Evaluation of Practices to Remove Nutrients and Sediment from Stormwater Runoff

by

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Abstract

Urban development contributes to increased pollutant loading. This includes sediment from construction sites and nutrients from impervious-surface runoff. Urban development has increased construction rates and the percentage of impervious cover. To help manage runoff, stormwater control measures (SCMs) are implemented, reducing runoff volumes and improving water quality.

Nutrients, such as nitrogen and phosphorus, are considered harmful pollutants in stormwater, yet are vital and limited resources for agriculture. To address concerns about high nutrient loading from stormwater and provide an alternative source, this study aimed to evaluate the performance of a standard infiltration trench stormwater control measure (SCM) and two additional modifying components: an iron-modified geotextile (FeGeotex) and iron-enhanced sand. These designs were tested independently within a lab-scale infiltration trench (8.0 ft [2.44m] x 2.5 ft [0.76 m] x 4.0 ft [1.22 m]) with synthetic stormwater under low-concentration (blank), stormwater-concentration (dosed), and high-concentration (stress) conditions. The concentrations of nitrogen and phosphorus in the outflow were measured and compared with those in the inflow to determine removal rates. The rates were compared using an ANOVA and a two-means t-test. Testing showed that changing the designs had no significant impact on nitrogen removal under blank, dosed, or stress conditions. The standard infiltration trench had average phosphorus removal rates of -4.3% (leached), 32.2%, and 40.2% for the blank, dosed, and stress conditions, respectively. The iron-enhanced sand showed the greatest phosphorus removal across all three conditions, with average removal rates of 38.9%, 76.9%, and 82.1% for the blank, dosed, and stress conditions,

respectively. The FeGeotex had significantly greater removal than the standard under both blank and dosed conditions, with removals of 13.8% and 42.5%, but was not significantly different from the standard under stress conditions, with 43.9% removal. All three designs proved capable of recovering phosphorus for reuse. The geotextile from the standard design recovered 0.033 mg-P/g-geotextile. The FeGeotex recovered 0.059 mg-P/g-geotextile, the top geotextile from the iron-enhanced sand design recovered 0.053 mg-P/g-geotextile, the iron-enhanced sand recovered 0.075 mg-P/g-media, and the bottom geotextile from the iron-enhanced sand design had the greatest phosphorus recovery with 0.102 mg-P/g-geotextile. Both modification components proved capable of enhancing phosphorus removal and providing phosphorus for reuse, with the iron-enhanced sand performing best for both criteria.

To remove sediment from runoff and prevent loss of sediment off-site, perimeter controls, such as sediment barriers, are typically implemented. To evaluate sediment barriers and compare their performance under different conditions, testing was conducted at the Auburn University – Stormwater Research Facility. Testing was conducted on two novel products: Product A and Product B, and three standard practices: silt fence, compost socks, and straw wattles. The silt fence and both products were subjected to triplicate back-to-back simulated storms for each of three installations, and Product A, the compost socks, and straw wattles were subjected to a single storm for each of three installations, as well as installed with additional impoundment area. For the triplicate testing, the silt fence had the greatest average sediment capture at 97%, followed by Product B at 88% and Product A at 74%. For single-storm testing, the compost sock had the highest sediment capture at 95%, followed by the straw wattle and Product A, both at 90%. A comparison of sediment capture for Product A under both testing regimes showed that the product performs statistically better with an increased impoundment area and with sufficient maintenance. A comparison of performance between the products and prior testing on various wattle designs and installation methods showed no significant difference in sediment capture. This testing showed that the products perform effectively and are similar to standard practices when installed correctly and maintained regularly.

These findings indicate that enhanced nutrient removal and recovery for reuse is plausible using iron-based modifying components, especially iron-enhanced sand. Testing of sediment barrier products and standard practices showed that installation and practice selection are important for effective use of sediment barriers as perimeter controls on construction sites.

Artificial Intelligence (AI) Use Disclosure Statement

In the preparation of this thesis, the following Artificial Intelligence (AI) tools were used: Grammarly and Microsoft Word. Grammarly was used primarily to aid with grammar, spell checking, and sentence structure. Microsoft Word was used to help guide the creation of alt text for figures. The author acknowledges full responsibility for the intellectual content of this work and has ensured that all AI-assisted sections have been reviewed and revised for accuracy and appropriate academic style. All AI-generated content was reviewed and validated for relevance, appropriateness, and accuracy before incorporation into the final document to maintain scholarly integrity of this research.

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Chapter One: Introduction

1.1 Background

Precipitation comes in many forms, including rain, snow, hail, etc., and occurs nearly everywhere on Earth with only a few exceptions. The contiguous United States on average receives enough precipitation to cover the lower 48 states in 30 in. (76.2 cm) of water each year, equivalent to 1,430 mi^3 (5960.5 km^3) of water; roughly enough to fill 2.384 billion Olympic swimming pools to a depth of 6.5 ft (2 m) (USGS 2019). Stormwater provides the fresh water necessary to most life on land; however, it also brings several potential challenges. These problems include flooding, erosion, and transport of sediment and other pollutants. Increased urbanization, especially within the U.S., has exacerbated these challenges. Urbanization increases impervious surface areas, leading to faster, larger runoff volumes that cause flooding and increased pollutant loads. Urbanization also leads to the clearing of vegetation for construction, prompting increased erosion and sediment loss from rainfall.

An estimated 2.4% of the U.S. consists of impervious cover, with that rising to 25.5% in urban areas (Nowak and Greenfield 2012). Increases in impervious cover limit the infiltration of stormwater into the ground and its uptake by vegetation. Stormwater runoff volumes increase from the loss of infiltration and evapotranspiration (Shuster et al. 2005). Increases in pollutant loading from impermeable surfaces, which are carried into natural water bodies, have also been observed. As stormwater runoff flows across impervious surfaces, it picks up pollutants such as nutrients, hydrocarbons, sediment, pesticides, and bacteria (Chithra et al. 2015). When untreated pollutants are directed into natural water bodies, they accumulate and increase in concentrations, negatively impacting human health, aquatic ecosystems, drinking water treatment, aquaculture, and recreation (US EPA 2025).

Urbanization requires large-scale land clearing for new construction, exposing large areas to erosion and risking topsoil loss from storm events. In March 2026, the U.S. Census Bureau estimated that total spending on construction in the U.S. was at an annual rate of $2.185 trillion (U.S. Census Bureau 2026). Initial stages of construction include clearing and grubbing natural vegetation or removing and demolishing existing infrastructure. This typically leaves bare soil exposed for long periods. The lack of cover and compaction of soils from equipment and prior infrastructure creates conditions for high rates of erosion and sediment loss off-site. Once vegetation is removed, there is no longer a protective cover or root system to hold the soil together and prevent erosion. Compacted soils prevent infiltration, leading to increased runoff volumes and velocities capable of intercepting and carrying sediment. Sediment has been classified by the U.S. Environmental Protection Agency (EPA) as the most common pollutant impacting natural waterbodies in the U.S. (USEPA 2010). Suspended sediment can cause many issues in natural waterways, including harming aquatic organisms and altering the natural flow of rivers and streams.

1.2 Stormwater Control Measures (SCMs)

To help establish methods for the protection of natural waterways in the U.S., the U.S. Congress passed the Clean Water Act (CWA) of 1972. The CWA established regulations for the discharge of pollutants into the waters of the United States (WOTUS) to restore and maintain the integrity of the WOTUS with the end goal of having all waters swimmable and fishable by 1983 (U.S. Congress 1972). Although the CWA's goals have passed their deadlines, the regulations established under the CWA remain in place. This includes the creation of the National Pollutant Discharge Elimination System (NPDES), which regulates the discharge of point-source pollution into U.S. waterways through a permitting system. The NPDES covers the discharge of stormwater from industrial sources, municipal separate storm sewer systems (MS4s), and construction sources (USEPA 2026). These regulations have led to the creation of various stormwater control measures. Stormwater control measures (SCMs) vary widely in their implementation and purpose.

SCMs can be broadly divided into construction best management practices (BMPs) and post-construction BMPs. Construction BMPs, also known as erosion and sediment control (E&SC) measures, target the prevention of soil erosion, the containment of on-site sediment, and the limitation of sediment transport off-site if it is picked up in stormwater runoff. The NPDES regulates the implementation of E&SC practices through the requirement of a Construction General Permit. A Construction General Permit is required for any activity on a construction site that disturbs over 1 acre (0.4 ha) of land or less than 1 acre (0.4 ha) but is part of a common development larger than 1 acre (0.4 ha) in total (USEPA 2022). Sites meeting these criteria must create a Stormwater Pollution Prevention Plan (SWPPP) that outlines the measures taken to prevent point-source pollution from stormwater. The SWPPP includes ESC practices that limit the movement of pollutants such as sediment and nutrients off-site and into natural bodies of water. This is done through a variety of strategies, including detention ponds, rolled erosion control products (RECPs), sediment barriers, and more, with the consistent goal of slowing runoff to reduce erosion and promote sedimentation.

Once construction of a site is complete and permanent stabilization has been installed, additional post-construction BMPs are implemented. Post-construction BMPs are necessary to control excess runoff from impervious surfaces to prevent flooding, as well as to treat pollutants before they enter the storm sewer system or natural body of water. Traditionally, post-construction BMPs focused on detaining water and reducing peak flows to manage and prevent flooding. Traditional practices include the use of dry or wet detention ponds to temporarily detain runoff and attenuate downstream flow in a watershed (Yang and Lusk 2018). In recent decades, however, alternative practices have grown in popularity, considering improving water quality in addition to managing volume. There are several categories and names for these practices, but they typically fall under green infrastructure (GI) or low-impact development (LID).

1.3 Green Infrastructure and Low Impact Development

GI/LID are both stormwater management strategies that focus on managing runoff and reducing pollutant loads in an environmentally friendly and cost-effective manner. GI is a broader category that includes infrastructure utilizing nature-based solutions to treat stormwater through evapotranspiration, infiltration, and filtration (USEPA 2025). GI also includes a wider variety of practices that are not for stormwater management, but for ecosystem protection or establishment, watershed management, or improving air quality. LID is typically defined as strategies or practices utilized on-site and close to the runoff source, designed to limit the post-development impact on site hydrology through reductions in stormwater runoff flow and velocity, and removal of pollutants (Zhang and Chui 2018). In the discussion of stormwater management, these strategies are typically referred to interchangeably and will be used synonymously in this report (Fletcher et al. 2015).

GI/LID both aim to manage stormwater in a decentralized manner, using strategies that work with or employ natural solutions that filter or infiltrate runoff. There is a wide variety of practices that are considered GI/LID; among the most common are bioretention cells, rain gardens, infiltration trenches, permeable/porous pavements, and green roofs. These practices are incorporated on a site-by-site basis, tailored to each site's needs, and work together to mimic the site's natural hydrology, reducing runoff and removing pollutants (USEPA 2018).

1.4 Sediment Barriers

A sediment barrier is a construction stormwater BMP that is installed temporarily during construction downstream of active work or an area of bare sediment to retain sediment on-site through impoundment and sedimentation, or, to a smaller degree, filtration and entrapment of sediment particles (Bugg et al. 2017). Sediment barriers are a sediment control practice that targets the removal of sediment already suspended in runoff before it leaves the site, as opposed to an erosion control practice, which prevents or limits erosion. Sediment barriers are typically implemented as perimeter controls, lining the outskirts of disturbed areas on sites. They often act as the last line of protection at the edge of sites, preventing sediment-laden water from being discharged offsite (Whitman et al. 2019b). Sediment barriers are often used in conjunction with other practices, such as sediment basins, erosion control blankets, or mulching, to ensure adequate site protection.

Sediment barriers vary widely in design, materials, and implementation, so proper installation is critical to ensure effective barriers. Their performance is based on effective impoundment of water, controlled dewatering, and adequate maintenance (Whitman et al. 2018). Since each practice or product differs from another, adequate understanding and installation of a sediment barrier are necessary to implement the best practices in the right situations. Proper design and implementation reduce the chances of sediment discharge off-site and decrease installation and maintenance costs.

1.5 Research Objectives

The research for this thesis consisted of two main objectives: to evaluate nutrient and sediment removal from E&SC practices and post-construction BMPs. The specific objectives for this study include:

1. Develop a method of implementation for an iron-modified geotextile (FeGeotex) in a post-construction BMP to maximize nutrient removal for phosphorus and nitrogen, with the ability to recover the geotextile for potential nutrient recovery and reuse.
2. Conduct large-scale testing on novel sediment barrier products under Alabama runoff conditions to evaluate sediment removal and water quality improvements and compare to results from additional testing of standard practices under the same conditions.

To meet these objectives, a plan of study was created as follows:

1. Conduct a comprehensive literature review on the utilization of geotextile in post-construction BMPs, specifically GI/LID, the ability of standard

GI/LID practices to remove phosphorus and nitrogen, what modifications have been studied before to enhance the removal of these nutrients, and prior studies and testing on sediment barrier practices and products.

2. Develop testing methodology for the implementation and evaluation of the FeGeotex and other modifications within a selected BMP, determined utilizing information found in the literature review.
3. Develop methodology for the large-scale testing of sediment barrier practices under conditions found in Alabama, for single and multiple storm events. The testing conditions, including sediment introduction and flow rate, and recorded variables were determined from the literature review.
4. Conduct pilot-scale testing of standard BMP and modifications to BMP, including FeGeotex, determining removal efficiencies of nitrogen and phosphorus under multiple inflow conditions for each flow rate.
5. Conduct large-scale testing of novel sediment barrier products and standard practices under conditions found in Alabama, at the Auburn University – Stormwater Research Facility (AU-SRF). Testing will be conducted on installations under one simulated storm event, as well as multiple storm events back-to-back.

1.6 Expected Outcomes

The outcomes of this research aim to enhance the stormwater and E&SC industries' ability to remove pollutants from stormwater runoff and improve water quality across the United States. The scientific data and results collected from lab-scale testing on nutrient removal will be used to provide recommended modifications to post-construction BMPs to improve targeted removal of nitrogen or phosphorus. This testing will also provide the feasibility of the recovery of phosphorus using a BMP as an alternative nutrient source. Large-scale testing of sediment barrier products provides a scientific analysis of sediment barriers and how products compare to standard practices, allowing for strengthened confidence and utilization of sediment barriers. Sediment capture and water quality results will provide guidance on where and when sediment barrier practices can be most effectively implemented and utilized. Overall, this study will enhance guidance on improving the removal of pollutants from stormwater, as well as recommend further research into improving the design and implementation of current BMPs to reduce the impact of urbanization on water quality.

1.7 Organization of Thesis

This thesis is divided into four distinct chapters that outline the process followed and the results obtained to achieve the previously outlined research objectives. Following this introduction chapter, Chapter Two: *Evaluating Components on Stormwater Control Measures for Removal and Recovery of Nutrients*, discusses previous studies on the removal capabilities of standard GI/LID practices, and the testing and results of implementing FeGeotex and other modifications in a chosen BMP to improve nutrient removal and possible recovery. Chapter Three: *Full-Scale Performance Evaluation of Sediment Barrier Products and Practices* discusses a review of testing previously conducted on sediment barrier practices and products, a review of the testing methodology developed for the analysis of the chosen novel products tested, the testing results, and a comparison of performance. Chapter Four: *Conclusions and Recommendations* provides a summary of the findings from this study, recommendations for implementing improvements determined for BMP nutrient removal and sediment barrier implementation, and identification of potential areas for further study to continue improving stormwater management.

Chapter Two: Evaluating Components on Stormwater Control Measures for Removal and Recovery of Nutrients

2.1 Introduction

Modern stormwater management targets reductions in runoff volume and velocity, and also treats pollutants picked up from impervious surfaces. While stormwater management aims to reduce nutrient loading, current research has not examined the potential recovery of these valuable nutrients alongside their removal. GI/LID practices currently vary in their ability to remove nutrients, and none currently offer the potential to recover those nutrients. Nutrients, especially phosphorus, are highly utilized and critical resources, and their recovery from stormwater would provide a valuable alternative source. This chapter outlines the importance of nutrients, the dangers they pose when present in excess, current nutrient management in GI/LID systems, and testing to implement modified components for enhanced nutrient removal and potential recovery for reuse.

2.2 Literature Review

The following section outlines a review of nutrient use as a resource, the problems nutrients pose as pollutants when in excess, the current ability of GI/LID practices to remove nutrients, and studies on possible modifications to improve nutrient removal. A review of typical GI/LID practices, including whether they include geotextiles, was conducted to guide the decision on which practice to test for enhanced nutrient removal and recovery.

2.2.1 Nutrients as a Resource

Nutrients are a vital, heavily used, and limited resource that could possibly be recovered from stormwater. Nutrients such as nitrogen and phosphorus play an important role in feeding a growing U.S. and global population, as they are essential for fertilizer in agriculture. In the U.S. alone, approximately 25 million tons (23 million tonnes) of phosphate rock were consumed throughout 2024. Phosphorus consumption comes primarily from use in fertilizers and animal feed supplements (U.S. Geological Survey 2025). Globally, approximately 51 million tons (46 million tonnes) of phosphorus and 120 million tons (109 million tonnes) of nitrogen were used in fertilizer for agricultural production in 2021, and the usage of both nutrients in fertilizer has been trending up, especially in Africa and South America (Food and Agriculture Organization of the United Nations 2023). There is no substitute available for phosphorus in fertilizer, as it is an essential nutrient for plant growth. Access to phosphorus is important for sustained modern agricultural practices; however, phosphorus availability varies globally. There are an estimated 82 million tons (74 million tonnes) of phosphate rock reserves worldwide; however, Morocco alone holds 67% of those reserves, with the top 7 countries accounting for 85% of global reserves (U.S. Geological Survey 2025). Morocco has twice the phosphate reserves of every other country on earth combined. Phosphate reserves are primarily mined using open-pit methods, which leave large scars on the land, as shown in Figure 2.1 of a Florida mine (Geissler et al. 2018). Since phosphorus is both a vital and limited resource that must currently be mined in unsustainable ways, research has been conducted to develop new methods and sources of phosphorus. One such study demonstrated the successful recovery of phosphorus from iron- and slag-amended soils (Wilson et al. 2025). This provides the opportunity to remove and recover phosphorus from stormwater utilizing GI/LID.

Figure 2.1: Photo of Phosphate Mine in Florida (Lopez and Center for Biological Diversity 2016)

2.2.2 Nutrients as a Pollutant

Alternatively, excess nutrients pose dangers to both the natural environment and human health. When infants ingest high concentrations of nitrate, it can lead to methemoglobinemia, or “blue baby syndrome,” which limits the ability of blood cells to transport oxygen throughout the body. High nitrogen concentrations have also been known to increase the risk of cancer and have negative reproductive effects (Dubrovsky et al. 2010). Increasing nutrient concentrations in waterbodies across the United States force drinking water treatment plants to work harder and use more expensive technologies to reduce these nutrients to safer levels (Mishra and Tripathi 2023). Excess nutrients also pose risks to aquatic ecosystems. They can cause eutrophication, in which excess nutrients promote rapid growth of plant life or microorganisms, which then deplete oxygen concentrations as they decay and are subsequently consumed by aerobic bacteria. Low oxygen concentrations kill many organisms that rely on dissolved oxygen in the water, creating dead zones, such as the one found in the Gulf of Mexico (Rabalais et al. 2002). In addition, excess nutrients can promote harmful algal blooms, in which toxin-producing algae take advantage of excess nutrients to rapidly grow and reproduce, taking over large areas of water. These toxins can harm human health if precautions are not taken (Dubrovsky et al. 2010). These impacts also have an economic cost. Dead zones limit the ability of fisheries to operate productively and harm tourism in surrounding areas. In one dead zone in the Black Sea, the value of fishing companies decreased by 90%, and they lost approximately $500 million in tourism revenue (Rabotyagov et al. 2012).

2.2.3 Nutrient Removal from Stormwater

Currently, a wide range of strategies are implemented to manage stormwater runoff and treat it for pollutants, such as nutrients. Many traditional strategies and practices emerged from an initial goal of managing stormwater and preventing downstream flooding by providing detention or directing flows from large storm events. Practices included in this category are dry stormwater ponds, wet stormwater ponds, and swales or grass channels. These practices primarily function by retaining stormwater to prevent flooding and mitigate downstream water quality issues. These measures do not necessarily focus on treating retained water. Practices can remove some nutrients depending on their implementation, but have also been shown to export more nutrients than were found in incoming runoff (Yang and Lusk 2018). Traditional practices, however, are typically easier to construct and install due to their simplicity and historical use and implementation.

More traditional strategies vary from more recent “alternative” practices, ranging from stormwater BMPs to GI/LID. These practices tend to focus on improved water management and space utilization (Yang and Lusk 2018). Alternative stormwater practices, including GI/LID, are intended to keep stormwater on site while managing volume and improving water quality. Infiltration trenches, bioretention cells/rain gardens, and permeable/porous pavements are a few examples of common GI/LID practices employed to manage stormwater. The primary goal of these practices is to manage the stormwater in a manner that more naturally imitates the original land (Ahiablame et al. 2012). This includes promoting infiltration of stormwater into the groundwater table, as well as treatment of the water by filtration and chemical or biological sequestration of pollutants (Yang and Lusk 2018). These practices typically have improved nutrient removal capabilities compared to traditional practices, thereby providing greater benefits to both human and environmental health through cleaner waters. One downside of these practices is that they tend to be more expensive and more complicated to design and implement. This is primarily due to the wide variety of GI/LID practices available and the different settings in which they would be more effective, often involving plants or more complex features. Both traditional and alternative strategies have undergone numerous studies evaluating their respective abilities to treat and manage stormwater for both water quantity and quality.

One common traditional stormwater management practice is the wet and/or dry stormwater pond. The primary purpose of these ponds is to detain large volumes of stormwater to prevent downstream flooding and to minimize peak flows from impervious areas. An example of a wet pond is shown in Figure 2.2. Studies have shown that these ponds have very limited nutrient removal, around 30% for both nitrogen and phosphorus, with a large variation in that removal (Yang and Lusk 2018). The size and configuration of the pond play a large part in its ability to remove nutrients. Larger ponds, which are common and used to capture sediment and reduce peak flows, tend to struggle to remove nutrients, especially nitrogen, because the deepest sections lack oxygen and limit denitrification (Koch et al. 2014). As these ponds age, they typically receive limited maintenance. As debris and trash accumulate, they can even become a source of nutrients rather than a sink. Wet ponds have been found to improve nutrient removal. This is likely due to a longer water residence time, allowing time for settling of particle-bound nutrients and adsorption of dissolved nutrients (Yang and Lusk 2018). Since these ponds do not filter the water, they rely primarily on sedimentation and biological nutrient removal, which can be limited by short detention times.

Figure 2.2: Wet Pond SCM (MnDOT 2024)

Grassed swales or vegetated channels are channels typically located along a roadway that collect and direct stormwater runoff. Swales promote infiltration and treat runoff through filtration and biological uptake. Vegetated swales enhance swales with plants to promote infiltration and handle runoff (Ahiablame et al. 2012). A vegetated swale is shown in Figure 2.3 below. The ability of swales to remove nutrients and other pollutants varies depending on their design and implementation. The slope, vegetation type, vegetation cover, and the length of the swale play an important role in the swale's ability to remove nutrients (Boger et al. 2018). The retention of nutrients was found to vary widely, ranging from 14% to 98% (Ahiablame et al. 2012). Nitrogen removal was typically moderate; however, phosphorus concentrations were sometimes observed to increase, likely due to phosphorus in vegetation used in the swales (Leroy et al. 2016). Swales with denser and taller vegetation tend to improve removal more than those with sparse vegetation. Swales were also observed to accumulate pollutants during dry periods and to export higher nutrient concentrations after longer dry periods (Boger et al. 2018). The main challenge with nutrient removal in vegetated swales is the short detention time and the rapid water movement through them, which limit the ability of nutrients to settle out or be biologically absorbed.

Figure 2.3: Vegetated Swale at Hickory Dickory Park, Auburn, AL

Bioretention cells and rain gardens are GI/LID practices that consist of shallow depressions in the ground, typically filled with engineered media and plants or other vegetation. These systems temporarily detain and slowly filter stormwater as it flows through the media. Bioretention cells and rain gardens are implemented with both water quality and aesthetics in mind for their functionality (Shrestha et al. 2018). A picture of a bioretention cell is shown in Figure 2.4 below. These practices rely on ecological principles and processes to remove nutrients and other pollutants from stormwater (Luo et al. 2020). The design of these practices relies on the characteristics of the surrounding soils. If soil is limiting infiltration, an underdrain may be required to prevent flooding of the cell. Removal of nutrients using these practices has been shown to be effective, with phosphorus removal around 80% of total phosphorus and 60% of total nitrogen (Ahiablame et al. 2012). The removal of nitrogen varies widely depending on the cell design. If the bioretention cell has adequate depth or an underdrain above the bottom of the cell, a saturated zone is formed, allowing for further treatment and removal of total nitrogen (Shrestha et al. 2018). Bioretention systems can also act as net exporters of nutrients under certain conditions if poorly implemented and maintained. Bioretention cells can struggle to handle large rainfall events and often leach nutrients from plant matter in the cells, which are carried off with large runoff volumes (Luo et al. 2020). The cells will also serve as a source of nutrients if vegetation is in poor health or in colder climates, where vegetation may go dormant. In both cases, the vegetation may take up minimal or no nutrients.

Figure 2.4: Bioretention Cell at Hickory Dickory Park, Auburn, AL

Permeable and porous pavements are LID practices that typically consist of a porous surface or impervious pavers with aggregate or spacing in between. They are designed to allow water to infiltrate into the base layer as it runs along the roadway surface, and to temporarily detain it before infiltrating into the ground or flowing to a secondary system (Yang and Lusk 2018). An example of a permeable pavement system is shown in Figure 2.5. The treatment from a permeable and porous pavement system primarily depends on the base layer or media used beneath the top surface. This layer filters the runoff before it infiltrates back into the ground or continues flowing downstream. These practices have been shown to remove up to 60% of total nitrogen and 80% of phosphorus; however, this was primarily due to sediment-bound nutrient removal, with most dissolved forms passing through (Winston et al. 2020). This is likely due to the low detention time in these systems, which results in sedimentation as the primary removal mechanism in the pavement base. The removal of nutrients using permeable pavers has been improved using different media, including aluminum from water treatment residuals. This media demonstrated consistent nutrient removal with typical substrates, with enhanced dissolved nutrient removal (Ostrom and Davis 2019). Other modifications, such as internal water storage layers and secondary treatment systems, offer potential for improved nutrient removal for these systems after the water has infiltrated off the roadway.

Figure 2.5: Permeable Pavers Parking Lot (US EPA 2022)

Green roofs are a GI/LID practice that involves applying vegetated media on the roof of a building or over an impervious area to detain and store rainfall, thereby limiting immediate runoff from the otherwise impervious surface. In densely urban areas, green roofs provide rainfall storage, preventing excess runoff from roadways and limiting nutrient loading (Ahiablame et al. 2012). There are two classifications of green roofs: extensive and intensive. Intensive describes a green roof with a thicker media layer and much larger vegetation, such as trees. Extensive green roofs have a much thinner media layer and typically feature lighter-weight vegetation such as grass or shrubs (Ahiablame et al. 2012). The ability of green roofs to reduce nutrient loading is difficult to determine and has had conflicting results. Some studies have shown that green roofs can be a source of nutrients due to fertilizer use and vegetation decomposition. Conversely, some studies have shown that with high rainwater retention, green roofs have lower nutrient concentrations in their effluent than typical roofs (Gong et al. 2020). While green roofs reduce runoff volumes and velocities, they can be expensive to implement and do not necessarily reduce nutrient loads from runoff.

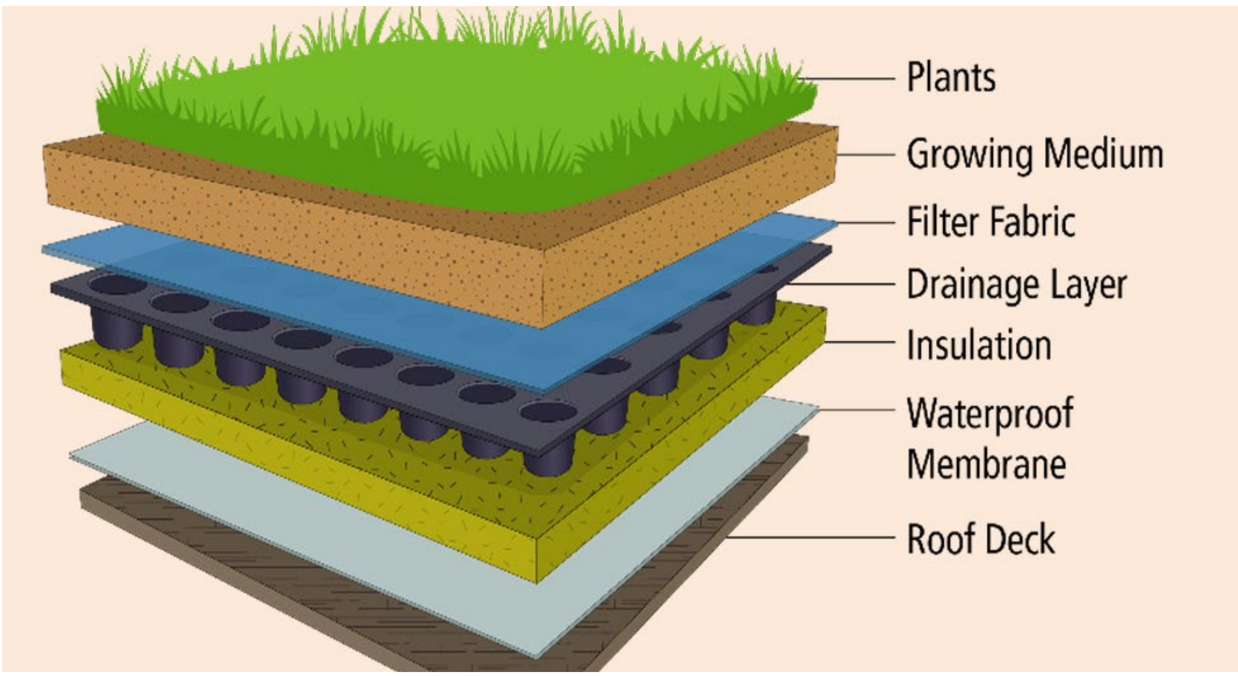


Figure 2.6: Cross Section of a Green Roof Design (US EPA 2021a)

Infiltration trenches are a LID measure designed to mimic infiltration at a site before its natural hydrology is altered by increased impervious areas. These practices primarily consist of a trench dug along the roadside, backfilled with gravel/rock, and covered with either sod or smaller gravel. The aim is to provide a storage area for runoff to collect and slowly infiltrate back into the ground. A cross-section outlining the design of an infiltration trench is shown in Figure 2.7. The efficacy of an infiltration trench relies heavily on the surrounding soil. Soils with higher infiltration rates support the function of the trench, but soils with lower void spaces and infiltration rates may require an additional underdrain or prohibit the use of an infiltration trench (Chahar et al. 2012).

When infiltration trenches are properly implemented, they have been shown to achieve around 83% nutrient removal and up to 100% with smaller rain events (Maniquiz et al. 2010). Infiltration trenches are effective for nutrient removal; however, several potential problems are associated with their use. Infiltration trenches are prone to clogging with sediment, severely hindering their ability to function effectively (Chahar et al. 2012). Another issue is the potential for groundwater contamination from rapid stormwater infiltration, especially in areas with high water tables. This may pose potential human health issues in areas that rely on groundwater as their source of potable water.

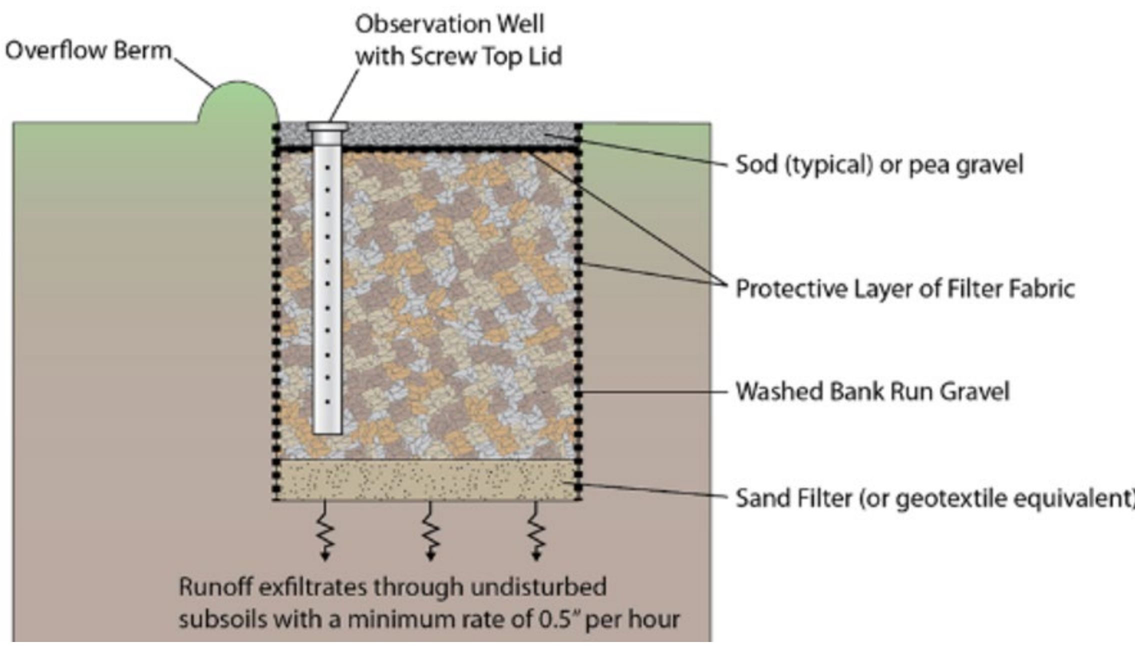


Figure 2.7: Cross Section of an Infiltration Trench Design (GDOT 2023)

2.2.4 Incorporation of Geotextile in Stormwater Control Measures

Geotextile is a highly versatile material used in a wide range of civil engineering applications. A multitude of geotextiles exist for these various purposes, varying by different categories of properties, including physical, mechanical, hydraulic, degradation, and endurance (Agrawal 2011). Wilson et al. developed a geotextile modified with iron embedded in its fiber matrix (FeGeotex) was developed to enable the removal and recovery of phosphorus (Wilson et al. 2025). To determine the best way to implement this geotextile in a stormwater control measure, a review of the Georgia Department of Transportation (GDOT) Stormwater Design Guide and the Alabama LID Handbook was conducted to identify which practices use geotextile and where they are used (ADEM 2014; GDOT 2023). This review helped guide the methodology for implementing the modified geotextile and other components evaluated.

In the Alabama LID Handbook, the evaluated practices include permeable pavements, bioretention cells, and green roofs. Permeable pavements typically contain a geotextile to separate the base layer of rock from the underlying soils beneath the practice. This is done for both hydraulic and structural reasons. The geotextile provides adequate drainage to the groundwater table and prevents the gravel base from settling into the underlying soils. Bioretention cells sometimes incorporate geotextile as a bottom layer separating the cell media from the native soil; however, this can limit root growth and water infiltration. Incorporating a geotextile is more feasible in a cell with an underdrain to help prevent prolonged ponding. Green roofs incorporate geotextile as the separation layer between the substrate that supports vegetation and the drainage mat or layer, preventing ponding and promoting drainage of excess water. The geotextile prevents the substrate from clogging the drainage layer and prevents root growth into the drainage layer and the roof surface (ADEM 2014).

For the GDOT Stormwater Design Guide, the following practices were evaluated for their incorporation and use of geotextile: bioretention cells, sand filters, and infiltration trenches. Bioretention cells, like the AL LID Handbook design, incorporate geotextile as a separating layer between the media and the native soil; however, they are also recommended for separating the media from the aggregate layer around an underdrain, provided the underdrain has a sufficient flow-through rate. Sand filters incorporate geotextile as a separation layer between the engineered soil mix surface layer and the sand filter bed, and to separate the underdrain system from the sand bed. Geotextile serves the same purpose at both locations: preventing clogging and migration of media components. Infiltration trenches use geotextiles in a very similar manner to sand filters, as a separation layer between the surface pea gravel or sod layer and the aggregate storage layer, or between the trench side walls and the surrounding native soil. This is primarily to keep the infiltration trench separate from the surrounding soil and prevent the aggregate layer from clogging (GDOT 2023).

2.2.5 Components for Enhanced Nutrient Removal

Various studies have evaluated the incorporation of different or modified components into SCMs to enhance the removal of pollutants, such as nutrients. One study by Wilson et al. investigated the removal and recovery of phosphorus from iron- and slag-amended GI soils (Wilson et al. 2025). This study indicated that iron- or slag-amended media could capture 0.746 mg-P per gram of media and 0.036 mg P per gram of media, respectively. The study also proved that an average recovery of 43% of phosphorus is possible from the amended media for reuse. This study proves that iron is a component that can improve phosphorus removal from stormwater and can be used as an alternative phosphorus source for reuse (Wilson et al. 2025). The iron-amended media consisted of iron in the form of iron hydroxide ($Fe(OH)_2$ and $Fe(OH)_3$).

Another common method for enhancing phosphorus removal is the use of iron-enhanced sand filters. Iron-enhanced sand filters consist of standard sand filter media with added iron filings. The Minnesota Department of Transportation (MnDOT) includes specifications for an iron-enhanced sand filter that outlines a sand filter bed containing a minimum of 5% and a maximum of 8% by weight of iron filings mixed into the sand media. The iron filings should be approximately 90% elemental iron (Fe^{3+}) and should be of a similar size to the sand (MnDOT 2024). According to MnDOT, the estimated pollutant removal for an iron-enhanced sand filter is 74% of the total phosphorus (TP), 85% of particulate phosphorus (PP), 60 % of dissolved phosphorus (DP), and 35% of total nitrogen (TN) (MnDOT 2024). One study on the capture of phosphates using iron-enhanced sand filters by Erickson et al. investigated the removal of phosphates by iron-enhanced sand filters and found that they remove an average of 88% of TP with only 5% iron filings by mass (Erickson et al. 2012). Based on these results, the study recommends the implementation of iron filings, or iron-sand media, in more stormwater practices where additional phosphorus removal is required.

2.2.6 Nutrient Removal Mechanisms

Nutrient removal has primarily been studied for water and wastewater treatment plants. Removal of nutrients is done utilizing one or a combination of three methods: physical, chemical, or biological. A growing focus has been on recovering nutrients, specifically phosphorus, in addition to their removal for reuse. Some of the more commonly implemented technologies for phosphorus removal include chemical precipitation, ion exchange, and adsorption (Zahed et al. 2022). Biological treatment methods for removing phosphorus typically use microorganisms and can be more sustainable than physicochemical methods. These strategies can be limited at lower concentrations due to microbial metabolic requirements. Physicochemical treatments have become more popular for enhancing phosphorus removal and enabling the possible recovery of phosphorus. Common physicochemical treatments include precipitation, ion exchange, and adsorption (Zahed et al. 2022). The primary removal methods considered in this study were precipitation and adsorption.

Adsorption is a method that follows a group of processes, including adsorption and precipitation. The pollutant is pulled out of the solution, adsorbed onto the sorbent surface, and moved within the sorbent material (Zahed et al. 2022). An effective sorbent provides a high surface area for interactions and a high adsorption capacity. Chemical precipitation, also known as crystallization, is a process in which the addition of a mineral or salt causes phosphate concentrations to spontaneously reach a supersaturation and precipitate out of solution (Zangarini et al. 2020). Some common chemicals used to precipitate phosphorus include iron (II), iron (III), aluminum, and calcium (Thistleton et al. 2002).

2.3 Materials and Methodology for Nutrient Removal Testing.

This section outlines the methodology developed to evaluate the nutrient-removal capacities of different components added to a stormwater control measure. This includes the choice of SCM, the design and construction of the testing apparatus, the testing methodology, the testing regime, and the analysis methods. The objective of this testing was to determine which component provides the best nutrient removal when implemented in the SCM.

2.3.1 SCM Selection

The selection of the SCM for evaluating components for enhanced nutrient removal was based on a literature review of GI/LID practices that incorporate geotextiles. The practices considered for implementation include permeable pavers, bioretention cells, green roofs, sand filters, and infiltration trenches. The bioretention cell and permeable pavers were deemed unfeasible for testing due to the geotextile's location in both designs. The geotextile in a bioretention cell is the very base layer, if included, and this is covered by layers of media and vegetation. This would make the removal of FeGeotex for phosphorus recovery expensive and unsustainable. Bioretention cells also have proven nutrient-removal capabilities through plant uptake and media adsorption, so a geotextile layer at the bottom of the design is unlikely to improve removal. In permeable pavements, the geotextile is located closer to the surface; however, recovering it would require removing and replacing all pavers, which would be costly and inefficient. Permeable pavers also see high concentrations of hydrocarbons from vehicles, which may inhibit nutrient removal.

Green roofs were determined to be ineffective SCMs for implementation for several reasons. One reason is that green roofs don't typically manage runoff; they only handle direct rainfall, limiting the amount of nutrients they interact with. The only nutrients the geotextile would remove would be those leaching from the vegetation or media incorporated into the green roof design. Another reason the green roof was deemed unfeasible was the vegetation and media cover over the geotextile layer. This would make geotextile recovery difficult without damaging the vegetation or requiring media replacement. A modular green roof was considered to facilitate recovery of the geotextile; however, limited nutrient treatment would reduce its effectiveness and limit possible nutrient recovery, which dissuaded further investigation.

Sand filters do have a geotextile near the surface, making recovery feasible; however, they are prone to clogging without adequate pretreatment. Sand filters also effectively remove nutrients without modification. Clogging of the FeGeotex in the sand filter could impair its ability to allow flow through and limit nutrient removal. Sand filters can be limited in their treatment volume due to slower treatment rates. While sand filters were generally a good fit for implementation, they were ultimately not chosen due to concerns about clogging, slower treatment rates, and their already effective nutrient removal.

The SCM chosen for implementation and further testing was the infiltration trench, specifically the GDOT design. The infiltration trench was chosen for implementation for several reasons. This includes the geotextile being located near the top of the design, allowing for easier recovery of the geotextile and captured nutrients. The infiltration trench provides a large storage and fast treatment of runoff, allowing components tested to have more opportunities to interact with nutrient-laden water. The infiltration trench also has a relatively quick dewatering time, allowing for efficient testing. Since infiltration trenches have minimal nutrient removal from the media itself, testing in an infiltration trench would help isolate the performance of components installed in addition to the standard media.

2.3.2 FeGeotex Fabrication

Large-scale FeGeotex fabrication was conducted in the laboratory of Dr. Kaushik Venkiteshwaran at the University of South Alabama, Mobile, Alabama. A 33 x 3 ft (10 x 0.9 m) section of 8 oz (227 g) non-woven geotextile (Supergeotextile, Inc.) was cut into 8 sections, each approximately 4 x 3 ft (1.2 x 0.9 m). The four fabric sections were secured to a custom support frame and positioned parallel to one another. The frame was then placed inside a 165-gal (625 L) Uline tote containing 100 gal (379 L) of tap water and ~ 7 kg of $FeCl_3 \cdot 5H_2O$. The solution was mixed for 2 hrs. using four drill mixers fitted with concrete mixing paddles.

Following initial mixing, 10 N NaOH was gradually introduced using a peristaltic pump. The initial solution pH was approximately 2.0, and NaOH was added over approximately 4 hours until the pH reached 8.3. The fabrics remained immersed in the resulting iron-precipitate suspension overnight at a pH of 8.3-8.5. The frame and fabrics were subsequently transferred to a second 165-gal (625 L) tote containing 100 gal (379 L) of clean tap water and mixed for an additional 2 hours to remove loosely attached iron particles.

The frame was slowly removed and suspended above the rinse tote to allow excess water to drain. A fan was used to dry the fabrics at room temperature for more than 24 hrs. Small fabric samples were randomly collected from each of the 8 sections for iron analysis. The measured iron impregnation ranged from 45 to 87 mg Fe/g FeGeotex. After drying and characterization, the FeGeotex sections were sealed in plastic bags for delivery to the Auburn University - Stormwater Research Facility for further testing.

2.3.3 Testing Apparatus

To evaluate the performance of FeGeotex and other components, a pilot-scale test was conducted. This would allow testing at a larger scale to better evaluate implementation in a real SCM and provide greater control over variables in a lab setting. This scale permitted the introduction of larger-scale flows while maintaining control over flow rate and nutrient concentrations. A pilot-scale infiltration trench box was constructed in the AU-SRF laboratory.

The infiltration trench was constructed using a reinforced wooden box consisting of treated wood. The box was designed to have internal dimensions of 2.5 ft (0.762 m) wide, 8.0 ft (2.44 m) long, and 4.0 ft (1.22 m) deep. A 4 in (10.2 cm) tall false floor was constructed to provide drainage of the trench. The false floor had holes drilled into its top to allow drainage and was covered with a mesh to prevent media loss. A 3 in. (7.6 cm) underdrain pipe collects flow and directs it out of the trench, and allows for sampling. Figure 2.8 (a) displays the trench box and the false floor. The inside of the box was coated with two layers of Herculiner's waterproof truck bed liner. The waterproofing layer can be seen in Figure 2.8 (b). The trench was also double-lined with 6 mil (0.15 mm) plastic sheeting from Project Source to prevent the trench from leaking between the wall and floor joints and to guide water to the designated PVC underdrain for sampling.

(a) infiltration trench box & false floor (b) waterproofing layer

Figure 2.8: Infiltration Trench Testing Apparatus

The trench design followed the Georgia Department of Transportation (GDOT) Stormwater Design Guide for roadside infiltration trenches (GDOT 2023)(GDOT 2023).

From top to bottom, the layers within the standard trench consisted of a 1.0 in. (2.54 cm) layer of pea gravel, a layer of geotextile, 2.5 ft (0.762 m) of #57 gravel, 4.0 in. (10.2 cm) of washed masonry sand, and 2.0 in. (5.08 cm) of pea gravel (Figure 2.9). All geotextiles in this study, including the geotextile used to make the FeGeotex, consisted of nonwoven, needle-punched polypropylene geotextile from Super Geotextile. The #57 gravel consisted of crushed stone within the size range of 0.5-1.5 in. (1.3-3.8 cm).

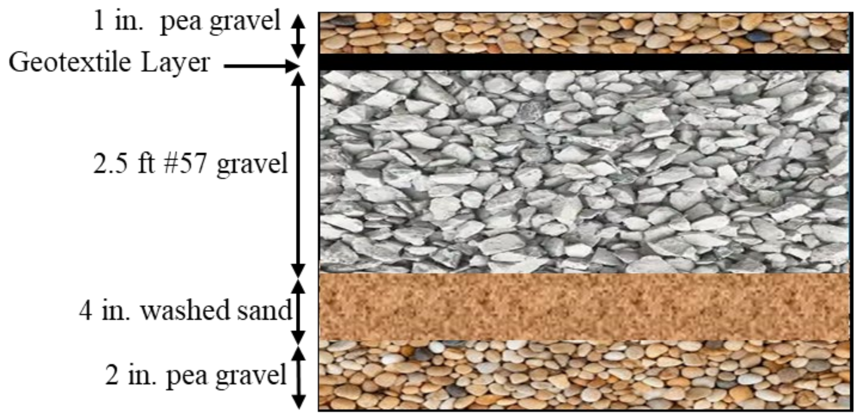
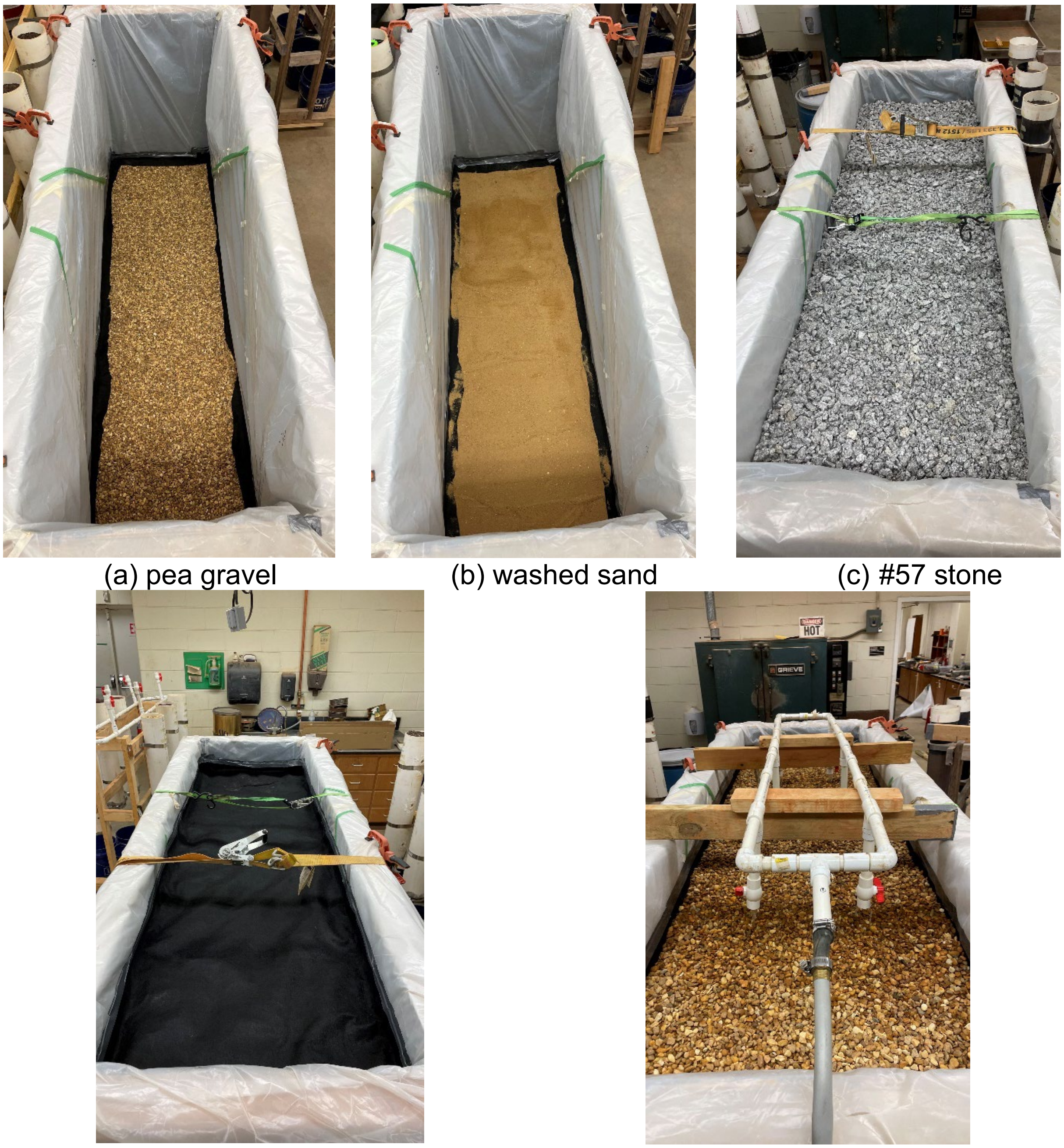


Figure 2.9: GDOT Standard Trench Design

After the plastic lining was installed in the trench, the false floor was placed in the box and over the underdrain. Then the layers of the standard trench were subsequently placed into the box layer by layer. Between each layer, a 6 in. (15.2 cm) wide strip of geotextile was taped to the plastic lining and draped over the media. This was done to direct water back toward the center of the trench and prevent water from bypassing the media by sliding down the plastic. Photos of the layering within the standard infiltration trench can be seen in Figure 2.10, as well as the inflow system and geotextile side sleeves.



(a) pea gravel (b) washed sand (c) #57 stone

(d) geotextile (e) pea gravel and inflow

Figure 2.10: Layering of the GDOT Standard Trench Design

2.3.4 Testing Methodology

Before the initial testing, the trench was flushed with tap water for four hours to remove any potential materials or pollutants that may have been attached to the media. This flush of water was also conducted after testing each infiltration trench design was complete, to wash out any remaining nutrients introduced during the first round of testing, returning the system to its original state before testing the next design. This was done with tap water and not deionized water (DI) because obtaining a large enough volume of DI was deemed infeasible.

Three rounds of testing were conducted for each infiltration trench design: 1) blank testing, 2) dosed testing, and 3) stress testing.

The first round of tests conducted on each infiltration trench design, referred to as blank tests, consisted of low-dosage tap-water tests to determine background nutrient leaching and evaluate nutrient removal under lower-concentration conditions. Three replicate tests were conducted, with a 48-hour period between each. The 48-hour dry period was consistent with the average storm occurrence in Montgomery, Alabama (Austin 2024)(Austin 2024). Tests were performed by pumping a 1.0 ft (0.31 m) head of tap water into the trench and distributing it across the top surface. This head volume was equivalent to 1.0 ft (0.31 m) of water above the top surface area of the trench, which is equivalent to 20.0 ft^3 (0.566 m^3) or 150 gal (568 L). This volume was chosen because SCMs are typically designed with a 1-ft head and a spillway at that depth to allow additional water to bypass that practice if needed (GDOT 2023)(GDOT 2023). The water is measured into two tubs: a 50-gal (189 L) and a 100-gal (379 L) tub, as shown in Figure 2.11 on the right and left, respectively. A sample of the water being pumped into the trench was taken to obtain an influent concentration, and four samples were taken during the test to obtain effluent concentrations during the simulated storm event. Samples were taken at the first outflow (~6 min.), after half of the influent volume had been pumped in (~10 min.), after all the influent volume had been pumped in (~15 min.), and at the end of trench dewatering (~50 min.). Six flow rate measurements were taken of the outflow throughout each test. The flow rate was determined by using a stopwatch to measure the time it took for a volumetric flask to fill from the outflow. Each sample, inflow and outflow, was read with HACH® Test ‘n Tube test kits to determine TP and TN concentrations. TP was measured for all tests, which includes organic and particulate phosphorus. TN was measured for all tests and includes ammonia, nitrate, and nitrite. The testing procedures for HACH® Test ‘n Tube test kits follow methods 10071 (TN) and 8190 (TP), which are both EPA-compliant. The limits of detection for TN were 0.5-25 mg/L N, and for TP were 0.02-1.10 mg/L P. The samples were also tested for pH, total dissolved solids (TDS), and electrical conductivity using an Oakton PCTSTestr 30 multiparameter probe, and for turbidity using an Oakton Portable Turbidity Meter calibrated with standard solutions.

Figure 2.11: Water Introduction Tubs

The second round of testing, conducted on each design and referred to as dosage tests, consisted of nutrient dosages consistent with typical stormwater runoff concentrations. As with the blank tests, three tests were conducted with a 2-day dry period between each. The inflow volume was spiked with ammonium sulfate

($(NH_4)_2SO_4$) and potassium phosphate monobasic ($(KH_2)PO_4$) for nitrogen and phosphorus, respectively. The target influent concentrations were 0.5 mg/L as TP and 5.5 mg/L TN. Both water introduction tubs were filled halfway with water, then the salts were introduced to bring each volume to the designated concentration. The tubs were then filled to their respective volumes to promote mixing of the dissolved salts, and were manually mixed for 2 min. The spiked influent was then pumped into the trench, as in the blank tests. Sampling was also done following the same procedures. Once testing had been completed on all designs of the infiltration trench, the results were compared to determine the impact of the iron-enhanced sand on the trench's performance.

The third and final round of testing, conducted on all trench designs, referred to as stress testing, consisted of high-concentration dosages of both nitrogen and phosphorus. The inflow was again spiked with ammonium sulfate ($(NH_4)_2SO_4$) and potassium phosphate monobasic ($(KH_2)PO_4$) for nitrogen and phosphorus, respectively. The target influent concentrations were 1.0 mg/L as TP and 6 mg/L TN. The phosphorus concentration was chosen because it was the highest end of the range the HACH® test could read. The nitrogen concentration was chosen because it was still similar to stormwater concentrations, and dose-testing results showed that each design struggled to remove it. The goal of the stress tests was to determine the maximum nutrient removal each design was capable of, and how performance would perform over a longer period. Each trench had stress tests introduced until the removal leveled out.

After stress testing was conducted on each design, the top layer of pea gravel was removed and washed to remove remaining pollutants for testing of the next design. The components tested were removed and sent to the University of South Alabama to determine the phosphorus recovery capability. The remaining media in the trench were then washed again for 4 hours with tap water to remove remaining pollutants or synthetic stormwater and reset for the next installation.

2.3.5 Testing Regime

Testing of the infiltration trench was conducted across three installation designs: the standard GDOT infiltration trench, a FeGeotex design, and an iron-enhanced sand design. The standard trench design and layers are shown in Figures 2.9 and 2.10. Testing on this design provided a baseline for infiltration trench nutrient removal with no additional components. The standard infiltration trench was the first design installed and tested.

The next design installed and tested was a design that incorporated an iron-enhanced sand layer. This component was added because the literature review showed that iron-enhanced sand has a proven capability to achieve high phosphorus removal. For the iron-enhanced sand modified infiltration trench, the layer of geotextile was replaced with a 2.0 in. (5.08 cm) layer of iron-enhanced sand placed between two layers of the same geotextile as the standard to prevent the iron-enhanced sand from mixing with the gravel layer below and improve contact time (Figure 2.12). The iron-enhanced sand layer consisted of 95% sand and 5% iron filings by volume. This medium was made by mixing washed masonry with iron aggregate sourced from Connelly GPM. The layer of iron-enhanced sand installed in the trench is shown in Figure 2.13.

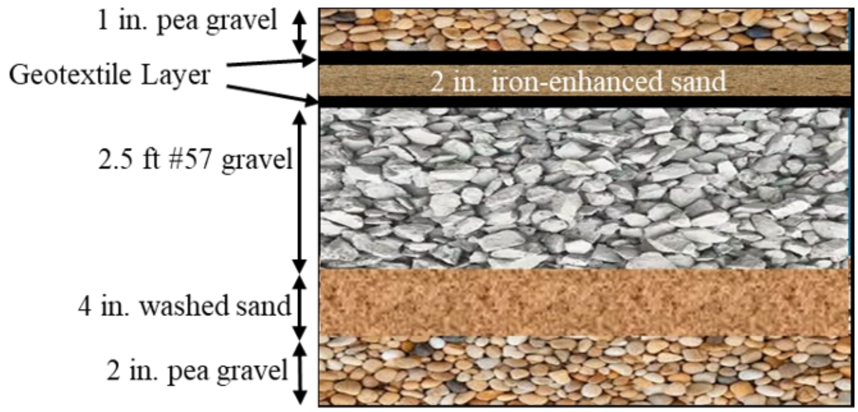


Figure 2.12: Iron-Enhanced Sand Trench Design

Figure 2.13: Iron-Enhanced Sand Layer

The third design installed and tested was identical to the standard design; however, the geotextile was the FeGeotex. The FeGeotex was a geotextile soaked in a bath with a high concentration of dissolved iron, and the pH was then increased so that the iron precipitated within the fibers of the geotextile. This component was tested as a minor design change to a standard infiltration trench, incorporating iron, which is known to adsorb phosphorus. This geotextile also facilitates easy removal for the recovery of adsorbed phosphorus. For the modified geotextile infiltration trench, the layer of geotextile was replaced by a geotextile dosed with iron, with the remaining layers staying the same (Figure 2.14). The FeGeotex was fabricated in smaller segments, which were stapled together to form a single sheet. The FeGeotex layer is shown in

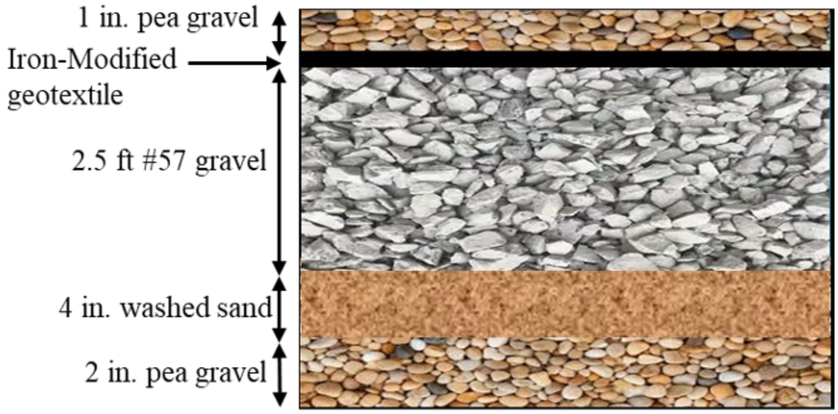


Figure 2.14: FeGeotex Tench Design

Figure 2.15: FeGeotex Layer

After reviewing the results from testing the first three infiltration trench designs, an additional test was conducted on a second installation of the standard infiltration trench. This was done to determine whether the material within the trench aided in nutrient removal during testing and whether its ability to remove nutrients decreased over time. This would mean the material in the trench contributed most to nutrient removal during the first install of the standard trench and least during the FeGeotex testing. Reinstalling and testing the standard trench design again allowed for a direct comparison between the two to determine how much the removal due to the media has decreased.

2.3.6 Analysis Methodology

The objective of this study was to statistically determine which design (an FeGeotex, an iron-enhanced sand, and a standard design) reduced the outflow nutrient concentration (nitrogen and phosphorus) the greatest from each of the three testing regimes. Therefore, the null hypothesis of this research was that the true mean removal of nitrogen and/or phosphorus was statistically equal across the infiltration trench designs. The alternative hypothesis was that the true mean removal of nitrogen and/or phosphorus differs across at least one of the infiltration trench designs. If the null hypothesis was rejected, further statistical analysis was conducted to determine which design has the greatest nitrogen removal and which has the greatest phosphorus removal.

The method used to analyze the data from this research was a three-variable analysis of variables (ANOVA) test. This test was the best option for determining whether one of the infiltration trench designs performed statistically differently from the others. The ANOVA allowed for further analysis of which trench had the best removal if one was statistically different. This would be done by comparing each design to the others using a two-sample t-test. This test allows the determination of which trench design yields the greatest removal for each nutrient. The main assumptions for ANOVA testing include that each data point is independent, that the data within each group are normally distributed, and that there are no significant outliers. The assumptions for the subsequent two-sample t-test were that the data points were independent, that each group's data was normally distributed, and that the variables measured were continuous.

The confidence level chosen for all statistical analyses for this study was 90%. This means that the significance level (α) for this testing was 0.10. These were the values used to determine whether the null hypothesis is rejected or not, based on the mean values measured from testing in this research.

2.4 Infiltration Trench Testing Results

The following section outlines the results obtained from testing on all three designs of the infiltration trench and the second installation of the standard infiltration trench. The test results include water quality results, nutrient removal results for all tests, and phosphorus recovery for each design.

2.4.1 Water Quality Results

Table 2-1 summarizes the water-quality parameters analyzed for influent and effluent from the infiltration trenches. The influent values shown in the table are averages across inflow results for all tests and designs. The dosed inflow water had a pH of 7.5, which was lower than 7.7 for the blank, but a higher conductivity and TDS, with values of 189.9 μS/cm and 138.7 mg/L compared to 143.5 μS/cm and 103.0 mg/L for the blank inflow. These changes are consistent with the addition of the ammonium sulfate ((NH4)2SO4) and potassium phosphate monobasic (KH2)PO4) to increase TP and TN inflow concentrations. All tests observed a decrease in pH from the inflow to the effluent, except for the FeGeotex. The standard decreased by 0.2 for both tests; the iron-enhanced sand decreased by 0.4 for the blank and 0.2 for the dosed; the second standard decreased by 0.1 for the blank and 0.2 for the dosed, and the FeGeotex decreased by 0.2 for the blank but stayed the same for the dosed. This decrease in pH was highly consistent across all tests and is likely due to acidification during interactions with the iron amendments in the modified trenches and with the geotextile and other materials in the standard trench. The dosed test for the FeGeotex possibly didn't undergo a dip in pH due to the iron powder dosed onto the geotextile washing away from the prior blank tests. All tests observed an increase in turbidity, with the highest increase observed in both iron-enhanced sand trench tests. The standard saw an 18.3 and 9.2 NTU increase, the iron-dosed trench saw a 16.2 and 17.0 NTU increase, the iron-enhanced sand saw a 24.6 and 26.8 NTU increase, and the second standard saw a 12.8 and 10.4 NTU increase for blank and dosed tests, respectively. Turbidity increase can be attributed to the mobilization of particulates within the trench materials. The larger increase in the iron-enhanced sand trench can be attributed to leaching from the additional iron-enhanced sand layer, which is not included in the other two designs. Leached material includes both particulates and a rusty material leached from the iron shavings. The FeGeotex test and the second standard showed increases in electrical conductivity and TDS in the effluent. The standard and iron-enhanced sand tests observed slight decreases. These similar responses are to be expected, as the two parameters are highly correlated. The increase in conductivity and TDS observed in the iron-dosed trench is likely due to the mobilization of iron. The iron that is loosely adhered to the geotextile likely was dissolved in the synthetic stormwater as it passed through. The increase in conductivity and TDS observed may have limited nutrient removal from the stormwater in the FeGeotex. Over repeated tests, the geotextile likely slowly lost iron, thereby reducing its ability to adsorb phosphorus. The iron removed in the stormwater likely also carried phosphorus through the trench, rather than removing it within the trench and keeping it within the geotextile. The second standard showed higher electrical conductivity and TDS than the average inflow values for all tests shown in the table; however, compared to the inflow values for the second standard alone, both conductivity and TDS decreased.

Table 2-1: Infiltration Trench Water Quality

Flow Type	Test Type	pH	Turbidity (NTU)	Conductivity (µS/cm)	Total Dissolved Solids (mg/L)
Synthetic Stormwater (inflow)	Blank	7.7	0.8	143.5	103.0
	Dosed	7.5	0.5	189.9	138.7
Standard Trench	Blank	7.5	19.1	127.3	98.4
	Dosed	7.3	9.7	178.3	127.2
FeGeotex Trench	Blank	7.5	17.0	178.2	123.8
	Dosed	7.5	17.5	218.2	155.6
Iron-Enhanced Sand Trench	Blank	7.3	25.4	139.6	99.2
	Dosed	7.3	27.3	167.1	128.3
Standard Trench (Install 2)	Blank	7.6	13.6	230.9	164.1
	Dosed	7.3	10.9	215.5	153.7

The water quality values for the stress testing were not included, as the goal of that testing was to evaluate the maximum nutrient removal performance and performance over a longer period.

2.4.2 Nutrient Removal Results

Table 2-2 summarizes the results of TP and TN removal from blank, dosage, and stress testing in the infiltration trenches. Each value is the average of the three tests conducted for each flow type. The first standard installation does not include data for stress testing because it was decided to conduct this testing after all testing was completed. The iron-enhanced sand trench outperformed both installations of the standard trench and the FeGeotex trench for phosphorus removal under blank, dosed, and stress testing, with removals of 38.9%, 76.9%, and 82.1%, respectively, compared to 29.3% and 53.2% for the first standard install and -4.3%, 32.2%, and 40.2% for the second standard install. The FeGeotex showed less removal than the iron-enhanced sand and the first standard install, but more than the second, with 13.8%, 42.5%, and 43.9% removal for blank, dosed, and stress, respectively. The iron-enhanced sand trench improved phosphorus removal by an average of 34% at high concentration compared to 26% at low concentration, indicating that the iron-enhanced sand enables the trench to better adsorb phosphorus at higher concentrations. The first standard and iron-enhanced sand designs had moderate nitrogen removal during the dosed test, and greater removal than observed with the FeGeotex. The standard and iron-enhanced sand designs showed removals of 31.3% and 25.5%, respectively, under high-dose conditions. The FeGeotex only had 22.1% removal under the same conditions, and the second standard had the lowest at 16.4%. All trench designs showed increased TN concentrations during blank testing, with increases of 113.6% for the first standard, 124.1% for the iron-enhanced sand, 93.3% for the FeGeotex, and 86.5% for the second standard, indicating nitrogen leaching from the materials in all designs. The iron-enhanced sand trench exhibited higher nitrogen leaching than the other two trench designs during the blank test. The geotextiles used in all three infiltration trenches undergo chemical treatments during their production. Chemical treatment could contribute to the TN leaching observed during the blank test in all trenches and explain the increase in leaching from the iron-enhanced sand trench, as that design uses an extra layer of geotextile compared to the standard design. It is proposed that the observed increase in TN suggests that one or more trench materials released nitrogen under the blank test conditions. Chemical treatments associated with the geotextiles are one possible source since they are the common addition compared to the other treatments; however, material-specific leaching tests were not performed, and the source of the nitrogen was not confirmed

Table 2-2: Infiltration Trench Nutrient Removal

Infiltration Tench	Inflow Type	TN Removal (%)	TP Removal (%)	Infiltration Rate (in/min)
Standard Trench	Blank	-113.6 ± 122.5	29.3 ± 3.0	13.5 ± 1.2
	Dosed	31.3 ± 15.3	53.2 ± 11.4	8.8 ± 1.6
FeGeotex Trench	Blank	-93.3 ± 36.7	13.8 ± 3.5	5.9 ± 0.3
	Dosed	22.1 ± 13.8	42.5 ± 9.0	6.3 ± 0.1
	Stress	-10.8 ± 20.9	43.9 ± 12.9	6.3 ± 0.3
Iron-Enhanced Sand Trench	Blank	-124.1 ± 84.2	38.9 ± 5.1	8.3 ± 0.5
	Dosed	25.5 ± 17.8	76.9 ± 2.1	7.1 ± 0.2
	Stress	13.2 ± 24.9	82.1 ± 6.6	6.6 ± 0.3
Standard Trench (Install 2)	Blank	-86.5 ± 198.2	-4.3 ± 2.7	6.0 ± 0.2
	Dosed	16.4 ± 7.4	32.2 ± 12.1	5.4 ± 0.3
	Stress	-3.2 ± 25.5	40.2 ± 13.6	5.0 ± 0.1

Note: negative values indicate an increase in concentration

2.4.3 Phosphorus Recovery

After all testing was completed on all designs, the geotextiles and iron-enhanced sand media were taken to the University of South Alabama for testing on possible phosphorus recovery. The materials were all exposed to a pH of 12.3 to desorb phosphorus from the iron. Table 2-3 shows the phosphorus recovery from each of the materials tested. As expected, the standard geotextile had the least phosphorus recovery; however, it did release some, at 0.033 mg-P/g geotextile. The FeGeotex and the geotextile installed on top of the iron-enhanced sand recovered nearly twice as much phosphorus at 0.059 and 0.053 mg-P/g geotextile. The iron-enhanced sand recovered 0.075 mg-P/g of media; however, this accounts for media containing only 5% iron. Recovery from just the iron filing in the sand may be even greater. The geotextile installed at the bottom of the iron-enhanced sand layer showed the greatest phosphorus recovery, at 0.102 mg-P/g geotextile. This high level of recovery is likely due to the iron in the sand becoming trapped in the geotextile as water passed through the sand layer and adsorbed phosphorus, acting very similarly to the FeGeotex. This likely performed even better than the FeGeotex, since the mass of iron in the iron-enhanced sand media was far higher than that attached to the FeGeotex.

Table 2-3: Phosphorus Recovery

Media/Geotextile	*Standard Geotextile*	*FeGeotex*	*Top Geotextile IES*	*Bottom Geotextile IES*	*IES*
Phosphorus Recovered (mg-P/g media)	0.033	0.059	0.053	0.102	0.075

Note: IES – Iron-Enhanced Sand

2.5 Infiltration Trench Design Comparisons

The following section compares nutrient removal across all three designs of the infiltration trench and the second standard infiltration trench installation. The first round of comparisons was conducted between the two modified components of the infiltration trench and the first standard installation. The results of this comparison led to retesting the standard to evaluate the hypothesis that the material in the trench had aided nutrient removal during the first installation of the standard design but had degraded in its nutrient-removal capacity over continued testing, resulting in worse nutrient removal in the two modified component installations. The second standard installation was compared with the first to determine the impact of the media on removal, and the second installation results were then compared with the two modified components.

For all statistical analyses, a confidence level of 90% was used, meaning a significance level (α) of 0.1 was used. This was done as it was determined to be an acceptable level of confidence given the limitations and uncertainties of the testing. This includes variance in results from the equipment and kits used to measure nutrient concentrations. This also includes time and cost limitations preventing a clean out of the trench between each test, as well as limiting the number of samples taken during each test.

2.5.1 Initial Nutrient Removal Comparisons

After testing was completed for all three designs of the infiltration trench, the mean removal was determined for each of the three tests run for both dosed and blank testing on the first standard installation, the iron-enhanced sand, and the FeGeotex. The mean removal for each design was compared to determine if any were statistically different from the four groups based on nutrient and inflow concentration: Phosphorus-Blank, Phosphorus-Dosed, Nitrogen-Blank, and Nitrogen-Dosed. The results of the ANOVA tests conducted on these groups are shown in Table 2-4. The Phosphorus-Dosed group was the only group with an F-value (20.74) greater than the F-crit (3.463), indicating that, with 90% confidence, at least one of the designs had better or worse phosphorus removal than the others. The remaining three groups had F-values less than the F-crit, indicating that there is no statistical difference in mean nutrient removal between the three designs for nitrogen under both dosed and blank conditions, and for phosphorus under blank conditions. The ANOVA results indicated that further analysis of the Phosphorus-Dosed data would be needed to determine the design with the best removal.

Table 2-4: ANOVA Results for Blank and Dosed Nutrient Testing

Source of Variation	Sum of Squares	Degrees of Freedoms	Mean Squares	F	F crit	Result
			Phosphorus-Blank			
Between Groups	0.0955	2	0.0477	2.828	3.463	No Statistical Difference
Within Groups	0.1013	6	0.0169	-	-	
Total	0.1967	8	-	-	-	
			Phosphorus-Dosed			
Between Groups	0.1854	2	0.0927	20.74	3.463	Statistically Different
Within Groups	0.0268	6	0.0045	-	-	
Total	0.2122	8	-	-	-	
			Nitrogen-Blank			
Between Groups	0.9003	2	0.4501	0.0739	3.463	No Statistical Difference
Within Groups	36.53	6	6.088	-	-	
Total	37.43	8	-	-	-	
			Nitrogen-Dosed			
Between Groups	0.0136	2	0.0068	0.1297	3.463	No Statistical Difference
Within Groups	0.3156	6	0.0526	-	-	
Total	0.3293	8	-	-	-	

Figure 2.16 below displays the inflow and outflow phosphorus concentrations for sampling across all three designs: standard, FeGeotex, and iron-enhanced sand, under dosed conditions. The figure shows that the iron-enhanced sand design exhibits more consistent, lower phosphorus outflow concentrations than the other two designs, indicating improved phosphorus removal. The standard and dosed geotextile designs both show consistent decreases in phosphorus concentration from the inflow; however, with much higher variability than seen with the iron-enhanced sand. The standard appears to have higher removal than the dosed geotextile, with some outflow concentrations being lower than those for the dosed geotextile.

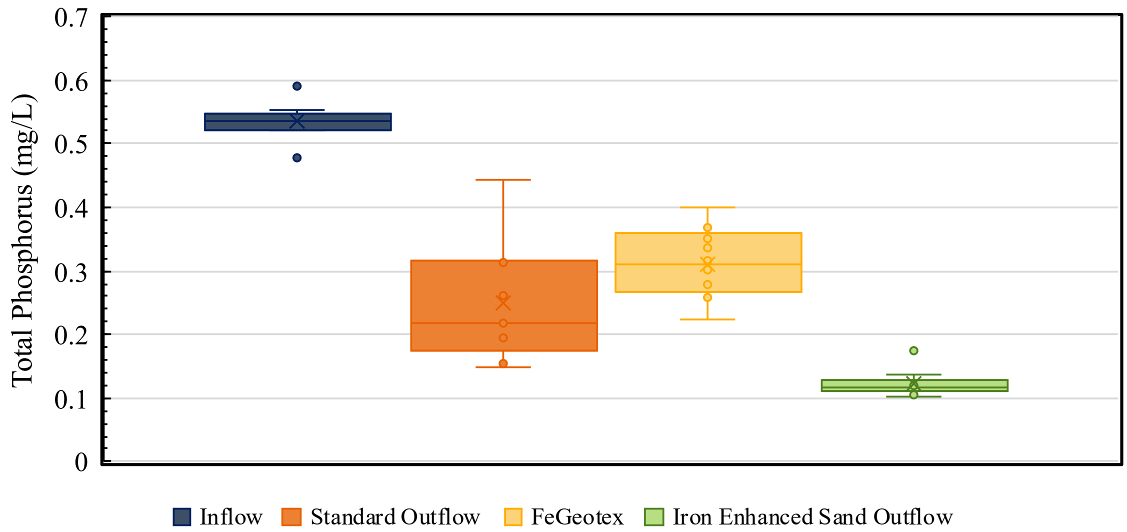


Figure 2.16: Dosed Testing Total Phosphorus Inflow vs. Outflow

To determine which design statistically removed the most phosphorus under the dosed conditions, two paired t-tests were used to compare each design against the others. The results of the three hypothesis tests completed are shown in Table 2-5. The testing showed that with 90% confidence, the iron-enhanced sand design had statistically greater nutrient removal than the standard and the FeGeotex, with p-values of 0.0262 and 0.0016, respectively. The comparison between the standard and the FeGeotex showed that, with 90% confidence, there is no statistical difference in their phosphorus removal, with a p-value of 0.1011.

Table 2-5: Two-Paired T-Test Results for Dosed-Phosphorus

H_0	H_1	df	P-value	α	Result
$\mu_{ies} \leq \mu_{std}$	$\mu_{ies} > \mu_{std}$	2	0.0262	0.10	Reject H_0
$\mu_{ies} \leq \mu_{FeG}$	$\mu_{ies} > \mu_{FeG}$	2	0.0016	0.10	Reject H_0
$\mu_{std} \leq \mu_{FeG}$	$\mu_{std} > \mu_{FeG}$	2	0.1011	0.10	Fail to Reject H_0

Note: ies – Iron Enhanced Sand, std – Standard, FeG – FeGeotex

These results indicate that including an iron-enhanced sand component in an infiltration trench will result in greater phosphorus removal at runoff concentrations than either the standard or the inclusion of an FeGeotex. The results also indicate that there was no difference in nitrogen removal between the three designs, and no difference in phosphorus removal at low concentrations. There was also no statistical difference in phosphorus removal between the standard design and the FeGeotex design. This was unexpected and led to testing on a second installation of the standard design.

2.5.2 Standard Installation Comparisons

Results from the first installation of the standard infiltration trench were compared with those from the second to determine whether nutrient removal had changed due to degraded nutrient adsorption in the trench's internal media. The results of the four hypothesis tests are shown in Table 2-6 below. The testing showed that, with 90% confidence, the first standard installation had a statistically greater phosphorus removal under blank conditions with a p-value of 0.0302, which is less than the significance level (α) of 0.10. The testing also showed that with 90% confidence, the first standard installation had statistically greater phosphorus removal under dosed conditions, with a p-value of 0.0890, which is less than α of 0.10. For nitrogen, the results show that, with 90% confidence, there is no statistical difference in nitrogen removal between the two installations of the standard design under both blank and dosed conditions, with p-values of 0.1313 and 0.3097, respectively, which are greater than α of 0.10.

Table 2-6: Standard Design Two-Paired T-Test Results

Test	H_0	H_1	df	P-value	α	Result
Phosphorus-Blank	$\mu_1 \leq \mu_2$	$\mu_1 > \mu_2$	2	0.0302	0.10	Reject H_0
Phosphorus-Dosed	$\mu_1 \leq \mu_2$	$\mu_1 > \mu_2$	3	0.0890	0.10	Reject H_0
Nitrogen-Blank	$\mu_1 \leq \mu_2$	$\mu_1 > \mu_2$	3	0.1314	0.10	Fail to Reject H_0
Nitrogen-Dosed	$\mu_1 \leq \mu_2$	$\mu_1 > \mu_2$	3	0.3097	0.10	Fail to Reject H_0

Note: 1 – Standard Install 1, 2 – Standard Install 2

These results indicate that the material within the trench contributed to phosphorus removal at a statistically higher level in the first than in the second standard installation. This finding indicates that across all the testing, the trench lost its ability to remove an average of 33% of phosphorus under blank conditions and 15% under dosed conditions.

2.5.3 Second Nutrient Removal Comparisons

To better compare the testing of the components to a baseline condition of the trench, the nutrient removal results from testing on the iron-enhanced sand and FeGeotex were compared to the second installation of the standard design. Only the phosphorus removals were compared, as only phosphorus removal was statistically lower in the second standard installation. The results of the ANOVA tests conducted on these groups are shown in Table 2-7. The Phosphorus-Blank, Phosphorus-Dosed, and Phosphorus-Stress groups had an F-value (16.51, 81.06, and 63.14, respectively) greater than the F-crit (3.463), indicating that, with 90% confidence, at least one of the designs had statistically better or worse phosphorus removal than the others. The ANOVA results indicated that further analysis of the Phosphorus-Blank, Phosphorus-Dosed, and Phosphorus-Stress data would be needed to determine the design with the best removal.

Table 2-7: Second Round ANOVA Results

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F	F crit	Result
			Phosphorus-Blank			
Between Groups	0.2832	2	0.1416	16.51	3.463	Statistically Different
Within Groups	0.0515	6	0.0086	-	-	
Total	0.3347	8	-	-	-	
			Phosphorus-Dosed			
Between Groups	0.3165	2	0.1583	81.06	3.463	Statistically Different
Within Groups	0.0117	6	0.0019	-	-	
Total	0.3282	8	-	-	-	
			Phosphorus-Stress			
Between Groups	0.3446	2	0.1723	63.14	3.463	Statistically Different
Within Groups	0.0218	8	0.0027	-	-	
Total	0.3664	10	-	-	-	

To determine which design statistically removed the most phosphorus under blank conditions, two paired t-tests were used to compare each design with the others, all at a significance level of 0.10. The results of the three hypothesis tests completed are shown in Table 2-8. The testing showed that with 90% confidence, the iron-enhanced sand design had statistically greater nutrient removal than the standard and the FeGeotex, with p-values of 0.0064 and 0.0281, respectively. The comparison between the standard and the FeGeotex showed that, with 90% confidence, the FeGeotex had statistically greater phosphorus removal with a p-value of 0.0161.

Table 2-8: Second Round Two-Paired T-Test Results for Blank-Phosphorus

H_0	H_1	df	P-value	α	Result
$\mu_{ies} \leq \mu_{std}$	$\mu_{ies} > \mu_{std}$	3	0.0064	0.10	Reject H_0
$\mu_{ies} \leq \mu_{FeG}$	$\mu_{ies} > \mu_{FeG}$	3	0.0281	0.10	Reject H_0
$\mu_{FeG} \leq \mu_{std}$	$\mu_{FeG} > \mu_{std}$	3	0.0161	0.10	Reject H_0

Note: ies – Iron Enhanced Sand, std – Standard, FeG – FeGeotex

To determine which design statistically removed the most phosphorus under dosed conditions, two paired t-tests were used to compare each design with the others, all at a significance level of 0.10. The results of the three hypothesis tests completed are shown in Table 2-9. The testing showed that with 90% confidence, the iron-enhanced sand design had statistically greater nutrient removal than the standard and the FeGeotex, with p-values of 0.0010 and 0.0016, respectively. The comparison between the standard and the FeGeotex showed that, with 90% confidence, the FeGeotex had statistically greater phosphorus removal with a p-value of 0.0487. These results correlate with the results from blank testing. The iron-enhanced sand component performs best at nutrient removal, followed by FeGeotex, and the standard performs the worst.

Table 2-9: Second Round Two-Paired T-Test Results for Dosed-Phosphorus

H_0	H_1	df	P-value	α	Result
$\mu_{ies} \leq \mu_{std}$	$\mu_{ies} > \mu_{std}$	2	0.0010	0.10	Reject H_0
$\mu_{ies} \leq \mu_{FeG}$	$\mu_{ies} > \mu_{FeG}$	2	0.0016	0.10	Reject H_0
$\mu_{FeG} \leq \mu_{std}$	$\mu_{FeG} > \mu_{std}$	3	0.0487	0.10	Reject H_0

Note: ies – Iron Enhanced Sand, std – Standard, FeG – FeGeotex

To determine which design statistically removed the most phosphorus under stress conditions, two paired t-tests were used to compare each design with the others, all at a significance level of 0.10. The results of the three hypothesis tests completed are shown in Table 2-10. The testing showed that with 90% confidence, the iron-enhanced sand design had statistically greater nutrient removal than the standard and the FeGeotex, with p-values of 0.0014 and 2.4×10^{-5}, respectively. The comparison between the standard and the FeGeotex showed that, with 90% confidence, there is no statistical difference in their phosphorus removal, with a p-value of 0.2185. These results indicate that under high concentrations, and long-term use, the FeGeotex performs similarly to the standard, and the iron-enhanced sand effectively maintains its performance.

Table 2-10: Second Round Two-Paired T-Test Results for Stress-Phosphorus

H_0	H_1	df	P-value	α	Result
$\mu_{ies} \leq \mu_{std}$	$\mu_{ies} > \mu_{std}$	2	0.0014	0.10	Reject H_0
$\mu_{ies} \leq \mu_{FeG}$	$\mu_{ies} > \mu_{FeG}$	5	2.4×10^{-5}	0.10	Reject H_0
$\mu_{FeG} \leq \mu_{std}$	$\mu_{FeG} > \mu_{std}$	4	0.2185	0.10	Fail to Reject H_0

Note: ies – Iron Enhanced Sand, std – Standard, FeG – FeGeotex

2.6 Nutrient Removal Testing Summary

This chapter outlined the components chosen for testing to improve the performance of the selected SCM, the results for each design, and a comparison between the three designs. The chosen components were an iron-dosed geotextile (FeGeotex) and an iron-enhanced sand layer. These components were selected for evaluation of their enhanced nutrient removal and nutrient recovery for reuse in a stormwater infiltration trench. Testing of a standard design of the trench initially showed that it could remove 29% and 53% under blank and dosed conditions, respectively. This was statistically far less removal than the iron-enhanced trench could remove, with 39% and 77%, respectively. However, the standard trench did not show significantly different phosphorus removal compared with the FeGeotex, which had removals of 14% and 43%, respectively. For Nitrogen removal, all trenches did not show significantly different performance in both blank and dose testing. All three designs leached nitrogen under blank conditions and had limited removal under dosed conditions, with 31%, 22%, and 26% for the standard, FeGeotex, and iron-enhanced sand, respectively.

The results for the FeGeotex and the standard were not significantly different, which was unexpected and prompted retesting the standard to determine whether the material within the trench had affected nutrient removal performance differently over time. The second installation of the standard trench design showed that phosphorus removal was statistically significantly lower, with -4% (leaching) and 32% for the blank and dosed conditions, respectively. This shows that the material within the trench removed an average of 33% and 15% more phosphorus under blank and dosed conditions, respectively, at the beginning of testing. The material within the trench, the sand, and #57 gravel, likely contains calcium carbonate, which can adsorb phosphorus. This adsorption becomes limited as testing continues, as phosphorus takes up available contact points, and flushing can only recover so much.

Comparisons with data from the second installation of the standard infiltration trench provide a better understanding of the performance differences among the designs. The iron-enhanced sand still proved to be the best design for phosphorus removal, with a statistically greater removal than the other designs for blank, dose, and stress testing. The FeGeotex showed statistically greater removal than the standard in both blank and dose testing; however, there was no significant difference in removal under stress testing. This indicates that the iron-enhanced sand is the better component for phosphorus removal at low and high concentrations and over long periods of use. The FeGeotex is also an effective component for enhancing phosphorus removal at both low and high concentrations; however, over long periods, it is likely to perform similarly to a standard trench.

Each design proved capable of recovering phosphorus after testing was completed. The standard trench had the lowest phosphorus recovery concentration at 0.033 mg-P/g geotextile. The top geotextile in the iron-enhanced sand design and the Fe-Geotex had similar phosphorus recovery at 0.053 mg-P/g geotextile and 0.059 mg-P/g geotextile, respectively. The iron-enhanced sand was the next highest at 0.075 mg-P/g media, and the bottom layer of geotextile from the iron-enhanced sand design had the greatest recovery at 0.102 mg-P/g geotextile. This shows that both components can serve as an alternative source of phosphorus, but the iron-enhanced sand offers greater recovery. This greater recovery is likely due to the increased mass of iron used in the design of the iron-enhanced sand compared to the FeGeotex. This increased mass of iron provides more areas for the adsorption of phosphorus.

Chapter Three: Full-Scale Performance Evaluation of Sediment Barrier Products and Practices

3.1 Introduction

Sediment barriers are an important last line of defense, preventing sediment and other pollutants from washing off-site, polluting natural waterways (US EPA 2021b). There are numerous sediment barrier practices, products, and standards available, making it difficult to determine which is most effective as a BMP for a site. Standards and requirements vary widely from state to state, country to country, and even between agencies within the same state. Oftentimes, installation and practice selection are based on historical usage or on how it has always been done within that region, agency, or company. Since sediment barriers are typically used as perimeter controls, hundreds or thousands of feet or meters of material and installation may be required. Significant material and manpower needs can be costly, making the choice of effective practice critical. Evaluations of sediment barriers have focused on their performance capabilities, primarily their ability to retain sediment, improve water quality, and maintain structural integrity over time. However, there is a lack of direct comparisons between sediment barrier types, including novel products, and between longevity performance and singular-event performance. This chapter is intended to provide an overview of available sediment barrier practices and products, a summary of prior performance evaluations of these practices, a methodology for large-scale testing of practices and products under single and multiple storm events, and the testing results, along with comparisons to prior performance evaluations.

3.2 Literature Review

Sediment barriers are used to intercept runoff from construction sites and prevent the discharge of sediment-laden water off-site into natural waterbodies. These practices are intended to imitate or support the ability of natural vegetated buffers to capture sediment. The primary method by which sediment is removed from runoff via sediment barriers is sedimentation in impoundments and the slowing of runoff, rather than filtration, which plays almost no role in sediment capture (Barrett et al. 1995). Effective sediment barrier practices should balance costs, from both installation and material, and performance, considering site-specific conditions and constraints. The selection of sediment barriers should consider several factors, including site topography, hydrology, climate, soil conditions, and construction timeline (Perez et al. 2016). There are many different practices available to match these various conditions, including standard practices and manufactured products. Some of the most common suggested practices for use as perimeter sediment control include silt fence, straw or hay bales, earth berms, wattles, rock berms, compost berms or socks, brush barriers, vegetated strips, mulch berms, sediment traps, sandbags, and triangular silt dikes (Burns and Troxel 2015). There are also numerous manufactured products available as substitutes or enhancements to these standard practices.

The performance of sediment barrier practices has been studied using a variety of methods and conditions, with various performance metrics. Testing of sediment barriers primarily focuses on sediment capture, water quality improvements, hydraulic performance, and structural integrity. The water quality improvements from sediment barriers focus on reducing total suspended solids (TSS) and turbidity in discharge downstream of the practice, but sometimes also include other pollutants, such as nutrients (Bhattarai et al. 2021; Faucette et al. 2008; Roche 2023; Whitman et al. 2018, 2019a; b; Zhang et al. 2022). The hydraulic performance of sediment barriers includes an analysis of the impoundment created by the practice and the flow-through rate (Roche 2023; Whitman et al. 2018, 2019b, 2021). Testing size ranges from smaller lab-scale tests to full-scale implementation and field testing. Testing of sediment barriers thus far has provided insight into their performance under specific constraints.

3.2.1 Silt Fence

A silt fence is a temporary sediment barrier that consists of porous fabric supported by posts, intended to intercept flow before it runs off-site. Silt fence is typically installed at the toe of slopes along the perimeter of sites. Silt fence is also installed as a J-hook or in a “smile” configuration to break up the impoundment of water into smaller sections. There are many different types of silt fence based on fabric, post type, and installation method. Fabric for a silt fence broadly fits into two categories: woven and nonwoven geotextiles. Woven geotextiles consist of strings or bands of polypropylene woven into a permeable sheet (Whitman et al. 2019a). Non-woven geotextiles are primarily formed by rolling polymer fibers together and bonding with heat, followed by punching holes with needles to provide permeability (Whitman et al. 2019a). Posts for silt fence are either hardwood stakes or steel T-posts. Installation of silt fence varies widely depending on site conditions and state or manufacturer specifications. Differences in installation include post spacing, the inclusion of wire backing or a dewatering board, and the method of inserting the fabric into the ground. The two most common methods for inserting the fabric into the ground are slicing with a machine or manually trenching (US EPA 2021b). Figure 3.1 shows a silt fence installed in a J-hook and a “smile” configuration.

(a) silt fence J-hooks (b) silt fence “smile” configuration

Figure 3.1: Implementation of Silt Fence (Perez 2016)

Silt fence is one of the most commonly implemented and widely accepted sediment control practices, and is therefore implemented on most construction sites (Whitman et al. 2018). Due to its widespread implementation, silt fence has also undergone the most performance testing. This testing varies widely in implementation method, testing scale, and the type of silt fence tested. Testing has yielded variable recommendations on the most effective installation and design for utilizing silt fence as perimeter control.

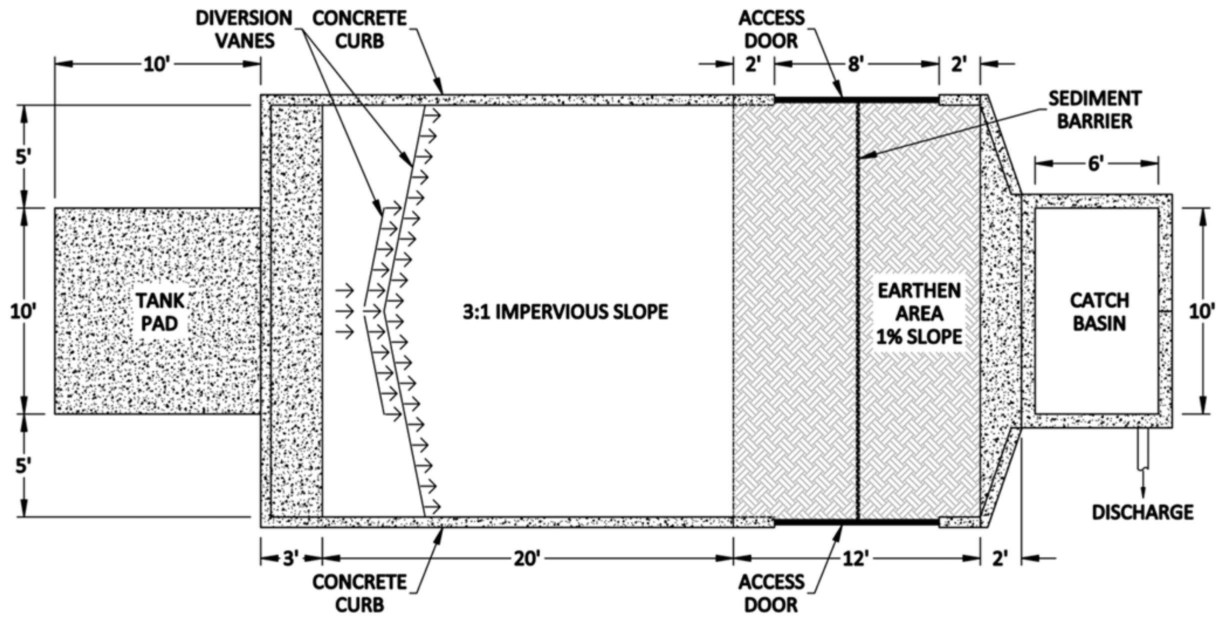
Small-scale testing of silt fence has focused primarily on the performance of the geotextile fabric at impounding and filtering sediment. Testing for the Alabama Department of Transportation (ALDOT) by Whitman et al. evaluated the performance of two nonwoven and three woven geotextiles used for silt fences. The testing followed a modified version of ASTM D514, which installed the geotextile 6 ft (1.8 m) away from the toe of the slope instead of at the toe, as well as utilizing a 1% slope after an introductory 3:1 (H:V) slope instead of just on an 8% gradient. These changes were made to better represent the impoundment ability of silt fence on a typical construction site. The flow and sediment introduction for testing was determined following the predicted peak flow from a 2-year, 24-hour storm event in central Alabama. The data recorded during testing included impoundment length and depth, sediment retention, and turbidity. Flow was introduced for 30 minutes, and dewatering was monitored for 90 minutes post-test. The non-woven geotextiles showed higher sediment capture rates (97% & 98%) than the woven geotextiles (87%, 94%, & 93%), with the non-woven geotextiles also showing lower flow through rates. Turbidity measurements upstream and downstream of the geotextiles were used to determine filtration efficacy, and the data showed negligible filtration during flow introduction (Whitman et al. 2019a).

Another small-scale evaluation of silt fence was conducted by Faucette et al., examining sediment and phosphorus removal from runoff with silt fence installed compared to compost socks. The testing was conducted in a unique manner, using a spinning turntable with soil chambers measuring 39 in. (100 cm) long, 14 in. (35 cm) wide, and 10 in. (25 cm) deep. The turntable spun the soil chambers at 1 rpm beneath a dripping rainfall simulator, introducing a flow rate of 2.93 in/hr. (7.45 cm/hr.) for 30 minutes. The plots were all set to a 10% slope, and flow was collected at the base of each plot’s slope. The geotextile was installed in a V-shape, with the ends pointing upstream, and the fabric was trenched in at a depth of 2.5 in. (6.4 cm). Runoff collected after the practices was analyzed for TSS, turbidity, and phosphorus concentrations, and the results were compared with those from bare-soil testing. The silt fence testing showed mean TSS removals of 87%, 71%, 66%, and 63%, mean turbidity removals of 76%, 54%, 50%, and 45%, and a mean phosphorus removal of 63%. These results show that silt fence effectively slows runoff compared to bare soil, thereby enhancing the removal of sediment and nutrients, such as phosphorus (Faucette et al. 2008).

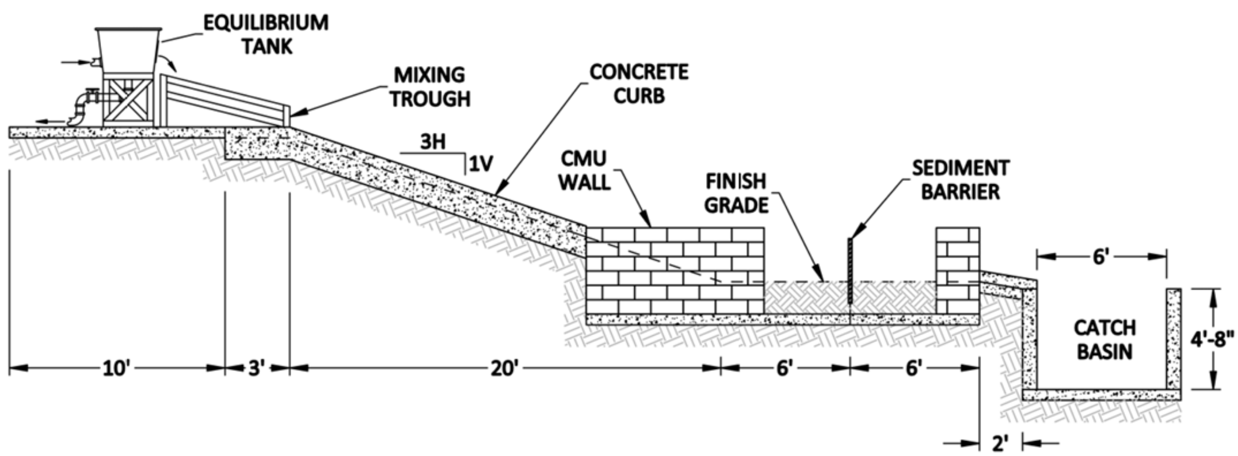
A third lab-scale evaluation of silt fence by Palmeira et al. analyzed the hydraulic performance of geotextiles under the introduction of varied slurries created from different flow rates and soil native to Brazil. Testing was conducted in a flume of dimensions measuring 19.7 ft (6 m) long, 3.3 ft (1 m) high, and 1.3 ft (0.4 m) wide. Testing followed a modified version of ASTM D5141-91, with a larger scale and steady flow rather than variable. Testing was conducted using a slurry at a concentration of 10 g/L, determined from field testing in Brazil. Flow was introduced at two flow rates, 3.96 gpm (0.25 L/s) and 15.85 gpm (1 L/s). Each geotextile underwent two subsequent tests. The first test introduced a new geotextile to a slurry mixture, and the second test was performed 24 hours later on the already-blinded geotextile. Four geotextiles from the same manufacturer were tested, with varying thicknesses and pore sizes. Results of testing indicated that thicker geotextiles with smaller pores had greater flow impoundment and were less influenced by flow rate. The testing also showed that higher flow rates caused greater blinding of the geotextiles. These results indicate that the geotextile's composition plays an important role in a silt fence's performance and must be selected to best meet the required criteria (Palmeira et al. 2008).

A review of testing on structural sediment barrier practices by Zhang et al. identified the pros and cons of various testing methodologies. Zhang et al. found that bench-scale testing methodologies are often effective for assessing the performance of individual components of a silt fence, particularly the fabric, under very specific conditions. However, some limitations of lab-scale testing are a lack of understanding of how the installation performs as a whole and under more accurate field conditions. Zhang et al. recommended that future small-scale testing follow a methodology similar to that developed by Whitman et al., in which the practice is subjected to more realistic flow and sediment-introduction conditions, and impoundment is allowed to form upstream of the practice (Whitman et al. 2019a). Zhang et al. determined that this form of testing is effective for specific site conditions and that testing must be conducted to assess specific performance under varied conditions arising from different hydrological circumstances (Zhang et al. 2024).

Larger-scale testing has also been conducted by Whitman et al. across two investigations. Testing was completed in the same manner for both reports, following the testing protocol developed by Bugg et al., using the same full-scale testing apparatus (Bugg et al. 2017). The testing apparatus, seen below in Figure 3.2, consists of a flow introduction tank followed by a 20-ft (6 m) long, 20-ft (6 m) wide, 3:1 (H:V) impervious metal slope with vanes designed to form sheet flow across the entire slope. The impervious slope leads into a 12-ft (3.7 m) long, 20-ft (6 m) wide, 1% slope earthen plot where the chosen sediment barrier is installed. Past the earth plot is a catch basin where the runoff is collected and where the flow rate can be measured. The flow rate was introduced by a pump and metered in the equilibrium tank by a calibrated weir. The flow rate introduced was 0.22 ft^3/s (6.23 L/s), determined using the same method as Whitman et al. used for their small-scale testing described previously. The sediment introduction was determined to be 1,127.8 lbs. (511.6 kg) over 30 min. using the Modified Universal Soil Loss Equation (MUSLE). MUSLE determines the soil loss for a specific soil type using peak flow rates and runoff volumes for a specific storm. The peak 30 minutes of a 2-yr, 24-hr storm event was used to determine soil loss for their testing. Both reports examined the structural performance, water quality, and sediment retention of the practices analyzed. Sediment retention was found using topography from a total station before and after sediment introduction, and knowing the volume of introduced sediment. One report investigated the performance of silt fence standard installations from ALDOT, sliced and trenched, and various modifications to determine the most effective installation. Modifications included stronger T-posts, closer post spacing, smaller fencing, and offset trenching from the T-posts. The results of this testing showed that the standard designs fail under multiple storm events due to undermining or overtopping. The modified fence, with stronger T-posts, closer post spacing, and offset trenching, demonstrated the best structural integrity. This design and the same design without offset trenching showed the best sediment retention at 90%, 91%, 98%, and 100%, 100%, 98%, respectively. This testing also investigated the use of a dewatering weir in the design, with all modifications. This was done because observations showed that the impoundment lasted over 24 hours, limiting the storage capacity for the next storm event. Testing with the dewatering weir showed a sediment capture of 96%, consistent with that without the weir, but with improved dewatering time (Whitman et al. 2018). The other testing conducted by Whitman et al. compared manufactured silt fence systems with other sediment barrier products and the previously determined most effective noncommercial silt fence. Testing was conducted on two manufactured silt fence systems: the GDOT Type-C System and a second company-manufactured silt fence. Manufactured silt fences are typically designed with fabric already attached to wooden posts, simplifying installation. This study found that common issues with these products include undermining around the posts caused by insufficient soil compaction; however, the wooden posts proved sufficient for structural integrity under longevity testing. The GDOT fence showed higher sediment retention than the Silt-Saver fence, with average rates of 90% and 85%, respectively. However, the most effective noncommercial silt fence design had the greatest average sediment retention of 93%. All sediment barrier designs resulted in degraded water quality rather than improved water quality (Whitman et al. 2019b). This indicates that silt fences remove sediment through sedimentation rather than filtration.



(a) plan view



(b) profile view

Figure 3.2: Layout of Sediment Barrier Testing Apparatus (Whitman et al. 2018)

Further testing of various sediment barrier practices as a replacement for silt fence was conducted by Zhang et al. This testing was conducted in accordance with ASTM D7351. The apparatus consisted of a mixing tank connected to a pipe lying perpendicular to the 3:1 slope, with holes drilled to spread the flow into sheet flow. The flow introduced followed a 29.5 ft (9 m) long impermeable 3:1 slope, then onto a 7.9ft (2.4 m) by 7.9ft (2.4 m) soil plot where the sediment barrier was installed. The inflow consisted of 5,005 lbs. (2,270 kg) of water and 300 lbs. (136 kg) of soil. This was based on a 10-yr, 6-hour storm event with a 25% occurrence within a 30-minute peak flow, 50% infiltration, and a 98.4 ft (30 m) by 19.7 ft (6 m) contributing area, using the MUSLE method. The silt fence was installed with wooden posts per Illinois Department of Transportation (IDOT) specifications. Testing analyzed the sediment retention upstream of the practice by mapping the topography before and after to determine the volume of sediment retained. This testing also analyzed the total solids concentration (TSC) of water downstream of the practice, in accordance with ASTM D3977-97. The results from this testing showed that the silt fence had a high probability of failure due to undercutting. The silt fence had a comparable TSC reduction to the wattle and coir log, but less reduction than the compost sock and Product A, a manufactured product tested for this report. The silt fence performed the worst of all practices for sediment retention with an average capture rate of 51% (Zhang et al. 2022).

A study by Kincl et al. examined the performance of sediment barriers, including a silt fence, in intercepting sheet flow and directing it into lateral runoff. Testing was performed on slopes of 8.5%, where a 49.2 ft (15 m) length of sediment barrier was located 19.7 ft (6 m) away from the flow introduction. On the lower-elevation side of the sediment barrier, flow would be directed around the end and into a Parshall flume to measure flow rate. Flow was introduced at rates of 79.2 gpm (5 L/s) and 158.5 gpm (10 L/s) over a 25 min period. No sediment was introduced, but erosion on the slope and the sediment subsequently captured were measured using topographic scanning. The silt fence tested had sediment retention rates of 90.5%, 91,.0%, and 90.0% (Kincl et al.

2022). This testing shows that a silt fence captures sediment eroded from a hillside, but not necessarily from a site upstream of the slope.

3.2.2 Wattles

A wattle, also known as a fiber roll, fiber log, or sediment log, is a common E&SC practice consisting of a tube-shaped netting stuffed with a fill material to slow and impound runoff, promoting sedimentation. While wattles can be used as a sediment barrier practice, they are also used as ditch checks, slope interrupters, and stockpile management (US EPA 2021b). Even though many wattles are marketed as filtering practices, their filtering capacity is negligible compared to the effectiveness of promoting sedimentation through impoundment of runoff (Whitman et al. 2021). Netting for wattles is typically made from either a plastic-based material, such as polypropylene, or a natural material, such as jute or coir. A wide variety of materials are used as fill for wattles, including wheat straw, wood fibers, coconut coir, recycled carpet, and grass fibers. When used as a sediment barrier practice, wattles are typically installed along the toe of a slope or just beyond it. The installation of the wattle plays an important role in its efficacy as a sediment barrier and hydraulic performance (Whitman et al. 2021). In general, wattles are installed perpendicular to a slope with the ends of the wattles either turned up slope or overlapped with the next wattle and held in place by wooden stakes and/or metal staples. One example install specification for a wattle can be seen below in Figure 3.3.

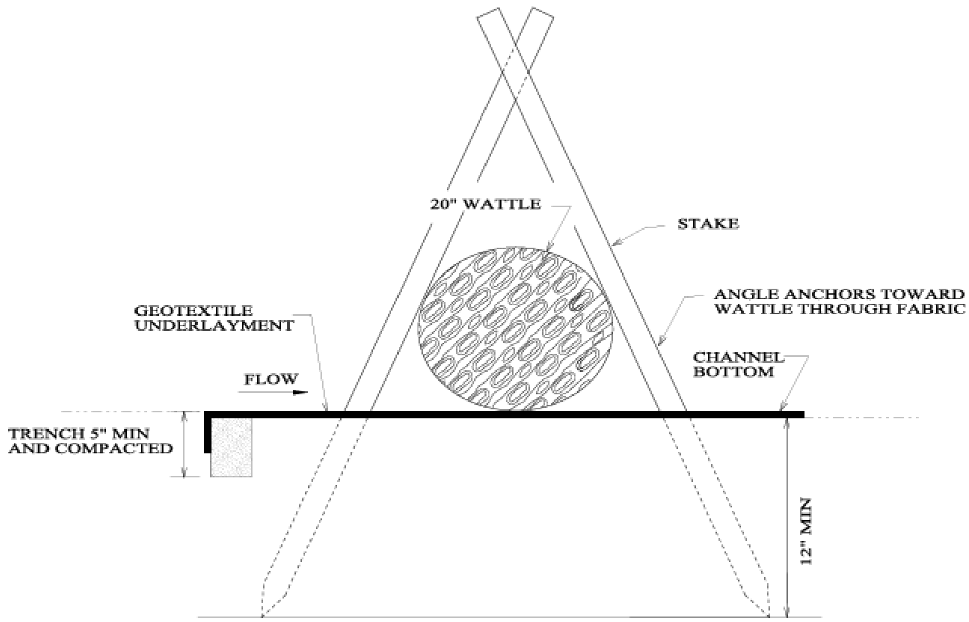


Figure 3.3: Wattle Installation Details (ALDOT 2021)

The hydraulic performance of a wattle provides insight into its effectiveness as a sediment barrier practice, describing its ability to slow and impound runoff. Whitman et al. conducted hydraulic performance testing on eight wattle designs based on fill and netting media. The eight wattle designs evaluated in this study were excelsior fiber in natural netting, wheat straw in high-density polyethylene (HDPE) netting, wheat straw in an HDPE sock, standard coconut coir in natural netting, premium coconut coir in natural netting, wood chips in a polyester sock, synthetic fiber in HDPE netting, and miscanthus fiber in a polyester sock. Testing was conducted in a flume measuring 38 ft (11.6 m) in length, 4 ft (1.2 m) in width, and 2 ft (0.6 m) in height. Wattles were subjected to increasing flow rates, and the resulting impoundment depths, length, and flow type (e.g., subcritical or supercritical) were recorded. These values were compared with the theoretical maximum impoundment length or depth for each wattle to determine the relative effectiveness of each wattle at impoundment and velocity reduction. The excelsior wattle proved to be the least effective fill material due to its large flow-through rate. The miscanthus wattle proved to be the most effective fill material with the least difference between experimental and theoretical impoundment. The results of this testing indicate the importance of using the best fill material for wattles to achieve an effective sediment barrier (Whitman et al. 2021).

Large-scale testing of aspen wood fiber sediment logs, coconut coir logs, and straw wattles was conducted by Bhattarai et al., comparing their performance with that of a silt fence. Their testing followed the same protocol as described previously for their testing of silt fence. Their testing evaluated aspen fiber sediment logs and straw wattles using two staking methods: perpendicular to the ground and at a 45-degree angle pointing upstream. The sediment log was also tested using three methods for joining two logs: overlapping, butt ends, and sleeving (inserting the end of one log into the end of another). The wattles were evaluated for their reduction in TSC and sediment retention. The testing showed that the sediment log had the best sediment retention among the three wattle practices when 45-degree staking was used. The coconut coir log was also found to be effective for sediment retention; however, it was prone to undercutting, likely due to poor ground contact since staking was behind the log rather than through it. The straw wattle performed the worst among the practices, primarily due to consistent failure in undercutting. The sleeving joint method was determined to be the most effective; however, sleeving increased installation effort. This testing provided guidance on how proper installation is critical for effective sediment capture and water-quality improvements with wattles, and that the manufacturer's guidelines might not be the best available method (Bhattarai et al. 2021).

Large-scale performance evaluations on wattles have also been conducted by both Roche and Whitman et al. at the AU-SRF. Both tests were conducted using the same apparatus as stated previously for silt fence testing by Whitman et al. In the same testing by Whitman et al. on manufactured silt fence, a performance evaluation was conducted on Western Excelsior Straw Wattles. The wattles were installed in accordance with ALDOT specifications, which state that the wattle is staked in an “A-frame” fashion, with wooden stakes angled on either side pressing the wattle into the ground. The wattle was also trenched into the ground 3 in. (8 cm) following the manufacturer's guidelines; however, for the last install, the wattle was installed on a geotextile underlay with no trenching due to observed undermining. Whitman et al. determined that the wattle had the least velocity reduction with the smallest impoundment. The wattle had an average sediment retention of 82%, which was higher than that of the compost sock but far lower than that of the silt fence (Whitman et al. 2019b). Roche conducted testing on similar straw wattles; however, they were installed in accordance with the Nebraska Department of Transportation’s (NDOT) specifications. This included staking through the middle of the wattle, trenching in 3 in. (8 cm), and was located 10 ft (3 m) from the toe of the slope. Modifications to installation were also tested, including using only sod staples and using sod staples and “A-frame” staking. The design that performed best included sod staples and angled staking. This design showed reductions in undermining, increased impoundment, and average sediment capture of 80.8%. Testing was also conducted on excelsior wattles installed using the best installation method determined for the straw wattles. The excelsior wattles performed worse with higher flow-through rates, lower impoundment levels, and a sediment capture rate of 75.3%. This testing differed from Whitman et al. in that sediment retention was measured by weighing the sediment that passed through the practice and collected in the catch basin. This sediment that passed was then subtracted from the sediment introduced to determine sediment retention of the practices (Roche 2023). The results of both tests highlight the importance of creating impoundments and maintaining good ground contact as keys to the effective use of wattles.

3.2.3 Compost Socks

Compost socks are E&SCs similar to wattles; they have a tubular mesh or netting that contains compostable media, and they are placed perpendicular to slopes to slow flow and create impoundment. Compost socks are considered an additional treatment mechanism for runoff, as they are known to remove other pollutants, such as nutrients and metals, in addition to sediment. The makeup of compost socks varies based on the sock material and the compost media. The sock can either be plastic-based, which may need to be removed after construction, or natural-based, which are biodegradable and can be left in place. The media within the compost sock vary, but typically include lawn clippings, mulch, biosolids, or manure. Like wattles, they are typically installed as perimeter control measures or along steeper slopes to reduce runoff velocity. Figure 3.4 shows a compost sock installed as a perimeter control at the toe of a disturbed slope. The benefits of compost socks compared to wattles are that they typically do not require trenching, can be left on site to aid in vegetation growth if biodegradable, and are normally filled as a single continuous unit, without overlapping or jointing of separate sections. One downside to compost socks is that they generally need to be filled on site, so compost needs to be trucked in and piped into the sock material. The quality of compost is important when using compost socks, as it can help prevent nutrient or pathogen leaching and the introduction of additional pollutants (US EPA 2021c).

Figure 3.4: Compost Sock Installed as Perimeter Control (Perez 2016)

Several studies have evaluated the performance of compost socks as a sediment control practice. One small-scale study by Faucette et al. evaluated sediment reduction and phosphorus removal with compost socks and whether adding polymers to the practice could improve performance. Their study was conducted utilizing the same methodology as described for their testing of silt fence. Three tests were conducted: one on the compost sock alone, one with polymers applied to the sock to enhance sediment removal (flocculant), and one with polymers applied to the sock to enhance phosphorus removal. The third test also had commercial fertilizer added to the soil. The results indicated that the compost sock removed 80% of TSS on its own, 96% with the sediment-targeting polymer, and 75% with the phosphorus-targeting polymer. This indicates that the compost sock performs effectively on its own and improves performance when flocculant is added. The compost sock removed 63% of total phosphorus on its own, and this increased to 97% with phosphorus-targeting polymers (Faucette et al. 2008). Compost socks have been shown to have effective nutrient-removal capabilities in addition to their sediment-removal capabilities.

Large-scale performance evaluations on compost socks, specifically mulch compost socks, have been conducted by both Whitman et al. and Zhang et al. Their testing was conducted according to the methodologies discussed for their silt fence testing. The main differences between their methodologies are the size of the installation area, the length of practice installed, the flow rate, the sediment weight introduced, and the number of storms introduced. For their compost sock testing, they also differed in the method of installation. Whitman et al. installed the compost socks by laying 3 segments in a pyramid configuration and using wooden stakes in an “A-frame” configuration to keep the compost socks pinned together. The results of this testing indicated that consistent undermining occurs, leading to flow bypassing. The sediment capture ranged from 67% to 93%, with the lower end due to undermining (Whitman et al. 2019b). Zhang et al. installed the compost sock as a single layer, hammered wooden stakes vertically through the sock, and pressed down the upstream side into the ground. The results from their testing indicated that the sock had consistent flow-through once impoundment reached a certain height and that there was no structural failure; however, overtopping was possible. The sock showed similar sediment capture to that reported by Whitman et al., with 74% capture (Zhang et al. 2022). The results from both tests show that sediment capture rates are consistent; however, they are not directly comparable due to differences in installation and methodology. This leaves gaps in knowledge about the practice's true performance.

3.2.4 Sediment Retention Barriers

Sediment retention barriers (SRBs) are a less commonly implemented practice consisting of two rows of fencing with straw or mulch in the middle, and sometimes include flocculant. SRBs are typically designed to enhance the treatment of stormwater runoff and are used in conjunction with other practices. An additional practice must be used downstream if flocculant is incorporated into the design to capture and remove it before discharge offsite (AL-SWCC 2018). There are several SRB designs available; one in the Alabama Soil and Water Conservation Commission (AL-SWCC) Handbook requires two rows of high-flow-through netting, with a jute blanket covered with loose straw and flocculant in the middle (AL-SWCC 2018). Another design is the ALDOT SRB, which does not use floc and recommends two rows of silt fence, with straw bales placed between to support the upstream fence (ALDOT 2021). A photo of an ALDOT design SRB can be seen in Figure 3.5.

Figure 3.5: Sediment Retention Barrier (Perez 2016)

Limited testing has been conducted on the performance of SRBs. Whitman et al. have conducted testing of both the ALDOT and AL-SWCC designs, comparing their structural, water-quality, and sediment-capture performance. Testing was conducted using the same methodology previously described for Whitman et al.'s studies. Testing on the ALDOT design showed that the hay bales effectively support the front row of silt fence; however, when the front row is overtopped, load transfer to the back row results in substantial deformation of the T-posts. Whitman et al. recommend stronger posts, closer post spacing, and a geotextile with a higher flow-through rate to alleviate these issues. The AL-SWCC design was noted to be overly structurally sound and could benefit from using more cost-effective materials, such as wooden posts and less straw, as the flow only went through the bottom of the installation. The ALDOT SRB outperformed the AL-SWCC with and without flocculant. The ALDOT design had an average sediment retention rate of 91%, whereas the AL-SWCC had 63% without flocculant, and 83% with flocculant. During testing, the AL-SWCC designs improved water quality more than that of the ALDOT design; however, during dewatering, turbidity increased within the first 10 minutes for the AL-SWCC designs due to the lack of impoundment (Whitman et al. 2019b). This testing shows that SRBs are an effective sediment barrier practice; however, there is a lack of definition regarding their design and proper functionality.

3.2.5 Slash Mulch Berms

Slash mulch berms, also known as brush barriers, are a simple sediment barrier practice that involves placing material such as mulch, branches, roots, or other plant debris in a mound along the edge of a site. The design of slash mulch berms sometimes includes the use of a filter fabric or geotextile overlay to help hold material in place. The material within the berm is also recommended to be mulched or shredded to a small enough size to prevent the formation of large voids. Some benefits of using slash mulch berms include the ability to use material already on site, created from clearing and grubbing, and the option to leave them in place or spread them across the site after construction is complete if no fabric is used (NDOT 2025). Potential limitations of slash mulch berms include ineffectiveness in areas of concentrated flow and limited time use due to material decay (US EPA 2021d). An image of a slash mulch berm implemented as a sediment barrier practice can be seen in Figure 3.6.

Figure 3.6: Slash Mulch Berm (Young 2023)

Roche has conducted performance testing of slash mulch berms to determine the most effective and feasible design for NDOT's use. The methodology was consistent with the other testing previously discussed for Roche. Three installation designs of slash mulch berms were evaluated: the NDOT standard, a shorter and thinner berm compacted in three lifts, and a shorter berm the same width as the standard compacted in two lifts. The standard design proved to have limited impoundment, with both modifications having improved impoundment. Roche selected the shorter, thinner berm as the most feasible and effective practice due to its impoundment, similar to the other modified berm design, but requiring less material. The best design proved effective at improving water quality, with an average 75% decrease in turbidity and 89% decrease in TSS. This design also proved capable of capturing 73.5% of the sediment upstream of the barrier and 25.4% within the berm (Roche 2023). This testing shows that slash mulch berms are an effective sediment barrier when implemented properly and can be cost-effective, depending on the availability of on-site material.

3.3 Sediment Barrier Testing Materials and Methodology

Testing of sediment barrier practices (wattle, silt fence, and compost sock) and products (Product A and Product B) was based on the methodology developed by Bugg et al. and conducted on the large-scale sediment barrier testing apparatus also described by Bugg et al. (Bugg et al. 2017). The testing methodology was adapted to test the performance of each practice under a single simulated storm with maximum impoundment length, as well as longevity across three simulated storms. Methodology for sediment barrier testing is described as follows: flow and sediment introduction rates, apparatus layout, experimental method, modified testing, and sediment barrier installation and materials.

3.3.1 Determination of Flow Rate and Sediment Load

The calculation of flow and sediment introduction rates was based on the methodology and process described by Bugg et al., and the resulting flow and sediment introduction rates were the same as those used for their testing (Bugg et al. 2017). This was done to ensure testing for this project was representative of conditions in Alabama, as in Bugg et al., and to allow the results to be directly compared with previously conducted testing. Sediment and flow rate were based on a representative drainage area consistent with the AL-SWCC design standard of 0.5 ac (0.2 ha) of drainage area maximum per 100 ft (30.5 m) of silt fence. This requirement was implemented for all sediment barriers and scaled down to a representative area of 0.1 ac (0.04 ha) for a maximum sediment barrier length of 20 ft (6.1 m) in the AU-SRF sediment barrier testing apparatus.

3.3.1.1 Calculation of Flow Rate

Sediment barrier practices are often designed for the peak 30-minute period of a 2-yr, 24-hr rain event. The average precipitation for this storm event in Alabama was determined to be 4.43 in. (11.7 cm). The curve number utilized for calculations was 88.5, which is the average curve number for cleared areas in Alabama (Perez et al. 2015). A representative drainage area for a typical construction site was created and shown in Figure 3.7. Using methodology from Technical Release 55 (TR-55) and Bentley PondPack, a hydrograph was created from an average rainfall depth of 4.43 in. (11.7 cm), a curve number of 88.5, and the dimensions of the representative drainage area. The average flow rate for the peak 30 min of this hydrograph was 0.22 ft^3/s (0.006 m^3/s). The flow rate of 0.22 ft^3/s (0.006 m^3/s) was used for testing all sediment barrier practices and products, as well as for sediment loading calculations.

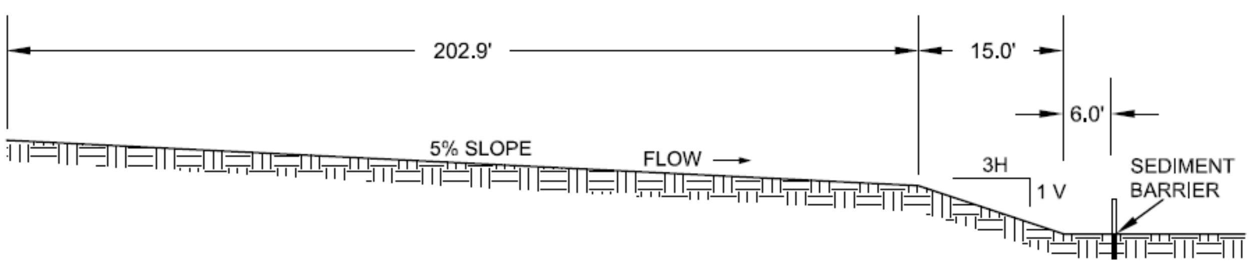


Figure 3.7: Profile View of Representative Drainage Area (Bugg et al. 2017)

3.3.1.2 Sediment Load Calculation

The sediment load created by a 2-yr, 24-hr storm event in Alabama was calculated using the Modified Universal Soil Loss Equation (MUSLE). MUSLE was used because it calculates soil loss from a specific storm event using site-specific factors. The MUSLE can be seen below in Equation 3.1.

$$S = 95 * \left(Q * q_p\right)^{0.56} * K * LS * C * P$$ **Equation 3.1**

Where:

S	=	sediment yield (tons)
Q	=	runoff volume (acre-ft)
q_p	=	peak flow (ft^3/s)
K	=	soil erodibility factor (dimensionless)
LS	=	length-slope factor (dimensionless)
C	=	cover factor (dimensionless)
P	=	practice factor (dimensionless)

The runoff volume (0.009 acre-ft [11.04 m^3]) and peak discharge (0.32 ft^3/s [0.009 m^3/s]) were determined using the hydrograph of the representative drainage area created for flow rate determination. The soil erodibility factor was determined to be 0.15 for a loamy sand, loamy fine sand, sandy loam, loamy silty loam (Pitt et al. 2007). The length-slope factor was determined to be 1.04 based on a composite of the two slopes in the representative area: 202.9 ft (61.8 m) at 5% slope and 15 ft (4.6 m) at 33% slope. Both the cover and practice factors were set to 1.0 because the representative area was assumed to be bare, with no cover or E&SC. The resulting sediment yield from MUSLE was 0.56 tons (0.51 tonnes), or 1,116 lbs. (506 kg), representing the sediment loss from the peak 30 min of a 2-yr, 24-hr storm. To determine the rate of sediment introduction, the total sediment yield was divided over 30 minutes, yielding a rate of 37.2 lbs./min (16.9 kg/min).

3.3.2 Testing Apparatus

The sediment barrier testing apparatus utilized in this testing is seen in Figure 3.2 and was the same apparatus designed by Bugg et al., and used by Whitman et al., and Roche in various other tests on sediment barrier practices (Bugg et al. 2017; Roche 2023; Whitman et al. 2018, 2019a; b). Water used for testing was stored in a nearby storage pond and pumped into a 300-gallon (1.14 m^3) tank using a 3-in. (7.62 cm) semi-trash pump. The tank was designed to act as an equalization tank and control the flow rate. The tank has a board across it to deflect and slow down the inflow, and two outflow valves that allow for calibration and adjustment of flow rates. Flow then passes through a calibrated weir and into a mixing trough, where sediment is introduced, and turbulent flow is created to enhance mixing of sediment and water. Flow then runs onto the 3:1 (H:V) impervious metal slope and through vanes, diverting the water across the whole 20 ft (6.1 m) width as sheet flow.

After the flow runs the length of the impervious slope, it flows into the testing plot. The 20 ft (6.1 m) wide and 12 ft (3.7 m) long testing plot consists of Alabama native soil. The plot is prepared before each installation to a 1% grade in the direction of flow and level perpendicular to it. Once the flow passes over the plot and through the sediment barrier practice, it is channeled into a catch basin. Since the volume of the introduced storm event exceeded the catch basin's storage capacity, the catch basin was pumped out and discharged using two 2-in. (5.1 cm) submersible pumps once the full volume was reached.

3.3.3 Experimental Methodology

The testing methodology followed was the same as outlined by Bugg et al.; however, some modifications made by Roche were also followed, as were additional modifications made for this series of testing (Bugg et al. 2017; Roche 2023). The modifications include using plastic to line the test plot upstream of the sediment barrier, measuring the depth of water in the catch basin, and installing several practices at the downstream end of the plot.

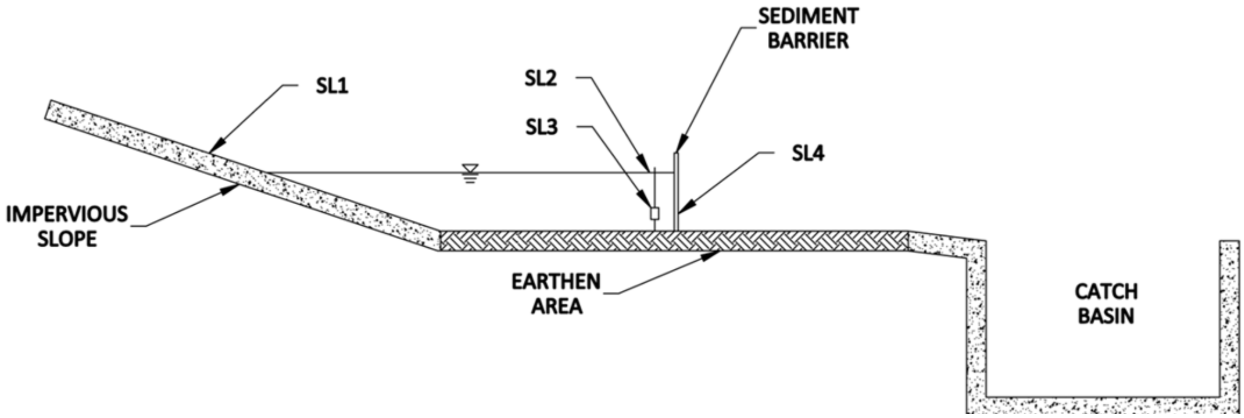
3.3.3.1 Pre-Test Preparation

Before testing each installation, several preparatory steps were followed, including establishing the plot and preparing sediment for introduction. Before every installation, the testing plot was tilled with a push-rear tined tiller. If the sediment was too wet, it was removed, discarded, and replaced with dry native soil from a stockpile located at the AU-SRF. After tilling, the loose soil was graded and compacted using a plate compactor to the desired grade: 1% in the direction of flow and level perpendicular to it. The soil used for the introduction to flow was also native Alabama soil. The soil was passed through a mechanical shaker to remove unwanted debris and reduce clumps to a finer gradation. The soil was then weighed out to 18.6 lbs. (8.4 kg) as a wet weight into 60 2-gallon (7.6 L) buckets. The moisture content of the sediment was determined for each test according to ASTM standards to determine the dry weight of sediment introduced (ASTM 2019).

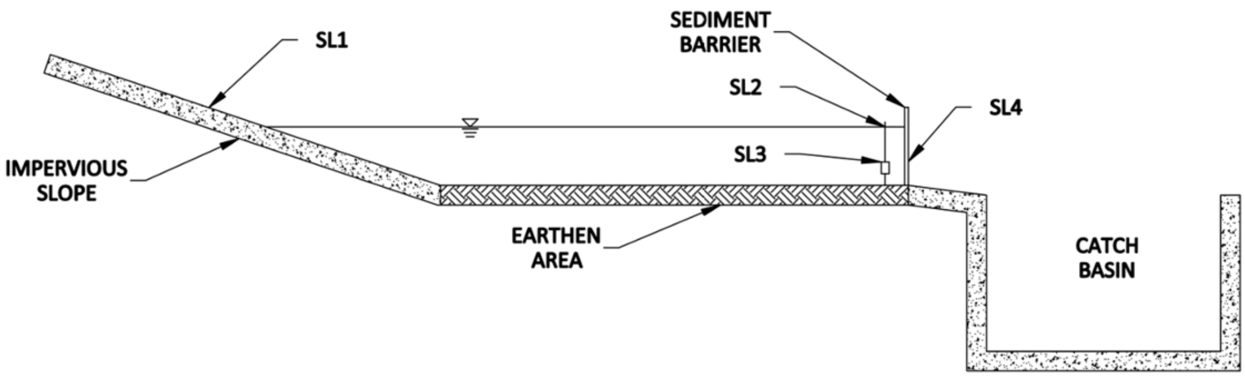
3.3.3.2 Testing Methods and Sampling

Sediment barriers were installed at two locations for longevity testing and single-storm testing. For longevity testing, the barriers were installed along the center of the plot, as was done in Bugg et al.'s testing (Bugg et al. 2017). For single-storm testing, sediment barriers were installed at the downstream end of the test plot. This was done to evaluate the performance with the maximum possible impound length and sediment retention area. Both installation locations can be seen below in Figure 3.8. For both install locations, plastic was installed across the testing plot to the upstream base of the sediment practice and taped flush to the impermeable slope. The plastic was installed to collect the sediment retained upstream of the practice and separate it from the soil plot.

During testing, once the flow was established, sediment was manually introduced by shaking it from the pre-filled buckets into the mixing trough at a rate of 30 seconds per bucket. Throughout the 30 minutes of testing, as water impounded against the installed barrier, the impoundment depth and length were recorded every 5 minutes. The depth was measured with a ruler placed at the upstream base of the barrier, and the impoundment length was measured with a tape measure along the wall of the testing plot. Water-quality grab samples were collected at four locations throughout testing, at the same 5-minute intervals as for the impoundment measurements. The locations of the grab samples for longevity testing and single-storm testing are shown in Figure 3.8. Samples were taken at the outlet of the mixing trough (SL1), the top of the impoundment (SL2), the bottom of the impoundment (SL3), and just downstream of the sediment barrier (SL4). When the flow passed through the barrier and into the catch basin, the water depth was measured with a Solinst Levelogger®. This was a pressure sensor that took a reading every 15 seconds and calculated depth. Using the change in depth between these increments, a flow-through rate of the sediment barrier was calculated throughout the test.



(a) Longevity Testing



(b) Single Storm Testing

Figure 3.8: Profile View of Sampling and Sediment Barrier Locations

Once the 30 minutes of flow and sediment introduction were completed, a 90-minute dewatering period was monitored, or until practice was fully dewatered, for a total test time of 120 minutes. During this dewatering period, water-quality grab samples and impoundment measurements were taken at 35, 40, 45, 60, 90, and 120 minutes. All grab samples were taken in 8 oz. (250 mL) bottles.

After dewatering was completed, the captured sediment was allowed to dry in place on the plastic to a more manageable water content for shoveling out. Sediment was then shoveled out in sections based on similar sediment size and moisture content. Sediment was shoveled out into hoppers and weighed. Moisture content grab samples were taken from each hopper to determine the dry weight of sediment retained upstream. Water quality samples were analyzed for TSS in accordance with ASTM D5907 and for turbidity in accordance with ASTM D7315 (ASTM 2017, 2018).

3.3.3.3 Testing Plan

The testing plan to meet the initial goal of comparing available sediment barrier practices and novel products was developed as follows. Testing of two products, Product A and Product B, would be compared with testing of the standard ALDOT silt fence design to determine their efficacy relative to silt fence. This testing was conducted with installations in the middle of the test plot and three back-to-back simulated storms. This was done to determine the efficacy of all practices across multiple events, as would likely be the case on a typical construction site, and to directly compare results from prior testing on the AU-SRF sediment barrier testing apparatus. Following this first round of testing, the performance of Product A indicated that it was comparable to the silt fence only during one storm event. Based on these results, further modified testing was developed. The modified testing was performed on Product A, a compost sock, and a straw wattle. Each practice was installed at the downstream edge of the testing plot and was subjected to only one simulated storm event. This was done to determine the practice's performance with the maximum possible impoundment and performance when maintenance is performed with frequency. The compost sock and wattle were installed according to the California Department of Transportation (Caltrans) specifications, as the product was developed in California, and then could be directly compared to their standards (Caltrans 2025). Testing was also done on a bare slope with no practice installed, with one storm introduced. This was done to serve as a sediment capture control for single-storm testing.

3.3.4 Triplicate Storm Sediment Barrier Materials and Installation Details

The materials used and specifications followed for the installation of the practices and products evaluated under the triplicate storm longevity testing are outlined in the following section. The same type of material was used for every installation of the same practice and product.

3.3.4.1 Product A Installation (Middle of Plot)

Product A was installed in accordance with the manufacturer's specifications. Figure 3.9 illustrates the installation details. Following manufacturer guidelines, two 6 in. (15.2 cm) nails were used to anchor each segment to the bottom of the trench, and the segments were butted together tightly. The manufacturer specified using 1 in. (2.5 cm) by 2 in. (5.0 cm) by 24 in. (61.0 cm) wood stakes in place of 1 in. (2.5 cm) by 1 in. (2.5 cm) by 18 in. (45.7 cm) to accommodate heavier rain events and clay-based soils. Due to the 20 ft (6.1 m) width of the testing area and the 7 ft (2.1 m) width of each segment of Product A, two full segments and one shortened segment were used to extend from wall to wall. To prevent flow around the product, a wood stake was placed on the downstream side of the product and flush with the wall.

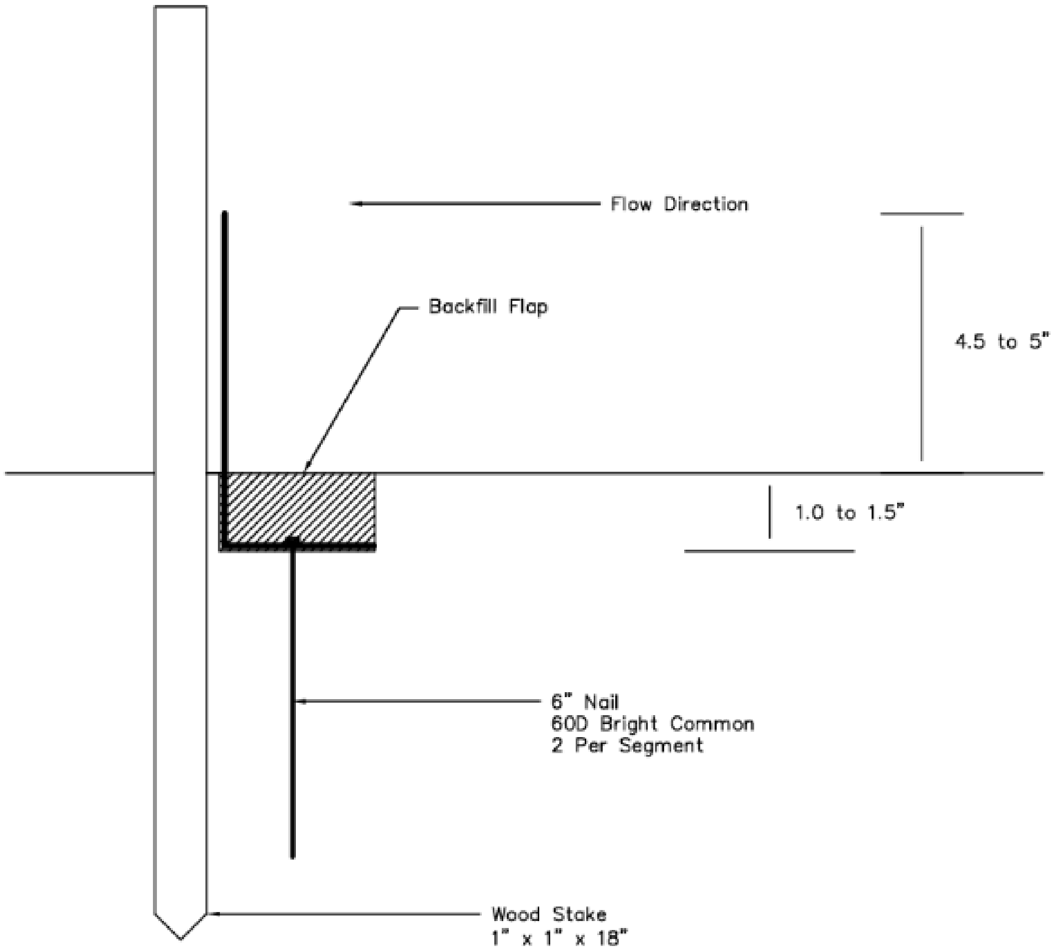


Figure 3.9: Product A Installation Details

The materials used to install the product include: three segments of Product A, six 6 in. (15.2 cm) 60D nails, and seven 1 in. (2.5 cm) by 2 in. (5.0 cm) by 24 in. (61.0 cm) wood stakes. Figure 3.10 shows both upstream and downstream views of the installation of Product A before the introduction of flow and sediment. Figure 3.11 shows a close-up photograph of Product A.

(a) view from upstream (b) view from downstream

Figure 3.10: Pre-Test Installation of Product A (Middle of Plot)

Figure 3.11: Product A Close-Up

3.3.4.2 Product B Installation

Product B was installed in accordance with the manufacturer's specifications. Figure 3.12 illustrates the installation details. Following the manufacturer's guidelines and recommendations, Product B was installed in a 3 in. (7.6 cm) deep, 3 in. (7.6 cm) wide trench. Four 1 in. (2.5 cm) by 2 in. (5.0 cm) by 18 in. (45.7 cm) stakes were used on the downstream side of the practice at each overlap, per the manufacturer's instructions. To connect the segments, they were overlapped by 4 in. (10.2 cm) and drilled into the wooden stakes using four 1 in. (2.5 cm) wood screws. Due to the 20 ft (6.1 m) width of the testing area and the 7 ft (2.1 m) width of each segment of Product B, two full segments and one shortened segment were used to extend from wall to wall. To prevent flow around the product, a wood stake was placed on the downstream side of the product and flush with the wall.

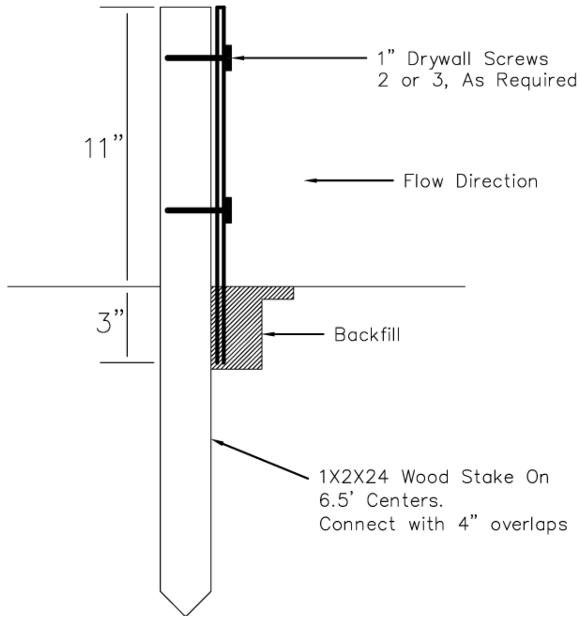


Figure 3.12: Product B Installation Details

The materials used to install Product B include: three segments of Product B, sixteen 1 in. (2.5 cm) wood screws, and four 1 in. (2.5 cm) by 2 in. (5.0 cm) by 18 in. (45.7 cm) wood stakes. Figure 3.13 shows both the upstream and downstream views of the installation of Product B before the introduction of flow and sediment. Figure 3.14 shows a close-up picture of Product B.

(a) view from upstream (b) view from downstream

Figure 3.13: Pre-Test Installation of Product B

Figure 3.14: Product B Close-Up

3.3.4.3 Silt Fence Installation

The silt fence was installed in accordance with ALDOT silt fence installation requirements. Figure 3.15 illustrates the installation details. In accordance with ALDOT guidelines, a nonwoven geotextile was used. The geotextile was trenched 6 in. (15.2 cm) into the ground, 6 in. (15.2 cm) from the upstream side of the wire backing, and the trench was backfilled and compacted over the buried geotextile. The posts used for the fence were 5-foot (1.5 m) studded steel T-posts weighing 1.25 lb./ft (1.86 kg/m). The posts were driven a minimum of 2 ft (0.6 m) into the ground, spaced 5 ft (1.5 m) apart, with the middle two posts spaced 2 ft (0.6 m) apart for the dewatering board. The dewatering board was constructed from 0.25-in. (1.9 cm) plywood, with four dewatering holes and a dewatering weir, and installed in the center of the plot. Downstream of the dewatering board, an excelsior fiber wattle and erosion control blanket were installed to prevent washout when water overtops the board (ALDOT 2021).

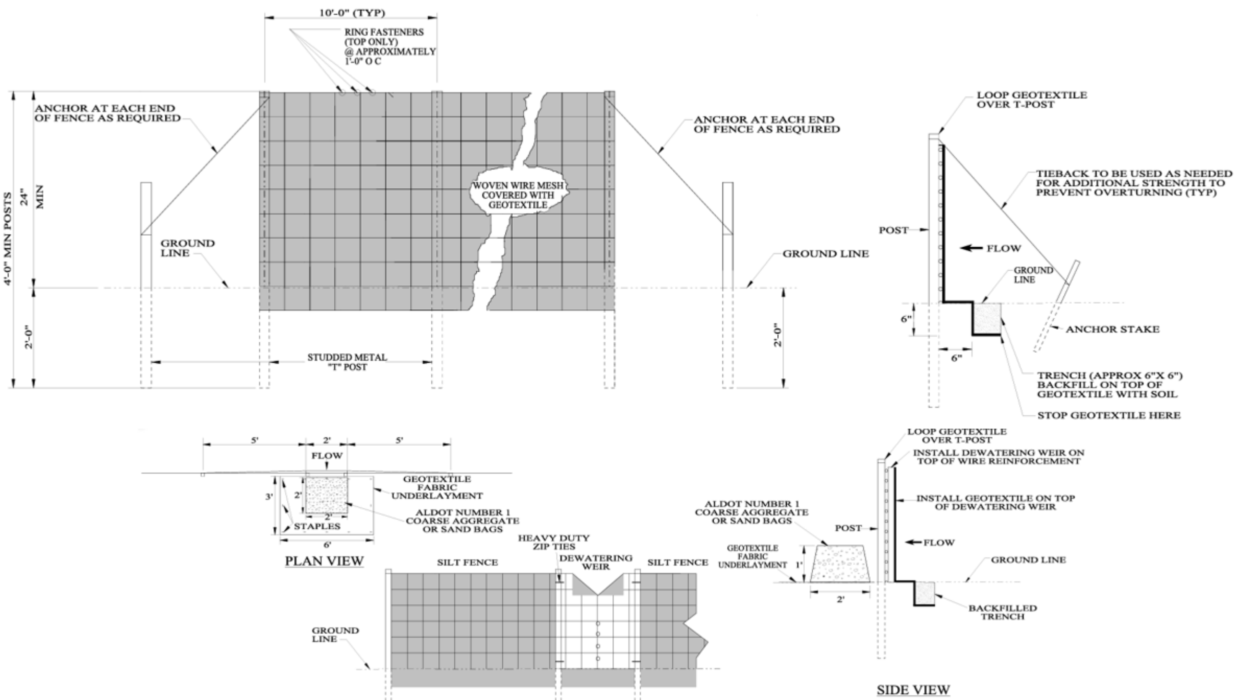


Figure 3.15: ALDOT Silt Fence Installation Details (ALDOT 2021)

The materials used to install the silt fence include: 20 ft (6.1 m) of nonwoven geotextile, 20 ft (6.1 m) of woven wire mesh, 6 studded steel T-posts, a dewatering board constructed from 0.25-in. (1.9 cm) plywood, a 4 ft (1.2 m) section of excelsior wattle, a 2 ft (0.6 m) by 2 ft (0.6 m) square of excelsior blanket, and 6 in. (15.2 cm) sod staples. Figure 3.16 shows the upstream and downstream views of the installation of the ALDOT silt fence before the introduction of flow and sediment.

(a) view from upstream (b) view from side

Figure 3.16: Pre-Test Installation of the ALDOT Silt Fence

3.3.5 Single Storm Sediment Barrier Materials and Installation Details

The materials used and the specifications followed for the installation of the practices and products evaluated under single-storm testing are outlined in the following section. The same type of material was used for every installation of the same practice and product.

3.3.5.1 Product A Installation (Downstream Edge of Plot)

Product A was also installed at the downstream end of the plot for single-storm testing. The product was installed using the same methodology previously described for longevity testing. Figure 3.9 illustrates the details for installation.

The materials used to install the product were the same as those outlined previously for longevity testing under triplicate back-to-back storms. Figure 3.17 shows both a side and downstream view of the installation of Product A, at the downstream end of the plot, before the introduction of flow and sediment.

(a) view from the side (b) view from downstream

Figure 3.17: Pre-Test Installation of Product A (Downstream Edge of Plot)

3.3.5.2 Compost Sock Installation

The compost sock used was a 12 in. (30.5 cm) diameter, pre-filled compost filter sock made of mesh and filled with wood mulch. The compost sock was installed in accordance with Caltrans installation requirements. Figure 3.18 illustrates the installation details. Following Caltrans guidelines, the compost sock met the minimum 12 in. (30.5 cm) in diameter, and the compost filling met quality requirements. The stakes used were 1 in. (2.5 cm) by 1 in. (2.5 cm) by 48 in. (121.9 cm), meeting the required dimensions of 1 in. (2.5 cm) by 1 in. (2.5 cm) by 24 in. (61.0 cm) for non-notched stakes. The stakes were driven through the center of the sock at each end and at 4 ft (1.2 m) intervals. The sock was cut and installed as a single 22 ft (6.7 m) section, with 1 ft (0.3 m) turned upstream at each end along the wall to prevent bypass flow (Caltrans 2025). Compost socks were thoroughly wetted before each test to simulate soaking from actual rainfall.

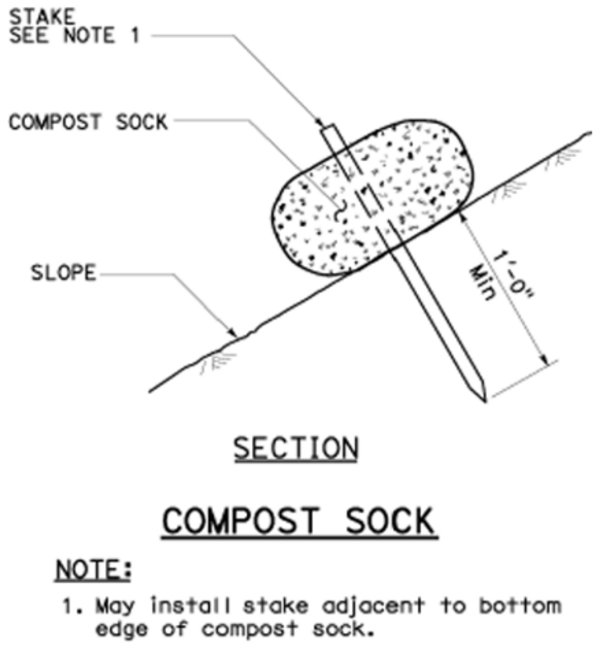


Figure 3.18: Compost Sock Installation Details (Caltrans 2025)

The materials used to install the compost sock include: one segment of compost sock and six 1 in. (2.5 cm) by 1 in. (2.5 cm) by 48 in. (121.9 cm) wood stakes. Figure 3.19 shows both the upstream and downstream views of the installation of the compost sock before the introduction of flow and sediment.

(a) view from upstream (b) view from downstream

Figure 3.19: Pre-Test Installation of the Compost Sock

3.3.5.3 Wattle Installation

The wattles were 10 ft (3.0 m) long and 12 in. (30.5 cm) in diameter sediment control logs filled with a weed-free wheat straw matrix. The wattle was installed in accordance with Caltrans fiber roll installation requirements. Figure 3.20 illustrates the details for installation. Per Caltrans guidelines, the wattle was 12 in. (30.5 cm) in diameter and had a linear density of at least 3.0 lb./ft (4.5 kg/m). The wattle was placed into a 2 in. (5.1) furrow dug into the test plot. The stakes used were 1 in. (2.5 cm) by 1 in. (2.5 cm) by 48 in. (121.9 cm), meeting the required dimensions of 1 in. (2.5 cm) by 1 in. (2.5 cm) by 24 in. (61.0 cm) for non-notched stakes. The stakes were driven through the center of the wattle at the ends of each and at 3.33 ft (1.00 m) intervals. Two wattles per test were used, overlapped by 1 ft (0.3 m) at the center, and had their ends turned upstream along the walls to prevent bypassing. Wattles were thoroughly wetted immediately prior to testing to simulate soaking of the wattle during actual rain events (Caltrans 2025).

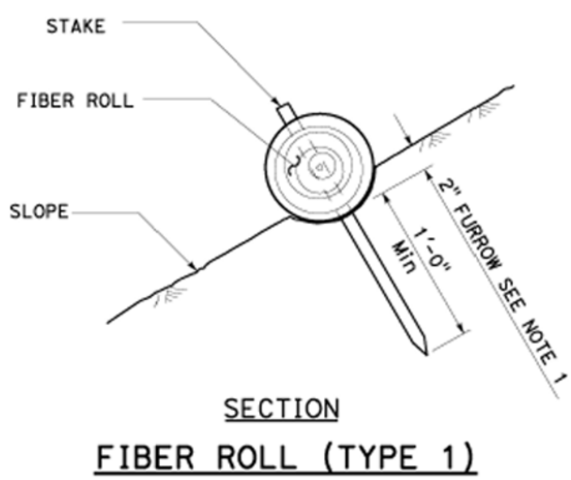


Figure 3.20: Straw Wattle Installation Details (Caltrans 2025)

The materials used to install the straw wattle include two segments of straw wattle and eight 1 in. (2.5 cm) by 1 in. (2.5 cm) by 48 in. (121.9 cm) wood stakes. Figure

3.21 shows the upstream and downstream views of the installation of the straw wattle before the introduction of flow and sediment.

(a) view from upstream (b) view from downstream

Figure 3.21: Pre-Test Installation of the Straw Wattle

3.4 Sediment Barrier Performance Results

The results for all sediment barrier testing are separated into three performance categories: impoundment, sediment capture, and water quality. Results for longevity testing are summarized first, followed by the results for single-storm testing. The results within each testing group varied across the different sediment barrier practices, indicating differences in their performance as effective sediment barrier practices.

3.4.1 Longevity Testing Results (Product A, Product B, and Silt Fence)

Longevity testing on each sediment barrier practice: Product A, Product B, and silt fence proved that each had vastly different performance over multiple storm events. The results of impoundment, sediment capture, and water quality (turbidity & TSS) describe how each practice reacted to the subsequent loading of three back-to-back storm events with no maintenance in between. All results describe data gathered from three simulated storm events introduced to three installations of each sediment barrier practice.

3.4.1.1 Impoundment

Table 3-1 displays the average impoundment depth created by each practice across all three introduced storm events. Product A was the shortest of the sediment barrier practices tested and struggled to maintain structural integrity during the second and third simulated storm events, resulting in its decreased impoundment depth. The product performed effectively during the first introduced storm event, but due to its short height and limited support, performance rapidly decreased in subsequent storm events. Product A tended to bend or deflect backward under the pressure of impounded water and captured sediment, thereby reducing the effective height of the practice. This was most severe in installation 2, which had the overall lowest impound depth across all installs and practices. The material's bending also channelized the flow over the top of the practice. This channelized flow resulted in undercutting of the first install, which is why it had the largest impound length and depth. The sediment that filled installations 1 and 2, limiting their impoundment, was not observed in installation 1 due to the observed undercutting.

Product B had similar structural issues to Product A, except they were magnified by its greater height and lack of ground support from material trenched into the ground parallel to the flow. While it was capable of larger impoundment than Product A, it struggled to impound to its theoretical maximum. Also similar to product A, channelization of overtopping flow led to undercutting during the first install, limiting sediment capture, and resulting in a larger average impoundment length because settled sediment did not fill in along the toe of the slope.

The silt fence had the largest average impoundment depth, by almost triple, and the largest average impoundment length by almost double. The silt fence was limited in its impoundment length by the impermeable slope. The silt fence showed no change in structural integrity, aside from slight sagging of the geotextile. This sagging, however, did not affect the practice's performance because overtopping was controlled by the dewatering weir.

Table 3-1: Summary of Average Impoundment During Test

Installation	**Product A**		**Product B**		**Silt Fence**	
	Avg. Impound Depth, in. (cm)	*Avg. Impound Length, in. (cm)*	*Avg. Impound Depth, in. (cm)*	*Avg. Impound Length, in. (cm)*	*Avg. Impound Depth, in. (cm)*	*Avg. Impound Length, in. (cm)*
1	3.3 (8.4)	64.1 (162.8)	4.7 (11.9)	72.1 (183.1)	13.2 (33.5)	104.9 (266.4)
2	1.9 (4.8)	26.1 (66.3)	5.4 (13.7)	61.3 (155.7)	13.4 (34.0)	106.4 (270.3)
3	2.1 (5.3)	25.8 (65.5)	4.6 (11.7)	55.6 (141.2)	13.5 (34.3)	103.8 (263.7)
Average	2.4 (6.1)	38.7 (98.3)	4.9 (12.4)	63.0 (160.0)	13.4 (34.0)	105.0 (266.7)

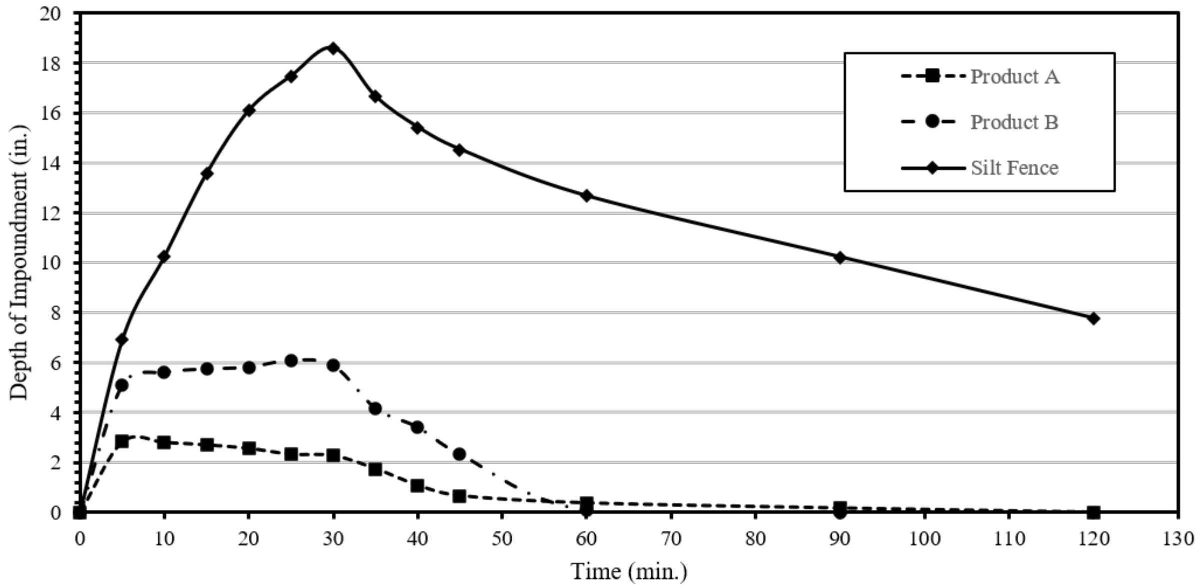
Table 3-2 below displays the maximum impoundment depth and length for Product A, Product B, and silt fence created during each installation tested. For Product A, the major difference between the maximum and average impoundment values is that for installs 2 and 3, the maximum is far greater than the average. This is because the available space for impounding water was gradually filled by captured sediment during the second and third storm events. Product B’s maximum impoundment values are closer aligned to its theoretical maximum impoundment than its averages, showing that a lack of structural integrity negatively impacts its performance.

Table 3-2: Summary of Maximum Impoundment During Test

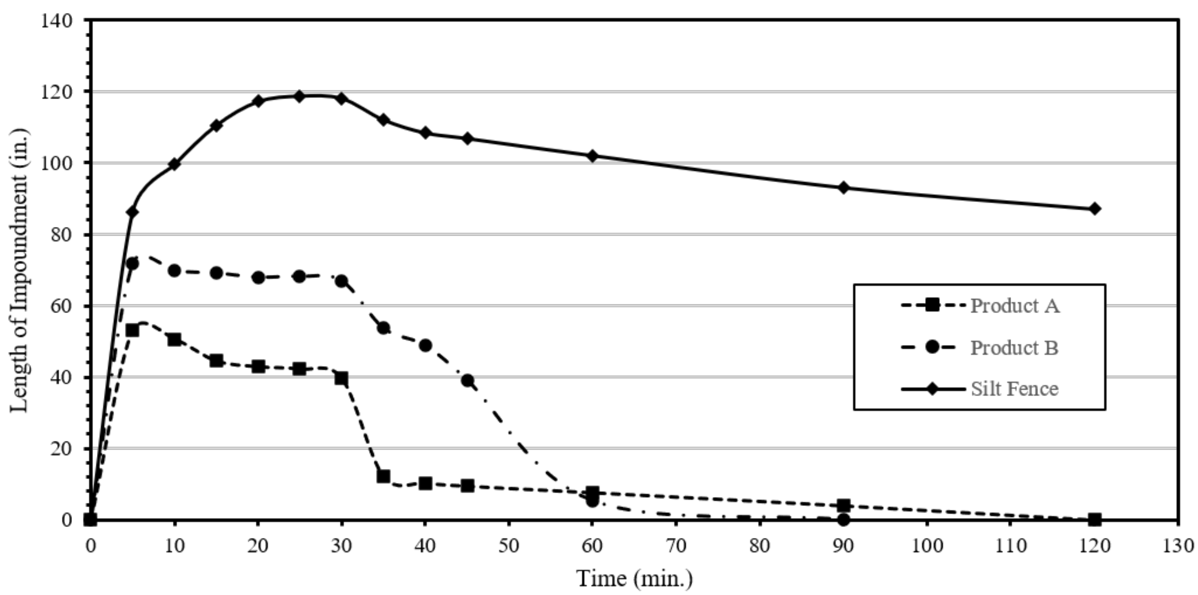
Installation	Product A		Product B		Silt Fence	
	Maximum Impound Depth, in. (cm)	*Maximum Impound Length, in. (cm)*	*Maximum Impound Depth, in. (cm)*	*Maximum Impound Length, in. (cm)*	*Maximum Impound Depth, in. (cm)*	*Maximum Impound Length, in. (cm)*
1	3.9 (9.9)	74.0 (188.0)	5.8 (14.7)	77.0 (195.6)	19.0 (48.3)	123.0 (312.4)
2	3.0 (7.6)	70.0 (177.8)	8.0 (20.3)	90.0 (228.6)	19.0 (48.3)	128.0 (325.1)
3	3.0 (7.6)	67.0 (170.2)	7.0 (17.8)	82.0 (208.3)	21.0 (53.3)	130.0 (330.2)
Average	3.3 (8.4)	70.3 (178.6)	6.9 (17.5)	83.0 (210.8)	19.7 (50.0)	127.0 (322.6)

Figure 3.22 displays the average impoundment depth and length created by each sediment barrier practice with respect to time. For impoundment length, the three datasets follow a very similar pattern with differing maximum depths and different dewatering times. They all saw a rapid increase in depth over the first five minutes, then leveled off at their maximum impoundment, except for the silt fence, which continued to increase until approximately 25 minutes into the test. This was likely due to the height of the silt fence providing additional room for impoundment depth and length before overtopping than Product B and Product A, which are shorter practices. After testing, Product B dewatered quickest, in approximately 60 minutes, while Product A and the silt fence took 90 minutes and over 90 minutes, respectively, to fully dewater. For impoundment depth, all three data sets showed a similar rapid increase in the first 5 minutes, but each followed a different pattern thereafter. Product B showed a constant impoundment depth once it reached its steady-state maximum after the first 5 minutes. Product A saw a steady decrease in impoundment depth after reaching its peak. This is due to sediment buildup upstream of the fence, limiting available impoundment. The silt fence showed a gradual increase in impound depth after the initial rapid increase, continuing until inflow was stopped. The rate at which the impound depth decreased

over time for the silt fence slowed as the depth reached additional dewatering holes and the dewatering weir.



(a) depth of impoundment



(b) length of impoundment

Figure 3.22: Impoundment Depth and Length

3.4.1.2 Sediment Capture

The dry weight of sediment introduced and captured upstream of each practice after the introduction of three storm events was recorded during testing of each practice.

This data, as well as the calculated percent capture, is displayed in Table 3-3. The percent capture was determined by comparing the dry weight of sediment captured on the plastic upstream to the dry weight of sediment introduced for that test. The silt fence had the highest average sediment capture weight of 2,918 lbs. (1,324 kg) and the highest capture rate at 97%. Product B had the next-highest average sediment capture weight at 2,562 lbs. (1,162 kg) and the second-highest percent capture at 88%. Product A had the lowest average sediment capture weight of 2,197 lbs. (997 kg) and a capture percentage of 74%. Install 1 for both Product A and B had much lower sediment capture rates than other installations due to undercutting observed on both installations.

Table 3-3: Summary of Sediment Capture

Sediment Barrier	Installation	Dry Weight of Introduced Soil, lbs. (kg)	Dry Weight of Captured Soil, lbs. (kg)	Percent Capture
Product A	1	3,044 (1,381)	1,930 (875)	63%
	2	2,805 (1,272)	2,109 (957)	75%
	3	3,067 (1,391)	2,553 (1,158)	83%
	Average	2,972 (1,348)	2,197 (997)	74%
Product B	1	3,044 (1,381)	2,250 (1,021)	74%
	2	2,834 (1,285)	2,696 (1,223)	95%
	3	2,890 (1,311)	2,740 (1,243)	95%
	Average	2,923 (1,326)	2,562 (1,162)	88%
Silt Fence	1	3,083 (1,398)	2,966 (1,345)	96%
	2	3,048 (1,383)	2,870 (1,302)	94%
	3	2,924 (1,326)	2,918 (1,324)	100%
	Average	3,018 (1,369)	2,918 (1,324)	97%

Figure 3.23, Figure 3.24, and Figure 3.25 show images from testing and post-testing for each sediment barrier practice. The pictures taken during testing were all taken during the third simulated storm event. The photo during testing for Product A shows that the practice is overtopping in two spots. The photo for Product B shows that the practice overtopped in one spot, where the fence's deflection lowered its height, limiting possible impoundment. The photo of the silt fence shows that the fence never

overtopped, and that flow was controlled through the dewatering board. The post-test photos for Products A and B show that sediment filled the available space behind the fence and between the impermeable slope, limiting future impoundment and sediment capture. For the silt fence, sediment builds up along the foot of the impermeable slope, indicating a slowing of flow velocity as sheet flow meets the impoundment created by the fence.

(a) during test (b) post test

Figure 3.23: During and Post-Test Photos of Product A

(a) during test (b) post test

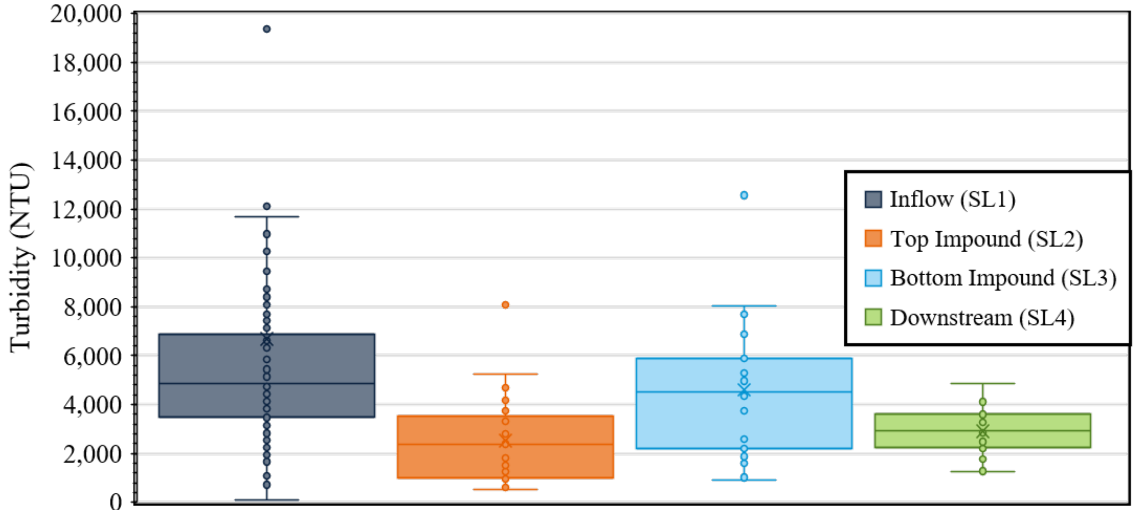
Figure 3.24: During and Post-Test Photos of Product B

(a) during test (b) post test

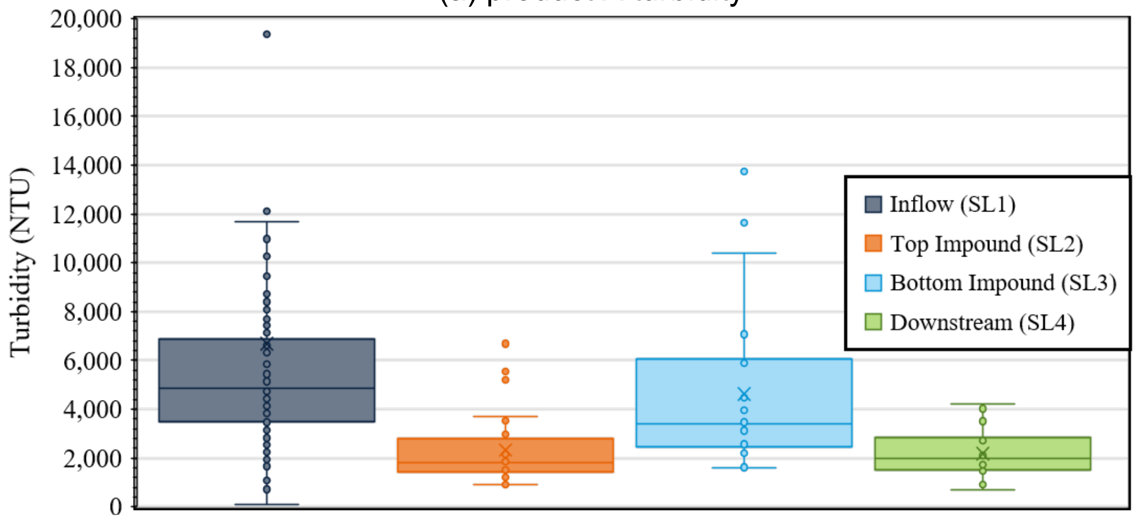
Figure 3.25: During and Post-Test Photos of Silt Fence

3.4.1.3 Turbidity

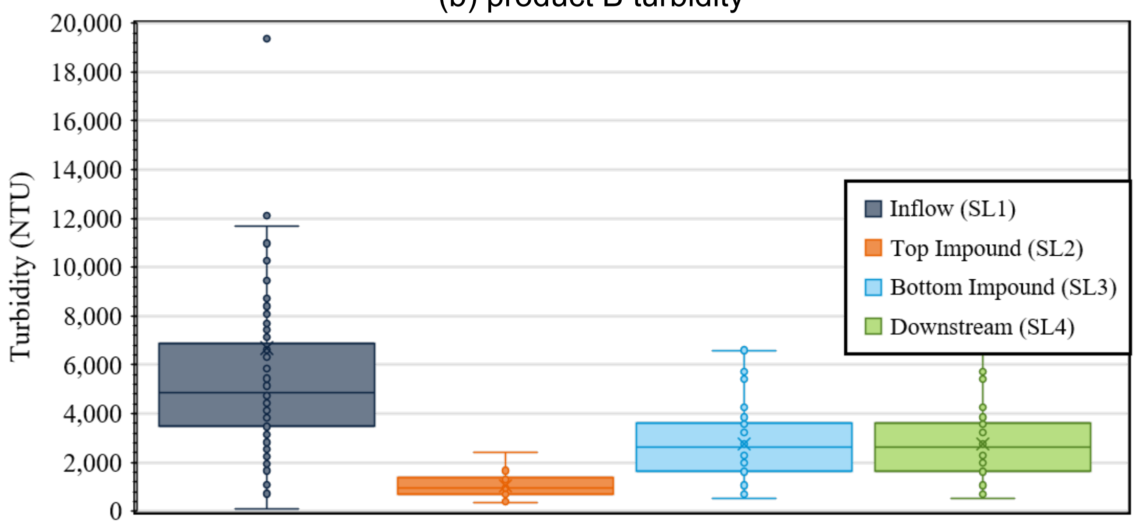
The turbidity data collected at the four sampling locations are shown in Figure 3.26. The legend reads top to bottom, which correlates to data read left to right. The data for the inflow contains data from tests conducted on all installations, as the introduction of sediment was the same for every test, and better represents the overall turbidity of the inflow. The sampling on the upstream impervious slope (SL1) indicated that inflow turbidity averaged 7,000 NTU across all tests. The downstream (SL4) turbidity for all three practices was less than the turbidity upstream for the inflow and at any place in the impoundment. This indicates that each practice captured sediment as the sediment-laden water passed through the sediment barrier in addition to settling out in the impoundment. The silt fence showed a decrease in turbidity from the inflow for all other sampling locations. Product A and Product B saw a decrease in turbidity downstream and at the top of the impoundment; however, the turbidity at the bottom of the impoundment was observed to be similar to that of the inflow, likely due to settling of sediment along the base of the practice. This was not the case for the silt fence, as most sediment settled out along the toe of the impermeable slope.



(a) product A turbidity



(b) product B turbidity



(c) silt fence turbidity

Figure 3.26: Turbidity of Sediment Barrier Practices

Figure 3.27 displays the downstream turbidity of each sediment barrier practice compared to the inflow turbidity. Product A and Product B showed similar decreases in turbidity downstream of the practice, with the silt fence providing the greatest turbidity reduction.

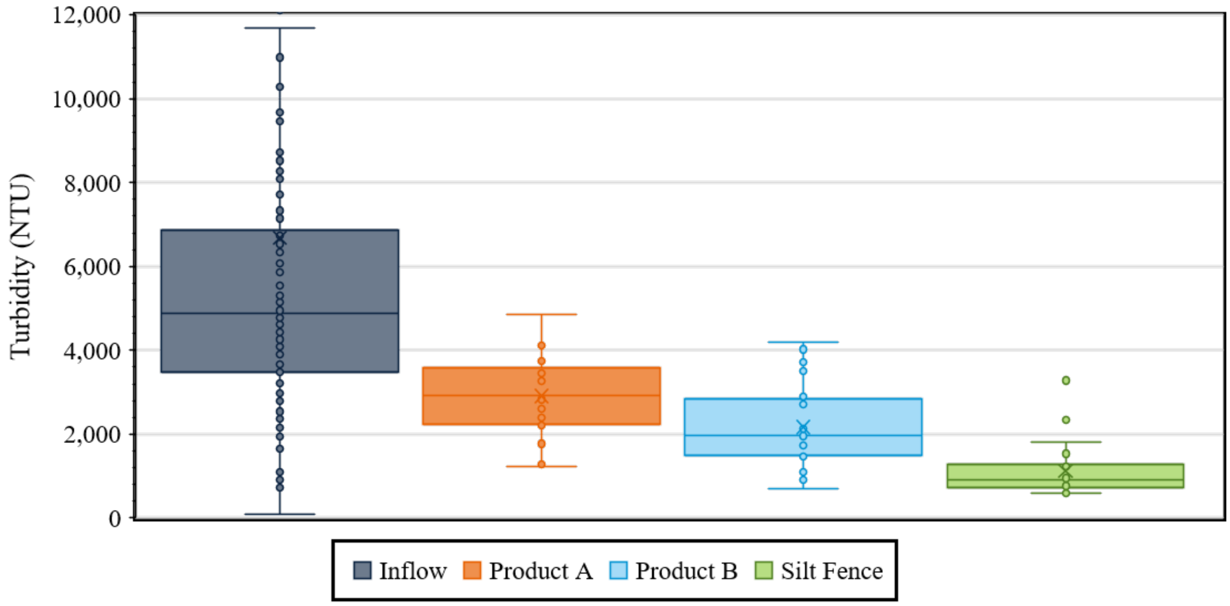


Figure 3.27: Downstream Turbidity Comparison

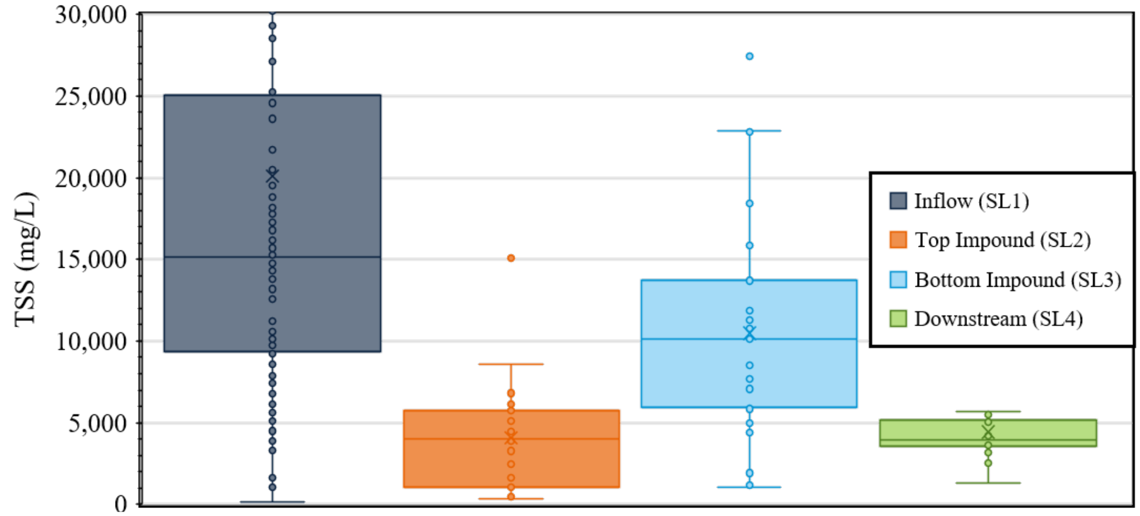
As shown in Table 3-4, the average downstream turbidity for the practices was 2,896 NTU, 2,333 NTU, and 1,124 NTU for Product A, Product B, and silt fence, respectively. The silt fence saw the lowest average downstream turbidity. Product A and Product B had higher average downstream turbidity than the silt fence. For the percent reduction, only data from each individual test was considered for the inflow data, as opposed to all inflow data, as was done for Figure 3.26 and Figure 3.27. The three practices showed varied percent removal, ranging from 48% to 84%, with the silt fence having the greatest and Product A having the lowest.

Table 3-4: Turbidity Improvement: Upstream vs. Downstream

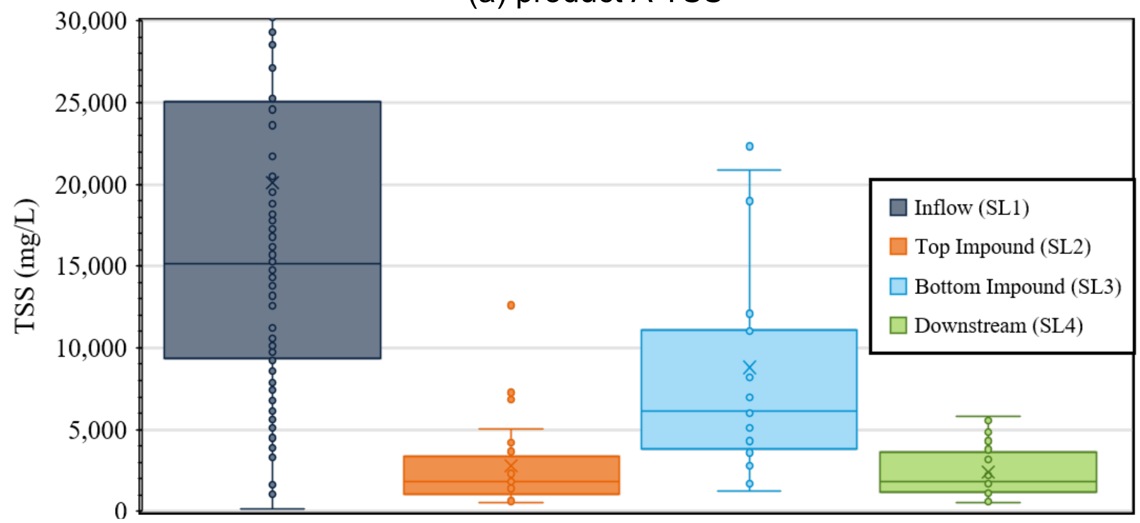
Sediment Barrier	Installation	Avg. Upstream Turbidity, NTU	Avg. Downstream Turbidity, NTU	Reduction
Product A	1	6,120	3,284	46%
	2	5,124	3,050	40%
	3	5,555	2,354	58%
	Avg. (SD)	5,600 (2,002)	2,896 (948)	48%
Product B	1	7,335	3,647	50%
	2	4,607	1,494	68%
	3	5,150	1,857	64%
	Avg. (SD)	5,697 (2,520)	2,333 (1,016)	59%
Silt Fence	1	6,938	1,332	81%
	2	6,628	1,089	84%
	3	7,145	951	87%
	Avg (SD)	6,904 (1,579)	1,124 (580)	84%

3.4.1.4 Total Suspended Solids

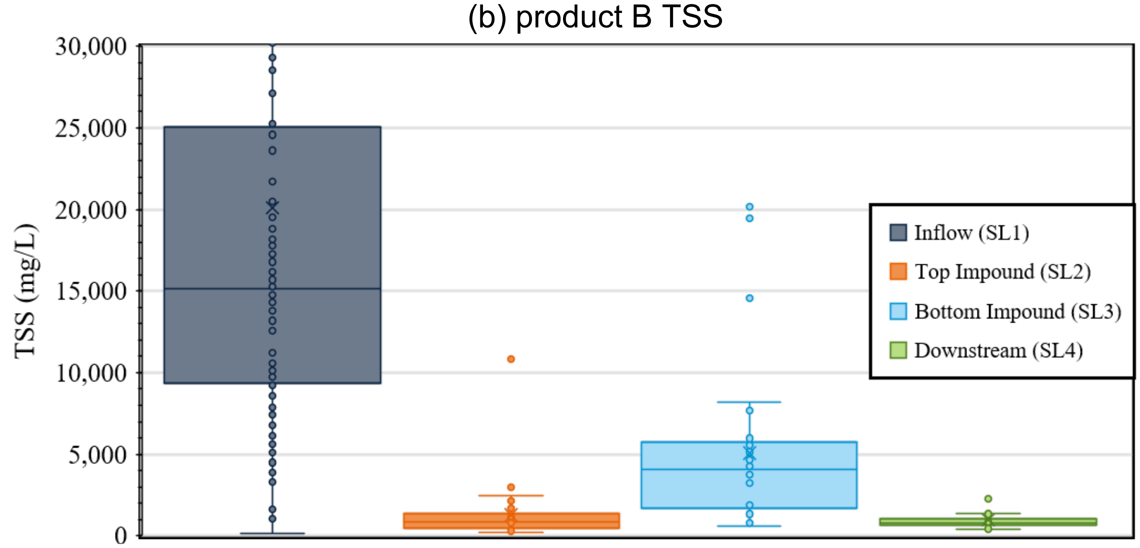
The TSS data collected at the four sampling locations are shown in Figure 3.28. The legend reads top to bottom, which correlates to data read left to right. As discussed for turbidity, the inflow data includes all three tests, since the sediment introduction was the same across them, and better reflects the inflow turbidity. Sampling on the upstream impervious slope (SL1) showed that the average inflow TSS was around 21,000 mg/L, with values ranging from 3,000 mg/L to 155,000 mg/L. The TSS data show a very similar pattern to that observed for turbidity. For all three practices, a decrease in TSS from the inflow to downstream (SL4) was observed. A decrease in TSS was also observed from the inflow to the top impoundment (SL2) for each practice. For the bottom impoundment, the silt fence saw a decrease in TSS, although not as great as for the downstream and the top of the impoundment, but Product A and Product B saw similar or slightly decreased TSS compared to the inflow.



(a) product A TSS



(b) product B TSS



(c) silt fence TSS

Figure 3.28: TSS of Sediment Barrier Practices

Figure 3.29 displays the downstream TSS of each sediment barrier practice compared to the inflow TSS. The data shows a pattern similar to turbidity, with Product A and Product B showing reductions in TSS downstream of the practice, with the silt fence providing the greatest TSS reduction.

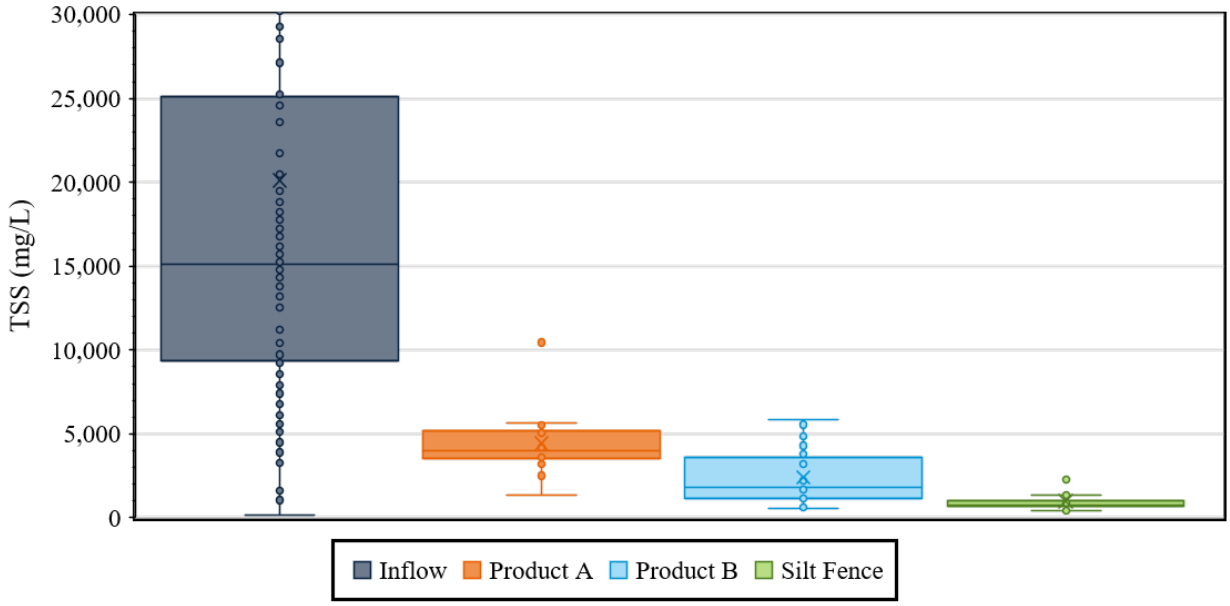


Figure 3.29: Downstream TSS Comparison

As shown in Table 3-5, the average downstream TSS for the practices was 4,437 mg/L, 2,630 mg/L, and 976 mg/L for Product A, Product B, and silt fence, respectively. Similar to turbidity, the silt fence saw the lowest average downstream TSS. Product B and Product A had higher average downstream TSS than the silt fence. For the percent reduction, only data from each individual test was considered for the inflow data, as opposed to all inflow data, as was done for Figure 3.28 and Figure 3.29. The three practices ranged from 74% to 97%, with the silt fence having the highest and Product A having the lowest.

Table 3-5: TSS Improvement: Upstream vs. Downstream

Sediment Barrier	Installation	Avg. Upstream TSS, mg/L	Avg. Downstream TSS, mg/L	Reduction
Product A	1	14,992	4,336	71%
	2	17,766	3,869	78%
	3	17,788	5,105	71%
	Avg. (SD)	16,849 (6,495)	4,437 (1,828)	74%
Product B	1	14,003	4,503	68%
	2	13,496	1,390	90%
	3	19,198	1,998	90%
	Avg. (SD)	15,566 (5,951)	2,630 (1,635)	83%
Silt Fence	1	26,369	1,049	96%
	2	22,010	946	96%
	3	40,416	932	98%
	Avg. (SD)	29,599 (9,917)	976 (546)	97%

3.4.2 Single-Storm Testing (Product A, Compost Sock, and Straw Wattle)

Single-storm testing on each sediment barrier practice: Product A, compost sock, and straw wattle proved that each had vastly different performance with extended impoundment area available, and under only one simulated storm event. The results of impoundment, sediment capture, and water quality (turbidity & TSS) describe how each practice performed during a single storm event, as if maintenance were performed after a qualifying event. All results describe data gathered from a single storm event applied to three installations of each sediment barrier practice, installed along the downstream edge of the testing plot. Each practice was also compared to sediment capture on a bare slope with no practice installed.

3.4.2.1 Impoundment (Single-Storm)

Table 3-6 displays the average impoundment depth created by each practice across all three introduced storm events. Product A performed very consistently across all three installations during the introduction of a single simulated storm event. The practice did overtop for all three installations, with only minor bending of the fence material. The practice's structural integrity remained intact throughout all three installations, with no failures observed. A decreased average impoundment length was observed for the third installment of Product A in comparison to the second installment, even though they had the same average impoundment depth. This was due to the sediment settling pattern in the third installment, which led to channelization of the flow, overtopping the practice rather than slowing and spreading out.

The compound sock had very consistent impoundment across all three installments and recorded the highest impoundment length and height of the three practices. The compost sock did not exhibit any major structural failures across all three installations; however, during testing, the flow bypassed the practice in some spots. This was not fully undercutting, as the weight of the compost sock kept the flow underneath limited and prevented the undercutting from growing. The average impound depth and length of the first installment were limited by a low spot in the sock that was not as well packed with mulch as the rest, allowing for a faster flow-through rate.

The straw wattle performed the worst of the three practices at impounding runoff across all three installments. The wattle acted more as a speed bump for the flow than as a dam, actually impounding the water. The installation's location at the downstream edge of the testing plot improved the wattle’s performance by slowing and spreading the flow before it interacted with the wattle. The wattle was soaked before each test, allowing it to sit in the furrow and impound water for the first 5 minutes of testing. However, after the first 5 minutes of the simulated storm event, the wattle was pushed up and floated, allowing most of the water to flow underneath.

Table 3-6: Summary of Average Impoundment During Test (Single-Storm)

Installation	Product A		Compost Sock		Straw Wattle	
	Avg. Impound Depth, in. (cm)	*Avg. Impound Length, in. (cm)*	*Avg. Impound Depth, in. (cm)*	*Avg. Impound Length, in. (cm)*	*Avg. Impound Depth, in. (cm)*	*Avg. Impound Length, in. (cm)*
1	2.6 (6.6)	63.8 (162.1)	4.5 (11.4)	87.8 (223.0)	1.7 (4.3)	21.0 (53.3)
2	3.0 (7.6)	94.7 (240.5)	5.2 (13.2)	120.3 (305.6)	1.4 (3.6)	14.0 (35.6)
3	3.0 (7.6)	79.0 (200.7)	5.6 (14.2)	91.3 (231.9)	1.8 (4.6)	23.3 (59.2)
Average	2.8 (7.1)	79.2 (201.2)	5.1 (13.0)	99.8 (253.5)	1.6 (4.1)	19.4 (49.3)

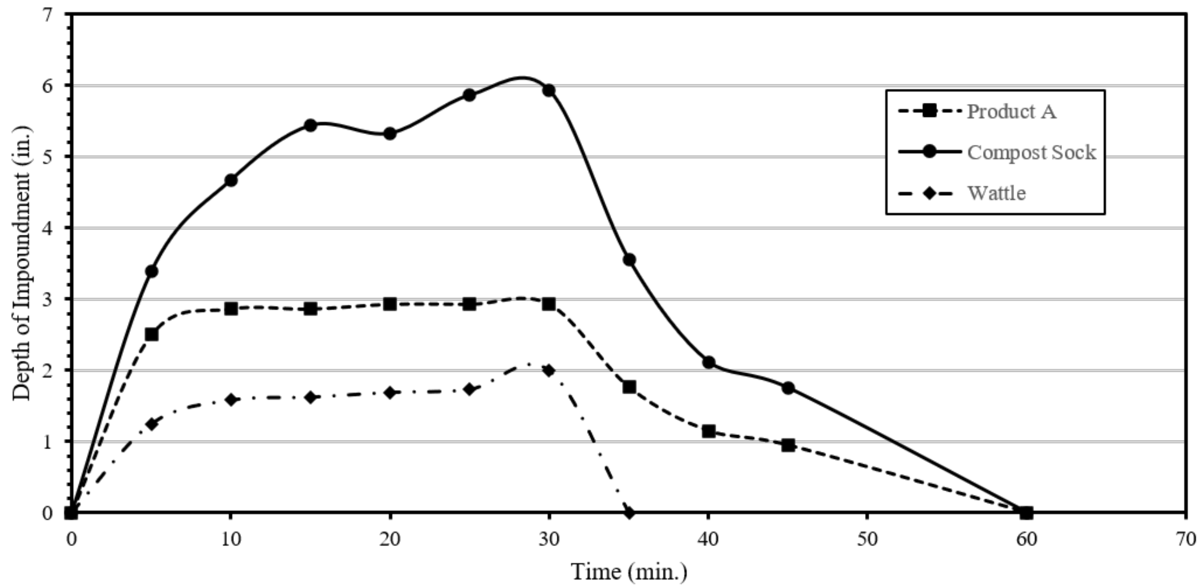
Table 3-7 below displays the maximum impoundment for Product A, the compost sock, and the straw wattle. Every practice had maximum impoundment measurements that were relatively close to their average impoundment values. This indicates that under one storm event, all three practices perform consistently. The straw wattle is heavily outperformed by the compost sock and Product A, as its maximum impoundment depth and length are only half that of Product A, and a quarter of the impoundment created by the compost sock.

Table 3-7: Summary of Maximum Impoundment During Test (Single-Storm)

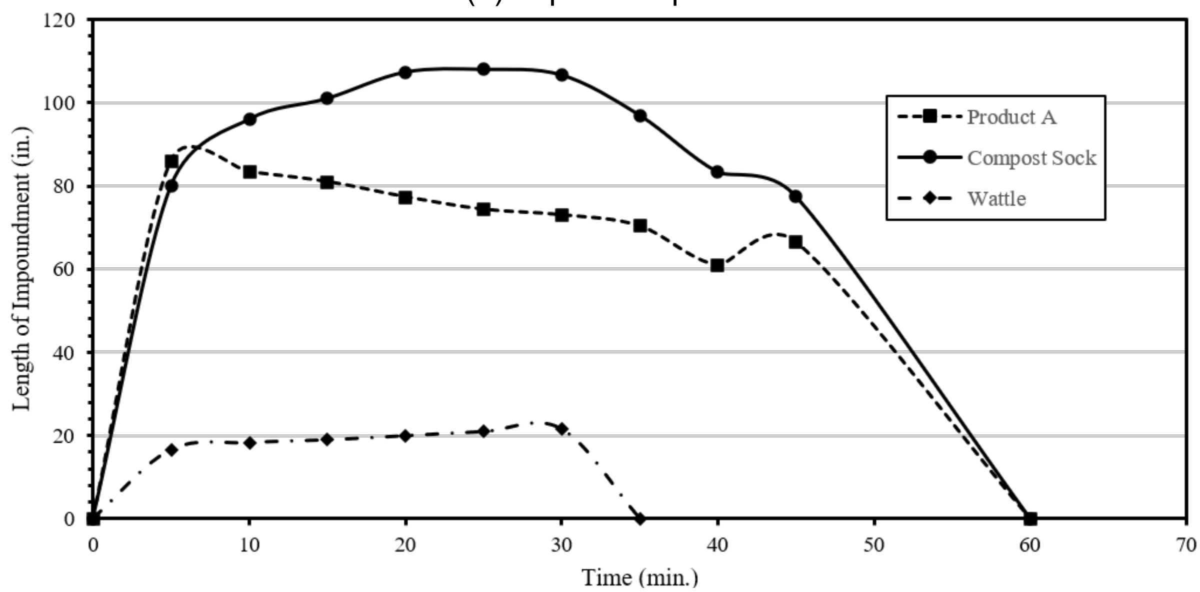
Installation	Product A		Compost Sock		Straw Wattle	
	Maximum Impound Depth, in. (cm)	*Maximum Impound Length, in. (cm)*	*Maximum Impound Depth, in (cm)*	*Maximum Impound Length, in. (cm)*	*Maximum Impound Depth, in. (cm)*	*Maximum Impound Length, in. (cm)*
1	2.8 (7.1)	67.0 (170.2)	5.4 (13.7)	101.0 (256.5)	1.8 (4.6)	23.0 (58.4)
2	3.0 (7.6)	120.0 (304.8)	6.0 (15.2)	130.0 (330.2)	2.0 (5.1)	16.0 (40.6)
3	3.0 (7.6)	89.0 (226.1)	6.4 (16.3)	103.0 (261.6)	2.3 (5.8)	26.0 (66.0)
Average	2.9 (7.4)	92.0 (233.7)	5.9 (15.0)	111.3 (282.7)	2.0 (5.1)	21.7 (55.1)

Figure 3.30 displays the average impoundment depth and length created by each sediment barrier practice over time. For impoundment depth, the three datasets follow a similar pattern with differing maximum depths. Product A and the straw wattle had a rapid increase in depth over the first 5 minutes, then leveled out at their maximum impoundment, whereas the compost sock slowly increased until flow introduction was

stopped. This was likely due to the height of the sock providing additional room for impoundment depth than the wattle and Product A, which are shorter practices. Product A reached its maximum impoundment just after its overtopping point, which occurred approximately 4 minutes into each test. After testing, the wattle dewatered within the first 5 minutes, while the compost sock and Product A took 30 minutes to fully dewater. For impoundment length, all three data sets showed a similar rapid increase in the first 5 minutes, but each followed a different pattern for the remainder of the test. The wattle showed constant impoundment length once it reached its maximum steady-state value after the first 5 minutes. Product A saw a steady decrease in impoundment length after reaching its maximum. This is due to sediment buildup at the base of the impervious slope, limiting impoundment length. The compost sock saw a slow increase in impound length after the initial rapid increase. This is due to the additional impoundment depth exceeding the sediment buildup, limiting the impoundment observed with Product A.



(a) depth of impoundment



(b) length of impoundment

Figure 3.30: Impoundment Depth and Length (Single-Storm)

3.4.2.2 Sediment Capture (Single-Storm)

The dry weight of sediment introduced and captured upstream of each practice after the introduction of one storm event was recorded during testing of each practice. This data, as well as the calculated percent capture, is displayed in Table 3-8. The percent capture was determined by comparing the dry weight of sediment captured on the plastic upstream to the dry weight of sediment introduced for that test. The compost sock had the highest average sediment capture weight of 966 lbs. (438 kg) and the highest capture rate at 95%. Product A had the next highest average sediment capture weight of 949 lbs. (430 kg), but the lower percent capture than the other practices at 90%. This is due to the higher observed weight of soil introduced than for the compost sock. The straw wattle had the lowest average sediment capture weight of 888 lbs. (405 kg), and a percent capture of 90%. The data shows that Product A had consistent performance in sediment capture, with all three tests having a sediment capture rate of 90%. The bare slope had an average sediment capture of 75%, which is 15% lower than the practices tested. The sediment capture for each bare-slope test was more variable than the practices tested. One test of the bare slope had greater capture than one of the wattle tests. This indicates that the wattle improves average performance compared to a bare slope; however, depending on how sediment settles, the sediment capture can be comparable to that of a wattle.

Table 3-8: Summary of Sediment Capture (Single-Storm)

Sediment Barrier	Installation	Dry Weight of Introduced Soil, lbs. (kg)	Dry Weight of Captured Soil, lbs. (kg)	Percent Capture
Product A	1	1,029 (467)	927 (420)	90%
	2	1,046 (474)	940 (426)	90%
	3	1,093 (496)	980 (445)	90%
	Average	1,056 (479)	949 (430)	90%
Compost Sock	1	1,034 (469)	993 (450)	96%
	2	978 (444)	944 (428)	97%
	3	1,034 (469)	961 (436)	93%
	Average	1,015 (460)	966 (438)	95%
Straw Wattle	1	985 (447)	828 (376)	84%
	2	986 (447)	945 (429)	96%
	3	986 (447)	889 (403)	90%
	Average	986 (447)	888 (403)	90%
Bare Slope	1	1,021 (463)	800 (363)	78%
	2	1,033 (469)	874 (396)	85%
	3	1,110 (503)	690 (313)	62%
	Average	1,055 (479)	788 (357)	75%

Figure 3.31, Figure 3.32, Figure 3.33, and Figure 3.34 show images from testing and post-testing for each sediment barrier practice and on a bare slope. The pictures taken during testing were all taken 25 minutes into the single simulated storm. The photo from testing of Product A shows that the practice is overtopping at three spots. The flow spread evenly across the length of the practice, promoting sedimentation. The photo for the compost sock shows that the practice did not overtop, and the flow either went under or through the sediment barrier. The photo for the wattle displays that the impoundment was much more limited than for the other two practices. The photo of the bare slope is very similar to that of the wattle. The sediment and flow are channelized at several points, extending from the metal slope to the end of the test plot. The post-test photos for Product A and the compost sock show that most sediment capture occurred at the toe of the impermeable slope. This was likely due to the impounded water slowing the incoming flow down and allowing for sedimentation to occur. For the wattle and the

bare slope, sediment is spread across the testing area because most sediment capture is attributed to flow slowing down along the testing plot rather than to impoundment. For both the wattle and the bare slope, sediment capture appeared to depend on how sediment settled over the course of the test. The settled sediment slowed the water and promoted further sedimentation.

(a) during test (b) post test

Figure 3.31: During and Post-Test Photos of Product A (Single Storm)

(a) during test (b) post test

Figure 3.32: During and Post-Test Photos of Compost Sock

(a) during test

(b) post test

Figure 3.33: During and Post-Test Photos of Straw Wattles

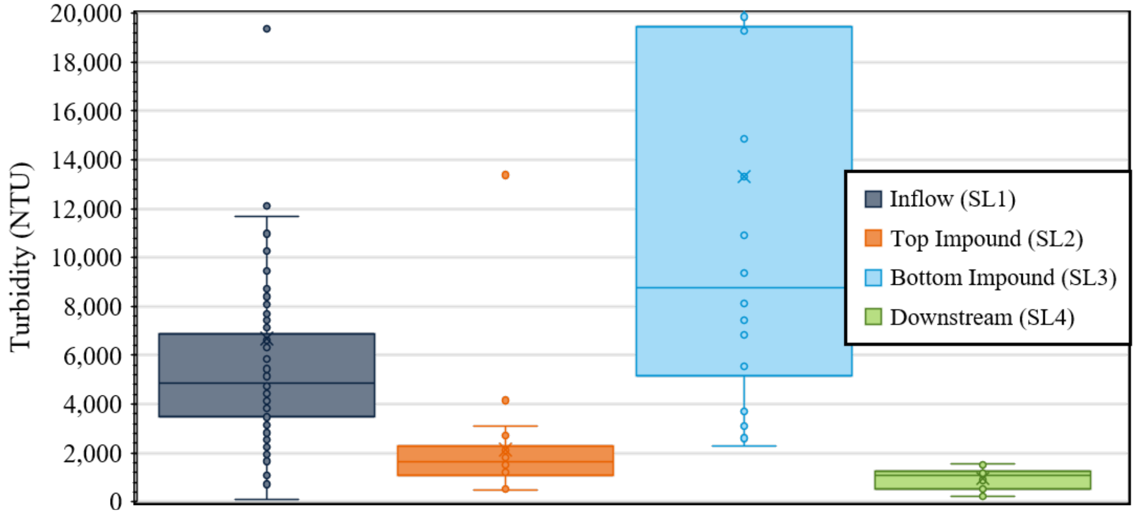
(a) during test

(b) post test

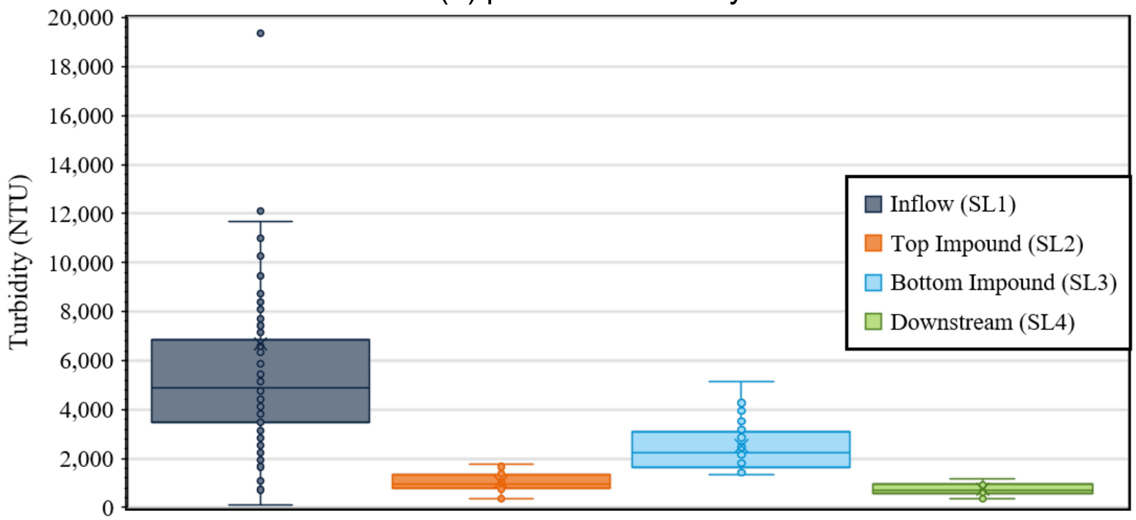
Figure 3.34: During and Post-Test Photos of Bare Slope

3.4.2.3 Turbidity (Single-Storm)

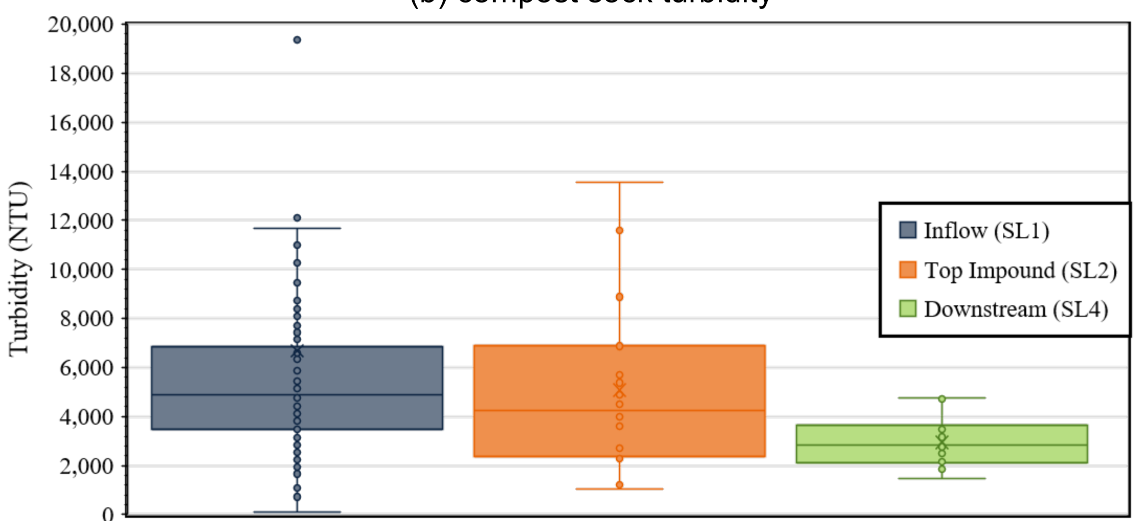
The turbidity data collected at the four sampling locations are shown in Figure 3.35. The legend reads top to bottom, which correlates to data read left to right. The straw wattle has data for only three sampling locations, as there was insufficient impoundment depth to take a sample at the bottom of the impoundment (SL3). The inflow data includes all three tests, as the sediment introduction was the same across them, and better reflects the inflow turbidity. The sampling on the upstream impervious slope (SL1) indicated that inflow turbidity averaged 7,000 NTU across all tests. The downstream (SL4) turbidity for all three practices was less than the turbidity upstream for the inflow and at any place in the impoundment. This indicates that each practice captured sediment as the sediment-laden water passed through the sediment barrier in addition to settling out in the impoundment. The compost sock showed a decrease in turbidity relative to the inflow at all other sampling locations. Product A and the straw wattle saw a decrease in turbidity downstream; however, they saw similar or occasionally greater turbidity than the inflow at the impoundment. For the straw wattle, since there was only one sample for the impoundment, and the impoundment was minimal, the samples likely had high turbidity due to captured sediment in the impoundment. For Product A, the bottom impoundment likely also had higher turbidity because of the sediment settling out in front of the practice being picked up by the sampling pump. The lower turbidity observed at the top of the impoundment (SL2) compared to the bottom for the compost sock and Product A was expected, as sediment settles out as the flow changes from faster sheet flow to slower flow in the impoundment.



(a) product A turbidity



(b) compost sock turbidity



(c) straw wattle turbidity

Figure 3.35: Turbidity of Sediment Barrier Practices (Single-Storm)

Figure 3.36 displays the downstream turbidity of each sediment barrier practice compared to the inflow turbidity. Product A and the compost sock showed similar decreases in turbidity downstream of the practice, with the straw wattle providing less turbidity reduction.

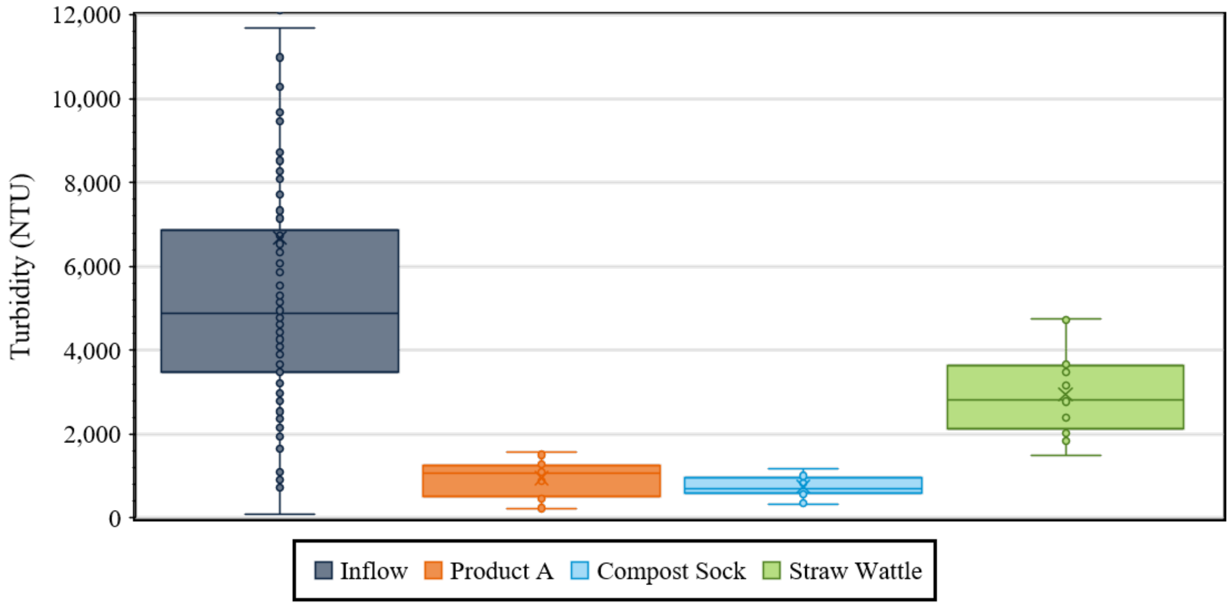


Figure 3.36: Downstream Turbidity Comparison (Single-Storm)

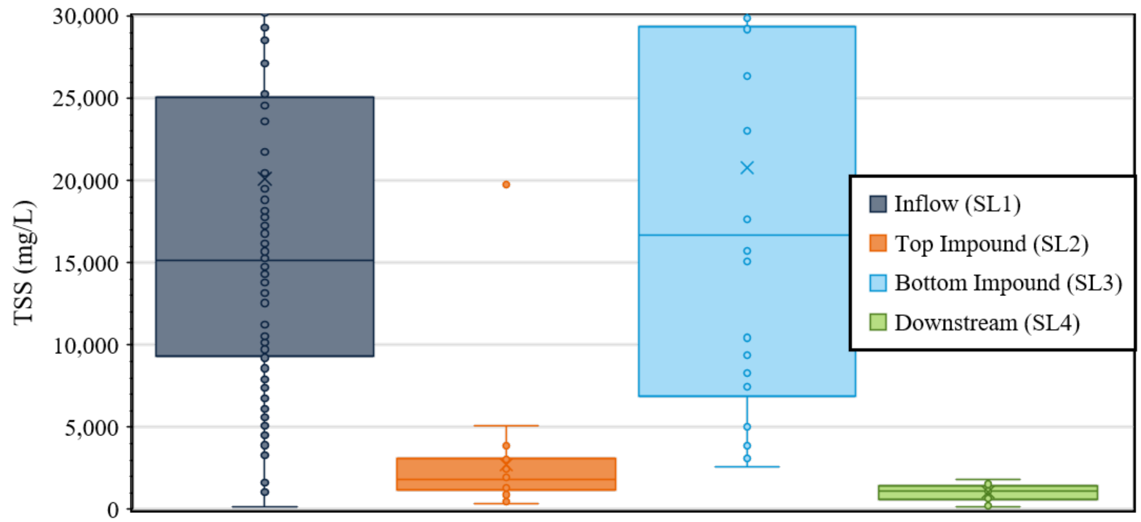
As shown in Table 3-9, the average downstream turbidity for the practices was 956 NTU, 756 NTU, and 2,952 NTU for Product A, the compost sock, and the straw wattle, respectively. The compost sock had the lowest average downstream turbidity, with Product A having a similar but slightly higher downstream turbidity. The straw wattle had a much higher average downstream turbidity than the other two practices. For the percent reduction, only data from each individual test was considered for the inflow data, as opposed to all inflow data, as was done for Figure 3.35 and Figure 3.36. The three practices showed similar average percent removal, ranging from 78% to 84%, with Product A having the greatest and the wattle having the least. The observed differences between the average downstream turbidity and percent reduction are due to the variance in upstream turbidity, as seen with the first installation of Product A.

Table 3-9: Turbidity Improvement: Upstream vs. Downstream (Single-Storm)

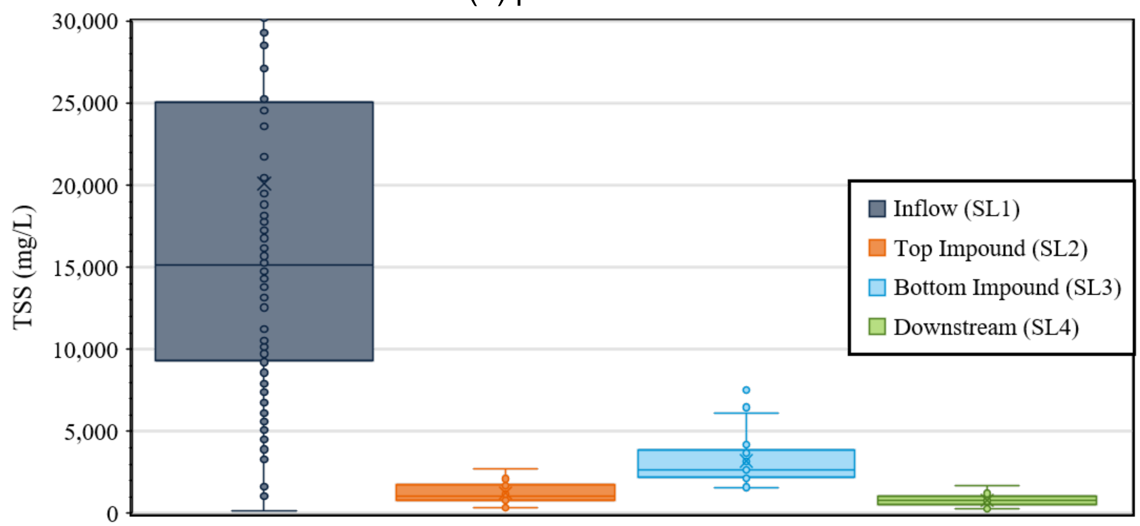
Sediment Barrier	Installation	Avg. Upstream Turbidity, NTU	Avg. Downstream Turbidity, NTU	Reduction
Product A	1	1,193	879	26%
	2	11,619	896	92%
	3	5,676	1,092	81%
	Avg. (SD)	6,163 (6,919)	956 (426)	84%
Compost Sock	1	5,693	824	86%
	2	3,422	867	75%
	3	2,897	575	80%
	Avg. (SD)	4,004 (1,916)	756 (239)	81%
Straw Wattle	1	4,251	2,472	42%
	2	22,945	2,592	89%
	3	12,606	3,791	70%
	Avg. (SD)	13,267 (24,858)	2,952 (941)	78%

3.4.2.4 Total Suspended Solids (Single-Storm)

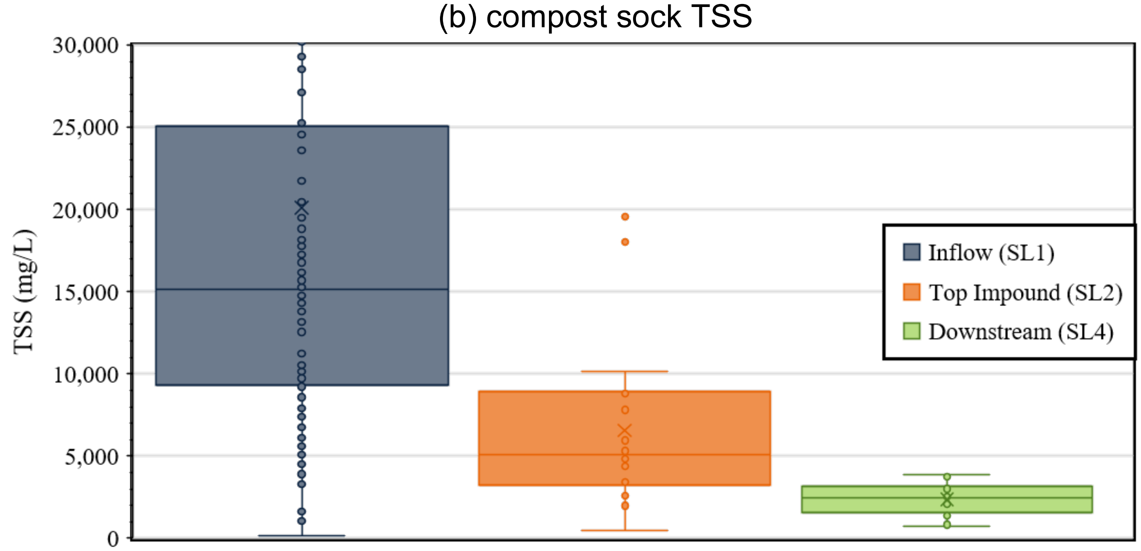
The TSS data collected at the four sampling locations are shown in Figure 3.37. The legend reads top to bottom, which correlates to data read left to right. As discussed for turbidity, the straw wattle has data from only three sampling locations because there was insufficient impoundment depth to collect a sample at the bottom of the impoundment. Also, as discussed for turbidity, the inflow data includes all three tests, since the sediment introduction was the same for each test, and better represents the inflow turbidity. Sampling on the upstream impervious slope showed that the average inflow TSS was 20,000 mg/L, with values ranging from 3,000 mg/L to 155,000 mg/L. The TSS data show a very similar pattern to that observed for turbidity. For all three practices, a decrease in TSS from the inflow to the downstream TSS was observed. A decrease in TSS was also observed from the inflow to the top impoundment for each practice. For the bottom impoundment, the compost sock saw a decrease in TSS, although not as much of a decrease as for the downstream and the top of the impoundment. Product A saw similar bottom-impoundment TSS as the inflow. This higher observed TSS is likely due to sediment buildup along the practice as it settles out in the impoundment. The lower TSS observed at the top of the impoundment and at downstream sampling locations across all practices suggests that each practice provides water-quality treatment through sedimentation.



(a) product A TSS



(b) compost sock TSS



(c) straw wattle TSS

Figure 3.37: TSS of Sediment Barrier Practices (Single-Storm)

Figure 3.38 displays the downstream TSS of each sediment barrier practice compared to the inflow TSS. The data shows a pattern similar to turbidity: Product A and the compost sock show similar reductions in TSS downstream of the practice, while the straw wattle provides less TSS reduction. The straw wattle shows a greater reduction in TSS than in turbidity.

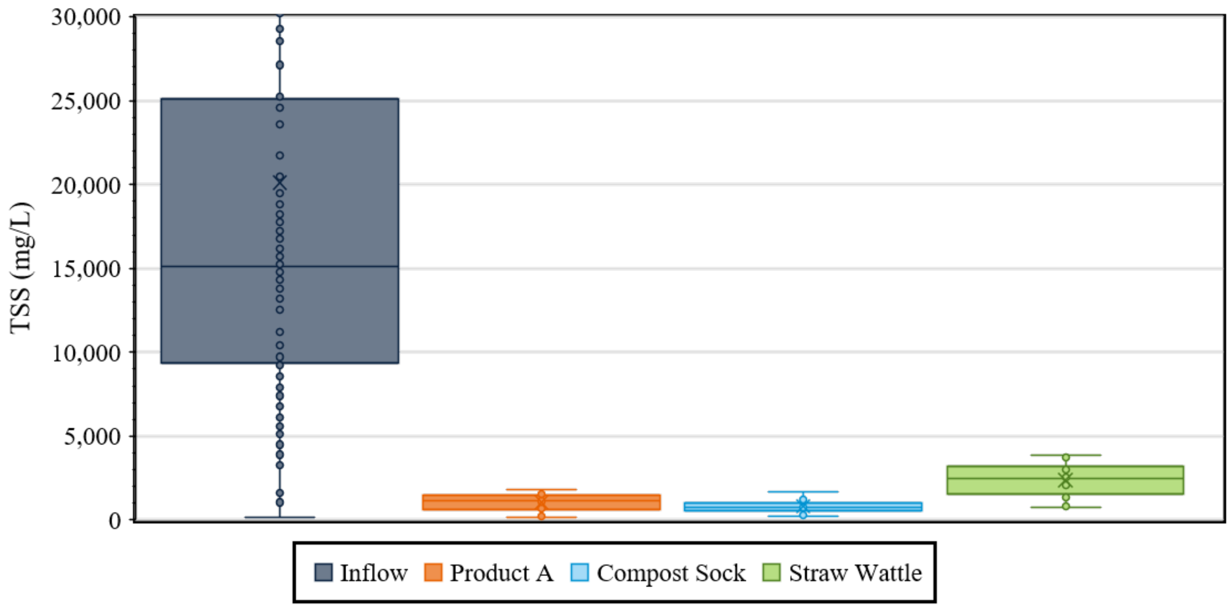


Figure 3.38: Downstream TSS Comparison (Single-Storm)

As shown in Table 3-10, average downstream TSS for the practices was 1,042 mg/L, 818 mg/L, and 2,379 mg/L for Product A, the compost sock, and the straw wattle, respectively. Similar to turbidity, the compost sock saw the lowest average downstream TSS, with Product A being slightly higher. The straw wattle had an average downstream TSS more than double that of the other two practices. For the percent reduction, only data from each individual test were considered for the inflow data, rather than all inflow data, as was done for Figure 3.37 and Figure 3.38. The three practices showed similar average TSS removal, ranging from 90-95%, with the compost sock having the greatest and the straw wattle having the lowest. While the straw wattle had a higher observed average downstream TSS, it had removal rates like those of the other two practices. This is due to the much higher TSS inflow observed in those tests.

Table 3-10: TSS Improvement: Upstream vs. Downstream (Single-Storm)

Sediment Barrier	Installation	Avg. Upstream TSS, mg/L	Avg. Downstream TSS, mg/L	Reduction
Product A	1	13,390	1,006	92%
	2	25,763	1,031	96%
	3	8,372	1,089	87%
	Avg. (SD)	15,842 (16,681)	1,042 (507)	93%
Compost Sock	1	34,130	1,070	97%
	2	8,103	812	90%
	3	8,858	571	94%
	Avg. (SD)	17,031 (26,735)	818 (352)	95%
Straw Wattle	1	3,805	1,348	65%
	2	41,043	2,512	94%
	3	30,093	3,278	89%
	Avg. (SD)	24,981 (37,518)	2,379 (959)	90%

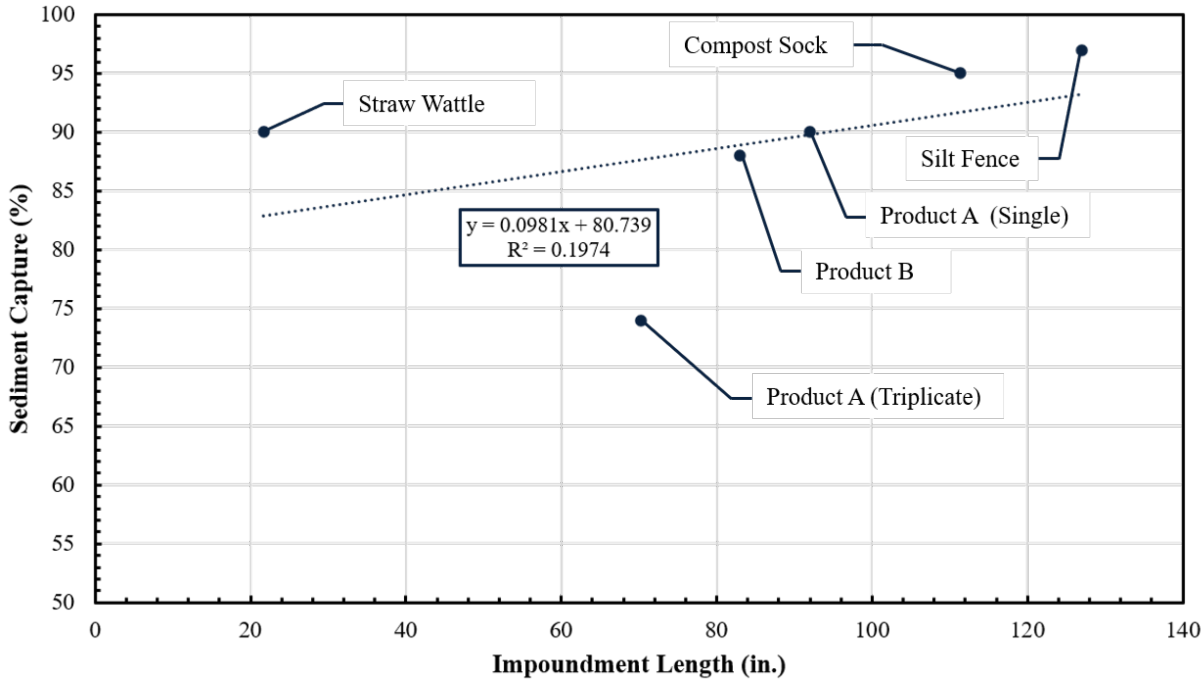
3.5 Sediment Barrier Performance Comparisons

Each sediment barrier practice varied in performance across all criteria considered for both types of testing: longevity and single storm. In this section, the impoundment and sediment capture for each practice are compared, and the performance of product A under a single simulated storm and triplicate storms will be compared. All triplicate tests will also be compared to prior testing done in the same manner at the AU-SRF sediment barrier testing apparatus.

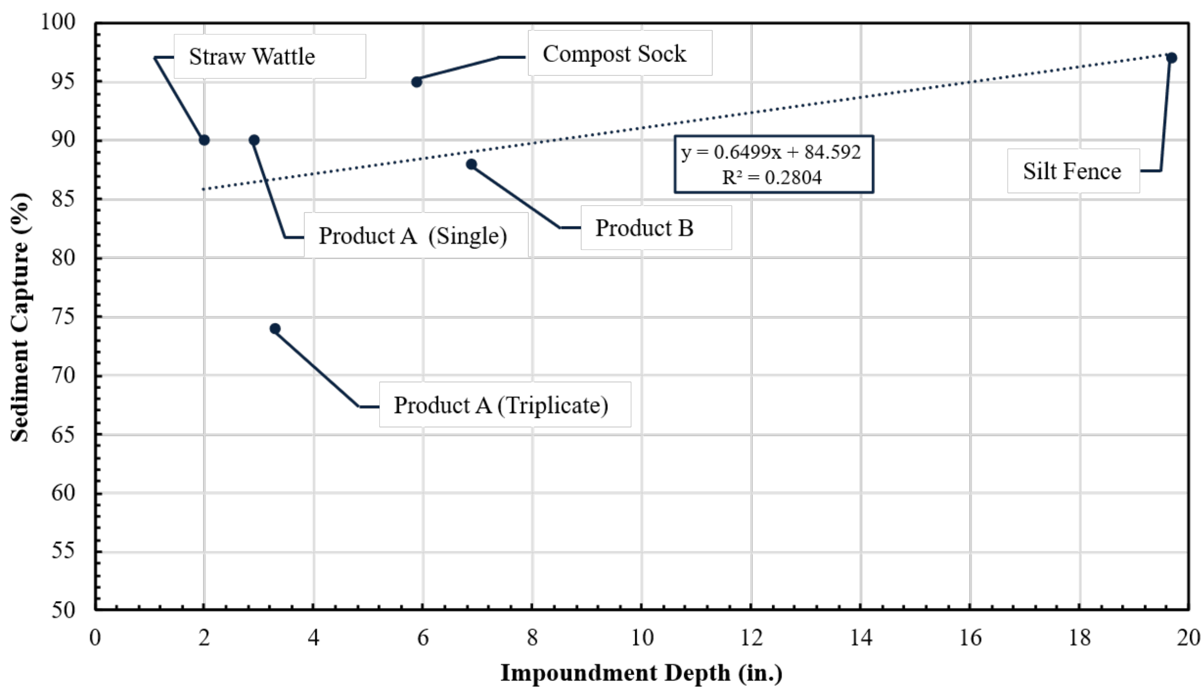
For all statistical analyses, a confidence level of 90% was used, meaning a significance level (α) of 0.1 was used. This was done as it was determined to be an acceptable level of confidence given the limitations and uncertainties of the testing. This includes variance in results due to the larger scale of testing, as well as minor variations between installations and with the shape of the testing plot.

3.5.1 Impoundment vs. Sediment Capture

The relationship between impoundment and sediment capture can be seen in Figure 3.39 for both impoundment length and depth. The figure shows the average maximum impoundment length and average sediment capture for each practice. A general trend of increased impoundment and sediment capture is evident across both impoundment depth and length. This relationship was evident in data for the silt fence and compost sock, as these had by far the greatest impoundment lengths; however, the compost sock had greater capture than Product B, which had a greater impoundment depth. This is likely due to the introduction of three storms for Product B, compared to a single storm for the compost sock, as well as the installation of Product B, which experienced severe undermining, limiting sediment capture. The straw wattle skews the trend and does not fit well into the relationship between impoundment and sediment capture. This is likely due to the increased impoundment length provided for that practice, as well as the single storm introduced. The physical observations of the straw wattle installations show that the sediment was captured by settling out due to the change in slope, rather than by impoundment. The captured sediment is similar to that observed on the control bare slope, spread across the testing plot rather than along the base of the metal slope. This trend indicates that sediment capture for most practices was due to impoundment of water, allowing sediment-laden water to slow, providing time for sediment to settle out. The graphs both have a linear trendline and R^2 value shown. The low R^2 values shown indicate that the relationship between the sediment capture and impoundment for the practices tested does not fit a linear trend.



(a) impoundment length vs. sediment capture



(b) impoundment depth vs. sediment capture

Figure 3.39: Impoundment Vs. Sediment Capture

3.5.2 Longevity vs. Single-Storm Testing

To compare the effects of multiple storm events and a reduced impoundment area on sediment capture rate, the performance of Product A under both testing regimes was evaluated. The sediment capture for both testing regimes was compared using ANOVA and subsequent t-tests to determine whether one method had significantly greater sediment capture.

The ANOVA was run to determine whether there was a statistically significant difference in capture rate between the two testing regimes. A significance level (α) of 0.1 was used, and Table 3-11 summarizes the results of the ANOVA. The F-value (7.62) was greater than the F-crit (4.54), indicating that with 90% confidence, there is a statistical difference in sediment capture between the two testing regimes.

Table 3-11: ANOVA Results for Product A Testing Regimes

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F	F crit	Result
Between Groups	380.75	1	380.75	7.62	4.544	Statistically Different
Within Groups	199.77	4	49.94	-	-	
Total	580.52	5	-	-	-	

Following the ANOVA, a two-sample t-test was conducted to determine which design had the greater sediment capture. A significance level (α) of 0.10 was used, and the results of the hypothesis test can be seen in Table 3-12. The testing showed that with 90% confidence, the testing conducted on Product A installed at the back of the testing plot and introduced to one simulated storm event had statistically greater sediment capture than the longevity testing installed in the middle. The p-value (0.0549) was less than α (0.10).

Table 3-12: Two-Mean Hypothesis Test Results for Product A Testing Regimes

H_0	H_1	df	P-value	α	Result
$\mu_{ss} \leq \mu_l$	$\mu_{ss} > \mu_l$	2	0.0549	0.10	Reject H_0

Note: ss – Single-Storm Testing, l – Longevity Testing

The results of this statistical analysis show that the installation of Product A with an increased impoundment area and increased maintenance in between storms can lead to increased sediment capture. The sediment capture was, on average, 16% greater for the installation with a larger impoundment area that was subjected to only one storm event. These results indicate that this product would likely perform better if installed farther from the toe of the slope, allowing a larger area for water to impound and preventing sediment from filling the available space. This also indicates that consistent maintenance of a practice after a qualifying event would likely improve its sediment capture performance.

3.5.3 Comparison to Previous AU-SRF Sediment Barrier Testing

Testing was compared to prior testing conducted at the AU-SRF, on the sediment barrier testing apparatus, by Whitman et al. and Roche (Roche 2023; Whitman et al. 2019b). Two sets of comparisons were made with the longevity testing conducted for this report: silt fence sediment capture and sediment capture for Product A and Product B, compared with prior wattle testing.

3.5.3.1 Silt Fence Performances

A summary of the sediment capture results of the ALDOT design silt fence from this report, the most feasible and effective installation (MFE-I) for NDOT determined by Roche, and the MFE-I non-proprietary silt fence (NPSF) determined by Whitman et al. can be seen below in Table 3-13 (Roche 2023; Whitman et al. 2019b). The NPSF was installed in the same manner as the ALDOT silt fence tested for this report, but without a dewatering board. The NDOT fence was installed using a woven fabric attached to studded T-posts with 4 ft (1.2m) spacing, fabric trenched in, T-posts offset 6 in. (15.2 cm) downstream, and with a dewatering weir at 12 in. (30.5 cm) high with 0.75 in. (1.91 cm) dewatering holes cut every 3 in. (7.6 cm) up the board.

Table 3-13: Silt Fence Sediment Capture Comparisons

Sediment Barrier	Installation	Captured
ALDOT	1	96.2%
	2	94.2%
	3	99.8%
	Average	96.7%
NDOT	1	81.6%
	2	82.0%
	3	83.0%
	Average	82.2%
NPSF	1	90.1%
	2	91.1%
	3	97.6%
	Average	93.0%

Note: ALDOT – This report, NDOT – Roche, NPSF – Whitman et al. (Roche 2023; Whitman et al. 2019b)

To compare the performance of different silt fence designs tested at the AU-SRF sediment barrier testing apparatus, the sediment capture rates of the ALDOT, NDOT, and NPSF designs were compared. The sediment capture for all three silt fence designs was compared using ANOVA and subsequent t-tests to determine whether any design had significantly greater sediment capture.

The ANOVA was run to determine whether there was a statistically significant difference in capture rate between the two testing regimes. A significance level (α) of 0.10 was used, and Table 3-14 summarizes the results of the ANOVA. The F-value (10.17) was greater than the F-crit (3.463), indicating that with 90% confidence, there is a statistically significant difference in sediment capture between the three silt fence designs compared.

Table 3-14: ANOVA Results for Silt Fence Comparisons

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F	F crit	Result
Between Groups	340.68	2	170.34	20.17	3.463	Statistically Different
Within Groups	50.66	6	8.44	-	-	
Total	391.34	8	-	-	-	

Following the ANOVA, three separate two-sample t-tests were conducted to compare the designs and determine which design captured the most sediment. A significance level (α) of 0.10 was used, and the results of the hypothesis tests can be seen in Table 3-15. The testing showed that, with 90% confidence, the ALDOT and NPSF designs had statistically greater sediment capture than the NDOT design, with p-values of 0.0046 and 0.0207, respectively. The comparison between the ALDOT and NPSF designs showed that, with 90% confidence, there is no statistical difference in their sediment capture performance, with a p-value of 0.1335.

Table 3-15: Two-Mean Hypothesis Test Results for Silt Fences

H_0	H_1	df	P-value	α	Result
$\mu_{aldot} \leq \mu_{ndot}$	$\mu_{aldot} > \mu_{ndot}$	2	0.0046	0.10	Reject H_0
$\mu_{aldot} \leq \mu_{npsf}$	$\mu_{aldot} > \mu_{npsf}$	2	0.1335	0.10	Fail to Reject H_0
$\mu_{npsf} \leq \mu_{ndot}$	$\mu_{npsf} > \mu_{ndot}$	2	0.0207	0.10	Reject H_0

Note: aldot – This Report, ndot – Roche, npsf – Whitman et al.

The results of this statistical analysis indicate that the NDOT design silt fence retains the least sediment out of the three silt fence designs. This could be due to multiple factors, including the woven fabric used in the NDOT design rather than the nonwoven fabric in the other two designs. This could also be due to the shorter height of the silt fence or to different flow and sediment introduction conditions included in the

NDOT design. These results also indicate that there is no significant difference in sediment capture due to the inclusion of a dewatering board. This supports the use of a dewatering board to help speed up dewatering and open up available impound area for the next storm event.

3.5.3.2 Product A and B Comparisons to Wattle Performance

A summary of the sediment capture results of Product A (PA) and B (PB) from this report, excelsior wattle testing by Whitman et al. (WE), and excelsior and straw wattle testing by Roche (RE & RS) can be seen in Table 3-16 (Roche 2023; Whitman et al. 2019b). This was done to determine the performance of the products in comparison to wattles. The WE were installed with A-frame staking pushing the wattle down onto a geotextile underlay. The RE and RS were installed in the same manner, with wattles stapled down on both sides by 6 in. (15.2 cm) sod staples every foot, a 2 ft (0.62 m) overlap joint of wattles, and wooden stakes installed in an A-frame manner at the joint.

Table 3-16: Product vs. Wattle Sediment Capture

Sediment Barrier	Installation	Percent Capture
PA	1	63.39%
	2	75.20%
	3	83.26%
	Average	73.95%
PB	1	73.90%
	2	95.14%
	3	94.82%
	Average	87.95%
WE	1	82.00%
	2	84.00%
	3	81.00%
	Average	82.33%
RE	1	83.82%
	2	75.57%
	3	66.54%
	Average	75.31%
RS	1	86.37%
	2	83.93%
	3	72.10%
	Average	80.80%

Note: PA – Product A, PB – Product B, WE – Excelsior Wattle Whitman et al., RE – Excelsior Wattle Roche, RS – Straw Wattle Roche (Roche 2023; Whitman et al. 2019b)

To compare the performance of novel products with wattle installations tested at the AU-SRF sediment barrier testing apparatus, sediment capture rates for the PA, PB, WE, RE, and RS were compared. The sediment capture for all tests was compared using ANOVA to determine whether the two products tested are comparable in performance to wattles and could be utilized in the same manner.

The ANOVA was run to determine whether there was a statistically significant difference in capture rates among the practices. A significance level (α) of 0.10 was used, and Table 3-17 summarizes the results of the ANOVA. The F-value (1.25) was less than the F-crit (2.605), indicating that, with 90% confidence, there is no statistically significant difference in sediment capture between the practices.

Table 3-17: ANOVA Results for Wattle Comparisons

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F	F crit	Result
Between Groups	383.73	4	95.93	1.25	2.605	No
Within Groups	766.43	10	76.64	-	-	Statistical
Total	1,150.17	14	-	-	-	Difference

The results of this analysis indicate that both Product A and Product B perform similarly in sediment capture compared to prior testing across different wattle installations. The products are both capable of providing sediment retention similar to that of excelsior and straw wattles and have the benefit of possible reuse. Product B had the greatest average sediment capture compared to all testing on wattles; however, it was prone to failure from undermining or from bending backward. Product A had the lowest average sediment capture among all practices, likely due to its short height rather than performance issues. The product would likely still perform well when implemented on a site, but would likely need adequate maintenance to ensure its continued performance.

3.6 Sediment Barrier Performance Testing Summary

The performance of the sediment barrier practices installed in the center of the testing plot, subjected to three back-to-back storms (Product A, Product B, and silt fence), and the practices installed at the downstream edge of the plot, subjected to a single storm (Product A, compost sock, and straw wattle), all varied across the criteria analyzed. Products A and B both experienced undermining and uncontrolled overtopping during longevity testing. Both products bent over once the flow reached a certain height, limiting their ability to impound and leading to channelization, which contributed to undermining. Product A was limited in its performance and ability to retain sediment due to its short height, as the area upstream of the practice filled with sediment during the first two tests, leading to flow overtopping and bypassing the practice. The two products, however, performed comparably to previous testing conducted on wattles at the AU-SRF sediment barrier testing apparatus. There was no significant difference in their sediment capture compared with that of both straw and excelsior wattles. Silt fence proved to greatly outperform the two products in sediment capture, water quality improvement, and impoundment. The ALDOT silt fence captured significantly more sediment than previous testing on an NDOT design, likely due to the use of a nonwoven geotextile in the ALDOT design rather than a woven geotextile in the NDOT design. The ALDOT design also had no significant difference in sediment capture compared to previous testing conducted on a similar design without a dewatering board. This result indicates that the inclusion of a dewatering board does not affect the sediment-capture performance of a silt fence but does provide faster dewatering, enabling greater storage capacity for back-to-back storm events.

The compost sock and Product A both outperformed the straw wattle during a single simulated storm event. The compost sock outperformed Product A on all criteria except turbidity, where Product A performed best among the three practices. The only practice with observed failure during the single-storm testing was the straw wattle. The straw wattle consistently floated up along the wooden stake, allowing most of the flow to bypass the practice entirely. The wattle had similar performance to one test on the bare slope, indicating limited performance over a single test, but improved performance over three installations. This difference is due to the high variability of testing on the bare slope. A different installation method using “A-frame” staking would likely improve the performance of the wattle by pressing it down and securing it to the ground, as shown in previous studies conducted at the AU-SRF (Roche 2023; Whitman et al. 2019b)(Roche 2023; Whitman et al. 2019b). Comparing the testing of Product A under both testing regimes showed that increasing the installation distance from the toe of the slope and introducing only one storm resulted in significantly greater sediment capture. This reinforces the understanding that adequate maintenance, clearing out captured sediment after qualifying storms, has a significant impact on a practice's performance. This comparison also showed that for some practices, increased installation from the toe of a slope, when feasible, can improve performance, allowing for greater impoundment and additional slowing of runoff velocity.

Chapter 4: Conclusions and Recommendations

4.1 Introduction

To improve stormwater management amid growing urbanization, enhanced pollutant removal is required during construction and post-construction. Stormwater management is regulated by the USEPA under the CWA to prevent sediment and other pollutants from being discharged into natural bodies of water. Stormwater management is carried out using SCMs, which can be broadly divided into construction and post-construction BMPs. The research completed for this study was split into two research objectives focused on enhancing SCMs to improve the water quality of stormwater discharged off-site:

1. Develop a methodology to implement a modified component in a post-construction BMP to enhance nutrient removal, with the potential for phosphorus recovery and reuse.
2. Evaluate standard sediment barrier practices as well as novel practices under Alabama runoff under differing testing conditions and compare them to prior testing conducted at AU-SRF on different practices.

To complete these research objectives, a research plan was completed in accordance with the following five tasks:

1. Completion of a literature review on GI/LID practices' nutrient removal capabilities, possible components for enhancing removal, and performance testing on sediment barrier practices and products.

2. Development of a repeatable testing methodology for the implementation of components within a selected BMP, and the evaluation of nutrient removal from those components in comparison to a standard.
3. Development of a methodology for large-scale sediment barrier testing under conditions found in Alabama, for single and multiple storm events.
4. Conduct pilot-scale testing on a standard infiltration trench and modification components, including FeGeotex and iron-enhanced sand, evaluating nutrient removal of both nitrogen and phosphorus, under low, high, and extreme inflow concentrations.
5. Conduct large-scale testing on novel sediment barrier products and standard silt fence, compost socks, and wattles under conditions found in Alabama, evaluating performance and comparing to prior testing.

By achieving these research objectives through the completion of the five tasks, this study provided an important evaluation of the capability of using iron-based components for enhanced phosphorus removal, with the possibility of recovery, and of the performance of standard sediment barrier practices and products. The results of this study provide guidance on implementing FeGeotex in an SCM, a repeatable methodology for evaluating nutrient removal from SCM components, and a methodology for comparing the performance of sediment barrier practices at both high and low levels of expected maintenance.

4.2 Nutrient Removal and Recovery Capabilities of Modifying Components

The first objective of this research was to develop a methodology for implementing and evaluating nutrient removal from modified components in an SCM.

The first step in completing this objective was conducting a literature review of the nutrient removal capabilities of typical GI/LID practices and whether and where they incorporate geotextiles, to determine which practice to evaluate the components in. A literature review was also conducted on previously implemented modifications to enhance nutrient removal to determine which components to test. Evaluation of GI/LID practices showed that there is a wide range of nutrient removal capabilities across the most common practices, and some may even leach nutrients depending on design and implementation. Bioretention cells and infiltration trenches have been shown to achieve higher nutrient removal rates. Bioretention cells were ruled out for evaluation because the geotextile is located at the bottom beneath media and vegetation, preventing practical nutrient recovery. The infiltration trench design incorporated geotextile near the top, allowing recovery and accommodating a large treatment volume in a small area, thereby exposing the component to higher phosphorus concentrations. Two iron-based components were identified as possible modifications to enhance phosphorus removal and facilitate recovery of adsorbed phosphorus: an iron-modified geotextile (FeGeotex) and iron-enhanced sand.

A pilot-scale wooden box with internal dimensions of 2.5 ft (0.762 m) wide, 8.0 ft (2.44 m) long, and 4.0 ft (1.22 m) deep was constructed and filled with media in accordance with GDOT specifications for a standard infiltration trench (GDOT 2023)(GDOT 2023). From top to bottom, the layers within the standard trench consisted of a 1.0 in. (2.54 cm) layer of pea gravel, a layer of geotextile, 2.5 ft (0.762 m) of #57 gravel, 4.0 in. (10.2 cm) of washed masonry sand, and 2.0 in. (5.08 cm) of pea gravel. The FeGeotex was installed as a replacement for the standard geotextile layer, and the iron-enhanced sand replaced the geotextile with a 2.0 in. (5.08 cm) layer of iron-enhanced sand placed between two layers of geotextile. Each component design was subjected to three testing regimes: blank (low concentration), dosed (runoff concentrations), and stress (high concentration).

The components' nutrient-removal performance varied widely across inflow conditions. The iron-enhanced sand trench outperformed all other designs for phosphorus removal under all three inflow conditions, achieving removals of 38.9%, 76.9%, and 82.1% for the blank, dosed, and stressed conditions, respectively. The standard infiltration trenches had 29.3% and 53.2% for the first installation and -4.3%, 32.2%, and 40.2% for the second standard installation. The FeGeotex showed less removal than the iron-enhanced sand and the first standard install, but more than the second standard install, with 13.8%, 42.5%, and 43.9% removal. The iron-enhanced sand trench increased phosphorus removal by an average of 34% at higher concentrations compared to 26% at lower concentrations. This indicates that the iron-enhanced sand generally performs better than the other designs and maintains performance at higher concentrations. All trench designs proved to leach nitrogen under blank conditions, likely due in part to very low inflow concentrations, and material within the trench contributing nitrogen. The first standard and iron-enhanced sand designs had moderate nitrogen removal. The standard and iron-enhanced sand designs showed removals of 31.3% and 25.5%, respectively, under dose conditions. The FeGeotex only had 22.1% removal under the same conditions, and the second standard had the lowest at 16.4%.

The iron-enhanced sand component proved to have the statistically greatest removal of phosphorus under all three inflow conditions. Iron-enhanced sand performed consistently across all tests, with minimal loss in phosphorus removal, indicating effective long-term use. The geotextile and iron-enhanced sand from the iron-enhanced sand design proved to provide the greatest recovery of phosphorus. This, in combination with its long-term performance, makes it a very capable component for enhancing removal from SCM and possibly providing an alternate source of phosphorus. The FeGeotex provided significantly greater phosphorus removal than the standard trench under both blank and dosed conditions, indicating that, for short-term conditions and during normal storm events, the FeGeotex enhances phosphorus removal, but under long-term conditions, it will likely perform similarly to the standard. The FeGeotex did provide greater phosphorus recovery than the standard, but not nearly as much as the iron-enhanced sand.

The results of this study provide guidance for DOT or federal designers to improve stormwater control measures (SCMs) to better address excess nutrients in stormwater. These results can provide guidance on alternative design standards for infiltration trenches and on possible modifications to other SCMs to enhance nutrient removal or recovery. The testing methodology outlined can be used to test the performance of other SCMs and components for nutrient removal. Additional testing could be conducted over a longer period of time to

This study was confined to a single storm event and to lab-scale tests on only three designs. Future work could examine additional modifications to SCMs to improve nitrogen removal, in addition to phosphorus, conduct long-term testing, and implement these practices in full-scale applications. While this work was tested on an infiltration trench designed for the Georgia DOT under U.S. runoff concentrations, the results can be transferable to improving other types of SCMs and in different regions of the world.

4.3 Performance Evaluation of Sediment Barrier Practices and Products

The second objective of this research was to evaluate the performance of standard sediment barrier practices and novel products, and to compare them with prior testing. The first step in achieving this objective was to complete a comprehensive literature review of prior testing on sediment barrier practices. This review presented performance results for various standard practices, including silt fence, wattles, compost socks, sediment retention barriers, and slash mulch berms, as well as several manufactured products. Testing conducted on these practices ranged from small lab-scale to full field-scale evaluations and showed that they provide a wide range of performance. Prior testing indicated that the installation method, structural integrity, and impoundment were critical to achieving high performance.

To evaluate the chosen standard practices and novel products, the sediment barrier apparatus and a modified version of the methodology outlined in Bugg et al. for testing at the AU-SRF were used (Bugg et al. 2017)(Bugg et al. 2017). The peak 30 minutes of a 2-yr, 24-hr storm in Alabama was used to determine the flow and sediment introduction rate for the simulated storm events to which each sediment barrier was subjected. Two stages of testing were performed: the first introduced three back-to-back storms to each installation of the sediment barrier practice (triplicate storm), and the second introduced only one storm event to each installation, installed at the downstream edge of the testing area (single storm). Testing was conducted on two manufactured products: Product A and Product B, and three standard sediment barrier practices: silt fence, compost socks, and wattles.

Testing of the practices under triplicate storm conditions showed that the silt fence performed best across all performance measures: impoundment, sediment capture, turbidity reduction, and TSS reduction. The silt fence also experienced no structural failures or lapses. Product A was the most limited in performance under longevity testing, primarily due to its short height. This limited its ability to impound water and capture sediment across all three introduced simulated storm events. Product B generally performed better than Product A but was also limited by its height and installation method. Product B experienced the worst failure among the three practices during the first installation due to massive undermining. Products A and B both had structural limitations with bending of the fence material under impoundment, limiting impoundment, channelizing overtopping, and sometimes leading to undermining.

Testing of the practices under single-storm conditions showed that the compost sock performed best, followed by Product A. The wattle consistently performed the worst across all performance measures. The compost sock and Product A both provided similar levels of turbidity and TSS reduction; however, the compost sock had greater sediment capture, likely due to its greater height and subsequent impoundment capabilities. The wattle provided very little impoundment and generally failed under all three installations. Water would flow underneath the wattle, bypassing the practice entirely. The sediment capture from the wattle was primarily due to the change in slope and additional capture area provided by installing it along the downstream edge.

Comparing Product A's performance under triplicate storms and single storms showed that the product statistically captured more sediment with increased impoundment area under single storms. These results indicate that the product performs better with more room to create impoundment and provide space for captured sediment, likely due to its limited height. Better performance under a single storm also indicates that adequate maintenance, including cleaning out captured sediment, greatly improves the practice's ability to capture and retain sediment on site.

Comparisons between silt fence testing and prior testing of other silt fence designs showed that adding a dewatering board did not significantly affect sediment capture. This provides an effective method for dewatering a silt fence, reestablishing storage room for the next storm event, and preventing additional sediment loss. These comparisons also showed that the woven geotextile on the NDOT silt fence might limit its sediment capture compared to the nonwoven geotextile used on the ALDOT silt fence. Comparisons between the products and prior testing on wattles showed that there is no significant difference between their performance. Products A and B can provide sediment capture performance similar to that of excelsior and straw wattles under different installation methods.

The results of this study provide recommendations on the capabilities of different sediment barrier practices and products under different conditions. They also provide recommendations on when implementing practices is applicable, as well as guidance on how best to implement and install them. The methodologies in this report also provide an additional method for evaluating sediment barrier practices, with differing impoundment areas and evaluations of performance with adequate maintenance provided under single storm events.

Testing for this study was limited to three standard practices and two manufactured products, with many different practices and products available for future study. This study was also able to examine only a short experimental length of each sediment barrier practice, rather than the longer lengths typically installed in the field. Testing was also stopped after three introduced storm events and did not evaluate testing under longer-term analyses. Future testing could evaluate flow types and sediment introduction in regions of the country that have not yet been evaluated.

4.4 Benefits From Findings and Implementation

The nutrient removal and recovery results, and the testing of sediment barrier practices, provide implementable guidance to regulatory agencies, such as DOTs and the USEPA. They provide suggestions for methods to improve stormwater quality in both construction and post-construction management. The methodology used in this testing provides a repeatable analysis of the effectiveness of different practices and modifications to manage and improve stormwater, thereby limiting the discharge of pollutants into natural waters.

The results of nutrient removal testing showed that the addition of iron-based components to SCMs enhances phosphorus removal. These components also provide phosphorus recovery when they are uninstalled from the SCM. Enhancing the removal of phosphorus and nitrogen in SCMs can improve downstream water quality and, in turn, both aquatic and human health. These reductions in nutrient levels can also help boost economic productivity in areas affected by dead zones. The recovery of phosphorus from SCMs can provide a secondary source of a critical, highly utilized resource that is limited in its availability. Improved nutrient removal and recovery provide both an ecological and economic benefit.

The results from sediment barrier testing found that the method of implementation, the maintenance provided, and the choice of sediment barrier practice play an important role in the ability to effectively utilize a sediment barrier practice to limit off-site sediment loss. Preventing off-site sediment protects aquatic environments, prevents water body discoloration, and can prevent financial damage. Correctly choosing the right sediment barrier practice is crucial for economically and effectively preventing the discharge of polluted water.

4.5 Recommendations for Future Study

The limitations and results from the testing conducted for this study provide ample room for future investigation. The methodology used to evaluate nutrient removal provides repeatable testing for analysis on other SCMs, such as bioretention cells or sand filters. The investigation of additional components to enhance phosphorus removal could be conducted, such as the incorporation of materials with high calcium carbonate content or the use of alum. Additional testing can also be conducted to improve nitrogen removal, in addition to the phosphorus removal observed with the current components, such as using biochar. Analyses could also be done on longer testing regimes to determine the true long-term performance of SCMs and modified components.

The methodologies used for the evaluation of sediment barrier performance under both triplicate storms and single storms can be readily replicated for further study. Future testing can be conducted on additional sediment barrier practices such as slash mulch berms, sediment retention barriers, sustainable sediment barriers, etc. Testing could also be conducted on erosion control blankets installed as a simple sediment barrier practice for use on smaller sites, with less expected sediment loss. Additional testing could be done with a single introduced storm event, but with the sediment cleaned out and an additional storm event introduced to better simulate maintenance on a practice and how well its performance can recover. Further testing can also be conducted utilizing storm conditions from different parts of the country yet to be investigated. Testing can also be conducted to determine the ideal impoundment length and depth for a sediment barrier practice.

4.6 Conclusions

The research conducted for this study aimed to improve the body of knowledge on the nutrient removal performance of SCMs and on the effectiveness of sediment barrier practices for perimeter control on construction sites. The methodology developed in Chapter 2 provides repeatable guidance for further study and comparisons of the nutrient-removal performance of SCMs and their modifications. This methodology can guide studies on further treatment of pollutants from post-construction SCMs and comparisons between modifications to determine the best SCM and applicable component to address a pollutant of concern. This methodology can also be used to support further evaluation of the feasibility of recovering nutrients for reuse from stormwater, providing a second source of these critical resources. The results from this study can help DOTs provide guidance on implementing iron into SCMs to enhance phosphorus removal without affecting overall performance. The sediment barrier research conducted for this study aimed to fill the research gap on a lack of comparisons between standard sediment barrier practices and products, as well as a comparison between the longevity and short-term performance of sediment barrier practices. Results from comparisons can help support the effective selection and implementation of sediment barrier practices on construction sites throughout the U.S. This study also supports proper and timely maintenance of these practices to sustain effective sediment capture and prevent failure. Overall, this study can be applied to improve the management of urban stormwater, both during construction and post-construction, especially by limiting the discharge of pollutants, such as nutrients and sediment, into natural waterbodies.

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Appendix A: Infiltration Trench Data

Standard Blank Average

	Tap water	1st	2nd	3rd	Average
Turbidity	1.077	15.750	23.290	18.237	19.092
pH	8.037	7.453	7.477	7.563	7.498
CE	119.900	152.667	112.067	117.300	127.344
TDS	84.733	112.233	98.867	84.167	98.422
Temperature	19.733	19.933	20.100	19.900	19.978

Phosphate	Mean		**Phosphorus {mg/L)**	
Tap water	0.702	/3.06	0.229	**Percent Removal**
1st	0.515	/3.06	0.168	27%
2nd	0.473	/3.06	0.155	33%
3rd	0.500	/3.06	0.163	29%

Average Removal
29.3%

Standard Deviation
3.0

Total Nitrogen	mg/L	
	Mean	
Tap water	**0.45**	**Percent Removal**
1st	**1.583**	-252%
2nd	**0.767**	-70%
3rd	**0.533**	-19%
DI	0	

Average Removal
-113.6%

Standard Deviation
122.5%

Timing/Flow Rates						
Time to first outflow	165	s	2.75	min	Trench Depth (in)	
Total Test Time	2825	s	47.08	min	37	
Flow Rate Test	Flow Rate (gal/hr)	Description			Infil Rate (in/min)	Standard Deviation
1	118.816	1st flow			13.45	1.2
2	351.349	end 1st		First Outflow (min)	Infil Rate (in/min)	
3	211.791	middle 2nd	Test 1	2.5	14.8	
4	422.675	after finish 2nd	Test 2	3	12.3	
5	96.008	after start 3rd	Test 3	2.75	13.5	
6	406.825					
	Mean Flow (GPH)					
	267.911					

Standard Dosage Average

	Dose 50 gal	Dose 100 gal	Average	1st	2nd	3rd	Average
Turbidity	0.457	0.370	0.413	7.443	13.357	8.223	9.674
pH	7.693	7.677	7.685	7.293	7.217	7.450	7.320
CE	142.567	156.100	149.333	182.367	180.267	172.167	178.267
TDS	105.500	112.000	108.750	130.333	128.333	123.000	127.222
Temperature	18.533	18.667	18.600	19.233	19.400	19.467	19.367

Phosphate	Mean		**Phosphorus (mg/L)**			
Tap 50 gal	0.807	/3.06	0.26			
Tap 100 gal	0.773	/3.06	0.25			
Dose 50 gal	1.740	/3.06	0.57	**Percent Removal**		
Dose 100 gal	1.535	/3.06	0.50	0.54	<----- Average Dose	
1st	0.555	/3.06	0.18	66%		Average Removal
2nd	0.833	/3.06	0.27	49%		53.2%
3rd	0.910	/3.06	0.30	44%		Standard Deviation
						11.4%

Total Nitrogen	mg/L			
	Mean			
Tap 50 gal	**-0.083**			
Tap 100 gal	**0.183**			
Dose 50 gal	**4.833**	**Percent Removal**		
Dose 100 gal	**5.850**	5.341666667	<----- Average Dose	
1st	**3.000**	44%		Average Removal
2nd	**3.433**	36%		31.3%
3rd	**4.583**	14%		Standard Deviation
DI	**0**			15.3%

Timing/Flow Rates						
Time to first outflow	253.333	s	4.22	min	Trench Depth (in)	
Total Test Time	1728.333	s	28.81	min	37	
Flow Rate Test	Flow Rate (gal/hr)	Description			Infil Rate (in/min)	Standard Deviation
1	102.807	1st flow			8.76	1.586888454
2	214.508	end 1st		First Outflow (min)	Infil Rate (in/min)	
3	388.333	middle 2nd	Test 1	3.5	10.57142857	
4	517.777	after finish 2nd	Test 2	4.2	8.88	
5	491.360	after start 3rd	Test 3	5	7.4	
6	649.863					
	Mean Flow (GPH)					
	394.108					

FeGeotex Blank Average

	50 gal	100 gal	Average	1st	2nd	3rd	end	Average
Turbidity	0.513	0.492	0.502	31.900	19.133	11.067	5.963	17.016
pH	7.630	7.623	7.627	7.500	7.460	7.530	7.547	7.509
CE	166.133	170.433	168.283	193.400	179.467	159.900	180.067	178.208
TDS	116.667	121.333	119.000	133.333	128.333	114.000	119.333	123.750
Temperature	19.433	19.433	19.433	19.433	19.600	19.533	19.467	19.508

Phosphate	Mean		**Phosphorus (mg/L)**			
50 gal	0.733	/3.06	0.240	**Percent Removal**		
100 gal	0.657	/3.06	0.215	0.23	<----- Average Dose	Average Removal
1st	0.610	/3.06	0.199	12%		13.8%
2nd	0.568	/3.06	0.186	18%		Standard Deviation
3rd	0.593	/3.06	0.194	15%		3.49%
end	0.625	/3.06	0.204	10%		

Total Nitrogen	mg/L			
	Mean			
50 gal	**0.766666667**	**Percent Removal**		
100 gal	**0.717**	0.74	<---- Average Dose	Average Removal
1st	**1.767**	-138%		-93.3%
2nd	**1.450**	-96%		Standard Deviation
3rd	**1.100**	-48%		36.7%
end	**1.417**	-91%		

DI

Timing/Flow Rates						
Time to first outflow	374	s	6.23	min	Trench Depth (in)	
Total Test Time	3100	s	51.67	min	37	
Flow Rate Test	Flow Rate (gal/hr)	Description			Infil Rate (in/min)	Standard Deviation
1	57.107	1st flow			5.9	0.3
2	93.107	end 1st		First Outflow (min)	Infil Rate (in/min)	
3	138.514	middle 2nd	Test 1	6.5	5.7	
4	359.274	after finish 2nd	Test 2	6.0	6.2	
5	443.809	after start 3rd	Test 3	6.3	5.9	
6	517.777					
	Mean Flow (GPH)					
	268.265					

FeGeotex Dosed Average

	Dose 50 gal	Dose 100 gal	Average	1st	2nd	3rd	Average
Turbidity	0.383	0.354	0.369	31.633	14.500	6.217	17.450
pH	7.557	7.570	7.563	7.467	7.503	7.547	7.506
CE	221.667	222.667	222.167	227.667	219.000	208.000	218.222
TDS	157.000	159.333	158.167	161.333	155.667	149.667	155.556
Temperature	19.150	19.250	19.200	19.950	19.950	19.700	19.867

Phosphate	Mean		**Phosphorus (mg/L)**			
Dose 50 gal	1.623	/3.06	0.53	**Percent Removal**		
Dose 100 gal	1.697	/3.06	0.55	0.54	<------Average Dose	
1st	0.943	/3.06	0.31	43%		Average Removal
2nd	0.787	/3.06	0.26	53%		42.5%
3rd	0.937	/3.06	0.31	44%		Standard Deviation
End	1.150	/3.06	0.38	31%		9.0%

Total Nitrogen	mg/L			
	Mean			
Tap 50 gal				
Tap 100 gal				
Dose 50 gal	**5.917**	**Percent Removal**		
Dose 100 gal	**6.317**	6.116666667	<------Average Dose	
1st	**4.183**	32%		Average Removal
2nd	**4.050**	34%		22.1%
3rd	**4.950**	19%		Standard Deviation
End	**5.883**	4%		13.8%
DI	**0**			

Timing/Flow Rates						
Time to first outflow	350.000	s	5.83	min	Trench Depth (in)	
Total Test Time	3360.000	s	56.00	min	37	
Flow Rate Test	Flow Rate (gal/hr)	Description			Infil Rate (in/min)	Standard Deviation
1	54.311	1st flow			6.3	0.1
2	125.482	end 1st		First Outflow (min)	Infil Rate (in/min)	
3	251.341	middle 2nd	Test 1	5.75	6.434782609	
4	406.825	after finish 2nd	Test 2	5.8	6.342857143	
5	443.809	after start 3rd	Test 3	5.9	6.253521127	
6	443.809					
	Mean Flow (GPH)					
	287.596					

FeGeotex Stress Average

	Dose 50 gal	Dose 100 gal	Average	1st	2nd	3rd	Average
Turbidity	0.562	0.544	0.553	23.867	9.265	4.035	12.389
pH	7.570	7.550	7.560	78.553	55.310	11.133	48.332
CE	215.000	213.500	214.250	151.863	242.000	222.467	205.443
TDS	161.333	152.500	156.917	178.333	172.667	157.667	169.556
Temperature	18.267	18.650	18.458	19.267	19.433	19.533	19.411

Phosphate	Mean		**Phosphorus (mg/L)**			
Dose 50 gal	3.067	/3.06	1.00	**Percent Removal**		
Dose 100 gal	3.328	/3.06	1.09	1.04	<------Average Dose	
1st	1.581	/3.06	0.52	51%		Average Removal
2nd	1.416	/3.06	0.46	56%		43.9%
3rd	1.817	/3.06	0.59	43%		Standard Deviation
End	2.358	/3.06	0.77	26%		12.9%

Total Nitrogen	mg/L			
	Mean			
Tap 50 gal				
Tap 100 gal				
Dose 50 gal	**6.140**	**Percent Removal**		
Dose 100 gal	**6.760**	6.45	<------Average Dose	
1st	**8.580**	-33%		Average Removal
2nd	**7.983**	-24%		-10.8%
3rd	**6.270**	3%		Standard Deviation
End	**5.760**	11%		20.9%
DI	**0.000**			

Timing/Flow Rates						
Time to first outflow	354.000	s	5.90	min	Trench Depth (in)	
Total Test Time	3421.000	s	57.02	min	37	
Flow Rate Test	Flow Rate (gal/hr)	Description			Infil Rate (in/min)	Standard Deviation
1	35.822	1st flow			6.3	0.3
2	71.326	end 1st		First Outflow (min)	Infil Rate (in/min)	
3	107.601	middle 2nd	Test 1	5.916666667	6.253521127	
4	246.790	after finish 2nd	Test 2	5.9	6.253521127	
5	379.774	after start 3rd	Test 3	5.4	6.830769231	
6	443.809		Test 4	6.083333333	6.082191781	
	Mean Flow (GPH)		Test 5	6.166666667	6	
	214.187					

Iron-Enhanced Sand Blank Average

	Tap water	1st	2nd	3rd	Average
Turbidity	0.790	36.967	31.133	8.003	25.368
pH	7.460	7.190	7.280	7.450	7.307
CE	132.233	148.667	148.367	121.633	139.556
TDS	93.900	105.500	105.333	86.700	99.178
Temperature	20.567	20.233	20.133	20.133	20.167

Phosphate	Mean		**Phosphorus {mg/L)**	
Tap water	0.595	/3.06	0.194	**Percent Removal**
1st	0.338	/3.06	0.111	43%
2nd	0.397	/3.06	0.130	33%
3rd	0.355	/3.06	0.116	40%

Average Removal
38.9%
Standard Deviation
5.05%

Total Nitrogen	mg/L	
	Mean	
Tap water	**0.783333333**	**Percent Removal**
1st	**2.217**	-183%
2nd	**2.050**	-162%
3rd	**1.000**	-28%
DI	0	

Average Removal
-124.1%
Standard Deviation
84.2%

Timing/Flow Rates						
Time to first outflow	281.6666667	s	4.69	min	Trench Depth (in)	
Total Test Time	2525	s	42.08	min	39	
Flow Rate Test	Flow Rate (gal/hr)	Description			Infil Rate (in/min)	Standard Deviation
1	68.063	1st flow			8.3	0.5
2	155.333	end 1st		First Outflow (min)	Infil Rate (in/min)	
3	367.199	middle 2nd	Test 1	4.6	8.5	
4	470.226	after finish 2nd	Test 2	4.5	8.7	
5	549.478	after start 3rd	Test 3	5.0	7.8	
6	507.210					
	Mean Flow (GPH)					
	352.918					

Iron-Enhanced Sand Dosed Average

	Dose 50 gal	Dose 100 gal	Average	1st	2nd	3rd	Average
Turbidity	0.697	0.810	0.753	38.767	29.633	13.353	27.251
pH	7.203	7.447	7.325	7.277	7.227	7.390	7.298
CE	187.367	150.400	168.883	167.933	171.033	162.333	167.100
TDS	147.333	121.667	134.500	131.333	130.333	123.333	128.333
Temperature	22.467	22.200	22.333	21.467	21.333	21.633	21.478

Phosphate	Mean		**Phosphorus (mg/L)**			
Dose 50 gal	1.562	/3.06	0.51	**Percent Removal**		
Dose 100 gal	1.663	/3.06	0.54	0.53	<------Average Dose	
1st	0.415	/3.06	0.14	74%		Average Removal
2nd	0.340	/3.06	0.11	79%		76.9%
3rd	0.352	/3.06	0.11	78%		Standard Deviation
End	0.383	/3.06	0.13	76%		2.1%

Total Nitrogen	mg/L			
	Mean			
Tap 50 gal				
Tap 100 gal				
Dose 50 gal	**4.767**	**Percent Removal**		
Dose 100 gal	**4.900**	4.833333333	<------Average Dose	
1st	**2.667**	45%		Average Removal
2nd	**3.100**	36%		25.5%
3rd	**4.500**	7%		Standard Deviation
End	**4.133**	14%		17.8%
DI	**0**			

Timing/Flow Rates						
Time to first outflow	327.333	s	5.46	min	Trench Depth (in)	
Total Test Time	2529.333	s	42.16	min	39	
Flow Rate Test	Flow Rate (gal/hr)	Description			Infil Rate (in/min)	Standard Deviation
1	63.401	1st flow			7.1	0.2
2	112.361	end 1st		First Outflow (min)	Infil Rate (in/min)	
3	312.251	middle 2nd	Test 1	5.3	7.358490566	
4	491.360	after finish 2nd	Test 2	5.6	6.923076923	
5	575.895	after start 3rd	Test 3	5.4	7.17791411	
6	634.013					
	Mean Flow (GPH)					
	364.880					

Iron-Enhanced Sand Stress Average

	Dose 50 gal	Dose 100 gal	Average	1st	2nd	3rd	Average
Turbidity	0.880	0.547	0.713	25.667	16.150	7.395	16.404
pH	7.553	7.500	7.527	9.203	7.100	7.240	7.848
CE	312.467	168.867	240.667	176.177	233.667	187.567	199.137
TDS	227.000	122.667	174.833	188.333	166.000	134.000	162.778
Temperature	22.950	22.650	22.800	20.650	20.500	20.550	20.567

Phosphate	Mean		**Phosphorus (mg/L)**			
Dose 50 gal	2.992	/3.06	0.98	**Percent Removal**		
Dose 100 gal	3.243	/3.06	1.06	1.02	<------Average Dose	
1st	0.430	/3.06	0.14	86%		Average Removal
2nd	0.405	/3.06	0.13	87%		82.1%
3rd	0.547	/3.06	0.18	82%		Standard Deviation
End	0.852	/3.06	0.28	73%		6.6%

Total Nitrogen	mg/L			
	Mean			
Tap 50 gal				
Tap 100 gal				
Dose 50 gal	**4.350**	**Percent Removal**		
Dose 100 gal	**12.225**	8.2875	<------Average Dose	
1st	**10.150**	-22%		Average Removal
2nd	**5.367**	35%		13.2%
3rd	**6.725**	19%		Standard Deviation
End	**6.525**	21%		24.9%
DI	**0**			

Timing/Flow Rates						
Time to first outflow	356.667	s	5.94	min	Trench Depth (in)	
Total Test Time	2760.000	s	46.00	min	39	
Flow Rate Test	Flow Rate (gal/hr)	Description			Infil Rate (in/min)	Standard Deviation
1	67.384	1st flow			6.6	0.3
2	104.815	end 1st		First Outflow (min)	Infil Rate (in/min)	
3	257.832	middle 2nd	Test 1	5.666666667	6.882352941	
4	443.809	after finish 2nd	Test 2	6.0	6.5	
5	433.242	after start 3rd	Test 3	6.2	6.324324324	
6	591.745					
	Mean Flow (GPH)					
	316.471					

Standard 2 Blank Average

	50 gal	100 gal	Average	1st	2nd	3rd	end	Average
Turbidity	1.554	0.338	0.946	31.633	13.600	6.507	2.797	13.634
pH	7.750	7.717	7.733	7.573	7.577	7.607	7.743	7.625
CE	156.567	150.933	153.750	284.833	248.633	195.300	194.733	230.875
TDS	121.267	107.733	114.500	201.667	177.000	139.000	138.667	164.083
Temperature	19.733	19.567	19.650	19.533	19.567	19.600	19.700	19.600

Phosphate	Mean		**Phosphorus (mg/L)**			
50 gal	0.730	/3.06	0.239	**Percent Removal**		
100 gal	0.720	/3.06	0.235	0.24	< ----- Average Dose	Average Removal
1st	0.780	/3.06	0.255	-8%		-4.3%
2nd	0.740	/3.06	0.242	-2%		Standard Deviation
3rd	0.763	/3.06	0.249	-5%		2.69%
end	0.740	/3.06	0.242	-2%		

Total Nitrogen	mg/L					
	Mean					
50 gal	**-0.416666667**	**Percent Removal**			Actual	
100 gal	**-0.383**	-0.40	<------Average Dose	Average Removal	Average Removal	Note:
1st	**0.217**	154%		113.5%	-86.5%	*Calculated averaging each independent% Removal
2nd	**0.383**	196%		Standard Deviation	Standard Deviation	
3rd	**0.017**	104%		84.5%	198.2%	
end	**-0.400**	0%	Note:			
DI			*Yellow is an inaccurate description of% Removal			

Timing/Flow Rates						
Time to first outflow	371.6666667	s	6.19	min	Trench Depth (in)	
Total Test Time	3300	s	55.00	min	37	
Flow Rate Test	Flow Rate (gal/hr)	Description			Infil Rate (in/min)	Standard Deviation
1	47.551	Istflow			6.0	0.2
2	75.025	end 1st		First Outflow (min)	Infil Rate (in/min)	
3	112.651	middle 2nd	Test 1	6.0	6.2	
4	216.244	after finish 2nd	Test 2	6.2	6.0	
5	347.650	after start 3rd	Test 3	6.4	5.8	
6	443.809					
	Mean Flow (GPH)					
	207.155					

Standard 2 Dosed Average

	Dose 50 gal	Dose 100 gal	Average	1st	2nd	3rd	End	Average
Turbidity	0.344	0.294	0.319	27.267	9.743	4.417	2.010	10.859
pH	7.437	7.503	7.470	7.197	7.190	7.280	7.433	7.275
CE	230.233	207.833	219.033	213.667	219.667	209.667	219.000	215.500
TDS	159.333	147.667	153.500	152.000	158.333	148.000	156.333	153.667
Temperature	20.450	19.800	20.125	19.500	19.650	19.700	19.800	19.663

Phosphate	Mean		**Phosphorus (mg/L)**			
Dose 50 gal	1.670	/3.06	0.55	**Percent Removal**		
Dose 100 gal	1.788	/3.06	0.58	0.57	<----- Average Dose	
1st	1.028	/3.06	0.34	41%		Average Removal
2nd	1.000	/3.06	0.33	42%		32.2%
3rd	1.203	/3.06	0.39	30%		Standard Deviation
End	1.457	/3.06	0.48	16%		12.1%

Total Nitrogen	mg/L			
	Mean			
Tap 50 gal				
Tap 100 gal				
Dose 50 gal	**4.700**	**Percent Removal**		
Dose 100 gal	**5.067**	4.883333333	<------Average Dose	
1st	**3.667**	25%		Average Removal
2nd	**3.900**	20%		16.4%
3rd	**4.350**	11%		Standard Deviation
End	**4.417**	10%		7.4%
DI				

Timing/Flow Rates							
Time to first outflow	408.333	s	6.81	min	Trench Depth (in)		
Total Test Time	3900.000	s	65.00	min	37		
Flow Rate Test	Flow Rate (gal/hr)	Description			Infil Rate (in/min)	Standard Deviation	
1	43.324	1st flow			5.4	0.3	
2	102.599	end 1st		First Outflow (min)	Infil Rate (in/min)		
3	119.054	middle 2nd	Test 1	6.416666667	5.766233766		
4	254.134	after finish 2nd	Test 2	6.9	5.34939759		
5	406.825	after start 3rd	Test 3	7.1	5.223529412		
6	443.809						
	Mean Flow (GPH)						
	228.291						

Standard 2 Stress Average

	Dose 50 gal	Dose 100 gal	Average	1st	2nd	3rd	4th	Average
Turbidity	0.267	0.258	0.262	29.233	9.300	3.613	1.139	10.822
pH	7.533	7.553	7.543	7.183	7.177	7.333	7.470	7.231
CE	212.000	211.000	211.500	225.333	228.333	220.667	217.333	224.778
TDS	151.333	148.000	149.667	160.333	161.667	156.667	153.667	159.556
Temperature	20.767	20.267	20.517	19.567	19.600	19.667	20.333	19.611

Phosphate	Mean		**Phosphorus (mg/L)**			
Dose 50 gal	3.047	/3.06	1.00	**Percent Removal**		
Dose 100 gal	3.288	/3.06	1.07	1.04	< ----- Average Dose	
1st	1.825	/3.06	0.60	42%		Average Removal
2nd	1.452	/3.06	0.47	54%		40.2%
3rd	1.817	/3.06	0.59	43%		Standard Deviation
End	2.485	/3.06	0.81	22%		13.6%

Total Nitrogen	mg/L					
	Mean					
Tap 50 gal						
Tap 100 gal						
Dose 50 gal	**5.133**	**Percent Removal**				
Dose 100 gal	**6.383**	5.758333333	<------Average Dose			
1st	**5.167**	10%		Average Removal		
2nd	**5.983**	-4%		-3.2%		
3rd	**7.983**	-39%		Standard Deviation		
End	**4.633**	20%		25.5%		
DI						
Timing/Flow Rates						
Time to first outflow	447.500	s	7.46	min	Trench Depth (in)	
Total Test Time	3900.000	s	65.00	min	37	
Flow Rate Test	Flow Rate (gal/hr)	Description			Infil Rate (in/min)	Standard Deviation
1	45.966	1st flow			5.0	0.1
2	74.271	end 1st		First Outflow (min)	Infil Rate (in/min)	
3	118.538	middle 2nd	Test 1	7.166666667	5.162790698	
4	209.224	after finish 2nd	Test 2	7.3	5.045454545	
5	420.034	after start 3rd	Test 3	7.6	4.879120879	
6	451.734					
	Mean Flow (GPH)					
	219.961					

Appendix B: Sediment Barrier Data

Product A (triplicate) Install 1 Summary					
Average TSS (mg/L)	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
	5	6313	4033	6087	5053
	10	10410	5760	7117	5497
	15	20477	5303	10933	5163
	20	19543	6153	22803	5680
	25	15660	5123	13727	4433
	30	17550	15083	22840	3193
	35		595	7855	1330
	40				
	45				
	60				
	90				
	120				
Average Turbidity (NTU)	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
	5	3,205	2,569	3,744	3,400
	10	4,319	4,688	4,970	3,764
	15	6,604	3,831	5,481	3,596
	20	6,004	4,160	12,563	4,853
	25	4,906	3,033	8,026	3,743
	30	11,683	8,075	4,380	2,393
	35		665	5,884	1,236
	40				
	45				
	60				
	90				
	120				
Average Impoundment (in)	Time (min)	Impoundment Depth	Impoundment Length	Overtopping (y/n)	Time (min)
	5	3.17	71.7	y	1.33
	10	3.42	72.7		
	15	3.54	72.7		
	20	3.54	72.7		
	25	3.50	72.7		
	30	3.42	73.0		
	35	2.58	13.7		
	40	0.00	0.0		
	45	0.00	0.0		
	60	0.00	0.0		
	90	0.00	0.0		
	120				
Flow Rate (ft3/s)	Time to Flow (min)	Avg Flow Rate	Max Flow Rate		
	1.92	0.14	0.22		
Sediment Retention	Sediment Introduced	Sediment Captured	Percent Capture		
	3044	1930	63%		

Product A (triplicate) Install 2 Summary

	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
Average TSS {mg/L)	5	14477	7197	5963	3433
	10	29300	8563	11140	3887
	15	18177	5750	18437	5550
	20	12750	5377	10103	3623
	25	15687	4010	27423	4213
	30	16203	2470	10755	2507
	35		1610	11980	
	40		2580	1050	
	45		1050	1920	
	60		530	5840	
	90				
	120				

	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
Average Turbidity (NTU)	5	5,304	5,261	4,558	2,921
	10	6,344	3,739	5,283	3,273
	15	5,612	3,540	5,380	4,106
	20	3,959	3,318	7,702	3,264
	25	4,781	2,983	7,722	3,458
	30	4,745	1,525	6,903	1,279
	35		1,255	6,878	
	40		1,718	912	
	45		1,016	1,586	
	60		613	2,577	
	90				
	120				

	Time (min)	Impoundment Depth	Impoundment Length	Overtopping (y/n)	Time (min)
Average Impoundment (in)	5	3.00	49.7	y	1.37
	10	2.67	47.7		
	15	2.42	36.0		
	20	2.00	34.2		
	25	1.75	34.2		
	30	1.75	28.2		
	35	1.33	8.7		
	40	0.92	7.3		
	45	a.so	6.7		
	60	0.42	5.3		
	90	0.17	4.0		
	120				

	Time to Flow (min)	Avg Flow Rate	Max Flow Rate
Flow Rate (ft^3/s)	1.92	0.13	0.17

	Sediment Introduced	Sediment Captured	Percent Capture
Sediment Retention (lbs)	2805	2109	75%

Product A (triplicate) Install 3 Summary

	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
Average TSS {mg/L)	5	10413	3270	11863	3670
	10	14147	6807	8520	3970
	15	17767	4433	13700	3560
	20	10713	3863	11287	3917
	25	20743	4820	15875	5063
	30	32943	2830	7655	10450
	35		870	7065	
	40		475	4395	
	45		600	4950	
	60		350	1190	
	90				
	120				

	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
Average Turbidity (NTU)	5	5,439	1,881	4,519	2,200
	10	4,117	1,798	5,081	2,473
	15	8,271	2,483	4,346	2,234
	20	3,067	2,795	4,448	2,833
	25	5,567	2,390	2,218	2,613
	30	6,868	1,586	2,213	1,771
	35		966	1,840	
	40		757	1,876	
	45		644	2,111	
	60		512	1,015	
	90				
	120				

	Time (min)	Impoundment Depth	Impoundment Length	Overtopping (y/n)	Time (min)
Average Impoundment (in)	5	2.33	38.0	y	1.67
	10	2.33	31.7		
	15	2.17	25.0		
	20	2.17	22.0		
	25	1.75	20.0		
	30	1.67	18.0		
	35	1.33	14.3		
	40	1.25	13.3		
	45	0.83	12.3		
	60	0.33	10.0		
	90				
	120				

	Time to Flow (min)	Avg Flow Rate	Max Flow Rate
Flow Rate (ft^3/s)	2.75	0.15	0.27

	Sediment Introduced	Sediment Captured	Percent Capture
Sediment Retention (lbs)	3067	2553	83%

Product A (triplicate) Summary					
	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
Average TSS (mg/L)	5	10401	4833	7971	4052
	10	17952	7043	8926	4451
	15	18807	5162	14357	4758
	20	14336	5131	14731	4407
	25	17363	4651	19008	4570
	30	22232	6794	13750	5383
	35		1025	8967	1330
	40		1528	2722	
	45		825	3435	
	60		440	3515	
	90				
	120				
	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
Average Turbidity (NTU)	5	4649	3237	4274	2840
	10	4927	3408	5111	3170
	15	6829	3285	5069	3312
	20	4343	3425	8238	3650
	25	5085	2802	5989	3271
	30	7765	3729	4499	1814
	35		962	4867	1236
	40		1237	1394	
	45		830	1848	
	60		563	1796	
	90				
	120				
	Time (min)	Impoundment Depth	Impoundment Length	Overtopping (y/n)	Time (min)
Average Impoundment (in)	5	2.83	53.1	y	1.46
	10	2.81	50.7		
	15	2.71	44.6		
	20	2.57	42.9		
	25	2.33	42.3		
	30	2.28	39.7		
	35	1.75	12.2		
	40	0.72	6.9		
	45	0.44	6.3		
	60	0.25	5.1		
	90	0.08	2.0		
	120				
Flow Rate (ft^3/s)	Time to Flow (min)	Avg Flow Rate	Max Flow Rate		
	2.19	0.14	0.22		
Sediment Retention (lbs)	Sediment Introduced	Sediment Captured	Percent Capture		
	2972	2197	74%		

Product B Install 1 Summary

	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
Average TSS (mg/L)	5	10143	4187	12093	4863
	10	19503	3660	11143	5073
	15	11213	5027	18973	5820
	20	23610	7263	20897	4290
	25	6993	6820	22323	3780
	30	12553	12603	31550	3190
	35				
	40				
	45				
	60				
	90				
	120				

	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
Average Turbidity (NTU)	5	5,144	3,542	7,068	3,720
	10	10,988	2,976	7,315	4,023
	15	4,955	3,691	10,391	4,204
	20	12,255	5,540	13,754	3,507
	25	4,061	5,191	11,651	3,528
	30	6,605	6,681	6,138	2,897
	35				
	40				
	45				
	60				
	90				
	120				

	Time (min)	Impoundment Depth	Impoundment Length	Overtopping (y/n)	Time (min)
Average Impoundment (in)	5	4.17	70.8	n	n/a
	10	4.67	72.1		
	15	4.58	73.0		
	20	4.46	71.5		
	25	5.04	72.5		
	30	5.29	72.9		
	35				
	40				
	45				
	60				
	90				
	120				

	Time to Flow (min)	Avg Flow Rate	Max Flow Rate
Flow Rate (ft^3/s)	2.17	0.12	0.21

	Sediment Introduced	Sediment Captured	Percent Capture
Sediment Retention (lbs)	3044	2250	74%

Product B Install 2 Summary

Average TSS (mg/L)	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
	5	9730	2137	6243	1780
	10	13900	1733	5103	1320
	15	16780	1830	3590	1703
	20	13810	1847	4300	2190
	25	18173	1490	6003	1923
	30	8583	1407	4513	1530
	35		763	3633	893
	40		740	1700	617
	45		553	1220	553
	60				
	90				
	120				

Average Turbidity (NTU)	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
	5	4,950	1,691	3,515	1,734
	10	4,877	1,739	2,371	1,580
	15	4,436	1,525	2,438	1,741
	20	3,330	1,601	2,559	1,895
	25	5,863	1,590	3,469	1,870
	30	4,183	1,860	2,672	1,997
	35		1,071	3,568	1,018
	40		907	1,609	908
	45		932	2,208	704
	60				
	90				
	120				

Average Impoundment (in)	Time (min)	Impoundment Depth	Impoundment Length	Overtopping (y/n)	Time (min)
	5	5.83	70.3	y	12.7
	10	6.33	68.0		
	15	6.33	67.3		
	20	6.67	67.0		
	25	7.25	67.0		
	30	6.67	64.7		
	35	4.00	55.0		
	40	3.33	49.3		
	45	2.33	42.7		
	60				
	90				
	120				

Flow Rate (ft^3/s)	Time to Flow (min)	Avg Flow Rate	Max Flow Rate
	2.25	0.13	0.23

Sediment Retention (lbs)	Sediment Introduced	Sediment Captured	Percent Capture
	2834	2696	95%

Product B Install 3 Summary

Average TSS (mg/L)

Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
5	24573	2350	8177	1913
10	10550	2087	8517	1720
15	28553	1710	5440	1777
20	18833	2357	6253	5560
25	18220	2307	11010	2220
30	14460	1627	6073	2277
35		963	6983	1130
40		750	2760	763
45		620	2997	620
60				
90				
120				

Average Turbidity (NTU)

Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
5	5,323	1,606	4,458	1,956
10	2,554	1,984	5,895	2,004
15	7,395	2,018	2,602	2,199
20	5,314	2,220	3,319	2,717
25	7,181	2,145	3,372	2,125
30	3,132	2,029	3,124	2,246
35		1,416	3,968	1,466
40		1,223	1,883	1,099
45		907	1,619	902
60				
90				
120				

Average Impoundment (in)

Time (min)	Impoundment Depth	Impoundment Length	Overtopping (y/n)	Time (min)
5	5.33	74.3	y	7.9
10	5.83	69.0		
15	6.33	67.0		
20	6.33	65.3		
25	6.00	65.0		
30	5.67	63.3		
35	4.33	52.3		
40	3.50	48.3		
45	2.33	35.7		
60	0.08	5.3		
90				
120				

Flow Rate (ft^3/s)

Time to Flow (min)	Avg Flow Rate	Max Flow Rate
2.17	0.14	0.23

Sediment Retention (lbs)

Sediment Introduced	Sediment Captured	Percent Capture
2890	2740	95%

Product B Summary

Average TSS (mg/L)

Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
5	14816	2891	**8838**	2852
10	14651	2493	8254	2704
15	18849	2856	9334	3100
20	18751	3822	10483	4013
25	14462	3539	13112	2641
30	11866	5212	14046	2332
35		863	5308	1012
40		745	2230	690
45		587	2108	587
60				
90				
120				

Average Turbidity (NTU)

Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
5	5139	2280	5014	2470
10	6140	2233	5194	2536
15	5595	2411	5144	2715
20	6966	3120	6544	2706
25	5702	2975	6164	2508
30	4640	3523	3978	2380
35		1244	3768	1242
40		1065	1746	1004
45		920	1913	803
60				
90				
120				

Average Impoundment (in)

Time (min)	Impoundment Depth	Impoundment Length	Overtopping (y/n)	Time (min)
5	5.11	71.8	y	10.3
10	5.61	69.7		
15	5.75	69.1		
20	5.82	67.9		
25	6.10	68.2		
30	5.88	67.0		
35	4.17	53.7		
40	3.42	48.8		
45	2.33	39.2		
60	0.08	5.3		
90				
120				

Flow Rate (ft^3/s)

Time to Flow (min)	Avg Flow Rate	Max Flow Rate
2.19	0.13	0.23

Sediment Retention (lbs)

Sediment Introduced	Sediment Captured	Percent Capture
2923	2562	**88%**

Silt Fence Install 1 Summary

Average TSS (mg/L)

Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
5	29493	10830	14670	2663
10	27437	1997	19460	1383
15	27377	2973	6350	1266
20	19580	1360	5140	1023
25	30563	1143	4757	920
30	23767	920	4257	933
35		677	3537	697
40		607	1883	727
45		590	1650	687
60		473	1330	560
90		420	923	687
120		337	863	1037

Average Turbidity (NTU)

Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
5	7,330	2,419	6,595	3,278
10	6,737	1,453	5,434	1,817
15	8,522	1,387	3,793	1,533
20	5,645	1,502	2,903	1,295
25	9,664	1,313	2,820	1,234
30	3,731	1,205	2,355	880
35		963	2,157	1,090
40		1,901	1,991	891
45		1,455	1,624	921
60		794	1,282	872
90		722	1,127	922
120		788	1,057	1,253

Average Impoundment (in)

Time (min)	Impoundment Depth	Impoundment Length	Overtopping (y/n)	Time (min)
5	6.33	86.7	y	20.S
10	10.00	100.0		
15	13.50	110.7		
20	15.33	117.3		
25	17.00	120.3		
30	17.83	115.3		
35	16.33	111.0		
40	15.17	108.3		
45	14.50	106.7		
60	12.50	100.7		
90	10.50	93.3		
120	9.00	88.3		

Flow Rate (ft3/s)

Time to Flow (min)	Avg Flow Rate	Max Flow Rate
6.25	0.05	0.20

Sediment Retention (lbs)

Sediment Introduced	Sediment Captured	Percent Capture
3083	2966	96%

Silt Fence Install 2 Summary					
Average TSS (mg/L)	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
	5	25513	2457	8183	2567
	10	27133	1680	7663	1620
	15	28523	1393	4667	1337
	20	16887	1167	4877	870
	25	19003	1000	4457	897
	30	15000	917	5547	770
	35		657	4817	663
	40		490	3337	663
	45		527	3413	637
	60		423	20190	460
	90		370	5787	433
	120		390	5973	433
Average Turbidity (NTU)	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
	5	6,332	1,750	5,706	2,340
	10	8,088	1,470	6,566	1,618
	15	8,309	1,215	2,950	1,585
	20	6,539	1,146	3,260	1,039
	25	6,082	995	3,627	1,075
	30	4,420	1,015	2,508	1,022
	35		808	3,234	803
	40		691	2,889	841
	45		700	2,358	848
	60		697	3,562	680
	90		539	3,788	622
	120		494	3,854	600
Average Impoundment (in)	Time (min)	Impoundment Depth	Impoundment Length	Overtopping (y/n)	Time (min)
	5	7.00	86.7	y	19.0
	10	9.92	99.7		
	15	13.17	112.3		
	20	16.33	119.0		
	25	17.67	117.0		
	30	18.83	118.0		
	35	16.00	113.3		
	40	15.42	111.0		
	45	14.67	109.0		
	60	13.17	104.7		
	90	10.67	97.0		
	120	7.50	89.3		
Flow Rate (ft3/s)	Time to Flow (min)	Avg Flow Rate	Max Flow Rate		
	5.75	0.06	0.19		
Sediment Retention (lbs)	Sediment Introduced	Sediment Captured	Percent Capture		
	3048	2870	94%		

Silt Fence Install 3 Summary					
Average TSS (mg/L)	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
	5	45667	1857	14573	2263
	10	35887	2163	3900	1370
	15	30427	1187	3257	1043
	20	42243	1030	3763	943
	25	52353	933	4410	733
	30	35920	767	2237	747
	35		2273	2197	940
	40		547	957	730
	45		393	997	527
	60		437	860	563
	90		237	810	640
	120		297	623	687
Average Turbidity (NTU)	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
	5	7,820	1,661	4,262	2,454
	10	4,834	1,371	2,772	1,298
	15	8,720	1,187	2,296	953
	20	6,369	932	1,655	690
	25	7,704	939	2,782	769
	30	7,424	777	2,058	694
	35		556	2,270	996
	40		564	1,100	664
	45		526	857	684
	60		479	893	603
	90		411	712	725
	120		365	524	886
Average Impoundment (in)	Time (min)	Impoundment Depth	Impoundment Length	Overtopping (y/n)	Time (min)
	5	7.42	85.7	y	19.7
	10	10.83	99.0		
	15	14.08	108.7		
	20	16.63	115.3		
	25	17.75	119.0		
	30	19.08	121.0		
	35	17.58	112.0		
	40	15.67	106.0		
	45	14.42	105.0		
	60	12.33	101.0		
	90	9.50	89.0		
	120	6.83	83.7		
Flow Rate (ft3/s)	Time to Flow (min)	Avg Flow Rate	Max Flow Rate		
	10.08	0.06	0.18		
Sediment Retention (lbs)	Sediment Introduced	Sediment Captured	Percent Capture		
	2924	2918	100%		

Silt Fence Summary

	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
Average TSS (mg/L)	5	33558	5048	12476	2498
	10	30152	1947	10341	1458
	15	28776	1851	4758	1215
	20	26237	1186	4593	946
	25	33973	1026	4541	850
	30	24896	868	4013	817
	35		1202	3517	767
	40		548	2059	707
	45		503	2020	617
	60		444	7460	528
	90		342	2507	587
	120		341	2487	719

	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
Average Turbidity (NTU)	5	7161	1943	5521	2691
	10	6553	1431	4924	1578
	15	8517	1263	3013	1357
	20	6184	1193	2606	1008
	25	7817	1083	3076	1026
	30	5192	999	2307	865
	35		776	2554	963
	40		1052	1993	798
	45		894	1613	818
	60		657	1912	718
	90		558	1876	756
	120		549	1812	913

	Time (min)	Impoundment Depth	Impoundment Length	Overtopping (y/n)	Time (min)
Average Impoundment (in)	5	6.92	86.33	y	19.7
	10	10.25	99.56		
	15	13.58	110.56		
	20	16.10	117.22		
	25	17.47	118.78		
	30	18.58	118.11		
	35	16.64	112.11		
	40	15.42	108.44		
	45	14.53	106.89		
	60	12.67	102.11		
	90				
	120				

	Time to Flow (min)	Avg Flow Rate	Max Flow Rate
Flow Rate (ft^3/s)	7.36	0.06	0.19

	Sediment Introduced	Sediment Captured	Percent Capture
Sediment Retention (lbs)	3018	2918	97%

Compost Sock Install 1 Summary

	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
Average TSS (mg/L)	5	11450	2730	6470	1690
	10	25250	2137	2750	1450
	15	121310	1538	1990	1130
	20	15820	2175	2520	1150
	25	21730	1138	1920	1220
	30	9220	862	4080	1130
	35		787	1750	530
	40		1100	2140	260
	45				
	60				
	90				
	120				

	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
Average Turbidity (NTU)	5	3,834	1,783	4,270	1,186
	10	5,600	1,308	2,164	1,090
	15		1,223	1,673	963
	20	9,528	1,157	2,067	428
	25	5,536	925	1,605	1,002
	30	3,966	786	3,183	991
	35		760	1,425	592
	40		756	1,580	342
	45				
	60				
	90				
	120				

	Time (min)	Impoundment Depth	Impoundment Length	Overtopping (y/n)	Time (min)
Average Impoundment (in)	5	2.90	67.0		
	10	4.00	76.0		
	15	5.30	86.0		
	20	4.10	96.0		
	25	5.20	101.0		
	30	5.40	101.0	n	
	35	2.40	88.0		
	40	1.10	69.0		
	45				
	60				
	90				
	120				

	Time to Flow (min)	Avg Flow Rate	Max Flow Rate
Flow Rate (ft3/s)	4.00	0.12	0.17

	Sediment Introduced	Sediment Captured	Percent Capture
Sediment Retention (lbs)	1034	993	96%

Compost Sock Install 2 Summary

Average TSS (mg/L)	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
	5	5610	2110	2390	1020
	10	13310	1760	1600	830
	15	10090	1690	2430	870
	20	7560	1960	3200	990
	25	8590	810	4230	1030
	30	3460	1040	4190	760
	35		830	2640	590
	40		710	3150	430
	45		640	7540	790
	60				
	90				
	120				

Average Turbidity (NTU)	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
	5	3,621	1,659	2,331	945
	10	2,826	1,686	1,598	859
	15	4,260	1,664	2,234	918
	20	2,909	1,481	2,543	1,065
	25	4,758	991	3,535	1,007
	30	2,160	1,232	3,935	863
	35		1,054	1,970	711
	40		941	2,471	608
	45		830	5,132	831
	60				
	90				
	120				

Average Impoundment (in)	Time (min)	Impoundment Depth	Impoundment Length	Overtopping (y/n)	Time (min)
	5	3.50	99.0	y	19.00
	10	4.75	130.0		
	15	5.25	128.0		
	20	5.63	127.0		
	25	6.00	122.0		
	30	6.00	116.0		
	35	4.00	105.0		
	40	2.50	93.0		
	45	1.50	81.0		
	60				
	90				
	120				

Flow Rate (ft3/s)	Time to Flow (min)	Avg Flow Rate	Max Flow Rate
	5.25	0.10	0.17

Sediment Retention (lbs)	Sediment Introduced	Sediment Captured	Percent Capture
	978	944	97%

Compost Sock Install 3 Summary					
Average TSS (mg/L)	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
	5	7780	1790	2810	610
	10	4490	820	2290	570
	15	4140	1200	3440	790
	20	14780	1330	3690	690
	25	16850	1070	2450	660
	30	5110	510	6110	680
	35		320	1590	460
	40		330	2530	390
	45		710		290
	60				
	90				
	120				
Average Turbidity (NTU)	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
	5	3,972	1,372	2,263	637
	10	2,154	836	1,610	572
	15	915	947	2,861	698
	20	4,509	1,135	2,992	687
	25	3,671	824	2,062	623
	30	2,164	632	4,470	643
	35		368	1,354	517
	40		440	1,805	443
	45		364		358
	60				
	90				
	120				
Average Impoundment (in)	Time (min)	Impoundment Depth	Impoundment Length	Overtopping (y/n)	Time (min)
	5	3.75	74.0	n	
	10	5.25	82.0		
	15	5.75	89.0		
	20	6.25	99.0		
	25	6.38	101.0		
	30	6.38	103.0		
	35	4.25	98.0		
	40	2.75	88.0		
	45	2.00	74.0		
	60				
	90				
	120				
Flow Rate (ft3/s)	Time to Flow (min)	Avg Flow Rate	Max Flow Rate		
	5.00	0.11	0.16		
Sediment Retention (lbs)	Sediment Introduced	Sediment Captured	Percent Capture		
	1034	961	93%		

Compost Sock Summary

Average TSS (mg/L)				
Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
5	8280	2210	3890	1107
10	14350	1573	2213	950
15	45180	1476	2620	930
20	12720	1822	3137	943
25	15723	1006	2867	970
30	5930	804	4793	857
35		646	1993	527
40		713	2607	360
45		675	7540	540
60				
90				
120				

Average Turbidity (NTU)				
Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
5	3809	1605	2955	923
10	3527	1277	1791	840
15	2588	1278	2256	860
20	5649	1258	2534	727
25	4655	913	2401	877
30	2763	883	3863	832
35		727	1583	607
40		712	1952	464
45		597	5132	595
60				
90				
120				

Average Impoundment (in)				
Time (min)	Impoundment Depth	Impoundment Length	Overtopping (y/n)	Time (min)
5	3.38	80.0	n (Only Once)	
10	4.67	96.0		
15	5.43	101.0		
20	5.33	107.3		
25	5.86	108.0		
30	5.93	106.7		
35	3.55	97.0		
40	2.12	83.3		
45	1.75	77.5		
60				
90				
120				

Flow Rate (ft^3/s)		
Time to Flow (min)	Avg Flow Rate	Max Flow Rate
4.75	0.11	0.17

Sediment Retention (lbs)		
Sediment Introduced	Sediment Captured	Percent Capture
1015	966	95%

Product A (single) Install 1 Summary

Average TSS (mg/L)	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
	5	150	2740	2570	1190
	10	13380	3400	9360	1770
	15	3490	2620	17620	1520
	20	12630	3050	23170	1550
	25	36360	3960	15740	1400
	30	14330	3880	29860	520
	35		19760	36870	670
	40		810		270
	45		890		160
	60				
	90				
	120				

Average Turbidity (NTU)	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
	5	90	1,914	2,290	1,175
	10	2,408	2,350	6,844	1,510
	15	721	1,805	10,904	1,435
	20	1,091	2,283	13,320	1,248
	25	1,940	3,107	9,360	1,094
	30	910	2,826	22,932	519
	35		13,380	21,450	453
	40		575		260
	45		585		218
	60				
	90				
	120				

Average Impoundment (in)	Time (min)	Impoundment Depth	Impoundment Length	Overtopping (y/n)	Time (min)
	5	1.75	54.0	y	4.92
	10	2.60	64.0		
	15	2.60	64.0		
	20	2.80	67.0		
	25	2.80	67.0		
	30	2.80	67.0		
	35	1.80	68.0		
	40	1.20	68.0		
	45	0.90	66.0		
	60				
	90				
	120				

Flow Rate (ft3/s)	Time to Flow (min)	Avg Flow Rate	Max Flow Rate
	4.75	0.14	0.22

Sediment Retention (lbs)	Sediment Introduced	Sediment Captured	Percent Capture
	1029	927	90%

Product A (single) Install 2 Summary					
Average TSS (mg/L)	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
	5	12880	2040	5030	1250
	10	9750	1690	7460	1150
	15	33970	2110	26330	1820
	20	70870	3170	43900	1530
	25	17250	1970	92140	1450
	30	9860	2460	32920	1070
	35		800	23030	530
	40		360	29200	250
	45		5110		230
	60				
	90				
	120				
Average Turbidity (NTU)	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
	5	10,980	1,887	3,708	894
	10	5,677	1,498	5,558	1,017
	15	19,369	1,869	19,271	1,561
	20	26,466	2,709	19,866	1,232
	25	5,565	1,854	45,163	1,284
	30	1,659	2,106	19,320	1,045
	35		653	7,434	470
	40		465	3,921	324
	45		4,147		236
	60				
	90				
	120				
Average Impoundment (in)	Time (min)	Impoundment Depth	Impoundment Length	Overtopping (y/n)	Time (min)
	5	2.75	120.0	y	3.22
	10	3.00	97.0		
	15	3.00	90.0		
	20	3.00	88.0		
	25	3.00	86.0		
	30	3.00	87.0		
	35	2.00	81.0		
	40	1.25	67.0		
	45	1.00	67.0		
	60				
	90				
	120				
Flow Rate (ft3/s)	Time to Flow (min)	Avg Flow Rate	Max Flow Rate		
	4.00	0.13	0.22		
Sediment Retention (lbs)	Sediment Introduced	Sediment Captured	Percent Capture		
	1046	940	90%		

Product A (single) Install 3 Summary

Average TSS (mg/L)	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
	5	3280	1660	3190	1270
	10	5310	1330	3890	1120
	15	6760	1540	8270	750
	20	6130	1280	3110	880
	25	13410	**1410**	17950	1430
	30	15340	1480	10440	980
	35		580	15060	1650
	40		460		630
	45				
	60				
	90				
	120				

Average Turbidity **(NTU)**	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
	5	4,762	1,482	2,611	1,211
	10	4,610	1,515	3,115	1,167
	15	4,468	1,474	7,538	983
	20	2,922	1,225	5,728	1,100
	25	9,452	1,353	14,852	1,418
	30	7,840	1,330	39,831	957
	35		672	8,136	1,349
	40		532		552
	45				
	60				
	90				
	120				

Average Impoundment (in)	Time (min)	Impoundment Depth	Impoundment Length	Overtopping (y/n)	Time (min)
	5	3.00	84.0	y	4.50
	10	3.00	89.0		
	15	3.00	89.0		
	20	3.00	77.0		
	25	3.00	70.0		
	30	3.00	65.0		
	35	1.50	62.0		
	40	1.00	48.0		
	45				
	60				
	90				
	120				

Flow Rate (ft^3/s)	Time to Flow (min)	Avg Flow Rate	Max Flow Rate
	4.50	0.12	0.20

Sediment Retention (lbs)	Sediment Introduced	Sediment Captured	Percent Capture
	1093	980	90%

Product A (single) Summary

	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
Average TSS (mg/L)	5	5437	2147	3597	1237
	10	9480	2140	6903	1347
	15	14740	2090	17407	1363
	20	29877	2500	23393	1320
	25	22340	2447	41943	1427
	30	13177	2607	24407	857
	35		7047	24987	950
	40		543	29200	383
	45		3000		195
	60				
	90				
	120				

	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
Average Turbidity (NTU)	5	5277	1761	2870	1093
	10	4232	1788	5172	1231
	15	8186	1716	12571	1326
	20	10160	2072	12971	1193
	25	5652	2105	23125	1265
	30	3470	2087	27361	840
	35		4902	12340	757
	40		524	3921	379
	45		2366		227
	60				
	90				
	120				

	Time (min)	Impoundment Depth	Impoundment Length	Overtopping (y/n)	Time (min)
Average Impoundment (in)	5	2.50	86.0	y	4.21
	10	2.87	83.3		
	15	2.87	81.0		
	20	2.93	77.3		
	25	2.93	74.3		
	30	2.93	73.0		
	35	1.77	70.3		
	40	1.15	61.0		
	45	0.95	66.5		
	60				
	90				
	120				

	Time to Flow (min)	Avg Flow Rate	Max Flow Rate
Flow Rate (ft^3/s)	4.42	0.13	0.21

	Sediment Introduced	Sediment Captured	Percent Capture
Sediment Retention (lbs)	1056	949	90%

Wattle Install 1 Summary

Average TSS (mg/L)

Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
5	3900	470		2060
10	4290	1990		1520
15	1060	2070		830
20	7890	3740		1590
25	1610	2590		730
30	4080	3750		1360
35				
40				
45				
60				
90				
120				

Average Turbidity (NTU)

Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
5	7,146	1,037		1,998
10	5,178	1,205		2,512
15	4,086	2,288		2,858
20	3,576	2,707		2,148
25	2,598	2,343		3,478
30	2,924	2,386		1,840
35				
40				
45				
60				
90				
120				

Average Impoundment (in)

Time (min)	Impoundment Depth	Impoundment Length	Overtopping (y/n)	Time (min)
5	1.50	18.0	n	
10	1.75	20.0		
15	1.75	20.0		
20	1.75	22.0		
25	1.75	23.0		
30	1.75	23.0		
35				
40				
45				
60				
90				
120				

Flow Rate (ft3/s)

Time to Flow (min)	Avg Flow Rate	Max Flow Rate
1.75	0.14	0.25

Sediment Retention (lbs)

Sediment Introduced	Sediment Captured	Percent Capture
985	828	84%

Wattle Install 2 Summary

	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
Average TSS (mg/L)	5	30210	4840		3040
	10	31900	7810		2630
	15	6200	10180		3270
	20	6400	5960		2120
	25	16190	9140		2370
	30	155360	5310		1640
	35				
	40				
	45				
	60				
	90				
	120				

	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
Average Turbidity (NTU)	5	6,490	3,674		3,493
	10	3,690	5,382		2,386
	15	8,400	8,878		3,659
	20	4,038	4,896		1,485
	25	12,240	6,868		2,505
	30	102,810	5,695		2,025
	35				
	40				
	45				
	60				
	90				
	120				

	Time (min)	Impoundment Depth	Impoundment Length	Overtopping (y/n)	Time (min)
Average Impoundment (in)	5	1.00	12.0	n	
	10	1.50	13.0		
	15	1.50	14.0		
	20	1.33	14.0		
	25	1.33	15.0		
	30	2.00	16.0		
	35				
	40				
	45				
	60				
	90				
	120				

	Time to Flow (min)	Avg Flow Rate	Max Flow Rate
Flow Rate (ft3/s)	2.75	0.13	0.18

	Sediment Introduced	Sediment Captured	Percent Capture
Sediment Retention (lbs)	986	945	96%

Wattle Install 3 Summary

Average TSS (mg/L)

Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
5	75470	18020		3010
10	44620	19550		3150
15	13180	8820		3350
20	17130	4390		3890
25	18870	5990		3750
30	11290	3440		2520
35				
40				
45				
60				
90				
120				

Average Turbidity (NTU)

Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
5	49,894	13,550		2,775
10	12,117	11,604		3,724
15	2,062	6,928		3,623
20	5,212	3,604		4,720
25	2,878	4,504		4,740
30	3,470	3,997		3,161
35				
40				
45				
60				
90				
120				

Average Impoundment (in)

Time (min)	Impoundment Depth	Impoundment Length	Overtopping (y/n)	Time (min)
5	1.25	20.0		
10	1.50	22.0		
15	1.63	23.0		
20	2.00	24.0		
25	2.13	25.0		
30	2.25	26.0	n	
35				
40				
45				
60				
90				
120				

Flow Rate (ft3/s)

Time to Flow (min)	Avg Flow Rate	Max Flow Rate
1.75	0.14	0.17

Sediment Retention (lbs)

Sediment Introduced	Sediment Captured	Percent Capture
986	889	90%

Wattle Summary

	Time (min)	Upstream	Water Surface	Bottom Impoundment	Downstream
Average TSS (mg/L)	5	36527	7777		2703
	10	26937	9783		2433
	15	6813	7023		2483
	20	10473	4697		2533
	25	12223	5907		2283
	30	56910	4167		1840
	35				
	40				
	45				
	60				
	90				
	120				
	Time (min)	**Upstream**	**Water Surface**	**Bottom Impoundment**	**Downstream**
Average Turbidity (NTU)	5	21177	6087		2755
	10	6995	6064		2874
	15	4849	6031		3380
	20	4275	3736		2784
	25	5905	4572		3574
	30	36401	4026		2342
	35				
	40				
	45				
	60				
	90				
	120				
	Time (min)	**Impoundment Depth**	**Impoundment Length**	**Overtopping (y/n)**	**Time (min)**
Average Impoundment (in)	5	1.25	16.7		
	10	1.58	18.3		
	15	1.63	19.0		
	20	1.69	20.0		
	25	1.74	21.0		
	30	2.00	21.7	n	
	35				
	40				
	45				
	60				
	90				
	Time to Flow (min)	**Avg Flow Rate**	**Max Flow Rate**		
Flow Rate (ft^3/s)	2.08	0.14	0.20		
	Sediment Introduced	**Sediment Captured**	**Percent Capture**		
Sediment Retention (lbs)	986	888	90%		