Engineering Design Procedures and Standard Drawings for Highway Construction Sediment Basins

Research Final Report from the University of Tennessee Knoxville | John S. Schwartz, Payton Smith, Cole Emmett, Jason Brown | May 29, 2024

Sponsored by Tennessee Department of Strategic Planning, Research and Innovation & Federal Highways Administration

(University of Tennessee – Knoxville, TN)

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Technical Report Documentation Page

1. Report No. RES 2020-22	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle *Engineering Design Procedures and Standard Drawings for Highway Construction Sediment Basins*		5. Report Date May 2024
		6. Performing Organization Code
7. Author(s) John S Schwartz, Payton Smith, Cole Emmett, Jason Brown		8. Performing Organization Report No.
9. Performing Organization Name and Address University of Tennessee Dept. of Civil & Environmental Engineering Knoxville, Tennessee 37996		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. RES 2020-22
12. Sponsoring Agency Name and Address Tennessee Department of Transportation 505 Deaderick Street, Suite 900 Nashville, TN 37243		13. Type of Report and Period Covered May 2022 – July 2024
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Stormwater discharges from highway construction that disturb soil greater than five acres are permitted by the Tennessee Department of Environment and Conservation (TDEC) where runoff sediment must be controlled meeting General Permit (TNR100000) requirements including development and submittal of a Stormwater Pollution Prevention Plan (SWPPP). Within a SWPPP many Erosion Prevention and Stormwater Control (EPSC) devices can be used to control runoff sediment from entering a receiving stream. One EPSC that is not often used is the sediment basin for various reasons including unfamiliarity with design criteria and concern over meeting TDEC performance requirements. Phase I of the project developed general guidelines for sediment basin design based on catchment drainage area, land slope, and soil type. This study as Phase II evaluated the Phase I guidelines. Phase I design guidance for sediment basins were found to adequately to achieve 80% removal of runoff sediment for a 24-hour, 25-year return frequency storm. Research also found that particle size distribution of runoff sediment substantially determines basin performance, thus the sizing of a sediment basin therefore it needs to be incorporated into the design protocols. A design tool was created to accomplish this basin design need. A second object of this research investigated sediment basin performance on a pilot-scale test basin to compare the TDOT standard basin design and one with a rock check dam, and the TDEC standard design with a forebay. The TDOT standard design with a rock check dam at the basin inlet approach area performs similarly to the TDEC standard design with a forebay, where both basin designs achieved greater than 95% removal of sediment in stormwater runoff. The RUSLE2 model computed sediment yields and PSD (sand, silt, and clay fractions) necessary for sizing sediment basins. Further monitoring data expanding on this research would be valuable.

17. Key Words	18. Distribution Statement
SEDIMENT BASINS; STORMWATER CONTROL MEASURES; HIGHWAY SOIL EROSION; WATER QUALITY	No restriction. This document is available to the public from the sponsoring agency at the website http://www.tn.gov/

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	50	

Acknowledgement

Research was funded by the Tennessee Department of Transportation (TDOT), Research Office and Engineering Division for funding through grant RES#2020-22 issued to the University of Tennessee Knoxville (UTK) Center for Transportation Research. We thank the major efforts by Ali Hangul in TDOT Headquarters in the development of the project and facilitating the necessary correspondence between TDOT staff and the on-site contractors. We also appreciate the support from TDOT Region I Office for assistance locating field sites including Danny Oliver, Kayla Grubb, Chris Ponder, and Deidera White. We thank Jeff Hoilman for his support as sediment basin design engineer. We thank Jerry Graham and Dale Barns of Charles Blalock and Sons, Inc. for construction of the sediment basins and assistance during our field operations. Data collection for the Bedford County site was assisted by Janette Wolf with Civil & Environmental Consultants, Inc. Staff in the UTK Department of Civil and Environmental Engineering assisting included Larry Roberts and Nancy Roberts. UTK faculty Dr. Daniel Yoder and Dr. Jon Hathaway provided technical support during the project. We thank the field work assistance of UTK students Brandy Manka, Alan Jolly, Will Luke, Bailee Young, Jeremy Melton, Nick Pettit, and Carter Groves.

Executive Summary

Stormwater discharges from highway construction activities that disturb land soil greater than five acres are permitted by the Tennessee Department of Environment and Conservation (TDEC) and runoff sediment must be controlled to meet permit requirements per General Permit (TNR100000) for *Stormwater Discharges Associated with Construction Activitie*s. TNR100000 permits require development and submittal of a Stormwater Pollution Prevention Plan (SWPPP). Within a SWPPP many *Erosion Prevention and Stormwater Control* (EPSC) devices can be used to control runoff sediment from entering a receiving stream. The most commonly used devices are silt fences and/or rock check dams (Hangul 2017). Sediment basins are one of the many EPSC devices in the TDOT Drainage Manual Chapter 10 to control soil erosion or trap eroded sediment from highway construction sites. As an EPSC device the sediment basin is not often designed within a SWPPP nor constructed on a highway construction project site. There are several reasons for the lack of use of sediment basins including construction site space constraints, effort to construct and maintain during construction, and unfamiliarity with design criteria.

Current engineering design guidance for sizing of sediment basin requires modeling and laborious calculations. Also engineering designs must accommodate differences between TDOT standard drawings and TDEC's standards where TDEC requires forebay increasing the area needed to construct. Information on the performance of sediment basins is limited for either design standard which may also contribute to its nominal use for highway construction sites. Design calculations could be simplified with improved guidance, where guidelines are only based on key factors such as site disturbed area, slope, and soil types. A critical research need is to improve the design criteria for sizing of sediment basins to construct them cost effectively and maximize sediment reductions meeting water quality/environmental standards.

This TDOT research need initiated Phase I of this project in 2012 to develop more time- and cost-efficient guidance for sediment basin design. In addition, the project was motivated by new rules promulgated by the US Environmental Protection Agency (USEPA) requiring numeral turbidity limits for stormwater discharges from construction site activities at 280 Nephelometric Turbidity Units (NTU). Stormwater treatment by any EPSC device to achieve water quality less than 280 NTU was problematic thus the USEPA withdrew their rule for further scientific review. Currently, the permit TNR100000 permit does not require numerical limits, rather relies on visual criteria stated as: "stormwater discharges must not cause an objectionable color contrast in the receiving stream" (TDEC Rules, Chapter 1200-4). Also, there shall be no visual solids or stream bottom sediment, or conditions where high turbidly impairs the designated beneficial uses. During the Phase I effort for this research, general design guidelines for construction site sediment basins were developed through the use of HydroCAD® and SEDCAD® models (Neff and Schwartz 2013). This initial work was based on uncalibrated hydrological and sediment transport/pond settling models. The key input model parameters were: 1) drainage area size from 1 to 50 acres, land slope (2-12%), and soil types (i.e., sand-silt, silt-loam, clay-loam-silt, etc.). This research project as Phase II primarily focused on collecting field data at active highway construction sites to verify the design guidelines generated in the Phase I work.

Specifically, the objectives of this Phase II research were to collect field data at TDOT constructed sediment basins and monitor flow/sediment inputs/outputs to estimate performance as % reductions in sediment and compare field measurements with the design guidelines developed during Phase I to confirm hydrologic and sediment transport modeling results. In addition, assess the performance of a pilot-scale sediment basin built on University of Tennessee property with a study design specifically aimed at comparing differences between sediment basins with a pre-basin rock check dam and one with a forebay pre-setting basin, and to the current TDOT standard design. The RUSLE2 model was applied to demonstrate its utility for sediment basin design by computing sediment yields for two of the active highway construction sites monitored.

Three study site sediment basins were designed based on guidelines in Neff and Schwartz (2013) differing in catchment drainage areas, land slopes, and soil types thereby following the key design factors developed in Phase I of this research project. The three sediment basins were constructed on highway projects in Morgan County (US 27), Knox County (I-640 interchange at Broadway Street), and Bedford County (US 41A, SR16). Each study site was equipped with a Davis® full weather station. Sediment basins were equipped at the inlet with a 1.0-ft. or 1.5-ft Tracom© H-flume with HOBO U20L Series water level (stage) logger placed in a 6-inch diameter stilling well for continuous flow measurements. Sediment samples were collected with an ISCO® 3700 Portable Sampler triggered to sample during storm events by an ISCO® 4230 Flow Meter. The outlets were equipped with either a Pinson et al. (2013) flow divider bucket system or 90º V-notch weir box, and also equipped with a HOBO U20L Series water level (stage) logger and ISCO® 3700 Portable Sampler. Sediment deposits at the H-flume approach area were collected manually. The number of storm events sampled were between 5 and 9 depending on the study site. Sediment mass concentrations and loads were computed and the difference in mass loadings were determined to be the percent sediment removed, or the basin performance. In addition, particle size distributions (PSD) were conducted on all samples.

Performance of the constructed sediment basins varied among the different sites. The variance in the performances appear to be mostly from differences in catchment sediment sources and it size characteristics, and the storm event characteristics in terms of magnitude, duration, and frequency. At the Morgan County study site, the sediment mass retained ranged between 47.7% and 97.5% with an average of 76.8%, a median of 80.1%, and a standard deviation of 18.9%. At this site, the Suspended Solid Concentration reduction between the basin influent and effluent ranged from 13.0% to 95.8% with an average of 72%. At the Knox County study site, the sediment mass retained ranged between 94.3% and 99.4% with an average of 97.4%, a median of 98.1%, and a standard deviation of 2.0%. The average SSC reduction at this site ranged between 75.6% and 97.4% with an average reduction of 86.7%. At the Bedford County site, the SSC reduction ranged between 58.6% and 94.0% with an average of 78.2%, and standard deviation of 9.9%. Results indicated that the TDOT standard sediment basin design generally performs over 80% sediment removed in stormwater runoff if the basin is sized adequately. However, it was observed that high intensity 0.5 in/hr., 30-minute duration storms, and continuous 3-4 days of precipitation with one daily magnitude over 1 inch generally reduced basin performance. Overall, this research suggests that the design tables developed by Neff and Schwartz (2013) sufficiently treat sediment laden stormwater runoff from construction sites for daily rainfall volumes less than the 25-year return frequency storm, and 72 hrs. between storms. Recall, these design tables provide sediment basin sizing criteria for east, middle, and west Tennessee, and based on catchment drainage area, land slope, and soil type.

A general observation from the monitoring effort at the active highway construction sites was the influent H-flume used to measure flow and collect flow-weighted sediment samples acted like a rock check dam were large amounts of sediment deposited. Mostly the larger size sediment, gravel and sand with some silt and clay mixed where the dominant deposited sediment at the H-flume approach area. Greater amounts of sediment deposited per storm event were correlated with higher rainfall intensities. It was measured that 4 inches or more of sediment were deposited for rainfall intensities if 1-inch or greater for 30-minutes intervals. This observation lead to the second Phase II study design assessing the effectiveness of a rock check dam at the basin inlet approach area for the TDOT standard design without a forebay, and to compare it with the TDEC standard design with a forebay.

The field experiment using a pilot-scale basin consisting of three designs to compare the performance of the TDOT standard and one with a rock check dam (TDOT CD), and the TDEC standard with a forebay. Testing results of the three designs provided valuable information on basin performance associated with the TDOT design standard with an inlet approach rock check dam. Performance of three sediment basin designs were evaluated by the total percent sediment removal for each. The TDEC design with a forebay achieved the highest percent sediment removal at 98.2 %, while the TDOT CD had very similar results compared to the TDEC design with a measured 97.9 % removal. The TDOT standard design preformed the lowest with a 95.4 % removal, although it still performed with greater than 80% removal, as required by TDEC's stormwater permit. The majority of the sediment settles within the first 20 hours with small SSC decreases in effluent from 20 to 72 hours. In general, it is the clay particle size remaining in suspension after 20 hours. Further investigation of the dewatering time is warranted in that a shorter time could provide the basin storage needed for the subsequent storm event. Basin performance data from the monitored basins at active highway projects suggest reduced volume capacity after number days of precipitation and lower sediment removal. **The key finding was a rock check dam in front of a TDOT standard sediment basin proved to be nearly as efficient in removing runoff sediment as the TDEC standard design with a forebay.** The importance of this finding is to minimize basin footprint at narrow corridors among highway construction sites. The TDOT CD design is most valuable for these highway construction sites since it requires less area than the TDEC design with a forebay. However, more frequent maintenance of the inlet rock check dam structure is likely required thus construction site management needs to account for the necessary maintenance efforts.

The RUSLE2 model can be used to estimate runoff sediment and total mass quantified in sand, silt and clay proportions. Sediment yields from the use of RUSLE2 can be applied to size the sediment basin. From this research, **sizing of sediment basins is dependent on the influent sediment PSD.** Because of this study's finding, a sediment basin design tool was created that relies on the influent sediment PSD and conforms to the other existing standard design criteria.

This design tool will be available on the web page of the University of Tennessee, Tennessee Water Resources Research Center.

In summary, this research provided new information on the performance of sediment basins. Current literature on performance is limited providing value to the outcomes of this research. It has provided TDOT with better design guidance to achieve better than 80% sediment removed in stormwater runoff from active highway construction sites.

Key Findings

- Design guidance for sediment basins developed during Phase I of this project based on catchment drainage area, land slope, and soil type appear to size the basin adequately to achieve 80% removal of runoff sediment for a 24-hour, 2-year return frequency storm.
- Sediment basin performance is reduced below 80% runoff sediment removed for high 30-minute intensity storm events > 0.5 in/hr. and continuous rainfall over 3-4 days with one daily magnitude over 1-inch depth.
- The particle size distribution (PSD) of runoff sediment characteristics as basin influent substantially determines basin performance, thus the sizing of a sediment basin; therefore, a sediment basin design tool based on PSD input was created as part of this project.
- The TDOT standard design with a rock check dam at the basin inlet approach area performs similarly to the TDEC standard design with a forebay, where both basin designs achieved greater than 95% removal of sediment in stormwater runoff.
- The RUSLE2 model computed sediment yields and PSD (sand, silt, and clay fractions) necessary for sizing sediment basins.

Key Recommendations

- Use the general guidelines per Neff and Schwartz (2013) for sediment basin design based on catchment drainage area, land slope, and soil type, for different Tennessee regions.
- For highway construction projects with suitable space to fit a sediment basin, use the TDOT standards design with a rock check dam at the inlet approach area, and provide an adequate maintenance plan in the SWPPP.
- Use the RUSLE2 model to compute sediment yields and PSD (sand, silt, and clay fractions) necessary for sizing sediment basins, and the new sediment basin design tool employing runoff sediment PSD.
- Though the Phase II study generated very useful information to improve sediment basin design on TDOT highway construction projects, the dataset is limited, and additional monitoring data is recommended, particularly for a study site in West Tennessee.

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Chapter 1 Introduction

1.1 Problem Statement

Stormwater discharges from highway construction activities are permitted by the Tennessee Department of Environment and Conservation (TDEC) and runoff sediment must be controlled to meet permit requirements. TDEC revised their NPDES General Permit (TNR100000) for *Stormwater Discharges Associated with Construction Activitie*s in 2016 and then in 2021. During highway construction the minimal land disturbance requiring a TNR100000 permit is one acre with runoff entering a receiving stream with unavailable conditions (water quality impaired), or otherwise greater than 5 acres. Most TDOT projects disturb land soils greater than five acres therefore require a TNR100000 permit and development of a Stormwater Pollution Prevention Plan (SWPPP). Within a SWPPP many *Erosion Prevention and Stormwater Control* (EPSC) devices can be used to control excessive sediment from entering a stream with the most common devices being silt fences and/or rock check dams (Hangul 2017). Sediment basins are one of the many EPSC devices in the TDOT Drainage Manual to control eroded sediment from highway construction sites. As an EPSC device the sediment basin is not often designed within a SWPPP nor constructed on a highway construction project site.

There are several reasons for the lack of use of sediment basins including construction site space constraints, effort to construct and maintain during construction, and unfamiliarity with design criteria. Current engineering design guidance for sizing of sediment basin requires modeling and laborious calculations, whereas it would be more efficient to have criteria based on key factors such as site disturbed area, slope, and soil types. Also engineering designs must accommodate differences between TDOT standard drawings and TDEC's standards where TDEC requires a pre-settling basin (forebay) which increases the area needed to construct. Overall, information on the performance of sediment basins is limited for either design standard which may also contribute to its nominal use for highway construction sites. The limited published data on the performance of sediment basins specifically does not include any on-site field data and the use of skimmer dewatering devices (McCaleb and McLaughlin, 2008). A critical research need is to improve the design criteria for sizing of sediment basins to construct them cost effectively and maximize sediment reductions meeting water quality/environmental standards.

Phase I of this research project was initiated in 2012 by TDOT because the US Environmental Protection Agency (USEPA) promulgated new rules requiring numeral limits for stormwater discharges from construction site activities at 280 Nephelometric Turbidity Units (NTU) for turbidity. The level of treatment to achieve 280 NTU was problematic, thus legal actions were initiated by the National Association of Homebuilders, the Utility Water Act Group, and others. The USEPA withdrew their rule temporally for further scientific review, and to this date has not offered any new rule changes per numeric NTU discharge limits. TDEC addresses potential water quality impacts from construction sites greater than one acre of disturbed land surface and regulated under the above described TNR100000 General Permit. Currently, this permit does not require numerical limits, rather relies on visual criteria stated as: "There shall be no turbidity, total suspended solids, or color in such amounts or of such character that will materially affect fish and aquatic life." (TDEC Rules, Chapter 1200-4-3 GENERAL WATER QUALITY CRITERIA). Also, there shall be no visual solids or stream bottom sediment, or conditions where high turbidly impairs the designated beneficial uses as defined by TDEC Rules, Chapter 1200-4-4. The Permit also requires several site management efforts to control soil erosion during rainfall events, including soil stabilization, buffer zone requirements, dewatering, and other pollution prevention measures. Meeting the visual water quality limits can be problematic for large highway construction projects.

During the Phase I effort for this research (FY 2011-2012), general design guidelines for construction site sediment basins were developed through the use of HydroCAD® and SEDCAD® models. This initial work was based on uncalibrated hydrological and sediment transport/pond settling models. The key input model parameters used in the Phase I work were: 1) drainage area size from 1 to 50 acres, land slope (2-12%), and soil types (i.e., silt-loam, clay-loam-silt, etc.). The final report for the Phase I research can be provided by TDOT (Neff and Schwartz 2013). Uncalibrated models provide reasonable results for basin performance; however, accuracy cannot be confirmed until the model input/output parameters are verified through site field measurements. Therefore, field research is needed to test on-site sediment basin performance, which constitutes the proposed Phase II research here within. Thus, the Phase II research was to collect performance data from constructed sediment basins on TDOT road project sites and an experimental controlled built basin and compare the measured data with the Phase I modeled estimates.

During initial field investigations for the Phase II research, it was observed that a pre-basin rock check dam may be as effective as the TDEC standards requiring a pre-settling basin. Recall as noted above, a pre-setting basin necessitates additional land area to construct. It requires about 25% more space which can be a constraint for highway construction corridors. The research objectives were adapted to include an experimental study comparing the performance between sediment basins with a pre-basin rock check dam and a forebay pre-setting basin. Overall, outcomes of the Phase II research provide better design guidance on basin site selection within limited right-of-way linear corridors of highway construction projects, and the expected sediment reduction performance for meeting TDEC's permit requirements.

Benefits to TDOT include: 1) improving design criteria and guidelines for the design of sediment basins, in order to meet USEPA and TDEC effluent limits for construction site runoff discharges, 2) reducing design costs by increased efficiency utilizing design tables rather than having to use hydrologic and sediment models for each site design, and 3) suggesting improved sediment basin designs that can be located among linear, narrow highway construction sites. Reductions in cost include: 1) the decreased time for design by TDOT staff, 2) direct decreased costs to TDOT on projects designed by consultants, and 3) providing guidance on identifying the most cost-effective design to implement during construction.

1.2 Project Objectives

Objectives of the Phase II research were to: 1) collect field data at TDOT constructed sediment basins and monitor flow/sediment inputs/outputs to estimate performance as % reductions in sediment, 2) compare field measurements with the design criteria developed during Phase I to confirm hydrologic and sediment transport modeling results, and if they differ adjust design criteria based on field measurements, and 3) estimate the performance of a built sediment basin on University of Tennessee property under controlled experimental runoff sediment conditions with a study design specifically aimed at comparing performance differences between a sediment basin with a pre-basin rock check dam and one with a forebay pre-setting basin.

1.3 Scope of Work

The scope of work for this Phase II consisted of monitoring TDOT constructed sediment basins for % reduction in runoff sediment quantifying basin performance at field sites. Purchased monitoring equipment was set-up at field sites. At monitored field sites, influent and effluent flows at the basin were measured, and water and sediment samples collected for laboratory analysis. The sediment basins monitored were designed based on TDOT standards with the new information provided by Neff and Schwartz (2013) assessing its suggested design guidance. As noted above this design guidance utilizes three factors: 1) drainage area size, 2) land slope, and 3) dominant soil type. During the design process, TDEC Erosion and Sediment Control Handbook design standards was also consulted.

The field locations to measure sediment basin performance included three sites at active highway construction sites, and one built basin on University of Tennessee property for use as a controlled experiment. The three active highway sites were in Morgan, Knox, and Bedford counties in Tennessee. Performance monitoring constructed sediment basins consists of measuring the % reduction in sediment concentration and loads in the basin effluent. The RUSLE2 model was applied for the Morgan and Knox County constructed basins, to compare measured and modeled sediment yields from the catchment generating a C-factor for use in the Universal Soil Loss Equation (USLE).

Results from the different sites and data collection methods are compiled, summarized, and interpreted to achieve the project's objectives. As an outcome of this research any updates to the current design guidance and standard drawings will be recommended. Additional, as an outcome of the research a new tool for sediment basin design was developed and described in this report.

Chapter 2 Literature Review

2.1 Sediment Discharge and Runoff Pollution

Sediment is the predominant pollutant from construction activities and is also one of the most common sources of impairment under Clean Water Act Section 303(d). According to the National Water Quality Inventory Report to Congress: 2002 Reporting Cycle (USEPA 2007), sediment is the main source of impairment for streams and rivers in the United States. Clearing, grading, and other construction activities remove vegetation and compact the soil increasing both runoff and erosion. Sediment pollution from construction sites can impact receiving surface waters in alteration of the natural physical and chemical environment, and resident biological communities. The most prominent and widespread pollutant parameters measured from construction sites are turbidity and TSS, which are primarily caused by fine sediment (Pitt et al. 2007).

Stream biotic integrity can be impaired from excessive fine sediment from construction site runoff (Ehrhart et al. 2002). Ecological impacts from sediment discharges to surface waters can be acute or chronic and vary in severity depending on the quantity of sediment discharged, the nature of the receiving waterbody and aquatic community, and the length of time over which discharges take place (Schwartz et al. 2008, 2011; USEPA 2006). Sediment can depress aquatic organism growth, reproduction, and survival, leading to declines in organism abundance and changes in community species composition and distribution (Henley et al. 2000; Drennen 2003). There are numerous processes by which sediment affects aquatic communities such as modifying certain types of benthic habitats by filling crevices and burying hard substrates, making recolonization by previously existing organisms difficult unless the sediment is removed. In the water column, increased turbidity levels block light needed for photosynthesis by submerged aquatic vegetation resulting in its reduced growth or death and affecting the entire ecosystem (Newcombe and MacDonald 1991; Eaton et al. 2005). Increased turbidity also impairs the ability of visual predators (e.g., many fish species) to forage successfully. Increased TSS concentrations in the water column can also impair fish gill function, reducing the ability of fish to breathe (Newcombe 2003). Overall sediment pollution impairs a greater length of stream segments than any other pollutant.

2.2 Regulations for Erosion Prevention and Stormwater Discharge Controls

Under Tennessee's NPDES General Permit for *Discharges of Stormwater Associated with Construction Activities* (TNR100000), TDEC regulates sediment pollution from construction sites. Per TNR100000 construction activities must meet an effluent standard requiring 80 percent reduction in total suspended solids (TSS). Discharges covered by the general permit include stormwater point source discharges where soil disturbing activities of one or more acres are located, discharges from support activities associated with a construction activity, and non-stormwater discharges identified in a stormwater pollution prevention plan (SWPPP). Also, the TN NPDES general permit states "the stormwater discharge must not contain total suspended solids, turbidity, or color in such amounts or character that will result in any objectionable appearance compared to the turbidity or color of the receiving water…", and also the "discharge not cause a condition in which visible solids, bottom deposits, or turbidity impairs the usefulness of the waters of the state for any of the uses designated for that waterbody" (Section 6.3.2.C TDEC 2021). Additionally, regulations require "the stormwater discharge shall not contain pollutants in quantities that will be hazardous or otherwise detrimental to humans, livestock, wildlife, plant life, or fish and aquatic life in the receiving stream" (Section 6.3.2.D TDEC 2021). Thus, it is important to meet these regulatory narratives and standards through construction site SCMs to prevent any negative impact on water or habitat quality.

This research was initiated because on January 4, 2011, the EPA implemented more stringent numeric regulations that indicated construction sites must adhere to a strict turbidity standard of 280 NTUs or less per day for stormwater discharge. This was applicable to 20-acre sites or larger by August 1, 2011, and 10-acre sites or larger by February 2, 2014 (Walters 2011). The numeric rule set in place by the EPA was withdrawn January 3, 2012, for additional research (Schaner and Farris 2012). The current regulations by TDEC are described above. All TDOT's prevention plans include the standard design and implementation of best management practices (BMPs) as SCMs.

2.3 TDOT EPSC Engineering Design Standards and Drawings

TDOT Drainage Manual Chapter X contains EPSC design standards and drawings (TDOT 2012). Two types of EPSC are recognized in this Manuel; they are vegetative and structural measures. Vegetative EPSCs protect the soil from being eroded from rainfall while structural EPSC or SCMs are physical structures designed to receive and treat stormwater. The most used structural SCMs employed on TDOT project sites are silt fence, silt fence with wire backing, rock check dams, enhanced rock check dams, and sediment tubes (Hangul 2017). All of which reduce sediment transport by slowing stormwater runoff, creating ponding, and allow for deposition of sediment at the structure. Another SCM used by TDOT is the sediment basin which detain stormwater runoff and reduce sedimentation by gravity settling discharging treated water.

In general, sediment basins at highway construction sites are less frequently used (Hangul 2017; WERF 2017). They are typically designed and implemented at sites with drainage areas between 10 and 50 acres; however, if the receiving waters have been classified as impaired or high-quality a basin will be required at contributing areas as small as 5 acres. Sediment basins can either be temporary or permanent and provide storage for a volume of runoff from a 2 or 5-year, 24-hour storm (TDEC 2012). They traditionally contain a sediment storage area, permanent pool, forebay, principal and emergency spillway, embankment, outlet protection, and dewatering system. TDEC's recommended length to width ratio of the basin is 4:1, but requires a no less than 2:1. This ratio is generally needed to prevent hydraulic short-circuiting. Short-circuiting is when the inlet water to the pond is directed to the outlet with minimal settling time, causing sediment laden water to flow from the basin outlet (Glenn and Bartell 2008). Basins are typically designed such that clean water over undisturbed soil is routed around the basin and only sediment laden water is transported into the basin cutting down on the constructed basin volume. Maintenance can be a factor for sediment basins where over time with enough deposited sediment a skimmer can become clogged, and the basin's performance is reduced (McCaleb and McLaughlin 2008). Also, the overfilling of a basin due to inconsistent maintenance during site stabilization, especially for smaller basins, can also lead to failure (Zech 2012). According to Hangul (2017), the seemingly high maintenance aspect of sediment basins is often a deterrent for use on TDOT highway projects. Regardless of these limitations, sediment basins can be a useful tool when the true contributing drainage area is large enough to warrant the design. A large, exposed area routing into a well-designed sediment basin provides flexibility to contractors who can work freely in the disturbed area (Hangul 2017).

In 2011, TDOT recognized the utility of sediment basins for certain highway sites and the need to update their sediment basin design. During Phase I of research on developing improved design guidelines for sediment basins the HydroCAD and SEDCAD models were used (Neff and Schwartz 2013). The key input model parameters were: 1) drainage area size from 1 to 50 acres, 2) land slope (2-12%), and 3) soil types (i.e., silt-loam, clay-loan-silt, etc.). Design tables were created utilizing these three site conditions, and regionalized among east, middle, and west Tennessee regions accounting for differences in precipitation patterns. This work was based on uncalibrated hydrological and sediment transport/sediment settling pond models. Phase I results produced valuable design guidance but field data on active highway construction sites were needed to verify its utility.

It is critical to assess construction site sediment basins independently of commercial or residential detention basins due to the variability of inputs and design between each practice. The Highway Research Center in Auburn, Alabama published a report detailing sediment basin design and use over 37 of the 50 US state departments of transportation (DOTs) (Zech et al. 2012). Out of 37 responding DOTs, 33 had experience with using sediment basins and 24 of those had standard designs. When designing, 19 of the 33 DOTs used 2:1 as their minimum length to width ratio and 20 did not specify a maximum ratio. The length to width ratio is important to prevent short circuiting of the basin, which could cause preferential flow and not allow enough time for the sediment to settle. Regarding allowable slopes for the inflow channel, 61% of the DOTs did not have a minimum slope and 67% did not have a maximum slope. Including TDOT, 13 DOTs used flocculent additives to percolate out fine sediment particles. According to the survey, 16 DOTs used baffles inside of the basin including TDOT. Baffles were most made of silt fence material or coir fiber netting. The DOTs were surveyed on what dewatering devices they used: 70% used perforated riser pipes, 58% spillway only, 33% floating skimmer, 30% solid riser pipe, 12% flashboard riser pipe, and 15% other. The data indicated that only 13 DOTs used the floating skimmer outlet. Sediment basin design criteria among different DOTs are summarized in Table 2-1.

2.4 Performance of Construction Site Sediment Basins

In general, research literature is limited on quantifying sediment basin performance although the sediment basin has been reported with the highest removal efficiencies of any other large-scale SCMs (McCaleb and McLaughlin 2008). McCaleb and McLaughlin (2008) assessed five sediment basin devices on construction sites over a 5 to 13 months period. Three of the basins had rock outlets and were designed for a 10-year storm with an alteration to the basic basin design that.

Table 2-1. Comparison of sediment basin design criteria among the State Agencies

Design Standard	State Departments					
	TDEC	**TDOT**	**SC DHEC**	**NC DEQ**	**PDOT**	**GSWCC**
Acre Range	5-50	5-50	5-30	5-100	5-100	<150
Minimum L:W	4:1	2:1 (4:1)	2:1	2:1	2:1	2:1
Minimum H:V	2:1	2:1	2:1	2.5:1	2:1	2.5:1
Dewater Time (hours)	Max, 72 Min, none	Max, 168 Min, 72	Max, 120 Min, 48	Max, 120 Min, 48	Max, 168 Min, 48	Max, 72 Min, None
Forebay Requirement	Yes, 25% of wet storage	No	Yes, 20% of sediment storage	No	No	No
Principle Spillway Design Storm	2 or 5-year, 24-hour	2 or 5-year, 24-hour	10-year, 24-hour	2-year, 24-hour	Varies	2-year, 24-hour
Emergency Spillway Design Storm	25-year, 24-hour	25-year, 24-hour	100-year, 24-hour	10-year, 24-hour	2 cfs/acre	25-year, 24-hour

made each unique: 1) over excavated to have three feet of standing water, 2) silt fence baffles with weirs, and 3) open and fully drained. The fourth basin was like the third but designed for a 25-year storm. The fifth was designed for a 25-year storm, with a floating surface outlet, solid riser spillways, and porous baffles in the basin. The only device of the five of these that would be comparable to TDOT's basin design standards rather than a sediment trap was the fifth design with the skimmer outlet. Overall, McCaleb and McLaughlin (2008) found that the sediment basin achieved the highest retention efficiency at 99.6 % while the second closest was the standard trap with silt fence at 45 % retention. The result of this study showed that the three 10-year storm sediment trap designs with rock dam outlets retained only < 45% of the sediment that entered the sediment trap. In addition, the sediment basin with a skimmer, 2H:1V side slopes, and porous baffles retained up to 99% of the sediment that entered the basin. It is also important to recognize the fact that over time the skimmer became bogged down with sediment and the efficiency was reduced significantly, indicating the importance of maintenance. Taylor et al. (2001) in the study by Caltrans for Los Angeles and San Diego, California monitoring retrofitted extended detention facilities on existing highway sites and designed per Pitt (2003) guidelines found an average suspended solids reduction of 73%. The study was also estimated that removal of settled sediment would need to occur every 10 years. Perez et al. (2015) produced an extensive research report detailing studies conducted on sediment basin design and general performance data (Table 2-2).

Table 2-2. A review of sediment basin design and general performance findings (Perez et al. 2015).

Study	Tested Parameters	Flow / Sediment Introduction	Data Collection Summary	Major Findings
Bhardwaj and McLaughlin 2008	physical and chemical treatments to control turbidity (i.e. baffles, active and passive PAM treatment), sediment basin (777 ft^3)	0.14 ft^3/s for 130 min, 1,543 lb. of sediment (settlement prior to introducing to test basin) 150 to 400 NTU	6 samplers @ 5 min. for NTU / TSS, bubbler mod. for spillway	active & passive PAM treatment reduced turbidity by 88%, active PAM treatment more effective at reducing TSS
Bhardwaj et al. 2008	sediment basin (777 ft^3): coir baffles, bottom inlet level spreader, PAM dosing	0.14 ft^3/s for 130 min, 1,543 lb. of sediment (settlement prior to introducing to test basin)	7 samplers @ 5 min. for NTU / TSS, bubbler mod. for spillway, clay mineralogy (x-ray diff. analysis), particle size dist. (hydrometer), baffle capture weights	reduced TSS by 45% to 65%
Bidelspach et al. 2004	sediment retention efficiency of delayed dewatering times on controlled sediment basin (5,000 ft^3)	3,531 ft^3 inflow hydrograph, 1000 lbs. of sediment	automated sampler at dewatering	sediment retention efficiencies for delayed dewatering of 0, 12, and 168 hrs resulted in 92, 94, and 98% capture effectiveness resp., infiltration contributed to dewatering
Engle and Jarrett 1995	sediment retention efficiency of filtered perforate riser outlets, lab scale basin (46.6 ft^3)	121 lbs of sediment	dewatering rates, sediment concentrations, sediment discharge rates, sediment retention efficiencies	no filter = 60-71% sediment retention, expanded polystyrene chips + 2-B gravel filter = 23-25% more effective
Griffin et al. 1985	dead storage characteristics of laboratory model using dye tracer tests	N/A	N/A	length to width ratios of 2:1 recommended for sediment basin design
Line and White 2001	trapping efficiency of sediment traps on construction sites in NC	natural storm events	water quality (total phosphorus, TSS, turbidity), sediment vol. via surveying, sediment analysis (hydrometer)	trapping efficiency ranged between 59 to 69%.
Logan 2012	trapping efficiency of sediment basin on construction site monitoring, 9.21 acre drainage basin @ 1,800 ft^3/acre	natural storm events	5 samplers, bubbler mod. for inflow, area velocity mod. for outflow, retained sediment analysis, baffle capture weights	correct selection of PAM critical to effective performance, resuspension evident after multiple events, basin volume should be increased to 3,600 ft^3/ac
McLaughlin et al. 2009	comparison of various design parameters (forebays, baffles, ditch stabilization, PAM, skimmers) on construction site sediment basins (~530 ft^3)	natural storm events	15 min. interval sampling for turbidity / TSS	water quality improvements by simple modifications, traps and skimmer did not contribute to improvement
Przepiora et al. 1997	compared efficiency of several calcium sulfate sources in reducing NTU of water samples collected from construction site sediment basins in NC	laboratory, bench-scale experiments	turbidity, pH, conductivity, and dissolved Ca	calcium sulfate applied at the rate of 350 to 700 mg/L reduced fine-grained suspended sediment in basins within 3 hours
Przepiora et al. 1998	evaluated the efficiency of calcium sulfate as a chemical flocculent in three construction site basins(1,590 to 5,830 ft^3) equipped with skimmer	natural storm events	100 mL grab samples from outlet	surface application of molding plaster significantly reduced both turbidity and the cumulative amount of suspended solids discharged
Thaxton and McLaughlin 2005	sediment basin (812 ft^3): vel. reduction by baffle types	0.50, 1.00, 1.50 ft^3/s	velocity at 50 points, bubbler mod. for flow rates	jute/coir and tree baffles most effectively diffuse inflow momentum

Fang et al. (2015) looked exclusively at one sediment basin design on a highway construction site that included a skimmer as the dewatering device, three baffles in the basin, PAM flocculant blocks, and ditch checks in the inflow channel. The results of this study showed that in the earlier stages of construction the basin removed 97.9 % and 83.7% of sediment generated on specific dates in November and December. It was noted that the influent likely contained higher percentages of large-sized sediment. It was also recognized that during high intensity storms the settled solids would become agitated again and cause a high level of turbidity in the basin, unrelated to what was coming in the inlet. In addition to collecting performance data, this report was useful for its summarized lessons learned. It was recommended from their research that the baffle height match or exceed full depth of the basin, as well as not be installed below minimum elevation of the emergency spillway. These recommendations would help keep the stormwater from overtopping the baffles and causing full mixing, negating the usefulness of the basin (Fang et al. 2015). It was also recommended to communicate efficiently with the contractors constructing the basin such that all aspects of it are installed correctly.

Studies have compared the outlet effectiveness between a surface skimmer and a perforated riser in a sediment basin. Faircloth skimmers have a higher retention efficiency compared to a perforated riser when subjected to the same conditions. Millen et al. (1997) showed a skimmer having a retention efficiency of 96.8% while the perforated riser was 94.2%. The sediment used for their experiment was a silt loam. The skimmer reduced sediment values from 454 kg to 14.3 kg (96.8% retention) when passing through the basin for a 2-year return period storm simulation. The basin also retained 100% of the soil larger than 75 μm and 86 to 87% of the 6 to 12 μm. A similar trend was seen in another study, showing a skimmer with a higher retention efficiency than a perforated riser, 94.2 % and 91.7 % (Rauhofer et al. 2001). Furthermore, **perforated risers are shown to have higher suspended sediment concentrations in the effluent of the basin when compared to a surface skimmer** reported in Millen et al. (1997). This is probably due that perforated risers do not strictly dewater the basin from the water surface like a skimmer would. Increasing the delay time between the inflow and outflow of the basin led to an increase in retention efficiency; no delay had 96.8%, 12 hours had 97.9% (Bidelspach et al. 2004). **Increasing the delay time allows for more sediment to settle into the permanent pool** and for some water to infiltrate into the ground.

Fennessey and Jarrett (1994) detailed the construction of a permanent sediment basin at Pennsylvania State University. The basin was built to account for the variability of sediment inputs from urban developed land and construction sites. The intention of this basin was to be able to control multiple factors: inflow, inflow sediment concentrations, particle size distribution (PSD), detention times, and resuspension of sediment in the basin. The basin was sized to Pennsylvania standards for a 1-acre drainage area, 2-year 24-hour rainfall event. This resulted in a modified rectangular basin volume of 6,250 ft^3 (231.5 cubic yards) with a plastic liner and changeable dewatering structure. The controllability of this sediment basin led to many other studies utilizing the structure to analyze variability between design aspects. Apart from outlet device and risers, spillway design and permanent pool depth have the potential to affect sediment retention in sediment basins.

Fennessey and Jarrett (1997) research examined 1) if the perforated riser principal spillway improved retention compared to a single-orifice, 2) whether an increase of 0.15 m to 0.46 m in the permanent pool depth would increase sediment retention, and 3) determine what portion of the basin's discharge was due to both resuspension in the basin and the physical degradation of the inner sides and bottom of the basin. Results indicated that the difference in performance was nearly none between the perforated riser and single orifice. There was a difference in retention from the permanent pool depth, with a depth of 0.46 m, the basin had 97.0% removal, where there was 94.7% removal at 0.15 m. The research also showed that 11.0 kg of the 23.1 kg total discharged soil was from the influent, the remaining 22.1 kg was from 3.0 kg resuspended from previous events, and the remaining from scouring off the sides and bottom of the basin. In another study conducted by Madaras and Jarrett (2000), the full-sized construction basin from Fennessey and Jarrett's (1994) research was utilized to assess spatial and temporal distribution of sediment concentration and PSD in sediment basins. The results suggested that lined basins result in a 36% lower sediment concentration in the influent compared to unlined. This study also noted that the most likely sediment to resuspend was smaller particles due to their tendency to settle last in addition to their size and mass. The results noted that there also tended to be an average trend of smaller particles in the unlined system.

One aspect about designing sediment basins that has even less literature on performance is basins with a forebay. No study has directly compared the performance of sediment basins with and without forebays nor quantified the PSD of sediment deposited. It is known that forebays capture a large about incoming sediment and could provide an ease of sediment cleanout; a large-scale study of one sediment basin showed that the whole basin captured 76 % of sediment with the forebay contributing 61.5% to that capture percentage (Fang et al. 2015). However, this study did not compare the sediment capture efficiency to another basin with same geometry and parameters without a forebay. Without this comparison it is difficult to determine the true performance a forebay has when added to the inlet of a sediment basin.

2.5 Construction Site Constraints for Sediment Basins

TDOT and other state transportation agencies have many challenges designing highway construction site BMPs for sites that are typically linear in area. Linear corridors limit the right-of-way (ROW) and purchasing additional land for larger BMP implementation may be cost prohibitive, corridors also affect design in terms of hydrologic and runoff patterns (Iyer 2007; Smith 2018). The typical method of designing sediment basins suggest the catchment area and runoff volume be computed from the total contributing area, however highway construction corridors may often consist of a series of linear drainage networks with multiple outfall locations (LIDC 2006). Designing for total disturbed drainage area may result in oversized sediment basins. The topography influences off-site drainage where runoff may not originate from the active construction site itself, and this excess water and potential sediment must be incorporated into the basin design (Iyer 2007). **Designing to minimize the cost of the stormwater system and still meet the pollutant discharge criteria is essential.**

2.6 RUSLE Model for Site Erosion and Sediment Yields

The RUSLE2 model is based on the empirical relationship developed in the Universal Soil Loss Equation (USLE). RUSLE2 can be downloaded from the USDA National Sedimentation Laboratory web site (ARS 2016). RUSLE2 uses conservation of mass to estimate long-term sediment loss on slopes due to rill and inter-rill erosion caused by rainfall and its overland flow. This is representative of rill and inter-rill erosion caused by rainfall and its overland flow. This is representative of hillslope erosion but does not include channelized flow. The calculation concept is represented in Figure 2-1, showing visually how RUSLE2 computes sediment yields (A). The USLE is: A = R·K·LS·C·P, where A is average annual soil loss, imperially in tons per acre; R is the rainfall erosivity factor, K is the soil erodibility factor, LS is the topographic factor, utilizing L for length and S for slope, C is surface-cover factor and P is management factor (Hillel 1998; Foster et al. 2003). RUSLE2 advanced with the use of subfactors for the C-factor.

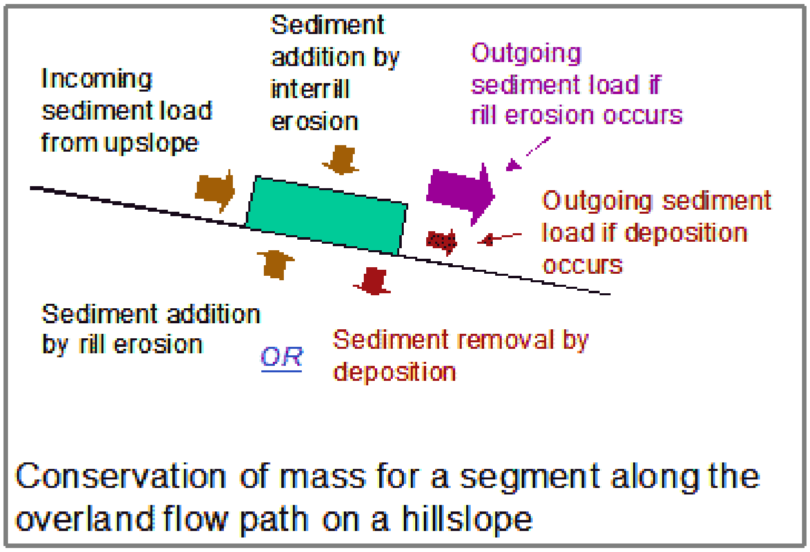


Figure 2-1. RUSLE2 diagram on mass conservation to estimate sediment yields including rill and inter-rill erosion (ARS 2016).

2.7 Sediment Basin Design Models

Only a few design tools are available for detention and/or sediment basins that includes hydrology and USLE relations: they include, Haestad Pond Pack® (CULTEC, Inc. 2012) and SEDCAD (Hoomehr and Schwartz 2013; CSD 2023). SEDspread an Excel spreadsheet program designs a sediment basin using a design storm event (Auburn Univ. 2021). Overall, data and studies model performance of sediment basins are limited.

Chapter 3 Methodology

3.1 Data Collection on Active Highway Construction Sites

3.1.1 Study Areas

Study objectives were to select various sites with differing drainage areas, land slopes, and soil types following the key design factors developed in Phase I of this research project. Two sites selected were in TDOT Region 1 within Morgan and Knox counties. A third site was selected in Region 3 in Bedford County. Locations of the three study sites are shown in Figure 3-1.

Morgan County Site: The sediment basin in Morgan County basin was constructed for a roadway expansion project on US Highway 27 north of Harriman, Tennessee (Lat. 36º 01' 50" N / Long. 84º 31' 11" W). The sediment basin captured a drainage area of approximately 0.6 acres with a slope of approximately 10% (Figure 3-2). It consisted of two different soils, which were a loam/gravelly clay loam and a silt loam/clay loam. Effluent from the sediment basin at this site fed downstream into a series of rock check dams that transported water from the basin and the road down to Bitter Creek (Figure 3-3). Six rainfall events were captured at this site (labeled event 6, 8, 9, 10, 14, and 15).

Knox County Site: The sediment basin in Knox County basin was constructed for a highway on-ramp design project in Knoxville, Tennessee, located at the intersection of North Broadway Street and I-640 (Lat. 36º 01' 10" N / Long. 83º 54' 35" W). This sediment basin captured a drainage area of approximately 1.75 acres on a catchment slope that varied but the main drainageway was approximately 3% to 5% (Figure 3-4). Apart from being classified as urban land, the soil was predominantly gravely silt loam, formed from a loamy residuum weathered from interbedded sedimentary rock. The basin effluent drained through a previously constructed rock check dam that surrounded a culvert (Figure 3-4). The culvert led from the construction area to Whites Creek and First Creek, which converged less than half a mile away from the site. Five rainfall events were captured at this site (labeled event 1, 2, 3, 5, and 6).

Bedford County Site: The sediment basin in Bedford County constructed for a roadway expansion project on US Highway 41A (SR16) between the cities of Tullahoma and Shelbyville (Lat. 35º 25' 35" N / Long. 86º 15' 15" W). This sediment basin captured a drainage area of approximately 7.2 acres on a catchment slope that varied but the main drainageway was approximately 15-20% (Figure 3-5). The soil types were predominantly silty clay loam and silty clay with some rock outcrops at the higher elevation areas. Nine rainfall events were captured at this site.

3.1.2 Sediment Basin Designs

Design criteria for sizing the basins was based on guidance in Neff and Schwartz (2013). Basin sizes were determined using a modeled minimum settling time associated with 100% silt removal. Sizes were determined to be for a minimum area of 5 acres for both Morgan County and Knox County sites, and 10 acres for the Bedford County site. Basin sizes were linearly interpolated because the modeled guidance was in 5 acres intervals to 20 acres. Outlet skimmer device sizing, length to width ratio, and other necessary features were designed based on current standards in the

TDOT Chapter 10 Drainage Manual. (TDOT 2012). The manual recommends sediment basins to have a 4:1 length to width ratio and 2H:1V side slopes. Standard sediment basin design drawings are shown in Appendix A. The outlet dewatering structure was recommended to have a minimum pond dewatering time of 72 hours, which influenced the size of the orifice on the structure. Standard skimmer sizing suggestions from J.W. Faircloth & Son Inc. were used. All design values reflected the various drainage areas, catchment slopes, soil types, and precipitation differences among the three study sites.

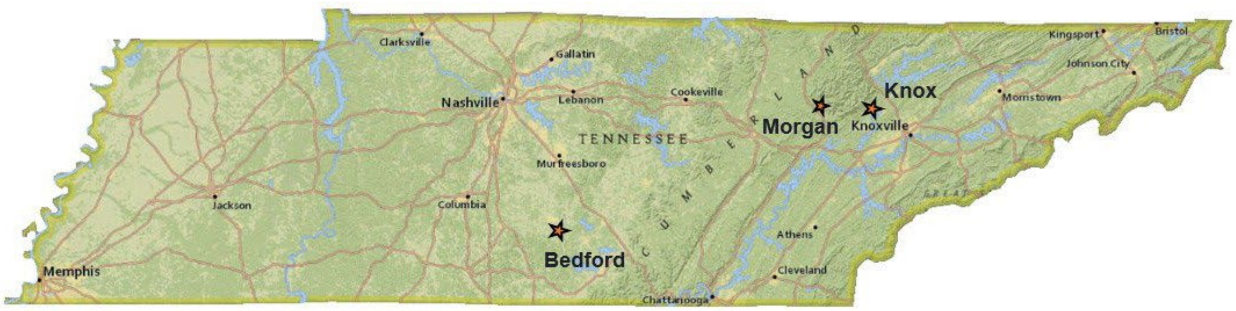


Figure 3-1. Location map of Morgan, Knox and Bedford counties study sites within Tennessee.

Figure 3-2. Photos of sediment basin and inlet flume at the Morgan County site.

Figure 3-3. Photos of sediment basin and outlet weir at the Knox County site.

Figure 3-4. Photos of sediment basin and inlet flume at the Bedford County site.

The sediment basin for Morgan County was constructed with a length to width ratio of 1:2 rather than 2:1 due to corridor restrictions, and standard side slopes at 2H:1V (Table 3-1). The sediment basin for Knox County was designed with a length to width ratio of approximately 1:1.7 through it was constructed to a length to width ratio of 1:2. The sediment basin for the Bedford County site was designed and constructed with a length to width ratio of approximately 3.5:1. Table 3-1 provides a summary of the design and constructed dimensions.

Table 3-1. Summary of sediment basin dimensions and drainage areas among the study sites.

Basin Quality / Dimensions (units)	Site		
	Morgan County	Knox County	Bedford County
Drainage Area (acres)	0.6	1.75	2.75
Basin Length (ft)	26	27	223
Basin Width (ft)	32	46	64
Basin Top Length (ft)	30	41	230
Basin Top Width (ft)	44	66	78
Basin Top Elevation (ft)	6	3	4.5

3.1.3 Precipitation and Water-Sediment Monitoring Equipment

Weather Station: A fully equipped weather station was installed at all study sites. Each station included a Davis® 0.01” Rain Gauge Smart Sensor, 12-bit Temperature/Relative Humidity Smart Sensor, Solar Radiation Shield Wind Speed Smart Sensor, and a 6W Solar Panel (Figure 3-5). The Morgan County site was equipped with the HOBO RX3000 Remote Monitoring Station Data Logger and used a cellular plan to remotely check weather station data and sensors. The Knox and Bedford County sites were equipped with a HOBO U30 USB Weather Station Data Logger that data could be manually retrieved from using a USB cable and the program HOBOLink Pro.

The weather equipment took readings every 5 minutes to ensure enough data was taken to be representative of changing weather conditions in the area. The manual rain gauge was used as a backup to check the tipping bucket rain gauge values. The tipping bucket rain gauge readings were used to define event periods and the beginning and end of flow events through the flume. Precipitation values were also used in the sediment yield modeling calculations of RUSLE2 to find each event's 30-minute intensity and thus contributed to the rainfall erosivity factor. Temperature, relative humidity, and wind speed were not used in this study, yet could be used in future studies.

Figure 3-5. Full weather station set-up at Knox County study site.

Sediment Basin Inlet Flume: Sediment basins were equipped at the inlet with a 1.0-ft. Tracom© H-flume at the Morgan County site and a 1.5-ft H flume at the Knox and Bedford counties study sites, stage recording device, ISCO® 3700 Portable Sampler, and ISCO® 4230 Flow Meter. The H-flume was outfitted with a 6-inch diameter stilling well for placement of a HOBO U20L Series water level (stage) logger. This device recorded water pressure and temperature once every minute in the stilling well through a 1-inch hole at the flume base. There was an identical device open to atmosphere to account for barometric pressure changes and was used to calculate the flume water levels. The H-flume was also equipped with treated plywood wing walls and a level 2-foot-long concrete entry pad. The concrete pad was positioned directly past the exposed soil slopping down from the catchment area. The ISCO® 3700 Portable Sampler tubing was secured facing upstream on a slopes half-pipe directly after the free flow coming from the H-flume. This system was triggered by an ISCO 4230 Flow Meter, whose tubing was fixed in the stilling well with the HOBO U20L Series water level logger. Photos of the inlet flumes for Morgan and Bedford counties study sites are shown in Figures 3.2 and 3.4.

Sediment Basin Outlet Flow Divider Bucket System: The outlet monitoring equipment for the Morgan County site was equipped with a flow divider bucket system as described by Pinson et al. (2004). The system was composed of 5-gallon buckets with flow dividers that contained a stainless-steel crown with various numbers of 22.5° V-notch weirs machined into it (Figure 3-6). The crown was water sealed to allow flow exclusively through the V-notch attached to a 5-gallon bucket. The bucket directly under the 90-degree 6-inch PVC outlet was chosen to handle higher flow rates with 12 V-notches around the rim to split flows evenly. This bucket handled up to 1.05 cfs, had a flow rate of 0.088 cfs per slot, and a 6-inch slot height. The following two buckets were designed to split flows at an optimal higher number of splits and contained twenty-four V-notches each around the rim. These buckets handled up to 0.24 cfs of flow, had a flow rate of 0.01 cfs out of each slot, and a 2.5-inch height for each slot. The last bucket did not have a crown. The system worked such that once one bucket was filled, water and sediment would be divided evenly among the V-notches and the flow from one such notch would be directed to the next bucket. These buckets were secured to a metal triangular leveling device and checked after each event.

Figure 3-6. Sediment basin outlet flow divider bucket system used at the Morgan County site.

Sediment Basin Outlet Weir Box: The outlet measurement device for the Knox and Bedford counties study sites were a 90-degree V-notch weir (Figure 3-7). This was sized for maximum outflow through a 6-inch pipe to accommodate the effluent steady-flow skimmer device. The weir box was 45 inches wide, 34 inches deep, and 18 inches tall. It included a baffle located halfway along its depth that had 4 inches of free space below it for water to pass through. The metal V-weir was 15 inches tall, 30 inches wide at its top, and had 3 inches of space below its tip. The water level was recorded in the weir box using a third HOBO U20L Series water level logger. Samples were taken using a second ISCO® 3700 automatic portable sampler with the tubing inserted at the bottom of the 6-inch outlet pipe. The sampler was triggered by an ISCO 4230 Flow Meter whose tubing was in the bottom of the weir box secured to the water level logger housing. Automatic samples were taken on 10-minute intervals and composed.

Figure 3-7. Sediment basin outlet 90-degree V-notch weir and box structure used at the Knox and Bedford counties study sites.

3.1.4 Flow Analysis at Sediment Basin Inlet and Outlet Measurement Devices

Inlet H-flume: Quantifying continuous water flow at each sediment basin's inlet utilized HOBO U20L Series water level (stage) logger recording stage every 1 minute. A stage-discharge relationship was utilized to build a hydrograph for each storm period utilized standard equations for H-flumes. The discharge (Q) for the 1.0-ft H flume in units of m^3/s is as follow:

$$llllll = 0.0206 + 2.5902llllll + 0.2281(llllll)^2$$

The discharge (Q) for the 1.5-ft H flume in units of m^3/s is as follow:

$$llllll = 0.0238 + 2.5473llllll + 0.2540(llllll)^2$$

The resulting metric discharge values were converted to cfs English units.

Flow Divider Bucket System: Flow dividers consisted of a stainless-steel circular crown containing weirs constructed with 22.5° V-notches, with the crown screwing onto the bucket (Figure 3-6). The first flow divider had 12 notches, while the second and third dividers had 24 notches. Once the bucket filled, overflow was evenly divided among the notches, with flow from one notch directed to the next bucket in the system. Calculating the total outlet volume required multiplying each full bucket by twelve or twenty-four, depending on how many notches that bucket had on its ring. Summing those values together plus an additional 5 gallons of water for the first fill, produced the maximum monitoring system volume. If the event did not completely fill up all four buckets, the measured non-full bucket(s) volume(s) were incorporated into the measurement and subtracted out (with its V-weir multiplier considered). Evaporation was neglected. Furthermore, buckets that had clean rainwater exclusively were not included in the calculation and rainwater depth was taken out of the volume measurement for each full bucket.

Sediment Basin Outlet Weir Box: Outlet volumes were determined using standard calculations for a 90° V-notch weir utilizing the monitored depth converted to flow estimates (Q). The following formula was utilized:

$$Q = \frac{8}{15} C_{de} \sqrt{2g} \tan\frac{\theta}{2} ll^{\frac{5}{2}}$$

The flow Q represents is in m^3/s, g represents gravity in m/s^2, and the variable θ represents the angle of the V-notch, which in this case is 90-degrees. The coefficient of discharge C_{de} is a value used in the Kindsvater-Carter formula for the V-notch discharge equation and obtained from standard tables/figures (Sturm 2010). H_e represents effective head in meters, which is the measured water depth (H) over the weir plus k_h the head correction value both in meters and obtained from standard tables in Sturm (2010).

Sediment Load Analysis

During a runoff event, inlet and outlet water-sediment samples were collected to determine suspended sediment concentrations (SSC) for each and multiplied by their respective influent and effluent volumes to obtain sediment loads per event (mass/time). All samples taken at the inlet for one event were combined to result in one inlet concentration measurement. The same was accomplished for each event's outlet samples. Samples were air dried using forced air drying over a period of 3 to 5 days. Once dry, the resulting sediment was weighed to quantify concentrations in g/L. These values were then assumed to be the average concentration for the duration of the storm. Total mass at the inlet was calculated by using the concentration and the flume stage discharge relationship outlined previously. Total mass at the outlet in Morgan County was found by pairing the flow divider bucket volume calculation and the concentration. Total mass at the outlet in Knox and Bedford counties study sites were calculated using the 90-degree V-notch weir discharge relationship and the calculated average concentration.

3.1.5 Sediment Deposition at Basin Approach Areas

The sediment deposited in the inlet flume on the concrete approach pad was sampled and mass quantified in order to estimate the total sediment load from the catchment drainage area. These sediment load estimates were not used when determining the performance of the basin. After each sampling event, the average depth of sediment accumulation in the flume and concrete entryway was recorded. A consolidated and thoroughly mixed sample was then taken in a 1-gallon bag for PSD analysis. The remaining deposited soil volume was estimated, and then cleaned from the flume concrete pad. The collected sample was taken back to the laboratory and dried to obtain a mass, which was then divided by the volume to obtain a concentration. The concentration was then multiplied by the estimated volume taken from the approach area and depth of sediment from the sampling period. This resulted in an estimated mass in kilograms of soil deposited in the approach area.

3.1.6 Sediment Particle Size Distribution Analysis

A PSD analyses on sediment samples were conducted by sieve analysis and laser diffraction. Sample analyses included suspended sediment from inlet and outlet water samples, as well as flume soil deposits, sediment basin soil deposits, and three samples taken from the runoff area upslope of the basin.

Sieve Analysis: Soil samples were air dried. Post drying, the samples were crushed using a mortar and rubber pestle, enough to break up caking, yet not enough to diminish the integrity of the larger particles in the sample. Next, the samples were dry sieved through a 2.0-mm (No. 10) sieve. This resulted in a sample that no longer contained larger than sand particles. After larger particles were sieved out, each sample was wet sieved through a 0.074-mm (No. 200) sieve. These samples were dried and weighed again to show the amount of sand versus silt and clay still left in the samples (ASTM 2017).

Laser Diffraction: Each sample, once sieved for sand and larger particles, was then prepared for use in a laser diffraction particle size analyzer. Preparing each exclusively silt and clay sample began by using a two-splitter riffle divider multiple times to pair the sample down to 2 grams of soil. This reduced sample was then resuspended in 15 milliliter tubes using 4 grams of a standard 40 g/L sodium-hexametaphosphate solution and left for a minimum of 24 hours to allow disaggregation of clay particles.

Once all previous steps had been completed, the Beckman Coulter LS 13 320 Laser Diffraction Particle Size Analyzer was utilized. The sample handling option utilized was the Universal Liquid Module (ULM). Each sample was mixed in the test tubes by constantly pipetting the liquid/sediment mixture using disposable plastic pipettes. The sample was then deposited into the ULM, which in addition to containing the sample, was constantly sonicating. To begin, a test sample was run three times to compare grab accuracy. Once it was ensured that the accuracy of a grab could be replicated, each sample was run one time. This resulted in very detailed information on the percentages of clay and silt in the samples.

3.2 Data Collection from on Pilot-scale Sediment Basins

The goal of this study was to build a scaled down physical model of a sediment basin to run controlled experiments with each basin modified to reflect the three different designs. Three different designs were chosen to test the sediment removal efficiencies as well as monitor the effluent being discharged. The three basin designs were: 1) a TDOT standard, 2) TDEC standard, and 3) a modified TDOT where a check dam is at the inlet of the basin. The designs were based on TDOT's Chapter 10 in the Erosion Prevention and Sediment Control Drainage Manual and TDEC's Erosion and Sediment Control Handbook (4th Edition). Both specify certain requirements for the design of a sediment basin as shown in Table 2-1.

3.2.1 Pilot Sediment Basin Design

For all three designs the main basin remained the same while only the inlet changed between the designs, essentially the TDOT design without an inlet check dam. The main basin design is summarized in Table 3-2 and design drawings in are shown in Appendix B. Experimental set-up photos for the pilot sediment basin are shown in Figure 3-8. The scaled-down physical model of the basin was not excavated, rather its frame was made using metal T-posts driven into the ground to achieve side slopes of 2:1 and then supported by a wooden support made of 2x4s. The frame was first lined with silt fence to evenly distribute the weight along the frame and then lined with 45 mil EPDM rubber roofing material to ensure the basin was watertight. For the TDEC design requiring a forebay, the existing ground before the basin was elevated roughly 1 foot and a plywood box with a length of 6.25 ft, width of 5.5 ft, and height of 1.5 ft was built.

Table 3-2. Key design criteria for pilot-scale sediment basin.

Design Parameter	Value
Bottom Length	23 ft
Bottom Width	1.5 ft
Top Length	28 ft
Top Width	9.5 ft
Side Slopes H:V	2.1:1
Total Height	2 ft
Permanent Pool Height	0.9 ft

Figure 3-8. Experimental set-up photos for the pilot sediment basin.

The forebay was also lined with the same rubber roofing material as in the main basin, Class A-1 rip-rap (D_{50} = 9 inches) was added where the main basin and forebay meet, and two porous baffles made of an erosion control blanket were put into the forebay as required by TDEC standards. Finally, to make the check dam, the forebay from the TDEC design was altered. The porous baffles were removed and the was cross section of the forebay was changed from rectangular to trapezoidal to comply with TDOT's design standard for a rock check dam (ET-STR-6). Since the TDOT design did not require a forebay/check dam, the section where the main basin and forebay/check dam meet was temporarily blocked off so only the main basin was being filled.

3.2.2 Pilot Basin Inlet Mixing Chamber

Since a known amount of water and soil was put into the basin during each experiment, a flume was used as a mixing chamber to allow the sediment to be evenly dispersed during the duration of pumping water into the basin. Afterwards, the sediment laden water was funneled to a 6-inch PVC pipe that discharged into the main basin for the TDOT standard design or the forebay/check dam for the TDEC and modified TDOT design (Appendix Figure B.2). During the TDOT pumping, a temporary pipe was used to bypass the forebay. For the two types of sediment used in the mixing chamber the soil composition was 33 and 42 % clay, 59 and 50 % silt, and 8 % sand. Using a soil texture triangle, the two sediments were classified as a silty clay and silty clay loam.

3.2.3 Pilot Basin Outlet Riser for Dewatering

A 72-hour dewatering time was chosen since TDOT required a minimum dewatering time of 72-hours and TDEC requires a maximum of 72-hours. The "dry storage" is the total volume of water that is to be dewatered down to the permanent pool elevation. Two commonly used types of dewatering devices are the Faircloth Skimmer or a perforated riser. For these experiments, a perforated riser was used as the main form of dewatering as the Faircloth Skimmer® would be harder to size for such a small basin. The final design for the perforated riser came out to be three 3/16-inch orifices spaced 6 inches apart in the vertical with the lowest orifice at the permeant pool height.

3.2.4 Pilot Basin Water and Sediment Sample Collection

Sediment samples, water samples, and stage data were collected throughout each experiment. The sediment used for each experiment was a mixture of a silty clay and silty clay loam. Two 5-gallon buckets of each soil type (roughly 40-50 pounds) were added for each experiment. Additionally, a centrifugal trash pump (Honda, WT20X, Knoxville, TN) with a 2- inch diameter discharge outlet was used to pump water from a nearby slough of the Tennessee River to mix with the sediment fill the experimental basin. Sediment samples from any settled sediment in the forebay/check dam were taken from each TDEC and TDOT CD experiment and saved to later determine a particle size distribution (PSD). During the initial pumping of the basin (roughly 1 hour), three grab samples of the inlet sediment laden water were collected to determine the SSC. For the effluent of the basin, an ISCO® 3700 Portable Sampler (ISCO®, Lincoln, NE) collected 24 samples over the 72-hour dewatering period, roughly 1 sample per 3.1 hours) and stored for SSC analysis. Finally, two HOBO™ U20L Series Water Level logger (Onset®, Bourne, MA) stage recording devices were used and collected a pressure measurement every 30 seconds. One was placed in the bottom of the basin main basin to calculate the flow entering the basin, and the other was open to the atmosphere to account for barometric pressure.

3.2.5 Pilot Basin Inflow and Outflow Measurements

A HOBO water level logger in the basin and open to the atmosphere were used to calculate stage in the basin using the difference in pressure between the two devices and a corrected density based on the water temperature at the time of the measurement. To obtain an inflow hydrograph, the stage and known geometry of the basin was used to calculate flow in gallons per minute. Additionally, the outflow of the basin was calculated using the stage from inside the basin and the known heights of the three orifices on the perforated riser to calculate flow (Q, English units in cfs). From the stage data, the outflow of the basin was calculated using the equation for orifice flow:

$$Q = C_d A \sqrt{2gH}$$

where, C_d is the discharge coefficient (dimensionless), A is cross-sectional area of the orifice (ft^2), g is gravity 32.2 ft/s^2, and H is the static pressure head (ft). Using a coefficient of discharge of 0.6 (TDEC, 2021), the flowrate was calculated using the stage data and converted from cubic feet per second to gallons per minute and plotted against the 72 hours dewater time. It is important to note that the TDOT values for stage and outflow were largest because the total volume is smallest since it does not include a forebay or check dam, thus it needed to be filled to a higher elevation than the other designs to properly be dewatered in 72-hours.

3.2.6 Particle Size Distribution and Suspended Sediment Concentration

For all sediment samples, a PSD following the standard test method for particle size distribution of fine-grained soils using the hydrometer analysis was completed (ASTM D7928). To calculate SSC from the influent and effluent water samples, the air-drying method was utilized. Each sample was deposited into a drying dish and was air dried over a period of 3 to 5 days. The remaining sediment was weighted to quantify SSC in g/L. Also see Section 3.1.7 for PSD.

3.2.7 Basin Performance Calculations and Statistical Analysis

To quantify the performance of each basin, total percent sediment removal was calculated through the following equation:

$$\text{Total \% Sediment Removed} = [Mass_{in} - Mass_{out} / Mass_{in}$$

where, $Mass_{out}$ is the total amount of sediment lost through the perforated riser. Using flow and SSC, $Mass_{out}$ can be calculated through the following equation:

$$Mass_{out} = \sum Q_i . \cdot SSC_i$$

where, Q_i is the outflow discharge and SSC_i is the suspended sediment concentration, both specific corresponding sampling time.

Each water sample had triplicate values of SSC to calculate mean and standard deviation. An ANOVA Single Factor test for the effluent SSC concentrations between the three design standards was completed to determine any statistically significant difference. Three replicant experiments were conducted per design.

3.3 RUSLE2 Sediment Yields from Active Highway Construction Sites

RUSLE2 Version 2.6.10.4 was used to compare modeled soil loss from catchment slopes to field validated masses at the Morgan and Knox counties study sites. This modeling investigation contributed to the understanding of how using the RUSLE2 can assist in characterizing soil loss from drainage slopes on TDOT construction sites. It provides an estimate if the potential sediment storage volumes needed for sediment basin designs.

The soil type assessed from field and laboratory results was used in RUSLE2 modeling as the soil input. The percent of soil cover was estimated for each site based on visual estimation. To represent the construction sites, the management selected was highly disturbed\bare\bare cut and the operation selected was no operation. The topography, length and slope of the site was estimated from GIS assessment. The rainfall data set was taken from the six representative storms at Morgan County and the five representative storms at Knox County. The rainfall data values inputted were rainfall depth (inches), erosivity, duration (hours), and max interval intensity (in/hr.) (30-minute maximum intensity).

Chapter 4 Results and Discussion

Results and discussion follow the same outline in Chapter 3 Methodology. They are: 1) monitoring of sediment basin performance on active highway construction sites, 2) performance measurement on a pilot-scale sediment basin from a controlled experimental design, and 3) sediment yield modeling using the RUSLE2 model. Monitoring of sediment basin performance on active highway construction sites included three sites located in Morgan, Knox, and Bedford counties.

4.1 Sediment Basin Performance on Active Highway Construction Sites

4.1.1 Catchment Sediment Size Characterization

The sediment source from the catchment and its PSD effects the performance of a sediment basin (Smith 2018). Sediment from upland three upland samples were analyzed to qualitatively characterize this soil physical property. Soil type for the Morgan County study site from the USDA Web Soil Survey was defined as a silt loam. The mean PSD values for this site were as follows: gravel 7.2%, sand 16.9%, silt 67.8%, and clay 8%. Soil type for the Knox County study site was defined as a sandy loam and its mean PSD values for this site were as follows: gravel 56.2%, sand 27.5%, silt 15.2%, and clay 1.1%. The Bedford County study site was defined as silty clay loam and silty clay. These results were used to estimate the catchment sediment yields and compared with modeled yields from RUSLE (Section 4.3).

4.1.2 Sediment Basin Inlet: Approach Area Soil Deposition

A key observation from this research was the substantial amount of sediment deposition at the inlet H-flume for all three study sites. Essentially, the H-flume was acting as a check dam resulting in this sediment deposition and functions as the forebay as part of the TDEC standard basin design (TDEC 2012). Figure 4-1 shows the deposited sediment at the inlet for the Morgan and Knox counties study sites, and the Bedford County site is shown in Figure 3-4. It was important to characterize this deposited sediment since its source was from eroded area from the highway construction site. This observation was a key element to the study design for the pilot sediment basin study with results presented in Section 4.2.

Figure 4-1. Sediment deposited at basin inlet H-flume for the Morgan County site (left) and the Knox County site (right).

The depth of deposited sediment at the Morgan County site varied between 3.5 inches and 5.0 inches, with an average of 4.3 inches for six storm events. The mass deposited varied between 35.1 and 52.1 kg, with an average of 41.3 kg. The depth of deposited sediment at the Knox County site varied between 1.5 and 5.0 inches, with an average of 3.3 inches for five storm events. The mass of deposited soil varied as well between 13.7 and 52.8 kg with an average of 35.5 kg. Sediment deposited at the inlet approach area for the Bedford County study site was not measured.

The amount of deposited sediment at the basin inlet approach was corrected with the 30-minute rainfall intensity (Figure 4-2). The 30-minute rainfall intensities ranged from 0.50 to 2.20 in/hr. with an average rainfall intensity of 1.10 in/hr. and median of 0.80 in/hr. for the Morgan County site. Intensities ranged from 0.30 to 1.14 in/hr. with an average rainfall intensity of 0.48 in/hr. and a median of 0.57 in/hr. for the Knox County site. Results showed a linear trend between intensity and deposition depth; the higher intensity storm, the greater amount of soil detachment, which resulted in higher amounts of deposited soil in the approach area.

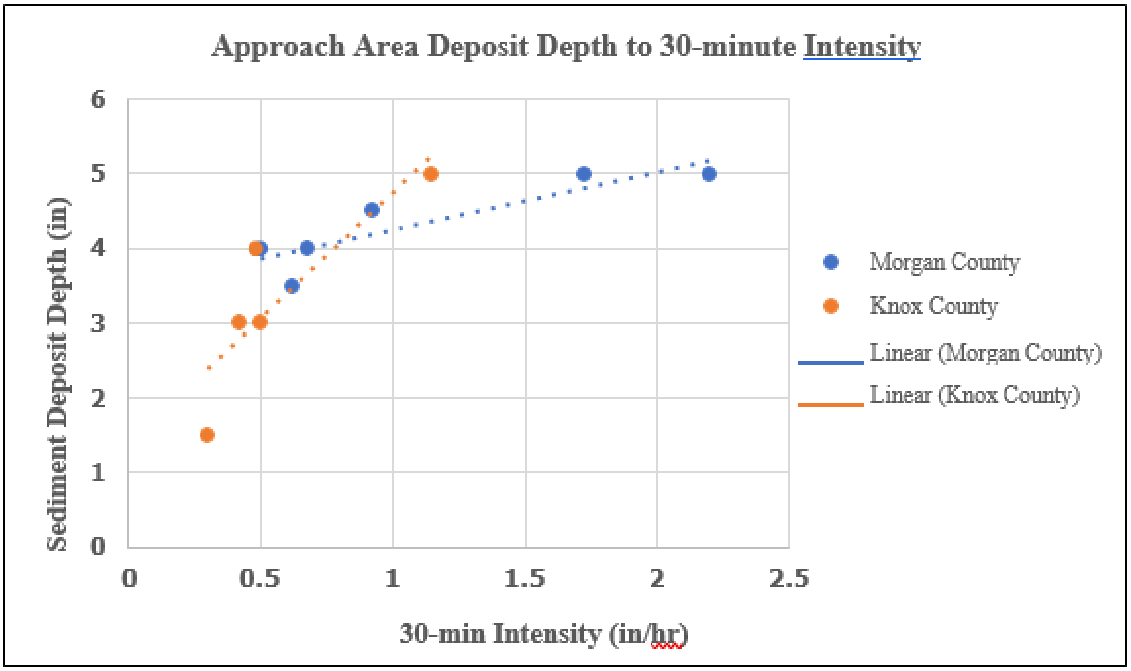


Figure 4-2. Rainfall 30-minute intensities and sediment deposited at basin inlet approach area for Morgan and Knox counties study sites.

4.1.3 Basin Inlet and Outlet Sediment Size Characterization

PSD data was analyzed assessing sediment collected at the inlet plus approach area, within basin deposition, and outlet discharge based on average individual particle size mass values. Inlet and approach sediment average values were combined to better quantify sediment loss from the catchment area being routed to the basin. For the Morgan County site, the percent reduction of various particle sizes was analyzed; there was a 100% reduction in gravel, 99.2% reduction in sand, 72.4% reduction in silt, and 72.7% reduction in clay (Table 4-1). For observation it was noted that the low reduction of 72% for silt and clay may have been from short-circuiting due to excessive sediment deposition reducing the length-to-width ratio. This observation illustrates the need for basin maintenance during its operation. For the Knox County site, the percent reduction of various particle sizes was a 100% reduction in gravel and 99.9% reduction in sand, silt, and clay. The sediment inlet masses were: 17.5 kg for gravel, 13.4 kg sand, 4.4 kg silt, and 0.3 kg for clay. The outlet masses were small leading to the near 100% reduction measured. The high reduction in sediment for all size classes was due to the catchment sediment source which was unusually dominated by sand and silt with rapid settled rates (see Section 4.1.1 for details). Differences between inlet and outlet sediment by size classes are also shown in Figure 4.3.

Table 4-1. Sediment particle sizes for basin inlet, outlet, and basin deposits, and estimates of % reductions for the Morgan County site.

Particle Size Class	Event-averaged Sediment Mass (kg)			Percent Sediment Reductions
	Inlet plus Approach	Basin Deposits	Outlet	
Gravel	47.4	142.5	0.0	100.0
Sand	151.4	682.0	4.6	99.2
Silt	1,233.5	1,591.6	341.1	72.4
Clay	128.1	161.6	34.7	72.7

Storm event detail results of the inlet and outlet sediment PSD as mass values are summarized below with data tables in Appendix C. The Morgan County site inlet gravel masses ranged between 2.6 kg and 119.4 kg with an average of 45.7 kg, where the outlet contained 0.0 kg of gravel. The sand inlet values ranged from 38.7 kg to 1449 kg, with an average of 553.0 kg, where the outlet ranged from 0.8 kg to 9.4 kg, with an average of 4.6 kg. The silt inlet mass values ranged from 189.0 kg to 2281.4 kg, with an average of 1210.9 kg, where the outlet values ranged from 4.1 kg to 693.4 kg, with an average of 341.1 kg. The clay inlet quantities ranged from 24.6 kg to 279.6 kg, with an average of 125.8 kg, and the outlet ranged from 1.3 kg to 69.2 kg, with an average of 34.9 kg. The Knox County site inlet gravel masses ranged between 0.0 kg and 7.2 x 10^{-6} kg, with an average of 1.4 x 10^{-6} kg, where the outlet contained 0.0 kg of gravel. The sand inlet values ranged from 0.0 kg to 323.4 x 10^{-6} kg, with an average of 82.4 x 10^{-6} kg, where the outlet ranged from 0.0 kg to 1.9 x 10^{-6} kg, with an average of 0.4 x 10^{-6} kg. The silt inlet mass values ranged from 162.4 x 10^{-6} kg to 5,171.7 x 10^{-6} kg, with an average of 1,362.6 x 10^{-6} kg, where the outlet values ranged from 1.7 x 10^{-6} kg to 320.7 x 10^{-6} kg, with an average of 70.3 x 10^{-6} kg. The clay inlet masses ranged from 17.7 x 10^{-6} kg to 555.9 x 10^{-6} kg, with an average of 143.9 x 10^{-6} kg, and the outlet ranged from 0.2 x 10^{-6} kg to 21.4 x 10^{-6} kg, with an average of 5.1 x 10^{-6} kg.

The PSD of the inlet sediment for the Bedford County site is shown in Figure 4-4. The inlet sediment % finer over nine measured storm events ranged between 5-20% gravel, 20-30% sand, 50-60% silts, and 40-50% clay. These ranges overlap but each storm event sampled summed to 100% finer. In general, the inlet sediment PSD for the Bedford County study site consisted dominantly of silt and clay which is the more common highway construction site condition for

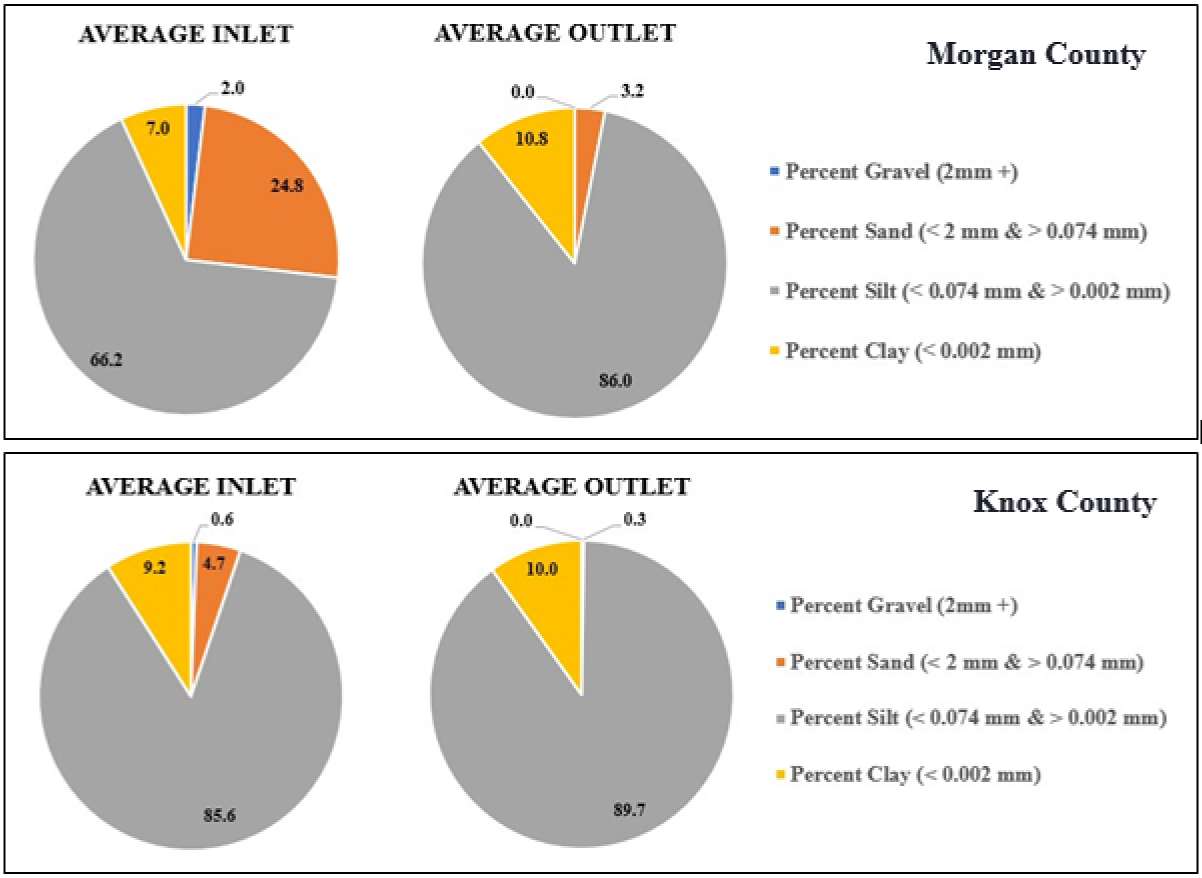


Figure 4-3. Sediment basin Inlet and outlet particle size distributions (note inlet does not include deposited approach sediment) for the Morgan County site (top) and Knox County site (below). Alt Texting needed in pie chart graphs

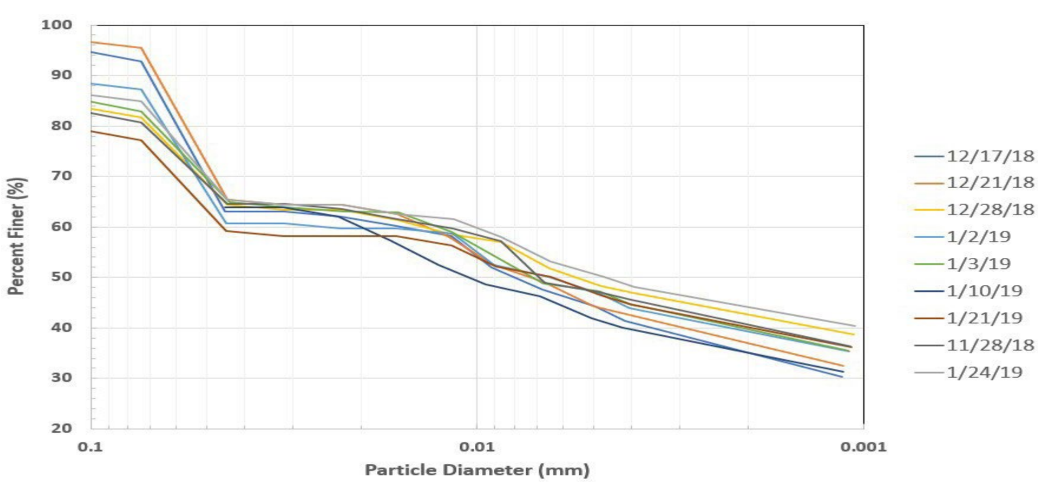


Figure 4-4. Sediment basin inlet particle size distribution for the Bedford County study site.

disturbed soil. This result contrasts with the Knox County site, which is more atypical, but it does demonstrate the importance of the PSD of the sediment source and its potential performance of sediment basin.

4.1.4 Sediment Basin Performance

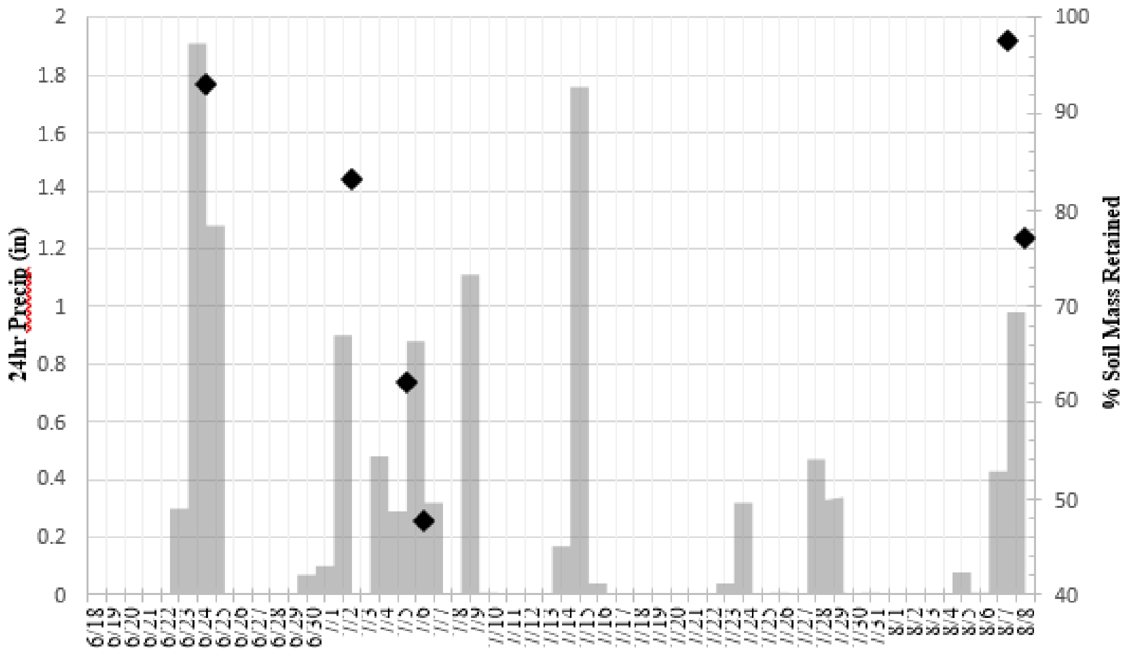
Both Morgan County and Knox County mass and SSC concentration inlet and outlet data were analyzed using the goodness-of-fit Shapiro-Wilk W test to check for normality. The data was also visually checked for normality. If the analysis did not result in a normal trend, the data was logarithmically transformed. All data was established as normal, log-transformed, and un-transformed, thus a paired t-test was used to compare the inlet to the outlet. The matched pair test was used to assess the significant difference between the inlet and outlet sediment masses and concentration values. This analysis was completed using JMP Pro 14.

To understand performance of the basin, total mass difference was analyzed for the inlet and outlet, which does not include sediment deposited in the approach area. Data details are summarized in Appendix D. At the Morgan County study site, the mass percent retained in the basin had an average of 76.8%, with a range between 47.7% and 97.5% mass reduction. The data also had a median of 80.1% and a standard deviation of 18.9%. The data was found to be normally distributed for a small sample size ($p = 0.72$). Average SSC reduction was 72% ranging between 13.0% and 95.8%. An event matched pair analysis was conducted for the Morgan County site's mass and SSC values for the inlet and outlet. The data was normality distributed. When comparing sediment mass values from inlet to outlet, the t-test ratio was -2.89 with a degree of freedom (df) of 5. The mean difference between the inlet and outlet masses was -1.6×10^3 kg, and it was significantly different ($p = 0.03$). When SSC inlet and outlet values were compared, the t-test ratio was approximately -2.20 with a df = 5. The mean difference between the inlet and outlet concentrations was -49.9 g/L ($p = 0.08$).

At the Knox County study site, the mass percent retained in the basin was an average of 97.4%, with a range between 94.3% and 99.4% retention (Appendix D). The data also had a median of 98.1% and a standard deviation of 1.98% but was not significantly different ($p = 0.59$). The average SSC reduction ranged between 75.6% and 97.4%, with an average reduction of 86.7%. The event matched pair analysis for the Knox County site data did not fit the normal distribution thus a log transformation was conducted on the dataset ($p = < 0.01$). When comparing sediment mass values from inlet to outlet, the t-test ratio was -10.35 with a df = 4. The mean difference between the inlet and outlet masses was -3.88×10^{-3} kg, and it was significantly different ($p < 0.01$). Comparing SSC values, the t-ratio was approximately -3.39 with a df = 4. The mean difference between the inlet and outlet concentrations was -0.00002 g/L ($p = 0.03$).

A qualitative assessment of the sediment basin performance data as it related to storm event frequency was completed by plotting a time series of daily rainfall volumes with the event-based reduction in sediment load from the sediment basins at the Morgan and Knox counties study sites (Figures 4-5 and 4-6). At the Morgan County site there were short durations without rainfall between sampling events, meaning consecutive events, in some cases less than 48 hours. Performance reduction percentages were reduced in sequence between events on July 1st, 3rd, and

5th as well as between events on August 7th and 8th. At the Knox County site there was often over five days of no precipitation in between monitored events. There was also less variation in mass reduction values in Knox County, however after the September 6th storm, sediment basin performance was greatly reduced. **In general, sediment basin performance is affected by the magnitude, duration, and frequency of storm events, with larger magnitude and greater frequency, or both, reducing sediment basin performance (% of sediment retained/deposited)**



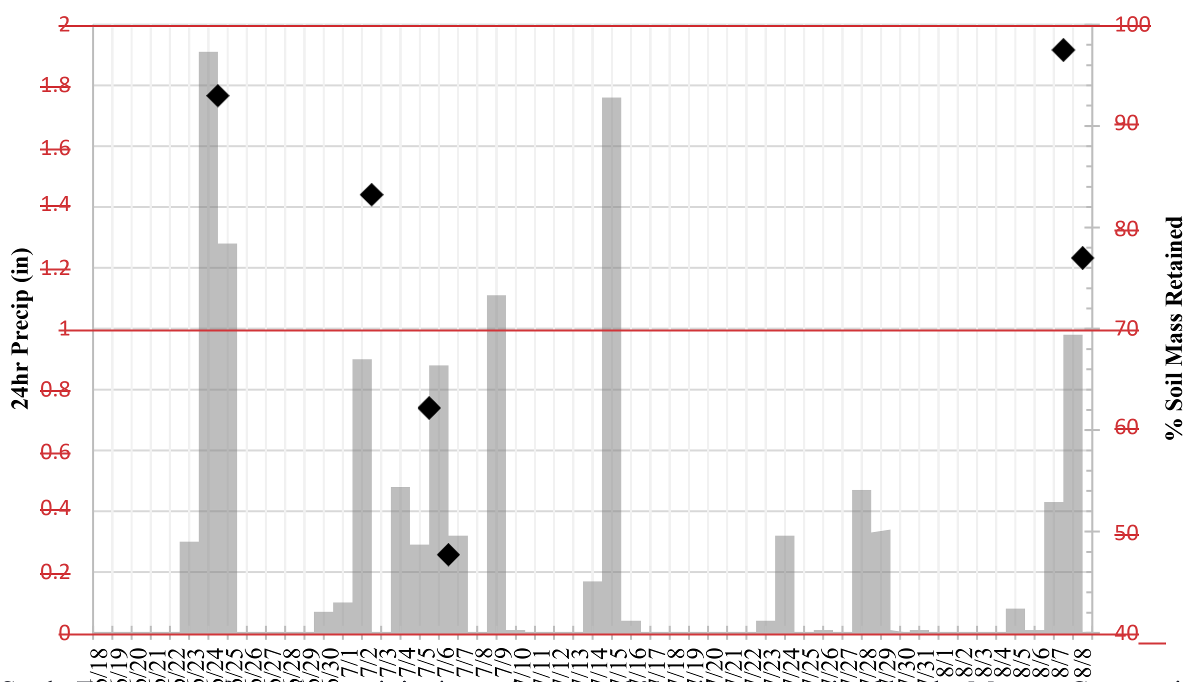


Figure 4-5. Study Time series for daily precipitation volumes and % soil mass retained by the Morgan County site sediment basin.

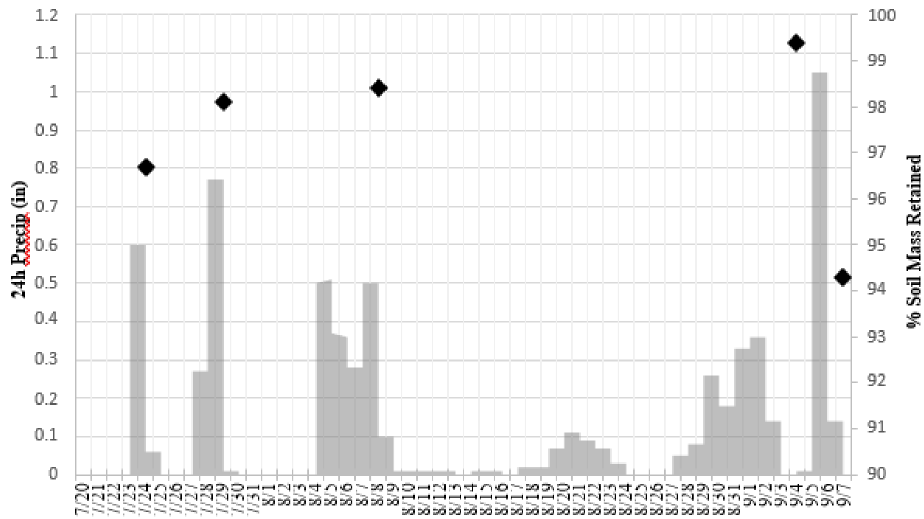


Figure 4-6. Study Time series for daily precipitation volumes and % soil mass retained by the Knox County site sediment basin.

Performance of the sediment basin at the Bedford County study site was based on SSC because mass load data was unavailable. Percent SSC reductions ranged from 58.63 to 93.95% with an average of 78.2% and standard deviation of 9.87 (Table 4.2). The one low performance event of 58.63% was during a wet period with a precipitation volume over 2.5 inches in the prior week and a daily maximum event volume of 0.78 inch. In general, the % sediment reduction in the basin corresponded with rainfall intensities and volumes and demonstrated with the Morgan and Knox Counties datasets (Figures 4.2, 4.5, and 4.6).

Table 4-2. Sediment basin performance data for the Bedford County study site.

Basin Sample	Date	SSC (g/L)	Reduction (%)
INLET OUTLET	11/23/18	7.0578 0.4271	93.95
INLET OUTLET	12/10/18	1.2629 0.1845	85.39
INLET OUTLET	12/17/18	1.8840 0.2984	84.16
INLET OUTLET	12/21/18	0.9249 0.2552	72.41
INLET OUTLET	12/28/18	2.2716 0.4926	78.32
INLET OUTLET	12/31/18	2.6546 0.5079	80.87
INLET OUTLET OUTLET	1/2/19	3.6196 0.9428 0.7294	73.95
INLET OUTLET	1/10/19	1.3373 0.5532	58.63
INLET OUTLET	1/21/19	1.4179 0.3327	76.53

Note: SSC = suspended sediment concentration.

Comparing research in this study to others found similar results for sediment basins with floating skimmers. Millen et al. (1997) was like that of Knox County, with an average retention of 96.8% compared to Knoxville at 97.4%, however the PSD of the sediment sources differed where they used a silt load. Differences with the Morgan County site may be attributed to the test runs by Millen et al. (1997) were in a highly controlled experimental environment, one that delivered sediment to the basin by injecting it into the system. The construction site sediment basin experiment by McCaleb and McLaughlin (2008) exhibited somewhat higher removal rates compared to the Morgan and Knox counties basins, where they measured a trapping efficiency was over 99%. However, their basin included baffles but had a similar dewatering device to as per this study.

The sediment basin experiment by Fang et al. (2015) also used baffles with a skimmer and used PAM blocks. It was unclear what the receiving soil type was from the catchment but assumed the sediment source contained substantial amounts of suspended clay particles. The efficiency of removal for the site for event one in November, when PAM was being used correctly, was 96.6% by concentration and 97.9% by total mass. The efficiency of removal for event two in December, when PAM was being used incorrectly, was 76.0% by concentration and 83.7% by total mass.

As a result of the study by Fang et al. it was suggested that a minimum volume to catchment area ratio of 251.9 m^3/ha (3,600 ft^3/ac or 133.33 cubic yard/ac) be used. The Morgan County basin was designed to have a total volume of 2,494.8 ft^3 for a drainage catchment of 0.6 acres. These values produce a ratio of 4,158 ft^3/ac, a 15.5% increase in the size of the suggested basin. The Knox County basin was designed to have a total volume of 5,030 ft^3 for a drainage catchment of 1.75 acres. These values produce a ratio of 2,874 ft^3/ac. The Knox County basin, which performed better, resulted in a lower ratio, thereby not holding up to the suggested standard by Fang at al. (2015). **This shows that sizing cannot be done linearly, rather the orientation and length to width ratio have more influence on the basin.**

4.1.5 Sediment Basin Site Selection on Highway Construction Projects

During the construction and monitoring phases of this study qualitative observations were made to site selection of sediment basins along highway constriction corridors. One lesson learned from this study was to be careful consider the potential seasonally high-water tables or in wetland areas. The first location and design for the Morgan County project site was made during the summer dry period. It was constructed only to result in continuous groundwater flow during the winter wet season. **Careful consideration of the fluctuating groundwater table levels is required**. Also, **location and a basin's design and construction most divert drainage from non-disturbed areas around the sediment basin so to not hydraulically overload it.**

Fitting a sediment basin in a narrow highway corridor can be challenging affecting the length-to-width ratio. Other land constraints are steep topography, rock outcrops, and easement boundaries. Sediment basins may take up space for staging of equipment thus use may be very temporary considering construction work on highway projects can occur rapidly. Hangul (2017) notes sediment basins are not commonly used, and road builders may be unfamiliar with constructing them. It is important to understand the constraints of a linear corridor and be able to alter a typical design if the constraints impact the potential performance of the basin, making it even more critical to install the basin correctly.

4.2 Performance of Pilot-scale Sediment Basin

As described in the methods, a pilot-scale sediment basin was constructed on the University of Tennessee Knoxville property and modified experimentally to assess three different basin design. They were: 1) TDOT standard without forebay, 2) TDEC standard with forebay, and 3) TDOT standard with approach check dam (TDOT CD). Results of the field experiments follow.

4.2.1 Sediment Basin Dewatering Time

A main design criterion for the sediment basin for all designs is that the dewatering time of the dry storage is 72 hours. TDOT sets the 72-hour minimum to adequately provide proper settling while allowing for multiple storms to happen within quick succession, however, some agencies have lower minimum dewatering times of 48 hours (Table 2-1). Additionally, most controlled studies determining the performance of a sediment basin dewatered the basin in only 24 hours. With such a wide range of dewatering times used in other studies and as required from different agencies, it spotlights highly variable definitions of an effective dewatering time. Rationale for dewatering times is limited in the literature but one could speculate the period of time relates to effluent quality so not to significantly impact a receiving stream.

Results from this study found all nine runs dewatered to the permanent pool elevation in 72 hours. Little variation between the three replicates for each design was observed. The standard deviation at the peak and 72-hour stage for TDOT was 0.048 ft and 0.12 ft; for TDEC, 0.016 ft and 0.11 ft; and for TDOT check dam (TDOT CD), 0.034 ft and 0.90 ft. Storm events that occurred during the run of the experiments are responsible for the elevated variation at the 72- hour stage recording. The average stage over the 72-hour dewatering time for each design is shown in Figure 4-7.

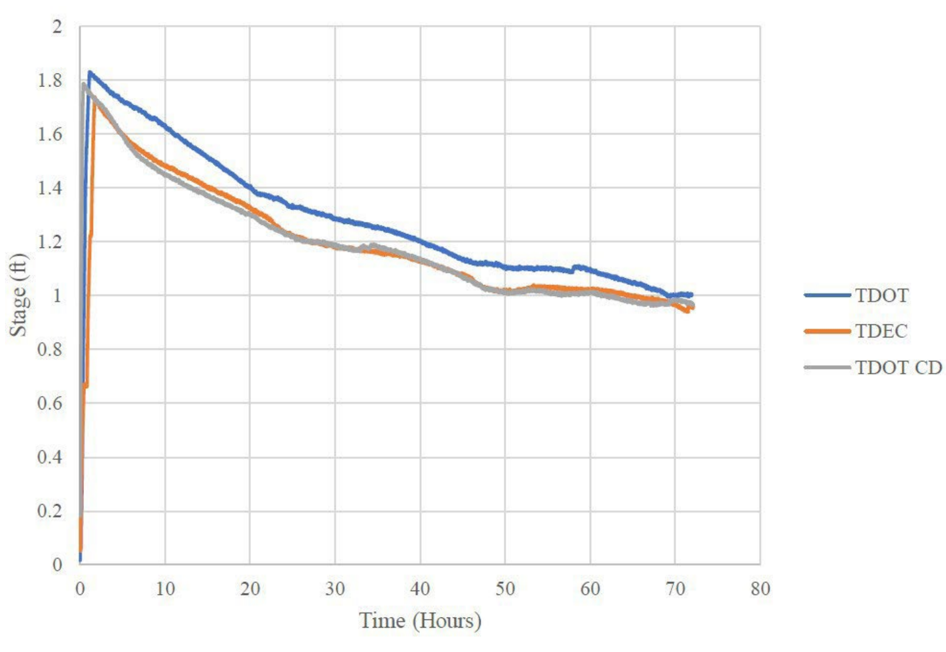


Figure 4-7. Basin stage versus 72-hour dewatering time for TDOT, TDEC, and TDOT CD designs.

4.2.2 Basin Water Volume Retention

In this field study a perforated riser was used because it was pilot-scale experiment and to operate a skimmer device of appropriate scale hydraulically would have been difficult. The perforated riser is more commonly used than the Faircloth skimmer, but both are recognized by TDOT and TDEC as a viable option to adequately dewater the basin (Zech et al. 2012). Perforated risers typically have higher peak discharges compared to a skimmer® and rapidly decrease until only one perforation is discharging (Millen et al. 1997). For all three design's outflows, this trend can be seen in Figure 4-8.

The outflow hydrograph for each design displayed little variability between three replicates of data, the standard deviation at the peak and 72-hour outflow for TDOT was 0.026 gpm and 0.094 gpm; for TDEC, 0.009 gpm and 0.083 gpm; and for TDOT CD, 0.021 gpm and 0.080 gpm. Storm events during the run of the experiments caused the larger variation at the 72-hour outflow. Thus, the outflow was averaged and plotted against the 72-hour dewater time (Figure 4-8). The TDOT outflow reached a peak of 0.66 gpm and rapidly decreased to only one perforation, the lowest outlet orifice at the surface of the permanent pool, discharging at around hour 20, then slowly reached 0.1 gpm linearly. The TDEC and TDOT CD design reached a smaller peak of 0.61 gpm and, rapidly decreased to one perforation around the 15-hour mark until slowly decreasing to 0.1 gpm.

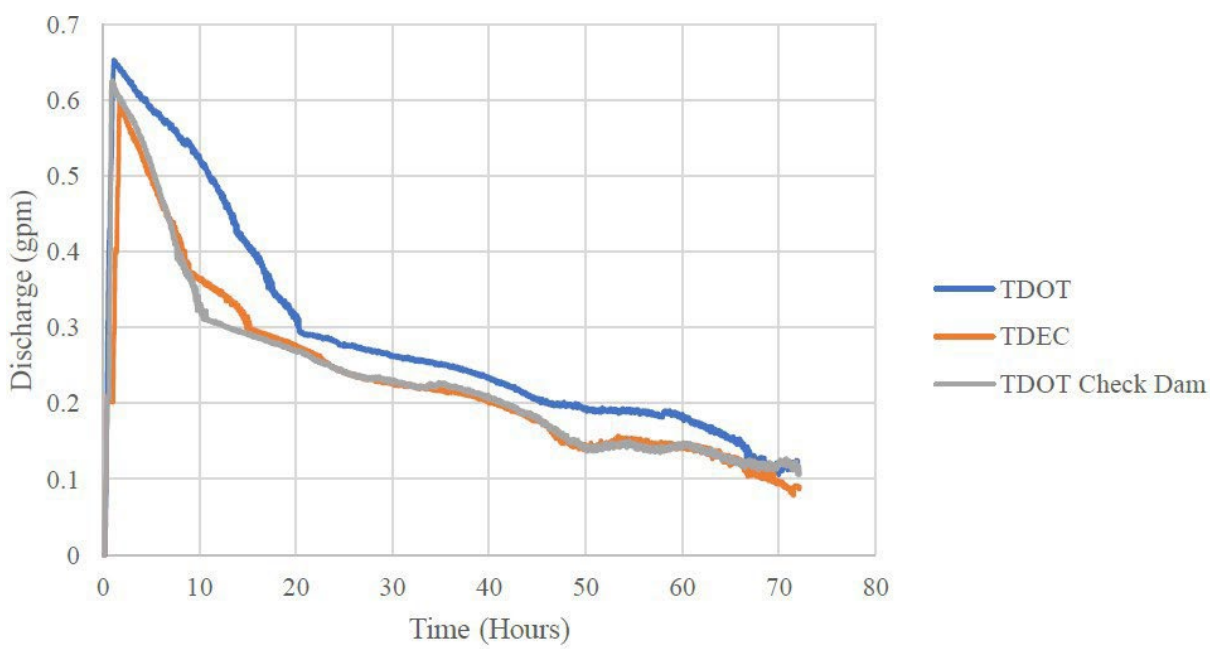


Figure 4-8. Outflow discharge versus 72-hour dewatering time for TDOT, TDEC, and TDOT CD designs.

Sediment basin lining or not can affect outflow and water volume reduction. Even though this study used a lined basin, it is important to note how **infiltration can potentially impact the outflow of an unlined sediment basin**. Soil composition is a huge factor for determining the infiltration rates and can be highly variable depending on site conditions. Bidelspach, et. al (2004) observed infiltration rates ranging from 0.4 mm/hr. (0.016 in/hr.) to 22.0 mm/hr. (0.87 in/hr.) from various sediment basins in Pennsylvania and found that a typical Pennsylvania sediment basin can be dewatered in 7 days or less when the infiltration rate exceeds 3 mm/hr. (0.12 in/hr.). If a sediment basin is fully dewatered strictly through infiltration 100 % of sediment will be removed. Thus, there is potential for site specific infiltration rates to be implemented into the dewatering device design of the basin.

4.2.3 Sediment and Pre-Basin Deposition Characteristics

For this experimental study a known amount of the sediment mass added was measured, and a PSD analysis conducted. Similarly, the averaged inlet soil composition was classified as a silty clay loam with 37.5 % clay, 54.5 % silt, and 8 % sand (Figure 4-9). The sediment settled in the forebay, at the check dam upstream face, and sediment mixing chamber before the basin inlet were measured and averaged, and a PSD analysis completed. Due to the standard TDOT design having no inlet structure, 100 percent of the sediment entered the main basin. As for the TDEC and TDOT CD, the percent of soil settled before or in the basin were identical in soil composition and classified as a silty clay loam with 36 % clay, 56 % silt, and 8 % sand (Table 4-3).

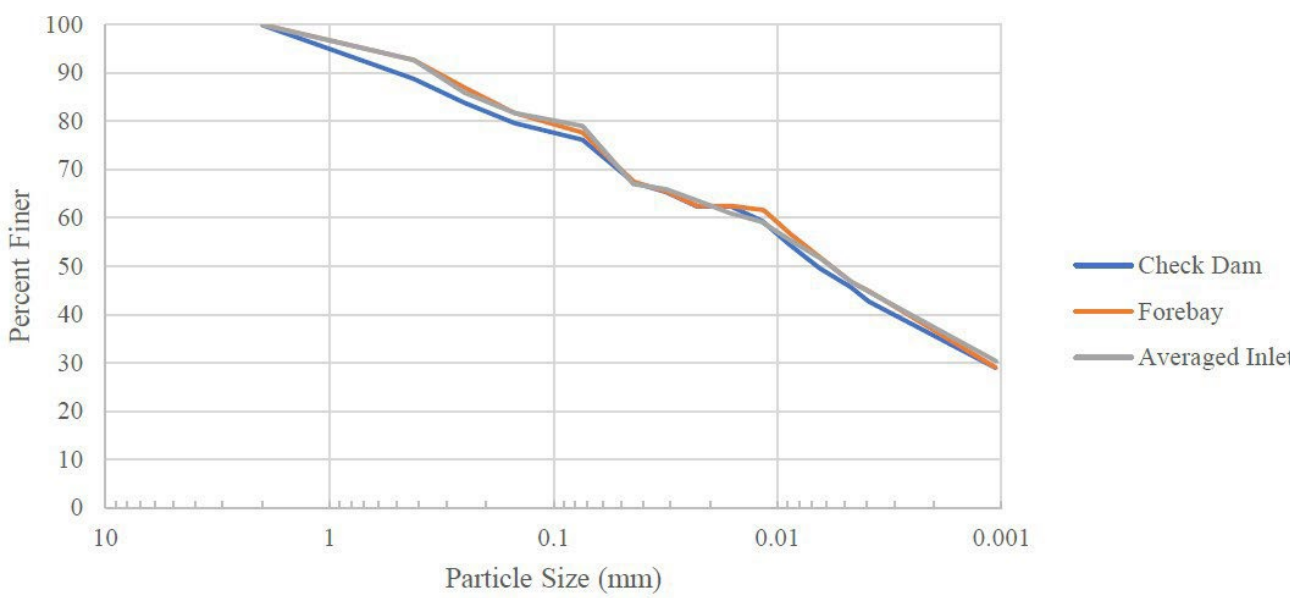


Figure 4-9. Particle size distribution of sediment collected at basin inlet, check dam, and forebay.

4.2.4 Effluent Suspended Sediment Concentration Characteristics

The effluent water samples SSC was averaged for the TDOT, TDEC, and TDOT CD design experiments and plotted against the dewatering time (Figure 4-10). Peak SSC values for TDOT, TDEC, and TDOT CD were 1.33 g/L, 0.62 g/L, and 1.09 g/L, respectively. After the first two samples, around hour 6 into the dewatering, the concentrations have little variation between the three different designs. An ANOVA Single Factor (α= 0.05) test between each of the designs at a specified sample time was completed to help show any statistical difference between the data. Only the first sample point, at hour 0 into the dewatering time, displayed any significant difference.

Table 4-3. Sediment settled as mass and percentage for TDEC forebay and TDOT check dam designs.

Performance Measure	TDEC Forebay			TDOT Check Dam		
	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3
Total Sediment Added (lbs.)	94.7	100.1	79.4	82.8	89.8	83.6
Percent of Sediment Settled Prior to Main Basin (%)	68.1	74.3	79.1	63.5	74.5	67.4
Percent of Sediment Entering Main Basin (%)	31.9	25.7	20.9	32.3	25.5	32.6

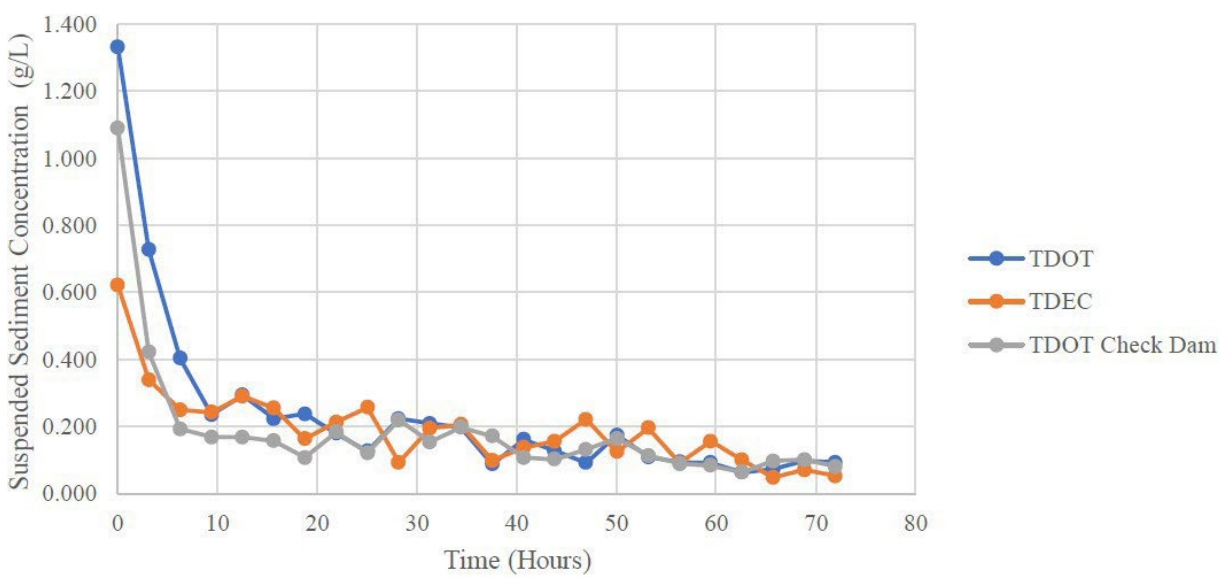


Figure 4-10. Effluent SSC versus 72-hour dewatering time for TDOT, TDEC, and TDOT CD designs.

between the three designs (p = 0.016), with the range of p-values for the other sampling times being 0.163-0.997. To better represent these data, box and whisker plots of specific groupings of sample times were created and shown in Figure 4-11.

As expected, the TDOT design had the highest starting SSC values due to a lack of any inlet protection such as a forebay or check dam (Figure 4-10). The TDEC design achieved the lowest starting SSC values and could be a result of the two porous baffles required in the forebay causing the sediment to aggregate and settle quicker (Thaxton & McLaughlin 2005). Following the peaks, the SSC for all designs declined exponentially until the last sample at 72-hours. The same exponential decline was observed by Millen et al. (1997) using a perforated riser, with a peak SSC just above 1.8 g/L and final value of just under 0.1 g/L over 16-hours. However, it is important to note that **perforated risers tend to have significantly higher peak SSC when compared to a surface outlet device (i.e. Faircloth Skimmer®)** (Millen et al. 1997).

From Figure 4-11 only the first two SSC samples (hours 0-5) were statistically different between all designs (p = 0.382), demonstrating that each design influenced the beginning SSC. However, all designs effectively reduced SSC to statistically similar values after hour 5. Another important observation is how little SSC changed from 20–40-hour until the 60–72-hour grouping, starting around 0.2 g/L and decreasing to roughly 0.1 g/L between all designs. Since there is such a small change in SSC over that period, **it might suggest a lower minimum dewatering time requirement.**

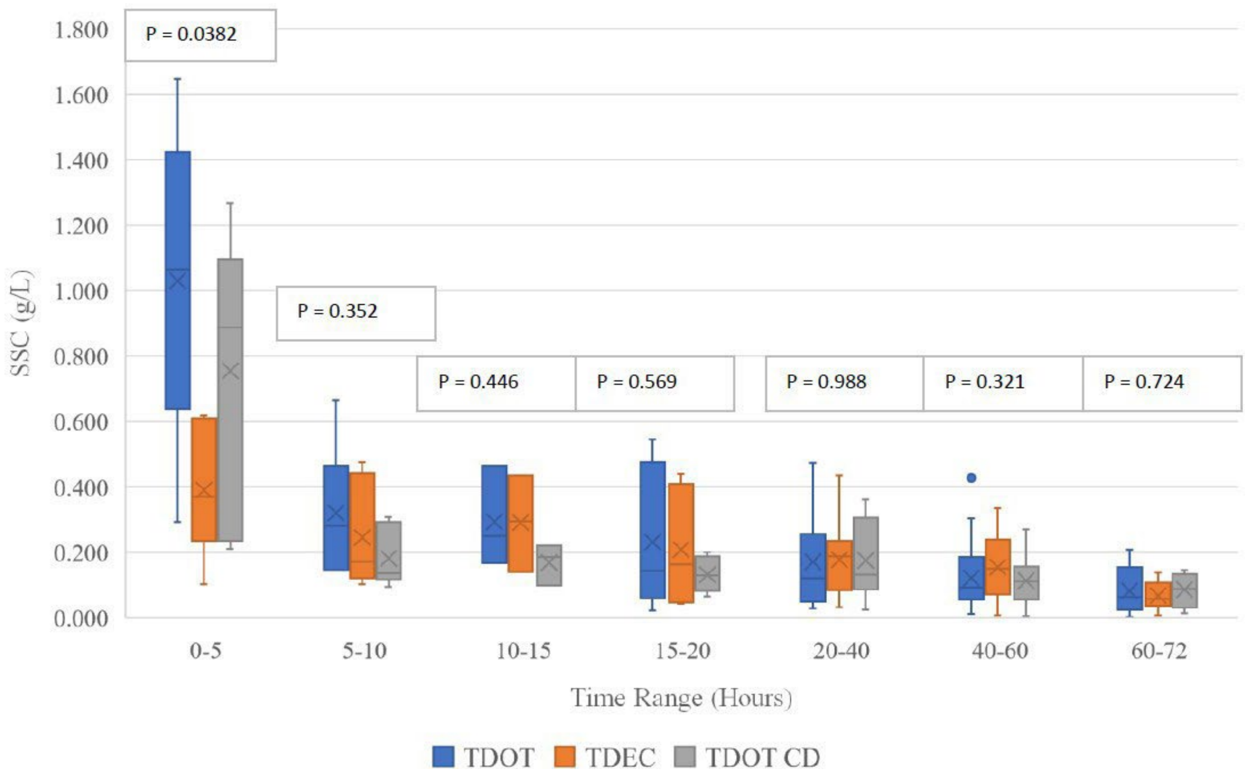


Figure 4-11. Effluent SSC over experiment time intervals (as box-and-whisker plots per interval).

4.2.5 Summary: Sediment Basin Performance

The total sediment basin performance, as percent sediment removal utilized a mass balance approach (Section 3.2.7). The mass balance included the total mass added (Min), cumulative sediment discharged (Mout), and the mass of the sediment that settled in the forebay/check dam (Mretained). A summary of the sediment removals for each experiment is in Table 4-4. The average total percent sediment removal for the TDOT, TDEC, and TDOT with check dam design is 95.4 %, 98.2 %, and 97.9 %, respectively. While the partial sediment removal of the forebay/check dam for TDEC and TDOT CD averaged to be 73.2 % and 68.5 %, respectively.

Table 4-4. Summary performance of different sediment basin design as percent sediment removal. (sediment mass is designated as M).

Experimental Run	Min (lbs)	Mretained (lbs)	Mretained (%)	Mout (lbs)	Total Percent Removal (%)
TDOT 1	98.0	0	0	3.80	96.1
TDOT 2	98.9	0	0	5.75	94.2
TDOT 3	97.0	0	0	3.85	96.0
TDEC 1	97.4	64.5	66.2	1.21	98.1
TDEC 2	100.1	74.3	74.2	2.98	98.0
TDEC 3	79.4	62.8	79.1	1.49	98.3
TDOT CD 1	82.8	52.6	63.5	1.57	98.1
TDOT CD 2	89.8	66.9	74.5	1.91	97.9
TDOT CD 3	83.6	56.3	67.4	2.02	97.6

It was hypothesized that the TDEC design would achieve the highest percent removal due to the addition of the forebay, while the TDOT design would achieve the lowest removal since there is no inlet protection. The addition of the **check dam** was thought to increase removal and the results reveal it is very similar to TDEC's design. This suggests that what **plays an important role in increasing the total percent sediment removal is the use of an inlet protection prior to the main basin.** Because this study used a rubber liner as the material for the basin the percent sediment removals for each design might be slightly elevated; according to Fennessey and Jarrett (1997), which concluded that there is a significant difference between lined (97.2 %) and unlined basins (94.9%) for percent sediment removal. However, this elevation might be offset because percent sediment removals for basins with perforated risers (94.2 %) tend to be slightly lower than ones with a Faircloth Skimmer® (96.8 %) (Millen et al. 1997). One sediment basin with a skimmer even achieved 99.6 % sediment removal (McCaleb and McLaughlin 2008).

Most of the effluent sediment was clay and potentially some silt. The settling velocity for a fine silt (0.01 mm) particle is 1.2 hours per foot (at 50 ^{o}F), whereas for a med-coarse clay (0.002 mm) it is 31 hours per foot (at 50 ^{o}F). A sediment basin design can achieve 100 percent silt removal by increasing the surface area to inflow ratio, however clay removal relies flocculation to settle particles in a reasonable time (TDEC 2021). A common flocculant recognized by TDOT and TDEC that can be used for removal of colloidal clays is polyacrylamide (PAM). However, site specific characteristics need to be accounted for since different formulations of PAM are designed to bind to different soil types.

4.2.6 Sediment Basin Design Tool

An Excel spreadsheet sediment basin design model (available on UT water resources center web page) was created to include PSD (or % sand, silt, and clay) as a main design factor to correctly size a sediment basin (Emmett 2020). The model still uses current design standards as required by TDOT: drainage area, design discharge, dry and wet storage volumes, basin geometry specifications, and dewatering time. An outlined step-by-step user manual detailing the computations and design process can be found in Appendix C.

4.3 RUSLE2 Sediment Yields from Active Highway Construction Sites

RUSLE2 was utilized to compare the measured soil yields to the modeled results. The model inputs for Morgan County were as follows. The soil was a silt loam, low to medium organic matter, medium permeability, and 5% rock. The management was highly disturbed\bare - bare, cut, smooth. The steepness was 10% and the length was estimated as 255 feet. The operational input was no operation. The adjusted residual burial level was normal. The rainfall erosivity was taken from the six Morgan County measured rainfall events (Smith 2018). The soil loss from the catchment slopes estimated by the Morgan County RUSLE2 run was 19 t/ac, and the measured field value was 22 t/ac.

For Knox County, the soil input was sandy loam and 10% rock. The management was highly disturbed\bare - bare, cut, smooth. The steepness was 4% and the length was an estimated 230 feet. The operational input was no operation. The adjusted residual burial level was normal. The rainfall erosivity was taken from the five Knox County measured rainfall events. The soil loss from the catchment slope estimated by the Knox County RUSLE2 run was 3.8 t/ac, and the measured value was 0.13 t/ac.

Hydrologic catchment sediment modeling, RUSLE2, yielded similar result for sediment yield at the Morgan County site with a value of 19.0 t/ac compared to 22.0 t/ac estimated from the field. This is an underestimation of 3.0 t/ac. The modeling efforts for Knox County fielded similar results with an estimated 3.8 tons, where the measured field results were 0.13 t/ac. This is an overestimation of 3.67 t/ac. RUSLE2 does not include estimates for channelization of flow, modeling values as similar as this to field results is satisfactory for not including a major source of characterization in erosion from construction sites, especially in longer corridors. **This research emphasized the utility of this tool for sizing sediment storage volumes in sediment basins.** RUSLE2 also provides the output of sediment in terms of sand, silt, and clay which values can be entered as input to the sediment basin design model created as part of this project (Section 4.2.6).

Chapter 5 Conclusion

5.1 Summary of Results

Sediment basin performance as percent sediment retained/removed was assessed for three basins constructed at active highway projects, and a pilot-scale basin constructed on the property of the University of Tennessee Knoxville. The three basins constructed on the active highway sites were designed based on TDOT standards and sized based on criteria developed by Neff and Schwartz (2013) which incorporates catchment drainage area, land slope, and soil type into its sizing formulation. Three sediment basins were constructed on highway projects in Morgan County (US 27), Knox County (I-640 interchange at Broadway Street), and Bedford County (US 41A, SR16). The pilot-scale basin consisted of three different designs and compared for a common soil type consisting of mostly of silt-loam-clay. The three designs were: 1) TDOT standard without forebay, 2) TDEC standard with forebay, and 3) TDOT standard with approach check dam. Results and lessons-learned from this study follow.

A general observation from the monitoring effort at the active highway construction sites was the influent H-fume to measure flow and to collect flow-weighted sediment samples acted like a check dam were large amounts of sediment deposited. Mostly the larger size sediment, gravel and sand with some silt and clay mixed where the dominant deposited sediment at the H-flume approach area. The amount of sediment deposited per storm event was correlated with rainfall intensity. It was measured that 4 inches or more of sediment were deposited for rainfall intensities if 1-inch or greater for 30-minutes intervals. This observation led to the second study design assessing the effectiveness of a check dam at the basin inlet approach for the TDOT standard design, and to compare it with the TDEC standard design with a forebay.

Overall performance of the constructed sediment basins varied for different sites, sediment types from catchment sources, and storm event characteristics. At the Morgan County study site, the sediment mass retained ranged between 47.7% and 97.5% with an average of 76.8%, a median of 80.1%, and a standard deviation of 18.9%. At this site, the SSC reduction ranged between 13.0% and 95.8% with an average of 72%. At the Knox County study site, the mass retained ranged between 94.3% and 99.4% with an average of 97.4%, a median of 98.1%, and a standard deviation of 1.98%. The average SSC reduced at this site ranged between 75.6% and 97.4% with an average reduction of 86.7%. At the Bedford Count site, the SSC ranged between 58.6% and 94.0% with an average of 78.2% and standard deviation of 9.9%. Results indicated that the TDOT standard sediment basin design generally performs over 80% sediment removed in stormwater runoff if sized adequately. Thus, this research suggests that the design tables developed by Neff and Schwartz (2013) sufficiently treat sediment laden stormwater runoff from construction sites for daily rainfall volumes less than the 2 or 5-year return frequency storm, and 72 hours between storms. Recall, these design tables provide sediment basin sizing criteria for east, middle, and west Tennessee, and based on catchment drainage area, land slope, and regional soil type. This study findings do indicate **when high-intensity storm events and/or longer rainfall durations over days, sediment basin performance declines.**

Results from this study demonstrated **the importance of knowing the influent sediment PSD, which is a function of the soil types within the catchment drainage area**. The size and its performance depend on the PSD characteristics of the influent sediment. Comparing the differences in influent sediment PSD for Morgan and Knox counties study sites one can see the wide variance in performance. With the Morgan County study site, the sediment basin removed 100% of the gravel, 99.2% of the sand, 72.4% of the silt, and 72.7% of the clay. The Knox County site removed essentially 100% of all size classes but lack any large amounts of silt and clay. The influent sediment and basin performance of the Bedford County site was like that of the Morgan County site, which in general is more commonly found at highway construction projects. Because of the importance of the influent sediment PSD on basin performance, and the fact no design tool has accounted for this parameter, the project created a working tool/model as a major deliverable (Section 4.2.5).

The field monitoring studies at active highway construction sites qualitatively provided useful information on site selection of sediment basins, or when they are to be used. With many highway projects operating within narrow easement corridors, fitting a sediment basin can be problematic. **The topography must provide flow pathways contained within an isolated catchment draining to the sediment basins**. Steep slopes and small valley can make placement difficult and achieving the appropriate basin length-to-width ratio, and side slopes. Another consideration for placement is the groundwater levels which is seasonally variable. **During the dry summer period a site may appear as a good location for a sediment basin however during the winter wet period a basin may intersect the local groundwater table lowering the sediment basin performance.** Sediment basins can take up space potentially needed for equipment staging. Other site conditions could be challenging as well.

Testing results of the pilot-scale sediment basin and three designs provided valuable outcomes to the performance associated with the TDOT standard design with an inlet approach check dam. The importance of this finding is to minimize basin footprint at narrow corridors among highway construction sites. **The TDOT CD design is most valuable for these highway construction sites since it requires less area than the TDEC design with a forebay.** The performance of three sediment basin designs were evaluated by the total percent sediment removal. The TDEC design with a forebay achieved the highest percent sediment removal at 98.2 %, while the TDOT CD had very similar results to TDEC design 97.9 % removal. The standard TDOT design performed the lowest with a 95.4 % removal, although it still performed with greater than 80% removal the target for TDEC's stormwater permit regulations. A check dam in front of a TDOT standard sediment basin proved to be nearly as efficient as the TDEC requirement to include a forebay, and two porous baffles suggesting the importance of an inlet structure. However, more frequent maintenance of the inlet structure is likely required thus construction site management needs to account for the necessary maintenance efforts.

Most of the sediment settles within the first 20 hours with small decreases in effluent SSC from 20 to 72 hours **suggesting a change in design criteria for the minimum basin dewatering time**. In general, it is the clay particle size remaining in suspension after 20 hours. The variable dewatering times among multiple regulatory agencies and other research studies suggests that more research on this design parameter is warranted. In general, the design criteria are to reduce more of the clay fraction of the suspended sediment and observed the release of effluent to a stream waterbody.

The RUSLE2 model can be used to estimate runoff sediment and total mass quantified in sand, silt, and clay proportions. **Sediment yields from the use of RUSLE2 can be applied to size the sediment basin.** From this research, **sizing of sediment basins is dependent on the influent sediment PSD**. Because of this study's finding, a sediment basin design tool was created that relies on the influent sediment PSD and conforms to the other existing standard design criteria.

5.2 Recommendations

Outcomes of the field monitoring data on sediment basins at active highway construction sites found that the design criteria from the Phase I part of this research (Neff and Schwartz 2013) sized basins adequately to meet a target of 80% sediment removal. The criteria were developed for east, middle, and west Tennessee applying basin site conditions of catchment drainage area, land slope, and regional soil types, and supports the existing standards in the TDOT Drainage manual Chapter 10 with its standard drawings. This includes the use of a floating skimmer device for effluent drainage. It is recommended that sediment yields and total yield fractions of sand, silt, and clay from the RUSLE2 model be used in the new spreadsheet design tool created to size the sediment basin. Rock check dams should be installed at the inlet approach area of a sediment basin, with or with a forebay. Stormwater management at highway construction sites need to provide adequate maintenance of the basin inlet approach or forebay, and the basin. Adequate maintenance is removal of settled runoff sediment, and cleaning frequency is site dependent.

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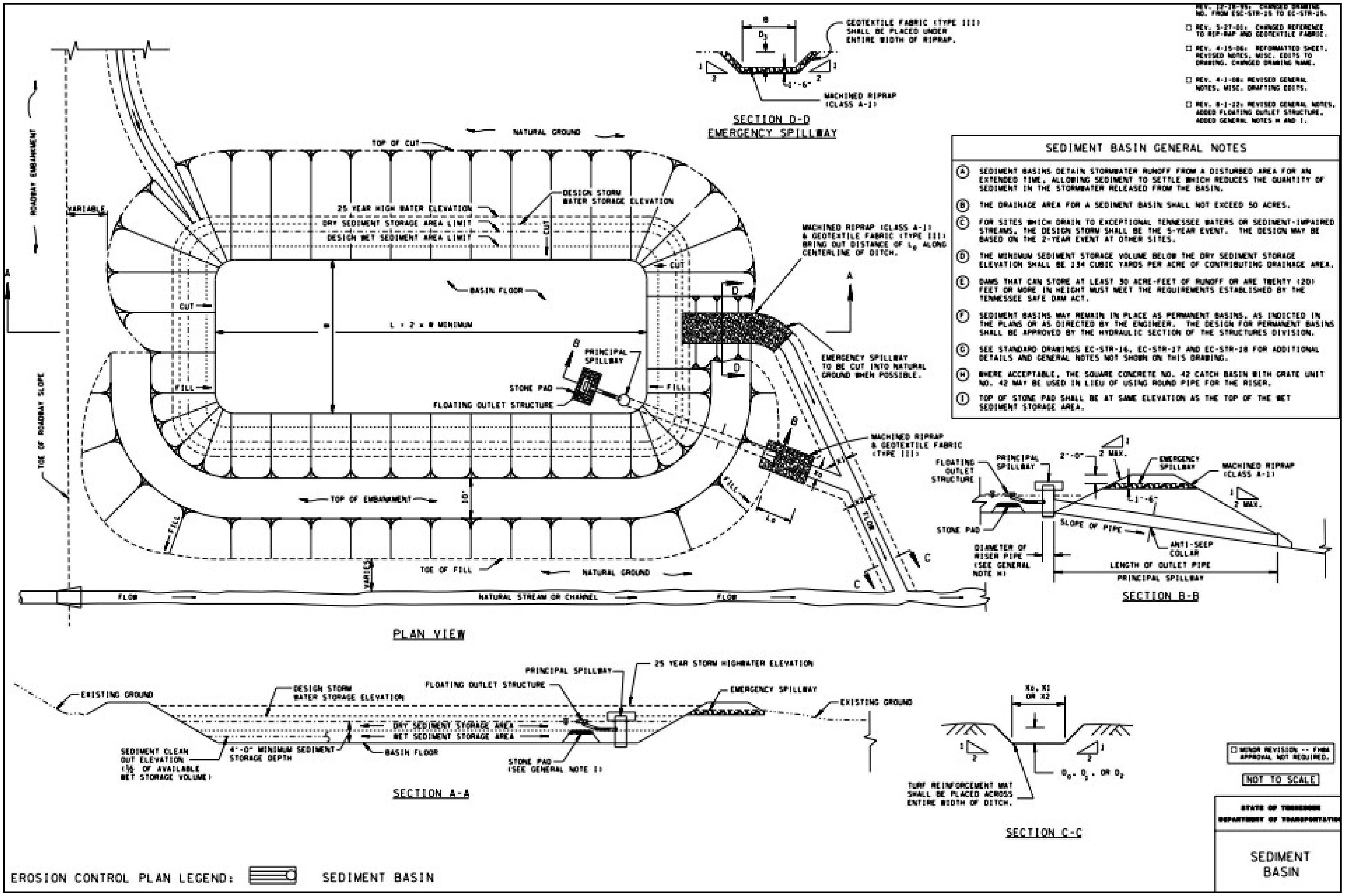
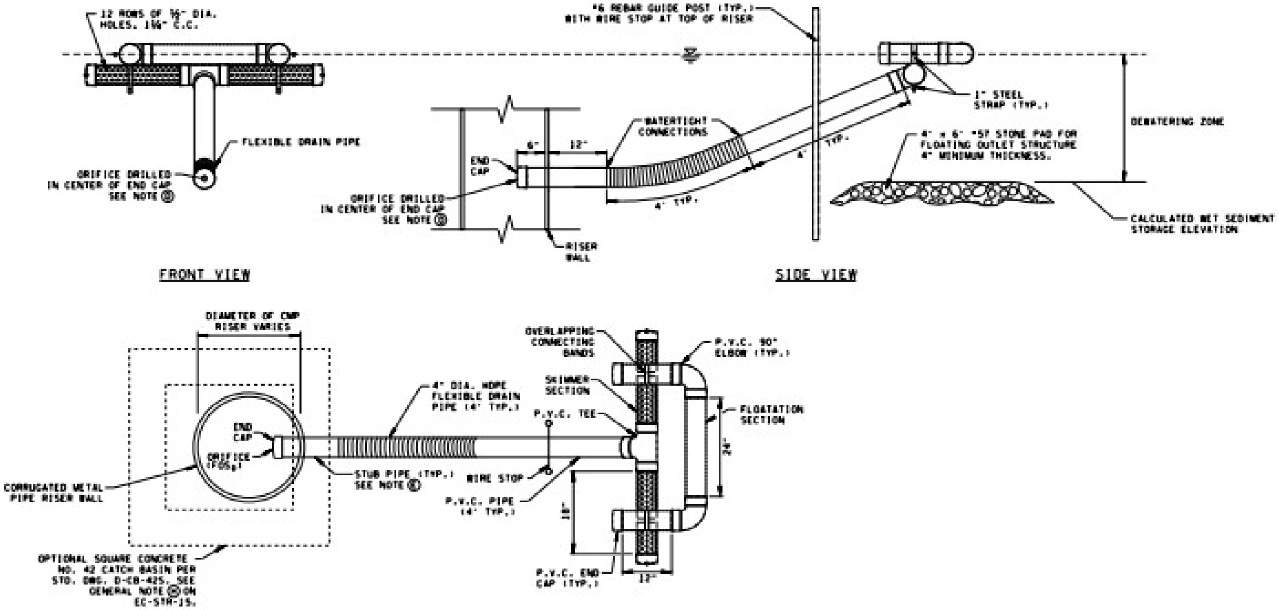
Appendices

Appendix A

A. TDOT Standard Design Drawings for Sediment Basin





PLAN VIEW

FLOATING OUTLET STRUCTURE

ORIFICE SIZE, FOS_R (IN.)	DISCHARGE, Q (FT^3/SEC)	EQUATIONS FOR MINIMUM AND MAXIMUM ORIFICE SIZE
1"	0.019	$Q_{MAX} = \frac{\text{DEWATERING ZONE VOLUME (FT}^3\text{)}}{259200}$
1.5"	0.041	
2"	0.074	
2.5"	0.116	
3"	0.167	$Q_{MIN} = \frac{\text{DEWATERING ZONE VOLUME (FT}^3\text{)}}{604800}$
3.5"	0.227	
4"	0.297	

PROCEDURE FOR ORIFICE SELECTION

(1) KNOWING THE SIZE AND SHAPE OF THE DEWATERING ZONE, CALCULATE THE VOLUME OF WATER (CUBIC FEET) FROM THE BOTTOM OF THE DEWATERING ZONE TO THE TOP OF THE DEWATERING ZONE.

(2) SOLVE FOR Q_{MAX} AND Q_{MIN} BASED ON THE VOLUME OF THE DEWATERING ZONE.

(3) SELECT AN ORIFICE SIZE (FOS_R) THAT HAS A CORRESPONDING DISCHARGE BETWEEN Q_{MAX} AND Q_{MIN}.

FLOATING OUTLET STRUCTURE GENERAL NOTES

(A) ALL P.V.C. PIPES ARE TO BE 4" I.D. SCHEDULE 40.

(B) ALL JOINTS OF THE FLOATATION SECTION SHALL BE SOLVENT WELDED TO ENSURE AN AIRTIGHT ASSEMBLY. CONTRACTOR TO CONDUCT A TEST TO CHECK FOR LEAKS PRIOR TO INSTALLATION. JOINTS OF THE SKIMMER SECTION NEED NOT BE WATER-TIGHT.

(C) 4" HDPE FLEXIBLE DRAIN PIPE IS TO BE ATTACHED TO THE BASIN OUTLET STRUCTURE WITH WATER-TIGHT CONNECTIONS.

(D) ORIFICE IS TO BE SIZED ACCORDINGLY TO STORAGE VOLUME AND TO SLOWLY RELEASE RUNOFF. THE BASIN DEWATERING TIME SHOULD BE NO LESS THAN 3 DAYS.

(E) FOR CORRUGATED METAL RISER, STUB PIPE SHALL BE SCHEDULE 40 STEEL PIPE TACK WELDED TO CREATE A WATERTIGHT SEAL. FOR CONCRETE RISER, STUB PIPE SHALL BE SCHEDULE 40 P.V.C. PIPE GROUTED TO CREATE A WATERTIGHT SEAL.

(F) MATERIALS:

SOLID PIPE - 4" SCHEDULE 40 P.V.C.
PERFORATED PIPE - 4" SCHEDULE 40 P.V.C.
90° TEE (1 EA.) - 4" SCHEDULE 40 P.V.C.
90° ELBOW (2 EA.) 4" SCHEDULE 40 P.V.C.
CAP (4 EA.) - 4" SCHEDULE 40 P.V.C., SOLID
FLEXIBLE PIPE - 4" CORRUGATED HDPE (NON-PERFORATED)
MINERAL AGGREGRATE - SIZE #57

(G) FLOATING OUTLET STRUCTURE SHALL BE PAID FOR UNDER THE FOLLOWING ITEM NUMBERS:

209-20.21 SEDIMENT BASIN OUTLET STRUCTURE (DESCRIPTION) L.S.

PAYMENT SHALL INCLUDE ALL MATERIALS AND LABOR NECESSARY FOR THE CONSTRUCTION, MAINTENANCE, AND REMOVAL OF THE FLOATING OUTLET STRUCTURE, INCLUDING REPLACMENT OF THE STONE PAD AS NECESSARY.

(H) SEE THE QPL FOR APPROVED ALTERNATE FLOATING OUTLET STRUCTURES. THE ORIFICE SIZING PROCEDURE ON THIS SHEET IS NOT VALID FOR ALTERNATE FLOATING OUTLET STRUCTURES. ALTERNATE FLOATING OUTLET STRUCTURES SHALL BE DESIGNED TO ACHIEVE A SIMILAR DEWATERING TIME.

(I) SEE STANDARD DRAWINGS EC-STR-15, EC-STR-16 AND EC-STR-17 FOR ADDITIONAL DETAILS AND GENERAL NOTES NOT SHOWN ON THIS DRAWING.

NOT TO SCALE

STATE OF TENNESSEE
DEPARTMENT OF TRANSPORTATION

SEDIMENT BASIN FLOATING OUTLET STRUCTURE

Appendix B

B. Design Drawings for Pilot Study Sediment Basin

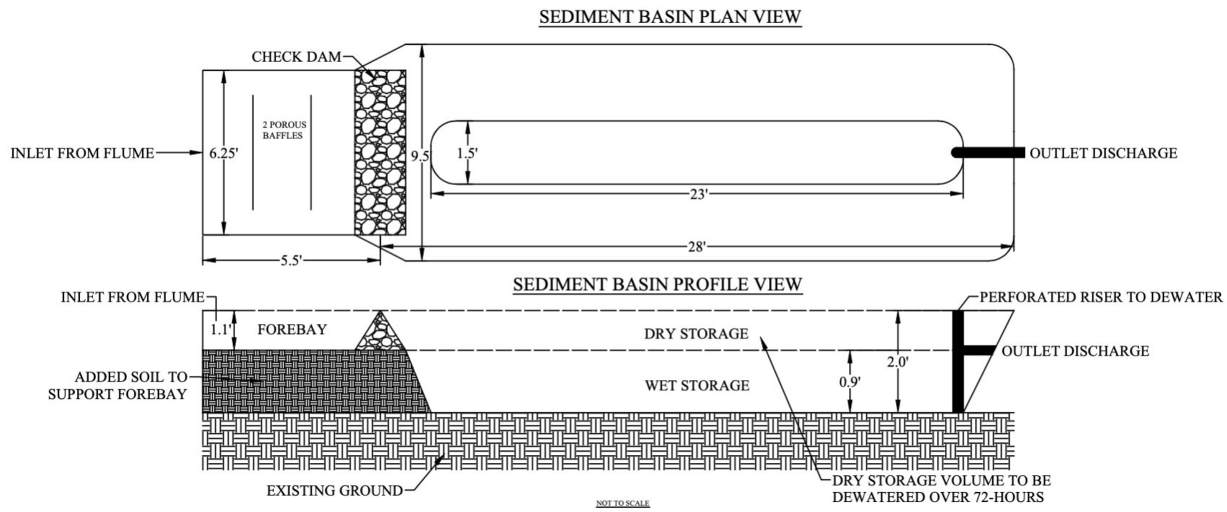


Figure B. 1. Sediment Basin Design Plan and Profile.

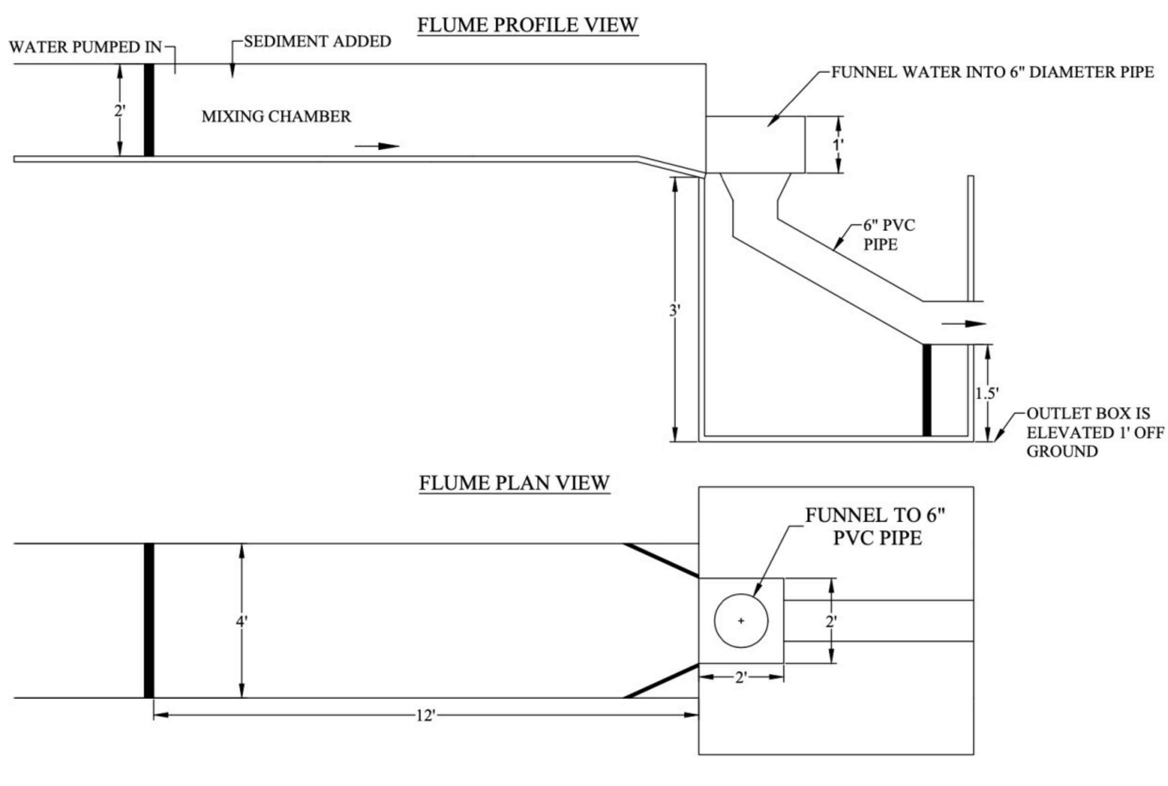


Figure B.2. Flume Design for Inlet Mixing Chamber.

Appendix C

C. Sediment Basin Inlet and Outlet Particle Size Distributions

Morgan County Study Site

	Mass Gravel (kg) 2 mm +		Mass Sand (kg) < 2 mm & > 0.074 mm		Mass Silt (kg) <0.074 mm & >0.002 mm		Mass Clay (kg) <0.002 mm	
Event #	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**
6	119.4	0.0	1449.0	0.1	2002.7	245.8	194.3	18.2
8	87.0	0.0	635.3	3.6	1362.8	335.9	134.0	32.9
9	22.5	0.0	276.0	6.5	927.7	424.9	69.0	57.8
10	7.7	0.0	168.0	9.4	501.6	342.3	53.0	30.3
14	2.6	0.0	38.7	0.8	189.0	4.1	24.6	1.3
15	35.1	0.0	751.0	6.9	2281.4	693.4	279.6	69.2
Average:	**45.7**	**0.0**	**553.0**	**4.6**	**1210.9**	**341.1**	**125.8**	**34.9**

Knox County Study Site

	Mass Gravel (kg) 2 mm +		Mass Sand (kg) < 2 mm & > 0.074 mm		Mass Silt (kg) <0.074 mm & >0.002 mm		Mass Clay (kg) <0.002 mm	
Event #	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**
1	7.2×10^{-6}	0	28.1×10^{-6}	0.1×10^{-6}	182.1×10^{-6}	7.1×10^{-6}	18.6×10^{-6}	0.8×10^{-6}
2	0	0	58.6×10^{-6}	0	$1{,}005.4 \times 10^{-6}$	19.4×10^{-6}	91×10^{-6}	2.6×10^{-6}
3	0	0	1.9×10^{-6}	0	162.4×10^{-6}	2.8×10^{-6}	17.7×10^{-6}	0.2×10^{-6}
5	0	0	0	0	291.5×10^{-6}	1.7×10^{-6}	36.5×10^{-6}	0.3×10^{-6}
6	0	0	323.4×10^{-6}	1.9×10^{-6}	$5{,}171.7 \times 10^{-6}$	320.7×10^{-6}	555.9×10^{-6}	21.4×10^{-6}

Appendix D

D. Sediment Basin Storm Event-based Performance Data

Morgan County Study Site

				Inlet Values			Outlet Values				
Event #	Start Date	Cum. Precip (in)	Duration (hrs)	Volume (L)	Conc. (g/L)	Soil Mass (kg)	Volume (L)	Conc. (g/L)	Soil Mass (kg)	Mass Reduction (%)	Conc. Reduction (%)
6	6/24/2017	1.28	1.4	161.8×10^3	23.3	3765.4	44.1×10^3	6.0	264.2	93.0	74.3
8	7/1/2017	0.43	2.1	13.4×10^3	165.7	2219.1	44.1×10^3	8.4	372.4	83.2	94.9
9	7/3/2017	0.77	32.7	24.5×10^3	52.8	1295.3	44.1×10^3	11.1	489.2	62.2	79.0
10	7/5/2017	0.87	0.8	72.7×10^3	10.0	730.3	44.1×10^3	8.7	382.0	47.7	13.0
14	8/6/2017	0.53	6.5	7.9×10^3	31.0	245.9	4.6×10^3	1.3	6.2	97.5	95.8
15	8/7/2017	0.88	9.8	48.2×10^3	69.4	3347.1	44.1×10^3	17.5	769.4	77.0	74.8
									Average	76.8	72.0

Knox County Study Site

				Inlet Values			Outlet Values				
Event #	Start Date	Cum. Precip (in)	Duration (hrs)	Volume (L)	Conc. (g/L)	Soil Mass (kg)	Volume (L)	Conc. (g/L)	Soil Mass (kg)	Mass Retained (%)	Conc. Reduction (%)
1	7/23/2017	0.65	2.0	20.4×10^3	11.6×10^{-6}	0.236×10^{-3}	4.1×10^3	1.9×10^{-6}	0.008×10^{-3}	96.6	83.6
2	7/28/2017	0.77	8.3	25.2×10^3	45.8×10^{-6}	1.155×10^{-3}	5.2×10^3	4.3×10^{-6}	0.022×10^{-3}	98.1	90.6
3	8/6/2017	0.58	10.0	17.7×10^3	10.3×10^{-6}	0.182×10^{-3}	2.1×10^3	1.4×10^{-6}	0.003×10^{-3}	98.4	86.4
5	8/31/2017	0.49	19.3	17.1×10^3	19.2×10^{-6}	0.328×10^{-3}	3.8×10^3	0.5×10^{-6}	0.002×10^{-3}	99.4	97.4
6	9/5/2017	1.15	23.7	217.3×10^3	27.9×10^{-6}	6.051×10^{-3}	50.7×10^3	6.8×10^{-6}	0.344×10^{-3}	94.3	75.6
									Average	97.4	86.7

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