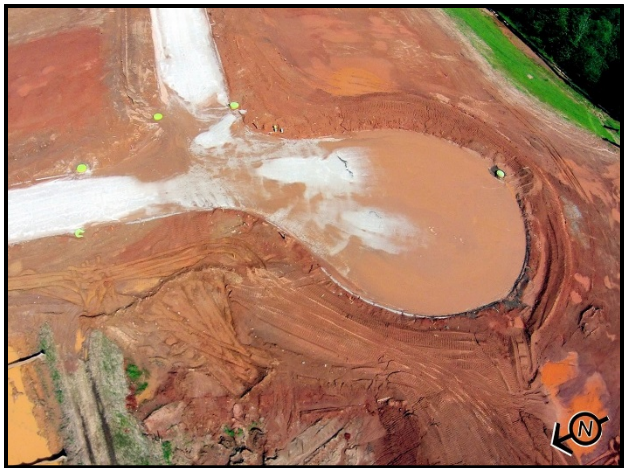
(c) rill and gully formations along slope (d) stormwater flow paths near inlets (Region G)

Note: major flow lines are illustrated on each figure with dotted arrows.

Figure 5.4 Stormwater Routing Aerial Vantage Points, 4/20/14.

In each of these cases, the contractor should have implemented various runoff conveyance measures (i.e., diversions, downslope drains, swales, and outlet protection) in an effort to control stormwater related runoff onsite and resulting polluted discharges offsite. Runoff conveyance measures would have conveyed stormwater away from sensitive site areas while also directing stormwater to more controlled areas of the site.

Clearly, identification of stormwater runoff routes can help identify which areas within the construction site are most susceptible to erosion and sedimentation. Figure 5.5(a) and (b) provide aerial photos of sedimentation following heavy rain events. Not only do these photos convey to an inspector where to conduct maintenance, but the documentation further serves to identify where improved ESC s are needed.



(a) sedimentation due to flooding (Region F)

(b) sedimentation near inlets (Region H)

Figure 5.5 Sedimentation on Roadway Base, 5/01/14.

These aerial perspective photographs show how sediment-laden runoff was conveyed onto the roadway base. The photographs depict how the contractor should improve the sediment control practices by providing perimeter controls between the stabilized and un-stabilized areas. Furthermore, by excavating sumps for the inlet protection practices to detain stormwater, roadway flooding could have been avoided.

5.5.2 TRACKING PROJECT PROGRESSION

Aerial images can be taken at various angles and altitudes to portray various stages of construction. The UAV provides flexibility in its capabilities to capture entire project images that provide a detailed documentation of project progression at various points in time. Figure 5.6(a) through (d) provide aerial photographs of the project site over the course of the UAV study period, documenting various stages of project progression. From these figures, it is apparent to the inspector or others involved in the construction operation which tasks have been completed by a particular date. For example, Figure 5.6(a) provides an aerial image illustrating the progression of land grading and the establishment of the initial roadway grade. Figure 5.6(b) illustrates the status of the project 22 days after initial roadway grading and after a major rainfall event. It is evident that the contractor made little stabilization progress during this time period. Since the site was inactive for more than 14 days, the contractor should have initiated stabilization practices in an effort to minimize erosion on various areas of the site. Figure 5.6(c) shows installation of the roadway base material 61 days after the initial grading activities documented on March 8, 2014. Lastly, Figure 5.6(d) shows the installation of curb, gutter, and base pavement being completed and the onset of vertical construction by June 30, 2014.

(a) initial roadway grading, 3/08/14

(b) rill erosion following heavy rainfall events, 3/30/14

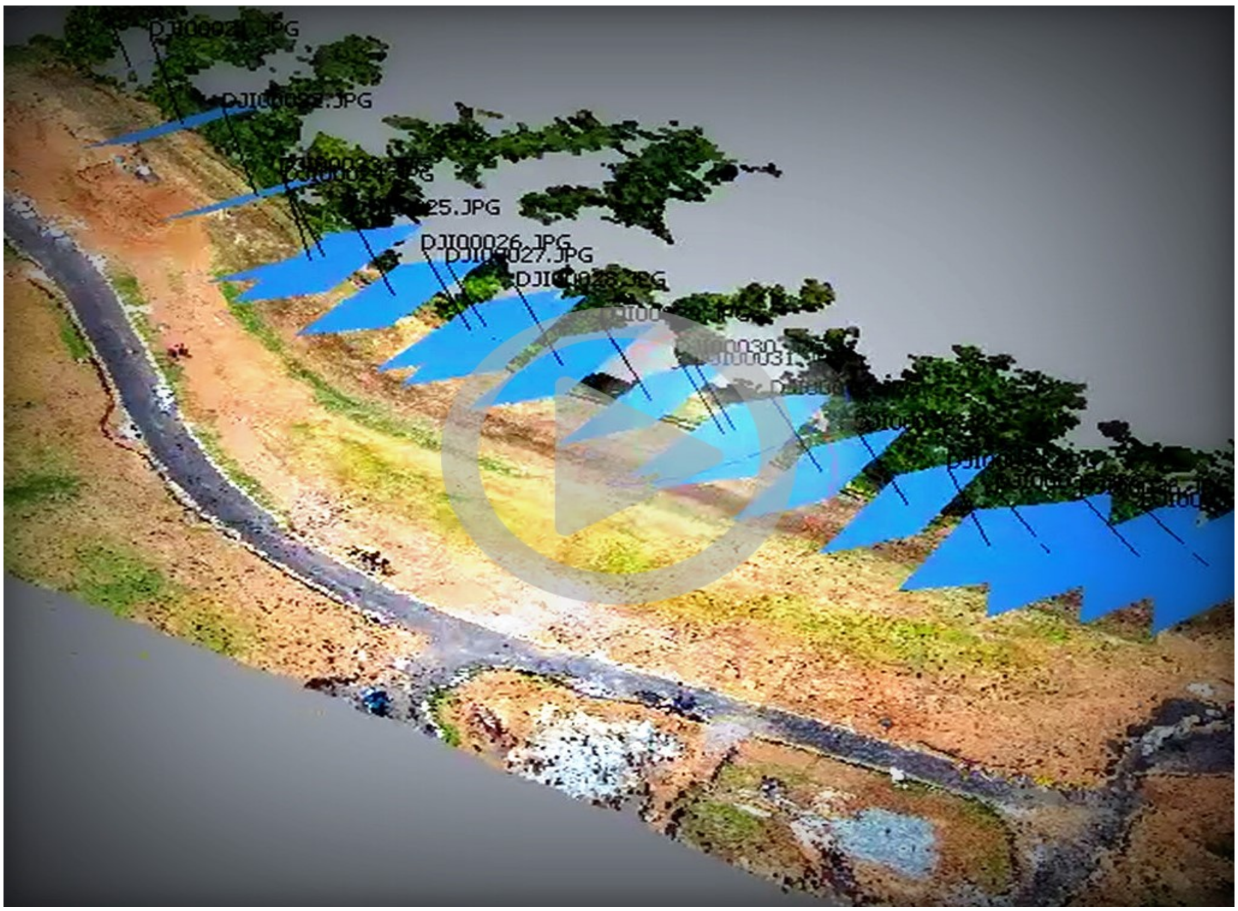
(c) roadway base layer installed, 5/01/14

(d) roadway, curb & gutter, and commencement of vertical construction phase, 6/30/14

Figure 5.6 Project Documentation / Progression Aerials.

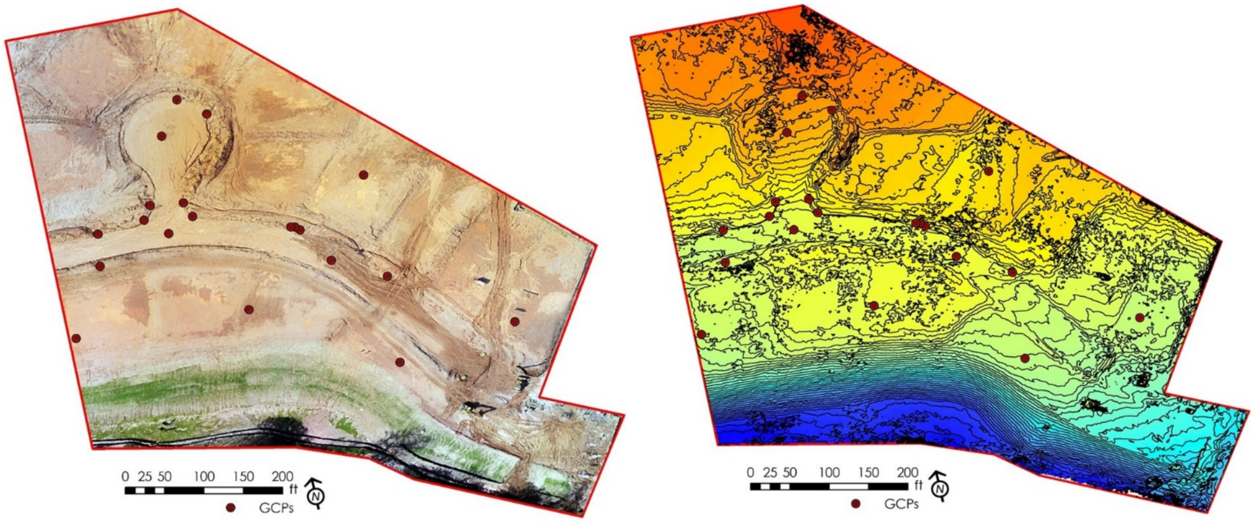
5.5.3 Digital Elevation Models

Post-processing photogrammetry software has the capability of automatically constructing three dimensional textured models using digital photos of the site. Surface meshes can be exported as a DEM for further topographic analysis in GIS software. Video 5.3 demonstrates the process of stitching images into an orthomosaic for conversion into a DEM.



Video 5.3 Development of DEM on Photogrammetry Software.

Figure 5.7 shows a region of the site that was converted to a DEM. Contours were created on Esri ArcMap to further characterize the slopes. With the addition of ground control points, highly accurate DEMs can be created and analyzed between flight dates to measure volumes of erosion and sedimentation that may have occurred on-site.



(a) partial site mosaic (b) DEM generated from site mosaic

Figure 5.7 DEM Development from Partial Site Mosaic, 4/10/14.

The aerial images developed from UAV site inspections can also be used to develop a project log and quantify material movement during large-earthwork operations in major cut and fill areas. The management of stockpiles for use at a later stage during the construction effort could also be tracked and managed accordingly. In fact, a major new use of UAV photogrammetric technology is in the assessment of stockpile volumes for a variety of manufacturing industries.

5.6 CONCLUSIONS

This work has identified applications in the performance of site inspections to monitor ESC practices and stormwater discharges. In addition, project progression tracking can be enhanced by use of UAVs. This project has shown some of the applicable attributes that UAVs offer regulatory agencies, departments of transportation, and contractors for monitoring construction site permitted discharges. UAVs offer a better resolution and repeatability for data collection than that afforded by satellite or manned aircraft. Flow paths, erosion and corresponding sediment sources, protocols for ESC implementations, vegetative establishment, earthwork calculations, inspections, and project progress logs can all be enhanced using technology provided by UAVs. Post-data processing applications can be used to create detailed site mosaics and DEMs. Further GIS analysis with a highly detailed DEM can divulge areas susceptible to increased erosion risk and be used to model vulnerable areas on future project sites. UAV technology not only revolutionizes the construction site inspection process, but also streamlines it, thereby reducing required inspection time, which may lead to reduced overall costs. The use of UAVs in the construction field will provide owners, inspectors, and contractors with greater technology and tools to help minimize construction related environmental impacts to receiving water bodies. The safe and efficient operation of UAVs will require a dedicated operator with appropriate training and practice. Additional work is needed to determine the associated costs of training. Future research is needed to produce methods for seamlessly collecting and analyzing the large data sets collected from UAVs. Further research should also focus on how to determine practical accuracy expectations from low altitude photogrammetry analyses.

CHAPTER SIX:
TRAINING AND OUTREACH

6.1 INTRODUCTION

Since the enactment of construction stormwater regulations, several organizations and associations have formed to provide related research, testing, and continuing educational resources for the construction industry. One such entity, the International Erosion Control Association (IECA), was formed in 1972 with the intent to collect and disseminate information, encourage industry research, promote professional skills and education, and develop industry standards. Today, IECA hosts a national conference, several regional conferences, field days, and webinars. The IECA University Partners Program is an initiative focused on involving research institutions and young professionals within the industry. ESC certification programs, such as those offered by EnviroCert International, Inc. serve to recognize professionals who have demonstrated qualifications based on education, experience, and examination. ASTM International and the American Association of State Highway and Transportation Officials (AASHTO) maintains standard test methods and procedures for evaluating performance of ESC technologies for the industry.

Traditionally, ESC practices are designed based on practical experience and “rules of thumb”, rather than on theory or research results. These “rules of thumb” have governed the selection and installation of many ESC practices currently employed in the industry. Practitioners refer to these design recommendations or requirements from various state ESC manuals, such as the Alabama Handbook for Erosion Control, Sediment Control and Stormwater Management on Construction Sites and Urban Areas published by the Alabama Soil and Water Conservation Committee (AL-SWCC) *(AL-SWCC 2014).* Through the results of recent research efforts, ESC designs are transitioning towards hydraulic and hydrologic based designs to better fit to site parameters and improve the performance of practices *(Donald et al. 2016; Perez et al. 2016[1]; 2016[2]).*

While educational and research resources for ESC designs have increased in availability, a need still exists to fill the gaps between the knowledge base developed through research and the needs of practitioners. Technology Transfer (T^2) provides the platform to disseminate knowledge, practice, and techniques with industry professionals *(Hood et al. 2014).*

6.2 ESC TRAINING IN ALABAMA

Several state environmental protection agencies maintain construction stormwater education and certification programs. The Alabama Department of Environmental Management (ADEM) requires Qualified Credential Inspector (QCI) certification for stormwater inspectors working in the state. Currently, an eight-hour QCI course is offered by two organizations: Thompson Engineering, and the Home Builders Association of Alabama. Inspectors are required annually to maintain their QCI status by completing a four-hour yearly refresher course.

In addition to formal QCI instruction, an annual seminar is hosted by the Alabama ESC Partnership, which offers the Clear Water Alabama Seminar and Field Day. The seminar provides an overview of changes in state regulatory requirements, new innovative practices and products, and research updates. The two-day event includes eight hours of presentations from industry experts, followed by an eight-hour field day consisting of site visits to various local construction sites to observe field installations and demonstrations.

ALDOT's statewide NPDES general permit for construction discharge and its MS4 regulatory permit require a measure of training and public education. ALDOT chooses to exceed these minimum requirements by investing heavily in internal and external learning through funding and efforts in training, research, and other contributions to the broader construction stormwater knowledge base. While these programs are effective in providing regulatory and design information, hands-on training is crucial. Hands-on training provides the means to disseminate practical field application of ESC practices and improvements effectively to industry (i.e., regulators, designers, inspectors, and installers).

Note: descriptions of stations A through P are provided below.

Figure 6.1 Aerial Photo of the AU-ESCTF and Training Stations.

6.3 AU-ESCTF FIELD DAYS

Since 2014, the AU-ESCTF has hosted four separate training events at the research facility: (A) Innovative ESC Research and Field Day, May 2014; (B) Innovative ESC Field Day, November 2014; (C) ESC Hands-On Installer Training, November 2015; and (D) Innovative ESC Field Day, November 2015. All events were hosted through the Alabama T^2 Center at Auburn University as part of the Local Technical Assistance Program (LTAP). The Alabama T^2 Center was established at Auburn University in 1983 and is supported by the Federal Highway Administration (FHWA) and ALDOT.

The primary goal of these workshops is to provide industry participants exposure to innovative research being performed on commonly employed ESC practices in both horizontal and vertical construction. This goal aligns well with the mission of the Alabama T^2 Center (and LTAP centers in general) to bring research and technology innovations to state and local transportation agencies in a cost-effective manner. Typical workshops presented by the Alabama T^2 Center are seminars held in classroom settings. However, the center has been interested in diversifying the types of workshops it offers as well as the modes of learning used. The collaboration with the AU-ESCTF to host hands-on, outdoor workshops has supported in this diversification effort. Studies of best practices on implementation of research results have noted that no single type of activity is the best solution for accelerating the use of research results or innovations *(Harder 2014)*. Therefore, a range of methods of technology transfer may facilitate the adoption of innovative problem-solving strategies into practice. The series of continuing education events held by AU-ESCTF and the Alabama T^2 Center include classroom seminar-style training, outdoor demonstrations of ESC practices, and hands-on opportunities for workshop participants to install and see installed practices.

The Alabama T^2 Center advertises events through their website, emails, and mailers. In addition, the AU-ESCTF website provides advertisements and links to the Alabama T^2 Center registration pages. The target audience for these field days include:

- technical staff or end users within DOTs;
- local agencies seeking to implement new technology that has been used on the state level;

- road builders, designers, land use planners, and engineers;
- county, city, and university MS4 officials, engineers, and environmental management consultants; and
- the environmental community and citizens interested in learning about ESC for construction sites.

The AU-ESCTF field days are intended to be innovation adoption processes, meaning the technology has been proven to be feasible, is available, and ready for implementation. Demonstrations show course participants the difference between traditional versus innovative installation techniques and the enhanced performance that is obtained by modifying the standard installation. Demonstrations have been identified to be a successful strategy for facilitating T^2, as they display the merits of the improved ESC practices *(Hood et al. 2014)*.

By sharing knowledge gained through research, industry participants are better prepared to achieve environmental compliance. In addition, participants gain the needed knowledge in governing compliance regulations, leadership tactics, and hands-on design and implementation tools to provide efficient, effective, and improved ESC practices.

6.4 DEMONSTRATION STATIONS

During the field days, various ESC practices are installed at the AU-ESCTF in several locations (or stations) to facilitate the instruction and demonstration activities. The locations of individual stations at the facility are shown in Figure 6.1. A description of each station is provided below.

6.4.1 STATION A: HYDROSEEDING

An area of exposed soil is used to provide demonstrations of a typical hydroseeding operation. Discussion on the type of seeding, germination, mulch, application rates, and application techniques are provided during events. Figure 6.2(a) shows a course participant applying hydromulch.

6.4.2 STATION B: CONSTRUCTION EXIT PAD AND HOUSEKEEPING

This station, illustrated in Figure 6.2(b) demonstrates a typical construction exit pad and an explanation of its construction specifications and function in removing soil from vehicle tires are discussed. This station also includes the demonstration of manufactured products equivalent to a typical construction exit pad.

6.4.3 STATION C: STOCKPILE MANAGEMENT

The stockpile management station, allows for the demonstration of various techniques in providing cover and protection to soil stockpiles to prevent erosion, sediment transport, and creating a source of sediment discharge.

6.4.4 STATION D: SEDIMENT BARRIERS

Through an ongoing sediment barrier research project, this station provides the ability to demonstrate the sediment retention capabilities of various practices and products used as perimeter controls. A sediment barrier is installed prior to the field day and a demonstration is performed, Figure 6.2(c), to exhibit flow impounding behind the practice.

6.4.5 STATION E: EROSION CONTROL BLANKETS

A bare slope is prepared prior to the field day to provide an erosion control blanket (ECB) demonstration. A description of the ECB's purpose and practice in protecting earthen slopes from rainfall induced impact and encouraging vegetative establishment is given. The station includes a demonstration of proper installation techniques including: ground preparation, seed and fertilizer spreading, trenching of the ECB at the top of the slope, unrolling of blanket, overlapping requirements, and stapling patterns to secure blanket to ground. A demonstration is typically performed using simulated sheet flow to compare erosivity of protected ground to a bare slope. Figure 6.2(d) shows the installation of an ECB during a demonstration.

6.4.6 STATION F: DITCH CHECK PRACTICES

A description of ditch check practices, purpose, and proper installation techniques for reducing runoff velocity and erosive potential of channelized flows is provided using a 350 ft (107 m) channel. Up to eight ditch check practices are installed in the channel. Vendor participants are invited to install products the day prior to the field day. Channelized flows are simulated in the channel to provide participants with demonstrations on impoundment capabilities and common failure modes of the installed practices and products. Featured installations follow testing results published by AU-ESCTF researchers *(Donald et al. 2013; Donald et al. 2016; Donald et al. 2015)*. Figure 2(e) shows the ditch check channel during flow simulation.

6.4.7 STATION G: CHANNELIZED FLOW

The AU-ESCTF has three 40 ft (12.2 m) channels dedicated to channelized flow testing of ditch check and inlet protection practices. These channels are used for research and product evaluation. During field days, practices are installed within channels to demonstrate the research apparatus and the performance of devices under simulated, real world, flow conditions. Figure 6.2(f) shows an inlet protection practice subjected to flow in one of the AU-ESCTF research channels.

6.4.8 STATION H: FLOATING SURFACE SKIMMER

The facility has two surface floating skimmers, one installed in the facility's sediment basin and the other in the research sediment basin. These skimmers are used during field days to demonstrate proper installation, maintenance, and function of the dewatering practices in basins.

6.4.9 STATION I: FLOATING TURBIDITY BARRIER

A floating turbidity barrier installed in the lower retention pond serves as a means to show the practice's purpose in limiting the spread of pollutants to a protected area within a water body. The proper installation technique and different barrier types are discussed.

6.4.10 STATION J: SILT FENCE INSTALLATION

Various silt fence types and installation techniques are shown at the silt fence installation station. Participants are educated on differences between woven and non-woven silt fence geotextile, as well as the different approved configurations for ALDOT and AL-SWCC specifications. Fences are installed during the field day to emphasize proper trenching, backfill, and post spacing requirements. In addition to the traditional manual installation, a tractor implement is used to demonstrate the installation of wire backed silt fence using a slicing technique. Figure 6.2(g) shows the silt fence installation demonstration station.

6.4.11 STATION K: PERIMETER CONTROL AND SLOPE INTERRUPTERS

Two silt fence installation configurations are showcased and participants are shown how to properly install a "smile" configuration and "j-hooks" commonly used in areas with longitudinal slopes. This area is also used to install and describe slope interrupters, Figure 6.2(h).

6.4.12 Station L: Slope Drains, Outlet Control, and Level Spreader

At this station, the purpose and installation techniques for slope drains are discussed. Participants are shown how to properly funnel stormwater into slope drains as well as proper drain installation and anchoring techniques. The difference between single and double wall drains is explained as well as flocculent introduction techniques at the drain inlet. Energy dissipation measures, such as upward turned drains, a rip-rap outlet, and a sandbag spillway are demonstrated at the drain outlet with simulated flows. A level spreader is also installed at one of the drain outlets to demonstrate the practice's purpose in detaining stormwater and discharging flow in sheet-flow conditions. Figure 6.2(i) provides an illustration of this station.

6.4.13 Station M: Sediment Basin

The AU-ESCTF has a 56 by 28 ft (17 by 8.5 m) sediment basin dedicated to large-scale research efforts. The basin is part of an on-going research project focused on improving the standard configuration through the use of high-rate lamella settlers *(Perez et al. 2016)*. The basin is used during field days to demonstrate how the sediment control feature functions on a construction site. Flows are simulated through the practice that allows participants to observe how the features within the basin function to remove suspended particles. Common installation errors, design recommendations, and current research findings are shared. The sediment basin station is shown in Figure 6.2(j).

(a) Station A: hydroseeding

(b) Station B: construction exit pad

(c) Station D: sediment barriers

(d) Station E: erosion control blankets

(e) Station F: ditch check practices

(f) Station G: channelized flow demonstration

(g) Station J: silt fence installation

(h) Station K: slope interrupters

(i) Station L: slope drains

(j) Station M: sediment basin

Figure 6.2 Demonstration Stations at the AU-ESCTF.

6.4.14 Station N: Inlet Protection Practices

Six concrete riser structures are dedicated to provide mock storm drain inlets. Inlet protection practices are installed around these devices to showcase improved practices that have emanated from an inlet protection research study performed at the AU-ESCTF *(Perez et al. 2014; Perez et al. 2016)*. In addition to the non-proprietary practices, vendors are allowed to place their products in this area to show how they are installed in the field. Figure 6.3 shows the inlet protection practice installation area.

(a) development of demonstration area

(b) installed practices during field day

(c) participants during hand-on installer seminar

(d) demonstration during field day

Figure 6.3 Inlet Protection Practices Demonstration Station

6.4.15 Station O: Pipe Inlet Protection

Pipe inlet protection practices are installed in a small section of pipe to showcase their applicability and function in reducing runoff velocity upstream of culverts. Product vendors are allowed to demonstrate their products near this station to aid in demonstrating each proprietary products purpose, function, and uniqueness.

6.4.16 STATION P: MEETING AND BREAK AREA

A 40 by 75 ft (12.2 by 22.9 m) tent is installed and outfitted with tables and chairs to provide seating and a gathering area for instruction, vendor setup and interaction, and breaks. The vendor setup areas allow for product manufacturers to showcase innovative products and provide course participants with marketing materials as shown in Figure 4(c).

6.5 INNOVATIVE ESC RESEARCH SHOWCASE AND FIELD DAY

The first T2 event hosted by the AU-ESCTF was a two-day seminar held on May 29-30, 2014. This event introduced participants to the research being performed by various universities in the southeast, with emphasis on solving ESC problems in the construction sector. The training effort was divided into classroom and outdoor field instructional sessions. The classroom sessions were hosted at the Auburn University Hotel and Conference Center in Auburn, AL [Figure 4(a)] and included presentations on: (1) U.S. Environmental Protection Agency's perspective on environmental compliance, (2) environmental leadership, and (3) the latest findings from cutting-edge research being performed by Auburn University, North Carolina State University, and the University of Georgia, on effective ESC practice implementation. The field instructional session was held at the AU-ESCTF and provided attendees with a hands-on opportunity to: (1) learn proper installation techniques on various ESCs to achieve improved performance, (2) observe full-scale, channelized flow testing demonstrations, and (3) interact with vendors and manufacturers of current ESC products. Participants who completed this seminar received 1.20 continuing education units (CEUs).

This event was hosted in partnership with the IECA University Partners Program to facilitate their mission of providing regional training events. To advance the University Partners Program mission of young professional engagement, undergraduate and graduate students were invited free of charge to attend this training. In addition, Thompson Engineering partnered with the event by providing QCI refresher course credit for attendees that participate in their QCI training program.

To engage participants with industry tools and to help offset costs associated with hosting the event, product vendors were invited to participate as sponsors in the training event. In return, vendors were recognized for their participation (Figure 6.4 [b]); given a booth area to display product information (Figure 6.4 [c]); and had the opportunity to install their product on select areas of the facility, allowing them to effectively market their devices to the course participants (Figure 6.4[d]).

(a) seminar presentations

(b) sponsor recognition

(c) vendor interaction with participants

(d) vendor installed product demonstration

Figure 6.4 ESC Research & Field Day Education and Vendor Interaction.

6.6 INNOVATIVE ESC FIELD DAY

On November 3, 2014, a field day was hosted in collaboration with an ALDOT classroom-based training event for stormwater designers. The purpose of the field day was to reinforce design concepts learned by participants in the classroom component with demonstrations of ESC practice installations and overall performance. The primary goal of this field day was to provide exposure to designers with innovative research being performed on commonly employed ESC practices with hands-on field demonstrations. The field instructional session provided attendees with a hands-on opportunity to: (1) learn proper installation techniques on various ESCs to achieve improved performance, and (2) observe full-scale, channelized flow testing demonstrations. As with the first event, vendors were invited to participate in the educational program. Participants attending this seminar received 0.60 CEUs. Video 6.1 highlights various stations during the field day.

Video 6.1 November 3, 2014 Field Day Summary.

6.7 ESC HANDS-ON INSTALLER TRAINING

A one and half day training event was hosted on November 18 and 19, 2015. The focus of this event was on providing classroom and hands-on training geared for participants involved in the installation of construction site ESC practices. A half-day classroom component covered a wide variety of topics that were reinforced with field installations during the following, full-day field component. The field component required trainee participation to install ESC practices in a typical field setting and included channelized flow demonstrations to show the effectiveness of properly installed practices. The event was targeted at smaller groups of participants and involved a much higher and more active level of engagement. Participants gained knowledge learned from research experience in hands-on installation and implementation tools to provide efficient and effective ESCs. This installer training was followed by an innovative ESC field day, held on November 20, 2015 that was geared towards demonstrating various innovative ESC practices, installed participants of the installer training, to a wider audience. Participants attending these seminars received 0.90 and 0.60 CEUs, respectively.

6.8 PARTICIPANT DEMOGRAPHICS

Through the four offered trainings, 445 attendees have participated. Of the participants, 355 individual attendees participated of which 20% have attended multiple AU-ESCTF events. The average field day attendance is 134 participants. A summary of individual seminar demographics is presented in Table 6.1

Table 6.1 Registration Demographics

Event	Date	Attendees					Cost	CEUs
		ALDOT	Other Public [A]	Private [B]	Other [C]	Total		
A: Research Showcase & Field Day	May 29-30, 2014	36	24	60	31	151	$250	1.2
B: Field Day	Nov. 3, 2014	58	27	59	0	144	$150	0.6
C: Hands-On Installer Training	Nov. 18-19, 2015	31	6	7	0	44	$450	0.9
D: Field Day	Nov. 20, 2015	59	12	35	0	106	$150	0.6
Total		**184**	**68**	**162**	**31**	**445**	**-**	**3.3**

Notes: [A] includes state environmental agencies, local/municipality, university employees, etc.
[B] includes private consultants, engineers, scientists, etc.
[C] includes students and invited speakers (instructors not counted)

Figure 6.5 is a map showing the counties in which individual participants reside. This map represents all hosted field days, and indicates that the largest density of participants came from the Alabama counties of Baldwin, Jefferson, Lee, Mobile, and Montgomery. The data was obtained from registrants addresses used during the event registration process.

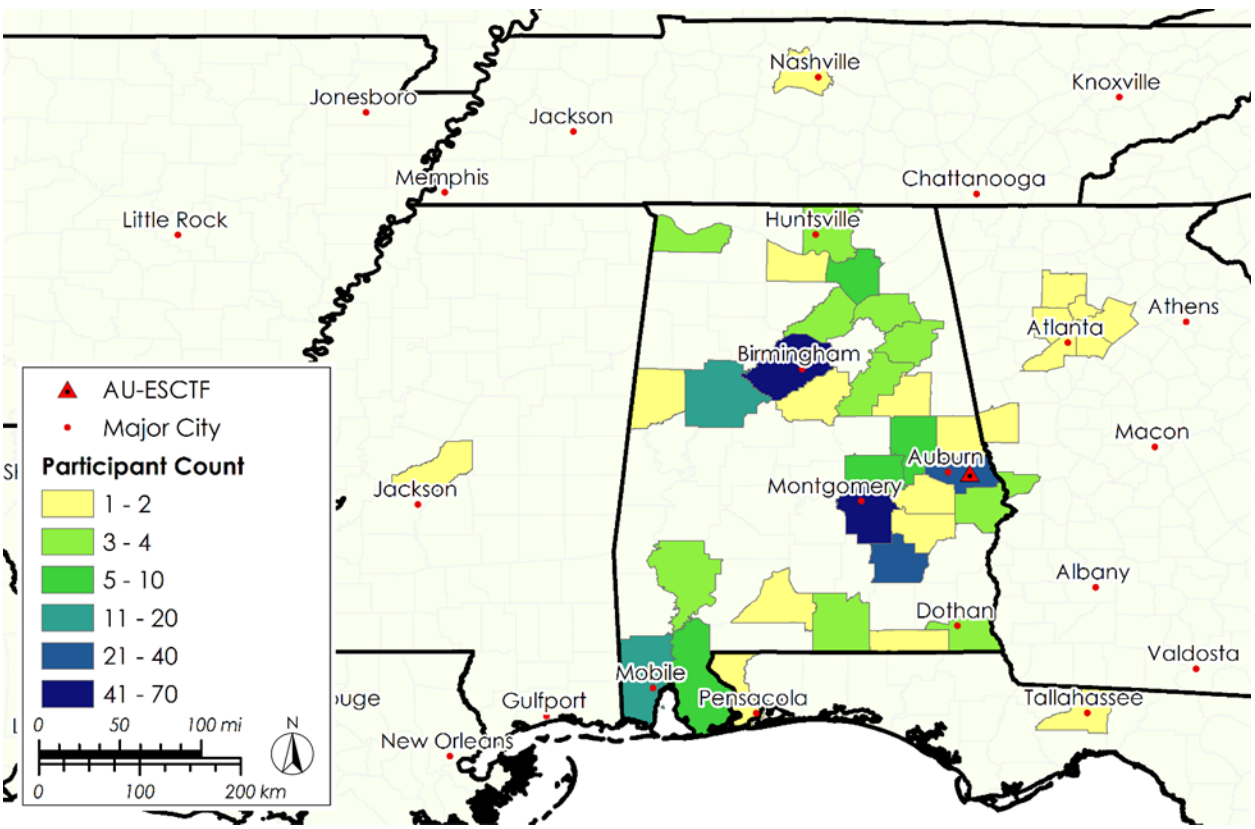


Figure 6.5 Distribution of Participant Registration Addresses.

6.9 ALDOT PERSPECTIVE

With the need for environmental stewardship becoming of upmost importance, DOT agencies across the country are embracing initiatives to promote and strengthen their environmental ethical responsibilities *(Venner 2003)*. ALDOT's environmental vision is for environmental responsibility to be an integrated culture of environmental consideration, stewardship, and advancement, which cultivates trust, enhancement, preservation, and compliance. ALDOT has decided that it must go beyond mere regulatory compliance in order to realize this vision. The primary components of the mission of the AU-ESCTF (research and development; product evaluation; and training) are helping ALDOT's vision to become reality in the area of construction stormwater management.

State transportation agencies that have embraced "environmental stewardship" have recognized the importance of the stakeholder community, which can help dictate whether public opinion and media review of a project are favorable and whether transportation objectives can be achieved *(Venner 2003)*. The work at AU-ESCTF is helping ALDOT achieve its regulatory requirements, and it is also evidence of action toward ALDOT's environmental goal and mantra of "Getting Better Every Day". Work at the facility has improved ALDOT design, construction, and maintenance practices; it has informed and improved ALDOT's standard drawings and specifications; and it has provided a forum where practitioners can see, first hand, how water and practices likely behave in a real-world setting. Perhaps, one of the most valuable outcomes of the research is a renewed realization and demonstration that challenging tradition and "rules of thumb" can lead to more effective and economical means of protecting Alabama waters.

An example of ALDOT implementation of AU-ESCTF research results is in the use of silt fence ditch checks with weirs along active construction sites. Figure 6.6(a) and (b) depict the installed practices along an active ALDOT construction project in Centerville, Alabama *(Donald et al. 2015).*

(a) series of silt fence ditch checks (b) silt fence weir installed in field

Figure 6.6 In-field Installation of Silt Fence Ditch Checks with Weirs.

6.10 CONCLUSIONS

Located in Opelika, Alabama, the AU-ESCTF serves as a center for research, product evaluation, and training. Over the last two years, the facility has hosted four successful training events used to disseminate research results to industry practitioners in an effort to close the gap between research and implementation.

To assess the quality of the seminars, surveys were distributed in paper format at the conclusion of each training event. Respondents are asked to provide a rating on a scale of 1 to5 (with 5 being the best) to a series of questions regarding individual components of the seminar including program content, instructor effectiveness, and course organization. A summary of the results is presented in Table 6.2.

Table 6.2 Summary of Survey Responses[A] for Individual Events

Event[B]	A	C	D	Avg.
The program as a whole was:	4.7	4.2	4.4	4.5
The program content was:	4.6	4.3	4.4	4.5
The program's application to my job is expected to be:	4.3	4.2	4.2	4.3
The speaker's knowledge on the subject was:	4.7	4.6	4.6	4.7
The speaker's effectiveness in teaching the subject matter was:	4.7	4.5	4.4	4.6
The program organization was:	4.5	4.3	4.2	4.3
The variety of topics covered was:	4.6	4.2	4.2	4.4
Interaction with Auburn University personnel was:	4.6	4.5	4.4	4.5
The facility was:	4.7	4.4	4.4	4.5
Average	**4.6**	**4.3**	**4.4**	**4.5**

Note: [A] each response was recorded on a scale of: Excellent (5), Very Good (4), Good (3), Fair (2), and Poor (1).
[B] A: Research Showcase & Field Day, May 29-30, 2014; B: Field Day, Nov. 3, 2014 (surveys not recorded); C: Hands-On Installer Training, Nov. 18-19, 2015; D: Field Day, Nov. 20, 2015

Survey respondents were additionally asked to leave personalized feedback on the seminar. The most common positive comments pertained to the hands-on components/field exercises, real world and practical applicability of demonstrations, course organization, and student involvement. Constructive comments received included the need to include stream restoration components, and the desire for handouts or take-home materials. Examples of participant survey feedback are included below:

- *"The program is well planned and well thought of."*
- *"I enjoyed the ability to see the best management practices in action and learn how they work in their environment."*
- *"I thought all the different stations, methods and products were very good. Visual learning was great."*

Improvements to the field days could include the use of take-home materials that provide key highlights for participants to take away from the demonstrations provided during activities, including proper installation procedures, diagrams, and photographs. Furthermore, the use of pre-test and post-test surveys may be useful for measuring the level of participants' change of knowledge from before to after the training. The seminar evaluation survey can be adapted to include elements of a researched evaluation model to measure the participants level of satisfaction, learning, impact, results, and return on investment *(Naugle et al. 2000)*. An additional follow-up survey can be electronically distributed to course participants after the event to evaluate whether the presented ESC technology is being adopted by attendees or agencies.

With each field day, course development, site preparation, and setup has become less resource and time consuming; however, the events still disrupt regular research activities as has been noted by other laboratories that perform T^2 activities *(Coursey and Bozeman 1992)*. In addition, the field days carry a high cost in acquiring demonstration materials, portable facilities, and meals/refreshments. When possible, materials were obtained through vendor donations to help offset the costs. Hosting a hands-on installer training the day prior to a field-day decreases the time and resources required to fully setup demonstration stations, as the course participants assist in the installation of the ESC practices. While the planned outdoor events have fortunately not been adversely disrupted by weather conditions, the nature of the activities leaves it highly vulnerable.

Due to the positive feedback received by attendees, another Hands-On Installer Training and Field Day will be hosted at the AU-ESCTF in November 16 and 17, 2016, followed by a field-day on November 18, 2016. The potential for an installer-based certification program can emanate from these training efforts, as industry leaders see the advantage in providing a hands-on approach to disseminating effective ESC practices to those who are in the field installing the devices.

CHAPTER SEVEN: CONCLUSIONS

7.1 INTRODUCTION

ESC has become essential component of construction activities. Federal, state, and local environmental protection regulations require construction generated pollution to be controlled on-site prior to discharge to avoid impairment of receiving waterbodies. The research in this dissertation explored improvements made in the design and application of ESC technologies through the development of SEDspread: a sediment basin design tool, large-scale testing of sediment basin practices at the AU-ESCTF, the use of unmanned aerial vehicles for construction inspection purposes, and the transfer of innovative ESC technology through the AU-ESCTF T^2 programs to the construction industry.

7.2 CONCLUSIONS

This section summarizes the conclusions of each of the explored research areas investigated in this dissertation. The major findings of this research are disseminated through the ESC Technology Transfer programs delivered at the AU-ESCTF provide the platform to distribute knowledge, practice, and techniques with industry professionals. This dissemination of research outcomes satisfies the technology transfer objectives of this dissertation.

7.2.1 SEDIMENT BASIN DESIGN TOOL: SEDSPREAD

To satisfy the first objective of this dissertation, A spreadsheet based tool, SEDspread, was developed to provide designers the ability to implement hydrologic based designs to allow for appropriately sized and configured sediment basins on construction sites based upon the regionally specific design criteria. The allows users to input site parameters and constraints to determine the required basin capacity and configuration, surface skimmer selection, size of the auxiliary spillway, and baffle configuration.

SEDspread includes geospatially derived data that allows for the automated selection of design hydrologic and soil conditions through the input of the U.S. ZIP code for the project location, or manual input as required. A case study was performed to compare the actual designs of two sediment basins from local construction sites to the designs generated through SEDspread using the 2 yr, 24 hr rainfall event. The case study resulted in a volumetric difference factor of 3.6 and 3.3, indicating the basins were severely under designed for the local 2-yr, 24-hr rainfall event.

This tool should allow designers to efficiently and effectively design sediment basins using local hydrologic and soil conditions. Furthermore, the tool can be used to supplement communication between designers and construction personnel to ensure basins are constructed as designed.

7.2.2 LARGE-SCALE PERFORMANCE EVALUATIONS OF SEDIMENT BASIN CONFIGURATION AND HIGH-RATE LAMELLA SETTLERS

The second objective of this dissertation was achieved through the design, construction, methodology development, and testing performed on a 2,790 ft^3 (79.0 m^3), large-scale sediment basin at the AU-ESCTF. Testing was performed on various sediment basin design configurations and high-rate lamella plate settler technology within the basin. Water quality data was used to evaluate the performance of various basin design configurations. Testing results indicated that the use of an excavated sump in the forebay of the sediment basin inflow channel and the use of a modified first baffle system provided no improvements to the performance of the basin. Testing showed that high-rate lamella settlers oriented in upward and parallel configurations were 18.2% and 29.0% more effective at reducing turbidity between Bay 1 and Bay 4 when compared to the ALDOT standard configuration, respectively.

During all overflow tests performed, the sediment basin had a higher efficiency during the overtopping event then did during the empty fill condition. This indicates that having dead storage in the basin is important to provide dilution to highly turbid receiving flows, and to dissipate the energy, reducing resuspension of settled particles.

7.2.3 UAV for Inspection Applications

Research was performed using remote sensing with UAVs to showcase the applicability in assisting QCIs in performing focused, strategic site inspections in an efficient and effective manner. This task satisfies the third objective of the dissertation. Research performed on an active construction site showed that UAVs have the potential to assist inspectors in performing thorough site inspections very efficiently and more strategically. By providing a complete detailed aerial view of the entire site at the onset of an inspection, the inspector has the ability to quickly identify problem areas, discharge points of concern, and determine whether further detailed investigations are warranted. Furthermore, photogrammetric techniques were used to provide analyses on the collected aerial data through the creation of DEMs.

7.3 LIMITATIONS AND RECOMMENDED FURTHER RESEARCH

The following section describes general limitations of the research performed and explores avenues by which the knowledge base can be expanded by performing additional studies and investigations.

7.3.1 SEDIMENT BASIN DESIGN TOOL: SEDSPREAD

SEDspread is limited to the design of new sediment basins. An enhancement that can be made to the tool would be to include the ability to perform analyses on existing basins based on as-built contours. This would be useful to determine if basins meet design recommendations and requirements. A further enhancement of SEDspread would be to include site soil parameters. This would allow a designer to determine the appropriate detention time based on a design soil size. It would also be useful to help determine if flocculent should be used for the basin application. Soils data can be mined from USDA web soil survey and can be incorporated into SEDspread by average soil composition based on ZIP code location. Lastly, to further ease the design process, SEDspread can incorporate a user input wizard to walk the designer through the step-by-step process of sizing a sediment basin.

7.3.2 LARGE-SCALE PERFORMANCE EVALUATIONS OF SEDIMENT BASIN CONFIGURATION AND HIGH-RATE LAMELLA SETTLERS

Soil and water samples were collected and stored for each series of testing performed. To better understand the performance of the basin, a grain size analysis of these samples should be conducted using a laser spectrometer. This would allow for the characterization of soil capture effectiveness across the various bays of the basin based on gradation.

Tests were performed in a large-scale sediment basin apparatus. While the basin was representative in scale, it was limited to a treatment area of 0.242 ac (0.098 ha). Most sediment basins in Alabama are designed to treat up to 10 ac (4.05 ha), and thus the AU-ESCTF sediment basin may not truly reflect typical sediment basin sizing. Furthermore, experiments were only performed using a loam soil type under a constant flow introduction rate of 1.50 ft^3/s (0.04 m^3/s). Larger diameter soils will perform differently in the basin and may respond more effectively to the high-rate lamella settler treatments as capturing larger particles requires less treatment time.

The behavior of the sediment basin under the tested treatments was evaluated under a single soil type. The results and findings of this research are limited to the particle size distribution of the tested soils and further research would be required to gain a better understanding of performance against varying soil types. Furthermore, the soil used in these experiments had a high content of fine material that is not expected to behave according to Stoke's law. Other settling physics would need to be taken into account such as the influence of wind, inter-particle electromagnetic forces, and hindered settling conditions.

The large-scale testing efforts of this research focused on the sediment basin's ability in reducing sediment discharge. Although sediment is the target pollutant associated and measured with construction stormwater regulations, other pollutants may be monitored for construction activities within sensitive or controlled watersheds. Other target water quality parameters such as: dissolved oxygen, nitrate, phosphate, and heavy metals could be monitored to determine a sediment basin's contribution in their reduction.

The high-rate lamella settler in upward flow configuration did not provide a true countercurrent flow direction as the sides of the tanks were open, allowing water to flow out the sides of the tanks, rather than out through the top. This was a limitation based on the nature of the sediment basin in not having a known or constant stage at all times, like would be experienced in a traditional water treatment clarifier system. For the lamella settlers to be practical for conventional use on construction site sediment basins, a redesign would be required to allow for the system to be economic, portable, light weight, and easy to maintain.

The high-rate settlers were installed in the basin and were subjected to treat flow rates up to 1.50 ft^3/s (0.04 m^3/s). These design flows would be expected to be even higher when the system is installed in a field-scale sediment basin. To overcome this limitation, it could be advantageous, from a treatment and practical standpoint, to develop a single settler box to be installed at the skimmer discharge outlet. This would allow already treated stormwater discharging from the skimmer, to be further polished through the high-rate settler. Furthermore, the settler would have a fixed inflow rate and constant water level, dependent on the skimmer selected. The high-rate settler system would be designed based on the skimmer to match the flow rate exiting through the skimmer. This would be a more practical approach for users to implement as it would result in a smaller device and would be easier to maintain and access. A valve could be installed near the bottom of the tank to allow for flush and clean out with a vacuum truck. The only drawback with this system would be that there would be no treatment during overtopping/spillway flow conditions. This system could also be modified to add for flocculent dosage and agitation to further enhance the performance of the treatment device. Figure 7.1 shows the schematic to a conceptual design for the described high-rate settler treatment device.

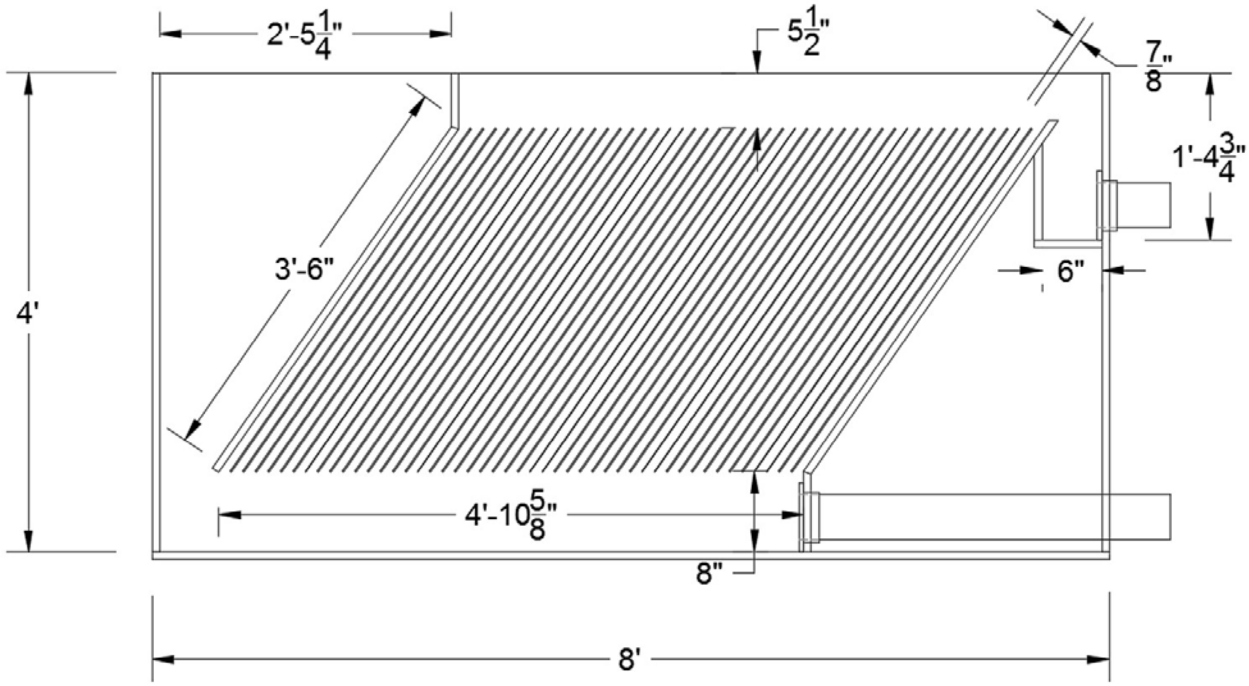


Figure 7.1 Design of Skimmer High-Rate Lamella Settler Treatment System.

The test basin and protocols used in this study had the advantage of evaluating treatments on a controlled environment (i.e. soil introduction, runoff quantity, sediment concentration, etc.). Investigations should be performed to assess the performance of these treatments on actual construction sites, which are susceptible to a wider range of uncontrollable variables. A field study could provide further insight on the performance of practices across a wide variety of rainfall scenarios and sediment loads. Remote sampling equipment could be used to capture water quality samples during actual storm events.

7.3.3 UAV for Inspection Applications

As demonstrated in this research, UAVs have a wide range of applicable solutions for construction inspection applications. Researchers should investigate the accuracy of developed DEMs across multiple sensor platforms, altitudes, and software. Accuracy of the generated DEMs were not evaluated as there were obvious persistent errors present when using the software to stich the model together. Future research should evaluate the accuracy of photogrammetrically derived DEMs. Comparisons should be made between different sensors, different image acquisition resolutions, and different altitude or distances from the ground. This will provide comparative means for a user to select the appropriate sensor and altitude to complete a mission. Further research should also be conducted using various sensors (i.e. thermal, NVDI, hyperspectral, multispectral, LiDAR, etc.). These sensors may provide a wide array of data that would be useful to other civil engineering and construction applications.

7.3.4 TRAINING AND OUTREACH

The training and outreach mission of the AU-ESCTF has the potential for further development and advancement. Currently, there is no statewide requirement for design professionals to undergo training in the design of ESC practices. Other states (i.e. Georgia) require designer based training for design professionals. The development of a one week "stormwater camp" offering 2.5 days of designer based training followed by the existing 1.5 day installer training and a full day field day. An additional enhancement in the AU-ESCTF training program could be in the evaluation of the training events. The current paper based survey template used to assess participant engagement lacks the ability to quantify a change in knowledge or willingness to take action or change behavior. An online based questionnaire that gauges the level of knowledge in specific target areas prior to and following the training event would allow for a measure of course/workshop effectiveness.

7.4 ACKNOWLEDGMENTS

This research is based on a studies sponsored by ALDOT and the Auburn University Highway Research Center. The author gratefully acknowledges this financial support. The

findings, opinions, and conclusions expressed in this thesis are those of the author and do not necessarily reflect the view of the sponsor.

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APPENDICES

Appendix A: ALDOT Special and Standard Highway Drawings for Erosion and Sediment Controls (Sediment Basin)

Appendix B: Turbidity and TSS Processing Procedures

Appendix C: Example Experimental Results (Test Data Log)

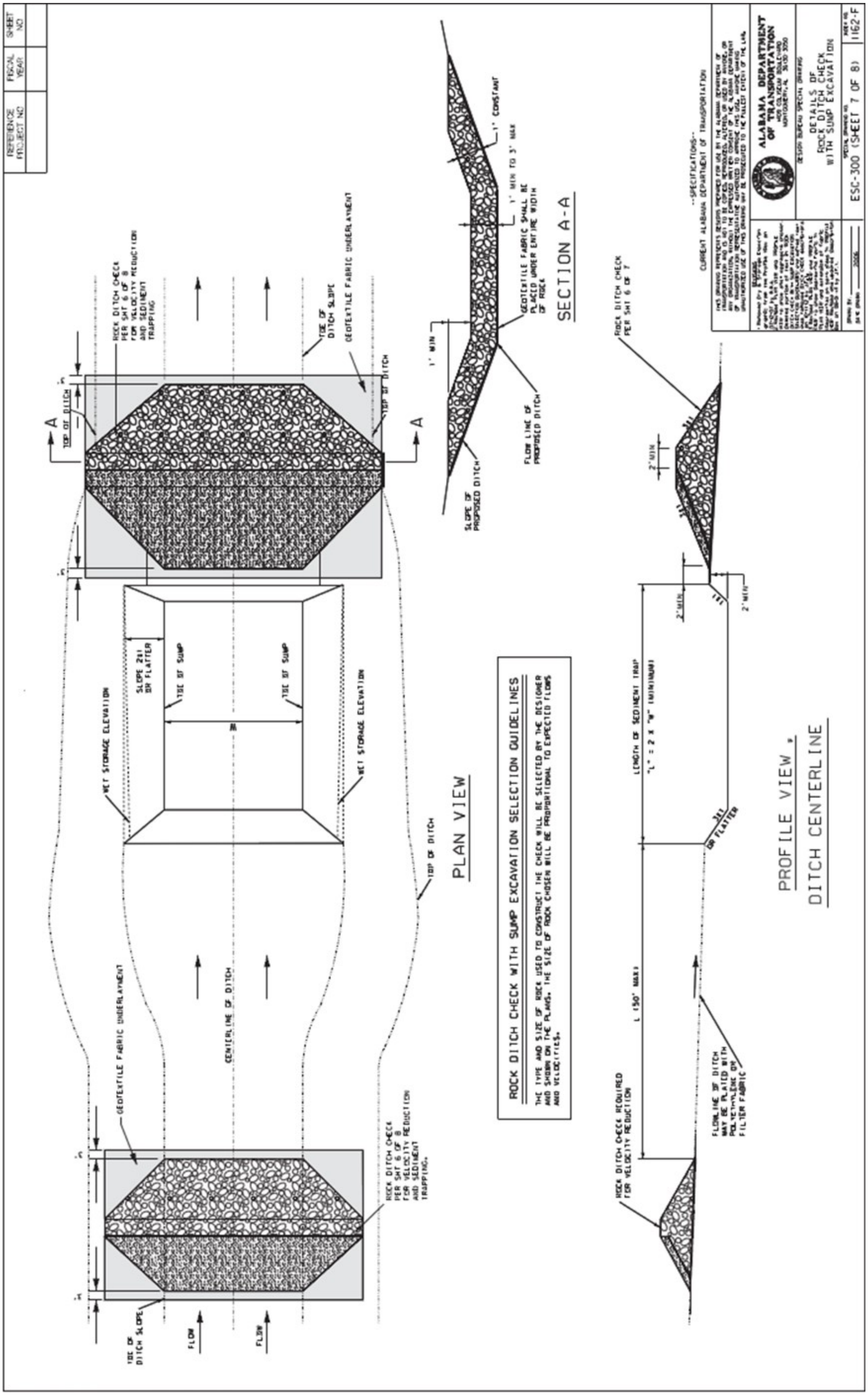
Appendix D: Sediment Basin Turbidity Data

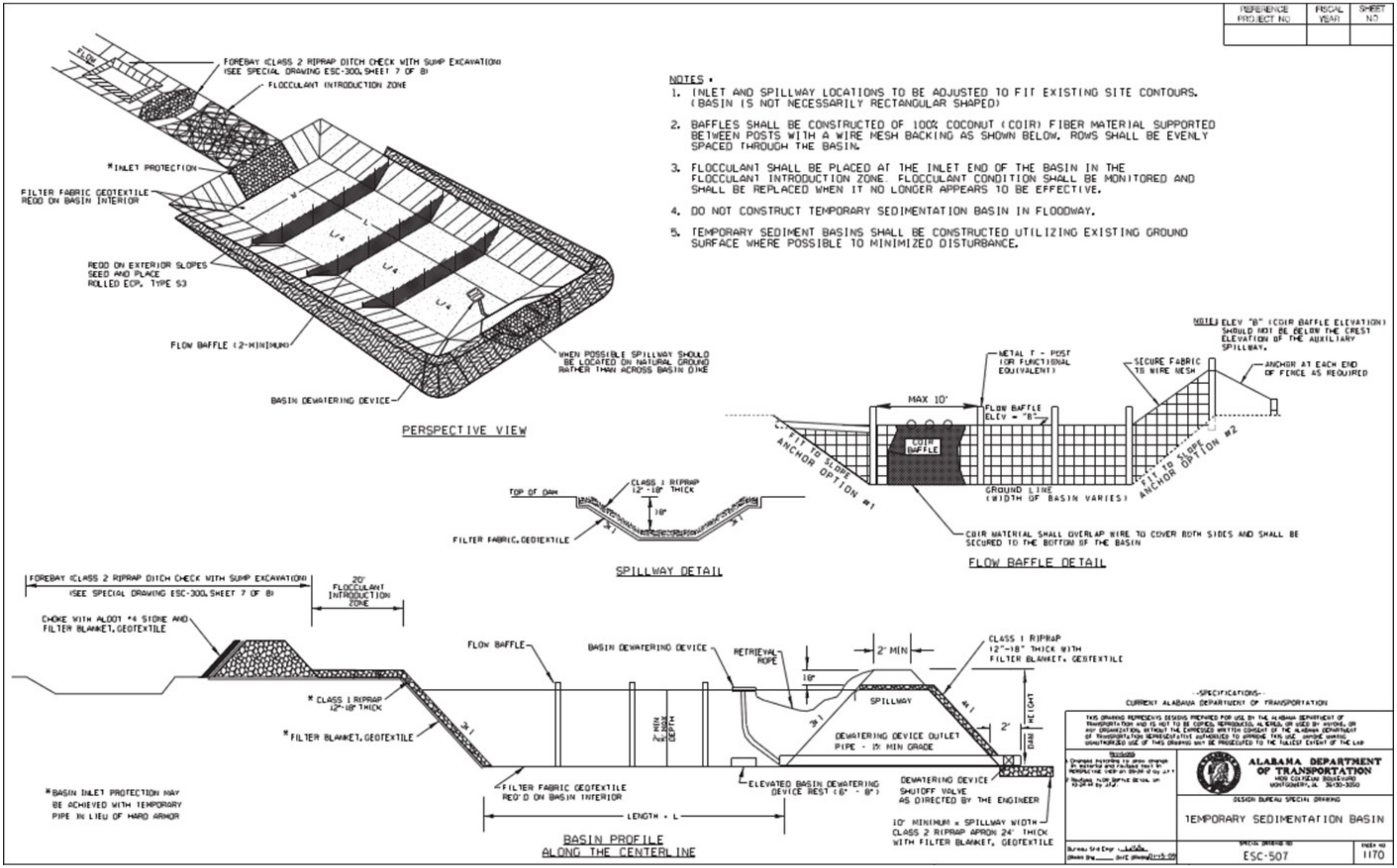
Appendix E: Temperature Normalized Sediment Basin Turbidity Data

Appendix F: As-Built Sediment Basin Survey

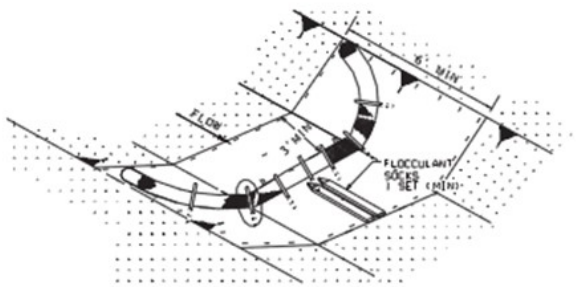
APPENDIX A

ALDOT SPECIAL AND STANDARD HIGHWAY DRAWINGS FOR EROSION AND SEDIMENT CONTROLS (SEDIMENT BASIN)

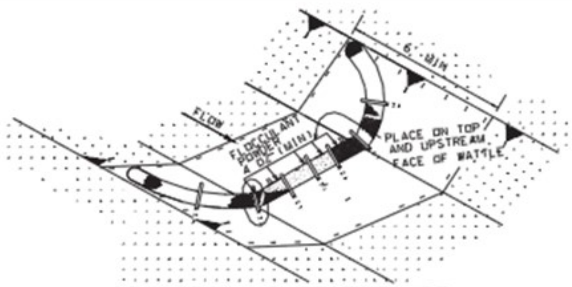

PLAN VIEW
SECTION A-A
PROFILE VIEW
DITCH CENTERLINE
ROCK DITCH CHECK WITH SUMP EXCAVATION SELECTION GUIDELINES
THE TYPE AND SIZE OF ROCK USED TO CONSTRUCT THE CHECK WILL BE SELECTED BY THE DESIGNER AND SHOWN ON THE PLANS. THE SIZE OF ROCK CHOSEN WILL BE PROPORTIONAL TO EXPECTED FLOWS AND VELOCITIES.
GEOTEXTILE FABRIC UNDERLAYMENT
CENTERLINE OF DITCH
WET STORAGE ELEVATION
TOE OF SUMP
SLOPE 2:1 OR FLATTER
TOP OF DITCH
TOE OF DITCH SLOPE
FLOW
ROCK DITCH CHECK PER SHT 6 OF 8 FOR VELOCITY REDUCTION AND SEDIMENT TRAPPING
1' CONSTANT
1' MIN TO 3' MAX
GEOTEXTILE FABRIC SHALL BE PLACED UNDER ENTIRE WIDTH OF ROCK
1' MIN
FLOW LINE OF PROPOSED DITCH
SLOPE OF PROPOSED DITCH
ROCK DITCH CHECK PER SHT 6 OF 7
2' MIN
LENGTH OF SEDIMENT TRAP
"L" = 2 X "W" (MINIMUM)
L (50' MAX)
ROCK DITCH CHECK REQUIRED FOR VELOCITY REDUCTION
FLOWLINE OF DITCH MAY BE PLATED WITH POLYETHYLENE OR FILTER FABRIC
--SPECIFICATIONS--
CURRENT ALABAMA DEPARTMENT OF TRANSPORTATION
ALABAMA DEPARTMENT OF TRANSPORTATION
DETAILS OF ROCK DITCH CHECK WITH SUMP EXCAVATION
ESC-300 (SHEET 7 OF 8)
1162-F


REFERENCE PROJECT NO
FISCAL YEAR
SHEET NO
NOTES:
1. INLET AND SPILLWAY LOCATIONS TO BE ADJUSTED TO FIT EXISTING SITE CONTOURS. (BASIN IS NOT NECESSARILY RECTANGULAR SHAPED)
2. BAFFLES SHALL BE CONSTRUCTED OF 100% COCONUT (COIR) FIBER MATERIAL SUPPORTED BETWEEN POSTS WITH A WIRE MESH BACKING AS SHOWN BELOW. ROWS SHALL BE EVENLY SPACED THROUGH THE BASIN.
3. FLOCCULANT SHALL BE PLACED AT THE INLET END OF THE BASIN IN THE FLOCCULANT INTRODUCTION ZONE. FLOCCULANT CONDITION SHALL BE MONITORED AND SHALL BE REPLACED WHEN IT NO LONGER APPEARS TO BE EFFECTIVE.
4. DO NOT CONSTRUCT TEMPORARY SEDIMENTATION BASIN IN FLOODWAY.
5. TEMPORARY SEDIMENT BASINS SHALL BE CONSTRUCTED UTILIZING EXISTING GROUND SURFACE WHERE POSSIBLE TO MINIMIZED DISTURBANCE.
FLOW
FOREBAY (CLASS 2 RIPRAP DITCH CHECK WITH SUMP EXCAVATION) (SEE SPECIAL DRAWING ESC-300, SHEET 7 OF 8)
FLOCCULANT INTRODUCTION ZONE
*INLET PROTECTION
FILTER FABRIC GEOTEXTILE REQ'D ON BASIN INTERIOR
REQ'D ON EXTERIOR SLOPES SEED AND PLACE ROLLED ECP, TYPE S3
FLOW BAFFLE (2-MINIMUM)
W
L
L/4
WHEN POSSIBLE SPILLWAY SHOULD BE LOCATED ON NATURAL GROUND RATHER THAN ACROSS BASIN DIKE
BASIN DEWATERING DEVICE
PERSPECTIVE VIEW
NOTE: ELEV "B" (COIR BAFFLE ELEVATION) SHOULD NOT BE BELOW THE CREST ELEVATION OF THE AUXILIARY SPILLWAY.
METAL T - POST (OR FUNCTIONAL EQUIVALENT)
SECURE FABRIC TO WIRE MESH
ANCHOR AT EACH END OF FENCE AS REQUIRED
MAX 10'
FLOW BAFFLE ELEV = "B"
COIR BAFFLE
FIT TO SLOPE ANCHOR OPTION #1
FIT TO SLOPE ANCHOR OPTION #2
GROUND LINE (WIDTH OF BASIN VARIES)
COIR MATERIAL SHALL OVERLAP WIRE TO COVER BOTH SIDES AND SHALL BE SECURED TO THE BOTTOM OF THE BASIN
FLOW BAFFLE DETAIL
TOP OF DAM
CLASS 1 RIPRAP 12"-18" THICK
18"
3:1
FILTER FABRIC, GEOTEXTILE
SPILLWAY DETAIL
FOREBAY (CLASS 2 RIPRAP DITCH CHECK WITH SUMP EXCAVATION) (SEE SPECIAL DRAWING ESC-300, SHEET 7 OF 8)
20' FLOCCULANT INTRODUCTION ZONE
CHOKE WITH ALDOT #4 STONE AND FILTER BLANKET, GEOTEXTILE
* CLASS 1 RIPRAP 12"-18" THICK
* FILTER BLANKET, GEOTEXTILE
FLOW BAFFLE
BASIN DEWATERING DEVICE
RETRIEVAL ROPE
2' MIN
18"
CLASS 1 RIPRAP 12"-18" THICK WITH FILTER BLANKET, GEOTEXTILE
SPILLWAY
2' MIN MAX DEPTH
DEWATERING DEVICE OUTLET PIPE - 1% MIN GRADE
4:1
2'
HEIGHT
DAM
FILTER FABRIC GEOTEXTILE REQ'D ON BASIN INTERIOR
ELEVATED BASIN DEWATERING DEVICE REST (6" - 8")
DEWATERING DEVICE SHUTOFF VALVE AS DIRECTED BY THE ENGINEER
LENGTH = L
10' MINIMUM x SPILLWAY WIDTH CLASS 2 RIPRAP APRON 24" THICK WITH FILTER BLANKET, GEOTEXTILE
*BASIN INLET PROTECTION MAY BE ACHIEVED WITH TEMPORARY PIPE IN LIEU OF HARD ARMOR
BASIN PROFILE ALONG THE CENTERLINE
-SPECIFICATIONS-
CURRENT ALABAMA DEPARTMENT OF TRANSPORTATION
ALABAMA DEPARTMENT OF TRANSPORTATION
DESIGN BUREAU SPECIAL DRAWING
TEMPORARY SEDIMENTATION BASIN
ESC-507
1170

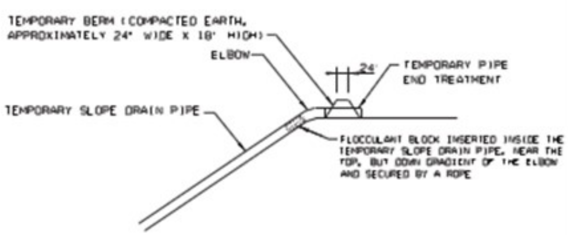
REFERENCE PROJECT NO	FISCAL YEAR	SHEET NO



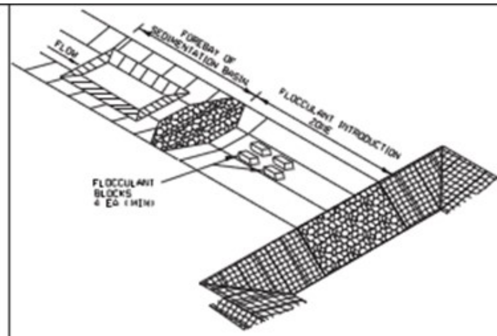
FLOCCULANT SOCK USE
WITH WATTLE DITCH CHECK
(SEE SPECIAL DRAWING ESC-300, SHEET 4 OF 8)



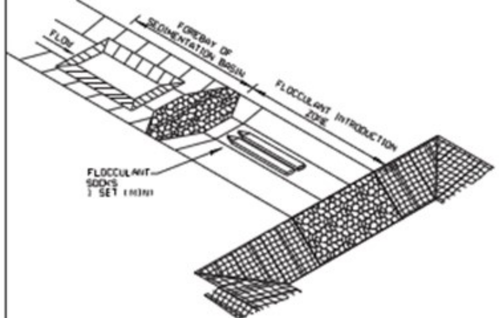
FLOCCULANT POWDER USE
WITH WATTLE DITCH CHECK
(SEE SPECIAL DRAWING ESC-300, SHEET 4 OF 8)



FLOCCULANT BLOCK USE
WITH TEMPORARY SLOPE DRAIN
(SEE SPECIAL DRAWING ESC-200, SHEET 2 OF 4)



FLOCCULANT BLOCK USE
WITH SEDIMENTATION BASIN
(SEE SPECIAL DRAWING ESC-507)



FLOCCULANT SOCK USE
WITH SEDIMENTATION BASIN
(SEE SPECIAL DRAWING ESC-507)

NOTES:

1. AN ALDOT LIST OF APPROVED FLOCCULANTS CAN BE FOUND IN THE MSDSAR MANUAL LIST II-24 "TEMPORARY EROSION AND SEDIMENT CONTROL PRODUCTS."
2. SOME FLOCCULANTS ARE SOIL SPECIFIC AND MUST BE SELECTED BASED ON SOIL AND RUNOFF TESTING.
3. HEAVY SEDIMENT AND SAND SHOULD BE REMOVED PRIOR TO THE LOCATION OF FLOCCULANT APPLICATION.
4. PASSIVE DOSING OF FLOCCULANTS REQUIRES FLOWING WATER WITH A MODERATE VELOCITY.
5. FLOCCULANTS REQUIRE AN INITIAL PERIOD OF MIXING/AGITATION FOLLOWED BY A PERIOD OF LOW VELOCITY TO ALLOW THE SETTLING OF PARTICLES.
6. SEDIMENT CONTROL MEASURES MUST BE UTILIZED TO CAPTURE THE FLOCCULATED MATERIAL AND PREVENT RE-SUSPENSION PRIOR TO DISCHARGE.
7. FLOCCULANT SHOULD NEVER BE APPLIED DIRECTLY TO LIVE STREAMS OR WATERS OF THE STATE.
8. FLOCCULANT BLOCKS CAN DRY OUT PREVENTING DISSOLUTION. BLOCKS MUST BE PROTECTED FROM THE SUN AND SHOULD REMAIN HYDRATED IF POSSIBLE.
9. FLOCCULANT SOCKS WILL FLATTEN WHEN EMPTY INDICATING THE NEED FOR REPLACEMENT.
10. POWDER FORMS OF FLOCCULANT TYPICALLY MUST BE REAPPLIED AFTER EACH RAIN EVENT.

--SPECIFICATIONS--
CURRENT ALABAMA DEPARTMENT OF TRANSPORTATION

ALABAMA DEPARTMENT OF TRANSPORTATION

DESIGN BUREAU SPECIAL DRAWING

FLOCCULANT USAGE GUIDE

SPECIAL DRAWING NO ESC-508

INDEX NO 1171

APPENDIX B

Turbidity and TSS Processing Procedures

TURBIDITY AND TSS PROCESSING PROCEDURES

Test Note: *These water quality testing procedures conduct Turbidity and TSS sampling simultaneously to maintain work efficiency and reduce dilution errors.*

Storage Note: *Refrigerate water samples for a maximum of 72 hrs. until testing.*

<u>TSS Analysis Preparation</u>

Step 1: Prepare glassware, deionized water, filtering apparatus, scales, turbidimeter, and vacuum pump.

Step 2: Prepare and label the required crinkle dishes and place filter membranes on each dish using clean tweezers. Do not use fingers.

Step 3: Prewash filter membranes by placing the filter disc on the filter holder of the filter apparatus with the wrinkled side upward, gridded side down. Attach the top funnel portion of the magnetic filter holder. Apply 10 mL of deionized water and provide suction to filter through membrane. Remove washed filter and place on corresponding crinkle dish. Repeat for all membranes.

Step 4: Place washed membranes in the oven at 103˚C for one hour. Remove crinkle dishes and membranes from the drying oven and place in a desiccator and allow to cool to room temperature.

Step 5: Weigh the crinkle dish and filter using an analytical balance. Record weight to the nearest 0.0001 g.

<u>Turbidity Analysis</u>

Step 6: Confirm or recalibrate turbidimeter using standard samples.

Step 7: Vigorously shake the sample bottle to thoroughly mix all sediment in the solution.

Step 8: Transfer sample to 1,000 mL beaker, insert stir bar and place on magnetic stirrer and mix until solution is uniform throughout. Mix continuously through steps 9 though 14.

Step 9: Set the pipette set at 7.5 mL volume and fill turbidity sample cell to the line with 15 mL of solution. Cap the cell.

Step 10: Place the cell into the turbidimeter with the white arrow on the cell facing the black arrow on the unit. Take a turbidity reading on the undiluted sample. If the turbidimeter over ranges, proceed to Step 5.

Step 11: If the sample over ranges: dilute the sample 1:2 by mixing 100 mL of original solution with 100 mL of deionized water in a beaker and mix.

Step 12: Pipette the 1:2 diluted sample into a sample cell. Read the turbidity. If the sample over ranges, repeat step 11-12 until a reading is taken. Record the measured turbidity value and the dilution factor. The dilution factor is calculated as $F = 2^x$, where x is the number of 1:2 dilutions performed (example for 3 dilutions, F = 8).

TSS Analysis

Step 13: Use tweezers to place the corresponding filter membrane on the filtering apparatus.

Step 14: Pipette 25 mL of diluted solution and place in apparatus.

Step 15: Filter sample through membrane using the vacuum pump. Rinse the filtrate on the filter with three 10 mL portions of deionized water.

Step 16: Slowly release the vacuum on the filtering apparatus. Gently remove the filter disc using the tweezers.

Step 17: Place the filter disc on its corresponding crinkle dish.

Step 18: Place membranes in the oven at 103˚C for one hour. Remove crinkle dishes and membranes from the drying oven and place in a desiccator and allow to cool to room temperature.

Step 19: Weigh the crinkle dish and filter using an analytical balance. Record weight to the nearest 0.0001 g.

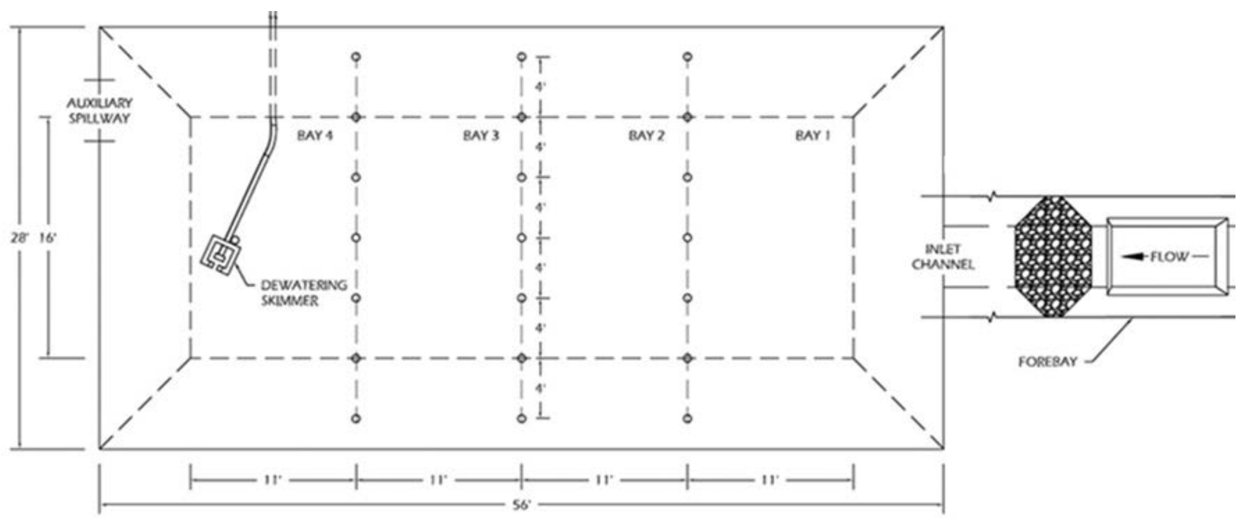
APPENDIX C

Example Experimental Results (Test Data Log)

SEDIMENT BASIN LABORATORY TEST LOG

Test ID	2008
Test Date	5/8/15
Series - Run	S2 - L1
Flow Rate	1.50 ft^3/s
Sediment Rate	0.57 ft^3/min
Flow Start:	2:59 PM
Flow Reach Bay 1:	3:03 PM
Flow End:	3:29 PM
Pre-Test Basin Level	0.0 in.
Post- Test Basin Level	32.0 in.
Forebay Impoundment	26.2 ft

Station	Designee
Pumps/Flow Monitor	GS
Soil Introduction	GS
Introduction Zone Sampling	GS
Basin Entrance Sampling	KW
Aux. Spillway Sampling	N/A
Stratification Sampling	JW
Auto. Samplers	MP
Velocity / Flow Sensor	MP
Turbidity Probes	MP
Level Loggers	MP



Basin Configuration Description: Second series of testing, ALDOT standard configuration with excavated sump upstream of check. Single riprap ditch check located 20 ft upstream of sediment basin entrance. Coir baffle on both sides of wire backed fence. Run No. 2.

Notes:
Upstream sample series: 100, downstream sample series: 200.
Auto Sampler B started five min. late b/c of error in overfilling.
Program emptied and sampler program restarted.

Samples BB 16-20 overflowed during collection and were discarded.

AUGER FLOW RATE DETERMINATION (TEST 2012)

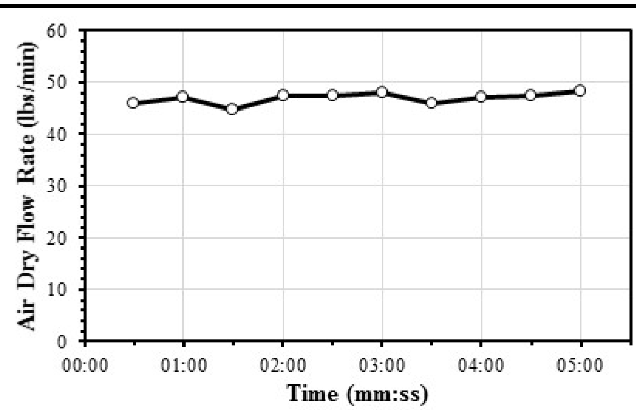
Time:		Sample Segment (sec):	30
Performed By:		Vol. Box Dim.(in.):	12 x 12
Sample	Time (mm:ss)	Weight (lbs)	Vol. Height (in.)
1	0:30	23.0	3.25
2	1:00	23.6	2.75
3	1:30	22.4	2.75
4	2:00	23.8	2.75
5	2:30	23.8	3.13
6	3:00	24.0	2.94
7	3:30	23.0	3.13
8	4:00	23.6	3.50
9	4:30	23.8	2.81
10	5:00	24.2	3.06
	Avg.	23.5	3.01

SEDIMENT MOISTURE CONTENT (TEST 2012)

Date / Time in:	6/5/15 2:23 PM	Oven Temp in (ºC):	108		
Date / Time out:	6/8/15 10:10 AM	Oven Temp out (ºC):	104		
Sample	Pan (g)	Moist Sample + Pan (g)	Dry Sample + Pan (g)	Dry Sample Weight (g)	Moisture Content (%)
1	151.3	886.2	822.2	670.9	9.54
2	150.5	926.5	857.1	706.6	9.82
3	149.4	761.7	709.1	559.7	9.40
				Avg. / Std. Dev.	9.59 / 0.18

SEDIMENT INTRODUCTION RATE (TEST 2012)

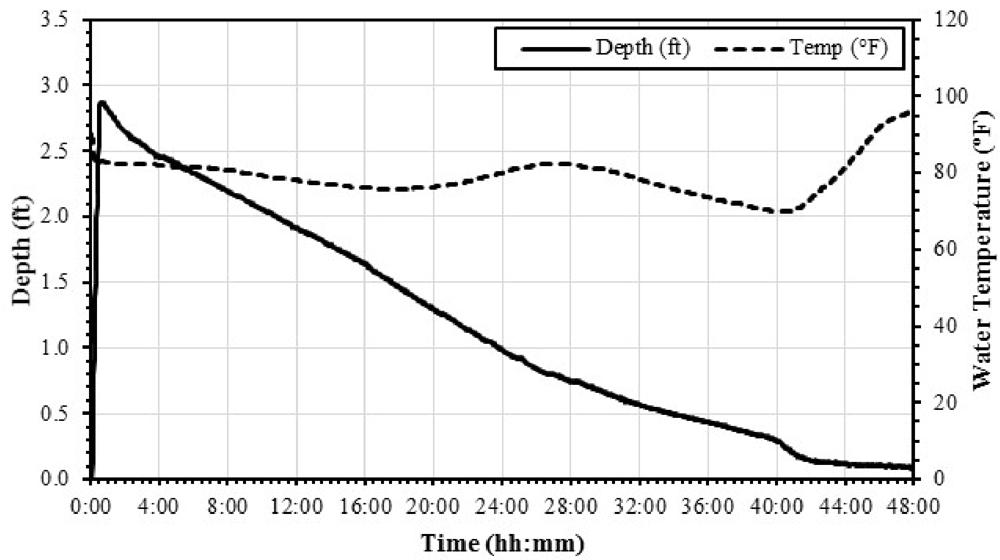
Measured Parameter	Total / Avg.
30 min. Air Dry Total (lbs)	1411.2
30 min. Oven Dry Total (lbs)	1287.8
30 min. Total Vol. (ft^3)	15.0
Air Dry Flow Rate (lb/min)	47.0
Air Dry Flow Rate (ft^3/min)	0.50
Oven Dry Flow Rate (lb/min)	42.9
Air Dry Bulk Density (lb/ft^3)	93.88
Oven Dry Bulk Density (lb/ft^3)	85.67
Air Dry Moisture Content (%)	9.59



FLOW INTRODUCTION RATE

Time (hh:mm)	Flow (ft^3/s)
0:02	1.50
0:04	1.55
0:06	1.50
0:08	1.50
0:10	1.50
0:12	1.55
0:14	1.50
0:16	1.50
0:18	1.50
0:20	1.50
0:22	1.55
0:24	1.55
0:26	1.50
0:28	1.50
Avg.	1.51

Basin Stage (ft) and Temperature (ºF) over Experiment



TURBIDITY & TSS DATA

Test ID: 2008	Sample Location: Upstream Ch.	Bottle Series: 100

TSS Rinse / Prep.		TSS Calibration		
Date & Time in/out:	5-12 1:36 / 5-12 2:36	DI Water Standard	Dry Filter + Crinkle Dish (g)	Dry Filter + Filtrate + Crinkle Dish (g)
Oven Temp. (ºC) in/out:	105 / 103			
Rinse Processed By:	HLR	STD 1	1.3636	1.3636
TSS Sample Filtration		STD 2	1.3713	1.3714
Oven Temp. (ºC) in/out:	106 / 106	STD 3	1.3669	1.3669
Date & Time in / out:	5-12 4:05 / 5-13 11:00	TSS Processed By: HLR		

Turbidity Calibration Standards			
10 NTU	20 NTU	100 NTU	800 NTU
9.2	21.0	102	835
Turbidity Processed By: HLR		Turbidity Process Date: 5/12/15	

Sample ID	Time	Dilution Factor	Turbidity Reading (NTU)	Dry Filter + Crinkle Dish (g)	Dry Filter + Soil + Crinkle Dish (g)	Calibrated NTU	Calibrated TSS
101	00:05	1	251	1.3575	1.3773	241	791
102	00:10	2	783	1.3588	1.3737	1500	1189
103	00:15	1	952	1.3765	1.3923	912	631
104	00:20	1	987	1.3681	1.3860	946	715
105	00:25	2	422	1.3632	1.3923	809	2325
106	00:30	2	611	1.3700	1.3910	1170	1677

TURBIDITY & TSS DATA

Test ID: 2008	Sample Location: Downstream Ch.	Bottle Series: 200

TSS Rinse / Prep.		TSS Calibration		
Date & Time in/out:	5-12 1:36 / 5-12 2:36	DI Water Standard	Dry Filter + Crinkle Dish (g)	Dry Filter + Filtrate + Crinkle Dish (g)
Oven Temp. (ºC) in/out:	105 / 103			
Rinse Processed By:	HLR	STD 1	1.3636	1.3636
TSS Sample Filtration		STD 2	1.3713	1.3714
Oven Temp. (ºC) in/out:	106 / 106	STD 3	1.3669	1.3669
Date & Time in / out:	5-12 4:05 / 5-13 11:00	TSS Processed By: HLR		

Turbidity Calibration Standards			
10 NTU	20 NTU	100 NTU	800 NTU
9.02	21.0	102	835
Turbidity Processed By: HLR		Turbidity Process Date: 5/12/15	

Sample ID	Time	Dilution Factor	Turbidity Reading (NTU)	Dry Filter + Crinkle Dish (g)	Dry Filter + Soil + Crinkle Dish (g)	Calibrated NTU	Calibrated TSS
201	0:05	2	827	1.3779	1.4382	1584	4821
202	0:10	1	835	1.3752	1.3930	800	711
203	0:15	2	625	1.3759	1.4119	1197	2877
204	0:20	2	618	1.3565	1.3799	1184	1869
205	0:25	2	657	1.3629	1.4084	1258	3637
206	0:30	2	638	1.3621	1.4063	1222	3533
207	0:35	1	698	1.3601	1.3754	669	611
208	0:40	1	390	1.3641	1.3707	374	263
209	0:45	1	275	1.3680	1.3716	264	143
210	0:50	1	185	1.3729	1.3753	178	95

TURBIDITY & TSS DATA

Test ID: 2008	Sample Location: Bay No. 1	Bottle Series: A1-A24

TSS Rinse / Prep.		TSS Calibration		
Date & Time in/out:	5-11 1:27 / 5-11 3:30	DI Water Standard	Dry Filter + Crinkle Dish (g)	Dry Filter + Filtrate + Crinkle Dish (g)
Oven Temp. (ºC) in/out:	104 / 102			
Rinse Processed By:	MAP	STD 1	1.3648	1.3651
TSS Sample Filtration		STD 2	1.3719	1.3719
Oven Temp. (ºC) in/out:	106 / 105	STD 3	1.3627	1.3632
Date & Time in / out:	5-13 3:45 / 5-14 11:15	TSS Processed By: MAP		

Turbidity Calibration Standards			
10 NTU	20 NTU	100 NTU	800 NTU
9.02	21.0	102	835
Turbidity Processed By: ACR		Turbidity Process Date: 5/13/15	

Sample ID	Time	Dilution Factor	Turbidity Reading (NTU)	Dry Filter + Crinkle Dish (g)	Dry Filter + Soil + Crinkle Dish (g)	Calibrated NTU	Calibrated TSS
A1	0:11	2	470	1.3665	1.3988	901	2563
A2	0:16	2	584	1.3636	1.3997	1119	2867
A3	0:21	2	507	1.3579	1.3894	971	2499
A4	0:26	2	456	1.3570	1.3822	874	1995
A5	0:31	2	458	1.3549	1.3824	878	2179
A6	0:36	1	680	1.3528	1.3664	652	533
A7	0:41	1	418	1.3534	1.3596	401	237
A8	0:46	1	299	1.3718	1.3767	287	185
A9	0:51	1	293	1.3577	1.3616	282	145
A10	0:56	1	296	1.3646	1.3682	284	133
A11	1:01	1	276	1.3565	1.3597	265	117
A12	1:06	1	275	1.3510	1.3552	264	157
A13	3:06	1	185	1.3581	1.3603	178	77
A14	5:06	1	167	1.3571	1.3598	161	97
A15	7:06	1	171	1.3507	1.3528	165	73
A16	9:06	1	151	1.3698	1.3711	146	41
A17	11:06	1	136	1.3571	1.3582	131	33
A18	13:06	1	137	1.3579	1.3592	132	41
A19	15:06	1	122	1.3590	1.3601	118	33
A20	17:06	1	105	1.3583	1.3590	102	17
A21	19:06	1	96.8	1.3621	1.3631	94	29
A22	21:06	1	73.5	1.3696	1.3702	71	13
A23	23:06	1	63.3	1.3684	1.3692	62	21
A24	25:06	1	79.9	1.3587	1.3593	78	13

TURBIDITY & TSS DATA

Test ID: 2008	Sample Location: Bay No. 2	Bottle Series: B1-B24

TSS Rinse / Prep.		TSS Calibration		
Date & Time in/out:	5-11 1:36 / 5-14 11:15	DI Water Standard	Dry Filter + Crinkle Dish (g)	Dry Filter + Filtrate + Crinkle Dish (g)
Oven Temp. (ºC) in/out:	103 / 105			
Rinse Processed By:	KMW / MAP	STD 1	1.3628	1.3643
TSS Sample Filtration		STD 2	1.3724	1.3738
Oven Temp. (ºC) in/out:	102 / 105	STD 3	1.3604	1.3618
Date & Time in / out:	5-15 9:20 / 5-18 3:50	TSS Processed By: HLR		

Turbidity Calibration Standards			
10 NTU	20 NTU	100 NTU	800 NTU
9.12	21.0	102	835
Turbidity Processed By: HLR		Turbidity Process Date: 5/15/15	

Sample ID	Time	Dilution Factor	Turbidity Reading (NTU)	Dry Filter + Crinkle Dish (g)	Dry Filter + Soil + Crinkle Dish (g)	Calibrated NTU	Calibrated TSS
B1	0:17	2	444	1.3639	1.3933	851	2237
B2	0:21	2	562	1.3525	1.3891	1077	2813
B3	0:26	2	569	1.3690	1.4061	1090	2853
B4	0:31	2	540	1.3660	1.4040	1035	2925
B5	0:36	2	574	1.3578	1.3953	1100	2885
B6	0:41	2	453	1.3554	1.3812	868	1949
B7	0:46	1	700	1.3670	1.3823	671	555
B8	0:51	1	520	1.3553	1.3658	499	363
B9	0:56	1	407	1.3721	1.3810	391	299
B10	1:01	1	352	1.3732	1.3812	338	263
B11	1:06	1	366	1.3584	1.3656	351	231
B12	1:11	1	340	1.3595	1.3667	326	231
B13	3:11	1	325	-	-	312	-
B14	5:11	1	204	-	-	196	-
B15	7:11	1	160	1.3567	1.3599	154	71
B16	9:11	1	165	1.3565	1.3598	159	75
B17	11:11	1	143	1.3652	1.3683	138	67
B18	13:11	1	129	1.3638	1.3667	125	59
B19	15:11	1	114	1.3657	1.3684	110	51
B20	17:11	1	106	1.3610	1.3641	103	67
B21	19:11	1	103	1.3692	1.3715	100	35
B22	21:11	1	97.5	1.3782	1.3808	94	47
B23	23:11	1	82.8	1.3601	1.3625	80	39
B24	25:11	1	140	1.3630	1.3672	135	111

TURBIDITY & TSS DATA

Test ID: 2008	Sample Location: Bay No. 2 Bottom	Bottle Series: BB1-BB24

TSS Rinse / Prep.		TSS Calibration		
Date & Time in/out:	5-11 11:15 / 5-11 3:30	DI Water Standard	Dry Filter + Crinkle Dish (g)	Dry Filter + Filtrate + Crinkle Dish (g)
Oven Temp. (ºC) in/out:	106 / 102			
Rinse Processed By:	MAP	STD 1	1.3581	1.3568
TSS Sample Filtration		STD 2	1.3586	1.3570
Oven Temp. (ºC) in/out:	104 / -	STD 3	1.3622	1.3612
Date & Time in / out:	5-14 2:35 / -	TSS Processed By: HLR		

Turbidity Calibration Standards			
10 NTU	20 NTU	100 NTU	800 NTU
9.15	21.0	102	835
Turbidity Processed By: HLR		Turbidity Process Date: 5/14/15	

Sample ID	Time	Dilution Factor	Turbidity Reading (NTU)	Dry Filter + Crinkle Dish (g)	Dry Filter + Soil + Crinkle Dish (g)	Calibrated NTU	Calibrated TSS
BB1	0:11	2	471	1.3546	1.3807	903	2176
BB2	0:16	1	654	1.3557	1.3694	627	592
BB3	0:21	1	648	1.3526	1.3646	621	524
BB4	0:26	1	485	1.3556	1.3637	465	368
BB5	0:31	1	452	1.3542	1.3608	434	308
BB6	0:36	1	401	1.3570	1.3625	385	264
BB7	0:41	1	361	1.3603	1.3642	347	200
BB8	0:46	1	325	1.3571	1.3608	312	192
BB9	0:51	1	296	1.3559	1.3599	284	204
BB10	0:56	1	266	1.3582	1.3615	256	176
BB11	1:01	1	247	1.3566	1.3601	237	184
BB12	1:06	1	238	1.3686	1.3695	229	80
BB13	3:06	1	174	1.3646	1.3659	168	96
BB14	5:06	1	180	1.3557	1.3559	173	52
BB15	7:06	1	160	1.3505	1.3517	154	92
BB16	9:06	1	-	-	-	-	-
BB17	11:06	1	-	-	-	-	-
BB18	13:06	1	-	-	-	-	-
BB19	15:06	1	-	-	-	-	-
BB20	17:06	1	-	-	-	-	-
BB21	19:06	1	101	1.3542	1.3548	98	68
BB22	21:06	1	80	1.3574	1.3594	78	124
BB23	23:06	1	81.3	1.3526	1.3517	79	8
BB24	25:06	1	74.8	1.3752	1.3745	73	16

TURBIDITY & TSS DATA

Test ID: 2008	Sample Location: Bay No. 3	Bottle Series: C1-C24

TSS Rinse / Prep.		TSS Calibration		
Date & Time in/out:	5-11 4:45 / 5-14 11:15	DI Water Standard	Dry Filter + Crinkle Dish (g)	Dry Filter + Filtrate + Crinkle Dish (g)
Oven Temp. (ºC) in/out:	101 / 105			
Rinse Processed By:	HLR	STD 1	1.3449	1.3446
TSS Sample Filtration		STD 2	1.3586	1.3579
Oven Temp. (ºC) in/out:	107 / 105	STD 3	1.3772	1.3770
Date & Time in / out:	5-15 2:15 / 5-18 3:50	TSS Processed By: TC		

Turbidity Calibration Standards			
10 NTU	20 NTU	100 NTU	800 NTU
9.24	21.0	102	835
Turbidity Processed By: HLR		Turbidity Process Date: 5/15/15	

Sample ID	Time	Dilution Factor	Turbidity Reading (NTU)	Dry Filter + Crinkle Dish (g)	Dry Filter + Soil + Crinkle Dish (g)	Calibrated NTU	Calibrated TSS
C1	0:17	0:11	1	817	1.3654	1.3854	783
C2	0:21	0:16	1	534	1.3641	1.3750	512
C3	0:26	0:21	1	505	1.3678	1.3770	484
C4	0:31	0:26	1	385	1.3693	1.3756	370
C5	0:36	0:31	1	414	1.3708	1.3775	397
C6	0:41	0:36	1	340	1.3592	1.3645	326
C7	0:46	0:41	1	334	1.3723	1.3773	321
C8	0:51	0:46	1	289	1.3704	1.3744	278
C9	0:56	0:51	1	294	1.3622	1.3659	282
C10	1:01	0:56	1	281	1.3672	1.3712	270
C11	1:06	1:01	1	262	1.3627	1.3669	252
C12	1:11	1:06	1	267	1.3578	1.3614	257
C13	3:11	3:06	1	170	1.3672	1.3692	164
C14	5:11	5:06	1	188	1.3622	1.3644	181
C15	7:11	7:06	1	177	1.3473	1.3494	170
C16	9:11	9:06	1	158	1.3657	1.3675	152
C17	11:11	11:06	1	141	1.3623	1.3642	136
C18	13:11	13:06	1	134	1.3683	1.3701	129
C19	15:11	15:06	1	132	1.3671	1.3686	127
C20	17:11	17:06	1	118	1.3640	1.3664	114
C21	19:11	19:06	1	108	1.3542	1.3549	104
C22	21:11	21:06	1	93.2	1.3652	1.3667	90
C23	23:11	23:06	1	84.9	1.3664	1.3677	82
C24	25:11	25:06	1	64.2	1.3723	1.3728	63

TURBIDITY & TSS DATA

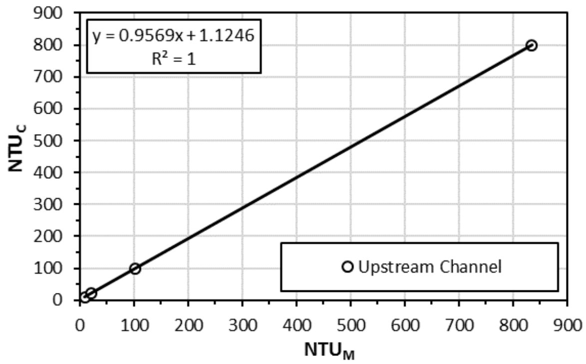
Test ID: 2008	Sample Location: Bay No. 4	Bottle Series: D1-D24

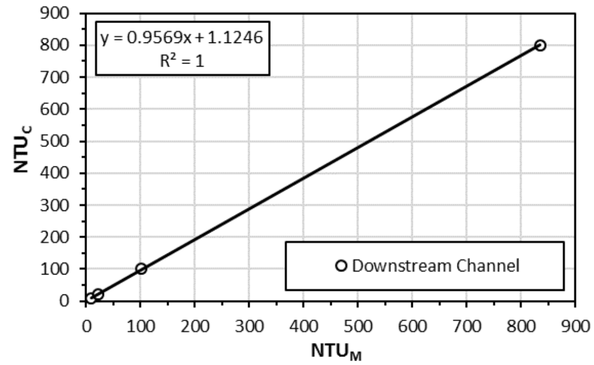
TSS Rinse / Prep.		TSS Calibration		
Date & Time in/out:	5-14 11:34 / 5-14 2:42	DI Water Standard	Dry Filter + Crinkle Dish (g)	Dry Filter + Filtrate + Crinkle Dish (g)
Oven Temp. (ºC) in/out:	107 / 104			
Rinse Processed By:	MAP	STD 1	1.3627	1.3631
TSS Sample Filtration		STD 2	1.3573	1.3571
Oven Temp. (ºC) in/out:	108 / 106	STD 3	1.3753	1.3755
Date & Time in / out:	5-15 4:00 / 5-18 3:50	TSS Processed By: HLR / TC		

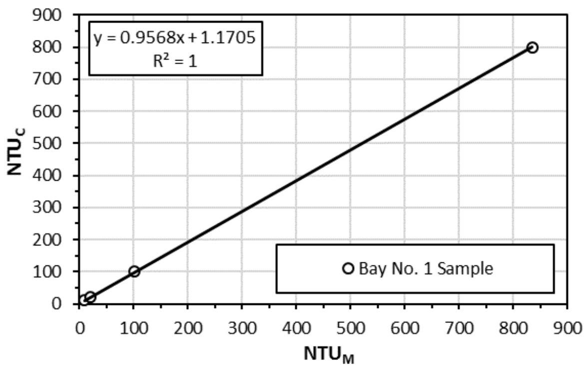
Turbidity Calibration Standards			
10 NTU	20 NTU	100 NTU	800 NTU
9.26	21.0	102	835
Turbidity Processed By: HLR		Turbidity Process Date: 5/15/15	

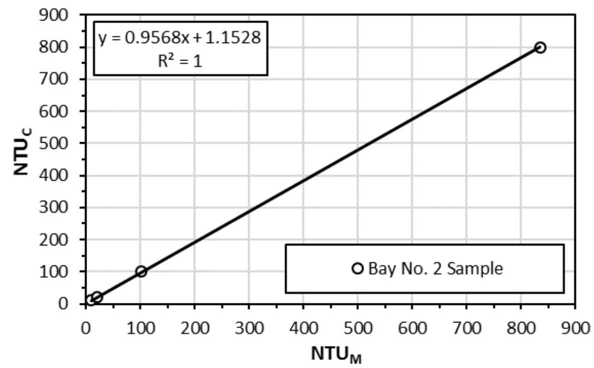
Sample ID	Time	Dilution Factor	Turbidity Reading (NTU)	Dry Filter + Crinkle Dish (g)	Dry Filter + Soil + Crinkle Dish (g)	Calibrated NTU	Calibrated TSS
D1	0:11	1	668	1.3616	1.3758	640	584
D2	0:16	1	586	1.3717	1.3816	562	412
D3	0:21	1	481	1.3536	1.3613	461	324
D4	0:26	1	428	1.3635	1.3698	411	268
D5	0:31	1	395	1.3563	1.3613	379	216
D6	0:36	1	354	1.3678	1.3734	340	240
D7	0:41	1	337	1.3569	1.3605	324	160
D8	0:46	1	303	1.3506	1.3549	291	188
D9	0:51	1	279	1.3690	1.3714	268	112
D10	0:56	1	281	1.3556	1.3592	270	160
D11	1:01	1	283	1.3546	1.3575	272	132
D12	1:06	1	268	1.3546	1.3571	258	116
D13	3:06	1	175	1.3585	1.3604	169	92
D14	5:06	1	191	1.3614	1.3633	184	92
D15	7:06	1	181	1.3596	1.3621	174	116
D16	9:06	1	154	1.3624	1.3630	148	40
D17	11:06	1	137	1.3609	1.3623	132	72
D18	13:06	1	132	1.3723	1.3729	127	40
D19	15:06	1	120	1.3697	1.3702	116	36
D20	17:06	1	93.2	1.3581	1.3581	90	16
D21	19:06	1	102	1.3699	1.3703	99	32
D22	21:06	1	84.1	1.3637	1.3641	82	32
D23	23:06	1	68.8	1.3570	1.3578	67	48
D24	25:06	1	67.9	1.3620	1.3619	66	12

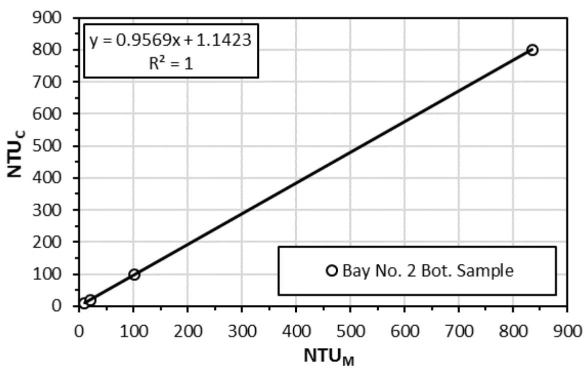
TURBIDITY CALIBRATION

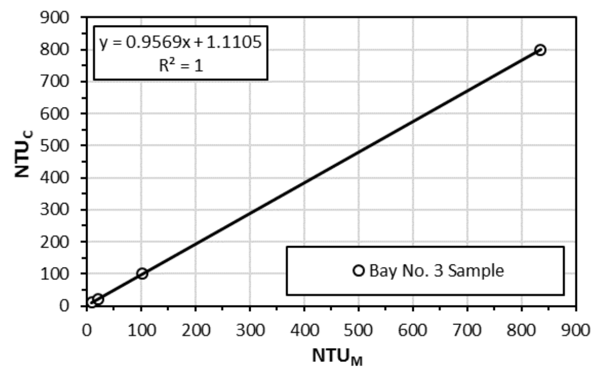


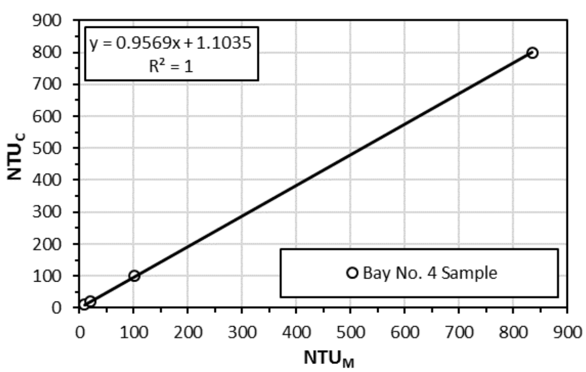




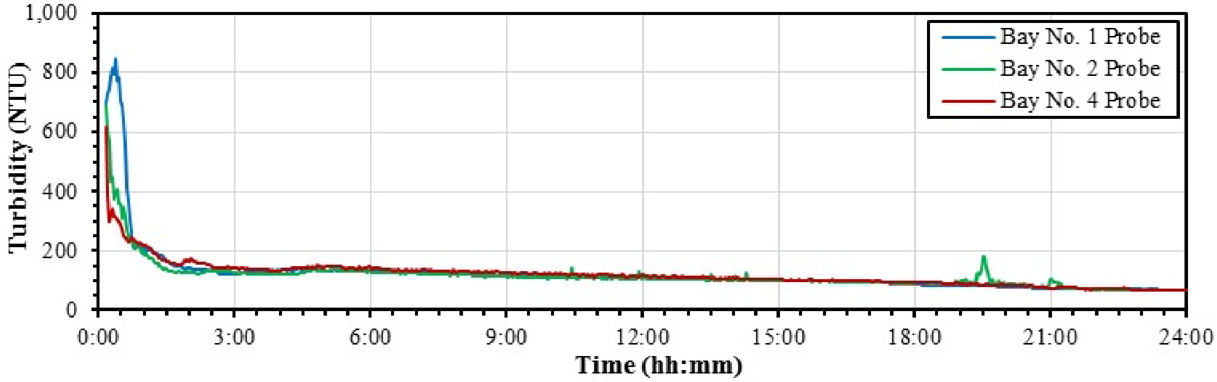


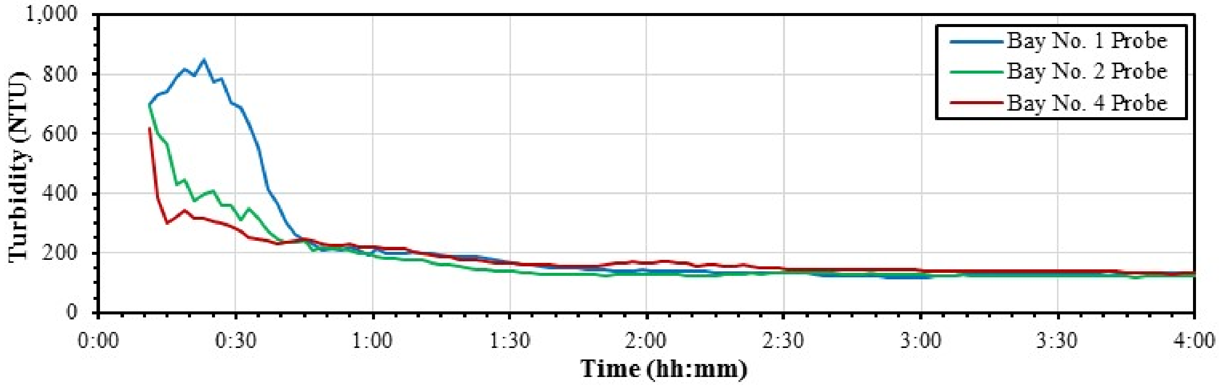


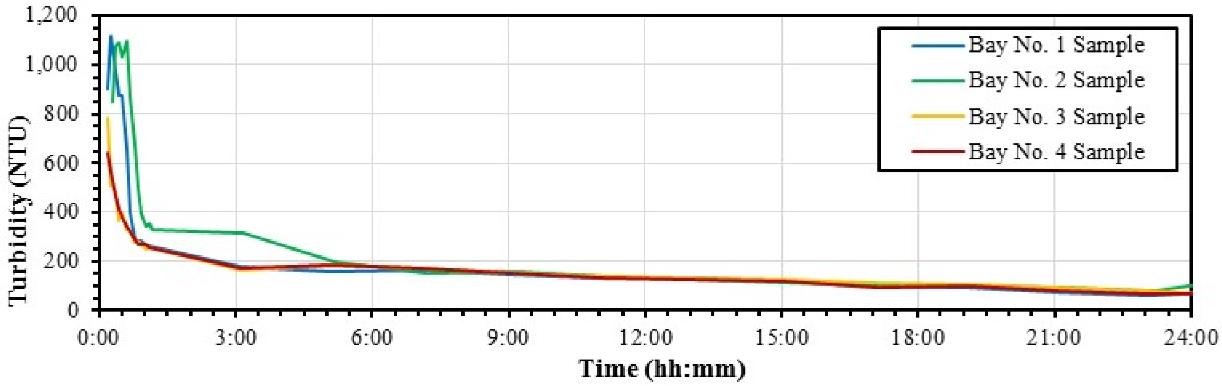


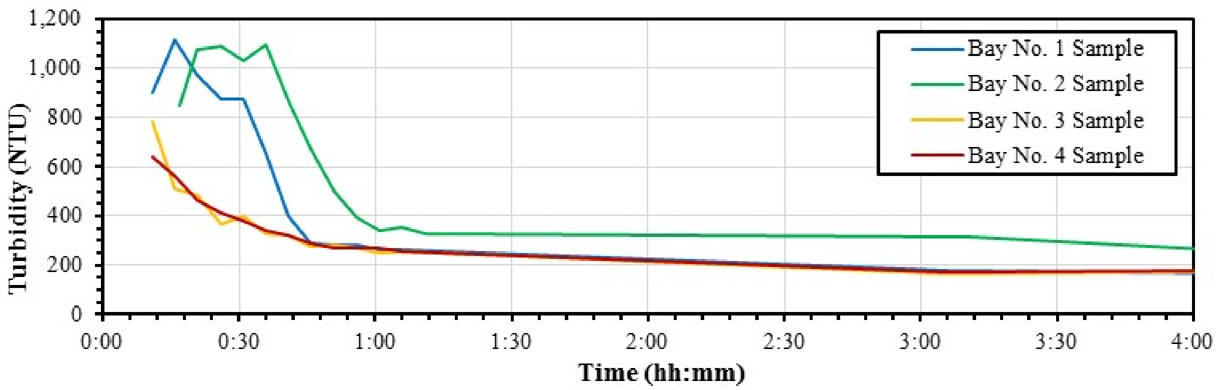


TURBIDITY CALIBRATION









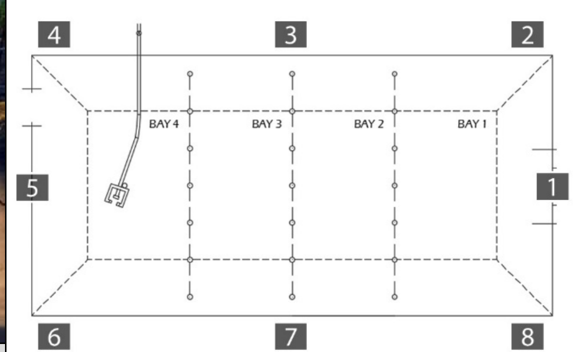
PRE-TEST PHOTO DOCUMENTATION

Location 4

Location 3

Location 2

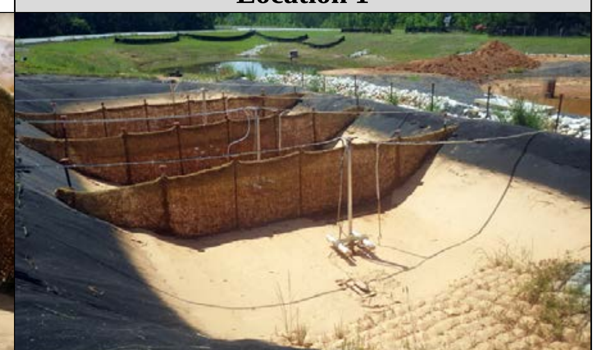
Location 5



Location 1

Location 6

Location 7



Location 8

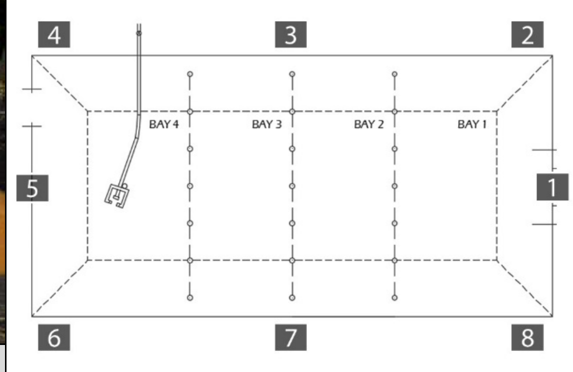
POST-TEST PHOTO DOCUMENTATION


Location 4


Location 3


Location 2


Location 5




Location 1

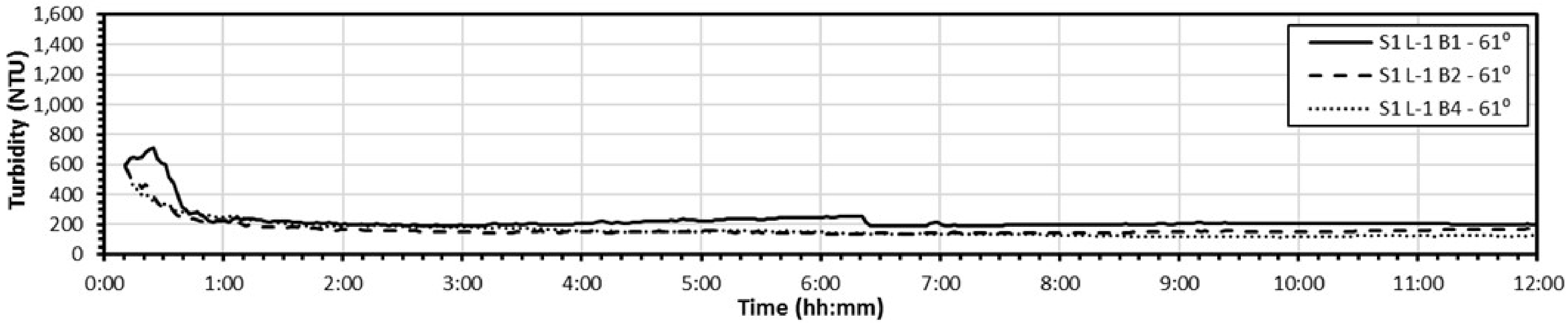

Location 6


Location 7

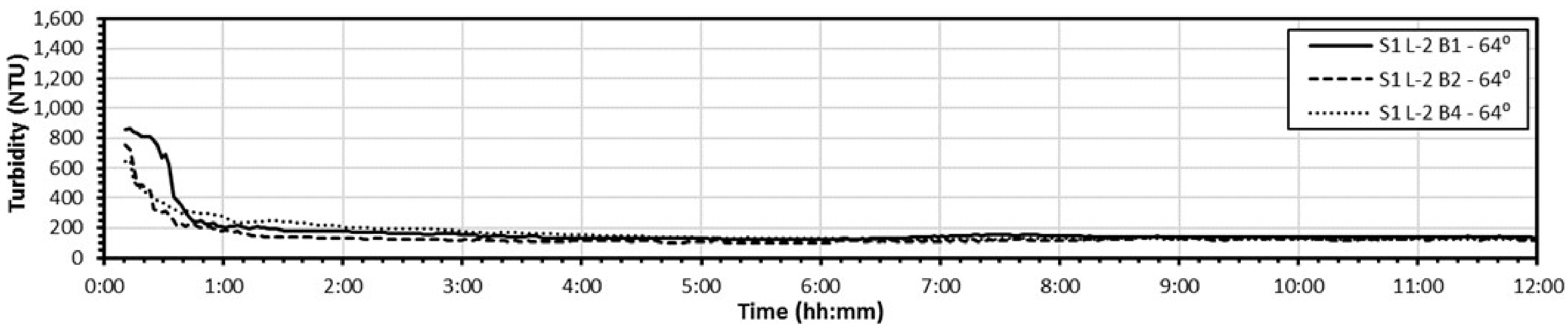

Location 8

APPENDIX D

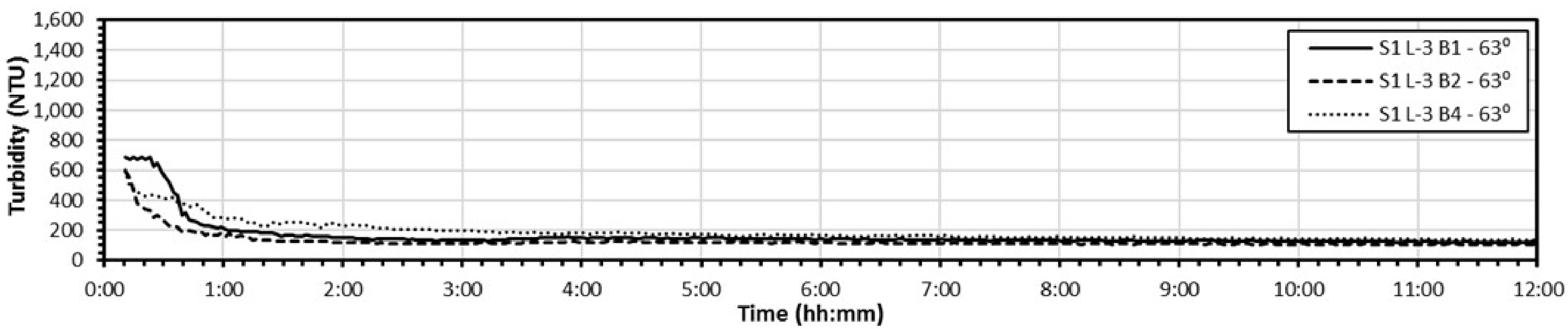
Sediment Basin Turbidity Data



(a) L-1

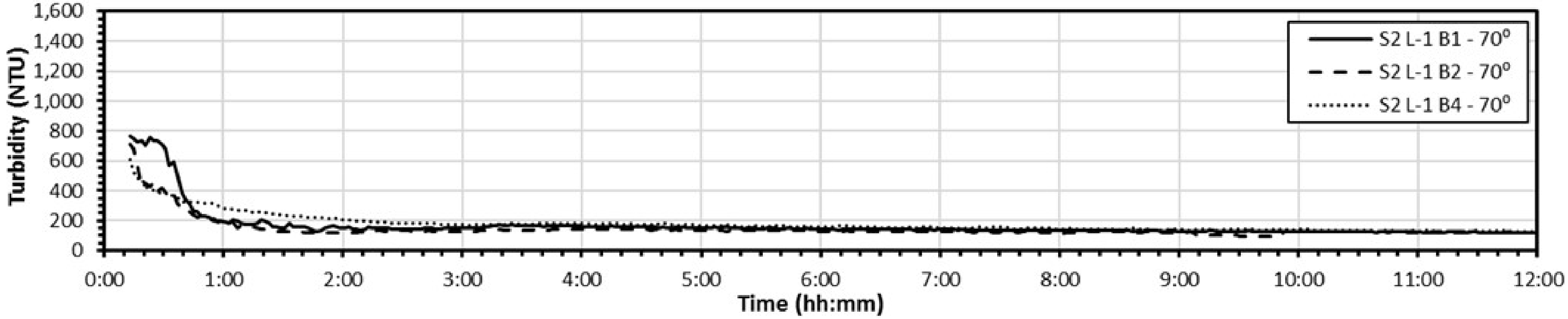


(b) L-2

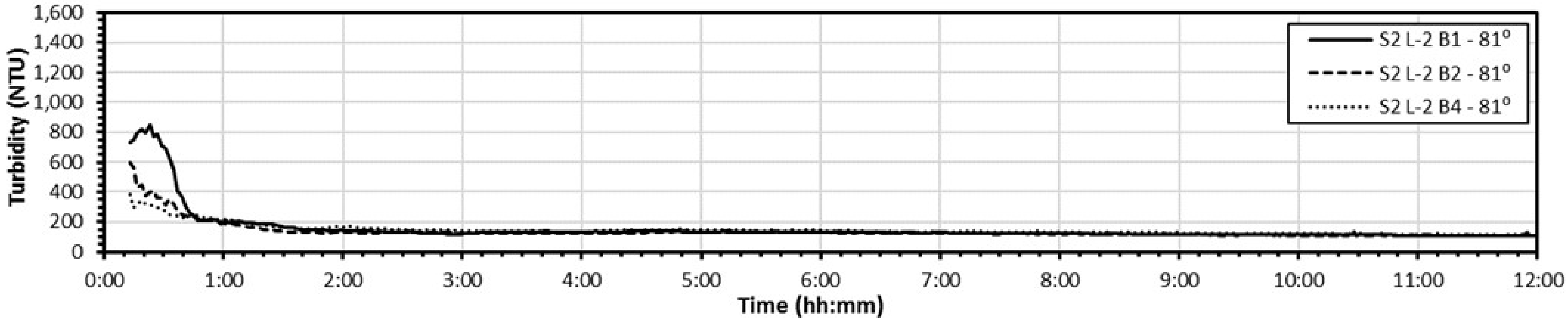


(c) L-3

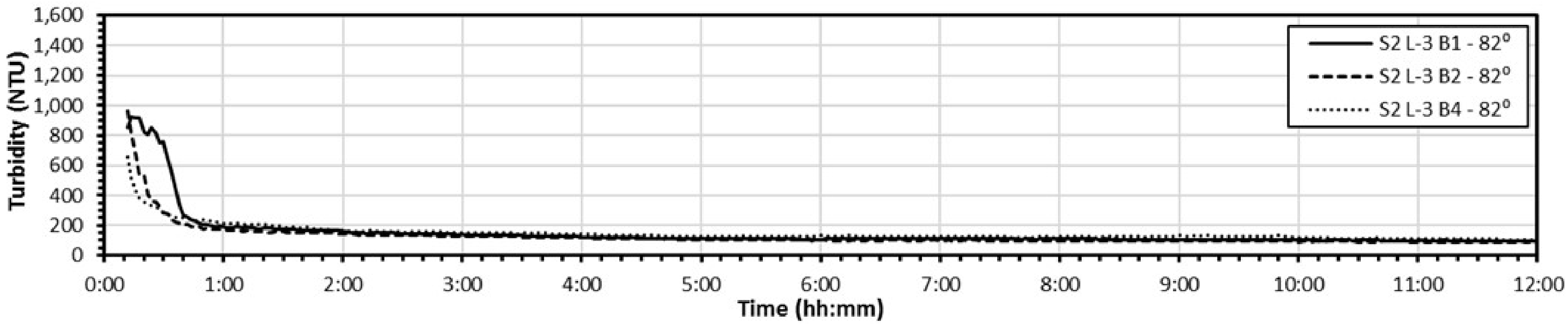
S1: ALDOT Standard without Excavated Sump



(a) L-1

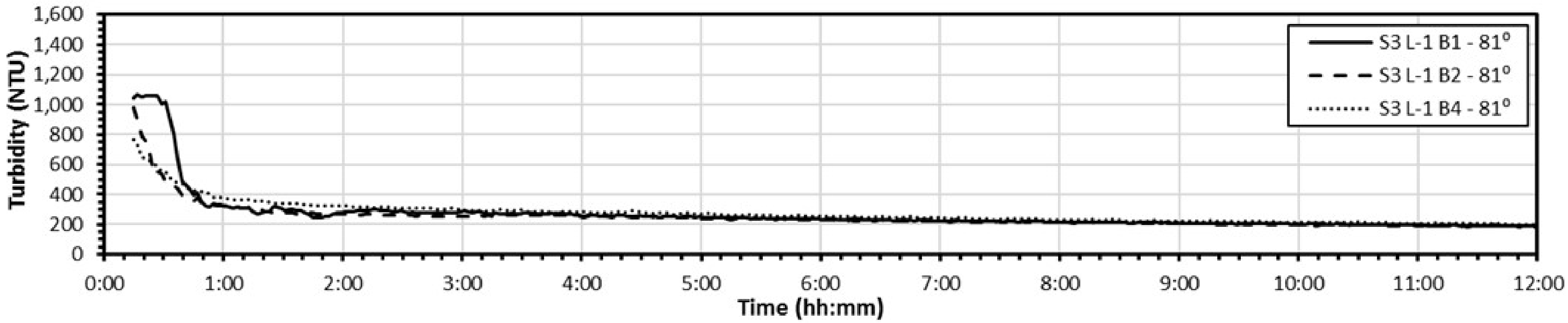


(b) L-2

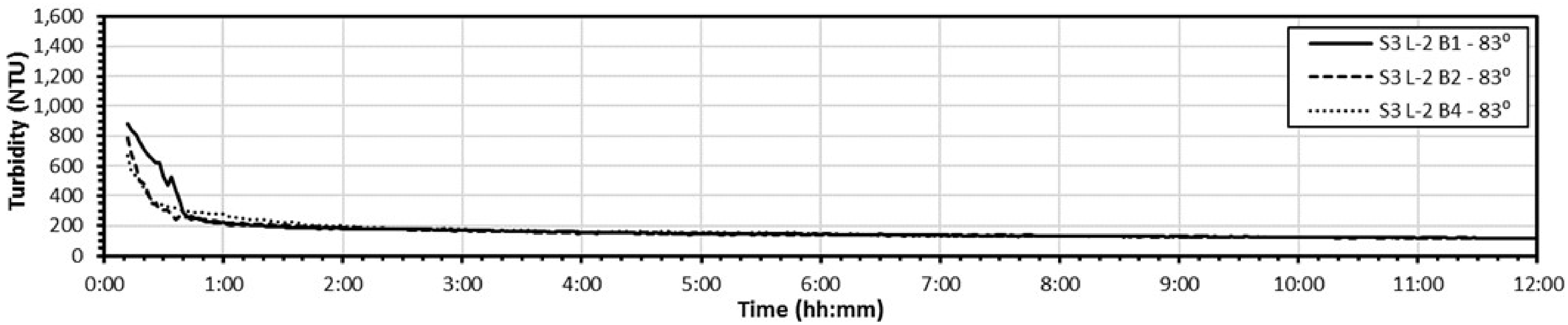


(c) L-3

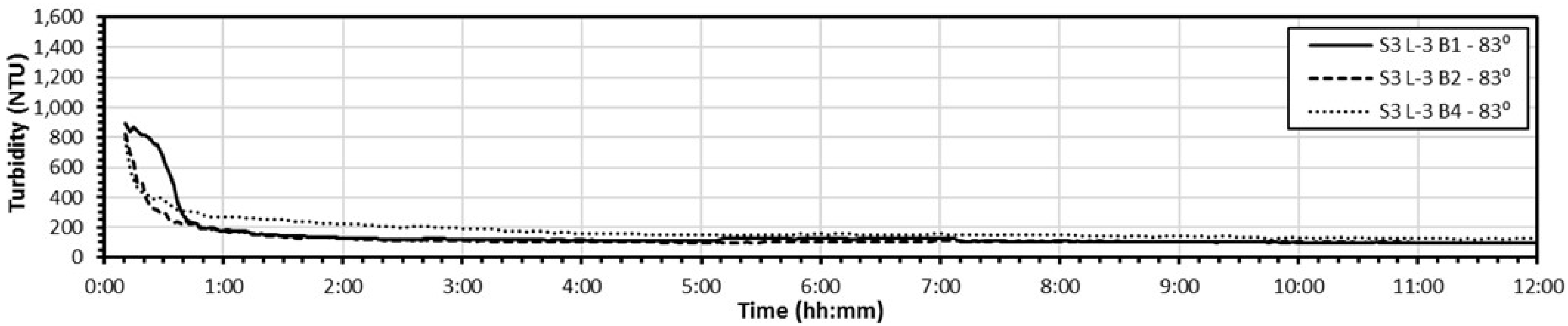
S2: ALDOT Standard + Sump



(a) L-1

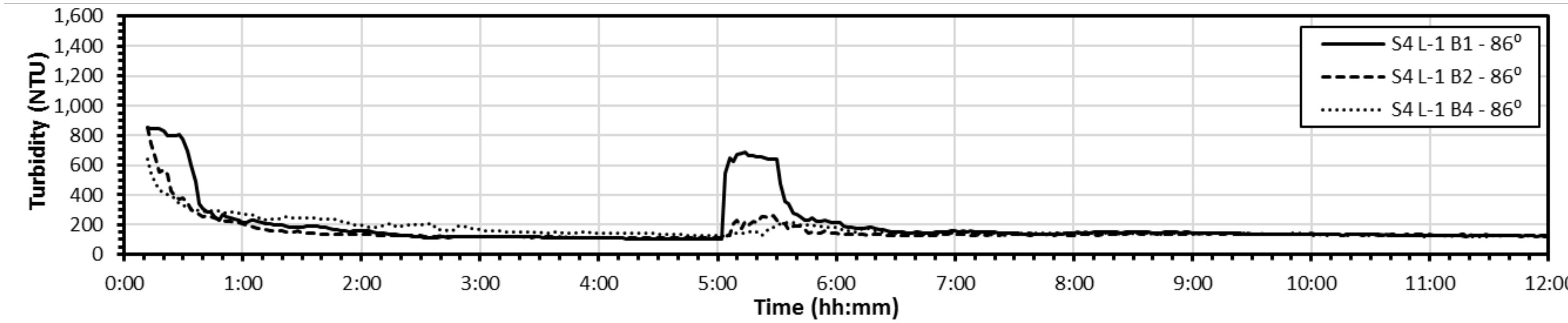


(b) L-2

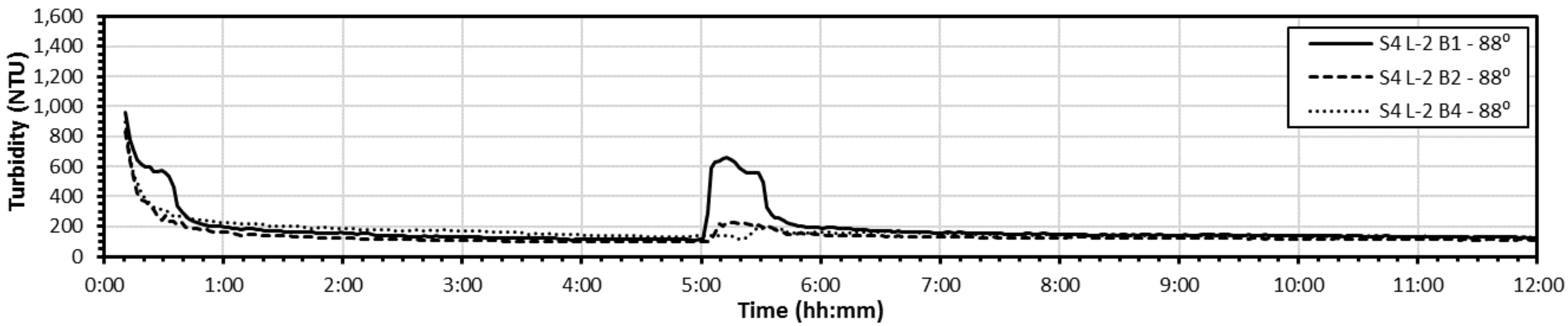


(c) L-3

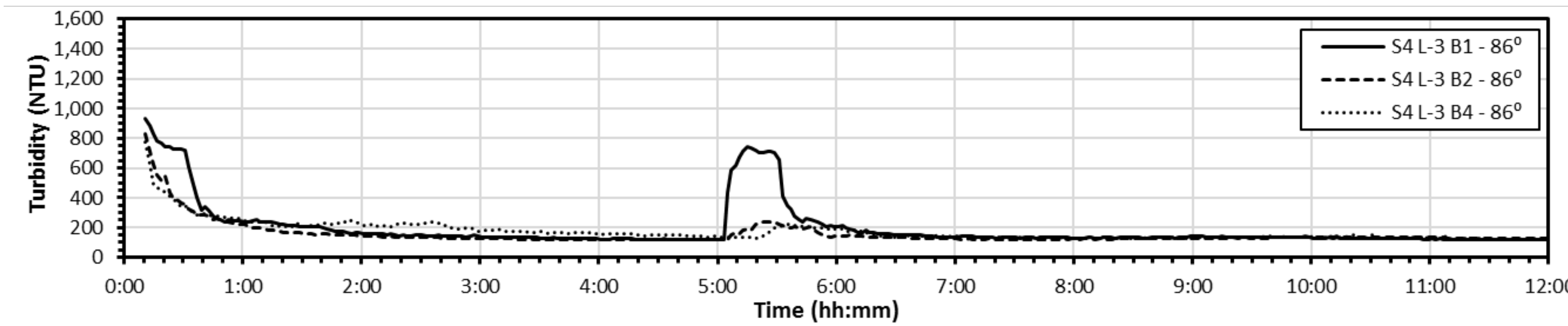
S3: ALDOT Standard + Excavated Sump + Modified First Baffle



(a) L-1

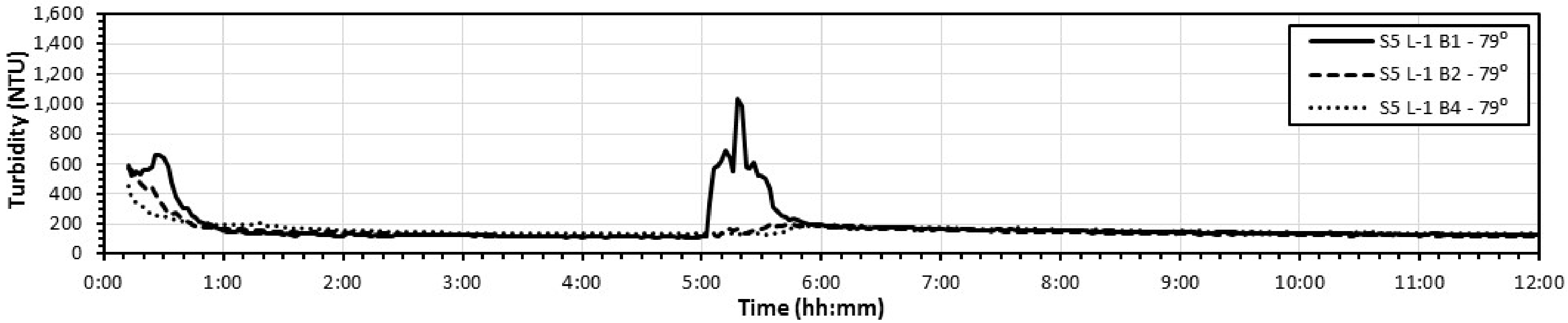


(b) L-2

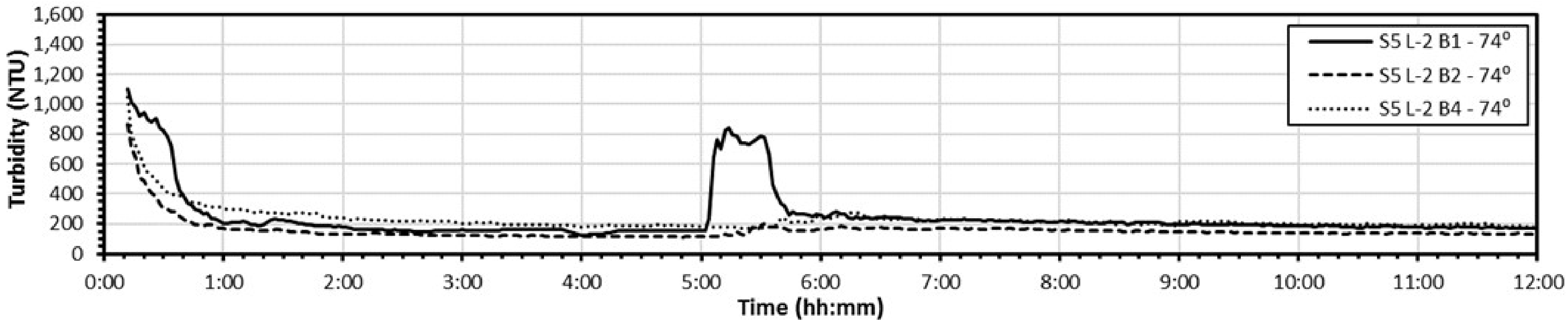


(c) L-3

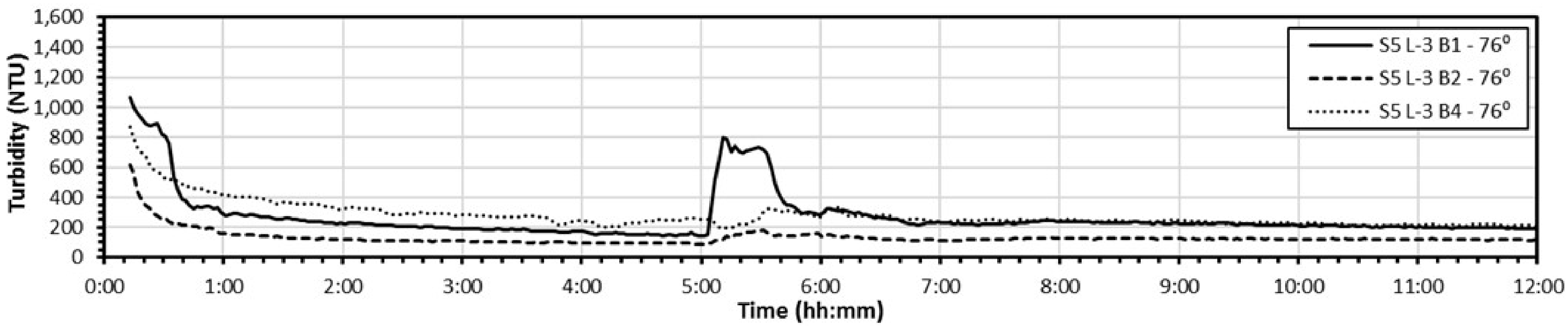
S4: ALDOT Standard + Excavated Sump + Modified First Baffle [overflow]



(a) L-1

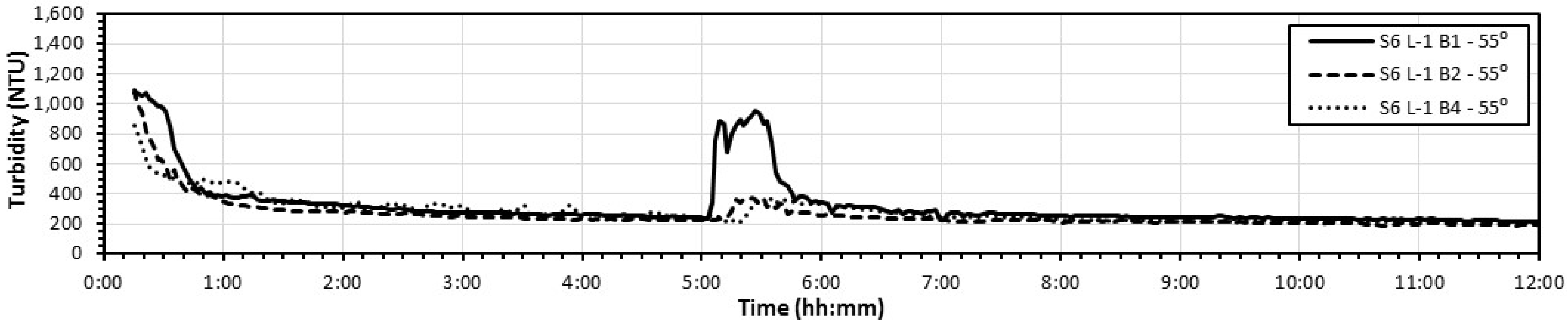


(b) L-2

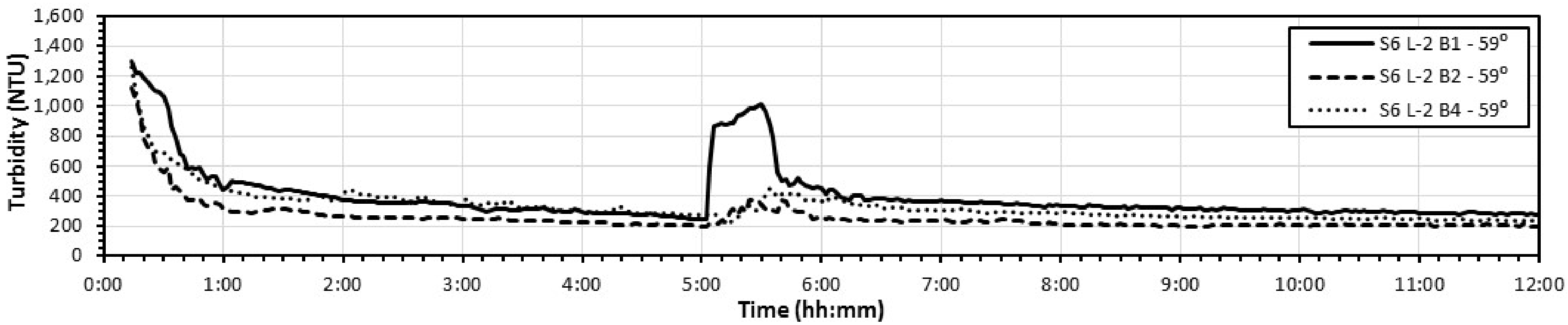


(c) L-3

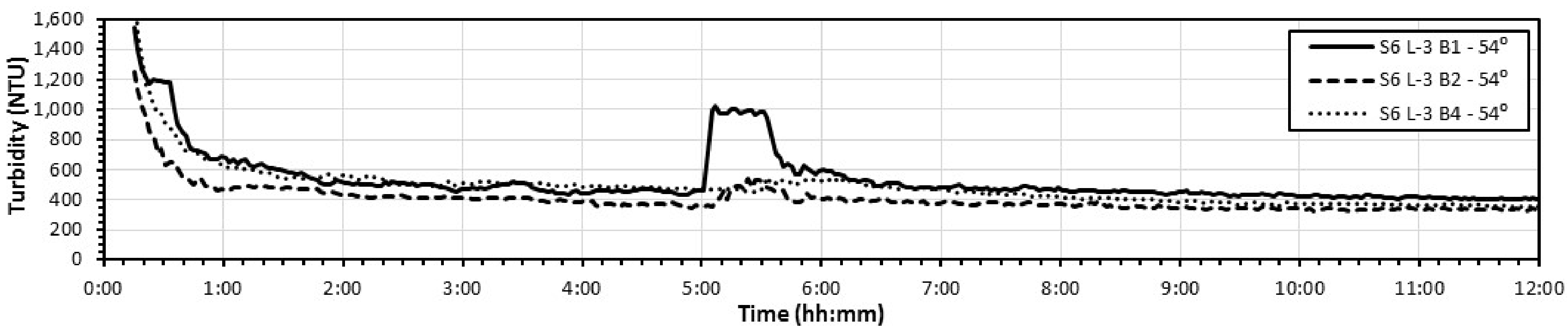
S5: ALDOT Standard + Sump [overflow]



(a) L-1

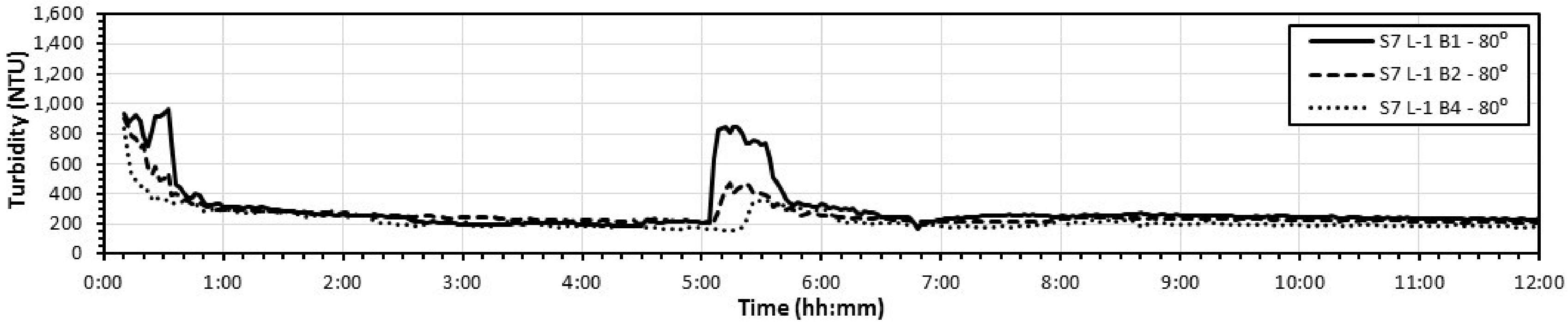


(b) L-2

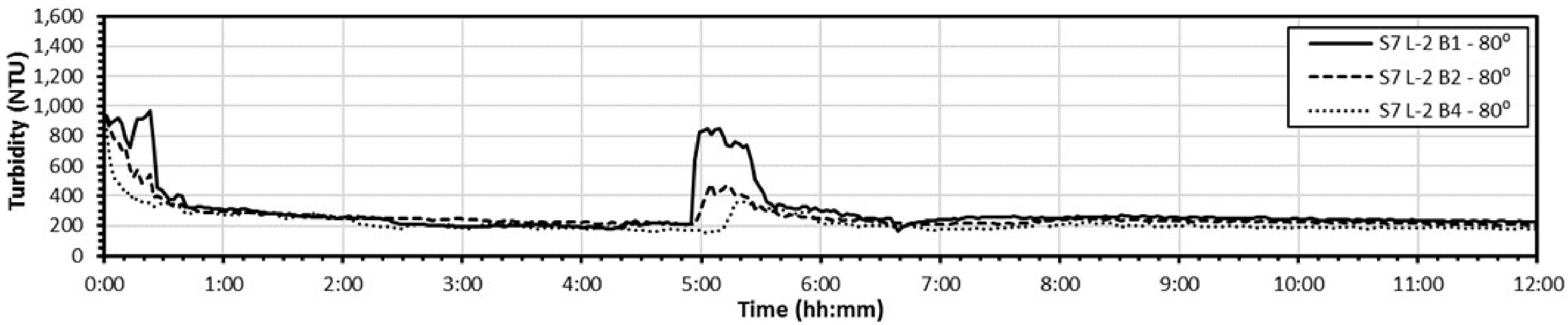


(c) L-3

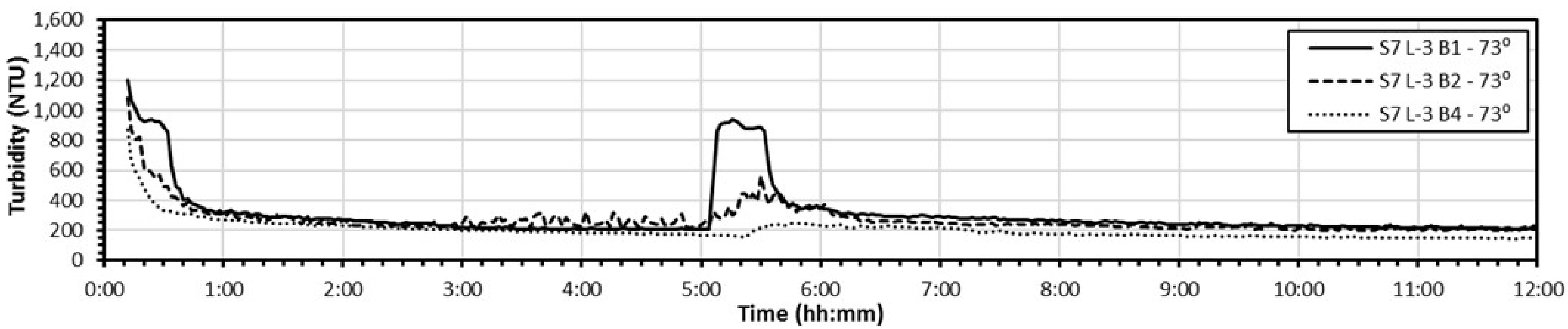
S6: Lamella Settler, Upward Flow [overflow]



(a) L-1



(b) L-2

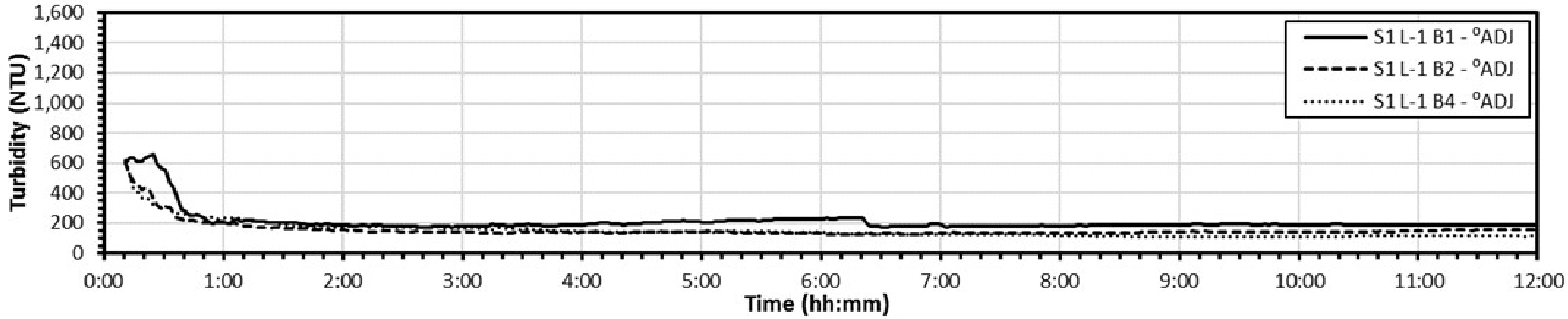


(c) L-3

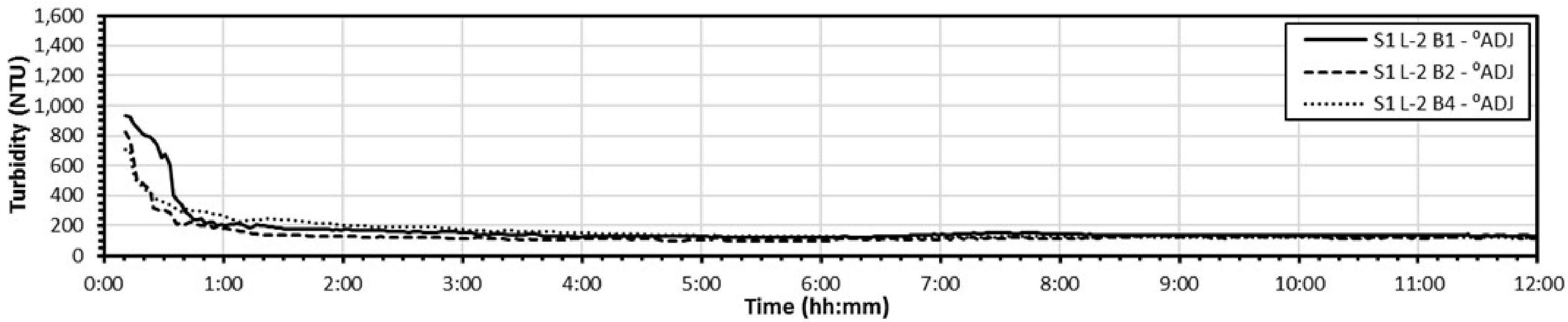
S7: Lamella Settler, Parallel Flow [overflow]

APPENDIX E

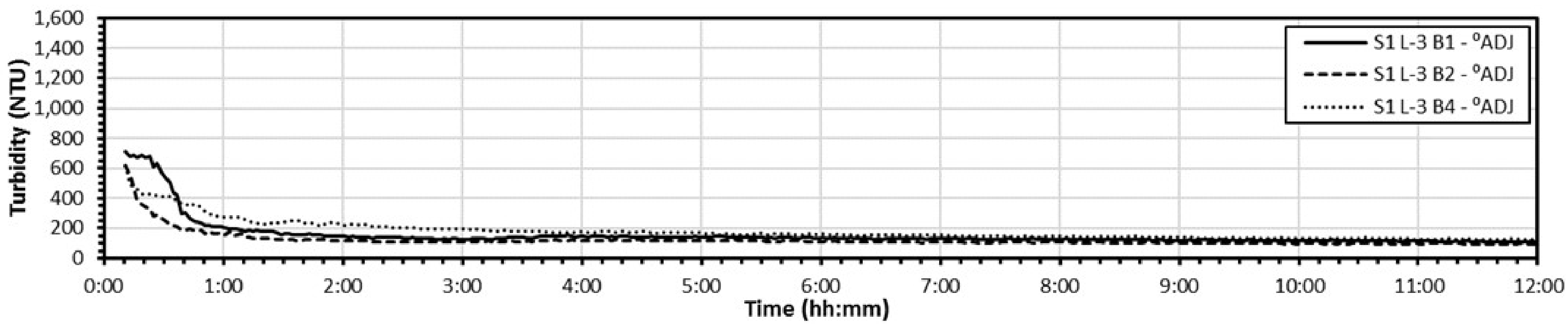
Temperature Normalized Sediment Basin Turbidity Data



(a) L-1

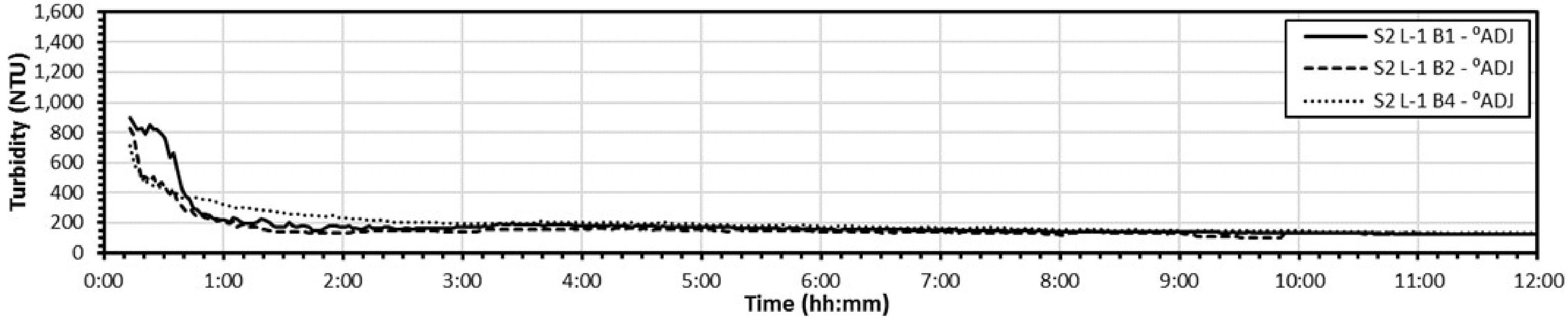


(b) L-2

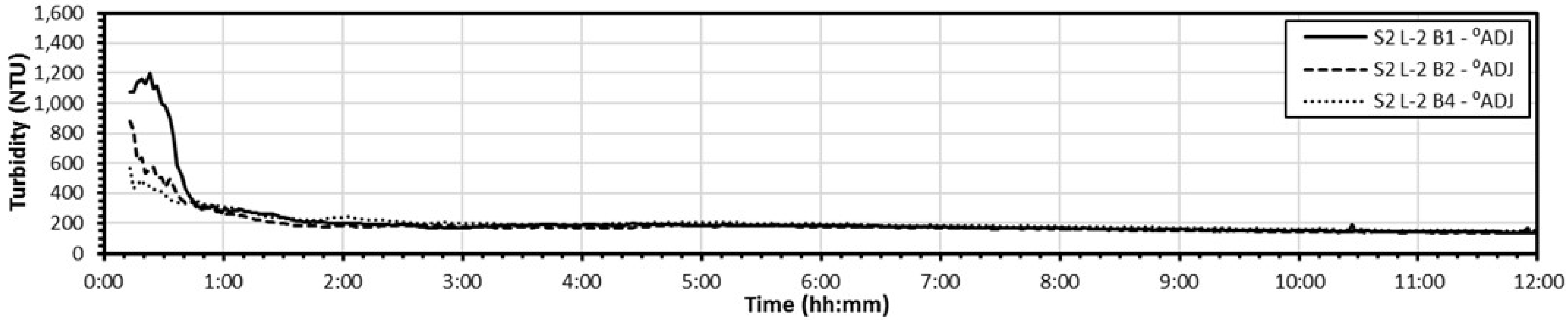


(c) L-3

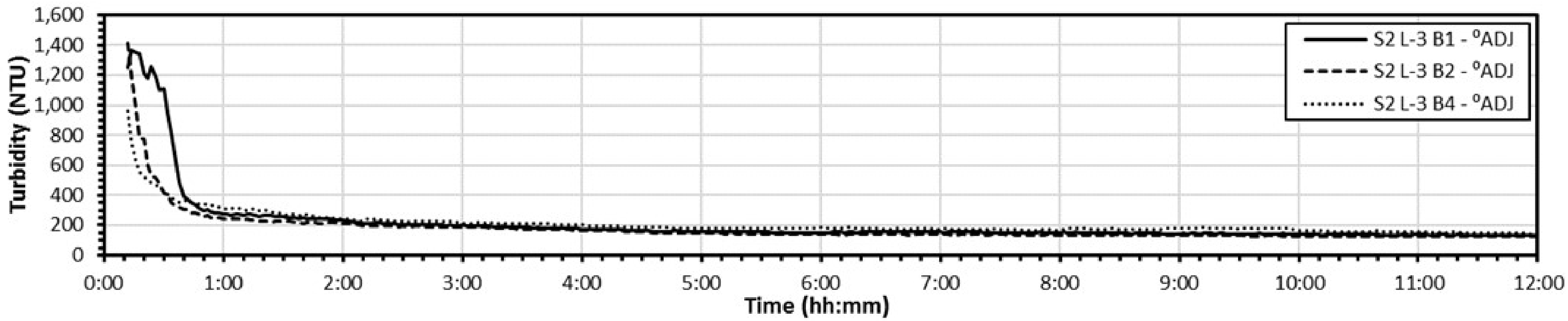
S1: ALDOT Standard without Excavated Sump, Temperature Adjusted



(a) L-1

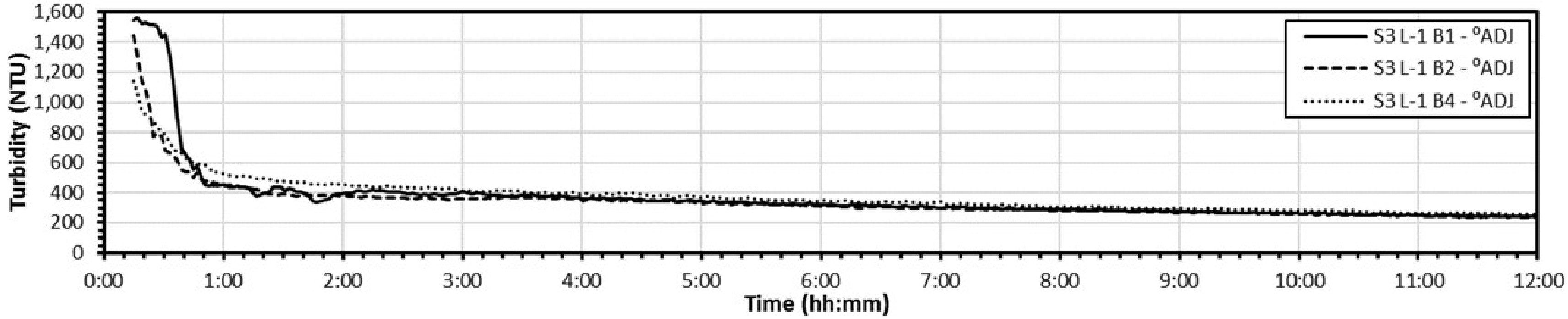


(b) L-2

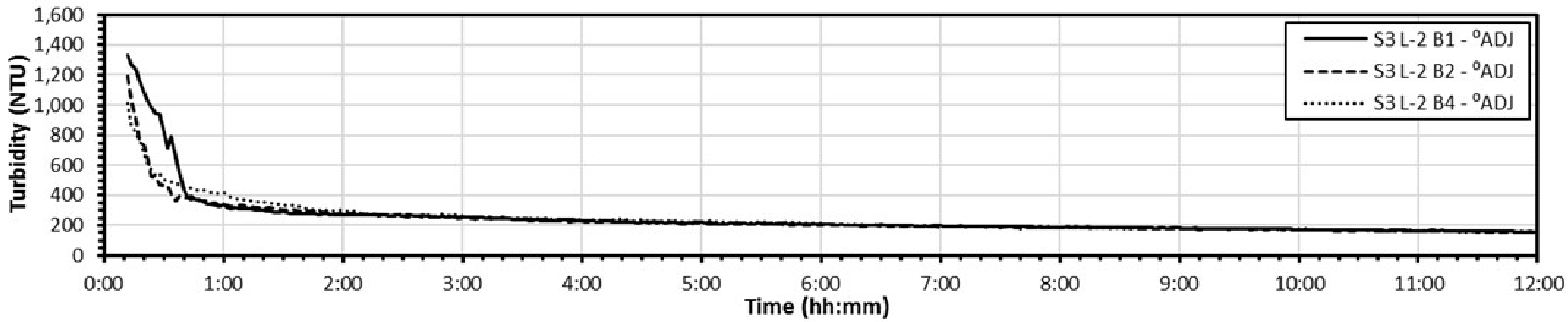


(c) L-3

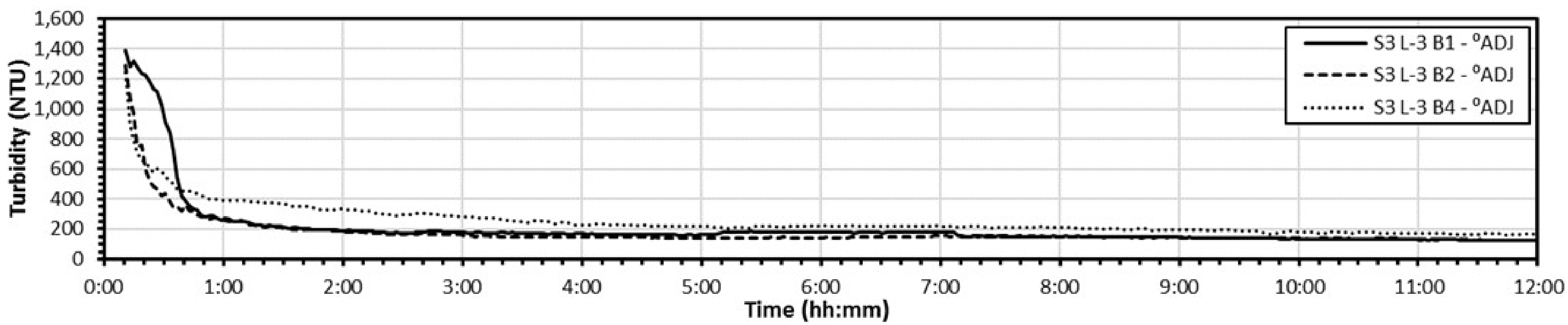
S2: ALDOT Standard + Sump, Temperature Adjusted



(a) L-1

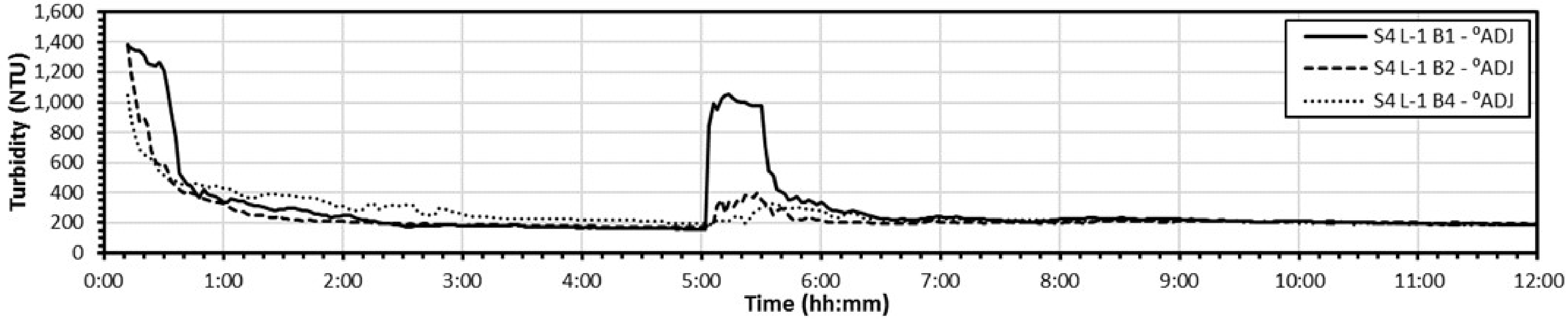


(b) L-2

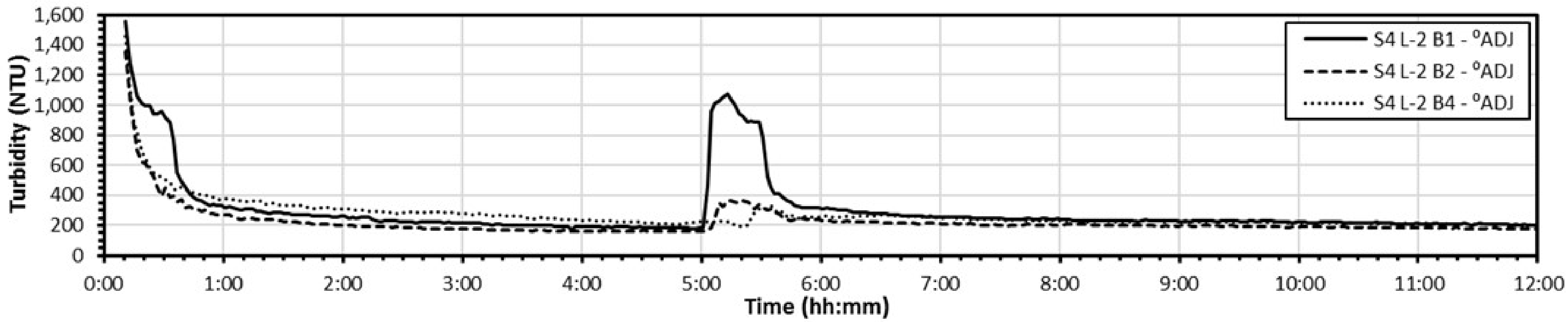


(c) L-3

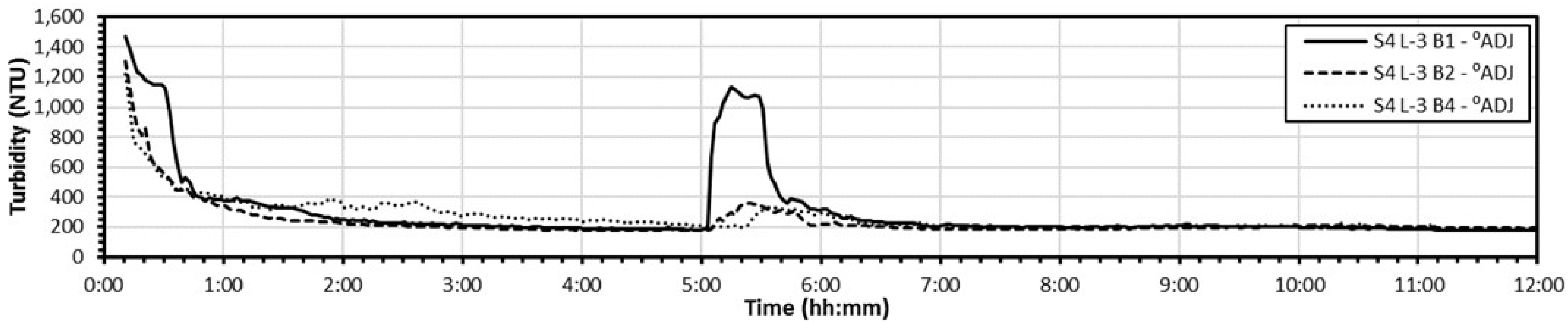
S3: ALDOT Standard + Excavated Sump + Modified First Baffle, Temperature Adjusted



(a) L-1

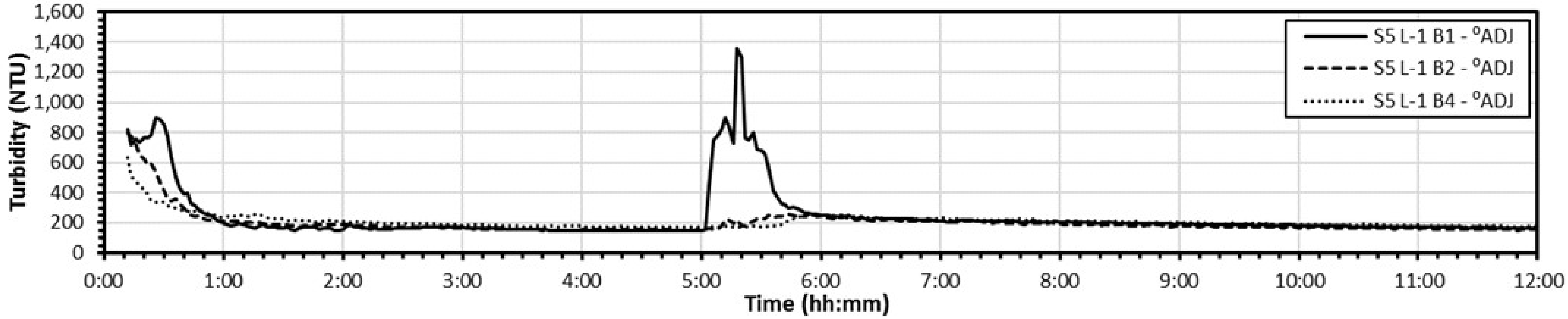


(b) L-2

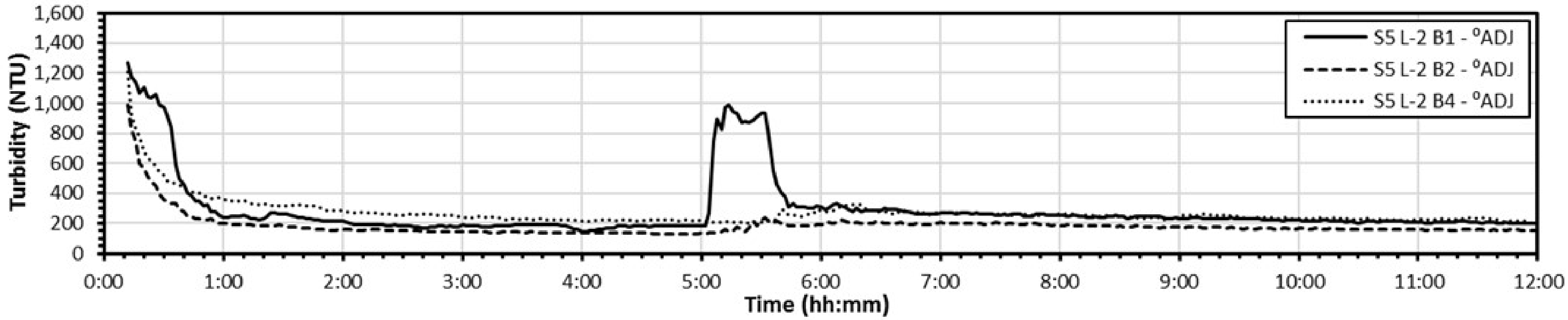


(c) L-3

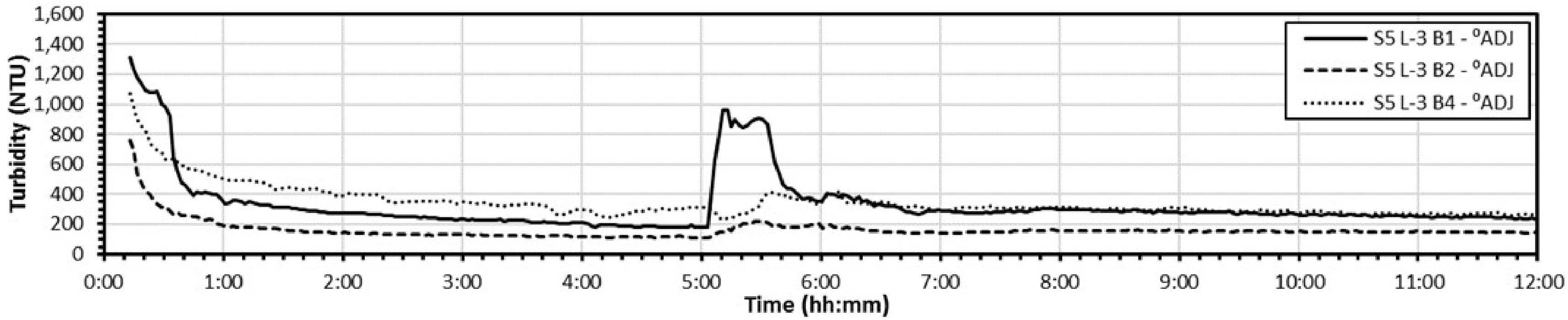
S4: ALDOT Standard + Excavated Sump + Modified First Baffle [overflow], Temperature Adjusted



(a) L-1

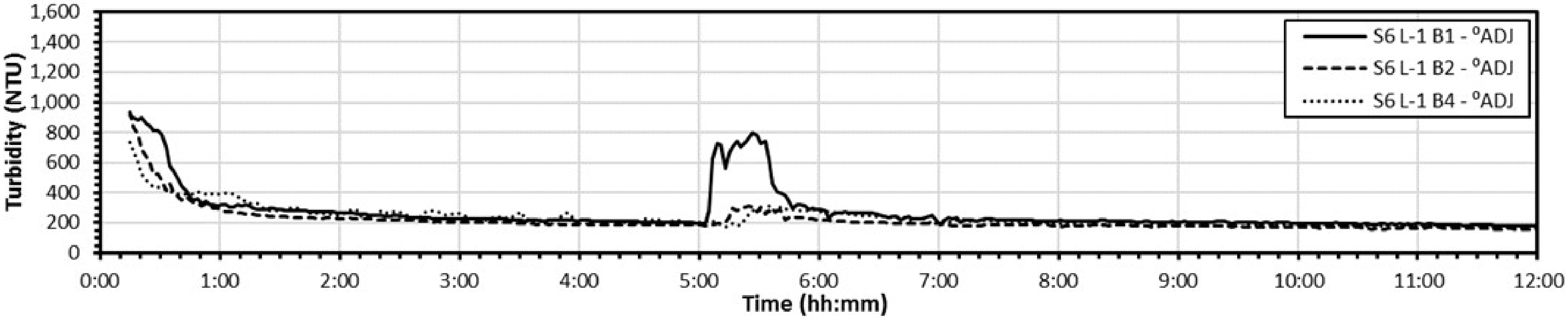


(b) L-2

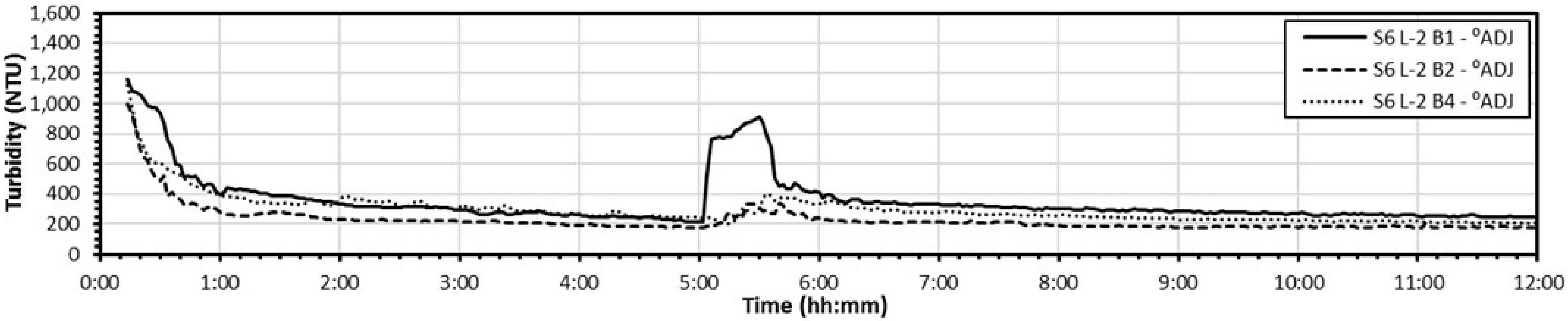


(c) L-3

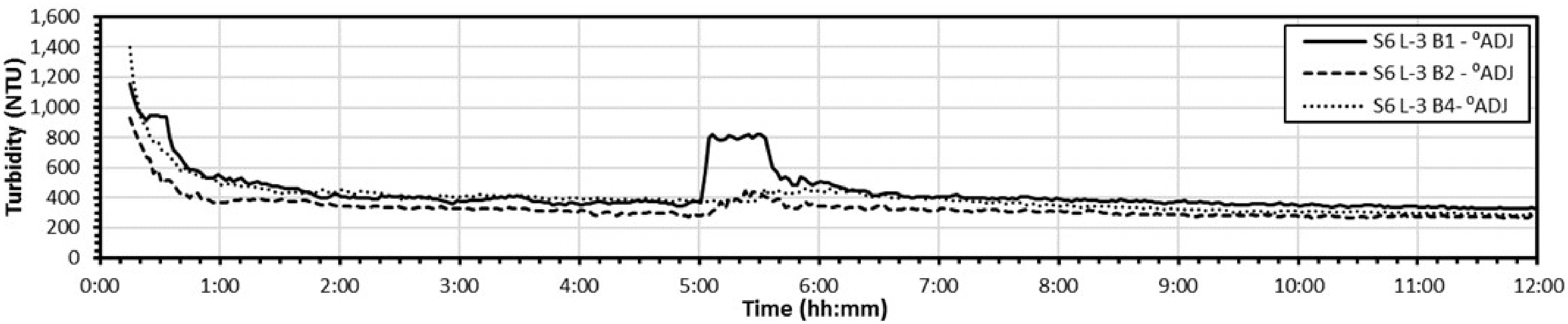
S5: ALDOT Standard + Sump [overflow], Temperature Adjusted



(a) L-1

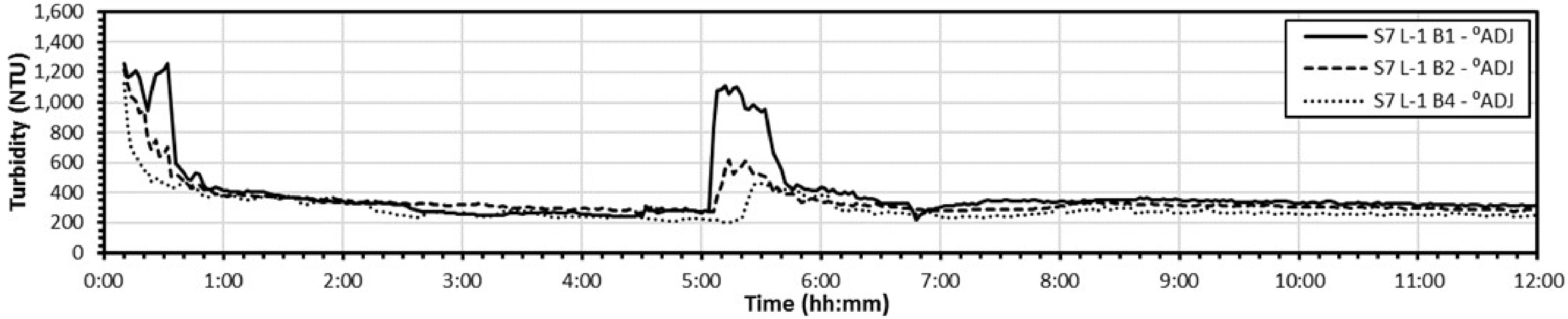


(b) L-2

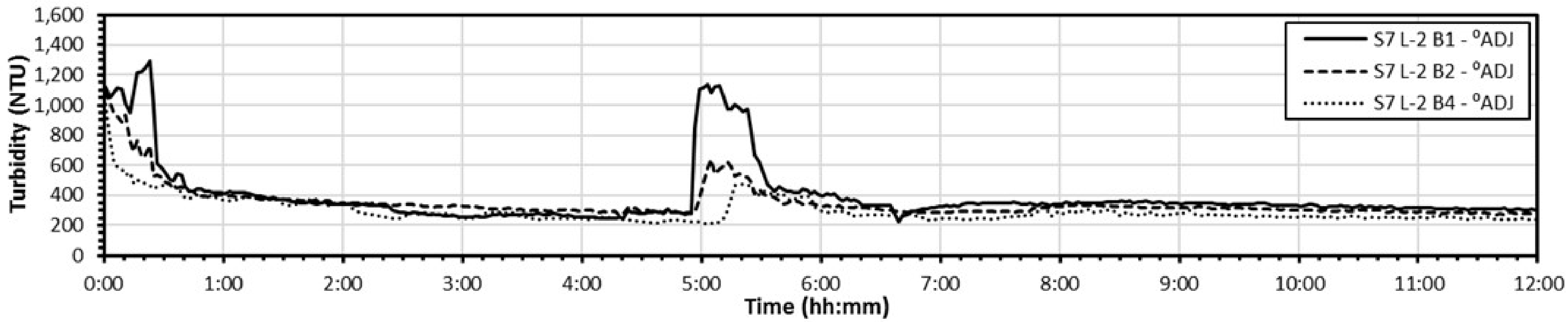


(c) L-3

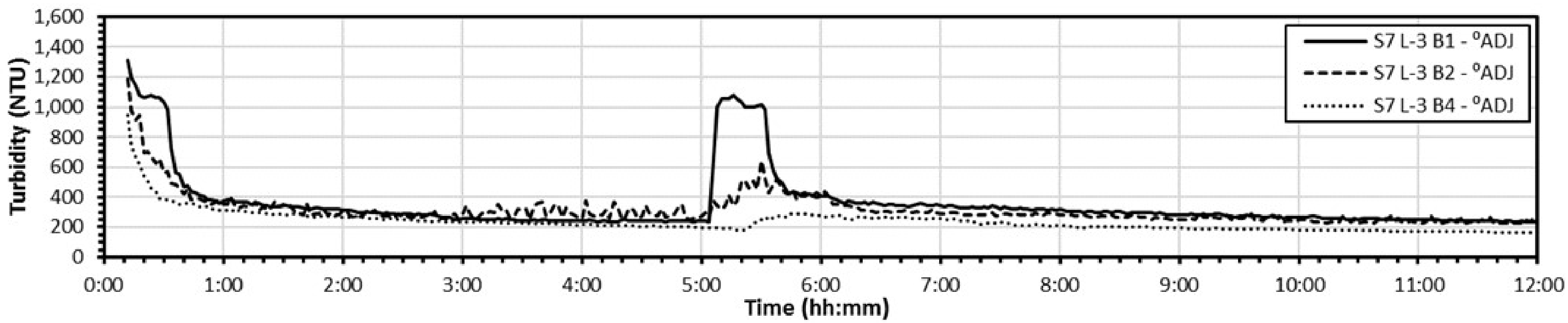
S6: Lamella Settler, Upward Flow [overflow], Temperature Adjusted



(a) L-1



(b) L-2

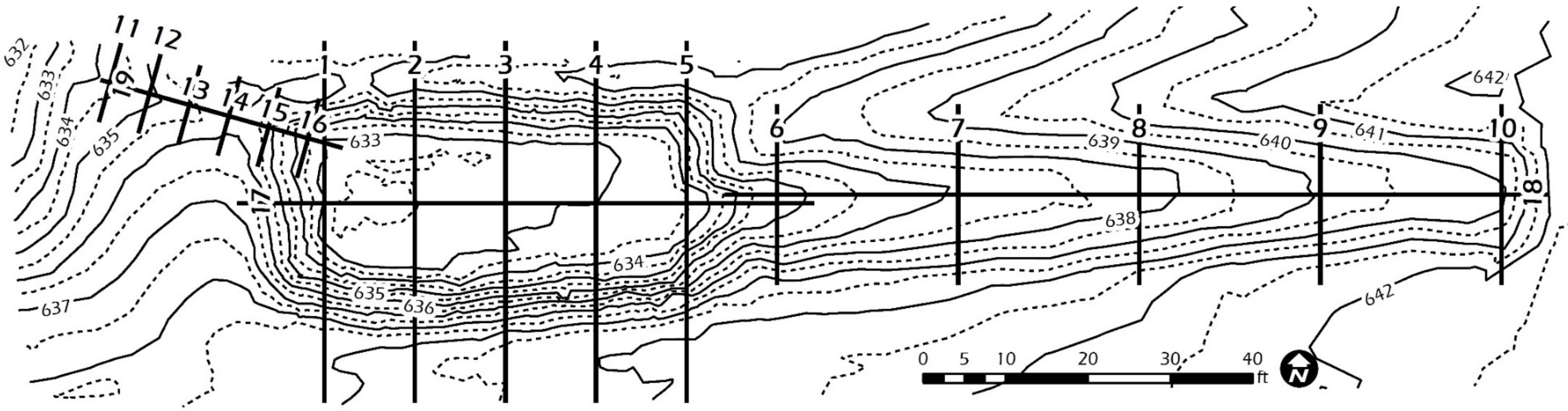


(c) L-3

S7: Lamella Settler, Parallel Flow [overflow], Temperature Adjusted

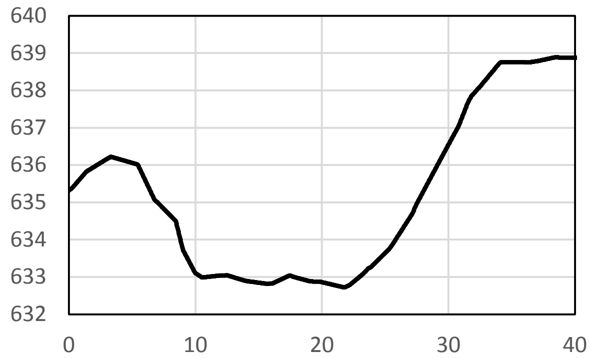
APPENDIX F

As-Built Sediment Basin Survey

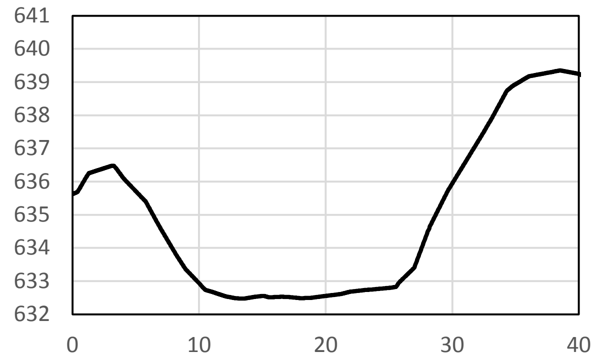


Sediment Basin Topography and Cross Sections

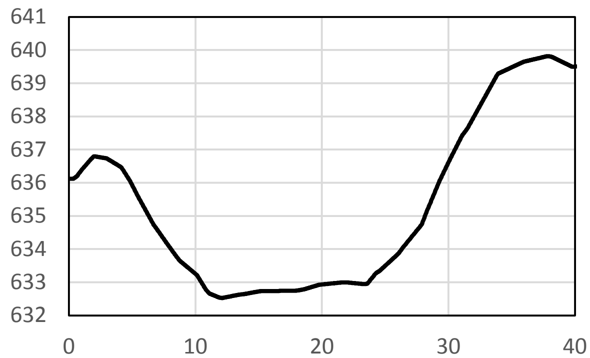
CS-1



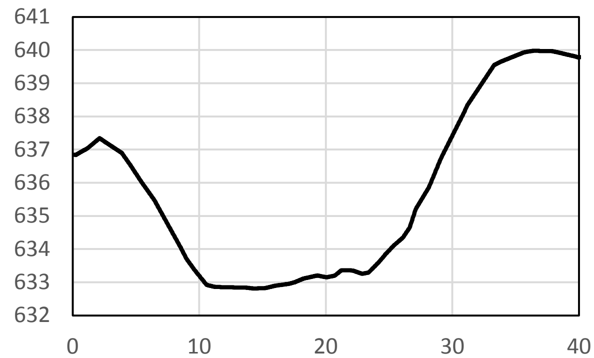
CS-2



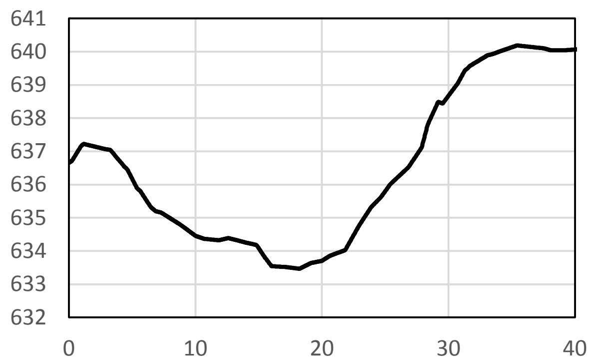
CS-3



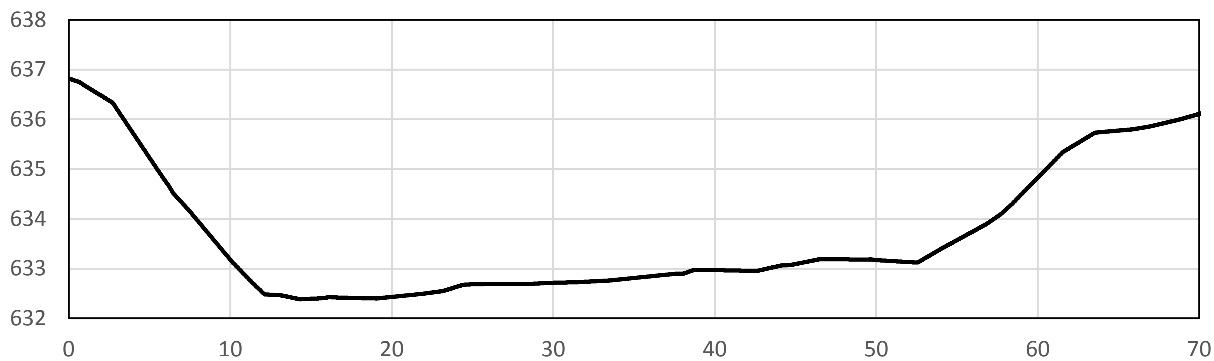
CS-4



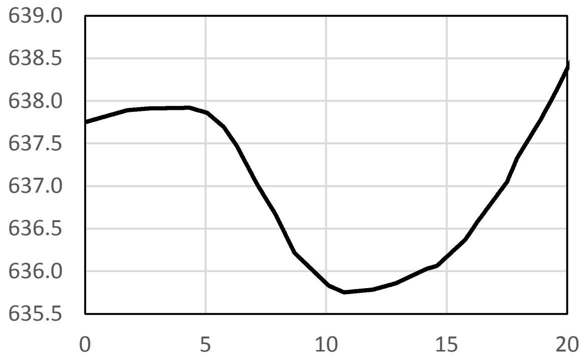
CS-5



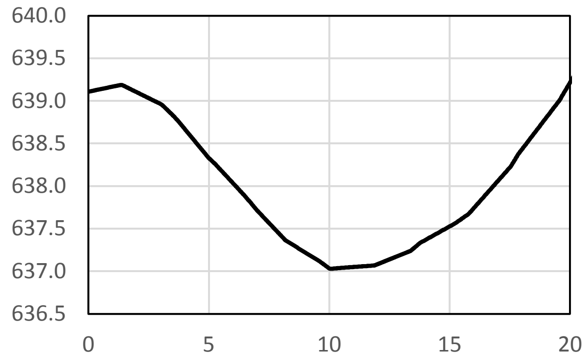
CS-17



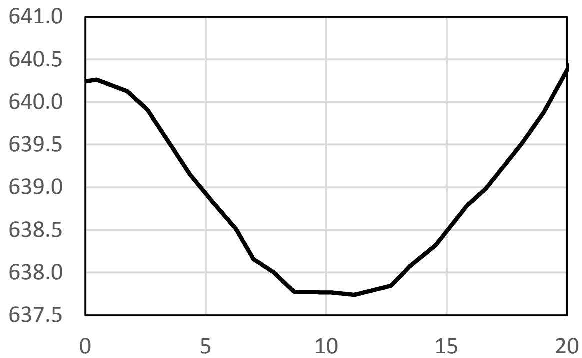
CS-6



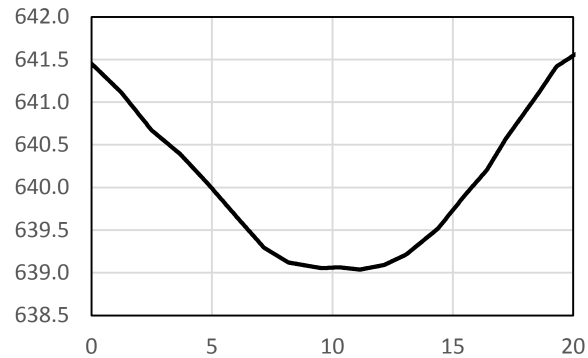
CS-7



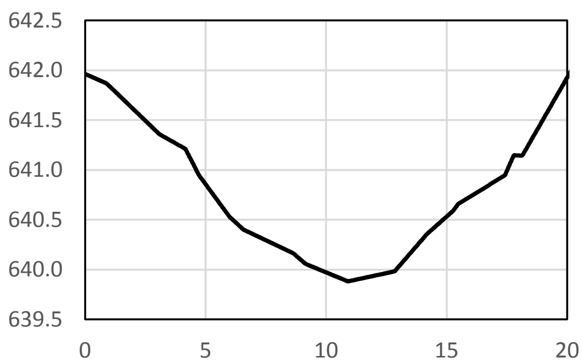
CS-8



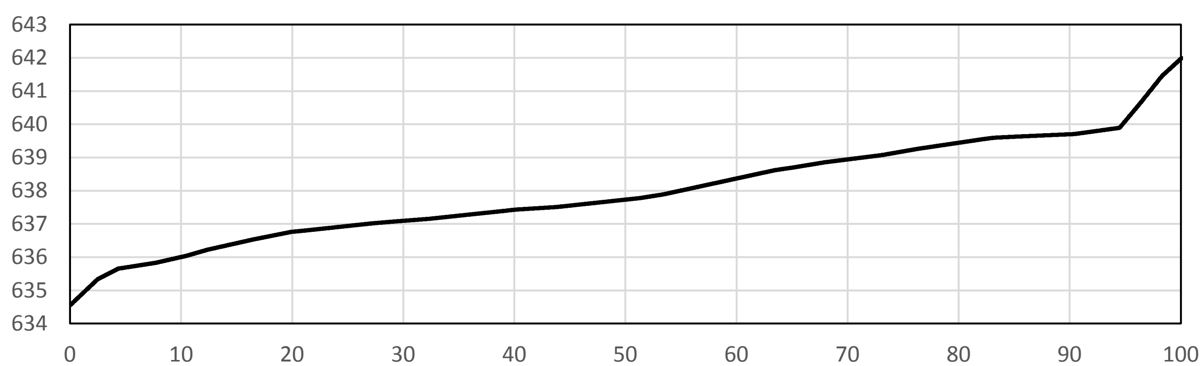
CS-9



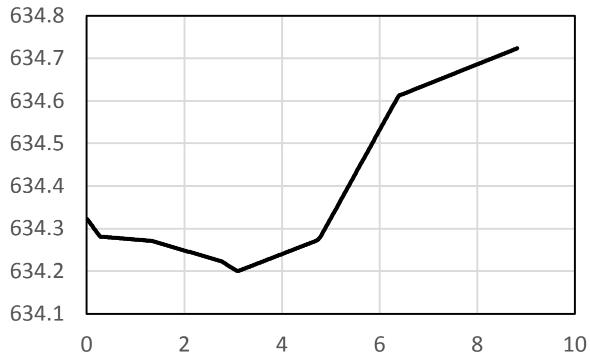
CS-10



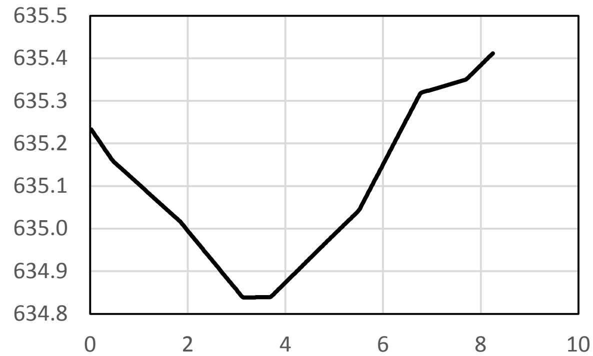
CS-18



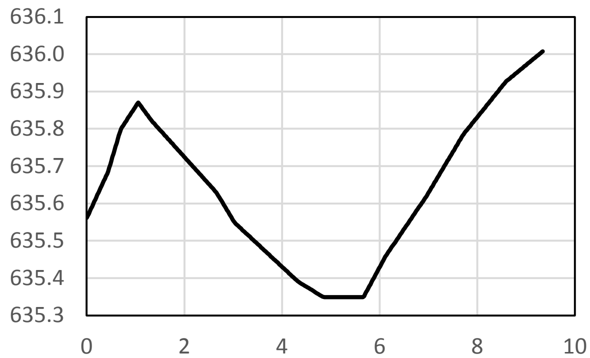
CS-11



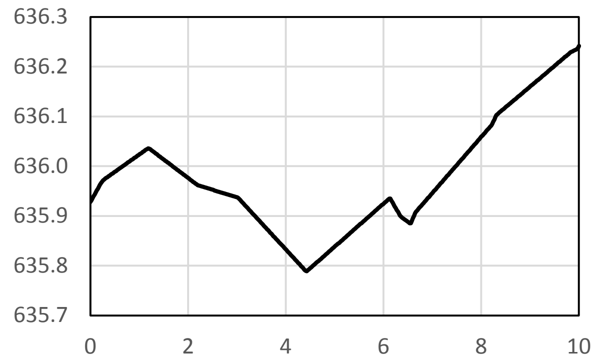
CS-12



CS-13

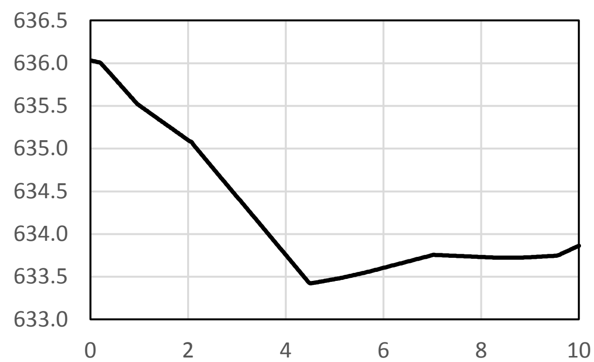


CS-14



CS-15

CS-16



CS-19