Evaluating Sediment Removal Efficiency of Catch Basin Inserts (CBIS) as a Post-Construction Water Quality Tool For Ohio Roadways

by

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ABSTRACT

Urban areas produce large amounts of stormwater runoff due to the land being covered with impervious materials such as concrete and asphalt. Stormwater inlets, or catch basins, are a commonly used method for collecting stormwater runoff and directing it away from streets and sidewalks via a storm sewer system before eventually discharging into local bodies of water. However, typically these stormwater systems only redirect the runoff without providing a means for removing potentially harmful pollutants (i.e, trash, debris, sediment, metals, and chemicals). These pollutants are then often discharged directly into local lakes, rivers, and streams, potentially harming native aquatic wildlife. Post construction stormwater practices are commonly used to treat runoff from urban areas by reducing the total runoff volume, lowering peak flow rates, and/or treating the runoff for potentially harmful pollutants carried in the runoff. However, some post construction stormwater practices in urban areas are often not viable options because of their large land, construction, and maintenance requirements.

Catch basin inserts (CBIs) are one type of post-construction BMP that are easy to install into existing catch basins and require no additional land use while still providing a means of removing pollutants from stormwater runoff before entering the municipal separate storm sewer system (MS4). However, limited data is available to demonstrate the expected performance of various CBIs to ensure that these practices meet the pollutant removal standards set forth by the USEPA.

This study, conducted at the Auburn University – Erosion and Sediment Control Test Facility (AU-ESCTF) evaluated the sediment removal capabilities of eight different proprietary CBI products for potential use as a post-construction stormwater tool for Ohio Department of Transportation projects.

CBIs were tested using different flow rates and soil types and analyzed for both initial performance and longevity.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE:

INTRODUCTION

1.1 BACKGROUND

As stormwater runoff flows over impervious surfaces, it suspends and transports various pollutants from their original location and often carries them into municipal separate storm sewer systems (MS4s) that will eventually discharge into lakes, rivers, streams, and other bodies of water. These MS4s are described by the Environmental Protection Agency (EPA) as public storm sewer systems that include roads with drainage systems, and municipal streets owned and operated by a public body that are not part of a combined storm and sanitary sewer (*EPA, 2017*). Pollutants of concern include heavy metals and petroleum products from urban roadways; common trash and debris; excess pesticides, herbicides and fertilizer from residential applications; and sediment from unstabilized areas such as improperly managed construction sites. These contributors, known as nonpoint source (NPS) pollutants, or pollutants from many diffuse sources, harm waterways and are detrimental to the environment (*EPA, 2016*). A National Rivers and Streams Assessment study conducted by the EPA estimated that 46% of accessed rivers and streams in the U.S. are in poor biological condition due to pollution (*EPA, 2009*).

The Nationwide Urban Runoff Program (NURP) was the first comprehensive study of urban stormwater runoff pollution across the U.S. NURP assessed stormwater runoff quality from 28 major metropolitan areas and verified urban runoff as a detriment to overall water quality (*EPA, 1983*). Since NPS pollutants threaten our national waterways through urban runoff, the EPA regulates effluent discharges conveyed by municipalities to ensure that it meets acceptable water quality standards before flowing into the surrounding environment through the National Pollutant Discharge Elimination System (NPDES) Phase II MS4 general permit (*EPA, 2017*).

Most municipalities and state highway agencies have developed stormwater management guidelines to ensure compliance with these EPA standards, including allowable methods and practices to remove pollutants from stormwater influent flowing into MS4s, prior to discharge. For example, the Ohio Department of Transportation (ODOT) has a comprehensive post-construction management plan including the use of numerous best management practices (BMPs) (*ODOT, 2018*).

To further understand the potential of CBIs as a post-construction stormwater BMP, ODOT has invested in this research project. The purpose of this investment is to determine whether CBIs are a plausible alternative to other currently used post-construction BMPs and to evaluate which proprietary products best meet the needs of ODOT projects.

1.2 PURPOSE OF CATCH BASIN INSERTS

Post-construction BMPs treat stormwater runoff through methods including detention, infiltration, or filtration. Catch basin inserts (CBIs) are one example of post-construction BMPs. CBIs are manufactured systems consisting of bags, baskets, or cartridges placed into existing storm sewer inlets, or catch basins, which treat influent runoff before entering the MS4. CBIs come in different shapes and sizes that are inserted into specific catch basins requiring treatment.

Bag-type CBIs are composed of a filter media attached to a frame, which secures the bag in position below the inlet grate. The filter media is designed to catch suspended particles as the influent flows through the bag. The fabric bag can become clogged with sediment and other debris, negatively affecting its ability to pass flows. For this reason, bags are typically designed with overflow mechanisms to allow for bypass during high flow events, instead of impounding on the street and creating localized flooding or safety hazards. Bag-type CBIs are generally considered easy to maintain because the insert can be quickly removed and cleaned, or replaced in the event a device is filled with debris (i.e., grass clippings, leaves, litter, sediment, etc.).

Basket-type CBIs often have filter fabric similar to bag type CBIs, but have a rigid support system around the fabric to provide greater support and durability.

Cartridge-type CBIs consist of a disposable cartridge that traps and filters sediment and debris from the influent stormwater. Cartridge-type CBIs are often considered easy to maintain because the disposable cartridges can simply be removed from the catch basin frame and replaced when maintenance is required.

Selecting the appropriate CBI type based upon the needs of a storm conveyance system is crucial to developing an effective post-construction stormwater pollution removal plan. To minimize stormwater pollution and meet the standards set forth under the NPDES, the Ohio EPA specifies that alternative post-construction BMPs have a minimum total suspended solids (TSS) removal of 80% under both laboratory and field conditions (*Ohio EPA, 2014*). However, limited data is available to demonstrate the actual in-field performance of various CBIs to ensure that these standards are reached.

1.3 RESEARCH OBJECTIVES

This research was divided into two primary components. The first component of the research focused on the development of a testing methodology and apparatus for conducting full-scale performance and longevity testing of manufactured CBIs. Full-scale testing of CBIs affords the opportunity to evaluate a CBI's sediment removal efficiency in a manner that would be both realistic by replicating field-like conditions, while also being a consistent and repeatable standard testing procedure. The second component of the research was to evaluate individual and longevity performance of eight proprietary CBI products to provide guidance for regulatory agencies regarding the use of proprietary CBI products on state and local governed roadway stormwater conveyances.

The objectives of this research are as follows:

(1) Evaluate performance characteristics of different CBI products based upon manufacturer claims,

(2) Develop a testing methodology, protocols, and apparatus that will best allow for installation and testing of CBIs to evaluate performance characteristics,

(3) Determine which CBIs are capable of meeting the Ohio EPA 80% TSS removal requirements,

(4) Test the CBIs for longevity to determine performance degradation over time, and

(5) Provide ODOT with results and analysis regarding the performance characteristics of the CBI practices.

The following tasks were performed to satisfy the research objectives:

(1) Identify and assess relevant literature on the performance evaluation of CBIs,

(2) Develop a testing methodology representative of post-construction stormwater runoff conditions for ODOT projects,

(3) Construct a full-scale apparatus that can be used to evaluate CBI performance in a consistent and repeatable manner,

(4) Conduct full-scale experiments on selected CBIs under the designed testing methodology, and

(5) Analyze collected experimental data to provide guidance regarding performance and longevity of CBIs.

1.4 EXPECTED OUTCOMES

The outcomes of this study can be used to provide guidance to regulatory agencies regarding the use of CBIs as a post-construction sediment removal practice. While the scientific data presented in this research is focused on eight common CBI products and was designed for runoff conditions representative of ODOT projects, the apparatus and methodology can be easily adapted to provide guidance on any number of products for various agencies throughout the U.S.

This system allows researchers to examine CBI performance in ways that would be much more difficult in a field or small-scale testing environment, such as evaluating sediment retention percentage, monitoring leakage between catch basin frame and CBI, measuring bypass flow rate, and evaluating TSS reduction capabilities.

The development of this research has the potential to substantially improve the evaluation of CBIs as a primary post-construction stormwater pollutant removal tool. The ability to simulate a field-like experience from a controllable testing environment allows regulators to more precisely assess sediment removal efficiency of CBI products to ensure compliance with environmental regulations, while also allowing manufacturers of proprietary CBIs to identify potential ways of improving their product.

1.5 ORGANIZATION OF THESIS

This thesis is divided into six chapters that describe the research and the steps taken to meet the objectives previously outlined. Chapter Two: *Literature Review*, examines governing regulations, existing research, and methods of evaluating CBIs. Chapter Three: *Means and Methods*, outlines the design of the testing methodology, including flow and sediment introduction, means of evaluation, and testing regime. Chapter Four: *Results and Discussion*, details the findings of the performed experiments. This chapter includes data, observations, and analyses conducted for all experiments performed as part of this effort. Chapter Five: *Conclusions and Recommendations* provides guidance on the use and performance of tested CBIs and discusses potential further research than can be used to further advance the industry.

CHAPTER TWO:
LITERATURE REVIEW AND EXISTING RESEARCH

2.1 GOVERNING REGULATIONS

As a means of regulating stormwater runoff from urban areas, the EPA issues National Pollutant Discharge Elimination Systems (NPDES) MS4 Permits to system operators. These permits require municipalities to develop a stormwater management plan (SWMP) to ensure effluent discharged from MS4s into nearby waterways is in compliance with water quality standards established by the EPA (EPA 2016).

MS4s are categorized into Phase I and Phase II permits. In 1990, Phase 1 MS4s were developed to regulate medium to large cities or certain counties with populations of 100,000 or more and required these municipalities to obtain NPDES permits for their stormwater discharge. In 1999, the EPA released the Phase II permit requiring small MS4s in small urban areas, as well as MS4s serving a population of at least 10,000 people outside urban areas that are designated by the permitting authority, to obtain NPDES permit coverage for stormwater discharges. There are approximately 750 current Phase I permits, and approximately 6,700 Phase II MS4s issued in the U.S. (EPA 2016).

2.2 TYPICAL POST-CONSTRUCTION BMPS

Urbanization creates changes to watersheds and increases pollution potential. During development projects, areas that were previously covered in pervious, vegetative materials are often stripped of that vegetation and replaced with impervious materials (e.g., buildings, hardscapes, roadways, parking lots, etc.). These developments affect the natural hydrology of the watershed by adding impervious areas, and affecting natural conditions such as terrain and topography. This can affect stormwater runoff by increasing volume and peak flow rates, and negatively impacting water quality. Post-construction BMPs are permanent stormwater management tools needed to reduce stormwater runoff and improve water quality by storing, treating, or infiltrating runoff. The following BMPs are practices commonly used to minimize the urbanization effect.

2.2.1 COMMON POST-CONSTRUCTION BMPs

There are numerous types of post-construction BMPs used to treat stormwater runoff from development projects of all sizes. Some common post-construction BMPs include: bioretention cells, retention/detention ponds, grassy swales, infiltration trenches, and sand filters. These BMPs are considered low impact development (LID) practices, or green infrastructure, meaning that they use natural materials and methods of infiltration to reduce stormwater runoff and improve water quality (EPA, 2017).

Bioretention cells [Figure 2.1(a)] are landscaped depressions designed to allow runoff to collect and eventually infiltrate through the soil, allowing some treatment to occur before releasing into the groundwater. Permeable soils used during construction of the bioretention cell allow for runoff collected from large impervious areas to be stored and treated within a smaller area, therefore making bioretention cells a popular option when project space is limited. Trees and other forms of vegetation can also be included to help incorporate the bioretention cell into the project landscaping and to aid in infiltration. The disadvantage of bioretention cells is that over time, sublayers of drainage material such as permeable soils or rocks can become clogged from particles captured during the treatment of runoff, limiting the capacity of the system (Brown & Hunt, 2012). In this case, properly maintaining the bioretention cell is important, as reduced infiltration rates can hinder the ability of the cell to store and treat large runoff volumes.

Retention and detention ponds, also known as wet or dry ponds respectively, are another common post-construction BMP. Retention ponds [Figure 2.1(b)] are designed to hold water throughout dry periods, while also being sized with enough live storage to store runoff from storm events. Detention ponds [Figure 2.1(c)] are designed to temporarily store runoff from storm events until the water is either infiltrated into the soil, or released downstream at a controlled rate.

Grassy swales [Figure 2.1(d)] are vegetated conveyance channels that treat stormwater runoff by vegetative filtration and by infiltration. Grassy swales take little space and can take the place of traditional curb and gutter systems. However, grassy swales can sometimes become overloaded during large storm events that generate high volumes of stormwater runoff. If not properly maintained, poor vegetation or steep slopes could cause grassy swales to contribute to pollutants in the runoff being conveyed. Maintenance requirements needed for longevity simply include mowing and periodic sediment clean out to allow for continued performance (Dorman et al., 1989).

Infiltration trenches [Figure 2.1(e)] are underground reservoirs created by filling excavated trenches with stone or some other porous material. Stormwater runoff is directed into the trench, where water is eventually allowed to infiltrate into the surrounding soil. Over time the filler material can become clogged and must be maintained in order to continue removing pollutants. Sand filters [Figure 2.1(f)] work similarly to infiltration trenches, as sand is used as the filtration media to filter pollutants from the stormwater runoff before the treated water is eventually discharged into a channel or stream.

(a) bioretention cell (Village of Downers Grove, 2018) (b) retention pond (Chris Jenkins, 2016)

(c) detention pond (City of Monroe, GA, 2018) (d) grassy swale (Delaware DOT, n.d.)

(e) infiltration trench (Trinkaus Engineering, LLC, 2018) (f) sand filter (Chesapeake Stormwater Network, 2018)

FIGURE 2.1 Common post-construction BMPs.

Table 2.1 summarizes characteristics of common post-construction BMPs. TSS removal efficiency commonly varies amongst studies, as different testing conditions can lead to different results. Another issue with common post-construction BMPs is that those that treat moderate to large drainage areas, tend to have high maintenance requirements. If these maintenance requirements are not met, performance suffers and the longevity of the BMP decreases.

TABLE 2.1 Summary of Common Post-Construction BMPs

(Wyoming Department of Environmental Quality, 1999)

BMP	Size of Drainage Area	Maintenance Burdens	Longevity	TSS Removal Efficiency (%)
Bioretention cell	Small	Low	Low if poorly maintained	20-80
Retention pond	Moderate to large	Low	High	(-30)-91
Detention pond	Moderate to large	High	High	5-90
Grassy swale	Small	Low	High if maintained	0-100
Infiltration trench	Moderate	High	Low	45-100
Sand filter	Widely applicable	Moderate	Low to moderate	60-95

Figure 2.1 demonstrates that these practices will typically require a significant amount of area to be constructed. However, urban areas typically do not have the available area needed to construct these practices. Therefore, other treatment options with smaller footprints may be needed to meet regulatory requirements.

2.3 CATCH BASIN INSERTS

To address the aforementioned concern associated with limited right-of-way (ROW) or the requirement of a smaller footprint, municipalities rely on other post construction stormwater practices to treat stormwater runoff. A CBI is a manufactured device that is installed into or affixed to a stormwater drainage inlet, and designed to remove pollutants while allowing influent stormwater to pass through and enter the MS4 (Kostaleros et al. 2010). CBIs have become an increasingly popular method of treatment because, unlike LID and other post-construction BMPs, CBIs require no additional land use. CBIs can also be retro-fitted into existing systems without major alterations to inlets, meaning less manpower and time needed for installation. Various CBI manufacturers design and produce products that treat stormwater through different mechanisms. The primary removal methods used in the design of CBIs are absorption, screening, and sedimentation (Remley et al. 2005). CBIs designed with absorbing mechanisms are primarily used to remove oils, greases, pesticides and other chemicals, while screening and sedimentation are methods used to remove suspended solids from the influent stormwater runoff. CBIs differ in size, shape, capacity, cost, maintenance requirements, and treatment methods, making them a practical implementation strategy for a wide variety of systems.

2.4 TYPES OF CBIS

There are three primary types of manufactured CBIs: (1) Cartridge Type, (2) Bag Type, and (3) Basket Type. Each of these types of CBIs have inherent advantages and disadvantages that should be considered when selecting the appropriate product to address project-specific needs or requirements.

2.4.1 Cartridge Type

Cartridge type CBIs, as shown in Figure 2.2, consist of a disposable cartridge that traps sediment, trash, and debris from the influent stormwater. Cartridge type CBIs are easy to maintain because the disposable cartridges can be removed from the catch basin frame and replaced when maintenance is needed.

FIGURE 2.2 Cartridge type CBI (Contech Engineered Solutions, 2017).

2.4.2 Bag Type

Bag type CBIs, as shown in Figure 2.3, are composed of filter bags attached to a steel frame that holds the bag in position. The filter material is used to catch particles as the influent passes through the bag. The fabric bag can become clogged with sediment, negatively affecting its ability to pass flows. For this reason, the bags are usually designed with an overflow mechanism consisting of holes or high flow fabric material to allow larger flows to bypass the bag instead of backing up onto the street or parking lot and creating a possible safety concern due to the resulting impoundment. Bag type CBIs are a simple structure that allow the bag to be quickly removed and cleaned, making them easy to maintain. The filled bag can be lifted out of the inlet, cleaned, and re-installed in minutes.

FIGURE 2.3 Bag type CBI (ADS , 2016).

2.4.3 Basket Type

Basket type CBIs, as shown in Figure 2.4, are shaped similarly to bag type CBIs and have many similar advantages and disadvantages. Similar to bag type CBIs, baskets require regular maintenance and are easy to remove, maintain, and reinstall. However, basket types have a steel or high-density polyethylene (HDPE) frame that provides support for the filter fabric media, generally making them more durable than bag types.

FIGURE 2.4 Basket type CBI (Environmental XPRT, n.d.).

Choosing the appropriate CBI type according to the direct needs of the project is crucial to developing an effective post-construction stormwater pollution removal plan. Table 2.2 provides a summary of the primary advantages and disadvantages of the three common pre-manufacture CBI types.

TABLE 2.2 Primary Advantages and Disadvantages of CBI Types

CBI Type	Advantages	Disadvantages
Cartridge	Disposable cartridges allow for easy maintenance.	Most are too large for smaller, single grate catch basins.
Bag	Ponding of water inside bag allows for some settling of finer particles.	Material can often be easily clogged with sediment or ripped, requiring maintenance.
Basket	Baskets are often durable and long-lasting.	Structural frames can add weight to CBI, making installation and removal more difficult.

2.5 DESIGN CONSIDERATIONS

When designing a post-construction stormwater system that includes CBIs, it is important to consider the capabilities of different devices and match those to specific characteristics of the installation site. Selection of the appropriate product is important to maximizing pollutant removal efficiency. Evaluating the size of the drainage area, soil types, other pollutants, and typical rain events common to the area will help determine the necessary volume and flow rate that the CBI should be able to handle while still effectively removing pollutants. The drainage area should also be inspected for potential obstructions (i.e., trees or trash) in the area that could clog CBIs and cause an accelerated maintenance schedule. In cases where CBIs are being selected for existing inlet structures, installation characteristics (i.e., size of the CBI and ease of installation) should be considered.

In addition, maintenance requirements should also be considered when selecting CBIs due to site specific conditions. In some cases, CBI maintenance could require lane closures or have maintenance employees working near an active roadway. When considering catch basins in high traffic areas, it is important to select CBIs with less stringent maintenance requirements, limiting lane closure times and allowing workers to avoid unsafe situations.

2.6 LIMITATIONS

CBIs have inherent limitations that should be considered when being implemented as a post-construction stormwater BMP. The biggest disadvantage of using CBIs is that they require consistent maintenance and cleaning to maintain performance while avoiding failure. Inserts can become filled with sediment, trash, or debris, restricting water flow through the device and causing polluted influent to bypass the device and continue untreated into the stormwater drainage system. If maintenance is ignored over time, CBIs have the potential to become a pollutant source because of resuspension of previously captured sediment. Maintenance schedules must be tailored to the specific area of installation, and to the season and climate of that area. Heavy snowfall in the winter or accumulation of leaves in fall can decrease CBI pollutant removal efficiency sooner than the designer and maintenance operator expected. It is also important to note that while CBIs readily catch trash, debris, and large sediment particles, many devices have difficulty removing finer particles from influent, specifically at higher flow rates (NJCAT 2005).

2.7 METHODS OF EVALUATING CBIs

To properly evaluate CBIs as a post-construction stormwater BMP, many different criteria must be considered. The CBI must remove pollutants at a rate that meets water quality standards and regulations set forth by the EPA, which is the primary focus of the study. In addition, CBIs must be easy to install in existing drainage systems, maintainable, and cost effective. The ability to adapt shape and size to fit various inlets is beneficial if CBIs are to be considered as a practical solution to post-construction stormwater treatment issues. Evaluation of long term performance and maintenance requirements should also be considered. Other studies have shown that over time, CBIs can become clogged with sediment or saturated with oils, causing the CBIs to lose their ability to effectively treat influent stormwater (Kostaleros et al. 2010). Finally, the cost-effectiveness of CBIs must be considered and evaluated, including the cost of purchase, installation, and long-term maintenance plans and procedures. A thorough literature review was conducted to evaluate existing procedures used for testing of CBIs through other studies.

2.7.1 Standard Test Methods

ASTM International (ASTM) D7351, titled *Standard Test Method for Determination of Sediment Retention Device (SRD) Effectiveness in Sheet Flow Applications*, establishes the standardized procedures for evaluating the effectiveness of a SRD in retaining sediment when exposed to sediment-laden sheet flow conditions. Standard flow rates and pollutant concentration levels are calculated based upon a 10-yr, 6-hr design storm event occurring in the mid-Atlantic US, equivalent to a 4 inch (10.2 cm) rainfall with approximately 25% of the rainfall occurring within a peak 30-minute period, and 50% of rainfall infiltrating into the ground over a 100 ft (30 m) slope length by 20 ft (6 m) wide area. A schematic of the channel setup can be found in Figure 2.8. The contributing area is designed to limit runoff to sheet flow conditions. Sediment loads were calculated according to the Modified Universal Soil Loss Equation (MUSLE), which calculates storm-specific quantity of sediment yield.

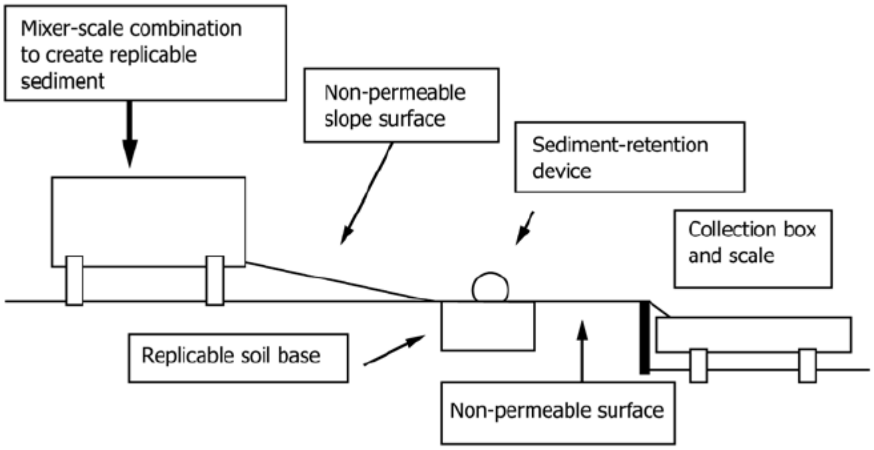


FIGURE 2.8 ASTM D7351 channel schematic (ASTM D7351 2013).

To obtain a sediment-laden water supply similar to the given storm conditions, 500 lb (2,270 kg) of water and 300 lb (136 kg) of soil are mixed continuously using a tank with an internal paddle mixer device, designed to create a consistent sediment concentration throughout the water supply. The volume is then discharged evenly for 30 minutes over the specified slope surface, at a rate of 198 lb (90 kg) of water per minute, and allowed to pass under, through or over the SRD. Grab samples are collected at the point of discharge from the mixing tank and at a location between the installed SRD and the collection tank using clean 8.5 oz (250 ml) bottles at 5 minute intervals. The weight of the collection tank is also recorded at 5 minute intervals so that soil retention percentage can later be calculated (ASTM D7351, 2013).

Grab samples are then analyzed to determine soil retention percentage through a series of calculations. Solids fraction of each sample is calculated according to Equation 2.1:

$$SF = \frac{W_{sediment}}{W_{mixture}} \qquad 2.1$$

SF = solids fraction, lb/lb (kg/kg)

$W_{sediment}$ = weight of sediment, lb (kg)

$W_{mixture}$ = weight of sediment and water, lb (kg)

A weighted average solid is then calculated according to Equation 2.2.

$$Weighted\ Average\ Solids = Solids\ Fraction \times \frac{t_{interval}}{t_{total\ test}} \qquad 2.2$$

WS_{avg} = weighted average soilds, lb/lb (kg/kg)

SF = solids fraction, lb/lb (kg/kg)

$t_{interval}$ = time of one sampling interval, min

$t_{total\ test}$ = time required to run entire test, min

Total solids fraction (TSF) is calculated as the summation of all weighted average solids. The mass of the collection tank and the masses of individual downstream samples are summed to determine the total downstream collected flow (TCF_{DS}). Finally, soil retention percentage is calculated according to Equation 2.3.

$$Retention\ \% = \left(1 - \frac{TCF_{DS} \times TSF}{\mathrm{k}}\right) \times 100\% \qquad 2.3$$

Retention % = percentage of soil retained, %

TCF_{DS} = mass of total collected flow downstream, lb (kg)

TSF = total solids fraction, lb/lb (kg/kg)

K = sediment load factor, 300 lb (136 kg)

The procedure detailed by ASTM D7351 has limitations that prevent the procedure from being a true representation of sediment removal efficiency for SRDs in specific locations. The procedure is designed for a 10-yr, 6-hr storm event of the mid-Atlantic region of the U.S., meaning it creates runoff characteristics that are specific to that region and may not represent other regions with differing climactic conditions. The procedure also specifies using a runoff surface of 10 ft (30 m) slope length by 20 ft (6 m) wide. The runoff surface is also designed to limit runoff to sheet flow conditions. However, in practical field conditions, contributing areas are much larger, and runoff usually reaches shallow concentrated flow before encountering the SRD. The TR-55 runoff calculation method limits sheet flow conditions to 100 feet or less, a distance that will be exceeded for most runoff entering stormwater inlets (USDA, 2009) Runoff volumes are calculated using a ground infiltration rate of 50%, which is much greater than expected infiltration rates of impervious surfaces. The limitations of this procedure can skew data and provide results that are not representative of true sediment removal rates for SRDs subjected to actual in-field conditions.

ASTM D5141, titled *Standard Test Method for Determining Filtering Efficiency and Flow Rate of the Filtration Component of a Sediment Retention Device*, details a standard testing procedure used to determine filtering efficiency and flow rate of the filtration component of a SRD. In this testing method, the filtration component of a SRD is placed vertically or over a horizontal opening at the end of a flume and sediment-laden water is allowed to pass through the filter. The amount of time for the mixture to pass through the filter and the amount of suspended sediment passing through the filter are measured. From this data, the amount of soil retained, filtering efficiency, and flow rate of the SRD are then calculated (ASTM D5141, 2011). This standard is not as detailed as ASTM D7351 and doesn't specify a particular storm event or flow rate, meaning the test method can be modified to simulate different flow and sediment conditions. However, because influent flow rates, concentrations and other conditions are not specified, there is potential for less consistency between repeated tests.

American Public Health Association Method 2540D (APHA 2540D) *Total Suspended Solids (TSS) Dried at 103-105℃* details standards for measuring TSS samples. Per the standard, the mixture is to be run through a glass-fiber filter so that sediment is retained and quantifiable. The sediment caked filter is then carefully removed and placed in an oven for at least one hour at 217-221° F (103-105° C). After drying, the filter and dried sediment are weighed together. Equation 2.4 is then used to calculate milligrams of TSS per liter (APHA 2540D, 1997):

$$TSS = \frac{A - B}{V_{sample}} \qquad 2.4$$

TSS = concentration of total suspended solids, lb/ ft^3 (mg/L)

A = weight of filter and dried sediment, lb (mg)

B = weight of filter, lb (mg)

V_{sample} = volume of sample, ft^3 (L)

This standard lacks detailed directions on determining influent flow rates and concentrations, but can be used as a guide to properly dry samples for more accurate weight measurements and for determining TSS reduction performance.

2.7.2 TSS vs SSC Analysis Methods

Two common methods of measuring sediment concentration of stormwater are the TSS and suspended sediment concentration (SSC) methods. TSS is measured by using a subsample as a representation of the entire sample volume in consideration, whereas SSC is measured using the entire volume of a sample. While the SSC method removes possible errors and bias resulting from subsampling, capturing the entire volume of stormwater runoff entering an inlet for a given storm is typically impractical, therefore the SSC method still maintains the possibility of error from sampling from an inconsistent concentration source.

2.7.3 CBI Studies from Controlled Testing Environments

A study performed by *Water Environment Research* (Remley et al. 2005) conducted bench-scale testing of four CBIs (AbTech Ultra Urban Filter®, AquaShield™ I, DrainPac™, Hydro-Cartridge®) using an average flow rate for the 6-month, 30-minute, National Resource Conservation Service (NRCS) Type II storm at typical pollutant loads for a transportation facility. The products were subjected to similar flow rates of

207 to 213 gpm (757 to 814 L/min) and TSS concentrations of 0.027 oz/gal (225 mg/L) for a total of 30 minutes. Influent samples were taken at the 2, 15, 17, and 30-minute marks during each test to ensure consistency. Effluent samples were taken at the 5, 10, 20, and 25 minute marks. Each product underwent 10 tests, with clean CBIs being used for each test, and the samples were averaged for a single effluent value. Analysis for TSS was conducted in accordance with the American Public Health Association (APHA) 2540D standard test method (APHA 2540D 1997) with TSS removal efficiencies ranging between 10 to 42%.

University of Arkansas also conducted lab testing on four products (AbTech Ultra Urban Filter, AquaShield™ II, Hydro-Cartridge, Suntree Technologies™) using similar testing methods. The AquaShield filters used in this study and the last were different CBIs from the same manufacturer. However, the AbTech and Hydro-Cartridge were used in both studies. Each different CBI type was tested five times for a total of 20 tests at influent rates of 0.007 cfs (0.216 L/s) and SSC concentrations of 0.022 oz/gal (180 mg/L), with clean CBIs being used for each test. Average SSC removal efficiency ranged from 25 to 62% for the four products (Remley et al. 2005).

Tennessee Tech University evaluated the performance of the Aqua-Swirl™ Concentrator Model AS-3 under flows ranging from 0.2 to 1.2 cfs (5.66 to 33.98 L/s) and using a target TSS concentration of 0.026 oz/gal (200 mg/L). Five influent and five effluent samples were taken during each test. Four tests were performed on the product at influent rates of 0.2, 0.5, 0.8 and 1.2 cfs (5.6, 14.16, 22.65, and 33.98 L/s) for a total of 20 tests, with clean products being used for each test. Water samples for TSS analysis were collected using the SSC methods described by United States Geological Survey (USGS). It was found that TSS removal rates ranged from 18 to 88.7%, with a decrease in efficiency as flow rate increased (NJCAT 2005). Table 2.3 summarizes the results of the study and highlights the correlation between influent flow rate and removal efficiency. As seen in Table 2.2, as flow rate increase the removal efficiency of the device decreases.

TABLE 2.3 TTU AquaSwirl Testing Results (NJCAT 2005)

Flow Rate [(cfs (L/s)]	Removal Efficiency
0.2 (5.6)	88.7 %
0.5 (14.16)	82.0%
0.8 (22.65)	56.9%
1.2 (33.98)	18.0%

Analytical Industrial Research Laboratories tested the sediment removal efficiency of the Aqua-Filter™ Cartridge at a target influent rate of 0.045 cfs (1.26 L/s) and target sediment concentrations of 0.013, 0.020, 0.026, 0.040 oz/gal (100, 150, 200 and 300 mg/L). Prior to testing, 800 gallons (3,028 L) of sediment free water was run through the cartridge, removing any possible residual dust from the media and simulating wet operating conditions. Ten simulation tests were performed at each target influent TSS concentration. Tests were run for four minutes for a total of 80 gallons (302.8 L) of water per test. It was found that average sediment removal rates were calculated between 78 to 83% for all tests and therefore, influent concentrations had little effect on sediment removal efficiency based upon this test method (NJCAT 2005).

A study from California Polytechnic State University (MacLure 2009) performed bench testing using a DrainPac Filter. The product was inserted in a flume intended to simulate a large-scale catch basin. Pond water was fed to the flume with sediment concentration measured to range between 0.004 and 0.007 oz/gal (30 to 50 mg/L). Suspended solids removal efficiency was tested at flow rates of 0.045, 0.134, 0.334, and 0.446 cfs (1.27, 3.79, 9.46, and 12.63 L/s). For each test, roughly 200 gallons (757 L) of pond water was conveyed through the filter before sampling was performed to build up solids in the bottom of the filter, simulating preloading. Three influent and three effluent samples were collected using clean 0.13 gal (0.5 L) plastic sample bottles. Influent and effluent samples were taken simultaneously at the spillway prior to the filter and at the concrete channel located after the flume. Average sediment removal efficiency for the different flowrates ranged from 82.9% to 90.9%.

Table 2.4 provides an overview of results obtained from lab testing of CBI TSS removal efficiency for several studies that were reviewed. TSS removal efficiencies varied greatly in some of these studies because of the differences in influent flow rates and concentrations.

TABLE 2.4 Summary of Previous CBI Lab Testing

Study	# of Products	Influent Flow Rate [cfs (L/s)]	Influent Concentration [oz/gal (mg/L)]	TSS Removal Efficiency Ranges (Average)
Morgan et al. 2003	4	0.46-0.48 (13.0-13.6)	0.030 (225)	10-42% (29.5%)
Remley et al. 2005	4	0.46 (13.0)	0.024 (180)	25-62% (48.3%)
NJCAT 2005 (TTU)	1	0.2-1.2 (5.7-34.0)	0.026 (200)	18-89% (61.4%)
NJCAT 2005 (AIRL)	1	0.04 (1.1)	0.013-0.040 (100-300)	78-83% (80.5%)
MacLure 2009	1	0.045-0.45 (1.3-12.7)	0.004-0.007 (30-50)	83-91% (86.6%)

2.7.4 CBI Studies from Field Testing Environments

One previous study performed field testing of six different CBIs: (AbTech Ultra, Urban Filter, FloGard Plus, Ultra HydroKleen®, Stream Guard Passive Skimmer, Stream Guard Catch Basin Insert, and Silt Sack®). Products were inserted at different locations. This meant that each product was exposed to different influent rates, different influent sediment concentrations, and different maintenance requirements. Products were also monitored for different periods of time. The Ultra Urban Filter, FloGard Plus, and Hydro-Kleen were installed adjacent to each other in a parking lot. The FloGard Plus and Hydro-Kleen were installed in series along the same curb with Hydro-Kleen being downstream of the FloGard Plus. The Silt Sack filter was located in a sidewalk curb near a picnic area, far-removed from any other filters. The Stream Guard Catch Basin Insert was installed in a parking lot area with a very mild slope, resulting in a slower runoff velocity and a lower concentration of sediment transport. The Stream Guard Passive Skimmer is a sorbent pillow designed to remove oils and chemicals from the captured runoff, and has no potential to capture sediment. All filters were monitored for maintenance purposes, and most filters were replaced at least once during the monitoring period due to failure over time. The number of CBI replacements and the dry weight of sediment captured were measured over the monitoring period and a daily sediment capture rate was calculated. Table 2.5 summarizes results of the field testing on the various CBIs (Kostaleros et al. 2010).

TABLE 2.5 Results of Previous Field Test (Kostaleros et al. 2010)

CBI	No. of Replacements	Monitoring Duration (Days)	Sediment Captured (kg)	Sediment Captured/day (kg)
Ultra-Urban	0	464	50.70	0.11
Flo Gard Plus	1	356	39.74	0.11
Hydro-Kleen	1	441	43.34	0.10
Silt Sack	0	375	93.72	0.25
Stream Guard	3	403	11.26	0.03
Passive Skimmer	2	373	-	-

Discrepancies amongst testing methods are evident upon a review of the literature. Test procedures varied amongst applied flow rates, sediment concentrations, location of installation, and flow durations simulating different experiences and producing a wide range of results. For example, TSS removal performance of the AbTech Ultra Urban Filter ranged from 45-62% when evaluated across different tests, and the Hydro-Cartridge TSS removal ranged from 40-59% across studies. A consistent methodology is needed that can be repeated amongst different tests, allowing for a more accurate comparison between products.

To represent a more realistic, field-like simulation, testing methods should include re-suspension of the materials. In studies that were observed during the literature review, each product was only used for one test before being cleaned, or disposed of and replaced for repeated tests. However, in field applications, filters will not be cleaned or replaced after each storm. For this reason, it is important to include a method for quantifying sediment re-suspension in an effort to assess long term performance of CBIs.

2.8 CONCLUSION

CBIs are easily implementable solutions for removing pollutants from stormwater before the runoff enters the storm sewer system. CBIs are designed in different shapes, sizes, and capacities that treat influent through different methods, making them a common pollutant removal option in a variety of settings. However, their limitations must be considered prior to implementation, and therefore, these limitations must also be known. CBIs require consistent maintenance and inspection to ensure that they do not fill with sediment, trash, and debris, restricting water flow and causing polluted influent to bypass the device and enter the storm sewer system.

Before installing CBIs, MS4 operators must ensure that the CBIs selected meet the needs of the particular inlet, such as inlet size, shape, and drainage area capacity, and will comply with all pollutant removal standards set forth by the EPA. Common methods of testing CBIs include measuring sediment captured over time and comparing influent and effluent TSS concentrations in both lab and field settings.

Based upon the results of this literature review, and the requirements by the Ohio Department of Transportation to affectively analyze different CBI options, a methodology to accurately and consistently test different CBI products was needed. Therefore, a testing apparatus and subsequent methodology to test CBI products for sediment removal efficiency and performance longevity were developed to better understand overall performance of each CBI under consideration.

CHAPTER THREE:

MEANS AND METHODS

3.1 INTRODUCTION

This section describes the testing procedures and methods developed for the full-scale testing of CBIs. The test methods to be described were developed through a comprehensive review of testing procedures used in other studies that focused on the evaluation of sediment removal performance of CBIs. The goal of this procedure was to measure and evaluate both initial CBI performance and longevity over multiple events, therefore resulting in two separate phases of the project. Test characteristics were determined by the project sponsor, the Ohio Department of Transportation (ODOT), and are considered representative of field characteristics experienced during a rain event in Ohio. The overall design of the apparatus was conducted in accordance with the *ODOT Location & Design Manual, Volume Two (L&Dv2)* (*ODOT, 2018)*. However, the apparatus is adjustable for flow and sediment concentration introduction as needed to satisfy other geographic locations.

3.2 TESTING REGIME

The testing protocol was divided into two primary phases: (1) performance evaluation, and (2) longevity evaluation. Performance evaluation testing was first conducted to determine the sediment retention performance for each CBI to determine if the product could meet the minimum sediment capture requirement as specified by ODOT. During performance evaluation testing, each CBI was tested at a low, medium, and high flow rate for a period of 70 minutes using two different soil types, and under both sheet flow and direct discharge conditions. The performance of each CBI was evaluated to determine whether the product captured 80% of the sediment introduced. Each test was performed using a new CBI. The two different soil types were based upon the ODOT request for proposal guidelines. The first soil type was an OK110 silica sand, tested in accordance with *ODOT Supplemental Specification 995 (SS995) Precast Water Quality Structure* (ODOT, 2012), and the second soil type was a United States Department of Agriculture (USDA) classified sandy loam soil that corresponds to standards specified in the *Technology Acceptance Reciprocity Partnership: Protocol for Stormwater Best Management Practices Demonstrations (TARP)* (TARP, 2003).

Longevity testing consisted of multiple consecutive tests on a single installed CBI. The longevity test flow rates were determined by the maximum flow rate that the product was capable of providing 80% sediment retention percentage determined from the performance evaluation tests. Sediment retention percentage was calculated for each individual test, as well as cumulatively across all longevity tests. The longevity testing cycle continued until it was determined that the CBI was no longer capable of reaching the 80% sediment retention percentage or until the CBI failed structurally. The longevity testing methodology provides a representative understanding of the number of storm events a CBI can effectively treat runoff from until maintenance or removal in the field is required, while still satisfying water quality standards.

3.3 DETERMINATION OF FLOW CHARACTERISTICS

L&Dv2 (*ODOT, 2018*) Section 1115 specifies that pre-manufactured, post-construction BMPs should be designed according to the runoff flow rate resulting from a 0.65 in/hr (16.5 mm/hr) storm event over the drainage area associated with the catch basin under consideration. Water quality flow (WQ_f) is calculated by the rational equation, found in L&Dv2 Section 1101.2.2 (*ODOT, 2018*), which specifies:

$$WQ_f = kCiA \tag{3.5}$$

Where,

WQ_f = water quality flow, ft^3/s (L/s)

k = unit conversion factor (equal to 1.008 though typically taken as 1)

C = coefficient of runoff

I = rainfall intensity, in/hr (mm/hr)

A = contributing drainage area, acre (ha)

k is a unit conversion factor of 1.0 for U.S. customary units (0.00278 for metric units). While the coefficient of runoff (i.e., 0.9 for impervious areas) and rainfall intensity, 0.65 in/hr (16.5 mm/hr), are specified by L&Dv2 (*ODOT, 2018*), an appropriate drainage area must be selected to determine the flow rate that CBI products are expected to treat based upon ODOT typical conditions. An examination of ODOT field installation sites concluded that typical drainage areas contributing runoff to catch basins ranged from approximately 0.10 to 0.25 acres (0.04 to 0.10 ha). Figure 3.1 details the distribution of drainage areas from the surveyed field sites. As a result, it was determined that each CBI would be evaluated at three different flow rates, representative of a small drainage area of 0.1 acre (0.04 ha), medium drainage area of 0.2 acre (0.08 ha), and large drainage area of 0.3 acre (0.12 ha). Flow rates associated with the small, medium, and large drainage area according to the rational equation can be found in Table 3.1.

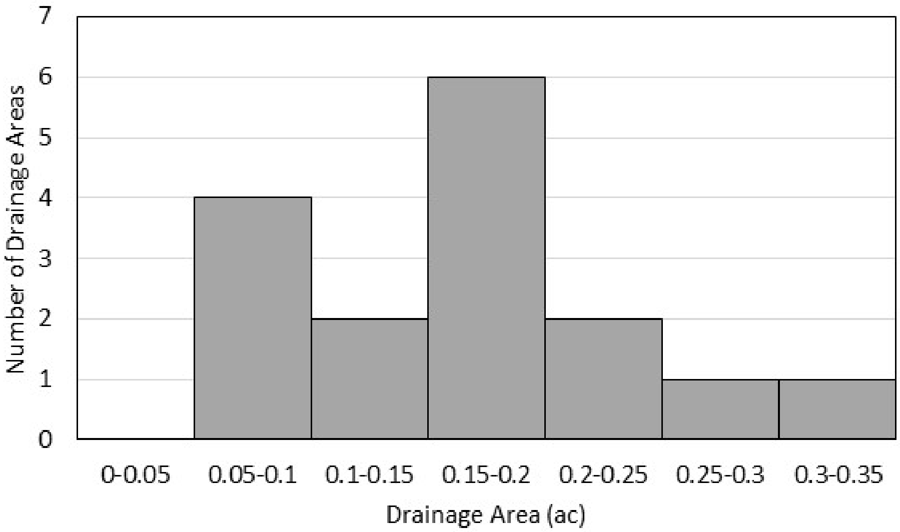


FIGURE 3.1 Distribution of surveyed field site drainage areas.

While L&Dv2 does not specify that pre-manufactured, post construction BMPs be designed to meet water quality volume standards, Ohio EPA's Construction General Permit (OH000004) specifies that "Alternative Post-Construction BMPs" could be used in place of BMPs typically used to treat stormwater runoff volumes with the requirement that the BMPs be able to treat the water quality volume (WQ_v) discharge rate (*Ohio EPA, 2013*). Therefore, the water quality volume calculation method was used to determine the total volume of water and flow durations for each test. WQ_v was calculated according to the following equation as specified in L&Dv2 (*ODOT, 2018*):

$$WQ_V = \frac{PAC_q}{k} \tag{3.6}$$

where,

WQ_V = water quality volume, ac-ft (m^3)

k = unit conversion factor

P = precipitation, in. (mm)

A = contributing drainage area, acre (ha)

C_q = coefficient of runoff (e.g, 0.9 for impervious drainage areas) *k* is a unit conversion factor of 12 for U.S. customary units (0.05 for metric units). L&Dv2 requires water quality volume be designed to a precipitation (*P*) of 0.75 in. (19.05 mm). WQ_v can be divided by WQ_f to determine the duration for each test. This will ensure that each practice is exposed to an adequate amount of runoff volume to determine overall performance. Table 3.1 summarizes the water quality flow rate, water quality volume, and duration of testing for each of the proposed drainage areas.

TABLE 3.1 Summary of Testing Characteristics for Proposed Drainage Areas

Drainage Area Size	Drainage Area, acre (ha)	Flow Rate, ft^3/s (L/s)	Volume, ft^3 (L)	Duration, min
Small	0.1 (0.04)	0.06 (1.7)	252.6 (7153.9)	70
Medium	0.2 (0.08)	0.12 (3.4)	504.0 (14271.7)	70
Large	0.3 (1.2)	0.18 (5.1)	756.0 (21407.5)	70

3.4 SEDIMENT INTRODUCTION

CBIs were tested using two different soil types. First, CBIs were tested in accordance with ODOT Supplemental Specification 995 (SS995) “Precast Water Quality Structure”, which specifies a laboratory test influent concentration of 0.028 lb/ft^3 (450 mg/L) while using an OK110 particle distribution with a specific gravity of 2.65 or less (ODOT, 2012). This influent concentration can be multiplied by the volume of water used during each test for the small, medium, and large drainage areas resulting in total sediment loads of 7.08, 14.16, and 21.24 lb (3.21, 6.42, and 9.63 kg), respectively.

CBIs were also tested using a United States Department of Agriculture (USDA) classified sandy loam soil type that corresponds to standards specified in the TARP protocol, which specifies that the sandy loam soil be introduced at a target concentration of 0.012 lb/ft^3 (185 mg/L). Over the duration of a test, this concentration results in target loads of 2.91, 5.82, and 8.73 lb (1.32, 2.64, and 3.96 kg), respectively. To obtain the required particle size distribution to meet the TARP standards, soil was taken from an onsite stock pile at AU-ESCTF. While the original particle size distribution of the stockpile did not meet the appropriate classification, soil was sifted to separate larger sand particles from finer silt and clay particles, and then mixed together at the appropriate ratio.

(a) stockpile soil (b) mechanical shaker (c) sandy loam soil

(d) seperated soils

FIGURE 3.2 Soil mixing process.

To determine the gradation of the mixed soil, a wet sieve analysis was conducted to determine the ratio of sands to fines. A sample of the fines were then collected and used to perform a hydrometer analysis, to further determine the ratio of silt to clay particles. The final distribution of the mixed soil was determined to be 64% sand, 27% silt, and 9% clay. Using the USDA soil classification triangular chart, seen in Figure 3.3, we can verify that this distribution does meet the required classification of a sandy loam.

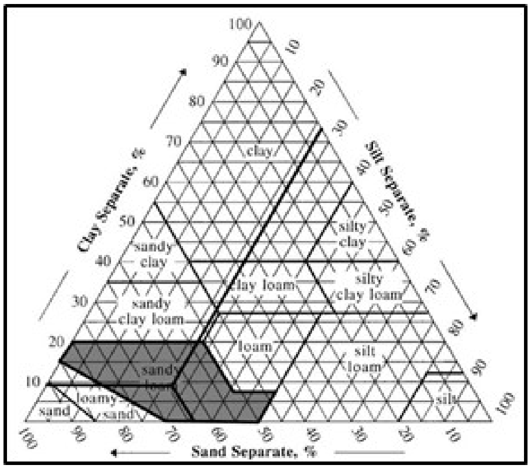
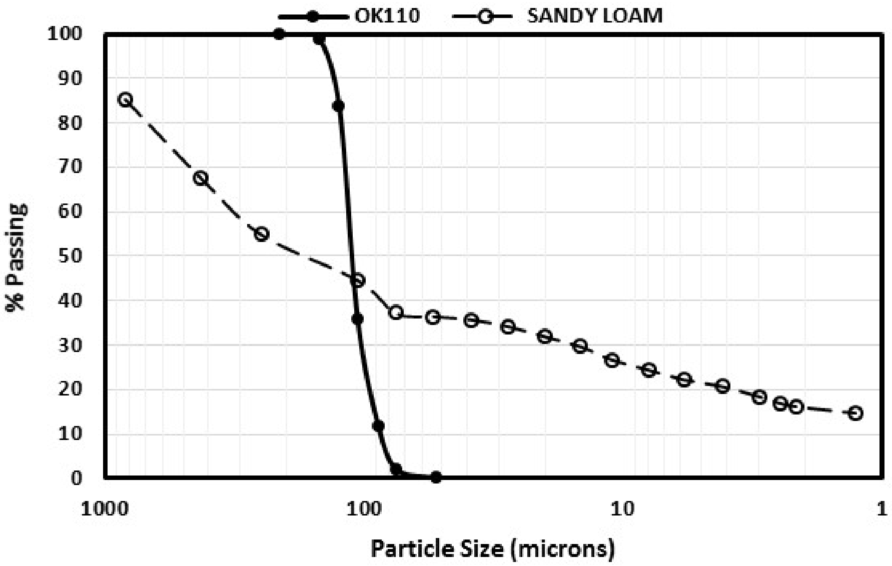
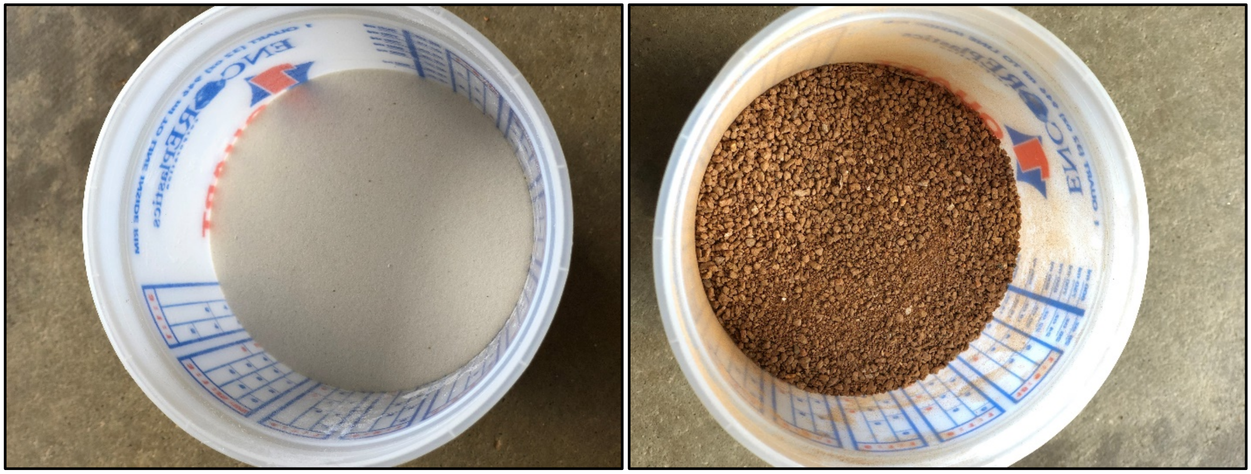


FIGURE 3.3: USDA soil classification triangular chart.

To compare the two soil types, the opposing particle size distribution curves for each soil can be seen in Figure 3.4(a). While the OK110 silica sand is primarily composed of sand particles ranging in diameter from 100-200 microns, the sandy loam soil is much more diverse, and contains clay particles, which can cause materials to become clogged, or blinded, affecting sediment removal performance. This is also supported by Figure 3.4(b) and Figure 3.4(c). Particle sizes range greatly in the sandy loam soil, whereas there is no visible difference in particle size in the OK110 silica sand. By testing CBIs with both soil types, we gain a greater understanding of how the product will perform under different influent conditions.



(a) PSD of two soil types



(b) ok110 silica sand

(c) sandy loam

FIGURE 3.4 Soil Type Comparison.

3.5 CONSTRUCTION OF APPARATUS

The construction of the CBI testing apparatus consisted of three primary components that included the water and sediment introduction system, flow conveyance system, and the drainage platform. Figure 3.5 provides the schematic design of the testing apparatus and major components. Figure 3.6 provides photographs of individual components of the testing apparatus.

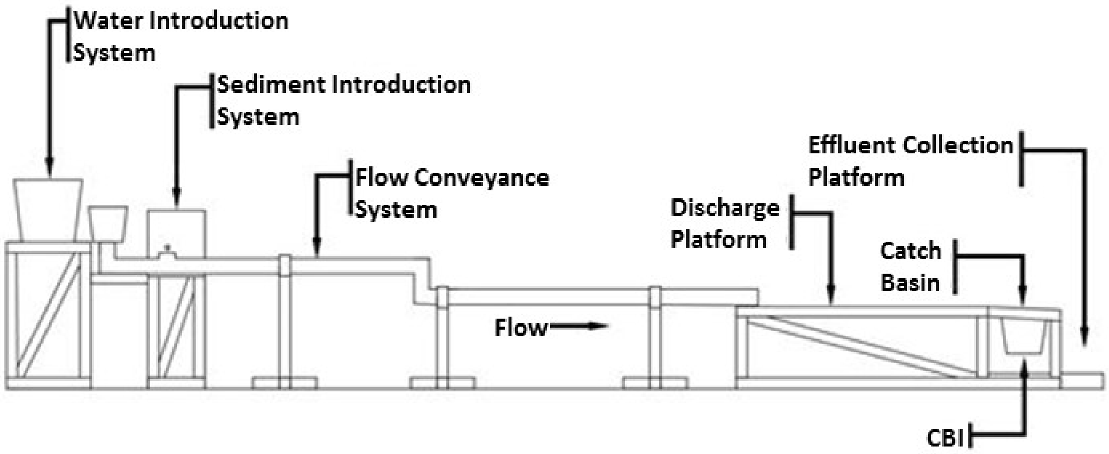


FIGURE 3.5 Schematic of CBI testing apparatus.

(a) water and sediment introduction system

(b) sediment introduction zone

(c) Schenck Process Model 106M Material Feeder

(d) flow conveyance and transition point

(e) discharge and test platform

(f) catch basin grate

(g) effluent collection platform

FIGURE 3.6 Catch Basin Insert (CBI) testing apparatus.

3.5.1 Water & Sediment Introduction System

Water is pumped from an on-site supply pond into a water equalization tank located at the upstream end of the apparatus, shown in Figure 3.6(a). This tank is equipped with a calibrated, 90-degree, V-notch weir that allows for controlled discharge into the flow conveyance system by adjusting drainage valves to maintain the water level in the tank at a desired depth. Effective head, or depth according to the weir, can be calculated according to Equation 3.3.

$$\mathrm{h_e} = \frac{\mathrm{Q}}{4.27997\mathrm{C}}^{2/5} \times 12 \tag{3.3}$$

Where,

h_e = effective head (in).

Q = flow rate (ft^3/s)

C = discharge constant (0.578)

Using Equation 3.3, the calculated effective heads for each of the three flow rates are 2.71, 3.58, and 4.21 in. (6.88, 9.09, and 10.7 cm), respectively. These effective heads were verified using a timed flow capture validation method to further calibrate and validate the desired discharges.

The V-notch weir discharges into a 6.0 in. (15.2 cm) polyvinyl chloride (PVC) pipe flow conveyance system. Immediately downstream of the water introduction point, a vertical tee is placed in the flow conveyance system that allows for the introduction of sediment into the flow, shown in Figure 3.6(b).

A Schenck AccuRate® series auger type volumetric feeder with a 0.75 in. (1.91 cm) diameter helix and a 0.25 ft^3 (7.08 liter) hopper was used for sediment introduction, which is shown in Figure 3.6(c). This system is equipped with a three-digit thumbwheel speed potentiometer that enhances repeatability by ensuring that auger speeds are consistent amongst tests, providing an accurate means of sediment introduction. The auger discharges into the flow conveyance system through a pre-drilled hole placed on the vertical tee end cap that was used to protect falling sediment from being disrupted by wind.

3.5.2 Flow Conveyance System

The flow conveyance system consists of 20 ft (6.1 m) in length by 6.0 in. (15.2 cm) inside diameter PVC pipe laid at a 2% slope that conveys sediment-laden water from the upstream introduction points to the drainage platform, as shown in Figure 3.6(d). A transition point was constructed in the middle of the flow conveyance system to produce turbulent flow for the sediment-laden water and cause soil particles to mix more evenly.

3.5.3 Discharge Platform

The discharge platform was constructed on a stable and level area so that influent would spread evenly across the platform. The lower support frame was then constructed using treated 4 x 4 lumber with treated 2 x 4 lumber as cross-bracing. The manufactured ODOT Type 3A catch basin (ODOT, 2016) frame was then placed on top of the lower support frame, and the upper platform was constructed around the catch basin frame. The upper platform consists of two 4 ft x 8 ft x 0.75 in. (1.22 m x 2.44 m x 1.9 cm) plywood sheets to create an 8 ft by 8 ft (2.44 m by 2.44 m) surface. The plywood was installed at a 2% slope both in the downstream direction and toward the middle of the platform to direct sheet flow into the catch basin from the discharge point of the flow conveyance system. The 2% slope was selected to be representative of a typical roadway cross-sectional slope. Additional plywood was installed at a location similar to the slope of the catch basin frame to simulate the curb.

The platform was then sealed with silicon caulking and covered with a rubber sealant material. The platform was sprayed with a LINE-X® coating to provide a water-tight seal. Finally, 14-gauge [0.08 in. (1.98 mm)] sheet metal was placed on top of the platform as a finished surface that would allow influent to flow as sheet flow into the catch basin without causing disturbances that could result in sediment falling out of suspension prematurely. Edges and corners were again sealed with silicone caulking to prevent leaking. The completed discharge platform is pictured in Figure 3.6(e).

A 6.0 in. (15.2 cm) PVC coupling was placed at the upstream side of the discharge platform. This allows the operator to change the length of pipe based upon the flow rate that the test is being performed at, as seen in Figure 3.7. For low flow rate tests, the flow conveyance pipe is extended closer to the catch basin, and for high flow rate tests, the conveyance system ends at the coupling, and no additional piping is used. The purpose of this adjustment is to ensure flow enters the catch basin grate [Figure 3.6(f)] at a consistent velocity across all three flow rates to prevent particles from falling out of suspension on the platform prematurely due to slowed velocity. Modifications were also made to the system to allow water to be directly discharged into the inlet opposed to influent sheet flow. Direct discharge modifications can be seen in Figure 3.7(d).

(a) low flow rate (b) medium flow rate

(c) high flow rate (d) direct discharge

FIGURE 3.7 Modifications to flow conveyance system based on flow rate and type.

3.6 PERFORMANCE EVALUATION OF CBIS

The primary focus of the CBI testing was to characterize performance by quantifying sediment removal efficiency. Weight measurements were used to accomplish this by analyzing the pre-test and post-test weight of the CBI. Prior to installation, the CBI was weighed to determine the pre-test weight. Each product was installed based upon manufacturer installation protocols and sediment-laden flow was introduced to the CBI based upon previously discussed flow and concentration requirements. Upon completion of the test, the saturated CBI was placed in an industrial oven at approximately 103°C (217°F) for at least 12 hours to ensure that all water was removed from the sediment and the filter media. The weight of the sediment introduction system was also recorded before and after the test to determine the amount of sediment introduced. Any excess sediment that may have fallen out of suspension on the platform prior to entering the catch basin was also collected and dried in the oven for at least 12 hours before being weighed. Sediment removal efficiency was calculated by dividing the weight of sediment captured in the CBI and the weight of sediment introduced.

The secondary focus of the CBI testing was to measure TSS reduction. TSS reduction was determined by analyzing 32 oz (1.0 L) grab samples taken at five minute intervals, upstream and downstream of the installed product throughout the duration of the test. The entire 32 oz (1.0 L) sample was used for TSS analysis. Upstream and downstream TSS was determined using the method specified by American Public Health Association Method 2540D *Total Suspended Solids Dried at 103-105°C* (*APHA, 1997*).

CBIs were also visually inspected during testing to monitor for structural degradation, clogging of material, and untreated flow bypass. Photo documentation was performed from predetermined and ad hoc locations to visually document pre- and post-test conditions. During each test, photo and video documentation was also performed to capture important flow characteristics.

Pre- and post-test weights, sediment introductions, photos, and any additional observations from the test were documented through data collection reports.

3.7 CALIBRATION OF APPARATUS

After the construction of the testing apparatus, the calibration and validation phases were essential for ensuring that the apparatus would satisfy design parameters developed in the first phase of the project, as well as, meet the original goal of simulating field-like conditions for CBI testing. The calibration phase consisted of adjusting water and sediment introduction rates to ensure design parameters were met. The validation phase consisted of performing tests on a non-proprietary CBI to ensure the system performed as expected and allow for evaluation of sampling and laboratory testing protocols.

3.7.1 Flow Rate Calibration

The calibration of the water introduction system was performed using a barrel in the shape of a truncated cone. The flow conveyance system introduced water into the barrel, and the time required to fill the barrel was measured. Knowing the dimension of the barrel, the volume of water inside the barrel could then be calculated using Equation 3.4:

$$V = \frac{1}{3}\pi({r_1}^2 + r_1 r_2 + {r_2}^2)h \qquad (3.4)$$

Where,

V = volume of the barrel, ft^3 (m^3)

r_1 = radius of the top of the barrel, ft (m)

r_2 = radius of the bottom of the barrel, ft (m)

h = depth of the water in the barrel, ft (m)

The flow rate of water could then be calculated knowing the volume of water in the barrel and the time to fill the barrel according to:

$$Q = \frac{V}{t} \qquad (3.5)$$

Where,

Q = flow rate, ft^3/s (m^3/s)

V = volume of the barrel, ft^3 (m^3)

t = time to fill barrel, s

3.7.2 Sediment Introduction System Calibration

The sediment introduction system came equipped with a three-digit thumbwheel speed potentiometer, allowing the speed setting to easily be modified between tests. The calibration of this device was performed similarly to the water introduction system. A speed was selected using the potentiometer and the system was allowed to transfer sediment from the hopper to a container for a measured amount of time. The container was weighed before and after being filled with sediment, and the sediment introduction rate was calculated according to Equation 3.6:

$$Q_S = \frac{W_{post} - W_{pre}}{t} \tag{3.6}$$

Where,

Q_S = sediment introduction rate, lb/min (kg/min)

W_{post} = weight of the container after filling, lb (kg)

W_{pre} = weight of the container before filling, lb (kg)

t = time to fill container, min

The sediment introduction rate was then multiplied by the duration of the test, 70 minutes, to determine if the rate was acceptable according to values presented in Table 3.1. This was repeated until a speed setting was correlated to the required sediment introduction rate. This process was repeated for all three sediment introduction rates for each soil type.

3.8 VALIDATION OF APPARATUS

A non-proprietary, bag-type CBI was developed to perform validation testing on the apparatus. The CBI was a 16.0 in. (40.6 cm) wide by 29.0 in. (73.7 cm) long by 18 in. (45.7 cm) in depth bag constructed of 3.5 oz./yd^2 (0.12 kg/m^2), nonwoven geotextile fabric with overflow openings positioned near the top of the CBI on all four sides. The non-proprietary CBI was tested under all previously discussed conditions at the three flow rates.


(a) interior of non-proprietary CBI (b) exterior of non-proprietary CBI

FIGURE 3.8 Non-proprietary CBI.

Table 3.2 summarizes the results from the three tests. While it was expected that the percent of sediment retained would decrease as flow rate increased, sediment retention percentage was actually highest during the medium flow rate test. However, there was a significant drop in sediment retention between the medium and high flow rate tests, and average TSS removal percentage did decrease with each increase in flow rate.

TABLE 3.2 Summary of CBI Performance

Flow Rate ft^3/s (L/s)	Weight of Sediment Introduced lb (kg)	Weight of Sediment Retained lb (kg)	Percent Retained (%)	Average Upstream TSS lb/ft^3 (mg/L)	Average Downstream TSS lb/ft^3 (mg/L)	Average TSS Removal (%)	Start of Over-flow (min)
0.06 (1.7)	7.38 (3.35)	4.58 (2.08)	62.1	0.029 (472.4)	0.013 (203.5)	57	N/A
0.12 (3.4)	15.14 (6.87)	9.85 (4.47)	65.1	0.020 (315.6)	0.009 (148.9)	53	24
0.18 (5.1)	23.65 (10.73)	12.13 (5.55)	51.7	0.022 (359.1)	0.011 (181.6)	49	13

At the low flow rate, the depth of water inside the CBI did not reach the overflow point as shown in Figure 3.9(b). However, as flow rates increased for the medium and high flow tests, the CBI did reach the overflow point, with overflow occurring sooner for the high flow test than the medium flow test. This caused a significant impact on the sediment retention capabilities of the CBI because large volumes of water exited the CBI through the bypass openings untreated. Bypass flow conditions also created turbulence inside the CBI, which may have resulted in re-suspension of particles previously settled in the bottom of the bag, further decreasing sediment retention and increasing downstream TSS. This is supported by the decrease in average TSS removal with increasing flow rate, as shown in Table 3.2.

Overflow conditions can be seen in Figure 3.9(c) and Figure 3.9(d) compared to pre-test conditions in Figure 3.9(a) and normal flow conditions in Figure 3.9(b).

(a) pre-test condition

(b) 0.06 ft^3/s (1.7 L/s) test

(c) overflow during 0.12 ft^3/s (3.4 L/s) test

(d) overflow during 0.18 ft^3/s (5.1 L/s) test

FIGURE 3.9 CBI Performance during testing of low, medium, and high flow rates.

Upon completion of the validation tests, it was determined that the apparatus was capable of meeting the design standards developed earlier in this chapter. Figure 3.10 provides a summary of the testing regime that will be used to evaluate CBIs during the next phase of the project. For each of the two soil types, CBIs will undergo performance evaluation testing and longevity testing. During performance evaluation testing, products will be tested at three different flow rates of 0.06 ft^3/s (1.7 L/s), 0.12 ft^3/s (3.4 L/s), and 0.18 ft^3/s (5.1 L/s), representative of a small drainage area of 0.1 acre (0.04 ha), a medium drainage area of 0.2 acre (0.08 ha), and a large drainage area of 0.3 acre (0.12 ha). Sediment will be introduced at a target concentration of 0.028 lb/ft^3 (450 mg/L) for the OK110 silica sand tests, and 0.012 lb/ft^3 (185 mg/L) for the sandy loam test, resulting in target sediment introductions found in Table 3.3. Upon completion of performance evaluation testing, CBIs will then undergo longevity testing. While clean

CBIs will be used for each test during performance evaluation testing, longevity testing will consist of multiple consecutive tests on the same CBI, simulating loading over multiple storm events. Longevity testing flow rate will be based upon performance testing results for both soil types, and will continue until the CBI is no longer capable of reaching the 80% sediment retention threshold, or until a structural failure occurs.

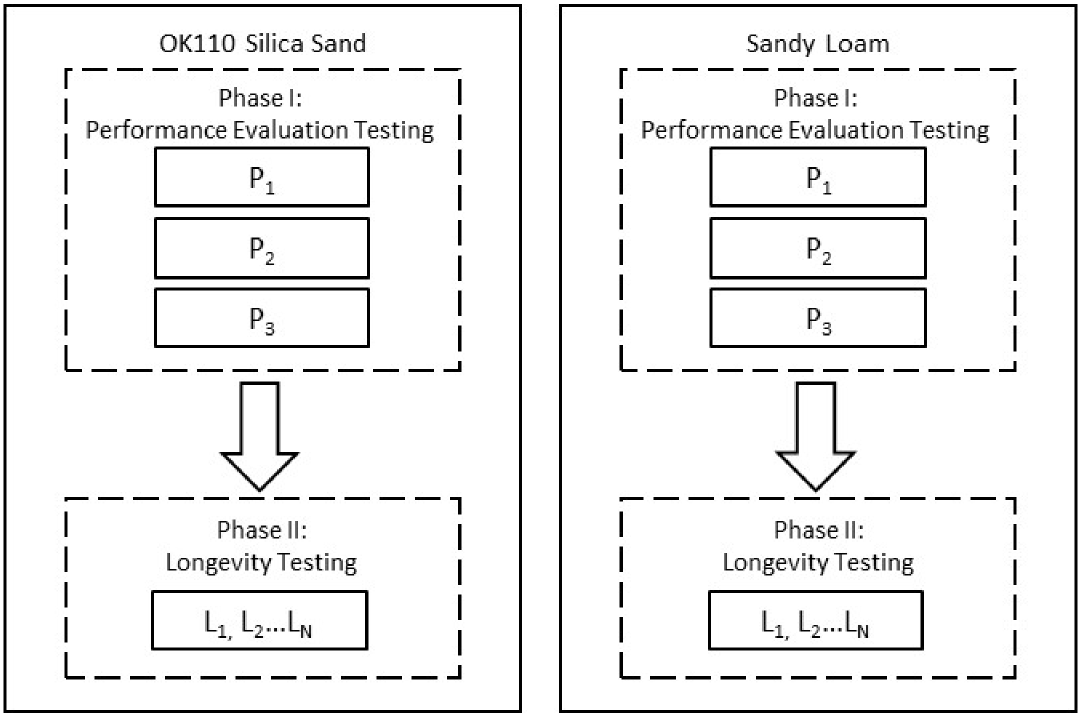


FIGURE 3.10 Testing Regime

TABLE 3.3 Testing Characteristic Summary

Test	Flow	Sediment Introduction	
		OK110	Sandy Loam
	ft^3/s (L/s)	lb (kg)	lb (kg)
P_1	0.06 (1.7)	7.08 (3.21)	2.91 (1.32)
P_2	0.12 (3.4)	14.16 (6.42)	5.82 (2.64)
P_3	0.18 (5.1)	21.24 (9.63)	8.73 (3.96)
L_N	TBD*	TBD*	TBD*

TBD*- Testing characteristics will be determined based off of performance evaluation testing results.

The developed testing plan is designed to simulate stormwater runoff conditions similar to those found in ODOT catch basins. By testing the proprietary CBIs under this testing methodology, the resulting data can be used to determine whether or not the product is capable of meeting performance standards set forth by ODOT and the Ohio EPA. Testing results and a discussion on product performance can be found in the following chapter.

CHAPTER FOUR:
RESULTS AND DISCUSSION

4.1 PERFORMANCE EVALUATION TESTING

The following section discusses the installation, testing, and performance of each catch basin insert (CBI) based upon performance testing. Each product was tested at the low, medium, and high flow rates of 0.06, 0.12, and 0.18 ft^3/s (1.7, 3.4, 5.1 L/s). Target sediment introductions for the low, medium, and high tests were 7.08, 14.16, and 21.24 lb (3.21, 6.42, and 9.63 kg) for OK110 silica sand tests and 2.91, 5.82, and 8.73 lb (1.32, 2.64, 3.96 kg) and for sandy loam tests. The results of CBIs tested and evaluated will be presented in the following order: Absorb-It, Drainpac, Flexstorm, FloGard Plus, Gullywasher; Storm Sentinel, Triton, and Water Quality Solutions.

4.1.1 Stormwater BMP Products Adsorb-It Stormfilters

The Adsorb-It is a basket-type CBI consisting of a heavy-duty polyvinyl chloride (PVC) coated wire mesh steel basket supported by a rigid stainless steel frame. The basket is also lined with a filtration fabric material. The basket has bypass openings on the two sides of the device, and is equipped with heavy-duty wire lifting cables that are supported under the frame for easy removal. The Adsorb-It CBIs that were shipped to Auburn University – Erosion and Sediment Control Testing Facility (AU-ESCTF) for large-scale laboratory testing were undersized and did not fit appropriately into the Ohio Department of Transportation (ODOT) Type 3A catch basin. Therefore, a plywood frame was constructed to fit inside the lip of the catch basin frame. The plywood frame was supported by 2x4's and was sealed to the existing catch basin frame using a silicon caulking to prevent water from passing between the two frames. This modification can be seen in Figure 4.1(a) (Stormwater BMP Products, 2016).

Photos of the Adsorb-It installed in the testing catch basin can be seen in Figure 4.1.


(a) location 1 (b) location 2


(c) location 3 (d) location 4


(e) location 5 (f) location 6

FIGURE 4.1 Pre-test installation for Adsorb-It.

Figure 4.2(a) – 4.2(c) shows images of the Adsorb-It during testing with OK110 silica sand under sheet flow and direct discharge conditions, and sandy loam soil under direct discharge conditions only. It was observed during the tests that a small amount of influent water was flowing into the catch basin and directly exiting through the bypass openings untreated, which may have had an effect on sediment removal efficiency.

0.06 cfs 0.12 cfs 0.18 cfs

(a) sheet flow testing with OK110 silica sand

0.06 cfs 0.12 cfs 0.18 cfs

(b) direct discharge testing with OK110 silica sand

0.06 cfs 0.12 cfs 0.18 cfs

(c) direct discharge testing with sandy loam soil

FIGURE 4.2 Adsorb-It during testing using various test methods and soil types.

Table 4.1(a) - 4.1(c) summarizes performance evaluation data for the Adsorb-It when introducing OK110 silica sand under sheet flow and direct discharge conditions, and sandy loam soil under direct discharge conditions only. The 80% sediment removal target was exceeded during two of the three low flow tests, and also at the medium flow test when introducing OK110 silica sand under direct discharge conditions. However, performance did decrease as flow rate increased.

TABLE 4.1 Summary of Performance Data for Adsorb-It for Various Test and Soil Types

(a) Sheet Flow Testing with OK110 Silica Sand

Flow Rate, cfs	0.06	0.12	0.18
Sediment Introduced, lb (% error)	7.02 (-0.85%)	13.78 (-2.68%)	21.77 (2.50%)
Sediment Captured, lb	5.42	8.87	10.60
Sediment Retention, %	77.2	64.4	48.7
Avg. TSS Removal, %	76.3	67.1	53.3
Time to Overflow, min	-	27	15

(b) Direct Discharge Testing with OK110 Silica Sand

Flow Rate, cfs	0.06	0.12	0.18
Sediment Introduced, lb (% error)	7.40 (4.52%)	14.43 (1.91%)	22.49 (5.89%)
Sediment Captured, lb	7.12	11.90	14.46
Sediment Retention, %	96.2	82.5	64.3
Avg. TSS Removal, %	92.4	85.6	69.0
Time to Overflow, min	-	32	18

(c) Direct Discharge Testing with Sandy Loam Soil

Flow Rate, cfs	0.06	0.12	0.18
Sediment Introduced, lb (% error)	2.87 (-1.4%)	5.97 (2.6%)	8.68 (-0.6%)
Sediment Captured, lb	2.45	3.83	4.38
Sediment Retention, %	85.4	64.2	50.5
Avg. TSS Removal, %	72.1	70.8	61.1
Time to Overflow, min	46	18	12

4.1.2 United Storm Water Drainpac

DrainPac consists of a metal basket lined with a filter fabric bag. A plastic netting attached to the metal frame also surrounds the fabric bag to provide structural support. The metal bag is equipped with large bypass openings on all four sides of the device. The DrainPac insert removes pollutants by both filtration through the mesh material and allowing particles to settle out of suspension while the influent accumulates in the bag prior to discharge. DrainPac insert variations include models for drop inlets, curb inlets, and round inlets, and can be made to specific sizes. The filter fabric material of the bag has been specified to have a maximum flow through rate of 0.31 cfs/ft^2, per manufacturer claims (United Storm Water Inc, n.d.).

A common issue with the Drainpac was that many of the products were slightly damaged when shipped to AU-ESCTF. When many of the products were removed from their respective shipping boxes, it was found that corners of the frame had been bent, as opposed to lying flat. These bent corners then create gaps between the CBI frame and the inlet frame which allow water to flow past the CBI untreated. Bent edges were attempted to be straightened before installation to mitigate the issue. Figure 4.3 provides an example of two of the damaged CBIs.

(a) 0.06 ft^3/s with OK110 under sheet flow (b) 0.18 ft^3/s with OK110 under sheet flow

FIGURE 4.3 Bent edges of Drainpac frame.

Photos of the Drainpac installed in the testing catch basin can be seen in Figure 4.4.

(a) location 1 (b) location 2

(c) location 3 (d) location 4

(e) location 5 (f) location 6

FIGURE 4.4 Pre-test installation for Drainpac.

Figure 4.5(a) – 4.5(c) shows images of the Drainpac during testing with OK110 silica sand under sheet flow and direct discharge conditions, and sandy loam soil under direct discharge conditions only. It was observed during the tests that a small amount of influent water was flowing into the catch basin and directly exiting through the bypass openings untreated, which may have had an effect on sediment removal efficiency.

0.06 cfs 0.12 cfs 0.18 cfs

(a) sheet flow testing with OK110 silica sand

0.06 cfs 0.12 cfs 0.18 cfs

(b) direct discharge testing with OK110 silica sand

0.06 cfs 0.12 cfs 0.18 cfs

(c) direct discharge testing with sandy loam soil

FIGURE 4.5 Drainpac during testing using various test methods and soil types.

Table 4.2(a) – 4.2(c) summarizes performance evaluation data for the Drainpac when introducing OK110 silica sand under sheet flow and direct discharge conditions, and sandy loam soil under direct discharge conditions only. The 80% sediment removal target was reached during the low flow test when introducing OK110 silica sand under direct discharge conditions. However, retention values were lower when introducing sandy loam and when using sheet flow conditions. This could possibly be accredited to the untreated flow bypassing the CBI due to the bent edges of the frame show in Figure 4.3 during sheet flow testing.

TABLE 4.2 Summary of Performance Data for Drainpac for Various Test and Soil Types

(a) Sheet Flow Testing with OK110 Silica Sand

Flow Rate, cfs	**0.06**	**0.12**	**0.18**
Sediment Introduced, lb (% error)	7.30 (3.11%)	14.67 (3.60%)	21.90 (3.11%)
Sediment Captured, lb	2.62	6.76	10.31
Sediment Retention, %	35.9	46.1	47.1
Avg. TSS Removal, %	45.4	56.4	57.6
Time to Overflow, min	-	47	21

(b) Direct Discharge Testing with OK110 Silica Sand

Flow Rate, cfs	**0.06**	**0.12**	**0.18**
Sediment Introduced, lb (% error)	7.27 (2.68%)	14.04 (-0.85%)	21.62 (1.79%)
Sediment Captured, lb	5.80	9.10	13.56
Sediment Retention, %	79.8	64.8	62.7
Avg. TSS Removal, %	76.0	64.9	71.6
Time to Overflow, min	67	25	20

(c) Direct Discharge Testing with Sandy Loam Soil

Flow Rate, cfs	**0.06**	**0.12**	**0.18**
Sediment Introduced, lb (% error)	2.98 (2.4%)	5.86 (0.7%)	8.48 (-2.86%)
Sediment Captured, lb	2.03	2.74	3.26
Sediment Retention, %	68.1	46.8	38.4
Avg. TSS Removal, %	63.6	51.7	33.8
Time to Overflow, min	27	7	6

4.1.3 Advanced Drainage Systems Flexstorm

The Flexstorm has a stainless steel frame that can be custom configured to fit most drainage structures. The frame is equipped with supported handles for installation and removal. The frame also is constructed with large flow bypass openings on all four sides to allow water to bypass the CBI untreated in the event that the influent flow is too great for the CBI to treat effectively, herein referred to as untreated bypass. A clamping mechanism is used to secure replaceable filtration bags to the frame. Woven geotextile filtration bags are lined with carpet fiber material to treat water exiting the bag. The bag also has a more permeable fabric that sits between the filtration bag and the stainless steel frame that allows water to flow through at a higher rate than the filtration bag while still provided some treatment, herein referred to as treated bypass. The Flexstorm has a manufacturer specified flow capacity of 0.45 ft^3/s, but it is not specified whether or not this capacity is based off of clean or sediment-laden influent (ADS , 2016).

Photos of the Flexstorm installed in the testing catch basin can be seen in Figure 4.6.

(a) location 1 (b) location 2

(c) location 3 (d) location 4

(e) location 5 (f) location 6

FIGURE 4.6 Pre-test installation for Flexstorm.

Figure 4.7 (a) - 4.7(c) shows images of the Flexstorm during testing with OK110 silica sand under sheet flow and direct discharge conditions, and sandy loam soil under direct discharge conditions only. The water level inside the CBI reached the treated overflow level for all tests. However, the untreated overflow was only reached at the 44 minute mark of the high flow test using sandy loam soil under direct discharge conditions.

0.06 cfs 0.12 cfs 0.18 cfs

(a) Flexstorm during sheet flow testing with OK110 silica sand.

0.06 cfs 0.12 cfs 0.18 cfs

(b) Flexstorm during direct discharge testing with OK110 silica sand

0.06 cfs 0.12 cfs 0.18 cfs

(c) Flexstorm during direct discharge testing with sandy loam soil

FIGURE 4.7 Flexstorm during testing using various test methods and soils.

Table 4.3(a) – 4.3(c) summarizes performance evaluation data for the Flexstorm when introducing OK110 silica sand under sheet flow and direct discharge conditions, and sandy loam soil under direct discharge conditions only. Sediment retention percentage was best at the low flow rate when directly discharging influent with OK110 silica sand, but was below the 80% target rate. With the exception of the low flow test under sheet flow conditions, sediment retention values decreased as flow rate increased.

TABLE 4.3 Summary of Performance Data for Flexstorm for Various Test and Soil Types

(a) Sheet Flow Testing with OK110 Silica Sand

Flow Rate, cfs	**0.06**	**0.12**	**0.18**
Sediment Introduced, lb (% error)	7.52 (6.21%)	14.89 (5.16%)	21.51 (1.27%)
Sediment Captured, lb	3.85	8.46	10.01
Sediment Retention, %	51.2	56.8	46.5
Avg. TSS Removal, %	66.2	42.0	51.1
Time to Overflow, min	46	24	9

(b) Direct Discharge Testing with OK110 Silica Sand

Flow Rate, cfs	**0.06**	**0.12**	**0.18**
Sediment Introduced, lb (% error)	7.29 (2.97%)	14.37 (1.48%)	22.70 (6.87%)
Sediment Captured, lb	5.20	7.21	8.25
Sediment Retention, %	71.3	50.2	36.3
Avg. TSS Removal, %	88.0	39.7	20.6
Time to Overflow, min	33	10	7

(c) Direct Discharge Testing with Sandy Loam Soil

Flow Rate, cfs	**0.06**	**0.12**	**0.18**
Sediment Introduced, lb (% error)	2.95 (1.4%)	5.33 (-8.4%)	9.33 (6.9%)
Sediment Captured, lb	1.93	3.11	4.10
Sediment Retention, %	65.4	58.3	43.9
Avg. TSS Removal, %	67.3	71.0	53.6
Time to Overflow, min	35	20	11

4.1.4 Oldcastle Stormwater Solutions FloGard Plus

The FloGard Plus has characteristics of both a bag-type and basket-type CBI. A plastic, large-mesh basket structure supports a woven filter fabric liner that is attached to a stainless steel frame. The frame is equipped with bypass openings on all four sides. The bypass openings also have a roof structure above them, preventing flow and contaminants from bypassing the device when entering the device from above, ensuring the only time flow exits through the bypass is when the CBI has become overloaded (OldCastle, n.d.).

Photos of the FloGard Plus installed in the testing catch basin can be seen in Figure 4.8.

(a) location 1 (b) location 2

(c) location 3 (d) location 4

(e) location 5 (f) location 6

FIGURE 4.8 Pre-test installation for FloGard Plus.

Figure 4.9(a) – 4.9(c) shows images of the FloGard during testing with OK110 silica sand under sheet flow and direct discharge conditions, and sandy loam soil under direct discharge conditions only. A reoccurring issue with the FloGard Plus was that there was never any impoundment of flow within the CBI. It appeared that the mesh opening size of the filter bag had a high flow through rate, inhibiting the CBI's ability to impound flow. The lack of impoundment greatly impaired the sediment removal efficiency of the product.

0.06 cfs 0.12 cfs 0.18 cfs

(a) sheet flow testing with OK110 silica sand

0.06 cfs 0.12 cfs 0.18 cfs

(b) direct discharge testing with OK110 silica sand

0.06 cfs 0.12 cfs 0.18 cfs

(c) direct discharge testing with sandy loam soil

FIGURE 4.9 FloGard during testing using various test methods and soil types.

Table 4.4(a) - 4.4(c) summarizes performance evaluation data for the FloGard when introducing OK110 silica sand under sheet flow and direct discharge conditions, and sandy loam soil under direct discharge conditions only. Sediment retention values showed no potential for meeting the 80% target removal rate, which is most likely due to the high-flow through rate of the fabric.

TABLE 4.4 Summary of Performance Data for FloGard for Various Test and Soil Types

(a) Sheet Flow Testing with OK110 Silica Sand

Flow Rate, cfs	0.06	0.12	0.18
Sediment Introduced, lb (% error)	6.99 (-1.27%)	14.68 (3.67%)	23.36 (9.98%)
Sediment Captured, lb	0.51	0.15	0.16
Sediment Retention, %	7.3	1.0	0.7
Avg. TSS Removal, %	18.5	11.5	16.7
Time to Overflow, min	-	-	-

(b) Direct Discharge Testing with OK110 Silica Sand

Flow Rate, cfs	0.06	0.12	0.18
Sediment Introduced, lb (% error)	7.40 (4.52%)	12.2 (-13.84%)	20.08 (-5.46%)
Sediment Captured, lb	0.77	0.10	0.44
Sediment Retention, %	10.4	0.8	2.2
Avg. TSS Removal, %	24.6	15.8	28.8
Time to Overflow, min	-	-	-

(c) Direct Discharge Testing with Sandy Loam Soil

Flow Rate, cfs	0.06	0.12	0.18
Sediment Introduced, lb (% error)	2.91 (0.00%)	5.67 (-2.58%)	8.94 (2.41%)
Sediment Captured, lb	0.72	1.12	1.97
Sediment Retention, %	24.7	19.8	22.0
Avg. TSS Removal, %	41.2	27.9	51.3
Time to Overflow, min	-	-	-

4.1.5 Gullywasher Metal Compliant CBIs

The Gullywasher Commercial Duty Frame Mounted Insert consists of a nonwoven geotextile filter fabric mounted on a rectangular metal frame. The bag has sewn-in tabs that hold the frame into proper position, ensuring that the bag does not move around and become unsupported under heavy loading. The bag is also supported by nylon straps that wrap under the bottom of the bag and support loads when the bag is full. Nylon straps are also placed on the inside of the bag as removal handles. Finally, the bag is equipped with overflow openings on both the upstream and downstream side of the CBI (Gullywasher, 2016).

Gullywasher CBIs were shipped to AU-ESCTF with extra fabric around the frame, and installation instructions directed the installer to cut the fabric to fit as needed. The Gullywasher before and after modifications can be seen in Figure 4.10.

(a) Gullywasher before modifications (b) Gullywasher after modifications

FIGURE 4.10 Gullywasher modifications.

Photos of the Gullywasher installed in the testing catch basin can be seen in Figure 4.11.

(a) location 1 (b) location2

(c) location 3 (d) location 4

(e) location 5 (f) location 6

FIGURE 4.11 Pre-test installation for Gullywasher.

It was observed during the low flow rate direct discharge test with OK110 silica sand that some influent water was flowing into the catch basin and directly exiting through the downstream bypass opening untreated, which may impact sediment removal performance. This was not an observed during other tests. Figure 4.12(a) – (c) shows images of the Gullywasher during testing with OK110 silica sand under sheet flow and direct discharge conditions, and sandy loam soil under direct discharge conditions only.


0.06 cfs 0.12 cfs 0.18 cfs

(a) sheet flow testing with OK110 silica sand


0.06 cfs 0.12 cfs 0.18 cfs

(b) direct discharge testing with OK110 silica sand


0.06 cfs 0.12 cfs 0.18 cfs

(c) direct discharge testing with sandy loam soil

FIGURE 4.12 Gullywasher during testing using various test methods and soil types.

Leaks were observed during the two high flow tests with OK110 silica sand that may have impacted sediment removal efficiency. The leaks can be seen in Figure 4.13.

(a) sheet with OK110 silica sand (b) direct discharge with OK110 silica sand

FIGURE 4.13 Leaks in Gullywasher at high flow rate tests.

Table 4.5(a) – 4.5(c) summarizes performance evaluation data for the Gullywasher when introducing OK110 silica sand under sheet flow and direct discharge conditions, and sandy loam soil under direct discharge conditions only. During the testing with OK110 silica sand under sheet flow conditions, there was more sediment captured during the medium flow test than the high flow test, despite the fact that more sand was introduced during the high flow test. One possible explanation for this is that the leak shown in Figure 4.13(a) impacted performance. Sediment retention decreased as flow rate increased for all test methods. The Gullywasher was one of the few products that actually performed slightly better under sheet flow conditions than under direct discharge conditions. One possible explanation for this would be that overflow was reached quicker during direct discharge tests than with sheet flow tests, meaning that a larger volume of water was able to be treated under sheet flow than direct discharge before passing the CBI.

TABLE 4.5 Summary of Performance Data for Gullywasher for Various Test and Soil Types

(a) Sheet Flow Testing with OK110 Silica Sand

Flow Rate, cfs	**0.06**	**0.12**	**0.18**
Sediment Introduced, lb (% error)	7.47 (5.51%)	14.45 (2.05%)	18.63 (-12.29%)
Sediment Captured, lb	5.66	8.49	7.64
Sediment Retention, %	75.8	58.8	41.0
Avg. TSS Removal, %	79.4	59.3	33.5
Time to Overflow, min	42	11	6

(b) Direct Discharge with OK110 Silica Sand

Flow Rate, cfs	**0.06**	**0.12**	**0.18**
Sediment Introduced, lb (% error)	7.66 (8.19%)	14.68 (3.67%)	23.34 (9.89%)
Sediment Captured, lb	5.14	7.01	8.34
Sediment Retention, %	67.1	47.8	35.7
Avg. TSS Removal, %	71.9	50.4	39.6
Time to Overflow, min	21	7	3

(c) Direct Discharge Testing with Sandy Loam Soil

Flow Rate, cfs	**0.06**	**0.12**	**0.18**
Sediment Introduced, lb (% error)	2.92 (0.3%)	6.03 (3.6%)	8.84 (1.26%)
Sediment Captured, lb	1.51	2.30	2.95
Sediment Retention, %	51.7	38.1	33.4
Avg. TSS Removal, %	62.4	62.8	23.6
Time to Overflow, min	16	6	5

4.1.6 Enpac Storm Sentinel

The Storm Sentinel is a bag-type CBI made out of a nonwoven geotextile fabric that is supported by an adjustable steel wire frame. The bag contains three openings to allow influent to bypass the bag, preventing flow from backing onto the street in the event that the bag becomes overloaded or the fabric is clogged. The Storm Sentinel is equipped with two nylon handles for easy maintenance and removal. Ranging in dimensions from 16 by 20 in. to 28 by 36 in. and weighing two pounds, the Storm Sentinel has a load capacity of up to 125 lb, and can handle flow rates up to 1.11 ft^3/s based upon manufacturer claims, which do not specify whether this capacity is based upon clean or sediment-laden flow (Enpac Group, 2016).

Photos of the Storm Sentinel installed in the testing catch basin can be seen in Figure 4.14.


(a) location 1 (b) location 2


(c) location 3 (d) location 4


(e) location 5 (f) location 6

FIGURE 4.14 Pre-test installation of Storm Sentinel.

It was observed during the high flow rate tests that the influent flow caused the filter bag to move around the adjustable frame, creating small gaps to open at the entrance to the CBI. The gaps, though small, could allow influent water to bypass the CBI completely and enter the catch basin untreated. The position of the bypass openings also allowed for some flow to directly exit through the openings untreated. These issues can be seen in Figure 4.15.

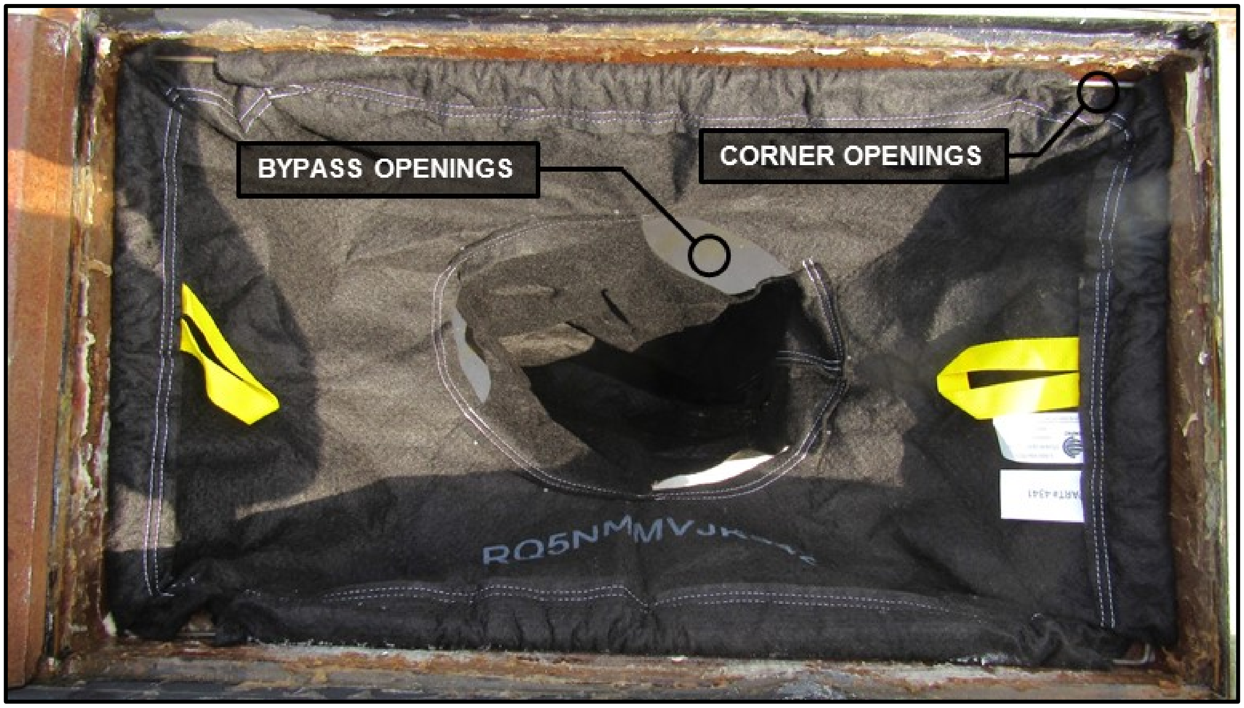


FIGURE 4.15 Openings in Storm Sentinel allow untreated bypass.

Figure 4.16(a) – 4.16(c) shows images of the Storm Sentinel during testing with OK110 silica sand under sheet flow and direct discharge conditions, and sandy loam soil under direct discharge conditions only.

0.06 cfs 0.12 cfs 0.18 cfs

(a) sheet flow testing with OK110 silica sand

0.06 cfs 0.12 cfs 0.18 cfs

(b) direct discharge testing with OK110 silica sand

0.06 cfs 0.12 cfs 0.18 cfs

(c) direct discharge testing with sandy loam soil

FIGURE 4.16 Storm Sentinel during testing using various test methods and soil types.

Table 4.6 (a-c) summarizes performance evaluation data for the Storm Sentinel when introducing OK110 silica sand under sheet flow and direct discharge conditions and sandy loam soil under direct discharge conditions only. Sediment retention was best when introducing OK110 silica sand under direct discharge, low flow conditions, and sediment retention values decreased as flow rate increased.

TABLE 4.6 Summary of Performance Data for Storm Sentinel for Various Tests and Soil Types

(a) Sheet Flow Testing with OK110 Silica Sand

Flow Rate, cfs	0.06	0.12	0.18
Sediment Introduced, lb (% error)	7.40 (4.52%)	13.94 (-1.55%)	21.88 (3.01%)
Sediment Captured, lb	4.38	5.72	4.75
Sediment Retention, %	59.2	41.0	21.7
Avg. TSS Removal, %	63.6	25.0	11.2
Time to Overflow, min	27	10	3

(b) Direct Discharge Testing with OK110 Silica Sand

Flow Rate, cfs	0.06	0.12	0.18
Sediment Introduced, lb (% error)	7.76 (9.60%)	14.66 (3.53%)	22.46 (5.74%)
Sediment Captured, lb	5.53	5.65	5.83
Sediment Retention, %	71.3	38.5	26.0
Avg. TSS Removal, %	90.7	76.0	35.1
Time to Overflow, min	16	5	3

(c) Direct Discharge Testing with Sandy Loam Soil

Flow Rate, cfs	0.06	0.12	0.18
Sediment Introduced, lb (% error)	3.05 (4.81%)	5.71 (-1.89%)	8.59 (-1.60%)
Sediment Captured, lb	1.27	1.72	1.74
Sediment Retention, %	41.6	30.1	20.3
Avg. TSS Removal, %	59.9	53.2	42.2
Time to Overflow, min	28	6	4

4.1.7 Contech Engineered Solutions Triton

The Triton is a cartridge-type CBI. The Triton base fits down into the catch basin and is sealed against the catch basin frame, preventing water from exiting the catch basin without passing through the replaceable filter cartridge that is installed on top of the base. The filter cartridge consists of a fine mesh medium, enclosed by a stainless steel housing that prevents debris from damaging the filter media. The cartridge also has a bypass opening at the top to allow water to exit the catch basin untreated by the filter cartridge in the event that the cartridge is too clogged to allow water to pass through adequately. While all other CBI's under consideration hung from the lip of the catch basin frame, allowing water to flow into the CBI, the Triton is designed to be supported from below, and allow water to impound around the device. Therefore, an acrylic box was constructed to simulate the sides of the catch basin. A large hole was cut into the bottom of the box to allow water to exit once it passed through the filter media of the CBI. A Triton platform was installed into the bottom of the box and sealed appropriately using a foam caulking to ensure water did not leave the box without passing through the filter (Contech Engineered Solutions, 2017).

Photos of the Triton installed in the testing catch basin can be seen in Figure 4.17.

(a) location 1 (b) location 2

(c) location 3 (d) location 4

(e) location 5 (f) location 6

FIGURE 4.17 Pre-test installation for Triton.

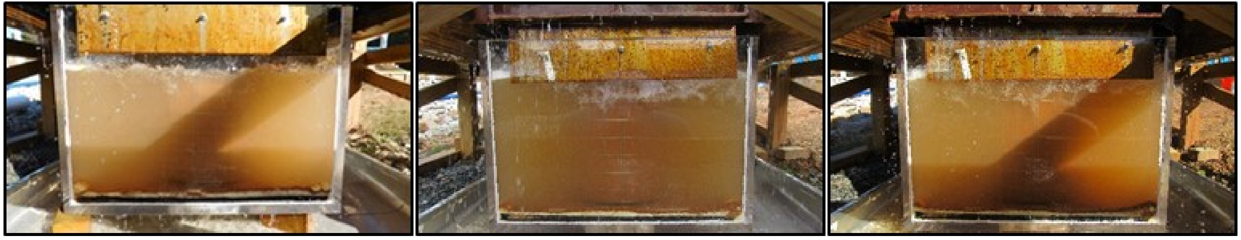
Figure 4.18 shows images of the Triton during testing with OK110 silica sand under sheet flow and direct discharge conditions and sandy loam soil under direct discharge conditions only.

0.06 cfs 0.12 cfs 0.18 cfs

(a) sheet flow testing with OK110 silica sand

0.06 cfs 0.12 cfs 0.18 cfs

(b) direct discharge testing with OK110 silica sand



0.06 cfs 0.12 cfs 0.18 cfs

(c) direct discharge testing with sandy loam soil

FIGURE 4.18 Triton during testing using various test methods and soil types.

Table 4.7 summarizes performance evaluation data for the Triton when introducing OK110 silica sand under sheet flow and direct discharge conditions, and sandy loam soil under direct discharge conditions only. The water level did not reach the bypass mechanisms for any of the tests. However, maximum impoundment depths are recorded in Table 4.7. Sediment retention values did not meet the 80% target removal rate.

TABLE 4.7 Summary of Performance Data for Triton for Various Test and Soil Types

(a) Sheet Flow Testing with OK110 Silica Sand

Flow Rate, cfs	**0.06**	**0.12**	**0.18**
Sediment Introduced, lb (% error)	7.27 (2.68%)	13.49 (-4.73%)	19.90 (-6.31%)
Sediment Captured, lb	4.32	6.61	8.99
Sediment Retention, %	59.4	49.0	45.2
Avg. TSS Removal, %	74.7	58.4	47.5
Time to Overflow, min	-	-	-
Max Impoundment, in.	9.5	14.0	15.25

(b) Direct Discharge Testing with OK110 Silica Sand

Flow Rate, cfs	**0.06**	**0.12**	**0.18**
Sediment Introduced, lb (% error)	7.23 (2.12%)	13.01 (-8.12%)	21.03 (-0.99%)
Sediment Captured, lb	4.95	7.77	9.44
Sediment Retention, %	68.5	59.7	44.9
Avg. TSS Removal, %	92.1	61.4	45.9
Time to Overflow, min	-	-	-
Max Impoundment, in.	13.75	15.0	15.5

(c) Direct Discharge Testing with Sandy Loam Soil

Flow Rate, cfs	**0.06**	**0.12**	**0.18**
Sediment Introduced, lb (% error)	2.75 (-5.5%)	5.60 (-3.8%)	7.59 (-13.0%)
Sediment Captured, lb	1.11	2.15	2.76
Sediment Retention, %	40.4	38.4	36.4
Avg. TSS Removal, %	40.0	58.1	49.7
Time to Overflow, min	-	-	-
Max Impoundment, in.	14.5	14.5	14.75

4.1.8 Water Quality Solutions Storm-Water Exfiltration BMP

The Water Quality Solutions (WQS) is a tray-type catch basin insert consisting of a hard-plastic outer shell with layers of filters stacked inside for a staged-treatment approach. The upper half of the CBI consists of four plastic mesh filters, each decreasing in mesh size deeper into the shell. The bottom half of the CBI consists of two fine mesh metal screens. The trays are arranged so that larger particles are captured near the top of the device, and finer particles are removed through the metal screens at the bottom of the device before treated flow exits the WQS through large holes in the bottom of the hard-plastic shell. Unlike other CBI's under consideration, the WQS has no bypass mechanism (Water Quality Solutions, LLC, 2017).

Photos of the WQS installed in the testing catch basin can be seen in Figure 4.19.

(a) location 1 (b) location 2

(c) location 3 (d) location 4

(e) location 5 (f) location 6

FIGURE 4.19 Pre-test installation for WQS.

Figure 4.20 shows images of the WQS during testing with OK110 silica sand under sheet flow and direct discharge conditions and sandy loam soil under direct discharge conditions only. Pictures are not available for the low and high flow rate tests in Figure 4.20(a) during the sheet flow testing with OK110 silica sand due to a corrupted file storage device.

NO PICTURE AVAILABLE

NO PICTURE AVAILABLE

0.06 cfs 0.12 cfs 0.18 cfs

(a) sheet flow testing with OK110 silica sand

0.06 cfs 0.12 cfs 0.18 cfs

(b) direct discharge testing with OK110 silica sand

0.06 cfs 0.12 cfs 0.18 cfs

(c) direct discharge testing with sandy loam soil

FIGURE 4.20 WQS during testing using various test methods and soil types.

It was noticed during installation that the plastic lip that supports the WQS on the catch basin frame may not have been strong enough to support the heavy weight of the CBI, causing the lip to become distorted, and allowing some flow to get around the CBI untreated. This can be seen by water flowing down the outside of the filter in Figure 4.21.

FIGURE 4.21 WQS with water flowing around device.

Since the WQS has no bypass mechanism, during the medium flow test using sandy loam soil under direct discharge conditions, the water level impounded inside the CBI until it was just below the bottom of the grate. However, when the flow rate was increased for the 0.18 cfs test, water flooded onto the platform by the 15 minute mark. By the 57 minute mark, water flooded the platform to the point of overtopping the 6 in. (15.24 cm) simulated curb. Images of the flooded platform can be seen in Figure 4.22.


(a) from side (b) from downstream (c) from upstream

FIGURE 4.22 Flooding during WQS high flow test using sandy loam soil under direct discharge conditions.

Table 4.8(a) – 4.8(c) summarizes performance evaluation data for the WQS when introducing OK110 silica sand under sheet flow and direct discharge conditions, and sandy loam soil under direct discharge conditions only. While sediment retention values did not meet the 80% target removal rate, it is worth noting that, on average, sediment retention values increased as flow rate increased. This was not common to the other CBIs that were evaluated. While it is impossible to monitor water levels inside the WQS during testing because of the many components inside, one possible explanation is that the low flow rate did not allow water to impound within the device, relying solely on the filter media to remove sediment. During higher flow tests, flow impounded during the tests, allowing particles to be removed via the filter media, and to fall out of suspension due to the impoundment.

TABLE 4.8 Summary of Performance Data for WQS for Various Test and Soil Types

(a) Sheet Flow Testing with OK110 Silica Sand

Flow Rate, cfs	**0.06**	**0.12**	**0.18**
Sediment Introduced, lb (% error)	7.48 (5.65%)	14.68 (3.67%)	22.43 (5.60%)
Sediment Captured, lb	0.20	4.00	6.01
Sediment Retention, %	2.7	27.3	26.8
Avg. TSS Removal, %	33.0	38.9	4.3
Time to Overflow, min	-	-	-

(b) Direct Discharge Testing with OK110 Silica Sand

Flow Rate, cfs	**0.06**	**0.12**	**0.18**
Sediment Introduced, lb	7.39 (4.38%)	14.47 (2.19%)	22.58 (6.31%)
Sediment Captured, lb	2.00	7.44	12.18
Sediment Retention, %	27.1	51.4	53.9
Avg. TSS Removal, %	40.2	48.5	52.0
Time to Overflow, min	-	-	-

(c) Direct Discharge Testing with Sandy Loam Soil

Flow Rate, cfs	**0.06**	**0.12**	**0.18**
Sediment Introduced, lb	2.81 (-3.44%)	5.85 (0.52%)	8.56 (-1.95%)
Sediment Captured, lb	1.20	2.89	4.32
Sediment Retention, %	42.7	49.4	50.5
Avg. TSS Removal, %	47.6	66.8	62.9
Time to Overflow, min	-	-	15

4.1.9 Summary of Performance Evaluation Testing

Table 4.9 summarizes all sediment retention percentage data for all performance evaluation tests. It can be seen that the Adsorb-It exceeded the 80% target removal rate multiple times, while other products failed to ever exceed the threshold. However, the Flexstorm, Storm Sentinel, Gullywasher, and Drainpac did come near the target, with sediment retention values reaching above 70%.

TABLE 4.9 Performance Evaluation Testing Summary

CBI UNDER CONSIDERATION	**FLOW TYPE**	**SHEET FLOW OK110**			**DIRECT DISCHARGE OK110**			**DIRECT DISCHARGE SANDY LOAM**		
	Flow Rate (cfs)	**0.06**	**0.12**	**0.18**	**0.06**	**0.12**	**0.18**	**0.06**	**0.12**	**0.18**
ADSORB-IT	Sediment Retention (%)	77.2	64.4	48.7	96.2	82.5	64.3	85.4	64.2	50.5
	TSS Reduction (%)	*59.1*	*67.1*	*56.6*	*92.4*	*85.6*	*69.0*	*72.1*	*70.8*	*61.1*
	Overflow Time (min)	-	*27*	*15*	-	*32*	*18*	*46*	*18*	*12*
DRAINPAC	Sediment Retention (%)	36.0	46.1	47.1	79.8	64.8	62.7	68.1	46.8	38.4
	TSS Reduction (%)	*45.4*	*56.4*	*57.6*	*76.0*	*64.9*	*71.6*	*63.6*	*51.7*	*33.8*
	Overflow Time (min)	-	*47*	*21*	*67*	*25*	*20*	*27*	*7*	*6*
FLEXSTORM	Sediment Retention (%)	51.2	56.8	46.5	71.3	50.2	36.3	65.4	58.3	43.9
	TSS Reduction (%)	*66.2*	*42.0*	*51.1*	*88.0*	*39.7*	*20.6*	*67.3*	*71.0*	*53.6*
	Overflow Time (min)	*46*	*24*	*9*	*33*	*10*	*7*	*35*	*20*	*11*
FLOGARD PLUS	Sediment Retention (%)	7.3	1.0	0.7	10.4	0.8	2.2	24.7	19.8	22.0
	TSS Reduction (%)	*18.5*	*11.5*	*16.7*	*24.6*	*15.8*	*28.8*	*41.2*	*27.9*	*51.3*
	Overflow Time (min)	-	-	-	-	-	-	-	-	-
GULLYWASHER	Sediment Retention (%)	75.8	58.8	41	67.1	47.8	35.7	51.7	38.1	33.4
	TSS Reduction (%)	*79.4*	*59.3*	*33.5*	*71.9*	*50.4*	*39.6*	*62.4*	*62.8*	*23.6*
	Overflow Time (min)	*42*	*11*	*6*	*21*	*7*	*3*	*16*	*6*	*5*
STORM SENTINEL	Sediment Retention (%)	59.2	41.0	21.7	71.3	38.5	26.0	41.6	30.1	20.3
	TSS Reduction (%)	*63.6*	*25.0*	*11.2*	*90.7*	*76.0*	*35.1*	*59.9*	*53.2*	*42.2*
	Overflow Time (min)	*27*	*10*	*3*	*16*	*5*	*3*	*28*	*6*	*4*
TRITON	Sediment Retention (%)	59.4	49	45.2	68.5	59.7	44.9	40.4	38.4	36.4
	TSS Reduction (%)	*74.7*	*58.4*	*47.5*	*92.1*	*61.4*	*45.9*	*40.0*	*58.1*	*49.7*
	Overflow Time (min)	-	-	-	-	-	-	-	-	*15*
WQS	Sediment Retention (%)	2.7	27.3	26.8	27.1	51.4	53.9	42.7	49.4	50.5
	TSS Reduction (%)	*33*	*38.9*	*4.3*	*40.2*	*48.5*	*52.0*	*47.6*	*66.8*	*62.9*
	Overflow Time (min)	-	-	-	-	-	-	-	-	-

In order to further analyze and compare performance of products, Table 4.9 was reorganized to rank performance of products based upon both sediment retention and TSS reduction for the direct discharge, low flow rate test with OK110 silica sand. From Table 4.10, it can be determined that the Adsorb-It was a top performing product in terms of both sediment retention and TSS reduction. The WQS and FloGard Plus were lower performing products for both performance metrics.

TABLE 4.10 Ranked Performance Evaluation Testing Results

(a) Sediment Retention Summary

	SHEET FLOW OK110			**DIRECT DISCHARGE OK110**			**DIRECT DISCHARGE SANDY LOAM**		
Flow Rate (cfs)	**0.06**	**0.12**	**0.18**	**0.06**	**0.12**	**0.18**	**0.06**	**0.12**	**0.18**
ADSORB-IT	77.2	64.4	48.7	96.2	82.5	64.3	85.4	64.2	50.5
DRAINPAC	36	46.1	47.1	79.8	64.8	62.7	68.1	46.8	38.4
FLEXSTORM	51.2	56.8	46.5	71.3	50.2	36.3	65.4	58.3	43.9
STORM SENTINEL	59.2	41	21.7	71.3	38.5	26	41.6	30.1	20.3
TRITON	59.4	49	45.2	68.5	59.7	44.9	40.4	38.4	36.4
GULLYWASHER	75.8	58.8	41	67.1	47.8	35.7	51.7	38.1	33.4
WQS	2.7	27.3	26.8	27.1	51.4	53.9	42.7	49.4	50.5
FLOGARD PLUS	7.3	1	0.7	10.4	0.8	2.2	24.7	19.8	22

Note: Products arranged according to DD-OK110-0.06 sediment retention.

(b) TSS Reduction Summary

	SHEET FLOW OK110			**DIRECT DISCHARGE OK110**			**DIRECT DISCHARGE SANDY LOAM**		
Flow Rate (cfs)	**0.06**	**0.12**	**0.18**	**0.06**	**0.12**	**0.18**	**0.06**	**0.12**	**0.18**
ADSORB-IT	59.1	67.1	56.6	92.4	85.6	69	72.1	70.8	61.1
TRITON	74.7	58.4	47.5	92.1	61.4	45.9	40	58.1	49.7
STORM SENTINEL	63.6	25	11.2	90.7	76	35.1	59.9	53.2	42.2
FLEXSTORM	66.2	42	51.1	88	39.7	20.6	67.3	71	53.6
DRAINPAC	45.4	56.4	57.6	76	64.9	71.6	63.6	51.7	33.8
GULLYWASHER	79.4	59.3	33.5	71.9	50.4	39.6	62.4	62.8	23.6
WQS	33	38.9	4.3	40.2	48.5	52	47.6	66.8	62.9
FLOGARD PLUS	18.5	11.5	16.7	24.6	15.8	28.8	41.2	27.9	51.3

Note: Products arranged according to DD-OK110-0.06 TSS reduction.

A multiple linear regression was conducted to determine the relative impact each of the four variables (e.g., product, discharge method, soil type, flow rate) has on sediment retention, independent of other factors. The dependent variable selected for the analysis, which is affected by each independent factor, was the sediment retention value associated with each test.

Table 4.11 summarizes findings from the product comparison portion of the linear regression analysis. The data allows us to compare the sediment retention capabilities of the products, while isolating the effect that the other factors (i.e., discharge method, soil type, flow rate) have on sediment retention. A p-value of less than α=0.05 suggests that there is a statistically significant difference between the product and the comparison. These comparison products are bolded in order to easily distinguish significant differences in performance. A significant p-value paired with a negative comparison coefficient suggests that the original product performs better than the comparison product, while a positive comparison coefficient suggests that the comparison product performed better. Therefore, the regression analysis suggests that the Adsorb-It retained sediment at a significantly higher rate than any of the other products, while the FloGard Plus retained sediment at a significantly lower rate than any of the other products.

TABLE 4.11 Product Comparison Using Linear Regression Analysis

Product	Product Coefficient	Comparison	Comparison Coefficient	p-value[1]
Adsorb-It	74.0	**Drainpac**	**-15.96**	**0.007**
		Flexstorm	**-17.06**	**0.004**
		Gullywasher	**-20.44**	**<0.001**
		Triton	**-20.74**	**<0.001**
		Storm Sentinel	**-31.52**	**<0.001**
		WQS	**-32.72**	**<0.001**
		FloGard Plus	**-60.50**	**<0.001**
Drainpac	58.04	**Adsorb-It**	**15.96**	**0.007**
		Flexstorm	-1.1	0.849
		Gullywasher	-4.49	0.438
		Triton	-4.78	0.424
		Storm Sentinel	**-15.57**	**0.009**
		WQS	**-16.76**	**0.004**
		FloGard Plus	**-44.54**	**<0.001**
Flexstorm	56.94	**Adsorb-It**	**17.06**	**0.004**
		Drainpac	1.1	0.849
		Gullywasher	-3.39	0.558
		Triton	-3.68	0.537
		Storm Sentinel	**-14.47**	**0.015**
		WQS	**-15.66**	**0.007**
		FloGard Plus	**-43.44**	**<0.001**
FloGard Plus	13.50	**Adsorb-It**	**60.50**	**<0.001**
		Drainpac	**44.54**	**<0.001**
		Flexstorm	**43.44**	**<0.001**
		Gullywasher	**40.06**	**<0.001**
		Triton	**39.76**	**<0.001**
		Storm Sentinel	**28.98**	**<0.001**
		WQS	**27.78**	**<0.001**
Gullywasher	53.55	**Adsorb-It**	**20.44**	**<0.001**
		Drainpac	4.49	0.438
		Flexstorm	3.39	0.558
		Triton	-0.29	0.961
		Storm Sentinel	-11.08	0.059
		WQS	**-12.28**	**0.033**
		FloGard Plus	**-40.06**	**<0.001**
Storm Sentinel	42.48	**Adsorb-It**	**31.52**	**<0.001**
		Drainpac	**15.57**	**0.009**
		Flexstorm	**14.47**	**0.015**
		Gullywasher	11.08	0.059
		Triton	10.79	0.074
		WQS	-1.20	0.832
		FloGard Plus	**-28.98**	**<0.001**
Triton	53.26	**Adsorb-It**	**20.74**	**<0.001**
		Drainpac	4.78	0.424
		Flexstorm	3.68	0.537
		Gullywasher	0.29	0.961
		Storm Sentinel	-10.79	0.074
		WQS	**-11.98**	**0.044**
		FloGard Plus	**-39.76**	**<0.001**
WQS	41.28	**Adsorb-It**	**32.72**	**<0.001**
		Drainpac	**16.76**	**0.004**
		Flexstorm	**15.66**	**0.007**
		Gullywasher	**12.28**	**0.033**
		Triton	**11.98**	**0.044**
		Storm Sentinel	1.20	0.832
		FloGard Plus	**-27.78**	**<0.001**

NOTE: [1] : $\alpha = 0.05$, bolded comparison products indicate significant difference in product coefficient

The regression analysis also analyzes the effects that the other products have on sediment retention analysis. Table 4.12 summarizes the regression results. Negative coefficients and significant *p*-values suggest that there is a significant decrease in sediment retention between low flow tests, and the medium and high flow tests. However, because the 0.06 ft^3/s flow was used as the constant during this regression analysis, it does not conclude whether there is a difference in sediment retention between medium and high flow tests. Therefore, a separate regression analysis was conducted with 0.12 ft^3/s as the base. The coefficient between the 0.12 ft^3/s and 0.18 ft^3/s flow rate was -7.25 with a *p*-value of 0.044, suggesting that there is a significant decrease in sediment retention going from the 0.12 ft^3/s tests to the 0.18 ft^3/s tests.

It can also be concluded that there was a significant increase in sediment retention between sheet flow and direct discharge method tests. This supports the observations that many of the products were allowing sheet flow to bypass the CBI, and therefore treating a smaller percentage of the runoff, and capturing less sediment. While the data does show that there was a small decrease in sediment retention amongst tests with sandy loam compared to tests with the OK110 silica sand, the *p*-value is greater than $\alpha=0.05$, meaning we cannot conclude that there is a significant difference in sediment retention amongst the two soil types.

TABLE 4.12 Test Characteristic Comparison

Factor	**Statistical Significance**	
	Coefficients	***p*-value[1]**
Constant	74.00	0.00
Flow (Base: 0.06 ft^3/s)		
0.12 ft^3/s	-8.14	0.024
0.18 ft^3/s	-15.39	<0.001
Discharge Method (Base: SF)		
DD	9.27	0.011
Soil Type (Base: OK110)		
Sandy Loam	-5.87	0.101

NOTE: [1] : $\alpha= 0.05$

4.1.9.1 Effect of Overflow on Sediment Retention

Sediment retention data was also used to analyze the effect overflow events had on CBI performance. Sediment retention data was separated into two categories: (1) tests where overflow does not occur, and (2) tests where overflow does occur. A two-sample t-test was then used to determine whether or not there was a significant difference in mean sediment retention between the two groups.

TABLE 4.13 Statistical Analysis of Overflow Characteristics

Factor	Mean Sediment Retention (%)	Observations	Difference (%)	*p*-value
Overflow does not occur	35.7	30	-16.5	0.002
Overflow does occur	52.2	42		

The *p*-value of 0.002 less than α=0.05 suggests that there is a difference in sediment retention results between tests where overflow does not occur and where overflow does occur. Average sediment retention results were actually higher during tests with an overflow event. A possible explanation for this is tests in which overflow events occur have maximized impoundment depths, which allow particles to settle out of suspension. This could also be an indication that sediment loss is greater through the fabric if flow never reaches the bypass. If fabric flow through is higher, then that may mean larger size sediment particles are able to pass through the fabric than what is allowed to be lost through the bypass. This could result in the larger mass fraction being contained within the product rather than it being passed through the fabric that has larger openings.

Another possible explanation for this is that of the 30 tests where overflow does not occur, nine tests were conducted using the FloGard Plus, which has already been proven statistically inferior to the other products. Observations of test concluded that during the nine FloGard Plus tests, little to no impoundment occurs, hindering the sediment retention capabilities, and possibly biasing the comparison between tests in which overflow does and does not occur. For this reason, the two-sample t-test assuming unequal variances was conducted again, but excluding the nine FloGard Plus tests. Results from this test can be seen in Table 4.14.

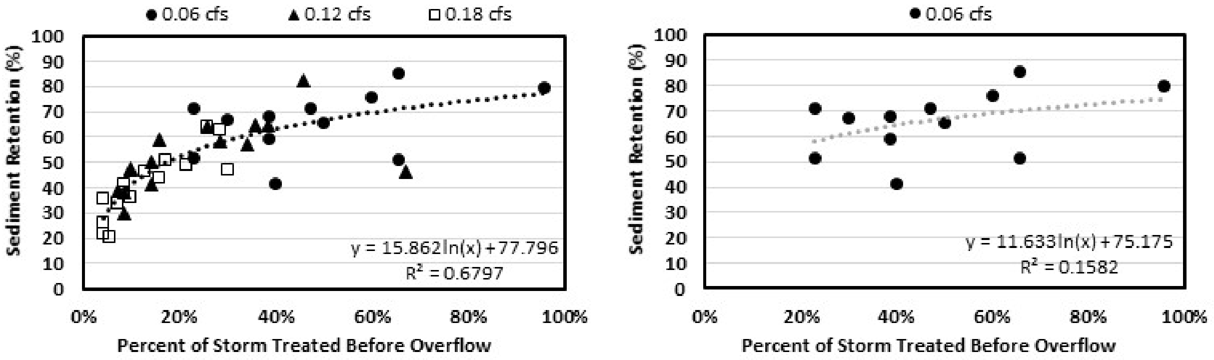
TABLE 4.14 Statistical Analysis of Oveflow Characteristics

Factor	Mean Sediment Retention (%)	Observations	Difference (%)	p-value
Overflow does not occur	46.8	21	-5.4	0.285
Overflow does occur	52.2	42		

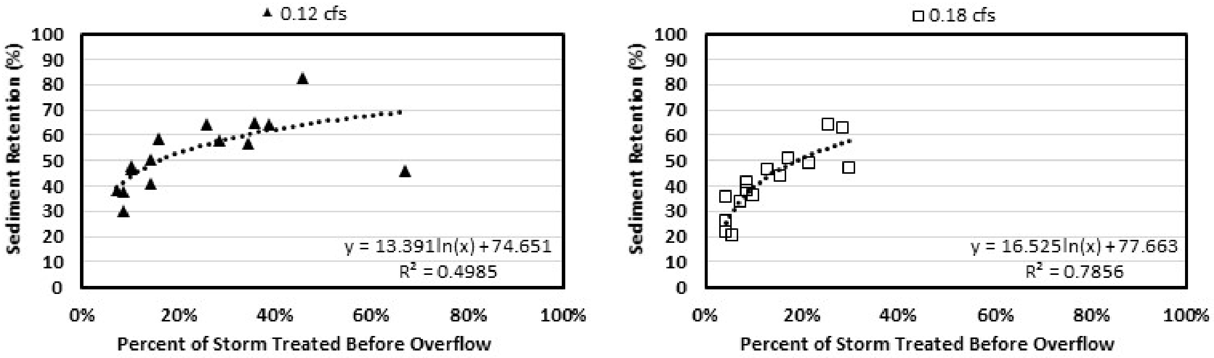
The *p*-value of 0.285 greater than *α*=0.05 suggests that there is no difference in sediment retention results between tests where overflow does not occur and where overflow does occur when excluding the nine FloGard Plus tests. Therefore, it is likely that overflow does not have an effect on sediment retention performance, and results from the previous statistical test were biased by the FloGard Plus results. This may also show that indeed, the flow through of the fabric has a greater effect on the performance of the product. In this case, the FloGard Plus created minimal impoundment, meaning a much greater flow through rate, resulting in much larger sediment particles to pass through the fabric, resulting in greatly decreased sediment retention.

To further analyze overflow characteristics, Figure 4.23 (a) plots sediment retention compared to the percent of the storm that was treated before overflow occurs. This illustrates the relationship between overflow and sediment retention values. For example, if 90% of the storm is treated before overflow occurs, sediment retention is likely to be greater than if only 10% of the storm was treated before overflow begins. The data was then fit with a logarithmic trend line to measure the relationship between the two variables. It can be seen from the coefficient of determination that there is a positive, moderately strong correlation between time at which overflow occurs and sediment retention. This means that tests that lasted longer before allowing overflow were more likely to retain a higher percentage of the introduced sediment. A logarithmic trend line provided the best-fit trend line because, while sediment retention does continue to increase with increase in time before overflow, sediment retention will eventually near a maximum and begin to plateau. Therefore, if overflow occurs early, one can expect much less sediment to be captured. However, overflow that begins near the end of the event has little impact on sediment retention. From these analyzes, it appears that the best performing product would be one that minimizes flow through the fabric to the point of water impounding to near the point of overflow. However, overflow should be minimal and begin near the end of the storm event, resulting in the largest percent of particle size capture.

Figure 4.23 (b) – 4.23(d) contain the same information as Figure 4.23 (a), but are separated by the flow rate tests used for testing. It can be seen that there is little correlation between overflow and sediment retention during low flow tests. However, correlation increases with flow rate. One possible explanation for this is that higher flow rates enter the CBI with greater energy, therefore causing re-suspension of captured particles, and hindering sediment retention. At low flow rates, the influent enters the catch basin with less energy and less potential for re-suspension, therefore having little effect on sediment retention.



(a) all flow rates (b) 0.06 ft^3/s



(c) 0.12 ft^3/s (d) 0.18 ft^3/s

FIGURE 4.23 Comparing Overflow to sediment retention.

4.2 LONGEVITY TESTING

Longevity testing was performed to better understand the performance characteristics of the products overtime. Based upon performance testing it was determined that the low flow rate of 0.06 ft^3/s would be used to test the products for longevity because, with the exception of the Adsorb-It, no CBI successfully captured 80% of the introduced sediment at the 0.12 ft^3/s or 0.18 ft^3/s flow rates. Therefore, target sediment introductions for the tests were 7.08 lb for OK110 tests and 2.91 lb for sandy loam tests. As with the performance testing, sediment capture was determined by pre- and post-test weight of the CBI. However, since the purpose of longevity testing is to determine temporal performance, pre- and post-test weights were determined for each longevity test, resulting in a cumulative sediment retention for each test. Tables and figures are presented with each product to show overall performance. Furthermore, figures with graphs showing the trends in the weight of sediment introduced, captured, and bypassed during the longevity tests are included. For example, when evaluating the graphs, the difference between the sediment introduction line and the sediment captured line will determine sediment capture performance over time. This is determined by the difference in the lines growing greater or smaller over time. If the difference increases, sediment retention decreases over time and vice versa. This distance is also equivalent to the value of the sediment bypassed line shown on each graph, which shows the amount of sediment bypassing, or not being captured by the products.

Note, test names are abbreviated, whereas L1 is longevity test 1, L2 is longevity test 2 and so on.

4.2.1 Stormwater BMP Products Adsorb-It Stormfilters

Four longevity tests of the Adsorb-It were conducted using each of the soil types. Overflow was not reached during the L1 test, but was reached during the remaining three tests at 40, 4 and 1 minutes, respectively when using OK110 silica sand. Overflow occurred during all four tests with sandy loam soil at 60 minutes for the L1 test, 2 minutes for the L2 test, and less than one minute for both the L3 and L4 tests. The rapid difference in overflow times between L1 and L2 tests indicate that the soils severely blinded the filter media, inhibiting flow-through and causing the device to fill quickly in subsequent tests.

Table 4.15 summarizes longevity data for the Adsorb-It when introducing OK110 silica sand and sandy loam. During the L1 test with OK110 silica sand, the Adsorb-It retained 95.6% of the introduced sediment, which was similar to the 96.1% sediment retention determined when evaluating the Adsorb-It under similar conditions during performance evaluation testing. The Adsorb-It was then tested again and retained 88.4% of the sediment introduced during the L2 test, bringing the cumulative retention to 92.0%. An L3 test was conducted with a sediment retention of 72.4% and a cumulative retention of 85.7% across the three tests. While the sediment retention performance for the L3 test was below the 80% rate, the cumulative retention was still well above, so it was determined that the Adsorb-It would be tested a fourth time, resulting in an individual retention of 55.7% and a cumulative retention of 78.9% falling below the required threshold. While a 78.9% cumulative retention is just below the 80% target, longevity testing was concluded at this point due to the steady decrease in individual test performance.

During the L1 test with sandy loam soil, the Adsorb-It retained 86.8% of the sediment introduced, which was similar to the sediment retention of 85.4% determined when using sandy loam soil at the low flow rate during performance evaluation testing. The Adsorb-It was then tested again and retained 49.8% of the sediment introduced during the L2 test, bringing the cumulative retention to 68.4%. An L3 test was conducted with a sediment retention of 53.6% and a cumulative retention of 63.5% across the three tests. During the testing of the L4 test, the Adsorb-It retained 53.8% of the sediment introduced for a cumulative retention of 61.6%, concluding longevity testing for the Adsorb-It. It is worth noting that the performance across the L2, L3, and L4 tests were very similar, and had similar overflow times. The results indicate that while the Adsorb-It is capable of reaching the 80% sediment retention rate with the sandy loam soil, maintenance must occur frequently in order to maintain performance overtime.

TABLE 4.15 Longevity Testing for Adsorb-It

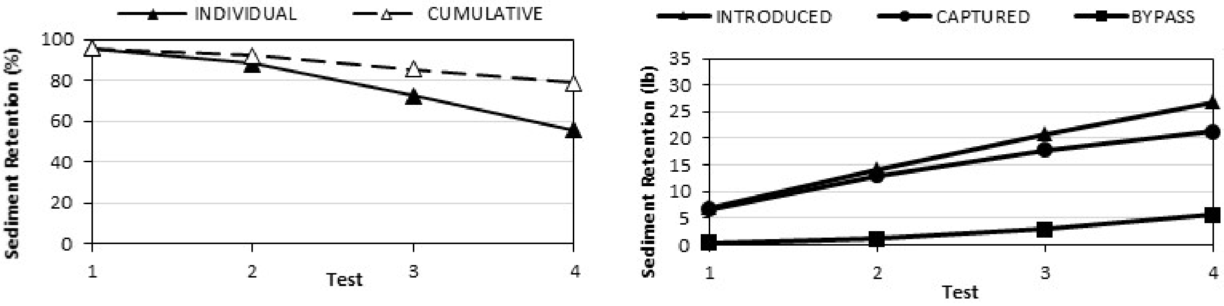
(a) Longevity Testing with OK110 Silica Sand

Performance Metric	L1	L2	L3	L4
Sediment Introduced, lb	7.04	7.09	6.64	6.10
Sediment Captured, lb	6.73	6.27	4.81	3.40
Sediment Retention, %	95.6	88.4	72.4	55.7
Collective Retention, %	95.6	92.0	85.7	78.9
Time to Overflow, min	-	40	4	1

(b) Longevity Testing with Sandy Loam Soil

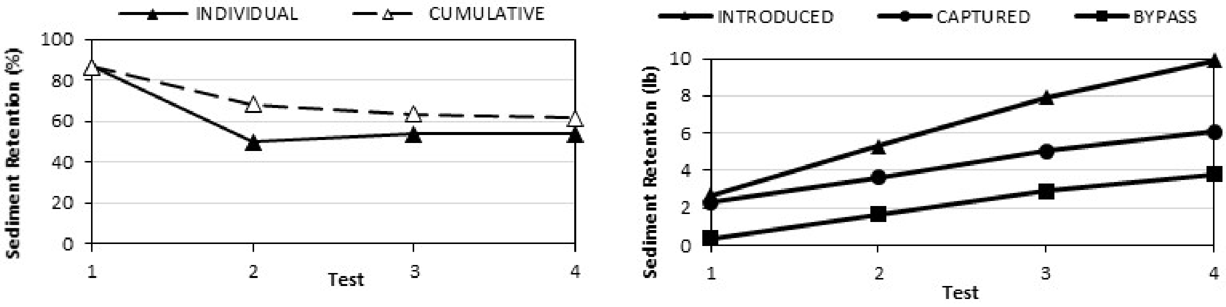
Performance Metric	L1	L2	L3	L4
Sediment Introduced, lb	2.66	2.63	2.63	1.97
Sediment Captured, lb	2.31	1.31	1.41	1.06
Sediment Retention, %	86.8	49.8	53.6	53.8
Collective Retention, %	86.8	68.4	63.5	61.6
Time to Overflow, min	60	2	1	1

Figure 4.24 shows sediment bypassing increases, or is not being captured at the same rate, over time by the Adsorb-It, indicating a decline in performance and a need for maintenance.



(a) OK110 silica sand – Percent Retained

(b) OK110 silica sand – Mass Retained



(c) Percent Retained - Sandy Loam Soil

(d) Mass Retained - Sandy Loam Soil

FIGURE 4.24 Overall sediment retention for Adsorb-It during longevity tests.

4.2.2 United Storm Water Drainpac

Eight longevity tests were conducted on the Drainpac using OK110 silica sand. Overflow was not reached during the L1 test, but was reached during the remaining tests at 65, 7, 14, 13, 8, 3, and 11 minutes, respectively. Tests L3 through L8 had little variance between overflow times, indicating that there was little change in flow-through rate after the blinding conditions were reached. Two longevity tests were conducted using the sandy loam soil, with overflow at 33 and 4 minutes, respectively. Overflow was reached much quicker during sandy loam soil tests than with OK110 silica sand, indicating that the high clay content in the sandy loam soil played a role in blinding the material more than the high sand content of the OK110 silica sand.

Table 4.16 summarizes longevity data for the Drainpac when introducing OK110 silica sand and sandy loam. During the L1 test with OK110 silica sand, the Drainpac retained 80.0% of the introduced sediment, which was similar to the 79.8% sediment retention determined when evaluating the Adsorb-It under similar conditions during performance evaluation testing. The Drainpac was then tested again and retained 81.7% of the sediment introduced during the L2 test, bringing the cumulative retention to 80.9%. An L3 test was conducted with a sediment retention of 68.4% and a cumulative retention of 76.7% across the three tests. Sediment retention fluctuated with each test, increasing in retention, decreasing in retention, and continuing. For this reason, longevity testing was expanded to eight tests to further observe the pattern and ensure that the Drainpac would not reach the 80% target in another test. After the eighth test, it was determined that longevity testing could be concluded.

During the L1 test with sandy loam soil, the Drainpac retained 60.3% of the sediment introduced, which was similar to the sediment retention of 68.1% determined when using sandy loam soil at the low flow rate during performance evaluation testing. The Drainpac was then tested again and retained 45.5% of the sediment introduced during the L2 test, bringing the cumulative retention to 53.0%. At this point, it was determined that longevity testing could be concluded. From the longevity testing, the Drainpac did not meet the requirement for retaining 80% of the introduced sediment under the sandy loam soil testing conditions.

TABLE 4.16 Longevity Testing for Drainpac

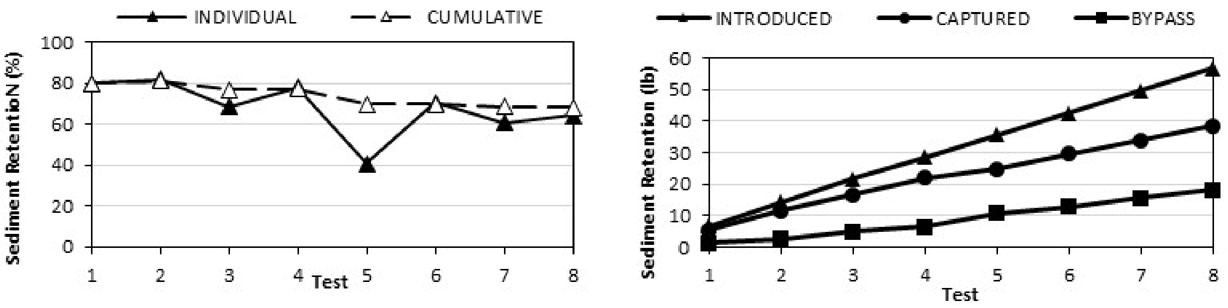
(a) Longevity Testing with OK110 Silica Sand

Performance Metric	L1	L2	L3	L4	L5	L6	L7	L8
Sediment Introduced, lb	6.74	7.55	7.35	6.84	7.10	6.84	7.15	7.17
Sediment Captured, lb	5.39	6.17	5.03	5.34	2.88	4.82	4.34	4.61
Sediment Retention, %	80.0	81.7	68.4	78.1	40.6	70.5	60.7	64.3
Cumulative Retention, %	80.0	80.9	76.7	77.0	69.7	69.8	68.5	68.0
Time to Overflow, min		65	7	14	13	8	3	11

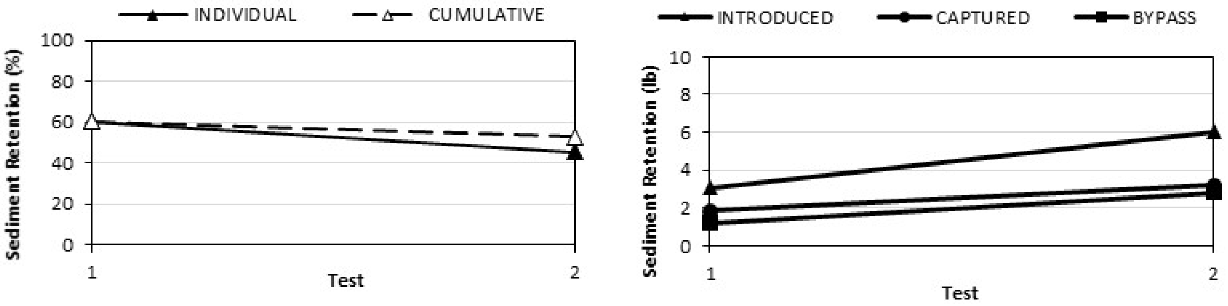
(b) Longevity Testing with Sandy Loam Soil

Performance Metric	L1	L2	L3	L4	L5	L6	L7	L8
Sediment Introduced, lb	3.05	2.97	-	-	-	-	-	-
Sediment Captured, lb	1.84	1.35	-	-	-	-	-	-
Sediment Retention, %	60.3	45.5	-	-	-	-	-	-
Cumulative Retention, %	45.5	53.0	-	-	-	-	-	-
Time to Overflow, min	33	4	-	-	-	-	-	-

Figure 4.25 was included to further analyze the Drainpac over the longevity tests. Sediment capture rate decreases overtime while bypass increases, indicating a decline in performance and a need for maintenance. Further analysis of Figure 4.25 also shows that, while sediment retention appeared volatile when considering the percentages individually for each test, it can be seen that sediment retention is actually fairly linear across all eight tests, with the exception of the one L5 tests, which could be considered an outlier.



(a) OK110 silica sand – Percent Retained (b) OK110 silica sand – Mass Retained



(c) Percent Retained - Sandy Loam Soil (d) Mass Retained - Sandy Loam Soil

FIGURE 4.25 Overall sediment retention for Drainpac during longevity tests.

Another observation during the eight longevity tests was the wear of the device after significant loading. A total of 56.74 lb of sediment was introduced with 38.58 lb of sediment captured over the eight longevity tests. A large portion of this sediment was stored between the metal basket frame and the filter fabric lining, putting excess loading on the bag which started causing the plastic netting to pull away from its anchor point. The damage can be seen in Figure 4.26 from both the front and side views.

(a) front view (b) side view

FIGURE 4.26 Damage to Drainpac after L8 tests.

4.2.3 Advanced Drainage Systems Flexstorm

Four longevity tests with OK110 silica sand were conducted with the Flexstorm. While the water level inside the Flexstorm never reached the untreated bypass mechanism built into the Flexstorm frame, treated bypass was reached during the four tests at 40, 29, 30, and 31 minutes, respectively. The Flexstorm also underwent two longevity tests with sandy loam soil. Again, water level inside the Flexstorm never reached the untreated bypass mechanism built into the Flexstorm frame. However, treated bypass was reached during the two tests at 45 minutes and 1 minute, respectively. The Flexstorm was affected differently by the two soil types, based upon the difference in overflow times. When using the OK110 silica sand, there was little change in overflow time, especially between the final three tests. However, with the sandy loam soil, overflow was reached much faster after the first test. This is likely due to the higher clay content in the sandy loam soil. The clay particles can cause the material to blind, or clog, which can reduce the flow-through rate of the material after the initial test.

Table 4.17 summarizes longevity data for the Flexstorm when introducing OK110 silica sand and sandy loam. During the L1 test with OK110 silica sand, the Flexstorm retained 88.3% of the introduced sediment, which was higher than the 71.3% sediment retention determined when evaluating the Flexstorm under similar conditions during performance evaluation testing. The Flexstorm was then tested again, with the 7.17 pounds of sediment collected from the L1 tests still contained within the product, and retained 64.5% of the sediment introduced during the L2 test. However, while the 64.5% was below the desired 80% retention, the collective retention percentage between the two tests was still at 76.8%. Therefore, it was determined that an L3 test would be conducted, which resulted in a 58.8% sediment retention, and a collective retention of 71.1% across the three tests. While the sediment retention performance did decrease from L2 to L3, the decrease was small. Finally, L4 test was conducted to strain the CBI until a significant drop in performance was seen. The Flexstorm only retained 31.2% of the introduced sediment during the L4 test, leaving the collective retention at 61.3%. At this point, it was determined that longevity testing could be concluded.

During the L1 test with sandy loam soil, the Flexstorm retained 64.8% of the sediment introduced, similar to the 65.4% sediment retention when using sandy loam soil at the low flow rate during performance evaluation testing. While this performance is already below the 80% target rate, an L2 test was performed to assure that the 80% rate would not be reached in a following event. During the L2 test, only 49.7% of the introduced sediment was retained, for a cumulative retention of 57.0% at which point longevity testing was concluded. The results from longevity testing show that the Flexstorm is not capable of meeting the 80% sediment removal rate under the testing conditions.

TABLE 4.17 Longevity Testing for Flexstorm

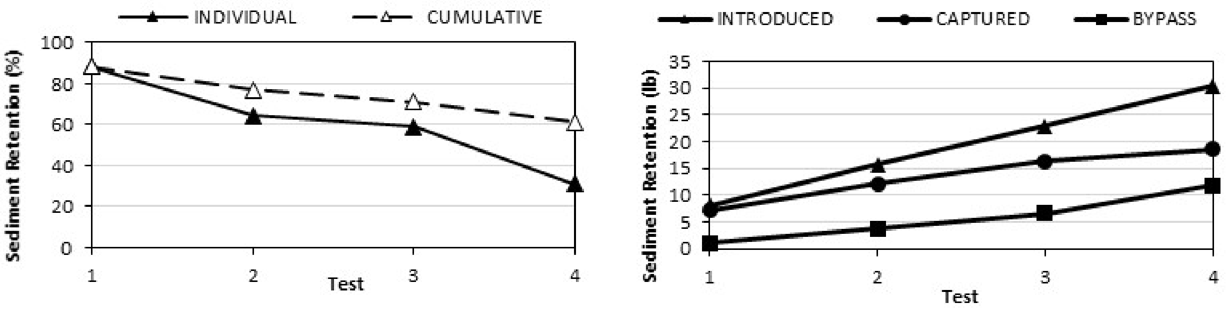
(a) Longevity Testing with OK110 Silica Sand

Performance Metric	L1	L2	L3	L4
Sediment Introduced, lb	8.12	7.60	7.21	7.50
Sediment Captured, lb	7.17	4.90	4.24	2.34
Sediment Retention, %	88.3	64.5	58.8	31.2
Cumulative Retention, %	88.3	76.8	71.1	61.3
Time to Overflow, min	40	29	31	30

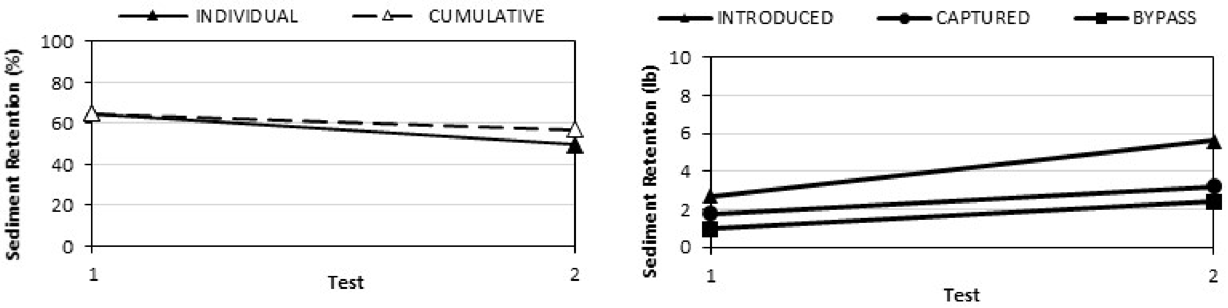
(b) Longevity Testing with Sandy Loam Soil

Performance Metric	L1	L2	L3	L4
Sediment Introduced, lb	2.70	2.90	-	-
Sediment Captured, lb	1.75	1.44	-	-
Sediment Retention, %	64.8	49.7	-	-
Cumulative Retention, %	64.8	57.0	-	-
Time to Overflow, min	45	1	-	-

Figure 4.27 further analyzes the Flexstorm performance over the longevity tests. Notice the difference between the sediment introduced and sediment capture increases with each test, indicating a decline in performance and a need for maintenance.



(a) OK110 silica sand – Percent Retained
(b) OK110 silica sand – Mass Retained



(c) Percent Retained - Sandy Loam Soil
(d) Mass Retained - Sandy Loam Soil

FIGURE 4.27 Overall sediment retention for Flexstorm during longevity tests.

4.2.4 Oldcastle Stormwater Solutions FloGard Plus

The FloGard Plus was only tested once per soil type for longevity because of low sediment retention performance that was verified when compared to performance testing results. Similar to performance evaluation tests, there was little to no impoundment within the CBIs and no overflow conditions occurred.

Table 4.18 summarizes longevity data for the FloGard Plus when introducing OK110 silica sand and sandy loam. During the L1 test with OK110 silica sand, the FloGard Plus retained 2.3% of the introduced sediment, which was similar to, but slightly lower than, the 10.4% sediment retention determined when evaluating the FloGard Plus under similar conditions during performance evaluation testing. During the L1 test with sandy loam soil, the FloGard Plus retained 18.0% of the sediment introduced, which was similar to the sediment retention of 24.7% determined when using sandy loam soil at the low flow rate during performance evaluation testing.

TABLE 4.18 Longevity Testing for FloGard Plus

(a) Longevity Testing with OK110 Silica Sand

Performance Metric	L1
Sediment Introduced, lb	6.91
Sediment Captured, lb	0.16
Sediment Retention, %	2.3
Cumulative Retention, %	2.3
Time to Overflow, min	-

(b) Longevity Testing with Sandy Loam Soil

Performance Metric	L1
Sediment Introduced, lb	2.72
Sediment Captured, lb	0.49
Sediment Retention, %	18.0
Cumulative Retention, %	18.0
Time to Overflow, min	-

Sediment retention and cumulative performance graphs were not developed for FloGard Plus results because there was only one data point for each metric on each graph.

4.2.5 Gullywasher Metal Compliant CBIs

Longevity testing of the Gullywasher using OK110 silica sand was conducted over three tests. Overflow was reached during the three tests at 24, 7 and 2 minutes, respectively. Longevity testing with sandy loam soil was concluded after two tests, with overflow times of 26 minutes and 1 minute, respectively. The difference in overflow times from L1 to L2 indicate that sandy loam soil severely blinded the fabric after the first tests, inhibiting flow-through rate and causing the CBI to fill to the overflow point very quickly. It can be seen in Figure 4.28 that the flow coming through the bypass during the L2 test was much more severe than the flow exiting the bypass during the L1 test.


(a) L1 (b) L2

FIGURE 4.28 Gullywasher during longevity testing with sandy loam soil.

Table 4.19 summarizes longevity data for the Gullywasher when introducing OK110 silica sand and sandy loam. During the L1 test with OK110 silica sand, the Gullywasher retained 75.9% of the introduced sediment, which was similar to, but slightly higher than, the 67.1% sediment retention determined when evaluating the Gullywasher under similar conditions during performance evaluation testing. The Gullywasher was then tested again, with the 5.81 pounds of sediment collected from the L1 test, and retained 64.9% of the sediment introduced during the L2 test, bringing the cumulative retention to 70.4%. An L3 test was conducted with a sediment retention of 50.8% and a cumulative retention of 64.2% across the three tests. At this point, it was determined that longevity testing could be concluded. While the Gullywasher never reached the 80% sediment retention target, results from the testing show the potential to perform near this threshold under these testing conditions. However, the longevity data can also be used to conclude that the Gullywasher would have to be maintained after almost every small storm event in order to continue performance.

During the L1 test with sandy loam soil, the Gullywasher retained 53.1% of the sediment introduced, which was similar to the sediment retention of 51.7% determined when using sandy loam soil at the low flow rate during performance evaluation testing. While this performance is already below the 80% target rate, an L2 test was performed assure that the 80% rate would not be reached in a following event. During the L2 test, only 39.8% of the introduced sediment was retained, for a cumulative retention of 46.9%, and longevity testing was concluded. The results from longevity testing show that the Gullywasher is not capable of meeting the 80% sediment removal rate under the testing conditions.

TABLE 4.19 Longevity Testing for Gullywasher

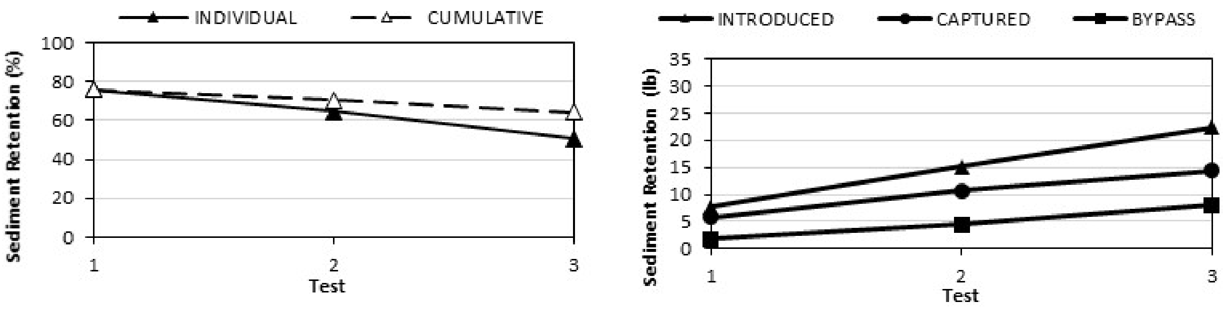
(a) Longevity Testing with OK110 Silica Sand

Performance Metric	L1	L2	L3
Sediment Introduced, lb	7.65	7.54	7.12
Sediment Captured, lb	5.81	4.89	3.62
Sediment Retention, %	75.9	64.9	50.8
Cumulative Retention, %	75.9	70.4	64.2
Time to Overflow, min	24	7	2

(b) Longevity Testing with Sandy Loam Soil

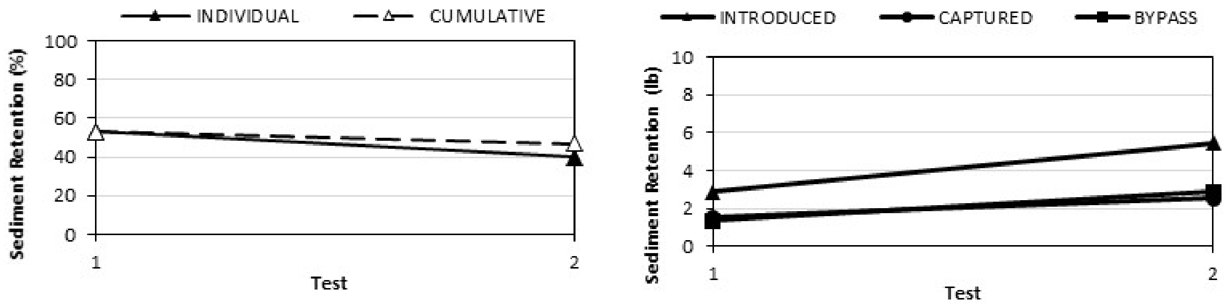
Performance Metric	L1	L2	L3
Sediment Introduced, lb	2.90	2.56	-
Sediment Captured, lb	1.54	1.02	-
Sediment Retention, %	53.1	39.8	-
Cumulative Retention, %	53.1	46.9	-
Time to Overflow, min	26	1	-

Figure 4.29 shows the difference between the introduced and captured lines is increasing with each tests, indicating a decline in performance and a need for maintenance.



(a) OK110 silica sand – Percent Retained

(b) OK110 silica sand – Mass Retained



(c) Percent Retained - Sandy Loam Soil

(d) Mass Retained - Sandy Loam Soil

FIGURE 4.29 Overall sediment retention for Gullywasher during longevity tests.

4.2.6 Enpac Storm Sentinel

Two longevity tests were conducted on the Storm Sentinel with both the OK110 silica sand and sandy loam soil. Overflow was reached during the two OK110 silica sand tests at 22 and 13 minutes, and 22 and 21 minutes during the two sandy loam soil tests.

Table 4.20 summarizes longevity data for the Storm Sentinel when introducing OK110 silica sand and sandy loam. During the L1 test with OK110 silica sand, the Flexstorm retained 46.2% of the introduced sediment, which was lower than the 71.3% sediment retention determined when evaluating the Storm Sentinel under similar conditions during performance evaluation testing. This difference could be contributed to variations in the product material. The Storm Sentinel was then tested again, with the 3.43 pounds of sediment collected from the L1 tests, and retained 44.1% of the sediment introduced during the L2 test, bringing the cumulative retention to 45.2%. Since there was little difference in performance from L1 to L2, and both tests were well below the 80% target rate longevity testing was concluded. The results from longevity testing show that the Storm Sentinel is not capable of meeting the 80% sediment removal rate under these testing conditions.

During the L1 test with sandy loam soil, the Storm Sentinel retained 41.6% of the sediment introduced, which was exactly the same sediment retention determined when using sandy loam soil at the low flow rate during performance evaluation testing. While this performance is already below the 80% target rate, an L2 test was performed in order to be sure that the 80% rate would not be reached in a following event. During the L2 test, only 36.0% of the introduced sediment was retained, for a cumulative retention of 38.8%, and longevity testing was concluded. The results from longevity testing show that the Storm Sentinel is not capable of meeting the 80% sediment removal rate under these testing conditions.

TABLE 4.20 Longevity Testing for Storm Sentinel

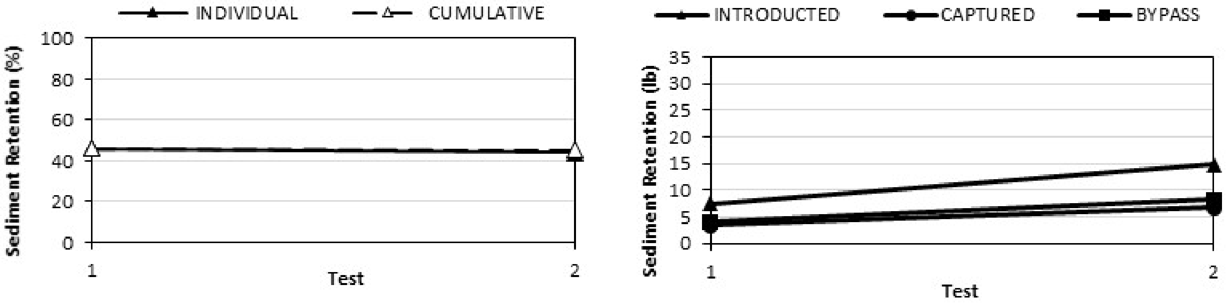
(a) Longevity Testing with OK110 Silica Sand

Performance Metric	L1	L2
Sediment Introduced, lb	7.43	7.43
Sediment Captured, lb	3.43	3.28
Sediment Retention, %	46.2	44.1
Cumulative Retention, %	46.2	45.2
Time to Overflow, min	22	13

(b) Longevity Testing with Sandy Loam Soil

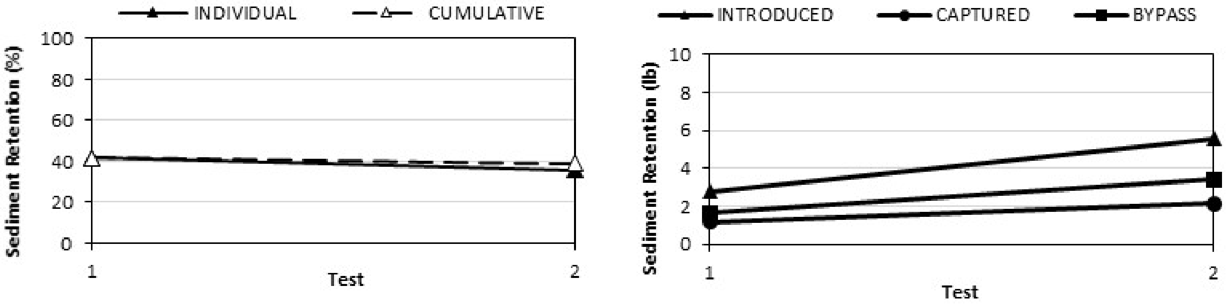
Performance Metric	L1	L2
Sediment Introduced, lb	2.79	2.78
Sediment Captured, lb	1.16	1.00
Sediment Retention, %	41.6	36.0
Cumulative Retention, %	41.6	38.8
Time to Overflow, min	22	21

Figure 4.30 shows the difference between the introduced and captured lines is increasing with each test, indicating a decline in performance and a need for maintenance.



(a) OK110 silica sand – Percent Retained

(b) OK110 silica sand – Mass Retained



(c) Percent Retained - Sandy Loam Soil

(d) Mass Retained - Sandy Loam Soil

FIGURE 4.30 Overall sediment retention for Storm Sentinel during longevity tests.

4.2.7 Contech Engineered Solutions Triton

Two longevity tests were conducted on the Triton for each soil type. Figure 4.31 was included to showcase how the sandy loam soil clogs the cartridge medium and fills the catch basin box faster than with the OK110 silica sand, which also lead to larger impoundment depths, even though untreated bypass was never reached for any of the tests.

(a) L1 test with OK110 silica sand (b) L1 test with sandy loam soil

FIGURE 4.31 Triton during longevity testing.

Table 4.21 summarizes longevity data for the Triton when introducing OK110 silica sand and sandy loam, respectively. During the L1 test with OK110 silica sand, the Triton retained 66.2% of the introduced sediment, which was similar to the 68.5% sediment retention determined when evaluating the Triton under similar conditions during performance evaluation testing. The Triton was then tested again and retained 20.8% of the sediment introduced during the L2 test, bringing the cumulative retention to 42.8%. Results from the longevity testing show that the Triton is not capable of meeting performance standards under these testing conditions.

During the L1 test with sandy loam soil, the Triton retained 66.7% of the sediment introduced, which was higher than the sediment retention of 40.4% determined when using sandy loam soil at the low flow rate during performance evaluation testing. The Triton was then tested again and retained 48.8% of the sediment introduced during the L2 test, bringing the cumulative retention to 57.7%, concluding longevity tests since the Triton is not capable of retaining 80% of the introduced sediment under these testing conditions.

TABLE 4.21 Longevity Testing for Triton

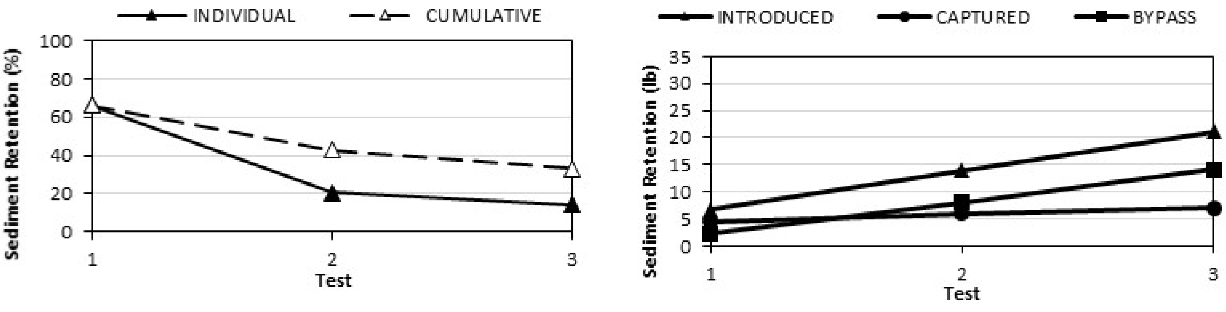
(a) Longevity Testing with OK110 Silica Sand

Performance Metric	L1	L2	L3
Sediment Introduced, lb	6.80	7.22	7.06
Sediment Captured, lb	4.50	1.50	1.00
Sediment Retention, %	66.2	20.8	14.2
Collective Retention, %	66.2	42.8	33.2
Time to Overflow, min	-	-	-

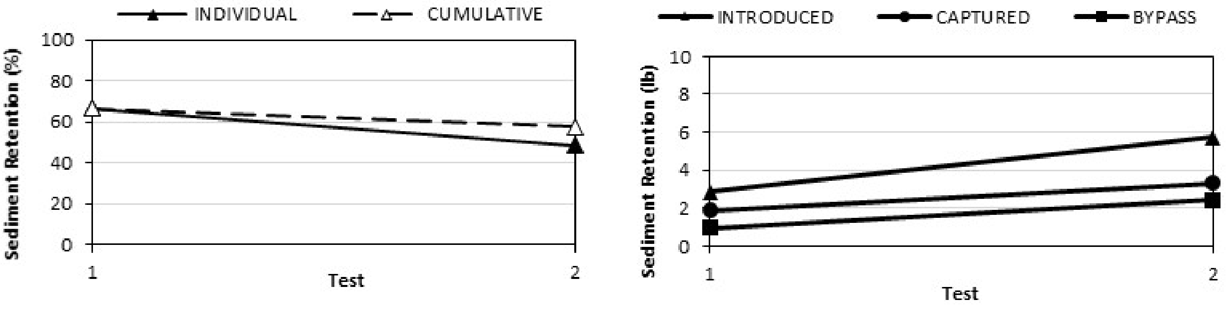
(b) Longevity Testing with Sandy Loam Soil

Performance Metric	L1	L2	L3
Sediment Introduced, lb	2.85	2.87	-
Sediment Captured, lb	1.90	1.40	-
Sediment Retention, %	66.7	48.8	-
Collective Retention, %	66.7	57.7	-
Time to Overflow, min	-	-	-

Figure 4.32 shows that the amount of sediment bypassing, the Drainpac grows with each test, indicating a decline in performance and a need for maintenance.



(a) OK110 silica sand – Percent Retained (b) OK110 silica sand – Mass Retained



(c) Percent Retained - Sandy Loam Soil (d) Mass Retained - Sandy Loam Soil

FIGURE 4.32 Overall sediment retention for Triton during longevity tests.

4.2.8 Water Quality Solutions Storm-Water Exfiltration BMP

Two longevity tests were conducted on the WQS for each soil type. The WQS is not equipped with an overflow bypass mechanism, therefore overflow was not observed during the longevity tests.

Table 4.22 summarizes longevity data for the WQS when introducing OK110 silica sand and sandy loam. Target sediment introductions for the tests were 7.08 lb for OK110 tests and 2.91 lb for sandy loam tests. During the L1 test with OK110 silica sand, the WQS retained 41.9% of the introduced sediment, which was higher than the 27.1% sediment retention determined when evaluating the WQS under similar conditions during performance evaluation testing. The WQS was then tested again and retained 55.3% of the sediment introduced during the L2 test, bringing the cumulative retention to 48.7%, concluding longevity testing with the OK110 soil. Results from the longevity testing show that the WQS is not capable of reaching the 80% sediment retention rate under the OK110 soil testing conditions. Unlike most other CBIs tested, the WQS actually performed better at the L2 test than at the L1 test. However, it is worth noting that sediment retention actually increased at higher flow rates with the WQS, suggesting that the product performance may benefit from pre-captured sediment.

During the L1 test with sandy loam soil, the WQS retained 62.7% of the sediment introduced, which was higher than the sediment retention of 42.7% determined when using sandy loam soil at the low flow rate during performance evaluation testing. The WQS was then tested again and retained 55.7% of the sediment introduced during the L2 test, bringing the cumulative retention to 59.2%. At this point, it was determined that longevity testing could be concluded. The results indicate that the WQS is not capable of reaching the 80% sediment retention rate with the sandy loam soil.

TABLE 4.22 Longevity Testing for WQS

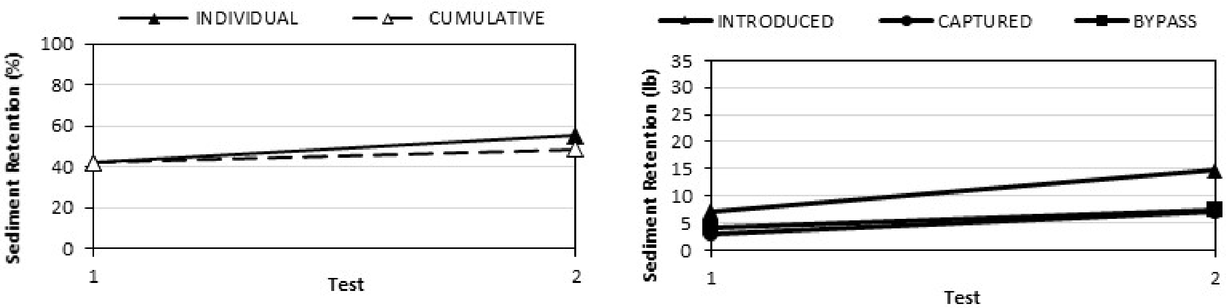
(a) Longevity Testing with OK110 Silica Sand

Performance Metric	L1	L2
Sediment Introduced, lb	7.23	7.48
Sediment Captured, lb	3.03	4.14
Sediment Retention, %	41.9	55.3
Collective Retention, %	41.9	48.7
Time to Overflow, min	-	-

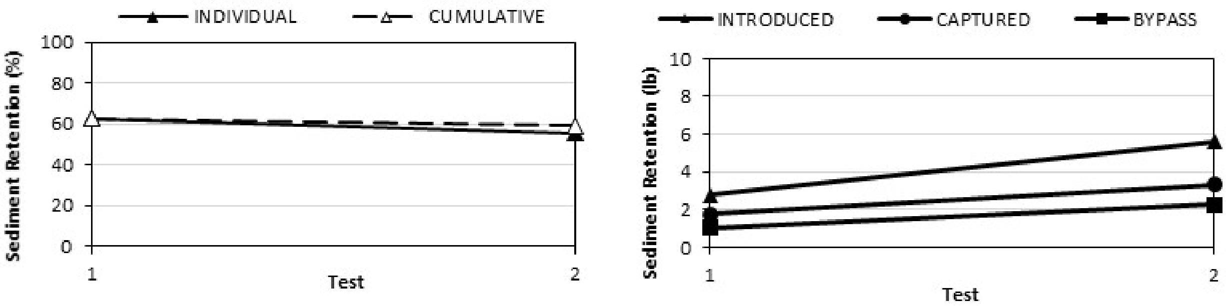
(b) Longevity Testing with Sandy Loam Soil

Performance Metric	L1	L2
Sediment Introduced, lb	2.79	2.80
Sediment Captured, lb	1.75	1.56
Sediment Retention, %	62.7	55.7
Collective Retention, %	62.7	59.2
Time to Overflow, min	-	-

Figure 4.33 shows the distance between the sediment introduction line and the sediment captured line grows greater as testing progresses, indicating a decline in performance and a need for maintenance.



(a) OK110 silica sand – Percent Retained (b) OK110 silica sand – Mass Retained



(c) Percent Retained - Sandy Loam Soil (d) Mass Retained - Sandy Loam Soil

FIGURE 4.33 Overall sediment retention for WQS during longevity tests.

4.2.9 Summary of Longevity Testing

Table 4.23 summarizes all sediment retention percentage data for all longevity tests. The Drainpac was tested eight consecutive times with OK110 silica sand. While individual tests values varied, it can be seen that there was little change in cumulative retention rate from test to test. Despite this performance, the Drainpac was only tested twice with the sandy loam due to low retention rates. The Adsorb-It performed similarly to the performance evaluation testing, having the highest retention values of all CBIs. While most products were tested at least twice to ensure that they were not able to meet the 80% target rate, the FloGard Plus was only test once per soil type due to its low performance, both during L1 tests and the performance evaluation testing.

TABLE 4.23 Summary of Sediment Retention Percentage of Longevity Tests

(a) Longevity Tests with OK110 Silica Sand

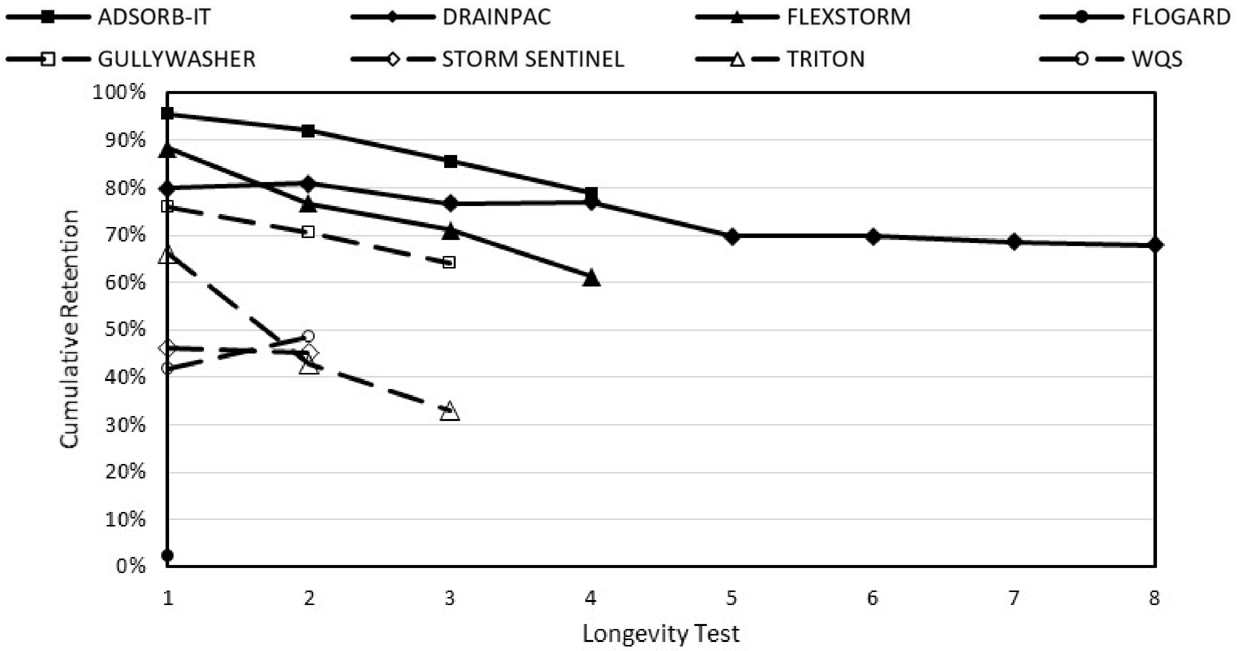
		L1	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**	**L8**
ADSORB IT	Indiv.	95.6%	88.4%	72.4%	55.7%	-	-	-	-
	Cumul.	-	*92.0%*	*85.7%*	*78.9%*	-	-	-	-
DRAINPAC	Indiv.	80.0%	81.7%	68.4%	78.1%	40.6%	70.5%	60.7%	64.3%
	Cumul.	-	*80.9%*	*76.7%*	*77.0%*	*69.7%*	*69.8%*	*68.5%*	*68.0%*
FLEXSTORM	Indiv.	88.3%	64.5%	58.8%	31.2%	-	-	-	-
	Cumul.	-	*76.8%*	*71.1%*	*61.3%*	-	-	-	-
FLOGARD	Indiv.	2.3%	-	-	-	-	-	-	-
	Cumul.	-	-	-	-	-	-	-	-
GULLYWASHER	Indiv.	75.9%	64.9%	50.8%	-	-	-	-	-
	Cumul.	-	*70.4%*	*64.2%*	-	-	-	-	-
STORM SENTINEL	Indiv.	46.2%	44.1%	-	-	-	-	-	-
	Cumul.	-	*45.2%*	-	-	-	-	-	-
TRITON	Indiv.	66.2%	20.8%	14.2%	-	-	-	-	-
	Cumul.	-	*42.8%*	*33.2%*	-	-	-	-	-
WQS	Indiv.	41.9%	55.3%	-	-	-	-	-	-
	Cumul.	-	*48.7%*	-	-	-	-	-	-

(b) Longevity Tests with Sandy Loam Soil

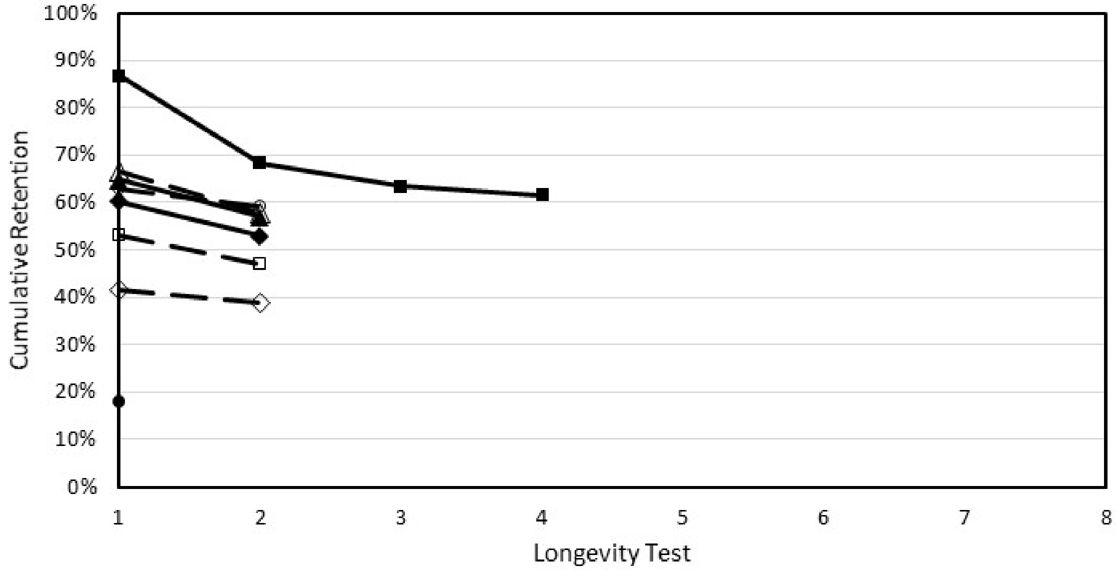
		L1	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**	**L8**
ADSORB IT	Indiv.	86.8%	49.8%	53.6%	53.8%	-	-	-	-
	Cumul.	-	*68.4%*	*63.5%*	*61.6%*	-	-	-	-
DRAINPAC	Indiv.	60.3%	45.5%	-	-	-	-	-	-
	Cumul.	-	*53.0%*	-	-	-	-	-	-
FLEXSTORM	Indiv.	64.8%	49.7%	-	-	-	-	-	-
	Cumul.	-	*57.0%*	-	-	-	-	-	-
FLOGARD	Indiv.	18.0%	-	-	-	-	-	-	-
	Cumul.	-	-	-	-	-	-	-	-
GULLYWASHER	Indiv.	53.1%	39.8%	-	-	-	-	-	-
	Cumul.	-	*46.9%*	-	-	-	-	-	-
STORM SENTINEL	Indiv.	41.6%	36.0%	-	-	-	-	-	-
	Cumul.	-	*38.8%*	-	-	-	-	-	-
TRITON	Indiv.	66.7%	48.8%	-	-	-	-	-	-
	Cumul.	-	*57.7%*	-	-	-	-	-	-
WQS	Indiv.	62.7%	55.7%	-	-	-	-	-	-
	Cumul.	-	*59.2%*	-	-	-	-	-	-

Note: Individual test data - Indiv. *Cumulative test data -Cumul.*

Figure 4.34 plots cumulative retention percentages for each CBI throughout their respective longevity testing tenure. It can be seen that, on average, CBIs went longer without requiring maintenance when using the OK110 silica sand than when using the sandy loam soil, despite the fact that the OK110 silica sand was introduced at higher rates. This is most likely due to the higher clay content in the sandy loam soil causing the filter material to become blinded, hindering flow-through ability and performance. For most CBIs, sediment retention percentage was also higher through the first few tests with OK110 silica sand than with sandy loam soil, indicating that the larger sized sand particles in the OK110 silica sand were easier to capture than the smaller silt and clay particles in the sandy loam soil.



(a) OK110 silica sand



(b) sandy loam soil

FIGURE 4.34 Longevity testing summary of cumulative retention data.

The lab testing conducted provides an in-depth analysis of how the selected CBIs will perform in terms of both sediment removal and need for maintenance over time. The results provided in this section, paired with the data collected during the field testing phase of the project, can be combined to make final recommendations on the performance on each of the products.

CHAPTER FIVE:
CONCLUSIONS

5.1 INTRODUCTION

The objective of this research was to develop a controlled system for the evaluation of catch basin insert (CBI) products under conditions representative of the Ohio Department of Transportation (ODOT) post-construction stormwater applications. Products were evaluated for sediment retention capabilities through performance evaluation tests and additional longevity testing to analyze maintenance needs and performance over time.

5.2 TESTING METHODOLOGY

The overall design of the apparatus was conducted in accordance with the ODOT Location & Design Manual, Volume Two (L&Dv2) (*ODOT, 2018)* since ODOT was the sponsor of the project. CBI testing was divided into two different phases: (1) performance evaluation testing, and (2) longevity testing. During performance evaluation tests, CBIs were tested at three different influent flow rates of 0.06, 0.12, and 0.18 ft^3/s (1.7, 3.4, and 5.1 L/s) for 70 minutes, representative of drainage areas of 0.1, 0.2, and 0.3 acres (0.04, 0.08, and 0.12 ha). CBIs were also tested using two different soil types, an OK110 silica sand gradation introduced at a target concentration of 0.028 lb/ft^3 (450 mg/L), and a sandy loam introduced at a target concentration of 0.012 lb/ft^3 (185 mg/L). Originally, CBIs were tested with the OK110 silica sand under sheet flow conditions. However, after these tests were completed, flow introduction methods were adapted to directly discharge the sediment-laden influent into the catch basin. CBIs were then tested with both soil types under the direct discharge testing method. CBIs were evaluated for sediment retention percentage and reduction in total suspended solids (TSS). TSS reduction was determined by taking upstream and downstream 32 oz (1.0 L) grab samples at five minute intervals, which were analyzed in the laboratory. Clean CBIs were used for each performance evaluation test.

Longevity testing consisted of multiple consecutive tests on a single installed CBI and were conducted using each soil type at the low flow rate. Sediment retention percentage was calculated for each individual test, as well as cumulatively across all longevity tests. The longevity testing cycle continued until it was determined that the CBI was no longer capable of reaching the 80% sediment retention percentage during an individual test event or until the CBI failed structurally. The longevity testing methodology provides a representative understanding of the number of storm events the CBI can effectively treat runoff until maintenance or removal in the field is required, while still satisfying water quality standards.

5.3 CONSTRUCTION OF APPARATUS

The apparatus consists of three primary components: (1) the water and sediment introduction system, (2) the flow conveyance system, and (3) the drainage platform. Water is pumped from an on-site supply pond into a water equalization tank located at the upstream end of the apparatus. The tank is equipped with a V-notch weir for regulated water flow rates into the flow conveyance system. A Schenck AccuRate® series volumetric feeder is used to introduce sediment into the flow, which allows for the controlled discharge of sediment-laden flow at the desired concentration into the 6.0 in. (15.2 cm) PVC flow conveyance system. During sheet flow testing, the flow conveyance system discharges onto the 8 ft by 8 ft (2.44 m by 2.44 m) drainage platform, allowing the sediment-laden sheet flow to enter the catch basin. The length of the flow conveyance system can be changed with flow rate to provide a more consistent sheet flow influent velocity from the platform, to the CBI. During direct discharge testing, the flow conveyance system is extended to the catch basin, where a vertical 90° elbow is used to direct the flow into the catch basin. The effluent collection platform then collects any flow exiting the catch basin and discharges off-site.

5.4 SEDIMENT RETENTION EVALUATION

Sediment retention percentage was the primary method of analyzing CBI performance. Table 5.1 summarizes sediment retention data for all performance evaluation tests. It can be seen that the Adsorb-It exceeded the 80% target removal rate multiple times, while other products failed to ever exceed the threshold. However, the Drainpac, Flexstorm, Gullywasher, and Storm Sentinel did come near the target, with sediment retention values reaching above 70%.

TABLE 5.1 Summary of Sediment Retention Percentage of Performance Evaluation Testing

CBI	SHEET FLOW OK110			DIRECT DISCHARGE OK110			DIRECT DISCHARGE SANDY LOAM		
	0.06 cfs	0.12 cfs	0.18 cfs	0.06 cfs	0.12 cfs	0.18 cfs	0.06 cfs	0.12 cfs	0.18 cfs
ADSORB-IT	77.2	64.4	48.7	96.2	82.5	64.3	85.4	64.2	50.5
DRAINPAC	36.0	46.1	47.1	79.8	64.8	62.7	68.1	46.8	38.4
FLEXSTORM	51.2	56.8	46.5	71.3	50.2	36.3	65.4	58.3	43.9
FLOGARD PLUS	7.3	1.0	0.7	10.4	0.8	2.2	24.7	19.8	22.0
GULLYWASHER	75.8	58.8	41.0	67.1	47.8	35.7	51.7	38.1	33.4
STORM SENTINEL	59.2	41.0	21.7	71.3	38.5	26.0	41.6	30.1	20.3
TRITON	59.4	49.0	45.2	68.5	59.7	44.9	40.4	38.4	36.4
WQS	2.7	27.3	26.8	27.1	51.4	53.9	42.7	49.4	50.5

A multiple linear regression analysis was conducted to determine the effect that each of the four variables (e.g., product, discharge method, soil type, flow rate) had on sediment retention percentage. It was determined that there were significant differences between performance of some products. Figure 5.1 plots sediment retention capabilities of each of the eight products based off of the multiple linear regression analysis. Labels on each bar identify other products that were determined statistically comparable to the considered product. Therefore, bars with no labels suggest that the sediment retention capability of the product was statistically different than all other products. The Adsorb-It was determined to have statistically higher average sediment retention percentages than all other products, while the FloGard Plus was determined to capture sediment at rates significantly lower than all other products.

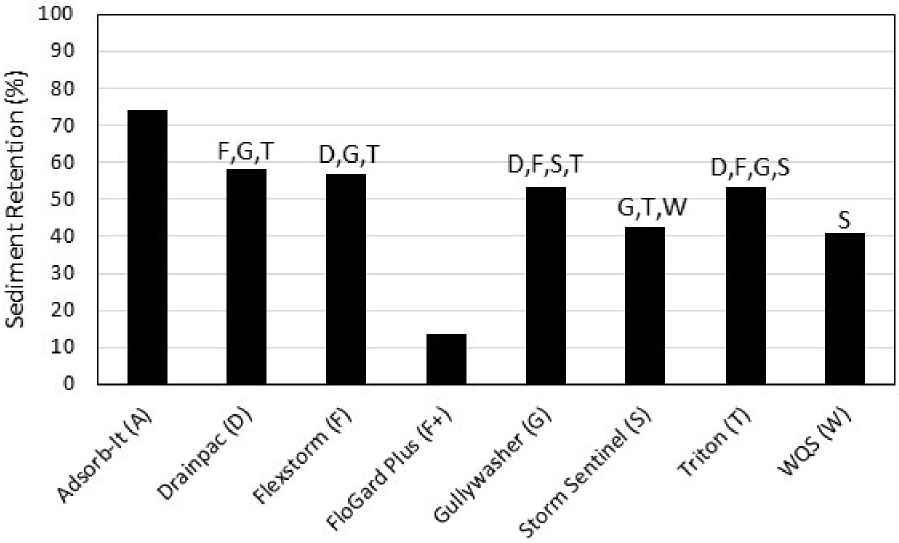


FIGURE 5.1 Comparison of sediment retention capabilities between products.

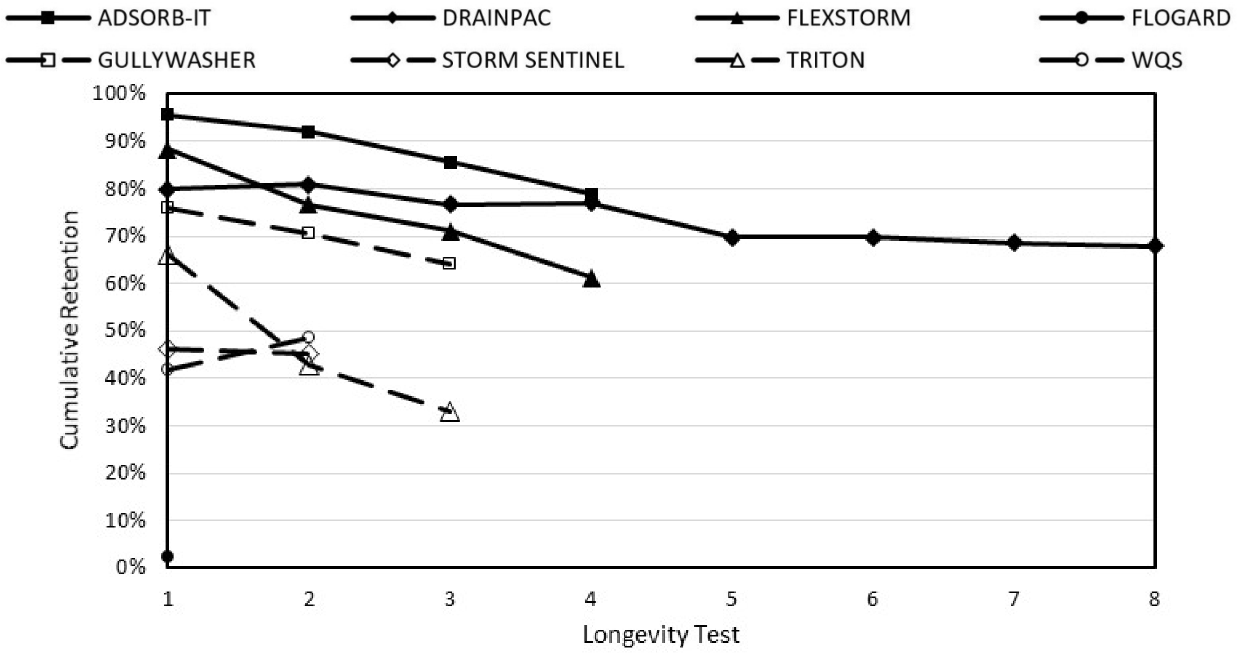
It was determined from the multiple linear regression analysis that discharge method did impact sediment retention percentage. Direct discharge tests had higher sediment retention percentages than sheet flow tests. One possible explanation for this is that, under sheet flow conditions, many of the products allowed the influent flow to bypass the CBI after entering the catch basin, therefore meaning a portion of the sediment-laden influent was not treated by the CBI but lost through the system. This was observed during many of the tests, and is noted in sections 4.1 and 4.2.

The third variable analyzed under the multiple linear regression was soil type. While average sediment retention percentages were slightly higher under tests with OK110 silica sand than those with sandy loam soil, there was not enough difference to conclude the issue was statistically significant. This is important because, in field settings, CBIs can be exposed to many different influent conditions and soil types, depending on the changing environment around the catch basin. From this research, we can conclude that changes in soil types should have little effect on the product performance. However, it is important to note that this regression analysis analyzed all eight of the products as a group. So while the group as a whole may have had little difference in performance between the two soil types, some of the products were affected more by different soil types than others. In order to analyze difference in performance between soil types on a product-by-product basis, more tests would have to be conducted in order to create a large enough sample size to draw statistically significant conclusions.

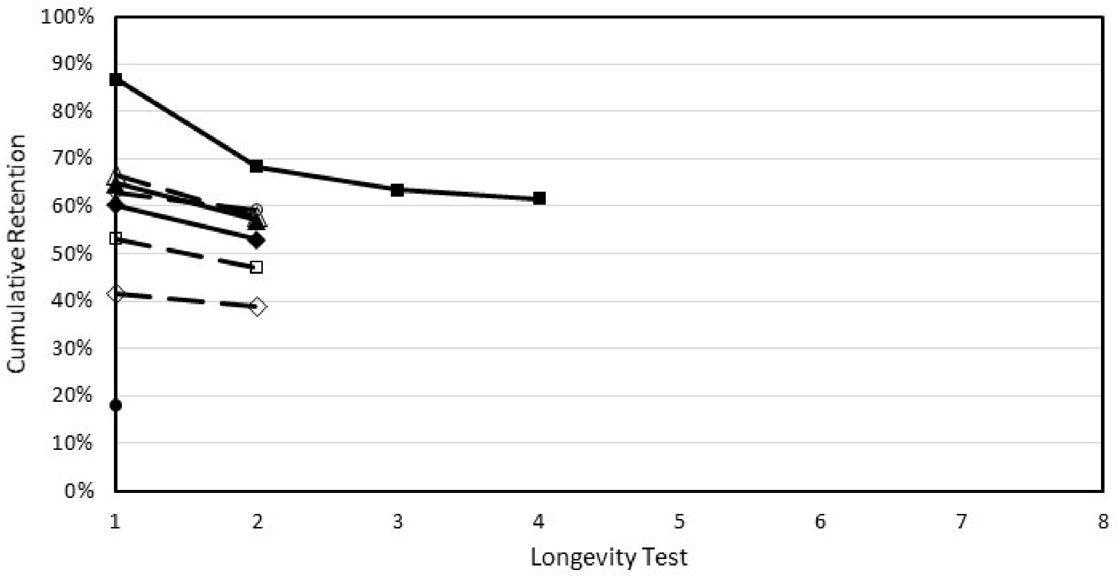
However, along with soil type, another variable that can change quickly dependent upon the location of the CBI, is influent flow rate. Results from the multiple linear regression show that sediment retention percentages significantly declined between each of the three increasing flow rates. This suggests that we can expect CBI performance to diminish when exposed to higher influent flow rates and larger runoff volumes from more severe storm events. Performance is diminished as a result of the influent exceeding the volumetric capacity of the CBIs and bypassing treatment by flowing through the overflow component of the device.

Statistical methods were also used to analyze the effect of overflow on sediment removal performance. While it cannot be said that tests in which overflow occurred resulted in losses in sediment retention, there is evidence that longer durations of overflow can affect performance. Therefore, if the CBI fills rapidly and reaches overflow early in the storm event, sediment retention is likely to be lower than if the overflow is not reached until near the end of the storm.

Longevity testing was performed to better understand the performance characteristics of the products over time. Products were exposed to consecutive tests until it was determined that the CBI was no longer capable of reaching the 80% sediment capture rate during an individual test event, or until structural failure. Figure 5.2 plots the cumulative retention for each of the products with the two soil types. It can be seen that most products were tested at least twice to ensure failure. However, the FloGard Plus was only tested once per soil type because the low sediment retention rate of the L1 tests, coupled with performance during performance evaluation tests, showed no potential for reaching the target retention rate. The Adsorb-It was tested four times for each soil type. The Drainpac was tested eight times with the OK110 silica sand, but only twice with the sandy loam soil, suggesting that the sandy loam soil hindered the CBI's sediment removable potential over time quicker than the OK110 silica sand.



(a) OK110 silica sand



(b) sandy loam soil

FIGURE 5.2 Longevity testing summary of cumulative retention data.

5.5 RECOMMENDED FUTURE RESEARCH

The presented CBI research is representative of ODOT runoff conditions. Influent flow rates were designed around the ODOT L&Dv2. Catch basins in other geographical locations would experience different runoff conditions based upon changes in climate. However, if flow rates were designed according to other locations, the system could easily be modified to represent those flow rates, providing results more accurate to the new location.

In performance evaluation tests, captured sediment can also be analyzed to determine particle size distribution (PSD). Comparing influent PSD to that captured in the CBI allows the researcher to further assess the CBI's sediment removal performance in terms of different particle sizes and soil types. The two soil types used during this testing provide some context on how performance changes with different influent particle sizes, but analyzing the PSD of captured sediment would provide a better understanding of the sediment capture capabilities of individual CBIs.

Though eight CBIs were evaluated as part of this research, there are numerous other proprietary CBI products available on the market. It is essential that manufacturers have propriety products undergo independent, third party testing to provide potential customers with evidence of product performance. This system presented as part of this research has the capability of performing this testing. The system can also be used to consult manufacturers on modifications that may improve performance of their product.

Another limitation to this study that could be further explored would be performing additional testing under the same conditions with the same products. At the current time, each product has been tested only once under each flow rate, soil type, and discharge method. This small sample size severely limits the statistical methods that can be used to analyze the data, therefore limiting the conclusions that can be drawn. For example, while a multiple linear regression was used to analyze the effect that soil type had on the group as a whole, it cannot be said whether a specific product performed significantly different with the two soil types. As a whole, the soil type had little effect on the sediment removal performance of the group of CBIs. However, at the low flow rate under direct discharge conditions, the Triton captured 68.5% of the sediment when tested with OK110 silica sand, but only 40.4% when tested with sandy loam. While this appears to be a large difference, it cannot be determined whether this is truly significant because there is only one value from each category to compare. Performing more tests to create larger sample sizes would not only strengthen conclusions that have been made, but allow products to be evaluated more in-depth.

5.6 ACKNOWLEDGEMENTS

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APPENDICES

Appendix A: Manufacturer Installation Guidelines & Product Information

Appendix B: Flow Rate and Sediment Introduction Calibration

Appendix C: Particle Size Distribution Data

Appendix D: QA/QC Protocol

Appendix E: TSS Processing Procedures

APPENDIX A

MANUFACTURER INSTALLATION GUIDELINES AND PRODUCT INFORMATION

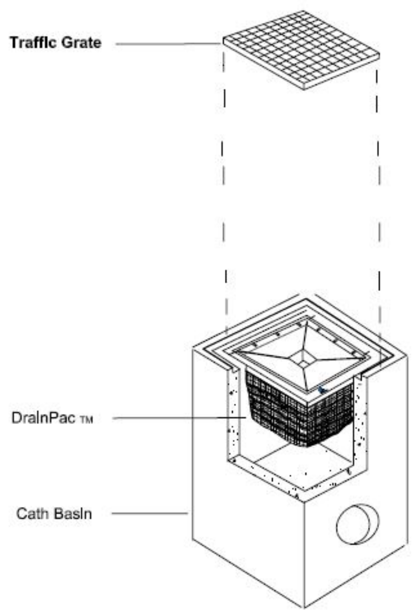
INSTALLATION PROCEDURES:

Prior to the installation of each ***ADSORB-it Stormfilter***, We strongly recommend that the following be performed:

1. Pre-Inspection and measurement of each in-ground storm water structure and external roof downspout to identify any defects and ensure a proper design fit of the ***ADSORB-it Stormfilter***.

2. A thorough cleaning and flushing of each storm water structure should be performed either manually or by a Vactor truck service. Roof gutters and downspout drains should also be inspected for accumulated sediments and organic debis.

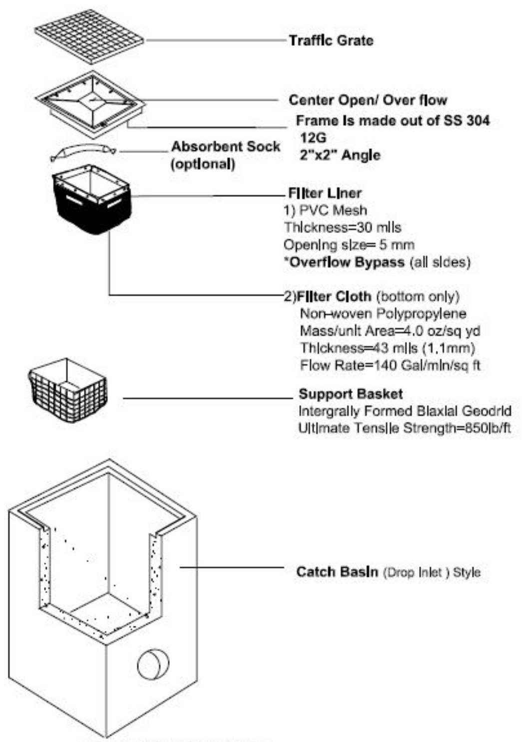
3. If installing ***ADSORB-it Stormfilters*** over entire storm drainage system, a complete and thorough cleaning of the entire storm drainage system should be performed, including Vactor hydro-jetting and cleaning the conveyance pipes between each catch basin structure.



INSTALLATION VIEW

Drawing Notes :

1) DrainPac TM ,
2) DrainPac TM Install in drop inlet type basins are self supported filter inserts that will rest (gravity held) on the existing catch basin grate frame
3) This product will aid in filtering constituents such as heavy metals,petroleum hydrocarbons,sediments,trash and debris



EXPLODED VIEW

DrainPac TM Installation Drawing: Drop Inlet

UNITED STORM WATER, Inc.
Protecting Our Water Resources

14000 E.Valley Blvd
City of Industry,CA 91746
Los Angeles:(877)717-8676
San Diego:(866)440-2790
www.unitedstormwater.com

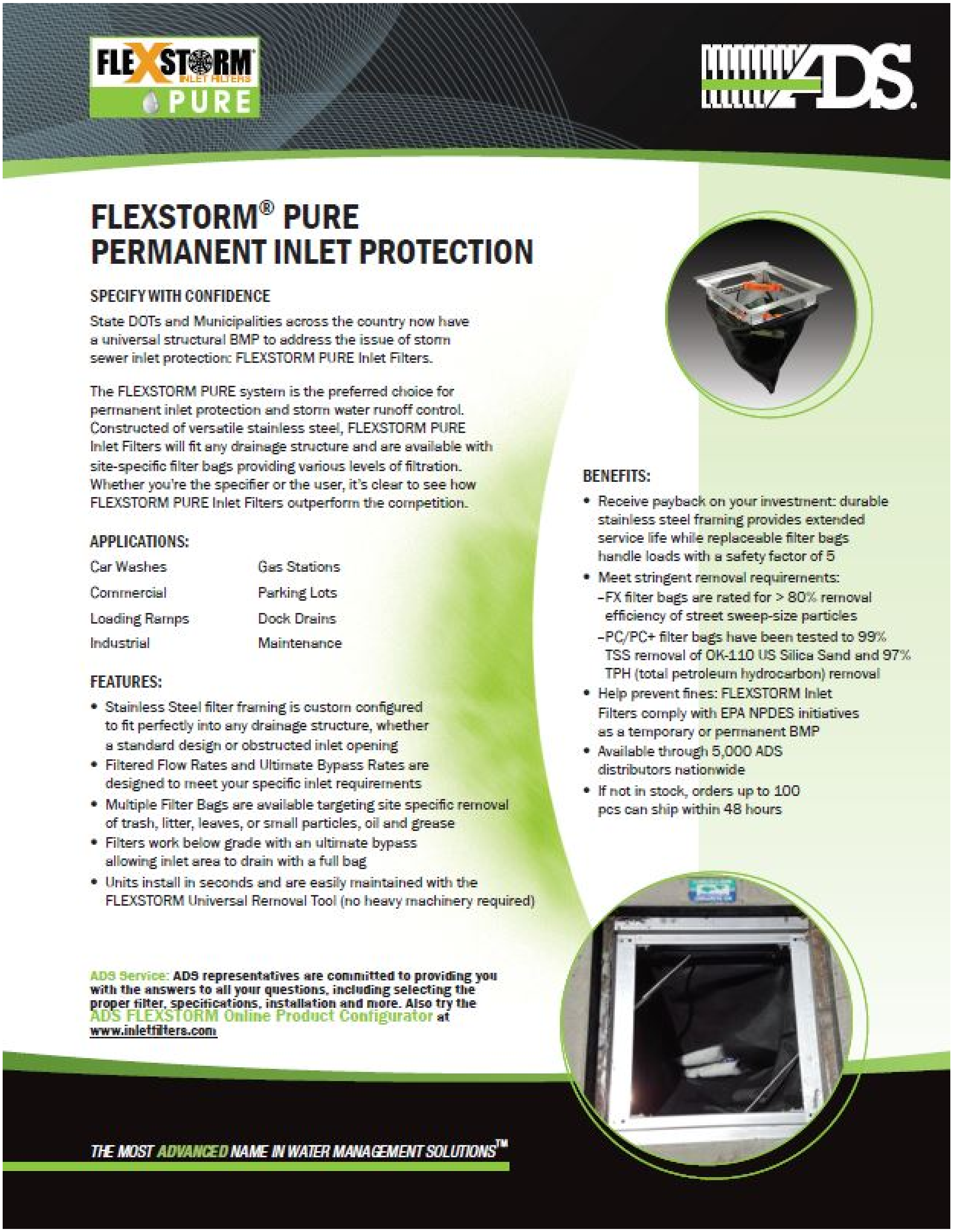
General Notes

No.	Revision/Issue	Date
1	7/15/10	

Firm Name and Address
UNITED STORM WATER, Inc.
14000 E, Valley Blvd
City of Industry, CA 91746

Project Name and Address
DrainPac
Model: Drop Inlet

Project: DrainPac
Date
Scale: Not to Scale
Sheet: 1 of 1



FLEXSTORM® PURE PERMANENT INLET PROTECTION

SPECIFY WITH CONFIDENCE

State DOTs and Municipalities across the country now have a universal structural BMP to address the issue of storm sewer inlet protection: FLEXSTORM PURE Inlet Filters.

The FLEXSTORM PURE system is the preferred choice for permanent inlet protection and storm water runoff control. Constructed of versatile stainless steel, FLEXSTORM PURE Inlet Filters will fit any drainage structure and are available with site-specific filter bags providing various levels of filtration. Whether you're the specifier or the user, it's clear to see how FLEXSTORM PURE Inlet Filters outperform the competition.

APPLICATIONS:

Car Washes
Commercial
Loading Ramps
Industrial
Gas Stations
Parking Lots
Dock Drains
Maintenance

FEATURES:

- Stainless Steel filter framing is custom configured to fit perfectly into any drainage structure, whether a standard design or obstructed inlet opening
- Filtered Flow Rates and Ultimate Bypass Rates are designed to meet your specific inlet requirements
- Multiple Filter Bags are available targeting site specific removal of trash, litter, leaves, or small particles, oil and grease
- Filters work below grade with an ultimate bypass allowing inlet area to drain with a full bag
- Units install in seconds and are easily maintained with the FLEXSTORM Universal Removal Tool (no heavy machinery required)

BENEFITS:

- Receive payback on your investment: durable stainless steel framing provides extended service life while replaceable filter bags handle loads with a safety factor of 5
- Meet stringent removal requirements:
  - -FX filter bags are rated for > 80% removal efficiency of street sweep-size particles
  - -PC/PC+ filter bags have been tested to 99% TSS removal of OK-110 US Silica Sand and 97% TPH (total petroleum hydrocarbon) removal
- Help prevent fines: FLEXSTORM Inlet Filters comply with EPA NPDES initiatives as a temporary or permanent BMP
- Available through 5,000 ADS distributors nationwide
- If not in stock, orders up to 100 pcs can ship within 48 hours

ADS Service: ADS representatives are committed to providing you with the answers to all your questions, including selecting the proper filter, specifications, installation and more. Also try the ADS FLEXSTORM Online Product Configurator at www.inletfilters.com

THE MOST ADVANCED NAME IN WATER MANAGEMENT SOLUTIONS™

FLEXSTORM PURE INLET FILTERS SPECIFICATION

IDENTIFICATION

The installer shall inspect the plans and/or worksite to determine the quantity of each drainage structure casting type. The foundry casting number, exact grate size and clear opening size, or other information will be necessary to finalize the FLEXSTORM part number and dimensions. The units are shipped to the field configured precisely to fit the identified drainage structure.

MATERIAL AND PERFORMANCE

The FLEXSTORM Inlet Filter system is comprised of a corrosion resistant steel frame and a replaceable geotextile filter bag attached to the frame with a stainless steel locking band. The filter bag hangs suspended at a distance below the grate that shall allow full water flow into the drainage structure if the bag is completely filled with sediment. The standard Woven Polypropylene FX filter bags are rated for 200 gpm/sqft with a removal efficiency of 82% when filtering a USDA Sandy Loam sediment load. The Post Construction PC filter bags are rated for 137 gpm/sqft and have been 3rd party tested at 99% TSS removal to 110 micron and 97% TPH removal of used motor oil hydrocarbon mix.

INSTALLATION

Remove the grate from the casting or concrete drainage structure. Clean the ledge (lip) of the casting frame or drainage structure to ensure it is free of stone and dirt. Drop in the FLEXSTORM Inlet Filter through the clear opening and be sure the suspension hangers rest firmly on the inside ledge (lip) of the casting. Replace the grate and confirm it is elevated no more than 1/8", which is the thickness of the steel hangers. For wall mount units, follow instructions for attaching the stainless steel mounting brackets using the provided concrete fasteners.

INSPECTION FREQUENCY

Construction site inspection should occur following each 1/2" or more rain event. Post Construction inspections should occur three times per year (every four months) in areas with mild year round rainfall and four times per year (every three months Feb-Nov) in areas with summer rains before and after the winter snowfall season. Industrial application site inspections (loading ramps, wash racks, maintenance facilities) should occur on a regularly scheduled basis no less than three times per year.

MAINTENANCE GUIDELINES

Empty the filter bag if more than half filled with sediment and debris, or as directed by the Engineer. Remove the grate, engage the lifting bars or handles with the FLEXSTORM Removal Tool, and lift from the drainage structure. Dispose of the sediment or debris as directed by the Engineer or Maintenance Contract in accordance with EPA guidelines.

As an alternative, an industrial vacuum may be used to collect the accumulated sediment. Remove any caked on silt from the sediment bag and reverse flush the bag with medium spray for optimal filtration. Replace the bag if torn or punctured to 1/2" diameter or greater on the lower half of the bag. Post Construction PC/PC+ Bags should be maintained prior to 50% oil saturation. The average 2' x 2' PC filter bag will retain approx. 86 oz (5.4 lbs) of oil at which time it should be serviced or replaced. It can be centrifuged or passed through a wringer to recover the oils, and the fabric reused with 85% to 90% efficacy. It may also be recycled for its fuel value through waste to energy incineration. When utilizing the Cleartec Rubberizer Pouches in the + bags, note that these oil skimmers will gradually turn brown and solidify as they become saturated, indicating time for replacement. Each pouch will absorb approximately 62 oz (4 lbs) of oil before requiring replacement. The spent media may also be recycled for its fuel value through waste to energy incineration. Dispose of all oil contaminated products in accordance with EPA guidelines.

FILTER BAG REPLACEMENT

Remove the bag by loosening or cutting off the clamping band. Take the new filter bag, which is equipped with a stainless steel worm drive clamping band, and use a screw driver to tighten the bag around the frame channel. Ensure the bag is secure and that there is no slack around the perimeter of the band.

Lift Handles ease installation and maintenance

Replaceable Sediment Bag

1/8" thick steel hangers& channels; precision **stampings configured to fit each individual casting**

CAD drawings, work instructions and test reports on website: **www.inletfilters.com**

For more information on FLEXSTORM Inlet Filters and other ADS products, please contact our Customer Service Representatives at 1-800-821-6710
Try the ADS FLEXSTORM Online Product Configurator at www.inletfilters.com.

THE MOST ADVANCED NAME IN WATER MANAGEMENT SOLUTIONS™

Advanced Drainage Systems, Inc.
1-800-821-6710 www.ads-pipe.com

FLEXSTORM www.inletfilters.com

Oldcastle Precast®

FLOGARD® CATCH BASIN INSERT FILTER

Removes Pollutants from Runoff Prior to Entering Waterways

Efficient System
Catches pollutants where they are easiest to catch, at the inlet.

Variable Design
Able to be retrofitted or used in new projects.

Treatment Train
Can be incorporated as part of a "Treatment Train".

No Standing Water
Helps to minimize bacteria and odor problems.

Focused Treatment
Removes petroleum hydrocarbons, trash and Total Suspended Solids (TSS).

Maximum Flexibility
Available in a variety of standard sizes to fit round and square inlets.

Economical
Earn a higher return on system investment.

Two-part stainless-steel insert to filter solids and oils/grease

Easy to install, inspect and maintain, even on small and confined sites

By the Numbers*:

Filter will remove up to 80% of Total Suspended Solids (TSS), at least 70% of oils and grease, and up to 40% of Total Phosphorus (TP) associated with organic debris as well as Polycyclic Aromatic Hydrocarbons (PAH) from oil leaks and spills.

**Approx. for urban street application*

Catch Basin Filter Test Results Summary

Testing Agency	% TSS Removal	% Oil & Grease Removal	% PAH Removal
UCLA	80	70 to 80	
U of Auckland Tonking & Taylor, Ltd. (for City of Auckland)	78 to 95		
U of Hawaii (for City of Honolulu)	80		20 to 40

Call us today **(800) 579-8819** or visit our website for detailed product information, drawings and design tools at **www.oldcastlestormwater.com**

Oldcastle Precast®

Multi-Purpose Catch Basin Insert Retains Sediment, Debris, Trash and Oils/Grease

FloGard® Catch Basin Insert Filters are recommended for areas subject to silt and debris as well as low-to-moderate levels of petroleum hydrocarbons (oils and grease). Examples of such areas include vehicle parking lots, aircraft ramps, truck and bus storage yards, business parks, residential and public streets.

Catch Basin Filter Competitive Feature Comparison

Evaluation of Catch Basin Filters (Based on flow-comparable units) (Scale 1-10)	Oldcastle Stormwater	Other Insert Filter Types**
Flow Rate	10	7
Removal Efficiency*	80%	45%
Capacity - Sludge & Oil	7	7
Service Life	10	3
Installation - Ease of Handling / Installation	8	6
Ease of Inspections & Maintenance	7	7
Value	10	2

*approximate, based on field sediment removal testing in urban street application **average

Long-Term Value Comparison (Based on flow-comparable units) (Scale 1-10)	Oldcastle Stormwater	Other Insert Filter Types
Unit Value - Initial ($/cfs treated)	10	4
Installation Value ($/cfs treated)	10	7
Absorbent Replacement (annual avg ($/cfs treated)	10	2
Materials Replacement Value (annual avg ($/cfs treated)	10	10
Maintenance Value (annual avg ($/cfs treated)	10	7
Total First Year ROI ($/cfs treated)	10	5
Total Annual Avg Value ($/cfs treated, avg over 20 yrs)*	10	5

Captured debris from FloGard Catch Basin Insert Filter in Dana Point, California

Combination Inlet

Flat-Grated Inlet

Circular Frame Catch Basin

(800) 579-8819

oldcastlestormwater.com

Storm Water Management & Erosion Control Products

Catch Basin Inserts

OIL/SEDIMENT and METAL COMPLIANT

Easy and Safe to Install and Remove

- Fast — Only Takes One Person to Install
- Self-Supporting — Unlike Other Inserts, No More Fishing
  - Our design will not fall into catch basin when the grate is removed
- Ergonomic Lift Straps
  - Lift the heavy inserts with your legs, not your back.
- High-Efficiencey Removal of Contaminants

Removes up to 85% Copper and 86% Zinc

As Easy To Install As 1-2-3-4-5!

#1 Remove grate with our Ergonomic Grate Puller.

#2 Clean inside lip of catch basin and check for proper wire frame size.

#3 Fit wire frame into position using fabric tabs on insert.

#4 Place Insert in catch basin with apron outside laying basin.

#5 Place grate back into position. If necessary, cut excess apron off.

DONE!

STORM SENTINEL®
ADJUSTABLE CATCH BASIN INSERT

The Storm Sentinel® adjustable catch basin insert helps companies comply with Stormwater Pollution Prevention Plans and Stormwater Best Management Practices by protecting your storm drains and catch basins. It is the sure way to catch oil and sediment headed into storm drains and sewers. Optionally equipped with an oil-absorbent media in a screened bag, the Storm Sentinel® guards against any potential discharge.

- 4341 & 4344 fit any size rectangular catch basin's from 16"x20" to 28"x36". XL version fits rectangular catch basin's up to 42"x42".
- 4340 & 4343 fit any size round catch basin from 27" to 29" in diameter.
- Up to 500 GPM overflow rate helps avoid ponding.
- Requires no special tools to install.
- Helps comply with NPDES, 40 CFR 122.26 when used as Best Management Practice in Storm Water Pollution Prevention Plans.
- Custom sizes available.
- Self supporting frame and easy installation.

*Patents Pending

ENPAC's enhanced design has increased the surface area for greater sediment retention.

STORM SENTINEL® CATCH BASIN INSERT

Part #	Description	Dimensions in. (cm)	Weight lb. (kg)
4340 4340-IB	Round Trash, Sediment, Debris Trash, Sediment, Debris, Oils, Hydrocarbons	27 up to 29 (68.6 up to 73.7)	2 (1) 3 (1.4)
4340-22 4340-24	Round Trash, Sediment, Debris Round Trash, Sediment, Debris	22 up to 24 24 up to 25	2 (1) 2 (1)
4341 4341-IB 4341-NO	Rectangular Trash, Sediment, Debris Trash, Sediment, Debris, Oils, Hydrocarbons Trash, Sediment, Debris - No Overflow	16 x 20 up to 28 x 36 (41 x 51 up to 71 x 97)	2 (1) 3 (1.4) 2 (1)
4341-XL 4341-XL-IB	Rectangular Trash, Sediment, Debris Trash, Sediment, Debris, Oils, Hydrocarbons	Extra Large Rectangular 25 x 25 up to 42 x 42 (64 x 64 up to 107 x 107)	3 (1.4) 4 (2)

Regulations: EPA, SPCC and NPDES

TO INSTALL: Remove grate and adjust wire frame to fit in recess.

Place insert into recess and frame into corners. Replace metal grate.

No part of the insert extends above the surface.

TO REMOVE: Simply lift the grate, grab the handle and pull out the insert.

The Storm Sentinel is a registered trademark of ENPAC, LLC, U.S. trademark reg. number 2,953,485

Triton Catch Basin Inserts

Triton Drop Inlet

This catch basin insert traps hydrocarbons and other contaminants such as metals, sand, silt and litter from stormwater runoff. The Triton is installed below the grate of storm drain inlets.

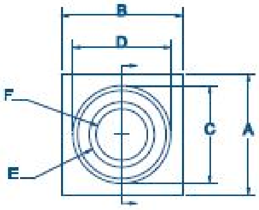
Specifications

- Easy to install in new and existing catch basins.
- Meets best available technology for use in stormwater best management practices (BMP).
- Round, square, rectangular, low profile and custom models.
- Non-reactive high density polyethylene (HDPE) plastic construction, with U.V. inhibitors.
- Media-Pak cartridges available for the removal of sediments, hydrocarbons, and litter.
- Quick and easy servicing made available by replaceable Media-Paks.

Standard Dimensions (in inches)

Model #	A*	B*	C	D	E	F	G**	# cartridges	H***	Basin Type
TR1212	15.0	15.0	11.0	11.0	6.75	3.50	6.0	1 Short	4.5	HDPE
TR12RD	Ø15.0		Ø11.0		6.75	3.5	6.0	1 Short	4.5	HDPE
TR1616	20.0	20.0	14.0	14.0	6.75	3.5	10.5	1 Std	8.5	HDPE
TR16RD	Ø20.0		Ø11.0		6.75	3.5	6.0	1 Short	4.5	HDPE
TR1818	24.0	24.0	18.0	18.0	10.0	6.25	10.5	1 Std	8.5	HDPE
TR18RD	Ø24.0		Ø16.5		6.75	3.5	10.5	1 Std	8.5	HDPE
TR1824	19.0	25.0	18.0	18.0	10.0	6.25	10.5	1 Std	8.5	HDPE
TR2024	21.0	25.0	18.0	18.0	10.0	6.25	10.5	1 Std	8.5	HDPE
TR24SR	27.0	27.0	23.5	23.5	14.0	10.0	13.0	1 Std	8.5	HDPE
TR24RD	Ø28.0		Ø21.0		14.0	10.0	13.0	1 Std	8.5	HDPE
TR2436	32.0	40.0	22.0	29.0	14.0	10.0	21.0	1 Tall	16.5	HDPE
TR3030	34.0	34.0	22.0	29.0	14.0	10.0	21.0	1 Tall	16.5	HDPE
TR36SR	36.0	36.0	33.0	33.0	14.0	10.0	22.0	1 Tall	16.5	FIBRG
TR36RD	Ø36.0		Ø33.0		14.0	10.0	22.0	1 Tall	16.5	FIBRG
TR42RD	Ø42.0		Ø33.0		14.0	10.0	22.0	1 Tall	16.5	FIBRG
TR4848	48.0	48.0	42.0	42.0	24.0	19.75	22.0	1 Tall	17.5	FIBRG
TR48RD	Ø48.0		Ø33.0		14.0	10.0	22.0	1 Tall	16.5	FIBRG

* Dimenions "A" and "B" can be adjusted to suit varying sizes of each basins.
** Dimension "G" is basin depth.
*** Dimension "H" is cartridge height.



Notes:

1. All dimenions are in inches
2. Units are constructed from HDPE plastic with U.V. inhibitors
3. Media cartridges can be interchanged with Geotrap series as site conditions change
4. Low profile cartridges are also available for shallow catch basins
5. Custom sizes are available to fit most applications
6. Optional trash and debris guard available
7. Dual stage and dual capacity cartridges also available

APPENDIX B

FLOW RATE AND SEDIMENT INTRODUCTION CALIBRATION

FLOW RATE CALIBRATION PROCEDURES

Step 1: Measure top diameter, bottom diameter, and height of water collection barrel.

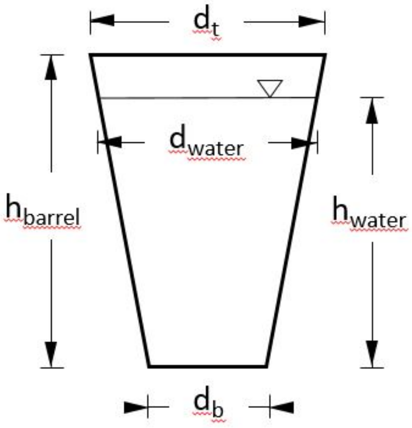
Step 2: Capped water collection barrel is placed beneath the discharge point of the flow conveyance system.

Step 3: Activate pump system and allow water level inside the equilibrium tank to reach the desired level. Water will be discharging from the flow conveyance system, but not entering the water collection barrel due to the cap.

Step 4: When the desired water level is reached, remove the cap, allowing water to flow into the water collection barrel, and activate the timer.

Step 5: When the water collection barely is nearly full, replace the cap, blocking more water from entering the barrel, and stop the timer. Turn off the pump to allow water flow to cease.

Step 6: Measure the depth of water inside the collection barrel. Knowing the other dimensions of the barrel, this water level can be used to calculate the volume of water inside the barrel.



$$V_{water} = \frac{1}{3}\pi\left((\frac{d_{water}}{2})^2 + \frac{d_{water}}{2} \times \frac{d_b}{2} + (\frac{d_b}{2})^2\right) h_{water}$$

Step 7: Divide volume inside the barrel by the time to fill, resulting in the flow rate exiting the weir at the considered water level.

$$Q = V/t$$

Step 8: Repeat procedure until appropriate water level is determined to reach desired flow rate.

Flow Rate Calibration Data

Trial	Weir Level (in)	h_{water} (in)	d_{water} (in)	d_b (in)	v_{water} (ft^3)	t (s)	Q (ft^3/s)
1	2.71	23.5	20.1	17.5	3.77	61.2	0.06
2	3.58	24.5	20.2	17.5	3.96	32.5	0.12
3	4.21	24.0	20.11	17.5	3.87	21.8	0.18

SEDIMENT INTRODUCTION AUGER CALIBRATION PROCEDURES

Step 1: Take weight of empty collection bucket. Place bucket so that discharged soil will fall into collection bucket.

Step 2: Set auger speed to estimated rate.

Step 3: Activate auger and allow discharge to occur for allotted time.

Step 4: Shut off auger and weigh collection bucket.

Step 5: Determine the weight of soil discharged by subtracting the filled bucket by the weight of the empty bucket. Calculate feed rate by dividing the weight of sediment by the time to fill.

$$Feed\ Rate = \frac{weight\ of\ soil}{t}$$

Step 6: If feed rate is not as desired, adjust auger speed setting and repeat steps. If feed rate is acceptable, it may be beneficial to repeat steps with a longer test duration to ensure consistency.

Step 7: Repeat auger calibration procedure for each soil type.

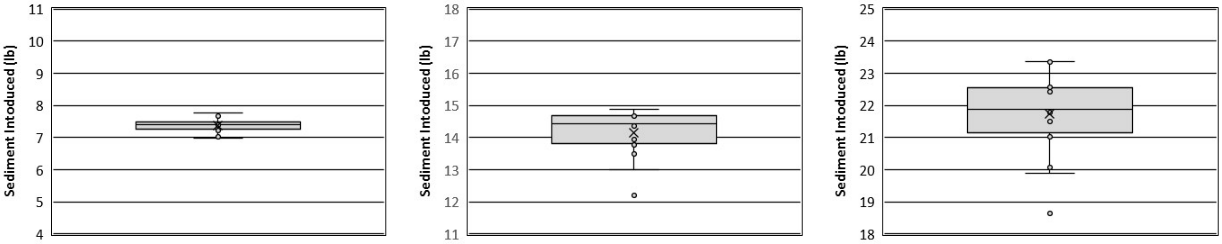
Summary of Sediment Introduction Values

(a) OK110 Silica Sand Introduction

Flow	Target	Minimum	1Q	Median	Average	3Q	Maximum
Low	7.08	6.99 (-1.3%)	7.27 (2.7%)	7.395 (4.4%)	7.37 (4.0%)	7.47 (5.5%)	7.76 (9.6%)
Medium	14.16	12.2 (-13.8%)	13.9 (-1.8%)	14.44 (2.0%)	14.15 (-0.1%)	14.67 (3.6%)	14.89 (5.2%)
High	21.24	18.63 (-12.3%)	21.39 (0.7%)	21.89 (3.1%)	21.73 (2.3%)	22.51 (6.0%)	23.36 (10.0%)

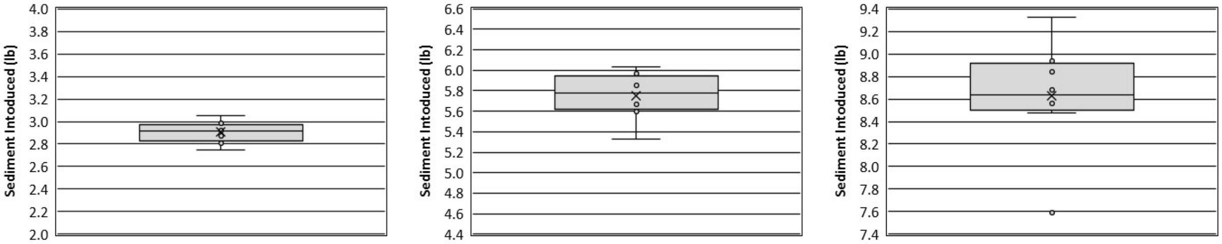
(b) Sandy Loam Introduction

Flow	Target	Minimum	1Q	Median	Average	3Q	Maximum
Low	2.91	2.75 (-5.5%)	2.86 (-1.9%)	2.92 (0.2%)	2.91 (-0.2%)	2.96 (1.6%)	3.05 (4.8%)
Medium	5.82	5.33 (-8.4%)	5.65 (-2.9%)	5.78 (-0.7%)	5.75 (-1.2%)	5.89 (1.2%)	6.03 (3.6%)
High	8.73	7.59 (-13.1%)	8.54 (-2.2%)	8.64 (-1.1%)	8.63 (-1.2%)	8.87 (1.5%)	9.33 (6.9%)



low flow medium flow high flow

(a) OK110 Silica Sand Introduction



low flow medium flow high flow

(b) sandy loam introduction

Boxplots of sediment introduction values.

APPENDIX C

PARTICLE SIZE DISTRIBUTION DATA

OK110 SILICA SAND

OK110 silica sand was purchased from a supplier. The following particle size distribution was provided.

Particle Size Distribution of OK110 Silica Sand

Sieve		% Retained		% Passing
Mesh	**Microns**	**Individual**	**Cumulative**	**Cumulative**
70	212	0.0	0.0	100.0
100	150	1.0	1.0	99.0
120	125	15.0	16.0	84.0
140	106	48.0	64.0	36.0
170	88	24.2	88.2	11.8
200	75	9.7	97.9	2.1
270	53	1.9	99.8	0.2
PAN		0.2	100.0	0.0

SANDY LOAM SOIL

Sandy loam was mixed from an existing stockpile on-site at Auburn University-Erosion & Sediment Control Testing Facility (AU-ESCTF). Three mix alternatives were tested using a wet sieve analysis method to determine the sands-to-fines ratio of the soils. While the stockpile was classified as sandy loam, "Alternative Mix #2" was used for testing.

Wet Sieve Analysis Data for Sandy Loam Mix

Mix	Weight of Sample	Weight of sands	Weight of Fines
Stockpile	79.2	45.5 (57.5%)	33.7 (42.5%)
Alternate Mix #1	90.7	47.5 (52.4%)	43.2 (47.6%)
Alternate Mix #2	91.9	59.1 (64.3)	32.8 (35.7%)

A sample of the fines collected from the wet sieve analysis of "Alternative Mix #2" were used to perform a hydrometer test. The results of the test are provided below.

Hydrometer Analysis Data for Sandy Loam Mix

t	R	RCP	%Finer	RCL	L (cm)	A	D (mm)
0.25	50	49.65	103.4375	50	8.1	0.0133	0.075705
0.5	49	48.65	101.3542	49	8.3	0.0133	0.054188
1	48	47.65	99.27083	48	8.4	0.0133	0.038547
2	46	45.65	95.10417	46	8.8	0.0133	0.027898
4	43	42.65	88.85417	43	9.2	0.0133	0.02017
8	40	39.65	82.60417	40	9.7	0.0133	0.014645
15	36	35.65	74.27083	36	10.4	0.0133	0.011074
30	33	32.65	68.02083	33	10.9	0.0133	0.008017
60	30	29.65	61.77083	30	11.4	0.0133	0.005797
120	28	27.65	57.60417	28	11.7	0.0133	0.004153
240	25	24.65	51.35417	25	12.2	0.0133	0.002999
360	23	22.65	47.1875	23	12.5	0.0133	0.002478
480	22	21.65	45.10417	22	12.7	0.0133	0.002163
1440	20	19.65	40.9375	20	13	0.0133	0.001264

APPENDIX D

QA/QC PROTOCAL

QUALITY CONTROL/QUALITY ASSURANCE PLAN FOR LARGE-SCALE LAB TESTING OF CATCH BASIN INSERTS (CBIs)

Introduction

The purpose of this document was to develop, record, and implement a quality control/quality assurance plan (QA/QC) for large-scale lab testing of CBIs. The first section of this document covers quality control (QC) measures that will be taken during the testing process to ensure data collected is an accurate representation of the performance of each product. The second section of this document covers quality assurance (QA) measures that will be taken when analyzing collected data so that reported data is precise and accurate.

QUALITY CONTROL

Water Introduction

Flow will be controlled by a 90° V-notch weir that is installed on the water equalization tank. The weir has been calibrated to introduce water at 0.06, 0.12, and 0.18 cfs based upon the depth of water inside the tank. The tank is equipped with a pressure head measuring device, which is a clear acrylic tube that is positioned vertically outside of the tank and is used to measure the depth of water inside the tank. The pressure head measuring device is used to ensure that the water depth inside the tank is consistent and accurate. Proper depths are required to meet the necessary flow rates exiting the water equalization tank and being introduced into the flow conveyance system. The pressure head measuring device will be checked at 5-minute intervals for the duration of the 70-minute test. If water depth varies from the desired level, a slight adjustment will be made to drain valves on the bottom of the tank to return the water level to the desired depth.

Sediment introduction

Numerous tests were conducted to determine the appropriate setting that the sediment introduction system should be set to in order to meet the necessary sediment loads over the 70-minute testing period. For each test, the sediment introduction system’s hopper was filled with sand. The system was then turned on and sand was discharged into a bucket for 70 minutes. The weight of the bucket and sand at the end of the 70 minutes was subtracted by the weight of the empty bucket to determine the amount of sand discharged. This was completed for the SS995 soil type, and will be completed with the TARP soil type once AU’s plan for mixing TARP soil on-site is approved. The speed setting was then changed and the test was performed again. These tests were conducted numerous times until the appropriate settings were determined for the three different flow rates. Once the appropriate settings were determined, the same tests were performed three times simultaneously to ensure that results were consistent for each setting. Table 2.1 details calibration test results for the SS995 soil type.

TABLE 2 Calibration Test Results for SS995 Soil Introduction

Target (lb)	Soil Introduction Rates		
	Low	**Medium**	**High**
	[7.08 lb]	***[14.16 lb]***	***[21.24 lb]***
Trial 1 (lb)	7.10	14.22	21.62
Trial 2 (lb)	7.04	14.00	21.37
Trial 3 (lb)	7.02	14.16	21.59
Average (lb)	7.05	14.13	21.53
Percent Error (%)	0.42	0.21	1.37

During testing, the hopper will be filled with a known mass of sediment. After testing, the sediment remaining in the hopper will be weighed and subtracted from the original mass of sediment within the hopper. These weights will be used to determine the mass of sediment introduced into the testing system.

$$w_{introduced} = w_{initial} - w_{remaining} \qquad \text{Equation 1}$$

A particle size distribution for the introduced sediment will be supplied on each lab testing data sheet to document that sediment being introduced during testing meets the necessary specifications for the respective soil type.

QUALITY ASSURANCE

Pre/Post Test Weighing of CBIs

Each CBI will be weighed prior to testing and pre-test weight will be recorded on the data sheet. After completion of the test, the CBI will be removed from the inlet and placed on a large pan to collect any material that my try to exit the CBI when disturbed. The weight of this pan will be recorded prior to the test. The pan and CBI will then be placed in a large lab oven to dry. The dry weight of the pan and CBI will be measured and recorded on the data sheet. If any CBI is too large to fit in the lab oven, the CBI will be left indoors to dry over time. Weights will be taken on a daily basis until it is determined that the CBI has fully dried.

These measurements will be used to determine the total amount of dried sediment retained by the CBI.

Sampling

Samples will be taken using clean, one liter sampling bottles at five minute intervals both upstream and downstream of the product. Each sampling bottle will have a unique identification number written on the bottle, and the identification number will be recorded on the lab testing data sheet with the location and time the sample was taken. Samples will remain refrigerated until they are analyzed.

One duplicate sample will be taken per 70-minute test, meaning two samples will be taken in separate bottles at the same time and from the same location. These duplicate samples will then be analyzed for both total suspended solids (TSS) and turbidity to determine consistency within the data analysis process.

At each sampling point, a 250 ml sample will also be collected simultaneously to the one liter samples. These samples will be used to analyze turbidity over time. A separate sample bottle is taken so that no subsample has to be taken from the one liter samples being used for TSS measurements.

TSS Analysis

TSS analysis will be conducted according to ASTM D5907-13 "*Standard Test Methods for Filterable Matter (Total Dissolved Solids) and Nonfilterable Matter (Total Suspended Solids) in Water*". All procedures, calculations, and quality assurance practices outlined in the TSS portion of this document will be followed to ensure quality in data analysis, with the exception that the entire one liter sample will be ran through the filter, as opposed to a subsample. This should provide more accurate TSS measurements.

Testing Documentation

The developed "CBI Lab Testing Data Sheets" will be used to document testing procedures. If manufacturer instructions for installation were provided, they will be included on the lab testing data sheet to ensure that products are installed correctly. Photos and video of the installation, testing, and removal of the product will be provided. Data sheets for each conducted test will be included as appendix items in the final lab testing report.

Corrective Actions

Data will be inspected for outliers that could be representative of an error in the data collection or analysis process. If it is concluded that an error occurred, the sample will be re-evaluated or another sample will be taken. If it is not possible to take another sample or re-evaluate the sample, a note will be made on the data in question that expresses the error. This data will be documented in the lab testing data sheets, but will not be included when determining sediment removal effectiveness of products.

APPENDIX E

TSS PROCESSING PROCEDURES

TSS PROCESSING PROCEDURES

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

TSS Analysis Preparation

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

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

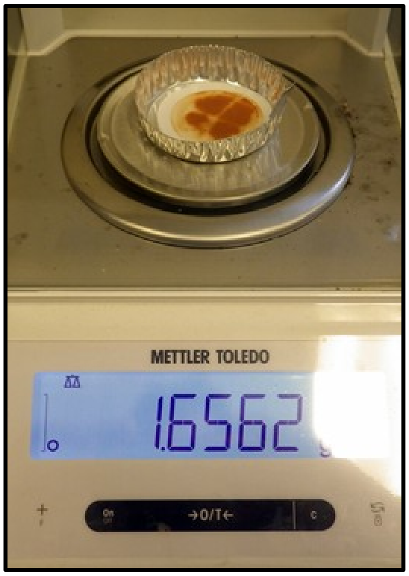
Step 3: Prewash filter membranes by placing the filter disc on the filter holder of the filter apparatus with the wrinkled side upward, gridded side down. Attach the top funnel portion of the magnetic filter holder. Apply 10 mL of deionized water and provide suction to filter through membrane. Remove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

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

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

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

Step 7: Pour entire sample into apparatus.



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

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

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

Step 11: Place membranes in the oven at 103˚C for one hour. Remove crinkle dishes and membranes from the drying oven and place in a desiccator and allow to cool to room temperature.

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