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ASSESSING PERFORMANCE CHARACTERISTICS OF SEDIMENT BASINS CONSTRUCTED IN FRANKLIN COUNTY

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ABSTRACT

The objective of the research project was to monitor the performance of newly designed sediment basins that were constructed on the ALDOT 502 project in Franklin County. The project included four tasks: (1) assess performance characteristics of sediment basins on the 502 project, (2) collect cost data and perform a literature review, (3) perform a survey of the current state-of-the-practice, and (4) prepare project reports. All tasks proposed have been completed. Through completing the study, the following conclusions have been developed:

- A field-scale data collection plan to monitor and evaluate sediment basin performance was developed and implemented using ISCO 6712 portable automatic stormwater samplers, flow modules, a rain gauge, and weirs.
- Sediment basin 4 on the 502 project did effectively remove sediments at the early stage of the construction when the basin's influent most likely contained relative large percent of large-size sediment particles. For example, sediment basin 4 removed 97.9% and 83.7% of sediments generated by rainfall events on 11/16/2011 and 12/5/2011.
- A floating skimmer allowed for effluent to be discharged uniformly and slowly, providing longer detention time for sediments to settle in the basin. Data analyses on decay (reduction) coefficients for total suspended solids (TSS) and turbidity allowed us to quantify the sediment-settling rate of soils on the 502 project in Franklin County, AL.
- Appropriate PAM (or floc log) added into inflow is crucial to aid sediment settling and reduce turbidity of effluent. For example, the performance of the basin 4 was superior for the rainfall event on 11/16/2011 when correct PAM was used in the inflow channel than the performance for the rainfall event on 12/5/2011 when wrong PAM was used.
- Rainfall events with subsequent high rainfall intensity impulses generated high turbidity inflows from the construction site and suddenly increased in-basin turbidity that could be several times higher than turbidity of water already in the basin.
- Resuspension of settled sediments significantly increased in-basin sediment concentration and turbidity when the basin has experienced a number of rainfall events with large amount of settled sediments inside basin.
- An under-designed sediment basin (from a volumetric standpoint) more frequently allowed highly turbid sediment-laden runoff to directly flow over the emergency spillway to downstream receiving water body.

Based upon the results of the data collected and observed site conditions throughout the research period, the following recommendations are provided to ALDOT to improve sediment basin design and installation to maximize performance efficiency and cost effectiveness:

- Use at least 3,600 cubic feet per acre draining to the basin from the contributing area to size the sediment basin.
- Increase the number of PAM floc logs placed at the bottom of inflow channel to properly dose for the average flow rate of 2-yr 24-hr runoff. The number of floc logs should be based on the manufacturer recommended dosage and the expected inflow rate of stormwater runoff.
- Consider increasing the number of floc logs placed on the sides of inflow channel to dose for the average flow rate of 10-yr 24-hr runoff. These storms will have higher water

depths, resulting in a greater amount of inflow, therefore requiring a higher dosage of PAM.

- The height of the baffles, once installed, should match the full depth of the sediment basin and not be installed below the minimum elevation of the emergency spillway.
- Include a sediment storage volume (e.g., 500 ft^3/acre disturbed) into the design specifications of sediment basins and a requirement to remove the sediment when it reaches one third of the height of the sediment storage volume.

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CHAPTER 1: INTRODUCTION

The discharge of sediment-laden stormwater runoff from construction sites has proven to be a substantial environmental problem leading to water quality degradation, second only to pathogens (USEPA 2005). Stormwater runoff, a form of nonpoint source (NPS) pollution, is a result of rainfall, flows from various land surfaces, often transporting natural and anthropogenic pollutants; and eventually discharges into lakes, rivers, and other water bodies. Based upon the amount and velocity of stormwater runoff at any particular time, flowing water can increase the likelihood of erosion and sedimentation when occurring over disturbed land areas, such as construction sites. Environmental concerns stem from implications that sediment-laden stormwater runoff is responsible for fish kills, degradation of aquatic habitats, and capacity reduction of navigable waterways (Novotny 1999). In an effort to provide a level of protection for natural resources in the U.S., federal and state regulations maintain that construction site owners and operators are to manage stormwater runoff in a way that prevents NPS pollution from occurring. The Clean Water Act, Section 319 was amended by Congress in 1987, establishing a national program focusing on the control of stormwater discharges, a form of nonpoint sources contributing to water pollution. Since that time, every state has adopted erosion, sediment, and pollution prevention programs to assist in controlling and reducing NPS pollution (USEPA 2003). However, the National Water Quality Inventory reported in 2000 that sedimentation impairs 84,503 river and stream miles, and sediment from construction site runoff is 10 to 20 times greater than those of agricultural runoff, and about 1,000 to 2,000 times greater than those of forest land runoff (USEPA 2005). It has been estimated that between 2 and 6 billion tons of eroded soil are deposited into U.S. water bodies every year (Line and White 2001). Much of this sediment-laden runoff could have been mitigated through the use of effective erosion and sediment control programs and practices; therefore, it is important to have better alternatives for controlling erosion and sediment on construction sites.

In 2008, the U.S. Environmental Protection Agency (USEPA) proposed a numeric limit of 13 nephelometric turbidity units (NTU) for construction site stormwater runoff. However, in November of 2009 the USEPA relaxed the stringent 13 NTU limit to a more realistic standard of 280 NTU – 40 CFR 450.22(a) and (b) (USEPA 2009b). This change came in response to comments suggesting that the 13 NTU limit would represent less than background levels at some sites and hence would be nearly impossible to meet the standard. The new policy required: (1) in 18 months (August 2011), construction sites 20 acres or larger will be required to monitor and comply with the numeric effluent limit, and (2) in four years (August 2014), construction sites 10 acres or larger will be required to monitor and comply with the 280 NTU numeric effluent limit. This was the first time that the USEPA imposed national monitoring requirements and enforceable numeric limitations on construction site stormwater discharges (USEPA 2009a). In November 2010, the USEPA posted a Federal Register notice advising that an indefinite stay would be placed on the numeric effluent limitation of 280 NTU and associated requirements effective on January 4, 2011. This action was necessary so that the USEPA could reconsider the basis for calculating the numeric effluent limitation (USEPA 2010). The USEPA issued another notice in the Federal Register in January 2012 requesting additional performance data of best management practices (BMPs) be used in controlling turbidity of water discharged from construction sites (USEPA 2012a).

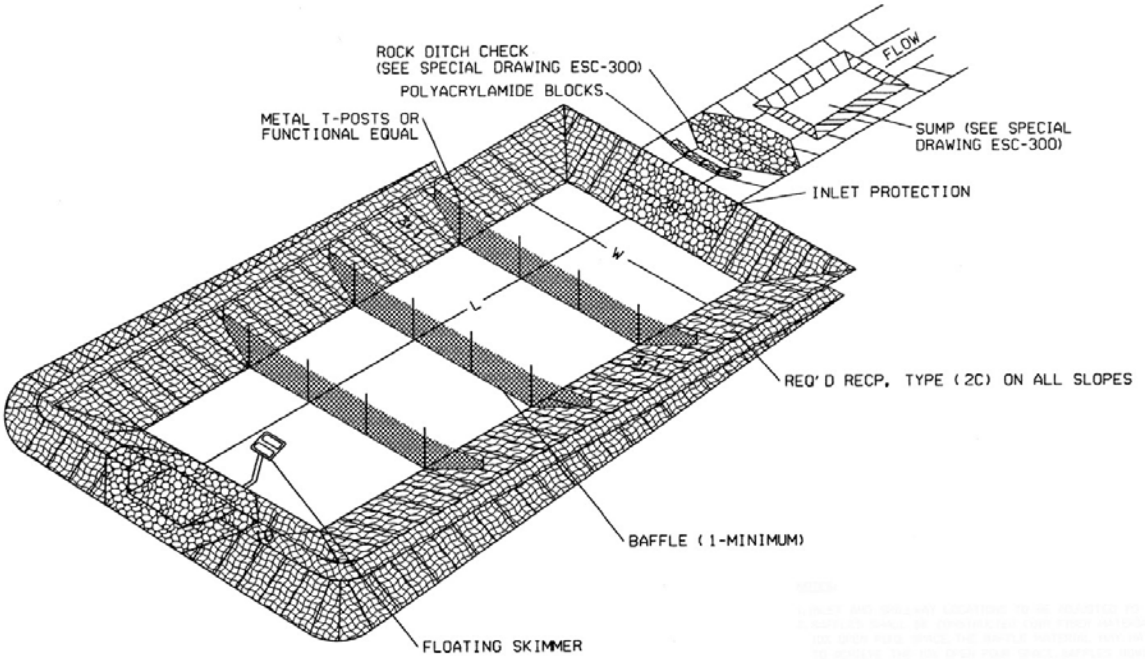
1.1 Background

Though the USEPA has stayed the proposed numeric effluent limit, the construction industry is still concerned about the implications of the new rules. In an effort to comply with USEPA regulations and maintain a daily average effluent discharge of 280 NTU from construction sites, many construction agencies currently employ structural and nonstructural BMPs that are aimed at reducing NPS pollutants to receiving water bodies. One of the most common practices employed on larger construction sites to reduce turbidity of stormwater runoff is to use sediment basins. Sediment basins are considered a structural measure on sites with earth disturbances (e.g., cut and fill sections) to minimize the amount of sediment leaving a site and entering receiving water bodies (Bidelspach and Jarrett 2004). Specifically, the Alabama Department of Transportation (ALDOT) uses sediment basins where it is practical on highway construction projects. Much of the design of sediment basins used on ALDOT sites originates from the Alabama Soil and Water Conservation Committee's (ASWCC) "*Handbook for Erosion Control, Sediment Control, and Stormwater Management on Construction Site and Urban Areas*," (also known as the Alabama Handbook) that provides general guidance on sediment basin design.

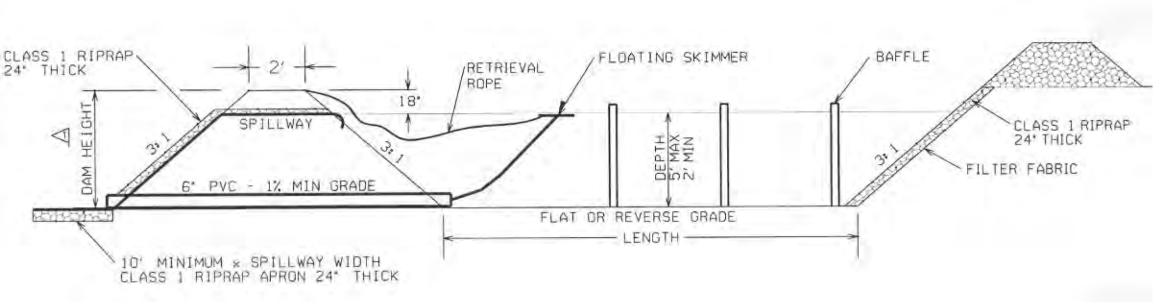
In the past, ALDOT highway construction sites have used a traditional sediment basin design adapted from the Alabama Handbook published in 2006. These basins used an 18" diameter, perforated riser pipe as the primary outlet structure as shown in Figure 1.1. The riser pipe also contained an opening at the top to act as an emergency spillway under extreme rainfall events. Routine stormwater inspections after rainfall events revealed that stormwater would seldom reach the top opening of the perforated riser pipe, thus indicating that sediment-laden stormwater was not being retained for a sufficient period of time and dewatering the basin from the entire height of the water column. Adequate detention time is necessary to allow enough residence time for suspended sediment particles to settle out. Inadequate residence time results in turbid water being discharged into nearby creeks. Therefore, using a perforated riser pipe for dewatering has proven to be an inefficient method for reducing turbidity of stormwater runoff entering a sediment basin due to the fact that it dewaters the basin from the entire height of the water column while also not providing enough residence time.

In an effort to improve the performance of sediment basins being used on highway construction projects and meet the new USEPA regulations, ALDOT updated the design provided in the 2006 Alabama Handbook to a newer, more efficient sediment basin design. The newly designed sediment basin, as documented in the 2009 Alabama Handbook, uses a Faircloth skimmer® as the primary dewatering device with a rock-lined emergency spillway for extreme rainfall events (Figure 1.2). The new basin design also uses three baffles inside basin, polyacrylamide (PAM) at the inflow channel, as well as a sump, rock ditch check, and rip-rap lined inflow channel. An optimal length-to-width ratio and minimum depth are also considered in the new sediment basin design to maximize turbidity reduction efficiency and promote settlement of suspended sediment.

Figure 1.1: Example of the 2006 sediment basin design with a perforated riser pipe.



(a) Isometric View



(b) Profile View

Figure 1.2 New sediment basin design used at ALDOT 502 construction project (ALDOT design drawing).

The ALDOT 501 construction project was to add additional lanes on SR-24 from SR-247 (east of Red Bay) to CR-21 at Dempsey in Franklin County, Alabama (7.8 miles in project length). In the 501 project, a traditional sediment basin design, with a perforated riser, was used (Figure 1.1). In the ALDOT 502 construction project in Franklin County, which added additional lanes on SR-24 from CR-21 at Dempsey (ending point of the 501 project) to CR-524 (through SR-49/187 near Belgreen), it was planned to install five sediment basins as a part of the sediment control measures. For the 502 construction project, it was the first time for ALDOT to implement the new design of sediment basins (Figure 1.2). Since this was a new design, currently the overall sediment removal and turbidity reduction performance of these five sediment basins using the new installation standard were not known.

1.2 Research Objective and Tasks

The objective of the study was to monitor and document the performance of newly designed sediment basins that were constructed for the 502 project in Franklin County. The following tasks were proposed by the research team to achieve the objective:

Task 1 – Assess performance characteristics of sediment basins on the 502 project,

Task 2 – Collect cost data and perform a literature review,

Task 3 – Survey of the current state-of-the-practice, and

Task 4 – Prepare final project reports documenting the findings.

For Task 1, originally five sediment basins were planned to be constructed on the 502 project. In the areas for which basins 2, 3, and 5 were planned to be constructed, bedrock was encountered during excavation within 3 feet of the surface. To construct the sediment basins, bedrock would have had to have been blasted, drastically increasing the associated installation costs. To stay within the budget, those three basins were omitted by ALDOT and other erosion/sediment controls were deployed in those areas to control erosion and sediment-laden discharges from the construction site after rain events.

Sediment basin 1 was constructed in March and April of 2011, but wet weather conditions at the location where the basin was constructed prevented researchers from properly installing the data collection equipment after the basin was initially built; therefore sediment basin 1 was not monitored. An equipment installation plan was developed before the construction of sediment basin 4. Therefore, all data collection for Task 1 was performed on sediment basin 4 at the 502 construction project in Franklin County.

1.3 Information on Sediment Basin 4

Sediment basin 4 was located in a fill section between STA 919+00 and 921+00 (Figure 1.3). The contributing drainage area of the basin was constantly evolving during the first four months of use, as progress was being made on a large cut section in the area upstream of the sediment basin. For this reason, two inflow channels were used to guide stormwater runoff into the basin. The first inflow channel built served as the primary inflow channel to the sediment basin for the first four months, until the majority of stormwater from the site could no longer reach that channel. Near the end of construction progress made on the cut section upstream from the sediment basin, a new primary inflow channel was constructed to accommodate the additional runoff generated on-site. The old inflow channel was kept active as a secondary inflow channel, as some of the runoff from the contributing area still flowed into that channel.

The size of sediment basin 4 in Franklin County, AL was originally designed to accommodate 670 yd^3 (18,090 ft^3) of stormwater, based on sediment basin dimensions given on Sheet No. 86-1 of the plan set in reference to project no. APD-0355(502). The bottom length and width of the basin were designed as 76 ft and 23 ft given on Sheet No. 86-1, respectively; therefore, the length to width ratio was 3.3:1. The side slopes of the basin were designed as 3:1 (horizontal:vertical), and the basin depth was 5 ft. Based on the design bottom length, width, and side slopes of the basin; computed storage for this trapezoidal sediment basin with a rectangular base using standard equation provided by Akan and Houghtalen (2003) was 654.3 yd^3 (17,665 ft^3) at the maximum design depth of 5 ft. If the bottom width was changed from 23 ft to 24 ft, computed storage would be 671.1 yd^3, which is greater than required storage of 670 yd^3.

A minor field adjustment during construction added an extra 1.5 ft of depth (i.e., sediment and dead storage) – adding 97.1 yd^3 (2,622 ft^3) of additional volume of storage to the basin. The dead storage was a 1.5 ft deep rectangular basin that had original design bottom length and width (76 ft by 23 ft). The total computed storage volume becomes 751.4 yd^3, or 20,287 ft^3, which is larger than originally designed storage of 670 yd^3 for the basin. Figure 1.4 shows storage as function of depth or water level for the sediment basin 4 with a maximum depth of 6.5 ft.

Considering the total contributing watershed area, 9.21 acres (Figure 1.3), intended to drain into the sediment basin, the storage provided by the basin was calculated to be approximately 2,203 ft^3/acre. Discounting the 97 yd^3 additional storage added during construction, the original sediment basin design provided 1,918 ft^3/acre of storage. Based on these calculations, the sediment basin was originally designed and sized using the out-of-date minimum sediment basin storage design standard to provide 1,800 ft^3/acre of contributing area draining into the basin.

A 2.5 inches (in.) Faircloth skimmer® (http://www.fairclothskimmer.com/), which can have a maximum 2.5 in. orifice size, was used as a primary dewatering or outflow control device for the basin. The skimmer was leveled at 1.5 ft above the basin bottom (or just above the dead storage) when the basin is empty. The stormwater in the basin flows through the skimmer orifice to a 2.5 in. short pipe section (19 in. long), then to a 1.5 in. PVC long pipe (70 in. long), followed by a 4 in. short pipe section, and finally flows through a 6 in. pipe for outflow (Figure 1.5). Therefore, the effective orifice opening for 2.5 in. Faircloth skimmer was unknown due to the flow restriction of 1.5 in. of PVC pipe. The flow rate from the skimmer was measured in the field using a bucket that holds 1.281 gallons when full, and the average fill time was 3.397 seconds from repeating to fill the bucket for 10 times. The outflow rate calculated for the skimmer was 22.626 gpm or 0.0504 cfs, which is almost equivalent to flow rate of a 2 in. orifice opening using standard equations provided by skimmer manufacturer J.W. Faircloth & Son Inc. Figure 1.4 shows dewatering time of the basin 4 at different water levels, and the dewatering time varies with the water level inside the basin. When the basin is full (6.5 ft depth), the dewatering time is 4.05 days (or 97.3 hours) to discharge a total of 17,655 ft^3 or 754.3 yd^3 (excluding dead storage) stormwater runoff from the basin.

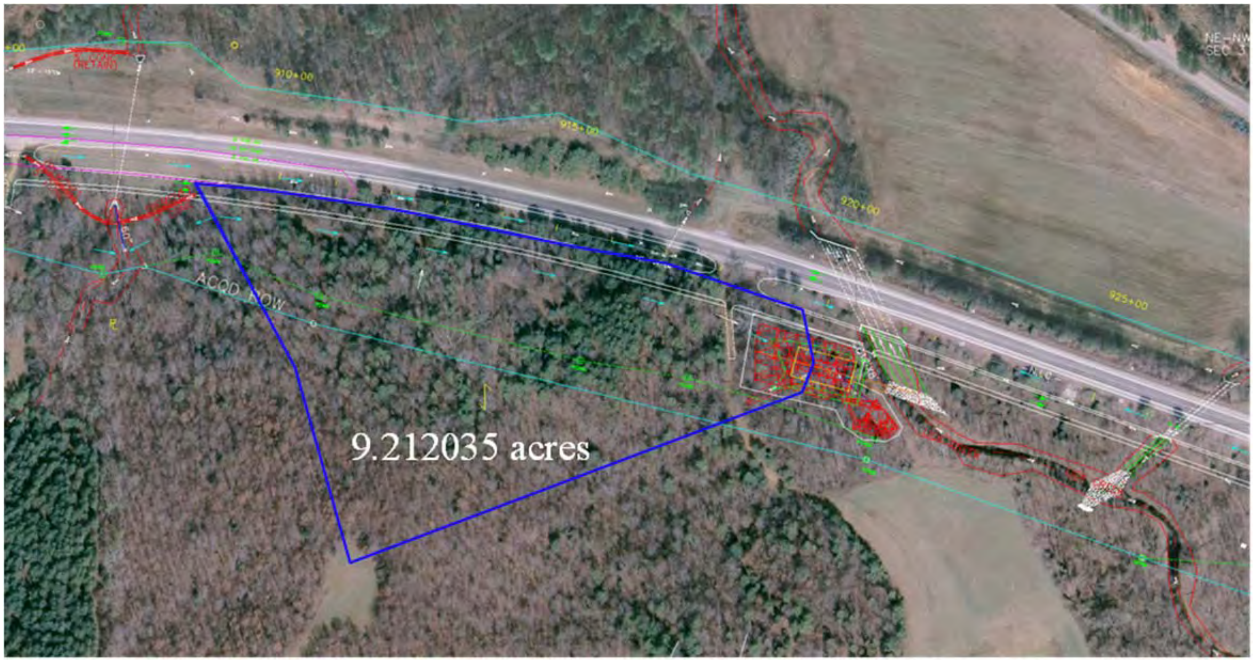


Figure 1.3: MicroStation overlay of sediment basin design and watershed area (aerial view of drainage area and sediment basin 4).

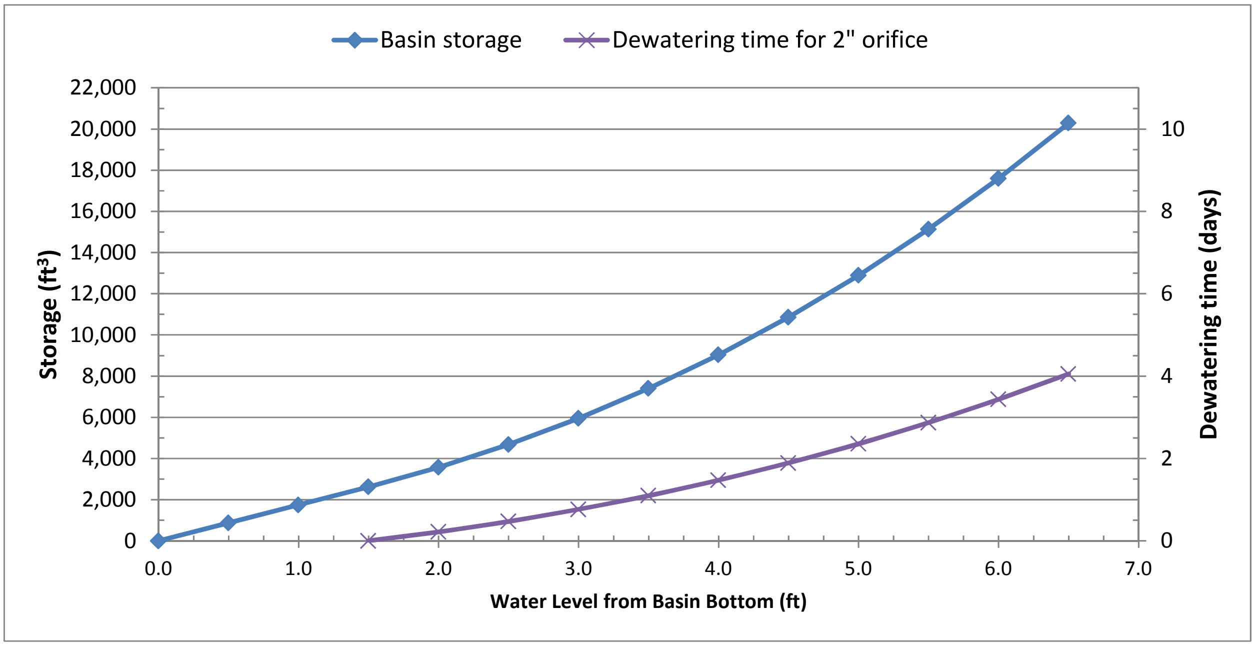


Figure 1.4: Storage and dewatering time of sediment basin 4 at different water levels.

(a) Basin 4 after construction (b) Faircloth skimmer

Figure 1.5: Sediment basin 4 with a 2.5 in. Faircloth skimmer.

1.4 Organization of Project Report

Two project reports were developed for the ALDOT project 930-791 to fulfill the Task 4 proposed. The first project report submitted was the summary of results from a survey that was conducted to evaluate the state-of-the-practice for sediment basin design, construction, maintenance, and inspection procedures by State Highway Agencies (SHAs) across the nation. The survey consisted of 68 possible questions in six categories: A. *Background and Experience*, B. *Design*, C. *Construction*, D. *Maintenance of Sediment Basins during Construction*, E. *Inspection and Monitoring*, and F. *Lessons Learned.* A total of 37 responses were received and analyzed. The responses included 37 SHAs (74% response rate) out of a total of 50 SHAs.

The objective of this report (Project Report No. 2) is to summarize results that the research team has accomplished through Task 1 and Task 2. The report only provides a concise summary of key information, methodology, findings of the study, and future recommendations. Detailed information related to the study can be founded from Christopher P. Logan's master thesis that is referenced in this report as Logan (2012). This report includes five short chapters. Following this chapter, '*Chapter 2*: *Literature Review*' examines the body of knowledge pertaining to research and experiments conducted to evaluate sediment basins as a whole, as well as different characteristic features of different types of sediment basins. '*Chapter* 3: *Methods of Data Collection*' outlines the design, methods, and procedures used in the data collection effort. '*Chapter 4: Results of Data Analyses and Discussion*', presents the basin-performance results of in-depth data analyses of rainfall, flow rate, total suspended solids (TSS) and turbidity data generated from rainfall events monitored at the sediment basin 4. '*Chapter 5: Conclusions and Recommendations*' provides an overall summary of the study and provides recommendations for ALDOT and future research development.

CHAPTER 2: LITERATURE REVIEW

Sediment basins are a structural BMP used on earth disturbance sites to minimize the amount of sediment leaving a site and entering receiving waters (Bidelspach and Jarrett 2004). Sediment basins are impoundment structures designed to receive sediment-laden stormwater runoff and provide an opportunity for the removal of suspended sediment. This process is achieved by detaining the runoff long enough for the suspended sediment to settle under the influence of gravity before discharging to the uncontrolled environment (Fennessey and Jarrett 1997; Millen et al. 1997). Sediment basins are commonly used for controlling sediment loss from construction and mining sites (Millen et al. 1997).

Sediment and detention ponds have shown high removal efficiencies for suspended solids and for heavy metals and organic compounds that have attached to soil particles (Bentzen et al. 2009). The removal efficiency of sedimentation control devices depends on factors such as the intensity and duration of storm events, topography and extent of construction sites, soil type, the amount of vegetative cover, and the system of practices implemented (Line and White 2001).

2.1 Sediment Basin Design Practices

2.1.1 *Sizing sediment basin*

A few major parameters must be carefully considered when designing a sediment basin. One such parameter is the size of the basin. The usual methods of regulating sediment basins are through performance standards, which specify effluent concentrations, and/or hydraulic design standards (Millen et al. 1997). According to hydraulic standards, sufficient volume must be provided to store sediment-laden runoff water so that the suspended sediment has time to settle from the water (Millen et al. 1997; Bidelspach et al. 2004). In the 2006 edition of the Alabama Handbook (ASWCC 2006), a sediment basin was considered to have sufficient volume if it was designed to capture 0.5 inch of runoff per acre of drainage area, which is equivalent to capturing 1,800 ft^3/acre of stormwater from the contributing drainage area and was adapted from NCDOT design standards (NCDOT 2006). A new design standard (ASWCC 2009), adopted by the state of Alabama, required capturing 3,600 ft^3/acre of stormwater from the contributing drainage area (ADEM 2011), or 1.0 inch of runoff per acre of disturbed area for sediment basins that serve an area with 10 or more disturbed acres at one time (Kalainesan et al. 2008). Different design rainfall depths falling on contributing areas with different antecedent moisture contents, surface covers, and soil types could produce the one inch of runoff from disturbed areas. Therefore, sizing sediment basins based on either 1,800 ft^3/acre or 3,600 ft^3/acre of disturbed area does not give designers any idea what risk the sediment basin would have during the lifespan of the basin under various rainfall events.

To size a basin properly, one must determine the particular design storm event that is being considered for the site. The most common storm events that are factored into sediment basin design are 2, 5, 10, 25, 50, and 100 year (return period) storms (Hershfield 1961). These storm depths are determined by the National Oceanic and Atmospheric Administration (NOAA) for each state taking into account the storm durations (i.e., 30 min, 1, 2, 3, 6, 12, or, 24-hr) and the probability of that storm occurring, based on historical data. For any hydrologic design, the probability *R*, called risk, that a *T*-year design storm will be equaled or exceed at least once in ***n*** successive years, is defined by equation (2.1) (Viessman and Lewis 2003).

$$R = 1 - \left(1 - \frac{1}{T}\right)^n \qquad \textbf{(2.1)}$$

The typical storm used for the design of sediment basins is a 2-year, 24-hour storm. In Franklin County, Alabama, a 2-year, 24-hour storm has a rainfall depth of 3.9 inches. The storm typically used to design an emergency spillway for a sediment basin is a 10-year 24-hour storm, which is equivalent to 5.6 inches of rainfall in Franklin County. If a sediment basin is designed using 3.9 in. rainfall depth, the risk that the basin will be overflowed for the next 2 year ($n = 2$) is 75% based on the equation (2.1). Using the precipitation depths, provided by NOAA, for the nearest location to the sediment basin, the volume of runoff generated for the design storm can be estimated after a rainfall loss method is selected and used; thus, a basin volume is determined.

To properly calculate the runoff volume for the design storm, it is necessary to select or use appropriate methods to compute effective rainfall depth after considering various rainfall losses. There are many factors affecting rainfall losses for converting rainfall into runoff. The major factors affecting runoff generated from a rain event are rainfall, antecedent moisture content, surface cover, and soils (Pitt et al. 2007).

For the first step sizing a sediment basin, an estimate of runoff volume in mm or inches is needed. Volumetric runoff coefficient R_v (Pitt et al. 2007; Dhakal et al. 2012) and NRCS curve number (NRCS 1986) can be used to compute runoff or effective rainfall for small watersheds such as construction sites. Pitt et al. (2007) recommends use of the SCS (NRCS) TR-55 method for construction site hydrology evaluations. The runoff depth in TR-55 is calculated using Equation (2.2) as (NRCS 1986):

$$Q = \frac{\left[P - 0.2\left(\frac{1000}{CN} - 10\right)\right]^2}{P + 0.8\left(\frac{1000}{CN} - 10\right)} \qquad \textbf{(2.2)}$$

where Q is the runoff depth in inches, P is the gross rainfall depth of a design storm, and CN is curve number as function of land use, hydrologic soil group, and antecedent soil moisture conditions (NRCS 1986; Viessman and Lewis 2003). For example, newly graded construction areas (no vegetation) with soils of the hydrologic soil group C have a curve number CN = 91 (NRCS 1986; Pitt et al. 2007). For 3.9 in. and 5.6 in. design storms in Franklin County, the runoff depths are 2.9 in. and 4.6 in., respectively, when CN = 91 is used. Sizing a basin solely on the 1,800 or 3,600 ft^3/acre standard procedures sometimes results in insufficient basin volume leading to frequent overflow through the basin's emergency spillway that can bring large amount of sediments to the downstream receiving waters.

Rauhofer et al. (2001) studied effectiveness of sediment basins that do not totally impound a runoff event. When a basin is undersized, the basin's ability to remove the sediment is controlled by the flow from both the principal and the emergency spillways because part of runoff flows directly to downstream receiving water body through emergency spillway. When sediment–laden runoff enters a sedimentation basin that has a volume only half the size of the runoff volume, a skimmer and a perforated rise as principle dewatering device yielded almost the same sediment retention efficiency (94.2% and 91.7%, respectively) (Rauhofer et al. 2001).

To properly calculate the runoff volume for the design storm, the contributing watershed area for the sediment basin must also be calculated. To correctly determine the contributing watershed area for a sediment basin, a watershed delineation must be established. There are five steps in creating a watershed delineation (Pitt et al. 2007).

To ensure that the proper size of the basin has been determined based on runoff hydrographs before and after the development and flow routing through the basin, a rainfall-runoff model is necessary to generate runoff hydrographs flowing into the basin. Many stormwater simulation models or methods have been developed (Viessman and Lewis 2003), for example, the modified rational method, SCS TR-20 method, SCS TR-55 tabular hydrograph method, SCS TR-55 graphical method, U.S. Army Corps of Engineers HEC-1/HEC-HMS (Pitt et al. 2007).

To implement various rainfall-runoff models, the designer must then calculate the time of concentration (T_c) for the watershed area. The T_c is defined as the total time for runoff to travel from the hydraulically most remote point to the point of interest, e.g., the outlet of the watershed that flows into a sediment basin. The T_c affects the peak and shape of the hydrograph of the inflow to the sediment basin, often changing based on the stage of construction (Pitt et al. 2007). Many empirical equations have been developed to estimate T_c (Viessman and Lewis 2003). Pitt et al. (2007) recommends two methods of estimating T_c: (1) the Kirpich method and (2) segmental method.

With the T_c calculated, the peak runoff rate can be calculated, e.g., using the rational method (Pitt et al. 2007). The rational method is an empirical formula used for computing peak rates of runoff that has been used in urban areas for more than 100 years. The Rational method is typically limited to areas of 20 acres or less that do not vary in surface character or have branched drainage systems.

2.1.2 *Estimation of sediment volume*

Sufficient volume must also be provided to store the sediment collected, in addition to the runoff volume (Bidelspach et al. 2004). Several factors need to be considered when determining the amount of sediment eroded in a given watershed area such as climate, soil characteristics, land shape, and land use (Pitt et al. 2007). Sizing a basin solely on the 1,800 or 3,600 ft^3/acre standard procedure sometimes results in insufficient sediment volume in the basin leading to sediment resuspension and release through the basin outlet, increasing the concentration of particulate contaminants leaving the basin (Kalainesan et al. 2009). To properly size the basin, a quantity estimation of the sediment volume for the total contributing area for stormwater runoff must be determined, e.g., by applying the Revised Universal Soil Loss Equation, or RUSLE (Kalainesan et al. 2009). RUSLE can be used to calculate the sediment yield from a sediment basin's watershed area, and thus, determine the sediment storage volume and associated frequency of sediment removal for the basin. RUSLE is a set of mathematical relationships that estimate average annual soil loss and sediment yields resulting from interrill and rill erosion. It was derived from the theory of erosion processes, using more than 10,000 plot-years of data from natural rainfall simulation plots (Kalainesan et al. 2009). RUSLE is mathematically defined by Equation (2.3) (Pitt et al. 2007; Kalainesan et al. 2008, 2009) .

$$\boldsymbol{A = R * K * LS * C * P} \tag{2.3}$$

where A is annual erosion rate, (tons/acre-year, tons/m^2-year), R is rainfall factor (rain energy), (ton-acre-hour/acre-foot-ton-inch, ton-m^2-hour/m^3-kN-cm), K is soil erodibility factor, LS is length–slope factor, (ft/ft, m/m), C is cover management factor, and P is supporting practices factor.

The latest version of RUSLE is RUSLE2, a Windows-based program that has a user friendly graphical user interface and can be applied to complex slope configurations including cut and fill slopes – typical of highway construction sites (Kalainesan et al. 2009). RUSLE2 can be used to estimate soil loss from construction sites, mined land, and reclaimed land, in addition to agricultural land. Applications that relate RUSLE2 to construction sites are assessment of hill slope configurations, obtaining erosion-control or erosion-reduction credit for the surface rock fragment covers, and analyses of the effects of straw mulch, random roughness, and changes through time due to mulch decomposition and deterioration of the surface roughness due to rainfall (Pitt et al. 2007; Kalainesan et al. 2009).

2.1.3 *Geometry of sediment basin*

In addition to sufficient volume being provided for sediment-laden stormwater runoff, the shape of a sediment basin also plays a key role in the overall performance (Bidelspach et al. 2004). The reduced efficiency of many basins is often due to short circuiting and dead-space within the basins (Millen et al. 1997; Bidelspach et al. 2004; Glenn and Bartell 2008). In an effort to promote settling and reduce the negative effects of short circuiting and dead storage, the USEPA recommends that the ratio of the length of flow path to the effective width be greater than 2:1 (Madaras and Jarrett 2000).

Surface area is one of the most important design considerations for sediment removal (Pitt et al. 2007). It has also been noted in previous studies that surface area should not be compromised in efforts to increase basin length (Madaras and Jarrett 2000). To ensure structural stability, a typical sediment basin is currently constructed with tapered side walls, and because of this, the surface area of the basin varies depending on the depth of the runoff in the basin (Kalainesan et al. 2008).

2.1.4 *Detention time of sediment basin*

Another factor that is important to consider in the design of sediment basins is the amount of detention time the sediment basin maintains. Basin detention time is the time required for steady-state flow to entirely displace the basin volume. In theory, it is also the amount of time each fluid particle stays in the basin – or in the specific case of a sediment basin, the amount of time required for the smallest settleable particle to be detained (Madaras and Jarrett 2000).

Removal of pollutants in a detention pond is considered to be a function of its detention time (Hossain et al. 2005). Requiring a minimum detention period ensures a minimum opportunity for removal of suspended sediment (Jarrett 1993). Research by Bidelspach (2004) observed that the sediment captured and sediment retention efficiency of sediment basins increased as the detention time increased, with as much sediment retention efficiency as 98% over a seven day detention period. However, researchers have found that designing a sediment basin based on detention time alone is not effective due to numerous other factors that affect efficiency (Bidelspach et al. 2004). Some of the important factors that can directly affect efficiency of a basin in retaining sediments and reducing turbidity include short-circuiting, resuspension, in-basin erosion, high turbidity influx from subsequent rainfall impulses, etc.

2.2 Sediment Basin Performance

The efficiency of a sediment basin is based entirely on the performance. A poorly performing sediment basin does not necessarily mean that the poor performance of the basin originated from a poor design. The ability of a sediment basin to remove suspended solids can be a function of pollutant concentration in the runoff, runoff volume, storm duration and intensity, antecedent dry period, and surrounding land uses (Barrett et al. 1998). Beyond design, there are several characteristics of sediment basins that have a large effect on the performance, or sediment removal efficiency, of the basin. These characteristics include various types of inflow control devices, particle settling agents, the use of baffles, erosion control and basin stability practices, and outflow control devices.

2.2.1 *Inflow control devices*

Inflow control devices include various types of check dams. Check dams are designed to impound flow in channels, thus reducing the velocity of water flowing through the channel. Check dams are often constructed of rock, gravel bags, sandbags, fiber rolls, or other reusable products (McLaughlin and McCaleb 2010). The location of a check dam has been shown to be an important management decision that determines the effectiveness of sediment trapping (Hassanli et al. 2009). McLaughlin and McCaleb (2010) found turbidity within channels to be significantly reduced with excelsior wattles compared to rock, with the rock covered with an intermediate excelsior blanket. The drawback to fiber roll check dams is that they lack the strength against high velocity flows and ultimately fail, where rock check dams are more readily able to provide adequate strength against such flow rates (Pitt et al. 2007).

2.2.2 *Particle settling velocity and settling agents*

The mechanism in wet ponds for removing suspended solids from stormwater is simply gravitational settling (Comings et al. 2000). A single particle in clear, quiescent water can eventually settle with a constant velocity (Zhou and McCorquodale 1992). This is known as the terminal velocity, according to Stoke’s Law (Pitt et al. 2007), where particle size is directly related to settling velocity using appropriate shape factors, specific gravity, and viscosity values (Zhou and McCorquodale 1992).

Stormwater runoff on construction projects may contain very fine suspended sediments, too small to settle under normal conditions. Smaller particles are more susceptible to resuspension due to position on the basin floor (e.g., last to settle), as well as size and mass (Madaras and Jarrett 2000). Bhardwaj et al. (2008) observed that neither TSS nor turbidity was reduced in the open stilling basin (with no baffles) at 1.5 hr and 24 hr detention times, suggesting that the suspended materials were very resistant to settling in a basin. It was discovered that clay and silt fractions are the greatest contributors to turbidity of runoff (Bhardwaj and McLaughlin 2008).

Chemical treatments using coagulants or flocculants promote the process of suspended sediment bonding together to enhance settling. The particle settling agent that is used in combination with a sediment basin is typically referred as polyacrylamide (PAM). PAM has been found to be an effective chemical flocculant without causing aquatic toxicity at typical treatment concentrations (Bhardwaj and McLaughlin 2008). PAM is a high molecular weight synthetic polymer that can be manufactured to have a variety of chain lengths and to be anionic, nonionic, or cationic in net charge (Bhardwaj and McLaughlin 2008). The preferred form of PAM is the anionic form due to its low aquatic toxicity, and because it binds to suspended sediment largely through rapid and irreversible cation bridging, pulling it together into flocs (Bhardwaj and McLaughlin 2008). The resulting flocculation process from PAM usage can reduce suspended sediment concentrations by up to 99%, depending on the sediment mineralogy (McLaughlin and Bartholomew 2007). Results of previous studies have shown that PAM reduced sediment and total phosphorus losses from irrigation furrows by 50% to 80% by both reducing soil erosion and increasing infiltration (Bjorneberg and Lentz 2005).

Physically, PAM comes in three different forms: granular (powder), emulsion, and floc logs (a.k.a floc blocks) (Pitt et al. 2007). PAM powder is typically applied manually or automatically with a broadcast spreader in a pound per acre distribution, where application rates vary depending on soil type. Polyacrylamide emulsion is one kind of liquid flocculant with high efficiency and high concentration when granular PAM is emulsified in water and commonly used in sewage treatment plants. When applied to a construction site sediment basin, PAM is typically applied either in granular or solid form (floc logs, a.k.a floc blocks). Solid PAM blocks, considered a passive PAM dosing method, were shown to reduce turbidity significantly relative to untreated water, and granular PAM had similar results (Bhardwaj and McLaughlin 2008). One disadvantage of the use of floc logs is that the exact dosage of granular PAM is unknown; however, passive PAM dosing is a viable, low cost option because passing water over a solid block requires no power (Bhardwaj and McLaughlin 2008). Bhardwaj et al. (2008) found that both types of passive PAM dosing (i.e., granular and floc logs) reduced the turbidity of the water by up to 88%, with turbidity levels <50 NTU in discharges.

2.2.3 *The use of baffles*

Another element that promotes particle settling and is commonly used in sediment basins is baffles. Baffles are commonly used as energy dissipaters and play an important role in providing particles an increased opportunity to settle by reducing turbulence, which contributes to prolonged suspension in the water column (Bhardwaj and McLaughlin 2008). Evidence of optimal open space fraction (the area occupied by open pores divided by the total area) of 5% to 10% had been suggested by Thaxton et al. (2004), but has not been further investigated.

It has been demonstrated that turbulence likely maintains particles in suspension much longer than previously expected in sediment basins (Millen et al. 1997; Bhardwaj and

McLaughlin 2008). Baffles are also used to increase the hydraulically effective width, creating a more uniform flow pattern in the basin (Bhardwaj and McLaughlin 2008). In a recent study, a short baffle was placed near the inlet of the sediment basin at an angle of 60 degrees, and dead volume was found to decrease to 6% with a longer actual residence time which was 79% of the theoretically calculated residence time (Hossain et al. 2005).

Extensive testing at a research site with a perforated riser pipe documented only 1.6% increase in efficiency when using porous baffles. Studies by Bhardwaj et al. (2008) observed that the introduction of porous baffles produced a pattern of high TSS near the surface within a sediment basin, but showed little improvement after the first three sampling points (immediately after each baffle). Thaxton and McLaughlin (2005) found that jute/**Error! Reference source not found.** baffles had 30% reduction in TSS and 40% reduction in turbidity, largely outperforming baffles made of silt fence or triple-layer tree protection by 20 to 40%.

Due to the small size and nature of some suspended particles in stormwater runoff on construction sites, the decrease in turbulence due to baffles does not have a significant effect on their settling, especially without chemical treatment for flocculation (Bhardwaj et al. 2008). This was confirmed by Thaxton and McLaughlin (2005) when they found that the improvement in hydraulics that porous baffles produce is not sufficient to settle the fine fraction. Baffles produce a more dramatic drop in TSS (26%) as opposed to the drop in turbidity (19%) when using a PAM treatment, however this is only noticeable after the first baffle and is inconsequential for subsequent baffles (Thaxton and McLaughlin 2005; Bhardwaj and McLaughlin 2008). Similar results were found in a related study by Bhardwaj et al. (2008) where coir baffles (3, centered and spaced 20% of total length of the 2:1 basin, **Error! Reference source not found.**) that were installed to reduce turbulence and induce plug flow had little effect except enhancing mixing and contact in the first basin cell during passive PAM treatment.

2.2.4 *Erosion control and basin stability practices*

The flow and geometry of a typical sediment basin create a complex combination of hydraulic processes that corrupt the ideal settling environment. The random eddies and currents accompanying turbulent flow cause scour currents in a basin. Scour currents induce forces that resuspend particles that would have otherwise settled to the bottom of the basin (Madaras and Jarrett 2000). Previous research observed that more than 25% of sediment by volume might be lost from the basin due to resuspension (Kalainesan et al. 2009). To prevent particle resuspension and basin scour, as well as promote controlled infiltration, erosion control products, such as excelsior matting and filter fabric, and basin stability practices (2:1 side slopes, rip-rap slope coverage, etc.) are often used with active sediment basins. Particle resuspension can be due to bed shear stresses that are caused by wind induced currents and waves in shallow basins (Bentzen et al. 2009).

It has been proven in past studies that high concentrations of resuspended particles during the first 30 minutes of an influent event were caused by the inflowing water eroding and resuspending the sediment delta left near the basin entrance from the previous event; however, as the basin’s water depth continued to increase, inundating the basin floor and previously deposited sediments, the percentage of resuspended sediment declined then remained nearly constant between 15% and 30% during the second half of the influent event (Madaras and Jarrett 2000). The majority of sediment loss from basins in past studies has been due to degradation and scouring of the basin abutment or dam (Fennessey and Jarrett 1997). Edwards et al. (1999)

found that sediments accumulated only on the bottom of the basin in close proximity to the outlet, where turbulence and scouring were minimized by the temporary pool of water during simulated storm events.

2.2.5 *Outflow control devices.*

Requiring a minimum detention period ensures a minimum opportunity for removal of suspended sediment. Alternatively, requiring a maximum dewatering period ensures that the basin's water storage volume will be available for storing subsequent runoff events. To achieve this control, the prescription of a particular type of primary dewatering device that takes into account the size and design storm of the sediment basin is often in order. Several different principle spillway configurations have been developed to reduce effluent concentrations. Primary dewatering devices come in many different forms, including natural infiltration, rock weir spillways, riser pipes, skimmers, and delay-time controlled valves just to name a few.

The least expensive, most desirable, and most common form of dewatering a basin is through gravitational dewatering. There are a few different types of gravitational dewatering principle spillways, including risers and skimmers. There are three common types of risers used for basin dewatering: (1) solid risers, (2) perforated risers, and (3) flashboard risers. Typical Faircloth skimmer (side view and close view) is given in Figure 2.1 (a) and (b).

(a) Typical Faircloth skimmer **(b) Close view of Faircloth skimmer**

Figure 2.1: Common risers and skimmer used for sediment basins.

Perforated riser principal spillways have been used extensively to control dewatering of sediment basins (Jarrett 1993) but are not effective in removing sediments. Millen et al. (1997) proposed the use of a skimmer as the principal spillway. This floating riser removed the basin water from the top of the water column where the highest quality effluent was expected (Bidelspach et al. 2004). A sediment basin equipped with a skimmer designed to dewater a construction site's 2-yr, 24-hr rainfall event has been shown to have a sediment retention efficiency of about 90% based only on those particles $< 45\ \mu m$ (Millen et al. 1997). Millen et al. (1997) determined that the majority of sediment loss from a basin with a skimmer occurred in the first 5 to 9 hrs after the start of the storm event.

Valves, often combined with delay-time control units, control the outflow of a sediment basin by opening to allow discharge after letting the sediment-laden runoff to be contained in the basin for a predetermined time period. The facts and experimental results of Bidelspach et al. (2004) have shown that when a delay-time was introduced between the inflow and outflow hydrographs, the sediment retention efficiency of the basin, with a 24 hr dewatering time, improved 92%, 94%, and 98% for particles >45 μm when the dewatering process was delayed by 0, 12, and 168 hrs, respectively. The delay-time control unit that can be paired with valves does three things: (1) continuously sense the depth of water in the basin, (2) receive and send electronic signals, and (3) open and close the valve inserted into the skimmer arm near the water surface (Bidelspach and Jarrett 2004). Programming the delay-time control unit according to accurate logic is important. Due to unfortunate circumstances of catastrophic equipment failure, the delay-time control unit and valve experiment conducted by Bidelspach et al. (2004) was never completed, thus no sediment retention efficiency results were ever attained.

In conclusion, there are several factors that must be simultaneously considered when planning and designing a sediment basin for use on a construction site. In order to have a sediment basin that not only detains water, but is also used as a polishing tool, the designer of the basin should consider the size of the watershed area, soil type, stormwater volume, and effluent TSS and/or turbidity limits – just to name a few. The next chapter provides a close look at various characteristics of a sediment basin, how to measure the performance of those characteristics, and a means of analyzing the data collected to reach an overall conclusion through results.

CHAPTER 3: METHODS OF DATA COLLECTION

The objective of the study was to monitor the performance of a newly designed sediment basin that was constructed for the 502 project in Franklin County. The specific tasks that were performed to accomplish the abovementioned research objectives include:

(1) Collect rainfall, flow-rate (i.e., inflow and discharge) data, and stormwater samples from inflow, in-basin, and outflow of the sediment basin.

(2) Perform laboratory analyses on collected samples for turbidity (NTU) and total suspended solids (TSS) (mg/L) levels.

(3) Sample retained sediment and perform gradation analyses.

(4) Determine sediment basin efficiency based on performance characteristics, sediment basin configuration, and results of data analyses.

The following section describes the methodology and data collection effort established for monitoring the performance of sediment basins on ALDOT 502 project. In total, five ISCO 6712 sampler units were used to collect water samples at various locations: inflow channels, within the sediment basin, and outflow of the basin. These five samplers were used in accordance with the following data collection plan.

3.1 Data Collection Plan

As a result of a large grading operation (cut) taking place in the upstream area of the construction site, this research project collected data from sediment basin 4 on ALDOT 502 project in Franklin County, AL in two phases. During the first phase of monitoring sediment basin 4, a single inflow channel (later to be deemed as the secondary inflow channel) was constructed to carry stormwater runoff into the sediment basin (as shown in Figure 3.1A). Figure 3.1B shows that there were two inflow channels during the second phase of monitoring sediment basin 4, with the newly added inflow channel acting as the primary inflow channel.

Figure 3.2 illustrates a typical sediment basin with a single inflow along with all the necessary structural members and sampling equipment used in the project. To monitor water quality in reference to sediment basin performance, five ISCO 6712 portable automatic stormwater samplers (i.e., samplers A, B, C, D, and E in Figure 3.2) were used to take stormwater samples at the following locations: inflow (samplers A and B shown in Figure 3.3A), within the sediment basin (samplers D and E), and outflow (sampler C), as shown in Figure 3.3B. The inflow sampler units monitored the inflow of stormwater into the basin from the primary channel (sampler B) that runs alongside the road bed, and from the secondary inflow channel (sampler A) coming from the hillside, as shown in Figure 3.1 and Figure 3.3.

Figure 3.4 shows a schematic diagram of the sediment basin 4 that gives approximate locations of the monitoring equipment (samplers A to E, inflow weirs, and rain gauge). The diagram (Figure 3.4) was used by the contractor to appropriately construct the basin (i.e., weir installation, baffle placement, PAM floc block placement, etc.) in order for the researchers to install all monitoring equipment in sediment basin 4.

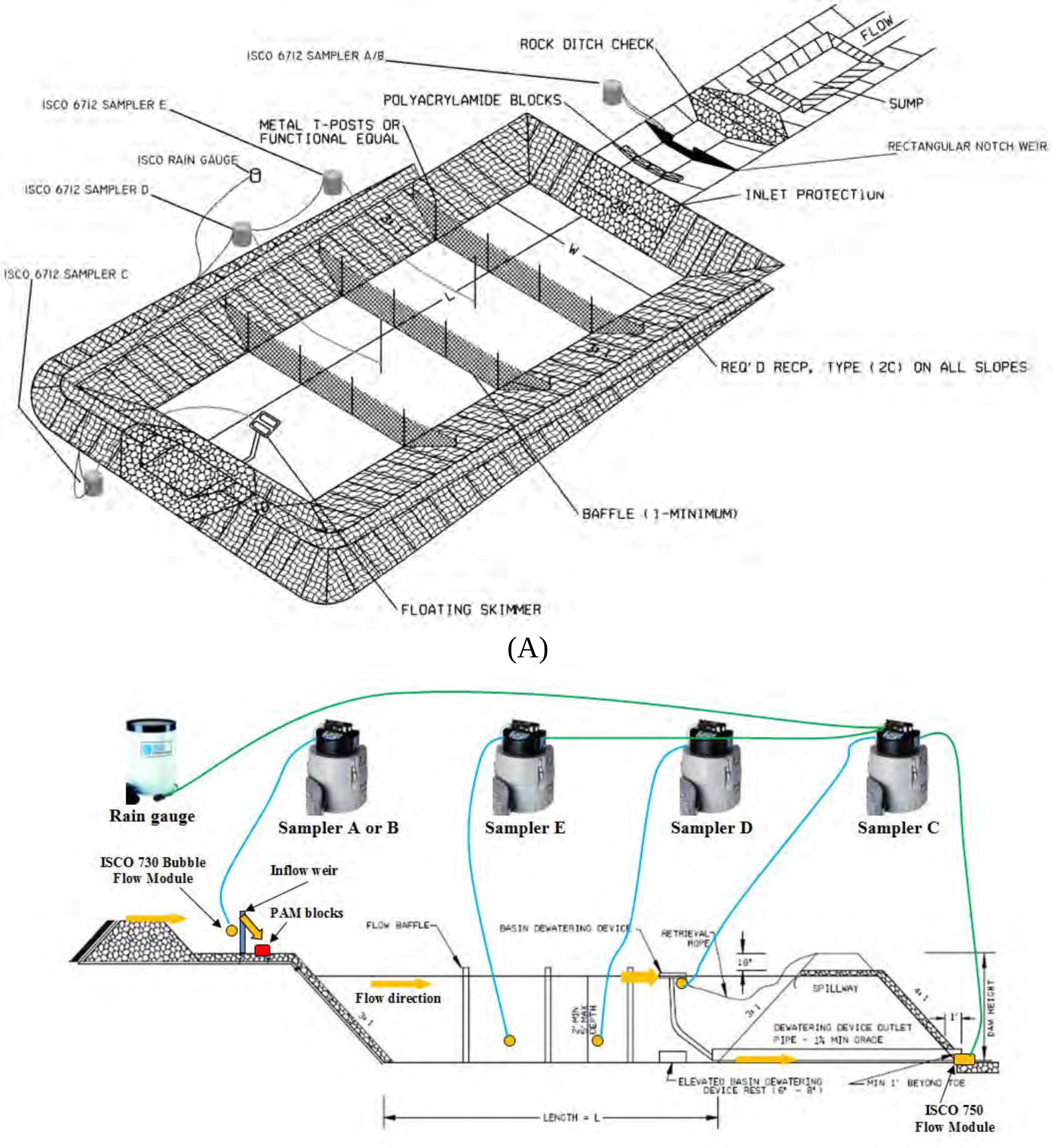
(A) Phase 1

(B) Phase 2

Figure 3.1: (A) ALDOT 502 project basin 4 phase 1 basin setup with one inflow channel and (B) phase 2 with two inflow channels. Arrows show runoff flow directions from contributing area into the basin.

3.1.1 *Utilizing PAM floc blocks*

For the new sediment basin design used on the ALDOT 502 construction project, the proper placement (location) of PAM floc blocks is important to ensure that sediment-laden stormwater inflow is properly dosed to promote flocculation of suspended sediment and deposition within the basin. Figure 1.2(a) and Figure 3.2(a) illustrate the special project drawing for the 502 project which shows the placement of 4 floc blocks in the inflow channel downstream of the rock ditch check structure. There is a special note given on Sheet No. 86-1 of the plan set in reference to project no. APD-0355(502) that states: “4. Payment for polyacrylamide block will be paid under item 655-W. Four (4) blocks shall be placed at the inlet end of the basin. Block condition shall be monitored and blocks shall be replaced when they have degraded to the point they no longer appear to be effective.” It was noted that the contractor followed this drawing and instruction on Sheet No. 86-1 of the plan set and only installed the requisite number (i.e., 4) of PAM floc blocks based upon the number shown on the special drawing without considering the actual amount of flow expected from the contributing drainage area.

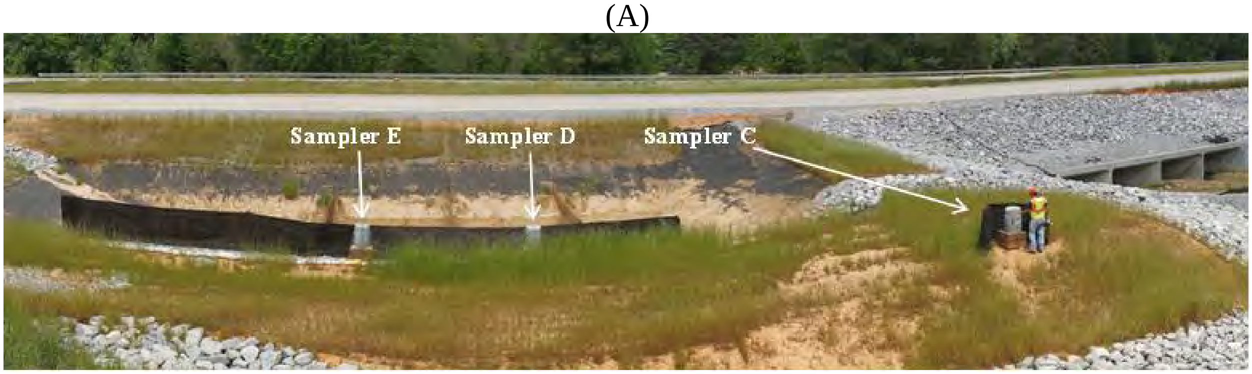


(A)

(B)

Figure 3.2: Typical data collection equipment setup for a sediment basin: (A) isometric view and (B) profile view.

(A)



(B)

Figure 3.3: (A) Samplers A and B for two inflow channels, and (B) Samplers C, D, and E for outflow and in-basin monitoring.

Soil samples were collected by the contractor and sent to Applied Polymer Systems (APS), Inc. for determining which type of floc block shall be used (Appendix A). APS recommended using floc log type of 706B and having a reaction or contact time of 40–45 seconds. The recommended dosage rate should be 50–60 gpm flow per each Floc Log placed in a series or in a row (Appendix A). Therefore, four floc blocks placed in the inflow channel downstream of the rock ditch check were dosed for a maximum inflow of 200 to 240 gpm or 0.446 to 0.535 cfs.

During the Phase 1 data collection period, the following situations occurred for the basin 4 creating the following conditions: (1) the correct type of PAM was used during 11/5/2011 to 12/4/2011, and (2) wrong floc logs were used from 12/5/2011 to 12/23/2011. During the Phase 2 data collection period, an inappropriate installation of weir at primary inflow channel (Figure 3.5) before 1/24/2012 resulted in limited contact between runoff and PAM for most of rain events from 1/7/2012 to 1/23/2012.

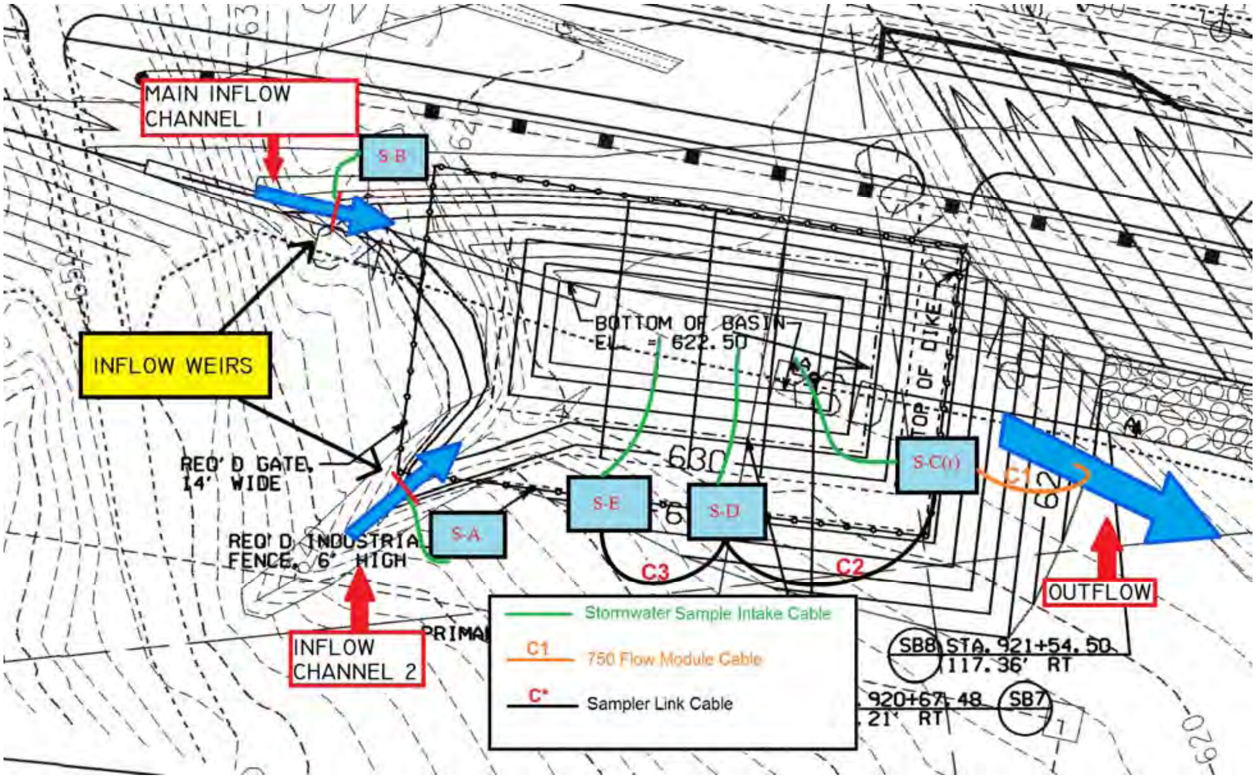


Figure 3.4: Schematic diagram for contractor to appropriately prepare the basin construction site assisting to install monitoring equipment in basin 4 [S-A stands for Sampler A, and S-C(r) stands for the Sampler C including a rain gauge].

3.1.2 *Rainfall and flow monitoring*

Sampler C was connected to an ISCO tipping bucket rain gauge (Figure 3.2 and Figure 3.4) to monitor the rain events on-site, giving accurate time stamped information regarding rainfall amounts and intensity.

Upstream of the sediment basin and following the rock ditch check dam, a rectangular notched weir was installed in each channel to gauge inflow into the basin as shown in Figure 3.2, Figure 3.4, and Figure 3.5. To properly accommodate flow in both channels, the rectangular notch weirs were cut to 3 ft. and 4 ft. in width for secondary and primary inflow channels, respectively, and 1.5 ft. in depth. The purpose of these weirs was to provide a means for determining the volume of stormwater inflow into the sediment basin as well as provide data collection points to take inflow water quality samples.

The ISCO 730 Bubbler Flow Module (Figure 3.2) was used to collect necessary data to determine inflow discharge and volume. The bubbler module took depth or pressure readings via a plastic tube (Figure 3.5) that was attached to the upstream side of the weir. The ISCO 730 bubbler module uses the plastic tube to emit a bubble in the upstream water and measures the pressure required to emit that bubble. With this, the module can calculate the depth of the water over the plastic bubble tube. The module has the particular type of weir (i.e., size and shape) programmed into it and was pre-calibrated to a zero level (based on mounting depth below the weir opening) at the base of the weir opening so that when water passed through the weir it was registered as a positive water level.

(a) Weir at secondary inflow channel.

(b) Weir at primary inflow channel

Figure 3.5: Weir installed on secondary and primary inflow channels, respectively. Bubbler tube for flow measurement and suction head pipe for collecting stormwater samples that were installed on primary (left) and secondary (right) inflow channels.

The water passing over each weir flowed over 4 anionic polyacrylamide (PAM) blocks (type 706B – Applied Polymer Systems, Inc.) that were secured on top of the riprap lined channels. The purpose of the PAM blocks was to aid in the flocculation of suspended sediment particles in the sediment-laden runoff and to promote quicker settling times of suspended sediment within the basin. These PAM blocks were specified by Applied Polymer Systems, Inc. to be the most efficient PAM blocks for the site based on a lab soil sample from the site. Immediately following the PAM blocks (in the direction of flow), the riprap inflow channel continued for 35 and 37 feet (for the secondary and primary inflow channels, respectively) before emptying into the basin. This provided a means of further agitating the sediment-laden stormwater through the remainder of the channel to aid in the flocculation of sediment particles that had been dosed with PAM.

The outflow of the sediment basin was monitored by an ISCO 6712 Sampler (sampler C), in conjunction with an ISCO 750 Flow Module, shown in Figure 3.6, mounted with a spring ring inside the specified 6 inch outflow pipe connected to a Faircloth Skimmer. The 750 Flow Module uses a radar producing instrument that senses the speed and depth of the water, in combination with the designed outflow of the skimmer determined using Manning's equation, collects one flow rate value per minute.

Figure 3.6: ISCO 750 Flow Module connected to the outflow pipe of the basin 4.

3.1.3 *Collecting stormwater samples*

Inflow sampler A took a 0.25L sample for every 50 ft^3 of inflow passing over the weir in the secondary inflow channel, and inflow sampler B took a 0.25L sample for every 150 ft^3 of inflow passing over the weir in primary inflow channel, because inflow volume is typically much larger from the primary inflow channel than from the secondary inflow channel. For each inflow sampler (A and B), four 0.25L were collected in a single 1L container to create a composite stormwater sample to provide a measure of incoming water quality over the course of a rainfall event. In total, each of the inflow samplers had the capability of each collecting up to 96, 0.25L samples in a single program spanning a single rainfall event with a combined maximum inflow volume of 19,200 ft^3. The inflow amounts (flow rates and volumes) were monitored using the ISCO 730 Bubbler Flow Modules mounted on the upstream side of the weirs and directly connected to the inflow samplers, as shown in Figure 3.2.

Sampler C was activated once 0.002 cfs of outflow was detected by the flow module inserted into the outlet pipe of the skimmer and pulled a water quality sample from just below the intake orifice of the Faircloth skimmer (schematically shown in Figure 3.2). Sampler C acquired water quality samples from inside the filter grate of the Faircloth skimmer, attached using plastic zip ties, ensuring that it was submerged when a sample was taken. Sampler C drew a sample immediately after outflow was detected and continued drawing samples at a one hour interval until the program was complete (23 hours). Sampler C collected a total of 24, 1L stormwater samples when the program was completely finished.

Two other ISCO 6712 sampler units (Sampler D and Sampler E) were positioned within the sediment basin to collect water quality samples from the minimum water depth of 1.5 ft (schematically shown in Figure 3.2) from the bottom of the basin. The suction heads for the samplers were positioned directly in the middle of the second bay (between the first and second baffle, with respect to flow) and in the middle of the third bay (between the second and third baffle, with respect to flow). Sampler D and Sampler E were connected directly to Sampler C via a special made “Y-cable” (schematically shown in Figure 3.2), manufactured by Teledyne ISCO specifically for this project. This enabled the program for Sampler D and Sampler E to draw a sample in sequential order after Sampler C had completed each sampling cycle. Sampler C sent a “pulse” signal once it completed its pumping cycle to Sampler D, triggering Sampler D’s pump cycle to draw a water quality sample. Likewise, Sampler D sent a “pulse” signal to Sampler E once its pump cycle was complete, triggering the pump cycle of Sampler E. Using this program and configuration, the samples within the basin were taken at relatively the same time as the outflow sample, providing a representative water quality sample in each bay of the sediment basin in relation to time.

All stormwater samples gathered by the ISCO 6712 sampling units have a recorded time stamp for each sample. Each individual sample container in each ISCO 6712 sampler was labeled in sequential order corresponding to the time samples were taken (1 through 24, as there are 24, 1L bottles being used in each ISCO 6712 sampler for the sampling program being run).

Once a program in one of the samplers was complete, the bottles containing the samples were then removed and replaced with clean bottles within 24 hours. The bottles containing the samples were sealed and placed on ice to prevent algae growth. The samples were then transported back to the lab at Auburn University for further measurements of turbidity and suspended solids. For each rainfall event, all data for each sampler were compiled into a spreadsheet containing time of sample, location of sample, flow rate, etc. This allowed for more distinguishable comparisons between collected data of various sample sets and established accurate results.

3.2 Quantifying Retained Sediment

An initial, pre-evaluation survey of the sediment basin was performed by ALDOT surveyors immediately after basin construction and prior to the deployment of ISCO sampling units to establish a baseline volume for the sediment basin. A post-evaluation survey was also conducted at the end of the monitoring period for the basin to establish the amount of sediment captured.

To determine the volume changes in the basin due to deposited sediments, a CAD program (MicroStation) was used to develop a three-dimensional digital model of the basin. Models were visually checked for accuracy for unusual shapes or depths of deposited sediment accumulation that do not match other numbers within the same survey. A retained sediment volume report was then generated by MicroStation, noting the net change in volume that was determined by subtracting the end-volume of the post-evaluation survey from the original volume of the pre-evaluation survey.

To obtain data on sediment deposited in the basin, samples were taken in the middle of each bay, with respect to length of the basin. The sediment basin had 4 bays, each being separated by a baffle. The sediment sample locations include: (1) between the inflow channel and first baffle, (2) between the 1st and 2nd baffle, (3) between the 2nd and 3rd baffle, and (4) between the last baffle and overflow structure. This process of collecting sediment samples at the four locations was repeated 3 times, with samples collected along each side of the basin as well as the middle of the basin, with respect to the width of the basin. Figure 3.7 provides a schematic of all sampling locations within the basin, while Figure 3.8 shows the sediment samples being taken from the sediment basin.

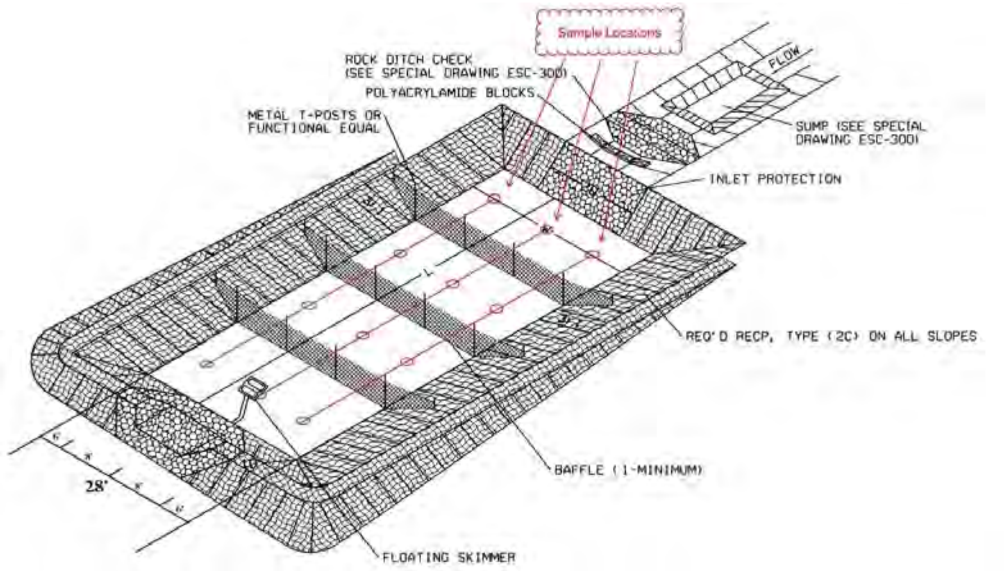


Figure 3.7: Deposited sediment sample location plan.

Figure 3.8: Sediment samples being taken from basin 4.

The sediment captured by the coir baffle material being used was visually observed by sampling three 4 ft^2 sections of each baffle prior to basin cleanout/maintenance, as shown in

Figure 3.9. This allowed for a visual comparison to be made versus a clean sample of coir baffle material to determine approximate sediment retention amounts.

Figure 3.9: Three 4 ft^2 samples were taken from each baffle.

Soil samples collected of deposited sediment at the locations identified in Figure 3.7 allowed for the evaluation of the grain size distribution of deposited sediment and assessment of the performance of the basin and baffles. This was done to determine whether or not the baffles were working correctly by dissipating energy and velocity of the incoming stormwater runoff and allowing sediment to settle more quickly. Also, three different sets of sediment samples were taken so that outliers in the samples were easily identified, and then an average grain size distribution was generated for each bay within the basin.

3.3 Quantifying Turbidity and TSS of Stormwater Samples

Using the stormwater samples collected by the ISCO 6712 samplers, an evaluation of turbidity and total suspended solids (TSS) was performed in the laboratory, as show in Figure 3.10. This allowed for the measurement of the water quality of stormwater runoff inflow, within the basin, and outflow. The water quality within the basin was evaluated to allow for determining the settling effect along the flow path from inflow to outflow (due to gravity) and any settling enhancement caused by the baffles being used within the basin.

Turbidity was measured using the HACH 2100Q Portable Turbidimeter. The maximum turbidity reading on this instrument is 1,000 NTU. In the case that a sample had a higher turbidity than 1,000 NTU, the test sample was diluted using a 1:2 ratio of low-turbidity deionized water according to instructions given in the *"Sample Dilution"* section of HACH Method 8366. An example of sample dilution can be seen in Figure 3.11 below. The sample dilution shown in Figure 3.11 represents a highly turbid inflow sample. In this procedure, the turbidity sample was diluted a total of 6 times, with a final turbidity reading of 458 NTU from the HACH turbiditimeter (called as T_H). The actual turbidity is calculated using equation (3.1). Since this particular sample (Figure 3.11) had a turbidity reading of 458 NTU, the actual turbidity, prior to dilution is calculated to be 29,312 NTU.

Figure 3.10: Turbidity and TSS laboratory analysis station.

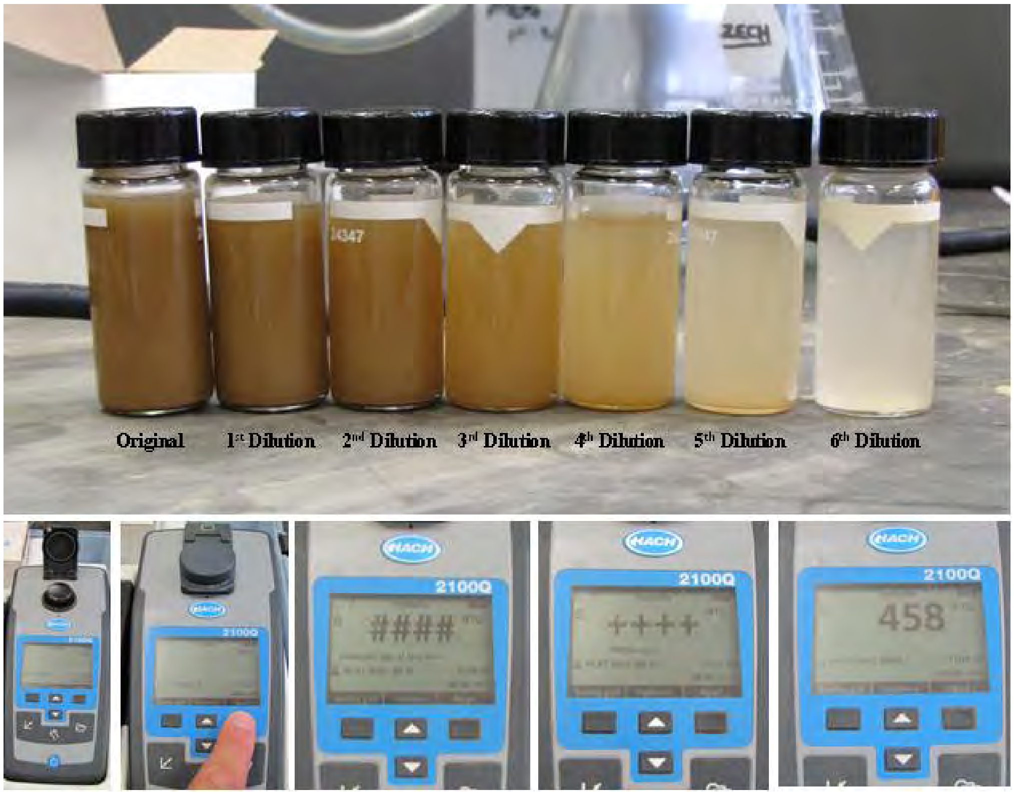


Figure 3.11: Sample dilution of an inflow stormwater sample.

$$T = T_H * 2^n \tag{3.1}$$

where:

T = actual turbidity (NTU),
T_H = turbidity reading from HACH turbidimeter, and
n = number of dilutions performed.

TSS of each sample was determined using vacuum filtration according to the *"Determining Total Suspended Solids"* section of HACH Method 8366. In this method, a crinkle dish with corresponding glass fiber filter was weighed using an accurate analytical balance and recorded to attain each filter's clean weight. The filter was then placed on the filter holder of the vacuum filter apparatus with tweezers and with the wrinkled side facing upward (Figure 3.12). The funnel portion of the magnetic filter holder was then attached to the filter holder. Then, 20 mL of each sample was accurately measured out into a pipette. It is important that the sample be well mixed to ensure a homogeneous sample prior to taking the 20 mL sub-sample (Figure 3.13). This was achieved by first completely emptying the 1L sample into a beaker, placing the beaker onto a stir plate, and allowing the sample to stir for 1 minute to ensure the sample was well mixed (Figure 3.13).

Using the filtering apparatus, the 20 mL sub-sample (Figure 3.14) was poured into the funnel portion of the vacuum filter apparatus, and the vacuum was turned on. If any residue remained on the outer walls of the funnel portion, low-turbidity deionized water was used to rinse all particulate onto the filter while the vacuum is still turned on. The filter was then rinsed 3 times with 10 mL of low-turbidity deionized water. Once all rinse water was vacuumed through the filter, the vacuum was shut off allowing the vacuum pressure to be slowly released. After all vacuum pressure had been released, the filter disc was gently removed from the apparatus using tweezers and placed back into the crinkle dish. The dish was then placed into an oven at 103° to 105°C for 1 hour, or longer, to completely dry the sample. After the dish and filter disc had been in the oven for the required amount of time to dry, it was removed, weighed again on an analytical balance, and the weight was recorded. This process allowed for TSS to be determined based on the difference in weight of the filter and crinkle dish. Figure 3.12, Figure 3.13, and Figure 3.14 below illustrate the vacuum filtration process performed on a single inflow sample.

Figure 3.12: Placing glass fiber filter on vacuum filtration apparatus.

Figure 3.13: Ensuring sample is well mixed for sampling turbidity and TSS.

Figure 3.14: Drawing 20 mL of stormwater sample and running through vacuum filtration.

The outlined data collection procedures were followed during the data collection effort to provide data sets for further analyses. The data analyses described in the following chapter will be used to assess the performance of sediment basin 4 on the ALDOT 502 project in Franklin County.

CHAPTER 4: RESULTS OF DATA ANALYSES AND DISCUSSION

4.1 Data Collection Summary and Data Analysis Techniques

The overall data collection effort for sediment basin 4 in Franklin County was divided into two phases. In Phase 1, a single inflow channel (called the secondary inflow channel during Phase 2) was constructed to carry stormwater into the sediment basin (Figure 3.1A), and in Phase 2, there were two inflow channels (Figure 3.1B) with the newly added inflow channel acting as the primary inflow channel. Table 4.1 and Table 4.2 summarize the information of rain events and data collection periods of stormwater samples for Phases 1 and 2, respectively. Automatic ISCO stormwater samplers collected: (1) 10 sets of inflow data (4 sets were incomplete or not accurate due to weir installation issues) and (2) collected 21 sets of stormwater samples inside the basin and at the outflow that provide valuable information for the data analyses and support recommendations presented in Chapter 5.

The research results of the data collection effort were grouped based upon sediment basin configuration and conditions. This chapter only reviews data sets that provide conclusive details of the performance of the sediment basin. A comprehensive listing of all raw data collected during the research period, including data sets not analyzed in this chapter, is documented as Appendix E by Logan (2012). In addition to raw data, a data collection log was also maintained for each data collection trip providing details of the trip – including abnormal site conditions, errors, and otherwise notable comments relating to the sediment basin performance. This log has been included and is documented as Appendix F by Logan (2012). A fully detailed account explaining the data and site conditions (i.e., construction activities, percent cover, and channel configuration) for each rain event was documented as an internal memorandum by Mr. Logan.

To determine the exact performance of the sediment basin, the raw data needed to be organized in such a way to understand the underlying pattern. To do this, TSS, turbidity, and rainfall (when available) data collected from each sampling location was plotted versus time for each data collection rain event. Additionally, TSS and turbidity were plotted against each other to see what type, if any, correlation existed. Other data collected included inflow rates versus time (when available), giving exact hydrographs for the inflow to the sediment basin.

To give a better overall performance report, data collected from several rain events or data collection periods were grouped together (when applicable) and plotted on one graph. This was done to show the total performance of the sediment basin for the entire dewatering period after several subsequent rain events. Rainfall data (cumulative rainfall or 5-minute rainfall intensity), TSS, and turbidity were all included in grouped data sets.

To further categorize and better determine the performance of the sediment basin, the data sets collected were grouped based upon primary site condition (e.g., based on PAM dosage of inflow). Grouping data in this manner allowed the overall performance of the sediment basin to be distinguishable depending on how the inflow was or was not being treated using PAM. This method resulted in two groups for Phase 1 data and two groups for Phase 2 data. Each group of

Table 4.1: Summary of Phase 1 data collection on the basin 4 for ALDOT project 930-791.

Day and depth of rainfall event	Time period of stormwater samples collected (Day and Hour:Minute)	Had inflow data? (Yes or no)	Had outflow? (Yes or no)	Note
11/16/11, 1.35”	(11/16) 8:48 – (11/17) 8:18	Yes	Yes	Rainfall data were not collected.
11/27-28/11, 1.4”	(11/27) 3:52 – (11/28) 16:51	Yes	No	Basin samples were quick over course of 2 hours due to 750 module malfunction where flow levels initiated the programming many times as the outflow level was hovering at the threshold to start programming. This was corrected for future data sets by changing program to “once enabled stay enabled”.
12/5-7/11, 1.58”	(12/5) 15:30 – (12/6) 14:47	Yes	Yes	4 new PAM blocks installed at weir – discovered to be wrong type.
	(12/10) 2:04 – (12/11) 1:21	No	No	Could not detect outflow due to freezing temperatures. Finally began pulling samples again on 12/10. Partial sample sets due to freezing temperatures at night.
12/15-16/11, 0.92”	(12/18) 6:01 – (12/19) 5:11	No	Yes	No inflow due to frozen water in suction tube for Sampler A. Freezing temperatures caused outflow not to be detected until 12/18 and only partial sample sets were collected due to freezing temperatures.
12/20/11, 0.05”	n/a	No	No	Did not create inflow to basin.
12/21/11, 0.43”	n/a	No	No	Did not create inflow to basin.
12/22/11, 2.06”	(12/22) 10:03 – (12/24) 12:02	Yes, but only 3 samples	Yes	Grading was causing problems with runoff getting into inflow channel. Most of water in basin was what was collected during rainfall.
12/26-27/11, 1.62”	(12/26) 19:37 – (12/27) 19:08	Yes but only 2 samples	Yes	Grading was causing problems with runoff getting into inflow channel. Most of water in basin was what was collected during rainfall.

Note: Rainfall events on 11/20/2011 (0.13”), 11/22/2011 (0.38”) and 12/15/2011 (0.09”) did not generate enough runoff to trigger ISCO samplers to collect the data.

Table 4.2: Summary of Phase 2 data collection on the basin 4 for ALDOT project 930-791.

Day and depth of rainfall event	Time period of stormwater samples collected (Day and Hour:Minute)	Had inflow data? (Yes or no)	Had outflow? (Yes or no)	Note
1/7/12, 0.91”	(1/7) 12:56 – (1/8) 11:56	No	Yes	Weir not properly installed – No accurate inflow data.
1/9/12, 0.26”	(1/9) 17:23 – (1/10) 16:23	No	Yes	Weir not properly installed – No accurate inflow data.
1/11/12, 0.82”	(1/11) 2:22 – (1/12) 13:28	Yes	Yes	Weir not properly installed – No accurate inflow data.
	(1/15) 9:11 – (1/16) 2:02	No	Yes	Freezing conditions caused some samples not to be pulled.
1/17/12, 1.22”	(1/17) 15:26 – (1/17) 17:00	Yes	Yes	Weir not properly installed – No accurate inflow data. Channel was washout and overflow occurred. No PAM.
	(1/19) 15:46 – (1/20) 14:54	No	Yes	Samples taken from rainfall that occurred on 1/17/12
1/21/12, 0.45”	(1/21) 15:34 – (1/22) 14:42	No	Yes	Weir not properly installed – No accurate inflow data. No PAM.
1/22/12, 0.31”	(1/23) 0:28 – (1/24) 10:57	No	Yes	Weir not properly installed – No accurate inflow data. No PAM.
1/23/12, 0.65”	(1/24) 12:37 – (1/25) 11:37	No	Yes	Weir not properly installed – No accurate inflow data. No PAM.
1/26/12, 0.68”	(1/26) 6:51 – (1/27) 5:27	Yes	Yes	Rock washed against bubbler tube at the inflow channel causing inflow readings to be higher than actual.
	(1/27) 15:06 – (1/28) 14:15	No	Yes	Continuation of previous rain event
	(1/28) 17:39 –(1/29) 16:48	No	Yes	Continuation of previous rain event.
2/1/12, 0.72”	(2/1) 7:42 – (2/2) 6:21	Yes	Yes	No errors, a complete set of data.
	(2/2) 14:24 – (2/3) 13:24	No	Yes	Continuation of previous rain event.
2/3/12, 0.88”	(2/3) 12:14 – (2/5) 14:03	Yes/No	Yes	Two large rain events 8 hour apart on 2/3/12. Got inflow samples only for the first one.

Note: Rainfall event on 1/8/2012 (0.32”) did not generate enough runoff to trigger ISCO samplers to collect the data.

data, based on PAM condition, was evaluated for TSS and turbidity reduction efficiency. The reduction efficiency at each sampling point within the basin was determined by fitting an exponential equation to the data collected to calculate future reduction efficiencies beyond the end point of data collected.

To visually distinguish differences in performance, two sets of graphs were developed, one for TSS and one for turbidity, plotting peak value reduction efficiency over the maximum design dewatering period. The grouped data, based on PAM condition, for each phase of data collection were also evaluated for correlations between TSS and turbidity at each data collection point. This allowed for trends to be observed between sampling locations, also providing an excellent indicator of particle size at each sampling location.

Each of these data analysis techniques were carefully planned and executed to provide the maximum accuracy in results. The results gathered using these techniques are presented below and ultimately show which features of the sediment basin performed well, as well as which features performed poorly. Moreover, the results from the data collection effort transition into providing useful recommendations in Chapter 5 to improve the overall sediment basin performance for use on construction projects in the future.

4.2 Results of Phase 1 Data Collection

Phase 1 data collection was performed from 9/26/2011 to 12/29/2011, during the early stages of the sediment basin, shortly after construction. During Phase 1, stormwater entered the sediment basin through a single inflow channel as the cut excavation progressed in the area upstream of the sediment basin (Figure 3.1A). Two conditions were observed during the Phase 1 data collection effort: (1) correct PAM placement in the inflow channel, and (2) incorrect (i.e., wrong type) PAM placement in the inflow channel. These two conditions herein will be referred to as '***w/PAM***' and '***w/wrong PAM***', respectively.

One data set was collected for each observed condition during Phase 1. Rain events for each PAM collection in both observed conditions were similar, producing 1.35 inches (in.) and 1.32 in., respectively. Based on 5-minute rainfall hyetograph data provided by RainWave® (http://www.rainwave.org/), the average 5-minute intensity on 11/16/2011 for the rain event with the 'w/*PAM*' condition in the inflow channel was 0.13 in./hr (starting from 11/6/2011 0:0 to 11/6/2011 10:10), with a peak observed intensity of 2.22 in./hr. The observed (using ISCO tipping rain gauge) average 5-minute intensity for the rain event on 12/5/2011 with the 'w/*wrong PAM*' condition in the inflow channel was 0.34 in./hr, with a peak observed 5-minnute intensity of 1.08 in./hr.

The inflow data collected was based upon inflow volume produced by each rain event as stormwater passed over the weir constructed in the inflow channel. Figure 4.1 shows an example of inflow turbidity distribution over time with respect to rainfall distribution for the 12/5/2011 rain event (*w/wrong PAM* condition). All data for each sampling location (i.e., bay 2, bay 3, and outflow) for each rain event discussed in this chapter are located in Appendix B. The inflow data collected for Phase 1 data collection was compiled and is shown in Table 4.3. Due to the phase of construction and little vegetation or ground cover (i.e., approximately 10%), observed turbidity and TSS values for the 11/16/2011 rain event were an average of 3,866 NTU and 4,125 mg/L higher, respectively, in comparison to the 12/5/2011 rain event, after some vegetative growth and ground cover (i.e., approximately 25%) had been established.

All samples collected during these two rain events were analyzed for TSS and turbidity. Figure 4.2 shows how exponential reduction trends from peak observed TSS values were applied to each data set to predict the sediment basin performance based upon particle settling rates for the 12/05/12 rain event. Fitted coefficients of exponential reduction function are displayed on graphs for all events and sampling locations and are given in Appendix B.

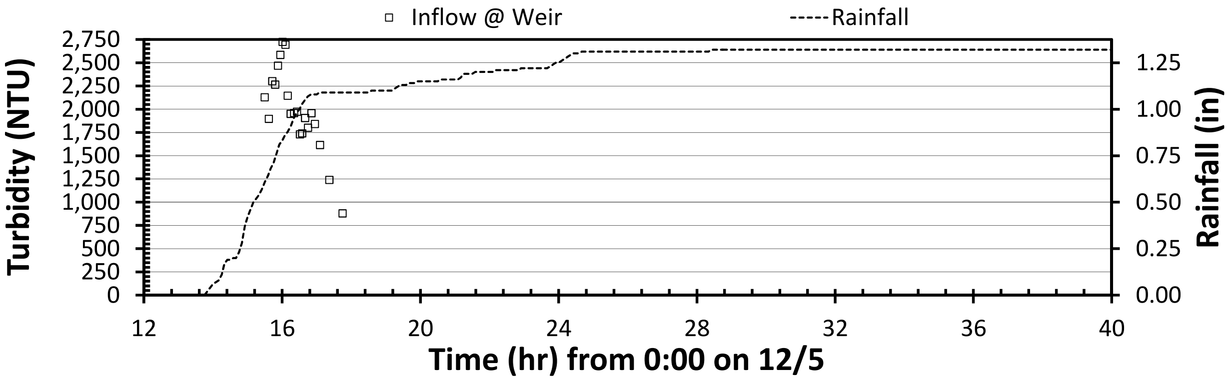


Figure 4.1: Phase 1 sampled inflow turbidity and rainfall distribution.

Table 4.3: Phase 1 inflow data for different PAM treatment types.

Date	Number of data	Turbidity (NTU)				TSS (mg/L)			
		Max	Min	Avg.	Std. Dev.	Max	Min	Avg.	Std. Dev.
11/16/2011 [1]	23	10,656	1,030	5,855	2,582	10,545	790	5,430	2,689
12/05/2011 [2]	21	2,724	878	1,989	446	1,950	465	1,305	380

Note: [1] – *With PAM* in the inflow channels, [2] – with *wrong PAM* in the inflow channels.

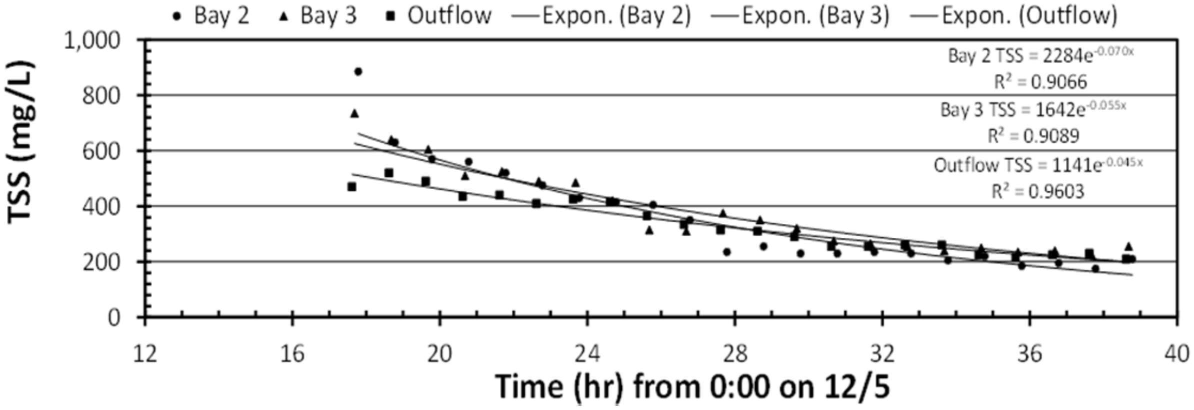
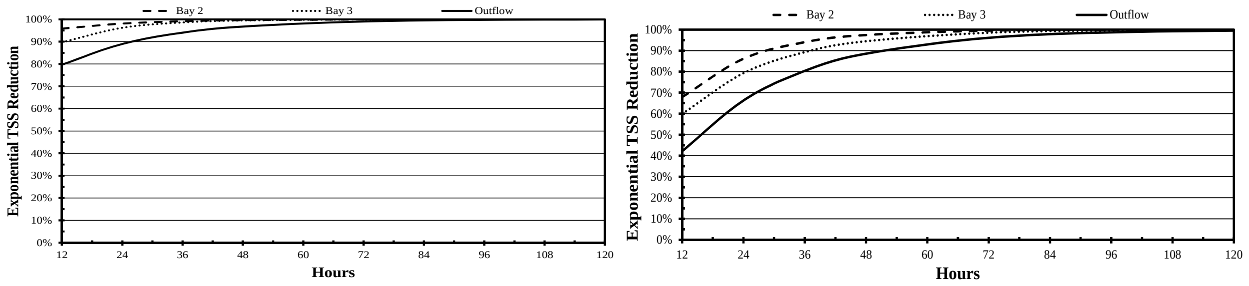


Figure 4.2: Exponential TSS reduction trends applied to 12/5/2011 data (*w/wrong PAM*).

Appendix C provides statistical summary (maximum, minimum, average, and standard deviation) of rainfall, turbidity, and TSS data at different sampling locations for all rain events monitored during Phases 1 and 2 data collection period. Figure 4.3, accompanied by Table 4.4, show the turbidity (NTU) and TSS (mg/L) reduction performance of each sampling location within the sediment basin for both PAM conditions. An initial performance increase at 12 hours of nearly 50% is observed at all sampling locations *w/PAM* versus with the *w/wrong PAM*.

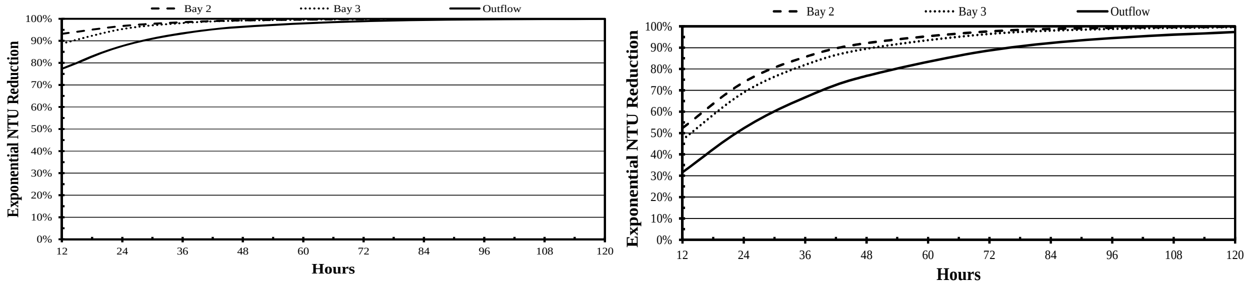
The outflow *w/PAM* reached a 90% or greater reduction efficiency within 36 hours of the peak observed value for both TSS and turbidity, whereas it took 72 hours for TSS and 96 hours for turbidity to reach a 90% or greater reduction in the outflow for the rain event *w/wrong PAM*. Bays 2 and 3 also showed similar trends to the outflow, reaching 90% or greater peak reduction in TSS and turbidity within 24 hours *w/PAM*, whereas it took as long as 72 hours to see 90% or greater reduction from peak values *w/wrong PAM*.

Table 4.5 provides a direct comparison between the TSS and turbidity reduction performance observed at the sediment basin for the two rain events and two conditions. The turbidity reduction performance *w/PAM* at the outflow was as much as 45% better at 24 hours after peak than *w/wrong PAM*. After 48 hours, little difference could be established in basin performance, with the greatest difference of 19% occurring in the outflow. The greatest difference in TSS occurred at 12 hours after the peak, where the bay 2 showed an 84% increase in reduction *w/PAM* as opposed to *w/wrong PAM*. Overall, the increase in TSS and turbidity removal *w/PAM* was most noticeable in the first 36 hours from peak – quickly tapering off and matching the performance *w/wrong PAM* by 96 hours after peak.



(a) w/PAM

(b) w/wrong PAM



(c) w/ PAM

(d) w/wrong PAM

Figure 4.3: Phase 1 TSS and turbidity (NTU) observed reduction performance.

Table 4.4: Phase 1 sediment basin performance

(a) Sediment Load Reduction Performance

Condition	Avg. (Peak) Inflow Rate (gpm)	Sample Location	Max TSS	Exponential TSS Reduction (%)						
				12hr	24hr	36hr	48hr	72hr	96hr	120hr
w/PAM	456 (1,518)	Bay 2	4,940	96	98	99	100	100	100	100
		Bay 3	2,145	90	96	99	99	100	100	100
		Outflow	895	80	89	94	97	99	100	100
w/wrong PAM	262 (554)	Bay 2	885	68	86	94	97	100	100	100
		Bay 3	800	60	79	89	94	99	100	100
		Outflow	520	42	66	80	89	96	99	100

(b) Turbidity Reduction Performance

Condition	Avg. (Peak) Inflow Rate (gpm)	Sample Location	Max Turbidity	Exponential Turbidity Reduction (%)						
				12hr	24hr	36hr	48hr	72hr	96hr	120hr
w/PAM	456 (1,518)	Bay 2	5,592	93	97	98	99	100	100	100
		Bay 3	3,856	89	95	98	99	100	100	100
		Outflow	1,646	77	88	93	96	99	100	100
w/wrong PAM	262 (554)	Bay 2	1,642	52	74	86	92	98	99	100
		Bay 3	1,552	47	69	82	89	96	99	100
		Outflow	1,112	32	52	67	77	89	94	97

Table 4.5: Phase 1 sediment basin performance comparison of *w/PAM* and *w/wrong PAM* conditions

(a) Sediment (TSS) Reduction Percent Improvement *w/PAM*

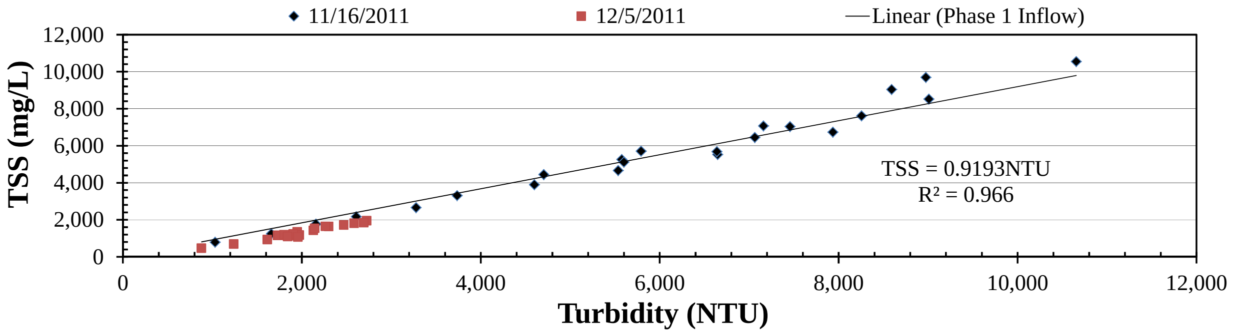
Sample Location	Max. TSS	TSS Percent Difference (%)						
		12hr	24hr	36hr	48hr	72hr	96hr	120hr
Bay 2	4,055	28	12	5	3	0	0	0
Bay 3	1345	30	17	10	5	1	0	0
Outflow	375	38	23	14	8	3	1	0

(b) Turbidity Reduction Percent Improvement *w/PAM*

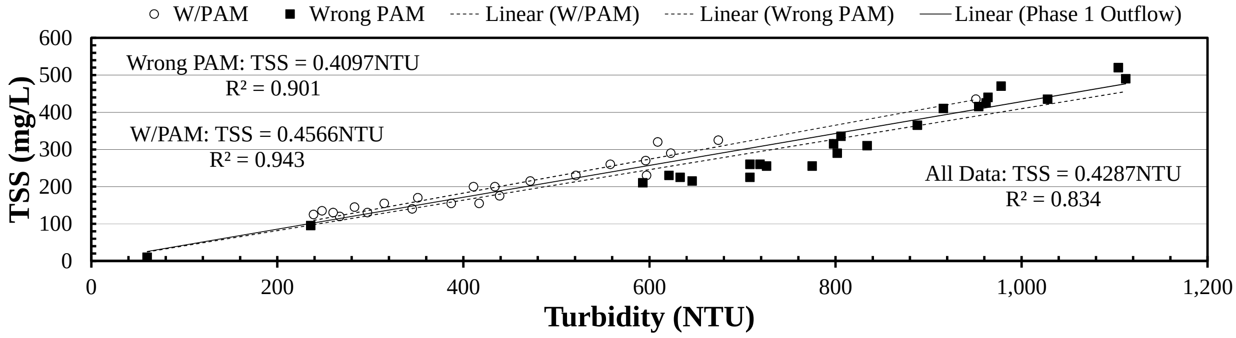
Sample Location	Max. Turbidity	Turbidity Percent Difference (%)						
		12hr	24hr	36hr	48hr	72hr	96hr	120hr
Bay 2	3,950	41	23	12	7	2	1	0
Bay 3	2304	42	26	16	10	4	1	0
Outflow	534	45	36	26	19	10	6	3

It is important to note that the inflow for the 11/16/2011 rain event *w/PAM* had much higher inflow TSS and turbidity values than what was observed for the 12/5/2011 rain event *w/wrong PAM* as seen in Table 4.3. In addition, the average inflow rate of the 11/16/2011 rain event was 194 gpm higher, with a peak inflow rate of 964 gpm higher than what was observed in the 12/5/2011 rain event. Based on the inflow rates observed for both events, it can be concluded that the rainfall on 11/16/2011 had a higher average intensity over a certain period of time (peak intensity of 2.22 in./hr at 8:10 AM based on rainfall data from RainWave), producing higher, more concentrated inflow rates. In addition, as stated earlier, the ground cover and established vegetation increased approximately 15% between the 11/16/2011 rain event and the 12/5/2011 rain event. Despite these differences, the overall performance of the sediment basin was superior for the 11/16/2011 rain event, in comparison to the 12/5/2011 rain event which had lower inflow rates and lower inflow TSS and turbidity amounts.

Also based upon PAM condition of the sediment basin, a TSS and turbidity correlation was determined for the inflow and outflow data collected during Phase 1. Separate correlations were determined for the inflow and outflow of the sediment basin, shown in Figure 4.4, due to the fact that significantly different correlations exist between the heavy suspended sediment in the inflow and the fine fraction contained in the outflow. The inflow turbidity and TSS on 11/16/2011 were lower than ones of the inflow on 12/5/2011 (Figure 4.4A). The inflow data correlation was determined to be TSS = 0.9193NTU and the outflow correlation was determined to be TSS = 0.4287NTU when all inflow and outflow data were used. The correlations of TSS and turbidity determined for outflow under w/PAM and wrong PAM conditions are similar (Figure 4.4B) even though outflow turbidity and TSS were lower for w/PAM than for wrong PAM. This might be because large sediment particles (both natural or formed due to flocculation of PAM) had settled down before reaching the outflow and finer particles near the water surface are about the same. The correlations determined, shown in Figure 4.4, can be used to determine TSS quickly in the field by taking a quick turbidity sample. This potentially could save a great deal of time and money when TSS measurements are needed in the field. The only limitation to this technique is that it is site-specific to the soil found on this project located in Franklin County.



(a) Inflow



(b) Outflow

Figure 4.4: Phase 1 TSS vs. turbidity data correlations.

4.3 Results of Phase 2 Data Collections

Phase 2 of the data collection was performed during a more mature stage of site construction. As shown in Figure 3.1B, stormwater runoff entered the basin through a new primary inflow channel, but the original inflow channel was also used as a secondary inflow channel for the basin due to the nature of the surrounding terrain.

During Phase 2, road bed excavation was nearing completion, such that the entire design contributing watershed area of 9.21 acres emptied into the sediment basin. The data collected during this phase was divided into two conditions based on site flow characteristics: (1) '*No PAM*', and (2) '*W/Limited PAM*'. Due to the new primary inflow channel and weir being improperly installed by the contractor, stormwater coming into the basin through the primary inflow channel flowed around and under the weir – not coming into contact with the floc logs placed on top of the riprap downstream of the weir, therefore PAM was never introduced to the stormwater runoff during the first condition. Only in the case of a large concentrated inflow would the stormwater pass over the weir and come into contact with the floc logs, providing very limited amounts of PAM being added to the inflow. After several rain events, this issue was corrected by reconstructing the primary inflow channel and properly installing the weir so that it maintained proper function, however the correct dosage of PAM recommended by the supplier in comparison to the amount of flow occurring over the weir resulting in a *limited PAM* treatment condition.

During the "*No PAM*" condition of Phase 2, inflow data that was collected was very limited based on the condition of the primary inflow channel and weir. Therefore, inflow rates were not collected and inflow samples did not always accurately represent the total amount of stormwater that entered the basin. For this category, basin performances from two rain events were analyzed, as shown in Table 4.6. The first rain event occurred on 1/17/2012 producing a large concentrated inflow, allowing for a full set of inflow samples to be taken to allow for some representation of the stormwater entering the basin. Due to the large concentrated inflow created by this rainfall, damage occurred to the primary inflow channel and weir, rendering them useless for future data collection until properly repaired. The second rainfall occurred on 1/21/2012 and might just cover the upstream portion of the contributing area. Due to the location of the rainfall, the ISCO rain gauge was unable to gather rainfall data; however, RainWave® software reported a total rainfall amount of 0.45 inches. A rainfall hyetograph provided by RainWave® showed the maximum 5-minute rainfall intensity of 1.74 in./hr and the average 5-minute intensity of 0.10 in./hr over 4.4 hr duration. Due to the relatively small time span between rain events and condition of the sediment basin after the 1/17/2012 rain event, both data sets collected for '*No PAM*' were considered a product of the 1/17/2012 rain event – but allow for separate sediment basin performance rates to be determined for each rain event.

The second category of data collected during Phase 2, '*w/Limited PAM*', spanned six rain events. Due to the nature of the rainfall events, continuous monitoring of the sediment basin, and overall performance of the sediment basin, samples collected with PAM were categorized by 4 rain events: (1) 1/26/2012, (2) 2/1/2012(a), (3) 2/1/2012(b), and (4) 2/4/2012.

The inflow data collected for Phase 2 were tabulated and are located in Table 4.7, below. The 1/17/2012 rain event produced the highest turbidity and TSS values observed over the entire data collection period. This was due to the nature of the rain event, creating an upset condition on-site (i.e., erosion of the primary inflow channel) and generating large concentrated inflow. The 1/26/2012 inflow had much lower observed turbidity and TSS values due to light rain and low inflow rates during the time which samples were being taken. The first rain event on 2/1/2012 produced enough inflow that the sampler collected all inflow samples for that rain event. Since the sampler had completed its sampling program during the inflow from the first rain event on 2/1/2012(a), no inflow samples were collected for the subsequent rain event occurring on 2/1/2012(b).

Due to the timing and amount of rainfall during Phase 2 data collection, some sets of data were back-to-back, showing continuous performance of the sediment basin overtime. In such situations, the closely spaced data sets were grouped together into group-sets of data. These group-sets of data were plotted together, as shown in Figure 4.5, and reduction trends were determined over the total dewatering period for each rain event – shown in Figure 4.6. Plotted group-sets of data and reduction trends for all group-sets are included in Appendix B.

Table 4.6: Phase 2 Rainfall Data

Start Date	Duration (hr:min)	Amount (in.)	Average Intensity (in./hr)	Maximum Intensity (in./hr)
1/17/2012	2:00	1.22	0.610	3.48
1/21/2012	4:25	0.45	0.098	1.74
1/26/2012	0:50	0.11	0.132	0.24
	5:30	0.47	0.085	0.24
	2:30	0.16	0.064	0.36
2/1/2012(a)	5:15	0.46	0.090	0.96
2/1/2012(b)	0:25	0.25	0.610	1.44
2/4/2012	6:55	0.88	0.130	0.60

Table 4.7: Phase 2 inflow data for different PAM treatment conditions[1].

Date	Turbidity (NTU)				TSS (mg/L)			
	Max.	Min.	Avg.	Std. Dev.	Max.	Min.	Avg.	Std. Dev.
1/17/2012 [2]	28,352	3,488	9,902	6,234	26,325	2,720	7,433	5,632
1/21/2012 [2]	--	--	--	--	--	--	--	--
1/26/2012 [3]	785	191	506	149	435	95	275	75
2/1/2012(a) [3]	3,688	508	1,905	1,067	2,645	250	1,105	745
2/1/2012(b) [3]	--	--	--	--	--	--	--	--
2/4/2012 [3]	3,892	616	1,944	914	2,315	255	1,068	561

Note: [1] – PAM was introduced after inflow samples reported above were taken,
[2] – No PAM in the inflow channels,
[3] – with limited PAM in the inflow channels.

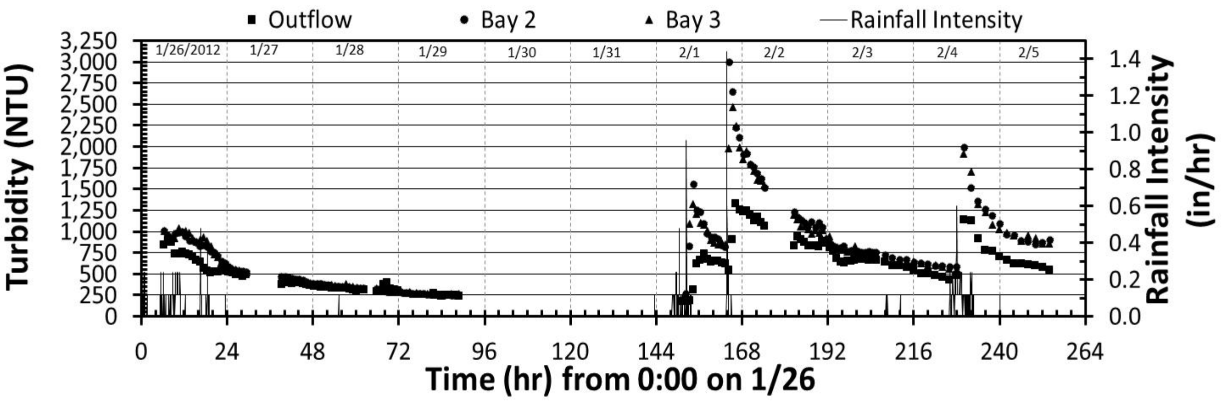


Figure 4.5: Phase 2 group-set of turbidity and rainfall data (from 1/26 to 2/5/2012).

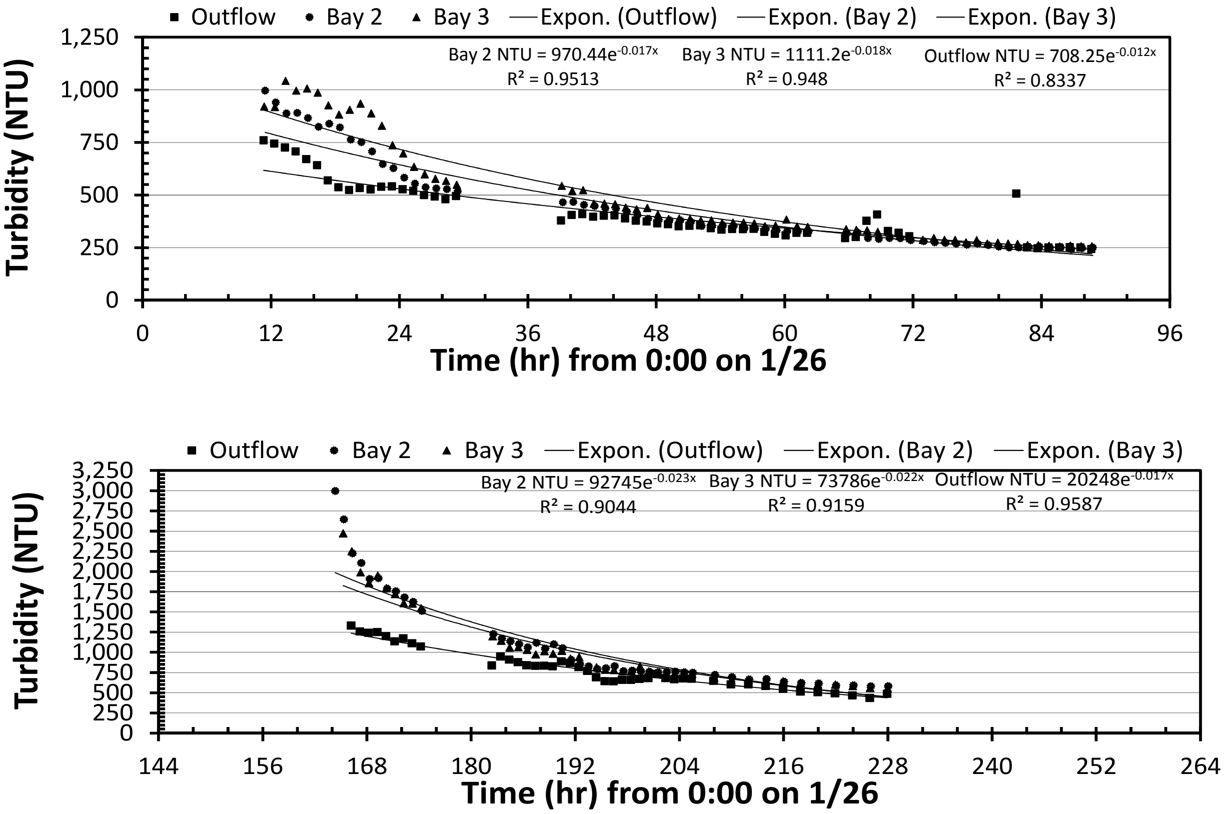
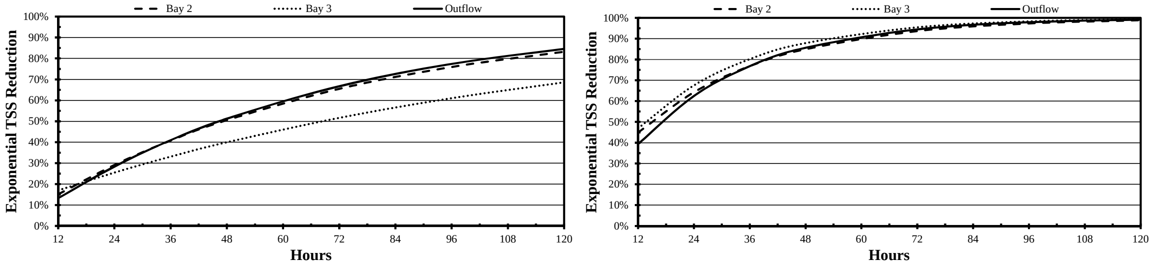


Figure 4.6: Phase 2 group-set turbidity reduction trends (from 2/1 to 2/5/2012).

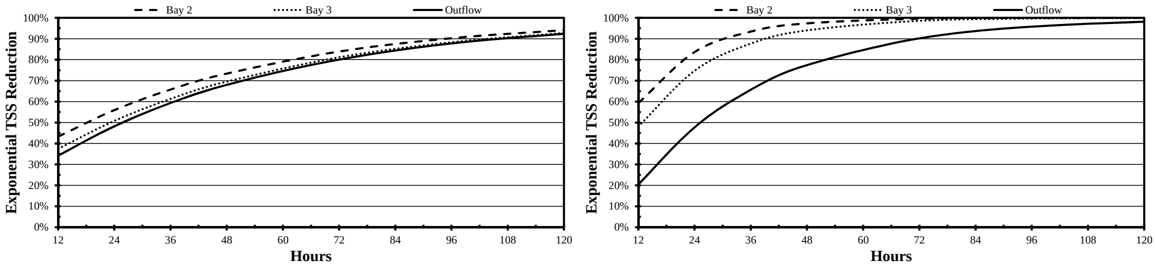
The observed TSS reduction performance by the sediment basin during Phase 2 was converted into exponential reduction rates and graphed in Figure 4.7, and summarized in Table 4.8. The TSS and turbidity reduction performance of the sediment basin with *No PAM* shows as much as a 33% lower initial reduction (at 12 hours) and 3 days slower overall reduction than some of the performance results *w/Limited PAM*. The TSS and turbidity reduction performance observed for the 1/17/2012 rain event shows that it took 5 days to achieve 85% TSS reduction and 80% turbidity reduction in the outflow. Based upon a designed dewatering time of 2-5 days, the sediment basin barely met 80% turbidity removal for the maximum design requirement of 5 days dewatering time for the 1/17/2012 rain event.

In addition to the overall performance with *No PAM*, the difference in performance between sampling locations (i.e., bay 2, bay 3, and outflow) is much less, showing outflow to have the maximum performance in TSS and turbidity reduction, rather than bay 2 or bay 3 as observed during phase 1. In comparison, the data *w/Limited PAM* collectively shows a much higher initial performance at 12 hours at all sampling locations, with the order of efficiency being the highest at bay 2 and lowest at the outflow. The reason for this order of reduction efficiency is due to sediment particle sizes, where the larger particles settled more quickly than smaller sediment particle sizes in bays 2 and 3 in comparison to the outflow portion of the basin.



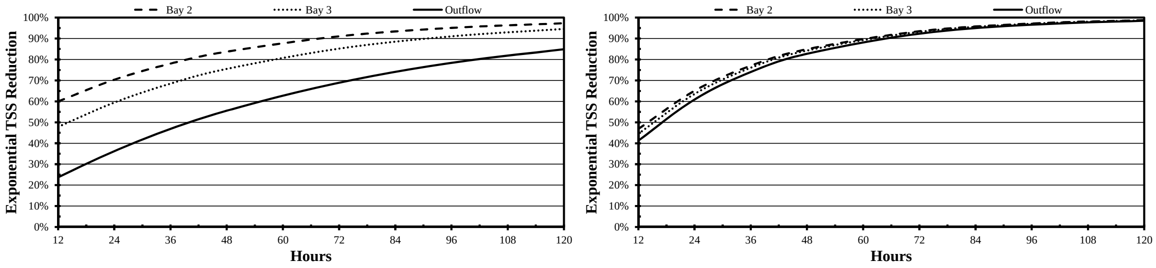
(a) 1/17/2012 *No PAM*

(b) 1/21/2012 *No PAM*



(c) 1/26/2012 *w/Limited PAM*

(d) 2/1/2012(a) *w/Limited PAM*



(e) 2/1/2012(b) *w/Limited PAM*

(f) 2/4/2012 *w/Limited PAM*

Figure 4.7: Phase 2 observed exponential TSS reduction performance.

Table 4.8: Phase 2 observed exponential TSS reduction performance.

(a) Sediment (TSS) Load Reduction Performance

Condition	Date	Inflow Rate (gpm) Avg. (peak)	Sample Location	Max TSS	Exponential TSS Reduction (%)						
					12hr	24hr	36hr	48hr	72hr	96hr	120hr
*No PAM**	1/17/2012	High Intensity Rainfall	Bay 2	805	15	29	41	51	65	76	83
			Bay 3	795	17	25	33	40	52	61	69
			Outflow	745	13	28	41	51	67	77	85
	1/21/2012	High Intensity Rainfall	Bay 2	810	45	64	77	85	94	97	99
			Bay 3	800	47	68	80	88	95	98	99
			Outflow	540	39	62	77	86	94	98	99
w/Limited PAM	1/26/2012	--	Bay 2	580	43	56	66	73	84	90	94
			Bay 3	510	37	51	61	70	81	88	93
			Outflow	385	34	48	59	68	80	88	92
	2/1/2012(a)	120 (643)	Bay 2	885	59	84	93	97	100	100	100
			Bay 3	660	48	75	88	94	99	100	100
			Outflow	340	20	48	66	77	90	96	98
	2/1/2012(b)	90 (898)	Bay 2	1,780	60	70	78	84	91	95	97
			Bay 3	1,255	48	59	68	75	85	91	95
			Outflow	585	24	36	47	56	69	78	85
	2/4/2012	162 (959)	Bay 2	930	47	65	77	85	93	97	99
			Bay 3	940	45	64	76	84	93	97	99
			Outflow	595	41	61	74	83	92	97	99

*May contain very limited amounts of PAM.

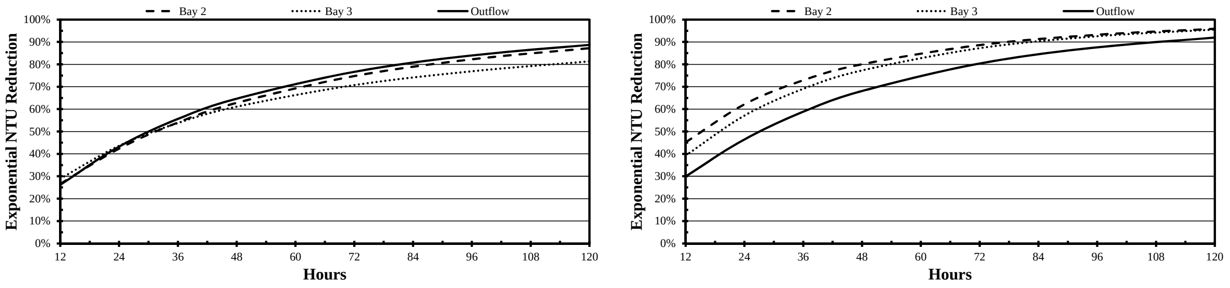
(b) Turbidity Reduction Performance

Condition	Date	Inflow Rate (gpm) Avg. (peak)	Sample Location	Max NTU	Exponential NTU Reduction (%)						
					12hr	24hr	36hr	48hr	72hr	96hr	120hr
*No PAM**	1/17/2012	High Intensity Rainfall	Bay 2	1,982	12	24	34	43	57	68	76
			Bay 3	1,926	13	21	28	35	46	56	63
			Outflow	1,858	12	25	36	45	60	71	79
	1/21/2012	High Intensity Rainfall	Bay 2	1,916	41	61	74	83	92	97	99
			Bay 3	1,956	45	66	79	87	95	98	99
			Outflow	1,170	40	61	75	84	93	97	99
w/Limited PAM	1/26/2012	--	Bay 2	1,008	35	47	57	65	77	85	90
			Bay 3	1,042	30	44	55	63	76	85	90
			Outflow	905	41	49	56	62	71	78	84
	2/1/2012(a)	120 (643)	Bay 2	1,552	51	77	90	95	99	100	100
			Bay 3	1,326	41	68	83	91	97	99	100
			Outflow	740	18	42	59	71	86	93	96
	2/1/2012(b)	90 (898)	Bay 2	2,996	49	62	71	78	87	93	96
			Bay 3	2,472	43	56	66	74	85	91	95
			Outflow	1,330	25	40	53	62	76	85	90
	2/4/2012	162 (959)	Bay 2	1,988	45	62	74	82	92	96	98
			Bay 3	1,914	43	60	72	81	91	95	98
			Outflow	1,146	35	54	68	77	89	94	97

*May contain very limited amounts of PAM.

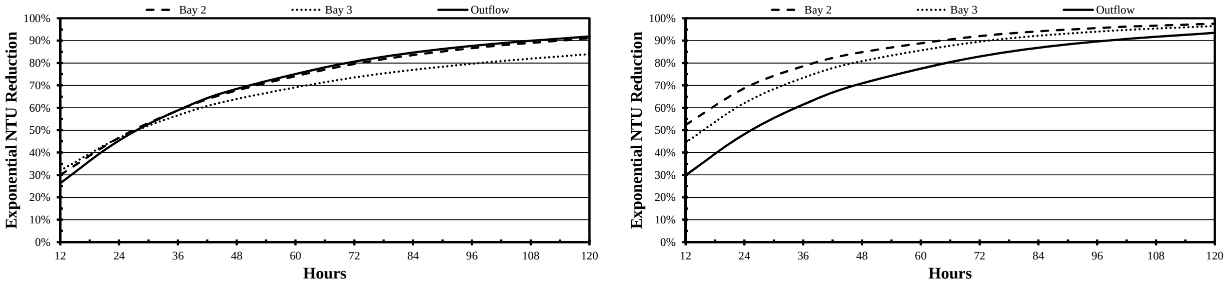
The two rain events on 2/1/2012 took place approximately 8 hours apart. The TSS reduction performances shown in Figure 4.7(d) and (e) and are theoretical based upon observed performance during that time period. The performance in Figure 4.7(d) and (e) vary primarily due to the resuspension of sediment that occurred after the second rain event, thus causing the performance efficiency to decrease in Figure 4.7(e) as compared to Figure 4.7(d).

To more easily quantify the sediment basin performance during Phase 2, the performance data from *No PAM* and *w/Limited PAM* individual rainfall events were averaged to compare results directly. Figure 4.8, accompanied by Table 4.9 show the average performance data from each sampling location under each basin condition. These performance data sets were then compared to each other to determine the % increase in efficiency, as shown in Table 4.10. TSS and turbidity reduction performance in the outflow showed the greatest increase *w/Limited PAM* in Bay 2, showing as much as a 22% increase in turbidity reduction and tapering off over time. All sampling locations showed an increase in TSS and turbidity reduction efficiency early (around 12 to 24 hrs after peak) and gradually decreased in % efficiency gain over the *No PAM* condition. The outflow *w/Limited PAM* showed the least amount of efficiency increase over *No PAM*, with a maximum efficiency increase of 4% in both TSS and turbidity reduction. This lack of efficiency gain *w/Limited PAM* was caused by two reasons: (1) the outflow primarily dealt with the fine fraction of sediment entering the basin, which was much slower to settle; and (2) the inflow rate of stormwater for the majority of the volume of inflow was higher than the recommended effective flow rate for the floc logs.



(a) *No PAM*

(b) *w/Limited PAM*



(c) *No PAM*

(d) *w/Limited PAM*

Figure 4.8: Phase 2 average TSS and NTU observed reduction performance.

Table 4.9: Phase 2 average observed exponential TSS and turbidity reduction performance.

(a) Average Sediment (TSS) Load Reduction Performance

Condition	**Sample Location**	**Max TSS**	**Exponential TSS Reduction (%)**						
			12hr	**24hr**	**36hr**	**48hr**	**72hr**	**96hr**	**120hr**
No PAM	Bay 2	808	30	47	59	68	80	87	91
	Bay 3	798	32	47	57	64	74	80	84
	Outflow	642	26	45	59	68	81	88	92
w/Limited PAM	Bay 2	1,044	52	69	79	85	92	96	98
	Bay 3	841	44	62	73	81	90	94	97
	Outflow	476	30	48	61	71	83	90	94

(b) Average Exponential Turbidity Reduction Performance

Condition	**Sample Location**	**Max Turbidity**	**Exponential Turbidity Reduction (%)**						
			12hr	**24hr**	**36hr**	**48hr**	**72hr**	**96hr**	**120hr**
No PAM	Bay 2	1,949	27	42	54	63	75	82	87
	Bay 3	1,941	29	44	54	61	71	77	81
	Outflow	1,514	26	43	56	65	77	84	89
w/Limited PAM	Bay 2	1,886	45	62	73	80	89	93	96
	Bay 3	1,689	39	57	69	77	87	93	96
	Outflow	1,030	30	46	59	68	80	88	92

Table 4.10: Phase 2 average sediment basin performance comparison of *No PAM* and *w/Limited PAM* conditions

(a) Sediment (TSS) Reduction Percent Improvement *w/Limited PAM*

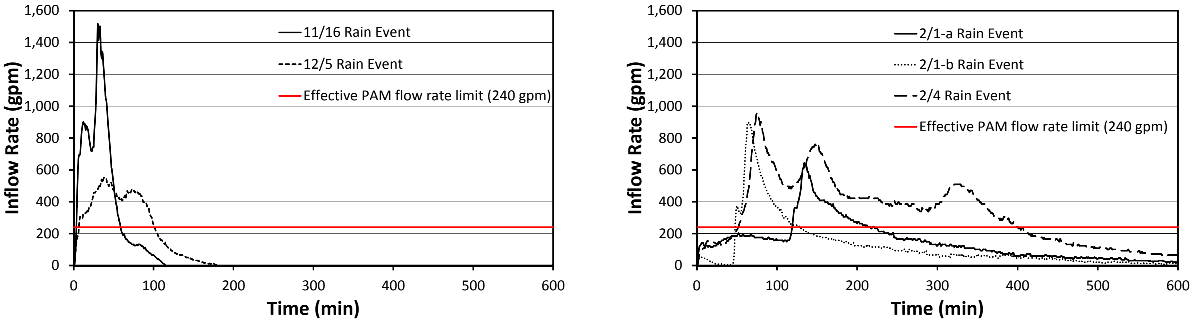
Sample Location	**Max TSS**	**Average TSS Percent Difference (%)**						
		12hr	**24hr**	**36hr**	**48hr**	**72hr**	**96hr**	**120hr**
Bay 2	63	19	20	19	17	14	11	9
Bay 3	253	10	13	15	16	17	16	14
Outflow	484	4	3	3	3	4	4	3

(a) Turbidity Reduction Percent Improvement *w/Limited PAM*

Sample Location	**Max Turbidity**	**Average Turbidity Percent Difference (%)**						
		12hr	**24hr**	**36hr**	**48hr**	**72hr**	**96hr**	**120hr**
Bay 2	-236	22	22	20	17	12	9	7
Bay 3	-44	13	16	17	17	16	14	13
Outflow	166	4	3	3	2	2	2	2

The overall performance of the sediment basin in Phase 2 *w/Limited PAM* versus what was observed *w/No PAM* is not as drastic as compared to what was observed in Phase 1 between *w/PAM* and *w/wrong PAM*. Flow rates and volumes collected for each rain event provide an adequate explanation for this difference in performance. The average and peak flow rates observed in Phase 1 were much higher than the average flow rates observed in Phase 2. The total volume of stormwater entering the sediment basin in Phase 1 was approximately 6 to 7 thousand cubic feet per rain event, whereas the total volume entering the basin during Phase 2 was approximately 20 to 30 thousand cubic feet per rain event. Further insight into the inflow rates for each rain event show that the duration of inflow during Phase 1 rain events lasted an average of 2 hours – thus explaining the higher average inflow rates. If the 2 hour peak inflow rate was taken from Phase 2 rain events, the average inflow rate would range from 370 to 645 gpm. This provides sufficient evidence to show that the sediment basin had much more volume being introduced per rain event for longer periods of time during Phase 2 than during Phase 1. The greater the volume of stormwater that was being introduced to the sediment basin, the more resuspension of sediment within the basin becomes an issue – driving the TSS and NTU reductions efficiency down and creating a fully mixed solution once the depth of the stormwater in the basin overtops the baffles. With this in mind, initial reduction efficiency within the first 36 hours after peak observed TSS and turbidity values *w/Limited PAM* in Phase 2 were much lower than what was observed *w/ PAM* (i.e. correct type of PAM) during phase 1, despite having the correct PAM being introduced to the stormwater inflow properly.

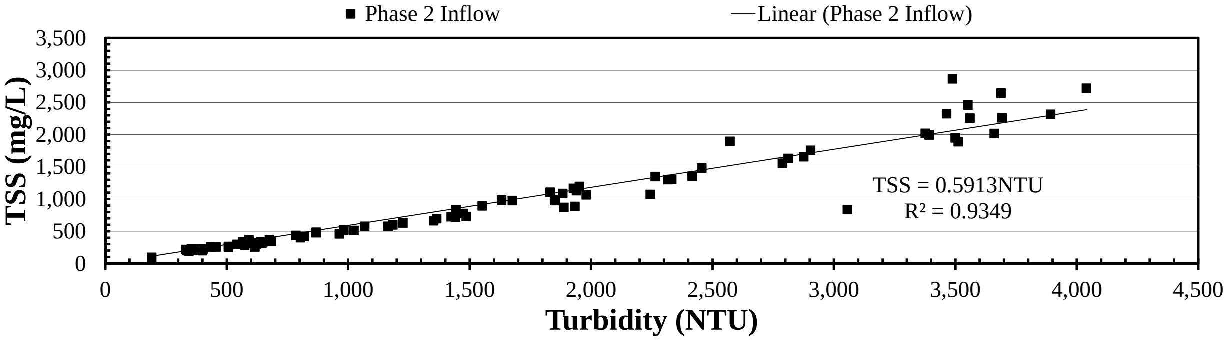
Nancy Olenic with Applied Polymer Systems (A.P.S.) recommended a flow rate of 50-60 gpm per floc log for maximum effective performance when being used in a sediment basin inflow channel application (see Appendix A). The ALDOT special project detail for sediment basin construction on sheet 86-1 in reference to Project No. APD-0355(502) states on Note: (4) "…Four blocks shall be placed at the inlet of the basin." Using only four floc logs essentially created a range of maximum inflow that can be effectively treated by the floc logs at a rate of 200 to 240 gpm. Figure 4.9 shows actual flow rates observed during Phase 1 and Phase 2 in relation to the recommended effective flow rate of the floc logs. It can be seen from Figure 4.9, based on inflow rates into the basin, the stormwater runoff was not effectively dosed (basically underdosed) to effectively promote flocculation and deposition.



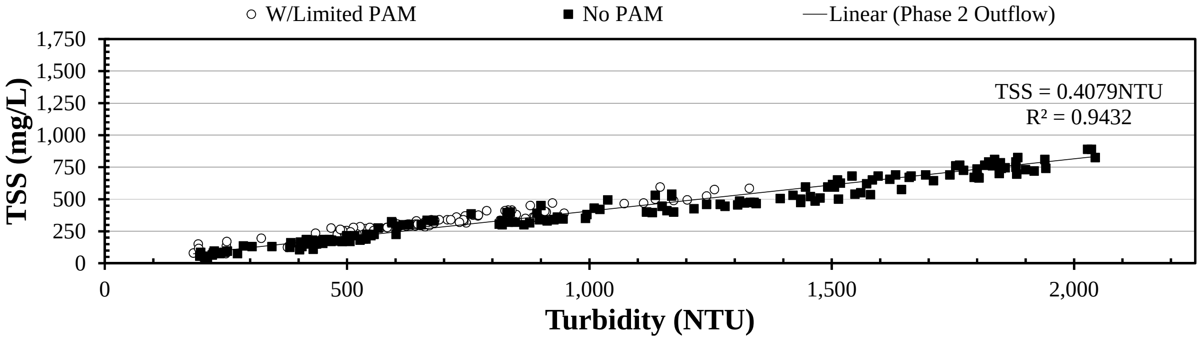
(a) Phase 1 flow rates (b) Phase 2 flow rates

Figure 4.9: Phase 1 and Phase 2 observed inflow rates and durations.

Phase 2 data was also evaluated for TSS vs. turbidity correlations to more easily determine TSS values in the field. Figure 4.10 presents the inflow and outflow correlations that were calculated for Phase 2 data. Since Phase 2 data collection was during a time that overall vegetative cover on-site was more developed than during Phase 1, the inflow TSS and turbidity values observed were considerably lower with a data correlation of TSS = 0.5913NTU. With this in mind, the inflow data correlation is highly dependent on site conditions and soil type. The Phase 2 outflow data correlation of TSS = 0.4079NTU is similar to the Phase 1 outflow data correlation of TSS = 0.4287NTU, however the accuracy of the correlation in Phase 2 is 11% higher, providing a much more accurate and usable correlation for outflow. The data correlations determined for Phase 1 and Phase 2 are only usable on the basin 4 site or sites with similar soils, as soil type plays a critical role in the correlation between TSS and turbidity in stormwater.



(a) Inflow



(b) Outflow

Figure 4.10: Phase 2 TSS versus turbidity data correlations.

4.4 Basin Performance on Trapping Sediments

The performance of a sediment basin can be evaluated in many different ways. USEPA regulations (USEPA 2009b) requires construction agencies employ structural and nonstructural

BMPs to maintain a daily maximum limitation of 280 NTU for effluent discharge from construction sites. Therefore, the time for a sediment basin to achieve a daily average outflow discharge of 280 NTU can be used to evaluate basin performance. In a well-controlled laboratory or field study, sediments flowing into and leaving (through outflow structures) from the basin can be quantified, and then the efficiency of retaining or holding sediments in the basin can be determined (McCaleb and McLaughlin 2008). In order to quantify sediments flowing into and leaving from a basin, both flow rate and TSS (or turbidity) should be monitored and quantified over the entire period of having inflow into and dewatering the basin. An alternative way is to determine the event mean concentration (EMC) from a few representative rainfall events, and then use EMC to estimate sediments into and out of the basin. The third method to evaluate the performance of a sediment basin over number of rainfall events monitored is to use pre- and post-operation surveys of the basin and determine the amount of sediment retained in the basin. All three methods are investigated below to examine the performance of sediment basin 4 constructed in Franklin County, AL.

4.4.1 *Time to 280 NTU Turbidity*

During the study period of monitoring sediment basin 4, 10 sets of outflow samples were collected by an ISCO 6712 portable automatic stormwater sampler (sampler C in Figure 3.3). Figure 4.11 and Figure 4.12 show two examples of in-basin and outflow turbidity of the basin 4 from 1/7 to 1/12/2012 and from 1/17 to 1/26/2012 including a red line representing turbidity of 280 NTU. Typically the maximum turbidity occurred shortly after stormwater runoff was generated from a rainfall event as evidenced in Figure 4.5, Figure 4.11, and Figure 4.12 (as high as 3,000 NTU on 2/1/2012). Average turbidity during a rainfall event is typically high, and turbidity started to exponentially decrease shortly after the rainfall stopped (Figure 4.5, Figure 4.11, and Figure 4.12). Turbidity often had a sudden and large increase due to a high intensity rainfall impulse, e.g., on 1/8/2012 (Figure 4.11), 1/21 and 1/23/2012 (Figure 4.12), 2/1 and 2/4/2012 (Figure 4.5).

The maximum turbidity and minimum or ending turbidity of each data collection period are summarized in Table 4.11. The minimum or ending turbidity is either measured turbidity at the end of data collection (typically about 24 hours) for single rain event or minimum turbidity just before turbidity had a large increase due to the second rain event. There were only three cases (11/16/2011, 1/8/2012, and 1/11/2012) in which measured minimum or ending turbidity was less than 280 NTU.

Based on time series of measured turbidity from stormwater samples at the outflow of sediment basin 4, elapsed times starting from measured peak (maximum) turbidity to 280 NTU turbidity for 10 rain events were determined and are summarized in Table 4.11. The elapsed time is either interpolated from time series of measured turbidity if measured ending turbidity (column 3 in Table 4.11) was less than 280 NTU or predicted from exponential reduction equation (Appendix B) if measured ending turbidity was higher than 280 NTU. The elapsed time to 280 NTU ranged from 19.0 hr (when maximum turbidity less than 280 NTU) to 147.5 hr (more than 6 days). Table 4.12 shows Phase 1 sediment basin performance comparison of *w/PAM* and *w/wrong PAM* conditions using elapsed time from peak turbidity to 280 NTU. The basin performance under *w/PAM condition* with shorter time to 280 NTU was superior in comparison to under *w/wrong PAM* condition. With PAM in the inflow channel on 11/16/2011, elapsed time to 280 NTU was about the same for Bay 2, Bay 3, and outflow. With *wrong PAM* in the inflow channel on 12/5/2011, elapsed time to 280 NTU increased from Bay 2 to Bay 3, and then to outflow, this might be because wrong PAM did not create any floc and large particles in Bay 2 and Bay 3 settled faster than finer particles in the outflow. Table 4.13 shows Phase 2 sediment basin performance comparison of *No PAM* and *w/Limited PAM* conditions using elapsed time from peak turbidity to 280 NTU. Except high turbidity created by heavy rainfall event on 1/17/2012 (Figure 4.12) that took much longer time to 280 NTU, other cases without PAM (1/21/2012) or with limited PAM did not have any distinct trend or pattern on elapsed time to 280 NTU.

The USEPA's 280 NTU turbidity limit is expressed as a maximum daily limitation, meaning that the average daily turbidity of samples collected within a calendar day may not exceed the maximum daily amount. This allows for temporary discharges of stormwater exceeding the turbidity requirement, such as discharges during an intense period of rainfall. "Notably, the new rule exempts discharges resulting from a storm event that exceeds the local two-year, 24-hour storm level" (Hain and Walters 2012). Average turbidity values for the first calendar day and days afterwards were calculated from either measured turbidity data or computed hourly turbidity from exponential reduction equation. Average turbidity for the first day derived from measured turbidity for each data collection period is summarized in Table 4.11. All 10 data sets had average turbidity for the first day greater than 280 NTU (Table 4.11, as high as 1,899 NTU). The day with daily average turbidity less than 280 NTU and corresponding daily average turbidity were also calculated and listed in Table 4.11. There were four cases (1/11/2012, 1/19/2012, 1/23/2012, and 2/2/2012) in which it could take more than 4 days to reach daily average turbidity less than 280 NTU, but in reality the situation would not happen because the basin 4 was completely dewatered about 4 days.

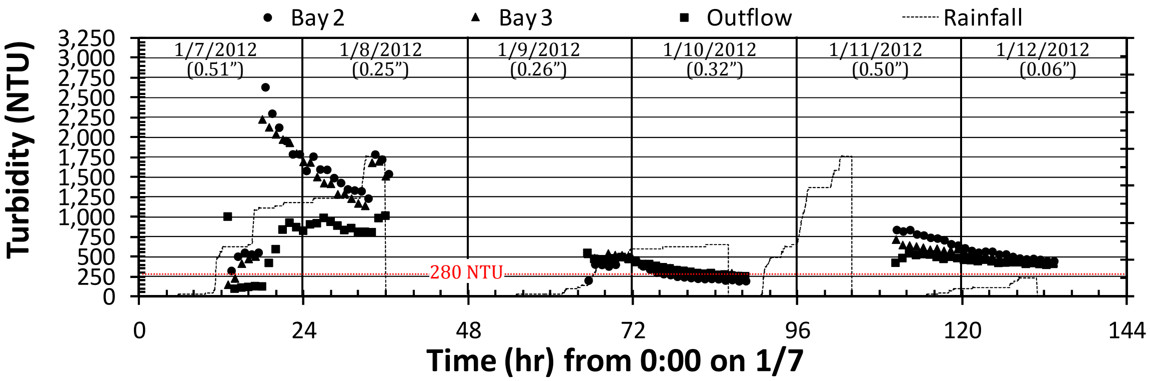


Figure 4.11: In-basin and outflow turbidity and rainfall data for 1/7 thru 1/12/2012.

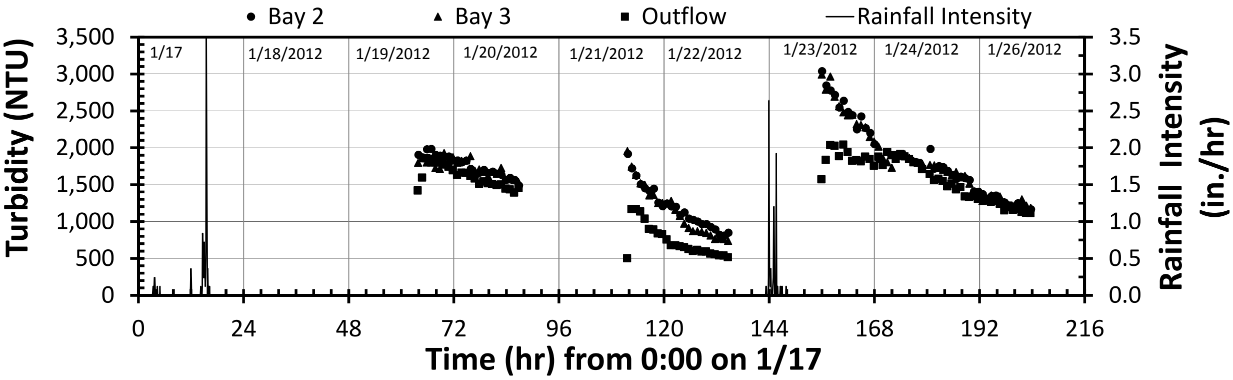


Figure 4.12: In-basin and outflow turbidity and rainfall intensity for 1/17 thru 1/26/2012.

Table 4.11: Evaluating basin performance using USEPA 280 NTU turbidity limit.

Date	Maximum Turbidity [1]	Minimum or Ending Turbidity [2]	Time (hr.) to 280 NTU	Average turbidity for the 1st day	The day with daily average turbidity less than 280 NTU (daily turbidity value)
11/16/11	1,646	239	19.0	605	2 (199)
12/5/11	1,112	593	45.3	989	4 (151)
1/8/12	1,010	260	57.5	815	4 (200)
1/11/12	945	215	75.0	491	5 (245)
1/19/12	1,858	1,456	147.3	1,748	8 (244) [3]
1/21/12	1,170	516	36.9	970	3 (223)
1/23/12	2,044	1,160	147.5	1,899	8 (220) [4]
1/26/12	905	495	66.0	667	4 (211)
2/2/12	1,330	435	78.8	1,277	6 (186) [5]
2/4/12	1,146	555	43.5	781	3 (262)

Note: [1] – Maximum measured turbidity (NTU) from stormwater samples collected (for some cases, it may not be the real maximum turbidity during or immediately after the rain event),

[2] – Turbidity at the end of data collection (typically about 24 hours) for single rain event or minimum turbidity just before turbidity had a large increase due to the second rain event,

[3] – High turbidity and low reduction rate on 1/19/2012 (about 48 hours after the rain event) was resulted from a heavy rainfall event (3.5 in./hr for peak impulse) occurred on 1/1/7/2012 (1.22 in.) that destroyed inflow weir,

[4] – High turbidity and slow reduction rate was resulted from a high rainfall intensity impulse (2.7 in./hr peak impulse) occurred on 1/22–1/23/2012 (~0.96 in.) after a rainfall event on 1/17/2012 (~1.22 in.), and

[5] – High turbidity and slow reduction rate was resulted from a high rainfall intensity impulse occurred in the later afternoon on 2/1/2012 after a rainfall event in the morning on 2/1/2012 (see Figure 4.5).

Table 4.12: Phase 1 sediment basin performance comparison of *w/PAM* and *w/wrong PAM* conditions using elapsed time from peak turbidity to 280 NTU.

Location/ Parameters	**PAM CONDITIONS**					
	w/PAM			***w/wrong PAM***		
	Max. Turbidity[1]	**Ending Turbidity[2]**	**Time (hr.) to 280 NTU[3]**	**Max. Turbidity[1]**	**Ending Turbidity[2]**	**Time (hr.) to 280 NTU[3]**
Bay 2	5,592	235	18.96	1,642	590	32.56
Bay 3	3,856	247	20.35	1,552	615	36.02
Outflow	1,646	239	**19.00**	1,112	593	**45.31**

Note:

[1] – Maximum measured turbidity (NTU) from stormwater samples collected (for some cases, it may not be the real maximum turbidity during or immediately after the rain event),

[2] – Turbidity at the end of data collection (typically about 24 hours) for single rain event or minimum turbidity just before turbidity had a large increase due to the second rain event,

[3] – Time in hours from the maximum turbidity occurred and elapsed time is either interpolated from measured turbidity distribution if measured ending turbidity is less than 280 NTU or predicted from exponential reduction equation if measured ending turbidity is higher than 280 NTU.

Table 4.13: Phase 2 sediment basin performance comparison of *No PAM* and *w/Limited PAM* conditions using elapsed time from peak turbidity to 280 NTU.

Conditions	**Date of rain event**	**Location/ Parameters**	**Max. Turbidity[2]**	**Ending Turbidity[3]**	**Time (hr.) to 280 NTU[4]**
No PAM[1]	1/17/2012	Bay 2	1,982	1,486	164.4
		Bay 3	1,926	1,532	235.7
		Outflow	1,858	1,456	147.3
	1/21/2012	Bay 2	1,916	847	52.9
		Bay 3	1,956	738	44.8
		Outflow	1,170	516	36.9
w/Limited PAM	1/26/2012	Bay 2	1,008	517	61.7
		Bay 3	1,042	523	65.2
		Outflow	905	495	66.0
	2/1/2012(a)	Bay 2	1,552	811	27.5
		Bay 3	1,326	844	31.7
		Outflow	740	522	38.5
	2/1/2012(b)	Bay 2	2,996	581	85.5
		Bay 3	2,472	551	85.6
		Outflow	1,330	486	78.8
	2/4/2012	Bay 2	1,988	902	55.7
		Bay 3	1,914	862	57.3
		Outflow	1,146	555	45.5

Note: The footnotes 1 to 4 are the same as footnotes for Table 4.12.

4.4.2 *Event mean concentration*

The event mean concentration (EMC in mg/L) is defined using equation (4.1) when the event load for specific contaminant (TSS for current study) and the event water volume are measured (Wanielista and Yousef 1993).

$$EMC = \frac{L}{R} \tag{4.1}$$

where L = sediment loading per event, mg;

R = volume of runoff per event, L (liter);

The loading for an event is determined by summing the loadings during each sampling period, provided that flow rate (or volume) data are available for the period. The equation (4.2) is used for computing loading L:

$$L = \sum_{i=1}^{n} R_i C_i \tag{4.2}$$

where R_i = volume proportional to flow rate at time interval *i*, L;

C_i = average concentration over the interval *i*, mg/L;

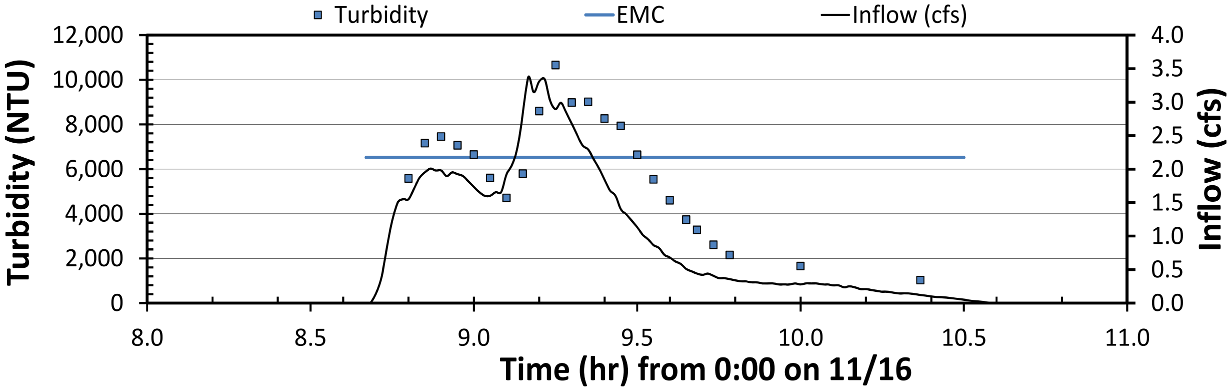
n = total number of samples during a single storm event.

Figure 4.13 shows time series of inflow turbidity and flow rate for rainfall events on 11/16 and 12/5/2011, and both events had about 1.4 in. total rainfall. These two rainfall events generated 6,488 ft^3 (about 3.2 ft water depth in the basin) and 5,944 ft^3 (3.0 ft water depth) of runoff, respectively. Based on inflow rate and measured TSS, computed sediment loadings on 11/16 and 12/5/2011 were 1,197.7 kg and 224 kg, respectively. More than one thousand kilograms of sediment loading on 11/16/2012 indicates stormwater runoff from the 502 project construction site did bring a large amount of sediments into the basin 4 at early stage of the construction (11/16) when a small portion of the site was stabilized (10% vegetation cover).

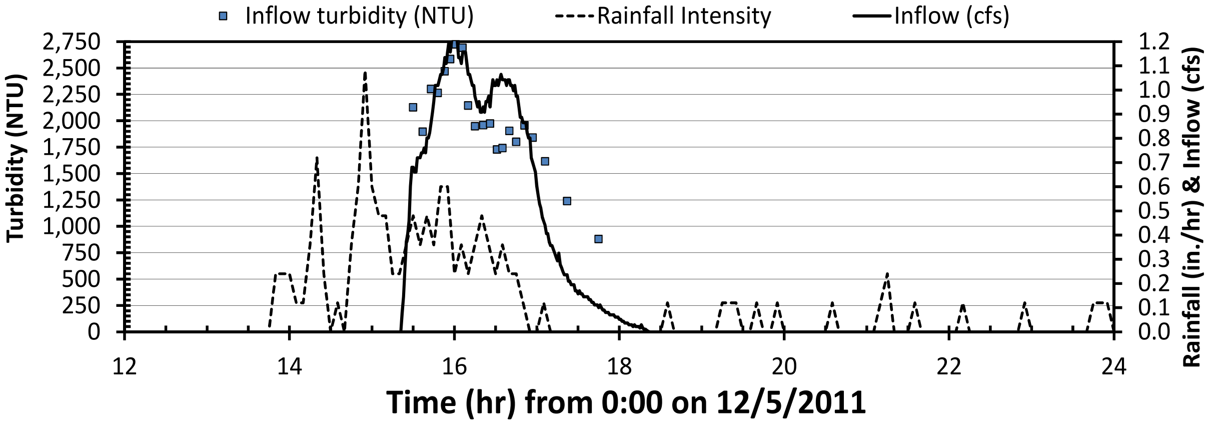
The maximum inflow TSS and turbidity on 11/16/2011 were 10,545 mg/L and 10,565 NTU, respectively, and calculated EMC for TSS and turbidity are 6,520 mg/L and 6,831 NTU. The maximum inflow TSS and turbidity on 12/5/2011 were much smaller: 1,950 mg/L and 2,724 NTU, respectively, and calculated EMC for TSS and turbidity are 1,331 mg/L and 2,024 NTU. Average inflow TSS and turbidity, which are not weighted by runoff volume, are 1,305 mg/L and 1,989 NTU, which are slightly less than EMC values. Based on Figure 1.4, the dewatering time for 3.2 ft of water in the basins is about 1 day, and then calculated EMC for TSS and turbidity for outflow on 11/16/2011 were 217.5 mg/L and 544 NTU. Calculated sediment leaving the basin through outflow was only 26.8 kg, therefore, the efficiency of the basin to remove TSS was 97.7%, even though daily average turbidity was greater than 280 NTU. After similar computations were performed, the efficiency of the basin to remove TSS was 83.7% for rainfall event on 12/5/2011, and results are summarized in Table 4.14.

Table 4.14: EMC for TSS and turbidity and removal efficiency for two rain events.

Rainfall event	Inflow (weir)			Outflow (skimmer)			Removal Efficiency		
	EMC TSS (mg/L)	EMC Turbidity (NTU)	TSS Load (kg)	EMC TSS (mg/L)	EMC Turbidity (NTU)	TSS Load (kg)	by TSS	by NTU	by Load
11/16/2011	6519.6	6830	1197.7	221.5	478	25.3	96.6%	93.0%	97.9%
12/5/2011	1331.2	2024	224.0	319.6	793	36.6	76.0%	60.8%	83.7%



(a) 11/16/2011 Rainfall Event



(b) 12/5/2011 Rainfall Event

Figure 4.13: Time series of inflow turbidity and flow rate for rainfall events on 11/16 and 12/5/2011. Measured 5-minute rainfall intensity was included for the event on 12/5/2012.

4.4.3 *Retained sediment analysis*

Twelve samples of sediments retained by the sediment basin were collected as described in Chapter 3 (Section 3.2). Sediment samples were analyzed by performing an ASTM gradation test on each sample, and then the samples for each bay were averaged, excluding outliers, into a single gradation for that bay. The gradations for each bay were then plotted against each other in Figure 4.14.

As can be seen in Figure 4.14, the retained sediment from the sediment basin shows a general trend of reduction in sediment particle size from the one bay to the next as runoff progresses through the basin. The only exception to this trend is between Bays 1 and 2, where Bay 2 shows a slightly larger particle size until the #80 sieve (0.177 mm), where Bay 2 continues on more of a linear trend and drops below Bay 1 and slightly below Bay 3. There was a significant gap in particle sizes observed between Bays 1 and 2 and Bays 3 and 4 for sizes 0.177 mm and larger. This shows that the larger particles of sediment had a strong tendency to fall out of the stormwater earlier in the sediment basin, allowing smaller particles to fall out later and further into the basin. This was exceptionally true in Bay 4, where gradation sizes remained smaller than any of the other bays observed. Based upon this sediment gradation data, showing a strong trend of continuously smaller particle sizes from entry of the basin to exit – especially from the first 2 bays to the last 2 bays, this can happen due to gravity settling alone. In this study, because there is no direct comparison that can be made from an identical basin without using baffles, the overall function of the baffles performing as they were designed is still not clear and remains as a future research topic.

To gain an overall perspective of how the sediment gradation stacks up against virgin soil gradation, they were plotted together in Figure 4.14. In the figure, the virgin soil gradation is indicated by the blue gradation line. The virgin soil gradation shows a slight gap in the grading from 0.1 to 0.5 mm, which explains gap-like grading trends shown by the sediment gradations for Bay 1 and 3 as well.

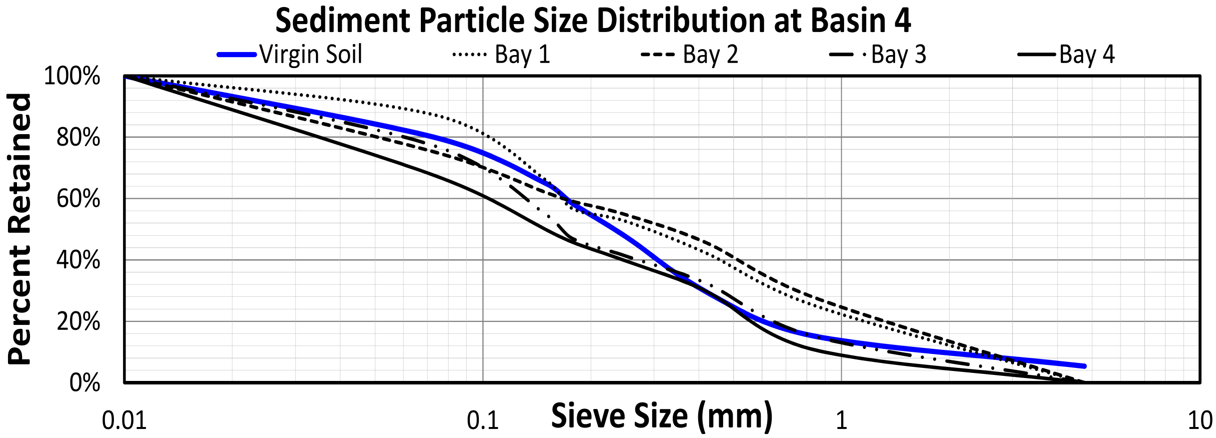


Figure 4.14: Retained sediment and virgin soil gradation.

A retained sediment volume report was generated by MicroStation, noting the net change in volume that was determined by subtracting the end-volume of the post-evaluation survey from the original volume of the pre-evaluation survey. Retained sediment volume for basin 4 was 62.89 yd^3 (1,698 ft^3) that resulted from sediment-laden runoff generated from rainfall events from 9/13/2011 to 4/26/2012. The retained sediment volume occupied 65% of dead storage (2,622 ft^3) of basin 4 and was only 8.4% of the total sediment basin volume (20,287 ft^3). If we assumed average sediment density is approximate 100 lbm/ft^3, retained sediments were about 169,800 lbm (77,020 kg).

We have conducted a national wide survey to determine the state-of-the-practice for sediment basin design, construction, maintenance, and inspection techniques employed by state highway agencies (SHAs) in the U.S. All responding agencies with sediment basin experience recommended that basin maintenance should be performed, and 85% of those recommend that basin cleanout should occur when the sediment basin loses 50% or less of its storage capacity. The Alabama Handbook (ASWCC, 2009) requires removing deposited sediments from the basin when approximately one-half of the design storage volume has been filled. Therefore, the maintenance or cleaning the basin was not necessary based on current ALDOT standard specifications for highway construction, and was not performed by the contractor.

4.5 Cost Analysis

To determine costs for basin 4, it was determined for simplicity that additional items for new sediment design, beyond the typical construction of a sediment basin, added to the basin would be quantified. Additional items included were listed at the plan/profile sheet for sediment basin 4 on sheet 86D in reference to project no. APD-0355(502). Also, additional items noted on site, such as a filter blanket lining for the entire basin, were also added to additional cost items, which are listed in Table 4.15, below.

Table 4.15: Additional cost items added to basin 4 on Sheet No. 86D

Item	Cost	Units [1]	Quantity	Total
Floc Log (for 2 inflow channels)	$164.75	EA	8 [2]	$1,318.00
Coir Netting (baffle material)	$5.40	LF	390	$2,106.00
R.E.C.P.	$5.00	SY	1819	$9,095.00
Faircloth Skimmer	$1,665.00	EA	1	$1,665.00
Filter Blanket Geotextile (Liner)	$3.63	SY	620	$2,250.60
Total Additional Cost:				**$16,434.60**

Note: [1.] LF stands of linear foot, SY stands for square yard; and [2.] 4 PAM blocks were used per channel resulting in 8 total PAM blocks for this sediment basin configuration.

Additional cost items were directly associated with the updated sediment basin design, with the addition of filter blanket geotextile lining the inside of the basin. Lining sides of a basin can reduce potential soil erosion of the side slopes preventing additional sediments from entering into the basin. As constructed, the total additional costs incurred using the new sediment basin design was $16,434.60.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

The objective of this research project was to monitor the performance of newly designed sediment basins that were constructed for the 502 project in Franklin County. All tasks proposed have been completed, and conclusions and recommendations of the study are summarized below.

5.1 Conclusions

Through completing the study, the following conclusions have been developed:

- A field-scale data collection plan to monitor and evaluate sediment basin performance was developed and implemented using ISCO 6712 portable automatic stormwater samplers, flow modules, a rain gauge, and weirs.
- Sediment basin 4 on the 502 project did effectively remove sediments at the early stage of the construction when the basin's influent most likely contained relative large percent of large-size sediment particles. For example, sediment basin 4 removed 97.9% and 83.7% of sediments generated by rainfall events on 11/16/2011 and 12/5/2011.
- A floating skimmer allowed for effluent to be discharged uniformly and slowly, providing longer detention time for sediments to settle in the basin. Data analysis on decay (reduction) coefficients for total suspended solids (TSS) and turbidity allowed us to quantify the sediment-settling rate of soils on the 502 project in Franklin County, AL.
- Appropriate PAM (or floc log) added into inflow is crucial to aid sediment settling and reduce turbidity of effluent. For example, the performance of the basin 4 was superior for the rainfall event on 11/16/2011 when correct PAM was used in the inflow channel than the performance for the rainfall event on 12/5/2011 when wrong PAM was used.
- Rainfall events with subsequent high rainfall intensity impulses generated high turbidity inflows from the construction site and suddenly increased in-basin turbidity that could be several times higher than turbidity of water already in the basin.
- Resuspension of settled sediments significantly increased in-basin sediment concentration and turbidity when the basin has experienced a number of rainfall events with large amount of settled sediments inside basin.
- An under-designed sediment basin (from a volumetric standpoint) more frequently allowed highly turbid sediment-laden runoff to directly flow over the emergency spillway to downstream receiving water body.

5.2 Recommendations

The following recommendations from the study are divided into the following sections: (1) basin size, (2) PAM floc block dosage, (3) baffle installation, (4) additional cost, and (5) recommendations for use of sediment basins on future projects.

5.2.1 *Basin size*

The size (storage or volume) of sediment basin 4 in Franklin County, AL was constructed to accommodate 751 yd^3, or 20,287 ft^3, after a minor field adjustment added an extra 1.5 ft of depth (dead storage). Considering the total contributing watershed area, 9.21 acres, intended to drain into the sediment basin, the storage provided by the basin was calculated to be approximately 2,203 ft^3/acre. Discounting the 97.1 yd^3 additional storage added during construction, the original sediment basin design provided 1,918 ft^3/acre of storage. Based on these calculations, the sediment basin was originally designed and sized (actually undersized) using the out-of-date minimum sediment basin storage design standard to provide 1,800 ft^3/acre of contributing area draining into the basin.

Actual inflow volumes observed during the Phase1 and Phase 2 data collection effort, shown in Table 5.1, show that observed inflow volumes during Phase 2 exceed the actual storage volume of the sediment basin designed using the out-of-date design standard. The problem with this is that the rain events observed in Phase 2 did not exceed the design storm volume of a 2-yr, 24-hr storm of 3.91 inches. Using Bentley's PondPack, estimated runoff volume for a 2-yr, 24-hr storm in Franklin County was 2.229 ac-ft or 97,095 ft^3 because direct runoff (or effective rainfall) was estimated as 2.9 in. for a newly graded area from a 3.9 in. rainfall from a total contributing area of 9.21 acres.

Table 5.1: Observed inflow volumes

Phase	Date	Inflow Volume (ft^3)
1	11/16/2011	6,941
	12/5/2011	6,218
2	2/1/2012	21,921
	2/4/2012	28,454

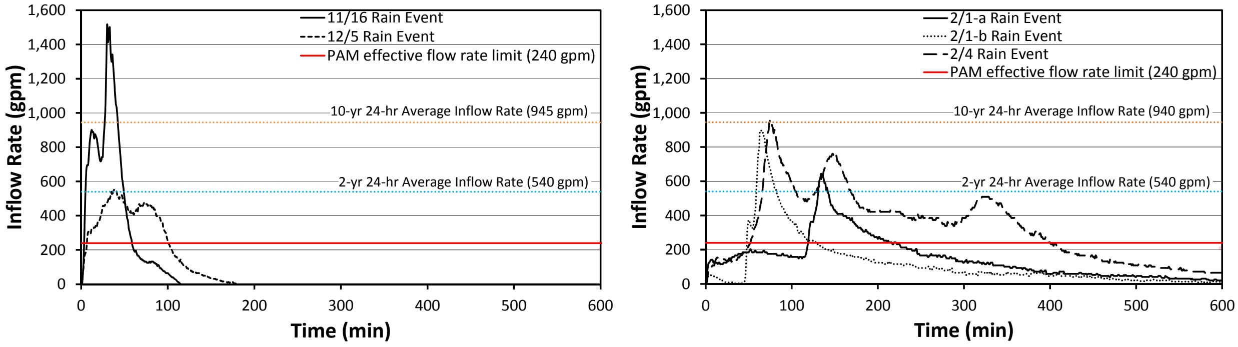
The current NPDES Construction General Permit (CGP) provides sediment basin design requirements in section 2.1.3.2-a-i to "Provide storage for either (1) the calculated volume of runoff from a 2-yr 24-hr storm, or (2) 3,600 cubic feet per acre drained" (ADEM 2011; USEPA 2012b). In this case, based upon current design standards and observed inflow volumes, 3,600 ft^3/acre design standard would provide 33,156 ft^3 of storage, which would be sufficient to hold the observed volumes produced by rain events during both Phase 1 and Phase 2 data collections shown in Table 5.1. The 3,600 ft^3/acre design standard is still not sufficient to hold the volume of a 2-yr, 24-hr storm event (97,095 ft^3) and is significantly undersized. The analyses of inflow volumes of the various storm events draining into sediment basin 4 indicate the basin was under designed and not size according to the new CGP standards. It is recommended that all sediment basin designs and sizes used on future projects be designed to the most current design standards at the time of construction to maximize sediment basin performance and efficiency. By properly sizing the basin, the inflow amount for the design storm will be captured allowing the sediment basin to perform as intended (i.e., providing adequate detention time for suspended sediment) and minimizing the chance that inflow from the design storm will be discharged via the emergency spillway. Using calculated volume of runoff from a 2-yr, 24-hr storm to design a sediment basin would result a huge basin, i.e., 2.229 ac-ft or 97,095 ft^3, and further study using 2-yr, 24 hr storm for sediment design is necessary.

5.2.2 *PAM floc logs*

The proper placement of PAM floc blocks is crucial and important to ensure that sediment-laden stormwater inflow is properly dosed to promote flocculation of suspended sediment and deposition within the basin. Figure 1.2(a) illustrates the special project drawing for the 502 project which shows the placement of 4 floc blocks in the inflow channel downstream of the rock ditch check structure. It was noted that the contractor followed this drawing and only installed the requisite number of floc blocks based upon the number shown on the special drawing without considering the actual amount of flow expected from the contributing drainage area.

Soil samples on the 502 project were sent to Applied Polymer Systems (APS), Inc. for determining which type of floc block should be used (Appendix A). APS recommended using floc log type of 706B and having a reaction or contact time of 40–45 seconds. The recommended dosage rate should be 50–60 gpm flow per each Floc Log placed in a series or in a row (Appendix A). Therefore, four floc blocks placed in the inflow channel downstream of the rock ditch check can handle a maximum flow of 200 to 240 gpm or 0.446 to 0.535 cfs.

Results presented in Chapter 4 exhibited that flow rates observed over the entire data collection period exceeded the effective flow rate limit (240 gpm) of the 4 floc logs that were in place in both channels during both phases. Figure 5.1 presents the observed flow rates of from Phase 1 and Phase 2, including average runoff flow rates of a 2-yr, 24-hr and 10-yr, 24-hr (1.2 and 2.1 cfs, respectively, calculated using PondPack software).



(c) Phase 1 flow rates

(d) Phase 2 flow rates

Figure 5.1: Phase 1 and Phase 2 observed inflow rates and durations.

Based upon the results of the data analyses, there are two recommendations to improve the performance of the floc logs being used in the inflow channels for sediment basins. First, it needs to increase the number of floc logs placed at the bottom of inflow channel to properly dose the average flow rate of 2-yr 24-hr runoff. Second, it should also consider to increase the number of floc logs placed on the side of inflow channel to properly dose the average flow rate of 10-yr 24-hr runoff. For basin 4 in Franklin County, AL, the average runoff flow rate for a 2-yr 24-hr storm, the CGP design storm for sediment basins, is 540 gpm. Nine to 11 floc logs, based upon manufacturer recommendations (Appendix A), would be required to be placed at the bottom of inflow channel to effectively dose and treat relative small inflows and up to average inflow rate from a 2-yr, 24-hr storm. The 10-yr 24-hr runoff flow rate would be chosen as a worst case scenario. To effectively treat the runoff flow rate of 940 gpm from a 10-yr 24-hr storm, 16 to 19 floc logs would need to be strategically placed at the sides of inflow channel, so that only sediment-laden runoff at high flow rates would contact those floc logs. Further research is necessary to study the number and placement of floc logs at different inflow rates.

5.2.3 *Baffles*

The purpose of the baffles was to help slow inflow velocities and spread the flow across the entire width of the basin increasing the potential for sedimentation (ASWCC 2009). Baffles are made of a coir fiber material that is porous, helping to slow velocities, distribute flow, and capture sediment (as a result of the fibrous material). The baffles installed in basin 4 consisted of 2 layers of coir net attached to steel wire assembled perpendicular to the direction of flow within the basin. The problem observed during data collection, as shown in Figure 5.2, is that when runoff from a rain event completely filled the basin, the water level within the basin overtopped the baffles, creating a fully mixed condition within the basin, disabling the designed function of the baffles. The contractor stated that the height that the baffles were constructed was consistent with the width of the rolls steel support mesh typically used with silt fences and coir baffle material, creating a simple installation. In the case of basin 4, the height of the baffles was 4 ft, whereas the full depth of the sediment basin was approximately 6.5 feet.

(a) basin empty – baffle orientation (b) basin filled to capacity – baffles overtopped

Figure 5.2: Stormwater overtopped the baffles when the basin was filled to capacity.

It is recommended that the height of the baffles match the full depth of the sediment basin and not be installed below the minimum elevation of the emergency spillway, preventing stormwater from overtopping them and creating a fully mixed condition. In order for the baffles to function properly, as designed, it is imperative that the height of the baffles be greater than the maximum potential water level within the sediment basin, just prior to discharge over the emergency spillway. ALDOT Special Project Detail No. 1170 has a correct drawing of sediment basin profile that shows the baffle height is above the crest of the emergency spillway, but it does not contain a specific note that clearly states the baffle height requirement.

5.2.4 *Sediment storage*

Haan et al. (1994) suggests that structure components (Figure 5.3) of a sediment basin that must be considered in the hydrologic design include the following:

- A sediment storage volume sized to contain the sediment trapped during the life of the structure or between cleanouts
- A permanent pool volume (if included) above the sediment storage to protect trapped sediment and prevent resuspension as well as providing a first flush of discharge that has been subjected to an extended detention period
- An active water quality (detention) volume that contains stormwater runoff for a period sufficient to trap the necessary quantity of suspended solids
- A principal spillway that can be a drop-inlet pipe and barrel, a trickle tube, skimmer, or other type of controlled discharge release structure
- Additional freeboard volume along with an emergency spillway that is designed to handle excessive runoff from the rarer events and prevent overtopping.

The sediment storage volume should be sufficient to store the sediment trapped during the life of the structure or between cleanouts. Many design specifications suggest the sediment storage volume on a volume per acre disturbed. For example, Pennsylvania specifies a sediment storage volume of 1,000 ft^3 per acre drained (see *Pennsylvania Erosion and Sediment Pollution Control Program Manual*). This volume is highly site-specific, depending on rainfall distributions, soil types, and construction techniques. Sediment storage volume can also be estimated on the basis of sediment yield using relationships such as the Revised Universal Soil Loss Equation (RUSLE) with an appropriate delivery ratio (Renard et al. 1994) or a computer model such as SEDIMOT III (Barfield et al. 1996) or SEDCAD (Warner et al. 1999).

The permanent pool volume provides additional volume above the sediment storage volume for a first flush of discharge to have an extended detention period and minimize resuspension of deposited sediments from pervious rainfall events. The recommended capacity of the permanent pool varies with the regulatory agency. USDOT, for example, recommends 67 cubic yards (1,800 ft^3) per acre (126 m^3/ha) (USDOT 1995). That standard has been adopted by many states as well (USEPA 2009c).

Current ALDOT design specifications require elevating the basin dewatering device (i.e. skimmer) at 6”–8” above the basin floor to prevent deposited sediments that may bury the device, which creates a small permanent pool volume. For basin 4, a minor field adjustment during construction added an extra 1.5 ft of depth or 97.1 yd^3 (2,622 ft^3, 285 ft^3/acre) of additional storage volume to the basin, which was functioned as sediment storage and permanent pool volume. In current ALDOT design specifications, there is no specific requirement on sediment storage volume and permanent pool volume. ALDOT standard specifications of highway construction state: “In no case shall sediment be allowed to exceed one third of the height of the forebay or drainage sump adjacent to the inlet of the basin”, however both of these features are before the actual sediment basin. However, the Alabama Handbook requires “sediment basins need to be inspected for depth of sediment on a monthly basis and built up sediment needs to be removed when ½ of the basin volume is filled." Based on observations of basin 4 in Franklin County, if it is allowed to fill sediment to half of the basin, sever resuspension would occur, and resuspension of deposited sediment could significantly increase outflow turbidity and TSS concentration.

Figure 5.3 shows different volume zones of a sediment basin including sediment storage volume and permanent pool volume that are not specially required in current ALDOT design specifications. The detention volume, also called active water quality volume, is required to provide from live storage to occur as a result of stormwater runoff from the site. This could be at least 3,600 ft^3/acre drained based on Alabama Handbook or a calculated volume based up the design storm event (e.g., 2 yr 24 hr). In addition, a certain amount of freeboard would need to be provided to allow for flow from larger storms to use the emergency spillway.

It is recommended to include a sediment storage volume for ALDOT design specifications for sediment basins, e.g., 500 ft^3/acre disturbed before additional study on sediment yields is performed using computer models. It is recommended to remove sediment when it reaches one third of the height of the sediment storage volume. Remaining of the 2/3 height of the sediment storage volume actually serves as the permanent pool volume to reduce resuspension.

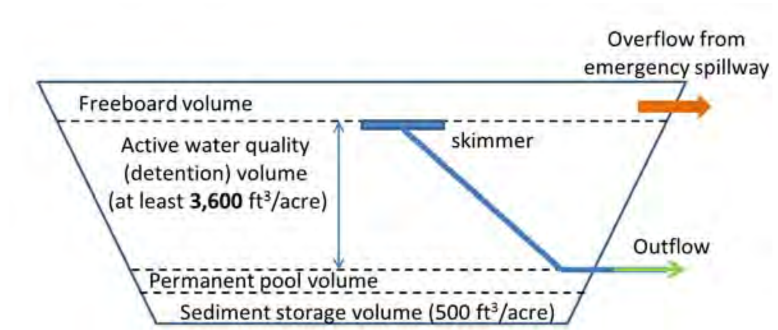


Figure 5.3: Schematic volume zones of a sediment basin.

5.3 Additional Cost

Additional costs associated with the abovementioned recommendations have been compiled with the associated costs of the new sediment basin design, given in Chapter 4, and are shown in Table 4.15. For option 1, the number of floc logs has been increased to accommodate the average flow rate produced by a 2-yr, 24-hr storm in each inflow channel and the coir netting baffle material has been increased to accommodate the extra height of the baffles. The total extra cost for option 1 beyond that which was expended on the basin as it was constructed in the field is $2,684.30. Option 2 contains the same items from option 1, with the addition of 19 floc logs placed along both side slopes of each inflow channel. These additional floc logs would only dose stormwater as the water elevation within the channel reached full depth as a result of the less frequent rain event. The total additional cost difference associated with option 2 is $5,814.55 above what was originally spent on the basin as it was constructed.

Table 5.2: Additional costs associated with recommendations.

Option	Item	Units	Cost	Quantity	Total	Increase
1	Floc Log [1]	Each	$164.75	18	$2,965.50	$1,647.50
	Coir Netting [2]	Liner ft	$5.40	582	$3,142.80	$1,036.80
Total Cost Increase						**$2,684.30**
2	Floc Log [3]	Each	$164.75	37	$6,095.75	$4,777.75
	Coir Netting [2]	Linear ft	$5.40	582	$3,142.80	$1,036.80
Total Cost Increase						**$5,814.55**

Note: [1] - for 2-yr 24-hr flow rate; 2 inflow channels; [2] - for total basin height; [3] - for 2-yr 24-hr flow rate; 2 inflow channels) + (10-yr 24-hr flow rate; emergency spillway);

5.4 Executive Summary

In an effort to improve current sediment basin design, construction, and performance, ALDOT has chosen to adopt a basin design from the North Carolina Erosion and Sediment Control Planning and Design Manual. To ensure that this new sediment basin design is performing at maximum TSS/turbidity reduction and cost efficiency, the Auburn University Highway Research Center performed research, collecting overall sediment basin performance data, and determined the inefficiencies of this design on the 502 project site in Franklin County, AL. Based upon the results of the data collected and observed site conditions during the research period, the following recommendations will provide ALDOT with a sediment basin design that will perform at better performance and cost efficiency.

- Use at least 3,600 cubic feet per acre drained to size the sediment basin for the detention volume to capture and detain stormwater.
- Increase the number of floc logs placed at the bottom of inflow channel to dose for the average flow rate of 2-yr 24-hr runoff. The number of floc logs should be dependent upon the manufacturer’s recommended dosage rate that is based upon laboratory analysis performed on site specific soil.
- Consider increasing the number of floc logs placed on the side slopes of the inflow channel to dose for the average flow rate of 10-yr 24-hr runoff. The number of floc logs should be based upon manufacturer recommended dosage rates.
- The height of the baffles, once installed, should match the full depth of the sediment basin and not be installed below the minimum elevation of the emergency spillway.
- Include a sediment storage volume (e.g., 500 ft^3/acre disturbed) into the design specifications of sediment basins and a requirement to remove the sediment when it reaches one third of the height of the sediment storage volume.

Another question that requires further consideration is: What is the risk of failure resulting from sizing a sediment basin using 3,600 cubic feet per acre drained from the contributing area vs. a 2-yr, 24-hr rainfall event? The risk can be quantified as how often the basin would be overtopped to allow high turbidity sediment-laden runoff (i.e., greater than 280 NTU) from a construction site directly flowing through the basin via the emergency spillway into downstream receiving water body. For all stormwater management practices, designers and mangers have to know design rainfall amounts and rainfall characteristics of the study area. There are some rainfall information available for DOT’s hydrologic designs, for example, rainfall intensity-duration-frequency (IDF) curves at different cities or counties, rainfall depths for return periods of 1 to 100 years and durations from 30 minutes to 24 hr from NOAA’s National Weather Service (NWS) Technical Paper 40 (TP-40), etc. However, there is no rainfall characteristic information in Alabama for the appropriate design of detention ponds and sediment basins for stormwater and erosion control practices. For example, sediment basins used by ALDOT on construction sites are designed to dewater the basin between 2 to 5 days with an average of 3 days. Sediment basins are currently being designed to capture 1” of runoff per acre drained, i.e., 3,600 cubic feet of runoff volume per acre of disturbed area. The amount of runoff generated from a construction site is dependent on rainfall depth, contributing area, rainfall losses related to antecedent moisture condition, vegetation cover, and soil types.

Currently, designers do not know what the rainfall depths of storm events with a minimum interevent dry period of 72 hours (3 days) at different return periods are, resulting in a potential under-design of a sediment basin that is intended to drain in 3 days. USEPA suggests capturing the 95th percentile rainfall event for onsite stormwater control measures. To design a sediment basin for adequate detention of rainfall prior to discharge, designers need to know the 95th percentile event rainfall depths for various cities in Alabama. If these rainfall characteristics are currently not available, it is impossible for designers to appropriately design certain stormwater and erosion control measures and understand the risk (potential failure) of these measures. Also rainfall intensity and duration play an important role on potential damage and have great impact on performance of a runoff/erosion control measures. Therefore, a study of rainfall characteristics in Alabama is important and necessary to help further understand the probability of failure associated with various erosion and sediment controls being employed in the field.

The performance of sediment basin 4 on the 502 project in Franklin County has been evaluated by collecting necessary field data such as rainfall, inflow (runoff), outflow, and stormwater samples inside the basin. McLaughlin et al. (2001) states, “field testing of existing and new sediment and erosion control products or systems has been problematic when conducted on active construction sites.” Therefore, a need exists for evaluating sediment basin design parameters using large-scale, experimental testing procedures to gain an understanding of performance while attempting to make improvements. Further research is necessary to test and improve sediment basin configuration with forebay, the proper use of flocculant additives (polyacrylamide, PAM), baffle placement and configuration, and discharge devices to obtain required detention time (e.g., skimmers).

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APPENDIX A Alabama Samples

(Silt Stop and Floc Log applications)

Sample	Location (108)	Description	APS Application	Results and Special Instructions
	1-30-12 Analysis done by NAO	**Soil Type / Sample**	**Floc Log Type**	**Reaction Time / NTU Reading**
	Sunshine Supplies	**W.S Newell, Franklin County**		
	1409 Republic Rd.			
	Birmingham, AL 35214	pH: 6.67	**Floc Log Type**	
	PHONE: 205-674-5656	NTUi: 62,700	706B	40 - 45 seconds / NTUf 15.4
	FAX: 205-674-7441	Hardness : 125 - 250 ppm CaCO3	**Soil Stabilization**	
			712	dry or spray application
	Devon Harper			
	dharper@sunshinesupplies.com			
	Chris Logan			
	logancp@auburn.edu			

Note: The Polymer Enhanced Best Management Practices Application Guide contains step by step instructions for using Silt Stop Products in soil stabilization and for using Floc Logs in water clarification. The guide can be found at www.siltstop.com.

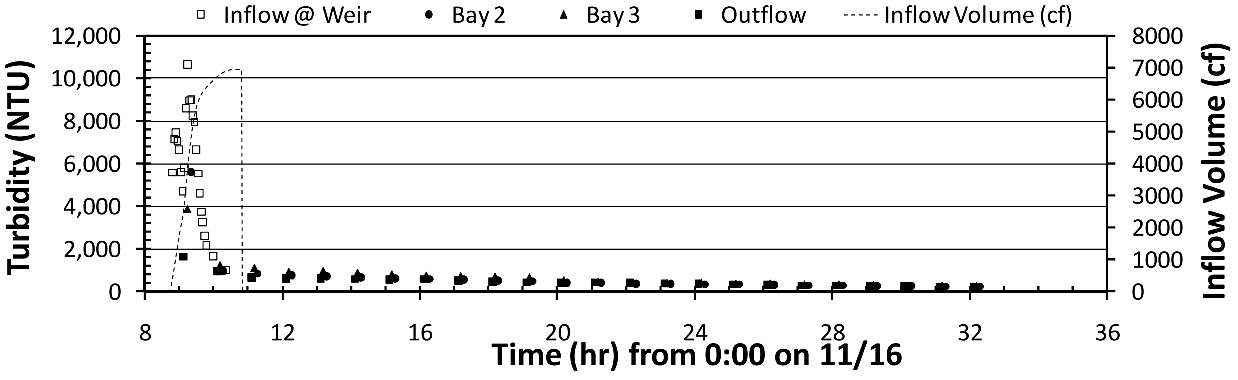
Floc Logs are designed to work in flowing water conditions. Mixing / reaction times will be very important when using the Floc Log listed above. Mixing must be continuous for the time stated to obtain the best results. A mixing ditch, pipe, or flume system may be used with either a pump or gravity flow to meet this requirement. **We recommend positioning the Floc Logs close to the source of disturbance. For a reaction time of 40 - 45 seconds, the dosage rate should be 50 - 60 GPM flow / each Floc Log placed in a series or in a row. Particulate formed may be captured by filtering through or across a series of jute matting after the mixing and reaction has been completed.** (Please see page 42 of the PEBMP for more on Particle Collection.)

Stabilization of the soil at the source may be obtained by spreading the site-specific Silt Stop powder onto the soil surface (can be mixed with other additives such as seed, fertilizer, etc.), then covering the soil with open-weave jute, coconut matting, mulch, or straw. This will perform as a stabilizer for reducing soil and clay movement into the runoff water, as a tackifier to hold the soil/organic matrix in place, as well as providing surface area for attachment of flocculated sediment. For detailed application rates and instructions, please see the Soil Stabilization section beginning on page 5 of the PEBMP.

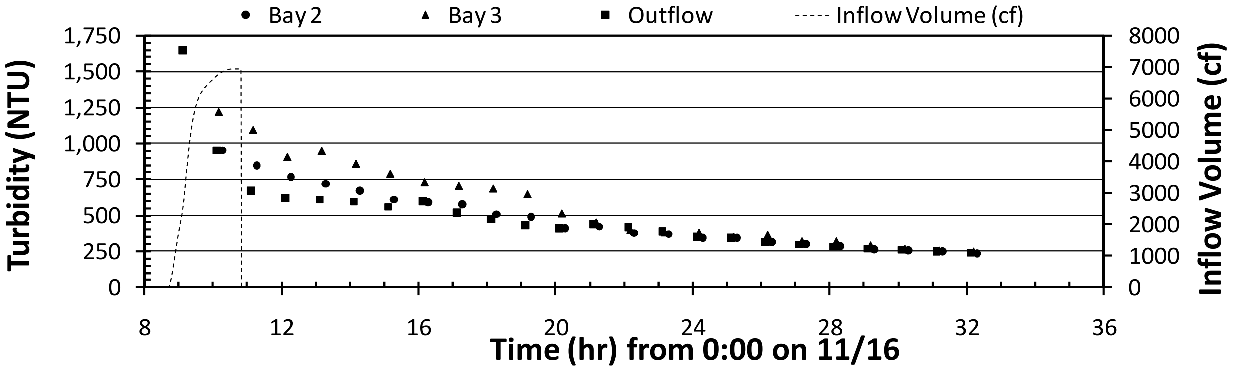
Areas where high water velocity may occur (ditch lines, swales, etc.) should be "soft armored" by placing "jute" matting flush to the ground surface then spreading the dry 712 powder over the jute. This will greatly reduce erosion in these areas. Please refer to pages 5 - 10 of the PEBMP.

We suggest using both methods to assure best stormwater quality discharges.

APPENDIX B



(a) Turbidity and inflow volume vs. time (including all data)



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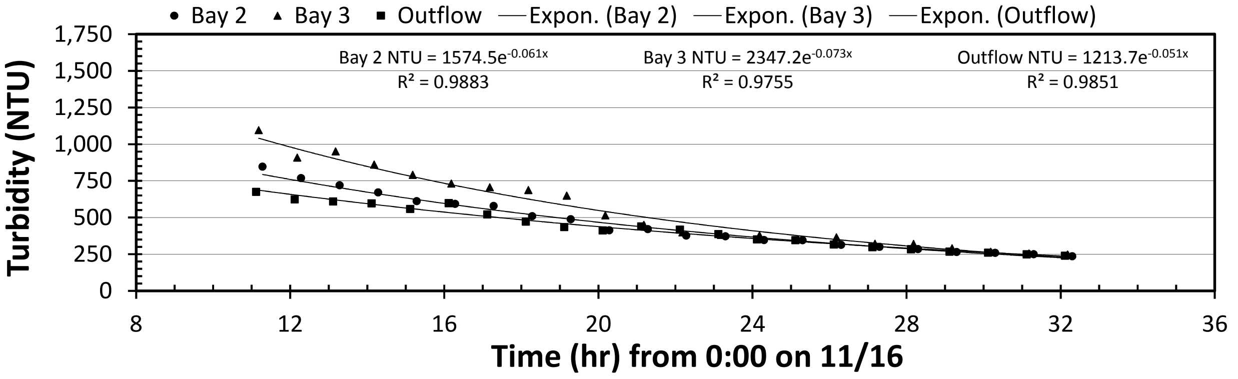
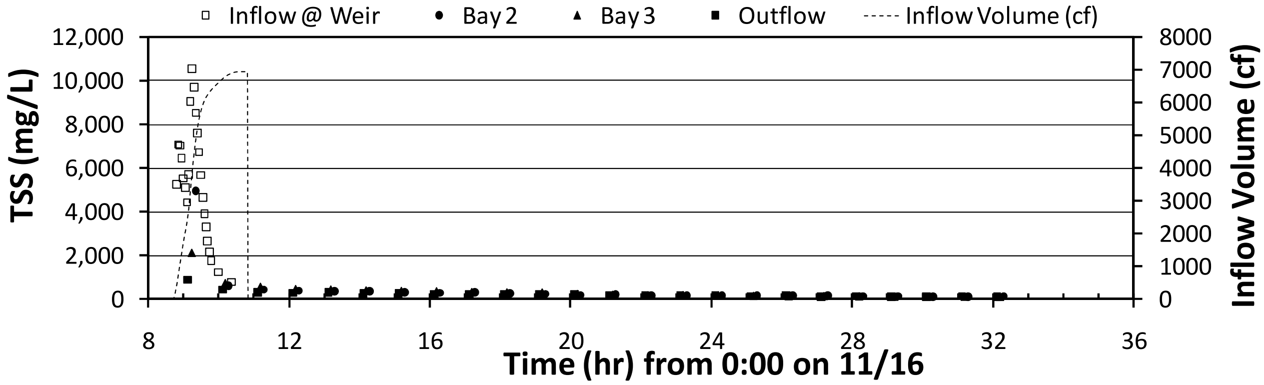


(c) Turbidity reduction fitting curves and equations

Figure B-1: Sediment basin performance data (i.e., time-series of **turbidity** at inflow, in-basin, and outflow) for rain event on **11/16/2011**.

APPENDIX B



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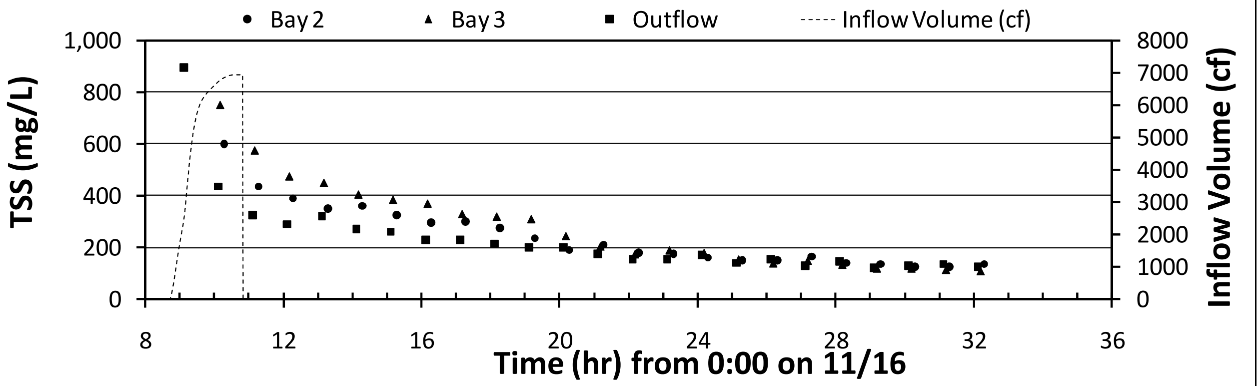
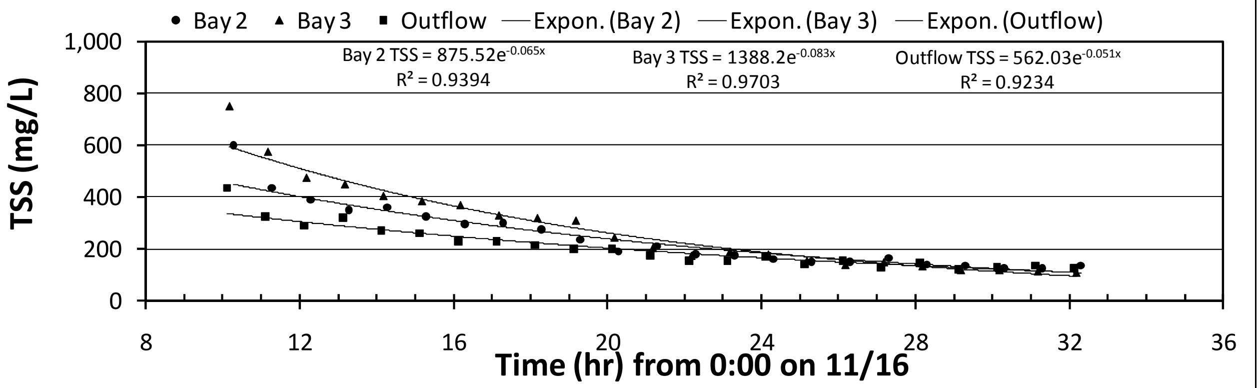


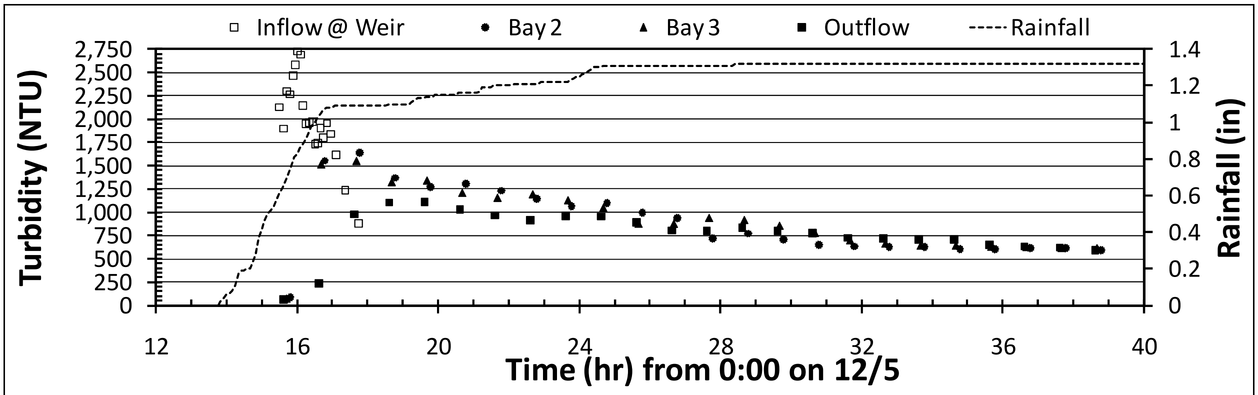
(b) TSS (excluding inflow data) and inflow volume vs. time



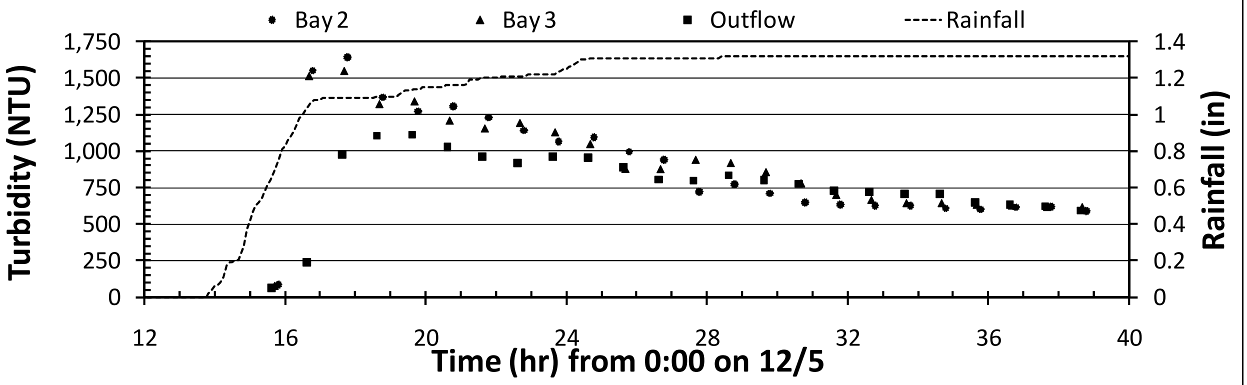
(c) TSS reduction fitting curves and equations

Figure B-2: Sediment basin performance data (i.e., time-series of **TSS** at inflow, in-basin, and outflow) for rain event on **11/16/2011**.

APPENDIX B



(a) Turbidity and inflow volume vs. time (including all data)



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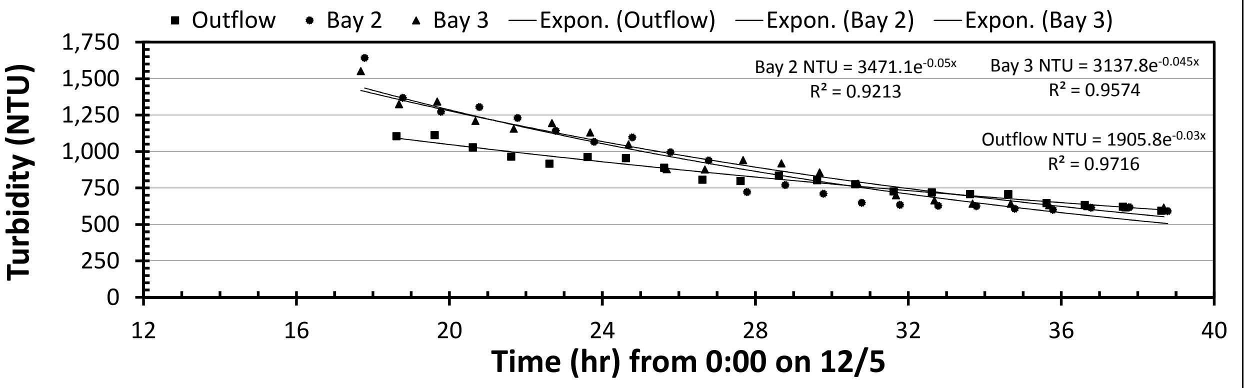
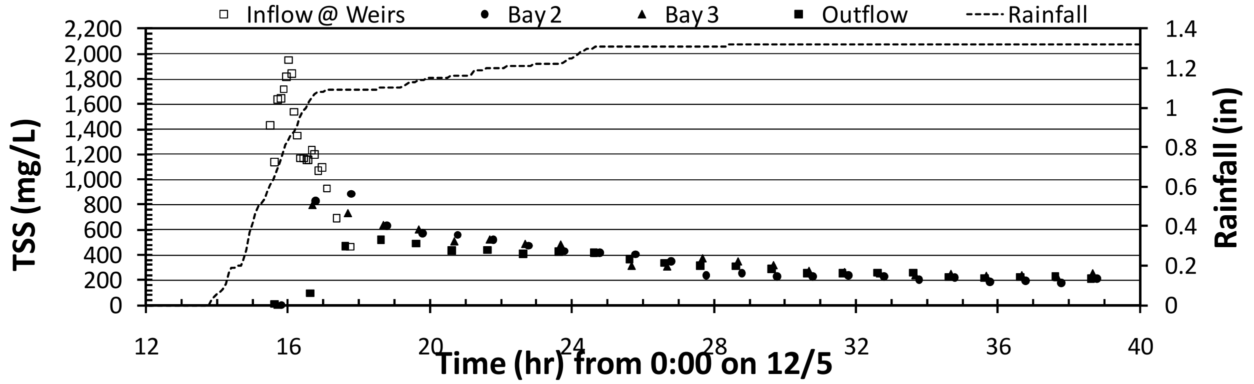


(c) Turbidity reduction fitting curves and equations

Figure B-3: Sediment basin performance data (i.e., time-series of **turbidity** at inflow, in-basin, and outflow) for rain event on **12/5/2011**.



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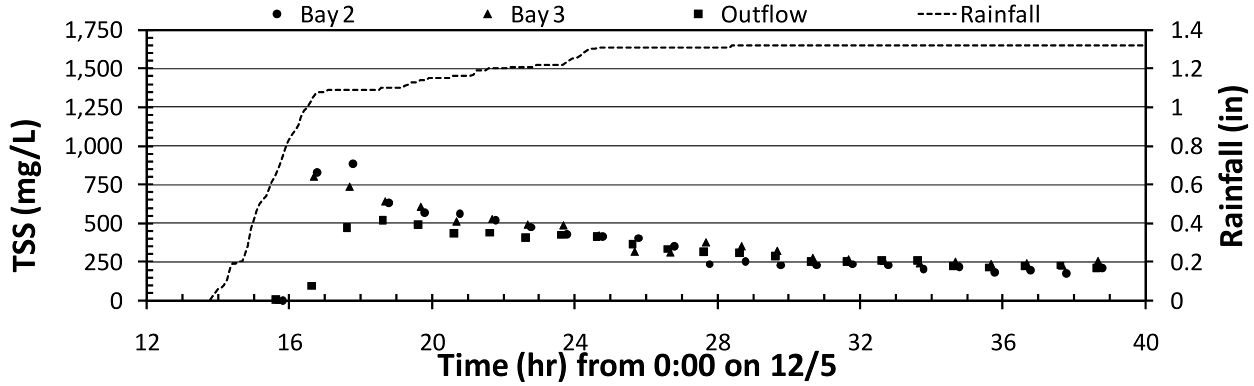

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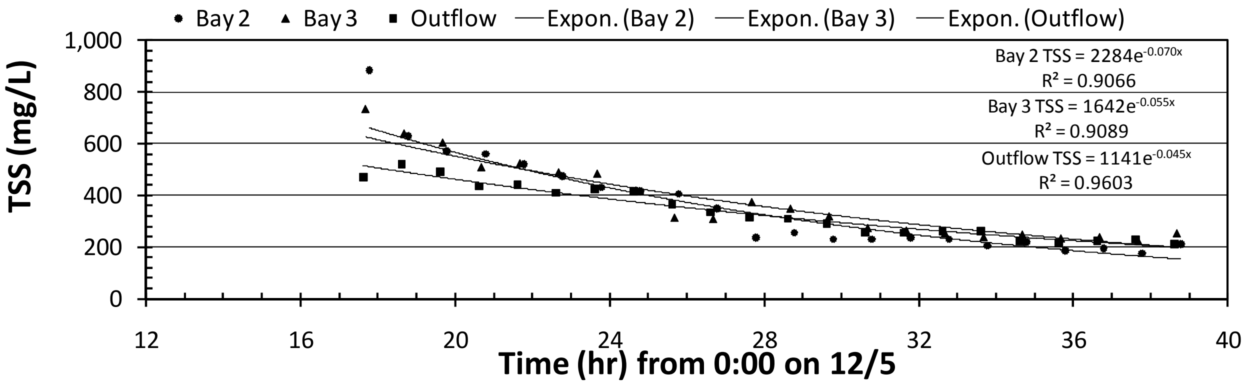
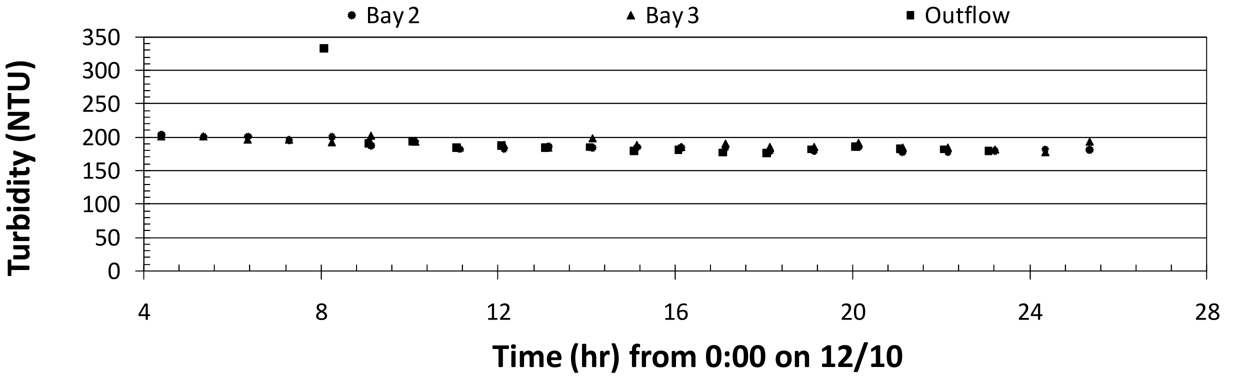


(c) TSS reduction fitting curves and equations

Figure B-4: Sediment basin performance data (i.e., time-series of **TSS** at inflow, in-basin, and outflow) for rain event on **12/5/2011**.



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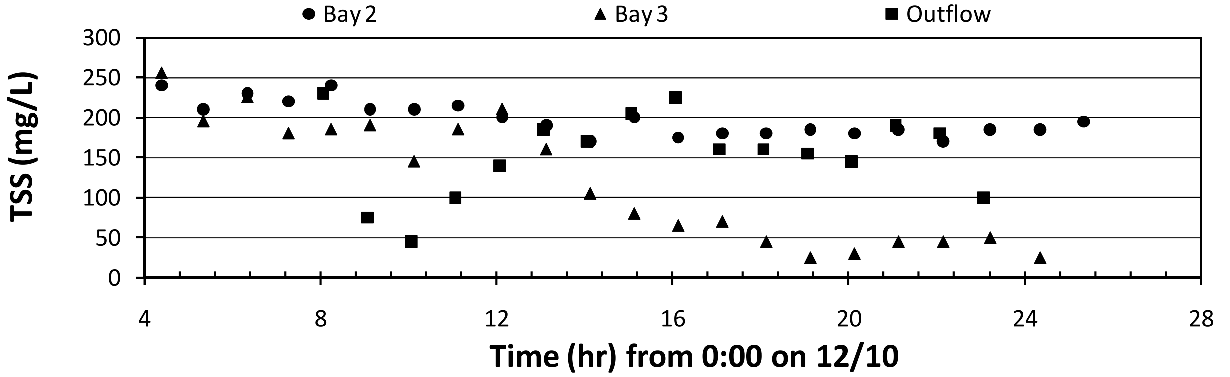
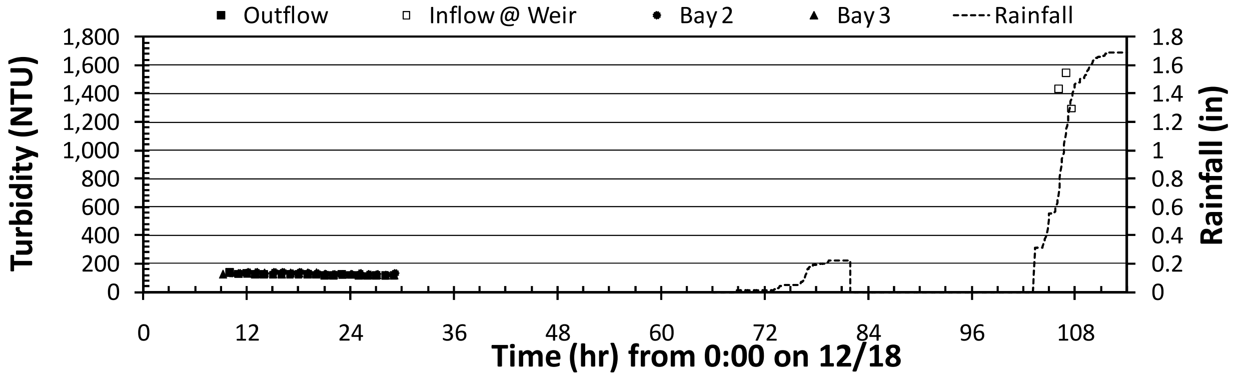


(b) TSS (excluding inflow data) vs. time

Figure B-5: Sediment basin performance data (i.e., time-series of **turbidity** and **TSS** at in-basin and outflow) for rain event on **12/5/2011**.



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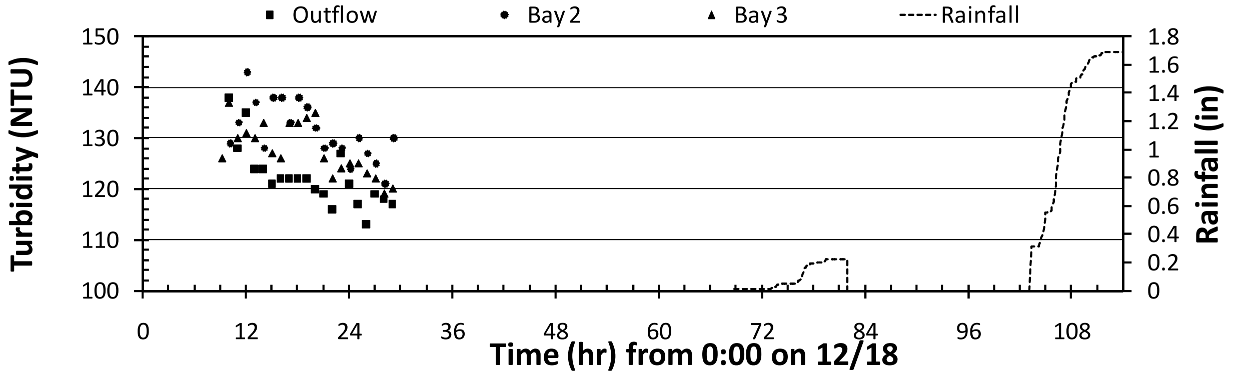
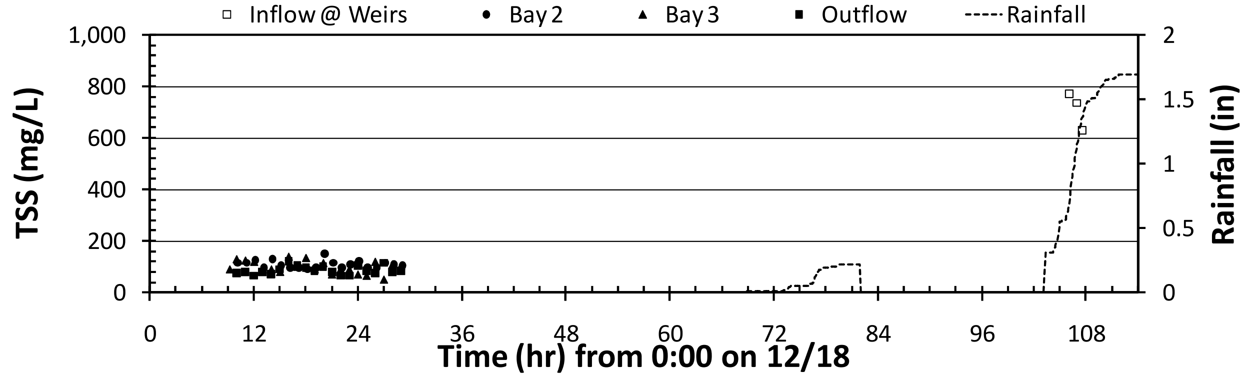
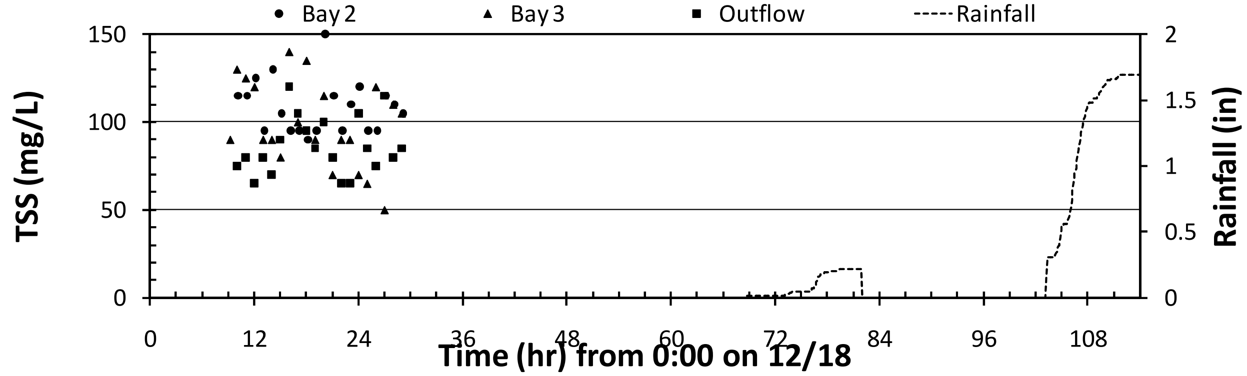


(b) Turbidity (excluding inflow data) and inflow volume vs. time

Figure B-6: Sediment basin performance data (i.e., time-series of **turbidity** at inflow, in-basin, and outflow) for rain event on **12/15/2011**.

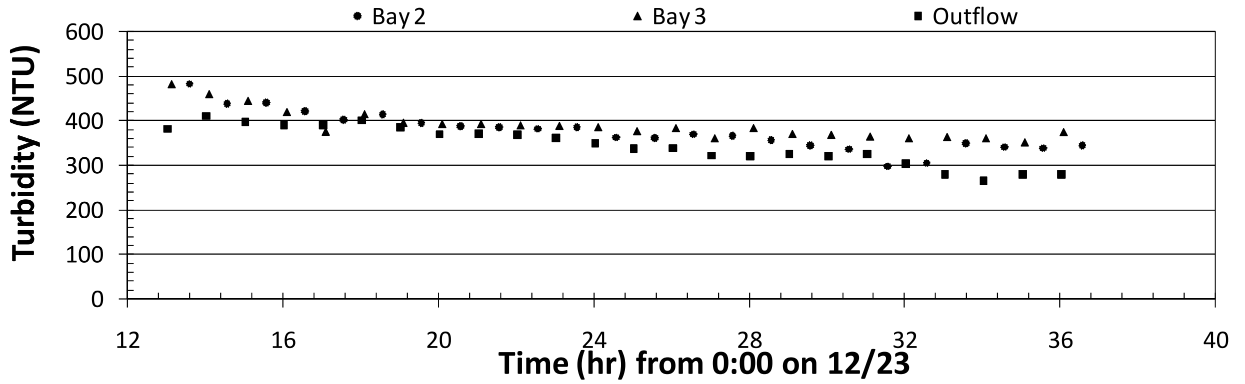


(a) TSS and inflow volume vs. time (including all data)



(b) TSS (excluding inflow data) and inflow volume vs. time

Figure B-7: Sediment basin performance data (i.e., time-series of **TSS** at inflow, in-basin, and outflow) for rain event on **12/15/2011**.



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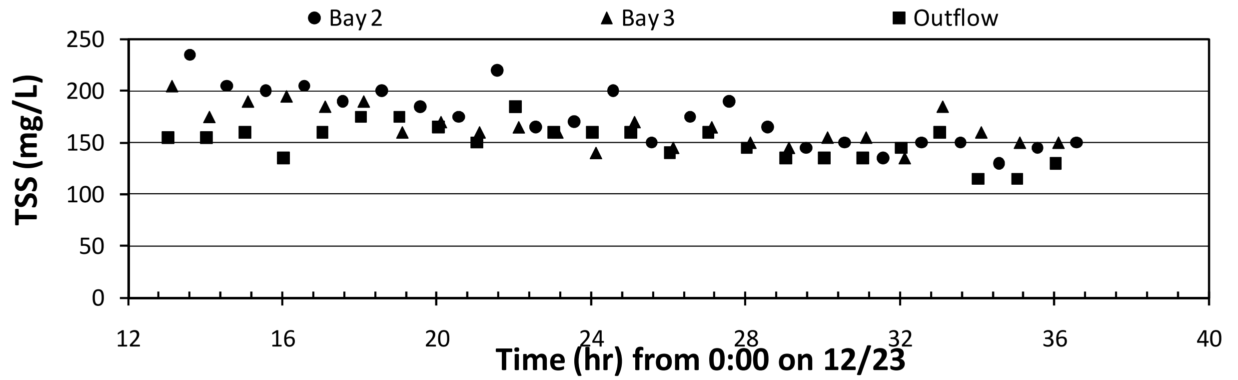
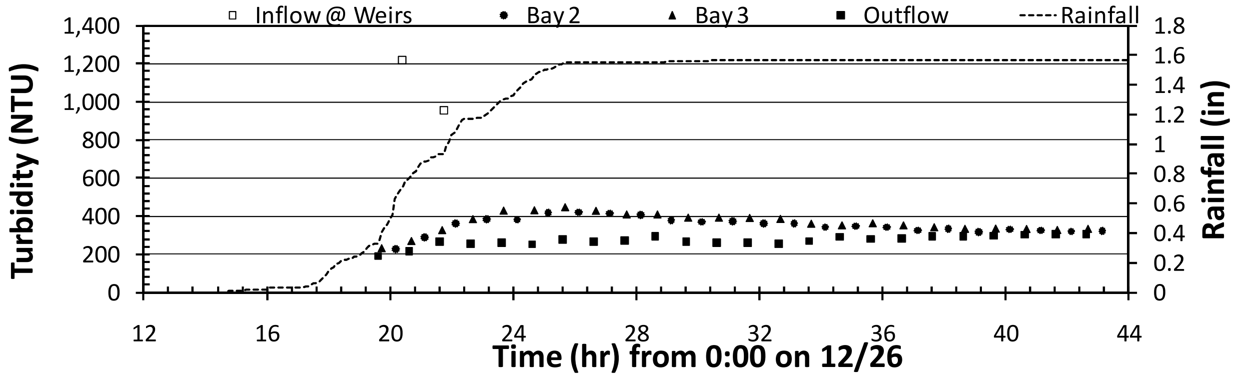
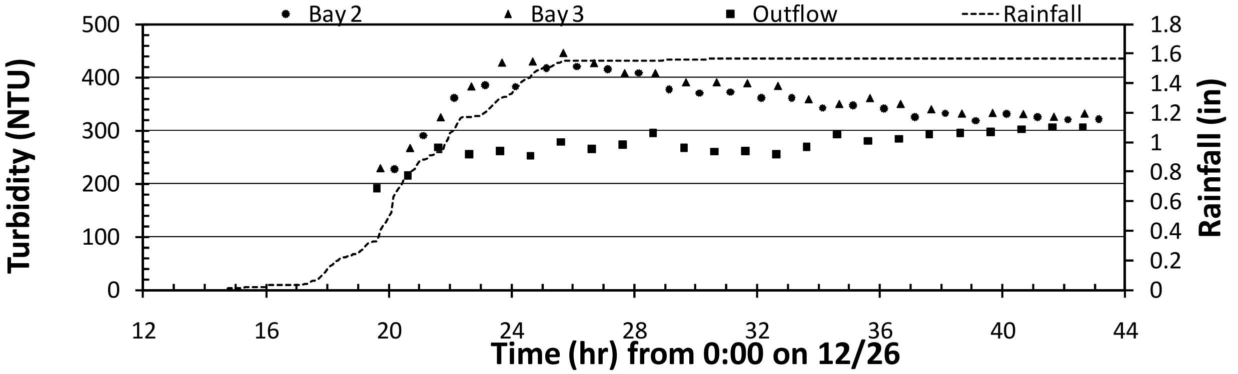


(b) TSS (excluding inflow data) vs. time

Figure B-8: Sediment basin performance data (i.e., time-series of **turbidity** and **TSS** at in-basin and outflow) for rain event on **12/22/2011**.

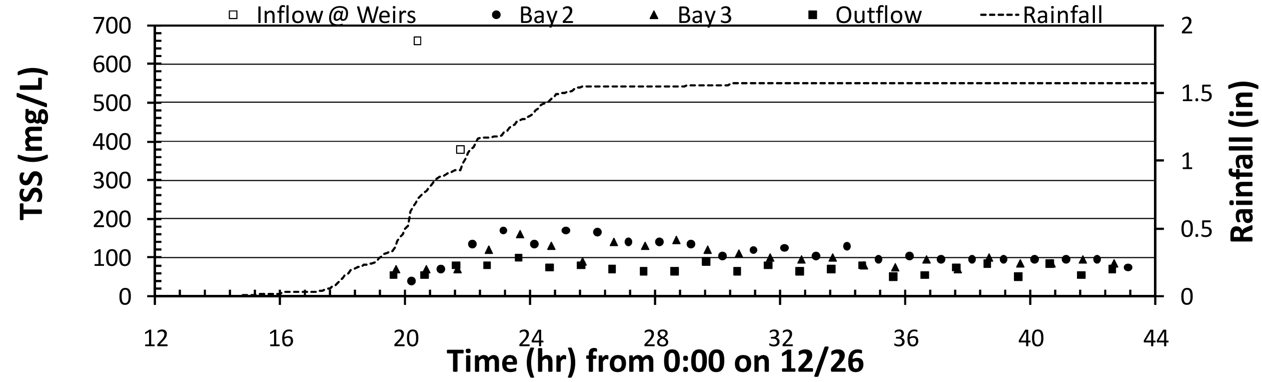


(a) Turbidity and inflow volume vs. time (including all data)

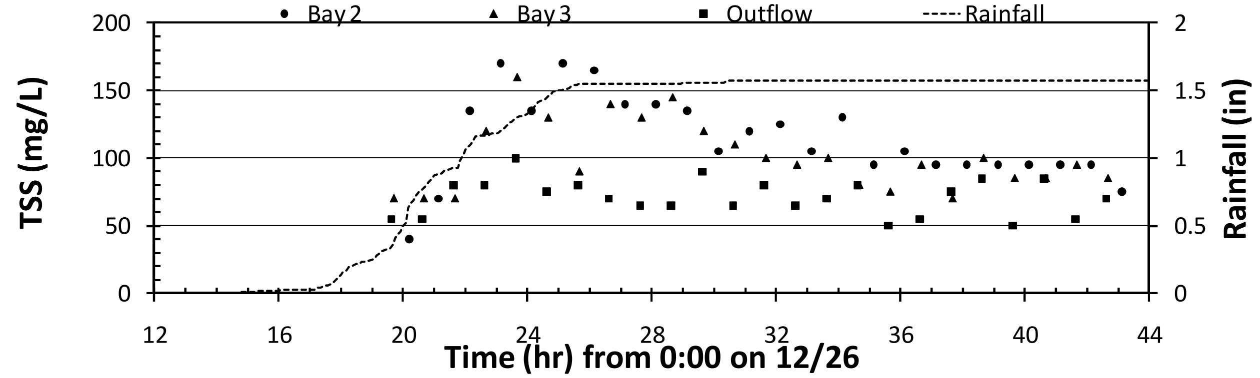


(b) Turbidity (excluding inflow data) and inflow volume vs. time

Figure B-9: Sediment basin performance data (i.e., time-series of **turbidity** at inflow, in-basin, and outflow) for rain event on **12/26/2011**.

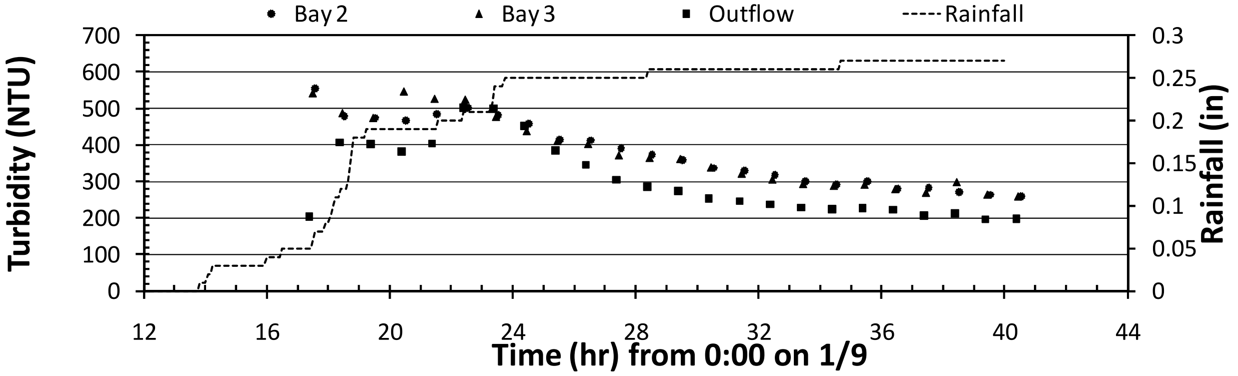


(a) TSS and inflow volume vs. time (including all data)



(b) TSS (excluding inflow data) and inflow volume vs. time

Figure B-10: Sediment basin performance data (i.e., time-series of **TSS** at inflow, in-basin, and outflow) for rain event on **12/26/2011**.



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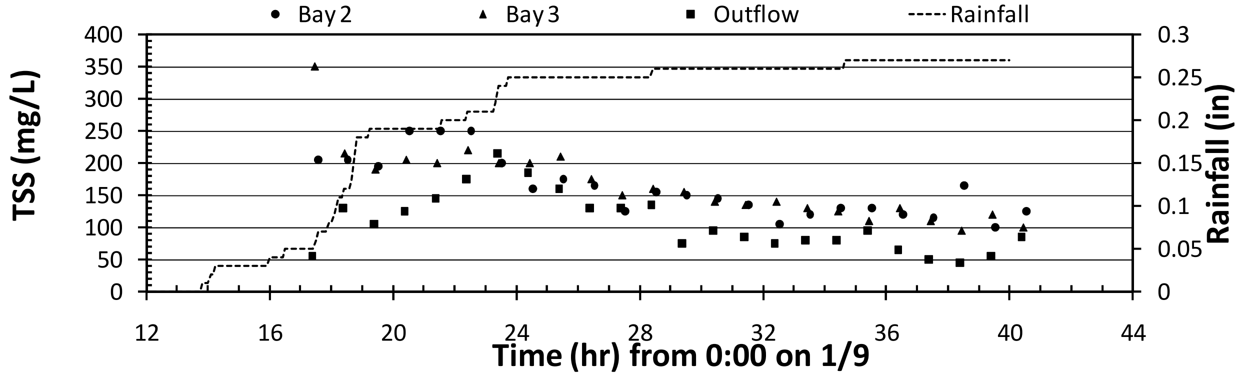
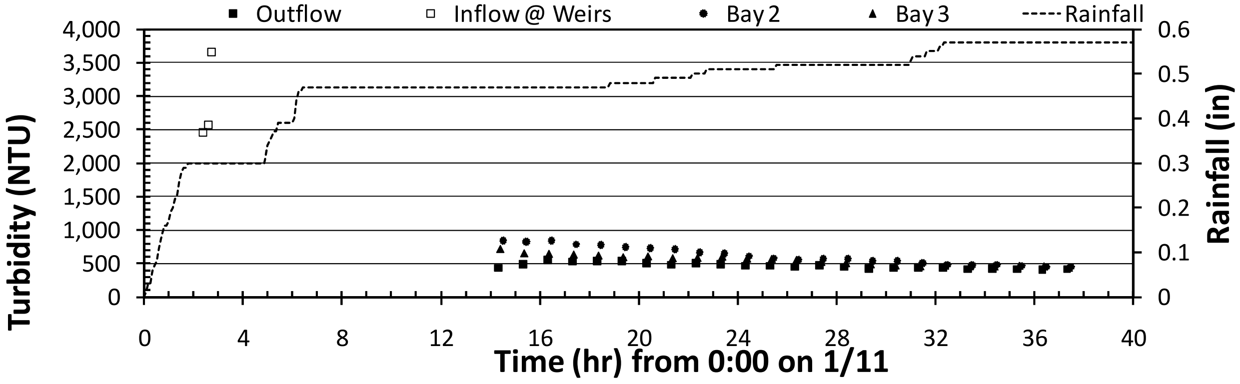


(b) TSS (excluding inflow data) and inflow volume vs. time

Figure B-11: Sediment basin performance data (i.e., time-series of **turbidity and TSS** at in-basin and outflow) for rain event on **1/9/2012**.



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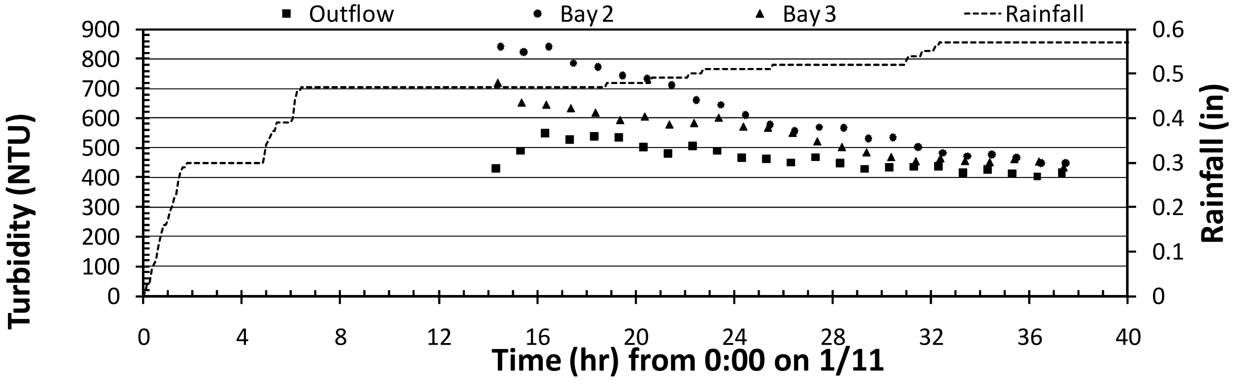
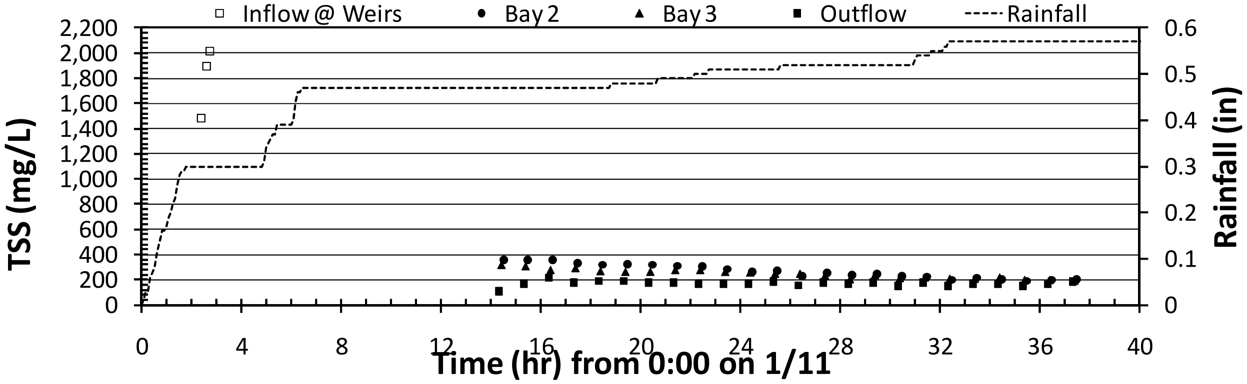


(b) Turbidity (excluding inflow data) and inflow volume vs. time

Figure B-12: Sediment basin performance data (i.e., time-series of **turbidity** at inflow, in-basin, and outflow) for rain event on **1/11/2012**.



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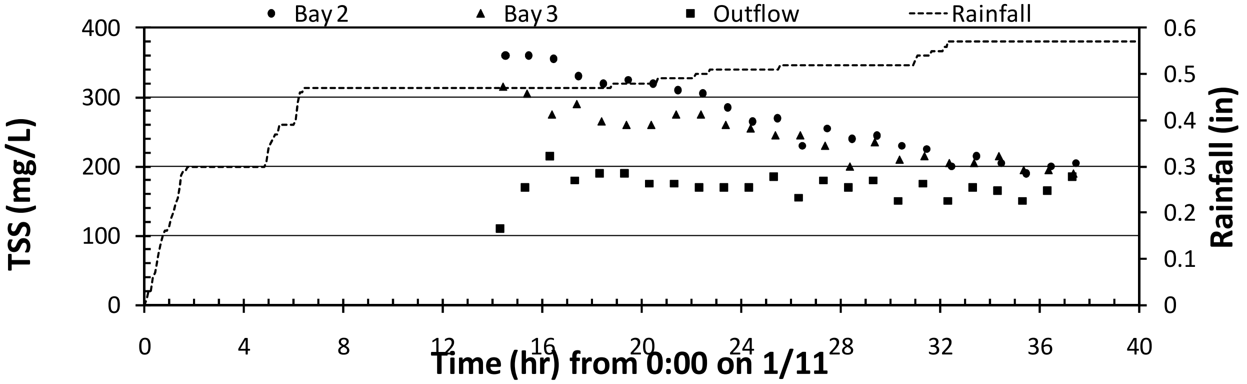
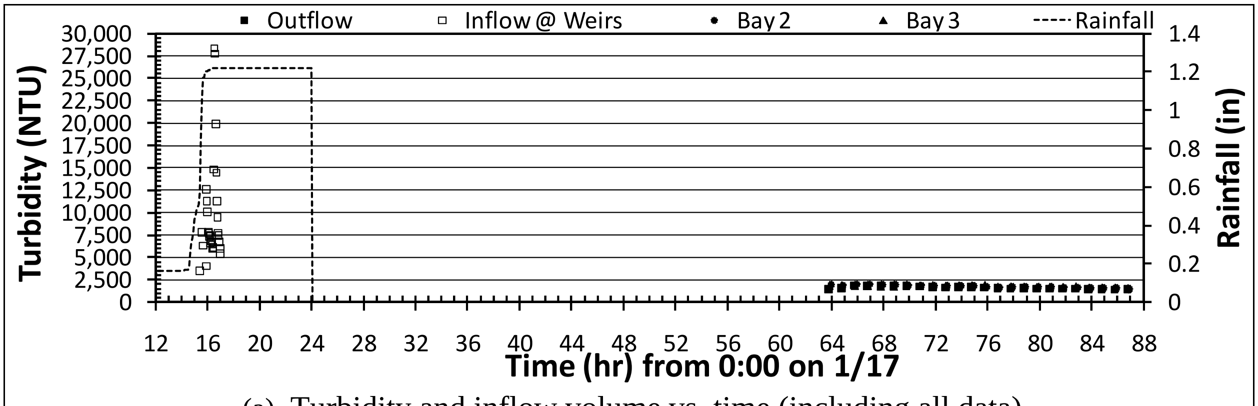
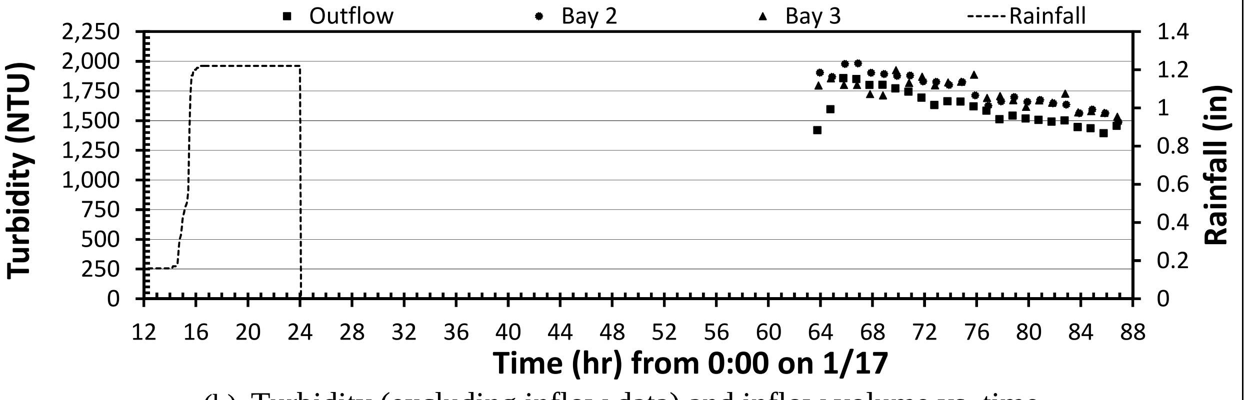


(b) TSS (excluding inflow data) and inflow volume vs. time

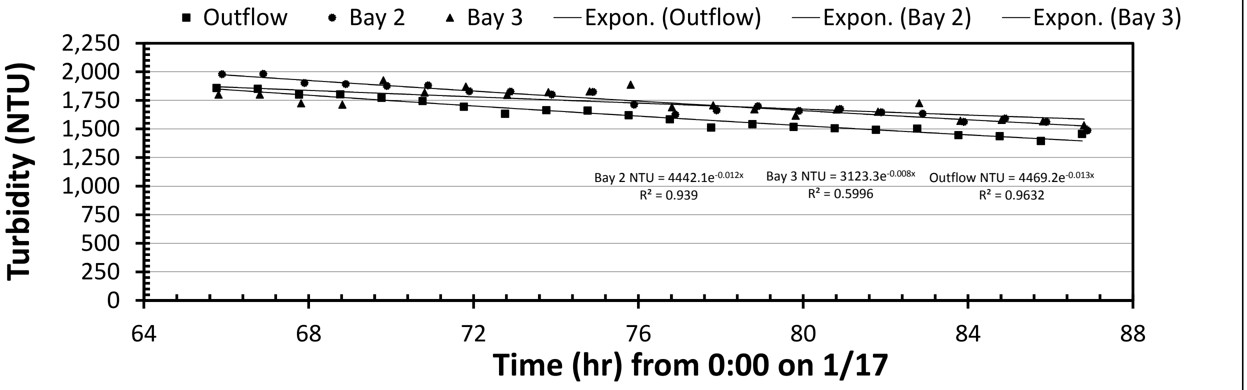
Figure B-13: Sediment basin performance data (i.e., time-series of **TSS** at inflow, in-basin, and outflow) for rain event on **1/11/2012**.



(a) Turbidity and inflow volume vs. time (including all data)

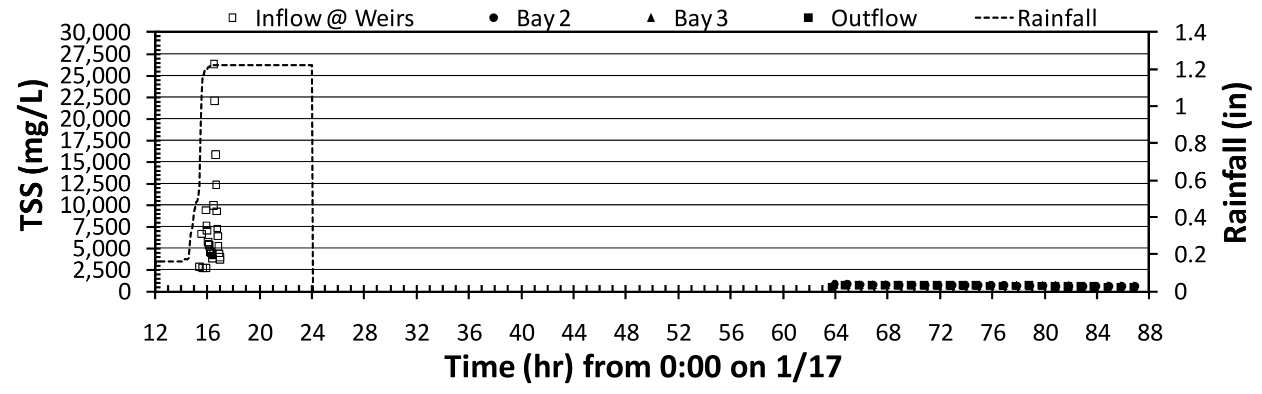


(b) Turbidity (excluding inflow data) and inflow volume vs. time

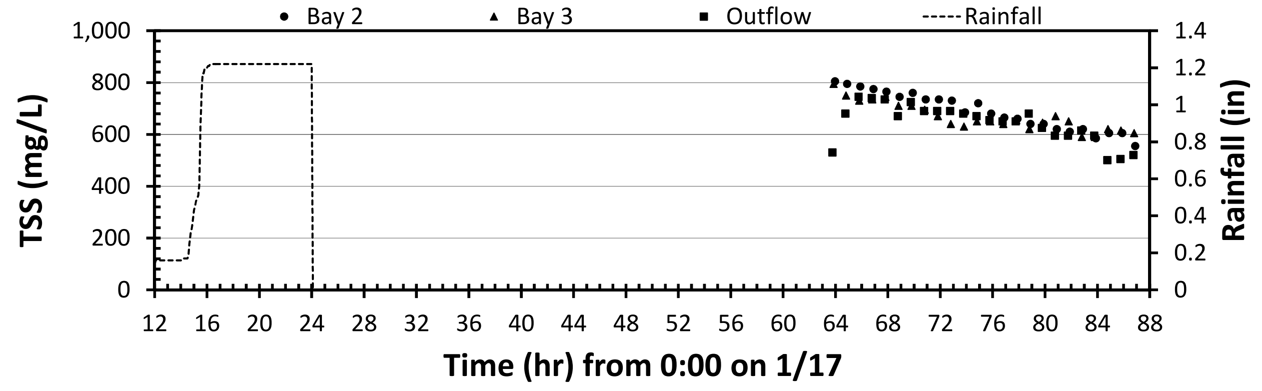


(c) Turbidity reduction fitting curves and equations

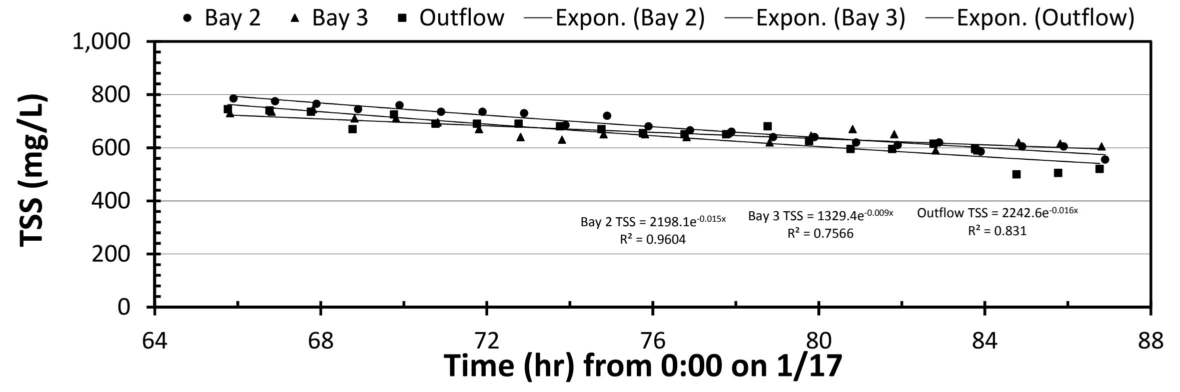
Figure B-14: Sediment basin performance data (i.e., time-series of **turbidity** at inflow, in-basin, and outflow) for rain event on **1/17/2012**.



(a) TSS and inflow volume vs. time (including all data)

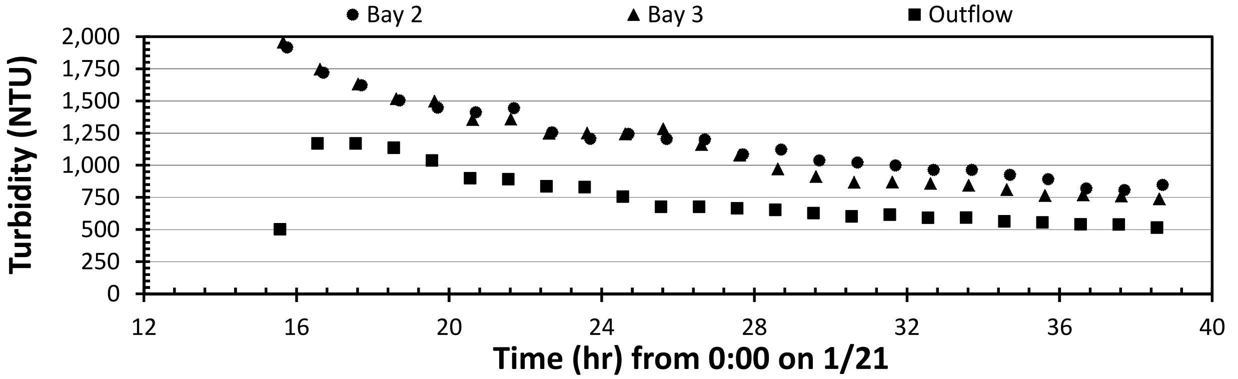


(b) TSS (excluding inflow data) and inflow volume vs. time

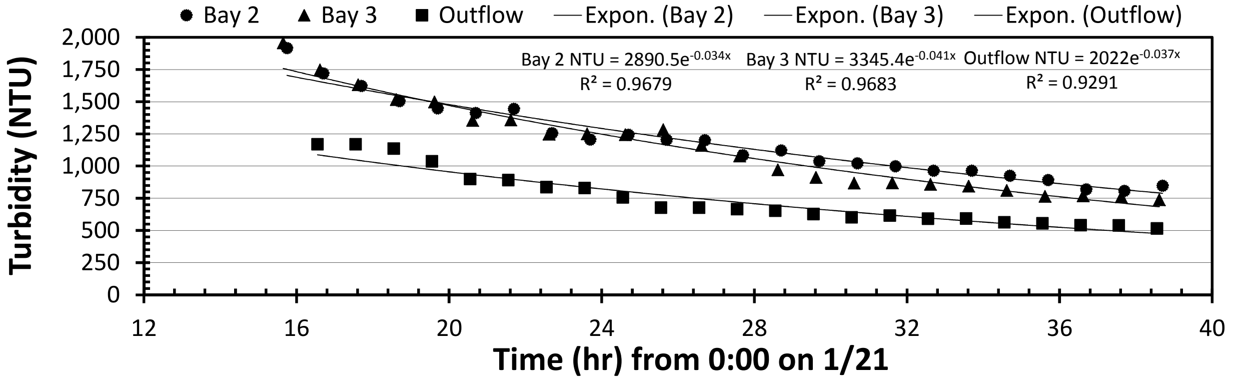


(c) TSS reduction fitting curves and equations

Figure B-15: Sediment basin performance data (i.e., time-series of **TSS** at inflow, in-basin, and outflow) for rain event on **1/17/2012**.

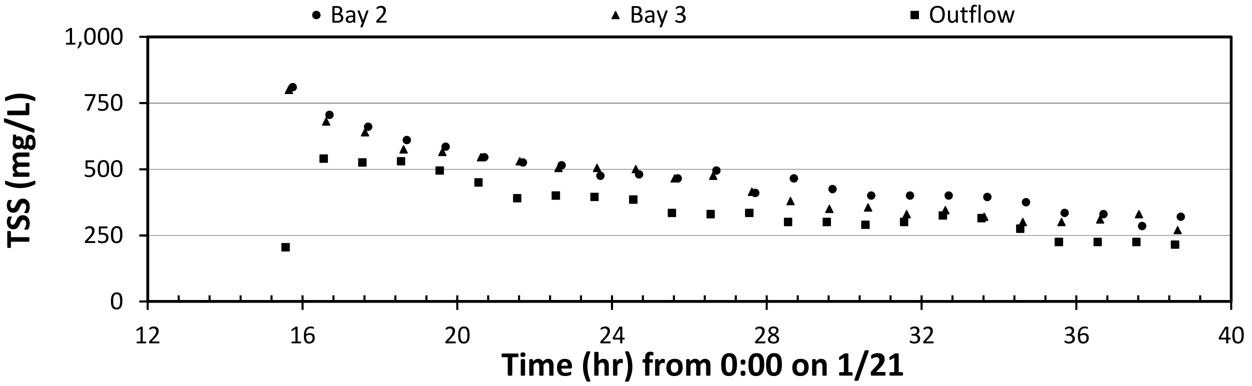


(a) Turbidity and inflow volume vs. time (including all data)

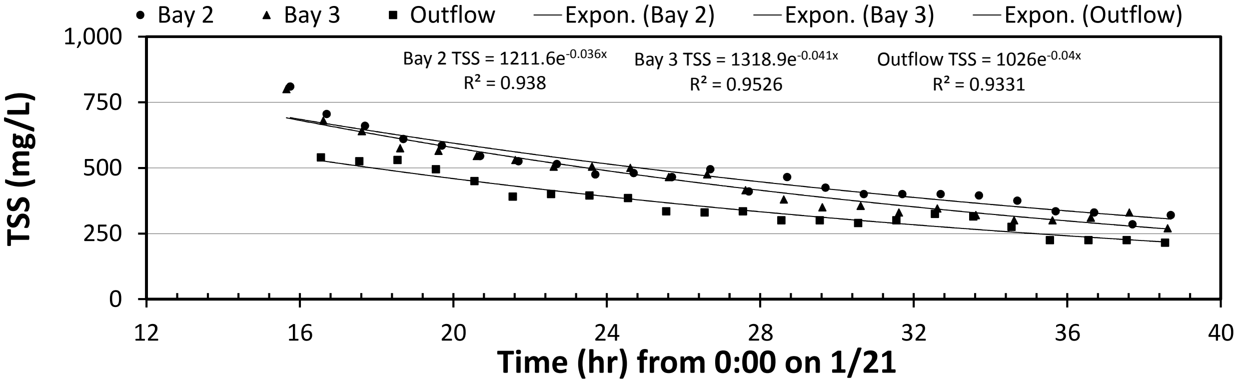


(b) Turbidity (excluding inflow data) and inflow volume vs. time

Figure B-16: Sediment basin performance data (i.e., time-series of **turbidity** at in-basin and outflow) for rain event on **1/21/2012**.



(a) TSS and inflow volume vs. time (including all data)



(b) TSS (excluding inflow data) and inflow volume vs. time

Figure B-17: Sediment basin performance data (i.e., time-series of **TSS** at in-basin and outflow) for rain event on **1/21/2012**.

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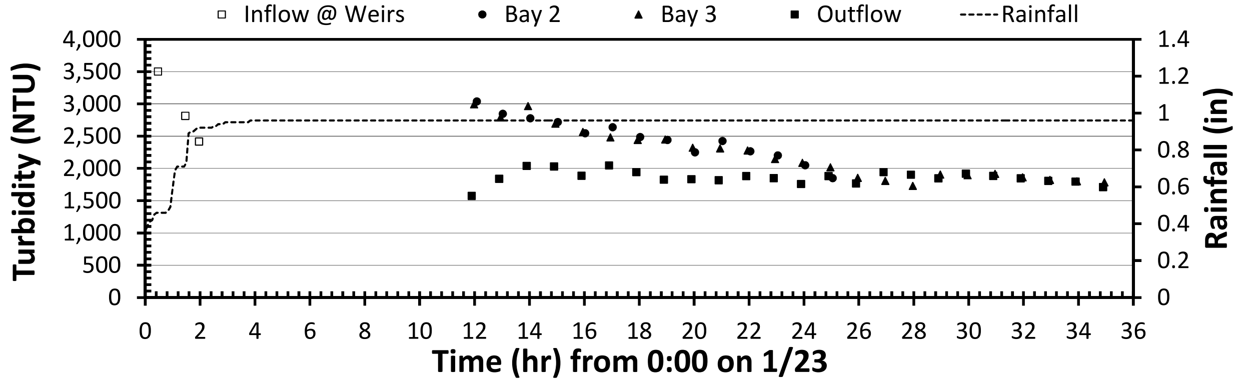
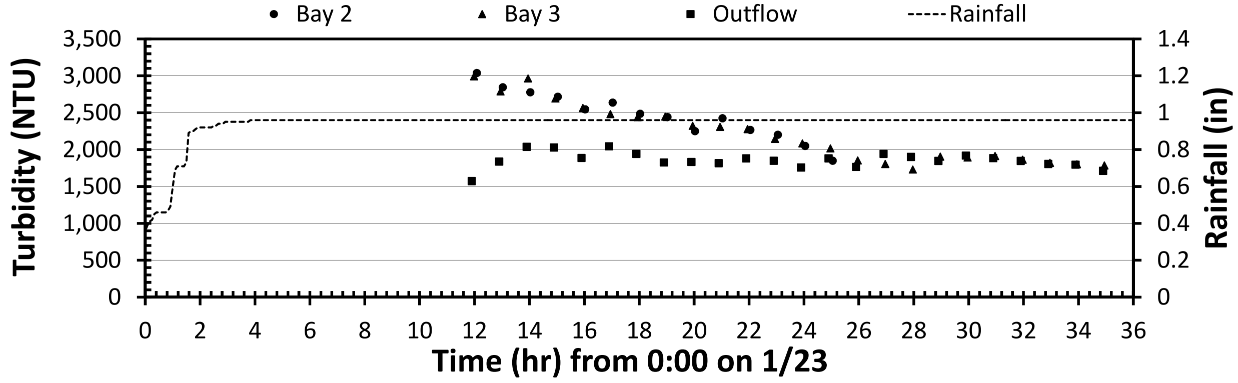
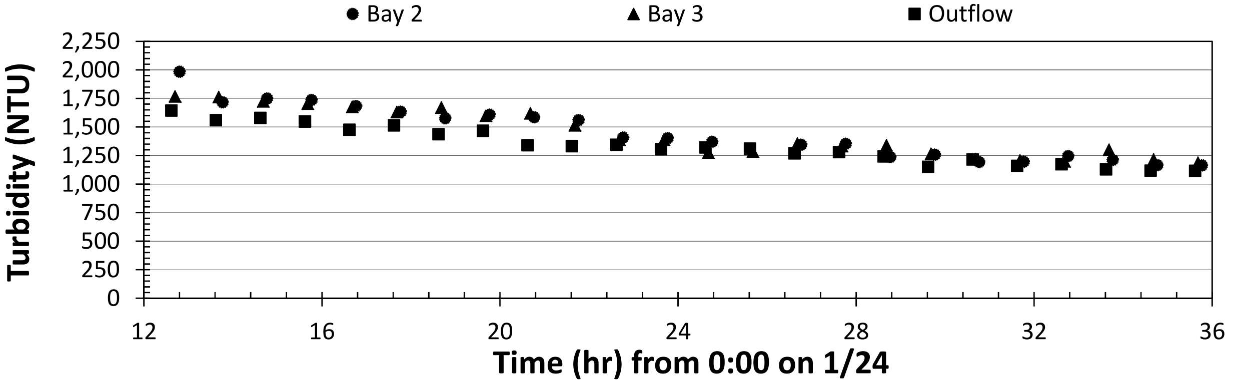


(a) Turbidity and inflow volume vs. time (including all data)

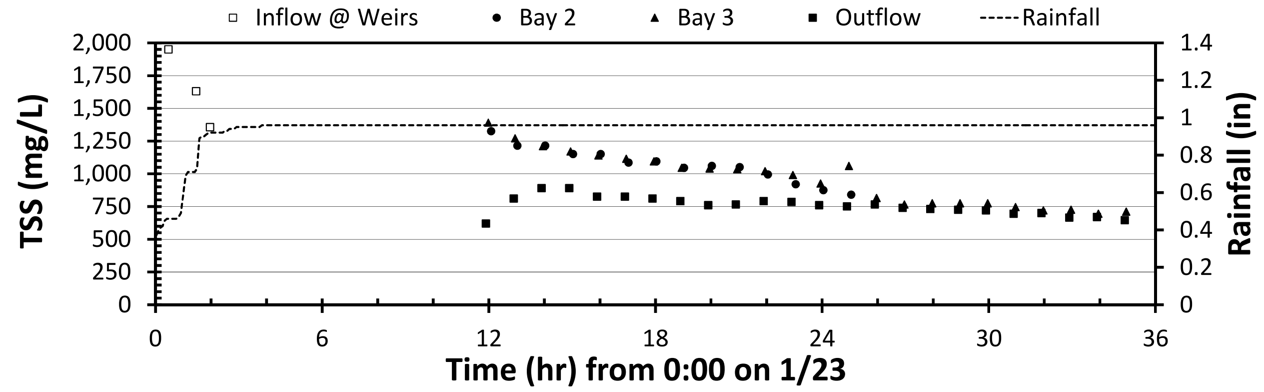


(b) Turbidity (excluding inflow data) and inflow volume vs. time

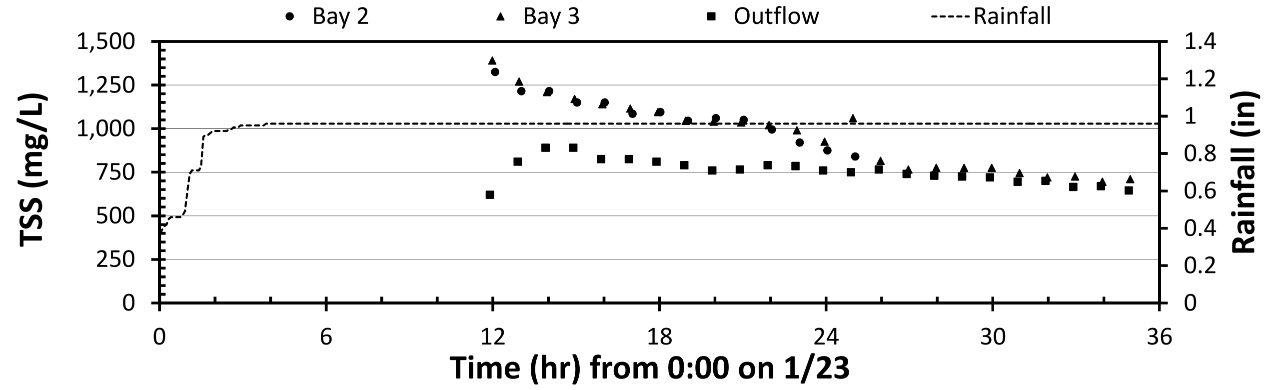


(c) Turbidity (excluding inflow data) vs. time

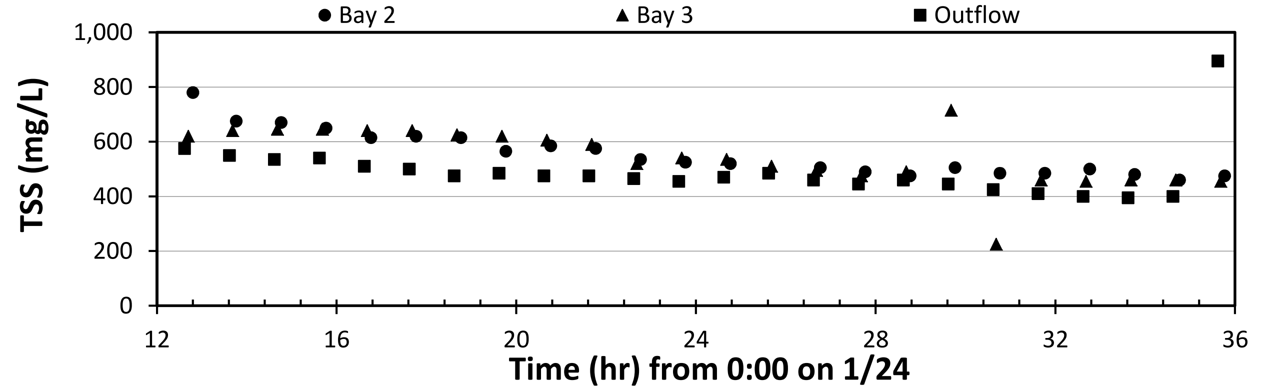
Figure B-18: Sediment basin performance data (i.e., time-series of **turbidity** at inflow, in-basin, and outflow) for rain event on **1/23/2012**.



(a) TSS and inflow volume vs. time (including all data)

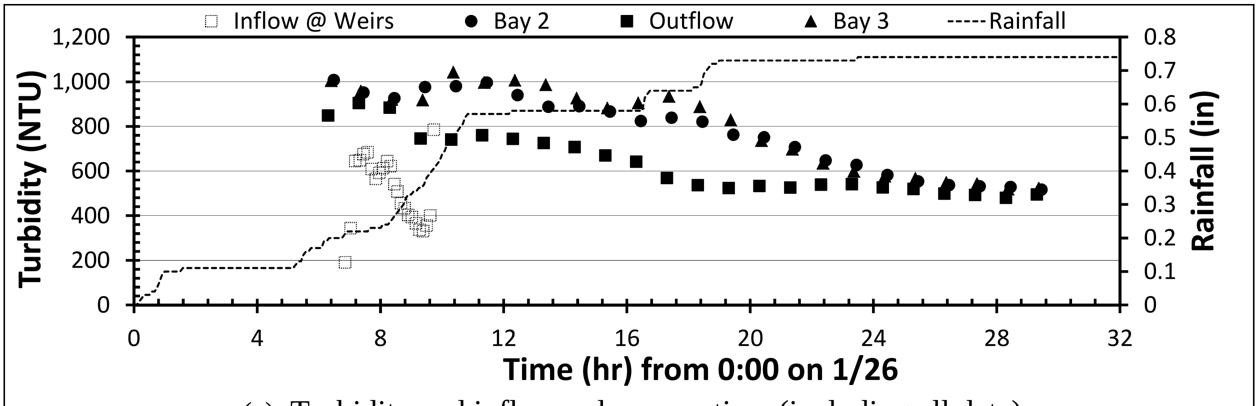


(b) TSS (excluding inflow data) and inflow volume vs. time

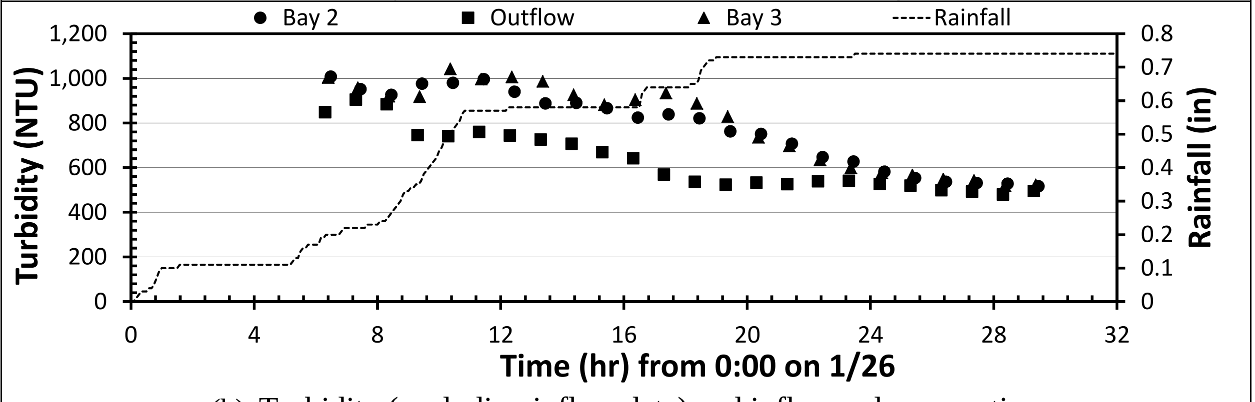


(c) TSS (excluding inflow data) vs. time

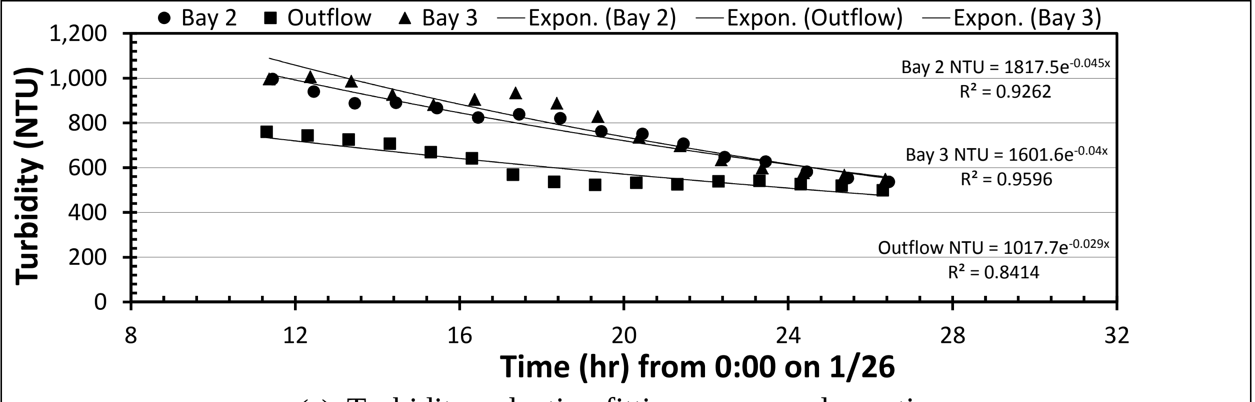
Figure B-19: Sediment basin performance data (i.e., time-series of **TSS** at inflow, in-basin, and outflow) for rain event on **1/23/2012**.



(a) Turbidity and inflow volume vs. time (including all data)



(b) Turbidity (excluding inflow data) and inflow volume vs. time



(c) Turbidity reduction fitting curves and equations

Figure B-20: Sediment basin performance data (i.e., time-series of **turbidity** at inflow, in-basin, and outflow) for rain event on **1/26/2012**.

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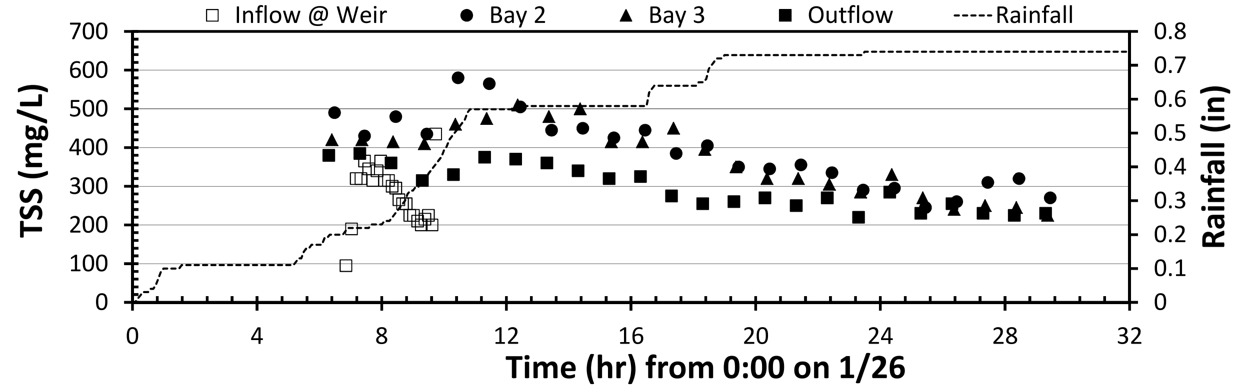
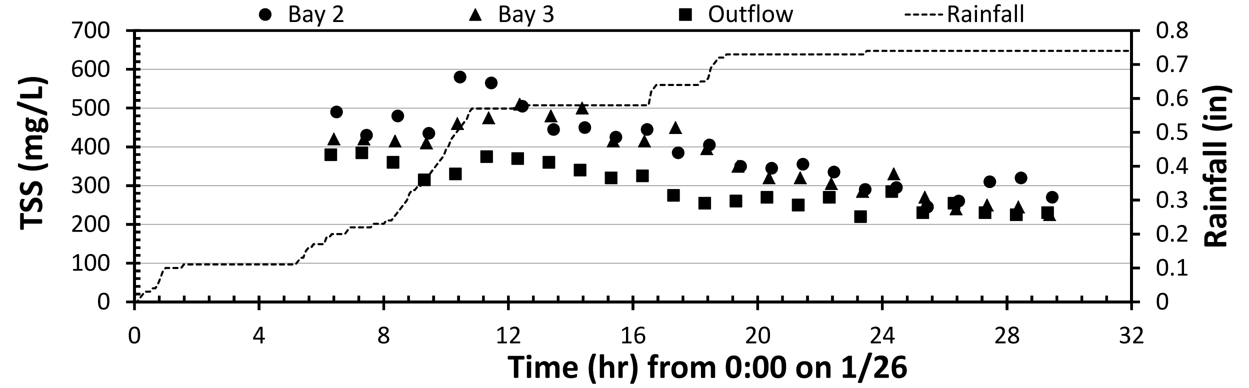
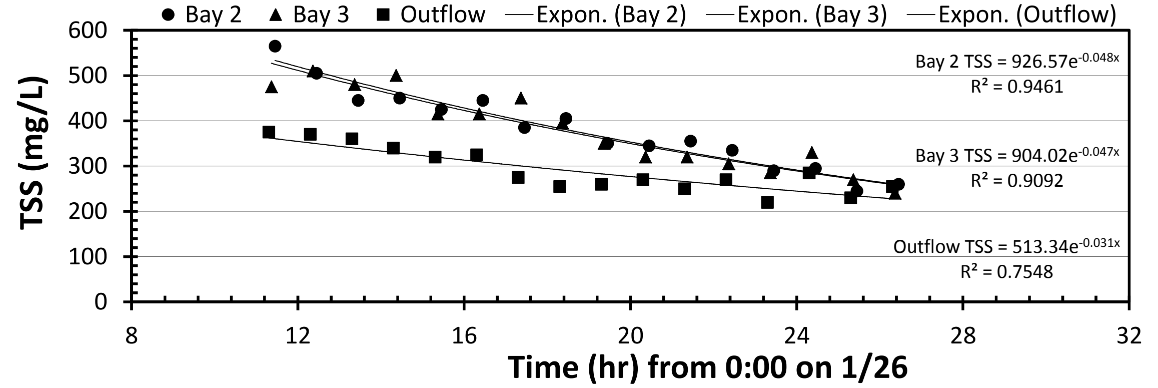


(a) TSS and inflow volume vs. time (including all data)

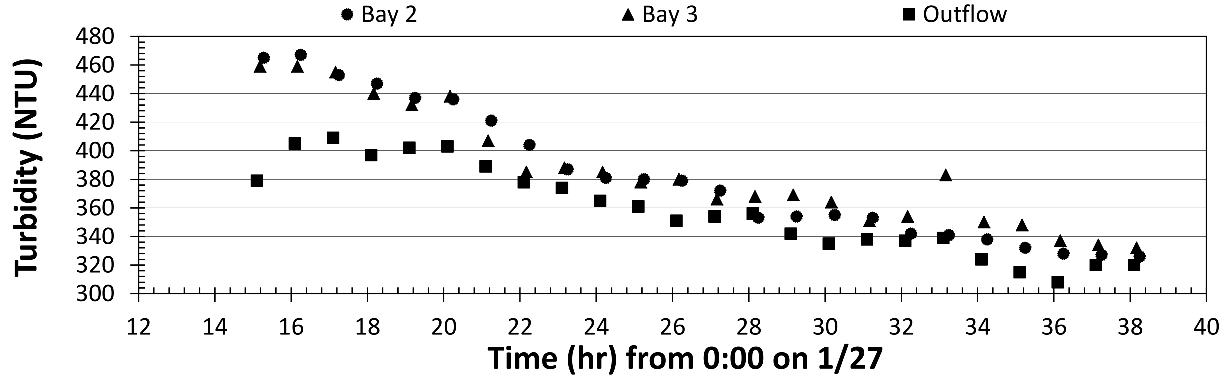


(b) TSS (excluding inflow data) and inflow volume vs. time

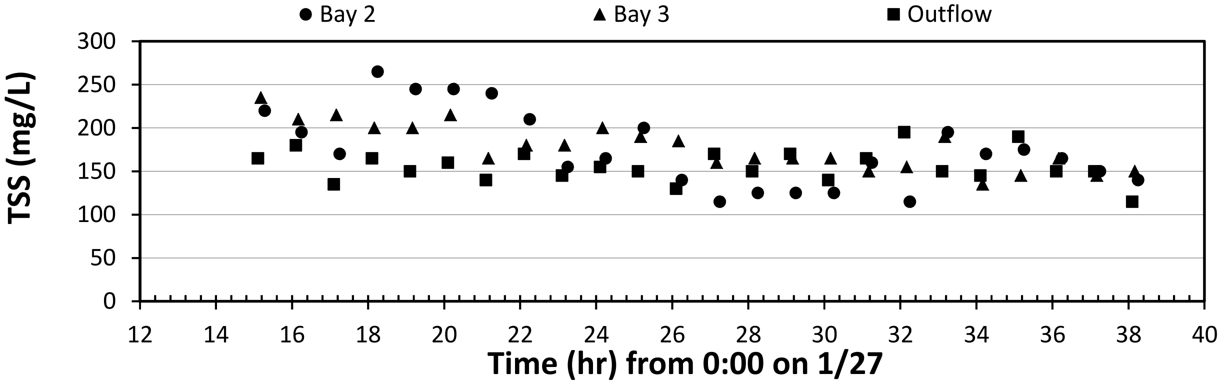


(c) TSS reduction fitting curves and equations

Figure B-21: Sediment basin performance data (i.e., time-series of **TSS** at inflow, in-basin, and outflow) for rain event on **1/26/2012**.

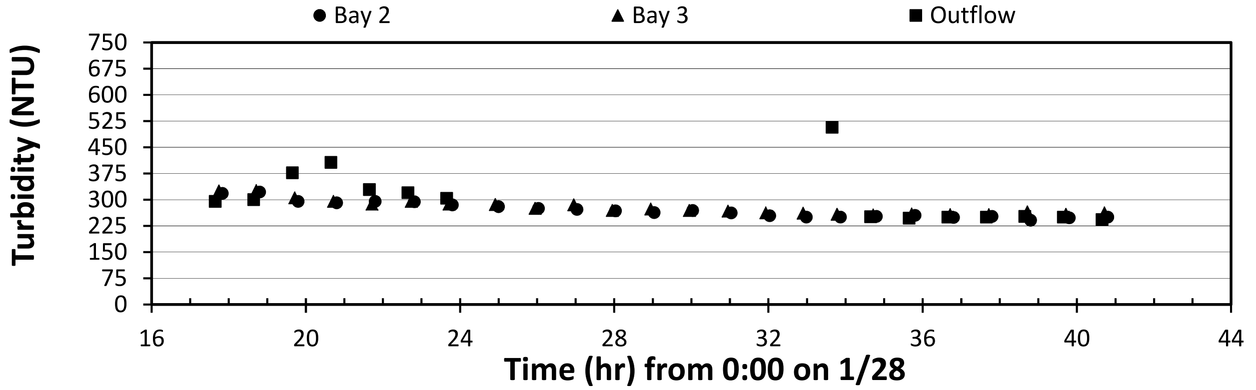


(a) Turbidity (excluding inflow data) vs. time

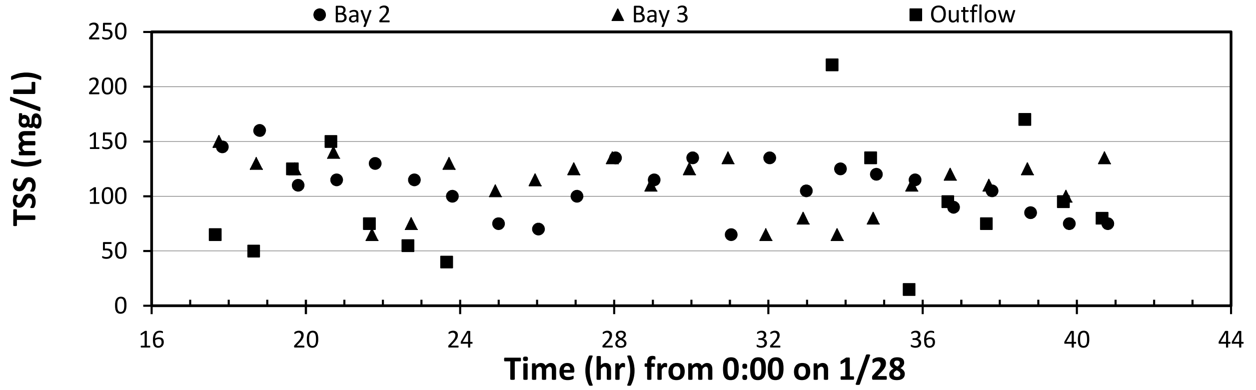


(b) TSS (excluding inflow data) vs. time

Figure B-22: Sediment basin performance data (i.e., time-series of **turbidity** and **TSS** at in-basin and outflow) for rain event on **1/26/2012**.



(a) Turbidity (excluding inflow data) vs. time



(b) TSS (excluding inflow data) vs. time

Figure B-23: Sediment basin performance data (i.e., time-series of **turbidity** and **TSS** at inflow, in-basin, and outflow) for rain event on **1/26/2012**.

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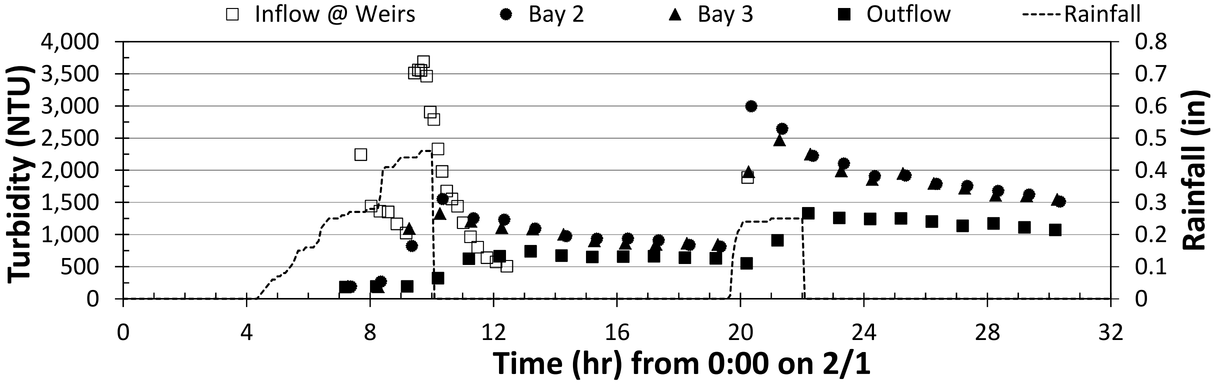
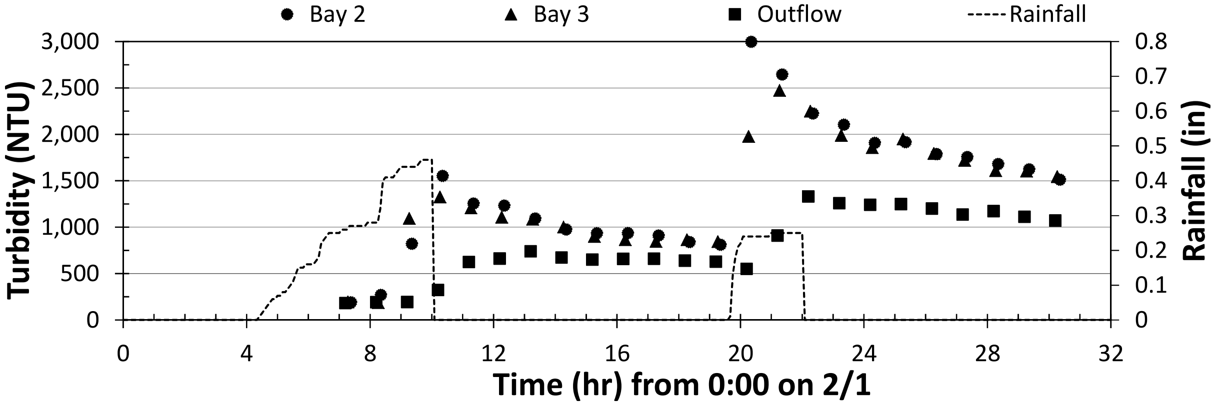
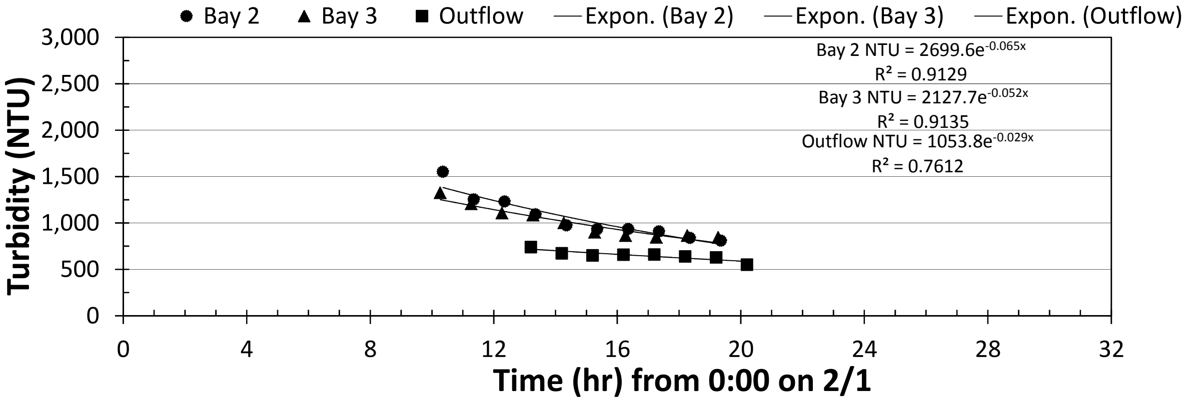


(a) Turbidity and inflow volume vs. time (including all data)

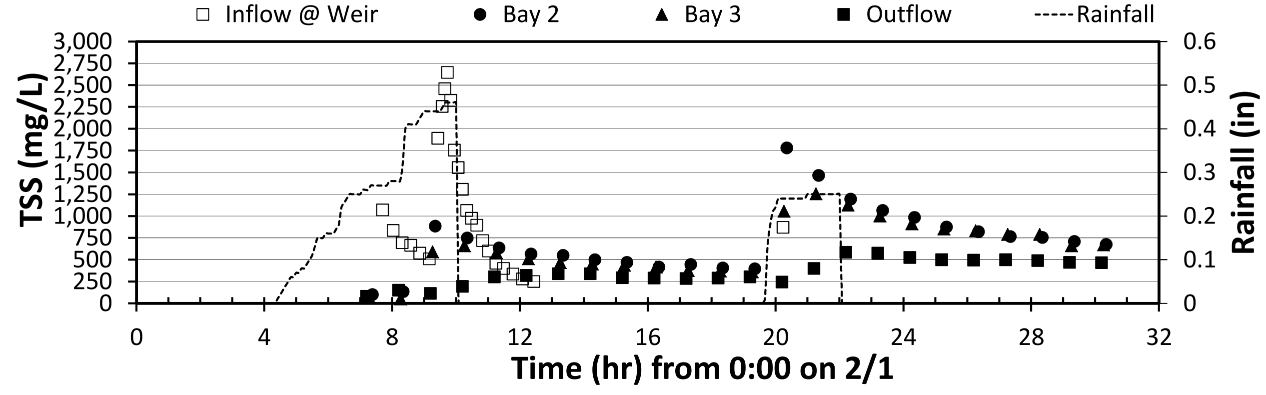


(b) Turbidity (excluding inflow data) and inflow volume vs. time

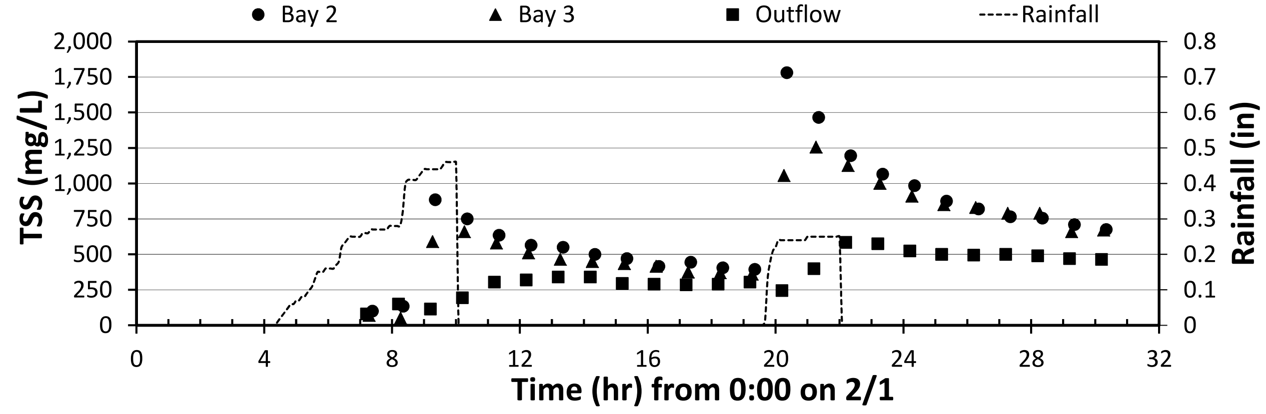


(c) Turbidity reduction fitting curves and equations

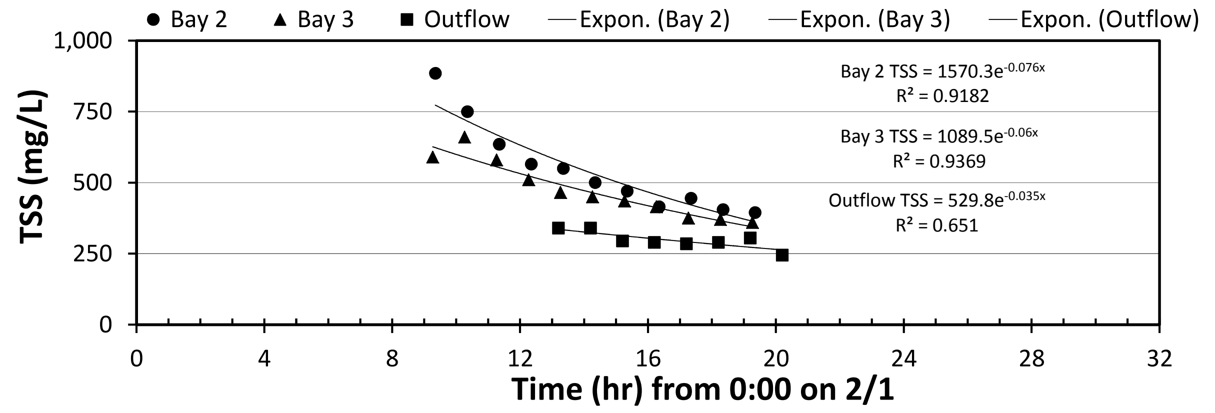
Figure B-24: Sediment basin performance data (i.e., time-series of **turbidity** at inflow, in-basin, and outflow) for rain event on **2/1/2012**.



(a) TSS and inflow volume vs. time (including all data)

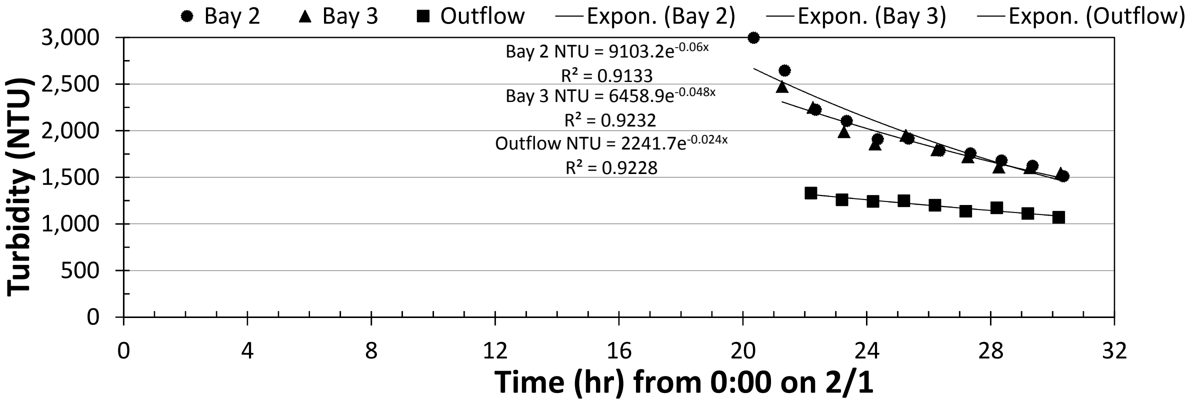


(b) TSS (excluding inflow data) and inflow volume vs. time

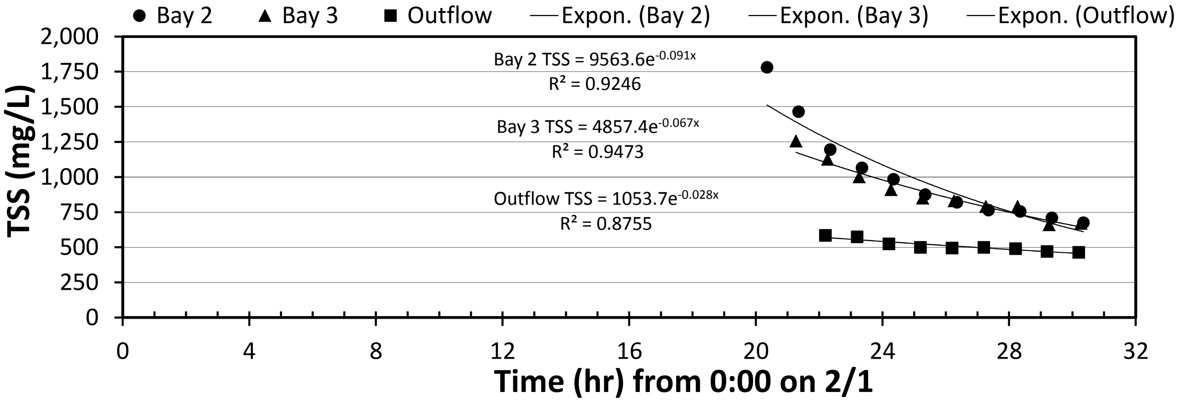


(c) TSS reduction fitting curves and equations

Figure B-25: Sediment basin performance data (i.e., time-series of **TSS** at inflow, in-basin, and outflow) for rain event on **2/1/2012**.

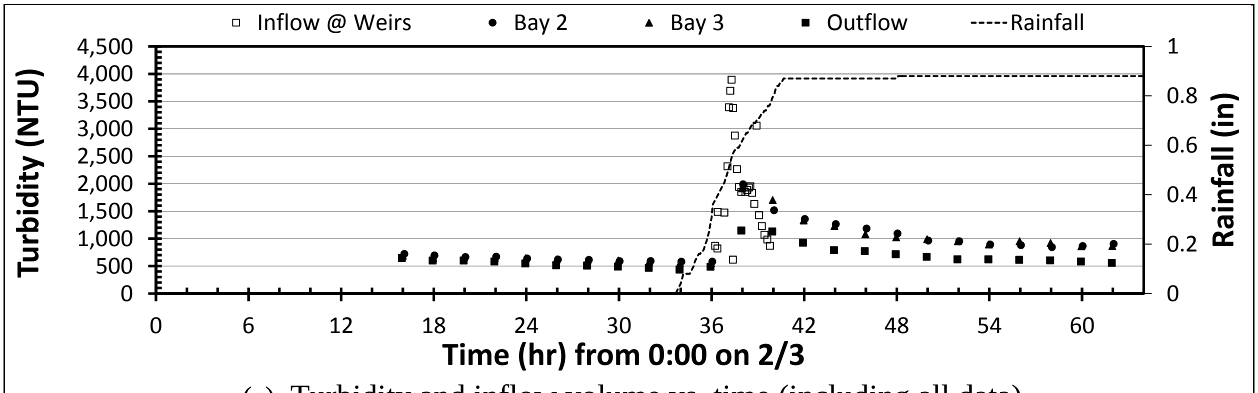


(b) Turbidity reduction fitting curves and equations

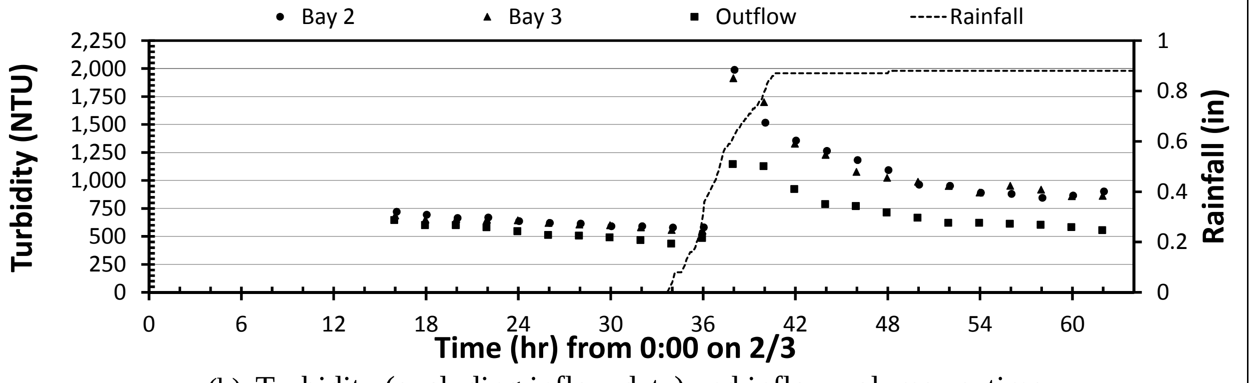


(c) TSS reduction fitting curves and equations

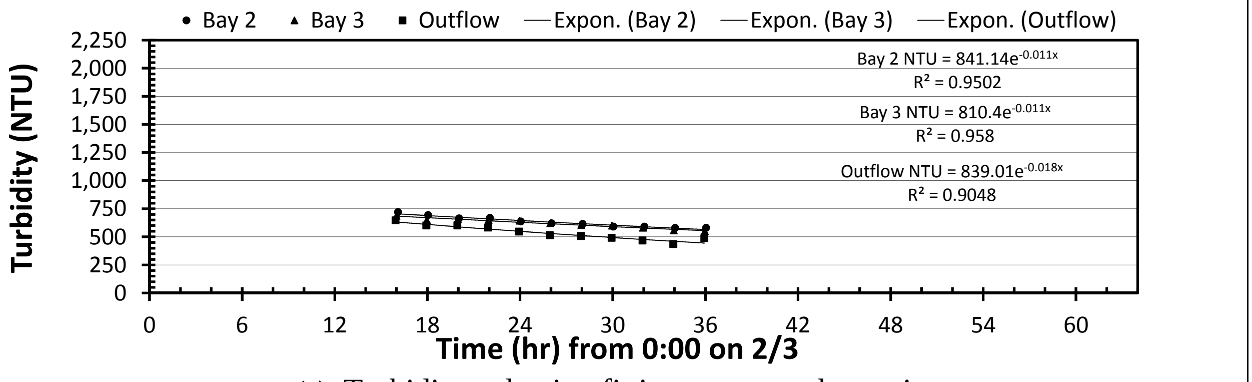
Figure B-26: Sediment basin performance data (i.e., time-series of **turbidity** and **TSS** at inflow, in-basin, and outflow) for rain event on **2/1/2012**.



(a) Turbidity and inflow volume vs. time (including all data)

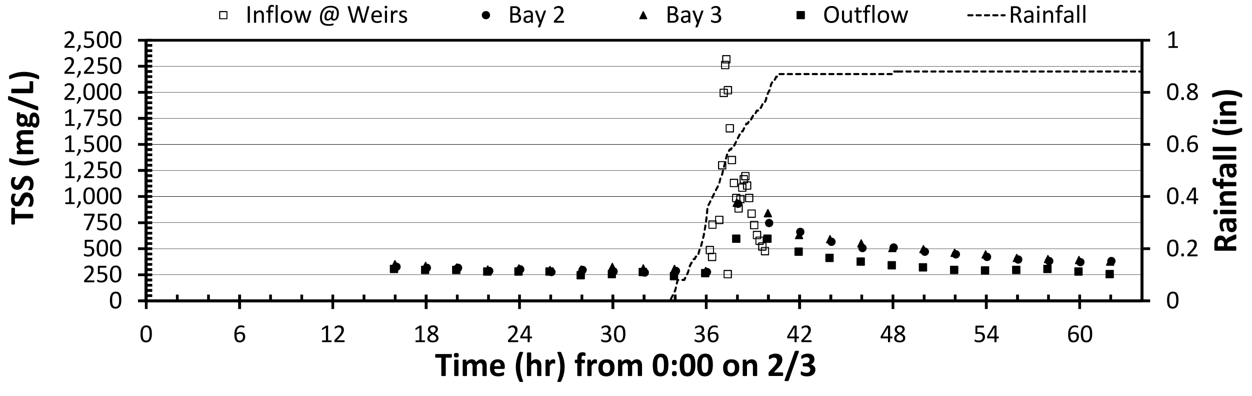


(b) Turbidity (excluding inflow data) and inflow volume vs. time

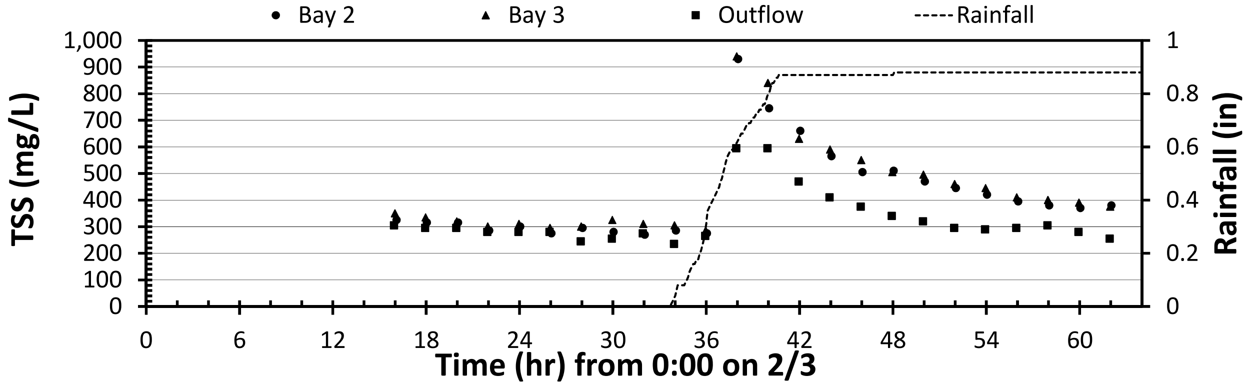


(c) Turbidity reduction fitting curves and equations

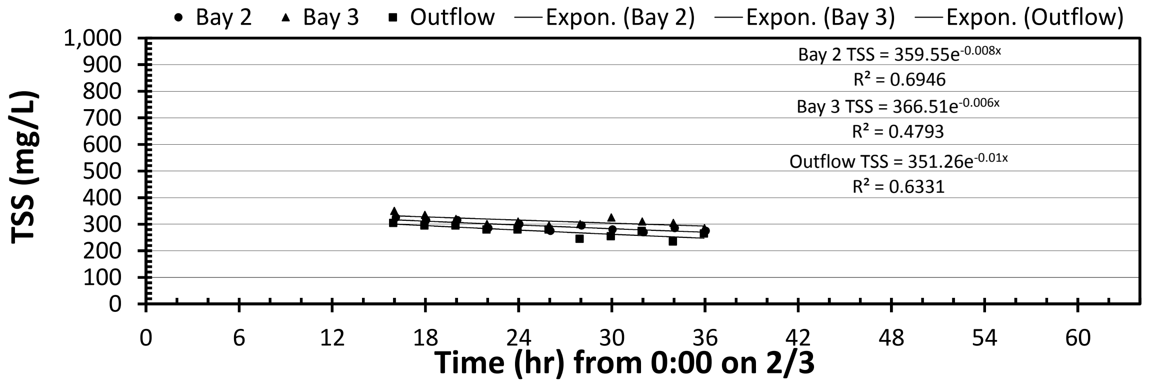
Figure B-27: Sediment basin performance data (i.e., time-series of **turbidity** at inflow, in-basin, and outflow) for rain event on **2/3/2012**.



(a) TSS and inflow volume vs. time (including all data)



(b) TSS (excluding inflow data) and inflow volume vs. time



(c) TSS reduction fitting curves and equations

Figure B-28: Sediment basin performance data (i.e., time-series of **TSS** at inflow, in-basin, and outflow) for rain event on **2/3/2012**.

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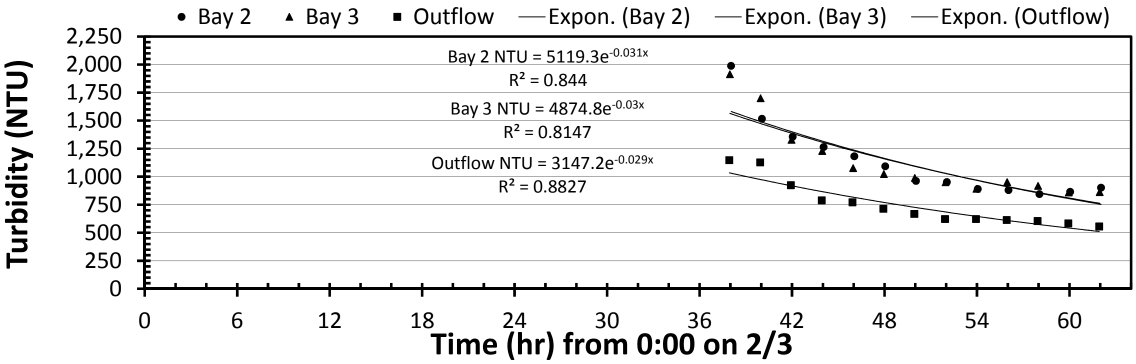
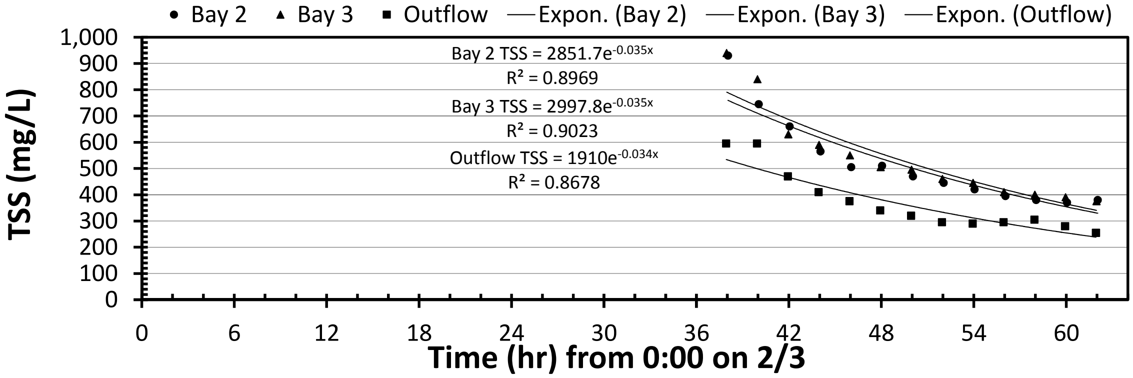


(a) Turbidity reduction fitting curves and equations



(b) TSS reduction fitting curves and equations

Figure B-29: Sediment basin performance data (i.e., time-series of **turbidity** and **TSS** at inflow, in-basin, and outflow) for rain event on **2/3/2012**.

APPENDIX C

Table C.1: Statistical summary of rainfall and turbidity (NTU) and TSS (mg/L) data collected at inflow channels of sediment basin #4.

Conditions of PAM	Rainfall Data								Inflow Data												
	Start Date	Start Time	Finish Date	Finish Time	Duration (Hr:Min)	Amount (in)	Average Intensity	Maximum Intensity	Start Date	Start Time	Finish Date	Finish Time	# of Samples	Max TSS	Min TSS	Average TSS	Std. Dev. TSS	Max NTU	Min NTU	Average NTU	Std. Dev. NTU
With PAM	11/16/2011	0:00	11/16/2011	10:10	10:10	1.35	0.127	2.22	11/16/2011	8:48	11/16/2011	10:22	**23**	**10,545**	**790**	**5,430**	**2,689**	**10,656**	**1,030**	**5,855**	**2,582**
Wrong PAM	11/27/2011	0:10	11/27/2011	6:50	6:40	0.58	0.085	0.60	11/27/2011	3:52	11/27/2011	3:52	1	340	--	--	--	547	--	--	--
	11/27/2011	15:50	11/28/2011	9:00	17:10	0.60	0.035	0.12	11/27/2011	23:50	11/28/2011	1:24	4	130	80	109	21	296	188	257	48
	11/28/2011	13:30	11/29/2011	4:20	14:50	0.41	0.028	0.12	11/28/2011	0.676	11/28/2011	16:51	2	80	60	70	14	229	171	200	41
	12/5/2011	13:50	12/5/2011	17:05	3:15	1.09	0.335	1.08	12/5/2011	15:30	12/5/2011	17:45	**21**	**1,950**	**465**	**1,305**	**380**	**2,724**	**878**	**1,989**	**446**
	12/5/2011	18:35	12/6/2011	0:40	6:05	0.23	0.040	0.24	--	--	--	--	0	--	--	--	--	--	--	--	--
No PAM	12/22/2011	7:15	12/22/2011	14:15	7:00	1.65	0.236	1.92	12/22/2011	10:03	12/22/2011	11:36	3	770	630	712	73	1,548	1,294	1,425	73
	12/26/2011	14:45	12/27/2011	1:40	10:55	1.55	0.142	1.32	12/26/2011	20:23	12/26/2011	21:45	2	660	380	520	198	1,220	955	1,088	187
	1/7/2012	10:55	1/7/2012	12:15	1:20	0.27	0.200	0.84	--	--	--	--	0	--	--	--	--	--	--	--	--
	1/7/2012	16:35	1/7/2012	16:55	0:20	0.21	0.630	1.08													
	1/8/2012	8:15	1/8/2012	9:10	0:55	0.28	0.310	0.36													
Limited or No PAM	1/11/2012	0:05	1/11/2012	1:45	1:40	0.30	0.180	0.36	1/11/2012	2:22	1/11/2012	2:44	3	2,015	1,480	1,797	281	3,660	2,456	2,896	664
	1/11/2012	4:55	1/11/2012	6:20	1:25	0.17	0.120	0.48	--	--	--	--	0	--	--	--	--	--	--	--	--
	1/11/2012	18:50	1/12/2012	8:20	13:30	0.10	0.007	0.12	--	--	--	--	0	--	--	--	--	--	--	--	--
	1/17/2012	14:15	1/17/2012	16:15	2:00	1.22	0.610	3.48	1/17/2012	15:26	1/17/2012	17:00	**28**	**26,325**	**2,720**	**7,433**	**5,632**	**28,352**	**3,488**	**9,902**	**6,234**
									--	--	--	--	0	--	--	--	--	--	--	--	--
	1/22/2012	23:15	1/23/2012	3:50	4:35	0.96	0.209	2.64	1/23/2012	0:28	1/23/2012	1:58	3	1,950	1,355	1,645	298	3,500	2,416	2,909	549
									--	--	--	--	0	--	--	--	--	--	--	--	--
With PAM	1/26/2012	0:10	1/26/2012	1:00	0:50	0.11	0.132	0.24	1/26/2012	6:51	1/26/2012	9:44	**24**	435	95	275	75	785	191	506	149
	1/26/2012	5:20	1/26/2012	10:50	5:30	0.47	0.085	0.24													
	1/26/2012	16:35	1/26/2012	19:05	2:30	0.16	0.064	0.36													
	2/1/2012	4:25	2/1/2012	9:40	5:15	0.46	0.090	0.96	2/1/2012	7:42	2/1/2012	12:26	**24**	**2,645**	**250**	**1,105**	**745**	**3,688**	**508**	**1,905**	**1,067**
	2/1/2012	19:40	2/1/2012	20:05	0:25	0.25	0.610	1.44	2/1/2012	20:14	2/1/2012	20:14	1	870	870	870	--	1,888	1,888	1,888	--
									--	--	--	--	0	--	--	--	--	--	--	--	--
	2/4/2012	9:45	2/4/2012	16:40	6:55	0.88	0.130	0.60	2/4/2012	12:14	2/4/2012	15:47	**27**	**2,315**	**255**	**1,068**	**561**	**3,892**	**616**	**1,944**	**914**

Note: Rainfall data on 11/16/2011 were from RainWave.

APPENDIX C

Table C.2: Statistical summary of rainfall and turbidity (NTU) and TSS (mg/L) data collected at Bay 2 of sediment basin #4.

	Rainfall Data								Bay 2 Data																
PAM	**Start Date**	**Start Time**	**Finish Date**	**Finish Time**	**Duration**	**Amount (in)**	**Average Intensity**	**Maximum Intensity**	**Start Date**	**Start Time**	**Finish Date**	**Finish Time**	**# of Samples**	**Max TSS**	**Min TSS**	**Average TSS**	**Std. Dev. TSS**	**% Peak TSS Reduction**	**% Avg. Inflow TSS Reduction**	**Max NTU**	**Min NTU**	**Average NTU**	**Std. Dev. NTU**	**% Peak NTU Reduction**	**% Avg Inflow NTU Reduction**
With PAM	11/16/2011	--	11/16/2011	--	--	1.35	--	--	11/16/2011	9:21	11/17/2011	8:18	24	4,940	125	439	2,689	97%	98%	5,592	235	688	1,064	96%	96%
Wrong PAM	11/27/2011	0:10	11/27/2011	6:50	6:40	0.58	0.085	0.60	--	--	--	--	0	--	--	--	--	--	--	--	--	--	--	--	--
	11/27/2011	15:50	11/28/2011	9:00	17:10	0.60	0.035	0.12	--	--	--	--	0	--	--	--	--	--	--	--	--	--	--	--	--
	11/28/2011	13:30	11/29/2011	4:20	14:50	0.41	0.028	0.12	--	--	--	--	0	--	--	--	--	--	--	--	--	--	--	--	--
	12/5/2011	13:50	12/5/2011	17:05	3:15	1.09	0.335	1.08	12/5/2011	15:49	12/6/2011	14:47	24	885	175	361	217	80%	87%	1,642	590	929	374	64%	70%
	12/5/2011	18:35	12/6/2011	0:40	6:05	0.23	0.040	0.24																	
	12/22/2011	7:15	12/22/2011	14:15	7:00	1.65	0.236	1.92	12/23/2011	13:36	12/24/2011	12:34	24	235	130	174	28	45%	82%	483	298	376	44	38%	79%
	12/26/2011	14:45	12/27/2011	1:40	10:55	1.55	0.142	1.32	12/26/2011	20:11	12/27/2011	19:08	24	170	75	114	32	56%	86%	420	318	352	34	24%	71%
Limited or No PAM	1/7/2012	10:55	1/7/2012	12:15	1:20	0.27	0.200	0.84	1/7/2012	13:30	1/7/2012	16:27	4	200	105	171	39	0%	--	556	327	495	96	0%	--
	1/7/2012	16:35	1/7/2012	16:55	0:20	0.21	0.630	1.08	1/7/2012	17:27	1/8/2012	7:28	15	1,315	515	727	266	61%	--	2,636	1,338	1,689	480	49%	--
	1/8/2012	8:15	1/8/2012	9:10	0:55	0.28	0.310	0.36	1/8/2012	8:28	1/8/2012	12:27	5	840	490	654	150	42%	--	1,790	1,236	1,525	242	31%	--
									1/9/2012	17:34	1/10/2012	16:32	24	250	100	161	46	60%	--	554	260	378	91	53%	--
	1/11/2012	0:05	1/11/2012	1:45	1:40	0.30	0.180	0.36	1/11/2012	14:31	1/12/2012	3:28	14	360	230	306	41	36%	87%	841	556	705	102	34%	81%
	1/11/2012	4:55	1/11/2012	6:20	1:25	0.17	0.120	0.48	1/12/2012	4:28	1/12/2012	8:28	5	245	200	228	18	18%	89%	568	483	524	32	15%	83%
	1/11/2012	18:50	1/12/2012	8:20	13:30	0.10	0.007	0.12	1/12/2012	9:28	1/12/2012	13:28	5	215	190	203	9	12%	89%	478	448	462	14	6%	85%
	1/17/2012	14:15	1/17/2012	16:15	2:00	1.22	0.610	3.48	1/19/2012	15:58	1/20/2012	14:54	24	805	555	688	74	31%	93%	1,982	1,486	1,753	143	25%	85%
									1/21/2012	15:45	1/22/2012	14:42	24	810	285	475	129	65%	96%	1,916	807	1,194	298	58%	92%
	1/22/2012	23:15	1/23/2012	3:50	4:35	0.96	0.209	2.64	1/23/2012	12:05	1/24/2012	1:03	14	1,325	840	1,073	136	37%	49%	3,036	1,848	2,465	326	39%	36%
									1/24/2012	12:48	1/25/2012	11:46	23	780	460	556	83	41%	72%	1,984	1,164	1,451	233	41%	60%
With PAM	1/26/2012	0:10	1/26/2012	1:00	0:50	0.11	0.132	0.24	1/26/2012	6:29	1/27/2012	5:27	24	580	245	392	94	58%	11%	1,008	517	777	172	49%	-2%
	1/26/2012	5:20	1/26/2012	10:50	5:30	0.47	0.085	0.24																	
	1/26/2012	16:35	1/26/2012	19:05	2:30	0.16	0.064	0.36	1/28/2012	17:50	1/29/2012	16:48	24	160	65	108	25	59%	76%	322	241	270	23	25%	52%
	2/1/2012	4:25	2/1/2012	9:40	5:15	0.46	0.090	0.96	2/1/2012	7:23	2/1/2012	19:21	13	885	395	481	215	55%	64%	1,552	811	909	368	48%	57%
	2/1/2012	19:40	2/1/2012	20:05	0:25	0.25	0.610	1.44	2/1/2012	20:21	2/2/2012	6:21	11	1,780	675	1,008	349	62%	22%	2,996	1,512	2,014	455	50%	20%
									2/2/2012	14:35	2/3/2012	13:33	24	570	315	420	89	45%	64%	1,226	747	910	167	39%	60%
									2/3/2012	16:06	2/4/2012	12:03	11	325	270	293	19	17%	69%	720	579	632	48	20%	69%
	2/4/2012	9:45	2/4/2012	16:40	6:55	0.88	0.130	0.60	2/4/2012	14:03	2/5/2012	14:03	13	930	370	521	167	60%	65%	1,988	844	1,130	334	58%	57%

APPENDIX C

Table C.3: Statistical summary of rainfall and turbidity (NTU) and TSS (mg/L) data collected at Bay 3 of sediment basin #4.

Phase		Rainfall Data								Bay 3 Data																		
	PAM	Start Date	Start Time	Finish Date	Finish Time	Duration	Amount (in)	Average Intensity	Maximum Intensity	Start Date	Start Time	Finish Date	Finish Time	# of Samples	Max TSS	Min TSS	Average TSS	Std. Dev. TSS	% Peak TSS Reduction	% Avg. Inflow TSS Reduction	Max NTU	Min NTU	Average NTU	Std. Dev. NTU	% Peak NTU Reduction	% Avg Inflow NTU Reduction
PH1	With PAM	11/16/2011	0:00	11/16/2011	10:10	10:10	1.35	0.127	2.22	11/16/2011	9:14	11/17/2011	8:11	24	2,145	110	356	415	95%	98%	3,856	247	708	729	94%	96%
	Wrong PAM	11/27/2011	0:10	11/27/2011	6:50	6:40	0.58	0.085	0.60	--	--	--	--	0	--	--	--	--	--	--	--	--	--	--	--	--
		11/27/2011	15:50	11/28/2011	9:00	17:10	0.60	0.035	0.12	--	--	--	--	0	--	--	--	--	--	--	--	--	--	--	--	--
		1/17/2012	13:30	11/29/2011	4:20	14:50	0.41	0.028	0.12	--	--	--	--	0	--	--	--	--	--	--	--	--	--	--	--	--
		12/5/2011	13:50	12/5/2011	17:05	3:15	1.09	0.335	1.08	12/5/2011	15:42	12/6/2011	14:41	24	800	225	311	125	72%	83%	1,552	615	914	345	60%	69%
		12/5/2011	18:35	12/6/2011	0:40	6:05	0.23	0.040	0.24																	
		12/22/2011	7:15	12/22/2011	14:15	7:00	1.65	0.236	1.92	12/23/2011	13:08	12/24/2011	12:06	24	205	135	165	19	34%	81%	482	352	390	33	27%	75%
		12/26/2011	14:45	12/27/2011	1:40	10:55	1.55	0.142	1.32	12/26/2011	19:43	12/27/2011	18:41	24	160	70	101	26	56%	87%	446	266	363	52	40%	76%
PH2	Limited or No PAM	1/7/2012	10:55	1/7/2012	12:15	1:20	0.27	0.200	0.84	1/7/2012	13:01	1/7/2012	16:00	4	185	30	117	70	0%	--	508	153	358	157	0%	--
		1/7/2012	16:35	1/7/2012	16:55	0:20	0.21	0.630	1.08	1/7/2012	17:00	1/8/2012	7:00	15	1,125	460	692	252	59%	--	2,232	1,236	1,614	445	45%	--
		1/8/2012	8:15	1/8/2012	9:10	0:55	0.28	0.310	0.36	1/8/2012	8:00	1/8/2012	12:00	5	755	470	606	135	38%	--	1,704	1,518	1,446	270	11%	--
										1/9/2012	17:29	1/10/2012	16:27	24	350	95	161	46	73%	--	546	260	381	98	52%	--
		1/11/2012	0:05	1/11/2012	1:45	1:40	0.30	0.180	0.36	1/11/2012	14:25	1/12/2012	3:23	14	315	230	268	23	27%	87%	720	522	604	49	28%	82%
		1/11/2012	4:55	1/11/2012	6:20	1:25	0.17	0.120	0.48	1/12/2012	4:23	1/12/2012	8:23	5	235	200	213	14	15%	89%	503	455	475	19	10%	84%
		1/11/2012	18:50	1/12/2012	8:20	13:30	0.10	0.007	0.12	1/12/2012	9:23	1/12/2012	13:23	5	215	190	200	10	12%	89%	462	434	452	11	6%	85%
		1/17/2012	14:15	1/17/2012	16:15	2:00	1.22	0.610	3.48	1/19/2012	15:52	1/20/2012	14:49	24	795	590	667	55	26%	92%	1,926	1,532	1,734	111	20%	85%
										1/21/2012	15:39	1/22/2012	14:37	24	800	270	450	139	66%	96%	1,956	738	1,145	348	62%	93%
		1/22/2012	23:15	1/23/2012	3:50	4:35	0.96	0.209	2.64	1/23/2012	11:59	1/24/2012	10:57	24	1,390	695	959	203	50%	58%	2,992	1,728	2,203	394	42%	41%
										1/24/2012	12:42	1/25/2012	11:41	24	715	225	544	105	69%	86%	1,768	1,186	1,442	207	33%	59%
	With PAM	1/26/2012	0:10	1/26/2012	1:00	0:50	0.11	0.132	0.24	1/26/2012	6:24	1/27/2012	5:22	24	510	225	371	89	56%	18%	1,042	519	797	187	50%	-3%
		1/26/2012	5:20	1/26/2012	10:50	5:30	0.47	0.085	0.24																	
		1/26/2012	16:35	1/26/2012	19:05	2:30	0.16	0.064	0.36	1/28/2012	17:45	1/29/2012	16:43	24	150	65	111	26	57%	76%	326	256	277	21	21%	49%
		2/1/2012	4:25	2/1/2012	9:40	5:15	0.46	0.090	0.96	2/1/2012	7:17	2/1/2012	19:16	13	660	50	410	180	92%	95%	1,326	844	886	343	36%	56%
		2/1/2012	19:40	2/1/2012	20:05	0:25	0.25	0.610	1.44	2/1/2012	20:16	2/2/2012	6:16	11	1,255	660	903	188	47%	24%	2,472	1,544	1,887	284	38%	18%
										2/2/2012	14:30	2/3/2012	13:28	24	585	355	429	70	39%	59%	1,196	722	886	147	40%	62%
										2/3/2012	16:00	2/4/2012	11:58	11	350	285	312	19	19%	67%	687	551	618	44	20%	71%
		2/4/2012	9:45	2/4/2012	16:40	6:55	0.88	0.130	0.60	2/4/2012	13:58	2/5/2012	13:58	13	940	375	541	175	60%	65%	1,914	859	1,130	333	55%	56%

APPENDIX C

Table C.4: Statistical summary of rainfall and turbidity (NTU) and TSS (mg/L) data collected at <u>outflow</u> of sediment basin #4.

Phase		Rainfall Data								Outflow Data																
	PAM	Start Date	Start Time	Finish Date	Finish Time	Duration	Amount (in)	Average Intensity	Maximum Intensity	Start Date	Start Time	Finish Date	Finish Time	# of Samples	Max TSS	Min TSS	Average TSS	Std. Dev. TSS	% Peak TSS Reduction	% Avg. Inflow TSS Reduction	Max NTU	Min NTU	Average NTU	Std. Dev. NTU	% Peak NTU Reduction	% Avg Inflow NTU Reduction
PH1	With PAM	11/16/2011	0:00	11/16/2011	10:10	10:10	1.35	0.127	2.22	11/16/2011	9:07	11/17/2011	8:07	24	895	120	234	162	87%	98%	1,646	239	498	298	85%	96%
	Wrong PAM	11/27/2011	0:10	11/27/2011	6:50	6:40	0.58	0.085	0.60	--	--	--	--	0	--	--	--	--	--	--	--	--	--	--	--	--
		11/27/2011	15:50	11/28/2011	9:00	17:10	0.60	0.035	0.12	--	--	--	--	0	--	--	--	--	--	--	--	--	--	--	--	--
		1/26/2012	13:30	11/29/2011	4:20	14:50	0.41	0.028	0.12	--	--	--	--	0	--	--	--	--	--	--	--	--	--	--	--	--
		12/5/2011	13:50	12/5/2011	17:05	3:15	1.09	0.335	1.08	12/5/2011	15:37	12/6/2011	14:37	24	520	95	311	125	82%	93%	1,112	236	774	245	79%	88%
		12/5/2011	18:35	12/6/2011	0:40	6:05	0.23	0.040	0.24																	
		12/22/2011	7:15	12/22/2011	14:15	7:00	1.65	0.236	1.92	12/23/2011	13:02	12/24/2011	12:02	24	185	115	150	18	38%	84%	411	266	345	43	35%	81%
		12/26/2011	14:45	12/27/2011	1:40	10:55	1.55	0.142	1.32	12/26/2011	19:37	12/27/2011	18:37	24	100	50	71	13	50%	90%	306	252	272	27	18%	77%
PH2	Limited or No PAM	1/7/2012	10:55	1/7/2012	12:15	1:20	0.27	0.200	0.84	1/7/2012	12:56	1/7/2012	17:56	4	430	0	72	175	100%	--	1,010	104	271	362	90%	--
		1/7/2012	16:35	1/7/2012	16:55	0:20	0.21	0.630	1.08	1/7/2012	18:56	1/8/2012	6:56	15	380	300	312	58	21%	--	995	833	839	155	16%	--
		1/8/2012	8:15	1/8/2012	9:10	0:55	0.28	0.310	0.36	1/8/2012	7:56	1/8/2012	11:56	5	420	300	341	49	0%	--	1,022	814	889	94	0%	--
										1/9/2012	17:23	1/10/2012	16:23	24	215	45	107	46	79%	--	501	196	304	100	61%	--
		1/11/2012	0:05	1/11/2012	1:45	1:40	0.30	0.180	0.36	1/11/2012	14:19	1/12/2012	3:19	14	215	110	174	23	49%	94%	549	430	493	36	22%	85%
		1/11/2012	4:55	1/11/2012	6:20	1:25	0.17	0.120	0.48	1/12/2012	4:19	1/12/2012	8:19	5	180	150	165	14	17%	92%	449	429	437	7	4%	85%
		1/11/2012	18:50	1/12/2012	8:20	13:30	0.10	0.007	0.12	1/12/2012	9:19	1/12/2012	13:19	5	185	150	167	13	19%	92%	426	404	415	8	5%	86%
		1/17/2012	14:15	1/17/2012	16:15	2:00	1.22	0.610	3.48	1/19/2012	15:46	1/20/2012	14:46	24	745	500	643	73	33%	93%	1,858	1,394	1,604	143	25%	86%
										1/21/2012	15:34	1/22/2012	14:33	24	540	205	346	103	62%	97%	1,170	502	736	213	57%	95%
		1/22/2012	23:15	1/23/2012	3:50	4:35	0.96	0.209	2.64	1/23/2012	11:54	1/24/2012	10:54	24	890	645	755	70	28%	61%	2,044	1,710	1,858	104	16%	41%
										1/24/2012	12:37	1/25/2012	11:37	24	895	395	489	99	56%	76%	1,644	1,116	1,335	160	32%	62%
	With PAM	1/26/2012	0:10	1/26/2012	1:00	0:50	0.11	0.132	0.24	1/26/2012	6:18	1/27/2012	5:18	24	385	220	296	56	43%	20%	905	480	632	135	47%	5%
		1/26/2012	5:20	1/26/2012	10:50	5:30	0.47	0.085	0.24																	
		1/26/2012	16:35	1/26/2012	19:05	2:30	0.16	0.064	0.36	1/28/2012	17:39	1/29/2012	16:39	15	220	15	96	55	93%	95%	507	243	305	75	52%	52%
		2/1/2012	4:25	2/1/2012	9:40	5:15	0.46	0.090	0.96	2/1/2012	7:12	2/1/2012	19:12	13	340	285	306	24	16%	74%	740	629	665	36	15%	67%
		2/1/2012	19:40	2/1/2012	20:05	0:25	0.25	0.610	1.44	2/1/2012	20:12	2/2/2012	6:12	11	585	400	500	53	32%	54%	1,330	1,072	1,197	82	19%	43%
										2/2/2012	14:24	2/3/2012	13:24	24	450	295	355	43	34%	66%	948	641	763	99	32%	66%
										2/3/2012	15:56	2/4/2012	11:56	11	305	235	274	22	23%	73%	646	435	534	66	33%	77%
		2/4/2012	9:45	2/4/2012	16:40	6:55	0.88	0.130	0.60	2/4/2012	13:56	2/5/2012	13:56	13	595	255	371	115	57%	76%	1,146	555	749	200	52%	71%