Evaluation of Sediment Basin Performance using Large-Scale Testing Techniques

Final Report
April 2022

AUBURN UNIVERSITY
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16. Abstract

The Iowa DOT is required to develop stormwater pollution prevention plans (SWPPPs) to minimize the risk of downstream pollution emanating from highway construction, as specified in the National Pollutant Discharge Elimination System General Permit No. 2 (NPDES Permit). The Iowa DOT commonly employs temporary sediment control basins to detain sediment from stormwater runoff before discharge. Sediment basins can be effective in capturing sediment if properly designed and implemented. The current Iowa DOT temporary sediment control basin standard specifies constructing an earthen dam across a conveyance channel to create an impoundment favorable for sedimentation, which is dewatered through a perforated riser pipe and auxiliary spillway. Results from the 18-SPR1-001 erosion and sediment control field monitoring project indicated that the installed and monitored temporary sediment control basins provided negligible turbidity and total suspended solids reduction when comparing inflow and discharge samples. Enhancements to the current design of sediment control basins could provide improved performance and reduce the sediment load discharged from Iowa DOT managed sites. Researchers at the Auburn University - Stormwater Research Facility examined the performance of an in-channel sediment basin design in response to several structural and chemical treatments to emulate an installation in an existing roadside conveyance channel. To quantify sediment retention and water quality performance, treatments were evaluated through large-scale, controlled flow and sediment introduction testing. Treatments included: (1) geotextile lining, (2) a floating surface skimmer, (3) porous flow baffles, (4) an upstream forebay, and (5) application of flocculant. Sediment retention was reported as high as 96% by weight when an upstream forebay, geotextile lining, surface skimmer, and surface were used as a system and 98% when flocculant was added to the basin. The sediment retention can be compared to 76% capture when only a geotextile liner was used. When flocculant was applied, turbidity reduction increased by 42%, and discharge turbidities were consistently below 100 NTU during dewatering periods. Flocculant reduced the captured D_{50} particle size by four times, on average, indicating that flocculant aids in the capture of fine-sized soil particles, which may decrease the required footprint for installation, required storage volume, and detention times in basins. In addition to experimental testing, a spreadsheet-based tool was developed to aid in implementing in-channel sediment basins and in the design of structural and chemical components that enhanced sediment capture and turbidity reduction. This research indicates that in-channel sediment basins are effective with proper design, installation, and maintenance. Improved sediment basin designs are expected to minimize sediment-laden discharge. It is anticipated that an in-channel sediment basin design may be adopted as an alternative basin design outside of Iowa due to minimized land easement and use of existing infrastructure contributing to decreased costs.

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EVALUATION OF SEDIMENT BASIN PERFORMANCE USING LARGE-SCALE TESTING TECHNIQUES

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Principal Investigator
Michael A. Perez, Ph.D., P.E., CPESC
Assistant Professor of Construction Engineering
Department of Civil and Environmental Engineering, Auburn University

Co-Principal Investigators
Wesley N. Donald, Ph.D., CPESC
Research Fellow
Department of Civil and Environmental Engineering, Auburn University

Xing Fang, Ph.D., P.E.
Arthur H. Feagin Chair Professor of Civil and Environmental Engineering
Department of Civil and Environmental Engineering, Auburn University

Graduate Research Assistant
Jaime Schussler, M.S.
Department of Civil and Environmental Engineering, Auburn University

Authors
Jaime Schussler, Michael A. Perez, Wesley N. Donald, and Xing Fang

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A report from:

Highway Research Center
Auburn University
238 Harbert Center
Auburn, AL 36849
Phone: (334) 844-4320
www.eng.auburn.edu/research/centers/hrc/

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NOMENCLATURE

AASHTO	American Association of Highway and Transportation Officials
ALDOT	Alabama Department of Transportation
AL-SWCC	Alabama Soil and Water Conservation Committee
ANOVA	Analysis of Variance
AU-SRF	Auburn University Stormwater Research Facility
CGP	Construction General Permit
CN	Curve Number
DOT	Department of Transportation
DNR	Department of Natural Resources
E&SC	Erosion and Sediment Control
HSG	Hydrologic Soil Groups
Iowa DOT	Iowa Department of Transportation
MUSLE	Modified Universal Soil Loss Equation
NCAT	National Center for Asphalt Technology
NPDES	National Pollutant Discharge Elimination System
NTU	Nephelometric Turbidity Unit
RUSLE	Revised Universal Soil Loss Equation
SWPPP	Stormwater Pollution Prevention Plan
TRM	Turf Reinforcement Mat
TS	Total Solids
TSS	Total Suspended Solids
USCS	Unified Soil Classification System
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency

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EXECUTIVE SUMMARY

The Iowa DOT is required to develop stormwater pollution prevention plans (SWPPPs) to minimize the risk of downstream pollution emanating from highway construction, as specified in the National Pollutant Discharge Elimination System General Permit No. 2 (NPDES Permit). The Iowa DOT commonly employs temporary sediment control basins to detain sediment from stormwater runoff before discharge. Sediment basins can be effective in capturing sediment if properly designed and implemented. The current Iowa DOT temporary sediment control basin standard specifies constructing an earthen dam across a conveyance channel to create an impoundment favorable for sedimentation, which is dewatered through a perforated riser pipe and auxiliary spillway. Results from the 18-SPR1-001 erosion and sediment control field monitoring project indicated that the installed and monitored temporary sediment control basins provided negligible turbidity and total suspended solids reduction when comparing inflow and discharge samples. Enhancements to the current design of sediment control basins could provide improved performance and reduce the sediment load discharged from Iowa DOT managed sites.

Researchers at the Auburn University - Stormwater Research Facility examined the performance of an in-channel sediment basin design in response to several structural and chemical treatments to emulate an installation in an existing roadside conveyance channel. To quantify sediment retention and water quality performance, treatments were evaluated through large-scale, controlled flow and sediment introduction testing. Treatments included: (1) geotextile lining, (2) a floating surface skimmer, (3) porous flow baffles, (4) an upstream forebay, and (5) application of flocculant. Sediment retention was reported as high as 96% by weight when an upstream forebay, geotextile lining, and surface skimmer were used as a system and 98% when flocculant was added to the basin. The sediment retention can be compared to 76% capture when only a geotextile liner was used. When flocculant was applied, turbidity reduction increased by 42%, and discharge turbidities were consistently below 100 NTU during dewatering periods. Flocculant reduced the captured D50 particle size by four times, on average, indicating that flocculant aids in the capture of fine-sized soil particles, which may decrease the required footprint for installation, required storage volume, and detention times in basins. In addition to experimental testing, a spreadsheet-based tool was developed to aid in implementing in-channel sediment basins and in the design of structural and chemical components that enhanced sediment capture and turbidity reduction.

This research indicates that in-channel sediment basins are effective with proper design, installation, and maintenance. Improved sediment basin designs are expected to minimize sediment-laden discharge. It is anticipated that an in-channel sediment basin design may be adopted as an alternative basin design outside of Iowa due to minimized land easement and use of existing infrastructure contributing to decreased costs.

1. INTRODUCTION

1.1. PROBLEM STATEMENT

Earthmoving activities associated with highway construction create an increased risk of downstream pollution from stormwater runoff *(USEPA 1972, 2005, 2022)*. Erosion, and the resulting sedimentation in waterways, have become one of the nation's most significant water pollution problems. The U.S. Environmental Protection Agency (USEPA) identifies sediment, 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 2016 and IDNR 2017)*. Improved 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.

Stormwater management has become an increasingly important aspect of construction activities in the state of Iowa. The National Pollutant Discharge Elimination System General Permit No. 2 (NPDES Permit) requires the Iowa Department of Transportation (Iowa DOT) develop a stormwater pollution prevention plan (SWPPP) for all construction activities that are covered by the permit *(IDNR 2017)*. The SWPPP includes the design, installation, and maintenance of erosion and sediment control practices to minimize downstream impact from stormwater discharges.

The Iowa DOT implements a suite of erosion and sediment control practices on active job sites to minimize the offsite discharge of sediment. Detention-based practices, such as temporary sediment control basins and silt basins, capture, detain and treat stormwater by providing residence time to promote gravitational settling of suspended particles prior to off-site discharge. Detention-based practices are prevalent on Iowa DOT highway construction sites. For example, over 72 sediment basins and 450 silt basins were included in the SWPPP for the U.S. Highway 30 widening project in Tama County. Sediment basins are often installed near discharge points on construction sites and used as a final opportunity to capture, detain and polish stormwater. Other state DOTs and environmental agencies have developed enhanced standardized guidance on sediment basin design and sizing to improve their sediment capture effectiveness. Design features include volume sizing factors, typical sizing geometries, use of energy dissipaters in the form of baffles, dewatering mechanisms, and chemical treatment *(International Erosion Control Association [IECA] 2021, ALDOT 2020, North Carolina DOT [NCDOT] 2015, Tennessee DOT [TDOT] 2020)*. However, a one-size-fits-all approach is not applicable across all construction sites, as local hydrologic, soil conditions, and site constraints influence the applicability of design features. Additionally, sediment basin design and installation techniques vary regionally. The current Iowa DOT standard implements an in-channel sediment basin design that utilizes existing conveyance channels to manage stormwater and provide an opportunity to maximize length-to-width flow ratios. As a result of the use of existing infrastructure, right-of-way acquisition, installation time, and costs are reduced.

Researchers have investigated the performance of sediment basins; however, controlled experiments on large-scale sediment basins have not been widely performed. In-channel sediment performance data is particularly limited. Standardized testing methods in a controlled environment allow researchers to quantify the performance of current standard sediment basin designs while also providing efficiency and performance improvements.

This research investigated the opportunity to enhance the performance of the Iowa DOT temporary sediment control basin design by evaluating the use of innovative structural and chemical treatment features within an in-channel sediment basin. Specifically, this research aimed to quantify performance enhancement provided by implementing an upstream forebay, geotextile lining, baffles, a floating surface skimmer, and the use of flocculants. Large-scale testing was conducted at the Auburn University – Stormwater Research Facility (AU-SRF), a state-of-the-art research center dedicated to evaluating and improving the performance of erosion and sediment control practices used for highway construction applications. The results from this research are expected to improve the performance of in-channel sediment basins, significantly reduce sediment-laden discharge offsite, and provide sediment basin design alternatives for the treatment of construction site stormwater runoff.

1.2. RESEARCH OBJECTIVES AND TASKS

This in-channel sediment basin research aimed to evaluate the sediment retention and water quality performance in response to various structural and chemical treatments and to develop design guidance to enhance the efficiency of Iowa DOT stormwater management standards. The following objectives were established to accomplish this goal:

1) Develop a large-scale testing procedure and apparatus that mimics the scale and hydrologic behavior of field-installed sediment basins;

2) Understand the sediment capture and turbidity reduction of the Iowa DOT standard sediment basin design and potential improvements provided by structural and chemical basin treatments; and,

3) Develop practical and cost-effective design and construction improvements for Iowa DOT sediment basin implementation.

Six tasks were identified to meet these objectives:

1) Consult with the Iowa DOT Technical Advisory Committee to understand current sediment deficiencies, define project scope, and expected outcomes;

2) Conduct a literature review summarizing sediment basin research and catalog sediment basin features used in existing state highway stormwater management plans to refine methodology and provide additional design guidance;

3) Construct and calibrate a large-scale testing apparatus at the AU-SRF that mimics field conditions;

4) Evaluate individual structural treatments to identify components to be used in the "most feasible and effective installation (MFE-I)," evaluate MFE-I with and without chemical flocculants;

5) Analyze sediment retention and water quality data to develop design recommendations; and

6) Compile the final report to communicate findings from the literature review, experimental results, data analysis, and design recommendations.

1.3. RESEARCH SIGNIFICANCE

Developing updated sediment basin design guidance will allow Iowa DOT designers to incorporate the latest technology in construction stormwater management. This investigation of in-channel sediment basins will allow Iowa DOT to better understand the performance of the current sediment basin standard design and provide recommendations to further enhance the construction stormwater management program. Enhanced sediment basins will protect water quality downstream of construction activities, reduce regulatory compliance issues, and improve public perception. It is anticipated that an effective in-channel sediment basin design will be adopted as an alternative basin design outside of just the sponsoring agency.

1.4. ORGANIZATION OF THE REPORT

This report is sectioned into six chapters that organize, illustrate, and describe the steps to meet the defined research objectives. Chapter Two: *Sediment Basin Design and Performance* reviews current sediment basin design standards and introduces the in-channel sediment basin design, cost, and field performance data. Chapter Three: *In-Channel Sediment Basin Performance Improvements through Large-Scale Testing* describes the design, testing apparatus, and procedures developed to evaluate sediment basin performance in response to various structural treatments. Water quality and sediment retention results from large-scale testing are presented and discussed in this chapter. Chapter Four: *Upstream Flocculant Application* builds from Chapter 3 by describing the introduction of flocculant into large-scale testing and reports on residual concentrations collected from the sediment basin discharge samples. Chapter Five: *In-Channel Sediment Basin Design Tool* describes the development and implementation of an Excel-based tool aid in the design and implementation of in-channel basins. Chapter Six: *Conclusions and Impact* summarize the major findings and impact of the in-channel sediment basin research effort.

2. SEDIMENT BASIN DESIGN AND PERFORMANCE

2.1. BACKGROUND

Sediment basins are a sediment-control practice, typically employed on the edge of disturbed watersheds to capture suspended solids by providing residence time for captured runoff, promoting sedimentation *(Thaxton et al., 2004)*. Sediment basins are used to provide volumetric storage, promoting gravitational settling, and have been shown to trap 75% - 90% of suspended solids, heavy metals, and other organic compounds *(Fennessy and Jarrett 1997, Bidelspach et al., 2004, Perez et al., 2016)*. Performance is dependent on basin parameters such as size, geometry, energy dissipation, dewatering mechanism, and use of flocculants, but the design and inclusion of these components vary nationwide.

Sediment basins capture, detain, and treat stormwater by providing residence time to promote gravitational settling of suspended particles prior to off-site discharge. The stormwater residence time within a basin is dependent on their design and construction. Sediment basin design includes volumetric sizing and geometries, inflow channel, dewatering mechanism, and emergency overflow or spillway; however, the "one size fits all" approach is not applicable for sediment basin design due to varying hydrologic and soil conditions across construction sites *(Fifield 2015, Perez et al., 2017)*. Additional components such as baffles and dewatering skimmers have been investigated through large-scale testing and proved to enhance the performance of sediment basins.

2.1.1. SIZING AND GEOMETRY

Sizing and geometry are arguably the most influential components to the efficiency of a sediment basin due to their influence on the residence time and resulting sediment capture. In a pioneering study by Hazen in 1904, sediment capture was determined to be proportional to sediment basin surface area; however, it was independent of the basin depth *(Hazen 1904)*. Sufficient volume is required to ensure stormwater will not overtop the basin, allowing untreated, sediment-laden water to exit the site. Basins should be designed long and narrow to optimize settling across the flow length. Typically, a minimum length to width ratio of 2:1 is recommended *(Chen 1975)*; however, recent studies have indicated sediment basin ratios of 1:2 may be just as effective as velocity is spread across a wider area *(Kang et al., 2015)*.

Early sediment basin design guidance required a storage volume of 1,800 ft^3 (125 m^3) of storage per drainage acre (hectare); however, in 1992, the USEPA identified a new design standard requiring storage volume of 3,600 ft^3 (252 m^3) of storage per drainage acre (hectare). This sizing guideline was based on the assumption that a 2-yr, 24-hour rainfall event of 3 in. (7.62cm), would produce 1.0 in (2.54 cm) of runoff, or approximately 3,600 ft^3 (252 m^3) of storage per drainage acre (hectare) *(USEPA 1992)*. This method was criticized for not providing sufficient storage to fully capture runoff from the 2-yr, 24-hr rainfall event, which is probable to occur on a highway construction project *(Fifield 2015)*. Currently, the USEPA CGP allows for sizing sediment basins using one of two methods: (a) the calculated volume of runoff from a 2-yr, 24-hr design storm, or (b) 3,600 ft^3 (252 m^3) of storage per acre (hectare) drained into the basin *(USEPA 2022)*. The two design methods may result in different volumes required depending on local hydrology. Sediment basin details include a primary and auxiliary spillway. Auxiliary spillways are utilized in overflow conditions and must be designed to safely pass larger storm events, such as the 10- or 25-yr storm event. To prevent washout, the auxiliary spillways are armored with a TRM, geotextile, or erosion stone *(IECA 2020, ALDOT 2020, NCDOT 2015)*.

Perez et al., *(2016)* developed a hydrologic-based design tool SEDspread, that allows designers to select site-specific parameters, including sizing factor (i.e., 2-yr, 24-hr design storm, or 3,600 ft^3/ac (252 m^3/ha) to provide basin capacity and configuration. In addition, designers can input a U.S. zip code from which soil and storm data is derived. A case study was performed on two local construction site sediment basins in Auburn, AL. The case studies compared basin design and implementation to SEDSpread outputs. The two basins in the case study were designed to the 3,600 ft^3/ac (252 m^3/ha) but were undersized for the 2-yr, 24-hr design storm by a factor of three *(Perez et al., 2016)*.

Fang et al., conducted a three-month field study that monitored a sediment basin during highway construction in Franklin County, AL *(2015)*. The monitored basin was excavated to accommodate 20,288 ft^3 (574.5 m^3) of stormwater runoff, which followed the 3,600 ft^3/ac (252 m^3/ha) USEPA sizing criteria. Five of sixteen storms during the monitoring period resulted in overflow over the auxiliary basin spillway. Larger storms generated highly turbid inflow and re-suspended previously settled material. The researchers suggest this could be due to the under-sizing of the basin by a factor of 4.8 when compared to the 2-yr, 24-hr design storm (97,115 ft^3 [2,750 m^3] determined from modeling) *(Fang et al., 2015)*.

2.1.2. FOREBAY

Several sediment basin designs include a forebay created by a ditch check and/ or excavated area upstream of the basin. The forebay is designed to capture rapidly settable solids in an easily accessible location. The forebay provides an area for concentrated deposition that is more easily maintained and reduces the sediment load introduced into the basin. Sediment capture in the forebay decreases dredging efforts in the basin and increases field longevity. Minimal research has been conducted on forebays, but they may be compared to a silt basin or sediment traps without a dewatering mechanism. McCaleb and McLaughlin *(2008)* determined that sediment traps with rock outlets and 3 ft. (1 m) standing pool trapped up to 73% of introduced sediment. Perez et al., *(2016)* tested two basin configurations with varying forebay components. The first implemented a rock check dam with geotextile overlay and the second implemented the same rock check dam with overlay with an excavated area just upstream of the check dam, which captured 76% and 80% of sediment, respectively.

2.1.3. LINING AND STABILIZATION

One of the most effective erosion control practices is minimizing disturbed areas on a site. This approach also applies to the implementation of sediment basins to prevent the basin from contributing to sediment discharge. Disturbed areas within and around sediment basins should be stabilized by (1) establishing vegetative cover or (2) lining with non-woven geotextile to prevent erosion *(IECA 2021)*. Stabilization prevents erosion of the inflow channel and basin. Minimal research exists examining the difference between lined and unlined basins, but a 2000 study by Madaras and Jarrett found 36% higher sediment yield in unlined basins.

2.1.4. FLOW DISSIPATION

Sediment basins are typically assumed to have laminar flow; however, turbulence may occur during intense rainfall events causing resuspension of previously deposited sediment (*Perez et al., 2016*). Baffles dissipate flow across the width of the basin and decrease turbulence. Turbulent flow conditions within a sediment basin are undesirable in that they cause resuspension and prolonged suspension of sediment *(Goldman et al., 1986)*. Baffles are installed perpendicular to the inflow, intercepting the flow, and should exceed the full depth of the sediment basin *(Perez et al., 2016)*. Baffles aid in minimizing the resuspension of finer particles. Goldman et al., *(1986)* states that any retention pond with a ratio smaller than 10:1 should employ baffles within the pond. Several DOTs have adopted porous baffles or energy dissipaters for sediment basins *(TDOT 2020, ALDOT 2020, NCDOT 2015)*.

Thaxton et al., conducted a sediment basin study at North Carolina State University, which compared the average particle size captured in a basin with and without baffles. The smallest grain size captured in a basin without baffles was between 2.7 x 10^{-3} to 3.4 x 10^{-3} in. (68-86 microns); however, the addition of baffles allowed capture for grains just 1.2 x 10-3 to 1.7 x 10-3 in. (30-42 microns). In the study, three materials were tested across three different flow velocities. Overall, an evenly installed jute/ coir baffle performed the best by most effectively absorbing inflow momentum, diffusing energy, and damping the turbulent density. The jute/coir baffles were a combination of distributed jute germination biotextile backed with coir fiber and reduced mean flow velocity by 75% compared to the control, open flow basin *(Thaxton et al., 2004)*.

2.1.5. DEWATERING

A dewatering mechanism is necessary for treated stormwater to exit the basin without permanent ponding *(Thaxton et al., 2004)*. The USEPA CGP requires dewatering sediment basins from the surface, presumably the least turbid portion of the water column, due to gravitational settling *(USEPA 2022)*. Traditionally, effluent has been discharged through perforated riser pipes, which pull water across a larger portion of the water column. There is contention within the field if a riser pipe is still considered a surface dewatering mechanism. Instead, floating surface skimmers have become more commonly implemented, sized, and selected based on the desired dewatering rate. Sediment basins are typically designed to detain stormwater for periods ranging between 24 to 72 hours but can be up to seven days *(Fang et al., 2015)*.

An adequate settling time can be determined, and the skimmer can be selected for solid removal prior to discharge *(Perez et al., 2016)*. Various sediment retention rates using a skimmer as the primary dewatering mechanism have been determined in controlled research studies. Examples include (1) Millen et al., found that a skimmer discharged 45% less sediment than a riser pipe *(1997)* and (2) Jarrett et al., concluded sediment loss from a basin equipped with a perforated riser principal spillway was 1.8 times greater than when a floating surface skimmer was used *(2001)*.

2.2. DESIGN

Basin design and construction vary across the U.S.; however, several DOTs implement all the sediment basin components described. As an example, the Alabama Department of Transportation (ALDOT) sediment basin detail is shown in Figure 2.1. The sediment basin is excavated with a length-to-width ratio of at least 2:1 and lined to prevent erosion within the basin. Channel armoring at the inlet protects the transition from channelized flow to the settling pond. The defined inflow channel is also lined and includes an excavated forebay, consisting of an excavated sump and riprap ditch check. This provides an easily accessible area to capture rapidly settling solids and maintain, decreasing the frequency of dredging requirements of the basin and providing additional stormwater storage. A dedicated flocculant introduction zone is shown downstream of the forebay to promote flocculation of the smaller, suspended particles. Three baffles split the basin into four sections, and a skimmer is installed in the fourth bay for dewatering *(ALDOT 2020)*.

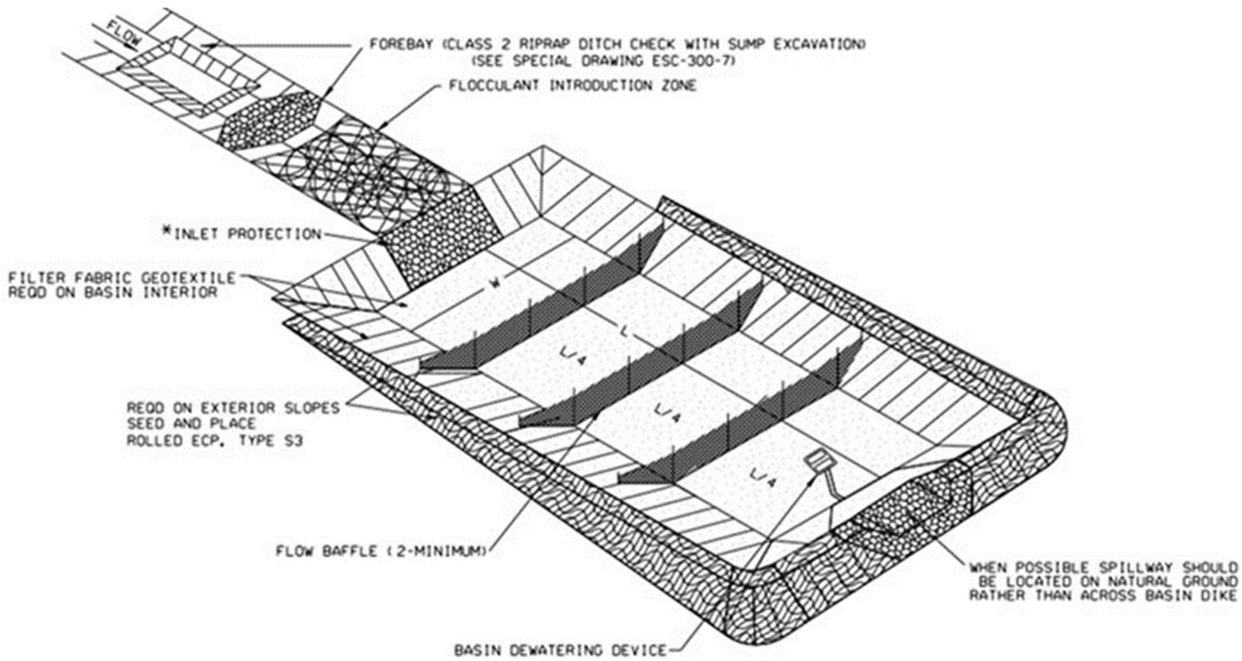
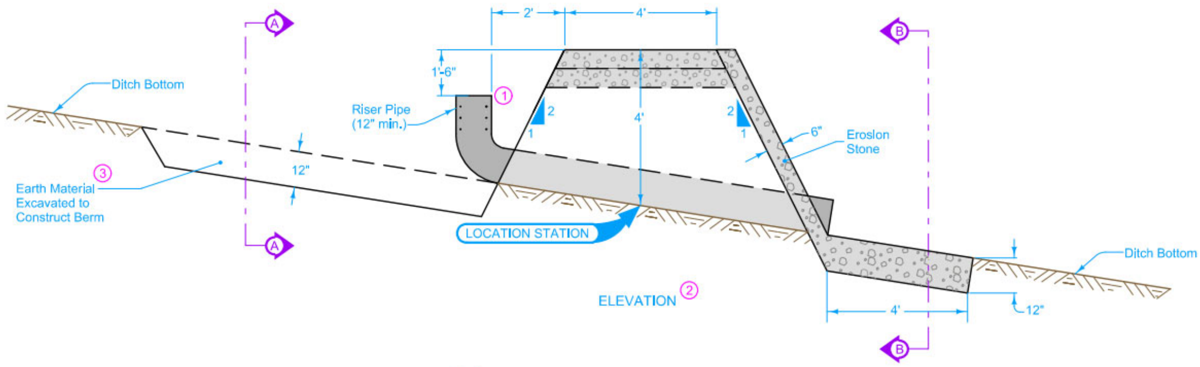
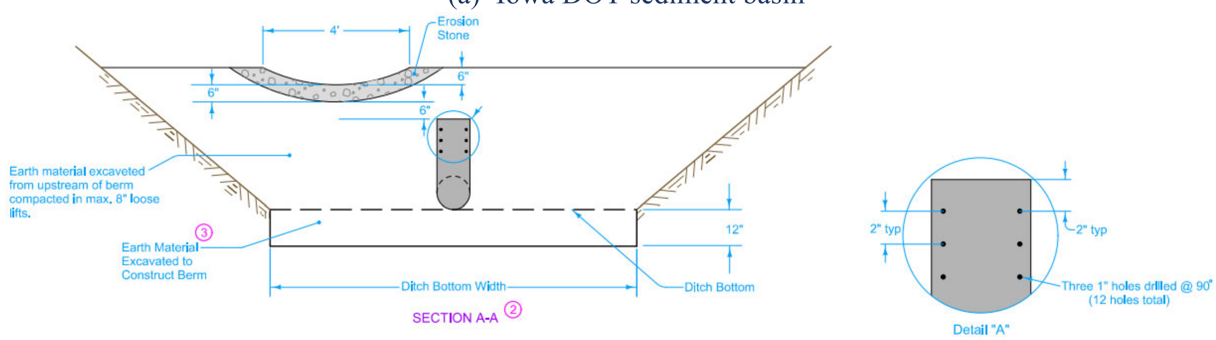


Figure 2.1. ALDOT sediment basin detail *(ALDOT 2020)*.

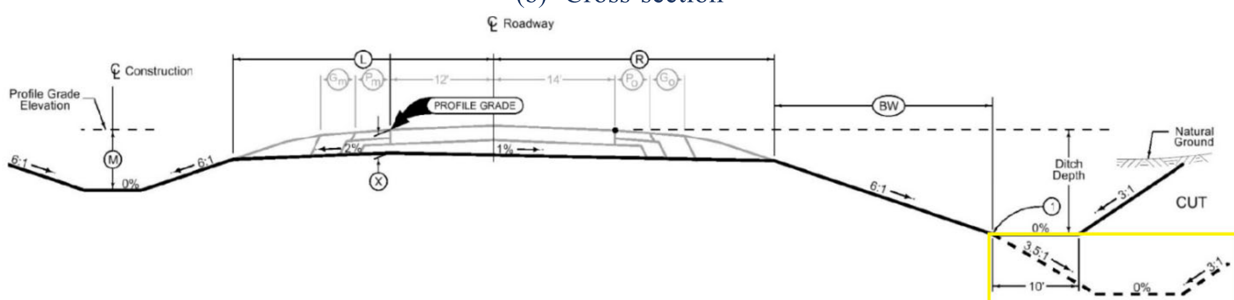
Many DOTs require a dedicated excavated pond and implement one or more of the sediment components described. However, additional sediment basin designs exist. The Iowa DOT's standard sediment basin detail is designed to create temporary detention within the typical channel environment. Iowa DOT design standards specify a trapezoidal channel with a 3.5H: 1V foreslope, 3H:1V backslope, 10 ft (3.0 m) channel bottom, and 3% grade. The basin portion was constructed by excavating an additional 12 in. (30 cm) and using the material to create an earthen berm. The berm has a 4 ft (1.2 m) top width and is 4 ft (1.2 m) high at the midpoint of the berm. Side slopes are 1H: 2V. Situated along the berm, a 4 ft (1.2 m) wide by 6 in. (15 cm) deep spillway allows runoff to bypass the sediment basin when the volume capacity is exceeded. The spillway is armored with erosion stone to prevent scour during overtopping events. A 4 ft (1.2 m) erosion stone apron extends beyond the toe of the berm along the downstream face of the sediment basin. A 12 in. (30 cm) diameter corrugated riser pipe was installed through the berm. The upstream face of the dewatering pipe is turned upward at a 90-degree bend to create a riser structure at the end of the sediment basin. The top of the riser pipe was drilled with three 1.0 in. (2.5 cm) holes spaced 2.0 in. (5 cm) along the top of the pipe at every quarter-turn for a total of 12 perforations.



(a) Iowa DOT sediment basin



(b) Cross-section



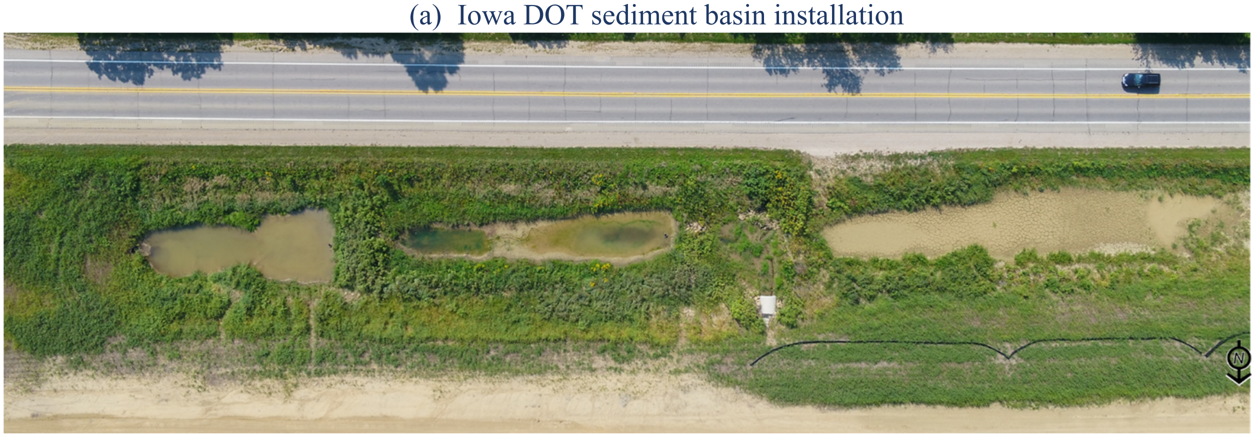
(c) Channel details

Figure 2.2. Iowa DOT standard design details *(2017 [a,b] and 2019 [c]).*

2.3. PERFORMANCE DURING FIELD-MONITORING

In 2018, the Iowa DOT led a field-monitoring project of erosion and sediment control practices, summarized in Schussler et al., *(2020)*. If functioning correctly, the sediment from sediment-laden runoff would be retained within the basin, and reflected in turbidity and total solids reduction prior to discharge. Several in-channel sediment basins were instrumented and monitored on the U.S. Highway 30 project. Teledyne™ ISCO 6712 automated water samplers were deployed to collect samples at the inflow and discharge of the evaluated sediment basins. A Teledyne™ ISCO 674 rain gauge was connected to one of the samplers, measuring rainfall depth occurring on-site. Samplers were programmed to take 25 oz (0.75 L) samples from the basin at regular 12-hr intervals. Each sample was collected in an individual 33.8 oz (1.0 L) pie-shaped bottle. Water samples from the basins were evaluated in a laboratory setting for turbidity and total solids; upstream and downstream measurements were plotted over time. The monitored sediment basins are shown in Figure 2.3.

(a) Iowa DOT sediment basin installation



(b) aerial photo of monitored basins

Figure 2.3. Sediment basins from field monitoring.

2.3.1. IN-CHANNEL SEDIMENT BASIN MONITORING

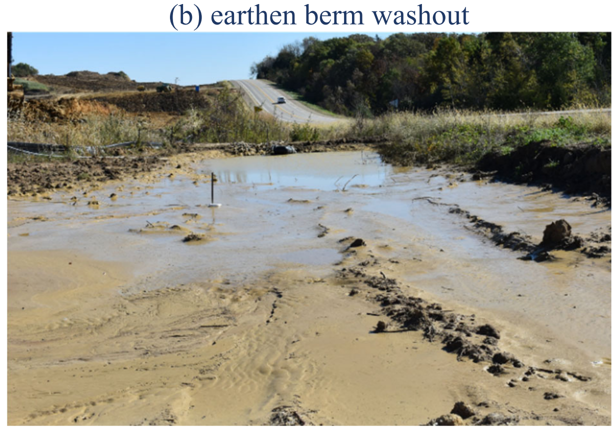
Initial monitoring occurred on a temporary sediment basin from September 21, 2018 through October 16, 2018. During this time period, 7.40 in. (18.8 cm) of rain were observed over seven qualifying rain events. A qualifying event was defined as more than 0.25 in. (0.64 cm) of rain within a 24-hr period. Across all collected data, average turbidity at the inflow and outflow sampling locations was 853 and 975 NTU with a standard deviation of 1,563 and 2,016 NTU, respectively. Turbidity in the basin ranged from 43 to 6,781 NTU at inflow and 45 to 9,236 NTU at discharge. Total solids concentrations ranged from 2.0 to 4,007 mg/L at inflow and 32 to 3,794 mg/L at discharge. The average total solids concentrations at the inflow and outflow sampling locations were 469 and 490 mg/L with a standard deviation of 894 and 892 mg/L, respectively. Concentrations peaked on October 9, 2018 after receiving nearly 2.30 in. (5.84 cm) of rain across a three-day period. During this measurement, turbidity values at discharge were measured at 9,236 NTU, which was more than 1.5 times greater than turbidity measured at the inflow. On average, the basin increased turbidity by 92 NTU prior to discharge, with a standard deviation of 760 NTU. The basin decreased total solids concentrations by an average of 15.5 mg/L with a standard deviation of 345 mg/L. The high standard deviations are indicative of the wide range of measured turbidity and total solids experienced during monitoring.

Consecutive storm events likely caused the site to reach field saturation, increasing runoff and erosive forces with each event. Increased sediment load and lacking maintenance likely caused sediment deposition to exceed the dead storage, or available volume beneath the discharge pipe, within the basin. In addition, increased flow velocities may have caused turbulence at the inflow of the basin, re-suspending and discharging previously settled material. Dewatering deficiencies were observed during monitoring. The dewatering riser pipe was inadequately anchored to the basin floor and became buoyant. This caused the basin to retain excessive stormwater causing subsequent events to flow through the auxiliary spillway. Erosion stone used to armor the spillway had washed out, resulting in erosion of the earthen berm. Discharge downstream of the earthen berm was not captured, as discharge samples were taken proximal to the discharge pipe. However, it is likely discharged turbidity and total solids concentrations were significantly higher than captured by the sampler due to suspending and transporting washed-out material. Several of the sediment basin deficiencies are included in Figure 2.4.

(a) buoyant riser pipe on side

(b) earthen berm washout

(c) no defined inflow path



(d) channel and basin erosion

Figure 2.4. Sediment basin deficiencies.

2.3.2. BASINS IN SERIES

In the subsequent construction season, two basins in series were instrumented and analyzed from May 17, 2019 through September 1, 2019. The first and second basins in the series had flow paths of approximately 75 ft (22.9 m) and 100 ft (30.5 m), respectively, with the first basin acting as a forebay to capture rapidly settable solids. The sediment basin system collected a drainage area of 6.56 ac (2.65 ha). The riser pipe from Basin 1 dewatered to Basin 2. In total, there were 15 qualifying events during monitoring. Four automated samplers were deployed between the two basins. Samplers A and B were used to sample the first basin at inflow and discharge, respectively. Samplers C and D were used to sample the second basin at inflow and discharge, respectively. Sampler B collected at the discharge of the first basin, which then discharged to the inflow at Sampler C. All samples were collected from the surface of the water column using floating sampling devices.

Over the course of sampling, 802 viable water samples were collected (190 A-inflow, 192 B-discharge, 214 C-inflow, and 206 D-discharge). Some sample bottles were empty due to dry basin conditions after dewatering. Samplers A and B sampled the first basin in the series, which presumably provided pretreatment for the second basin allowing the rapidly settable solids to drop from suspension. Due to the accumulation of sediment at the inflow of the upstream basin, Sampler A's intake became beached, resulting in several periods without sample collection. Increased algae growth, plant materials, and gastropods were observed in water samples, attributed to the warmer sampling season. Due to this contamination affecting total solids measurements, turbidity was used as the primary measurement for evaluating performance of the basins in series.

The first basin provided an average sediment reduction of 215 NTU with a standard deviation of 511 NTU (comparing Samplers B to A). The second basin decreased turbidity by an average of 870 NTU with a standard deviation of 1,282 NTU (Comparing Samplers D to C). Basin 1 dewatered through a riser pipe to Basin 2. Thus, data collected from Sampler B and Sampler C should have reflected similar turbidity values, however, due to the floating intakes, Sampler B represented a skimmer-like dewatering system. When evaluated as a system, an average turbidity reduction of only 9 NTU with a standard deviation of 88 NTU was achieved. A large increase in turbidity was observed between sample location C and sample location B. This suggests a large amount of sediment-laden stormwater was introduced to sampling point C through the riser structure that hydraulically connected the two basins.

2.3.3. FIELD STUDY CONCLUSIONS

Water quality results (i.e., turbidity and total solids) indicated that sediment basins were providing negligible water quality improvements. In several cases water quality had increased levels of turbidity and total solids prior to discharge. In the single basin, turbidity increased by an average 92 NTU after residence in the basin, whereas the basins in series provided a turbidity decrease of 9 NTU, negligible treatment when considering turbidity values reaching a magnitude of 10^3 NTU. Average treatment of the basin system provided 0.5% reduction. The lack of water quality improvements was attributed to: (1) sediment contribution from destabilized sediment basin and channel, (2) resuspension of sediment deposited on the basin floor, (3) lack of energy dissipation upstream and within the basin, and (4) inadequate detention time and dewatering.

2.3.4. LIMITATIONS

Monitoring was conducted on existing in-channel basins, and conditions including live and dead storage capacities were unknown. Installation of the basins was not monitored and could have varied from DOT specification; therefore, results cannot be directly extrapolated to other basins. The monitored sediment basins were subject to unpredictable site conditions, including rainfall, soils, drainage areas, and changing topography due to ongoing grading. While results may be indicative of the basins on the Tama US 30 site, the repeatability of results on other construction sites is uncertain. Samplers were programmed on 12-hr time-based intervals and were collected every 12 days. In several samples, there was algae growth or other organic matter that may have interfered with water quality testing. The presence of organic matter often only allowed for measurements of turbidity rather than total solids. Total solids tests would have provided a better measure of the rapidly settable solids that are not characterized in turbidity readings.

2.3.5. IMPACT AND CONTINUED RESEARCH

The SWPPP for the Tama U.S. 30 expansion included more than 70 sediment basins and 450 silt basins, indicating that detention practices were heavily relied on for sediment capture prior to offsite discharge *(Johnson et al., 2017)*. The installation cost was $3,200 per temporary sediment control basin, according to contract documents, totaling more $200,000 for only sediment basins on the Tama U.S. 30 project *(Skogerboe 2020)*. Considering this significant investment and the potential to enhance sediment capture, research was continued to assess methods to enhance the treatment efficiency of the Iowa DOT sediment control basin design. Following a literature and SWPPP review, potential modifications to the standard design were proposed and included an upstream forebay, stabilization of the channel and sediment basin through geotextile lining, energy dissipation within the basin from porous baffles, and surface dewatering. To minimize the unknowns related to field-testing, modifications to the basin design have been tested using large-scale testing techniques at the AU-SRF. This research effort is detailed in Chapter 3 of this report.

3. SEDIMENT BASIN PERFORMANCE IMPROVEMENTS THROUGH LARGE-SCALE TESTING

3.1. INTRODUCTION

Sediment basins capture, detain, and treat stormwater by providing residence time to promote gravitational settling of suspended particles prior to off-site discharge. In-channel basins utilize existing channels on-site to treat stormwater and provide an opportunity to maximize length-to-width flow ratios. As a result of the use of existing infrastructure, installation time and costs are reduced; however, minimal performance data exists. The field monitoring during Iowa DOT active construction, presented in Section 3.3 Performance during Field-Monitoring, concluded that the basins provide negligible treatment. Although turbidity reduction was inconsistent in the systems, the single monitored basin increased turbidity by an average of 92 NTU, and the basins in series provided an average turbidity reduction of 9 NTU. Sampled inflow turbidities reached up to 10,000 NTU, thus the turbidity reduction in the two monitored systems were considered negligible. This research, conducted at the AU-SRF, implemented large-scale testing techniques to evaluate in-channel basin performance in response to various structural treatments. Research findings are expected to guide the design and implementation of effective, sediment control basins for enhanced environmental stewardship during construction.

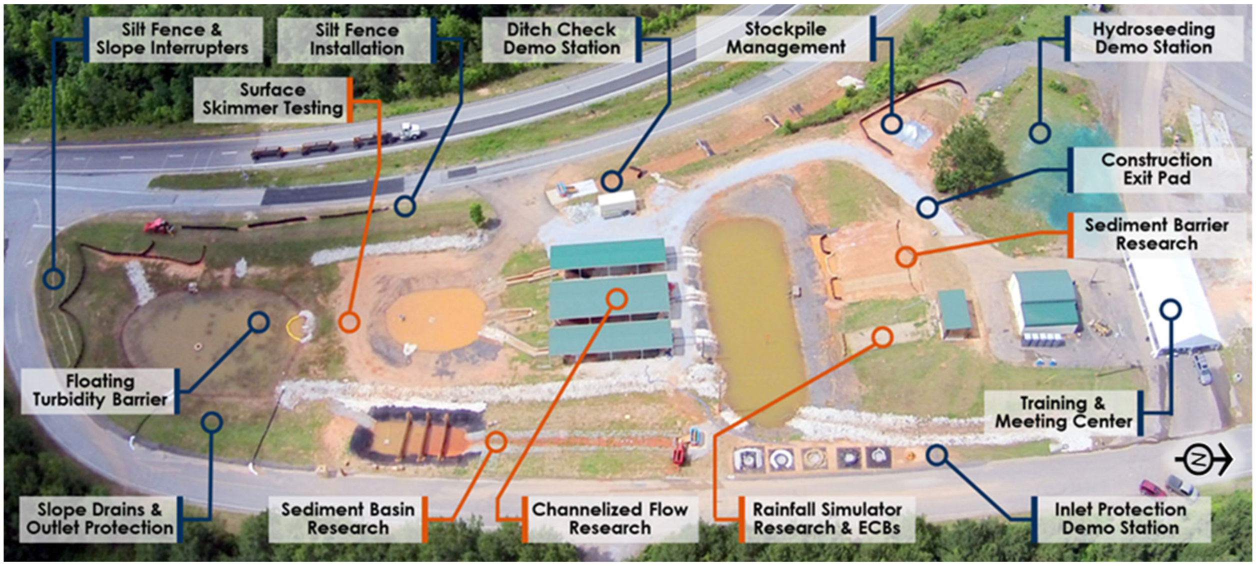
3.2. ABOUT THE AUBURN UNIVERSITY STORMWATER RESEARCH FACILITY

The AU-SRF is an outdoor research center aimed to improve and develop stormwater technologies and strategies, situated at the National Center for Asphalt Technology (NCAT) Test Track Facility in Opelika, AL. It was designed and constructed in 2009 to evaluate E&SC practices implemented by ALDOT during roadway construction but hosts research projects for additional state highway agencies and product manufacturers. Researchers at the AU-SRF have designed sediment, flow, and rainfall introduction apparatuses to evaluate the design, installation, and maintenance of ditch checks, inlet protection practices, sediment basins, sediment barriers, and erosion control practices. The findings from these projects have been presented in academic journals, technical reports, and conference proceedings, reflected in DOT standards, and communicated within the industry at annual in-person training events.

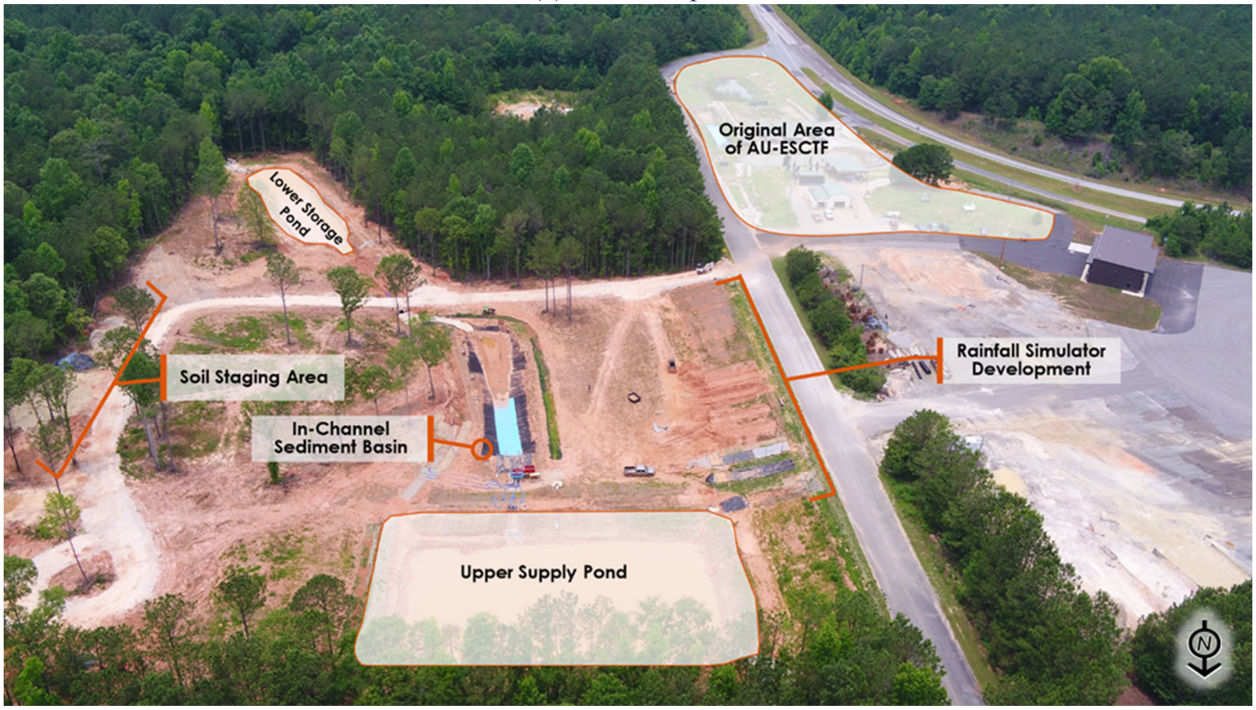
Since its inception, the AU-SRF has aimed its mission to create "environmental stewards within the construction industry by developing improved erosion and sediment control stormwater technologies and practices; advancing the body of knowledge through research and development, product evaluation, and training *(Samuel Ginn College of Engineering, 2021)*." This mission encompasses three primary focus areas: (1) research and development, which occurs through large-scale, performance-based testing (2) product evaluation, conducted through third-party, standardized testing methods and (3) training at hands-on field days and workshops for knowledge and technology transfer. Researchers at the AU-SRF are constantly engaged with the industry and identify industry needs through field and training events, professional organizations and meetings, mentorship, and connections with graduate students who have entered the workforce.

The AU-SRF recently entered its second decade, and the area and capabilities of the outdoor laboratory were expanded. The once 2.25 ac (1.00 ha) facility recently gained an additional 7.5 ac

(3.04 ha) through expansion activities. The expansion included two new storage ponds to increase the original water storage volume from 73,000 to 253,993 ft^3 (2,067 to 7,192 m^3). The AU-SRF before and after the expansion is pictured in Figure 3.1(a) and (b), respectively.



(a) before expansion



(b) post-expansion 2021

Figure 3.1. Auburn University Stormwater Research Facility.

3.3. CONSTRUCTION

After evaluating the available area for construction at the AU-SRF, a 200 ft (61 m) channel was designed using AutoCAD™ following the Iowa DOT channel and basin design specification. The channel cross-section and profile, as designed, are shown in Figure 3.2.

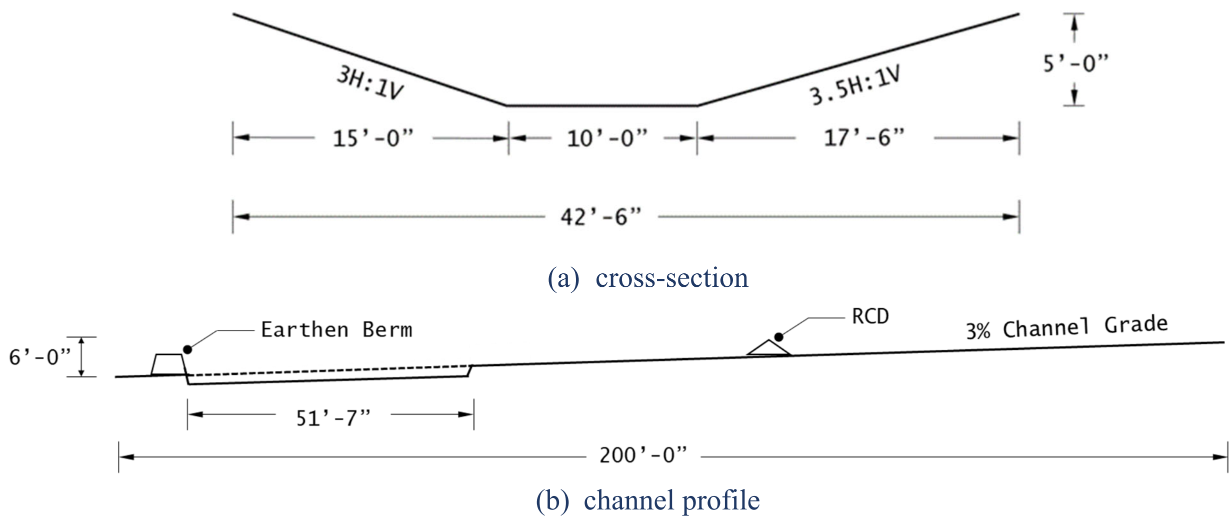


Figure 3.2. Channel design from AutoCAD™ Civil 3D.

A storage volume of 3,031 ft^3 (85 m^3) was determined based on the AutoCAD™ design. The channel was staked out using a Trimble robotic total station using this design. The channel was excavated with a excavator (CAT 320D), graded with a bulldozer (CAT D5), and compacted with a vibratory soil compactor (CAT CP44B). Approximately 20 yd^3 (15 m^3) of excavated material was used to construct the earthen berm, and the excess material was stockpiled. Construction was completed within two days using four total operators. Following construction, a Bobcat E32 Compact Excavator was used to dig out a portion of the earthen berm to install a 12 in. (0.3 m) PVC pipe, which tied the dewatering riser pipe into an adjacent conveyance channel. The earthen berm was backfilled and compacted. A 4 ft (1.3 m) wide section above the installed pipe was shaped into a 1 ft. (0.3 m) deep channel to serve as the auxiliary spillway. Twelve perforations were drilled into a 12 in (0.3 m) 90° PVC elbow following the Iowa DOT standard dewatering riser and attached to the 12 in. (0.3 m) PVC pipe running through the earthen berm on the sediment basin side. An 8 oz (227 g) geotextile fabric was anchored to the basin and over the auxiliary spillway area to protect the grade and maintain the structural integrity of the basin until testing commenced. Images from channel and sediment basin construction are shown in Figure 3.3.

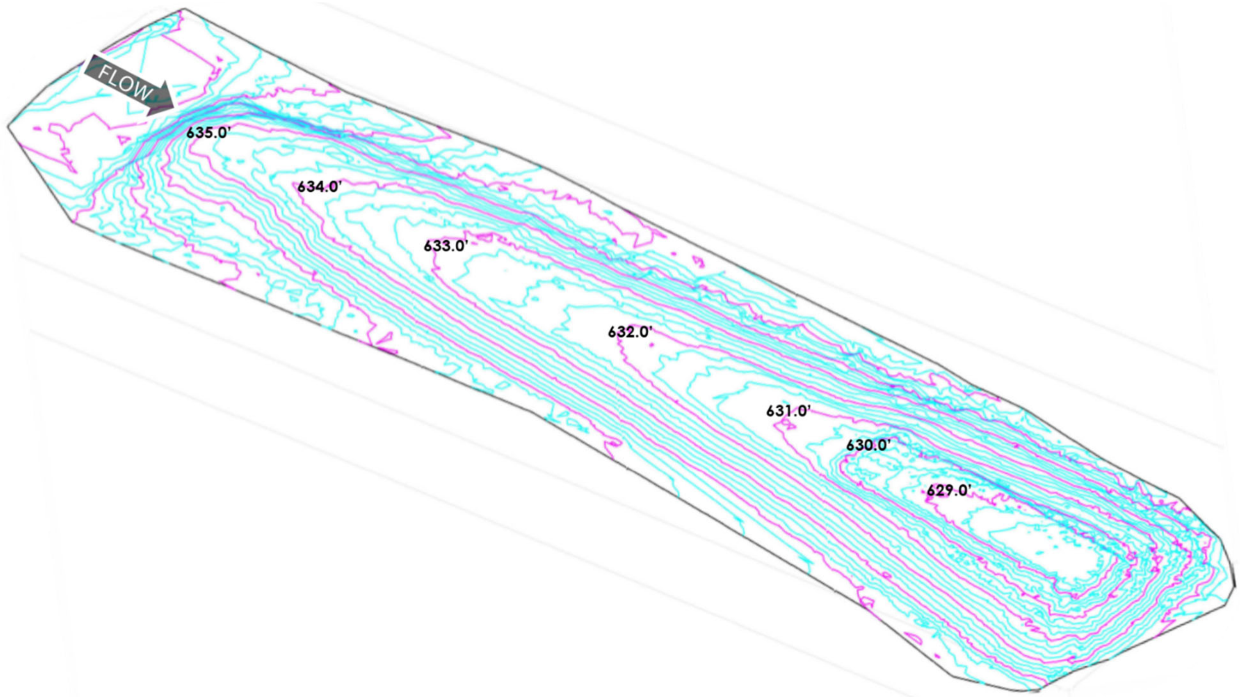
(a) channel grading

(b) excavating basin and surveying grade

(c) auxiliary spillway construction

Figure 3.3. Channel construction.

Before testing, the geotextile was removed, and a Trimble™ SX 10 Scanning Total Station and Trimble™ R2 GNSS RTK were used to survey the basin as-built on February 25, 2021. The scan of the as-built basin resulted in a volume of approximately 3,031 ft^3 (86 m^3). A contoured diagram of the basin is shown in Figure 3.4.



Note: contour interval 0.25 ft (0.8 m)

Figure 3.4. Contour diagram of as-built sediment basin.

The base scan was placed and analyzed in AutoCAD 3D™. Stage-Storage was determined using the surface contour method, the graph of the relationship is shown in Figure 3.5 below.

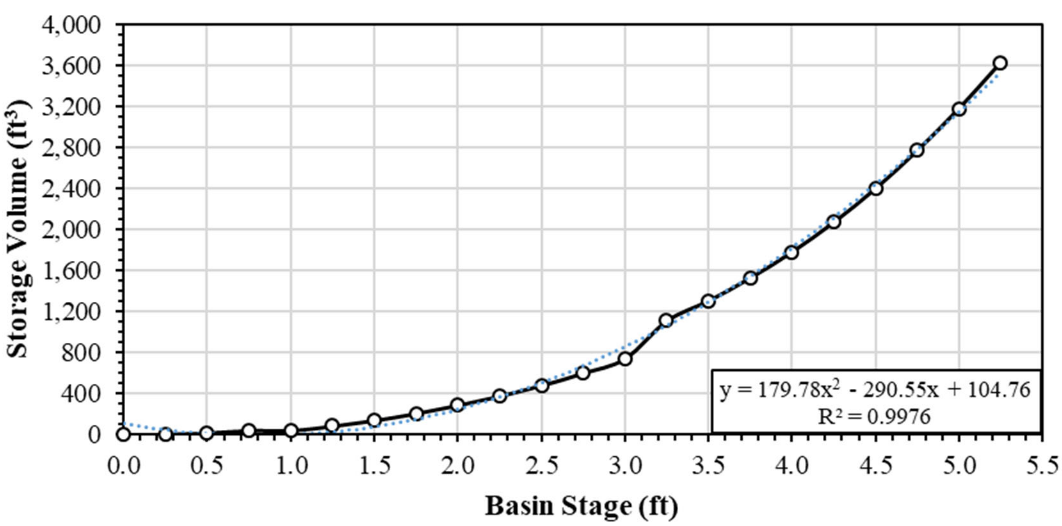


Figure 3.5. Stage-storage relationship.

After scanning, new 8 oz (227 g) geotextile fabric was anchored to the basin to protect the grade and maintain the structural integrity of the basin until testing commenced. A 10 × 10 ft (3.1 × 3.1 m) concrete pad was poured at upstream side of the basin to host the flow and sediment introduction apparatuses. A rigid plastic liner was placed and anchored directly downstream of the concrete pad to prevent erosion from occurring where flow is highly concentrated. A turf reinforcement mat (TRM) was installed where the 12 in. (0.3 m) PVC pipe daylighted in the conveyance channel to prevent erosion at discharge. Class D erosion stone was installed on top of the TRM and over the depression in the earthen berm to satisfy the auxiliary spillway requirements.

Following several natural fill and dewatering cycles from rainfall on-site, it was observed that flow and sediment were discharging into the basin at many locations longitudinally down the channel, and water was flowing underneath the dewatering pipe through the earthen berm. A small earthen berm was constructed spanning the length of the channel to divert flow away from the basin. This channel was covered in a TRM and seeded to provide permanent stabilization. The second issue was rectified by peeling back the geotextile near the discharge, excavating approximately 1 ft (0.3 m) material around the dewatering pipe, and backfilling with bentonite HolePlug®, which swelled when wet to prevent flow under the dewatering pipe. A 3 in. (7.6 cm) depth of native soil was packed on top of the HolePlug® and re-covered with geotextile. An aerial of the basin prior to testing is shown in Figure 3.6.

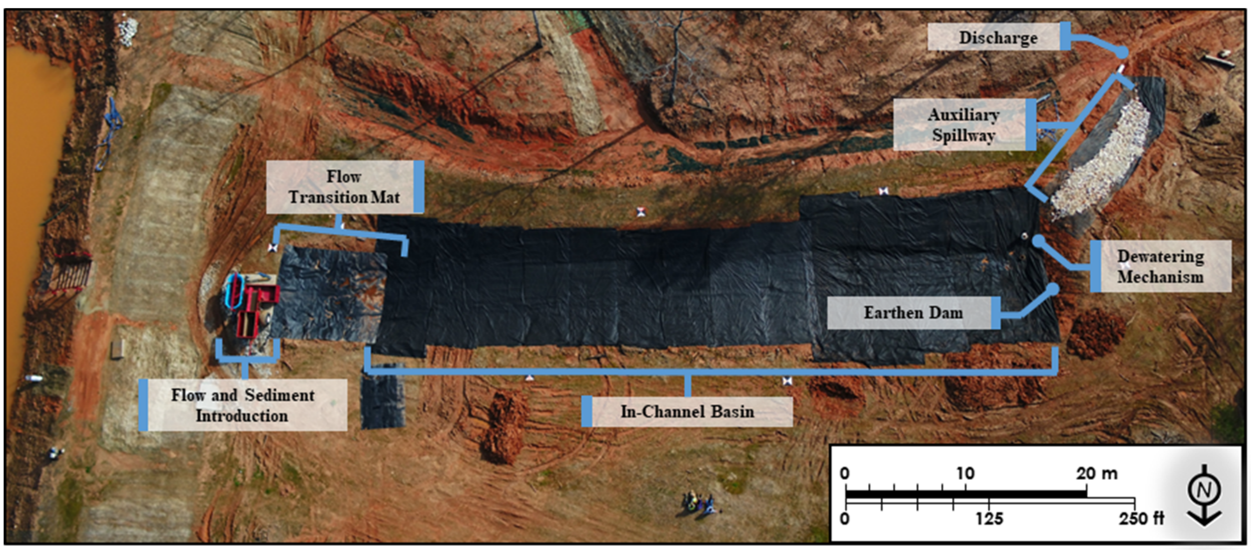


Figure 3.6. Aerial image of in-channel sediment basin at AU-SRF.

3.4. MATERIALS AND METHODS

This section describes the methods, procedures, and experimental testing regimen to evaluate the performance of the in-channel basin constructed at AU-SRF. Before testing, a flow and sediment introduction rate representative of Iowa DOT construction sites was determined. Flow and sediment introduction apparatuses were constructed and calibrated based on this determination. Data collection included water quality, quantity, and sediment quantity measures. Each of these steps is discussed in detail in the following sections.

3.4.1. RUNOFF ANALYSIS AND FLOW RATE

Under section 2.2.12 of the USEPA's NPDES Construction General Permit (CGP) provides two methods for sediment basin storage: (a) 2-yr, 24-hr design storm runoff volume, or (b) 3,600 ft^3 (252 m^3) of storage per acre (hectare) drained *(2022)*. Iowa DOT follows the state-specific sizing guidance provided by Iowa Department of Natural Resources (DNR) NPDES General Permit No. 2, which requires sediment basins serving areas with more than 10 ac (4.05 ha) of disturbance to be sized to provide 3,600 ft^3 (252 m^3) of storage per acre (hectare) drained. The sizing parameter was increased from 1,800 ft^3, to detain approximately the first flush, or the first 1.0 in. (2.5 cm) of runoff from a 3.0 in (7.6 cm) storm event. The 3.0 in. (7.6 cm) storm event was selected by the USEPA to be representative of the 2-year, 24-hour storm in selected locations as published in the 1992 Federal Register *(USEPA 1992).* The USEPA further assumed the 3.0 in (7.6 cm) storm event would produce 1.0 in. (2.5 cm) of runoff. The first flush is presumably the most polluted, or most sediment-laden runoff. The "one-size fits all" sizing parameter was documented in the Federal Register in 1992. The rationale is as shown in Eq. 3.1:

$$1\ in. \times \frac{1\ ft}{12\ in.} \times 1\ ac \times \frac{43{,}560\ ft^2}{1\ ac} = 3{,}637.5\ ft^3 \qquad \textbf{Eq. 3.1}$$

The TR-55 Urban Hydrology for Small Watersheds design approach calculated 1.0 in. (2.54 cm) of runoff from 24-hour distributed storms for a single drainage acre in Iowa *(USDA 1986).* Runoff was calculated using Eq. 3.2:

$$Q = \frac{\left(P - \frac{200}{CN} + 2\right)^2}{P + \frac{800}{CN} - 8} \qquad \textbf{Eq. 3.2}$$

where,

Q = runoff depth (in.)
P = rainfall depth (in.)
CN = curve number

For Eq. 3.2, Q was set to 1.0 in. (2.54 cm), and P was solved using CNs representative of soil types in Iowa. A GIS analysis was conducted to identify representative hydrologic soil groups and associated CNs for newly graded and developing areas, shown in Figure 3.7.

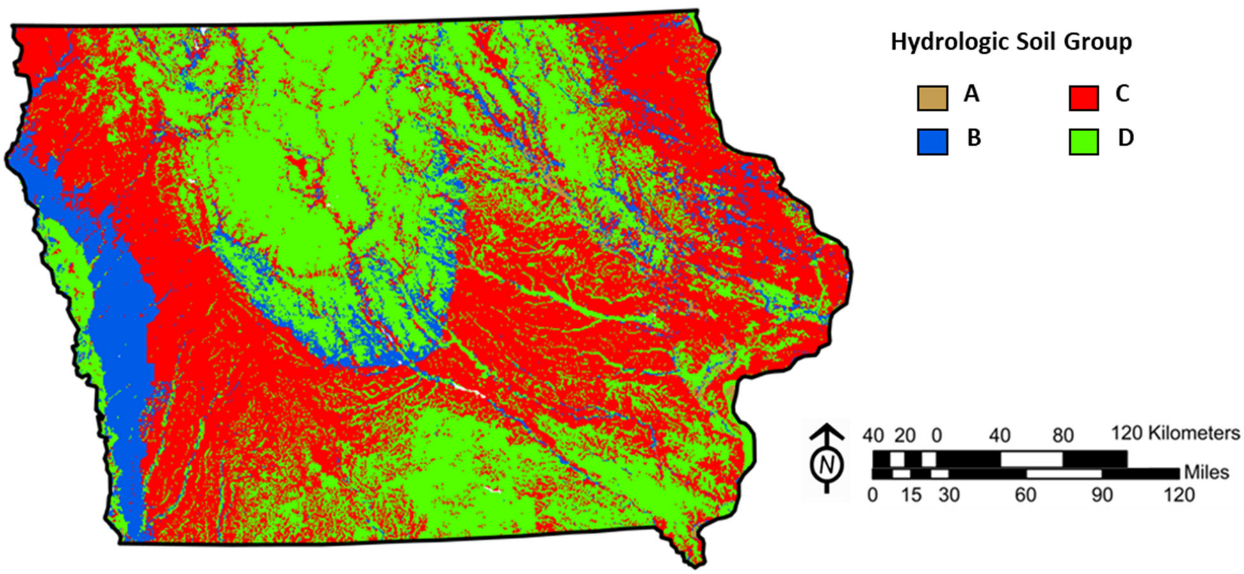


Figure 3.7. Curve number distribution for newly graded or developing areas in Iowa.

These *CNs* and respective rainfall depths were used to develop hydrographs within AutoCAD Civil 3D. Volumes were slightly above the expected 3,600 ft^3 (252 m^3) for a contributing area of 1.0 ac (0.4 ha), so rainfall was calibrated through an iterative process to most closely align with the 3,600 ft^3/ac (252 m^3/ha) sizing parameter.

Using the Iowa DOT 3,600 ft^3/ac (252 m^3/ha) sizing guidance, the designed AU-SRF sediment basin [3,031 ft^3 (86 m^3)] was determined to be representative of a 0.84 ac (0.34 ha) treatment area. The curve numbers and rainfall depths were applied to a 0.84 ac (0.34 ha) treatment area. Hydrologic soil groups (HSG), curve numbers (CN), calibrated rainfall depths (P), runoff volumes, and respective peak discharges (Q) are summarized in Table 3.1.

Table 3.1. Peak discharge and runoff values from modeled storm calibration

HSG	CN	P *in. (cm)*	1.0 ac. (0.40 ha) Contributing Area		0.84 ac (0.34 ha) Contributing Area	
			Vol. *ft^3 (m^3)*	Q *ft^3/s (m^3/s)*	Vol. *ft^3 (m^3)*	Q *ft^3/s (m^3/s)*
A	77	2.85 (7.24)	3,625 (103)	1.80 (0.05)	3,045 (86)	1.51 (0.04)
B	86	2.16 (5.49)	3,638 (103)	1.81 (0.05)	3,056 (87)	1.52 (0.04)
C	91	1.78 (4.52)	3,645 (103)	1.79 (0.05)	3,061 (87)	1.50 (0.04)
D	94	1.54 (3.91)	3,641 (103)	1.76 (0.05)	3,059 (87)	1.48 (0.04)
Avg.[a]	91.6	1.73 (4.39)	3,635 (103)	1.78 (0.05)	3,053 (86)	1.50 (0.04)

Note: average determined using weighted values from GIS analysis.

Using the state average curve number (91.6) and 1.73 in. (4.39 cm) of rainfall depth in a 24-hour distribution, the simulated storm produced 3,053 ft^3 (86 m^3) of runoff for a 0.84-acre (0.34- ha) drainage area. A flow rate of 1.70 ft^3/s (0.05 m^3/s) was used to fill the basin storage volume within a 30-minute test duration, as calculated in Eq. 3.3:

$$3{,}053\ \frac{ft^3}{test} \times \frac{1\ test}{30\ min} \times \frac{1\ min}{60\ sec} = 1.70\ \frac{ft^3}{sec} \qquad \textbf{Eq. 3.3}$$

3.4.2. SEDIMENT LOSS AND INTRODUCTION RATE

Soil loss was calculated using the Modified Universal Soil Loss Equation (MUSLE) *(NRCS 2006)*, which uses runoff variables to estimate soil loss with respect to runoff rather than rainfall, and is shown in Eq. 3.4:

$$S = 95(QP_p)^{0.56}KLSCP \qquad \textbf{Eq. 3.4}$$

where,

S = sediment yield (tons)
Q = runoff volume (ac-ft)
P_p = event peak discharge (ft^3/s)
K = soil erodibility factor
LS = slope length and steepness factor
C = cover discharge (ft^3/s)
P = practice factor

Runoff volume and peak discharge from Table 3.1 were used to determine S. The K factor was estimated to be 0.26 from soil testing conducted during the Erosion and Sediment Control Field Monitoring project *(Schussler et al., 2020)*. The LS factor 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 that would be considered consistent with newly graded construction conditions *(Pitt et al., 2007)*. C and P factors were estimated to be 0.5, assuming erosion and sediment control practices (i.e., mulching, seeding, ditch checks, etc.) would be implemented upstream of the basin in a treatment train. Sediment loss (tons), sediment introduction (lbs/min), and estimated soil per test (yd^3) are shown in Table 3.2.

Table 3.2. Sediment introduction modeled for AU-SRF in-channel sediment basin

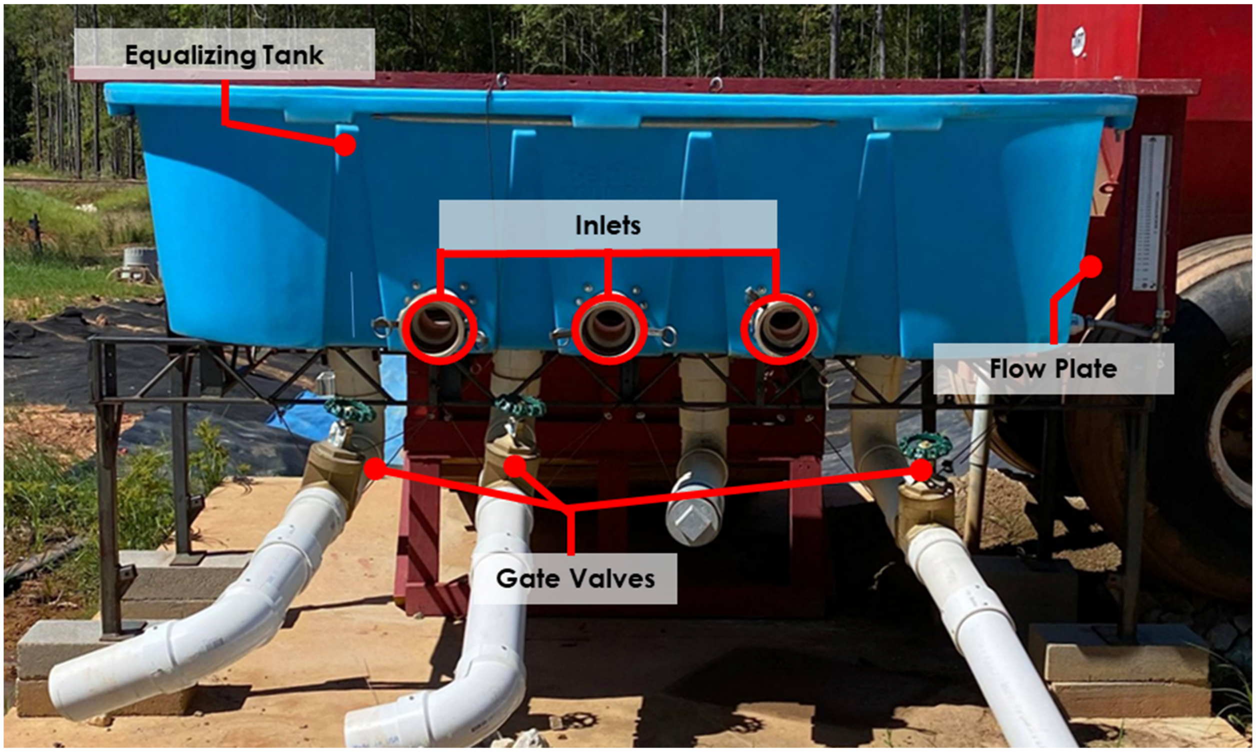
HSG	Q *ft^3 (m^3)*	P_p *ft^3/s (m^3/s)*	S *lbs (kg)*	Sediment Introduction[a] *lbs/min (kg/min)*	Soil per Test [b] *yd^3 (m^3)*
A	1,257 (36)	1.70 (0.05)	1,889 (857)	63.0 (28.6)	0.70 (0.54)
B	1,372 (39)	1.70 (0.05)	1,944 (882)	64.8 (29.4)	0.72 (0.55)
C	1,343 (38)	1.70 (0.05)	1,966 (892)	65.5 (29.7)	0.73 (0.56)
D	1,346 (38)	1.70 (0.05)	1,968 (893)	65.6 (29.8)	0.73 (0.56)
Avg.	1,341 (38)	1.70 (0.05)	1,961 (889)	65.4 (29.7)	0.73 (0.56)

Notes:
[a] sediment introduction rate and volume calculated for 30 minutes of flow introduction
[b] soil volume estimated $S \times 0.74\ \frac{tons}{yd^3}$

3.4.3. FLOW AND SEDIMENT INTRODUCTION APPARATUS

Attaining and maintaining accurate flow and sediment introduction rates were crucial for the performance evaluation of the sediment basin. A four-stage introduction process was developed to introduce and mix flow and sediment. The developed process included a pump system, equalizing tank with a weir, sediment introduction hopper, and mixing trough.

To introduce flow, three DuroMax 4 in. (10 cm) semi- trash water pumps (Model No. XP904WP) were used to convey water from the upper supply pond to a 300 gal (1,136 L) tank. The equalizing tank was outfitted with three 4 in. (10 cm) inlets for the pumps to tie in with flexible hosing, a rectangular weir on the basin side, and three 4 in. (10 cm) adjustable gate valves on the backside. The gate valves were adjusted to allow water to leave the tank to prevent overflows, allow pumps to be primed and pressurized before testing, and regulate the flow rate to meet testing requirements. A wooden baffle was installed perpendicular to the incoming flow through the middle of the trough to reduce turbulence. Flow passed through the rectangular weir and entered the wooden mixing trough. The water level above the weir corresponded to a flow rate shown on an accompanying gauge that was calibrated and printed on a plate. A 0.5 in. (1.3 cm) clear rubber pressure tube was run from the inside of the equalizing tub and up the side of the flow plate, which was placed and secured during flow calibration. The plate was placed when the water level reached the bottom of the weir but was not yet entering the channel; this level corresponded to the plate reading "0.00 ft3/s." The calibration was verified by tracking the time required to reach several volumetric measurement markers, in a series of 5-gal (19-L) buckets. The flow introduction system is shown in Figure 3.8. Flow introduction system.



(a) back of system


(b) weir


(c) flow plate

Figure 3.8. Flow introduction system.

Sediment was introduced using a steel hopper equipped with a hydraulically-driven conveyor belt. Sediment introduction was regulated by the height of a gate installed on the hopper and the speed determined by the hydraulic machine. A Bobcat E32 Compact Excavator was used to attach and control the hydraulics for all sediment basin testing. The end of the conveyor belt was positioned hallway over the mixing trough to allow for ample mixing of introduced flow and sediment. Diversion drains were mounted within the trough to amplify mixing before entering the test channel. The Bobcat E32 Compact Excavator was set on its second hydraulic speed option, and the gate was adjusted. To calibrate the system, the time was tracked to introduce 32.7 and 65.4 lbs (14.8 and 29.7 kg) of sediment, which needed to reach 30 and 60 seconds, respectively. The system is shown in Figure 3.9.

Figure 3.9. Flow and sediment introduction system.

3.4.4. EXPERIMENTAL DESIGN AND TESTING REGIMEN

A staged-experimental testing regimen was developed to evaluate the treatments independently and as a system. Eight basin configurations, or series, were developed (S1-S8). Each series was comprised of three test days (L1-L3), and each test included two filling periods (A/B) for 48 total tests. L1-A started with an empty, sediment-free basin. Flow and sediment were introduced for 30 minutes, or the first filling period. The basin was then left to dewater for 4.5 hours before flow and sediment were introduced for another 30 minutes, or the second filling period (L1-B). The second filling period, simulated a second runoff event, which may be experienced as back-to-back storm events in the field, when the basin is partially full. The second event evaluated the resuspension potential and performance if the auxiliary spillway was activated. The basin then dewatered for at least 48 hours before the remaining impoundment was pumped from the basin.

Subsequent tests (L2 and L3) were conducted once the basin was completely dewatered; however, deposited material from the preceding tests was not removed. This testing regimen represented a newly constructed basin subjected to several storm events before maintenance (i.e., dredging deposited material).

Since the in-channel basin was based on the Iowa DOT standard design, it was important to understand the behavior of the basin with Iowa-native soil. Despite basin evaluations conducted in Auburn, Alabama, Iowa-native soil was delivered in five mobilizations. The testing regimen utilized Alabama-native soils for calibration and base condition testing since it was abundant on-site. Figure 3.10 below represents the testing regimen and testing sequence.

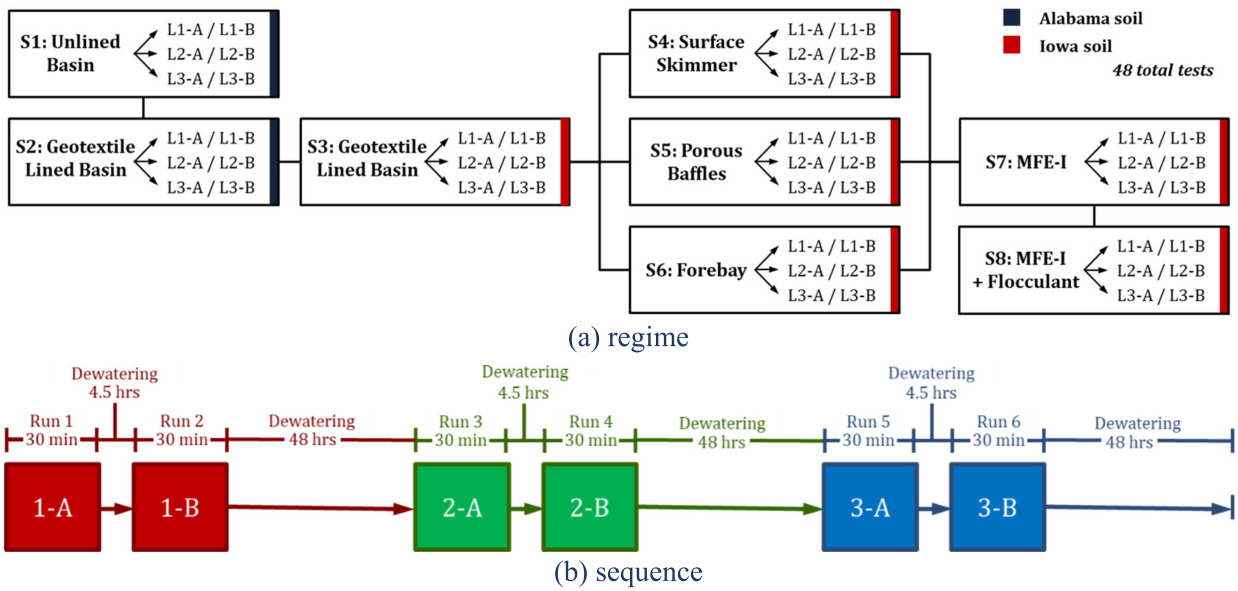


Figure 3.10. Sediment basin testing regimen.

3.4.5. IOWA NATIVE SOIL DELIVERY

Iowa native soil was mobilized from Tama U.S. 30 and delivered to the AU-SRF via five tractor trailer loads. When the soils arrived, there were observed color and particle size differences, indicating the soil was likely excavated from various locations and soil horizons on the size. The first delivery and soil from subsequent deliveries are shown in Figure 3.11.

(a) first delivery from Tama U.S. 30

(b) soil loads after delivery

Figure 3.11. Iowa soil delivery.

To ensure homogeneity during testing, the soils were well-mixed, using the Bobcat mini-excavator, compacted, and covered for storage. When testing began, soil was pulled from various locations in the stockpile, mixed again, and crushed to pass through the one-quarter inch shaker. Photos of the soil delivery and storage are shown in Figure 3.12.

(a) soil mixing

(b) compacted and covered stockpile

Figure 3.12. Iowa soil stockpile.

3.4.6. SOIL PARAMETERS

Before testing, soils were dried, crushed, and sieved through a 0.5 in. (1.3 cm) screen to remove large aggregate and debris. Both soil types used were classified according to AASHTO and USCS soil classifications. To classify these soils, dry and wet sieve analyses, Atterberg limits test, and hydrometer analyses were conducted according to ASTMs C136/C136M-19, D4318-00, and D7928-17, respectively. Following the required tests, the Alabama-native soil was classified as USCS Clayey Sand and AASHTO Fair to Poor Clayey soil. The Iowa- native soil was classified as USCS Sandy Lean Clay and AASHTO Clayey Soil. The soil gradations are shown in Figure 3.13.

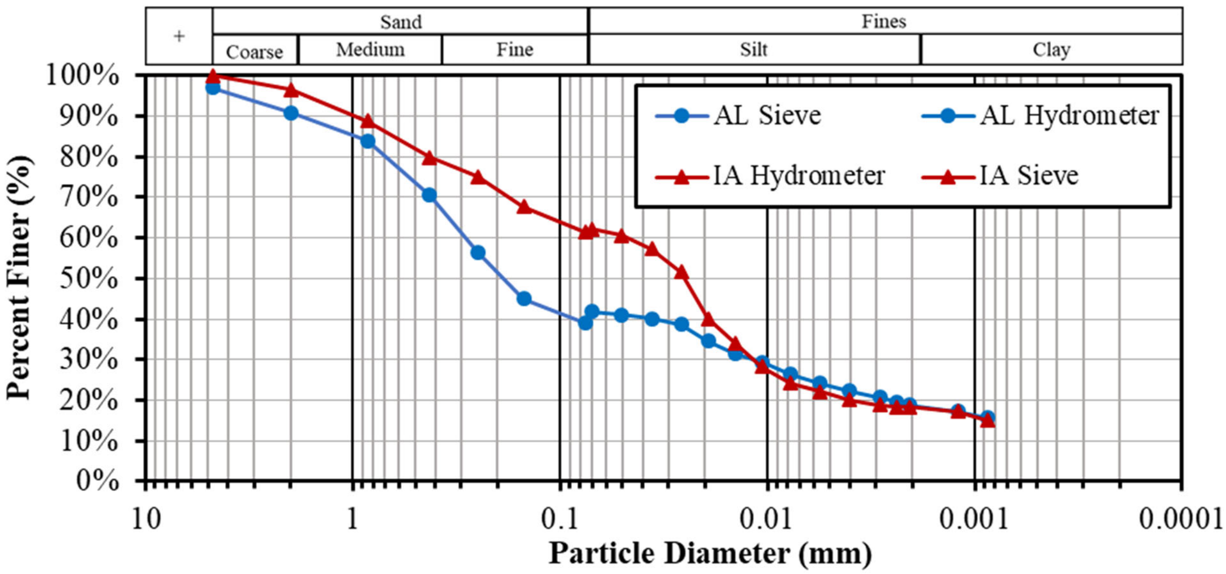


Figure 3.13. Soil gradation.

3.4.7. DATA COLLECTION

Various soil and water parameters were measured during testing to evaluate and compare the effects of the structural treatments on basin performance. Data collection included water samples for water quality analysis, stage levels within the basin, and sediment deposition after each test.

Three Campbell Scientific OBS3+ turbidity probes were placed in the basin. One sensor was located at the top of Bay 2 and the other two probes were located at the top and bottom of Bay 4. The CR850 Campbell Scientific data logger was mounted near the sensors and was powered by a 12V deep cycle marine battery. A set of Solonist M5 Levelogger and a M 1.5 Barologger were used to monitor the stage of the basin. The Levelogger was installed 6 in. (15.2 cm) off the basin floor in the fourth bay near discharge in a perforated PVC tube to protect it from direct sunlight. The logger recorded a measurement every 60 seconds. A Barologger was installed on-site and recorded atmospheric pressure every 15 minutes. Data were collected from the loggers in the Levelogger 4.5.1 Software. Levelogger data was corrected with the Barologger data, which resulted in the basin stage. The basin stage was plugged into the stage-storage relationships, shown in Figure 3.5, to monitor volume over time. This provided insight on dewatering times for the various installations.

Five Teledyne ISCO 6712 Portable automated samplers were used to collect water samples in the (1) inflow channel, (2) second bay, (3 and 4) top and bottom of the fourth bay, and (5) discharge. For samplers 2, 3, and 5, the suction tubing was mounted to floating skimmers in the center of the bays. Sample collection began when the water level reached the height of the floating skimmers. The suction tube for samplers 1 and 4 was mounted to cinder blocks and anchored in the inflow channel and Bay 4, respectively. The samplers each housed a set of 24 bottles of 34 oz (1.0 L) volume. Sampler 1 was programmed to take a 34 oz. (1.0 L) sample every two minutes during the 30-minute inflow periods for 15 samples. The second, third, fourth, and fifth samplers were programmed to take a composite sample comprised of a 17 oz. (0.5 L) sample every two minutes.

Therefore, one bottle was filled every four minutes during the first fill and subsequent dewatering period. The samples were started once the flow reached the intake of the sampling location. The bottles provided adequate volume to capture samples for the 96 minutes following sampling start. The start times for each sampling location under a certain basin configuration is shown in

Table 3.3. Sampling Start Times

Sampling Location	S1, S2, S3, S5	S4	S6	S7, S8
Inflow	2 min	2 min	2 min	2 min
Bay 2	16 min	16 min	24 min	24 min
Bay 4 Top	4 min	4 min	4 min	4 min
Bay 4 Bottom	4 min	4 min	4 min	4 min
Discharge	16 min	8 min	24 min	24 min

During the second fill, the inflow sampler was again programmed to take a 34 oz. (1.0 L) sample every two minutes during the 30-minute inflow periods for 15 samples. The second, third, fourth, and fifth samplers were programmed to take a composite sample, comprised of a 17 oz. (0.5 L) sample every two minutes during filling, but were transitioned to longer sampling times to capture the basin behavior during the extended dewatering period. Samplers 2-4 were programmed to take a composite sample of a 17 oz. (0.5 L) sample every 75 minutes. This provided water samples from the first 45 hours of dewatering. Sampler 5 followed the same program; however, sampler 5 was programmed to take a sample every 10 minutes when the riser pipe was used for dewatering. This was due to the increased stage level required to dewater from the perforations in the riser pipe. Meanwhile, the skimmer allowed the basin to dewater for approximately 50 hours post-initial fill cycle. Water sampling locations and intervals are shown in Figure 3.14.

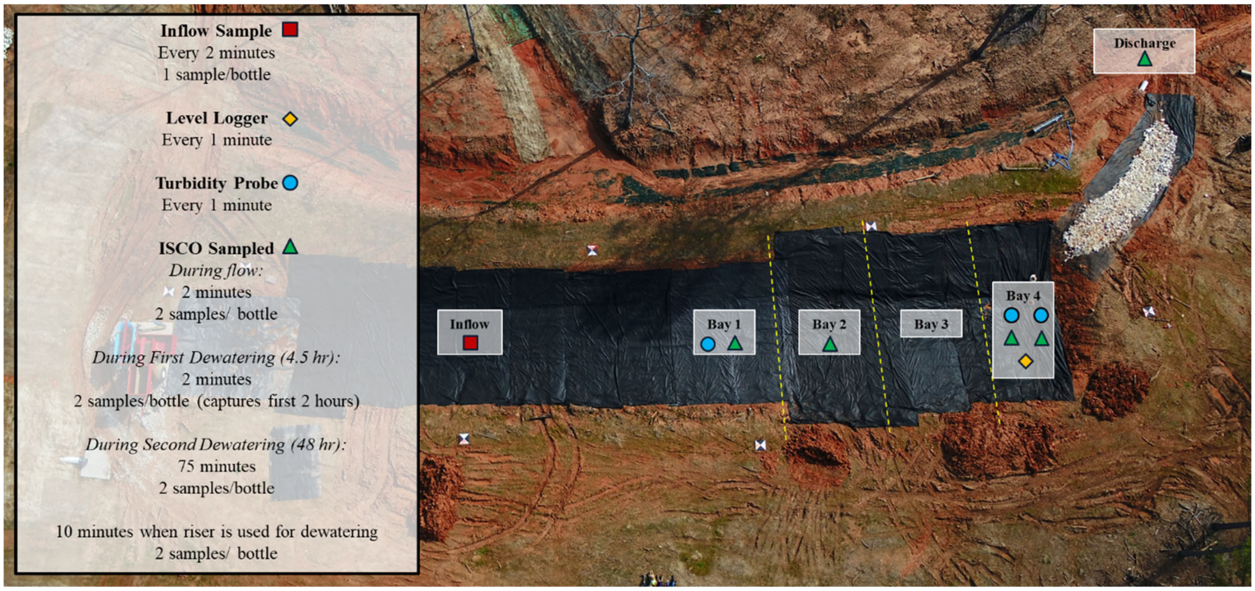


Figure 3.14. Water sampling locations.

Following each series of tests, the sediment basin was drained and the deposited material was dredged out and measured following each series of tests. Five sedimentation gauges were installed in an x-configuration in each bay, and sedimentation depths were measured after the basin was completely drained between tests. The sedimentation gauges were used for observation between tests. Methods to quantify sediment retention are outlined in the following section.

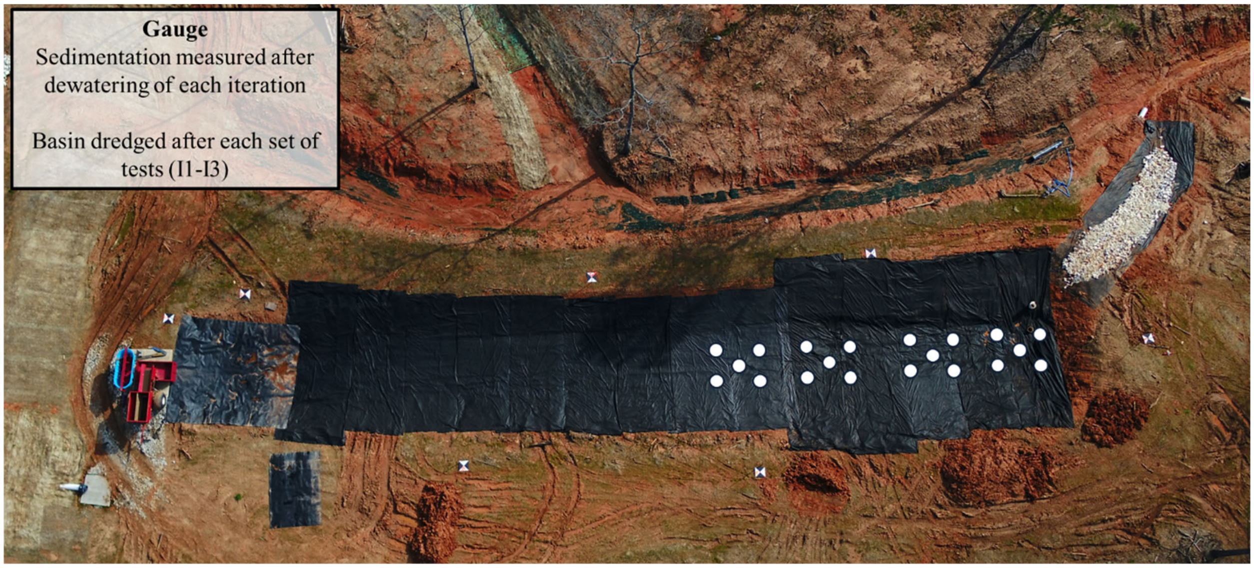


Figure 3.15. Sedimentation gauge configuration.

3.4.8. SEDIMENT RETENTION QUANTIFICATION

To quantify sediment retention, the sediment basin was completely drained using a 2 in. (5.1 cm) submersible pump. The deposited material was dredged out and measured following each series of tests. Each bay was dredged and measured independently. Sediment volume and weight were measured by filling a 15.3 ft^3 (0.43 m^3) metal bin. After volumetric measurements, a 1 ft^3 (0.03 m^3) sample was taking from the larger bin to correct for the dredged sediment's moisture content.

The bin was filled with the deposited material, and a depth measurement was recorded. The depth measurement was multiplied by the cross-sectional area to result in a total sediment volume. The 1 ft^3 (0.03 m^3) box was then filled with sediment from the bin. The 1 ft^3 (0.03 m^3) of sediment was transferred to a metal baking pan and weighed. The weight was corrected to exclude the weight of the empty pan, W_{wet}. The sediment was dried in an oven for at least 36 hours and reweighed and corrected for weight of empty pan. The dry weight, W_{dry}, was multiplied by the total volume to estimate the weight of sediment retained in the bay, W_1. The water content, W_c, was determined using Eq. 3.5.

$$W_c = \frac{(W_{Wet} - W_{Dry})}{W_{dry}} \quad \textbf{Eq. 3.5}$$

The geotextile liner captured a portion of the sediment and made it difficult to quantify all deposited sediment. To account for this, a 2 × 2 ft (0.61 × 0.61 m) geotextile square sample was removed from each bay and dried. The representative squares were then weighed and corrected for the weight of the geotextile without deposited material. Each bay was measured for the area, divided by the 4 ft^2 (0.37 m^2) representative square, and multiplied by the resulting weight of each representative square. This result represented the weight of soil retained in the geotextile in each bay, W_2. W_1 and W_2 were combined to estimate the total weight retained in each bay. In between the testing series, the geotextile was pressure washed to remove any captured sediment. The weights were analyzed as a percentage of the total soil weight introduced to the basin during test L1-L3.

3.4.9. WATER QUALITY ANALYSIS

For series S1 and S2, turbidity and total solids analyses were conducted for all water samples. Turbidity was determined using a combination of the HACH® 2100Q Portable Turbidimeter (0-999 NTU) and Hach® TL23 Series Turbidimeter (0- 9,999 NTU). Total solids testing was conducted following ASTM standards D3977-97 *(ASTM 2015)*. Sediment concentrations were expected to be above 200 ppm; therefore, the evaporation test method (Test Method A, ASTM D3977-97) was selected. Due to a large number of samples, the analyses were time, labor, and material intensive. The turbidity and total solids concentrations from S2 were plotted and evaluated for a relationship to minimize the impact in the laboratory. After observation, inflow values skewed any relationship. To improve the relationship, the inflow was removed, and sample pairs (turbidity- total solids) were sorted based on turbidity value. The values were split into 10 ranges (0-99, 100-199, 200-299… 900-999, 1000+). Each range was independently evaluated, and samples with outlying total solids concentrations were removed.

The remaining turbidity and total solids values were plotted on the x- and y-axis, respectively, as shown in Figure 3.16 and resulted in a relationship shown in Equation 3.6.

$$y = 0.0417x^{1.34} \quad \textbf{Eq. 3.6}$$

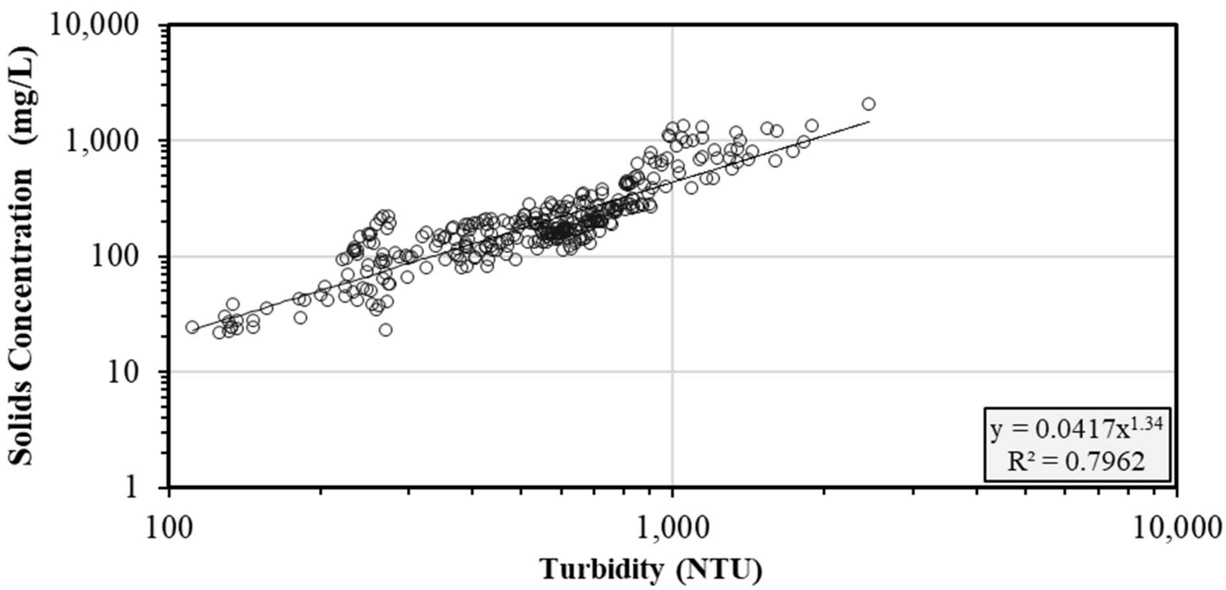


Figure 3.16. Turbidity and total solids relationship.

For the remaining series, inflow water samples were analyzed for turbidity and total solids; however, water samples from locations 2-5 were only analyzed for turbidity, and values were plugged into the relationship shown in Eq. 3.6 to estimate total solids concentrations.

The basin configurations were analyzed for turbidity reduction (%) from the water samples by comparing representative inflow turbidity to turbidities from downstream sampling locations. Representative inflow turbidity for each test (L1-A, L1-B, L2-A, L2-B, L3-A, L3-B) were calculated by averaging the inflow samples from a filling period after removing the outliers. Outliers were determined as values that were 1.5 times higher or lower than the interquartile range. An example of calculating the representative inflow for the S3 LX-A data set is shown in Table 3.4. This process would be repeated for the second filling period S3 LX-B, etc. The strikethrough text represents an outlier, which was not used in average calculations.

Table 3.4. Example for S3 (lined, IA-soil)

Time (min)	S3: L1-A (NTU)	S3: L2-A (NTU)	S3: L3-A (NTU)	Average (NTU)
2	1,636	1,383	2,793	1,938
4	4,022	1,620	1,431	2,358
6	3,025	1,307	1,656	1,996
8	2,248	1,268	2,854	2,123
10	3,285	~~2,519~~	2,215	2,673
12	1,606	1,173	1,027	1,269
14	1,993	1,228	913	1,378
16	1,564	1,016	1,235	1,272
18	1,195	987	1,257	1,146
20	885	923	1,084	964
22	899	946	918	921
24	875	948	900	908
26	979	1,092	757	943
28	987	1,032	992	1,004
30	1,636	1,383	2,793	1,938
Avg.	**1,800**	**1,148**	**1,431**	**1,460**

The average turbidity values from the samples at the remaining sampling locations were divided by the representative inflow value, subtracted from 1 to determine a turbidity reduction (%), and plotted over the 48-hour observation period. Table 3.5 illustrates the pairings of representative inflow turbidities with discharge time ranges for comparison.

Table 3.5. Turbidity comparison pairs

Inflow Turbidity Value	Compared to Discharge Turbidity Values at Times
Average Turbidity (00:00-00:30)	0:00-2:00
Average Turbidity (5:00-5:30)	5:00-48:00

An example, showing the turbidity reduction analysis for S3 (lined with IA soil) is shown in Table 3.6. Example turbidity reduction calculation for S3 series.

Table 3.6. Example turbidity reduction calculation for S3 series

Time (hh:mm)	L1-A *Avg. Inflow 1,800 NTU*	Turbidity Reduction (%)	L2-A *Avg. Inflow 1,148 NTU*	Turbidity Reduction (%)	L3-A *Avg. Inflow 1,431 NTU*	Turbidity Reduction (%)
00:16	27740	-1,441%	1,148	0%	1,308	9%
00:20	37287	-1,971%	1,344	-17%	1,541	-8%
00:24	1616	10%	921	20%	1,223	15%
00:28	813	55%	818	29%	1,148	20%
00:32	750	58%	727	37%	1,227	14%
00:36	661	63%	674	41%	854	40%
00:40	613	66%	733	36%	896	37%
00:44	585	68%	707	38%	839	41%
00:48	573	68%	719	37%	774	46%
00:52	579	68%	692	40%	769	46%
00:56	509	72%	662	42%	806	44%
01:00	510	72%	632	45%	745	48%
01:04	535	70%	592	48%	693	52%
01:08	473	74%	590	49%	704	51%
01:12	541	70%	575	50%	701	51%
01:16	431	76%	607	47%	705	51%
01:20	462	74%	594	48%	683	52%
01:24	437	76%	577	50%	656	54%
01:28	400	78%	567	51%	644	55%
01:32	405	78%	577	50%	610	57%
01:36	389	78%	564	51%	597	58%
01:40	412	77%	545	53%	610	57%
01:44	395	78%	552	52%	625	56%
01:48	396	78%	405	65%	1,308	9%

Table 3.7. Example turbidity reduction calculation for S3 series

Time (hh:mm)	L1-B *Avg. Inflow 1,193 NTU*	Turbidity Reduction (%)	L2-B *Avg. Inflow 1,588 NTU*	Turbidity Reduction (%)	L3-B *Avg. Inflow 2,712 NTU*	Turbidity Reduction (%)
5:02	270	77%	859	46%	675	75%
5:06	301	75%	851	46%	643	76%
5:10	1,844	-55%	810	49%	717	74%
5:14	2,695	-126%	755	52%	839	69%
5:18	1,918	-61%			1,350	50%
5:22	605	49%			1,416	48%
5:48	575	52%			1,167	57%
6:08	541	55%			1,034	62%
6:28	552	54%			901	67%
6:48	554	54%			758	72%
7:08	519	57%			739	73%
7:28	427	64%			713	74%
8:08	347	71%			687	75%
8:28	355	70%			625	77%
8:48	339	72%			616	77%
9:08	282	76%			610	77%
9:28	264	78%			632	77%
9:48	267	78%			610	77%
10:08	250	79%			607	78%
10:48	222	81%			606	78%

Note: discharge sampler malfunctioned during L2-B sampling, so no discharge values were recorded.

Treatments were evaluated for statistical significance using a traditional multiple linear regression model. Structural treatments (e.g., skimmer, baffles, forebay) were recorded as unique, independent variables using values of 1 if present or 0 if absent for an installation. The dependent variables were turbidity reductions between -100% - 100%. The regression model determined the relative impact of each treatment on turbidity reduction, independent of other treatments. The model equation, as written by Donald et al., *(2013),* is shown in Eq. 3.7:

$$f(x) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 \qquad \textbf{Eq. 3.7}$$

where,

$f(x)$ = dependent variable (e.g., turbidity reduction [%])
β_0 = coefficient intercept
β_i = ordinary least squares coefficient
x_i = independent variables (e.g., skimmer, baffles, forebay)

Due to the great variability in turbidity the R^2 values were relatively low, but statistical significance was determined based on the p-value at the 95% confidence interval. For analyses, the 30-minutes of flow introduction in LX-A and LX-B were considered the first and second “filling periods.” The 30- minutes following, or first hour, was considered “rapid settling,” and the remaining dewatering time was considered “polishing.”

3.5. STRUCTURAL TREATMENTS

After conducting a thorough literature review, several sediment basin components and treatments were cataloged and selected for evaluation based on the potential to improve water quality and sediment capture. The treatments selected included lining the basin with geotextile, dewatering surface skimmer, coir flow baffles, rock check dam to create a forebay within the channel, and application of flocculant.

3.5.1. IOWA DOT CONFIGURATION

The Iowa DOT has drawings and specifications for the design and construction of temporary sediment control basins used on their sites *(Iowa DOT 2018)*. This configuration is described in the Design section of this proposal and illustrated in Figure 2.2. This configuration was considered S1, or the control installation during testing, and is shown in Figure 3.17a. It is important to note that the S1 installation at the AU-SRF appeared and was expected to perform differently than the Iowa DOT site sediment basins due to the differences in the subgrade. Alabama-native site soil was introduced to the basin rather than the Iowa soil since separating the settled material from subgrade would be difficult without the geotextile lining. While water quality evaluations followed the procedures described above, the sediment retention evaluation was modified since the bounds of dredging would also be difficult without the geotextile. Instead, a pre- and post-test survey was conducted to compare sedimentation.

Three sedimentation cubes were placed every 25 ft (8 m) to capture settled material, which were then measured, dried, and re-measured to account for the shrink-swell due to moisture. These cubes are shown in Figure 3.17(b).

(a) S1 configuration

(b) sedimentation cubes

Figure 3.17. S1 installation at AU-SRF.

3.5.2. GEOTEXTILE LINING

Geotextile lining was used for installations S2 and S3. The geotextile lining was expected to stabilize the basin floor. Additional stabilization was expected to reduce erosion of the basin and resuspension of settled particles. An 8 oz. (227 g), non-woven geotextile was secured to the basin with 6 in. (15.2 cm) round top pins. Where necessary, the geotextile was overlapped a minimum of 1.0 ft (30.5 cm). The geotextile liner remained in place for S2-S8 testing. The lined basin is shown in Figure 3.6.

3.5.3. SURFACE SKIMMER

A surface skimmer was the subsequent treatment applied and used for S4 evaluations. Surface skimmers have been adopted by many state environmental regulatory agencies, following section 2.2.12 of the CGP, as the principal dewatering mechanism, replacing the use of perforated riser pipes *(ALDOT 2020, NCDOT 2015, TDOT 2020)*. Section 2.2.12 of the CGP requires stormwater to be withdrawn from the surface unless determined infeasible. Although infeasible cases are rare, exceptions are considered in locations and time when freezing is expected *(USEPA 2022)*.

The skimmer functions by floating at or near the water surface of the basin, allowing dewatering to occur through one or several orifices. Skimmers are sized according to the basin volume and desired detention time. A figure for installation is shown in Figure 3.18

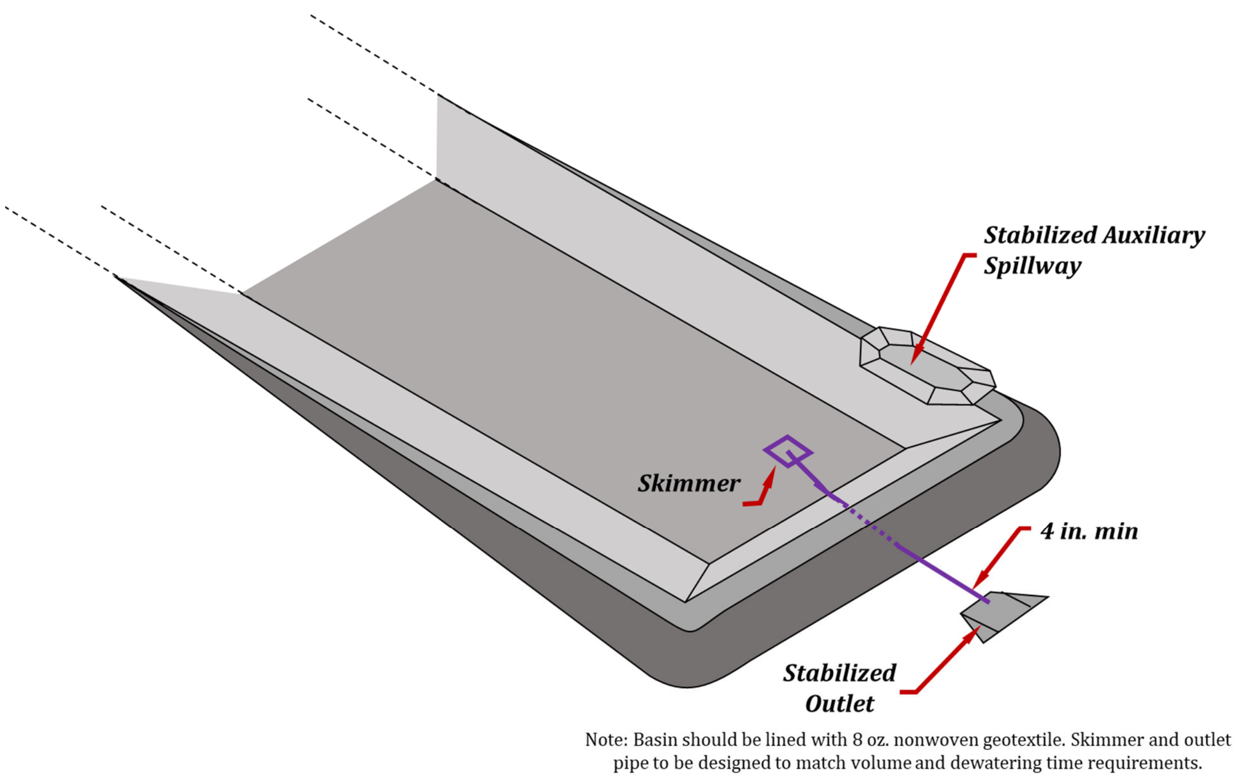
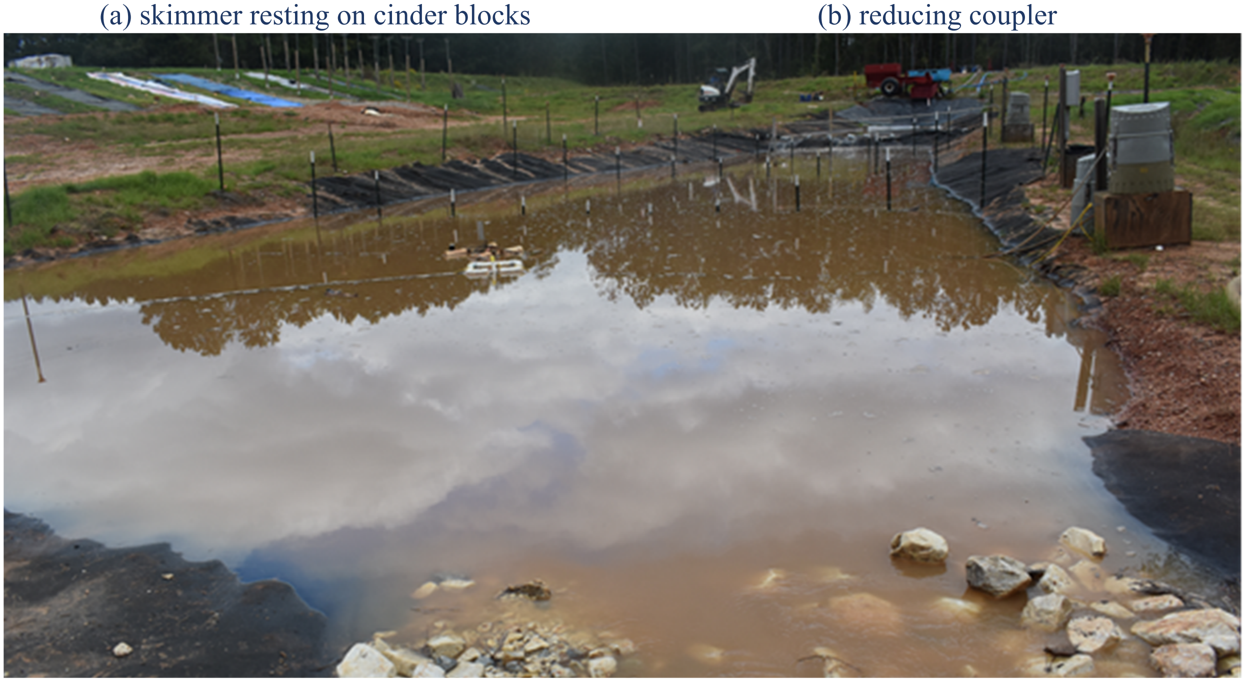


Figure 3.18. Skimmer design.

When used in the basin at the AU-SRF, the floating mechanism was attached to a reducer and then connected to the 12 in. (30.5 cm) outlet. A 2 in. (5.1 cm) Faircloth Skimmer® Surface Drain was used during testing. A dewatering time of 48 hours was used to determine the orifice size, as described in the skimmer's installation directions *(J.W. Faircloth & Son, 2007)*. Using a volume of 3,031 ft^3 (86 m^3), the required orifice radius was 0.6 in (1.52 cm). Two cinder blocks were used as the skimmer rest to ensure the skimmer would not become stuck in deposited material after complete dewatering. The skimmer installation is shown in Figure 3.19.

(a) skimmer resting on cinder blocks

(b) reducing coupler



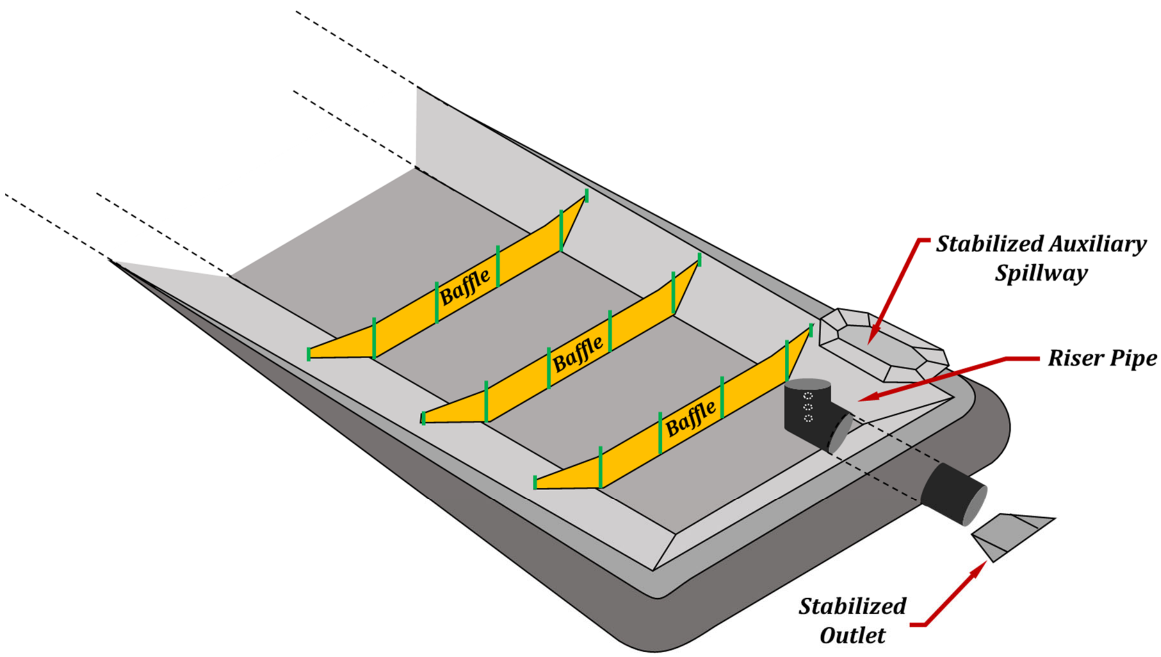
(c) dewatering basin

Figure 3.19. Skimmer in the basin at the AU-SRF.

3.5.4. COIR BAFFLES

A series of three coir baffles were installed for S5, which separated the basin into four bays. The baffles were intended to reduce turbulence and provide lower-velocity flow conditions. The baffles dissipated flow energy, which allowed water to flow across the width of the basin uniformly. This reduces short-circuiting by preventing inflow from moving directly to the outlet and increases the effective width.

For S5 testing, the baffles were installed every quarter-length of the basin. Baffle installation included driving T-posts at least 24 in. (61 cm) into the ground with an extension of at least 48 in. (91 cm) above the basin floor. Wire mesh reinforcement was then tied to the posts, and a double layer of 700-900 g/m^2 (2.3-3.0 oz/ft^2) coir was attached to the reinforcement. The baffle was secured to the bottom of the basin using staples. A schematic of the baffle installation is shown in Figure 3.20.



Note: Basin should be lined with 8 oz. nonwoven geotextile. Baffles should include two layers of 700-900 g/m^2 coir supported by t-posts and mesh backing, and secured to channel bottom.

Figure 3.20. Baffles design.

The coir baffles installation is shown in Figure 3.21.

(a) coir baffles after install

(b) coir baffles during flow

Figure 3.21. Coir baffles in basin at the AU-SRF.

3.5.5. FOREBAY

A forebay was installed for S6 evaluations. A forebay is a section upstream of a sediment basin designed to capture rapidly-settable solids. Forebays can improve the overall capture effectiveness of a sediment basin system while allowing the basin itself only to receive smaller grain-sized particles. This decreases the frequency of dredging and provides additional stormwater storage. An Iowa DOT Rock Check Dam (EC-301) was installed 100 ft (33.3 m) from flow introduction *(Iowa DOT 2018).* Class D riprap was used, and the rock check dam was covered with an 8 oz (227 g) non-woven geotextile. A schematic is shown in Figure 3.22.

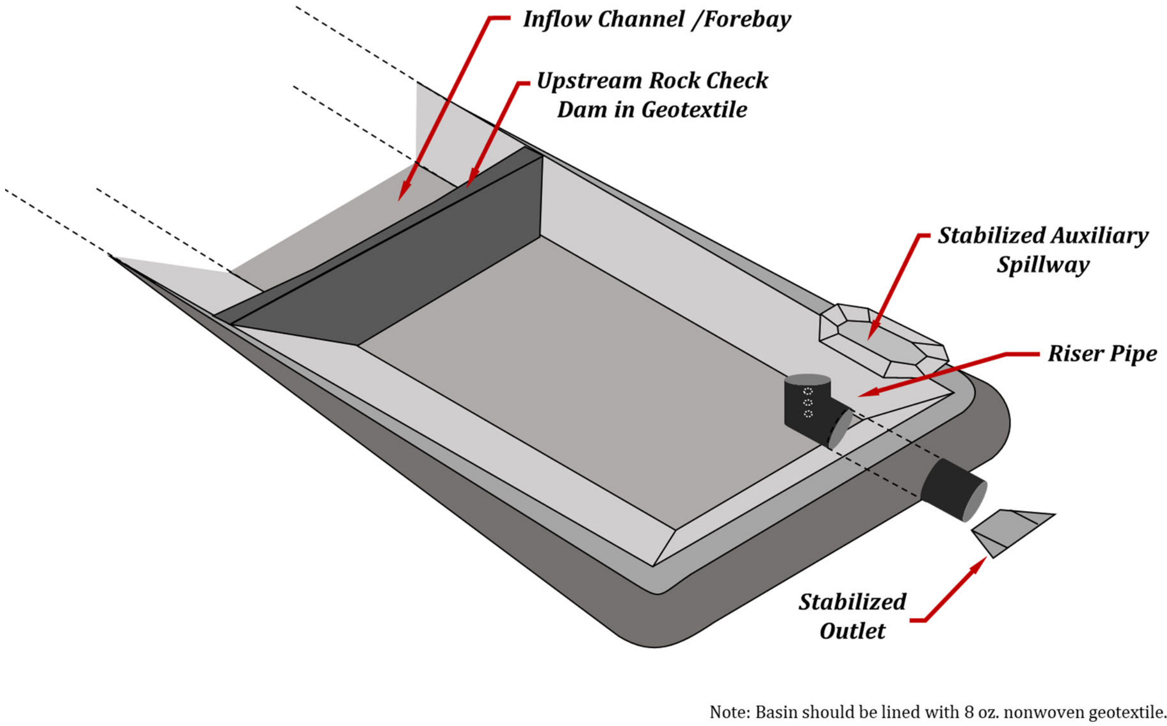
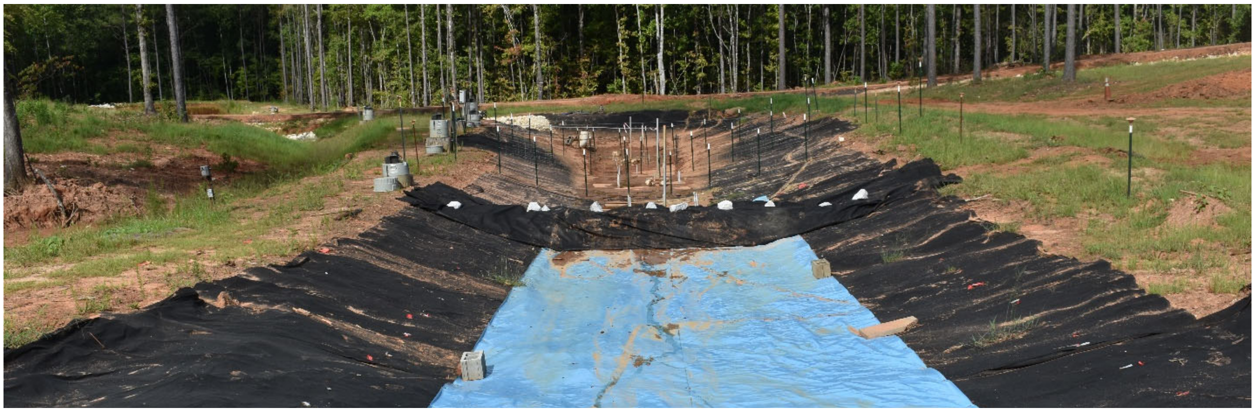


Figure 3.22. Forebay design.

This installation provided approximately 900 ft^3 (25 m^3) of additional storage volume, as shown in Figure 3.23.



(a) forebay installation

(b) forebay during flow

Figure 3.23. Forebay installation.

3.5.6. MOST FEASIBLE AND EFFECTIVE INSTALLATION

The Most Feasible and Effective Installation (MFE-I) comprised a combination of treatments, including geotextile liner, forebay, and skimmer, and tested for S7. The treatments were selected based on individual effectiveness and feasibility, considering site installation and maintenance. This is shown in Figure 3.24.

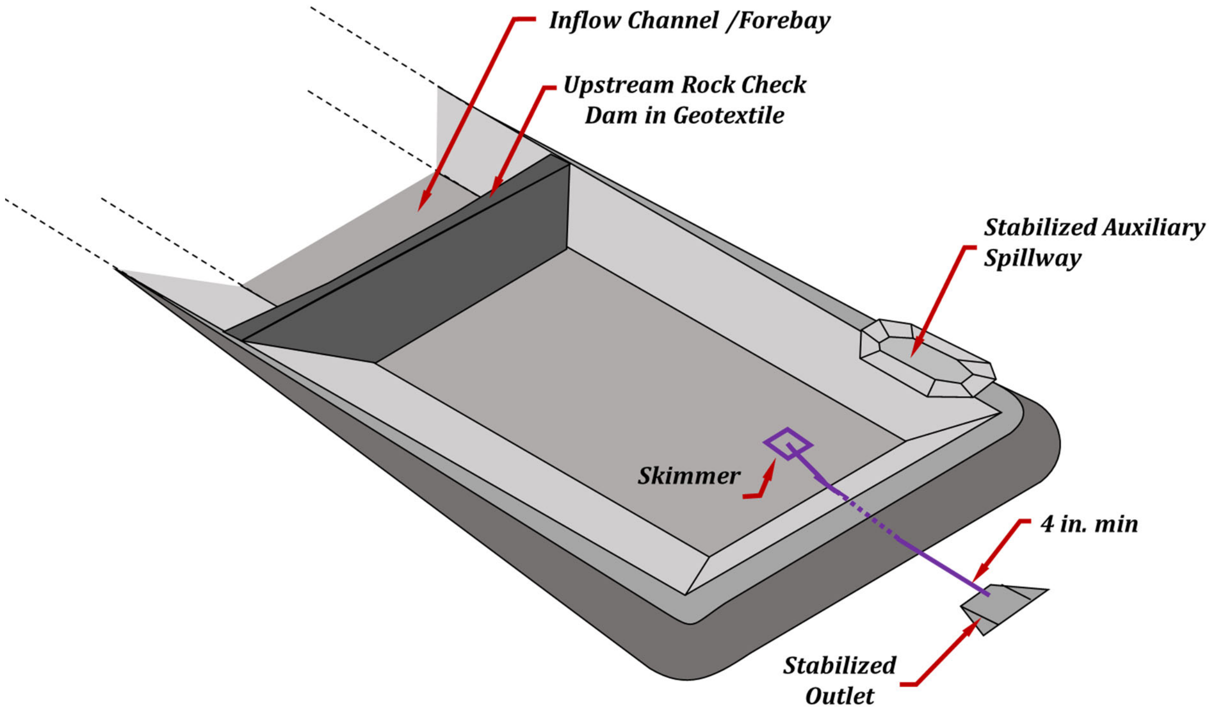


Figure 3.24. MFE-I design.

The MFE-I (S7) configuration was also used for S8 with the addition of flocculant. MFE-I (S7) and MFE-I + Flocculant (S8) are detailed and compared in Chapter Five.

3.6. RESULTS AND DISCUSSION

The following section summarizes the findings from the unlined and lined basin configurations tested with Alabama-native soil and the lined, skimmer, baffles, forebay, and combination configurations tested with Iowa-native soil. Each configuration was subjected to six 30-minute filling periods where 1,960 lbs (890 kg) of sediment was introduced. Each configuration was evaluated for sediment retention and water quality improvements.

3.6.1. SEDIMENT RETENTION

Sediment retention was quantified after each set of testing (6 total filling periods), and methods to evaluate configurations S2-S8 were described in the previous section. Sediment retention by weight for individual bays and the entire system is illustrated in Figure 3.25.

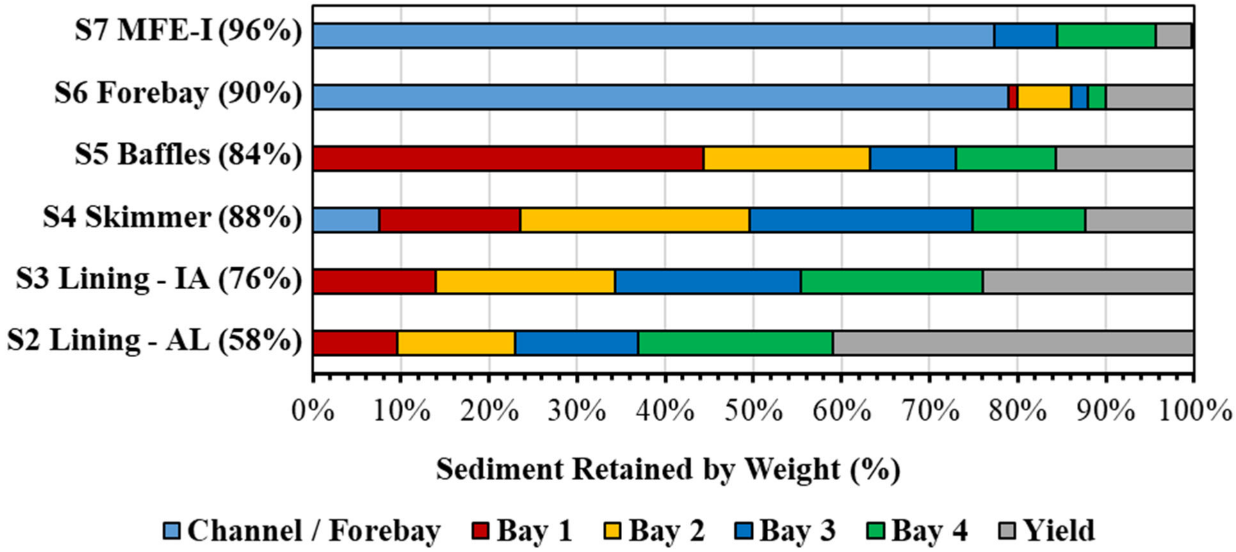


Figure 3.25. Sediment retained by percent weight.

The two-lined configurations were initially compared. More Iowa soil was retained within the basin than Alabama soil. Percent retention was 76% and 59%, respectively. While this was initially counterintuitive due to the fraction of sand present in the Alabama soil and absent from the Iowa soil, the difference was attributed to the Iowa soil being difficult to break down due to the high clay fractions creating colloids for testing at the AU-SRF. Increased particle size typically increases the mass and resulting settling velocity. Although the soil was dried, processed, and shaken through a 0.5 in. (1.27 cm) sieve, colloidal particles may have skewed the gradation compared to the laboratory soil tests.

When the skimmer was installed to dewater the basin, the impoundment depth and length were increased. Consequently, sedimentation occurred over a greater length within the basin and resulted in 88% retention. Sedimentation in the channel due to the skimmer installation is shown in Figure 3.26.

Figure 3.26. In-channel sedimentation due to skimmer installation.

The next treatment applied to the basin was coir baffles, which intercepted and dispersed the inflow across the width of the channels. Based on the sediment retention results, the first two bays captured the largest fraction of settled material, likely the coarsest sediment, shown in Figure 3.27. The sedimentation in Bay 4 with baffles installed was within 2% of the sediment retained when the skimmer was installed. The baffles, or S5 configuration, retained 84% of the introduced sediment by weight.

Figure 3.27. In-channel sedimentation due to coir baffle installation.

Overall sediment retention increased to 90% when the forebay was installed. Sediment retention of 79% occurred within the forebay. This sediment impoundment was visibly coarse after draining, as seen in Figure 3.28.

The forebay exhibited the most sediment capture at 90%, with most of the capture occurring in the forebay. Bay 1 retained the most sediment for the baffle installation. The rock check dam used to create the forebay could also be considered an enhanced first baffle *(NCDOT 2015, IECA 2021)*. The rock check dam and first baffle seemed to function similarly during their respective installations. The first baffle slowed and dissipated flow, which allowed larger particles to settle out in the first bay. Of the 84% of sediment retained, about 45% was captured in the first bay. The rock check dam not only slowed and dissipated flow during the forebay installation but also provided additional storage.

After evaluating sediment retention and water quality improvements and consulting with the Iowa DOT Technical Advisory Committee, the MFE-I, or S7, was developed. This installation included the combination of geotextile lining, a surface skimmer, and a forebay. Baffles were not adopted for the MFE-I (S7) evaluation due to the perceived difficulties with installation, additional material costs, labor, and maintenance considerations. Sediment retention for the MFE-I increased to 96% total capture, with 77% occurring in the forebay. Sediment retention in the forebay was within 2% of each other when comparing the S6 and S7 configurations, validating repeatable and reliable results during large-scale testing.

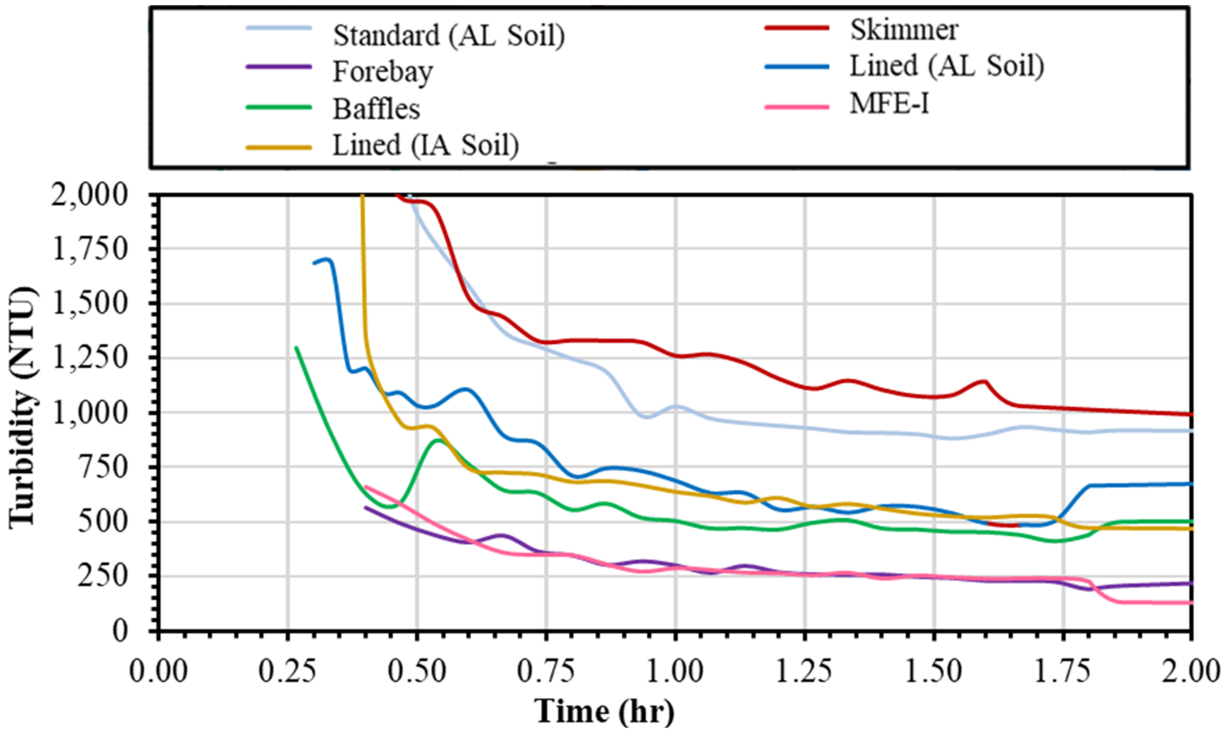
Figure 3.28. In-channel sedimentation due to forebay installation.

3.6.2. WATER QUALITY

Turbidity was monitored in several locations throughout the basin, however, the most observed and analyzed sampling location was at the discharge outlet of the basin. Figure 3.29 plots the discharge turbidity for all basin configurations. The trends in discharge turbidity largely follow the sediment retention trends, with increased sediment retention corresponding to decreased turbidity. However, the skimmer configuration does not fit into this general trend.

The increased turbidity with the skimmer installed was not expected and did not follow the expected behavior, as described in the literature *(Millen et al., 1997 and Jarret et al., 2001)*. After closer examination, turbidity reduction differences were observed between the sampling location at the top of Bay 4 and the discharge for the skimmer, or S4, installation. Although the turbidity was increased during the initial dewatering period, the skimmer was still included in the MFE-I, or S7 configuration, considering the increased sediment retention resulting from its installation and the ability to allow turbidity to decrease beyond the other treatments by decreasing flowrate as shown in Figure 3.29(b).

The forebay provided an additional 900 ft^3 (25 m^3) of storage volume and impounded water until it overtopped the rock check dam. The discharge dispersed flow across the channel and slowed the velocity, which decreased the volume reaching the basin during the filling period; thus, discharge did not start until later into the filling period, as shown in Figure 3.29.



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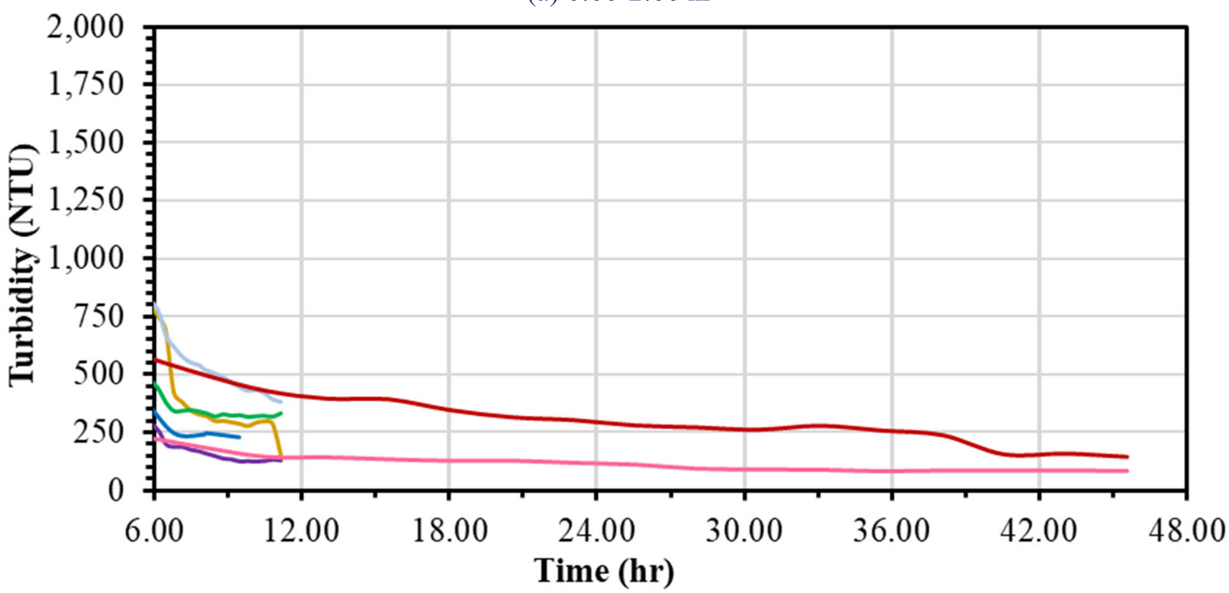

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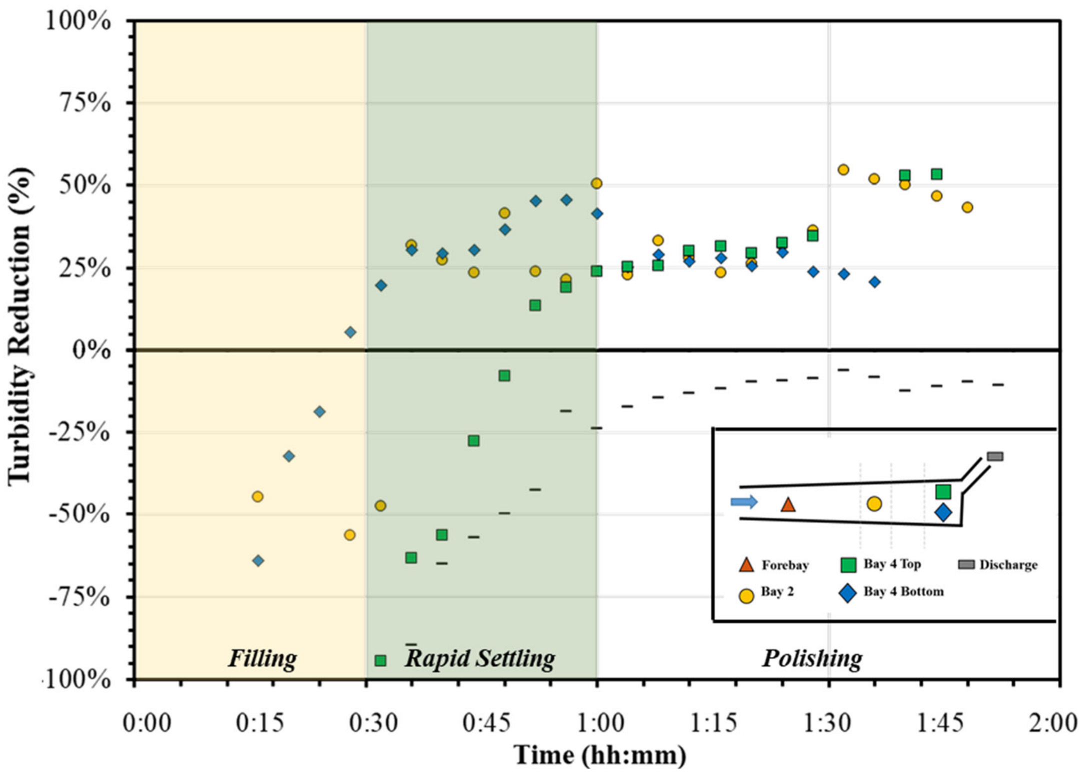
Figure 3.29. Turbidity during monitoring of structural treatments

In addition to the increased sediment retention, the sediment basin was dewatered over the 48-hour monitoring period when the skimmer was installed instead of the traditional perforated riser pipe. The skimmer had a lower, terminal dewatering point, or permanent pool at approximately 2 ft (0.61 m), as dictated by the invert of the discharge pipe through the earthen berm. As a result, the basin stage was drawn further down with the skimmer installed, which allowed increased stormwater storage for subsequent filling or storm events.

When the riser pipe was used, the basin stage quickly raised and thus consumed a large portion of the basin volume. The basin was only able to dewater through the orifices but eventually was impounded to reach the top of the riser pipe, and the total diameter of the 12 in. (0.30 m) pipe was overcome with the flow. As a result, the auxiliary spillway was never utilized during controlled testing, as it would take an increased volume of runoff to do so. The basin quickly dewatered when the stage was above the pipe elevation but slowed to a more controlled rate when only discharging through the orifices. The permanent pool, or stage, for the riser pipe and forebay with riser pipe installations, equalized at approximately 3 ft (1 m), reached in 12 hours.

Although sediment retention was not quantified for the unlined S1 configuration, water samples were taken in Bay 2, Bay 4 Top and Bottom, and Discharge locations. As shown in Figure 3.30(a), the discharge turbidity reduction was negative during the first filling, rapid settling, and polishing period, indicating the turbidity was higher at discharge than average inflow. This observation was similar to the field observations documented in Performance during Field-Monitoring. Increased turbidity could have been due to the resuspension of fine particles or the additional sediment load resulting from channel erosion during high flow. Turbidity reduction was the lowest following the filling period and slowly increased. Turbidity reduction reached 0% by nine hours after the first fill and nearly 25% after twelve hours when dewatering through the riser pipe was completed. Turbidity reduction was highest in Bay 2 but did not follow a pattern in Bay 4.



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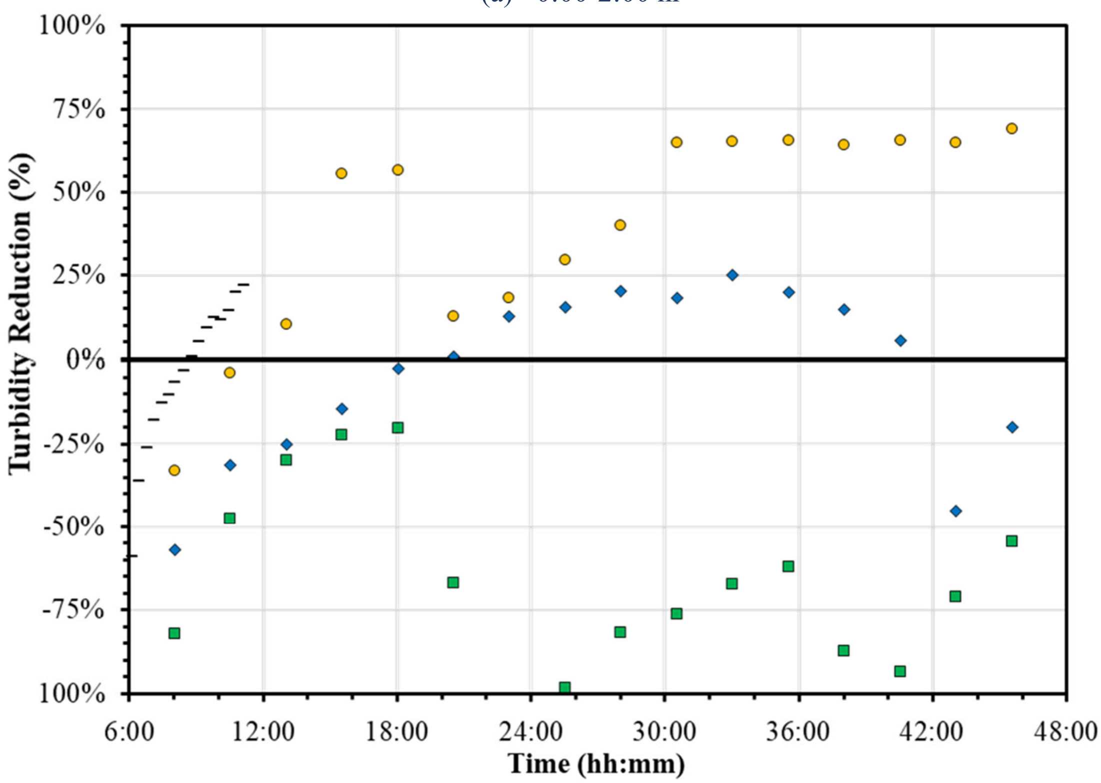

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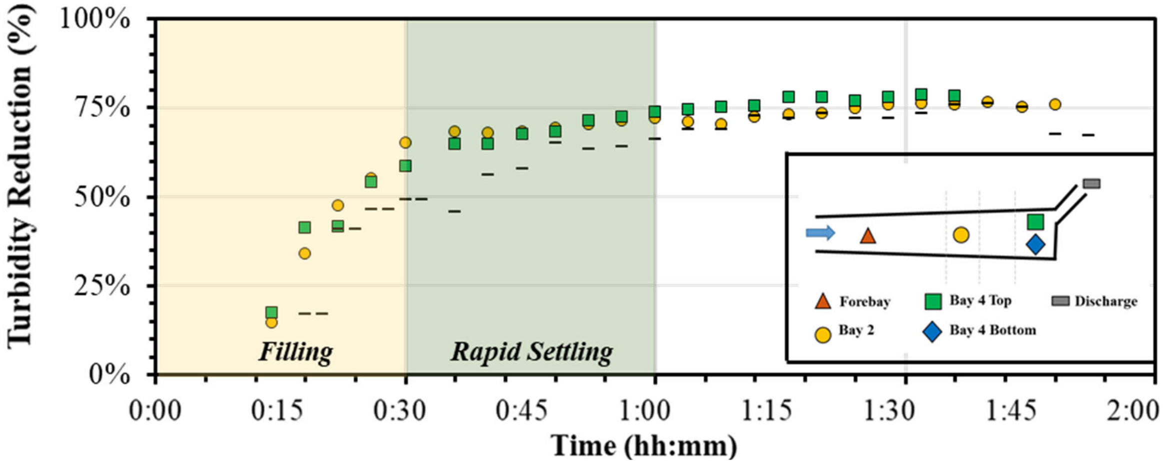
Figure 3.30. Turbidity reduction during unlined testing (AL soil).

Turbidity reduction from S1 was compared to the lined S2 configuration and subject to Alabama-native sediment-laden flow. Discharge turbidity reduction was positive throughout basin monitoring and more closely followed the turbidity reduction trends of Bay 2 and Bay 4. Turbidity reduction was above 75% when dewatering commenced; however, Bay 2 and Bay 4 were continuously monitored and indicated potential removals up to 90%.



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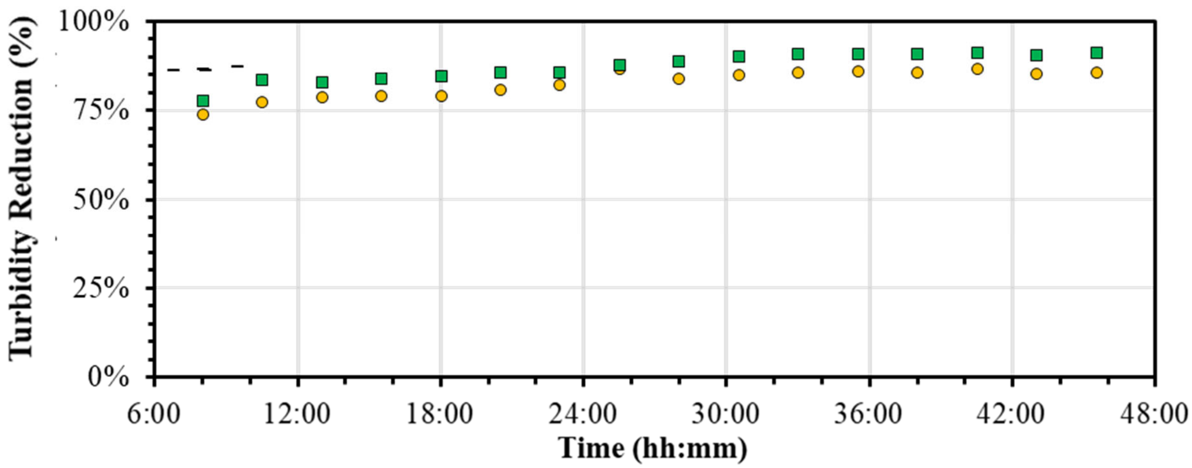

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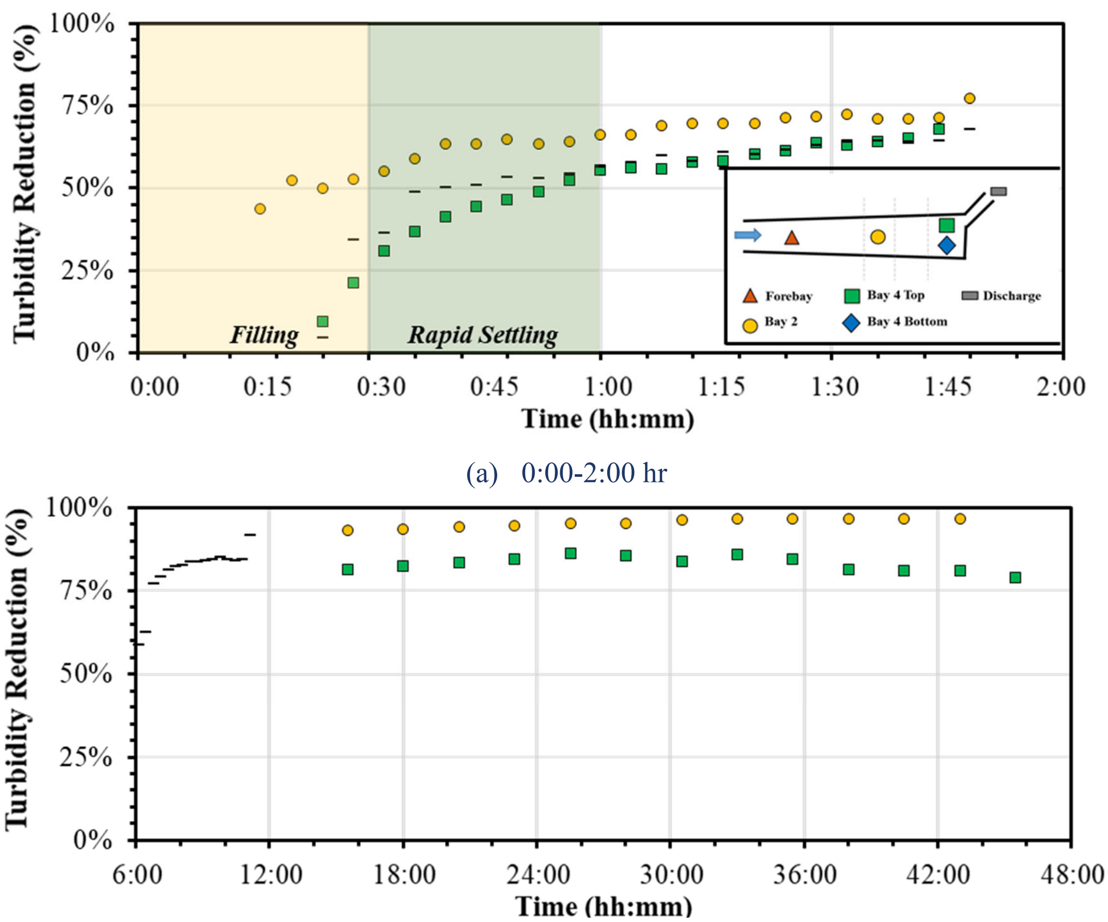
Figure 3.31. Turbidity reduction during lined testing (AL soil).

Turbidity reductions at discharge for the S1 and S2 configuration were compared using a traditional regression model for statistical relevance, with S1 as the base case. The lining was considered an independent value and proved to be statistically significant. Turbidity reduction was estimated to be significantly higher when the geotextile lining was implemented during all periods of the test, as indicated by the coefficient in Table 3.8. The predicted increase in turbidity reduction is hypothesized to be in response to a decreased sediment load by minimizing channel erosion, since the geotextile aided in stabilization. This is due to the highest coefficient for the geotextile lining occurring during the filling period, when channel erosion is most likely to occur.

Table 3.8. Linear regression model comparing S2 and S1

Test Period	Treatments	Coefficients	P-value
Entire Test	**Intercept**	-0.52	1.63 E-27
$R^2 = 0.68$	**Geotextile Lining**	1.17	6.49 E-58
Filling	**Intercept**	-1.42	5.14 E-24
$R^2 = 0.71$	**Geotextile Lining**	2.00	3.57 E-28
Rapid Settling	**Intercept**	-0.49	1.71 E-09
$R^2 = 0.75$	**Geotextile Lining**	1.09	2.23 E-15
Polishing	**Intercept**	-0.18	5.53 E-05
$R^2 = 0.74$	**Geotextile Lining**	0.90	2.22 E-26

The S2 configuration was re-evaluated using Iowa- native soils for the S3 configuration. Turbidity reduction for the S3 configuration is shown in Figure 3.32. Discharge turbidity reduction followed Bay 2 and 4 trends but was not as high as the S2 configuration. The decreased turbidity reduction values were expected when Iowa-native soil was introduced due to an increase of fine particles.



(a) 0:00-2:00 hr

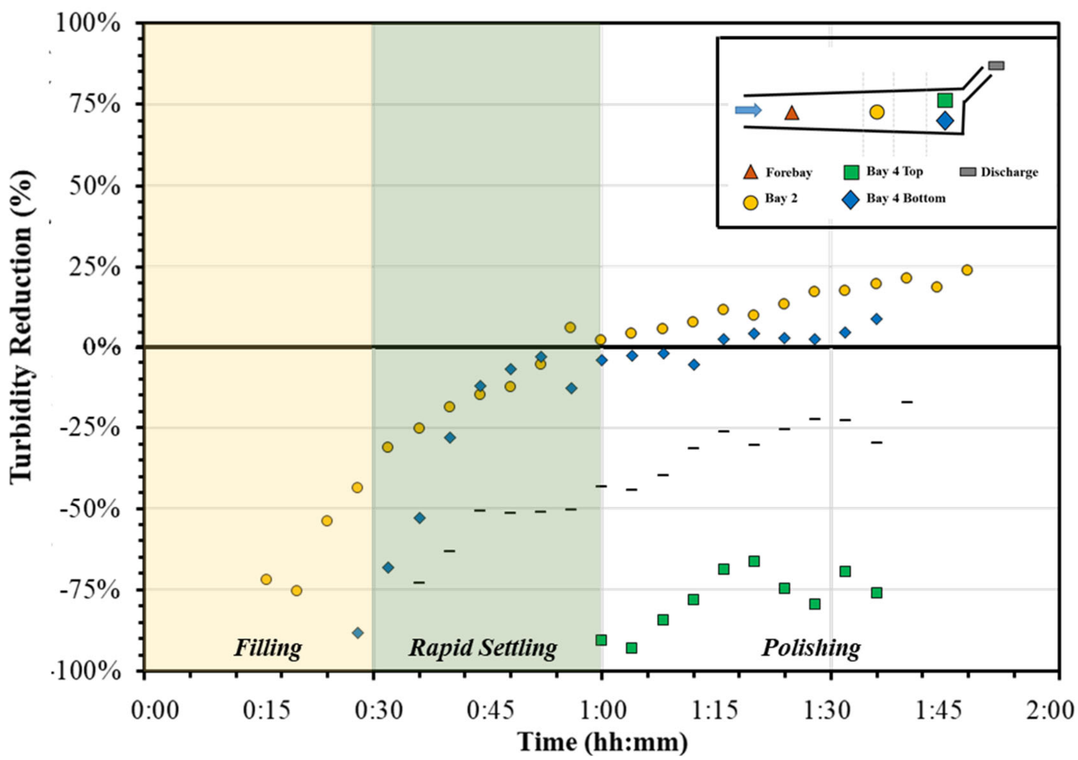
(b) 6:00-48:00 hr

Figure 3.32. Turbidity reduction during lined testing (IA soil).

An additional linear regression was modeled to evaluate the significance of using Iowa-native soil instead of Alabama soil. The regression model returned low R^2 values during all periods of the test, indicating a lacking relationship; however, the Iowa-native material was statistically significant in each period of testing. Table 3.9 provides a summary of the estimated model. The testing regimen then compares individual structural treatments, including the skimmer, baffles, and forebay testing shown in Figure 3.33, Figure 3.34, and Figure 3.35, respectively

Table 3.9. Linear Regression model comparing S3 and S2

Test Period	Treatments	Coefficients	P-value
Entire Test	**Intercept**	0.65	3.40 E-119
$R^2 = 0.03$	**Iowa Soil**	-0.07	2.00 E-3
Filling	**Intercept**	0.58	5.59 E-02
$R^2 = 0.06$	**Iowa Soil**	-1.39	1.01 E-02
Rapid Settling	**Intercept**	0.59	3.40 E-24
$R^2 = 0.12$	**Iowa Soil**	-0.11	1.51 E-02
Polishing	**Intercept**	0.72	3.58 E-66
$R^2 = 0.05$	**Iowa Soil**	-0.06	1.37 E-02



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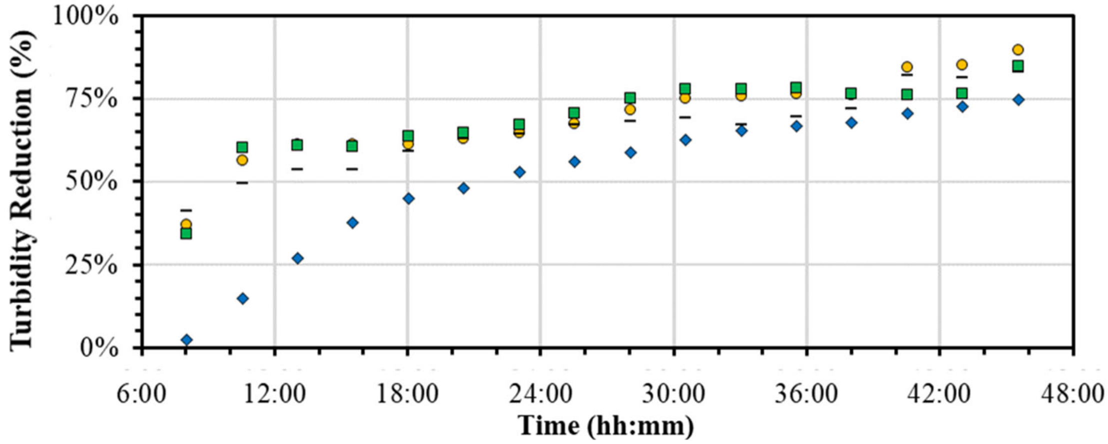

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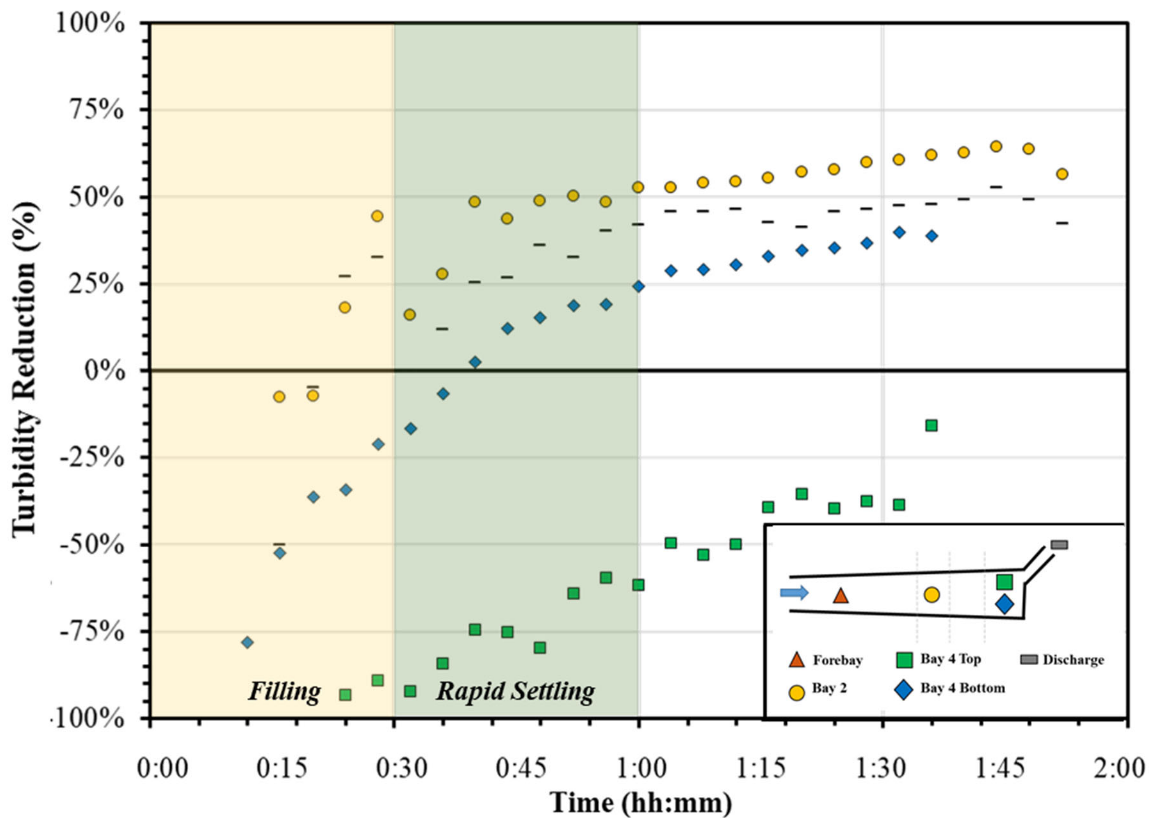
Figure 3.33. Turbidity reduction during skimmer testing (IA soil).

Although the discharge turbidity reduction was negative during the first filling, rapid settling, and polishing periods of S4, the turbidity reduction percentages were positive throughout the second polishing period. The discharge turbidity reduction split the turbidity reduction comparisons between the top and bottom of Bay 4.

Similar to the S4 performance, the S5 discharge turbidity reduction was negative during the first filling, rapid settling, and polishing periods; however, the turbidity reduction percentages were positive throughout the second polishing period but did not reach removal percentages experienced during the S5 configuration. There was a shift in trend between the top and bottom sampling locations in Bay 4 during the first filling, rapid settling, and polishing period, as seen in Figure 3.34. This may be because the coarse particles were captured in earlier bays, leaving just the finest particles, the slowest to drop from suspension, in Bay 4. In the extended dewatering period, differences in turbidity reductions between the two sampling locations were decreased.



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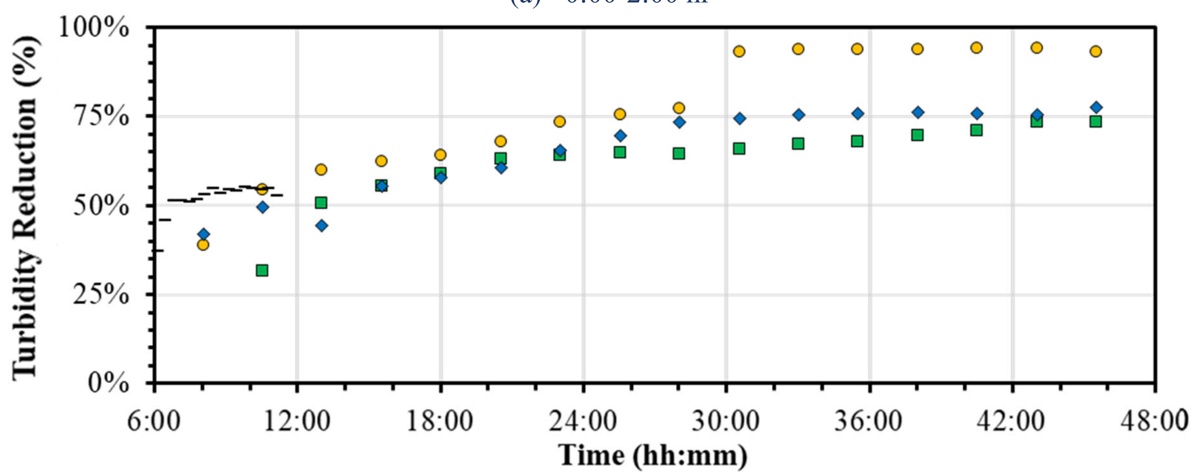

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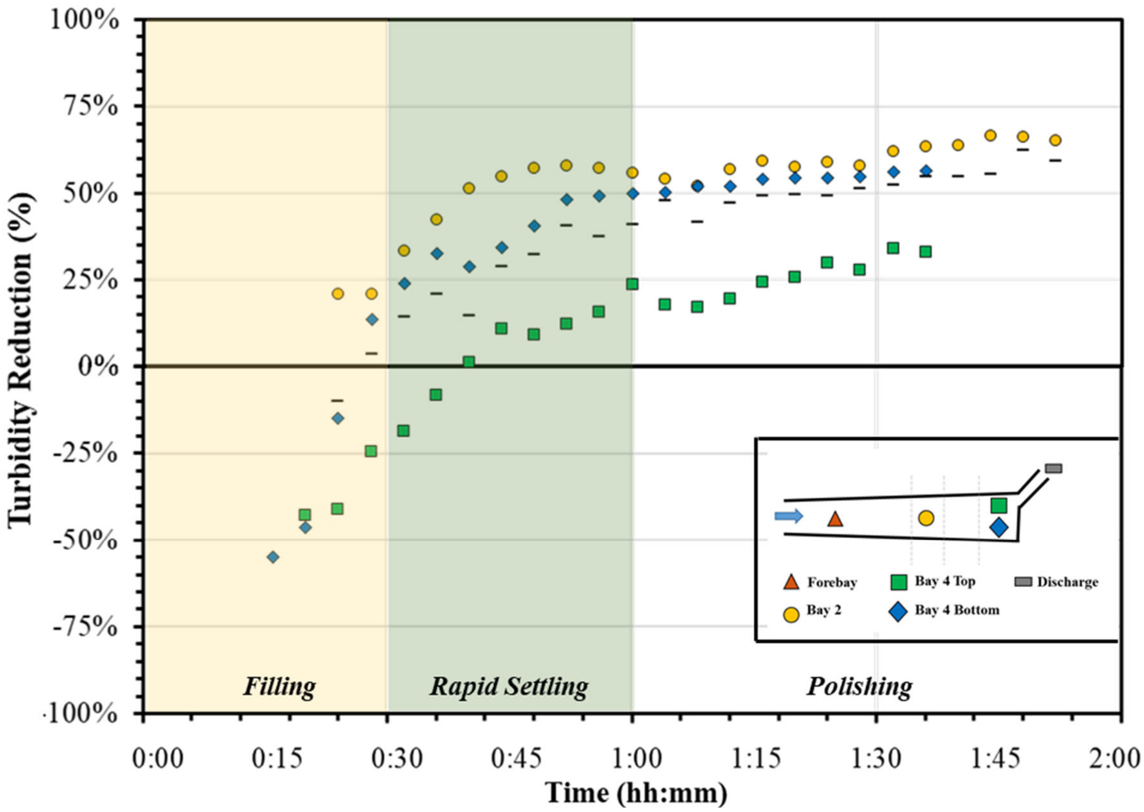
Figure 3.34. Turbidity reduction during baffles testing (IA soil).

The final evaluated structural treatment was the forebay, with the greatest sediment retention and the lowest turbidity values of all individual structural treatments. The discharge turbidity reduction percentages were positive, even during the first filling period, and reached 80% before dewatering commenced.



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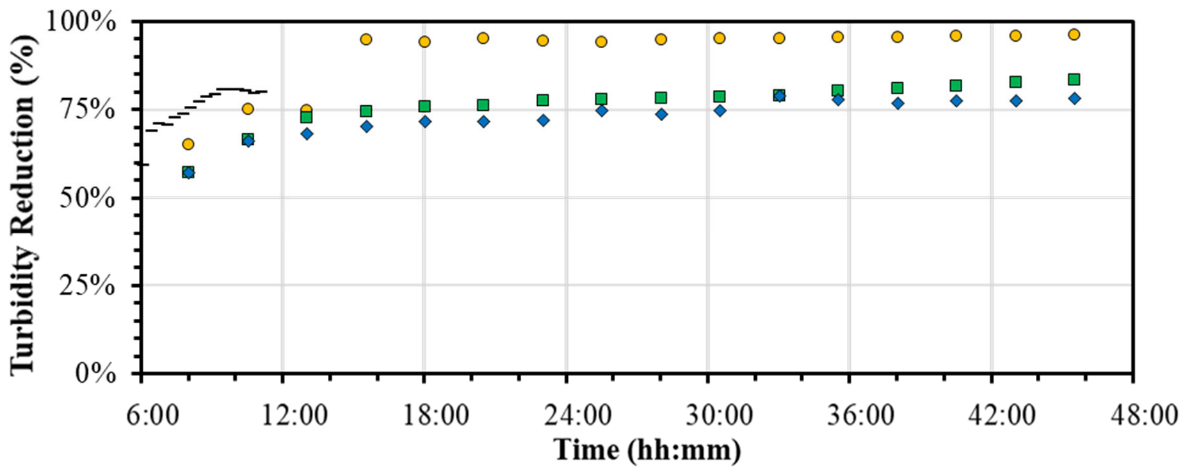

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Figure 3.35. Turbidity reduction during forebay testing (IA soil).

As hypothesized, the turbidity reduction decreased for all configurations as time increased in the second extended polishing period. Interestingly, Bay 2 seemingly had the highest, consistent turbidity reduction in the polishing periods, consistent with Perez *(2016),* despite the differences in channel geometry. Dewatering from the top of Bay 2 may yield the greatest turbidity reduction before offsite discharge.

The MFE-I (S7) configuration was recommended based on the individual structural treatments' sediment retention and water quality improvements and included the geotextile lining, skimmer, and forebay. A linear regression model was developed to evaluate the statistical significance of the structural treatments on turbidity reduction and followed the model described in 3.4.9 Water Quality Analysis. Results from the S7 configuration were also included when developing the model.

Table 3.10. Linear regression model for structural treatments

Test Period	Treatments	Coefficients	P-value
Entire Test	**Intercept**	0.44	8.15 E-28
$R^2 = 0.13$	**Skimmer**	-0.35	2.69 E-15
	Baffles	-0.25	1.89 E-05
	Forebay	0.19	1.47 E-05
Filling	**Intercept**	-1.01	1.16 E-02
$R^2 = 0.08$	**Skimmer**	-0.53	2.53 E-01[a]
	Baffles	0.89	1.55 E-01[a]
	Forebay	1.54	1.06 E-03
Rapid Settling	**Intercept**	0.24	1.85 E-02
$R^2 = 0.31$	**Skimmer**	-0.82	2.23 E-10
	Baffles	-0.24	1.18 E-01[a]
	Forebay	0.33	6.65 E-03
Polishing	**Intercept**	0.56	4.41 E-38
$R^2 = 0.15$	**Skimmer**	-0.28	2.13 E-10
	Baffles	-0.28	2.19 E-06
	Forebay	0.14	1.57 E-03

Note: [a] indicates not statistically significant at 95% confidence.

Despite the low R^2 value, indicating a weak relationship, the forebay was statistically significant, based on the p-value, during all periods of the test and aided in turbidity reduction. Based on the model, the skimmer and baffles were expected to decrease turbidity reduction percentage or increase turbidity; however, the baffles were not statistically significant during the filling and rapid settling periods of the test. The skimmer was not significant during filling. All points were considered in the linear regression model to increase the accuracy and prediction of the basin's behavior as a system during and after a storm event.

MFE-I (S7) was also used for S8 evaluations, with the addition of flocculant. The sediment retention and water quality performance of the MFE-I (S7) and MFE-I + Flocculant (S8) are detailed and compared in Chapter Five.

4. UPSTREAM FLOCCULANT APPLICATION

4.1. INTRODUCTION

Settling fine sized soil particles (i.e., clay and silt) requires long detention times that exceed typical sediment basin treatment conditions. Chemical treatments such as coagulants and flocculants have the potential to bond finer particles to create larger flocs that gravitationally settle more rapidly. Sediment basins present an opportunity to introduce chemical flocculant in construction stormwater management plans and capture the flocs before offsite discharge. Flocculant has the potential to improve sediment capture within the basin and decrease required detention time to achieve certain discharge water quality standards, including TSS and turbidity goals. Proper contact and mixing time are required for the flocculant to be fully activated and effective. There is little known about the effects if the flocculant is not appropriately mixed with runoff and bonded to chemicals. This research effort aimed to quantify the benefits of sediment capture, turbidity reduction, and residual flocculant concentrations from the basin discharge.

Kazaz et al., reported that 39% of state DOTs apply flocculant during construction in a recent state of the practice survey, and 54% of those rely on manufacturer guidance for implementation *(2021)*. Flocculant application is especially prevalent in states where numeric effluent discharge limitations exist, such as North Carolina where turbidity cannot exceed more than 50 NTU above background levels and New Jersey where 80% of TSS must be removed from construction runoff (*North Carolina Department of Environmental Quality 2019*, *New Jersey Department of Environmental Protection 2004*).

Although various flocculant types are used in stormwater treatment, including synthetic flocculants; inorganic flocculants; bio/natural flocculants; and stimuli-responsive flocculants, synthetic flocculants are the most commercially available and applied within the industry. Synthetic flocculants are categorized according to their net positive / negative charge or as cationic / anionic, respectively cationic flocculant application is typically avoided due to the potential of binding with the negatively charged hemoglobin in fish gills, resulting in fish kills *(USEPA 2005)*. Anionic flocculant is more widely applied as environmental toxicity implications occur at higher concentrations.

Polyacrylamide (PAM), a flocculant type, is most commonly used in construction stormwater and is available in various forms, including granular, emulsion, and blocks. Selecting the appropriate PAM for site soils is essential for performance and efficiency. It is common practice for several jar tests to be conducted, which compare settling and water quality characteristics in response to PAM application for a specific site soil. When applied to a construction site, PAM is typically applied by spreading granular powder on upstream practices or placing blocks in a conveyance channel to allow for proper contact and mixing time.

If properly introduced, chemical flocculant can drastically decrease turbidity levels by increasing the settling velocity. Flocculant is particularly helpful in sediment basin efficiency by reducing the settling time from several hours to minutes (*Fang et al., 2015, Kang et al., 2015*). Bhardwaj and McLaughlin (*2008*) determined that the addition of flocculant reduces turbidity up to 66 to 88% when actively and passively dosed, respectively. Despite the potential to enhance construction stormwater management programs, Kazaz et al., *(2021)* reported that 31 state DOTs do not permit the use of flocculants on active sites. When further questioned why flocculants were prohibited, 50% of these states responded that the current E&SC practices were sufficient, and 35% responded that there was a perceived risk for receiving waterbodies *(2021)*. This research aimed to compare the performance of the sediment basin with and without the presence of flocculant. Additionally, residual testing was conducted on samples from the sediment basin effluent to quantify the concentration of flocculant being discharged.

4.2. MATERIALS AND METHODS

This section describes the method employed to select a flocculant to introduce to the basin, performance comparisons of the MFE-I with and without flocculant, and procedures to quantify residual concentrations in sediment basin effluent. A combination of innovative laboratory and large-scale testing techniques was implemented. This research was a collaborative effort, developing from dosage and application research concurrently conducted by B. Kazaz, M.A. Perez, W.N. Donald, X. Fang, and J. Shaw for ALDOT.

4.2.1. FLOCCULANT SELECTION

Flocculants were selected based on a methodology developed by Kazaz et al., *(2022b)*. Iowa native soil was classified as USCS Sandy Lean Clay and AASHTO Clayey Soil, as described in 3.4 Materials and Methods of this report. Sediment-laden samples were made by mixing the soil with 3.8 oz (1,000 mL) of water to achieve turbidity of 1500 NTU (± 300 NTU). Fourteen flocculant products were mixed with the independent solutions and compared for the most favorable settling and water quality improvements. Flocculants were ranked on a points system, which considered floc size, formation time, settling rate, and effluent color. Flocculant products compared in the study included eight commercially available polyacrylamides, sodium montmorillonite, two chitosan-based flocculants, agricultural gypsum, and alum-based products.

Floc sizes were visually observed, compared to known particle diameters, categorized into eight particle size ranges. The categories and point allocations are shown in Table 4.1.

Table 4.1. Floc size point allocation

Size (mm)	3.01-4.50	2.26-3.00	1.51-2.25	1.01-1.50	0.76-1.00	0.51-0.75	0.30-0.50	0-0.29
Points	10	9	8	7	6	5	4	0

After mixing the flocculant into the sediment-laden samples, the time taken for flocs to form was recorded and categorized into 11-time ranges. The categories and point allocations are shown in Table 4.2.

Table 4.2. Floc formation time point allocation

Time (s)	0-10	11-20	21-40	41-50	51-60	61-80	81-100	101-120	121-140	141-160	>160
Points	10	9	8	7	6	5	4	3	2	1	0

Flocs were visually observed during settling for several minutes. Several time measurements since settling started and corresponding depths in the water column were recorded to determine settling velocity. The settling velocity was averaged for each sample and categorized into 11 ranges. The categories and point allocations are shown in Table 4.3.

Table 4.3. Floc settling velocity point allocation

Vel (in./hr)	>3501	3,001-3,500	2,501-3,000	2,001-2,500	1,500-2,000	1,001-1,500	801-1,000	601-800	401-600	201-400	0-200
Points	10	9	8	7	6	5	4	3	2	1	0

The effluent color was compared with five categories of control colors. The categories and point allocations are shown in Table 4.4.

Table 4.4. Effluent color point allocation

Size (mm)	1 (Clear)	2 (Light yellow)	3 (Dark Yellow)	4 (Brown)	5 (Dark Brown)
Points	10	8	6	4	0

The points allocated in each category were summed for an individual flocculant and ranked. The top-three best-performing products were considered for use in large-scale testing. If more than one flocculant had the same number of points, the flocculant was selected on availability in flocculant blocks, as desired by the research sponsor for ease of application and cost. Based on the match test results, the H_{30} Floc Flat, a semi-hydrated flocculant block from Carolina Hydrologic, was selected for sediment basin testing.

4.2.2. FLOCCULANT INSTALLATION

Flocculant was applied to the basin under the MFE-I configuration. Although flocculants are also available in granular, emulsion, and sock forms, blocks were selected for ease of application. Flocculant blocks were placed and secured in the channel upstream of the rock check dam to ensure ample contact and mixing time before reaching the forebay. Sediment-laden flow was diverted to the center of the channel using rock gabions to maximize contact with the flocculant blocks. Flocculant blocks were secured to the channel using t-posts and sod staples, as shown in Figure 4.1a. The blocks under flow conditions are also shown in Figure 4.1(b).

Since the blocks were semi-hydrated, the manufacturer suggested storing or covering the blocks with trash bags in between runs to minimize the effects of drying out from the sun. While researchers wanted to evaluate the sediment retention and water quality benefits of flocculant application, it was important all research was practical and implementable for the research sponsor. Researchers understood that it would be difficult to adequately cover and uncover all flocculant blocks on-site at the appropriate times. The two smaller blocks are shown in Figure 4.1(a) were used to compare if a block was covered instead of left in the elements within the channel. All testing MFE-I testing was conducted between November 16 and December 15, 2021, and the blocks were subjected to approximately 19,000 ft^3 (538 m^3), during testing. Between tests, the blocks were measured for length, width, height, circumference, and weight to compare degradation.

(a) placement in channel

(b) under flow conditions

Figure 4.1. Flocculant block installation.

4.2.3. SEDIMENT RETENTION AND WATER QUALITY EFFECTS

Sediment retention and water quality behavior were measured following the methods outlined in 3.4 Materials and Methods, subsections Data Collection and Sediment Retention Quantification. Turbidity reduction was evaluated using the linear regression model described in Chapter 3 with the addition of flocculant as an independent variable. An additional model was developed, comparing just the MFE-I (S7) and MFE-I + Flocculant (S8) installations. Additionally, the differences of average turbidity during the filling, rapid settling, and polishing periods for the S7 and S8 configurations were evaluated for statistical relevance at the 95% confidence interval, using two-tailed equal variance t-tests

Sediment retention was compared to that of the MFE-I (S7) as a system and within individual bays. In addition, a particle size analysis was conducted using the Malvern Mastersizer 3000, a laser diffraction particle size analyzer, on settled material from the forebay, Bay 3, and Bay 4 with and without the presence of flocculant. It was noted that the Malvern Mastersizer 3000 provided more accurate results for silts and clays, so the deposited material was dried and passed through the number 18 sieve to remove particles greater than 1.0 mm.

The Malvern Mastersizer 3000 was initially employed to compare particle sizes with and without flocculant, with the hypothesis that the flocculant would create larger particle sizes. The settled, dried, and sieved material was added to a beaker of deionized water until the Malvern Mastersizer 3000 reached an obscuration percentage between 15-20%. The Malvern Mastersizer 3000 provided five individual particle size analyses for each sample and an average curve. An analysis was considered accurate if the percent error between analyses was less than 5%; however, the percent errors were much greater when water was used as the dispersant. Only the last three of the five analyses could be used for each sample. The error in the first two runs was likely due to residual material in the machine from previous samples, causing some clogging within the machine.

Sodium hexametaphosphate, a dispersant, was added to all samples to improve the function of the machine and the accuracy of results. After the dispersant was added, the samples were sonicated for at least 24 hours before being processed in the Mastersizer 3000. The addition of the dispersant would allow the smallest particle sizes to be observed. It was hypothesized that the flocculant would aid in the capture of finer particles. Results from the particle size analyses were plotted by size against percent volume in the sample.

Although sediment retention and captured particle size are important metrics for sediment basin performance, water quality was hypothesized to be more sensitive to flocculant application. Water quality behavior was measured following the methods outlined in 3.4 Materials and Methods, with slight modifications. Due to the forebay causing an impoundment overtaking the automated inflow sampling location, inflow samples were hand sampled at the outfall of the mixing trough into the channel. An additional hand sampling location was added to capture the water quality overtopping the forebay and entering the basin. The sampling frequency was every two minutes during MFE-I testing and every three minutes during the MFE-I + Flocculant testing due to the addition of a hand sampling location downstream of the flocculant block for residual testing infeasible to hand sample three locations every two minutes.

Discharge turbidities were plotted for an initial visual comparison of water quality being discharged from the basin with and without the application of flocculant. Further analysis included averaging the inflow turbidity measurements for each set of tests (MFE-I and MFE-I + Flocculant) from 0- 30 minutes to get representative inflow turbidity for each test, following the procedures outlined in Sediment Basin Performance Improvements through Large-Scale Testing. As an example, the inflow turbidities and corresponding time stamps for the MFE-I+ Flocculant set are shown in Table 4.5. The turbidity values were averaged and resulted in a representative inflow value of 753 NTU.

Table 4.5. Example for MFE-I1 + Flocculant (S8)

Time (min)	S8: L1-A (NTU)	S8: L2-A (NTU)	S8: L3-A (NTU)	Average (NTU)
3	363	174	169	235
6	932	724	728	795
9	596	1,710	1,731	1,346
12	584	432	432	483
15	884	1,280	1,293	1,152
18	520	449	449	473
21	522	556	557	545
24	234	706	710	550
27	562	1,454	1,470	1,162
30	324	1,013	1,021	786
Avg.	**552**	**850**	**856**	**753**

Turbidities at the remaining sampling locations were divided by the representative inflow value, subtracted from 1 to determine a turbidity reduction, and plotted over the 48-hour observation period. For numerical comparisons, the turbidities were averaged and corrected for outliers, following the same procedure described for inflow and illustrated in Table 4.5 for the filling, rapid settling, and polishing periods. These values are reported as turbidity reduction compared to inflow. The pairings to calculate turbidity reduction are shown in Table 3.5.

4.2.4. RESIDUAL TESTING

Although flocculants can significantly reduce sediment concentrations in stormwater effluent, high residual flocculant concentrations can potentially impact aquatic life downstream of an application site. Kazaz et al., *(2022a)* determined a method to detect residual concentrations by comparing the settling velocities of site samples with residual flocculants and to the settling velocities observed using known, dosed flocculant concentrations. Residual testing for this project followed the methods detailed by Kazaz et al., *(2022a),* using the selected PAM-based flocculant product, which was installed in block form in the sediment basin. Dosed concentrations ranged from 0-40,000% of the manufacturer's dosage recommendation of 5 μg/L to create the residual curves. The residual curve is displayed in Figure 4.2.

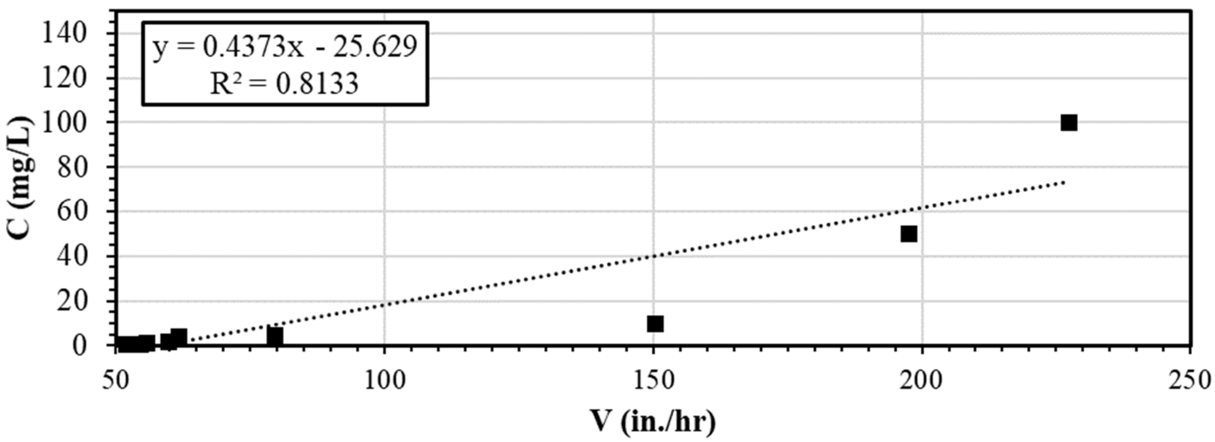


Figure 4.2. Residual curve for selected PAM flocculant.

4.3. RESULTS AND DISCUSSION

While flocculants can decrease sediment concentrations, it is essential that appropriate flocculant selection, application, and dosage techniques are used. If improperly dosed or mismanaged, flocculants can harm the receiving water's health. This section summarizes flocculant selection, water quality and sediment retention improvements, and residual concentrations. Flocculant identification and residual concentration results from this study are products of the testing procedures outlined in Kazaz et al., *(2022b)*.

4.3.1. FLOCCULANT SELECTION AND INSTALLATION

In total, fourteen flocculants were added to solutions using Iowa-native soil and deionized water. The flocculants were ranked on a points system, which considered floc size, formation time, settling rate, and effluent color, and are shown in Table 4.6. When compared, three of the flocculants achieved exactly the same amount of points, which are bolded below.

Table 4.6. Total flocculant point allocation

Product	Color	Pts.	Floc Formation mm:ss	Pts.	Size Floc mm	Pts.	Settling Rate in./hr (cm/hr)	Pts.	Total Pts.
1	1	10	0:00	10	1.0-1.5	7	653 (1,659)	3	30
2	1	10	0:00	10	1.0-1.5	7	440 (1,118)	2	29
3	1	10	0:07	10	1.0-1.5	7	759 (1,928)	3	30
4	3	6	0:00	10	1.5-2.25	8	80 (203)	0	24
5	1	10	0:04	10	0.75-1.0	6	1,050 (2,667)	5	31
6	2	8	0:03	10	1.0-1.5	7	215 (546)	1	26
7	2	8	0:00	10	1.0-1.5	7	145 (368)	0	25
8	1	10	0:05	10	1.0-1.5	7	622 (1,580)	3	30
9	1	10	0:07	10	0.75-1.0	6	1,125 (2,858)	5	31
10	1	10	0:00	10	1.0-1.5	7	975 (2,477)	4	31
11	2	8	0:38	8	2.25-3.0	9	56 (142)	0	25
12	1	10	1:02	5	1.5-2.25	8	59 (150)	0	23
13	1	10	0:11	9	1.5-2.25	8	65 (165)	0	27
14	1	10	0:00	10	1.0-1.5	7	476 (1,209)	2	29

Product 10 was excluded from the study as it caused a rapid change in pH, as observed by B. Kazaz, which could be detrimental to receiving waterbodies. PAMs were the two best performing flocculants (Products 5 and 9). The manufacturers of the two products were contacted, and the chemical composition of the flocculants was requested in block form.

PAM is widely used in construction stormwater management and are available in various compositions. Many of the tested flocculants are widely applied and may perform well across many soil types; similarly, soils may respond well to multiple flocculants. If a soil responds well to many flocculant types, it is suggested to consider application and maintenance plan and cost. Product 9 was available in block form in this testing, which was the desired dosing mechanism, and therefore used in the channel for all MFE-I +Flocculant testing.

Despite tracking the length, width, height, circumference, and weight of the two blocks left covered and uncovered to evaluate degradation, some limitations made the experimental results challenging to evaluate. The results are shown in Table 4.7.

Table 4.7. Measured dimensions of flocculant blocks

Parameter	Uncovered			Covered		
	MFE-I + F01	MFE-I + F02	MFE-I + F03	MFE-I + F01	MFE-I + F02	MFE-I + F03
Length in. (cm)	7.25 (18.4)	8 (20.32)	9.5 (24.1)	8 (20.32)	8 (20.32)	9 (22.9)
Width in. (cm)	5 (12.7)	4.5 (11.4)	5 (12.7)	4.75 (12.1)	5 (12.7)	5.5 (14.0)
Height in. (cm)	2.75 (7.0)	2.75 (7.0)	2.75 (7.0)	3 (7.6)	3 (7.6)	2.5 (6.4)
Circumference in. (cm)	-	16 (40.6)	13.25 (33.7)	-	16.25 (41.3)	13.5 (34.3)
Weight lb. (kg)	4 (1.8)	5.2 (2.4)	5 (2.3)	4.4 (2.0)	6 (2.7)	5 (2.7)

After examining results, it was evident there was no clear trend. The measurements of the blocks were dependent on shrink-swell due to moisture content, and the blocks could not be oven-dried without losing their effectiveness during testing. Additionally, sediment would adhere to the flocculant blocks in between testing, creating a "caking" effect. This affected the length, width, height, and circumference measurements. Additionally, this caking layer protected the uncovered flocculant block from elements. Caking was scraped from the flocculant blocks after measurements but before the next test. According to manufacturer guidance on flow capabilities, the one-month evaluation subjected the blocks to less than 20% of the sediment-laden flow the blocks were capable of treating. Additional lab-based research is suggested to examine degradation over the block's suggested lifetime, using controlled flow and sediment introduction and environmental chambers.

4.3.2. SEDIMENT RETENTION AND WATER QUALITY IMPROVEMENTS

Sediment retention was measured following the methods outlined in Chapter 3. The sediment retained was quantified for each section of the basin and the entire system. Sediment retention was compared for the MFE-I with and without flocculant. A visual display of the results is illustrated in Figure 4.3.

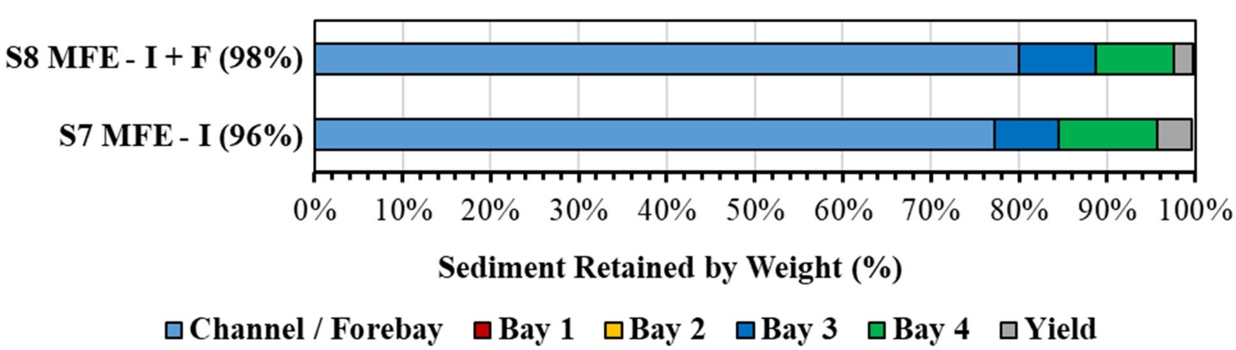


Figure 4.3. Sediment retained by percent weight.

The MFE-I had 77% sediment capture by weight in the forebay, 7% in Bay 3, and 11% in Bay 4. When flocculant was applied, sediment capture increased by 3% in the forebay, 2% in Bay 3, and decreased by 2% in Bay 4. The basin captured 96% of sediment by weight without flocculant and 98% when flocculant was applied.

The settled material from the forebay, Bay 3, and Bay 4 from MFE-I and MFE-I + Flocculant Testing were preserved, dried, sieved, and analyzed for particle size. Table 4.8 displays the D10, D50, and D90 for each sample. Figure 4.4 displays the particle sizes when deionized water was used to suspend the samples.

Table 4.8. Particle size analysis with deionized water buffer

Parameter	FB-MFE-I	FB-MFE-I + Flocculant	B3-MFE-I	B3-MFE-I + Flocculant	B4-MFE-I	B4-MFE-I + Flocculant
D_{10} (µm)	3.17	3.48	2.76	2.42	2.79	2.73
D_{50} (µm)	25.9	27.2	21.7	16.7	19.1	16.5
D_{90} (µm)	74.6	80.4	66.1	57.7	57.9	63.3

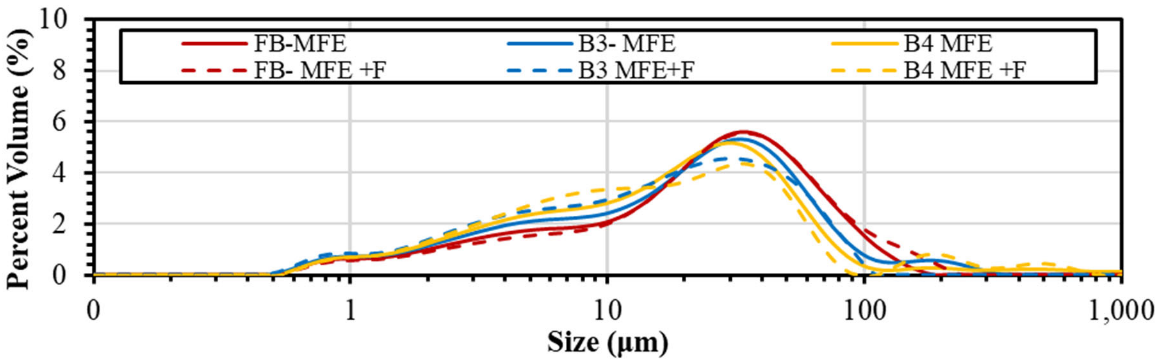


Figure 4.4. Particle size analysis with deionized water buffer.

Some general trends were observed from this analysis, confirming that the largest grain sizes were captured early in the basin and decreased as the flow path progressed. For example, the largest grains were captured in the forebay, followed by Bay 3 and Bay 4. However, the analysis was not very revealing of grain size comparisons when flocculant was and was not applied. In the following analyses, sodium hexametaphosphate was used to disperse the samples, with the intent to capture the smallest grain sizes for all samples. Table 4.9 displays the D_{10}, D_{50}, and D_{90} for each sample. Figure 4.5 displays the particle sizes when dispersant was used to soak and suspend the samples.

Table 4.9. Particle size analysis with sodium hexametaphosphate buffer

Parameter	FB-MFE-I	FB-MFE-I + Flocculant	B3-MFE-I	B3-MFE-I + Flocculant	B4-MFE-I	B4-MFE-I + Flocculant
D_{10} (µm)	1.72	1.00	1.02	0.747	1.48	0.95
D_{50} (µm)	11.7	4.37	4.85	2.96	8.28	4.59
D_{90} (µm)	54.3	15.5	17.9	8.05	36.0	14.3

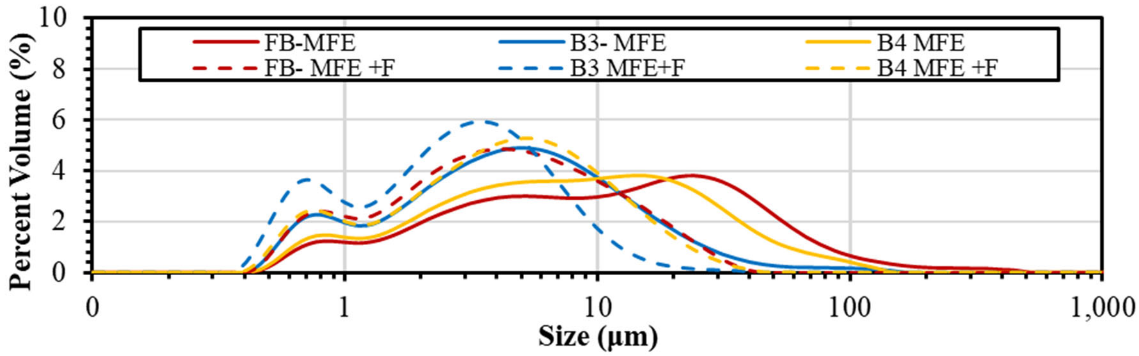


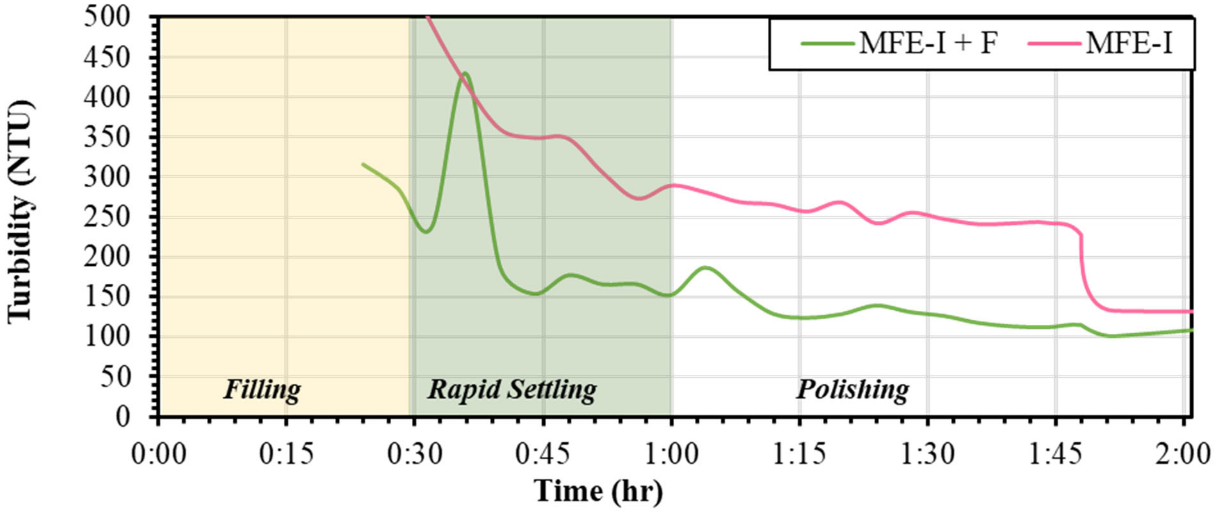
Figure 4.5. Particle size analysis with sodium hexametaphosphate buffer.

This analysis confirmed the hypothesis, indicating that the addition of flocculant captures the finest particles, which are most likely to remain suspended within the water column. The addition of flocculant provides an opportunity to aggregate the finest particles, increasing the overall particle diameter, which would promote settling, according to Stoke's Law. The capture of these particles was presumed to be correlated to a reduction in turbidity.

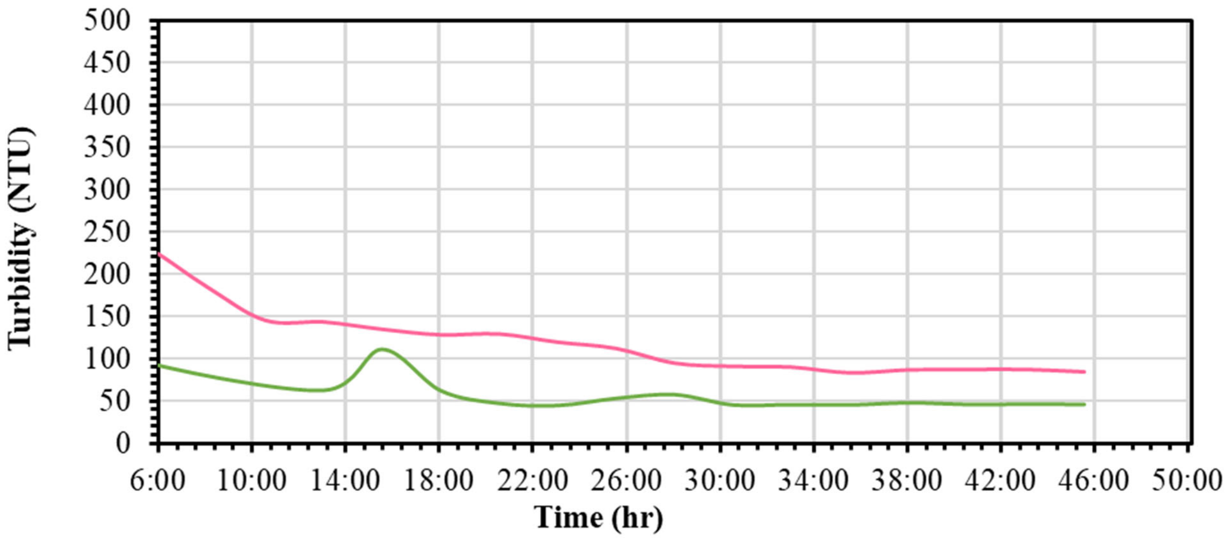
Despite sediment retention and particle size capture being important metrics for the sediment basin performance and indicating enhanced performance due to flocculant, water quality was hypothesized to be more sensitive to flocculant application. Turbidity measurements were compared at various locations in the basin to quantify the water quality impacts. Figure 4.6 illustrates the average discharge turbidity during MFE-I testing without flocculant in pink and with flocculant in green.

As indicated in the Results and Discussion section of Sediment Basin Performance Improvements through Large-Scale Testing, the 30-minutes of flow introduction in LX-A and LX-B are considered the first and second "filling periods." The 30- minutes following, or first hour, is considered "rapid settling," and the remaining dewatering time is considered "polishing." During the rapid settling period, discharge turbidity values are approximately 100 NTU lower when flocculant is applied. The difference in turbidity decreases to approximately 50 NTU during the polishing period, but further analysis was conducted to compare the discharge and inflow water quality more precisely.

The average inflow for MEF-I and MFE-I + Flocculant Testing was 334 and 753 NTU, respectively, during first fill testing, and 440 and 430 NTU, during the second fill testing. Inflow turbidity was affected by material deposited in the mixing trough washing out, background turbidity in the supply pond, and soil introduction parameters. As displayed in Table 4.5, inflow turbidity values for MFE-I+F02 and F03 were higher than F01, causing the average to be higher. Although the background turbidity of the supply pond would vary, it was always under 150 NTU. Differences in first flush inflow turbidity were most likely due to residual soil from previous testing being stuck or deposited in the sediment hopper and mixing trough. While all soil was air-dried and sieved in the same fashion, soil introduction was highly variable due to weather and soil moisture content affecting the consistent performance of the sediment hopper. In higher moisture, the hopper would clog, forcing hand introduction until the clog was relieved.



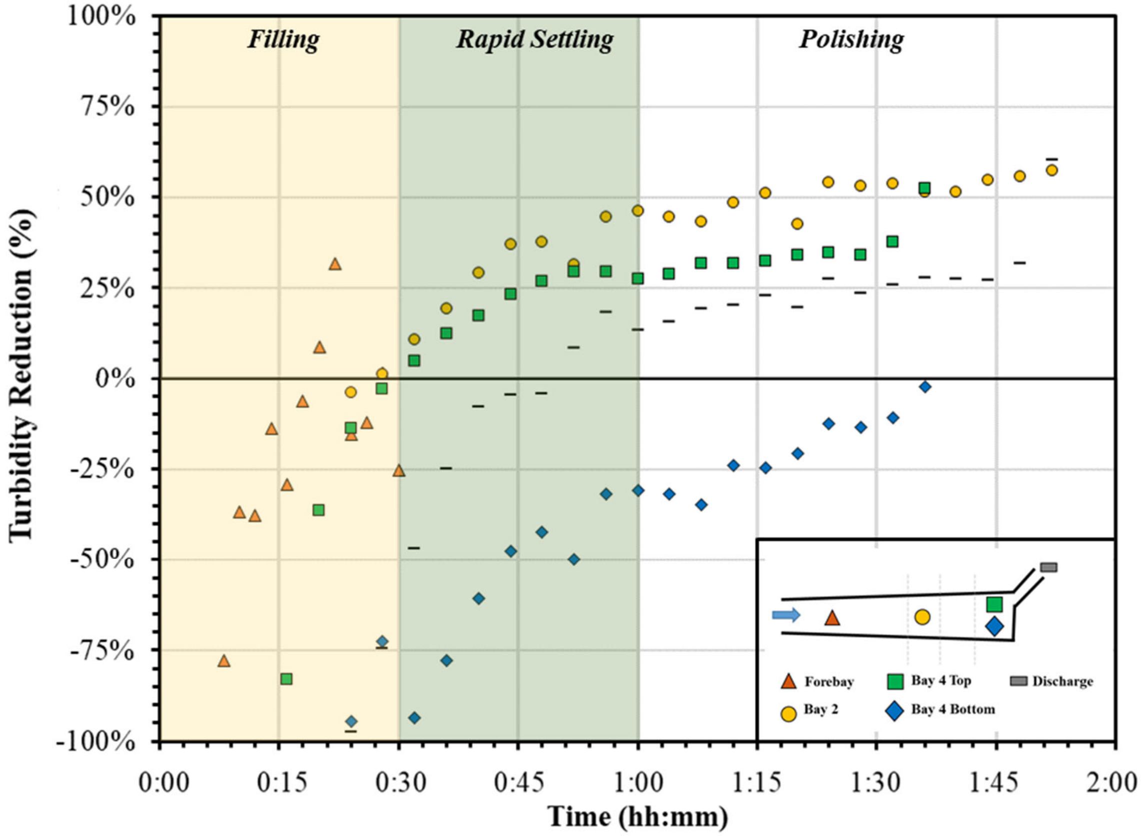
(a) 0:00-2:00 hr



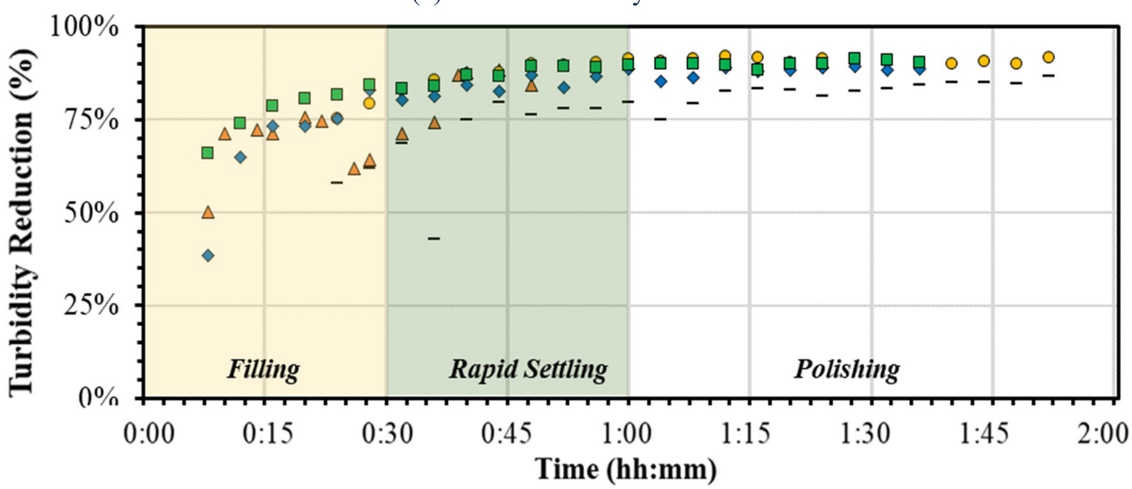
(b) 6:00-48:00 hr

Figure 4.6. Observed turbidity with flocculant application.

The turbidity reduction from samples overtopping the forebay in Bay 2, the bottom of Bay 4, the top of Bay 4, and the discharge from 0:00-2:00 hr are displayed in Figure 4.7. These measurements were recorded after the first filling period. It is important to note the y-axis on the graphs, the turbidity reduction for MFE-I is graphed to -100%. Any value less than 0% indicates the water samples taken had higher turbidity than the average inflow.



(a) MFE-I turbidity reduction



(b) MFE-I + Flocculant turbidity reduction

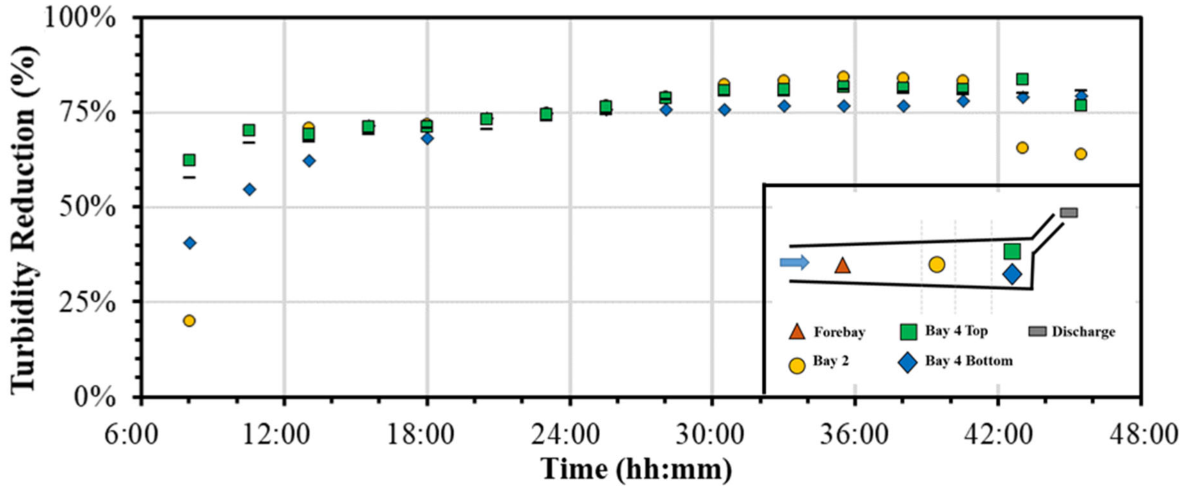
Figure 4.7. Turbidity reduction 0:00-2:00 hr.

Without flocculant, turbidity improvements at discharge did not occur until after flow introduction ended. However, turbidity improvements immediately started when flocculant was applied, as shown in Figure 4.7(b). Turbidity was reduced by 50% during the rapid settling period and reached 87% removal by the end of the two-hour monitoring period compared to 30% removal when no flocculant was applied. The discharge turbidity ranged between 102-187 NTU in hours 1:00-2:00 with flocculant and 133-290 NTU without flocculant.

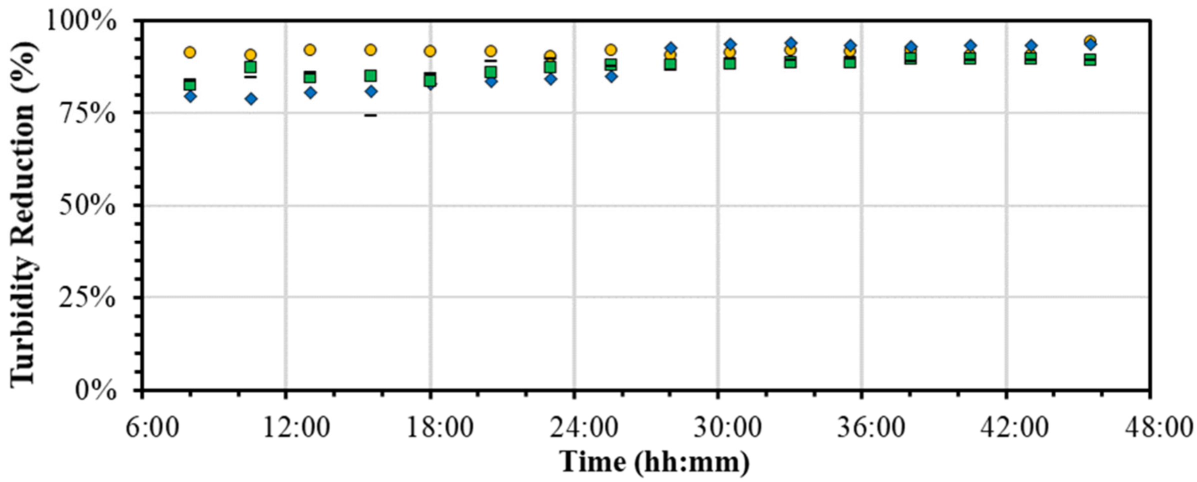
The basin behavior was more similar across all sampling locations when flocculant was applied; however, the turbidity reduction was more variable between sampling locations when flocculant was not applied. In theory, the samples taken at the top of Bay 4 and discharge would have similar turbidity values since a skimmer was used for dewatering the basin, but as shown in Figure 4.7(a), Bay 4 had a greater turbidity reduction than observed at discharge. The skimmer was installed to the 12 in. (31 cm) discharge pipe through the earthen berm, as shown in Figure 3.19. The discharge sampling location was roughly 3 ft (1 m) into the downstream pipe. The discrepancy in turbidity reduction without flocculant could have been due to deposition occurring in the 12 in. (31 cm) dewatering pipe, which was installed with no slope.

Additionally, there was armoring at the outfall of the dewatering pipe to avoid downstream erosion. This armoring decreased flow velocity and created a small impoundment at discharge, allowing some settling, and affecting measurements. However, the same effects would likely be observed during field implementation.

The second fill occurred at 5:00 hours. Water quality following this test was observed for up to 48 hours to evaluate the effects of prolonged detention. Figure 4.8 displays the turbidity reduction from samples overtopping the forebay in Bay 2, the bottom of Bay 4, the top of Bay 4, and the discharge during the polishing period from 6:00-48:00.



(a) MFE-I turbidity reduction



(b) MFE-I + Flocculant turbidity reduction

Figure 4.8. Turbidity reduction 6:00-48:00 hr.

Without flocculant application, turbidity reduction at discharge reached 80% after 36 hours in the basin. However, discharge turbidity reduction reached 80% immediately following the first and second filling periods. After 23 hours of detention, turbidity was reduced by 90% with flocculant, indicating that detention times may be decreased if flocculant is applied, and the same turbidity reduction can be achieved as prolonged detention times in sediment basins without flocculant application. At the end of the 48 hours, the discharge turbidities were 46 and 85 NTU, with and without the application of flocculant.

When flocculant was added to the linear regression model, the base case being S3 configuration, as described in Sediment Basin Performance Improvements through Large-Scale Testing Water Quality Analysis, the R^2 of the estimated model ranged between 0.11-0.42, depending on test period. Although these R^2 values still did not indicate a well-fit line, flocculant was statistically significant during the rapid settling and polishing periods. The coefficients and p-values are shown in Table 4.10.

Table 4.10. Linear regression model for structural and chemical treatments

Test Period	Treatments	Coefficients	P-value
Entire Test	**Intercept**	0.44	9.90 E-33
$R^2 = 0.24$	**Skimmer**	-0.35	7.22 E-18
	Baffles	-0.25	3.19 E-06
	Forebay	0.19	2.38 E-06
	Flocculant	0.54	2.49 E-25
Filling	**Intercept**	-1.01	6.37 E-03
$R^2 = 0.11$	**Skimmer**	-0.53	2.16 E-01[a]
	Baffles	0.89	1.24 E-01[a]
	Forebay	1.54	4.00 E-04
	Flocculant	0.71	2.43 E-01[a]
Rapid Settling	**Intercept**	0.24	1.13 E-02
$R^2 = 0.42$	**Skimmer**	-0.82	8.17 E-12
	Baffles	-0.24	9.26 E-02[a]
	Forebay	0.33	3.52 E-03
	Flocculant	1.04	7.19 E-11
Polishing	**Intercept**	0.56	6.42 E-46
$R^2 = 0.29$	**Skimmer**	-0.28	2.56 E-12
	Baffles	-0.28	1.81 E-07
	Forebay	0.14	4.94 E-04
	Flocculant	0.45	2.02 E-18

Note: [a] indicates not statistically significant at 95% confidence.

When MFE-I + Flocculant was independently compared to MFE-I (base case), the R^2 of the estimated model increased, indicating a stronger correlation between flocculant application and turbidity reduction. Flocculant was again statistically significant. The components of the linear regression model are displayed in Table 4.11.

Table 4.11. Linear regression model comparing S7 and S8

Test Period	Treatments	Coefficients	P-value
Entire Test	**Intercept**	0.40	2.99 E-47
$R^2 = 0.38$	**Flocculant**	0.42	1.99 E-30
Filling	**Intercept**	0.24	5.40 E-03
$R^2 = 0.23$	**Flocculant**	0.46	2.85 E-04
Rapid Settling	**Intercept**	0.01	8.13 E-01
$R^2 = 0.63$	**Flocculant**	0.77	1.31 E-11
Polishing	**Intercept**	0.49	8.72 E-54
$R^2 = 0.46$	**Flocculant**	0.38	1.23 E-25

Additional numerical turbidity comparisons are shown in Table 4.12 and Table 4.13. The turbidity values at each location were compared to the inflow values to determine the statistical significance of turbidity reduction at the 95% confidence interval, using two-tailed equal variance t-tests.

Table 4.12. Average turbidity during MFE-I testing (NTU)

First Fill Avg. Inflow Turbidity: 334 NTU	**Forebay**	**Bay 2**	**Bay 4 Bot.**	**Bay 4 Top**	**Discharge**
Filling Period (0:00-0:30)	393	338	1364[b]	5781	621[b]
Rapid Settling (00:31- 1:00)	-	227[a]	515[b]	262	354
Polishing (1:00+)	-	164[a]	399	223[a]	254[a]

Second Fill Avg Inflow Turbidity: 440 NTU	**Forebay**	**Bay 2**	**Bay 4 Bot**	**Bay 4 Top**	**Discharge**
Filling (5:00-5:30)	406	290[a]	266[a]	178[a]	188[a]
Rapid Settling (00:31- 1:00)	-	182	257	187	231
Polishing (1:00+)	-	108[a]	112[a]	107[a]	113[a]

Note: [a] indicates significant turbidity reduction, and [b] indicates significant turbidity increase, compared to inflow, at the 95% CI

During the filling and rapid settling periods associated with the first fill testing, there was an increase in turbidity compared to the inflow. While there was an observed decrease in turbidity following the second fill, turbidities never reached below 100 NTU. Hand samples overtopping the forebay were completed at 30 minutes. Thus, there was no data during the rapid settling and polishing periods; however, it was observed that the forebay continued dewatering for approximately 10-minutes post inflow. Hand samples were taken up to 40 minutes during MFE-I + Flocculant testing. Thus, the data is displayed in Table 4.13.

Table 4.13. Average turbidity during MFE-I + Flocculant testing (NTU)

First Fill Avg. Inflow Turbidity: 753 NTU	**Forebay**	**Bay 2**	**Bay 4 Bot.**	**Bay 4 Top**	**Discharge**
Filling (0:00-0:30)	224[a]	171[a]	240[a]	169[a]	302
Rapid Setting (00:31- 1:00)	134[a]	89[a]	118[a]	96[a]	178[a]
Polishing (1:00+)	-	68[a]	90[a]	73[a]	125[a]

Second Fill Avg. Inflow Turbidity: 430 NTU	**Forebay**	**Bay 2**	**Bay 4 Bot.**	**Bay 4 Top**	**Discharge**
Filling (5:00-5:30)	134[a]	69[a]	108[a]	88[a]	101[a]
Rapid Settling (00:31- 1:00)	92[a]	61	103	84	95
Polishing (1:00+)	-	38[a]	53[a]	55[a]	53[a]

Note: [a] indicates significant turbidity reduction, compared to inflow, at the 95% CI

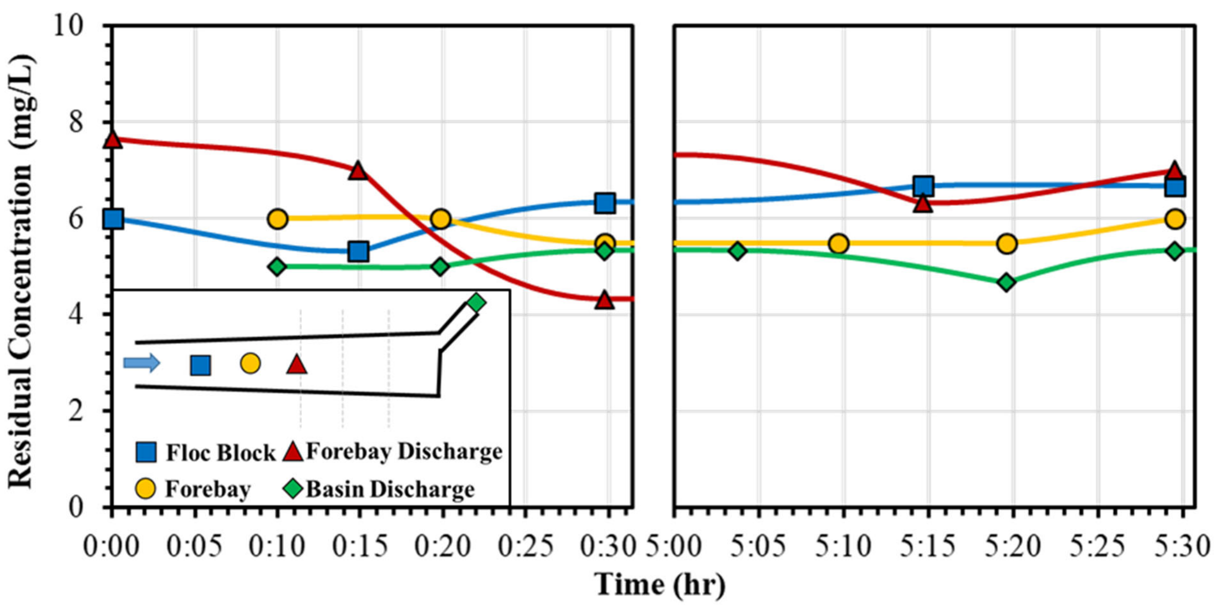
Following the second filling period, turbidities were reduced to 101 NTU, or less, at discharge and reached as low as 45 during extended dewatering. MFE-I and MFE-I + Flocculant were compared at each sampling location and time period using two-tailed equal variance t-tests. In all comparisons, MFE-I + Flocculant had significantly less turbidity at the 95% confidence interval.

4.3.3. RESIDUAL CONCENTRATIONS

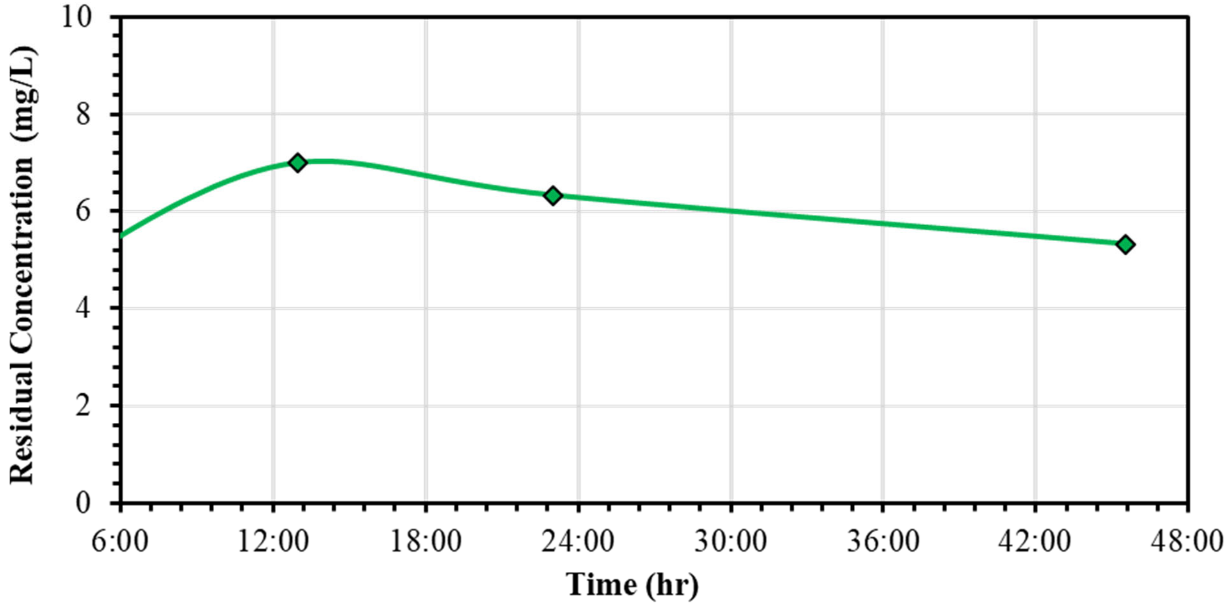
Although flocculant significantly impacted water quality, improved sediment retention, and fine grain size capture, the downstream effects of flocculant dosing were unknown. Manufacturer guidance was referenced for application, maintenance, and toxicity limits. Since flocculant blocks were used for the application, it was difficult to measure the inflow dosage compared to granular or emulsion forms. The manufacturer's guidance recommended one semi-hydrated, five-pound (2.27 kg) flocculant block to treat 800,000 gallons (128,000 ft^3 [3,625 m^3]) of sediment-laden flow but provided little information regarding the chemical makeup.

Residual concentrations were determined for several water samples by comparing the settling velocities of site samples with residual flocculants and to the settling velocities observed using known, dosed flocculant concentrations, as described in Kazaz et al., *(2022b)*. The method developed by Kazaz would allow residual testing to be conducted in the field, provided the known concentrations, such as the one shown in Figure 4.2, are created in advance.

Water samples for residual testing were taken during inflow directly downstream of the flocculant block, within the forebay, discharging from the forebay, and discharging from the basin. Discharge samples were analyzed for residual flocculant concentrations throughout the 48-hour dewatering period. The residual concentration plots are displayed in Figure 4.9.



(a) average residual flocculant concentrations in discharge during filling periods



(b) average residual flocculant concentrations in discharge during dewatering

Figure 4.9. Average residual concentrations.

Residual concentrations never exceeded 8 mg/L but, on average, remain roughly 6 mg/L. It was important to compare these concentrations with the manufacturer's material safety data sheet (MSDS). This particular product had an MSDS that did not provide a toxicity concentration but indicated that it was unlikely to be toxic to fish, algae, and daphnia even at high concentrations, due to low solubility. However, the product had unknown chronic toxicity and was not readily biodegradable, so proper management of flocculated and settled material on a site is important to consider. The acute toxicity report indicated that the product was non-toxic for humans, dermally or orally *(Carolina Hydrologic 2016)*. Although this particular flocculant product does not seem to be a threat to receiving waters during sediment basin testing, continued match, application, and dosage testing is being conducted by B. Kazaz, M.A. Perez, W.N. Donald, X. Fang, and J. Shaw for ALDOT for implementation guidance.

5. IN-CHANNEL SEDIMENT BASIN DESIGN TOOL

The large-scale testing effort described in the previous two chapters provided performance data for structural and chemical components, which indicated enhanced sediment capture and turbidity reduction within an in-channel sediment basin; however, the in-channel sediment basin configuration and several of its components are anticipated to be newly introduced to design specifications. An Excel-based tool was developed to aid in design and implementation of in-channel sediment basins. The Excel tool considers basin geometry and dewatering systems to determine detention volume and discharge characteristics. These characteristics can also be applied to a specific storm event, if the user elects to input a hydrograph. Additionally, the tool includes a section to input a specific soil gradation to determine if flocculant should be applied. Flocculant application is suggested if less than 80% of the sediment is predicted to settle within the desired dewatering time. Additional outputs include skimmer size selection, orifice diameter, plots of the channel cross-section at the earthen berm, stage-storage curve, and stage-discharge curve for design tables and reports. The user input is shown in Figure 5.1. Red text specifies areas for user input, red outline indicates a drop-down list for user selection, and the black text is output. Graphical outputs are described in the following section.

In-Channel Sediment Basin Design Tool

User Provided Input Paramters (Red)

Project & Location: | *Designer:* | *Date:*

Channel Configuration	
Foreslope (H:V)	3.50
Backslope (H:V)	3.00
Channel Bottom Width (ft)	10.00
Longitudinal Slope (%)	3.00%

Dam/ Auxiliary Spillway Configuration	
Top of Dam (ft)	4.50
Slope of Dam Face (%)	200.00%
Spillway Width (ft)	4.00
Spillway Height (ft)	4.00

Dewatering System	
Dewatering Structure	*Skimmer*
Desired Dewatering Time (days)	3
Riser Elevation (ft)	3.00
Riser Diameter (in.)	12.00
Elevation of Orifice Row 1 (in.)	24.00
Elevation of Orifice Row 2 (in.)	26.00
Elevation of Orifice Row 3 (in.)	28.00
Orifices in Row	4.00
Orifice Diameter (in.)	1.00
Skimmer	
Skimmer rest or pipe invert elevation (in.)	6.00

Site Soil Gradation		
Sieve No.	*(mm)*	% Finer
4	4.7500	100%
10	2.0000	96%
20	0.8500	89%
40	0.4250	80%
60	0.2500	75%
100	0.1500	68%
120	0.1250	61%
200	0.0750	62%
Pan- Hydrometer Analysis	0.0522	61%
	0.0379	57%
	0.0279	52%
	0.0213	40%
	0.0156	34%
	0.0118	28%
	0.0085	24%
	0.0061	22%
	0.0043	20%
	0.0031	19%
	0.0025	18%
	0.0022	18%
	0.0013	17%
	0.0009	15%

Expected Temperature in Basin (°F)	70

Hydrograph Routing	
Route Hydrograph?	Yes
Initial Discharge Elevation (ft)	0.50

User Input Hydrograph	
Time (hr)	Q_{in} **(ft^3/s)**
0.00	0
0.02	0
0.03	0
0.05	0
0.07	0
0.08	0
0.10	0
0.12	0
0.13	0
0.15	0
0.17	0
0.18	0
0.20	0
0.22	0
0.23	0
0.25	0
0.27	0

Storage	
Standing Pool (ft^3)	91.46
Stormwater Storage (ft^3)	8,840.54
Aux. Spillway Flow (ft^3)	3,020.68

Skimmer	
Skimmer Size (in.)	2
Orifice Diameter (in.)	1.41

Flocculant	
Settled Sediment (%)	79.90%
Apply Flocculant?	Yes

Notes

This tool is to be used for design guidance only. The engineer of record is responsible for final design. Dam height is limited to 5 ft, as maximum specified in 3.4.6 of IECA Sediment Basin Design Standard (2021). Skimmer is limited to design for the Faircloth Skimmer. If the skimmer size or orifice diameter results in #N/A, dewatering time must be increased. Inflow hydrograph is limited to 2000 time step entries. Flocculant suggested if settled sediment is less than 80%.

Figure 5.1. User input in spreadsheet-based tool.

5.1. GEOMETRY AND VOLUME

Although the Iowa DOT, for whom this research was conducted, has a standard in-channel sediment basin design *(EC-601, Iowa DOT, 2018),* the channel environments are expected to vary across sites. Additionally, it is anticipated that if the in-channel sediment basin design is adopted elsewhere, the channel design may need to be modified. Altering the channel design affects the detention volume. The first consideration of the tool was to estimate the available storage in the basin and develop a stage-storage curve for design tabulation. The tool requests the user to input the channel geometry, including the foreslope, backslope, channel bottom width, longitudinal slope, dam height, and the width of the auxiliary spillway. Next to the requested inputs, the Iowa DOT standard roadside ditch and temporary sediment control basin geometries are listed for reference. The auxiliary spillway height was calculated, subtracting six inches from the dam height, as specified by the Iowa DOT temporary sediment control basin design. Similarly, the top of the riser was calculated by subtracting 1.5 ft (0.45 m) from the dam height, if applicable, as specified by the Iowa DOT temporary sediment control basin design *(EC-601, Iowa DOT, 2018).* This design is included in Figure 2.2.

Detention volume characteristics, including impoundment length, surface area, and storage volume, are calculated based on the user input channel geometry over stage increments of 0.1 ft (3.0 cm). For a detailed illustration of basin behavior, the basin's stage increments were set to 0.1 ft (3.0 cm). The impoundment length is determined by dividing the stage by the user-input longitudinal slope. Next, the surface area is calculated following the surface component in the volume equation of the Iowa DOT Roadside Detail Temporary Sediment Control Basin Tabulation (100-33). The equation is shown in Eq. 5.1.

$$SA = \left(\frac{1}{4} \times FS \times h^2\right) + \left(\frac{1}{2} \times CB \times h\right) + \left(\frac{1}{4} \times BS \times h^2\right) \qquad \textbf{Eq. 5.1}$$

where,

SA = surface area (ft^2)
FS = foreslope (X:1)
BS = backslope (Y:1)
CB = channel bottom width (ft)
h = basin stage (ft)

The storage is determined by multiplying the surface area equation by the impoundment length, as shown in the Iowa DOT 100-33 in Figure 5.2; however, the tool also considers the volume directly upstream of the sloped earthen dam, rather than assuming an exactly vertical depth at the dam.

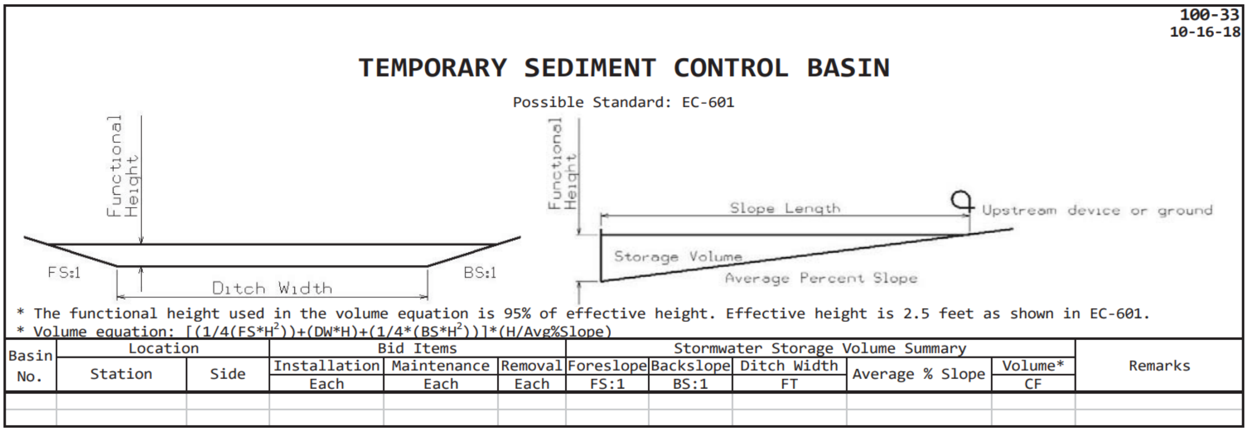


Figure 5.2. Temporary sediment control basin tabulation ***(Iowa DOT 2018).***

The stage-storage curve is automatically plotted at 0.1 ft (3.0 cm) increments, with a displayed best-fit equation and R^2 value to gauge the strength of the relationship. An example of the stage-storage curve is shown in Figure 5.3.

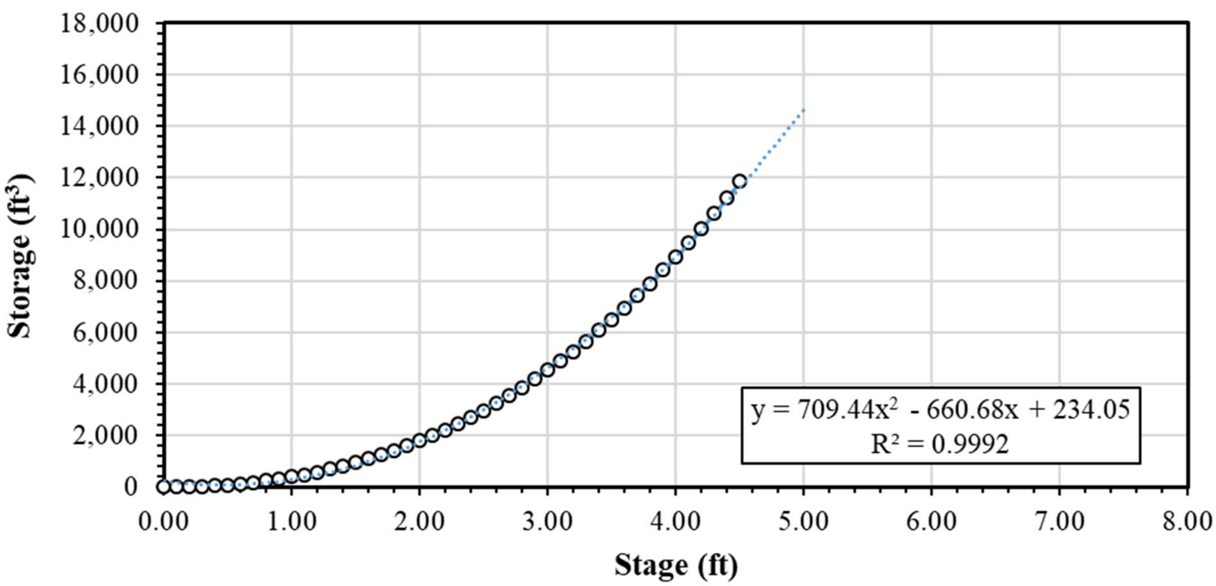


Figure 5.3. Plotted stage-storage curve.

5.2. DEWATERING

The second portion of the tool allowed the user to select a dewatering system. The user could toggle between a rock spillway, riser pipe, and skimmer. Outputs from this portion of the tool included a stage-discharge curve. The discharge was calculated according to the system selected. The flow over the rock spillway followed the broad-crested weir relationship, shown in Eq. 5.2 *(Finnemore and Franzini 2002)*.

$$Q = L \times \sqrt{g} \times (\frac{2}{3})^{\frac{3}{2}} \times (h - H)^{\frac{3}{2}} \quad \textbf{Eq. 5.2}$$

where,

Q	=	flow over weir (ft^3/s))
L	=	spillway width (ft)
g	=	acceleration of gravity (32.2 ft/s^2)
H	=	height of spillway (ft)
h	=	basin stage (ft)

No additional user input was required outside the basin geometry block if the rock spillway was selected. This spillway type would allow users to apply the tool for the detention created behind rock check dams, or the component of the forebay in this research, and the flow over an auxiliary spillway. The rock spillway was included because it served as the auxiliary spillway for the riser pipe and skimmer dewatering systems. Additionally, this would be the outlet type for the silt basins.

As shown in EC-601, the traditional dewatering pipe was also included as a dewatering option. If the riser pipe was the selected system, the tool requested the diameter of the riser pipe and orifices. Additional user input included the elevation of each orifice row and the count of orifices at a single elevation. Equations 7E-12.01 and 7E-12.02 from the Iowa Statewide Urban Design and Specifications were used to calculate weir and orifice flow. Weir flow was considered when the stage in the basin was greater than the top of the riser pipe's elevation. Rows of orifices were incorporated into the discharge as the stage in the basin overcame their elevation. The equations are shown in Eq. 5.3 and Eq. 5.4.

$$Q = 10.5 \times d \times h^{\frac{2}{3}} \quad \textbf{Eq. 5.3}$$

$$Q = 0.6 \times A \times \sqrt{2 \times g \times H} \quad \textbf{Eq. 5.4}$$

where,

Q	=	flow through (ft^3/s))
d	=	riser diameter (ft)
g	=	acceleration of gravity (32.2 ft/s^2)
H	=	allowable head over riser (ft)
A	=	open orifice area (ft^2)

The skimmer from the MFE-I installation was included as the third dewatering system option. If this option was selected, the user was requested to input the desired dewatering time in days, skimmer rest, or pipe invert elevation, which would govern the water level available to drain through the skimmer. Skimmer design was based on calculations for Faircloth skimmers, as used in the large-scale research effort. The tool outputs the skimmer size and orifice diameter based on user input. The skimmer maximum flow capacities, orifice factors, and skimmer heads were referenced in the tool, following the Faircloth Technical Sizing Instructions *(2007).* The skimmer orifice was calculated by dividing the basin volume, determined by the geometry, by the skimmer factor. This calculation provided the required open orifice area, which the orifice diameter was then calculated from using the area of a circle. The discharge from the skimmer was calculated by substituting the orifice area into Eq. 5.4.

A stage-discharge curve auto-populates based on the dewatering system selected and input parameters. An example, using the riser pipe, is shown in Figure 5.4

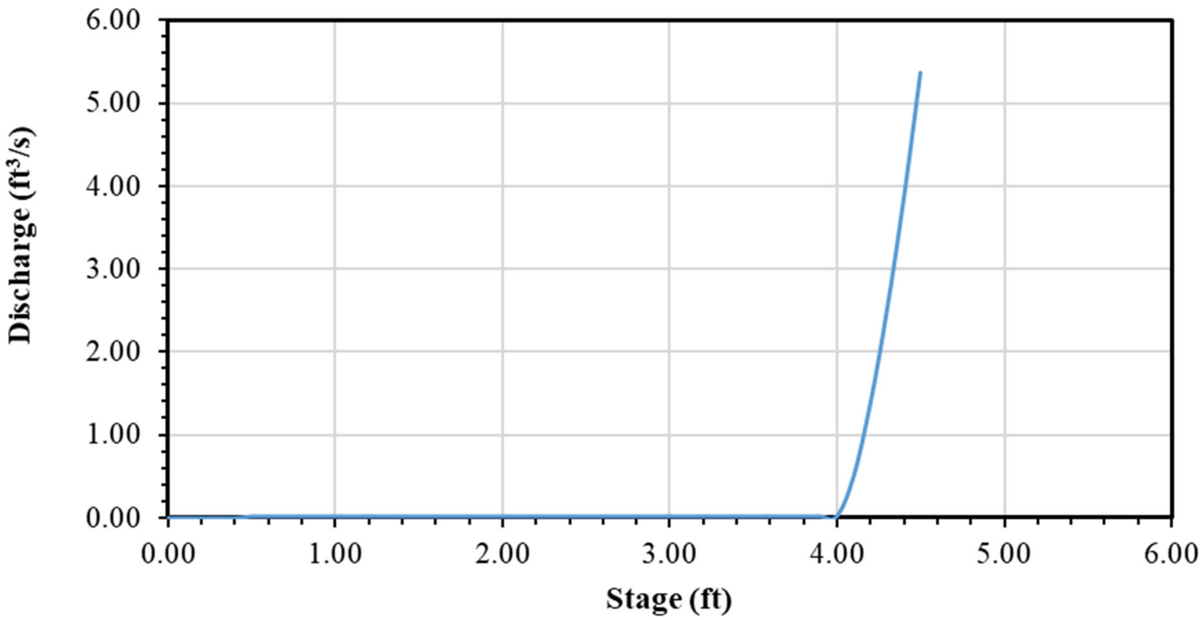


Figure 5.4. Stage discharge curve.

Additionally, a schematic of the basin cross-section at the dam is populated based on the geometry and dewatering user input. An example, using the riser pipe, is shown in Figure 5.5.

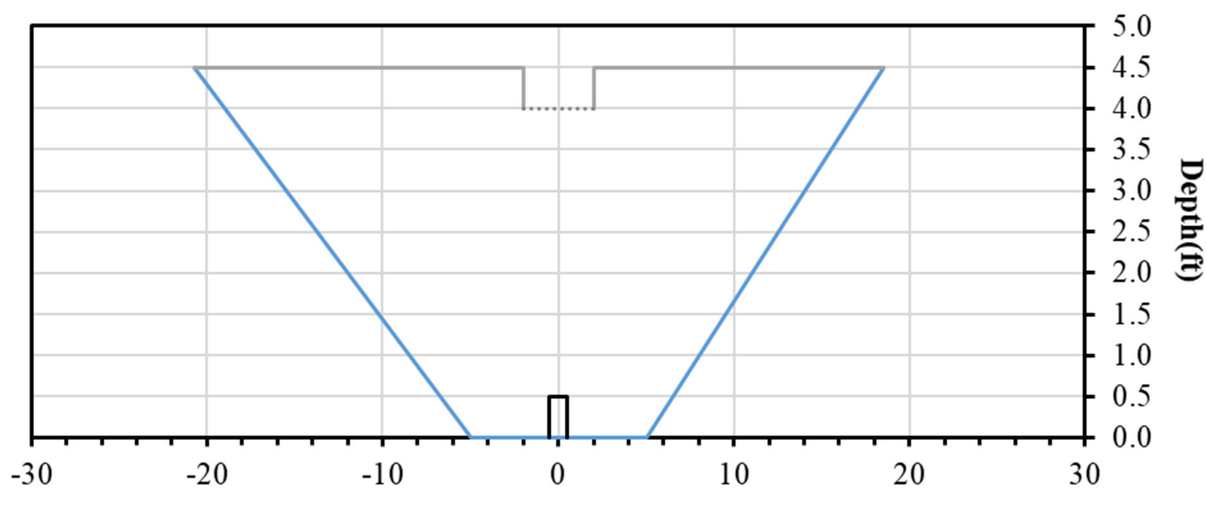
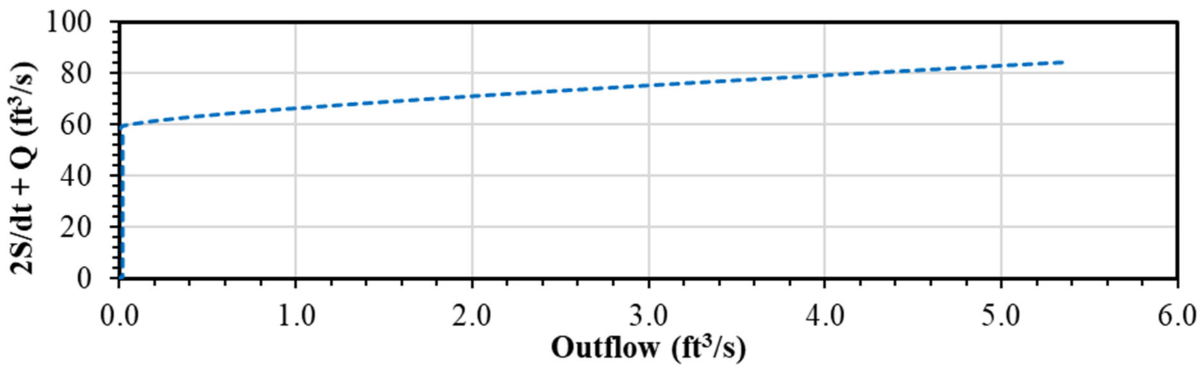
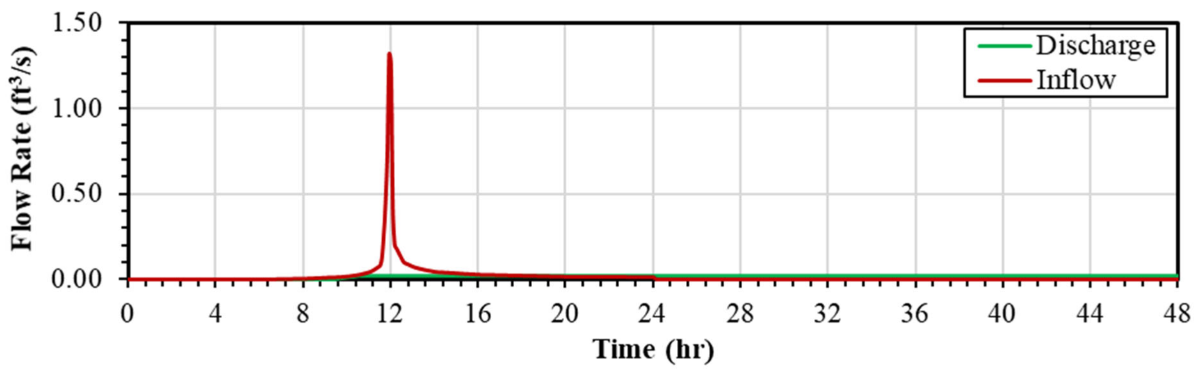


Figure 5.5. Basin cross section schematic.

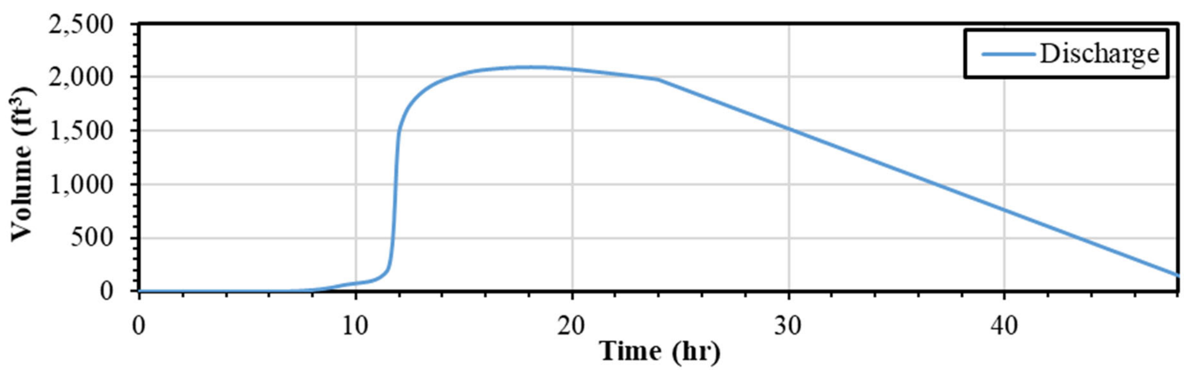
The user may also input time and flow rate into available hydrograph parameters. If the user elects to input a hydrograph, the tool relies on the Muskingum Routing method at 5 min (300 second) time steps to model the hydrological flow into and discharged from the basin. This method considers the discharge capacity of the selected dewatering device. When routing is utilized, the tool supplies users with a created storage indication curve used to predict discharge, an inflow and discharge hydrograph, and the basin's volume over time to illustrate dewatering. Examples of the graphical outputs are shown in Figure 5.6.



(a) storage indication curve



(b) inflow and discharge hydrograph



(c) dewatering behavior

Figure 5.6. Hydrograph routing graphical output.

5.3. SEDIMENT CAPTURE AND FLOCCULANT

The last portion of the tool allows the user to input a soil gradation from a combined sieve and hydrometer analysis. Additionally, the tool allows the user to adjust the expected water temperature, starting with freezing, in the basin to adjust settling calculations. If no temperature is selected, 70 °F (20 °C) is the default. To predict settling, Stoke's Law was applied to determine if a particular sediment particle size class would settle within the user-specified dewatering time. If no dewatering time is specified, three days is considered the default. Stoke's law, was used to estimate the settling velocities of particles based on diameter, following the form of:

$$V = \frac{g\left(\frac{\rho_1}{\rho_w} - 1\right) d^2}{18\nu} \quad \textbf{Eq. 5.5}$$

where,

- V = flow through (m^3/s))
- ρ_w = density of water
- g = acceleration of gravity (9.81 m/s^2)
- ρ_1 = density of particle (kg/m^3)
- d = particle diameter (mm)
- ν = kinematic viscosity

The settling velocity for each particle size class was multiplied by the desired dewatering time to determine a settling distance. If the settling distance was greater than the user-input spillway height, or maximum stage level, the particle size class was assumed to be settled. If the settling distance was less than the spillway height, the particle size class was considered to be still suspended. If more than 20% of all sediment was still considered to be suspended, flocculant application was recommended. The settling distance was auto-populated based on soil gradation, basin geometry and conditionally formatted to indicate the particle classes that settled in green and were suspended in red. Additionally, the soil gradation was plotted with the particle size classes that settled in green and particle size classes suspended in red. The color-coded soil gradation plot is shown in Figure 5.7. If flocculant is recommended, users may reference the flocculant selection tool described by Kazaz et al., *(2022b).*

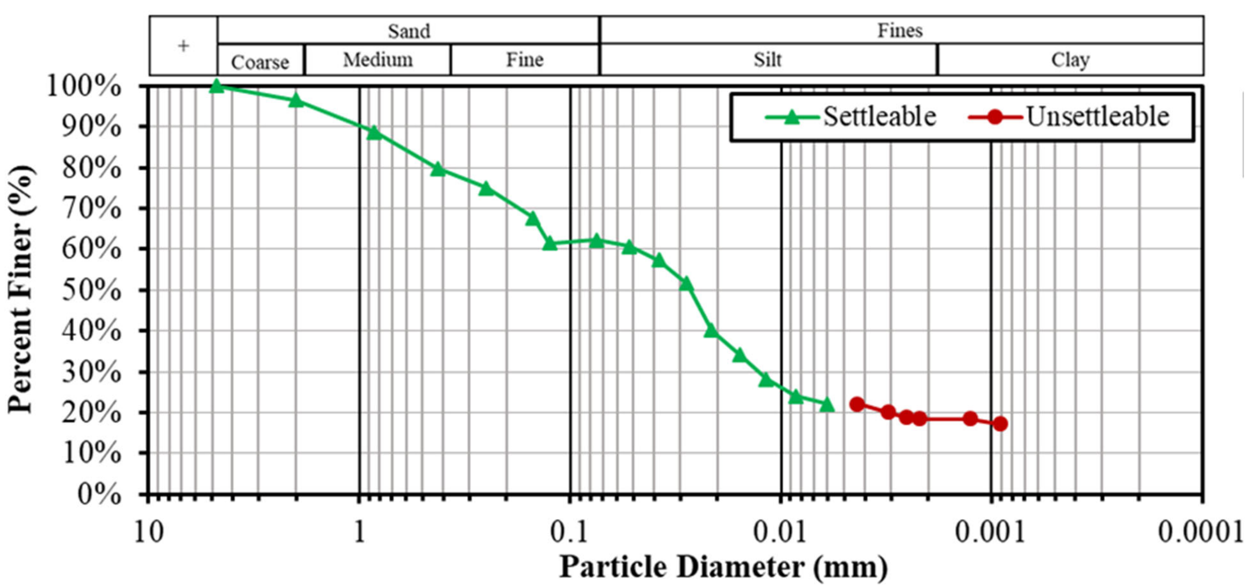


Figure 5.7. Particle settling estimation.

This tool is expected to aid the Iowa DOT in implementing new technologies to improve sediment capture and turbidity reduction, including the skimmer, forebay, and flocculant application. Additionally, the tool is anticipated to aid other state agencies and construction operators when adopting the in-channel sediment basin design configuration. Outputs provide skimmer sizing, cross-sectional schematics with the dewatering system, stage-storage and stage-discharge curves, which may be used in design tabulations and reports.

6. CONCLUSIONS, LIMITATIONS, AND RECCOMMENDATIONS

6.1. INTRODUCTION

This study sought to improve the performance of sediment control basins used by the Iowa DOT. The project developed a large-scale testing procedure and apparatus that mimics the scale and hydrologic behavior of field-installed sediment basins that allowed researchers to evaluate the performance of various treatments within the basin. This testing allowed for the understanding of the sediment capture and turbidity reduction capabilities of the Iowa DOT standard sediment basin design and improvements provided by structural and chemical basin treatments. Ultimately research findings led to recommendations towards developing practical and cost-effective design and construction improvements for Iowa DOT sediment basin implementation.

6.2. IN-CHANNEL SEDIMENT BASIN PERFORMANCE IMPROVEMENTS

Traditional sediment basins are designed with an excavated pond with dead and live storage volume designations and have exhibited up to 90% capture of suspended solids in controlled research studies *(Fennessy and Jarrett 1997, Bidelspach et al., 2004, Perez et al., 2016)*. However, this research evaluated the Iowa DOT EC-601 temporary sediment control basin design, which relies on existing site conveyance structures. Results from field monitoring indicated that the in-channel basins had negligible treatment in the field during active construction; however, the dynamics of the site made it difficult to identify the exact cause. It was suspected that channel and basin were eroded during inflow and added to the sediment load, lacking maintenance resulted in resuspension of previously settled material, and inadequacies in the dewatering system caused increased turbidity at basin discharge. Additionally, the basin sizing and installation failed to consider contributing drainage areas and relied heavily on ditch checks and perimeter controls to provide additional storage. Field findings indicated that upstream practices may not have provided sufficient management of erosion and sediment, contributing additional flow and sediment loads to the basin. While these field observations were essential to understanding a real-world site and case study, it also highlighted the need for large-scale, reproducible sediment basin testing techniques to improve current practice and field performance

A large-scale in-channel sediment basin was constructed to evaluate water quality and sediment retention performance in response to structural sediment basin treatments. Structural treatments included (1) geotextile lining, (2) a floating surface skimmer, (3) porous flow baffles, and (4) an upstream forebay. The components were installed and evaluated individually before identifying the best combination for a treatment system. The evaluated system with the best sediment retention and turbidity reduction performance included a geotextile liner, forebay, and skimmer. Baffles were not included in the system due to installation costs, effort, and maintenance challenges.

The geotextile liner stabilized the channel to reduce erosion within the channel. With the use of a skimmer, dewatering can occur over an extended period to promote settling, decrease discharge rates, alleviate pressure applied to receiving waters, and provide additional stormwater storage for subsequent storms. The forebay created detention to capture rapidly settable solids and increased the storage volume by nearly 33%. The forebay was accessibly located to ease cleanout requirements and extend times between basin dredging. This alternative basin design captured up to 96% of the sediment introduced and reduced discharge turbidity by nearly 400% compared to the unlined standard. This research is expected to provide an alternative basin design backed by performance data from large-scale testing.

The findings from the large-scale testing effort are limited by the flow and sediment introduction rates subjected to the basin. The evaluations were conducted under known flow and sediment introduction rates based on historical data; however, storm intensities and frequencies are increasing due to a changing climate. The field performance of the tested basin configurations will likely vary based on these factors. The AU-SRF in-channel sediment basin was 3,031 ft^3 (86 m^3) and was determined to represent a 0.84 ac (0.34 ha) treatment area. Sediment basins may treat up to 10 acres (4 ha) of drainage, and the configuration, particularly the skimmer, may need to be adjusted to dewater an increased volume if the basin is expected to capture runoff from a larger drainage area. Skimmers are sized based on the basin design volume and a desired dewatering time. In the United States, skimmers are proprietary products, and DOTs are suggested to follow manufacturer sizing guidance. In this project, a Faircloth skimmer was used. Faircloth has an online sizing calculator for this skimmer type. Additionally, the implementation tool described in Chapter 5 provides users the appropriate skimmer and orifice sizing based on the geometry and desired dewatering time.

Despite evaluating an Iowa DOT design, the large-scale in-channel sediment basin testing was conducted in Alabama. Although Iowa-native soil was used for the majority of the controlled testing, the subgrade of the basin was Alabama site soil. The standard basin specification did not include a liner; therefore, the subgrade was exposed during control testing. Soil erodibility should be accounted for, as it affects the channel erosion behavior and thus additional sediment load. Future controlled testing may account for the variability in soil erodibility in in MUSLE calculations. Site soil was also used for sediment introduction in unlined and lined large-scale testing configurations. Soil gradations indicated the Iowa- and Alabama- native soils were similar in coarse sand and fine silt and clay fractions but different in fine sands and coarse silts fractions. Sand fractions above 0.85 mm or the No. 20 sieve, and below 0.02 mm, were within 5% of one another. Differences in gradation likely affected the suspension and settling behaviors. Although the staged testing regimen allowed the comparisons to build on one another, it was difficult to compare large-scale testing results to the pilot field-monitoring effort. Part of the performance of the in-channel sediment basin will be dependent on site soil characteristics.

Additionally, sediment retention was measured using a combination of volume and weight, which allowed for moisture corrections. Sediment quantification was manageable when the geotextile liner was installed, separating settled material from the subgrade; however, the methods did not apply to standard installation testing when a liner was not installed. Instead, a survey was conducted pre-and post- series. When the surveys were compared, sediment retention results indicated that more sediment was retained than introduced due to the swell of the soil. Since standard testing was conducted during the winter, the soil never dried enough to get accurate results. Although sample depth measurements and moisture contents were recorded and applied for correction, the sediment retention results for the standard test were skewed. Instead, turbidity reduction was compared to classify the performance. The sediment retention for all treatments is shown in Figure 6.1.

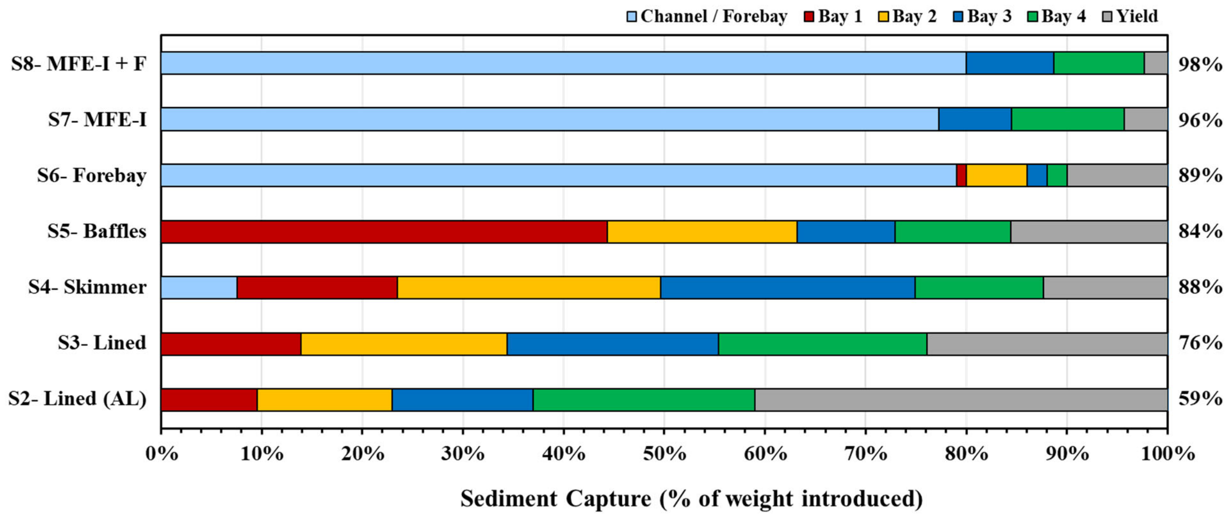


Figure 6.1. Combined sediment retention comparison.

6.3. UPSTREAM FLOCCULANT APPLICATION

Following the performance evaluations of the sediment basin in response to the structural components, flocculant blocks were added to the inflow channel, and water quality and sediment retention were quantified. In total, 13 flocculant products were applied to sediment-laden samples. The sediment used in the samples was Iowa-native soil to ensure an appropriate product was selected for application in large-scale testing. Based on the designated point system, three flocculant products received 31 points. Another three products received 30 points. Although all of these products would have likely provided similar results, the product eventually used in large-scale testing was selected based on the availability in block form, the desired application mechanism of the project Technical Advisory Committee.

Sediment retention in the system increased by 2% when flocculant was used, and the D_{50} decreased by nearly 50% in all areas of the basin, validating that the finer particles can be captured when flocculant is applied. The turbidity was significantly reduced when flocculant was applied in the basin. The estimated turbidity reduction was 42% more with flocculant, based on a linear regression model comparing the MFE-I and MFE-I + Flocculant. Residual concentrations were measured following the methods outlined by Kazaz et al., (*2022)* to ensure there would not be harmful downstream effects if this flocculant was applied on site. At discharge, residual concentration never exceeded 8 mg/L but averaged 6 mg/L. Due to the product's low solubility, the MSDS indicated it was unlikely to be toxic to aquatic life even at high concentrations.

The findings of this research are expected to provide an example of the water quality benefits and serve as scientific-based evidence for the adoption of flocculant in construction stormwater management. While the method for detection of residual concentration is attributed to Kazaz et al., (*2022)*, this research effort provides evidence that, if properly dosed, flocculant sorbs to the aggregated particles and drops from suspension rather than being discharged to receiving waters. The detected concentrations in this study would not be harmful to receiving waters by the metrics provided in the manufacturer's safety data sheets (MSDS).

Although sediment-laden samples were dosed with various flocculants at the bench scale, only one PAM product was selected for the large-scale sediment basin testing. Although PAM is widely applied in construction stormwater management, turbidity reduction and sediment grain-size capture are highly dependent on the interaction of a particular flocculant and site soil. Results from this study may be used as an example of sediment retention and water quality benefits if the appropriate flocculant is selected; however, the bench-scale evaluation is essential for selection. Sediment retention and turbidity reduction may not be reproducible if another flocculant, soil type, or application mechanism is used. In this study, three flocculant products received the same number of points with 31 points. Another three products received 30 points. Although one product was selected for large-scale testing based on its block form, real-world site constraints such as cost and availability may benefit from selecting various, similarly-performing products. Further testing should include a sensitivity analysis to understand the water quality impact of using flocculants with certain point designations

In this testing, flocculant blocks were used to dose sediment-laden inflow with flocculant. Flocculant blocks are easily applied, but tracking the concentration of flocculant applied to the inflow was challenging. Additional lab-based research is suggested to examine degradation, estimate dosed concentrations, and determine flocculant blocks' longevity and maintenance requirements. Additional research may be conducted using controlled flow, sediment introduction, and environmental chambers to emulate changing site weather and drying conditions.

The residual concentration determination was conducted following the methods of Kazaz et al., *(2022)* for field detection; however, the methods are observational based on settling gradient, timing, and results likely vary based on the executor of the procedure. Additionally, a specific soil was required for the analysis. Since inflow concentration was challenging to track due to the application mechanism, residual concentration comparisons were impossible.

6.4. IN-CHANNEL SEDIMENT BASIN DESIGN TOOL

A spreadsheet-based tool was developed to aid in implementing in-channel sediment basins and the various structural and components that enhanced sediment capture and turbidity reduction, as indicated through large-scale testing results. The development of this tool provided design guidance for the implementation of in-channel sediment basins. Users are prompted to input basin geometry and desired dewatering systems to determine detention volume and discharge characteristics and are provided with skimmer size selection, orifice diameter, plots of the channel cross-section at the earthen berm, stage-storage curve, and stage-discharge curve for design tables and reports. Additionally, the tool recommends if flocculant should be applied. Flocculant application is suggested if less than 80% of the sediment load is predicted to settle within the desired dewatering time, determined by a user-input soil gradation.

The tool allows designers to size an in-channel sediment basin within a particular channel environment and evaluate the discharge from various mechanisms. Three dewatering systems are considered in the basin- a rock spillway, a traditional perforated riser, and a Faircloth skimmer. The rock spillway option allows designers to determine the volume and discharge of detention behind a rock check dam, considered a forebay in large-scale testing. Additionally, this outlet type allows the tools to be applied to silt basins, which were highly relied upon the field-monitoring research conducted on the Tama U.S. 30 project.

The spreadsheet-based tool is anticipated to help in the adoption of in-channel sediment basin and several of the structural and chemical components tested through the large-scale testing efforts described in this report. The outputs of this tool are expected to aid communication in design and installation. The tool is currently limited to a trapezoidal channel geometry. Additionally, the dewatering systems are limited. Although numerous skimmer systems exist, the current tool only considers the design parameters from Faircloth *(2007)*. Future iterations of this tool may also allow the skimmer type to be selected for dewatering comparisons. Cost comparison between skimmers of similar sizing and drawdown time may also be included.

Although additional spillway geometries exist for forebay and auxiliary spillway design, the rock spillway is considered a broad-crested weir. Currently, a designer would need to conduct at least two iterations in the tool if a rock check dam was being implemented to create a forebay upstream of a detention basin. Further improvements to the tool may include the forebay into the basin design. Similarly, the current tool only recommends if flocculant should be applied; however, Kazaz *(2022b)* created a tool to aid in flocculant selection. These tools may be linked in the future, and a flocculant recommendation may be based on soil type from benchmark soils if determined to be applicable through testing.

6.5. IMPLEMENTATION RECOMMENDATIONS AND ESTIMATED COSTS

In the 2020 field monitoring study conducted by Schussler et al.,, the in-channel sediment design was providing negligible turbidity reduction. Despite the lacking stormwater treatment, each temporary sediment control basin was estimated at a cost of $3,200 *(Skogerboe 2020)*. This report documents the findings of this large-scale sediment basin research, which aimed to develop practical and cost-effective design and construction improvements for Iowa DOT sediment basin implementation. Based on the study results, implementing several additional basin components is recommended. These components include a geotextile lining, upstream forebay, and surface skimmer within the in-channel sediment basin. Additionally, flocculant application should be considered, particularly in areas with fine-grained soils or where site constraints prevent adequate volume and detention times. The use of baffles should also be considered if field inspections reveal that short circuiting or resuspension is occurring in basins. While each of these components induce an additional cost to the standard basin design, sediment retention and turbidity reduction have indicated significant improvement.

When compared to the standard, unlined basin, the geotextile liner significantly increased turbidity reduction within the basin. The increase in turbidity reduction is likely a result of the stabilized channel bottom and sides reducing the additional sediment load. During testing, the entire basin was lined with 8 oz. nonwoven geotextile, costing approximately $800 in materials. When installed with the geotextile liner, the upstream forebay increased sediment retention to 90% and improved turbidity reduction by nearly 20%. The forebay consisted of a standard rock check dam *(Iowa DOT EC-302, 2018)* covered in geotextile. According to contract documents from the 2020 field monitoring study, a rock check dam was estimated at $13.90 per linear ft ($45.59/m) *(Skogerboe, 2020)*.

When the skimmer was installed for dewatering, 88% of the sediment introduced during testing was retained within the basin. In addition to the increased sediment capture, the skimmer allowed the basin to dewater at a controlled flow rate over an extended period of time. The lower, controlled flow rate will minimize erosion and downstream implications of increased flow rates and water quantity. The skimmer dewatered the basin to a lower stage, creating available stormwater storage volume for subsequent storm events. When a skimmer is implemented, a designer can select the desired dewatering time that considers site conditions such as available area for basin installation and site-specific soils. Although skimmer types, sizes, and availability, affect the cost, the field monitoring study conducted by Schussler et al *(2020)* documented a 4 in. surface skimmer at $1,328. Although skimmers induce an additional upfront cost, skimmers can be reused on sites. Adjustable dewatering orifices, available on many commercial sediment basin skimmer, allows a single skimmer to be designed for various sites and conditions.

As a system, the liner, forebay, and skimmer exhibited a sediment retention of 96% and significantly reduced turbidity throughout dewatering. This system, named the MFE-I, was evaluated with and without upstream flocculant application. When flocculant was applied, turbidity reduction was increased by 41% and the captured D_{50} grain size was decreased by 51%, indicating fine particle capture. Residual flocculant concentrations were monitored at discharge to quantify potential downstream risks. During monitoring the average discharge residual concentration was 6 mg/L, or the dosage recommended for turbidity of 1,500 NTU. Although the product's MSDS did indicate a numerical threshold for downstream consequences, it noted that the product posed no risk at very high concentrations. The improvements in sediment retention, water quality, and minimal downstream risk contribute to the recommendation for flocculant dosing in sediment basins. Additionally, flocculant increases particle size and thus settling velocity. If flocculant is applied, sediment basin detention volume and times may be decreased. The flocculant blocks used for application are a passive treatment mechanism, and one block is noted to treat 800,000 gallons (3,637 m^3) of stormwater runoff. The flocculant blocks in this testing were quoted at $75 per block, and are sold in cases of five blocks *(Carolina Hydrologic)*. Flocculant is also available in powder, emulsion, sock, and block forms. Based on the product and dosing mechanism, the cost will vary.

This project developed a large-scale testing procedure and apparatus that mimicked the scale and hydrologic behavior of field-installed sediment basins to understand the sediment capture and turbidity reduction of several modified basin configurations. The suggested configuration includes a geotextile liner for stabilization, surface dewatering via a skimmer, an upstream forebay to capture rapidly settleable solids, and flocculant application for fine-grained soil capture.

REFERENCES

1. ALDOT. 2020. Standard and Special Drawings for Highway Construction. Alabama Department of Transportation. Montgomery, AL.

2. ASTM Standard C136-01. 2017. Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates. ASTM International, West Conshohocken, PA.

3. ASTM Standard D4318-17e1. 2018. Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. ASTM International. West Conshohocken, PA, USA.

4. ASTM Standard D7928-21e1. 2021. Standard Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis. ASTM International, West Conshohocken, PA.

5. ASTM Standard D3977-97(2019). 2019. Standard Test Methods for Determining Sediment Concentration in Water Samples. ASTM International. West Conshohocken, PA, USA.

6. Bidelspach, D. A. and A. R. Jarret. 2004. Electro-mechanical outlet flow control device delays sediment basin dewatering. *Applied Engineering in Agriculture* 20: 759-763.

7. Bidelspach, D. A., A. R. Jarrett, et al., 2004. Influence of increasing the delay time between the inflow and outflow hydrographs of a sediment basin. *Transactions of the American Society of Agricultural Engineers* 47: 439-444.

8. Carolina Hydrologic. 2016. H30 PAM. Safety Data Sheet. Hilton Head, SC.

9. Chen, C. N. 1975. Design of Sediment Retention Basins. National Symposium on Urban Hydrology and Sediment Control. Lexington, KY.

10. Donald, W. N., Zech, W. C., Perez, M. A., and X. Fang. 2013. Ditch Check Installation Evaluations of Wheat Straw Wattles Used for Velocity Reduction. *Transportation Research Record*, 2358(1): 69-78. doi.org/10.3141/2358-08.

11. Hazen, A. 1904. On Sedimentation. *Transactions of ASCE*, Vol. 53, No. 980, pp. 45–88.

12. Fang, X., Zech, W. C., and C. P. Logan. 2015. Stormwater field evaluation and its challenges of a sediment basin with skimmer and baffles at a highway construction site. *Water,* 7(7):3407–30. doi.org/10.3390/w7073407

13. Fennessey, L. A. J. and A. R. Jarrett (1997). Influence of principal spillway geometry and permanent pool depth on sediment retention of sedimentation basins. *Transactions of the American Society of Agricultural Engineers* 40: 53-59.

14. Fifield, J. S. 2015. Designing effective sediment basins and traps. Part 1: The myth of capturing 3,600 cubic feet per acre. *Stormwater*, Forester Press, Santa Barbara, CA.

15. Finnemore EJ, Franzini JB. 2002. *Fluid Mechanics with engineering Applications*. McGraw Hill: New York.

16. Goldman, S. J., Jackson, K., and T. A. Bursztynsky. 1986. *Erosion and Sediment Control Handbook*, McGraw-Hill, New York, NY.

17. Iowa DNR. 2017. National Pollutant Discharge Elimination System (NPDES) General Permit No. 2 for Storm Water Discharge Associated with Construction Activities. Iowa Department of Natural Resources. Des Moines, IA.

18. Iowa DOT. 2017. Standard Road Plan Erosion Control Standards. Iowa Department of Transportation. Ames, IA.

19. Iowa DOT. 2019. Design Manual, Cross-Sections. Iowa Department of Transportation. Ames, IA.

20. IECA. 2021. Temporary Sediment Basin Standard. International Erosion Control Association, Aurora, CO.

21. Iowa SUDAS. 2020. Iowa SUDAS Design Manual. Statewide Urban Design and Specifications . Iowa State University, Ames, IA.

22. Jarrett, A.R. 2001. Designing Sedimentation Basins for Better Sediment Capture. *ASABE Soil Erosion Research for the 21st Century*. Honolulu, HI.

23. Johnson, A. K., Claman, D. R., and J. A. Christiansen. 2017. Tama County Grading Plans. Iowa Department of Transportation. Ames, IA.

24. J.W Faircloth & Son Inc. 2007. Determining the Skimmer Size and the Required Orifice for the Faircloth Skimmer Surface Drain. Hillsborough, NC.

25. Kang, J., King, S. E., and R. A. McLaughlin. 2015. Flocculated Sediments Can Reduce the Size of Sediment Basin at Construction Sites. *Journal of Environmental Managem*ent, Vol. 166, 2016, pp. 450–456. doi.org/10.1016/j.jenvman.2015.10.049

26. Kazaz, B., Perez, M. A., and W. N. Donald. 2021. State-of-the-Practice Review on the Use of Flocculants for Construction Stormwater Management in the United States. *Transportation Research Record*, 2675(7):248-258. doi.org/10.1177/0361198121995192.

27. Kazaz, B., Perez, M. A., Donald, W. N., Fang, X., J. N. Shaw. 2022. Detection of Residual Flocculant Concentrations in Construction Stormwater Runoff. *Transportation Research Record.* doi.org/10.1177/03611981221077985.

28. Kazaz, B. 2022. Improvements in Construction Stormwater Treatment Using Flocculants [Doctoral Dissertation Under review]. Auburn University. Auburn, AL

29. McCaleb, M. M., and R. A. Mclaughlin. 2008. Sediment Trapping by Five Different Sediment Detention Devices on Construction Sites. *Transactions of the ASABE*, Vol. 51, No. 5, pp. 1613–1621.

30. Millen, J. A., Jarrett, A. R., and J. W. Faircloth. 1997. Experimental Evaluation of Sedimentation Basin Performance for Alternative Dewatering Systems. *American Society of Agricultural Engineers*, Vol. 40, No. 4, pp. 1087–1095.

31. NCDOT. 2015. Erosion & Sediment Control Design and Construction Manual. North Carolina Department of Transportation. Raleigh, NC.

32. NCDENR. 2019. NCDENR Stormwater BMP Manual. North Carolina Department of the Environment and Natural Resources. Raleigh, NC.

33. NJ DEP. 2004. New Jersey Stormwater Best Management Practices Manual. New Jersey Department of Environmental Protection. Trenton, NJ.

34. NRCS. 2006. Sediment Loss from Water Erosion. Model Simulation of Soil Loss, Nutrient Loss, and Change in Soil Organic Carbon. Natural Resources Conservation Service. Washington, D.C..

35. Perez, M. A., Zech, W. C., Donald, W. N, and X. Fang. 2016. SEDspread: A Sediment Basin Design Tool for Construction Sites. *ASCE Journal of Irrigation and Drainage Engineering*, 142(12): 04016064-1-11. doi.org/10.1061/(ASCE)IR.1943-4774.0001099.

36. Perez, M. A., Zech, W. C., Fang, X., and J. G. Vasconcelos. 2016. Methodology and Development of a Large-Scale Sediment Basin for Performance Testing. *ASCE Journal of Irrigation and Drainage Engineering*, Vol. 142, No. 10, p. 04016042. doi.org/10.1061/(ASCE)IR.1943-4774.0001052

37. Perez, M. A. 2016. Improvements in the Design and Application of Erosion and Sediment Control Technologies for the Construction Industry. Auburn University. Auburn, AL.

38. Pitt, R., Clark, S. E., & Lake, D. W. 2007. *Construction site erosion and sediment controls: Planning, design and performance*. DEStech Publications, Inc.

39. Samuel Ginn College of Engineering. About AU-ESCTF. 2021. Samuel Ginn College of Engineering, Research Centers, Auburn University Erosion and Sediment Control Test Facility. https://www.eng.auburn.edu/research/centers/auesctf/about-us/index.html. Accessed July 1st, 2021.

40. Schussler, J. C., Perez, M. A., Cetin, B., and J. B. Whitman. 2020. Field Monitoring of Erosion and Sediment Control Practices and Development of Additional Iowa DOT Design Manual Guidance. Final Report. Ames, IA.

41. Skogerboe, Dustin. 2020. Email to Jaime Schussler. 27 January 2020.

42. TDOT. 2020. Erosion Prevention and Sediment Control. Tennessee Department of Transportation Standard Roadway Drawings. Nashville, TN.

43. Thaxton, C. S., Calantoni, J. and R. A. McLaughlin. 2004. Hydrodynamic Assessment of Various Types of Baffles in a Sediment Retention Pond. *Transactions of the ASABE*, Vol. 47, No. 3, pp. 741–750.

44. USDA. 1986. Urban hydrology for small watersheds TR-55. Technical Release. United States Department for Agriculture Soil Conservation Service, Washington DC.

45. USEPA. 1972. Guidelines for Erosion and Sediment Control Planning and Implementation. United States Environmental Protection Agency. Washington, D.C.

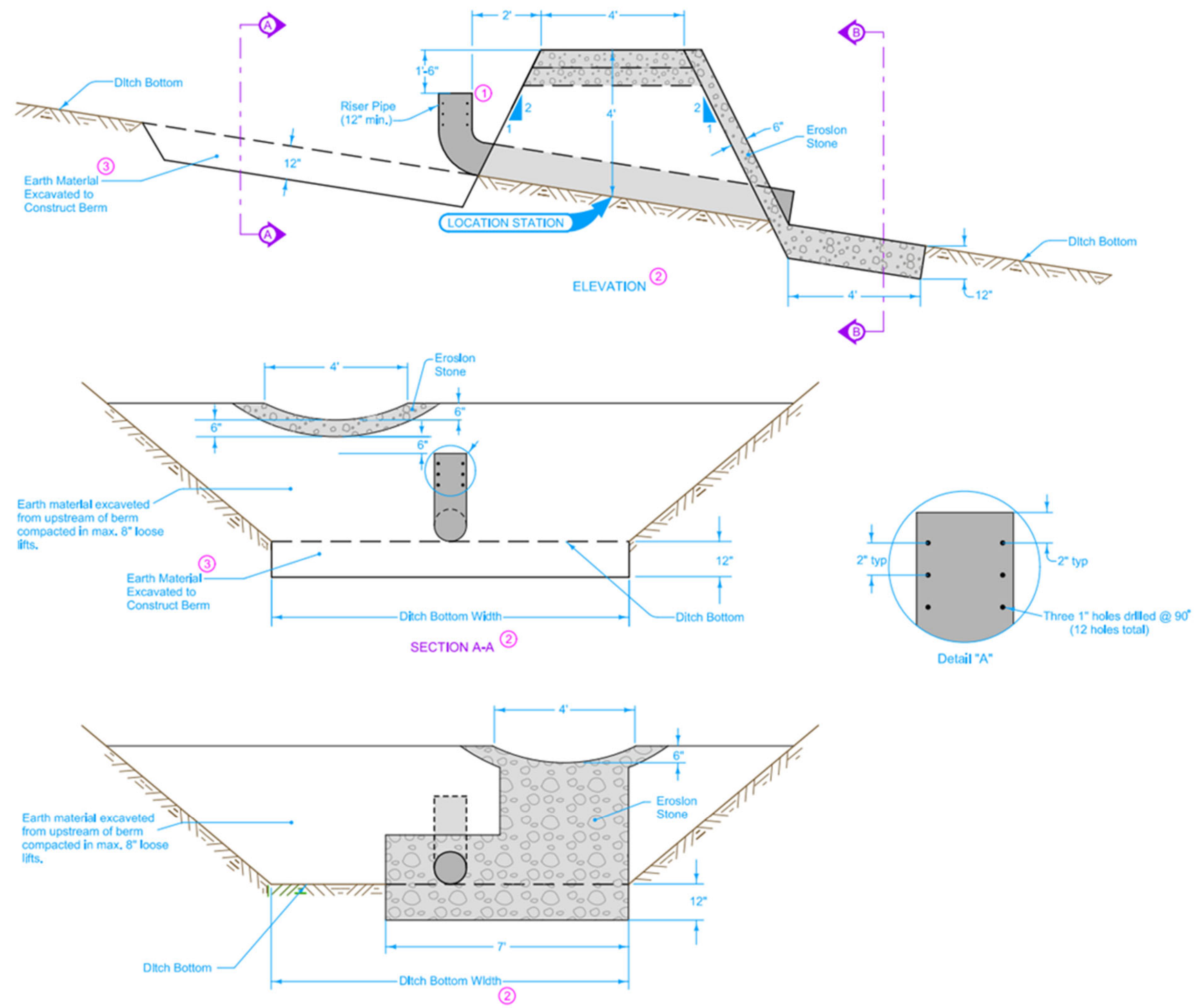
46. USEPA. 1992. Federal register. Final NPDES general permits for storm water discharges from construction sites; notice. United States Environmental Protection Agency. Washington, DC.

47. USEPA. 2005. National Management Measures to Control Nonpoint Source Pollution from Urban Areas. United States Environmental Protection Agency. Washington, D.C.

48. USEPA. 2016. National Nonpoint Source Program - A Catalyst for Water Quality Improvements. United States Environmental Protection Agency. Washington, D.C.

49. USEPA. 2022. National Pollutant Discharge Elimination System Construction General Permit (CGP) for Stormwater Discharges from Construction Activities. United States Environmental Protection Agency. Washington, D.C.

APPENDIX A. IOWA STANDARD HIGHWAY DRAWINGS FOR EROSION AND SEDIMENT CONTROL



1. Ensure Riser Pipe remains vertical.
2. Dimensions shown are minimums.
3. When Temporary Sediment Control Basin is removed, if basin has not silted in to designed ditch grade, use topsoil to bring up to designed ditch grade.

Possible Contract Items:
- Temporary Sediment Control Basin
- Maintenance of Temporary Sediment Control Basin
- Removal of Temporary Sediment Control Basin

Incidental to Temporary Sediment Control Basin:
- Erosion Stone
- Pipe
- Excavated Earth Material

Possible Tabulation:
- 100-33

IOWA DOT	REVISION	
STANDARD ROAD PLAN	New	10-16-18
	EC-601	
	SHEET 1 of 1	

REVISIONS: New. Replaces Design Detail 570-3

APPROVED BY DESIGN METHODS ENGINEER

TEMPORARY SEDIMENT CONTROL BASIN

IOWADOT
Office of Design

3G-1

Roadway Ditches

Design Manual
Chapter 1
Cross Sections
Originally Issued: 09-13-12
Revised: 11-16-17

Ditches are described as having a depth that is measured from profile grade and bottoms that typically have a normal cross slope of 0%. The normal ditch depth for rural highways is 5 feet and the normal ditch width is 10 feet. For divided roadways, the median ditch depth is 4 feet, as defined by 'M' in Figure 1 below.

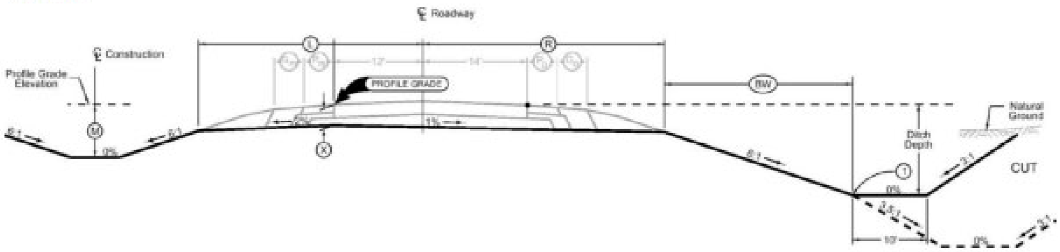


Figure 1: Typical cross section of a normal ditch.

Ditching Guidelines

Consider the following guidelines when determining ditching for a project:

- The proposed drainage layout should conform to the existing drainage pattern.
  - Avoid crossing ridge lines with ditch grades whenever possible.
  - Legal problems can arise when drainage is taken from its existing drainage area and diverted into another drainage area
- Consider impacts to underground utilities.
- When water is draining from a cut section to a fill section, consideration should be given to carrying the water to the draw in a special ditch to contain flow and avoid silt accumulating in an adjacent field. Refer to Road Design Detail 4204 for more information on special ditches.
- If adjusting ditch width, always make width increase with the direction of flow. Erosion may occur if ditch width decreases with increasing flow.
- Limit the length of variable ditches used to tie into structures to no more than 100 feet, except in isolated cases.
- Careful consideration should be given to ditching in critical areas, e.g. front yards, etc.
- 'V' ditches are less desirable than flat bottom ditches due to erosive tendencies; however, they can be used where site conditions are restrictive.
- When the backslope is 10 feet or higher, an intercepting ditch may be necessary. Refer to Section 3G-2 and Road Design Details 4101 and 4102 for more information regarding intercepting ditches.
- If the backslope exceeds 25 feet, or if foreslope or backslope stability is required, refer to Road Design Detail 4104 and Section 3J-1.
- Review ditching for possible letdown structures when roadway grade exceeds 5%.

- Consider the following guidelines relating to the use of ditch grades:
    - Refer to Section 20D-2 for guidance on proper naming conventions for ditch grades in design files.
    - Compute ditch grades to tenths of a percent and elevations to tenths of a foot.
    - Minimum acceptable ditch grades range from 0.2% to 1.0%.
    - Desirable ditch grades range from 1.0% to 3.0%.
    - Do not run ditch grades closer than +/-25 feet to a draw or waterway. This will allow for minor adjustments of the flowline without re-ditching.
    - The minimum desirable ditch depth is 3 feet.
    - Minimum acceptable ditch depth is 2 feet. This is to allow for proper installation and function of longitudinal subdrains.
- Show ditch description on plan sheets as outlined in Section 1F-5b.
    - If ditch width is something other than standard, indicate the width in the ditch description on the ditch bar graph.

Permanent Erosion Control Guidelines

The Roadside Development Section in the Office of Design typically designs permanent erosion control projects for the Department.

Temporary Erosion Control Guidelines

Temporary sediment control devices such as silt fence, ditch checks, and perimeter and slope sediment control devices are used to control sediment on new projects until permanent seeding is established. Temporary erosion control measures also include silt ditches, silt dikes, and silt basins as outlined in Standard Road Plan EW-403. Refer to Section 10C-1 for additional information on these temporary erosion control measures, as well as additional measures.

Refer to Section 2602 of the Standard Specifications for information relating to water pollution control (soil erosion).

APPENDIX B. WATER QUALITY LABORATORY PROCEDURES

TURBIDITY AND TOTAL SOLIDS PROCESSING PROCEDURES

Turbidity Analysis

Step 1: Prepare lab space with stirring plate and turbidimeter. Prepare ample DI water should the samples require dilution.

Step 2: Confirm turbidimeter readings using standard samples (10, 20, 100, and 800 NTU). If outside of threshold, recalibrate turbidimeter.
Step 3: Vigorously shake ISCO sample bottle to resuspend any settled solids. Transfer contents to a 1000 mL beaker, insert stir bar, and place on stir plate. Continue mixing until sample appears to be homogeneous.
Step 4: Set pipette to 7.5 mL and carefully extract 15 mL from the sample to fill turbidity cell to line. Cap the cell. Using a soft cloth, wipe the cell to ensure there is no residue on the outside.

Step 5: Place the cell into the turbidimeter, matching the arrow on the cell to the arrow on the turbidimeter. Secure the cell and read the NTU value. If the value is over range, proceed to Step 6.
Step 6: If the sample is outside of the range, dilute the sample 1:2 by mixing 25 mL of the sample with 25 mL of deionized water in a beaker using the stir plate.
Step 7: Repeat steps 4 through 6 as necessary.

Dilution Note: If the sample is still outside of ranger after dilution, transfer the sample from the cell and add another 25 mL of water and reread. Continue this process until you get a reading. The dilution factor will be DF=(NTU)×(x+1), where x is the amount of times 25 mL of water is added. For example, DF=(NTU)×(2+1) after two dilutions are performed.

Total Suspended Solids Processing Procedures

1. **Step 1:** Prepare glassware, deionized water, filtering apparatus, scales, turbidimeter, and vacuum pump.
2. **Step 2:** Prepare and label the required crinkle dishes and place filter membranes on each dish using clean tweezers. Do not use fingers.
3. **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.
4. **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.
5. **Step 5:** Weigh the crinkle dish and filter using an analytical balance. Record weight to the nearest 0.0001 g.

6. **Step 6:** Use tweezers to place the corresponding filter membrane on the filtering apparatus.

7. **Step 7:** Pipette 25 mL of diluted solution and place in apparatus.

8. **Step 8:** Filter sample through membrane using the vacuum pump. Rinse the filtrate on the filter with three 10 mL portions of deionized water.

9. **Step 9:** Slowly release the vacuum on the filtering apparatus. Gently remove the filter disc using the tweezers.

10. **Step 10:** Place the filter disc on its corresponding crinkle dish.

11. **Step 11:** 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.

12. **Step 12:** Weigh the crinkle dish and filter using an analytical balance. Record weight to the nearest 0.0001 g.

<u>Total Solids Processing Procedures</u>

Step 1: Allow all collected samples to be refrigerated for a minimum of 24 hours to allow sediment to settle out. After at least 24 hours, continue with the experiment

Step 2: Mark and weigh all evaporating dishes. Record the mass to the nearest 0.0001g.

Step 3: Using a vacuum pump and flask, vacuum the supernatant from the samples using a hose with a j- hook attachment. Vacuum the maximum amount of water without disturbing the sediment. Retain supernatant in the flask and record the volume.
Step 4: Measure the remaining water in the original sample bottle by marking the water level line.

Step 5: Use DI water to wash the sediment and remaining water into an evaporating dish.

Step 6: With the empty sample bottle, refill the bottle to the marked level line. Transfer the water to a graduated cylinder and record the volume.

Step 7: Bake the samples in a laboratory oven at 210 ºF (99) for 3 hours. Ensuring that the water has evaporated, increase the temperature to 221 ºF (105) for another 2 hours.

Step 8: After the samples have completed baking, weigh the dishes with the samples to the nearest 0.0001 gram. Discard the sediment.

The following steps are to determine the dissolved solids correction factor.

Step 9: Weigh empty evaporating dishes. Record the mass.

Step 10: Transfer a measured volume (100 mL), using a pipette, from the supernatant from Step 3 to an evaporating dish.
Step 10: Dry the samples as defined in Step 7.

Step 11: After baking, record the mass of the dish and sample to the nearest 0.0001 g and discard the sample.

Step 12: Calculate the dissolved solids correction factor using:

$$DSc = (DS/Va) \times Vs$$

where
DSc =Dissolved-Solids Correction,
(g) DS =Weight of Dissolved
Solids, (g)
Va =Sample Volume for Dissolved Solids,
(mL) Vs =Volume of Supernatant with
Sediment, (mL)

Step 13: Subtract this correction factor from the net weight.

Step 14: Divide the net weight of the sediment by the net weight of the sample, multiply the quotient by 1,000,000. This will provide a sediment concentration result in parts per million.

Repeat this process for each sample taken.

APPENDIX C. FAIRCLOTH SKIMMER TECHNICAL SIZING GUIDANCE

Determining the Skimmer Size and the Required Orifice for the *Faircloth Skimmer®* Surface Drain

November 2007

> ***Important note:*** *The orifice sizing chart in the Pennsylvania Erosion Control Manual and reproduced in the North Carolina Design Manual* ***DOES NOT APPLY*** *to our skimmers. It will give the wrong size orifice and not specify which size skimmer is required. Please use the information below to choose the size skimmer required for the basin volume provided and determine the orifice size required for the drawdown time, typically 4-7 days in Pennsylvania and 3 days in North Carolina.*

The **size** of a Faircloth Skimmer®, for example a 4" skimmer, refers to the maximum diameter of the skimmer inlet. The inlet on each of the 8 sizes offered can be reduced to adjust the flow rate by cutting a hole or ***orifice*** in a plug using an adjustable cutter (both supplied).

Determining the skimmer size needed and the orifice for that skimmer required to drain the sediment basin's volume in the required time involves two steps: **First**, determining the size skimmer required based on the volume to be drained and the number of days to drain it; and **Second,** calculate the orifice size to adjust the flow rate and "customize" the skimmer for the basin's volume. *The second step is not always necessary* if the flow rate for the skimmer with the inlet wide open equals or is close to the flow rate required for the basin volume and the drawdown time.

Both the skimmer size and the required orifice radius for the skimmer should be shown for each basin on the erosion and sediment control plan. Make it clear that the dimension is either the radius or the diameter. It is also helpful to give the basin volume in case there are questions. During the skimmer installation the required orifice can be cut in the plastic plug using the supplied adjustable cutter and installed in the skimmer using the instructions provided.

The plan review and enforcement authority may require the calculations showing that the skimmer used can drain the basin in the required time.

Determining the Skimmer Size

Step 1. Below are approximate **skimmer maximum flow capacities** based on typical draw down requirements, which can vary between States and jurisdictions and watersheds. If one 6" skimmer does not provide enough capacity, multiple skimmers can be used to drain the basin. For drawdown times not shown, multiply the 24-hour figure by the number of days required.

Example: A basin's volume is 29,600 cubic feet and it must be drained in 3 days. A 3" skimmer with the inlet wide open will work perfectly. (Actually, the chart below gives 29,322 cubic feet but this is well within the accuracy of the calculations and the basin's constructed volume.)
Example: A basin's volume is 39,000 cubic feet and it must be drained in 3 days. The 3"

skimmer is too small; a 4" skimmer has enough capacity but it is too large, so the inlet will need to be reduced using step 2 to adjust the flow rate for the basin's volume. (It needs a 3.2" diameter orifice.)

1½" skimmer: with a 1½" head	1,728 cubic feet in **24 hours** 3,456 cubic feet in **2 days** 5,184 cubic feet in **3 days**	6,912 cubic feet in **4 days** 12,096 cubic feet in **7 days**
2" skimmer: with a 2" head	3,283 cubic feet in **24 hours** 6,566 cubic feet in **2 days** 9,849 cubic feet in **3 days**	13,132 cubic feet in **4 days** 22,982 cubic feet in **7 days**
2½" skimmer: with a 2.5" head	6,234 cubic feet in **24 hours** 12,468 cubic feet in **2 days** 18,702 cubic feet in **3 days**	24,936 cubic feet in **4 days** 43,638 cubic feet in **7 days**
3" skimmer: with a 3" head	9,774 cubic feet in **24 hours** 19,547 cubic feet in **2 days** 29,322 cubic feet in **3 days**	39,096 cubic feet in **4 days** 68,415 cubic feet in **7 days**
4" skimmer: with a 4" head	20,109 cubic feet in **24 hours** 40,218 cubic feet in **2 days** 60,327 cubic feet in **3 days**	80,436 cubic feet in **4 days** 140,763 cubic feet in **7 days**
5" skimmer: with a 4" head	32,832 cubic feet in **24 hours** 65,664 cubic feet in **2 days** 98,496 cubic feet in **3 days**	131,328 cubic feet in **4 days** 229,824 cubic feet in **7 days**
6" skimmer: with a 5" head	51,840 cubic feet in **24 hours** 103,680 cubic feet in **2 days** 155,520 cubic feet in **3 days**	207,360 cubic feet in **4 days** 362,880 cubic feet in **7 days**
8" skimmer: with a 6" head	97,978 cubic feet in **24 hours** 195,956 cubic feet in **2 days** 293,934 cubic feet in **3 days**	391,912 cubic feet in **4 days** 685,846 cubic feet in **7 days**

Determining the Orifice

Step 2. To determine the orifice required to reduce the flow rate for the basin's volume and the number of days to drain the basin, simply use the formula volume ÷ **factor** (from the chart below) for the same size skimmer chosen in the first step and the same number of days. This calculation will give the **area** of the required orifice. Then calculate the orifice radius using Area = πr^2 and solving for *r*, $r = \sqrt{(Area/3.14)}$ .The supplied cutter can be adjusted to this radius to cut the orifice in the plug. The instructions with the plug and cutter has a ruler divided into tenths of inches. Again, this step is not always necessary as explained above.

An alternative method is to use the orifice equation with the head for a particular skimmer shown on the previous page and determine the orifice needed to give the required flow for the volume and draw down time. C = 0.59 is used in this chart.

Example: A 4" skimmer is the smallest skimmer that will drain 39,000 cubic feet in 3 days but a 4" inlet will drain the basin too fast (in 1.9 days) To determine the orifice required use the factor of 4,803 from the chart below for a 4" skimmer and a drawdown time of 3 days. 39,000 cubic feet ÷ 4,803 = 8.12 square inches of orifice required. Calculate the orifice radius using Area = πr^2 and solving for r, $r = \sqrt{(8.12/3.14)}$ and r = 1.61". As a practical matter 1.6" is about as close as the cutter can be adjusted and the orifice cut..

Factors (in cubic feet of flow per square inch of opening through a **round** orifice with the head for that skimmer and for the drawdown times shown) for determining the **orifice radius** for a basin's volume to be drained. This quick method works because the orifice is centered and has a constant head (given above in Step 1).

1½" skimmer:	960 to drain in **24 hours** 1,920 to drain in **2 days** 2,880 to drain in **3 days**	3,840 to drain in **4 days** 6,720 to drain in **7 days**
2" skimmer:	1,123 to drain in **24 hours** 2,246 to drain in **2 days** 3,369 to drain in **3 days**	4,492 to drain in **4 days** 7,861 to drain in **7 days**
2½" skimmer: Revised 11-6-07	1,270 to drain in **24 hours** 2,540 to drain in **2 days** 3,810 to drain in **3 days**	5,080 to drain in **4 days** 8,890 to drain in **7 days**
3" skimmer:	1,382 to drain in **24 hours** 2,765 to drain in **2 days** 4,146 to drain in **3 days**	5,528 to drain in **4 days** 9,677 to drain in **7 days**
4" skimmer: Revised 11-6-07	1,601 to drain in **24 hours** 3,202 to drain in **2 days** 4,803 to drain in **3 days**	6,404 to drain in **4 days** 11,207 to drain in **7 days**
5" skimmer:	1,642 to drain in **24 hours** 3,283 to drain in **2 days** 4,926 to drain in **3 days**	6,568 to drain in **4 days** 11,491 to drain in **7 days**
6" skimmer:	1,814 to drain in **24 hours** 3,628 to drain in **2 days** 5,442 to drain in **3 days**	7,256 to drain in **4 days** 12,701 to drain in **7 days**
8" skimmer:	1,987 to drain in **24 hours** 3,974 to drain in **2 days** 5,961 to drain in **3 days**	7,948 to drain in **4 days** 13,909 to drain in **7 days**

J. W. Faircloth & Son, Inc.
Post Office Box 789
Hillsborough, North Carolina 27278

Telephone (919) 732-1244 FAX (919) 732-1266

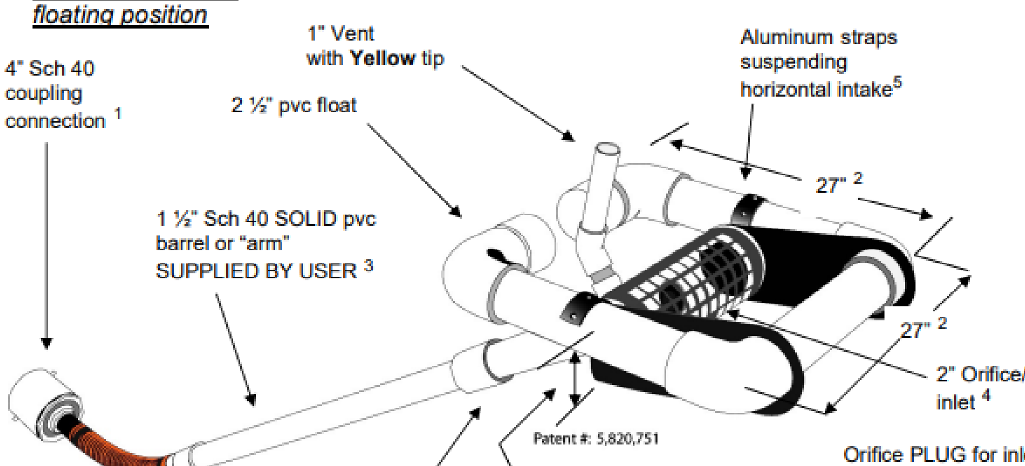
FairclothSkimmer.com

2" Faircloth Skimmer® Cut Sheet

J. W. Faircloth & Son, Inc.

www.FairclothSkimmer.com

Skimmer shown in floating position



Orifice PLUG for inlet[6]

1. Skimmer can be attached to a straight 4" sch 40 pipe through the dam but the pipe may need to be anchored to the bottom at the connection so it is secure. Coupling can be removed and hose attached to outlet using the threaded 2" fitting. Typical methods used: a) on a metal structure a steel stub out welded on the side at the bottom with a 2" threaded coupling or reducer(s); b) a concrete structure with a hole or orifice at the bottom - use a steel plate with a hole cut in it and coupling welded to it that will fit over the hole in the concrete and bolted to the structure with sealant; or c) grout a 4" pvc pipe in a hole in the concrete to connect the skimmer.

2. Dimensions are approximate, not intended as plans for construction.

3. Barrel (solid, not foam core pipe) should be 1.4 times the depth of water with a minimum length of 6' so the inlet can be pulled to the side for maintenance. If more than 8' long, weight may have to be added to inlet to counter the increased buoyancy.

4. Orifice/inlet tapers down from 2" maximum inlet to a 1 ½" barrel and hose. Barrel is smaller to reduce buoyancy and tendency to lift inlet but is sufficient for flow through inlet because of slope. The orifice/inlet can be reduced using the plug and cutter provided to control the outflow rate – see #6.

5. Horizontal intake is 4" pipe between the straps with aluminum screen door for access to the inlet and orifice inside.

6. **Capacity:** 3,283 cubic feet per day maximum with 2" inlet and 2" head. Inlet can be reduced by installing a smaller orifice using the plug and cutter provided to adjust flow rate for the particular drawdown time required. Please use the sizing template available at www.fairclothskimmer.com .

7. Ships assembled. User glues inlet extension and barrel, installs vent, cuts orifice in plug and attaches to outlet pipe or structure. Includes float, flexible hose with fittings, rope, orifice plug & cutter. Does NOT include 1 ½" Sch 40 SOLID pvc barrel or "arm" SUPPLIED BY USER.

2inchCut 5-1-19

APPENDIX D. TURBIDITY MEASUREMENTS BASED ON LOCATION DURING EACH TEST

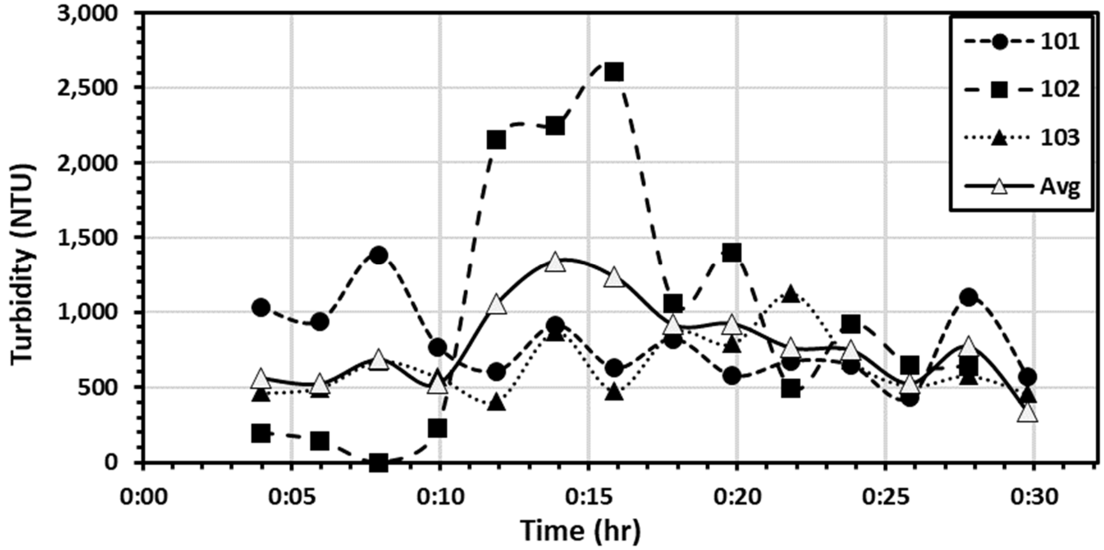
Table D.1. Key for Iowa DOT Testing Code (XYZ)

X		Y		Y	
Treatment	**#**	**Soil**	**#**	**Iteration**	**#**
Calibration	0	AL	0	L-1	1
Unlined	1	IA	1	L-2	2
Geotextile	2			L-3	3
Skimmer	3				
Baffles	4				
Forebay	5				
MFE-I	7				
MFE-I + Flocc	8				

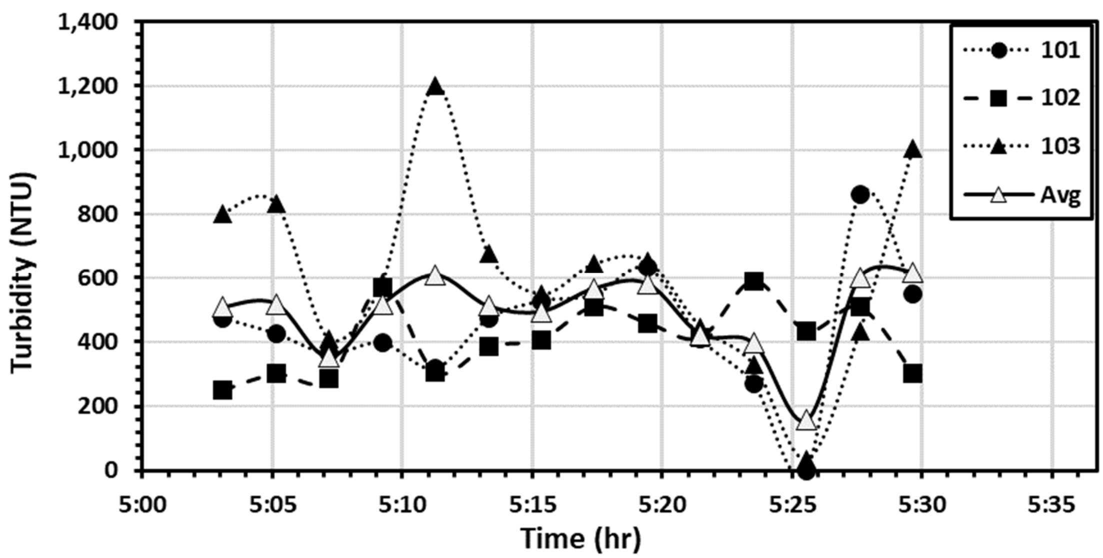
Example: Test 403 indicates baffle treatment with Alabama Soil, iteration L-3

Note y-axis changes for observation on turbidity variance between tests.

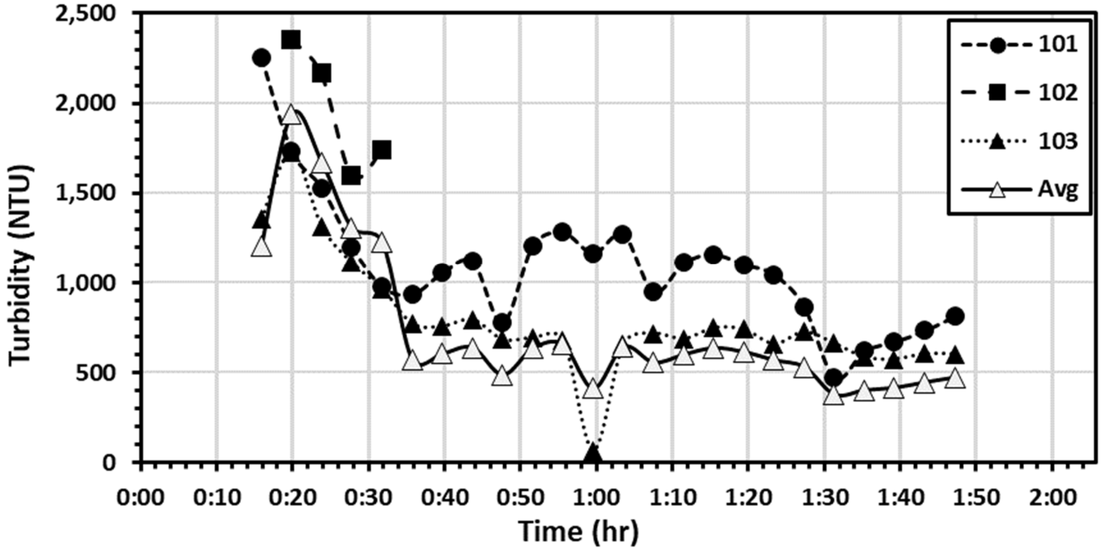
S1- Unlined Testing with Alabama Soil (Standard)



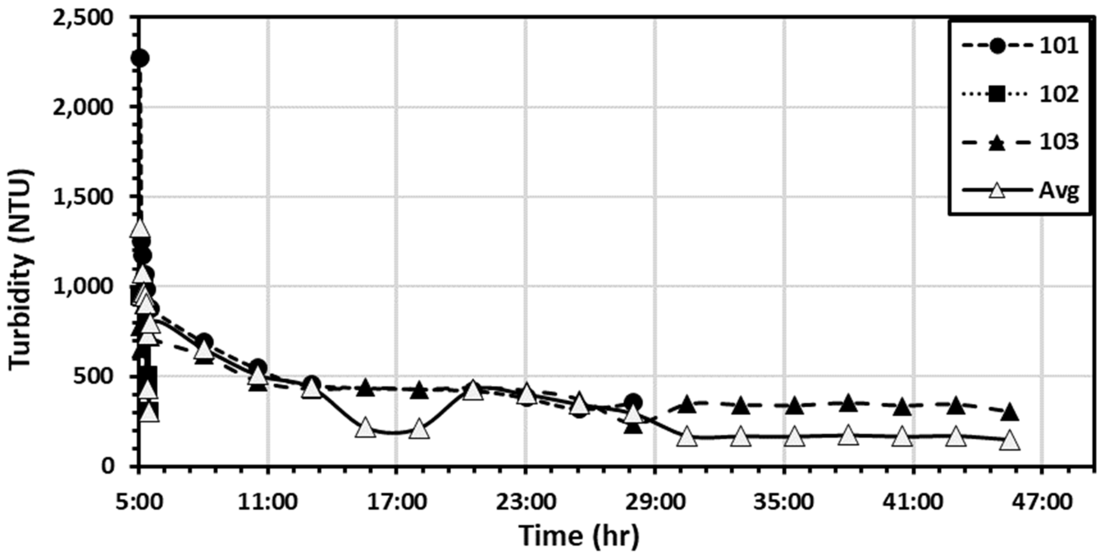
Inflow Sampling Location



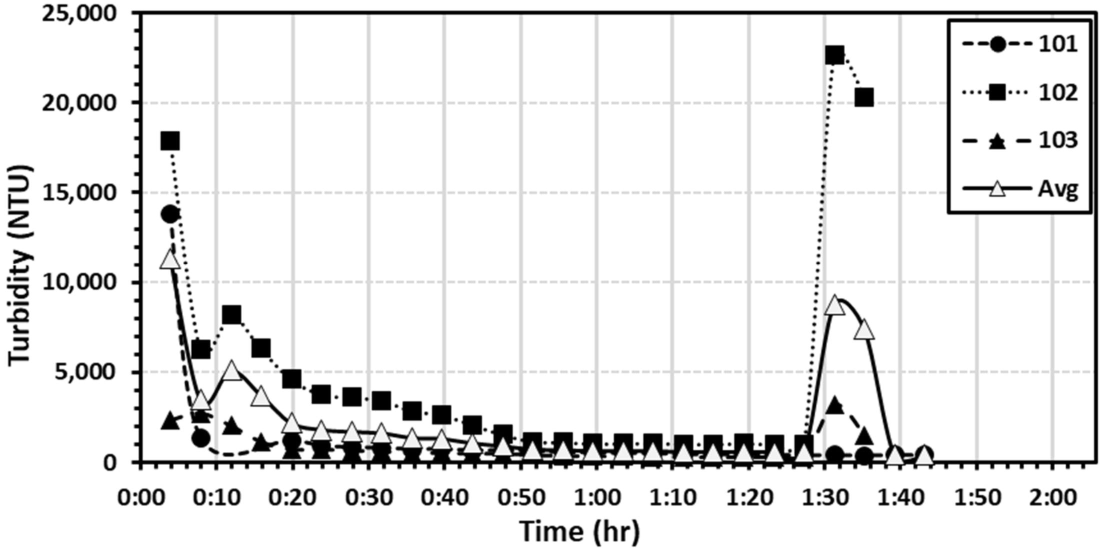
Inflow Sampling Location



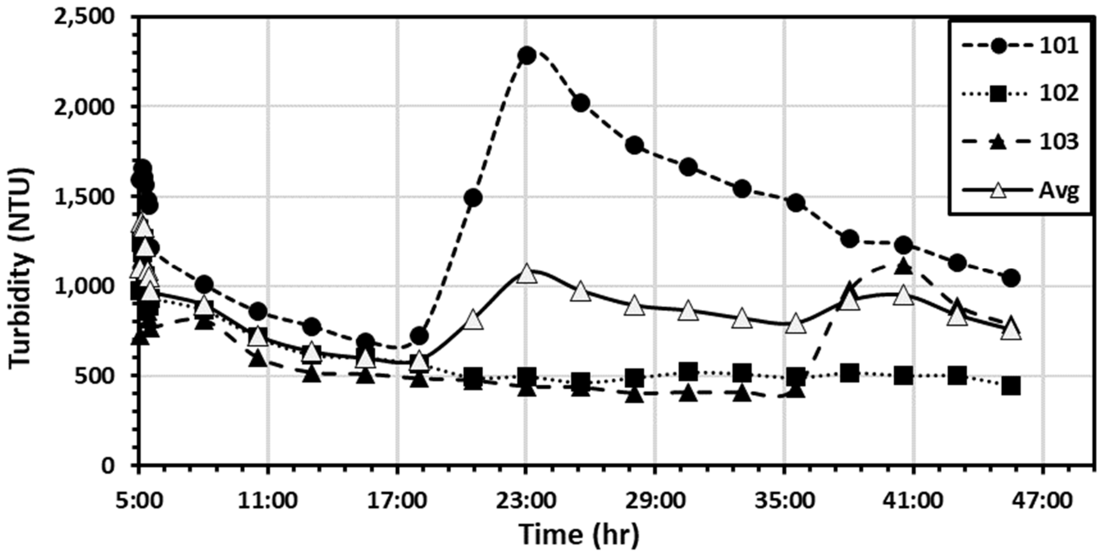
Bay 2 Sampling Location



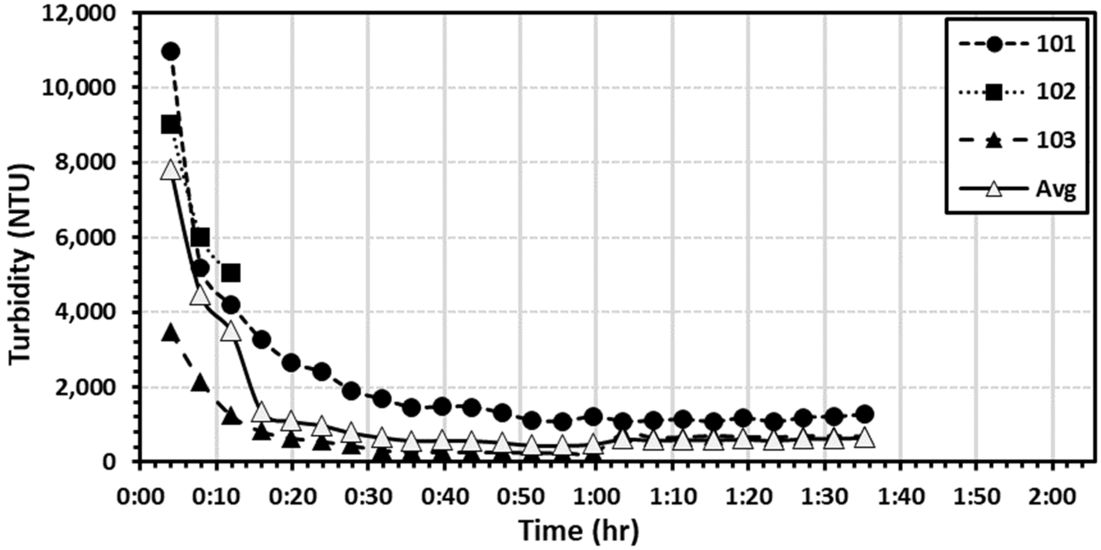
Bay 2 Sampling Location



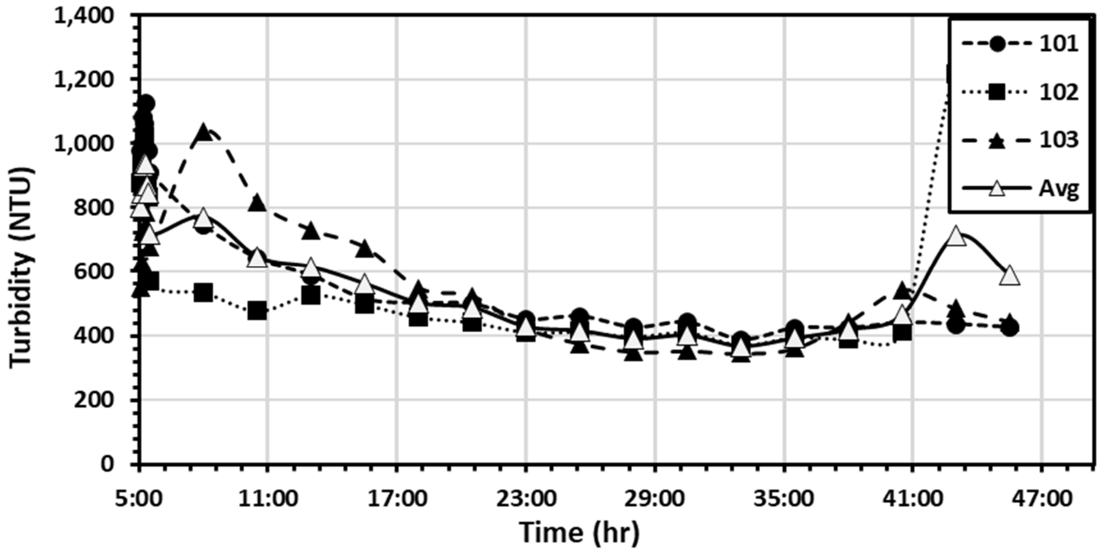
Bay 4 Bottom Sampling Location



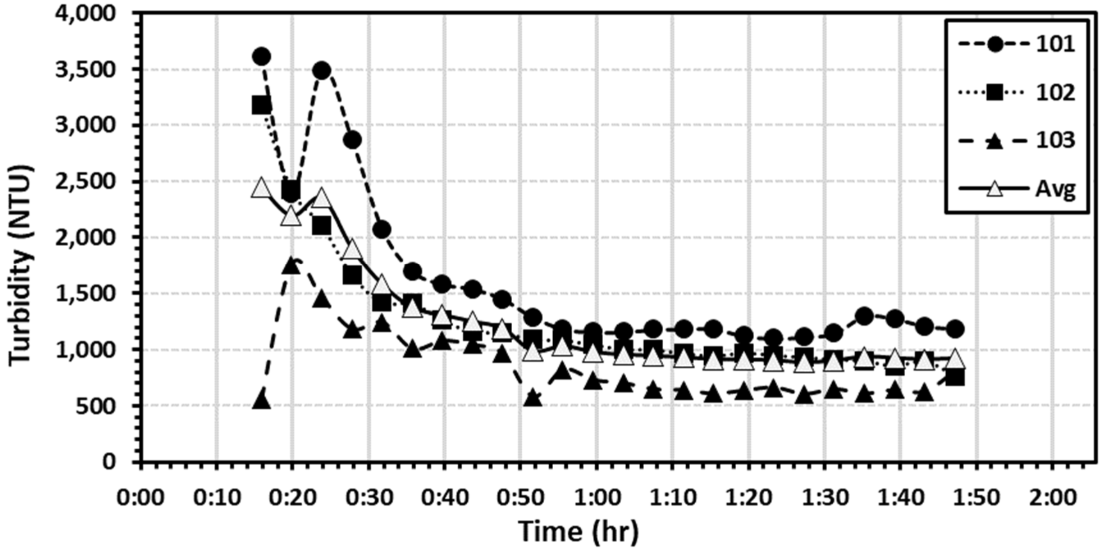
Bay 4 Bottom Sampling Location



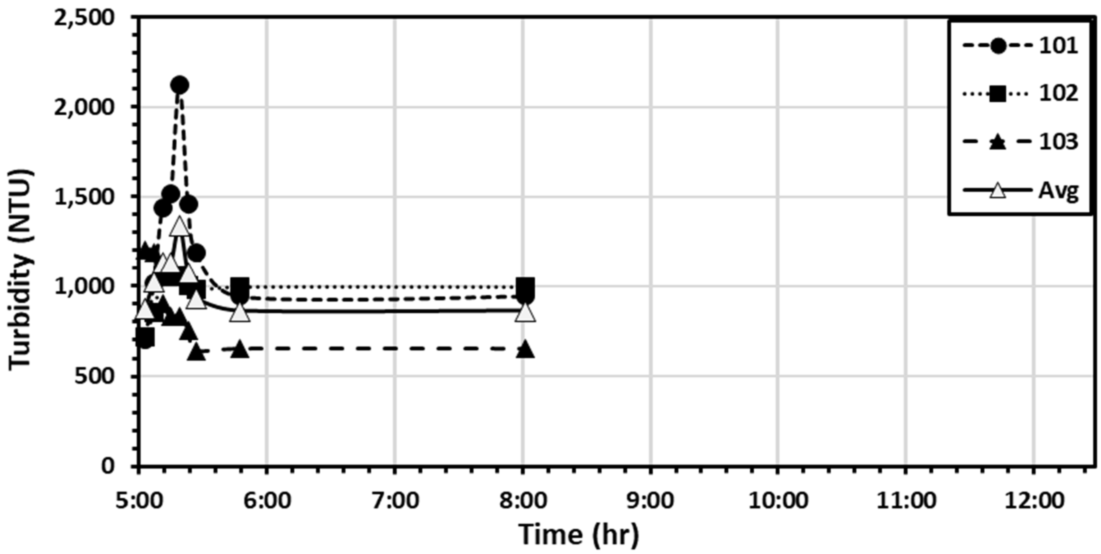
Bay 4 Top Sampling Location



Bay 4 Top Sampling Location

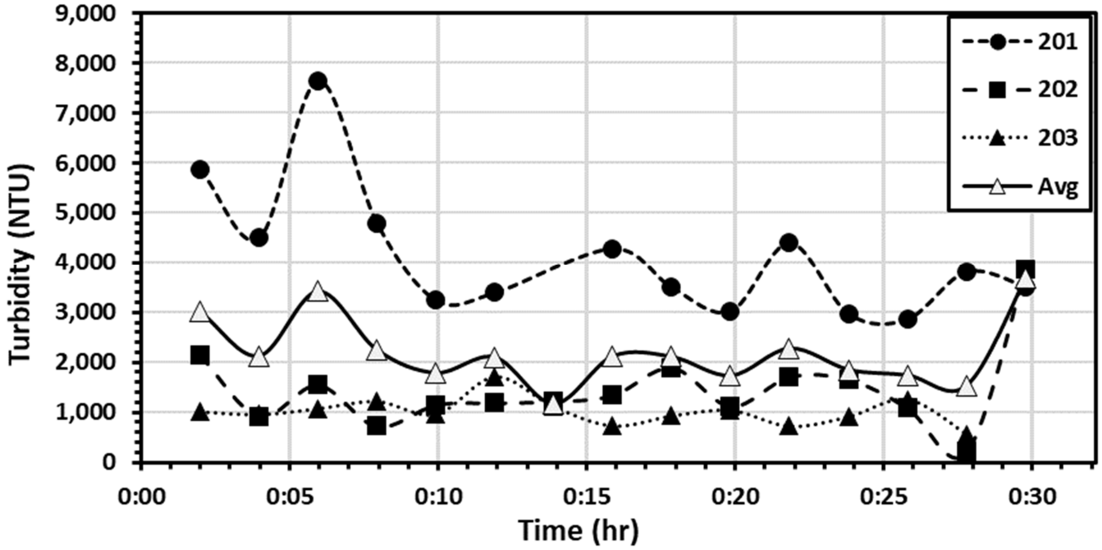


Discharge Sampling Location

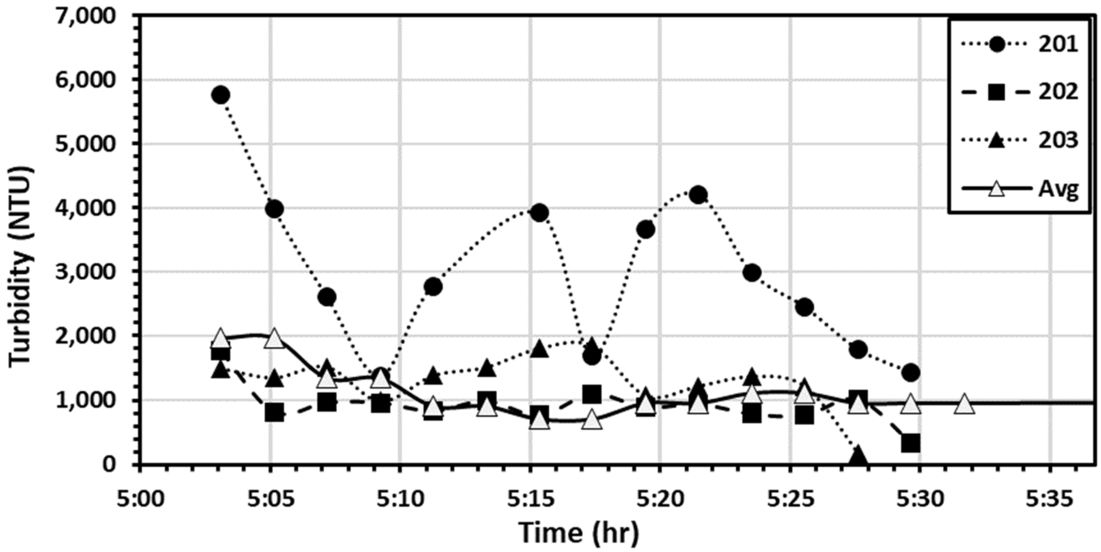


Discharge Sampling Location

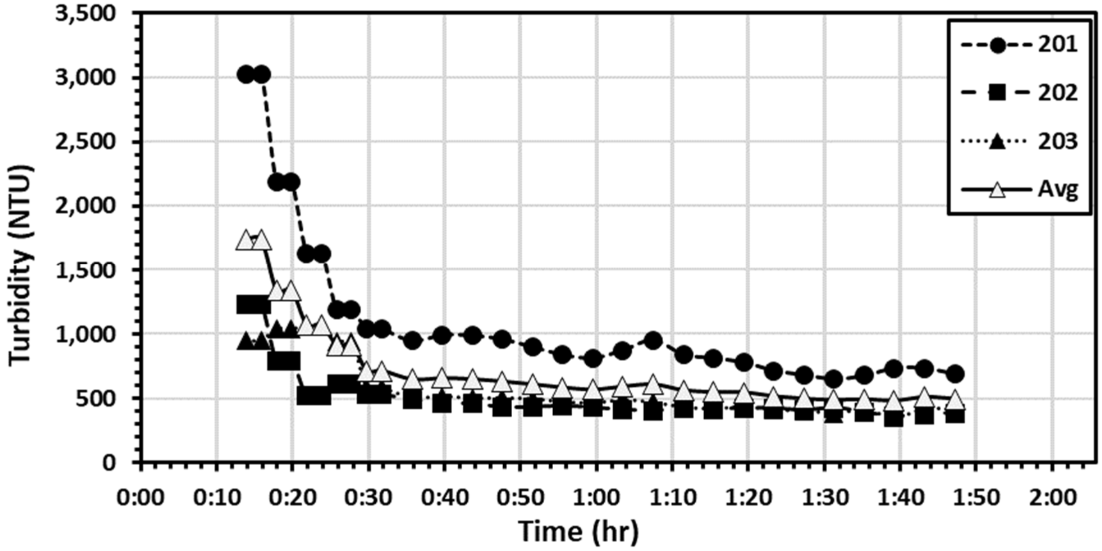
S2-Lined Testing with Alabama Soil



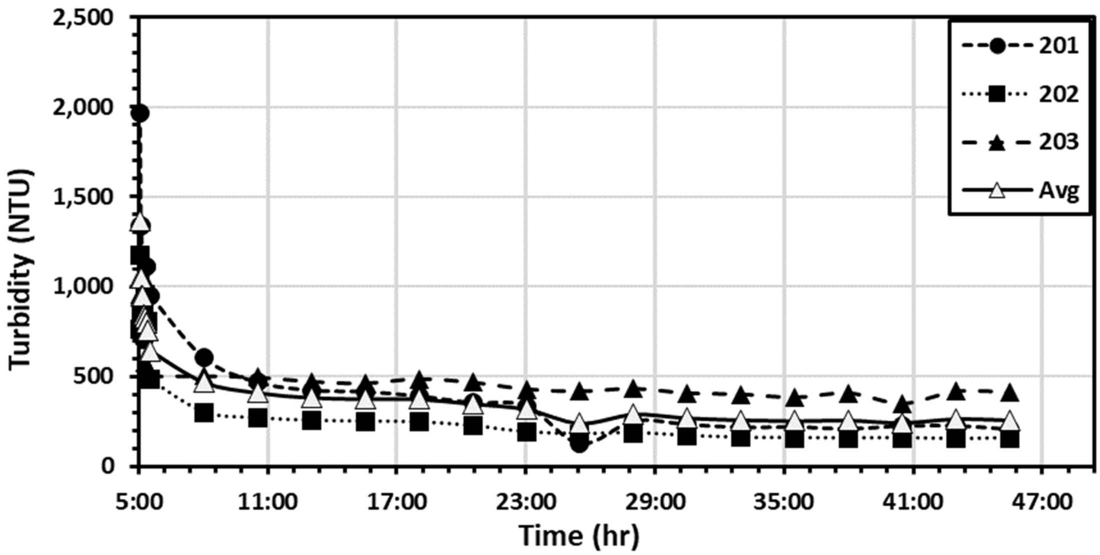
Inflow Sampling Location



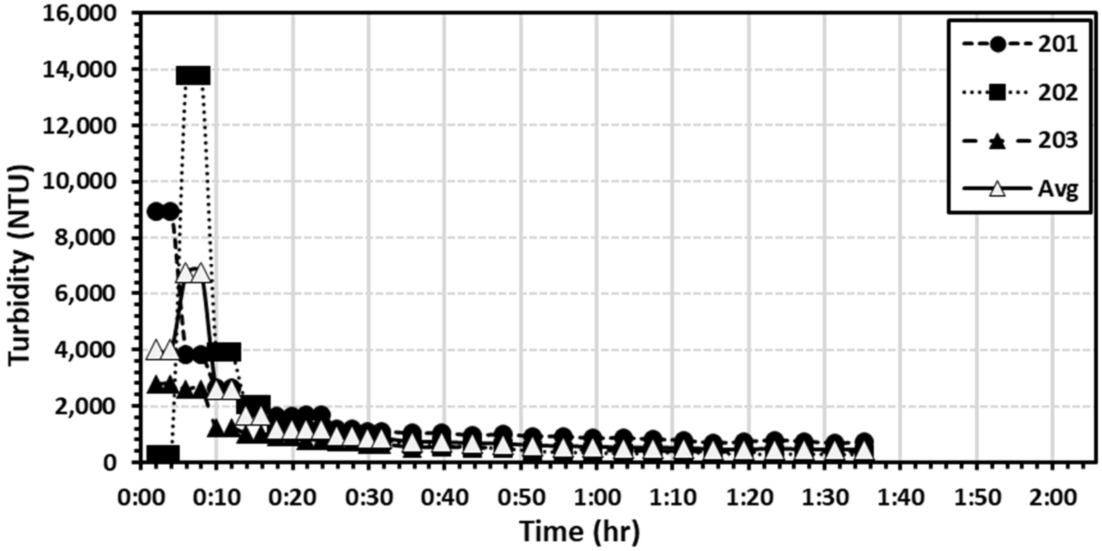
Inflow Sampling Location



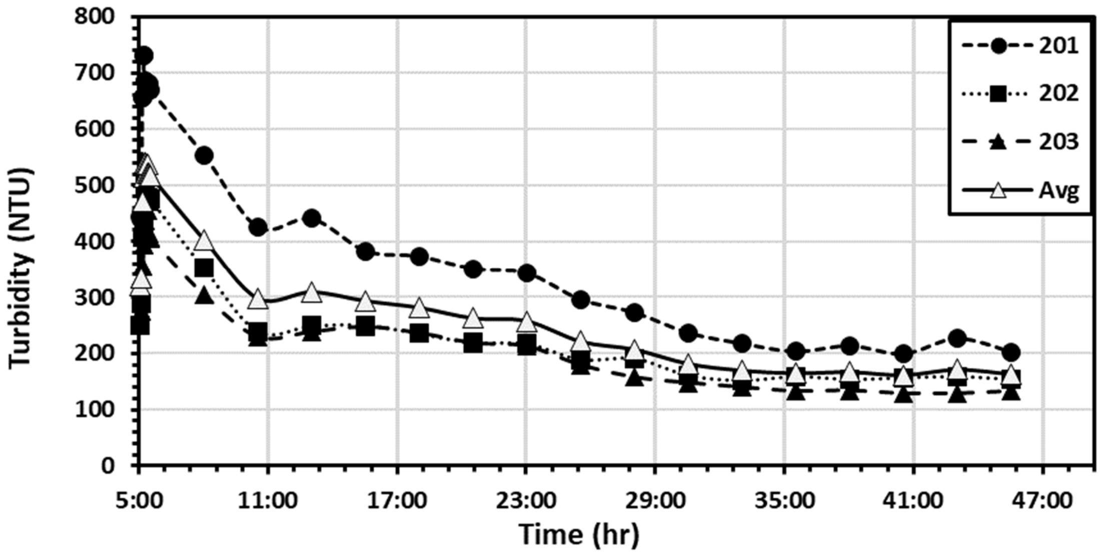
Bay 2 Sampling Location



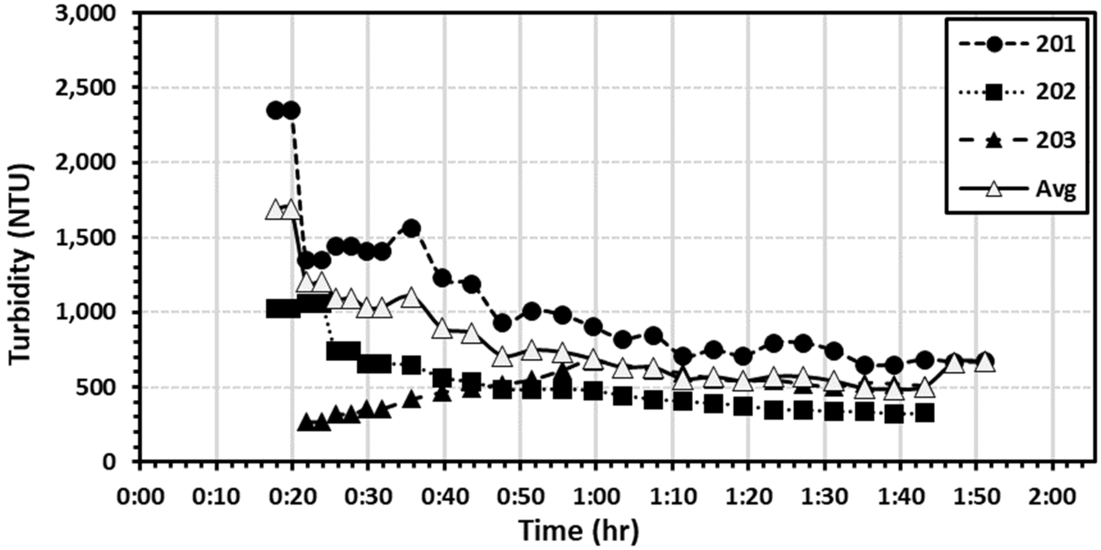
Bay 2 Sampling Location



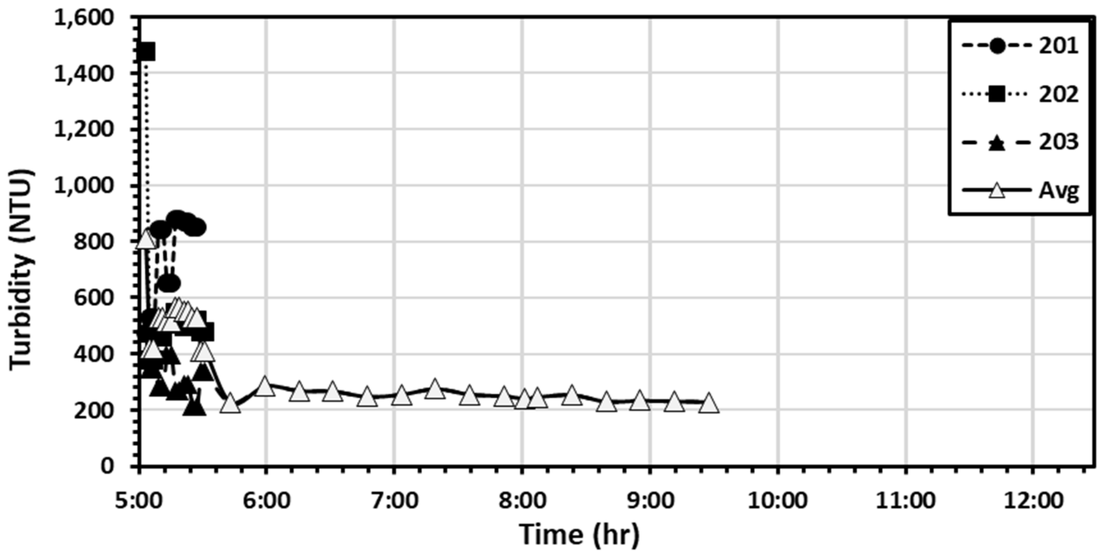
Bay 4 Top Sampling Location



Bay 4 Top Sampling Location

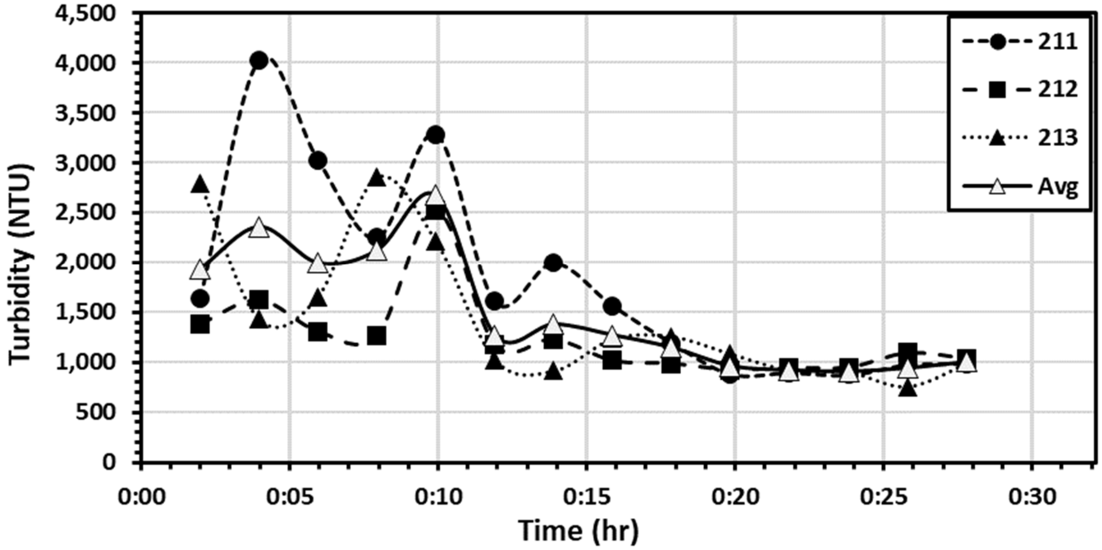


Discharge Sampling Location

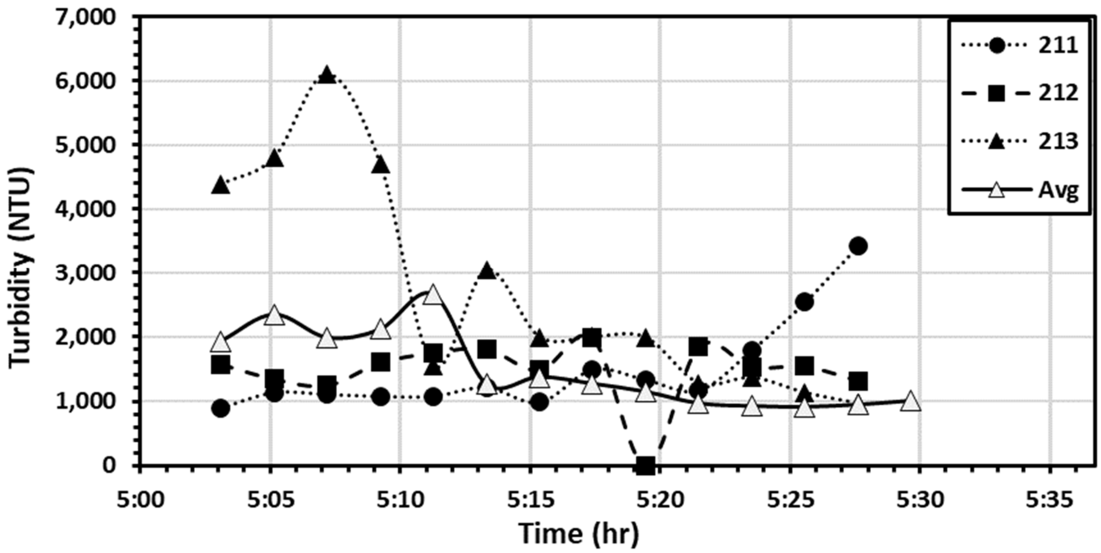


Discharge Sampling Location

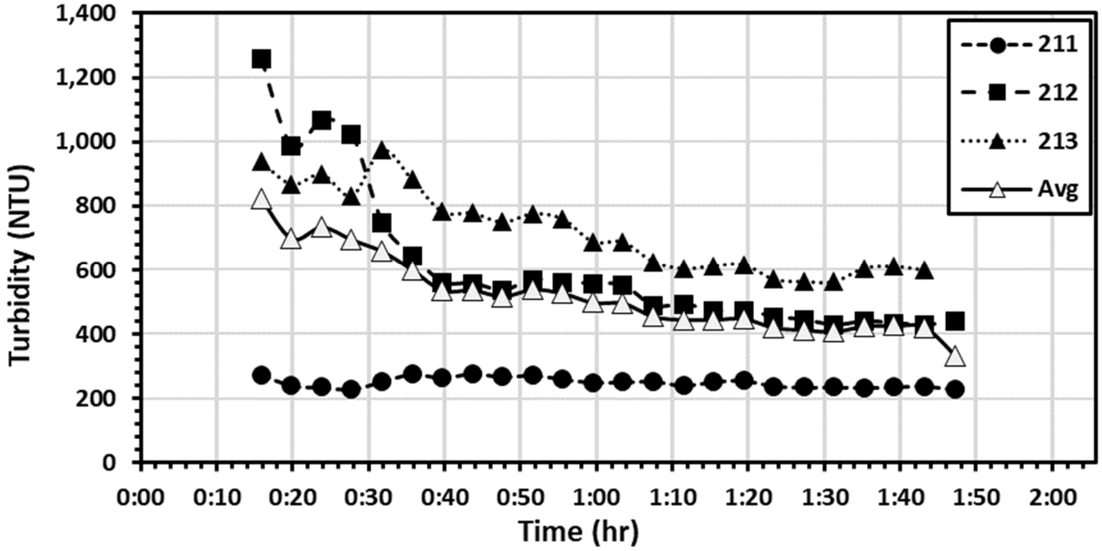
S3-Lined Testing with Iowa Soil



Inflow Sampling Location



Inflow Sampling Location



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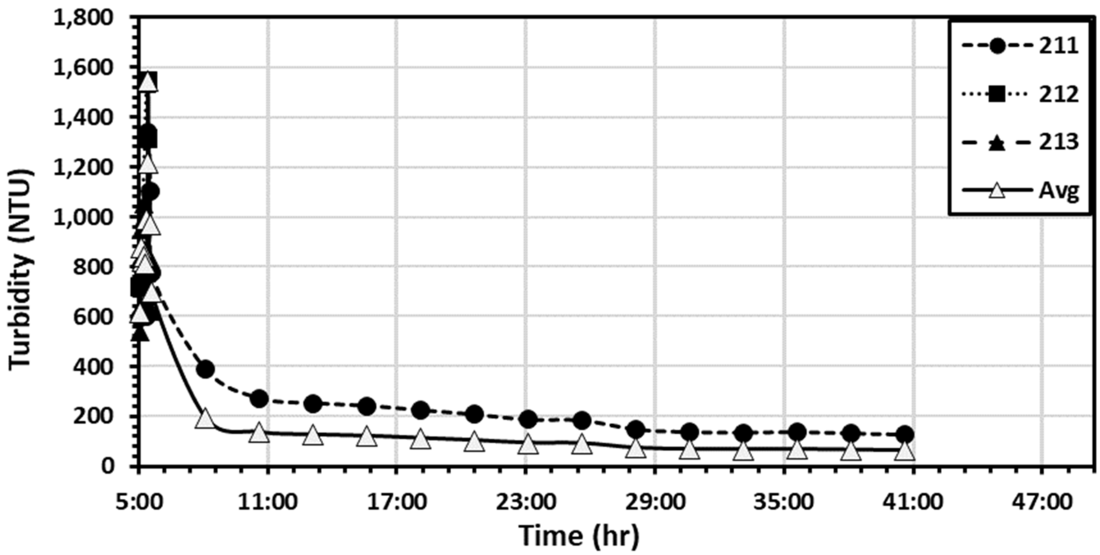

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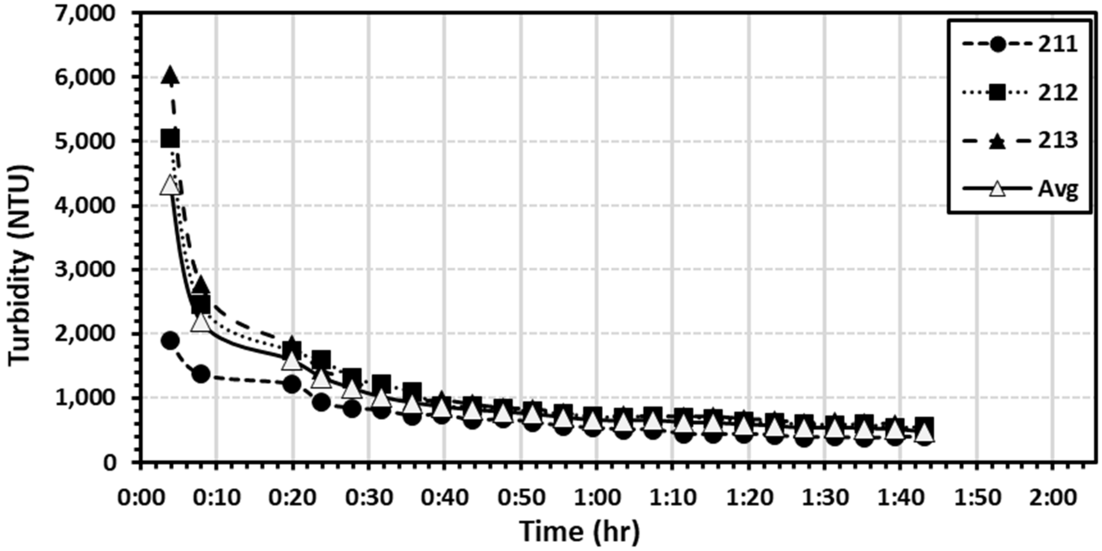
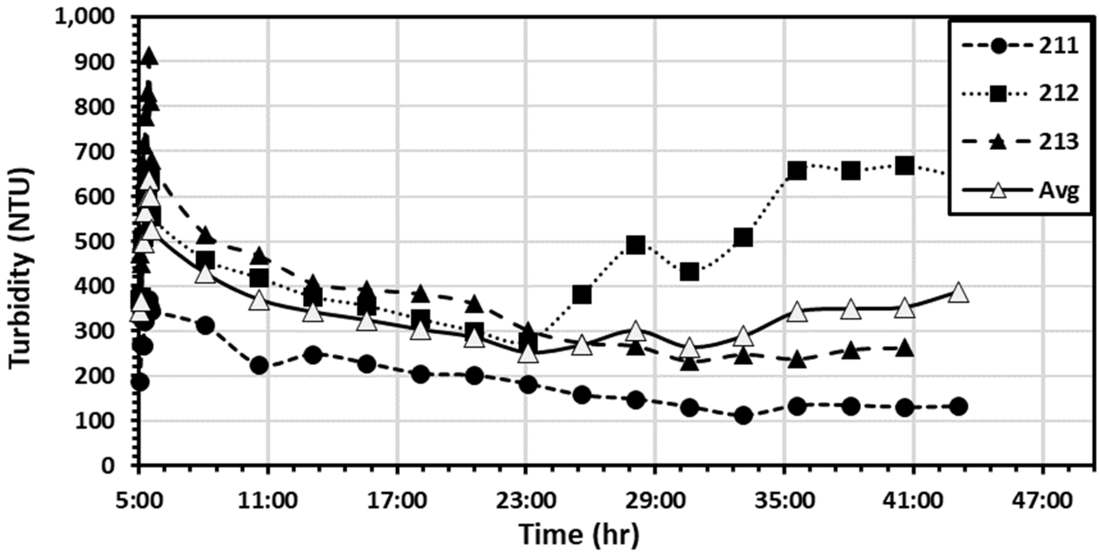
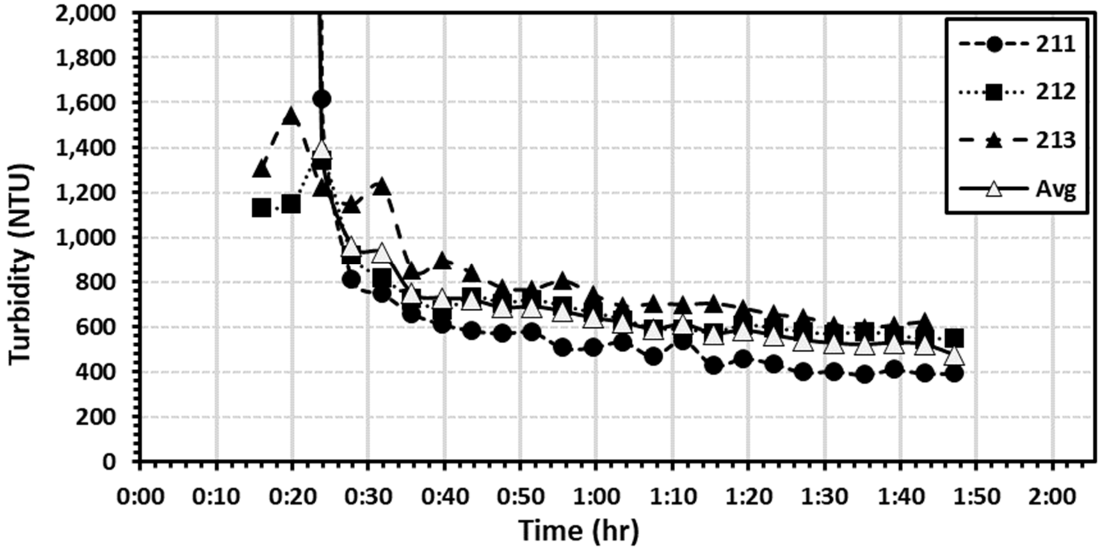


Bay 4 Top Sampling Location



Bay 4 Top Sampling Location



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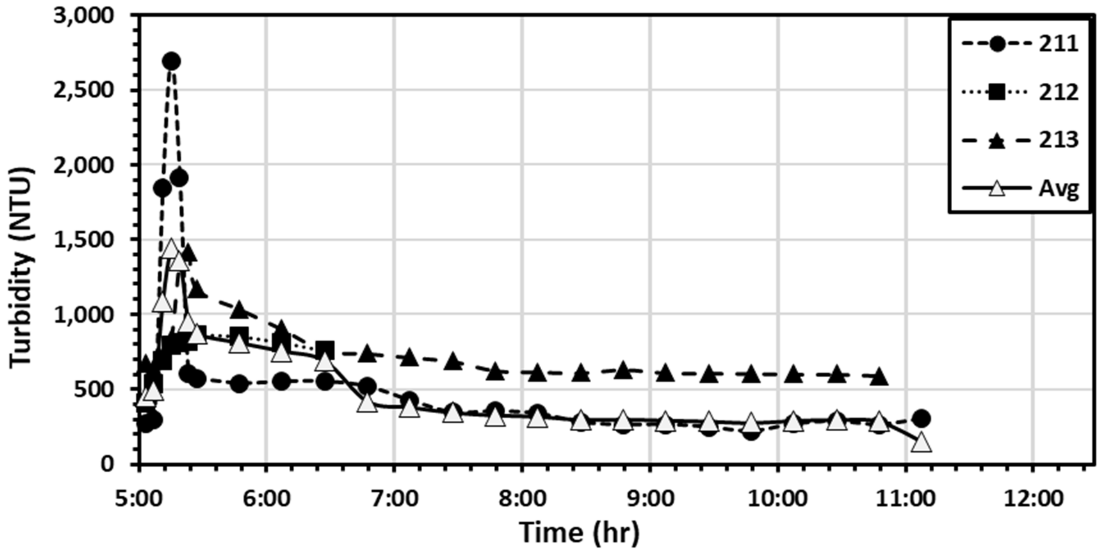
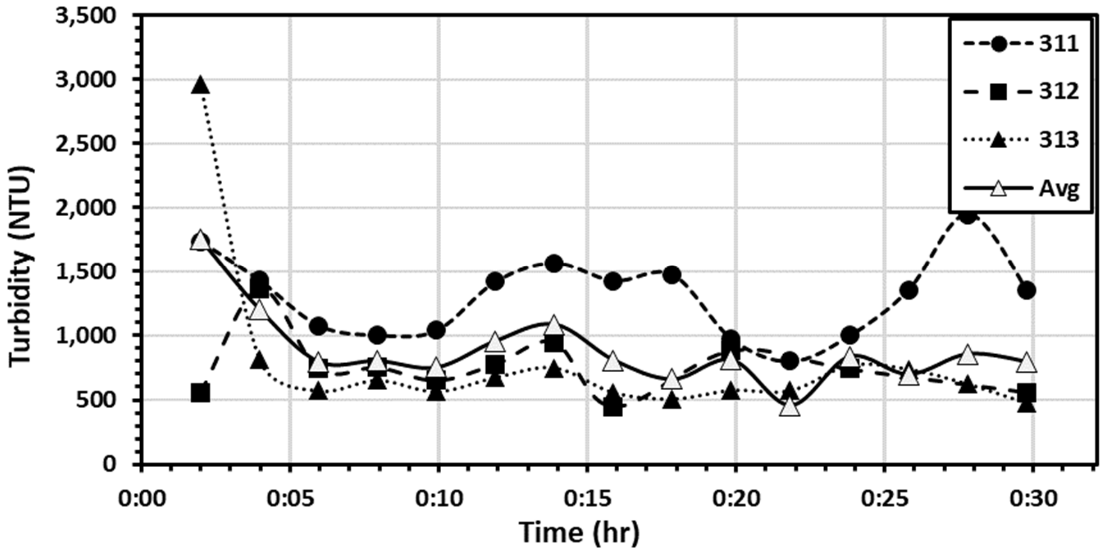


Discharge Sampling Location

S4-Lined Testing with Skimmer



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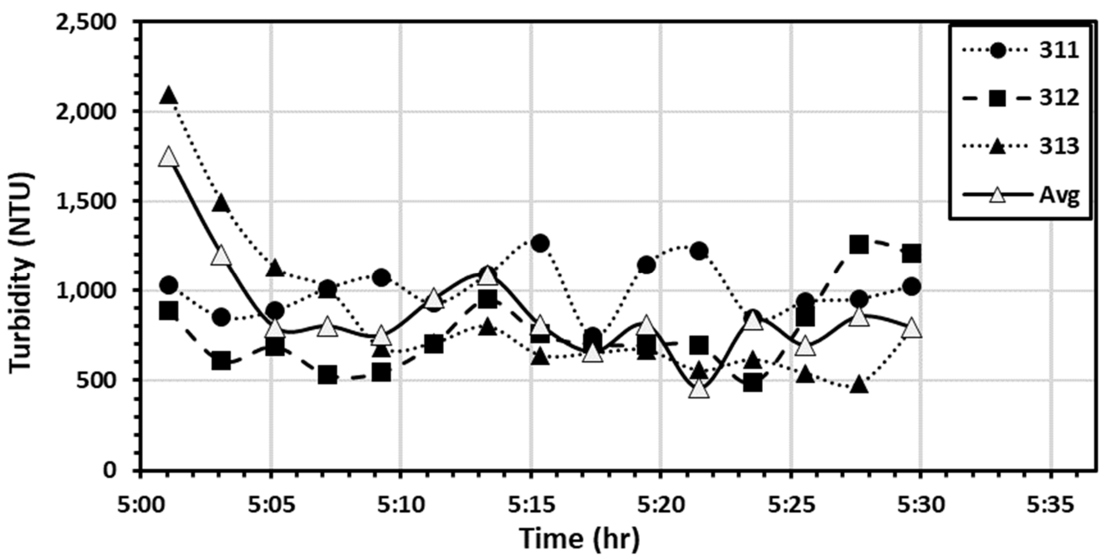
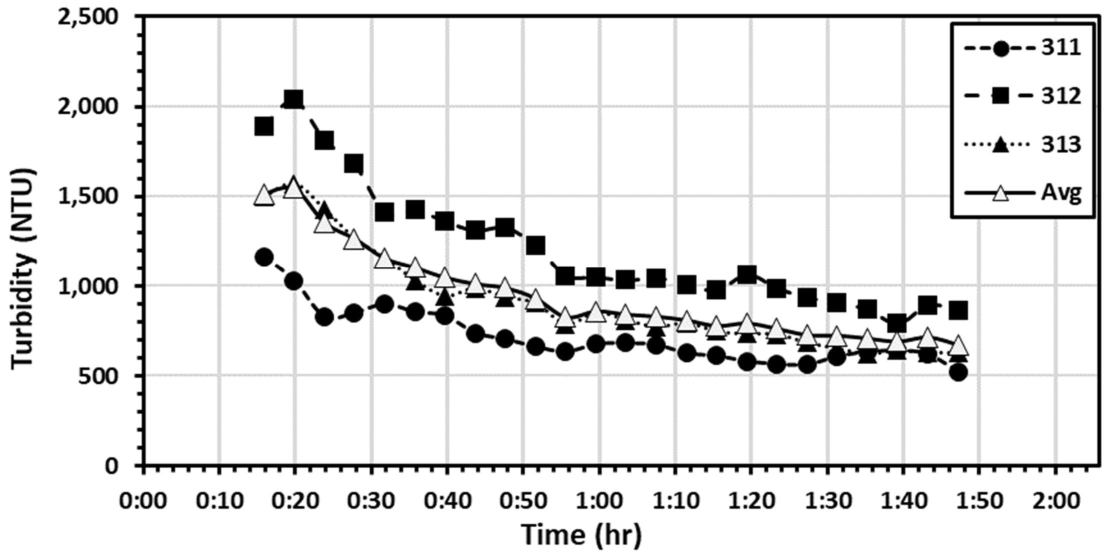
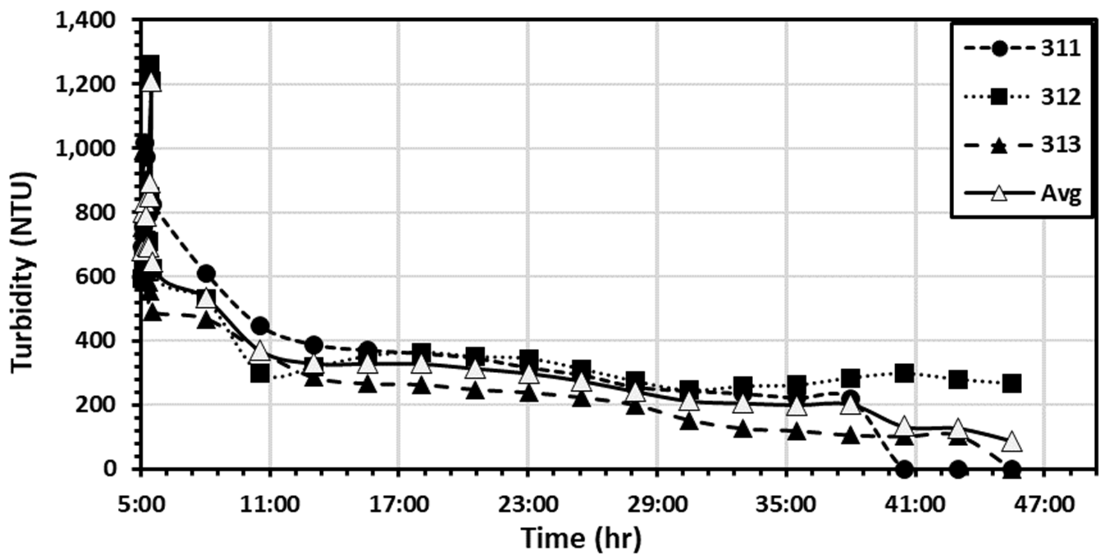


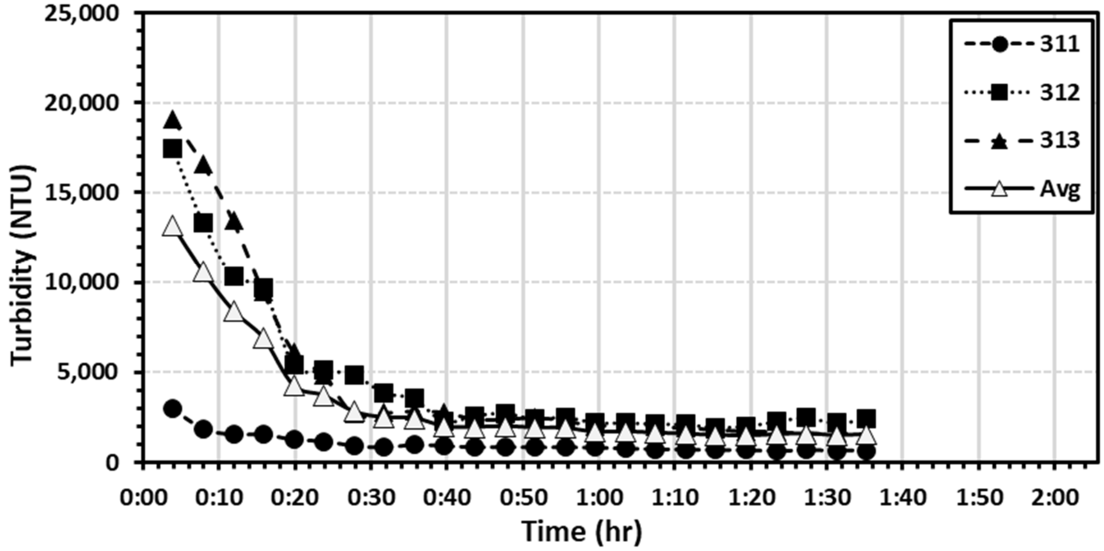
Inflow Sampling Location



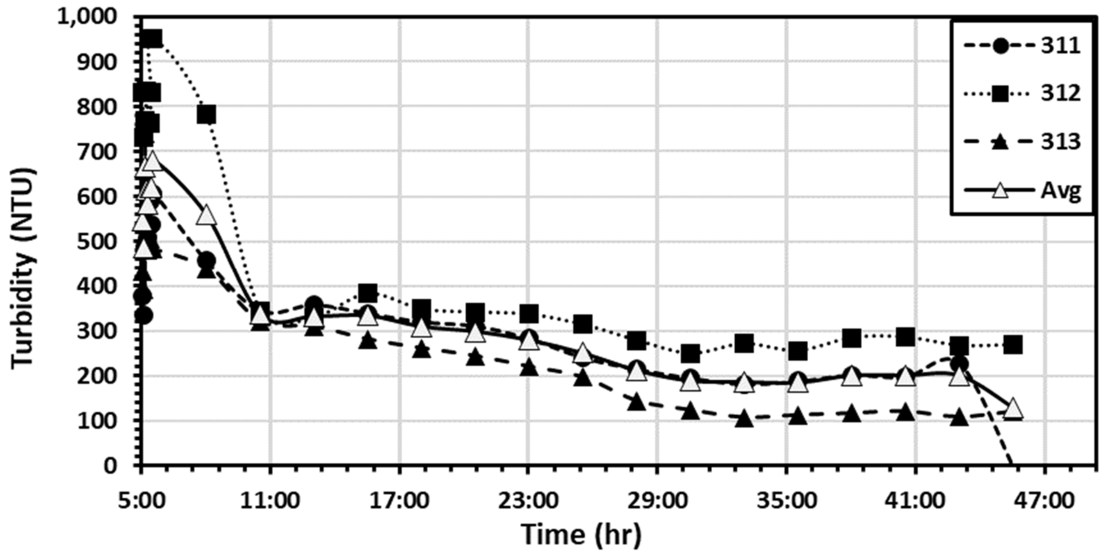
Bay 2 Sampling Location



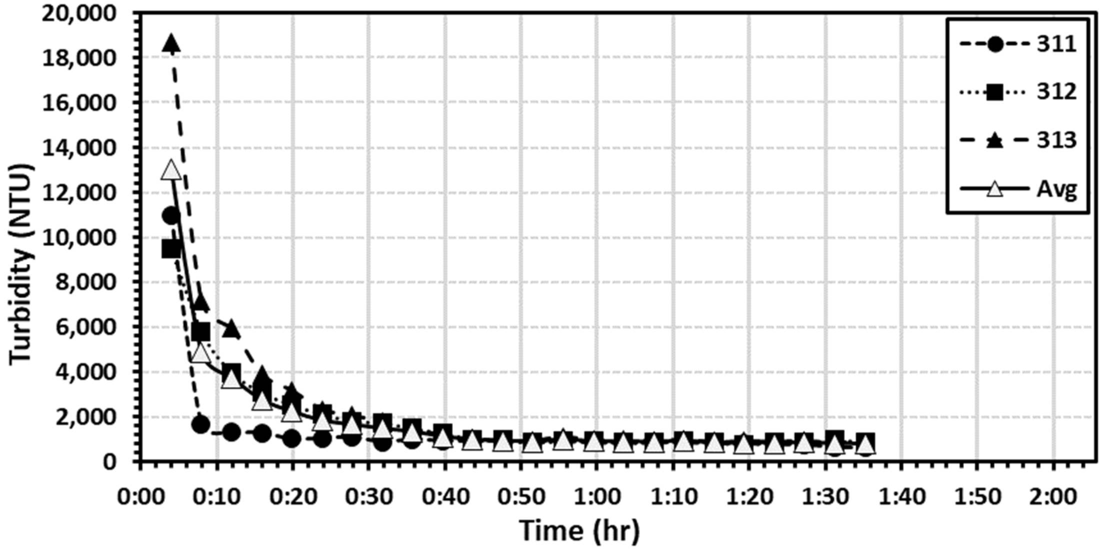
Bay 2 Sampling Location



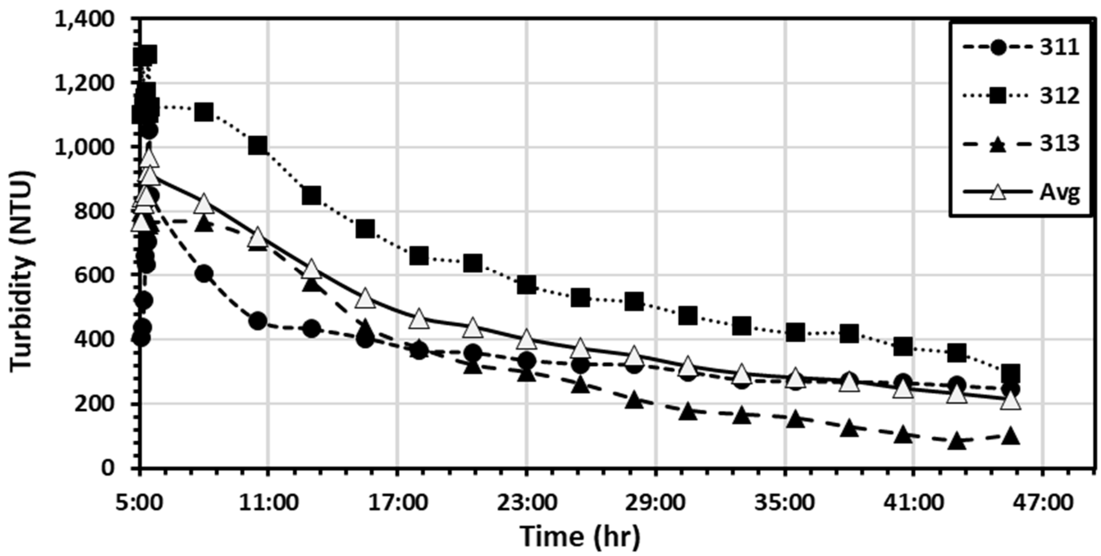
Bay 4 Bottom Sampling Location



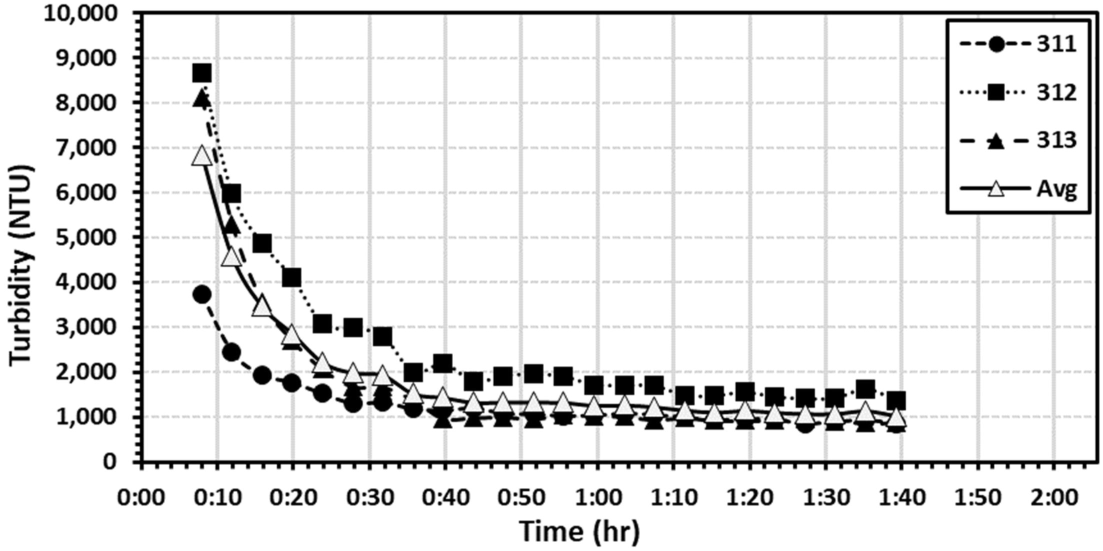
Bay 4 Bottom Sampling Location



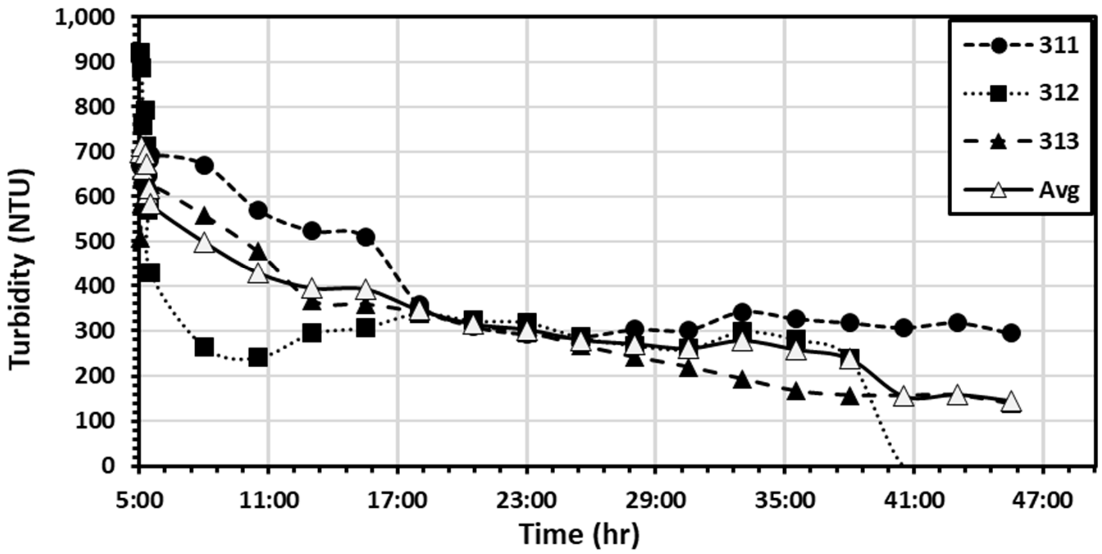
Bay 4 Top Sampling Location



Bay 4 Top Sampling Location

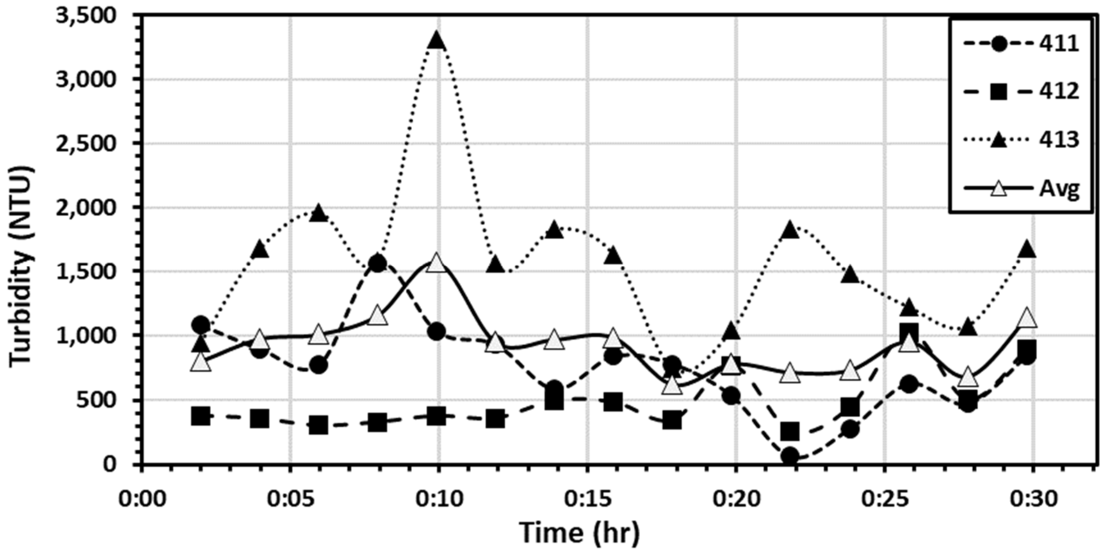


Discharge Sampling Location

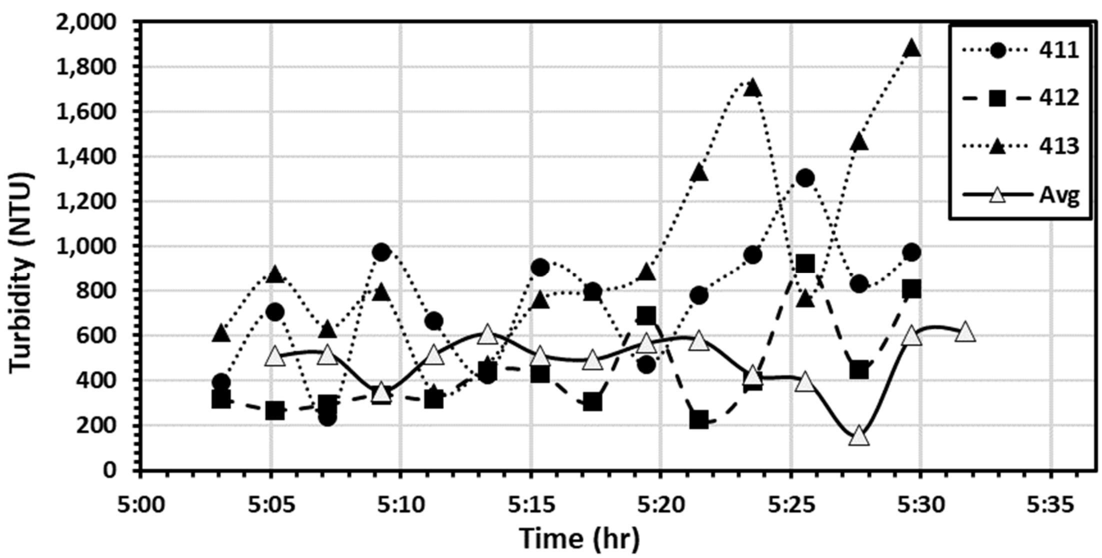


Discharge Sampling Location

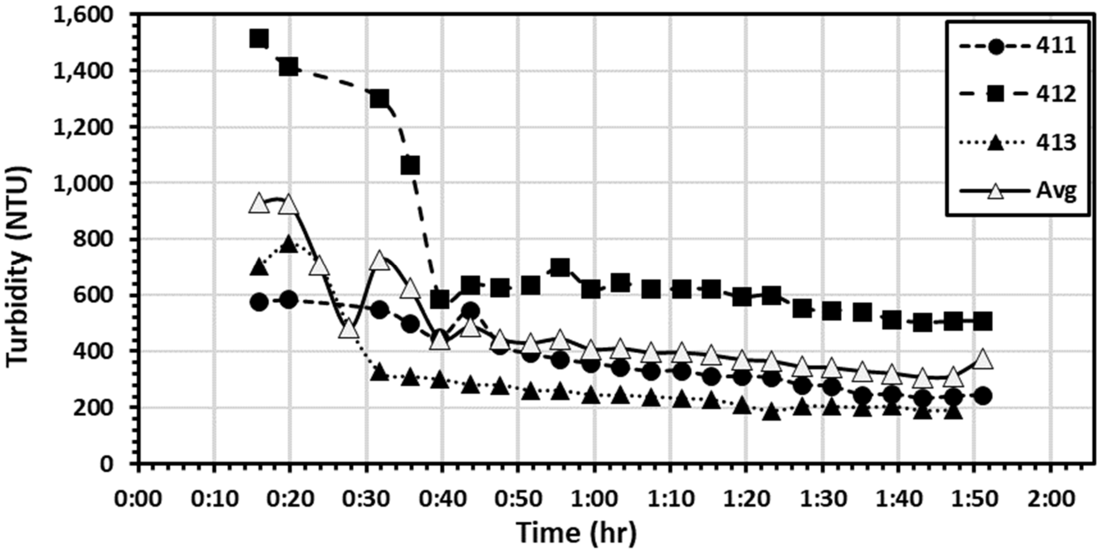
S5-Lined Testing with Baffles



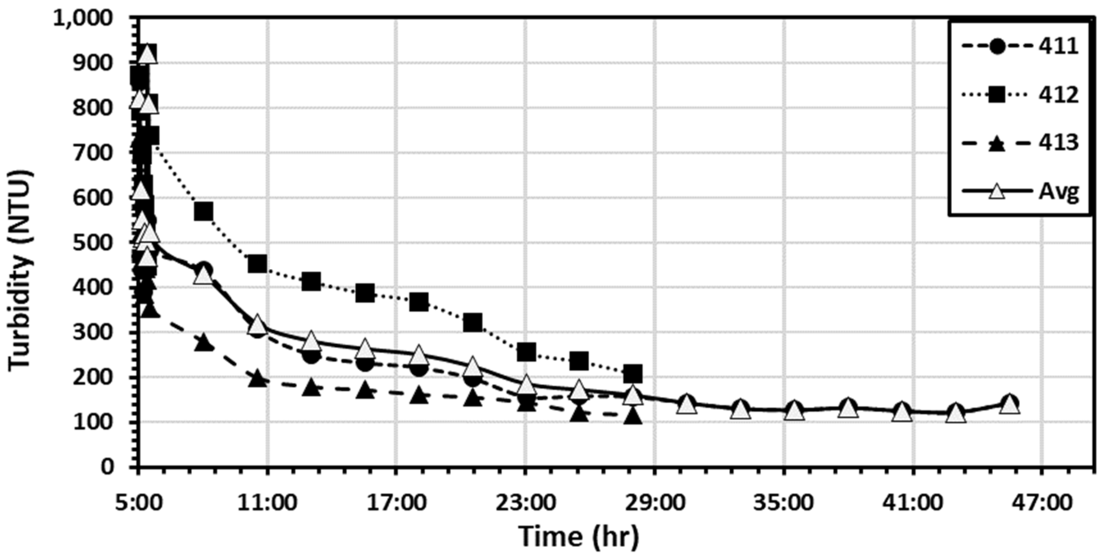
Inflow Sampling Location



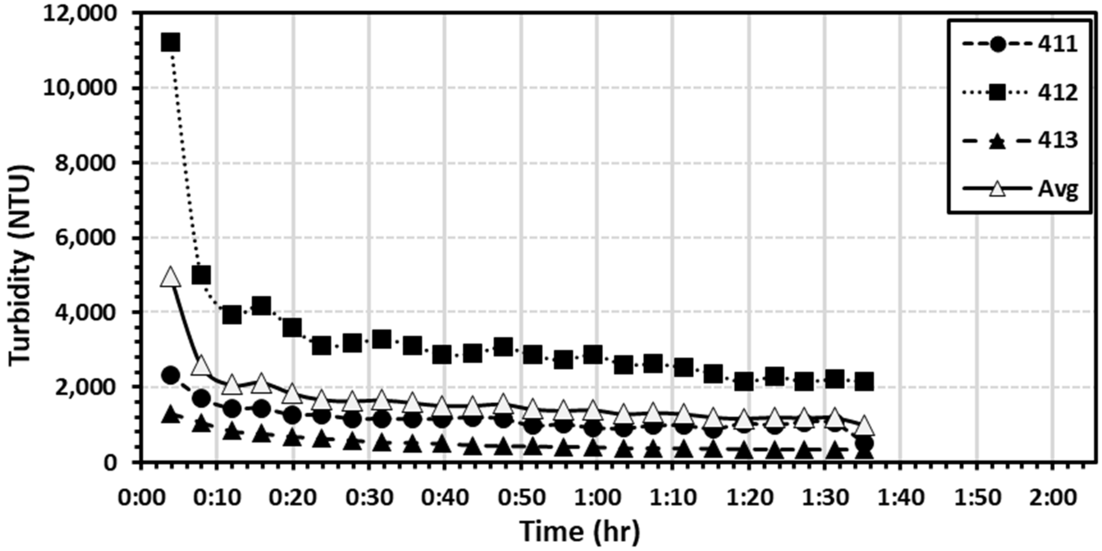
Inflow Sampling Location



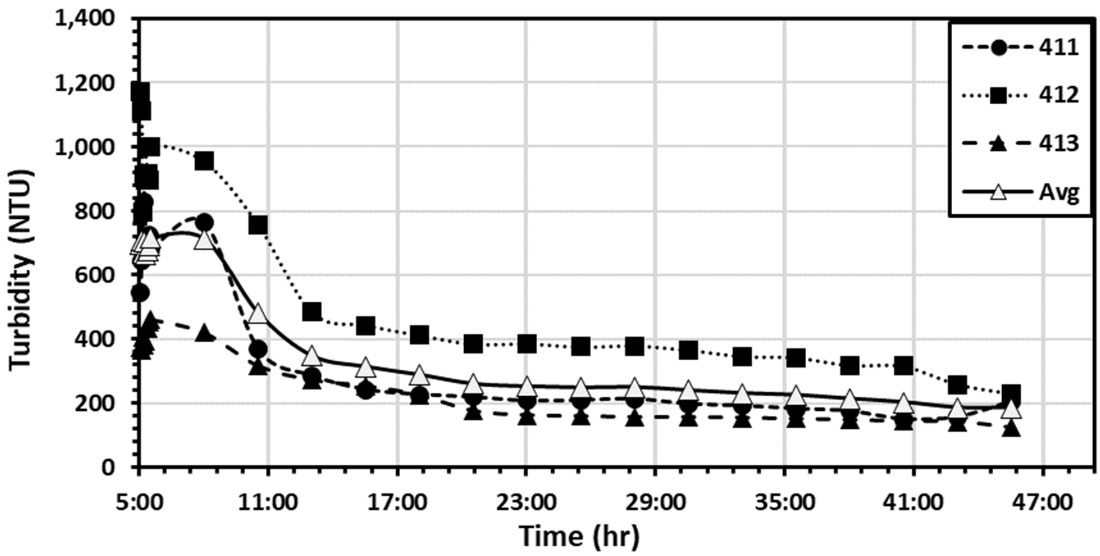
Bay 2 Sampling Location



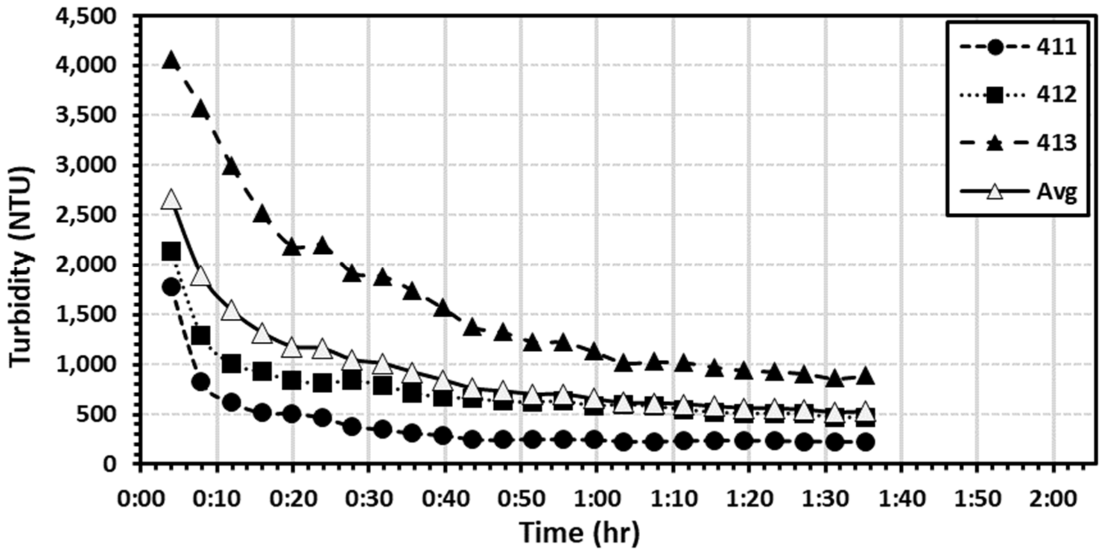
Bay 2 Sampling Location



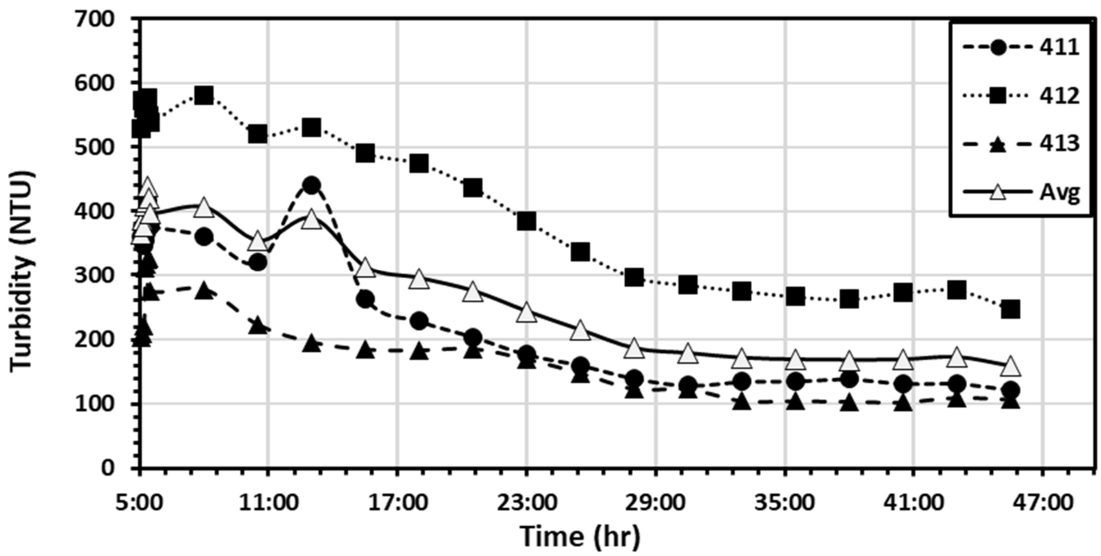
Bay 4 Bottom Sampling Location



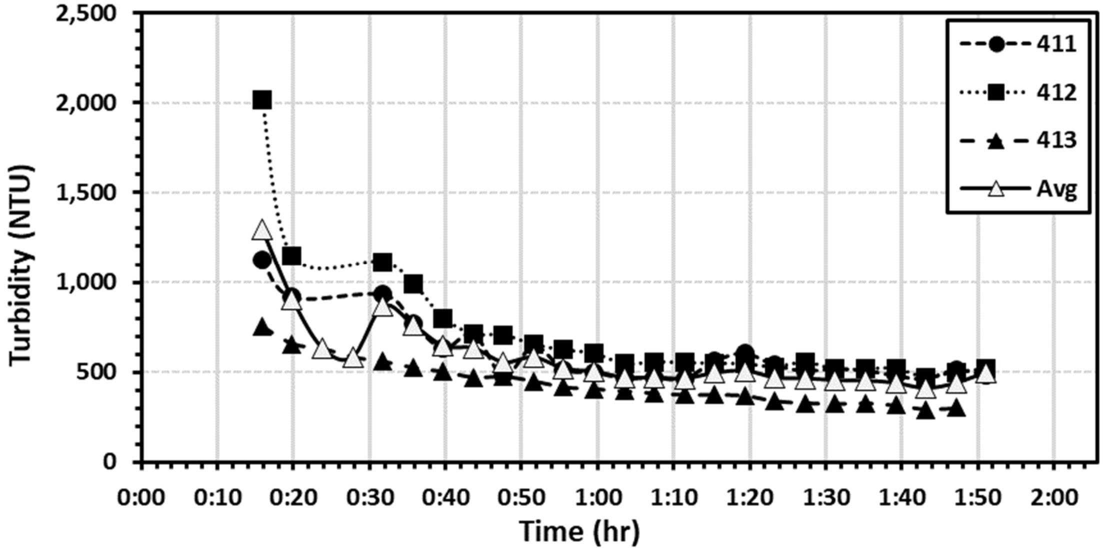
Bay 4 Bottom Sampling Location



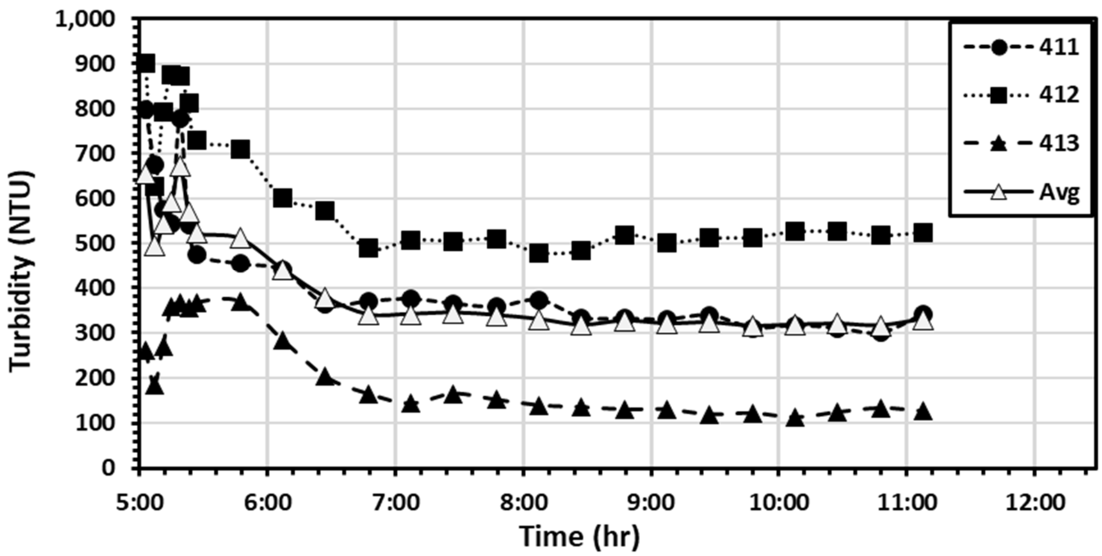
Bay 4 Top Sampling Location



Bay 4 Top Sampling Location

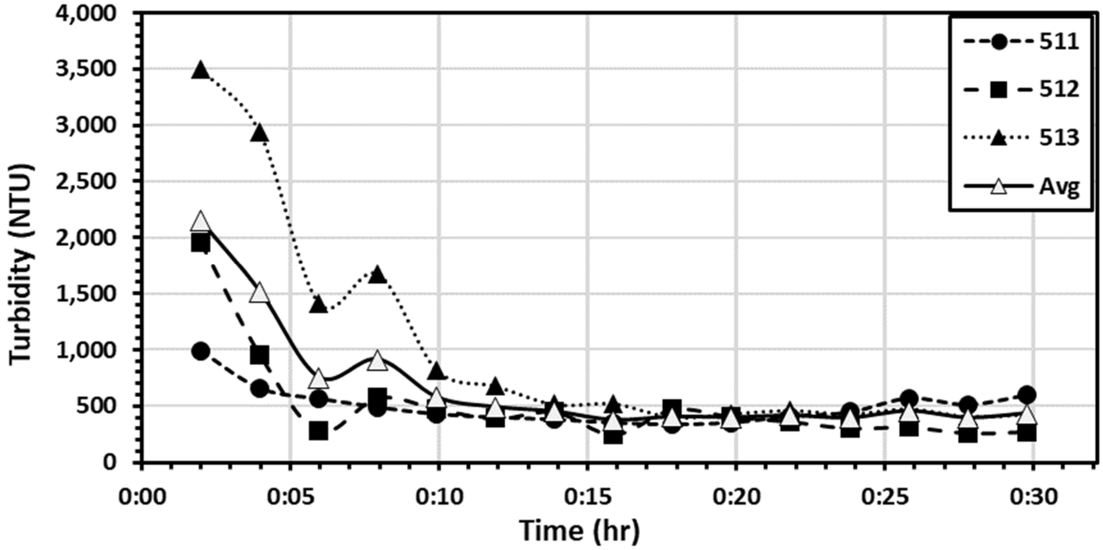


Discharge Sampling Location

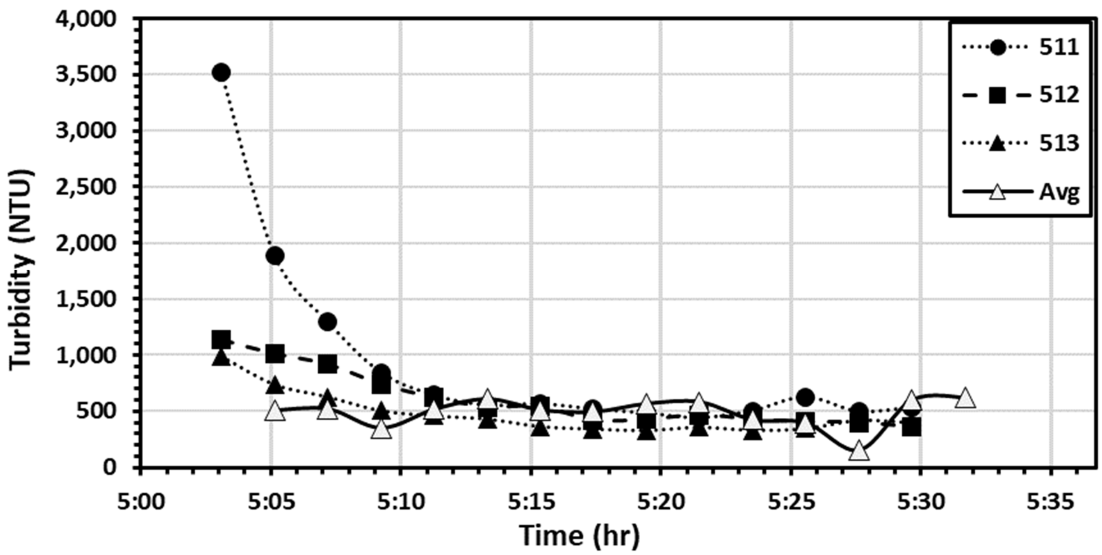


Discharge Sampling Location

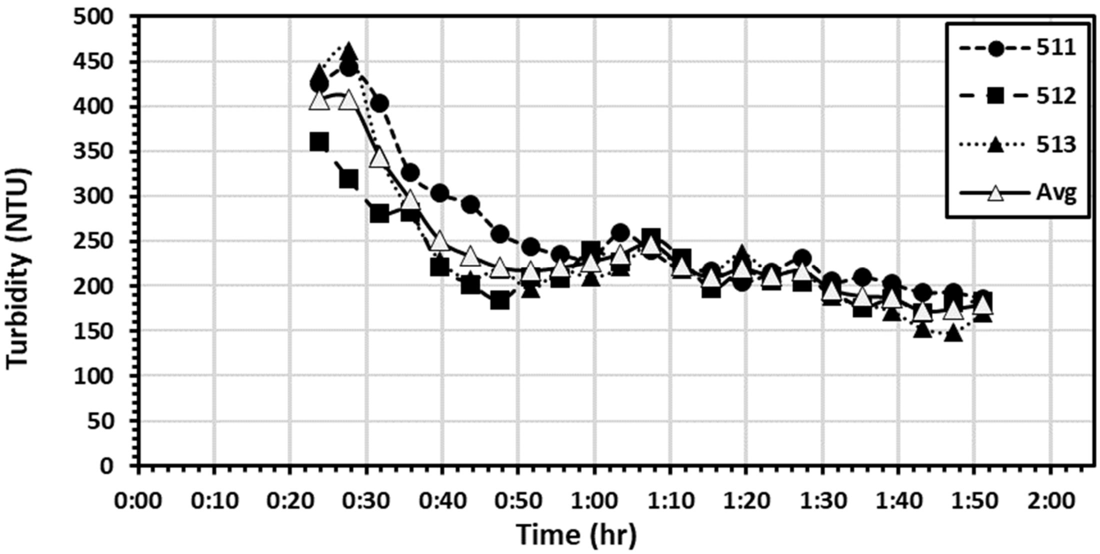
S6-Lined Testing with Forebay



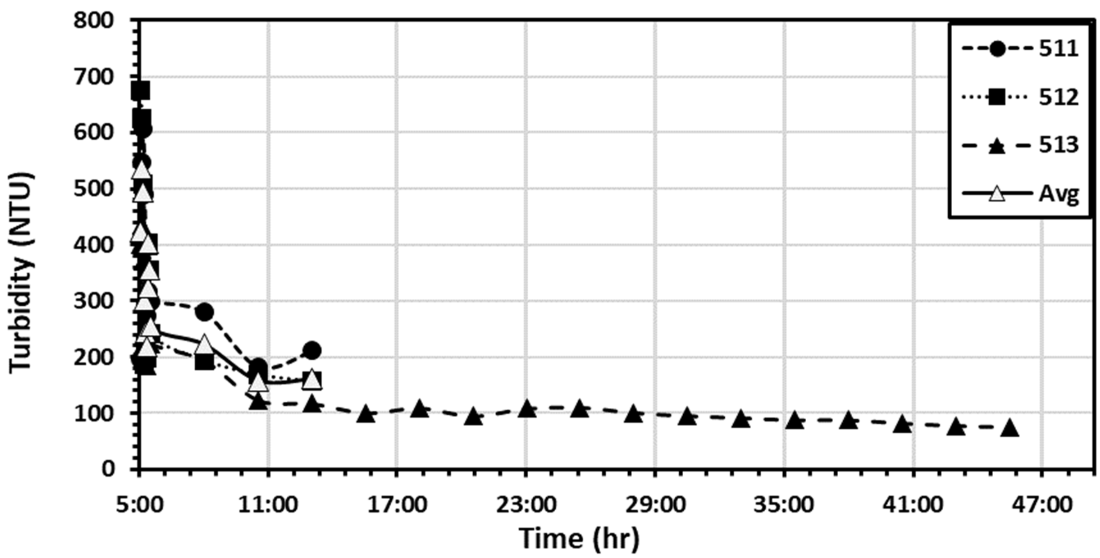
Inflow Sampling Location



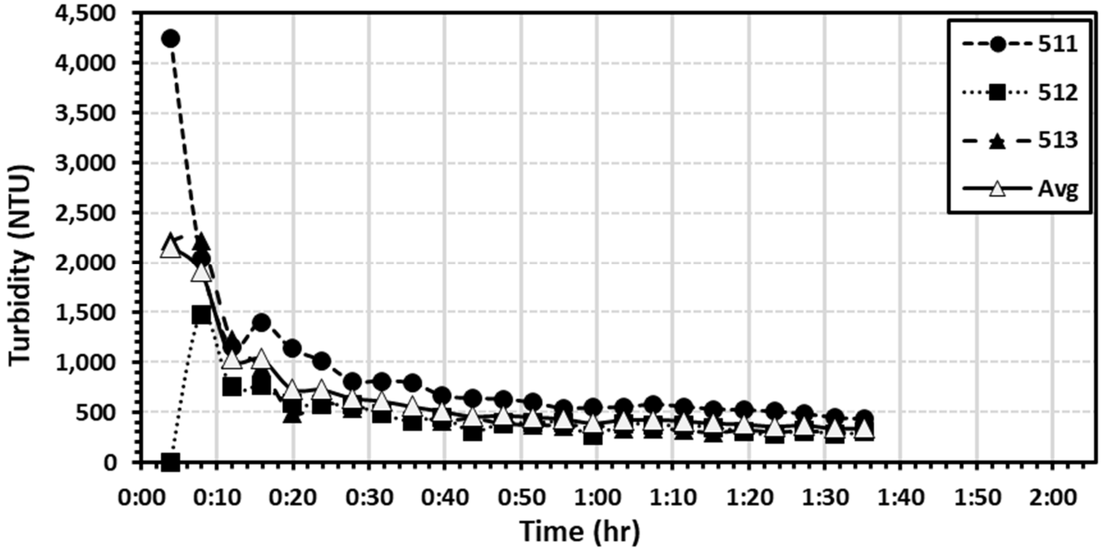
Inflow Sampling Location



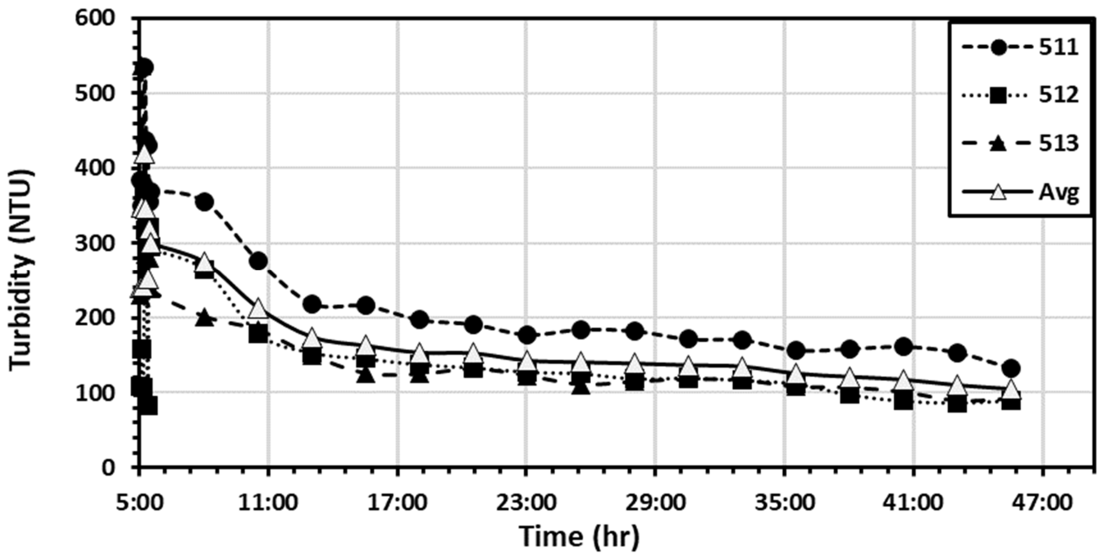
Bay 2 Sampling Location



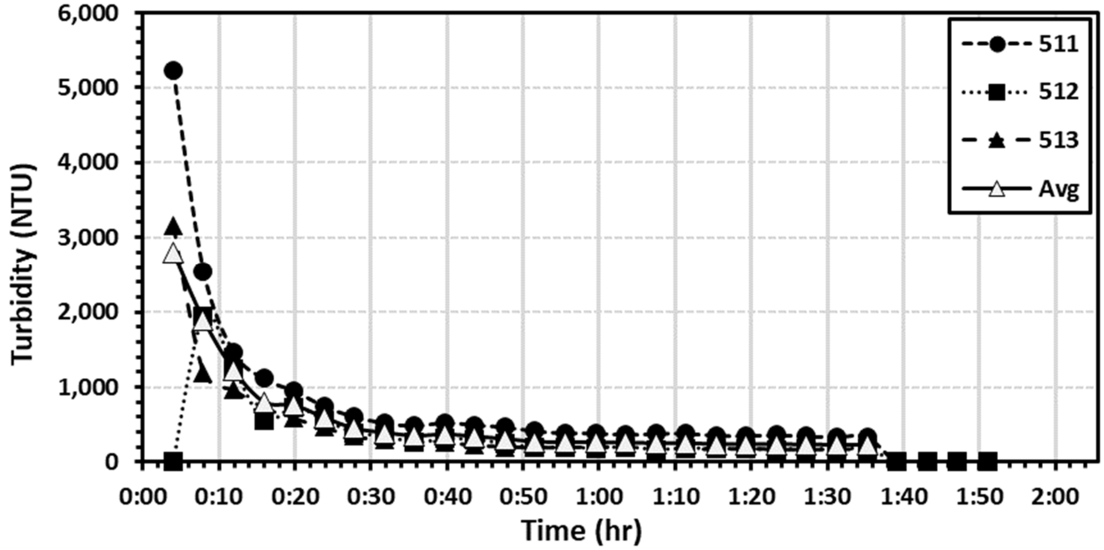
Bay 2 Sampling Location



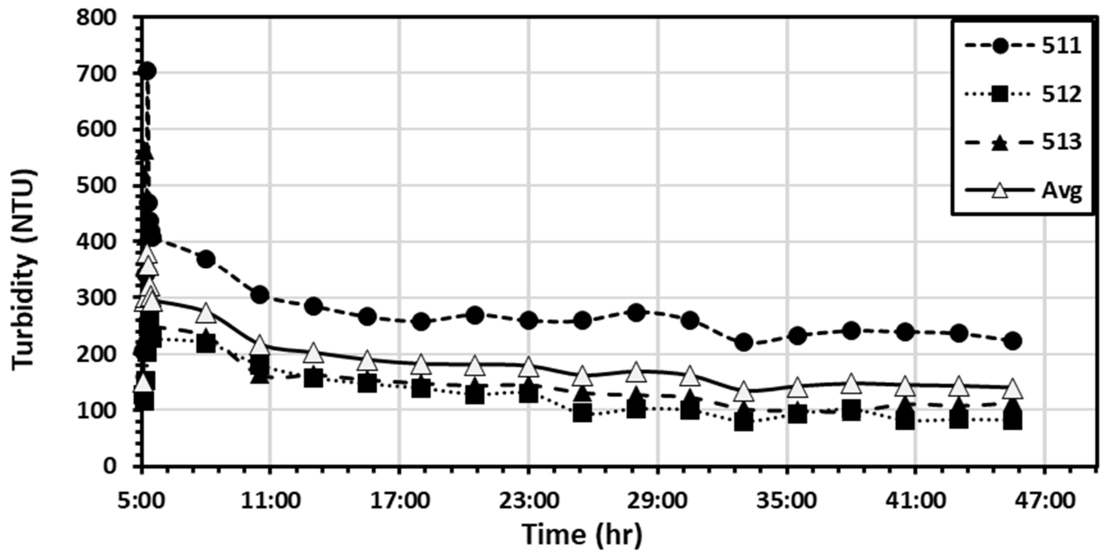
Bay 4 Bottom Sampling Location



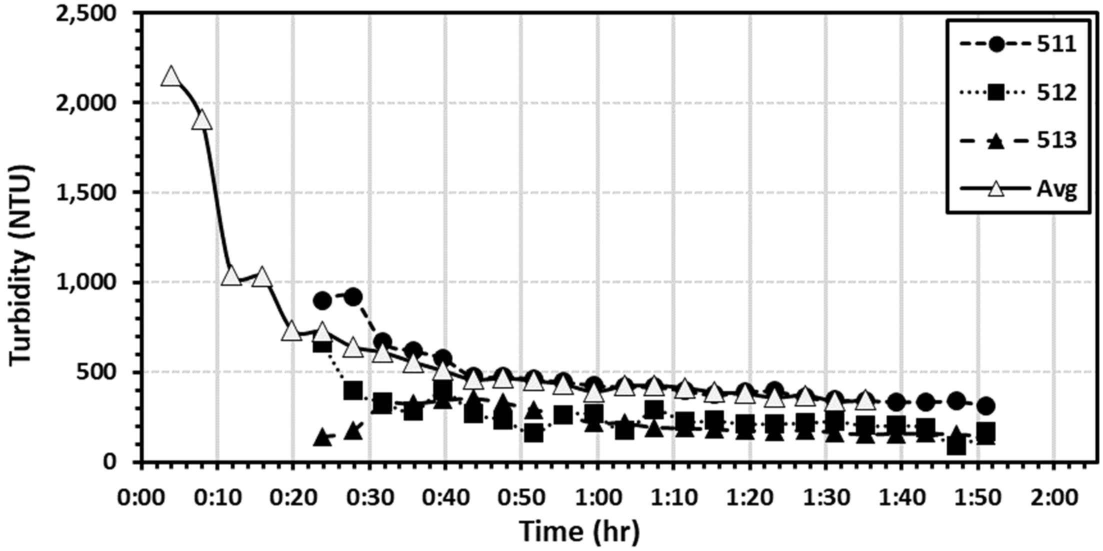
Bay 4 Bottom Sampling Location



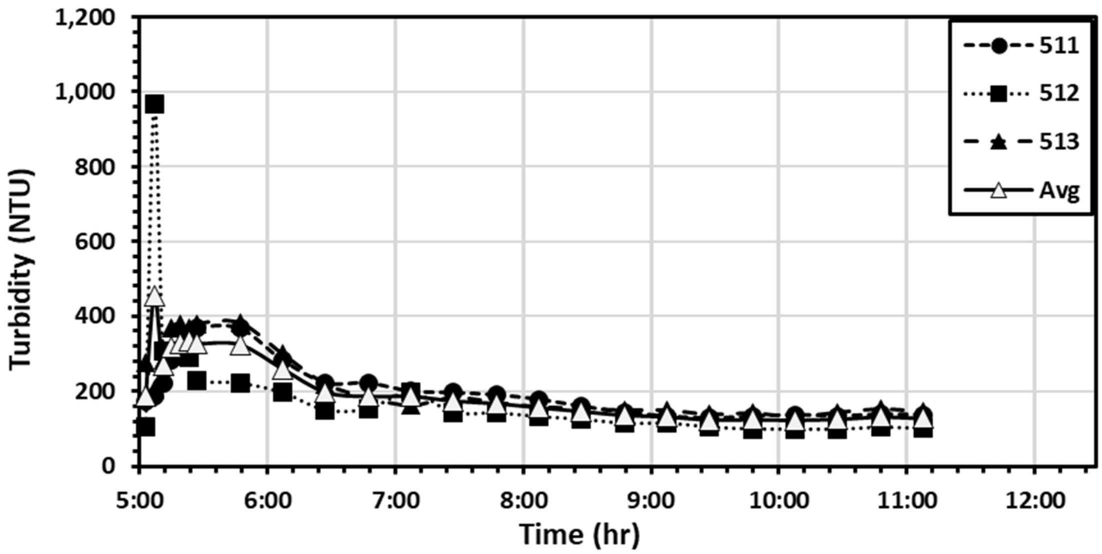
Bay 4 Top Sampling Location



Bay 4 Top Sampling Location

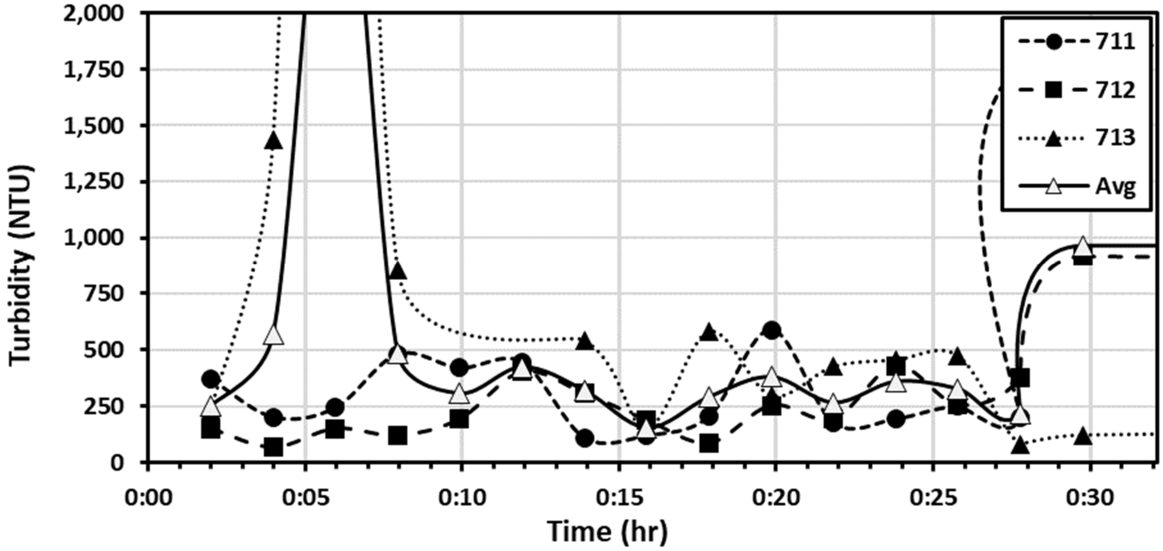


Discharge Sampling Location

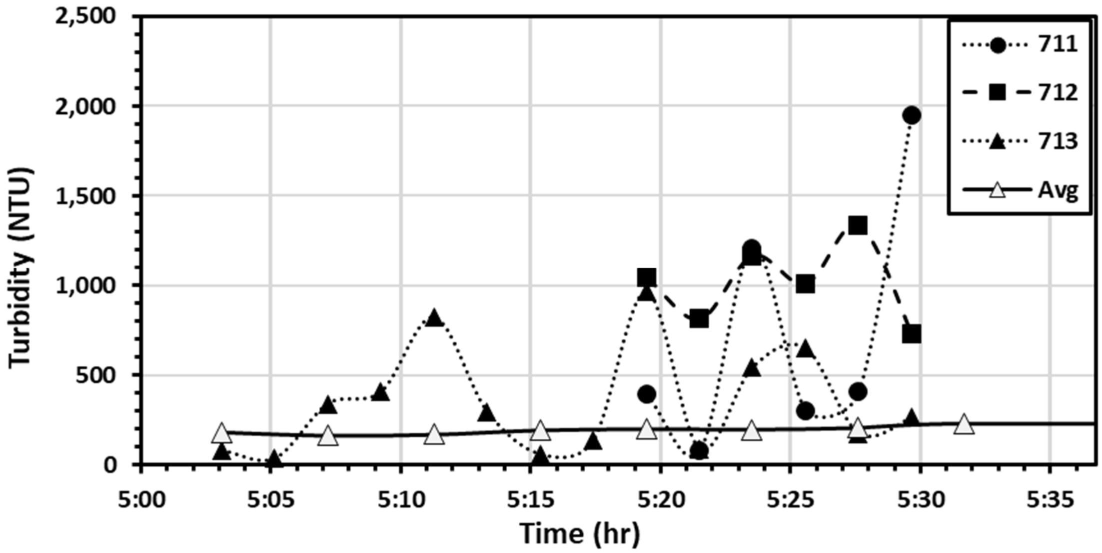


Discharge Sampling Location

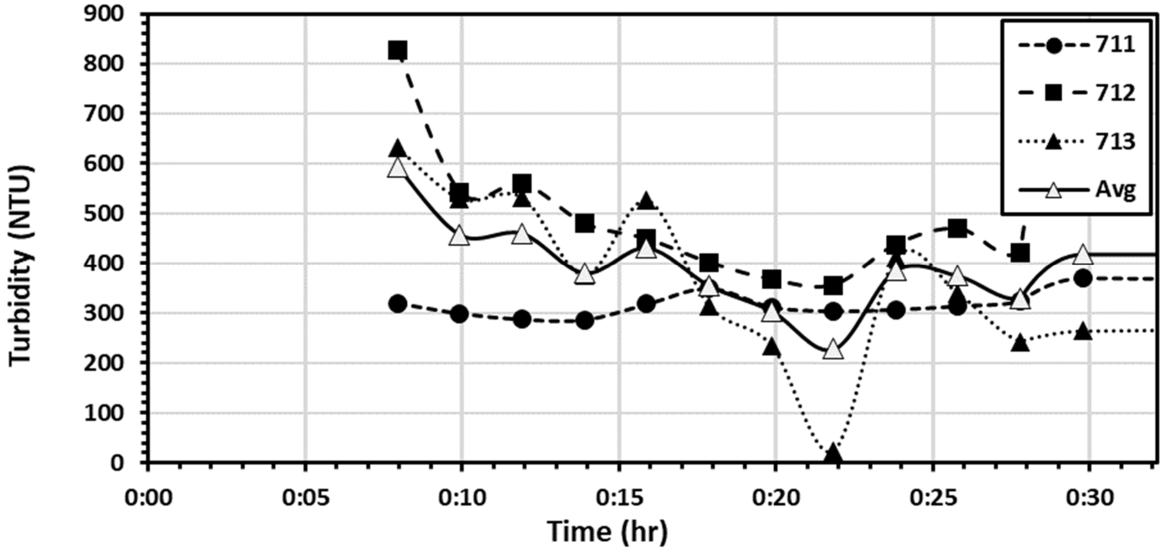
S7-MFE-I Testing



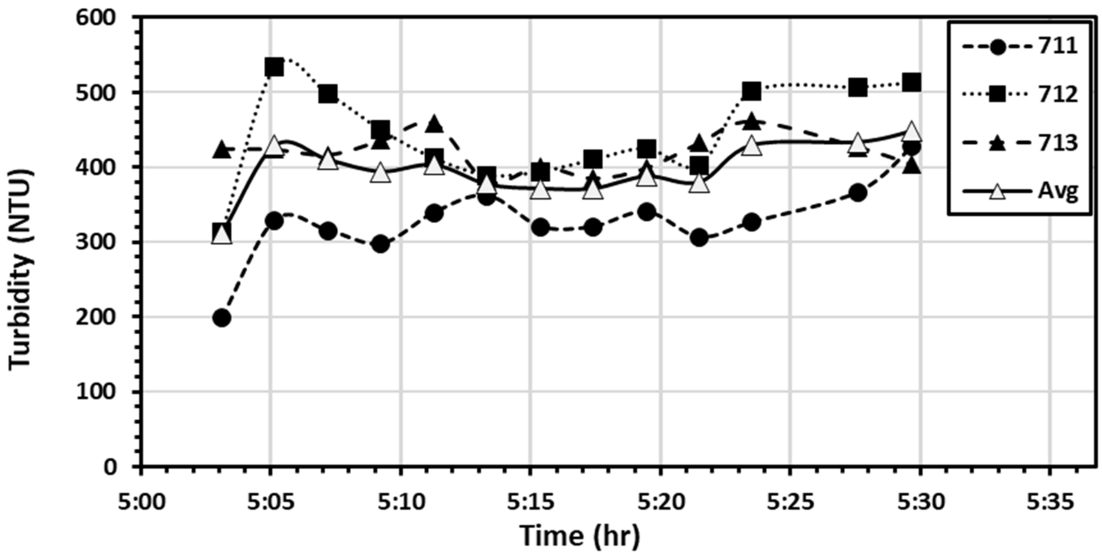
Inflow Sampling Location



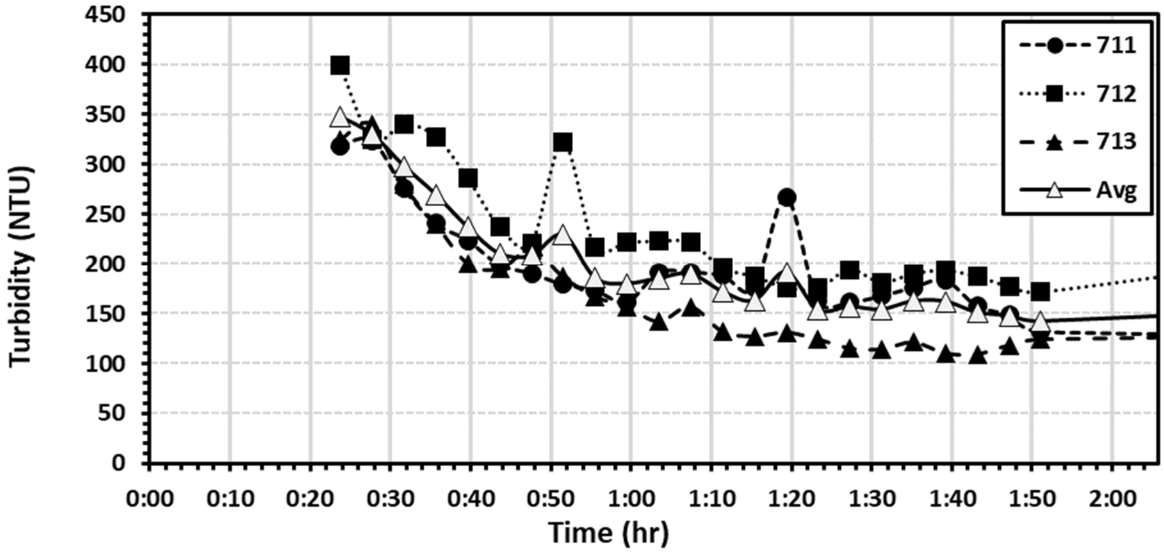
Inflow Sampling Location



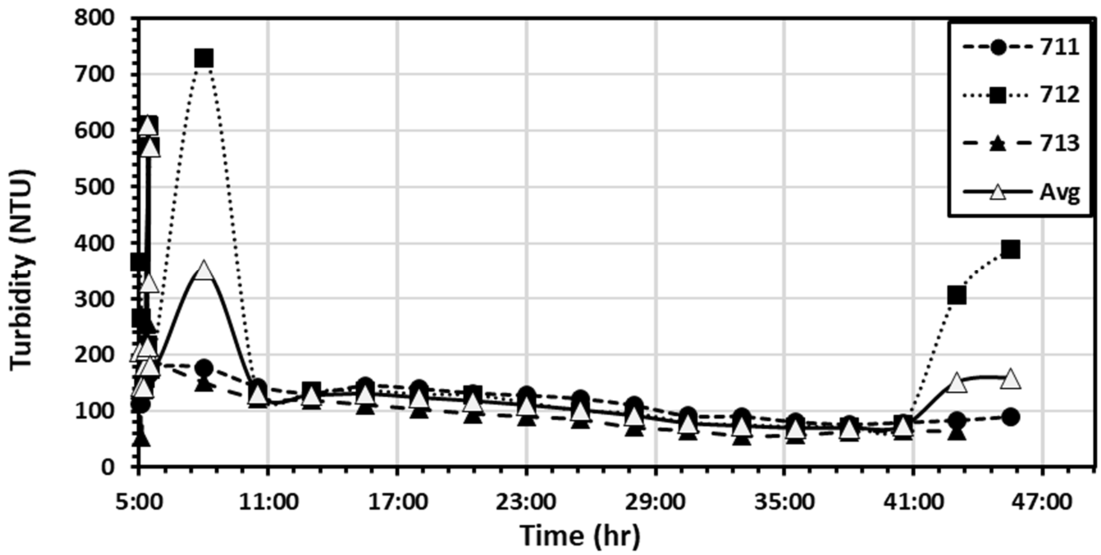
Forebay Sampling Location



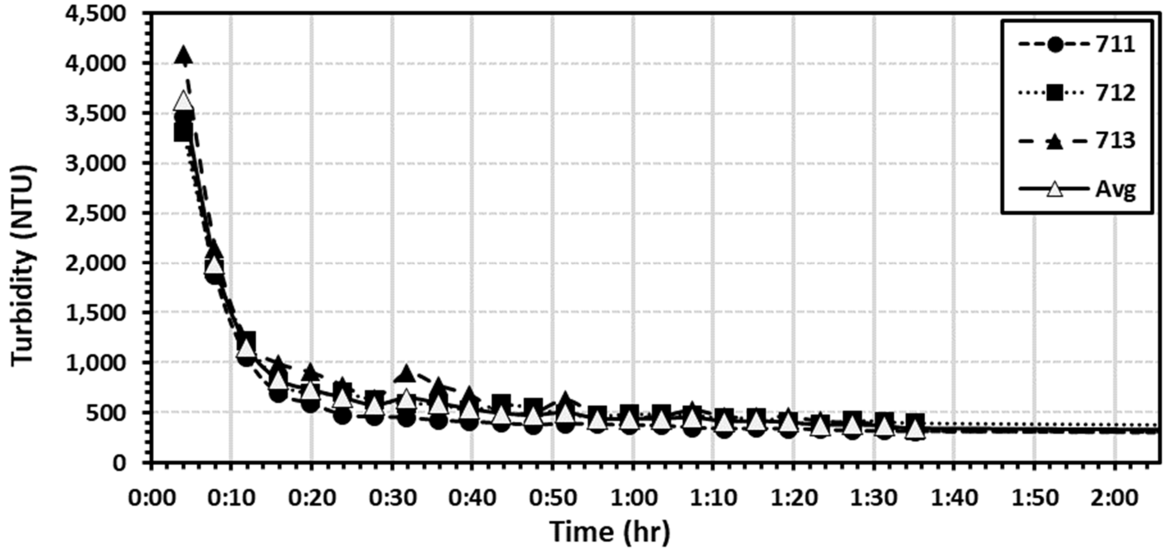
Forebay Sampling Location



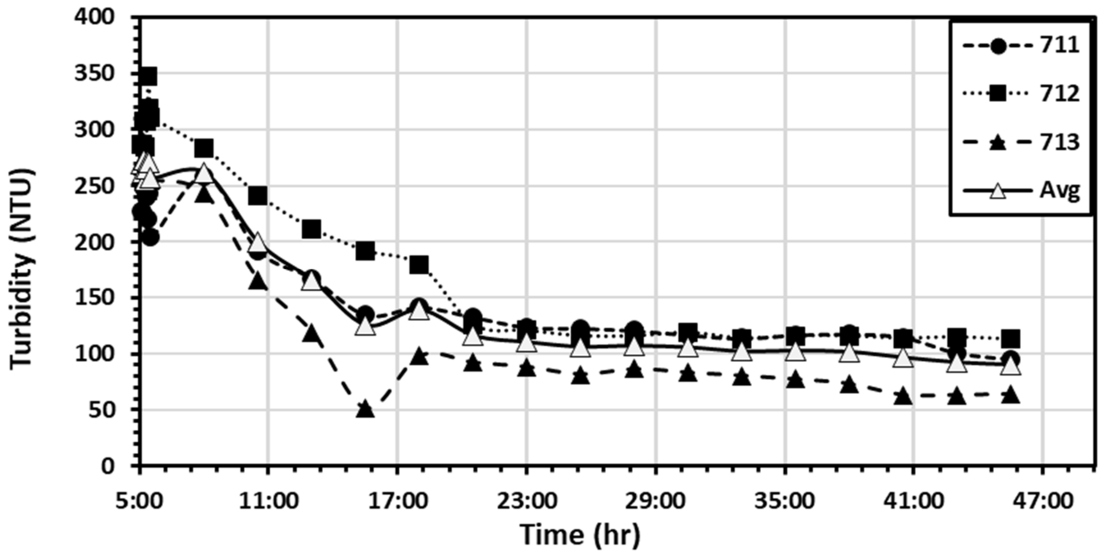
Bay 2 Sampling Location



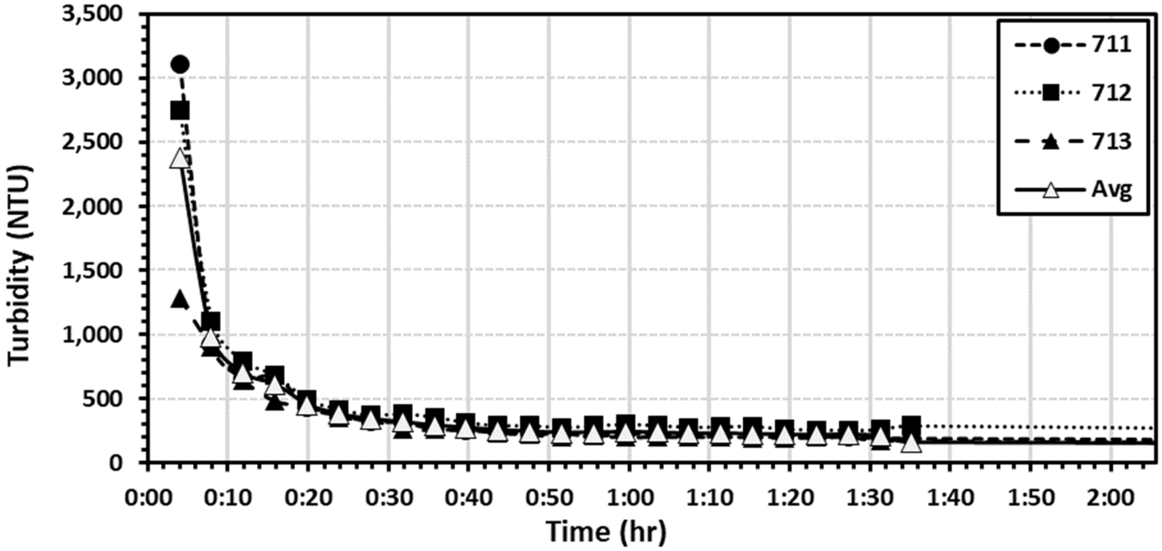
Bay 2 Sampling Location



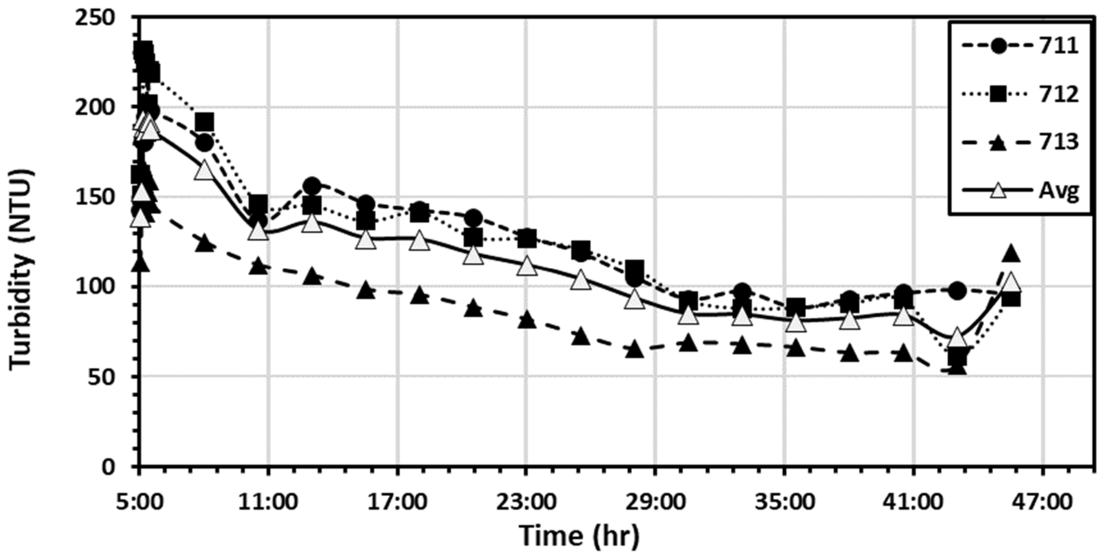
Bay 4 Bottom Sampling Location



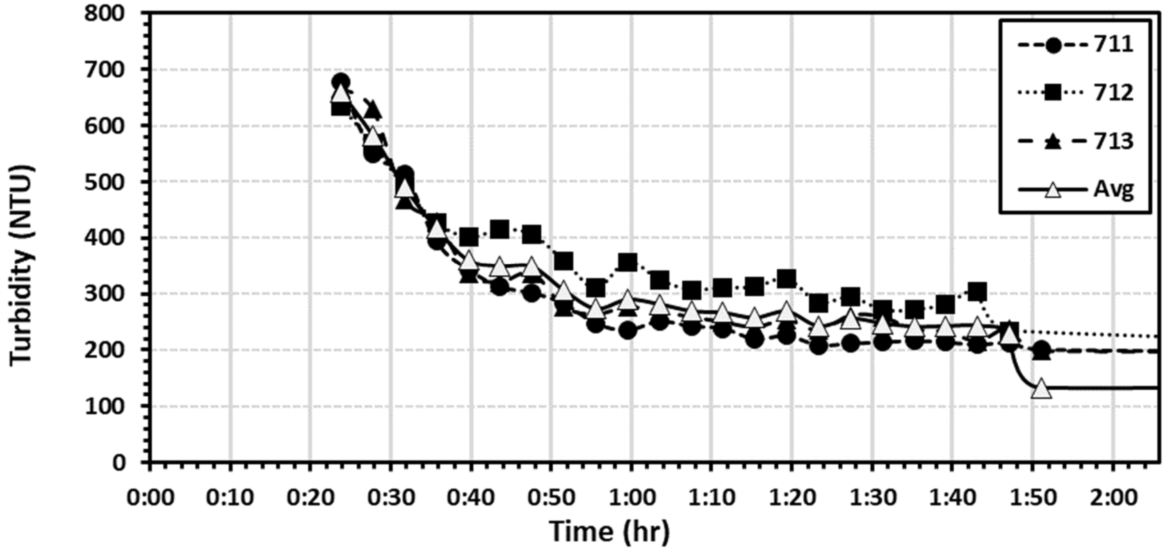
Bay 4 Bottom Sampling Location



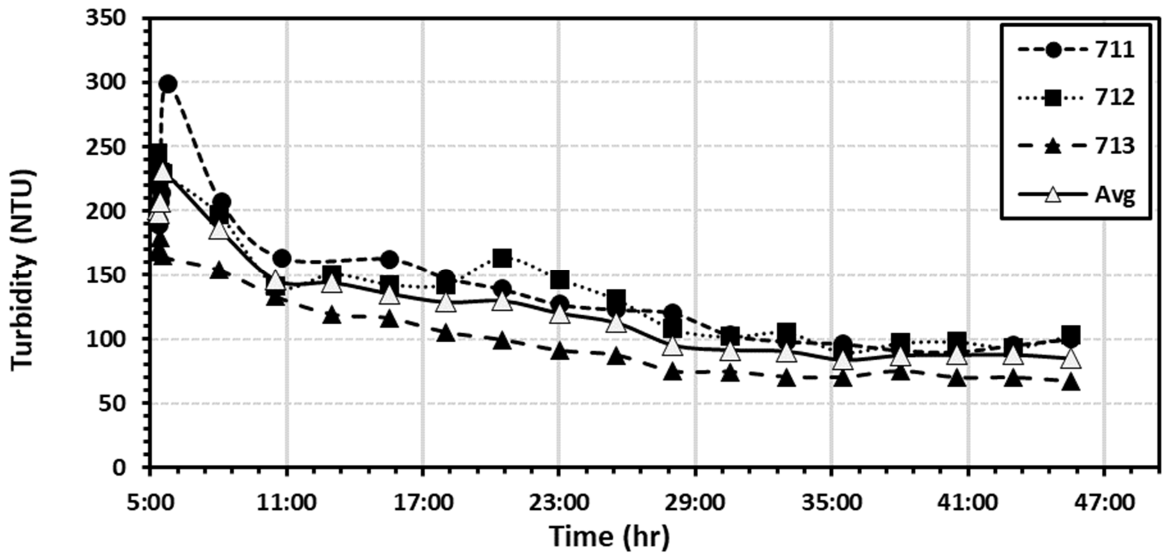
Bay 4 Top Sampling Location



Bay 4 Top Sampling Location

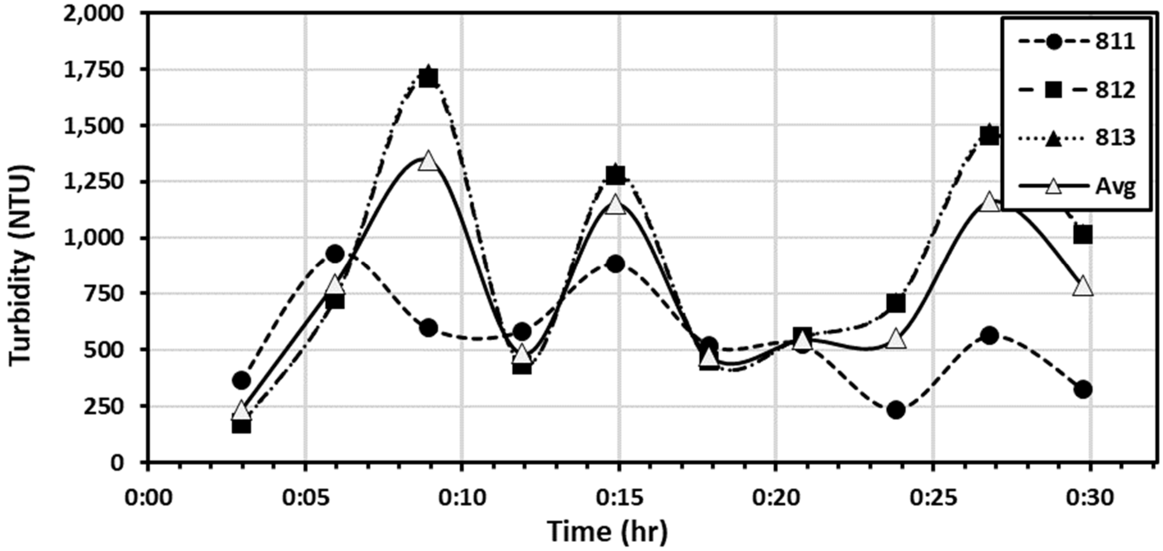


Discharge Sampling Location

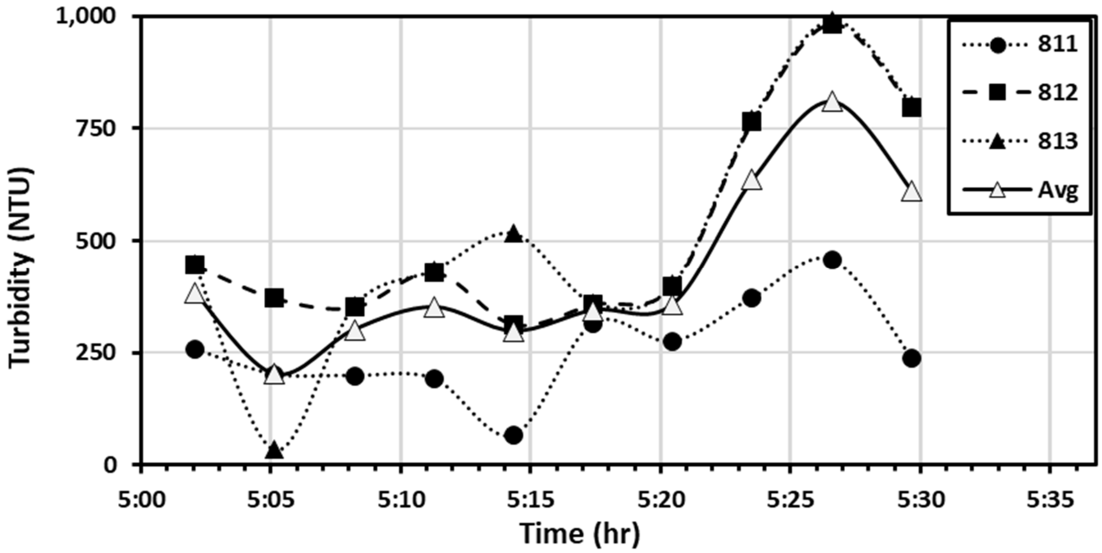


Discharge Sampling Location

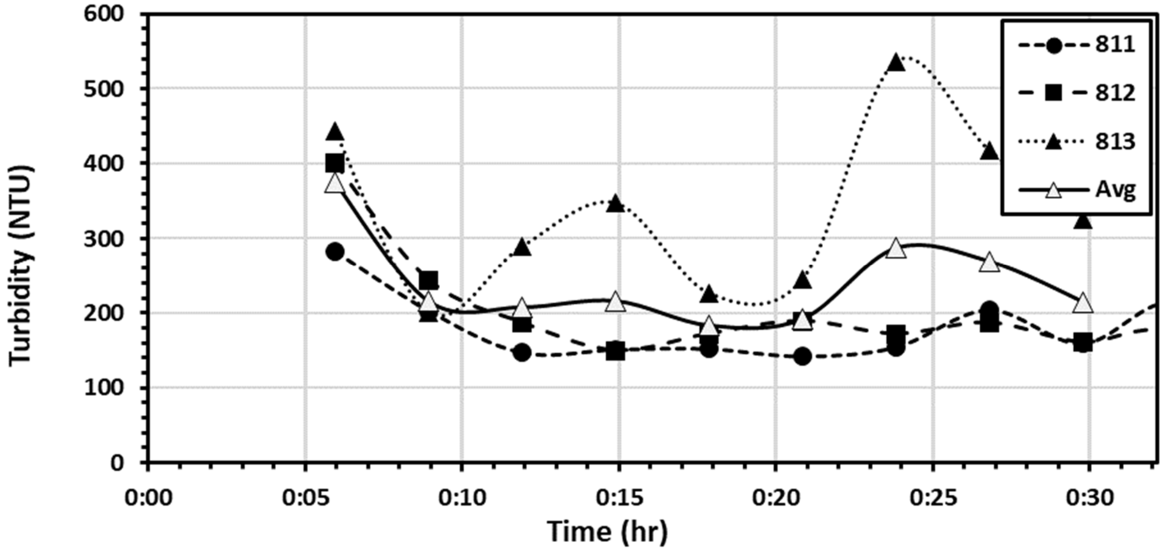
S8-MFE-I +Flocculant Testing



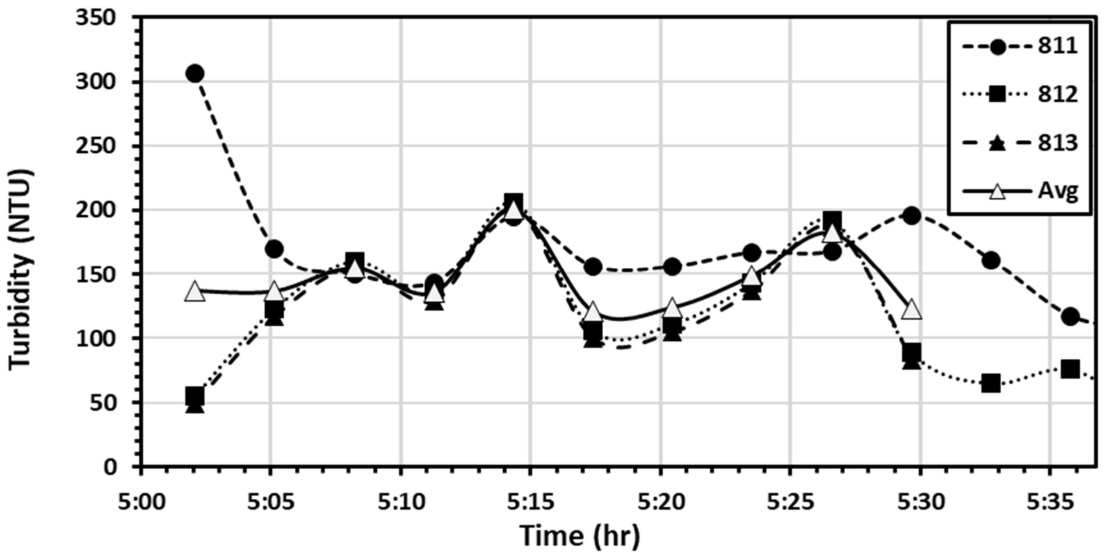
Inflow Sampling Location



Inflow Sampling Location



Forebay Sampling Location



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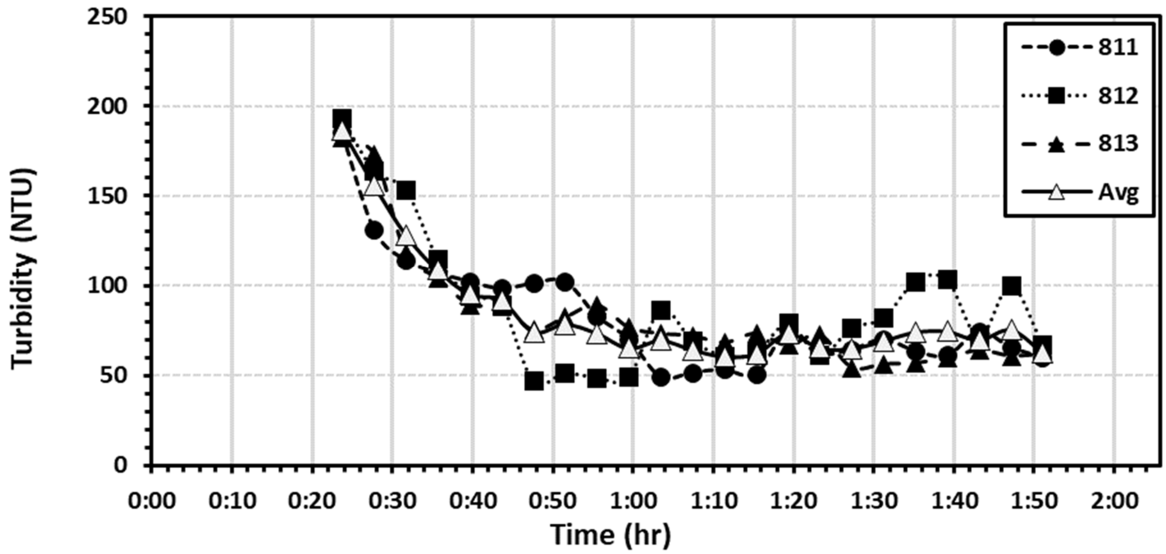
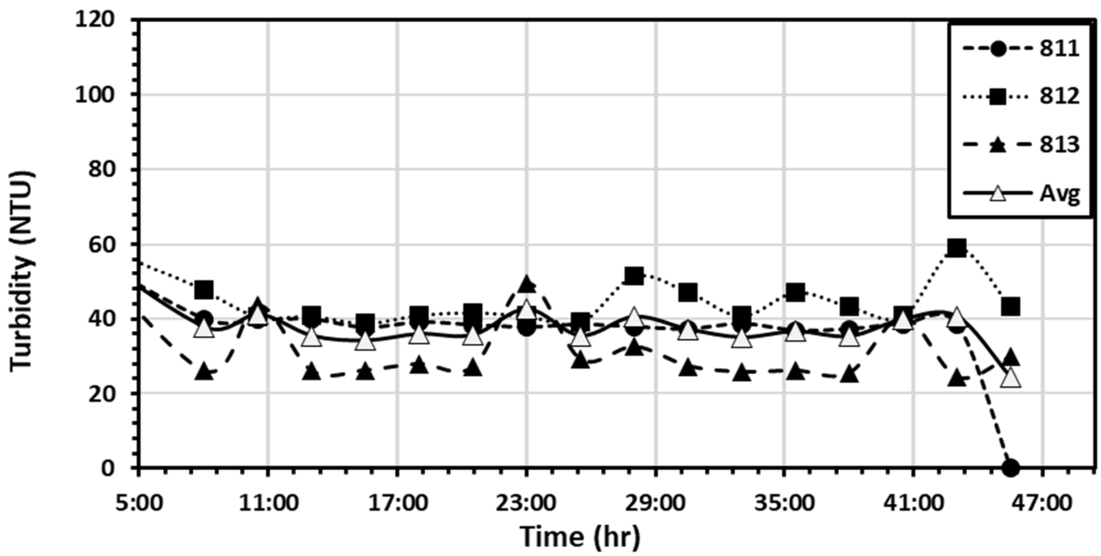
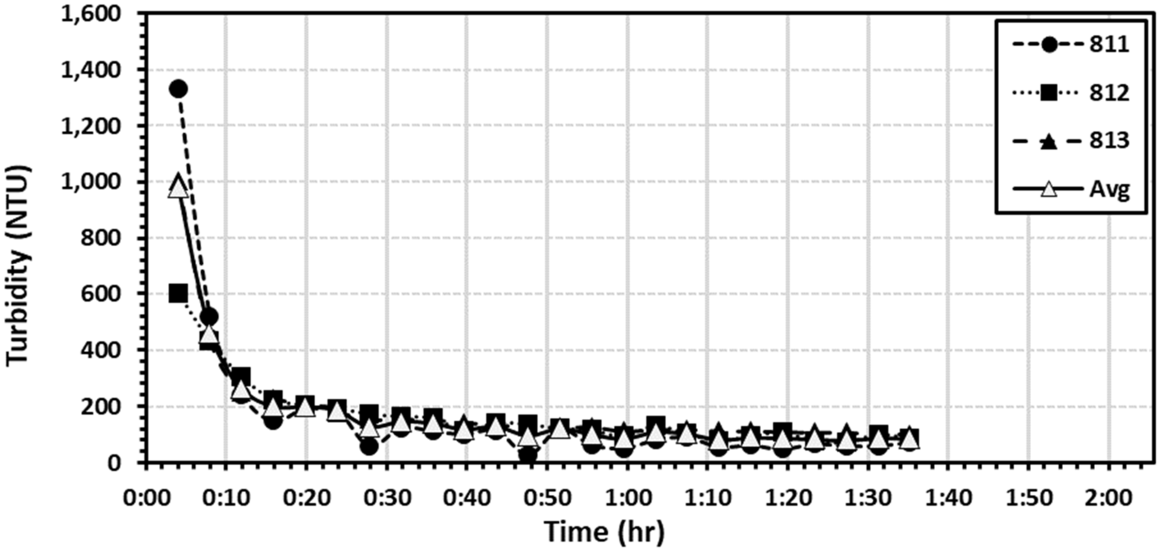


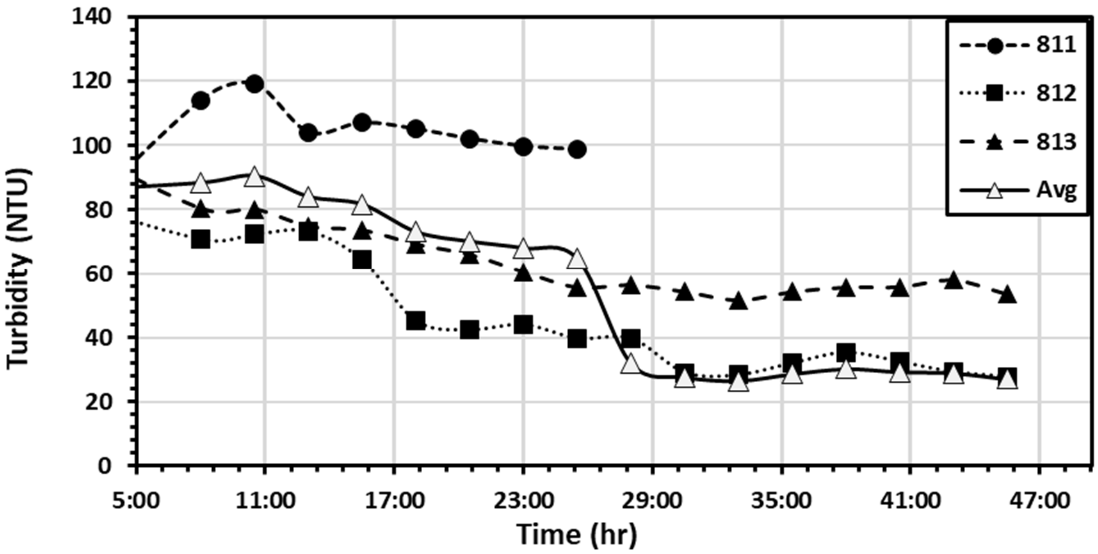
Bay 2 Sampling Location



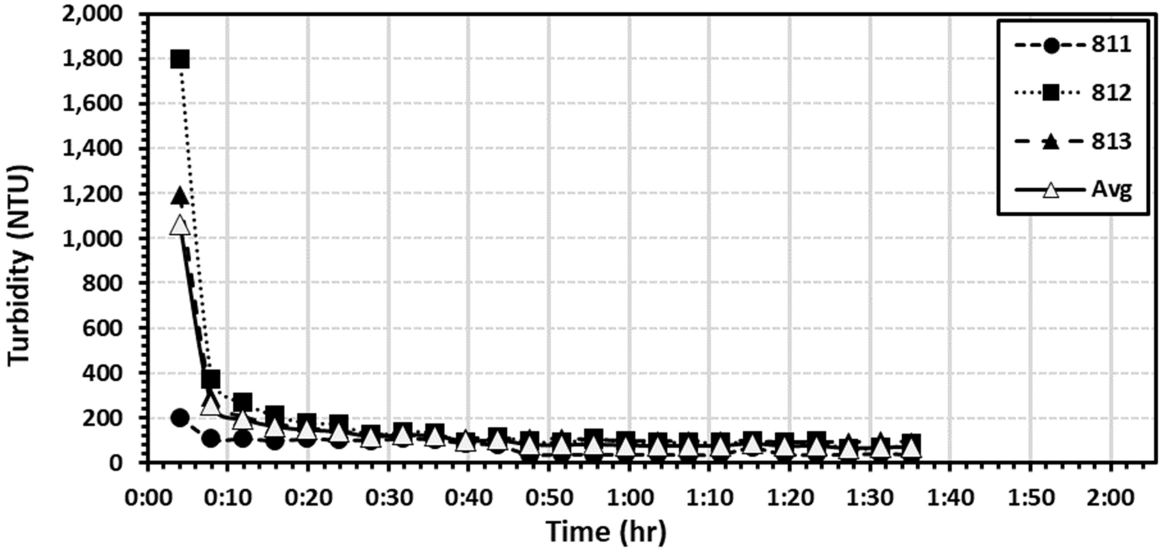
Bay 2 Sampling Location



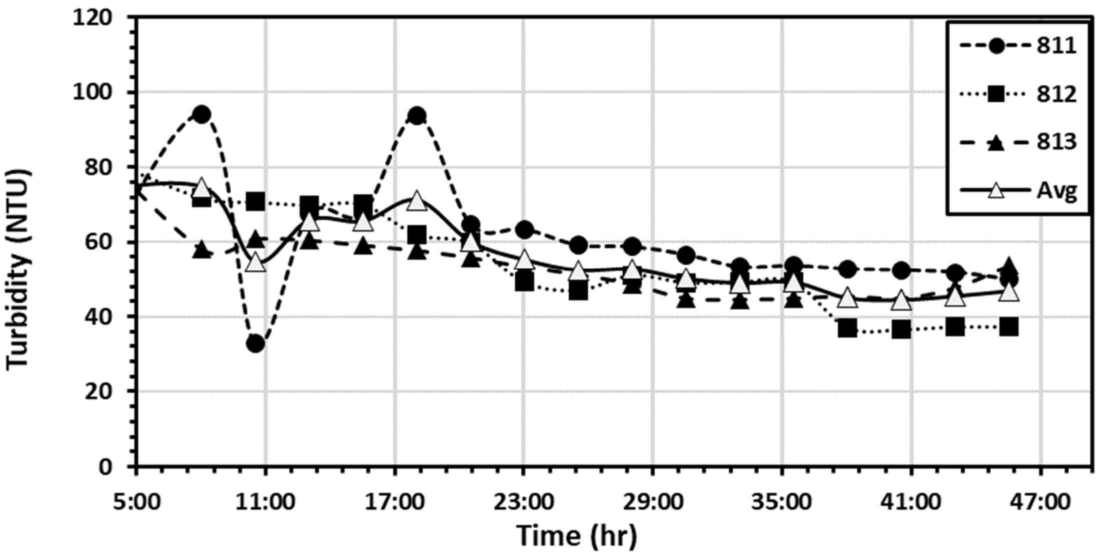
Bay 4 Bottom Sampling Location



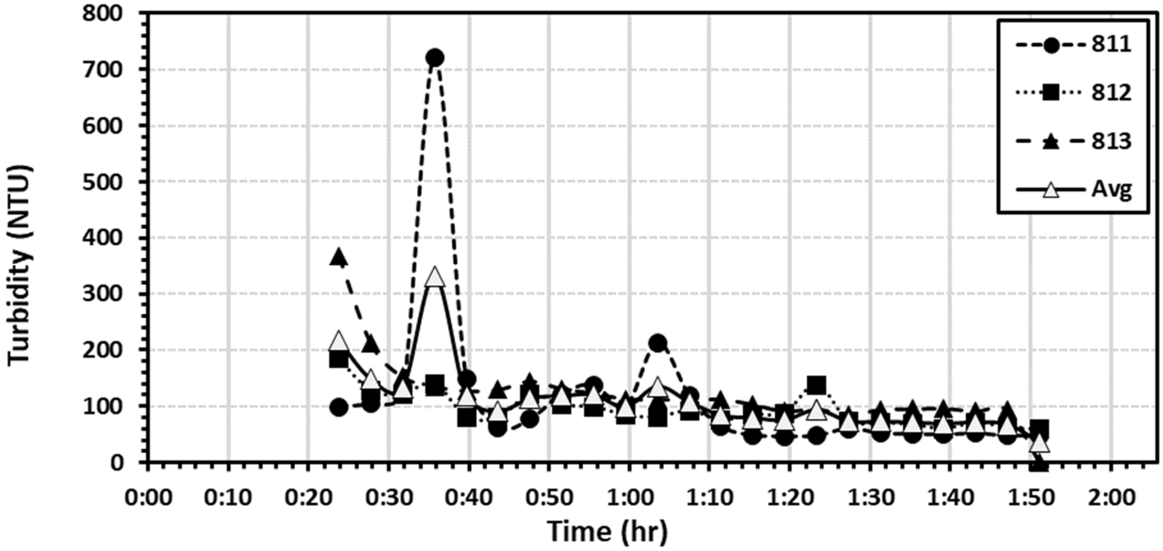
Bay 4 Bottom Sampling Location



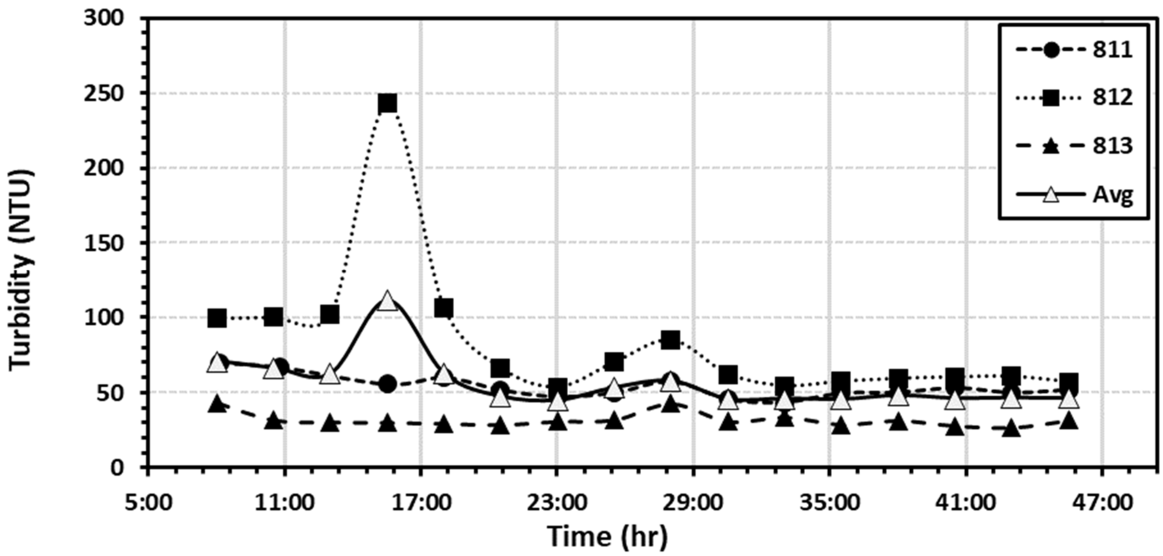
Bay 4 Top Sampling Location



Bay 4 Top Sampling Location



Discharge Sampling Location



Discharge Sampling Location

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