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Final Report

EVALUATION OF INLET PROTECTION PRACTICES USING LARGE-SCALE TESTING TECHNIQUES

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16. Abstract

Most roadway construction efforts disturb existing vegetation thereby exposing bare soil to environmental variables that cause erosion. Soil eroded during storm events is conveyed by stormwater runoff and may become deposited in receiving waterways. Inlet protection practices (IPPs) are temporary erosion and sediment controls commonly used around inlet drainage structures to prevent erosion while retaining sediment on-site. Increased effluent limitation regulation stringency coupled with greater public awareness with regards to surface water pollution have created the need for understanding the performance of commonly used erosion and sediment control practices. This study developed a methodology and testing apparatus for large-scale replicable performance-based testing of standard IPPs at the Auburn University Erosion and Sediment Control Testing Facility (AU-ESCTF). A two-phased testing regime comprised of clean water structural evaluations and sediment-laden performance evaluations was developed. Data collection procedures included pre- and post-test channel surveys, flow through rates, total suspended solids, and turbidity analysis.

The performance of drop inlet protection standards developed by the Alabama Department of Transportation (ALDOT), was assessed through the developed methodology. The study evaluated the performance of aggregate sandbag, silt fence, wattle, and manufactured devices. Structural improvement recommendations, called most feasible and effective installations (MFE-Is), were provided to current practices, and testing protocols were established for future product evaluation.

Sediment retention averaged approximately 77% for replicate tests. Retention ranged between 49% for the wattle barrier up to 84% for the silt fence MFE-I during the longevity tests. The results of this research can be used to provide IPP performance guidance to designers, contractors, and inspectors. Furthermore, developed IPP improvements, shown in Appendix C can be used to provide enhanced in-field installations.

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ABSTRACT

Most roadway construction efforts disturb existing vegetation thereby exposing bare soil to environmental variables that cause erosion. Soil eroded during storm events is conveyed by stormwater runoff and may become deposited in receiving waterways. Inlet protection practices (IPPs) are temporary erosion and sediment controls commonly used around inlet drainage structures to prevent erosion while retaining sediment on-site. Increased effluent limitation regulation stringency coupled with greater public awareness with regards to surface water pollution have created the need for understanding the performance of commonly used erosion and sediment control practices. This study developed a methodology and testing apparatus for large-scale replicable performance-based testing of standard IPPs at the Auburn University Erosion and Sediment Control Testing Facility (AU-ESCTF). A two-phased testing regime comprised of clean water structural evaluations and sediment-laden performance evaluations was developed. Data collection procedures included pre- and post-test channel surveys, flow through rates, total suspended solids, and turbidity analysis.

The performance of drop inlet protection standards developed by the Alabama Department of Transportation (ALDOT), was assessed through the developed methodology. The study evaluated the performance of aggregate sandbag, silt fence, wattle, and manufactured devices. Structural improvement recommendations, called most feasible and effective installations (MFE-Is), were provided to current practices, and testing protocols were established for future product evaluation.

Sediment retention averaged approximately 77% for replicate tests. Retention ranged between 49% for the wattle barrier up to 84% for the silt fence MFE-I during the longevity tests. A summary of hydraulic performance characteristics, sediment retention, and estimated cost data for the four tested MFE-Is are provided in Table A.1.

Table A.1 Performance Characteristics and Cost of Developed MFE-I IPPs

Inlet Protection Practice	Hydraulic Performance			Sediment Retention		Material Costs[a]
	Impoundment Length (ft)	Dewatering Time (min)	Ponding Length (ft)	Replicates	Longevity	
Aggregate MFE-I	18.1	13	1.0	76%	71%	$135
Sandbag MFE-I	14.5	120	4.8	71%	59%	$85
Silt Fence MFE-I	31.0	90	2.3	91%	84%	$95
Wattle MFE-I	10.4	9	4.6	71%	49%	$107

Notes: [a] cost per installation, does not account for labor and equipment costs

The results of this research can be used to provide IPP performance guidance to designers, contractors, and inspectors. Furthermore, developed IPP improvements, shown in Appendix C can be used to provide enhanced in-field installations.

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

The construction industry represents one of the largest economic sectors in the United States. Presently, construction is the largest product producing industry with over $1.7 trillion spent on construction projects in the U.S. in 2007. The investment in the construction of highways, streets, and bridges account for $107 billion (U.S. Dept. of Commerce 2007). Highway construction projects commonly require clearing, grading, excavation, fill, paving, and the erection of bridges and drainage structures. These construction activities involve heavy earthmoving activities that typically disturb several acres of land. Highway construction is generally managed by state or local highway departments. The Alabama Department of Transportation (ALDOT) is responsible for the construction and maintenance of the 11,800 mi (18,990 km) network of state roadways. As of June 2013, ALDOT reported 118 active construction contracts throughout the state of Alabama.

The most damaging environmental impact of roadway construction and maintenance emanates from the erosion of exposed soil. Although erosion is a naturally occurring process, the act of disturbing vegetative cover on a construction site will result in significantly higher erosion rates than natural erosion rates, when subjected to similar rainfall conditions. Construction generated erosion in the Southeastern U.S. predominantly occurs due to rainfall and stormwater runoff, however, it can also be driven by wind. Erosion and the resulting sedimentation in waterways has become Alabama's largest water pollution problem (Alabama Water Watch Association 2013). The U.S. Environmental Protection Agency (USEPA) has documented that sediment is the major pollutant of streams and rivers in the United States (USEPA 2000-1). Sediment runoff rates from construction sites can be 10 to 20 times higher than those of agricultural lands and 1,000 to 2,000 times greater than those of forested lands(USEPA 2000-2). It is estimated that 3.9 billion tons (3.5 billion metric tons) of sediment are washed into U.S. streams and rivers annually (Mitchell et al. 1991). An estimate of 80 million tons (73 million metric tons) of sediment is washed from construction sites alone into receiving waterways (Novotny 2003; Zech et al. 2008; 2009).

Federal, state, and local regulations and stormwater permits require construction generated pollution to be controlled on-site to avoid impairment to receiving waterways. Enforcement requires construction sites to provide erosion and sediment controls throughout all phases of land disturbing activities. In some cases, numerical discharge effluent limitations are imposed to provide maximum allowable pollutant discharge concentrations from disturbed sites.

1.2 DEFINITION AND PURPOSE OF INLET PROTECTION PRACTICES

In active construction areas or highway medians, area storm drain inlets are used to collect and direct stormwater into the subsurface drainage system. Inlets provide opportunities for eroded sediment to clog storm sewers and reduce conveyance capacities. With restricted conveyance, storm sewers may become vulnerable to decreased performance and thus susceptible to failure. A reduction in the designed performance hydraulic capacity of a stormwater network may result in catastrophic flooding during severe rainfall events. Stormwater impoundments can create undesirable situations such as flooding roadways, creating driving hazards, and damaging adjacent property. Implementing an effective inlet protection plan (IPP) plan is an approach to minimize pollutant discharge from a construction site and to reduce conveyance restrictions in stormwater management systems.

Federal and state stormwater discharge regulations require that storm drain inlets be protected if the inlets discharge stormwater directly to a surface water and is not first treated through a sediment basin, trap, or similar control (USEPA 2012). Storm drain IPPs can minimize sediment transport by temporarily impounding runoff before entering the inlet, preventing erosion of the channel median while allowing suspended sediment to settle (California Stormwater Quality Association [CASQA] 2003). IPPs should be implemented before large-scale disturbance of a project area is undertaken, while also allowing storm drains to be used during the subsequent stages of construction. This approach prevents eroded sediments from entering drainage systems during construction and pre-stabilization phases, prior to vegetation being established. IPPs can be used as a last resort for sediment control when no other means are practical, however they should not be implemented without other upstream erosion and sediment controls (South Carolina Dept. of Health and Environmental Control [SC-DHEC] 2005). It is generally believed that IPPs can serve as an effective tactic to reduce and mitigate sediment discharge as unprotected inlets become a point source for contaminant and sediment release into stormwater conveyance systems, which may discharge to receiving water bodies. IPPs can act as a “last chance” defense against discharging eroded sediments and pollutants into receiving waterways.

IPP are categorized as sediment retention devices (SRDs). SRDs are sediment control practices that trap sediment primarily through impounding water and allowing for suspended particles to settle. The primary purpose of SRDs is to reduce the transport of eroded soil from a disturbed site via water runoff by trapping and facilitating soil particle settlement (ASTM Standard D7351-07 2007). SRDs (i.e., fencing, straw and excelsior products, and sediment basins and traps) impound water and allow discharge through porous mediums. The filtering capacity of porous practices (i.e. silt fence, hay bales, etc.), provides limited sediment trapping capabilities. Once clogged, or blinded, materials become less porous and, resulting in greater impoundment capabilities (Haan et al. 1994).

As the erosion and sediment control industry expands due to increasing needs for effective practices, the marketplace for SRDs is rapidly growing. However, the overall performance and effectiveness of newly manufactured devices in common field situations is unknown, solely based on manufacturer claims, or simple field observations. Currently a need exists for independent third-party evaluations to characterize the performance of SRDs used at construction sites. To gain insight on the performance, durability, and maintenance needs of IPPs, large-scale, replicable experiments need to be conducted to comparatively evaluate varying material effectiveness, installation methods, and practices typically employed. Field evaluations of erosion and sediment controls are difficult to systematically perform and are virtually impossible to replicate since researchers are at the mercy of unpredictable storm events that vary in intensity and duration (McLaughlin et al. 2001). In contrast, large-scale evaluations have the capability of producing controllable and replicable testing conditions to perform comparative analyses of various erosion and sediment controls, which has been proven in previous testing (Donald et al. 2013).

1.3 RESEARCH OBJECTIVES

This research was divided into two primary components. The focus of the research is on: (1) the development of a large-scale testing methodology to perform replicable performance and longevity tests on IPPs, and (2) the evaluation of typical IPPs and development of most feasible and effective installation (MFE-I) for each practice tested. Testing focused on IPPs commonly employed on ALDOT projects. ALDOT classifies inlet construction phases into four stages. Practices used during the Stage 3 construction phase is the primary focus of this research, which takes place after inlet structure is installed, backfilled, and graded prior to establishing permanent stabilization.

As a continuation to this project, a second phase will scientifically evaluate the performance of the developed MFE-Is. Performance evaluations will provide comparisons between various IPPs and manufactured devices. Ultimately, results of standard IPPs will assist researchers in establishing baseline performance standards to support ALDOT in evaluating and accepting the use of manufactured products. Furthermore, the results of this research provide guidance to designers in specifying appropriate IPPs based upon project specific conditions. Additionally, contractors and inspectors will have a better understanding of how to properly install and maintain various IPPs to improve their overall in-field performance.

The specific research objectives of this research are as follows:

(1) Analyze hydrologic conditions for IPPs in roadway median applications,
(2) Develop a large-scale testing methodology, protocols, and testing apparatus for large-scale performance-based testing of IPPs,
(3) Identify installation deficiencies and provide structural improvements to develop MFE-Is for each tested practice, and
(4) Provide design guidance on proper design and installation techniques for the various IPPs tested.

The project was divided into the following tasks to satisfy the research objectives as follows:

(1) Identify, describe, evaluate, and critically assess pertinent literature on the state-of-the-practice regarding IPPs used by other state agencies,
(2) Develop rainfall models using GIS techniques to characterize the design storm across the state of Alabama,
(3) Develop an applicable methodology and testing apparatus for large-scale performance-based testing of IPPs based upon Alabama runoff conditions and current testing methods and technology,
(4) Conduct large-scale experiments to establish the MFE-I for identified IPPs,
(5) Analyze collected experimental data to provide performance and construction cost comparisons between IPPs, and
(6) Develop and conduct classroom and field training for designers, inspectors, and contractors in the proper selection, installation, and maintenance of IPPs.

Future tasks not included as part of this research include: (1) the comparison of the performance of identified MFE-I practices using large-scale experimental testing techniques, and (2) development of engineering design guidelines to categorize and select IPPs by various performance characteristics.

1.4 EXPECTED OUTCOMES

The outcomes of the study are to provide the erosion and sediment control industry knowledge, resources, and educational outreach opportunities required to conform to growing USEPA effluent regulations through the use of improved IPPs. By providing scientific results from this study, new and improved guidelines for properly implementing and installing IPPs will provide practitioners the required platform to guide and govern designers, inspectors, and contractors. This research will provide a deeper understanding and knowledge on various IPPs and their effectiveness in retaining sediment. The research outcomes can thus be used as a guide to provide proper guidance on IPP selection to satisfy various project goals. Additional research efforts should emanate from this project allowing further opportunities for increasing knowledge and technology in the erosion and sediment control industry.

1.4 ORAGANIZAITON OF FINAL REPORT

This final report is divided into five chapters that organize, illustrate, and describe the steps taken to meet the defined research objectives throughout the duration of this project. Following this chapter, Chapter Two: *Literature Review*, examines governing regulations, and current IPPs employed by ALDOT and various other institutions, as well as past research and experiments that have evaluated the performance of IPPs. Chapter Three: *Rainfall Analysis*, provides an approach to determine applicable design and testing flow rates based on Alabama rainfall and soil characteristics. Chapter Four: *Means and Methods*, outlines the design, apparatus, methods, and procedures developed for preparing and preforming large-scale IPP experiments. Chapter Five: *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 Six: *Conclusions and Recommendations* provides insight on the use and performance of tested IPPs. Additionally, this chapter identifies further research that can be conducted to further advance this research effort.

CHAPTER 2: LITERATURE REVIEW

2.1 BACKGROUND

Land development and construction activities associated with clearing, grubbing, excavating, and grading, expose soil to natural dispersive influences of weather induced erosion. Barren soil becomes highly susceptible to displacement through rain and wind events. Construction sites have measured erosion rates of approximately 20 to 200 tons per acre per year (Pitt et al. 2007). Studies have also shown that construction operations disturbing in-situ soil material increase sediment yields by as much as 10,000 times when compared to natural, undisturbed sites (Haan et al. 1994). Further construction development creates impervious surfaces (i.e., driveways, sidewalks, parking lots, and roads) which reduce infiltration of rainfall and stormwater runoff. A decrease in permeable surfaces increases runoff quantity and peak discharge rates, which increases the vulnerability of on-site erosion (Clark and Pitt 1999). Sediment emanating from slope and channel erosion are transported into existing stormwater conveyance systems. Other pollutants stemming from construction activities can also be introduced to the local environment through the improper use and disposal of chemicals and hydrocarbons.

Stormwater conveyance systems typically discharge into natural water systems (i.e., receiving water bodies). Unprotected stormwater conveyance networks result in increased turbidity levels emanating from high runoff velocities, which suspend clays and other solids (Huang and Ehrlich 2003). Water quality in impacted water bodies and wetlands becomes extremely vulnerable to harm and degradation through the process of sedimentation. Turbidity and suspended solids reduce the light available beneath the water surface that may affect wetland integrity by damaging the health of submerged vegetation. When suspended solids settle by means of sedimentation, the nature of the streambed is changed that can result in a reduction of aquatic seedling emergence and can deprive organisms of oxygen supply. Silts and sediments that settle in these ecosystems can have a detrimental effect on the native biota impacting necessary life functions of the aquatic habitat and species (i.e., photosynthesis, respiration, growth, and reproduction) (Gleason et al. 2003).

In addition to environmental implications, sedimentation can cause vast economic problems. The loss of aquatic habitat and diminished water quality is difficult to quantify, however some impacts (i.e., the cost of dredging and disposing of accumulated sediment) are easier to assess. Furthermore, the cost of eroded soil replacement comes at a high price. Eroded sediments may include the loss of soil nutrients necessary for plant growth. This nutrient loss can lead to topsoil replacement actions to satisfy proper vegetative growth (Goldman et al. 1986). Better methods and practices for controlling erosion, sedimentation, and other pollutants from construction sites are needed to meet the demands of increasing growth and development throughout the U.S., without compromising the integrity of nearby waterways.

The benefits of efficient erosion and sediment control practices can be applied to the triple bottom line approach. This method accounts for the dynamic relationships between environmental impacts, social justice, and sustainable economic development outcomes in construction and infrastructure improvement projects. The use of efficient controls can help meet this sustainable approach by:

(1) reducing environmental impacts – pollutant loads on receiving waterways, improving water clarity and quality, minimizing detrimental impact to aquatic life, etc.,
(2) social justice – the action of not endangering waterways with pollutants that may cause harm to aquatic life and humans, and,
(3) economics – not only will increased upfront investments on erosion and sediment controls provide life cycle cost reductions in mitigating damages that may have resulted from erosion and sedimentation, but proper controls may provide economic benefit from the seafood industry that may have been impacted due to pollution.

2.2 GOVERNING REGULATIONS

Increased public awareness and enactment of state and federal regulations have come as a response to nonpoint source pollution such as stormwater runoff from construction sites. The Federal Water Pollution Control Act of 1972 (Clean Water Act or CWA), passed by congress is the primary legislation governing the protection and improvement of water quality in the U.S. The U.S. Environmental Protection Agency (USEPA) is authorized under the CWA to issue National Pollutant Discharge Elimination System (NPDES) permits for point and non-point source pollutant discharges. The NPDES requires project operators, the parties responsible for control over construction plans and specifications and day-to-day of construction activities, to obtain coverage under the Construction General Permit (CGP), which regulates stormwater runoff as a pollutant. A CGP is required for land disturbing projects that disturb an area of one acre or greater. The permit enforces that operators design, install, and maintain erosion and sediment controls that minimize the discharge of pollutants from earth-disturbing activities. Minimal disturbance areas, timely control implementation, and proper maintenance requirements are part of CGP compliance.

Compliance with the CGP includes meeting USEPA's construction and development (C&D) effluent limitations. These effluent limitations were promulgated in 2009 through the NPDES Phase II permitting as non-numeric requirements for all sites, and numeric limits for turbidity for larger construction sites. The non-numeric limitations are specific control requirements that include: the provision of buffers near surface waters, the use of perimeter controls, minimizing sediment track-out, the control of discharge from stockpiles, minimizing dust pollution, minimizing disturbance to steep slopes, preserving topsoil, minimizing soil compaction, and protecting storm drain inlets. The numeric limitation on turbidity applies to sites that disturb ten or more acres at a time. The limit sets the daily maximum turbidity value to be no greater than 280 nephelometric turbidity units (NTUs). The effluent limitation does not apply for days where storms larger than the local 2-yr, 24-hr storm event are recorded.

Since the proposal of the numeric limit, the USEPA discovered that the data used to calculate the numeric limit for turbidity was misinterpreted and that there was insufficient data to support the established effluent limit of 280 NTU. The numeric limit was stayed indefinitely until the EPA gathers and collects data to support the recalculation of the turbidity limit, however the non-numeric effluent guidelines are still part of the latest CGP *(USEPA 2012)*.

The NPDES CGP also includes specific monitoring requirements for sites that discharge stormwater to sediment or nutrient-impaired waters. These waterways have been identified by the USEPA and state agencies as sensitive waters that are too polluted or otherwise degraded to meet water quality standards. These impaired waters have been assigned a total maximum daily load (TMDL), or a maximum amount of a pollutant that a water body can receive and still safely meet water quality standards. Construction activities under the CGP that discharge stormwater to listed impaired waterways may be subject to additional water quality-based limitations on a site-specific basis that need to be considered and satisfied.

The USEPA has authorized 46 states to issue NPDES permitting. These state permits meet the federal permit requirements and in many cases are more stringent than their federal counterpart. For example, the New Jersey Department of Environmental Protection (NJDEP) requires an 80% TSS removal from construction site runoff *(NJDEP 2004).*

The Alabama Department of Environmental Management (ADEM) manages the NPDES permitting process for the state. The permit requires operators to develop a detailed stormwater pollution prevention plan (SWPPP) or construction best management practices plan (CBMPP) prior to submitting a notice of intent for a CGP. The CBMPP is a comprehensive site plan of action to prevent the pollution of the environment surrounding a project area through the use of temporary erosion and sediment control measures and best management practices (BMPs). The CBMPP is used to confront the problems associated with sediment migration from construction sites to receiving waterways, by incorporating proper erosion and sediment control measures into construction projects during land disturbing phases. Similarly to the USEPA, ADEM enforces increased compliance regulations for sediment or nutrient impaired waterways. ADEM limits turbidity of effluent discharged from a construction site to a 50 NTUs increase above background levels *(ADEM 2013).*

2.3 BEST MANAGEMENT PRACTICES

BMPs are practices, and procedures selected by designers and implemented by contractors that control or abate the discharge of pollutants from construction sites. BMPs include appropriate erosion and sediment control program oversight, construction site planning and management, proper site housekeeping and materials management, erosion and sediment control implementation and maintenance, and pollution prevention. ADEM stipulates that BMPs shall be designed and maintained to minimize erosion and maximize sediment removal resulting from a 2-yr, 24-hr storm event as defined by the National Weather Service and Technical Paper No. 40, *"Rainfall Frequency Atlas of the U.S." (ADEM 2011)*.

As the largest manager of state highway construction and maintenance projects in the state of Alabama, ALDOT has established a CBMPP to guide designers, inspectors, and contractors in environmental and stormwater compliance. An ALDOT CBMPP includes a design and operational component that is created and maintained for every ALDOT construction project requiring an ADEM CGP. The ALDOT CBMPP standard specifications and general applications include a set of special drawings that demonstrate the ALDOT established standard practices for stormwater runoff BMPs. These drawings include the implementation and installation of: temporary slope drains, sediment barriers, erosion control practices, ditch checks, inlet protection practices (IPPs), sediment basins, and various other common erosion and sediment control practices.

Although ALDOT has developed standard drawings and specifications for BMPs, the performance of these practices needs to be evaluated to understand the overall effectiveness of practices. By having knowledge of performance, ALDOT can help improve and strengthen the stormwater program where BMP deficiencies are found. The understanding of BMP effectiveness is becoming increasingly critical for designers and contractors to ensure proper implementation and maintenance of practices to meet current and expected increasingly stringent stormwater effluent compliance regulations.

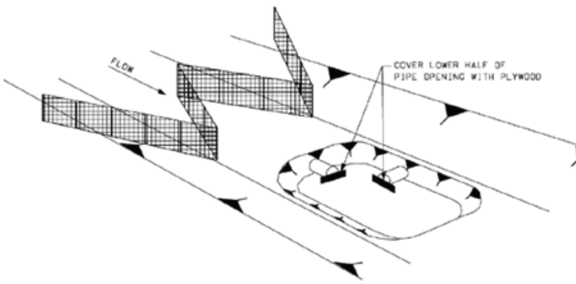
2.4 INLET PROTECTION PRACTICES

Typical IPPs include the use of aggregate, fabric, sandbag, and wattle barriers, along with a wide variety of manufactured devices placed inside and around storm drop and curb inlet structures. Permanent protection is provided with sodding, which reduces flow velocities and captures sediments (USEPA 2012).

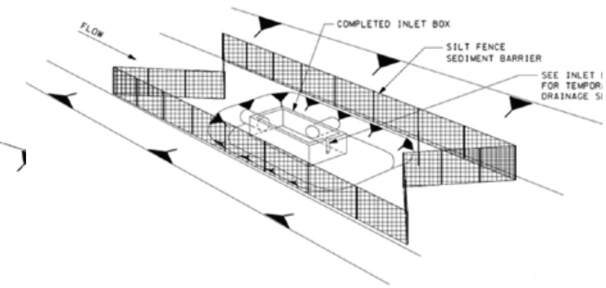
Temporary inlet protection controls should be installed before major land disturbance activities and can include a combination of techniques. With present technologies, hydrologic computations are not necessary. A limitation of drainage areas to one acre per inlet establishes maximum flow rates. Fabric barriers are recommended for smaller, relatively flat drainage areas, while aggregate based protection can be used for higher flow scenarios (USEPA 2009). Installing barriers around a drop inlet should only be used when the drain is located in a low area or sump that receives runoff from surrounding areas. Drainage areas larger than one acre should be routed through a temporary sediment trap prior to discharge (Midwest Research Institute et al. 2003). Unless otherwise stated, the protective practices and devices presented in this section are for a maximum drainage basin of one acre. As with most other SRDs, proper maintenance of controls after storm events is necessary to prevent clogging and ensure efficient operation. Immediate inlet protection maintenance is required by the CGP whenever sediment performance is compromised. ADEM requires poorly functioning erosion and sediment controls shall be corrected as soon as possible, but not to exceed five days unless prevented by unsafe weather conditions (ADEM 2011).

2.5 CURRENT ALDOT INLET PROTECTION PRACTICES

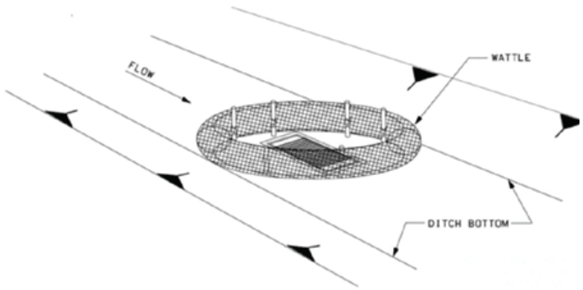
As previously mentioned, the ALDOT CBMPP standard specifications and general applications maintain special drawings and specifications for BMPs. IPPs are described in detail in the specifications. ALDOT categorizes inlet protection into four separate categories depending on the stage of construction (i.e., Stage 1 through 4). ALDOT Special Drawing ESC-400 (Sheets 1–5) provides detailed descriptions of IPP installations. ALDOT organizes the applicable IPP selection based on the inlet construction stages. Figure 2.1 illustrates the four inlet construction stages with examples of applicable protection (ALDOT 2012).



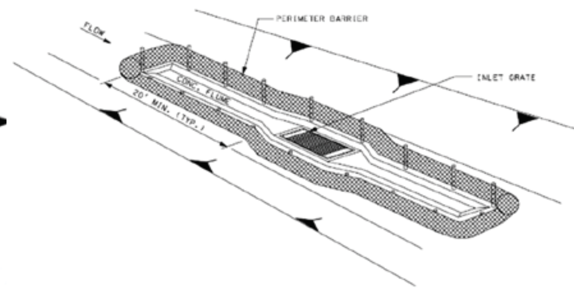
(a) Stage 1: inlet location excavated



(b) Stage 2: inlet constructed but not backfilled



(c) Stage 3: inlet constructed and backfilled



(d) Stage 4: completed with impermeable surface

Figure 2.1 Standard ALDOT Installation Inlet Protection Practices (ALDOT 2012).

Table 2.1 outlines the four inlet construction stages and the applicable IPP that are recommended for used during the stage. The focus of this research is on Stage 3 IPPs. ALDOT specifies that Stage 3 IPPs are required “after inlets are completed through grate installation and prior to complete stabilization of the area surrounding the inlet” (ALDOT 2012). Stage 3 IPPs include the use of: (1) manufactured inlet protection devices, (2) coarse aggregate, (3) wattles, and (4) and sandbag barriers (ALDOT 2012). Common practices employed by ALDOT used in bare earth conditions are described in the following section.

Table 2.1 Inlet Installation Stages and Applicable Protection Practices (ALDOT 2012)

Stage	Construction Condition	Protection Practices
1	Outflow drainage has been installed, inlet structure has not been installed or constructed	Ditch Check Sediment Barriers
2	Inlet structure has been constructed, but has not been backfilled to final grade	Sediment Barrier Wattles
3	Inlet grate has been installed, backfilled, stabilization may not be complete	Manufactured Device Coarse Aggregate Sandbags Barrier Wattles
4	Completed inlet with surrounding impervious area	Manufactured Device Hay Bales Wattles Sandbags

2.5.1 Coarse Aggregate Inlet Protection

Aggregate based IPPs are specifically tailored towards drop inlets located on roadway and highway medians. The device is constructed of coarse aggregate, ALDOT No. 4 stone, which is arrayed in a square berm around the inlet. The inside edge of the stone structure is positioned at a minimum of 2 ft beyond the edge of inlet and is held in place by a 2 x 6 in. raised board that prevents aggregate from obstructing the inlet grate. The berm has a 1 ft top width that ties back towards the ground at a 1:1 slope for a minimum height of 1.5 ft. A polyethylene or geotextile fabric is used to line the base of the berm and extends 3 ft beyond the toe of the riprap structure. Wing walls can be constructed on the structure to prevent bypass for situations where flows are received from one direction. ALDOT only recommends the use of coarse aggregate inlet protection for Stage 3 inlet construction situations. Figure 2.2 depicts the ALDOT standard installation.

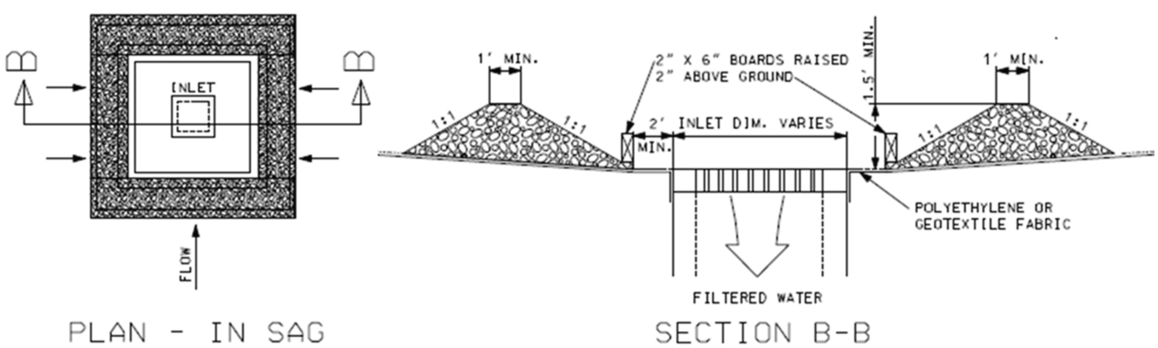


Figure 2.2 Examples of Aggregate Inlet Protection Detail (ALDOT 2012).

The Florida Department of Environmental Protection (FDEP) cautions that this installation has no overflow mechanism. Ponding is likely and must be taken into account when installing near areas that may endanger an exposed fill slope. Flooding consideration must also be given near areas of traffic movement, nearby structures, working areas, and adjacent property (FDEP 2008).

2.5.2 *FABRIC / SILT FENCE BARRIER*

The ESC-400 drawings do not provide specific drawings for installing of a silt fence barrier and refer to the ALDOT Standard Specifications for Highway Construction for installation guidance. Silt fences shall be a geotextile filter supported between posts with a wire mesh backing. The posts shall be strong enough to provide and retain the structural integrity of the fence. Typical post spacing is 10 ft with ring fasteners securing the fabric to wire backing at 2 ft intervals along the top of the fence. Currently, ALDOT only specifies the use of nonwoven geotextiles (ALDOT 2014). Figure 2.3 shows typical silt fence protection installation and possible performance (i.e, failure mode).

(a) typical installation on bare soil (b) improperly maintained installation

Figure 2.3 Typical Silt Fence Inlet Protection Installation and Failure Mode.

Various state manuals include fabric barrier IPPs in their manuals with varying installation details and recommendations. The California Stormwater Management Handbook recommends that a filter fabric fence barrier be used in drainage basins with a maximum of 5% slopes, sheet flow conditions, and flows less than 0.5 ft^3/s (CASQA 2003). The Maryland Standard and Specifications for Soil Erosion and Sediment Control provides two types of woven silt fence installations for inlet protection. A Type A installation using 2 x 4 in. framed barrier is used for a maximum drainage area of 0.25 ac, which a Type B installation using chain link fence post support barrier is used for a one acre drainage basin maximum (Maryland Department of the Environment [MDE] 2011). These two practices are depicted in Figure 2.4 below:

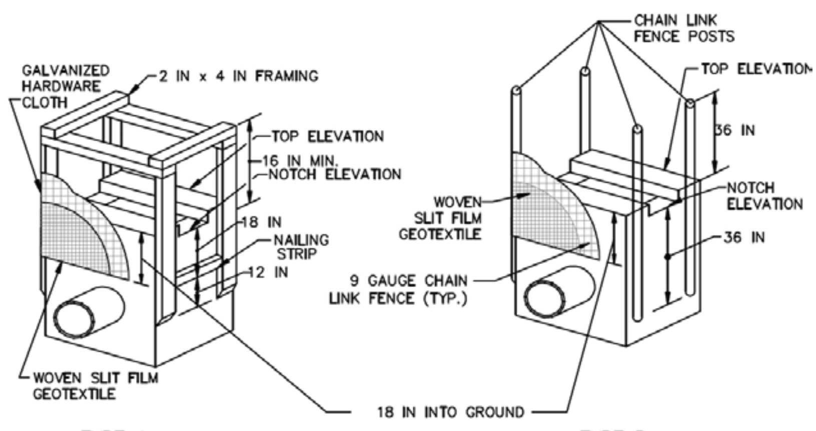
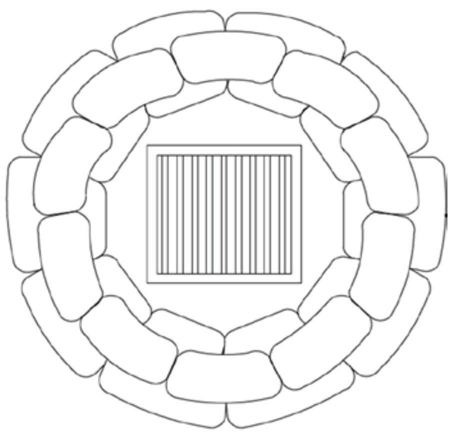


Figure 2.4 Maryland Silt Fence Inlet Protection Barrier (MDE 2011).

The Oregon Sediment Control BMPS manual indicates that a silt fence barrier should only be used in areas where grading has been completed and final soil stabilization and seeding is pending. The practice should only be used for inlets receiving sheet flows. The standard drawing includes the use of a geotextile blanket between the fence barrier and drain inlet (O-DEQ, 2005). The South Carolina Department of Health and Environmental Control states that filter fabric IPPs should be designed to have an 80% removal efficiency goal of total suspended solids (TSS) in the inflow (SC-DHEC 2005).

2.5.3 *SANDBAG BARRIER INLET PROTECTION*

The sandbag barrier setup is constructed by stacking sandbags around a drop inlet in a circular ring. ALDOT specifies the ring should have a minimum inside diameter of 8 ft. The stacking is to be done in a manner that will not leave any open gaps between the bags. Installation plans call for the stacking to be three bags high in a staggered manner, two rows wide for the first two layers and a single row for the top layer. Sandbags should only be used in inlet construction Stages 3 and 4.



(a) ALDOT standard detail (ALDOT 2012)

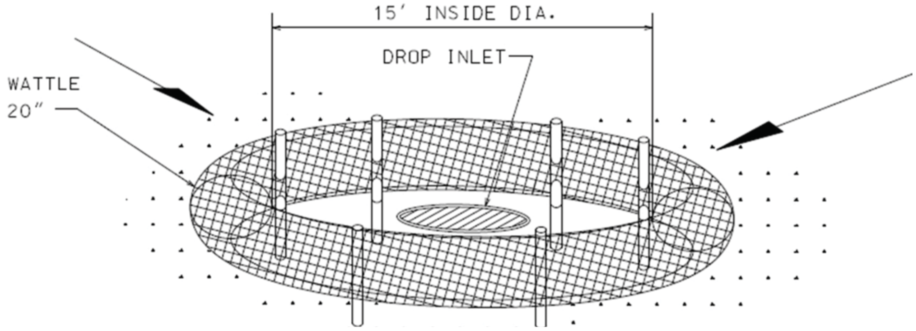
(b) sandbag inlet protection

Figure 2.5 Sandbag Inlet Protection.

2.5.4 *WATTLE BARRIER INLET PROTECTION*

Wattles are manufactured temporary erosion and sediment control barriers comprised of interwoven materials such as coir, straw, excelsior, synthetic fibers, or wood chips in biodegradable or photodegradable netting (Donald et al. 2013). Wattles have cylindrical cross sections available in 8 to 20 in. diameters and 10 to 40 ft in length. Wattles are commonly used as ditch checks, sheet flow interceptors, and IPPs to prevent erosion and control sediment. These devices are coveted by today's industry because they are available in biodegradable versions, are easy to install, and have a comparable or lower installed cost than other traditional IPPs (e.g., silt fencing, aggregate inlet protection, etc.).

The wattle inlet protection practice, as specified by ALDOT, is a 20 in. wattle installed in a circular ring around a drop inlet. The ring is placed at a minimum of 5 ft away from the outside edge of the inlet. The wattle is secured by stakes spaced at a maximum of 3 ft and shall be sized and be of a material that effectively secures the wattle. The wattle should be overlapped as per manufacturer's recommendations, with the joint positioned away from the directional surface flow. ALDOT specifies that wattles can be used as inlet protection on construction sites for "low to medium flow" conditions and under inlet construction Stages 2, 3, and 4. Wattle trenching is a common design detail. Figure 2.6(a) shows the ALDOT standard installation detail. Figure 2.6(b) and (c) depict typical wattle installations around an inlet.



(a) ALDOT standard detail (ALDOT 2012)

(b) typical installation

(c) varying installation

Figure 2.6 Wattle Inlet Protection Applications.

ALDOT's standard specifications state that:

A wattle shall be a tubular shaped product specifically manufactured for erosion and sediment control. It shall be made from interwoven biodegradable plant material such as straw, coir, or wood shavings in biodegradable or photodegradable netting that is of sufficient strength to resist damage during handling, installation and use.

The circumference of a wattle will be measured after installation. The circumference measured anywhere along the length of the wattle shall be within 10% of the circumference of a circular cross section calculated from the required diameter of the wattle (ALDOT 2012).

2.5.5 Manufactured Inlet Protection Devices

The ESC-400 specification for a manufactured inlet is essentially a fabric drop inlet protection device. These devices are composed of a geotextile barrier, secured to a cylindrical dome frame, and placed over a drop inlet. This practice is useful for drainage areas with slopes of less than 1% and where inlets are located in "sump" conditions. Pre-manufactured drop inlet protective structures should be installed and maintained as per manufacturer's specifications. Prior to installation, the surrounding soil should be compacted and shaped to store the runoff on an almost level area. The structural frames should be rigid enough to prevent buckling, fabric sagging, or fabric undermining. The fabric portion of the device is generally secured with ballast (i.e. blocks, gravel, rip-rap) on compacted soil around the inlet. ALDOT specifies that manufactured IPPs be used only in inlet construction Stages 3 and 4. Currently, ALDOT only permits the use of 60 in. diameter Silt-Saver R-100A and S-200A frame and filter assembly products (ALDOT 2014). Figure 2.7 shows the ALDOT standard install detail for a typical fabric drop IPP.

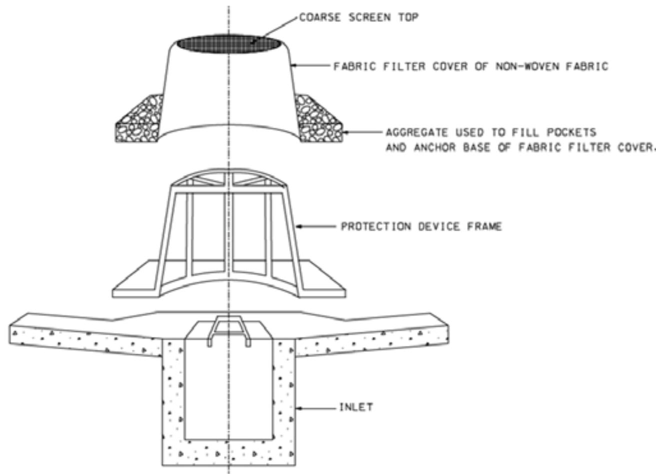


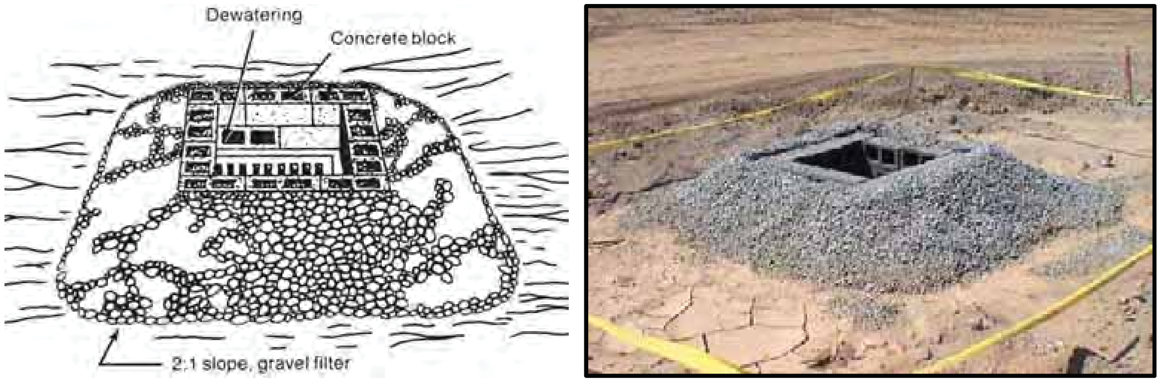
Figure 2.7 ALDOT Manufactured Device Detail (ALDOT 2012).

2.6 ALABAMA SOIL AND WATER CONSERVATION COMMITTEE

The Alabama Soil and Water Conservation Committee (AL-SWCC) authored the '*Alabama Handbook for Erosion Control, Sediment Control and Stormwater Management on Construction Sites and Urban Areas*'. The two volume handbook was created to provide guidance towards developing sound erosion and sediment control plans and to assist in the design and implementation of BMPs including their proper installation, maintenance, and inspection (AL-SWCC 2009). The committee also authored a '*Field Guide of Erosion and Sediment Control on Construction Sites in Alabama*'. The field guide serves as a synopsis of the Alabama Handbook printed in the format of a small handbook for users to easily access on a work site. The handbook includes two specific drop IPPs, block and gravel inlet protection, and fabric drop inlet protection. The field guide includes the two aforementioned practices and an excavation drop IPP (AL-SWCC 2004). Block and gravel and excavation drop IPP are described in detail below, while the fabric drop inlet protection practice was described above in the aforementioned Manufactured IPPs.

2.6.1 *BLOCK AND GRAVEL INLET PROTECTION*

This sediment control barrier is constructed around storm drain inlets using standard concrete block and gravel. This practice can be applied to both drop and curb inlets and can facilitate heavy flows; however the approach is limited to maximum slopes of 1%. The barrier height should be limited to 12 to 24 in. to prevent excess ponding. The top elevation should be at least 6 in. lower than the downslope ground elevation. The first height of blocks should be recessed 2 in. below the opening of the storm drain, laying some blocks on their side to provide for dewatering. Gravel should be placed to the top of the structure height at a maximum 2:1 slope around the blocks with 0.5 in. hardware cloth covering overturned blocks to allow for dewatering. Lateral support is provided by using 2 x 4 in. wood studs (North Carolina Dept. of Environmental and Natural Resources [NC-DENR] 2013). Figure 2.8 depicts a typical block and gravel inlet protection installation around a drop inlet structure. The California Stormwater Management Handbook recommends the use of block and gravel practices for flows greater than 0.5 ft^3/s.

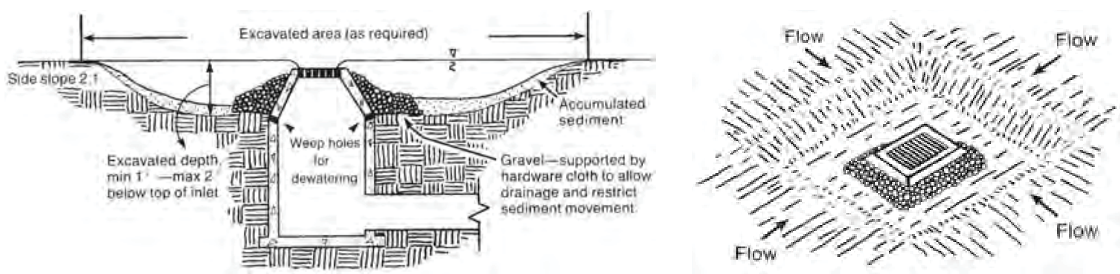


(a) installation detail (NC-DENR 2013) (b) Field Installation (SC-DHEC 2005)

Figure 2.8 Typical Block and Gravel Installation.

2.6.2 *EXCAVATED DROP INLET PROTECTION*

The field book mentions and depicts the excavated drop IPP; however some details were added to this description from the North Carolina Erosion and Sediment Control Planning and Design Manual. The excavated drop IPP consists of an excavated area around the drop inlet that allows runoff to pool, slowing down the flow energy and allowing for sediments to settle. The practice can accommodate heavy flows, however regular and frequent maintenance and temporary flooding is expected. The excavated depth should be between 1 to 2 ft with slopes no steeper than 2:1. Excavated volume should be targeted at 1,800 ft³/ac disturbed. Weep holes are installed on the inlet structure to provide for drainage of the temporary pool and to avoid standing water after heavy rains. Construction considerations to follow include: uniform grading of the inlet approach, gravel protection at weep hole locations, and proper compaction. Inspections should be performed after each storm event and sediments shall be removed when half of the basin has been filled. Figure 2.9 demonstrates the typical excavated drop inlet protection practice.



(a) cross-sectional view (b) isometric view

Figure 2.9 Typical Details of Excavated Drop Inlet Protection (NC-DENR 2013).

2.7 OTHER INLET PROTECTION PRACTICES

The erosion and sediment control industry is flooded with a variety of innovative IPPs and products that are not currently approved for use by ALDOT. This section describes a selection of these practices and innovative products for drop inlet protection. Focus is placed on the design, application, installation, assessment, and maintenance requirements to identify common practices used throughout the nation that have the greatest potential to be adopted and tested.

2.7.1 *Hardware Cloth & Gravel Inlet Protection*

This method utilizes wire-mesh hardware cloth wrapped around steel posts, and washed stone placed around the opening of the drop inlet. This practice is useful for yard inlets, grated storm drains, or drop inlets. The setup is practicable for areas which will have light to moderate sheet flows with surrounding areas of less than 1%. Construction of this practice is done using steel T posts with a minimum length of 5 ft. The posts should have grooves to facilitate fastening of the hardware cloth. The posts should be spaced at no more than 4 ft apart and driven to the ground at the minimum of 2 ft. A 19 gauge wire mesh should be used with 0.25 in. hardware cloth mesh openings. A minimum total height of the device should be 2 ft. The perimeter stone is installed at a height of 16 in. with a 2:1 outside slope. The elevation at the top of the structure must be at least 12 in. lower than the elevation at the downslope away from the inlet. Maintenance for this device is required weekly, or after significant rain events. The mesh shall be cleared of any debris that block flows and stone shall be replaced as needed (NC-DENR 2013). Figure 2.10 depicts the installation detail for the hardware cloth and gravel protection. Hardware cloth and gravel protection should be designed to have an 80% removal efficiency goal of total suspended solids in the inflow (SC-DHEC 2005).

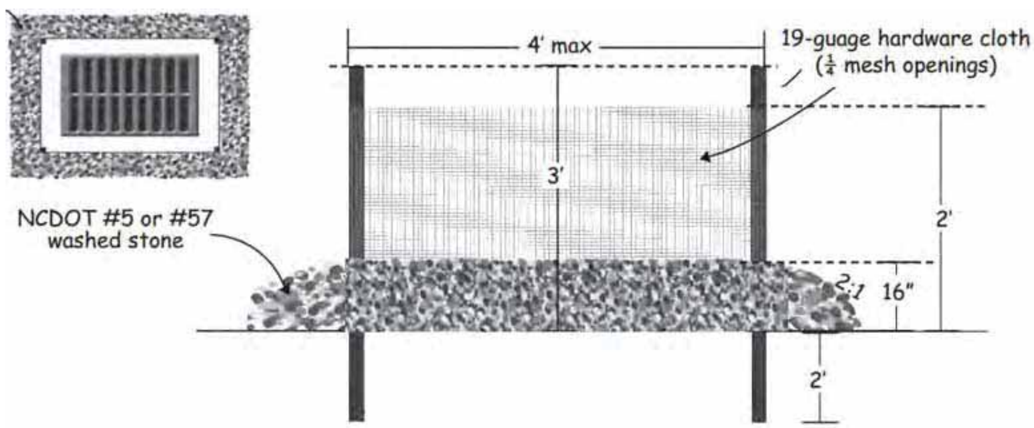


Figure 2.10 Hardware Cloth & Gravel Inlet Protection Detail (NC-DENR 2013).

2.7.2 *Rock Doughnut Inlet Protection*

The rock doughnut protection structure is round shaped dam which prevents sediments from entering a drop inlet. This practice is useful for inlets that receive high velocity flows from multiple directions or can be modified if flows are received from only one direction. The device is constructed of Class B structural riprap with a 2:1 slope and minimum crest width of 18 in. The structures height should be between 2 to 3.5 ft with the outside face of riprap covered in a 12 in. layer of #5 or #57 washed stone. The top elevation of the structure should be at least 12 in. lower than the ground elevation downslope from the inlet. Sediments should be removed when half of the storage volume has been filled (NC-DENR 2013). Figure 2.11 depicts the detail drawings for a rock doughnut inlet protection installation.

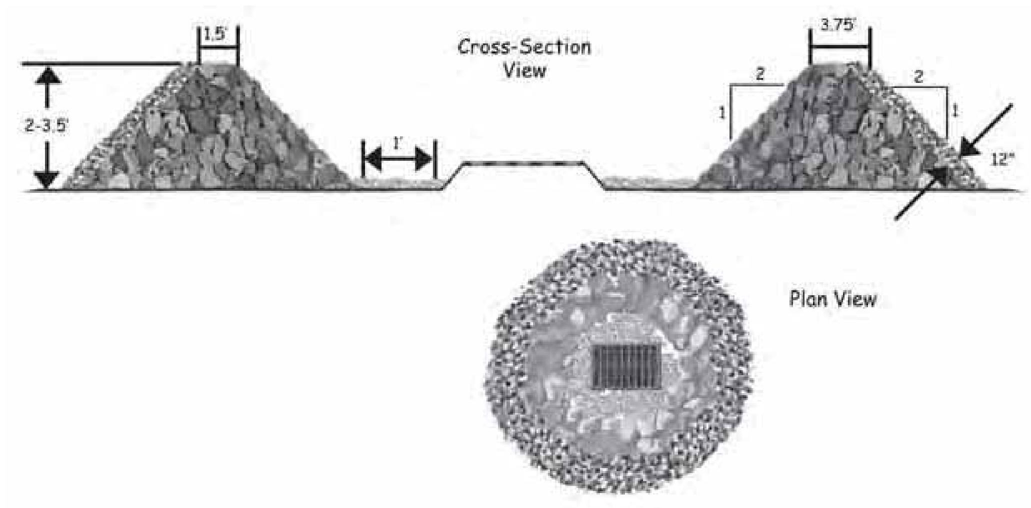
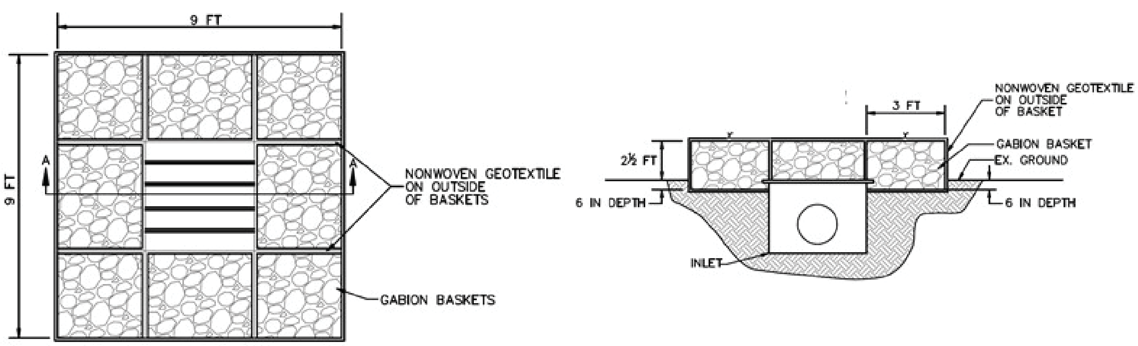


Figure 2.11 Rock Doughnut Inlet Protection Detail (NC-DENR 2013).

2.7.3 Gabion Inlet Protection

The gabion IPP is used around drop inlets with drainage basins up to 1.5 ac. The device is installed around the perimeter of an inlet in a square shape as shown in Figure 2.12. The installation consists of stone filled 3 x 3 ft, 11 gauge gabion baskets wrapped with a nonwoven geotextile. The stone should be clean 4 to 7 in. stone or equivalent recycled concrete without rebar or mesh. The baskets are trenched to a depth of 6 in. below the existing ground surface (MDE 2011).



(a) plan view of installation (b) cross-sectional view

Figure 2.12 Gabion Inlet Protection (MDE 2011).

2.7.4 Winged Median Inlet Protection

This IPP is specifically catered towards drop inlets located on roadway and highway medians. The device consists of a rock weir on the receiving face of the structure, and a silt fence lining the remaining three sides of the device. When the inlet is in a sump condition, the wing walls are placed on the two opposite receiving faces. The device is intended to receive concentrated flows along the stone faces, and sheet flows on the silt fence faces. This installation can accommodate up to a one acre drainage basin per wing walled side. In the construction of this device, nonwoven geotextile is used between stone layers on the receiving face of the weir. The weir should be placed 10 in. above the invert of the channel with the opening at the same width as the channel bottom. Stone 4 to 7 in. in diameter lines the front of the weir, which is adjoined by wing structures (MDE 2011). Figure 2.13 depicts the typical median inlet protection detail.

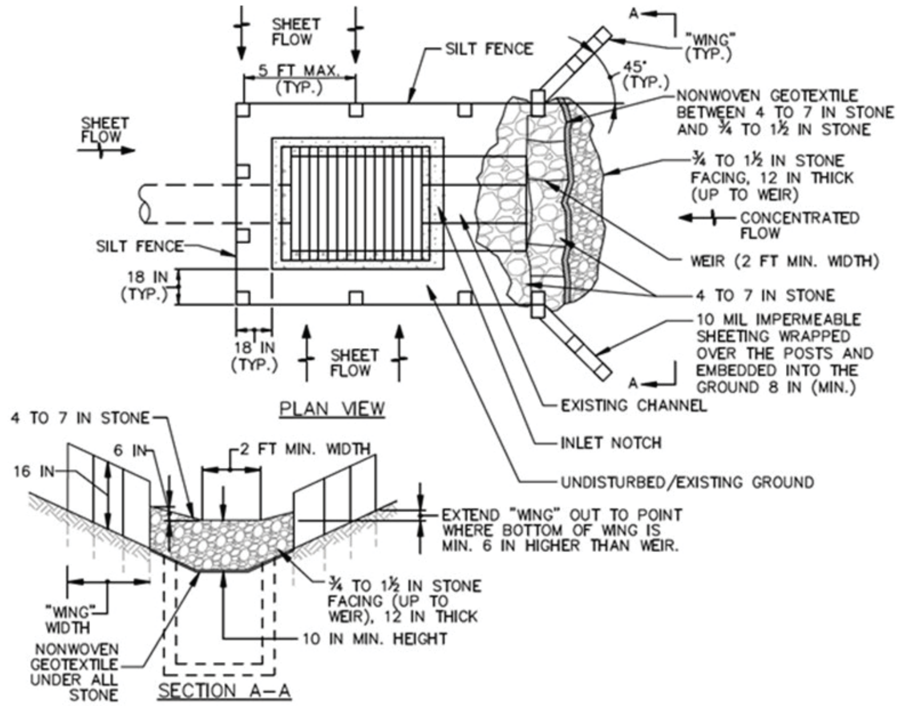
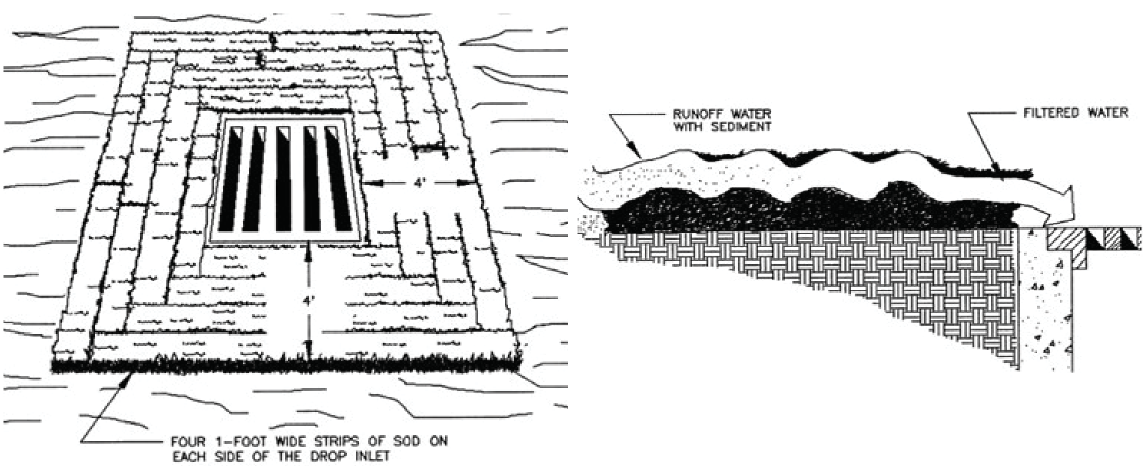


Figure 2.13 Median Inlet Protection Detail (MDE 2011).

2.7.5 *SOD DROP INLET PROTECTION*

The sod drop IPP is used in areas where the contributing drainage area has been permanently seeded and mulched. The practice is applicable to drainage basins of up to two acres. This setup is practicable for lawns adjacent to large buildings. Contributing velocity is limited to 5 ft/s over the sod area. A turf mat is created with the sod strips to cover the soil surface for a distance of at least 4 ft from each side of the drop inlet. Slopes should not exceed 4:1. Sod strips need to be laid out in a staggered configuration, perpendicular to flow direction. Proper maintenance of this practice includes fertilizing, watering, and mowing of the grass. Figure 2.14 depicts the sod drop IPP.



(a) plan view of installation (b) cross-sectional view

Figure 2.14 Sod Drop Inlet Protection (MDEQ 2011).

2.8 OTHER MANUFACTURED INLET PROTECTION DEVICES

This section describes other innovative manufactured IPPs. These devices are available for installation above, around, and below drop inlet structures.

2.8.1 *DANDY POP (DANDY PRODUCTS)*

The Dandy Pop is a folding device manufactured to fit over an inlet structure. The product secures to an inlet grate in an effort to reduce flows and facilitate sedimentation through settlement. The device is composed of a geotextile fabric dome with a support frame designed to enclose the grate. The product height is approximately 24 in. Maintenance is recommended after each rain event (Dandy Products 2014). Figure 2.15 shows the system detail and typical installation over an inlet structure.

(a) device installation detail (b) typical installation

Figure 2.15 Dandy Pop Device (Dandy Products 2014).

2.8.2 *EROSION EEL (FRIENDLY ENVIRONMENT)*

Erosion Eels are woven polypropylene geotextile tubes filled with recycled tire chips. The manufacturer clams that the device requires no staking for areas not subject to concentrate flows. Similar to wattles, the three-dimensional product can be arranged around an inlet to create a barrier. Custom sizes are available, however the most common are 9.5 in. (24 cm) diameter tubes in either 4.5 or 10 ft lengths, weighing 40 to 150 lbs respectively. The Eels are designed to be reusable and the manufacturer recommends periodic maintenance by cleaning with high pressure wash or brushing the surface with a broom (ACF Environmental 2014; Friendly Environment 2014). Figure 2.16(a) depicts the manufacture's recommended installation for use as an IPP. Figure 2.16(b) shows a typical field installation on a pervious surface.

(a) inlet protection installation detail (b) installation on pervious surface

Figure 2.16 Erosion Eel Installation (Friendly Environment 2014).

2.8.3 *FLEXSTORM™ CATCH IT INLET FILTER (INLET & PIPE PROTECTION, INC.)*

The Flexstorm™ inlet protection device is a reusable filter bag installed below inlet grates. The filter system is comprised of a corrosion resistant steel frame and a replaceable geotextile sediment bag attached to the frame with a locking band. The product serves to filter and collect silt and sediment from stormwater runoff, and includes an overflow feature. It is available for a variety of inlet structure shapes and sizes. The standard filter bag has a flow through rate of 200 gal/min/ft^2. The manufacturer recommends inspection following storm events greater than 0.5 in., and emptied when the bag has been filled halfway. Bag replacement is needed when tears become present on the device (Inlet & Pipe Protection 2014). ASTM D7351 SRB testing performed by TRI/Environmental, Inc. reported 82.2% soil retention effectiveness with "no significant" decreases in turbidity (TRI/Envionmental 2009). Figure 2.19 shows a round frame assembly and a square frame assembly installed.

(a) round frame assembly (b) square assembly installed

Figure 2.17 Grate Pyramid Applications (Inlet & Pipe Protection 2014).

2.8.4 *GEOHAY (GEOHAY, INC.)*

GeoHay produces tubular products manufactured from pre-and post-consumer synthetic carpet fiber material. The reusable product is available in standard diameter sizing ranging from 9 to 18 in. and lengths from 4 to 20 ft. To provide protection around an inlet, GeoHay tubes are arranged around the perimeter of the inlet and staked using 2 x 2 in. wooden stakes. Flow through rates for the device are reported as high as 6.7 gal/min/ft^2 (GeoHay 2014). ASTM D7351 SRB testing performed by TRI/Environmental, Inc. reported up to a 99.4% soil retention effectiveness

(TRI/Envionmental 2008; TRI/Envionmental 2010). Figure 2.18(a) depicts the inlet barrier installation detail. Figure 2.18(b) shows a typical in-field installation of the device.

(a) installation detail (b) in-field installation

Figure 2.18 Geo Hay Installations (GeoHay 2014).

2.8.5 *Grate Pyramid (ACF Environmental, Inc.)*

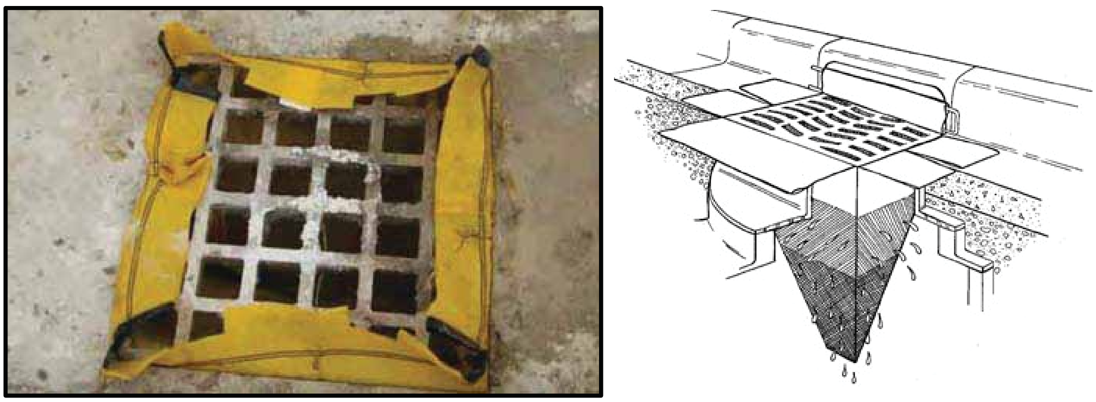
The Grate Pyramid inlet protection device is a reusable and portable manufactured assembly composed of a metal frame and geotextile skirting. The device has a flow through rate of 200 gal/min/ft^2. A high-flow geotextile skirt on the device can be replaced when maintenance is required. The Grate Pyramid is available to fit over both a square (Type A) and round (Type B) inlet. A Type C Grate Pyramid is also available for smaller inlet diameters. The device fits over a grate inlet and anchors down with hooks or can be secured to a round riser pipe with an attachment belt (ACF Environmental 2014). ASTM D7351 SRB testing performed by TRI/Environmental, Inc. reported 86.4% soil retention effectiveness with “modest” decreases in turbidity (TRI/Envionmental 2011). Figure 2.19 shows the typical Type A and Type B installations

(a) Type A Grate Pyramid installation (b) Type B Grate Pyramid installation

Figure 2.19 Grate Pyramid Applications (ACF Environmental 2014).

2.8.6 *SILTSACK® (ACF ENVIRONMENTAL, INC.)*

The Siltsack® is a filtering device that fits inside of a drop inlet. The product is secured in position by the weight of the inlet's grate. This manufactured product is made of a permeable geotextile that retains silt and sediment from passing through the inlet. The device is available through several manufacturers in regular 50 gal/min/ft^2 and high 200 gal/min/ft^2 flow version and has the option of overflow holes to allow dewatering in higher flows (ACF Environmental 2014). The manufacturer recommends inspections after every major rain event. Figure 2.20 illustrates a standard curb and gutter installation of the Siltsack®.



(a) Siltsack® product (b) curb inlet installation detail

Figure 2.20 Siltsack® Protection Device (ACF Environmental 2014).

2.8.7 *SILT-SAVER (SILT-SAVER®, INC.)*

Currently, the Silt-Saver domes are the only approved manufactured devices for use in ALDOT projects. The device is available in a round base (R-100A) or square frame (S-200A) and both are intended to fit over 5 ft outer diameter inlet structures. Various fabric covers are available to fit over the frame, providing various flow through rates. Fabric covers are secured to the ground by filling the fabric pockets with aggregate. Maintenance is recommended when sediment deposits cover 50% of the device. The manufacturer claims a 102 gal/min/ft^2 flow through rate through the unwoven fabric material and boasts an increase of efficiency of 85% when compared to typical methods (Silt-Saver 2014). Figure 2.21(a) and (b) depict typical in field installations of the Silt-Saver round frame with filter.

(a) installation on bare soil (b) damaged installation

Figure 2.21 Round Frame, High-Flow, Silt-Saver Installations.

2.8.8 *ULTRA BASIN GUARD (ULTRATECH INTERNATIONAL, INC.)*

The Ultra-Basin Guard is a manufactured protective apparatus that fits over inlet grates. The 36 in. (91 cm) diameter device is comprised of a nonwoven polypropylene geotextile and is intended to keep sediment and oils from entering inlets. The product has a flow through rate of 90 gal/min/ft^2 (0.37 L/min/cm^2) (UltraTech International 2014).The Basin Guard is available in both a round unit and a rectangular configuration as illustrated in Figure 2.22.

(a) grate inlet (b) grate inlet with filter fabric

Figure 2.22 Ultra-Basin Guard Installations(UltraTech International 2014).

2.9 INLET PROTECTION PRACTICES SUMMARY

The abovementioned IPPs and devices above show many common practices that are employed in the field by ALDOT and other state agencies across the country. Several other manufactured devices exist, and new and novel products are constantly entering the marketplace. The presented IPP are summarized below in Table 2.2. Manufactured devices are presented in Table 2.3.

Table 2.2 Summary of Presented IPPs

Practice	Drainage Area Size / Flow Velocity / Rate / Type	Typ. Dimensions
Coarse Aggregate Barrier [a]	1 acre	22 x 22 ft 18 in. height
Block & Gravel	“heavy flows”	8 x 8 ft 16 in. height
Excavated	“heavy flows”	1,600 ft^3/acre 1 to 2 ft depth
Fabric / Silt Fence Barrier [a]	1 acre / 0.5 ft^3/sec / sheet flow	6 x 6 ft 32 in. height
Gabion Basket	1.5 acres	9 x 9 ft 2.5 ft height
Hardware Cloth & Gravel	1 acre / “light to moderate flows” / sheet flow	10 x 10 ft 16 in. height
Rock Doughnut	1 acre	40 x 40 ft 3.5 ft height
Sandbag Barrier [a]	1 acre	8 ft diameter 2 ft height
Sod Barrier	2 acres / 5 ft/sec / sheet flow	12 x 12 ft
Wattle Barrier [a]	“medium flows”	15 ft diameter 20 in. height
Winged Median	1 acre/face / concentrated Flow	10 x 15 ft 32 in. height

Notes: [a] ALDOT approved practice

Table 2.3 Summary of Presented Manufactured Devices

Device (Manufacturer)	Flow Through Rate [a]	Typ. Dimensions
Dandy Pop (Dandy Products)	250 gal/min/ft^2	24 in. height
Erosion Eel™ (Friendly Environment)	N/A	9.5-20 in. x 4. -10 ft / 40 lb-150 lb
FLeXstorm™ Catch It (Inlet & Pipe Protection, Inc.)	200 gal/min/ft^2	22 in. depth
GeoHay (GeoHay, Inc.)	6.7 gal/min/ft^2	9 to 18 in. diameter 4 to 20 ft length
Grate Pyramid (ACF Environmental Inc.)	200 gal/min/ft^2	custom ordered
Siltsack® (ACF Environmental, Inc.)	50 or 200 gal/min/ft^2[b]	-
Silt-Saver [c] (Silt-Saver)	102 gal/min/ft^2	5 ft diameter
Ultra Basin Guard (UltraTech International, Inc.)	90 gal/min/ft^2	36 in. diameter

Notes: [a] flows are based on the amount of water able to pass the device per ft^2 of material
[b] a low and high flow model are available
[c] ALDOT approved device

2.10 EXISTING TESTING PROCEDURES

Determining the effectiveness and overall performance of various IPP and devices is difficult when performing in-field monitoring of installations at construction sites. The difficulty is due to the "uncertainty of runoff quantity and quality due to weather patterns and construction activities makes objective, replicated experiments very difficult" (McLaughlin et al. 2001). To properly evaluate the performance of an IPP, several water quality parameters should be monitored throughout the experimental process.

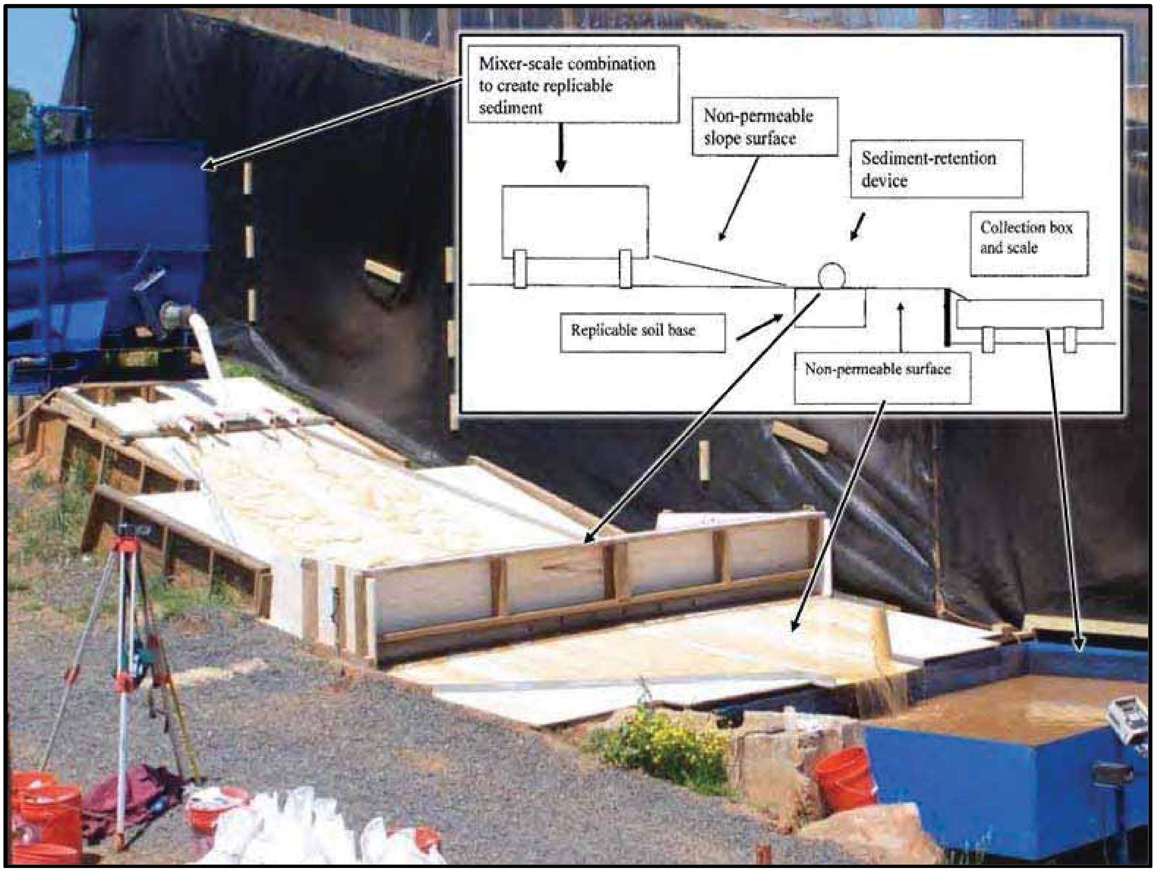
Adequately determining and comparing the effectiveness and overall performance of each IPP would be particularly difficult solely from field observations due to the lack of environmental control and similar landscape available from one construction site to another. Therefore, the focus of this study is to employ replicable, large-scale experimental techniques to scientifically evaluate the performance of inlet protection practices under controlled conditions.

A literature review was conducted to identify current IPP testing practices. Although there is currently no widely accepted testing standard published for the testing and evaluation of IPPs, an ASTM test method and a study conducted by the University of Central Florida's Stormwater Management Academy (UCF-SMA) were identified.

2.10.1 *ASTM D7351-07 STANDARD TEST METHOD*

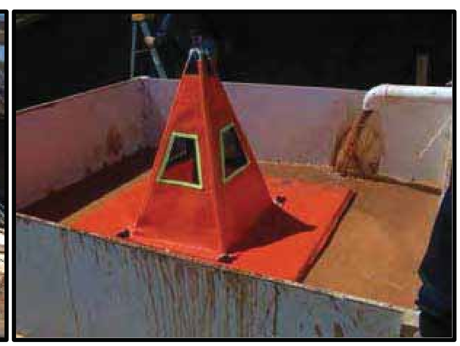
The ASTM Standard D7351, entitled "*Standard Test Method for Determination of Sediment Retention Device (SRD) Effectiveness in Sheet Flow Applications*" describes the test method for determining the effectiveness of SRDs (ASTM D7351 2007). This method describes the procedure for executing an experiment and quantifying the ability of an SRD to retain eroded sediments caused by sheet flowing water under full-scale testing conditions.

The ASTM D7351 standard test method constitutes of mixing a known quantity of sediments with clean water in a tank and releasing the sediment-laden water as sheet flow through a non-permeable sloped channel and then flow into an installed SRD in the installation zone, which is 20 ft long x 6.5 ft wide. The installation zone consists of a replicable loam soil base. Discharged effluent downstream of the SRD is then collected in a retention box. The test discharges a consistent flow of 0.044 ft^3/s for 30 minutes and requires grab samples to be collected at five minute intervals. Sediments that pass the SRD are collected and dried, while grab samples are tested for turbidity and percent solids. The performance of the SRD under consideration is based upon its effectiveness to retain sediments over the duration of the test (ASTM D7351 2007). Figure 2.23(a) shows the ASTM D7351 testing equipment schematic with an actual testing configuration being conducted on an SRD by TRI/Environmental, Inc. at their Denver Downs Research Facility in Anderson, South Carolina. Figure 2.23(b) shows modifications made for testing IPPs.



(a) standard testing installation

(b) modification for inlet Protection testing



(c) flow introduction

Figure 2.23 ASTM D7351 Testing (TRI/Envionmental 2011).

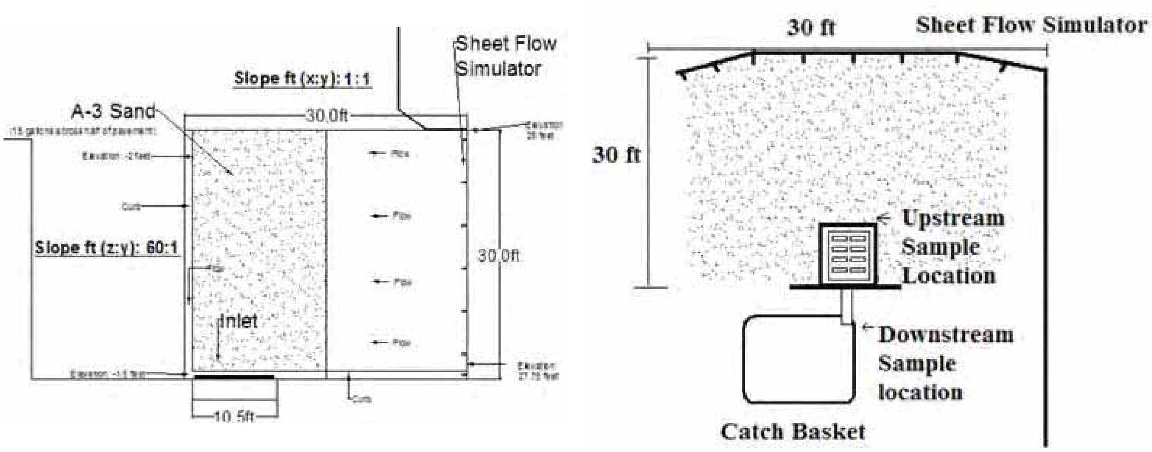
This test procedure has several inherent limitations. First, the test assumes that all SRD's are subjected to the same flows. The USEPA stipulates in the CGP that all erosion and sediment control practices shall meet storm runoffs generated from the local 2-yr, 24-hr event. Furthermore, IPP can be used in drainage basins up to 1 acre (0.4 ha) in size. The prescribed flow rate for the ASTM test was based on calculations for a 10-yr, 6-hr storm event (mid-Atlantic region of the U.S.) with a theoretical contributory area of 100 x 20 ft (30.5 x 6.1 m), or about 0.05% of the maximum contributory area. The method also tests a SRD under sheet-flow conditions even though inlets are typically subjected to shallow concentrated flows. In addition, the calculations used to determine the runoff quantity to determine a test flow rate, assumes an interception rate of 50%, a gross over-estimation by most accounts.

A further limitation of the standard is that devices are not assessed on a ground surface mimicking typical in-field installations. Therefore, the ground anchoring, surface interaction, undermining, and erosion potential, cannot be determined. Furthermore, the introduced sediment-laden flow is not directed to the device in the expected sheet or concentrated flow. Figure 2.23(c) illustrates the introduction of flow during an inlet protection test.

The presented limitations result in a test that is not representative of actual IPP in-field performance behaviors when installed in bare soil conditions and subjected to greater flows from the entire drainage area.

2.10.2 *INLET PROTECTION TESTING*

The University of Central Florida's Stormwater Management Academy recently conducted a study on the effectiveness of thirteen inlet protection devices for the Florida Department of Transportation (Wanielista 2010). The study was performed by evaluating seven manufactured IPP for drop inlets. The study evaluated the devices' flooding and pollution removal potential under 3.5 minute simulated rain events (i.e., two clean water and one sediment-laden tests which produced a maximum flow rate of 0.18 ft^3/s). Grab samples were collected every minute upstream and downstream of the inlet to measure water quality parameters over the seven minute duration for device evaluation. Parameters measured include the flow capacities of the inlet protection devices, turbidity, pH, alkalinity, nitrogen, and phosphorus. A sieve analysis was also conducted to evaluate sediment removal efficiency in relation to particle size. The results of the study indicated that drop inlet protection practices achieved turbidity and total suspended solid reductions of 0.9 to 39.1% and 1.3 to 33.2%, respectively. The protection devices were also able to achieve 1.9 to 8.7% alkalinity removal, 1.7 to 28.3% nitrogen removal, and 2.0 to 24.7% phosphorus removal. A plan view of the testing areas for the curb and drop inlet testing is shown in Figure 2.24.



(a) plan view of curb inlet test configuration (b) plan view of drop inlet test configuration

Figure 2.24 Curb and Drop IPP Testing Configurations (Wanielista et al. 2010).

The study recommended placing an IPP upstream of the inlet to control flow rates while also placing a filtering product beneath the grate in an effort to improve removal efficiencies and improve the quality of stormwater effluent discharge. The study solely focused on product performance evaluations of manufactured IPPs and did not attempt to improve installations to achieve higher efficiencies (Donald et al. 2013). The study also focused on investigating the performance of manufactured IPPs rather than traditional practices, limiting the ability to draw performance comparisons. The drainage area used for the tests was limited to 900 ft^2, which is 2% of the maximum one acre drainage area that most IPPs are designed to handle. Furthermore, the study only investigated storm drain inlets in a permanently stabilized condition, rather than during construction phases where the largest contribution of sediment-laden stormwater is likely generated.

2.11 INLET PROTECTION FAILURE MODES

A critical component of assessing IPP performance is determining when a practice is considered to have failed. Two identified testing methods, ASTM D7351 and the University of Central Florida IPP research project, measured the performance of devices through quantifiable parameters such as pollutant reduction, but fail to address characteristics constituting failure (ASTM D7351 2013; Perez et al. 2014; Wanielista et al. 2010). IPP failure can be defined by identifying the designed and expected performance parameters of a practice or device that may include: structural integrity, impoundment capabilities, filtering capabilities, and sedimentation potential.

Structural Integrity – A device or practice installed around a storm drain inlet must be able to withstand the hydrostatic forces acting upon it. High stormwater flow rates experienced at drop inlets with large contributory drainage basins can alter structural performance of a device by: undermining an installation through erosive forces, dislodging device anchoring materials, and complete structural failure.

Impoundment Capabilities – IPPs remove suspended solids from stormwater by reducing velocities, creating an impoundment, which in turn creates a favorable environment for sedimentation. The volume of water pooled behind a device can be quantified to evaluate a practice's ability in promoting sedimentation. It should also be noted that excessive impoundment of water may be undesirable and become hazardous under some conditions (e.g. flooding of adjacent roadways). Depending on the intended device operation, large impoundment volumes and containment times can either be considered a desired parameter or a failure mode.

Filtering Capabilities and Dewatering Mechanisms – Several practices and devices are marketed as providing filtration of sediment-laden stormwater. Once a practice or device has been subjected to sediment-laden stormwater for a period of time, its filtering capacity is reduced as a result of material clogging. Once clogged, the practice will lose flow-through capacity and eventually filtering capability, resulting in overflow. Although clogged, the device has not necessarily failed due to the increased ability to impound and detain stormwater. As previously mentioned, settlement of particles by creating an impoundment is considered desirable. Furthermore, when practices become clogged, impoundments may cause flooded conditions if an IPP does not have an overflow mechanism to allow for proper drainage. The Maryland Department of Environmental Quality (MDEQ) considers IPPs to be clogged when the installation fails to completely drain and dewater an area within 24 hours following a storm event (MDE 2011).

Dewatering is important in situations where a device could be subject to subsequent storm events within short intervals that generate volumes exceeding the capacity of an IPP. Efficient dewatering is important to avoid flooding or additional burden on downstream devices.

Sedimentation Potential – The purpose of installing IPPs is ultimately to prevent sediment from entering inlets. Therefore, a practice that does not provide a reduction in sediment transport should be considered to be ineffective, resulting in failure.

Due to the dynamic performance characteristics of IPPs, failure cannot be defined in a simple pass/fail criterion. Instead, failure must be addressed for certain situational conditions where specific performance is desired. For example, a device that creates an excessive impoundment with low flow-through rates will impound flows, promoting sedimentation and less sediment will enter an inlet. This type of device will perform ideally in a sump condition with proper detention volume to retain water without causing adverse conditions. However, this same device can fail if placed on a sloped median where water is subsequently diverted around the inlet towards downstream outfalls. Under this situation, the IPP will cause additional burden on downstream devices by increasing the flow rate and volume for receiving outfalls, which may lead to increased channel erosion, failure of downstream practices, and/or flooding. Figure 2.25 depicts the presented situation along inlets placed in a sloped channel. Although the installed practice has effectively impounded water, performing well structurally, and reduced sediment discharge, the device may be considered to have failed due to the burden placed on downstream controls.

Therefore, the exampled device will have failed for the sloped median, but performed as desired for an inlet in sump.

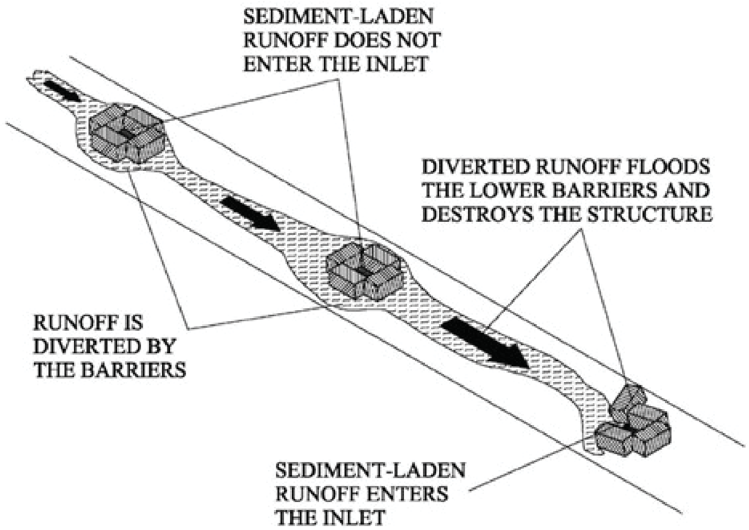


Figure 2.25 Inlet Protection Failure (FDEP 2008).

This example demonstrates that a single practice may not work effectively throughout an entire project. Design and field guidance are needed to ensure that proper device selection is conducted based on the specific site conditions. Figure 2.26 depicts common IPP failures observed in the field.

(a) short-circuiting flows

(b) undermining

(c) structural failure and flow bypass

(d) manufactured device dislodgement

(e) improper trenching of installation

(f) poor maintenance practices

Figure 2.26 Common IPP Installation Deficiencies and Failure Modes.

2.12 SUMMARY

This section described the current need for effective inlet protection from both an environmental standpoint and for regulatory compliance. ALDOT standard IPPs were discussed for various inlet construction stages. Additionally, several other common practices and products were introduced. An existing ASTM test method for evaluating IPP performance, as well as a University of Central Florida study were discussed. Limitations of the testing procedures were evaluated and has thus led towards the need for a better understanding and performance testing methods of devices and practices. Finally, common IPP failure modes were identified and discussed.

CHAPTER 3: RAINFALL ANALYSIS

3.1 INTRODUCTION

Most construction erosion and sediment control practices are typically designed to withstand a 2-yr, 24-hr storm event. A 2-yr, 24-hr storm has a 50% chance of occurring on any given year. The precipitation distribution and quantity for such a storm varies drastically across the country, therefore there is no one-size-fits-all approach (Mather 2014). For example, in the state of California alone, the 2-yr, 24-hr storm can vary from 1.0 in. of precipitation, up to 6.0 in (15.2 cm) (Hershfield 1961). This vast irregularity in precipitation quantity subjects various erosion and sediment controls to a wide range of flow rates and intensities. Furthermore, soil conditions are vastly assorted and diverse throughout the country. Soil types vary in physical and chemical composition leading to differing erosion potentials. Soil grain size distribution can create disparity in suspended sediment concentrations and settling times. To appropriately determine suitable erosion and sediment control testing conditions, prescribed flow and sediment loads should rely on regional storm characteristics and soil conditions.

Erosion and sediment control designs and performance vary regionally based on storm characteristics and soil conditions, thus the effectiveness of different practices will vary from site to site. To assess performance of various practices, products, and devices, testing should mimic in-field conditions, replicating regional precipitation and soil conditions.

The contributing drainage basin will also impact the quantity and quality of stormwater received and contained by an erosion and sediment control practice. Typical design drainage basins can vary tremendously by practice and are provided in Table 3.1.

Table 3.1 Typical Erosion and Sediment Control Design Drainage Basin Sizing

ESC Practice	Max. Design Drainage Basin
Inlet Protection; Ditch Checks	1.0 ac (USEPA 2012)
Sediment Basin	10 to 100 ac[a] (ALDOT 2010; NCSCC 2013)
Perimeter Control Practices	100 ft^2/ft

Note: [a] Maximum design drainage basin varies depending upon regional runoff characteristics and available design guidance from governing agencies.

Rainfall, soil hydrology, and a design drainage basin are required to predict resulting runoff quantities. With these data, a geographic information systems (GIS) model was developed to predict the 2-yr, 24-hr stormwater runoff volumes and flow rates for a highway median conveyance channel discharging into storm drain inlets. The analysis was used for appropriately designing and sizing various runoff conveyance practices (i.e., ditch check and IPPs) typically used during roadway construction. The method applied the mean rainfall and soil hydrologic curve number values to a design drainage basin. For consistency, all GIS layers were rendered with a cell resolution of 328 x 328 ft (100 x 100 m). Furthermore, all projections were kept in North American Vertical Datum-16 North.

To select a testing flow rate that would be representative of expected conditions in the state of Alabama, a GIS study was performed to analyze regional rainfall and runoff characteristics. Since ditch checks and IPPs are generally designed to handle a 2-yr, 24-hr storm, this design storm event was selected. Rainfall contour curves were input as a raster image on esri® ArcGIS™ from Technical Paper No. 40 (Hershfield 1961). The portable document format (pdf) image was geo-referenced over a polygon shape file of the state and county borders of the U.S. The projection of the storm data was in Albers equal-area conical projection and provided some distortion against the shape file created in Mercator projection. However, since the extent of the analysis was limited to the state of Alabama, distortion was removed by sacrificing the geo-referencing precision of bordering states. Once the image was rectified, rainfall intensity contours were digitized using a straight-line polyline vector shape file through the edit feature within the software. In an effort to smooth the digitized curves, the created vectors were exported to the Autodesk® software AutoCAD®. In AutoCAD, the straight-line vectors were converted to splines curves to produce smooth lines. This new layer was imported into ArcGIS to perform further analysis. Using the editor tool, a new attribute was created to specify the rainfall in inches to each curve. The rainfall curve data were used to create a triangulated irregular network (TIN) layer based on the rainfall attribute and was converted into a raster image (Figure 3.1). This process interpolated the area between the provided rainfall contours. The raster was trimmed to the extents of the Alabama state border. Contours were then created from the raster to provide greater interval details between the provided data. It was found from this analysis that the 2-yr, 24-hr rainfall depth in the state ranges between 3.7 and 6.0 in. with an average of 4.43 in. A shape file was also created to delineate the state boundary between Type II and Type III rainfall distribution types. Type II and Type III rainfall distributions were delineated using the Alabama Supplements to the National Engineering Field Handbook (United States Department of Agriculture [USDA] 2004). The Type III rainfall distribution is the predominant type making up 73.3% of the state by area (Viessman and Lewis 2003).

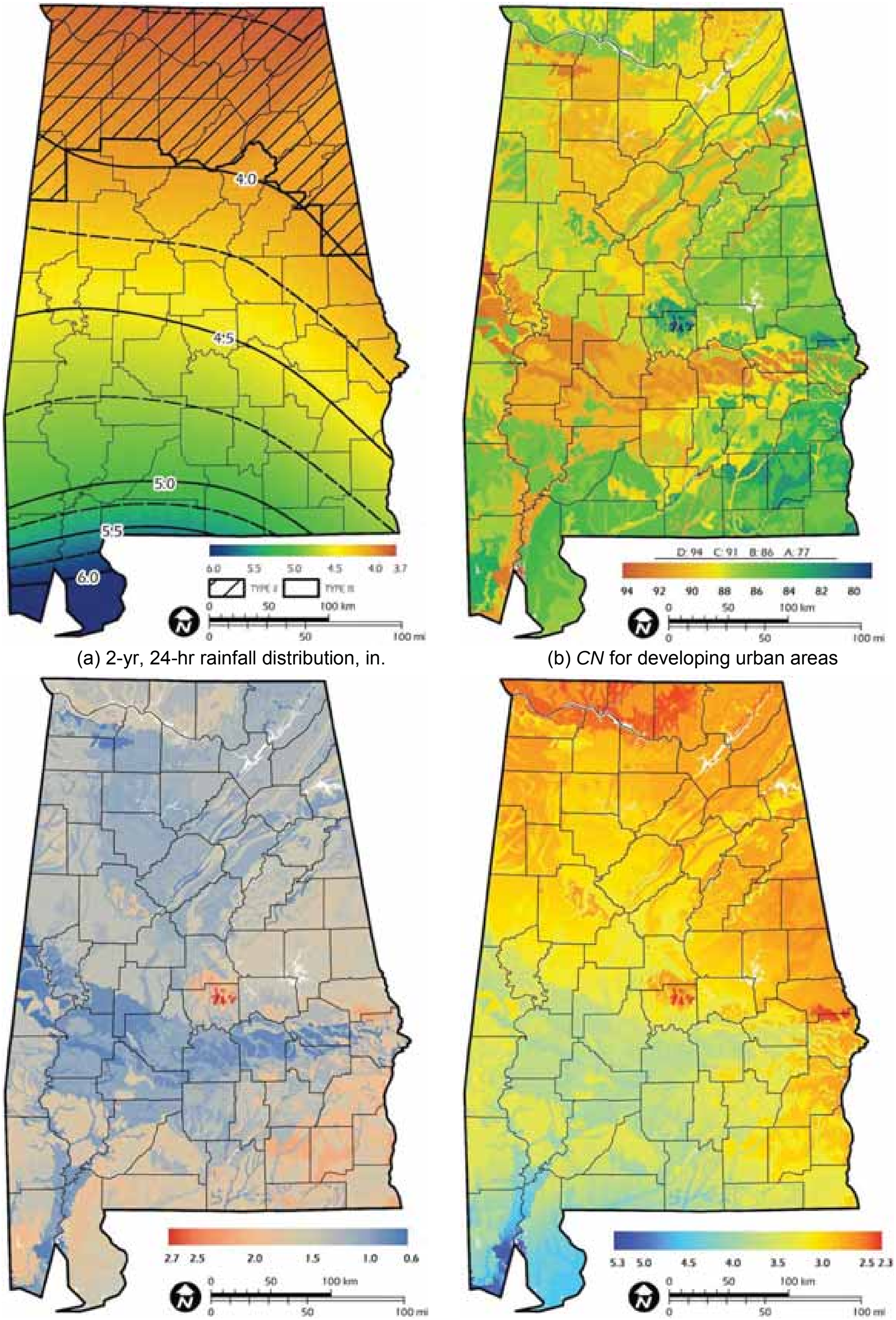
3.2 SOIL HYDROLOGY

A runoff-potential characteristic of land cover and land use (i.e., soils, plants, impervious area, interception, and surface storage) can be described using runoff curve numbers (*CN*) that are assigned to areas based on cover type and hydrologic soil groups. *CNs* are an efficient method for determining the approximate amount of direct runoff from a rainfall event in a particular area. *CNs* range from 0 to 100; the higher the value, the greater the runoff potential of the soil. Lower *CN* values indicate higher soil permeability and do not allow runoff to occur until initial abstraction has been met. Soils are also divided into four hydrologic soil groups (HSGs) (i.e. A, B, C, and D) according to their minimum infiltration rate. The HSGs further serve as an indication of the transmission rate of the soil. The soil group classifications are provided in Table 3.2 (USDA 1986).

Table 3.2 Hydrologic Soil Group Characteristics (USDA 1986)

HSG	Soil Profile	Texture	Infiltration Rate	Transmission Rate (in/hr)
A	deep, well to excessively drained sand or gravel.	sand, loamy sand, or sandy loam	high (low runoff potential)	> 0.30
B	moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures	silt loam or loam	moderate	0.15 to 0.30
C	soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture	sandy clay loam	low	0.05 to 0.15
D	consist chiefly of clay soils with a high swelling potential, soils in high water tables, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material	clay loam, silty clay loam, sandy clay, silty clay, or clay	very low (high runoff potential)	< 0.05

HSG data for the state were mined from CONUS-Soil datasets (Miller and White 2006). The data were extracted from ArcInfo interchange file format and provided percent occurrence of HSGs within given map areas, or units. Separate map units were available for surface waters (e.g., lakes, reservoirs, rivers), which were removed from the analysis. The data attributes were exported to a spreadsheet to allow for further computation.



(a) 2-yr, 24-hr rainfall distribution, in.

(b) *CN* for developing urban areas

(c) retention after runoff – *S*, in.

(d) runoff amount – *Q*, in.

Figure 3.1 Storm Runoff Characteristics for the state of Alabama (Perez et al. 2016).

To compute a weighted average *CN* for a construction site in a given area, the land use for each soil classification was first assigned as "*Developing Urban Areas with Newly Graded Areas (pervious only, no vegetation)*" and then corresponding *CNs* were specified to the soil classes (*CNs* are 77, 86, 91, and 94 for HSG A, B, C, and D, respectively, Figure 3.1[b]). Using the percent occurrence of each soil classification per map unit, the resulting weighted average *CN* was a composite *CN* for each map unit under developing urban conditions (under construction). After spreadsheet computation, the layer was added and joined to the polygon shape file of *CN* in the state. The average Alabama *CN* was determined to be 88.5, which is categorized for a soil between hydrologic soil groups B and C.

Using the created statewide *CN* distribution raster layer, retention after runoff (*S*) was created using the ArcGIS raster calculator tool and depicted in Figure 3.1(c). Retention after runoff is a characteristic of the quantity of water soil can retain based on its *CN*. The equation for retention is presented in Equation 3.1.

$$S = \frac{1000}{CN} - 10 \tag{3.1}$$

where,

S = potential max. retention after runoff begins (in.)
CN = curve number

From the precipitation distribution and retention after runoff rasters, a runoff amount (*Q*) raster (Figure 3.1[d]) was generated again using the raster calculator tool. The equation for computing *Q* is presented in Equation 3.2.

$$Q = \frac{(P-0.2S)^2}{P+0.8S} \tag{3.2}$$

where,

Q = runoff (in.)
P = rainfall (in.)
S = potential max. retention after runoff begins

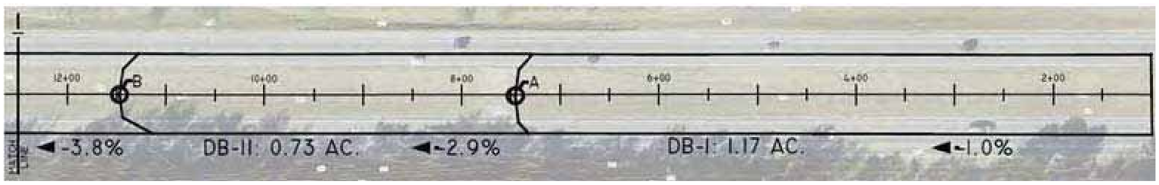
Although the presented calculation is universally accepted (Viessman and Lewis 2003), recent publications indicate that the factor 0.2*S* may be too high and recommend a lower constant (ASCE/EWRI Curve Number Hydrology Task Committee 2008). Table 3.3 provides statistical details of developed raster images and Figure 3.1 depicts the developed raster layers.

Table 3.3 Summary of Statewide Statistical Data

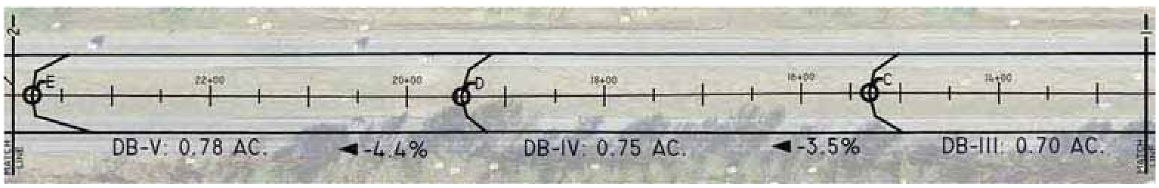
		Statewide	Type II Region	Type III Region
P: 2-yr, 24-hr Rainfall (in.)	*min.*	3.69	3.69	3.94
	avg.	4.44	3.89	4.64
	max.	6.00	4.18	6.00
	std. dev.	0.52	9.18	0.47
CN	*min.*	78.6	85.8	78.6
	avg.	88.4	88.9	88.2
	max.	94.0	93.3	94.0
	std. dev.	2.40	1.61	2.59
S: Retention (in.)	*min.*	0.64	0.72	0.64
	avg.	1.33	1.25	1.32
	max.	2.72	1.65	2.72
	std. dev.	0.31	0.19	0.31
Q: Runoff (in.)	*min.*	2.30	2.35	2.30
	avg.	3.18	2.72	3.35
	max.	5.30	3.16	5.30
	std. dev.	0.49	0.16	0.46

3.3 DESIGN DRAINAGE BASIN

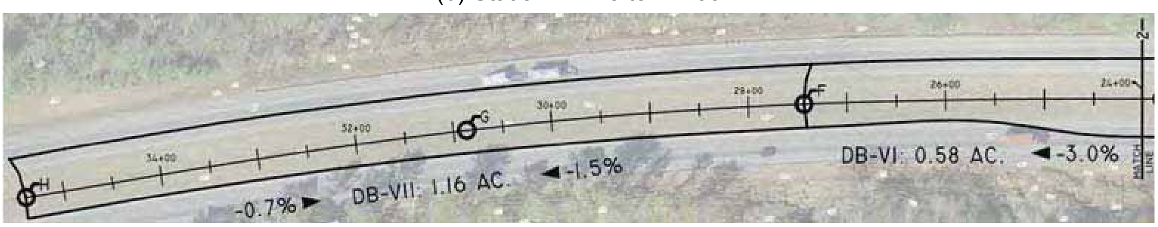
To create a representative drainage basin for a typical median drop inlet, a field survey of a local four lane highway was conducted. A 0.75 mi stretch of interstate 85 (I-85) near mile marker 56 in Auburn, Alabama was studied. Inlet placement and spacing along the roadway median were identified and included an aerial photograph obtained from the Auburn GIS portal (City of Auburn 2013). Topographic contours were added as a layer and served to delineate the contributory area for each of the eight inlets measured. The results of the field survey are shown in Figure 3.2. Inlet drainage basins ranged between 0.58 to 1.17 ac, with the average area being 0.73 ac. Slopes along the corridor ranged between 0.7 and 4.4%.



(a) Station 0+00 to 12+25



(b) Station 12+25 to 24+00



(c) Station 24+00 to 34+75

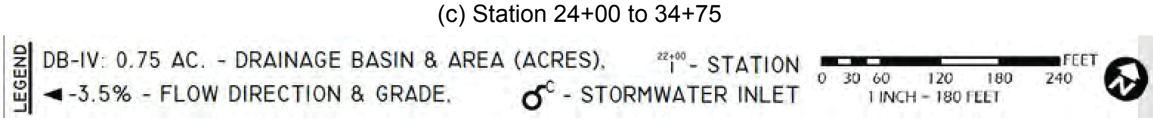
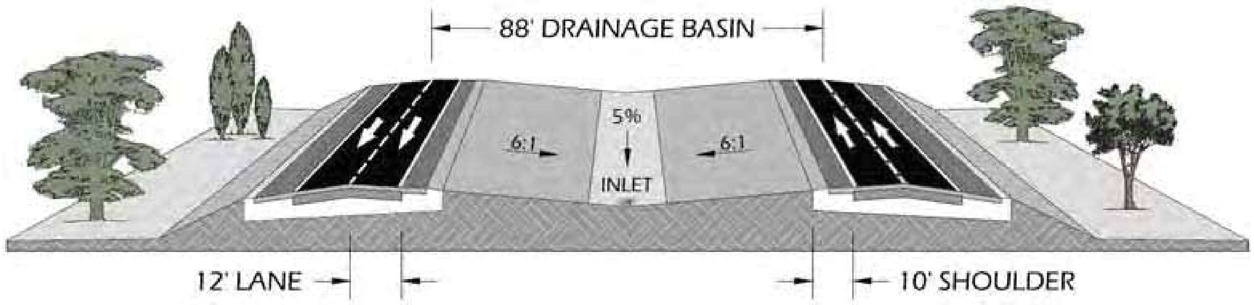
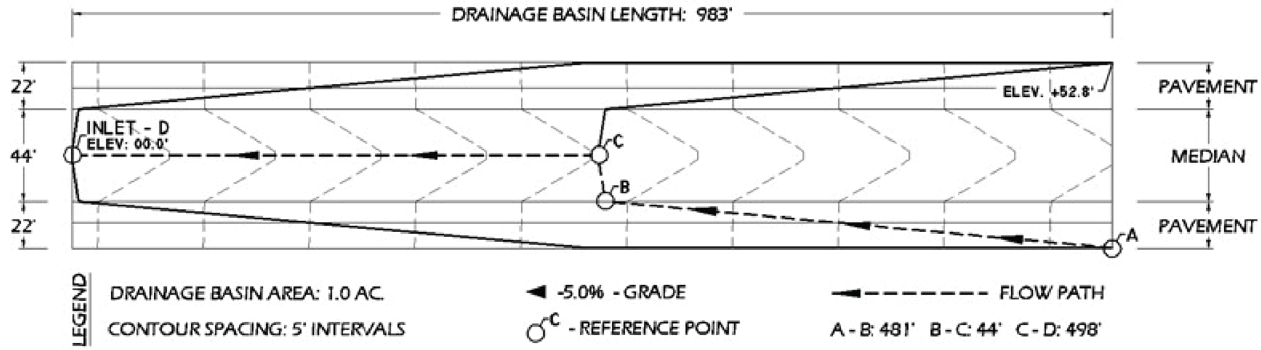


Figure 3.2 I-85 Field Survey.

To represent runoff emanating from a typical ALDOT roadway median, a one acre design drainage basin was developed. Figure 3.3(a) illustrates the typical drainage basin cross-section developed. Two 12 ft lanes each with 10 ft shoulders drain towards the 44 ft (13.42 m) median. The basin is sloped at 5% towards the outlet, which is represented by the storm drain inlet located on the lower end of the median centerline. Figure 3.3(b) shows the plan view of the drainage basin. The flow path, A-B-C-D, illustrates the furthest reach considered in the time of concentration computation as flow originates from point A and discharges at D. This approach was mirrored for both left and right sub-basins. The drainage basin was determined to have approximately 49% impervious roadway surface.



(a) cross-sectional view



(b) plan view

Figure 3.3 Typical Drainage Basin used in Analysis.

3.4 RESULTS AND ANALYSIS

Using the developed 2-yr, 24-hr rainfall distribution, *CNs* for developing urban areas, and the design drainage basin, a sensitivity analysis was performed to facilitate the modeling of expected runoff quantities. Runoff hydrographs were produced using the Technical Release 55 (TR-55) methodology and Bentley® PondPack™ software. A matrix was created to test various combinations of rainfall values and *CNs* that are within the range calculated for the respective SCS rainfall distributions (i.e., Type II, Type III). *CNs* were weighted (CN_w) based on the percent of the roadway drainage basin expected to be impermeable (49%) using Equation 3.3.

$$CN_w = 0.51(CN) + 0.49(98) \tag{3.3}$$

The analysis used the developed one acre drainage basin as a constant feature, however various iterations of expected rainfall and soil characteristics developed through the GIS modeling were conducted. The Type II storm distribution was analyzed for 60 iterations using a rainfall range between 3.7 and 4.2 in., and CN_w ranging from 91.9 to 95.6 using the minimum and maximum *CN* values. Similarly, Type III storm distribution areas were analyzed for 111 iterations using a rainfall range between 3.9 and 6.0 in., and CN_w ranging from 88.2 to 96.0. These ranges represent the minimum and maximum for each respective region. The sensitivity analysis produced tabular hydrographs for each of total 171 iterations attempted. The hydrographs have a precision detail of 0.01 hr intervals. From these hydrographs, peak flow rates, and peak 30, 60, and 90 minute volumes were gathered/calculated. Figure 3.4 demonstrates a graphical example of a hydrograph generated by the analysis process.

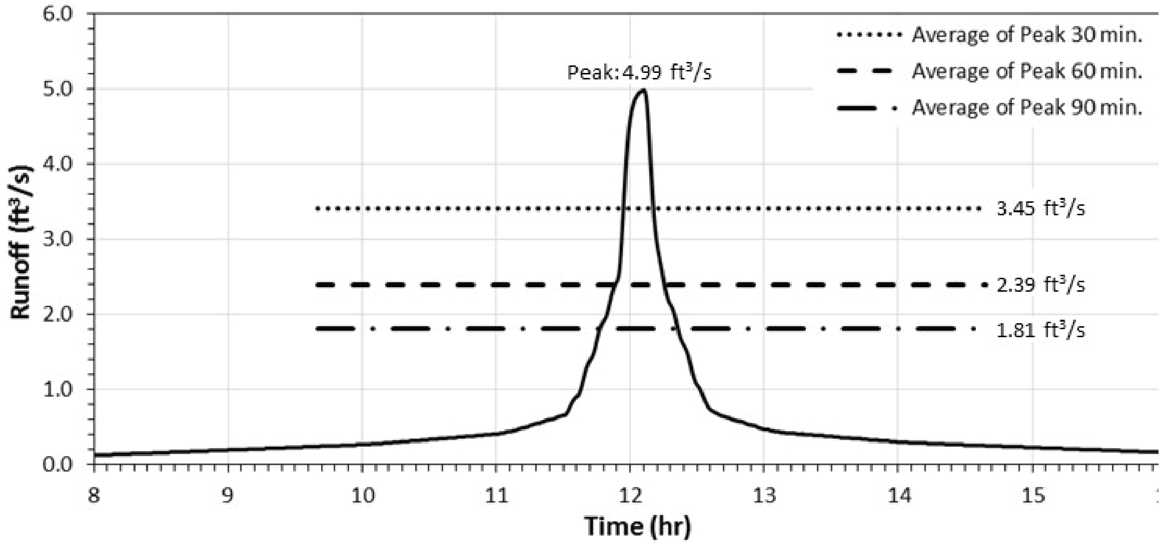


Figure 3.4 Example Hydrograph Result (*CN_w*: 96, *Q*: 6.0 in.).

A multiple linear regression was performed on the simulated data to develop equations to calculate the expected total storm volume (V_{24}), peak flow rate (Qp), and the average flows for the 30 (Q_{30}), 60 (Q_{60}), and 90 (Q_{90}) minute peak volumes based on input rainfall values *P* and CN_w. The regression analysis of the Type II storm data is presented in Equations 3.4 through 3.8. For all regression relationships (i.e., Equations 3.4-3.13), the R^2 value was reported as 1.0.

$$V_{24} = -38198 + 383.2(CN_w) + 3560(P) \quad (3.4)$$
$$Q_P = -9.620 + 0.097(CN_w) + 1.349(P) \quad (3.5)$$
$$Q_{30} = -6.262 + 0.063(CN_w) + 0.782(P) \quad (3.6)$$
$$Q_{60} = -3.718 + 0.037(CN_w) + 0.472(P) \quad (3.7)$$
$$Q_{90} = -2.808 + 0.028(CN_w) + 0.347(P) \quad (3.8)$$

The regression analysis of the Type III storm data is presented in Equations 3.9 to 3.13.

$$V_{24} = -38566 + 383.7(CN_w) + 3533(P) \quad (3.9)$$
$$Q_P = -6.065 + 0.061(CN_w) + 0.876(P) \quad (3.10)$$
$$Q_{30} = -4.525 + 0.045(CN_w) + 0.600(P) \quad (3.11)$$
$$Q_{60} = -3.335 + 0.034(CN_w) + 0.422(P) \quad (3.12)$$
$$Q_{90} = -2.534 + 0.025(CN_w) + 0.319(P) \quad (3.13)$$

Where,

V_{24} = Total storm volume (ft^3) for a 2-yr 24-hr storm
Q_P = Peak flow rate (ft^3/s)
Q_{30} = Peak 30-minute average flow rate (ft^3/s)
Q_{60} = Peak 60-minute average flow rate (ft^3/s)
Q_{90} = Peak 90-minute average flow rate (ft^3/s)
CN_w = Weighted Curve Number, and
P = 2-yr, 24-hr rainfall (in.)

Further relationships were derived from the data to represent the direct correlation between Q_p and V_{24}, Q_{30}, Q_{60}, and Q_{90}. R^2 values for V_{24} was reported as 0.96 for Type II storm distribution and 0.98 for Type III distribution. R^2 values for Q_{30}, Q_{60}, and Q_{90}, were all reported as 1.0. Equations 3.14 through 3.17 show the relationships for the Type II storm distribution data.

$$V_{24} = 2945.1(Q_P) - 2336.8 \quad (3.14)$$
$$Q_{30} = 0.596(Q_P) - 0.122 \quad (3.15)$$
$$Q_{60} = 0.358(Q_P) - 0.063 \quad (3.16)$$
$$Q_{90} = 0.266(Q_P) - 0.058 \quad (3.17)$$

Equations 17 through 20 show the relationships for the Type III storm distribution data.

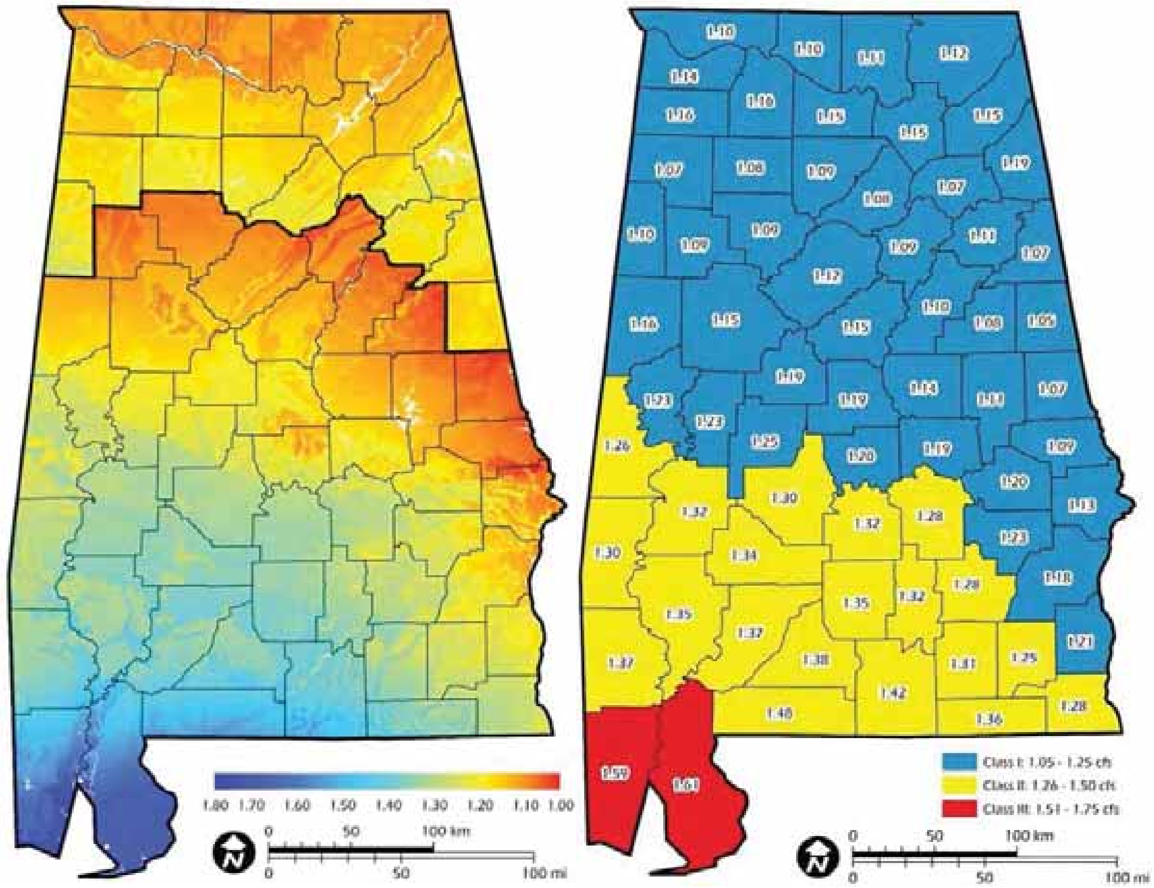
$$V_{24} = 4181.9(Q_P) - 1496.9 \quad (3.17)$$
$$Q_{30} = 0.690(Q_P) - 0.042 \quad (3.18)$$
$$Q_{60} = 0.486(Q_P) - 0.047 \quad (3.19)$$
$$Q_{90} = 0.368(Q_P) - 0.036 \quad (3.20)$$

Using the Rater Calculator tool within ArcGIS, statistical measures were determined for V_{24}, Q_p, Q_{30}, Q_{60}, and Q_{90}. Table 3.4 summarizes the statewide statistical data for both Type II and Type III storm events.

Table 3.4 Summary of Statewide Computed Data

		Type II Region	**Type III Region**
V_{24} (ft^3)	*min.*	10,410	10,450
	avg.	11,440	13,490
	max.	12,770	19,450
	std. dev.	436.7	1,622
Q_p (ft^3/s)	*min.*	4.33	3.01
	avg.	5.15	5.03
	max.	4.68	3.66
	std. dev.	0.14	0.40
Q_{30} (ft^3/s)	*min.*	2.46	1.99
	avg.	2.67	2.44
	max.	2.94	3.39
	std. dev.	8.53	0.27
Q_{60} (ft^3/s)	*min.*	1.45	1.46
	avg.	1.57	1.78
	max.	1.74	2.46
	std. dev.	5.11	0.19
Q_{90} (ft^3/s)	*min.*	1.06	1.02
	avg.	1.16	1.27
	max.	1.28	1.78
	std. dev.	3.79	0.15

Large-scale channelized flow testing for inlet protection and ditch check practices can use the Q_{90} to determine applicable test flow rates (Perez et al. 2014). Using the Zonal Statistics tool within ArcGIS, the Q_{90} was calculated using the appropriate developed regression relationship (i.e. Equation 3.13 for Type II rainfall distribution and Equation 3.17 for Type III distribution) for each county within the state of Alabama. From the analysis, the state was divided into three equal interval sections based on the average Q_{90} for each county. These sections were categorized as Class I, Class II, and Class III which have Q_{90} ranges between 1.00 to 1.25 ft^3/s, 1.26 to 1.50 ft^3/s, and 1.51 to 1.75 ft^3/s, respectively. Figure 3.5(a) shows the distribution of Q_{90} throughout the state, and Figure 3.5(b) depicts the three developed sections within the state, with the average Q_{90} for each county.



(a) statewide analysis (ft^3/s) (b) county averages (ft^3/s)

Figure 3.5 Classification Based on Q_{90} Flow Rate Tiers.

This approach can be used for selecting test flow rates representative to various regions within a state. Devices can be tested under the three class flow rate ranges to determine suitability to each part of the state.

This analysis provides site specific and detailed values for the flow parameters. The developed regression equations can be applied to any combination of rainfall and CN values within the state to determine the V_{24}, Q_p, Q_{30}, Q_{60}, and Q_{90} flow rates for a 2-yr, 24-hr storm event matching the 1 acre (0.4 ha) design drainage basin. With this data, experimental testing on ditch checks and IPPs can be performed using expected in-field storm runoff characteristics. The results of this analysis will be used to provide standardized testing guidance for ditch check and inlet protection installations used throughout the state of Alabama. Furthermore, this effort will serve to aid designers in selecting appropriate ditch checks or IPPs based upon performance under various project specific flow conditions.

3.5 SUMMARY

The GIS analysis conducted has shown the need to evaluate regional rainfall and soil characteristics to provide a means for determining representative large-scale testing protocols for erosion and sediment control practices. An analysis was performed on the state of Alabama conditions for runoff conveyance practices typically installed along roadway medians in a 1 acre (0.4 ha) drainage basin. The method and advantages of providing a GIS analysis to compute stormwater flow rates were shown. From this, regression analyses developed a set of equations which can be used to determine V_{24}, Q_p, Q_{30}, Q_{60}, and Q_{90}.

Not only does this analysis provide applicable testing flow rates for large-scale evaluations, but the analysis further provides a practical decision making tool for designers to use when selecting various runoff conveyance measures for use on projects across the state of Alabama. With knowledge of just two factors, *CN* and *P*, designers can predict the expected runoff characteristics for the 2-yr, 24-hr design storm. Furthermore, flow characteristics can be obtained on a county-wide average.

CHAPTER 4: MEANS AND METHODS

4.1 INTRODUCTION

This section describes the testing procedures and methodology developed for the large-scale testing of IPPs. The testing methodology developed in this study is based on current standard practices and reviewed literature on IPP testing. The methodology aims at providing performance evaluations as well as installation improvements of practices while addressing the limiting factors of published IPP testing efforts. The developed testing protocols subject tested IPPs on expected in-situ conditions typical to the state of Alabama.

The purpose of these experimental tests is to evaluate and structurally improve the performance of IPPs using large-scale testing techniques. Improvements will be based on the device's structural integrity, ability to impound and detain water, and reducing the downstream transport of eroded material suspended in stormwater runoff. The IPPs identified for testing account for a total of six practices including: (1) coarse aggregate, (2) fabric / silt fence barriers, (3) sandbag barriers, (4) wattle barriers and (5) manufactured devices. In addition, three manufactured products were selected for testing: (1) Erosion Eel, (2) Grate Pyramid, and (3) Silt Saver. The type and order in which selected IPPs were selected for testing was based upon the need and priority identified by ALDOT via the Project Advisory Committee (PAC).

4.2 EXPERIMENT DESIGN & TESTING REGIME

A two phased testing protocol was created to provide installation improvements and evaluate IPP performance. Phase I testing performed a series of installation improvement tests using clean water and constant flow over 30 minutes. The first test for each IPP evaluated the current standard installation and determined whether the installation could be improved for retaining sediment and reducing erosion. Up to six subsequent improvement (Phase I) tests were performed to improve the standard installation. Test data collected was summarized for each test and evaluated to determine if an installation could be further improved using a different installation configuration. The most feasible and effective installation (MFE-I) was identified upon completion of Phase I testing. When testing a manufactured device, only the manufacturer's specified installation was tested with no attempts made to improve the installation practice. Figure 4.1 is a flowchart summarizing the testing regime that was followed for each of the five IPPs.

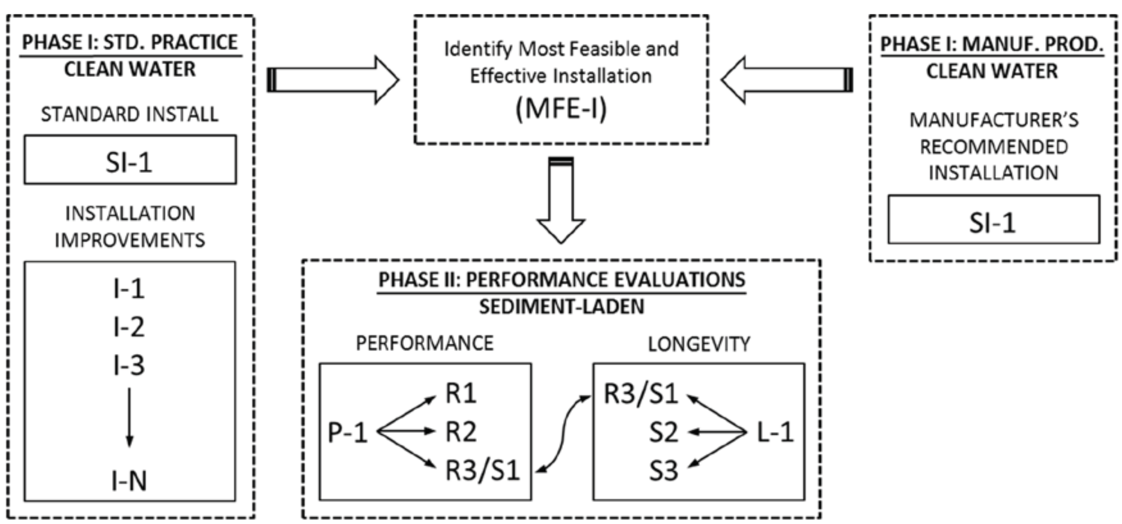


Figure 4.1 Experimental Testing Regime.

Phase II testing evaluated the MFE-Is using sediment-laden water to determine the performance and longevity characteristics of the installation. Three replicate, 30-minute sediment-laden, single storm tests evaluated the performance of the MFE-I. In addition, a longevity test was performed to mimic three sequential rain events during a single installation to evaluate the structural rigor and clogging potential of the MFE-I, and its overall response to sediment build-up. Data collected from the performance tests and longevity evaluation were used to assess and compare the performance of the practice with the other four tested practices. Table 4.1 provides a summary of the test design breakdown. A total of 72 tests were specified to conduct the ALDOT study.

Table 4.1 Summary of Inlet Protection Tests

Inlet Protection	Sediment Introduction	Installation	Test Type	Replications	No. of Tests
Std. Practice	Clean Water	SI-1	ALDOT Standard	1	1
		I-(#1-4) [a]	Installation Improvements	1	6
	Sediment Laden	MFE-I[b]	Performance	3	3
			Longevity	1 (2) [c]	2
				SUBTOTAL =	12
					X 4 IPPs
			TOTAL NO. OF STD. PRACTICE TESTS =		48
Manuf. Device	Clean Water	SI-1	Manuf. Rec. Install	1	1
	Sediment Laden	MFE-I[b]	Performance	3	3
			Longevity	1 (2) [c]	2
				SUBTOTAL =	6
					X 4 IPPs
			TOTAL NO. OF MANUFACTURED DEVICE TESTS =		24
				TOTAL NO. OF TESTS =	**72**

Notes: [a] I-# represents one of six standard installation improvements to be evaluated per inlet protection
[b] MFE-I represents the most feasible and effective installation identified from the clean water tests
[c] Longevity tests will be replicated once and includes two additional tests

Experimental testing was conducted on each IPP installation method identified by ALDOT and AU researchers to evaluate the various installations and comparatively evaluate them in an effort to identify the MFE-I practices. The MFE-I practices will be comparatively analyzed against all the other MFE-I IPPs. The result of these analyses will provide a basis for developing IPP selection procedures during design along with installation and maintenance recommendations to be followed during a construction project.

4.3 TESTING FACILITY

Testing was conducted at the Auburn University-Erosion and Sediment Control Testing Facility (AU-ESCTF) located at the pavement test track site of the National Center for Asphalt Technology (NCAT) in Opelika, Alabama. The 2.5 ac AU-ESCTF was developed through ALDOT project 930-655 with the purpose of designing and constructing a facility geared towards testing, evaluating, and improving erosion and sediment control practices and products typically used on highway construction projects. The AU-ESCTF further serves as a training facility to educate designers, contractors, and inspectors in proper design, installation, maintenance, and inspection practices.

The facility currently has the capabilities of intermediate-scale testing of erosion control practices using simulated rainfall and large-scale testing of erosion and sediment control practices in simulated channelized flows. The test facility also has the capabilities of monitoring sediment basin performance, and testing rolled erosion control products for longevity. The three large-scale test channels developed at the facility are supplied water from a 28,000 ft^3 upper storage pond. Flows from the test channels are received by a 12,000 ft^3 capacity sediment basin equipped with a skimmer that discharges to a 45,000 ft^3 lower retention pond. The upper storage pond can be recharged by pumping water from the lower retention pond.

(a) view from upper storage pond

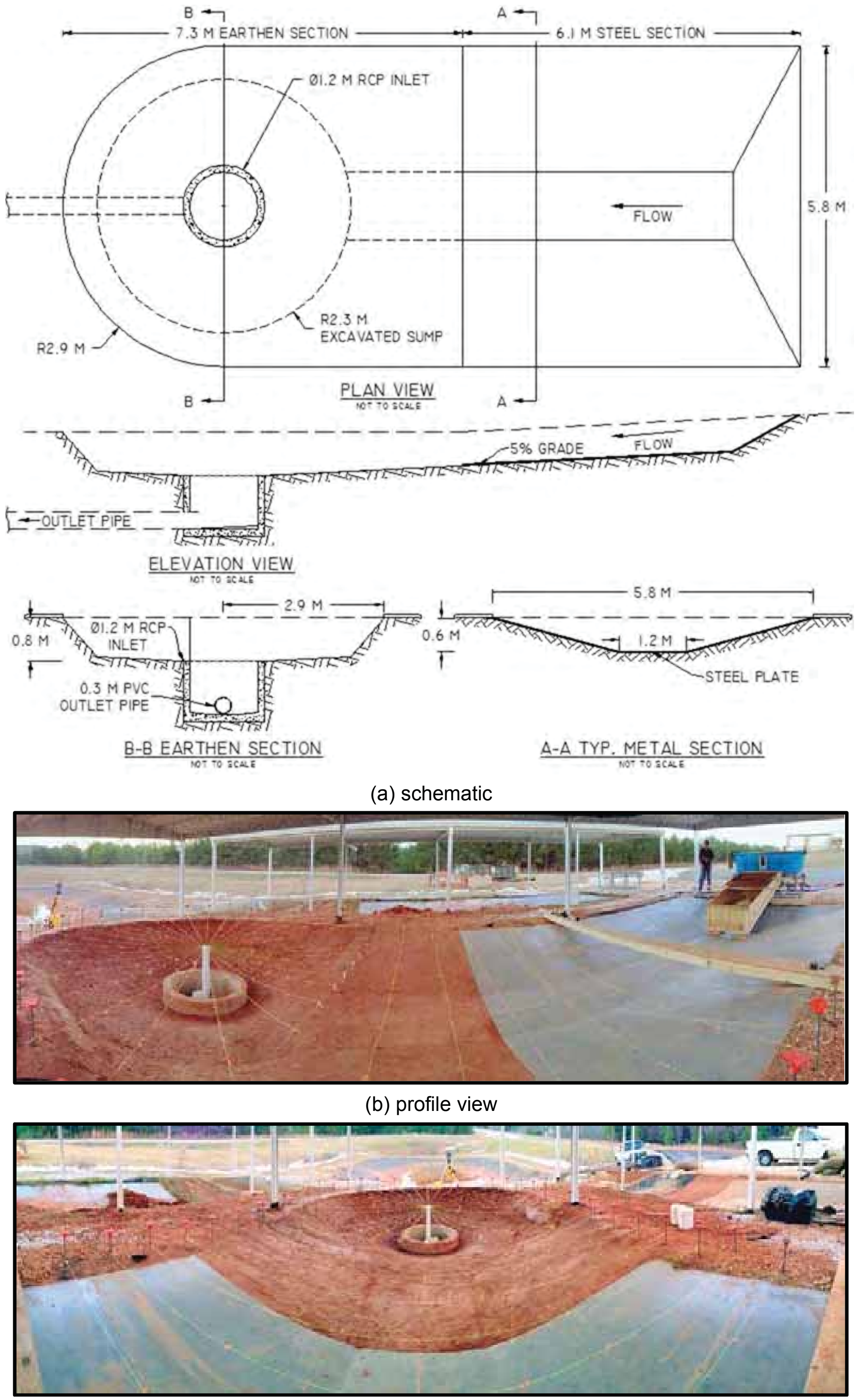
(b) view from lower storage pond

(c) aerial view

Figure 4.2 AU-ESCTF.

4.3.1 Test Channel

IPP testing channels should mimic expected site conditions where practices are typically implemented. The intent in the developed channel was to duplicate typical ALDOT roadway median stormwater conveyance channels. The test channel (Figure 4.3) measures approximately 44 ft in length, 19 ft wide and is at a 5% longitudinal slope. A concrete pad at the upstream end of the channel was constructed to support the water and sediment introduction systems. A 20 ft galvanized metal section makes up the upper portion of the channel, which allows introduced flow and sediment to evenly spread over the 4 ft bottom width of the channel. The metal sheeting further serves to minimize channel grading efforts and any effects that upstream channel erosion may have on the performance of IPPs being testing. A 24 ft earthen section makes up the lower half of the channel, which includes a 4 ft inside diameter reinforced concrete storm drain inlet structure that drains to a 12 in. polyvinyl chloride (PVC) discharge pipe. This round earthen section mimics a typical ALDOT median inlet installation which includes a berm behind the structure to prevent stormwater from bypassing the inlet. Figure 4.3(a) depicts the channel configuration in plan, elevation, and section views. Figure 4.3(b) and (c) show the constructed channel from two perspectives for a typical test setup.



(a) schematic

(b) profile view

(c) upstream view

Figure 4.3 Typical Test Channel Configuration.

4.3.2 Channel Preparation

Before each test was performed, the earthen section of the channel was prepared through a labor-intensive process of earth grading and compaction. The preparation process included the removal of the previous test remnants, such as: protection devices, stakes and staples, filter fabric underlays, and deposited sediment. Additional clean soil was added to the channel with the aid of a mini track loader (Bobcat® MT52) and a skid steer loader (Caterpillar® 216B). Tilling was performed at a depth of approximately 6 in. using a counter-rotating rear-tine tiller (Troy-Bilt® Bronco CRT) to produce a homogenous mixture with the in-place soil. The next step in the preparation process was to hand grade the channel to the grate crest. Upon final grading, compaction is achieved through hand tamping and mechanically using an upright tamper rammer (Tiger® TGR-80) with a compaction plate of 14 x 11.5 in., an impact count of 600 blows/min. and a compaction force of 2,400 lb. Compaction requirements of achieving 95% standard proctor density are verified periodically through standard methods (ASTM D7351 2010). The channel construction equipment are pictured in Figure 4.4. Once the channel rebuilding process is complete, the IPP is installed and tested. Compaction goals of achieving 95% of the standard proctor were verified periodically. Figure 4.4 shows the channel preparation equipment.

(a) mini track loader (b) tamper rammer

(c) skid steer loader (d) rear-tine tiller

Figure 4.4 Channel Preparation Equipment.

Once the channel rebuilding process was completed, the inlet protection practice to be tested was installed.

4.4 WATER INTRODUCTION

A major component of the inlet protection testing was the introduction of water. The inflow used for experiment testing mimicked in-situ conditions that inlet protective measures would be subjected to in the field. The determination of testing flow rates was computed using a statewide GIS analysis.

The movement of water and control of flow rates for testing was achieved via an intricate water introduction system detailed in this section.

4.4.1 Flow Rate Determination Using a GIS Approach

Using the described GIS analysis, a hydrograph was produced to model typical inlet inflow (Figure 4.5) that was used to select an applicable testing flow rate.

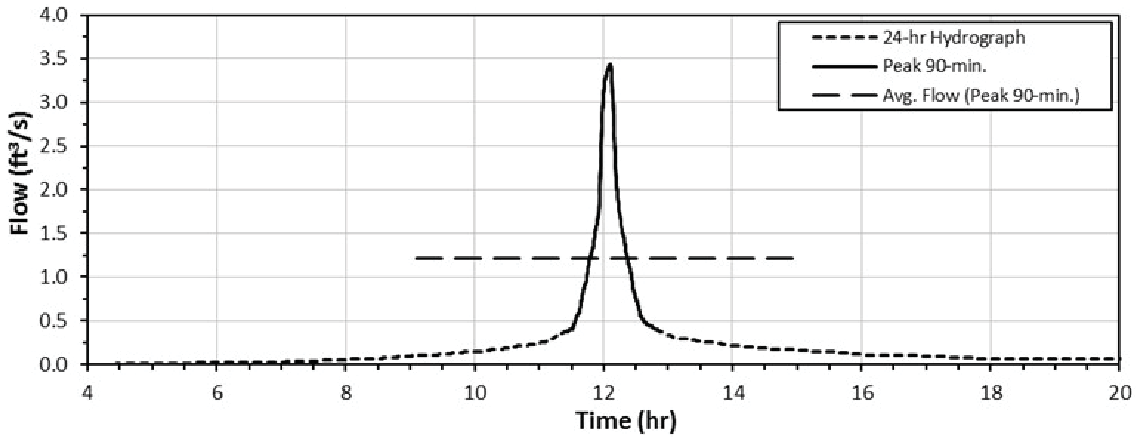


Figure 4.5 IPP Hydrograph.

The peak 90 min. of the event defines the most intense flows with a max. flow rate of 3.43 ft^3/s occurring at 12.1 hrs. This 90 min. peak produces a runoff of 6,622 ft^3 and accounts for 52% of the 24 hr. event runoff volume. Converting the peak 90 min. volume into an average flow rate results in 1.25 ft^3/s. This flow rate was selected as the testing flow rate since it characterizes the most intense portion of the storm event and accounts for 98% of the experienced 24 hr. hydrograph flow rates.

4.4.2 Flow Introduction Apparatus

The introduction of water into the test channel was designed in a fashion that would allow for accurate flow rate configuration and ease of use. To achieve the desired flow control necessary for testing, a four-stage water introduction process was developed. This setup consists of a pump system, a tank for equalizing and staging flows, a discharge weir for controlling flow rates to the test channel, and a soil-water mixing trough for creating sediment-laden flow.

The pumping system used consisted of a series of three NorthStar Semi-Trash pumps. These pumps are driven with Honda GX160 engines and are equipped with three inch ports. The pumps have a capacity of 0.59 ft^3/s. These pumps transported water from the storage supply pond into the equalizing tank located at the base of the inlet test channel. This 300 gal capacity tank was customized with three inlets and four outlets. The inlets are located on the back side of the tank and are connected directly to the pumps via 3 in. flexible hosing and plumbing fittings. The 4 in. outlets, located directly beneath the tank, are controlled by individual gate valves. These outlets are used to prevent overflows leaving the tank by returning flow to the supply pond via 4 in. flexible hosing. By having all outlet valves open, the system allows for pumps to be primed and pressurized prior to commencing a test. Valves are adjusted to introduce water into the test channel at a desired flow rate. Images of all water introduction components are shown in Figure 4.6 and Figure 4.7.

(a) pump station

(b) inlet and outlet hoses

(c) gate valves

(d) 300 gal. equalizing tank

(e) manufactured trough baffle

(f) installed weir plate

Figure 4.6 Components for Water Introduction System.

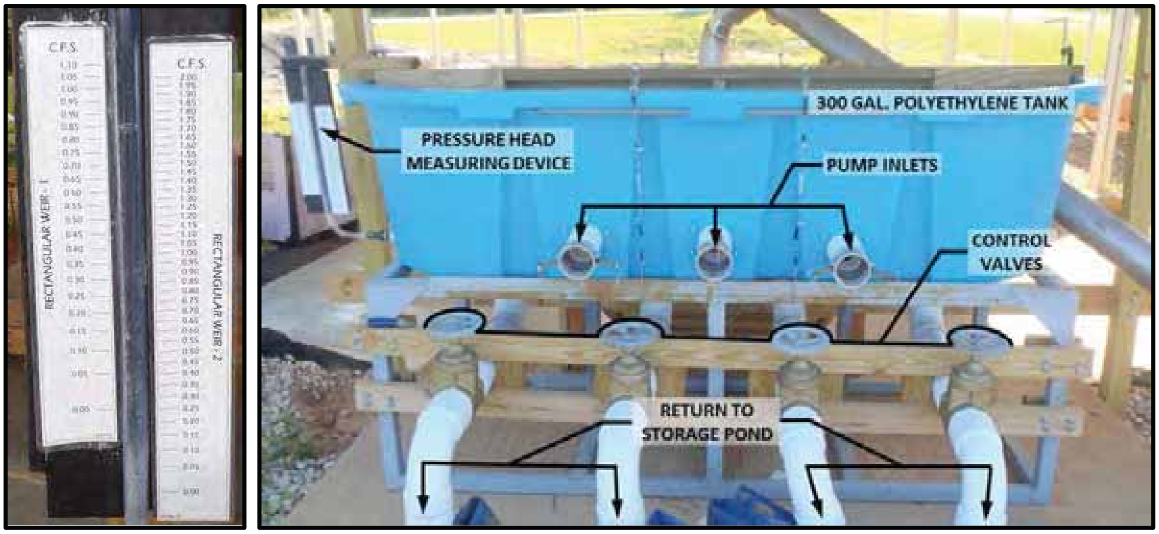
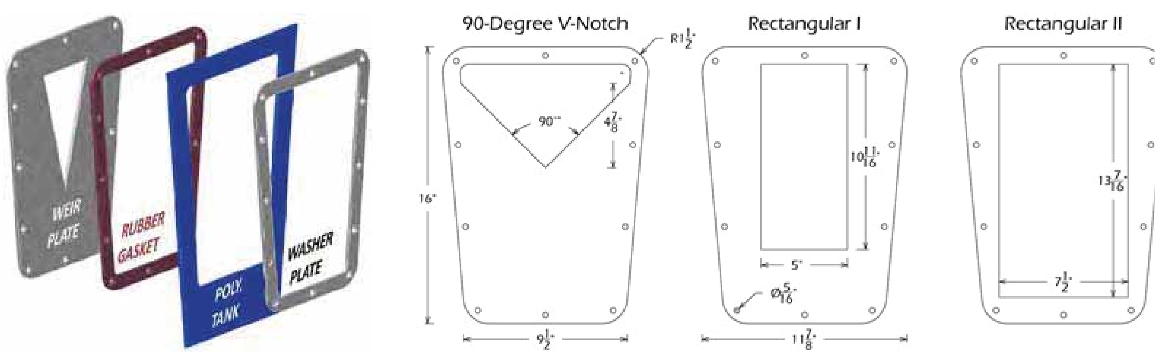


Figure 4.7 Flow Regulation System.

Water flowing into the test channel was measured through a fabricated rectangular weir plate attached to an opening cut on the channel face of the equalizing tank. The weir was constructed to allow for different weir plates to be easily interchanged for controlling varying flow ranges. This interchangeable system allowed for any opening to be cut into an approximate 16 in. high by 10 in. blank sheet metal plate which fit into the designed opening. The weir plate was secured to the polyethylene tank by bolts and butterfly nuts to a manufactured washer plate located on the inside of the equalizing tank. Between the tank and washer plate, a rubber gasket was fitted to provide a water tight seal. Two rectangular and a 90-degree V-notch interchangeable weir plates were fabricated for these experiments. Figure 4.8(a) demonstrates the weir plate assembly. Figure 4.8(b) shows the dimensions of the three weir plates.



(a) plate assembly (b) plate dimensions

Figure 4.8 Interchangeable Weir Plate Design.

The V-notch weir was designed to be used for lower flow rates up to 0.3 ft^3/s, while the two rectangular weirs were developed for flows up to 1.0 and 2.5 ft^3/s respectfully. The smaller weirs allowed for more precise flow readings as greater head height produced lower flows than the larger weir. Table 4.2 summarizes the three weir plate flow ranges and reading precisions.

Table 4.2 Weir Plate Flow Rates

Weir Plate	Flow Range (ft^3/sec)	Precision (ft^3/sec)
90-Degree V-Notch	0.0-0.3	± 0.01
Rectangular I	0.0-1.0	± 0.05
Rectangular II	0.0-2.5	± 0.10

4.4.3 Water Introduction System Calibration

The weirs were calibrated by pumping water through the plates at varying water heights. Water flowing through the plate was collected, measured, and timed to calculate flow rate. The data were then plotted and compared to the theoretical flow curve. The equation derived from the exponential fit of the plotted experimental points was used to create a calibrated scale for the pressure head measuring device. The scale was attached to a 1.0 in. clear acrylic tube used to measure water depth in the tank, allowing researchers to adjust the flow valves to achieve the desired experimental flow rate. The V-Notch weir plate was designed using the Kindsvater-Shen relationship for fully contracted notches as shown in Equation 3.21 (Kulin and Compton 1975).

$$Q = 4.28 C_e \tan\left(\frac{\theta}{2}\right) h_e^{5/2} \tag{4.1}$$

where,

Q = discharge over weir (ft^3/sec)
C_e = effective discharge coefficient
h_e = $h_1 + k_h$, effective head (ft): measured head with correction
θ = angle of V-notch

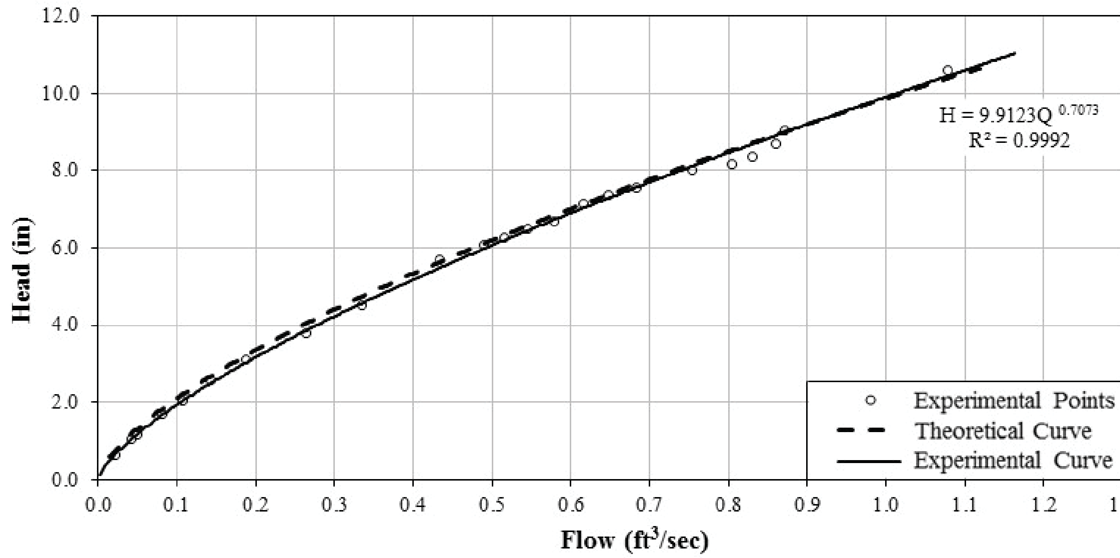
Similarly, the two rectangular weirs were designed using the basic head-discharge equation modified for partially contracted thin plate weirs (Kindsvater and Carter 1959) as shown in Equation 3.22.

$$Q = C_e \frac{2}{3} \sqrt{2g}\, b_e\, h_e^{3/2} \tag{4.2}$$

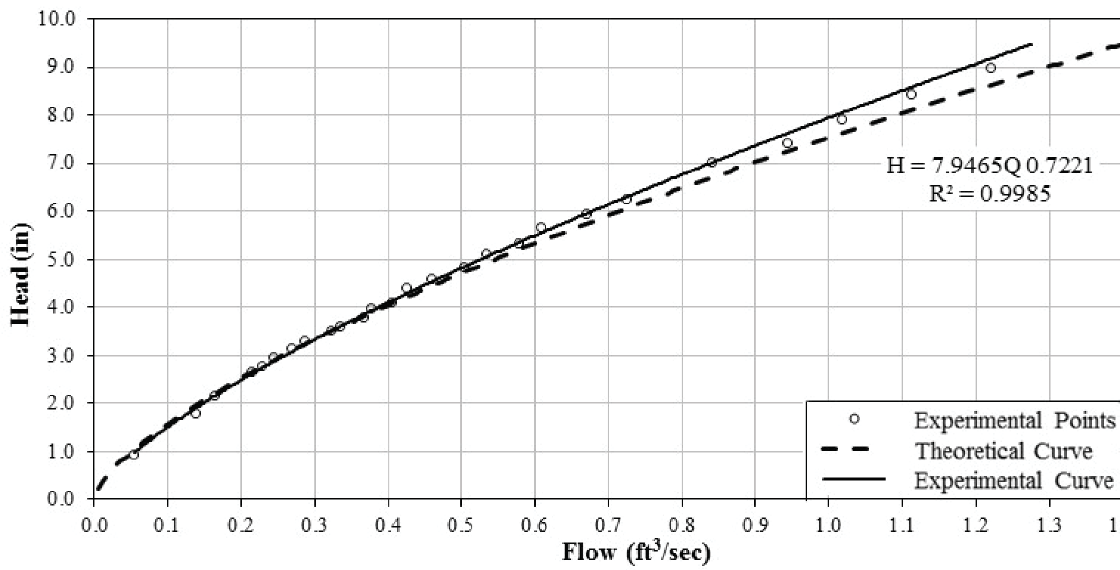
where,

Q = discharge over weir (ft^3/sec)
C_e = effective discharge coefficient
b_e = $b_c + k_b$, effective breadth (ft): weir width with correction
h_e = $h_1 + k_h$, effective head (ft): measured head with correction

The Rectangular Plate II was the predominant weir used for the inlet protection experiments due to the required testing flow rates. The calibration curves for the rectangular weir I and rectangular weir II are shown below in Figure 4.9.



(a) Rectangular Weir I



(b) Rectangular Weir II

Figure 4.9 Calibration Curves for Rectangular Weirs.

The equations derived from the exponential curves of the plotted experimental points were used to create calibrated scales for the pressure head measuring device. The scales were attached to the measuring device and allowed the controller to adjust the flow valves to achieve the desired experimental flow rate.

4.5 SEDIMENT INTRODUCTION

The introduction of sediment is a crucial part of the IPP experiments. Sediment-laden stormwater allows IPPs to be evaluated for their ability to impound water and create a condition where suspended sediment will deposit prior to entering the storm drain inlet. Sediment was introduced into the experimental inflow to create sediment-laden flows that mimicked in-situ conditions. This metered sediment introduction system allowed for inlet protective measures to be tested against expected in-field conditions.

4.5.1 Sediment Introduction Rate Determination

To determine inlet protection testing sediment introduction rates that would be representative of sediment yield observed for a typical installation, the Modified Universal Soil Loss Equation (MUSLE) was used to produce an estimation mimicking in-field scenarios. The method is described below with assumptions made to imitate realistic installation practices.

4.5.2 MUSLE Method

To mimic expected sediment transport in the designed inlet protection experiments, sediment rates were computed using the MUSLE, which allows for sediment yields to be estimated per storm event (Williams 1975). The MUSLE, which is a modified form of the USLE (Wischmeier, 1960) (Wischmeier and Smith 1960), uses individual storm flow rates to model soil loss on the basis that runoff is a superior indicator of sediment yield rather than rainfall. The MUSLE is given by the following:

$$S = 95(Qp_p)^{0.56}KLSCP \tag{4.3}$$

where,

S	=	sediment yield (tons)
Q	=	30 minute runoff volume (acre-ft)
p_p	=	event peak discharge (ft^3/s)
K, LS, C, P	=	USLE parameters

Based upon experimental flow calculations conducted for the state of Alabama, the MUSLE equation was applied to the 30 min. 2,250 ft^3 testing volume that is discharged at a rate of 1.25 ft^3/s. A soil erodibility factor, *K* of 0.045, was selected for sandy-silt. The slope-length and steepness factor (*LS*) was determined to be 0.83, representative of 16% slopes at 20 ft lengths for conditions of high rill to interrill erosion ratios (Pitt et al. 2007). Although erosion control practices (i.e., mulching, temporary seeding, etc.) would be implemented alongside sediment controls, the worst-case design scenario for a vegetative cover practice factor (*C*) of 1.0 was chosen for bare soil conditions. Similarly, the ponding or erosion control practice factor (*P*) was selected to be 1.0. This situation may be encountered where IPPs are implemented prior to final site grading and the installation of erosion controls and/or vegetative establishment.

Using the aforementioned variables, total sediment yield was computed for an output of 2,804 lbs. Taking into account the 50% impervious area in the designed drainage basin, the sediment load is reduced to the targeted metering rate of 46.7 lbs/min over the 30 minute test duration.

4.5.3 Apparatus

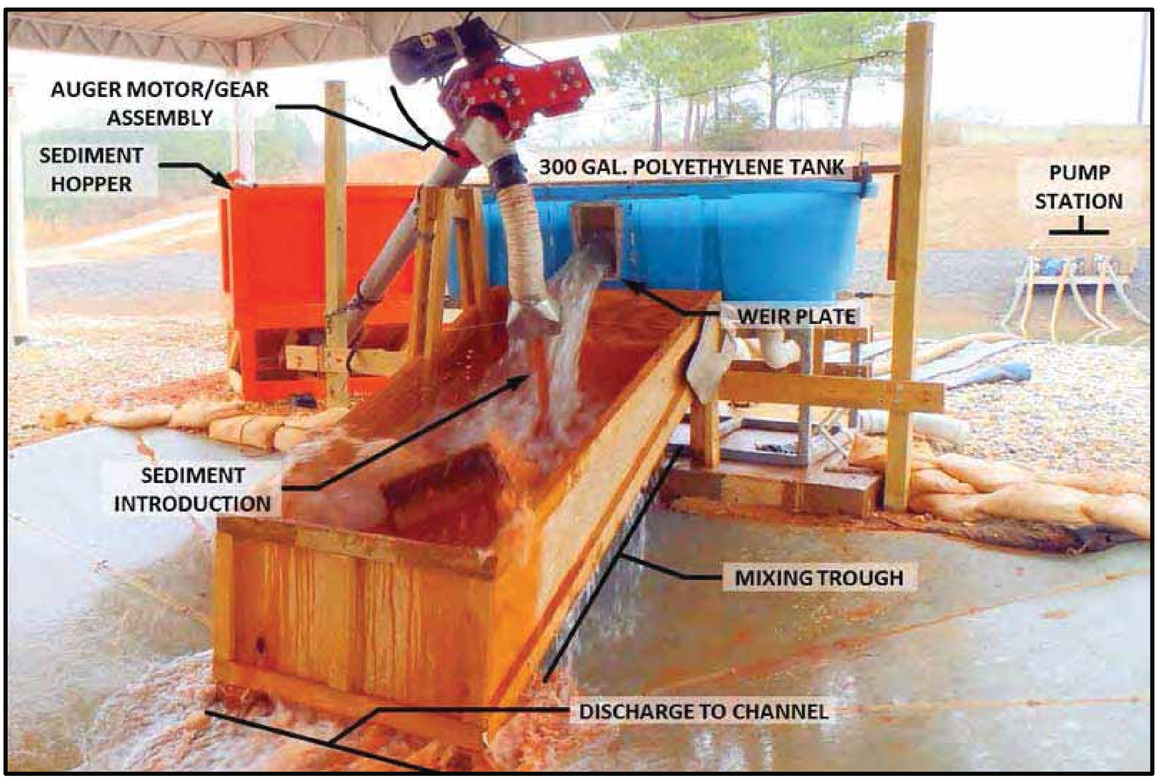
Sediment introduction was designed using a 6 in. diameter, 11 ft long auger that allowed sediment to be introduced into the water/sediment mixing trough at a controlled rate. The system was mounted at a height where the exit head assembly was approximately 4 ft above the mixing trough.

(a) soil hopper

(b) 6 in. auger

(c) motor, gearbox, sprockets, and chain

(d) mixing trough



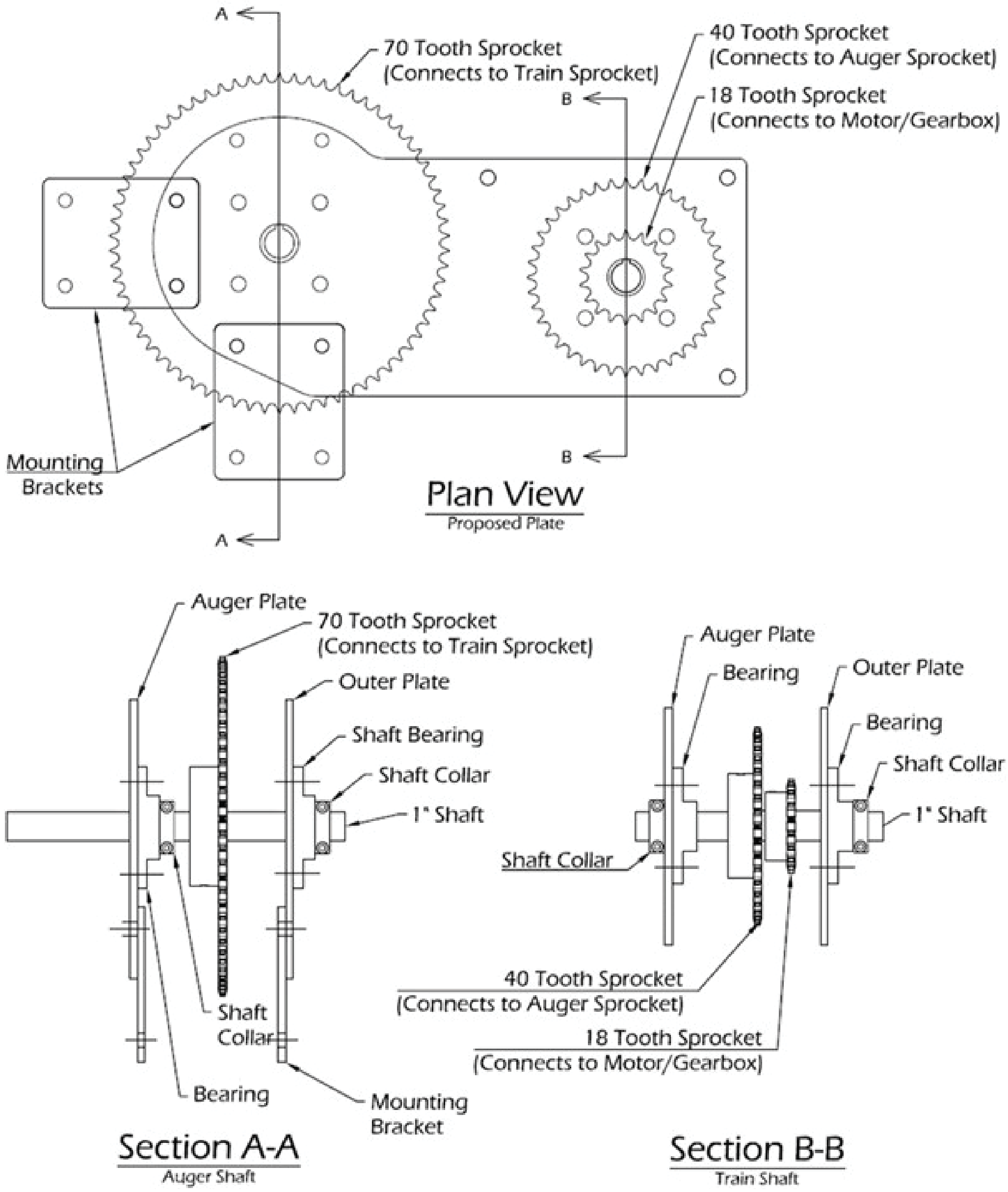
(e) system during testing

Figure 4.10 Sediment Introduction System.

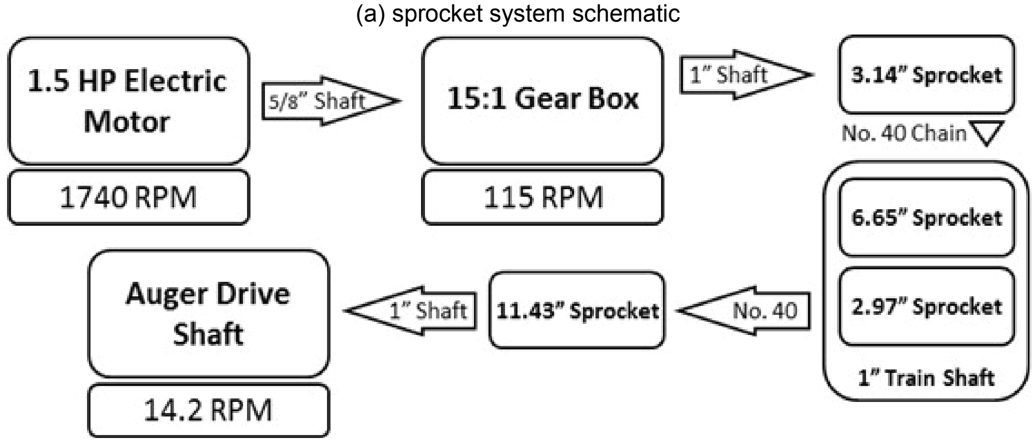
This elevation provided clear distance from the equilibrium tank, minimizing moisture exposure to the auger's electrical components. A hopper was fabricated to allow the system to be loaded with sediment during an experiment. Figure 4.10 illustrates the sediment introduction assembly.

The motor, gear box, and sprocket system, were designed for the desired sediment introduction rate. A 1,740 rpm, 1.5 hp single phase motor (North American Electric, Inc.) was installed with a gear box reducer with ratio of 15:1 (WorldWide Electric Corp.). The gear box turned a 3.14 in. sprocket which was connected to a 1.0 in. (2.54 cm) diameter train shaft. This train shaft turned two sprockets. A 6.65 in. sprocket connected to the gearbox sprocket, and a 2.97 in. sprocket connected to the auger drive shaft. The auger drive shaft had an 11.43 in. sprocket. All sprockets were connected using via a No. 40 roller chain. This gear ratio system reduced the auger drive shaft speed to approximately 14.2 rpm. The diagram in Figure 4.11 summarizes the gear and drive design for the auger.

The motor was equipped with a thermal protection switch and powered via single phase, 220 V electricity. 15 amp fuses were installed in the electrical circuit to further protect the motor from overheating.



(a) sprocket system schematic



(b) gear ratio flow chart

Figure 4.11 Auger Gear and Drive Design.

4.5.4 Calibration

The sediment introduction system was calibrated by running sediment through the auger and collecting the output sediment in a 5.62 gal. The series of tests were timed and averaged to determine the expected flow exiting the auger. The auger delivered sediment at a rate of 0.46 ft^3/min. This rate is equivalent to 0.032 ft^3 per auger shaft revolution. Adjustments to the sediment delivery system for future testing can be made by changing the sprocket combinations to achieve various flow rates.

4.6 SOIL GEOTECHNICAL ANALYSIS

This section describes the soils that were used for channel preparation and sediment introduction. Geotechnical soil analysis included determination of soil gradation, compaction, and Atterberg limits.

4.6.1 Soil Geotechnical Analysis for Earthen Section

The soil used in the earthen section of the test channel was native to the AU-ESCTF. A particle size analysis as well as a compaction test was conducted for the soil. The particle size distribution of the soil is shown in Figure 4.12.

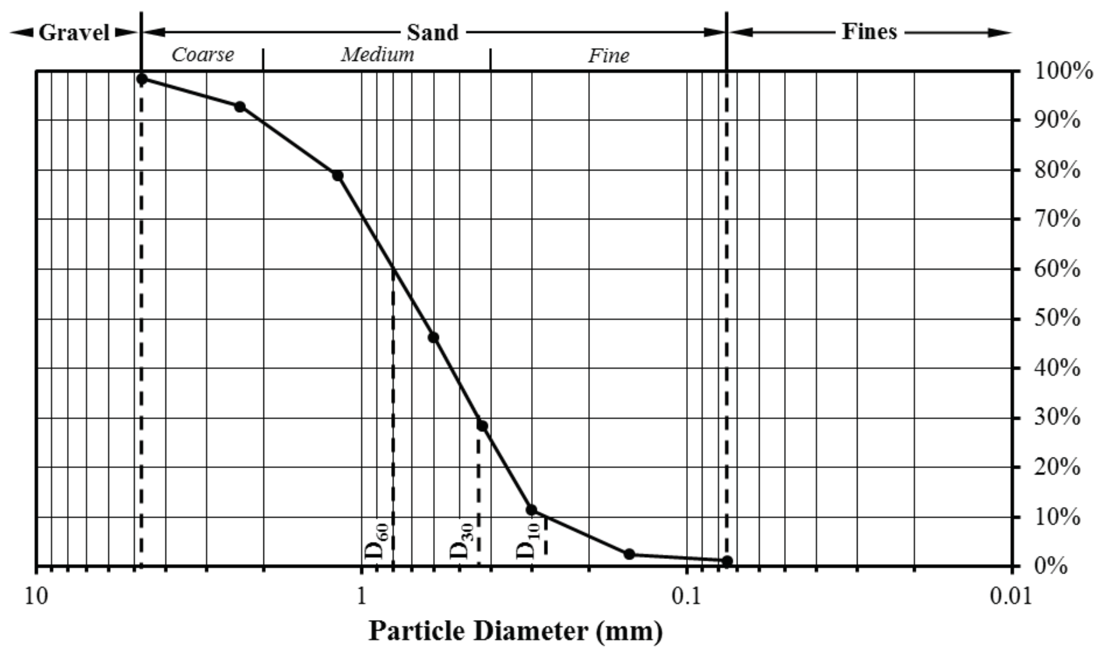


Figure 4.12 Grain Size Distribution for Earthen Section Soil.

Table 4.3 displays the sieve analysis of the soil used for the earthen section. The test was conducted per ASTM Standard D422-07. Using the soil properties summarized in Table 4.4, the soil was classified by the Unified Soil Classification System (USCS) as: well-graded sand, fine to coarse sand (SW). The American Association of State Highway and Transportation Officials (AASHTO) soil classification describes the soil as: stone fragments, gravel and sand (A-1-A). Table 4.3 lists the data collected during the sieve analysis.

Table 4.3 Sieve Analysis of Earthen Section Soil

Sieve	Apparent Opening Size (mm)	Mass Retained (g)	Percent Retained (%)	Percent Finer (%)
#4	4.750	11.4	1.47	98.53
#8	2.360	44.2	5.70	92.83
#16	1.180	107.9	13.92	78.91
#30	0.600	252.7	32.60	46.30
#40	0.425	139.0	17.93	28.37
#50	0.300	131.6	16.98	11.39
#100	0.150	2.44	8.93	2.46
#200	0.075	9.5	1.23	1.24
Pan	0.000	9.6	1.24	0.00

Table 4.4 Properties of Earthen Section Soil

USCS: Well-Graded Sand, Fine to Coarse Sand (SW)		
AASHTO: Stone Fragments, Gravel & Sand (A-1-A)		
D_{60} = 0.031 in. (0.79 mm)	D_{30} = 0.013 in. (0.33 mm)	D_{10} = 0.007 in. (0.18 mm)
C_u = 4.39	C_c = 0.23	% Gravel = 1.47
LL = XX	PL = XX	PI = XX

Notes:
USCS: Unified Soil Classification System
AASHTO: American Association of State Highway and Transportation Officials
D_{60}, D_{30}, or D_{10} = soil particle diameter at which 60%, 30%, or 10% of the mass of a soil sample is finer
C_u / C_c = coefficients of uniformity / curvature
LL = liquid limit = percent of water content of a soil at the boundary between the semi-liquid and plastic states
PL = plastic limit = percent water content of a soil at the boundary between the plastic and semi-solid states
PI = plasticity index = percent difference in moisture content of soil between the liquid limit and plastic limit

The soil was also analyzed for the maximum practically achievable density. A standard proctor test (ASTM Standard D698-12 2012) was performed on the soil to determine the maximum dry density (ρ_{dmax}) and the optimum moisture content (OMC) for the soil. The ρ_{dmax} was determined to be 116.0 lbs/ft^3 at an OMC of 11.2%. This determination was used to ensure the channel compaction was within 95% of the maximum compaction. The developed proctor curve is shown in Figure 4.13.

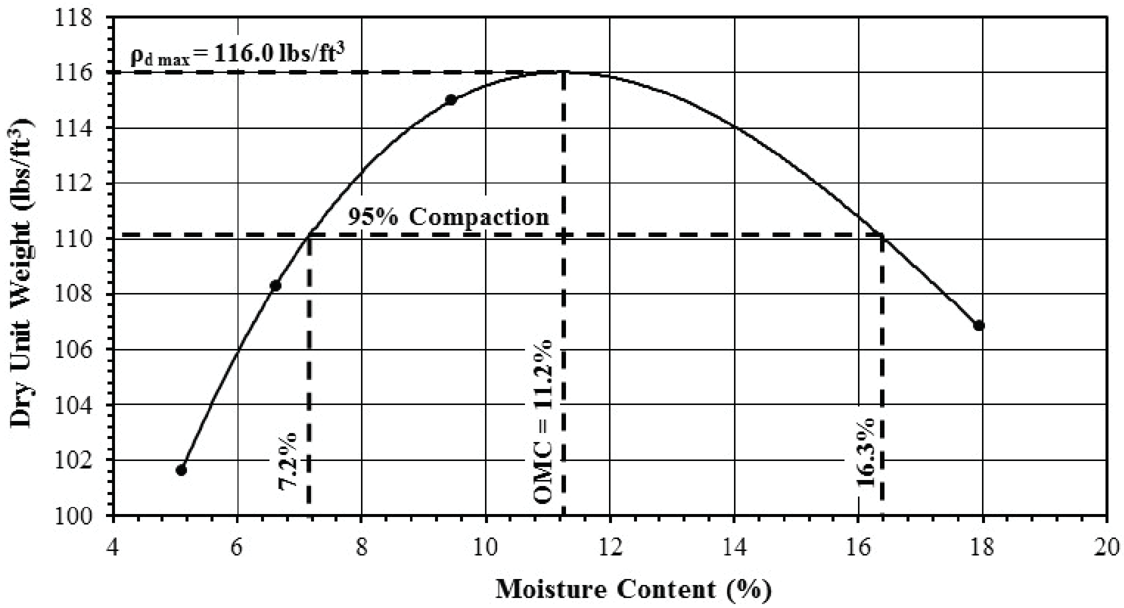


Figure 4.13 Proctor Curve for Earthen Section Soil.

The dry unit weight for 95% compaction was calculated to be 110.2 lbs/ft^3 (1,765 kg/m^3) with a moisture content ranging between 7.2 to 16.3%. The test data for the proctor curve is shown in Table 4.5.

Table 4.5 Proctor Test Data for Earthen Section Soil

n	Moisture Content (%)	Bulk Density (lbs/ft^3)	Dry Density (lbs/ft^3)
1	5.10	106.77	101.59
2	6.62	115.46	108.29
3	9.46	125.87	114.98
4	17.95	126.02	106.84

Field compaction on the earthen section of the test channel was tested regularly using a density drive hammer and thin walled Shelby tubes (ASTM Standard D2937-10 2010).

4.6.2 Soil Geotechnical Analysis for Sediment Introduction Soil

The soil used for sediment introduction was sourced from Birmingham, AL. The stock was sifted through the No. 4 sieve and was stored in a drying storage -room prior to test use. A particle-size analysis was conducted to classify the soil. Results are shown in Figure 4.14 and Table 4.6.

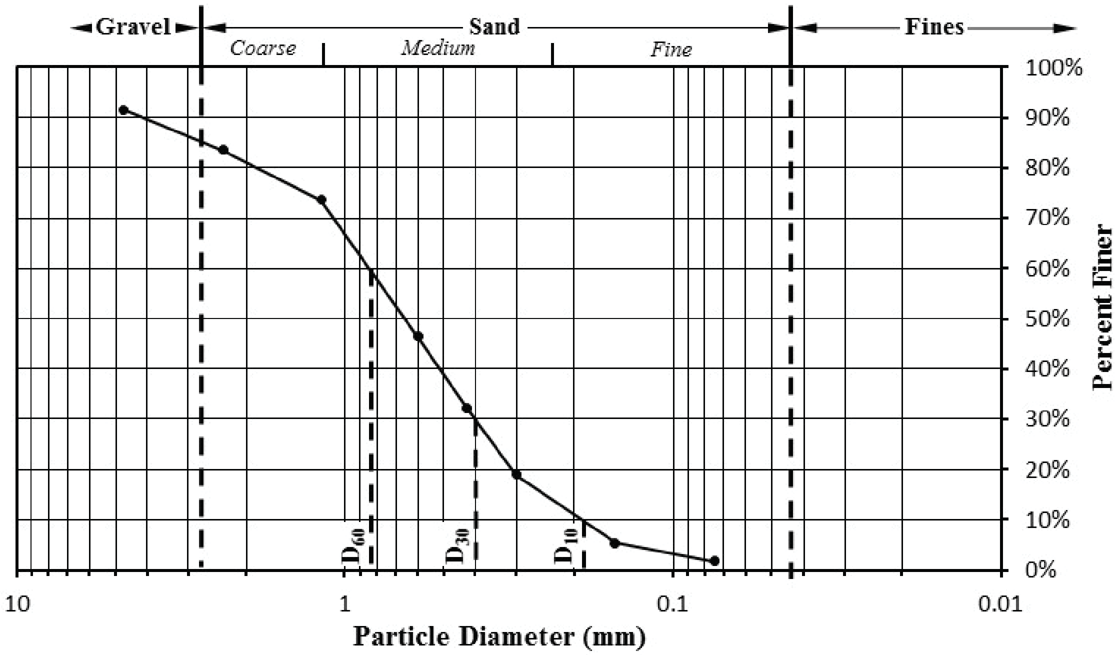


Figure 4.14 Grain Size Distribution for Sediment Introduction Soil.

Table 4.6 Sieve Analysis of Sediment Introduction Soil

Sieve	Apparent Opening Size (mm)	Mass Retained (g)	Percent Retained (%)	Percent Finer (%)
#4	4.750	54.2	8.48	91.52
#8	2.360	50.9	7.96	83.57
#16	1.180	64.0	10.01	73.56
#30	0.600	173.3	27.10	46.46
#40	0.425	91.9	14.37	32.09
#50	0.300	84.0	13.14	18.95
#100	0.150	86.7	13.56	5.39
#200	0.075	23.3	3.64	1.75
Pan	0.000	11.2	1.75	0.00

Using the soil properties summarized in Table 4.7, the soil was classified by the USCS as well-graded sand, fine to coarse sand (SW). The AASHTO soil classification system describes the soil as; Silty or Clayey Gravel & Sand (A-2-4).

Table 4.7 Properties of Earthen Section Soil

USCS: Well-Graded Sand, Fine to Coarse Sand (SW) AASHTO: Silty or Clayey Gravel & Sand (A-2-4)		
D_{60} = 0.032 in. (0.81 mm)	D_{30} = 0.016 in. (0.40 mm)	D_{10} = 0.008 in. (0.20 mm)
C_u = 4.05	C_c = 0.25	% Gravel = 8.48
LL = 30	PL = 25	PI = 5

Notes:

USCS: Unified Soil Classification System

AASHTO: American Association of State Highway and Transportation Officials

D_{60}, D_{30}, or D_{10} = soil particle diameter at which 60%, 30%, or 10% of the mass of a soil sample is finer

C_u / C_c = coefficients of uniformity / curvature

LL = liquid limit = percent of water content of a soil at the boundary between the semi-liquid and plastic states

PL = plastic limit = percent water content of a soil at the boundary between the plastic and semi-solid states

PI = plasticity index = percent difference in moisture content of soil between the liquid limit and plastic limit

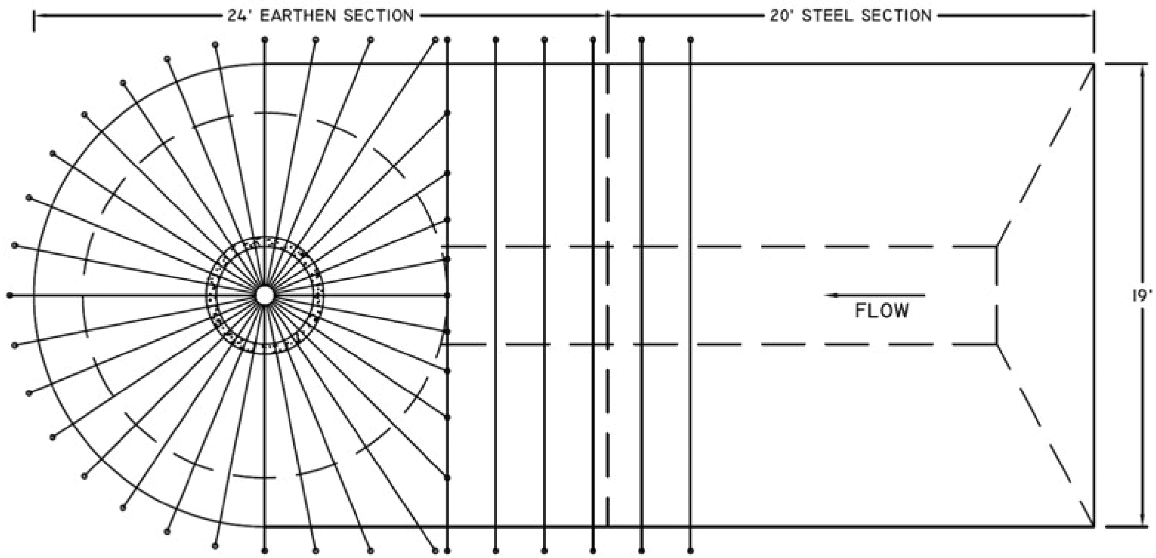
4.7 DATA COLLECTION EFFORTS

Evaluation of IPP performance is based on data and observations collected throughout the experiment. Physical data collection included: erosion and deposition surveys, ponding length and depth, flow velocities, turbidity, and total suspended solids (TSS). These parameters are used to assess the overall performance of the tested IPPs.

4.7.1 Erosion and Deposition

Complete surveys of the test channel are conducted pre- and post-test to record deposition and/or erosion within the channel. The surveys are conducted using a Trimble® S6 Robotic Total Station. Measurements are taken in the test channel at predetermined locations to ensure a comprehensive analysis of the test channel based upon precise x, y, and z measurements. String lines are setup over the center of the inlet, flagged at 12 in. intervals along the length of each string, and leveled to establish measurement points throughout the channel. Figure 4.15(a) is a schematic depicting the established string line protocol. Figure 4.15(b) shows the survey equipment and collection process.

Analysis of collected topographical data is conducted through the use of esri® ArcGIS™. This software converts raw data points to a triangulated irregular network for a three-dimensional representation of the channel surface. This allows the tested channel topography to be compared between pre- and post-test conditions. Surfaces can be subtracted to determine locations and quantities of erosion and/or deposition that occur within the channel. The complete procedures for collecting and analyzing erosion and deposition data are included in Appendix E and F.



(a) string line protocol

(a) survey data equipment and collection process

Figure 4.15 Survey Data Protocol and Collection.

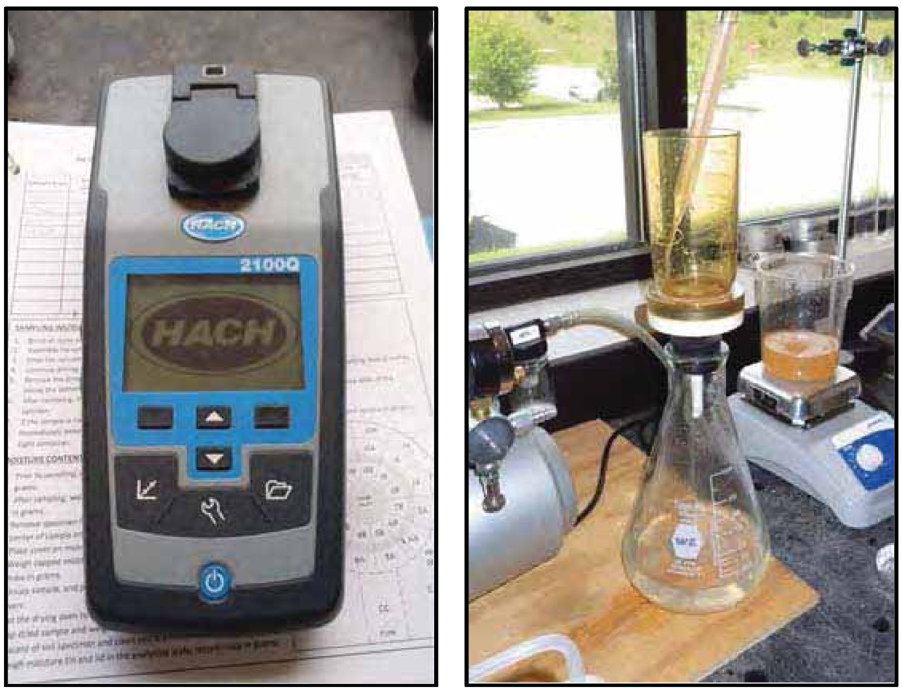
4.7.2 Ponding Depth and Discharge Flow

Once steady-state flow conditions are achieved during testing, water ponding depth, pool length, and discharge flows are measured in the test channel. Ponding is measured using a standard ruler/tape and confirmed with high water marks collected during surveying. A Teledyne ISCO® 750 Area Velocity Flow Module is installed in a pipe at the discharge point of the inlet to log the discharge flow rate of the inlet throughout the duration of a test. The intent of collecting these data is to evaluate the performance of the IPP with respect its ability to impound water. Impoundments typically reduce flow velocity, catalyze settling, and reduce erosion potential around the inlet (Barrett and Malina 2006).

4.7.3 Turbidity and TSS

Water quality measurements serve as performance parameters for sediment-laden tests performed on the MFE-I. Grab samples of 8.0 oz. are taken at two minute intervals throughout the duration of the longevity tests upstream of the installed IPP and downstream of the practice at the inlet discharge point. These samples are used to determine turbidity (NTU) and TSS concentration (mg/L) in runoff, as well as sediment removal efficiency for the IPPs tested. Turbidity serves as a measure of water clarity and is quantified by measuring the amount of light that can pass through a sample of water. Elevated turbidity levels can affect the color, temperature, and oxygen levels in water. Turbidity is assessed using a Hach® 2100Q Portable Turbidimeter. TSS is measured by passing 0.85 oz. water samples through a membrane filter, and assessing the quantity of solids captured by the filter, quantifying the amount of suspended solids in a sample.

The complete procedures developed for measuring turbidity and TSS for the inlet protection testing is provided in Appendix D. Figure 4.16 shows the TSS and turbidity measuring equipment.



(a) Hach® turbidimeter (b) TSS filtering apparatus

Figure 4.16 TSS and Turbidity Measuring Equipment.

4.8 SUMMARY

This section provides an overview of the experimental design and the testing regime that was developed and will be followed during testing of IPPs as part of this research. A summary of existing testing methods identified in the literature review and the developed methodology is shown in Table 4.8 to provide comparisons between the studies. As can be seen in Table 4.8, the test method developed by the AU-ESCTF for this research provides a more realistic testing condition that simulates, representative flow and sediment loads typically experience by IPPs installed on roadway construction sites.

Table 4.8 IPP Test Method Summary

Study	Focus	Design Storm	Drainage Basin	Test Flow	Sediment Load	Test Duration
TRI/Environmental ASTM D7351 [a]	Performance	10-yr, 6-hr	2,000 ft^2 0.05 ac	0.04 ft^3/s	300 lbs	30 min
FDOT UCF-SWA [b]	Performance (Manufactured Devices)	0.5 in. event	900 ft^2 0.02 ac	0.18 ft^3/s	N/A	3.5 min
ALDOT AU-ESCTF [c]	Installation Improvement / Performance / Longevity	2-yr, 24-hr	43,560 ft^2 1 ac	1.25 ft^3/s	1,400 lbs	30 min

Notes: [a] (ASTM Standard D7351-07 2007)
[b] (Wanielista et al. 2010)
[c] (Perez et al. 2014)

Using the design parameters from Table 4.8, the test channel was designed and constructed to mimic and simulate expected site conditions for typical median inlet installations on ALDOT projects. The following means and methods were developed to standardize the testing and evaluation of IPPs under consideration: (1) preparation of the channel prior to installing an IPP, (2) water and sediment delivery systems and introduction rates, and (3) data collection efforts.

CHAPTER 5: RESULTS AND CONLUSIONS

5.1 INTRODUCTION

All tested practices were installed using materials typical and readily available to the construction industry. Table 5.1 provides a list of materials used for the installation of the various tested IPPs.

Table 5.1 Common Installation Materials

Item	Properties	Dimensions	Unit Cost
C-Ring Staples	16. Ga. Galvanized Steel	11/16 in.	$0.02/ea.
Concrete Block	Concrete	8 x 8 x 16 in.	$1.38/ea.
Fence Posts	Galvanized Steel	2.4 x 2.4 in. x 8 ft	$22.57/ea
Fill Sand	-	-	$8.37/yd^3
Filter Fabric Underlay	Nonwoven Polypropylene	8 oz./yd^2	$3.51/yd^2
Hardware Cloth	19 Ga. Steel	3 ft height, 0.5 in. openings	$1.84/ft
Lumber (2x4)	Southern Yellow Pine (Treated)	1.5 x 3.5 in.	$0.48/ft
Sandbag	Polypropylene	14 x 26 in.	$0.62/ea.
Studded T-posts	Steel	5 ft	$2.50/ea.
Silt Fence Fabric	Nonwoven Polypropylene	3.5 oz./yd^2	$0.74/yd^2
Sod Pins	11 Ga. Steel Wire	6 in.	$0.05/ea
Staples	Galvanized Steel	0.5 x 0.5 in.	$10.67/5,000 count
Stone, No. 4	Granite	0.75 to 1.5 in.	$16.44/yd^3
Sod Staples	11 Ga. Steel Wire	1 x 6 in.	$0.03/ea
Tie Wire	11 Ga. Aluminum Wire	6.5 in	$0.06/ea.
Wattle	Wheat Straw w/Synthetic Netting	20 in. x 10 ft	$24.00/ea.
Wire Mesh Backing	14 Ga. Galvanized Steel	45 in. height, 6 x 6 in. min. opening	$0.27/ft
Wooden Stakes	Southern Yellow Pine (Untreated)	1 x 2 x 36 in.	$0.58/ea

Installations were designed to be practical with consideration to installation difficulty, equipment requirements, labor, and material costs. Select materials commonly used in installations are pictured in Figure 5.1(a)-(f).

(a) C-ring staples and tool (b) studded T-post and driver (c) filter fabric and wire backing

(d) sod pins (e) sod staples (f) wooden stakes

Figure 5.1 Common Installation Materials.

5.2 TESTED INLET PROTECTION PRACTICES (IPPs)

Evaluation of IPP performance is based on data and observations collected throughout the experiment. Physical data collection includes: erosion and deposition surveys, impoundment length and depth, flow-through velocities, and dewatering time. These parameters are used to assess overall performance of IPPs tested. The focus of IPP installation enhancements was an increase in impoundment volumes, structural integrity, and acceptable dewatering times. The volume of impoundment behind an IPP is an indication of a device’s ability to detain stormwater. Large impoundments provide areas of subcritical flow, characterized by low velocities and a decrease in the erosion potential of stormwater runoff. Subcritical flow conditions allow sedimentation of rapidly settable solids, with the majority of settlement observed to be in proximity of the hydraulic jump, or transition between supercritical flow and subcritical flow conditions (Donald et al. 2013). Impoundment lengths are measured from the flow facing edge of the IPP to the hydraulic jump. Longer dewatering times provide increased time for suspended sediment to settle prior to passing into an inlet.

Four presented IPPs were first evaluated for their performance under ALDOT specified installation details, which included: (1) Aggregate Barrier, (2) Sandbag Barrier, (3) Silt Fence Barrier, and (4) Wattle Barriers. Subsequent tests provided installation enhancements to improve the structural performance of the IPPs (Perez et al. 2016). Two additional innovative IPPs were developed and tested. The remaining four IPPs tested were manufactured products installed per the manufacturer specifications with no attempt to improve the structural integrity or performance of the installation.

5.3 AGGREGATE BARRIER INLET PROTECTION

Aggregate based IPPs are specifically tailored towards drop inlets located on roadway and highway medians. Various installation parameters exist and standard details vary between state agencies (ALDOT 2012; CASQA 2003; FDEP 2008; MDE 2011; NCSCC 2013; SC-DHEC2005; VDEQ 1992). Some typical installations include a variation of coarse aggregate, typically No. 4 gradation, arranged around a barrier (i.e. concrete block, hardware cloth, lumber box) to prevent aggregate from washing into the inlet. Five various aggregate barrier installations were tested: (1) ALDOT standard installation, (2) hardware cloth and gravel, (3) concrete block and gravel, (4) enhanced block and gravel, and (5) block, no gravel.

5.3.1 ALDOT Standard Installation

As with the developed testing regime, the ALDOT standard practice was first evaluated in the IPP test channel as shown in Figure 5.2(a). The ALDOT standard aggregate barrier was installed as prescribed by the standard details as shown in Appendix A. The practice resulted in an inability to effectively impound flows, with impoundment length of 8.6 ft as shown in Figure 5.2(b). Dewatering of the device required approximately two minutes.

5.3.2 Hardware Cloth and Gravel Modification

Installation enhancements to the ALDOT standard were geared towards improved impoundment volume of the device, and increased dewatering time. A variation of the standard aggregate barrier practice was tested that included a hardware cloth and gravel installation (NCSCC 2013). This enhanced installation replaces the lumber used in the ALDOT detail with a 36 in. tall hardware cloth wrapped around T-posts installed at the inside corners of the barrier at a depth of 24 in. No. 4 aggregate was arranged around the perimeter at a height of 16 in. with a 12 in. top width and 1H:1V side slopes as shown in Figure 5.2(c). Similar to the ALDOT standard installation, the hardware cloth and gravel system had a low impoundment volume, and high dewatering rate, at two minutes.

5.3.3 Concrete Block and Gravel Modification

Another installation variation iteration was developed from typical concrete block and gravel systems (NCSCC 2013; SC-DHEC 2005; VDEQ 1992). The concrete block and gravel practice consists of stacking two rows of concrete block in a square perimeter. Aggregate is backfilled around the blocks similarly to the aforementioned practices. Blocks may be installed on their sides and wrapped in hardware cloth to provide for dewatering. The tested installation was installed with two overturned blocks at the base of the structure wrapped in hardware cloth to prevent aggregate from washing through. Due to the decreased permeability of the structure compared to the ALDOT standard aggregate barrier practice, the device impounded a considerably larger volume of water, however it did not reach the full height of the structure and had a relatively short dewatering time. Ponding is shown in Figure 5.2(d).

5.3.4 Block, no Gravel

A block system without backfilled aggregate was also tested to determine if the perimeter stone was a necessary component of the installation. The test resulted in the concrete block perimeter deflecting towards the inlet due to the hydrodynamic and hydrostatic pressure of the flows as shown in Figure 5.2(e). The deflection caused larger gaps to open at the block seams, forcing a larger flow rate through the device.

5.3.5 ENHANCED BLOCK AND GRAVEL MODIFICATION

To further increase the detention time of the practice, the blocks were wrapped in filter fabric and the dewatering blocks were reduced to a fourth of the open area of one overturned block as shown in Figure 5.2(f)-(h). It was found that the wrapped block and gravel system provided less flow through the seams of the placed concrete blocks and thus the impoundment reached the full height of the IPP with length of the subcritical impoundment increased by 110% from the ALDOT standard to a length of 18.1 ft, shown in Figure 5.2(g). The dewatering time for the installation also increased from two minutes (standard installation) to 13 minutes, providing greater detention time of contained stormwater.

5.3.6 Aggregate Barrier Inlet Protection Installation Enhancement Summary

A summary of the tested installation improvement iterations is provided in Table 5.2. The geotextile wrapped block and gravel installation (i.e., enhanced block and gravel) was identified as the MFE-I for aggregate practices. The MFE-I and its conditions during the test are pictured in Figure 5.2(f)-(h). Complete installation details are provided in Appendix C.

Table 5.2 Aggregate Barrier Installation Enhancement Evaluations

Install	Tested Configuration	Hydraulic Performance			
		Overtopping (mins)	Ponding Height (ft)	Ponding Length (ft)	Dewatering (mins)
SI-1	Standard ALDOT Installation	DNO[a]	NR[b]	NR	NR
I-1	Block & Gravel	DNO	NR	NR	NR
I-2	Hardware Cloth & Gravel	DNO	0.41	NR	2.0
I-3	Block, No Gravel	DNO	1.13	14.7	8.0
I-4[c]	Block & Gravel + Filter Fabric	4.0	1.24	18.1	13.0

Notes: [a] DNO: did not overtop
[b] NR: data not collected
[c] identified most feasible and effective installation (MFE-I)

(a) ALDOT standard installation

(b) standard installation, max. impoundment

(c) hardware cloth & gravel, max. impoundment

(d) block and gravel, max. impoundment

(e) block, no gravel, barrier deflection

(f) MFE-I

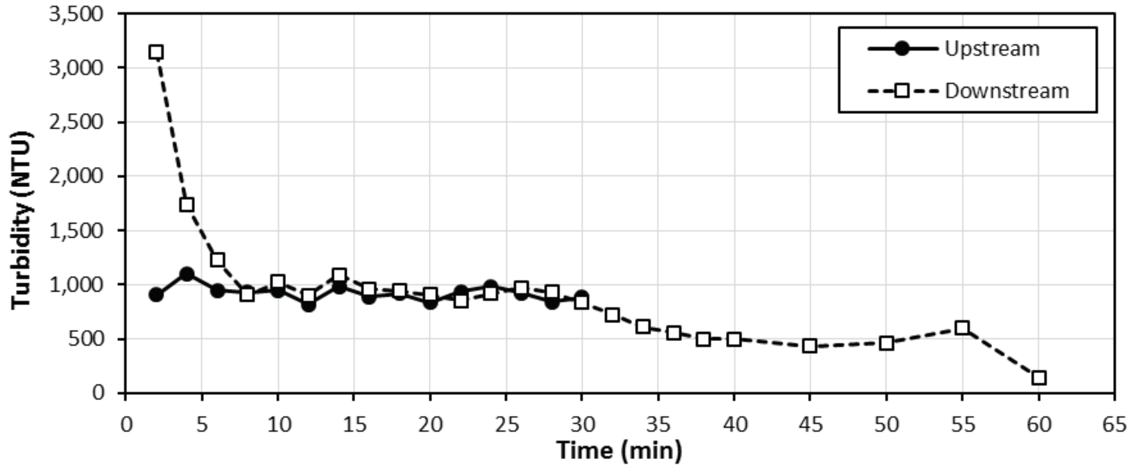
(g) MFE-I at full impoundment

(h) MFE-I dewatering mechanism

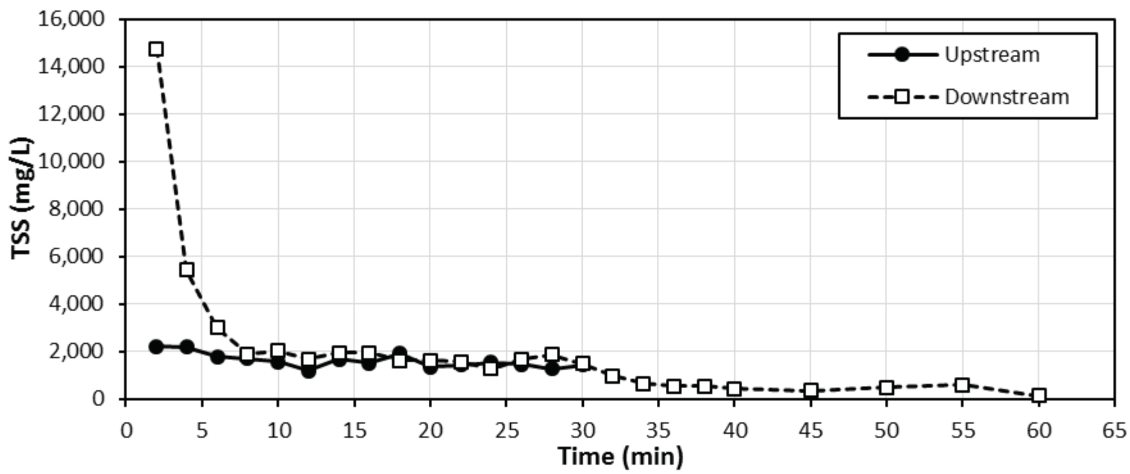
Figure 5.2 Aggregate Barrier IPPs Spec., Installations, and Conditions during the Test.

5.3.7 Aggregate Barrier MFE-I Performance

The aggregate barrier MFE-I, enhanced block and gravel, was tested in Phase II testing as per the developed testing regime. Phase II testing used sediment-laden flow to evaluate the practice's ability to improve turbidity and TSS of stormwater runoff. Average water quality results for the five tests performed on the aggregate barrier MFE-I are presented in Figure 5.3. The results indicate that the aggregate barrier had no effect in improving water quality during the 30 min. test duration. Turbidity and TSS decrease during the dewatering period.



(a) turbidity



(a) TSS

Figure 5.3 Aggregate Barrier MFE-I Water Quality Results.

Pre and post-test surveys of the channel were conducted to quantify the total amount of sediment retained upstream of the device. The average sediment retained upstream of the aggregate barrier for the three replicate tests was 76%. Sediment retention was reduced to an average of 71% during the longevity evaluation.

5.4 SANDBAG BARRIERS

Sandbag barriers are typically used along curb and gutter IPP applications. Their use in roadway median drop inlets is not common practice. ALDOT does however provide standard design details for use as a stacked configuration oriented in a circular ring around an inlet. Four different installation configurations were tested including: (1) ALDOT standard installation, (2) rotated configuration, (3) square configuration, and (4) gravel filled bags.

5.4.1 ALDOT Standard Installation

The standard installation as detailed required 125 bags to install in the test channel as shown in Figure 5.4(a). Thirteen minutes into the evaluation, a bag along the top row dislodged causing a massive release of impounded water, which in turn washed several more bags off the structure, which can be seen in Figure 5.4(b). With the failure, impoundment length was reduced from 12.3 to 8.5 ft. It was also noted that significant undercutting had occurred under the barrier, causing short circuiting and decreasing detention time to six minutes. Figure 5.4(b) shows the failure along the top row of the installation.

5.4.2 Square Configuration Modification

A square stacking configuration, as shown in Figure 5.4(c)–(d) was attempted in which sandbags were oriented in an 8 by 8 ft square barrier. Similar to the standard practice, the installation structurally failed with sandbags toppling after only two minutes into the test, which was considered a failure. Subsequent installations abandoned the square configuration as it required additional bags and proved to be ineffective.

5.4.3 Gravel Filled Bags

The Oregon Department of Environmental Quality states that gravel filled bags are intended to intercept and filter sediment-laden stormwater runoff from disturbed areas, retaining the sediment and releasing water (ODEQ 2005). Sandbags filled with No. 57 aggregate were tested in with the developed improvements. Bags were configured in a round barrier orientation with an inside diameter of 6 ft. The gravel filled bags impounded a length of 16 ft. Although the gravel filled bags provided strong friction between stacked rows, the high porosity of the structure due to the angularity of the stone, coupled with large seams along bag abutments caused significant flow-through and a relatively low detention time of 21 minutes during dewatering. The installation is depicted in Figure 5.4(e).

5.4.4 Rotated Configuration Modification

To enhance the installation, various stacking configurations were tested. In addition, a filter fabric underlayment was included in all installation improvement tests to prevent scour under the structure. The square shaped underlay was extended 1 ft beyond the barrier and pinned using round top pins spaced at 5 in. intervals around the perimeter of the fabric and around the inlet.

To provide improved friction contact between rows of bags, the middle row of bags was rotated 90 degrees to be perpendicular to the bottom and top rows as shown in Figure 5.4(f). In addition, the inside structure diameter was reduced to 6 ft. The smaller diameter provided a reduction of 41 bags from the ALDOT standard detail installation. The improved installation remained structurally sound throughout the test duration, providing 14.5 ft of impoundment length, a 171% increase in comparison to the ALDOT Standard Installation. The bags provided a tight seal with complete dewatering requiring 120 minutes. The sandbag barrier installation and full impoundment condition is shown in Figure 5.4(g) and (h), respectively. Subsequent tests included the rotated middle row modification.

5.4.5 Sandbag Barrier Inlet Protection Summary

A summary of the tested installation improvement iterations is provided in Table 5.3. The MFE-I for sandbag barriers was determined to be the 6 ft diameter sand filled bags with rotated middle row (i.e., rotated configuration), shown in Figure 5.4(f)-(h). Complete installation details are provided in Appendix C.

Table 5.3 Sandbag Barrier Installation Enhancement Evaluations

Install	Tested Configuration	Hydraulic Performance			
		Overtopping (mins)	Ponding Height (ft)	Ponding Length (ft)	Dewatering (mins)
SI-1	Standard Installation	5.0	1.10[a]	12.33[a]	6.0
I-1[b]	Rotated Second Row w/8 oz. FF	3.0	1.08	14.5	120
I-2	I-1 + Square Configuration	2.0	NR[c]	10.0[a]	NR
I-3	I-1 + Gravel Filled Bags	7.0	1.28	16.0	21.0

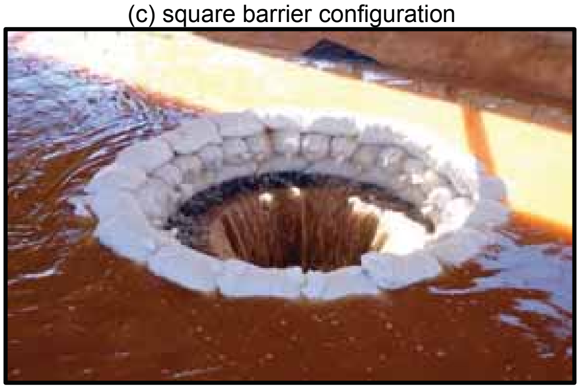
Notes:
[a] recorded prior to device structural failure
[b] identified most feasible and effective installation (MFE-I)
[c] NR: data not collected


(a) ALDOT standard installation


(b) ALDOT standard installation failure


(c) square barrier configuration


(d) square barrier failure


(e) gravel filled bags, max. impoundment


(f) MFE-I stacking configuration


(g) MFE-I

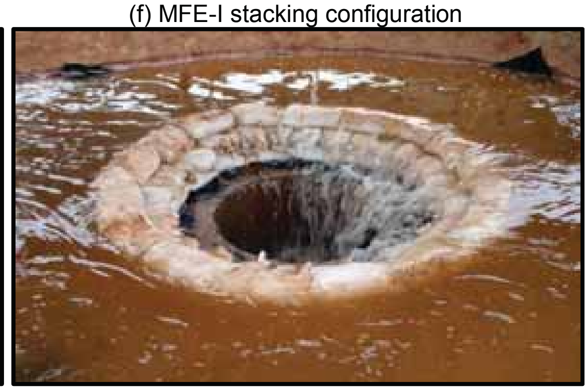
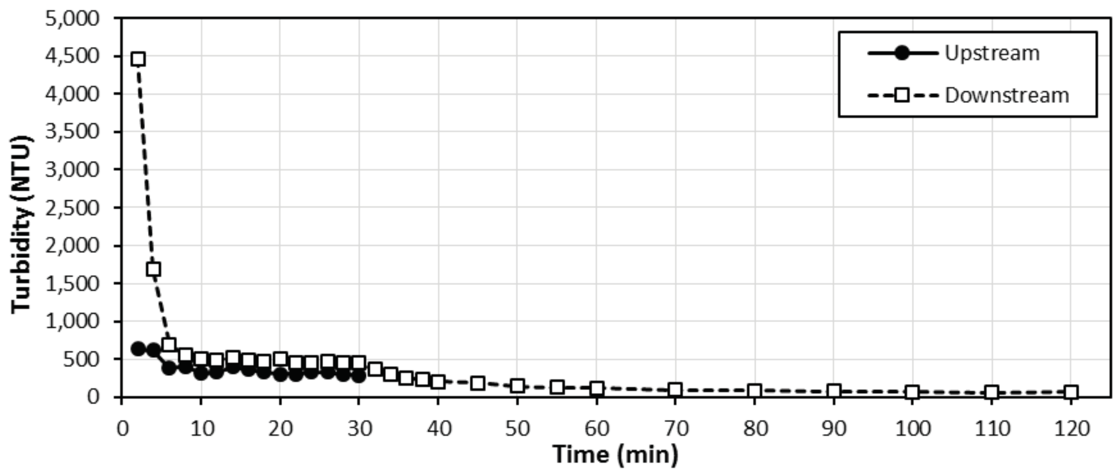

(h) MFE-I at full impoundment

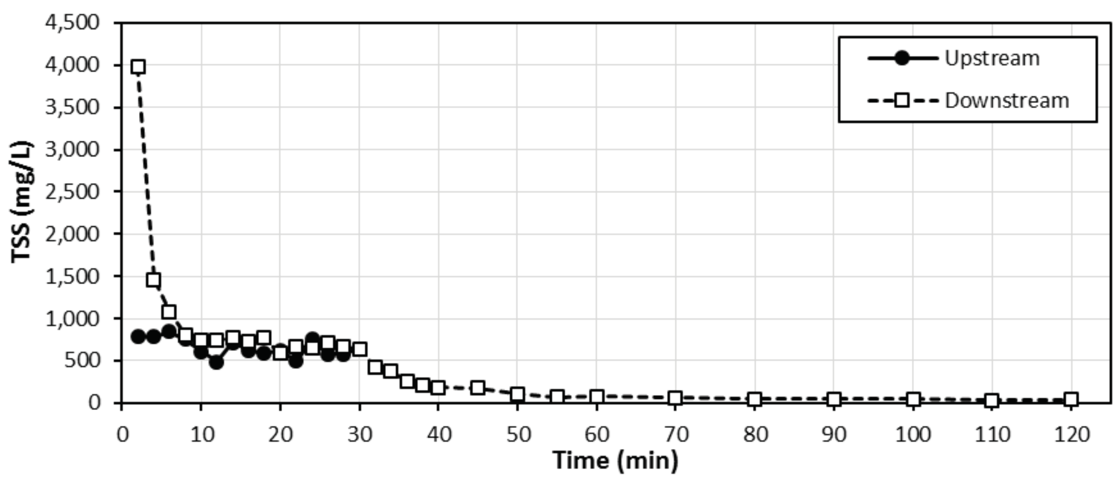
Figure 5.4 Sandbag Barrier IPPs Specifications and Installations in Test Channel.

5.4.6 Sandbag Barrier MFE-I Performance

The sandbag barrier MFE-I, rotated configuration, was tested in Phase II testing as per the developed testing regime. Phase II testing used sediment-laden flow to evaluate the practice's ability to improve turbidity and TSS of incoming runoff. Average water quality results for the five tests performed on the aggregate barrier MFE-I are presented in Figure 5.5. The results indicate that the sandbag barrier had no effect in improving water quality during the 30 min. test duration. Turbidity and TSS decrease during the dewatering period.



(a) turbidity



(a) TSS

Figure 5.5 Sandbag Barrier MFE-I Water Quality Results.

Pre and post-test surveys of the channel were conducted to quantify the total amount of sediment retained upstream of the device. The average sediment retained upstream of the sandbag barrier MFE-I for the three replicate tests was 71%. Sediment retention was reduced to an average of 59% during the longevity evaluation.

5.5 SILT FENCE BARRIER

Silt fence or fabric barrier IPPs are one of the most common IPPs installed on construction sites. The practice uses materials that are readily available and commonly used for other erosion control practices (i.e., sediment retention barriers, ditch checks, etc.). Although ALDOT does not maintain silt fence barriers as a standard IPP detail in their standard drawings, it is commonly used in the state and thus its performance was investigated. Five varying installations were tested: (1) typical installation, (2) hexagon configuration, (3) fence post installation, (4) 2x4 lumber installation, and (4) reinforced T-post installation.

5.5.1 Typical Installation

The typical installation was developed from ALDOT details specifying the use of silt fence as sediment retention barriers and ditch check applications. The installation, depicted in Figure 5.6(a) consisted of four T-posts oriented in a square perimeter with posts spacing at approximately 7 ft. Posts were inserted into the ground at a depth of 24 in. A 6 x 6 in. trench was excavated around the toe of the device. Wire backing was installed around the posts and geotextile was secured to the backing using hog rings spaced 24 in. apart along the top of the fencing. The wire backing and geotextile were inserted into the trench and backfilled. The height of the installation was 32 in. Approximately 2.5 minutes into testing, the impounded water forced the structure to cave-in towards the inlet and cause a massive release of water as shown in Figure 5.6(b). In addition, water overtopping the barrier caused scouring on the downstream earthen section of the barrier.

5.5.2 Hexagon Configuration

To improve the rigidity of the structure, subsequent testing focused on providing greater support against hydrodynamic and hydrostatic pressure generated by impounded stormwater. In addition, a geotextile underlay was used for all further silt fence barrier testing. The initial installation modification doubled the amount of T-posts which were installed in a hexagonal barrier configuration. Similarly to the original installation, the barrier catastrophically failed within 2.5 minutes into testing, overtopping towards the inlet, as shown in Figure 5.6(c). Removal of the installation divulged T-posts that were bent at nearly 45 degrees near the installation base.

5.5.3 Fence Post Installation Modification

Mimicking MDEQ specifications, a silt fence barrier configuration was tested that specified fence corner posts in lieu of T-posts and the use of a support wire along the top perimeter of the wire backed geotextile for additional support (MDE 2011). A geotextile underlay was included to reduce scour on the inside face of the practice. To improve installation ease, an alternative to trenching was developed. The geotextile fabric was pinned with round top pins along the perimeter of the IPP. Pins were installed in two rows spaced 10 in. on-center in a staggered pattern. The pinned installation secures the silt fence fabric to the ground without having to trench in the fabric, saving installation time and effort and reducing further land disturbance created by the trench. The installation was tested and provided a slightly more rigid installation as shown in Figure 5.6(d). The silt fence between posts deflected slightly less, however significant and permanent deformation in the fence posts were noted. Due to the significantly higher cost of posts and difficulty in installation compared to the T-post counterpart, the material was abandoned and the subsequent test used 2x4 lumber as stakes.

5.5.4 2x4 Lumber Installation Modification

A 2x4 lumber installation used lumber stakes inserted into the ground at 24 in. depths. The installation was braced around the top by installing 2x4 lumber around the perimeter. This configuration proved to be very effective in structurally supporting the impounded water. No deformation or structural deficiencies were noted with the installation. Dewatering time however was noted as undesirably long, in excess of 24 hours.

5.5.5 Reinforced T-post Installation Modification

To improve the installation ease, a combination of the T-post installation with 2x4 lumber bracing was developed. The installation calls for T-posts to be inserted at 30 in. spacing. 2x4 lumber is outfitted with holes 1.5 in. in diameter at the location of T-posts and arranged around the top perimeter of the installation. In addition, two 2x4 lumber cross braces are added to further support the structure. The cross braced installation is shown in Figure 5.6(f). The pinning configuration is depicted in Figure 5.6(e) and (g). The 2x4 lumber provided rigidity to the installation, creating a self-supporting system. Through various installation tests, it was found that the geotextile material quickly clogs with sediment and dramatically decreases the flow-through rate of the fabric. In turn, detention times exceeded 24 hours. To combat this problem, a dewatering device was created for the installation. The device is a 2x4 lumber board with 14 holes drilled into the board. Holes range from 0.25 to 1.5 in., with the larger holes drilled furthest up the board. This design provides slower dewatering rates at the bottom of the water column where water is theoretically the most turbid. The board is inserted into the ground on the inlet side of the barrier. A staple gun provided staples to adhere the geotextile and wire mesh to the board. Slits were cut out at the drilled hole locations as depicted in Figure 5.6(f). These holes provide for efficient dewatering. The size and spacing of the drilled holes can be adjusted based on expected flow conditions. This improved installation impounded water the entire length of the channel, 31 ft beyond the face of the barrier. Complete dewatering of the installation required 90 minutes. Figure 5.6(h) shows the installation under full impoundment.

5.5.6 Silt Fence Barrier Inlet Protection Summary

A summary of the tested installation improvement iterations is provided in Table 5.4. The MFE-I for silt fence barriers was determined to be the reinforced T-post installation. Complete installation details are provided in Appendix C.

Table 5.4 Silt Fence Barrier Installation Enhancement Evaluations

Install	Tested Configuration	Hydraulic Performance Overtopping (mins)	Ponding Height (ft)	Ponding Length (ft)	Dewatering (mins)
SI-1	Typical Installation	2.5	0.97	5.0	NR[a]
I-1	SI-1 + Additional Posts	2.5	1.23	8.0	NR
I-2	Cross Braced	3.0	1.61	NR	NR
I-3	2x4 Posts, Cross Braced	NR	NR	NR	NR
I-4	Fence Posts	9.0	2.07	26.8	NR
I-5[b]	Reinforced T-post	10.0	2.25	31.0[c]	90

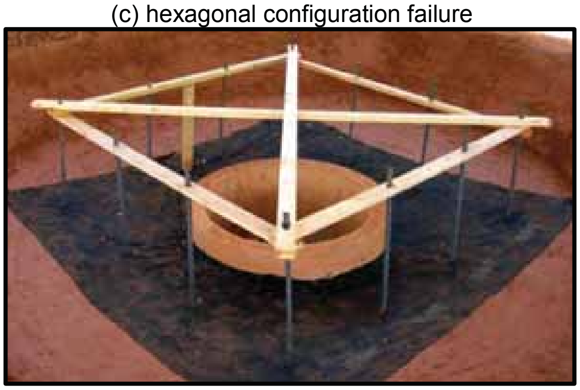
Notes: [a] NR: data not collected
[b] identified most feasible and effective installation (MFE-I)
[c] full channel impoundment

(a) typical installation

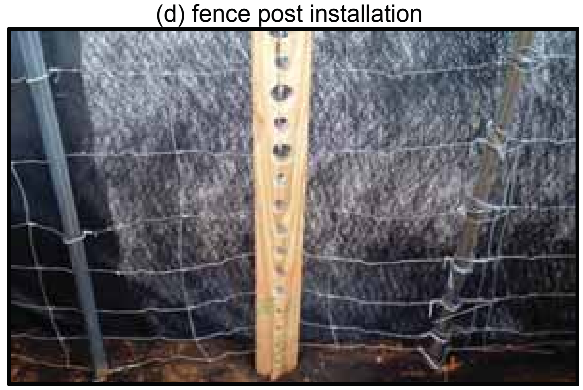
(b) typical installation failure

(c) hexagonal configuration failure

(d) fence post installation

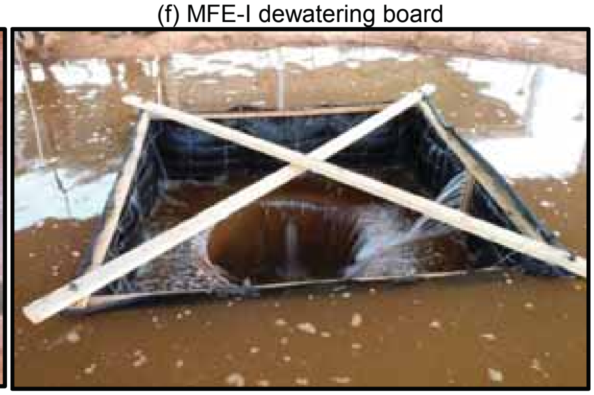


(e) T-post bracing / reinforcement



(f) MFE-I dewatering board

(g) MFE-I

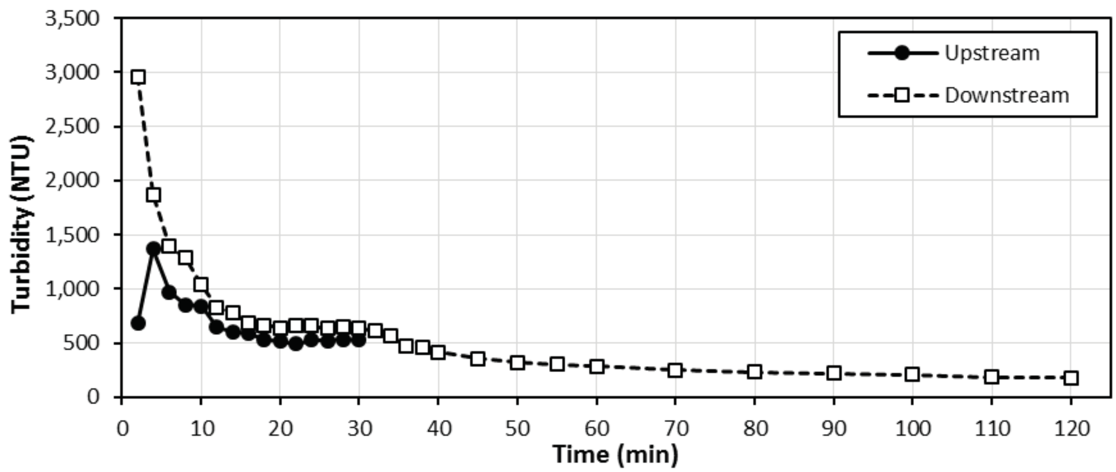


(h) MFE-I impoundment

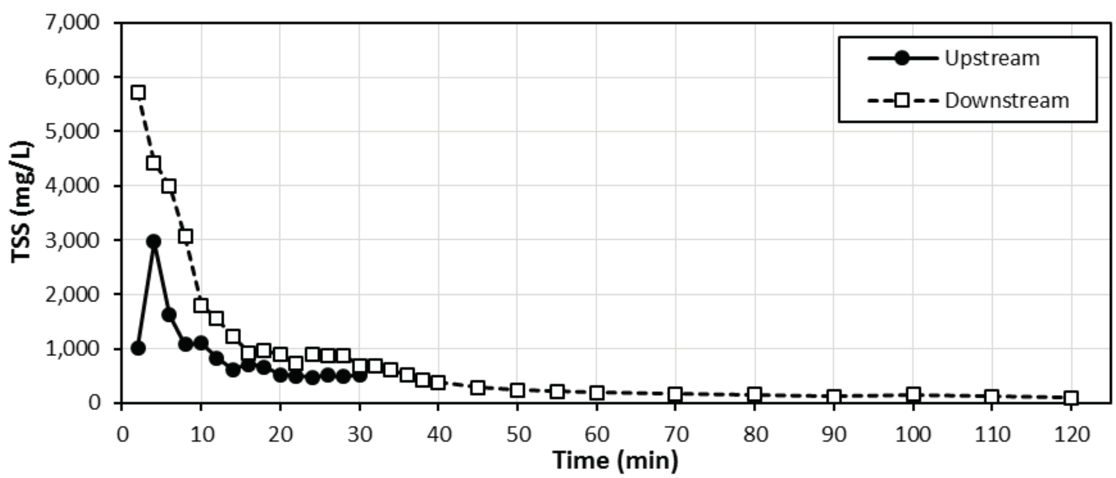
Figure 5.6 Silt Fence Barrier IPPs Installations in Test Channel & Conditions during the Tests.

5.5.7 Silt Fence Barrier MFE-I Performance

The silt fence barrier MFE-I, reinforced T-post installation, was tested in Phase II testing as per the developed testing regime. Phase II testing used sediment-laden flow to evaluate the practice's ability to improve turbidity and TSS of incoming runoff. Average water quality results for the five tests performed on the silt fence barrier MFE-I are presented in Figure 5.7. The results indicate that the silt fence barrier had no effect in improving water quality during the 30 min. test duration. Turbidity and TSS decrease during the dewatering period.



(a) turbidity



(a) TSS

Figure 5.7 Silt Fence Barrier MFE-I Water Quality Results.

Pre and post-test surveys of the channel were conducted to quantify the total amount of sediment retained upstream of the device. The average sediment retained upstream of the silt fence barrier MFE-I for the three replicate tests was 91%. Sediment retention was reduced to an average of 84% during the longevity evaluation.

5.6 WATTLE BARRIER

Wattle barriers were tested in the test channel to provide an assessment of performance to the standard detail and to provide installation improvements. Several installation modifications were made through a series of installation evaluations, however the two main variations tested were: (1) ALDOT standard installation, and (2) stapled installation.

5.6.1 ALDOT Standard Installation

The ALDOT standard installation (Figure 5.8(a)) required four wattles joined in a circular ring around the inlet and secured into place using staking. Stakes are specified at every 2 ft on both the inside and outside of the wattle in a tee-pee configuration. Additional stakes are placed through the wattles at connection points. All stakes are driven 24 in. into the ground. Prior to testing, wattles were pre-saturated by spraying water for five minutes, which simulated the effects of rainfall and runoff from the contributing area with a time of concentration of five minutes. The ALDOT standard installation test showed that undercutting was the most severe problem. The installation lacked structural stability to impound water and allowed sediment to pass through the barrier. Undercutting was a direct result of the prescribed staking parameters, where the wattle was visibly buoyant and moving up and down during testing. The staking was unable to effectively secure the wattle to the ground, preventing flow from going directly underneath. The subcritical flow pool length upstream of the device was 1 ft as shown in Figure 5.8(b) during maximum impoundment condition. The channel section upstream of the IPP was severely eroded due to the installations inability to impound water. Eroded material was deposited along the inside face of the barrier as depicted in Figure 5.8(c). The goal of subsequent testing was aimed at improving the wattle-to-ground contact interface by altering the staking configuration.

5.6.2 Stapled Installation Modification

To reduce undercutting, 8 oz./yd^2 nonwoven filter fabric geotextile underlays were included to protect the channel bottom at the wattle-channel interface in all subsequent wattle improvement tests. Underlays were installed using round top pins. Wattle IPP improvement tests investigated several staking configuration and spacing variations (i.e. non-destructive tee-pee vs. through-product destructive, upstream vs. downstream wattle staking, 1 ft spacing vs 2 ft spacing, etc.) After a slew of tests, it was found that impoundment improvements were minimal regardless of stake quantity and configuration. Further ground contact was required, thus U-shaped sod staples were included in the installation. Sod staples were spaced 10 in. apart along the inside and outside of the device to secure the wattle to the ground as shown in Figure 5.8(f). In addition, staking depth was decreased to 12 in. and the staking configuration developed decreased the total number of stakes used from 24 to 18. Shorter stake depth proved to be as structurally effective as the deeper staked counterpart, however the shorter depth helps prevent the wooden stakes from splitting and decreases the installation time required for installing the practice. Furthermore, staking was configured in a non-destructive tee-pee configuration, which helps maintain the integrity of the wattle and adds additional downward support against stormwater forces (Donald et al. 2013). The inside diameter of the installation was decreased to 7 ft, reducing the number of wattles required from four to three. In addition, the wattle abutment was increased from 12 in. to 18 in. as shown in Figure 5(e). The improved installation is shown in Figure 5.8(d). Impoundment depth was recorded to the full wattle height of 20 in producing 10.4 ft of subcritical impoundment as shown in Figure 5.8(g). Compared to the standard installation, impoundment length increased by over ten times. Overtopping time was recorded at 5 minutes and dewatering time was achieved within 9 minutes. Undercutting was reduced and device buoyancy was negated. As a result of the increased performance measures, erosion and deposition pattern seen in the initial ALDOT standard installation test was improved. The earthen channel eroded less due to the protection provided by the greater impoundment and kinetic energy decrease with subcritical flows. Furthermore, sediment was deposited around the outside perimeter of the barrier. The MFE-I identified for wattle

IPP is shown in Figure 5.8(d)-(h) The post-test condition of the MFE-I installation is shown in Figure 5.8(h). Complete installation details are provided in Appendix C.

5.6.3 Wattle Barrier Inlet Protection Summary

A summary of the tested installation improvement iterations is provided in Table 5.5. The MFE-I for Wattle barriers was determined to be the stapled and reduced diameter installation. Complete installation details are provided in Appendix C.

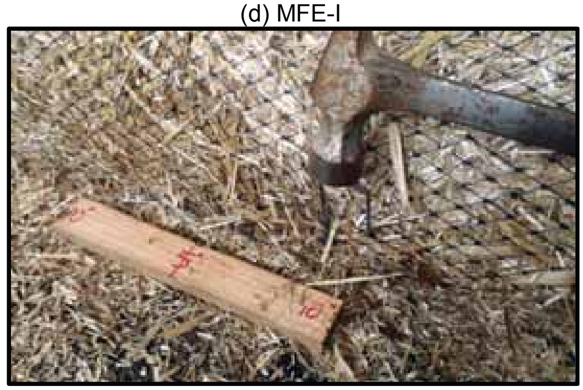
Table 5.5 Wattle Barrier Installation Enhancement Evaluations

Install	Tested Configuration	Hydraulic Performance			
		Overtopping (mins)	Ponding Height (ft)	Ponding Length (ft)	Dewatering (mins)
SI-1[a]	Standard ALDOT Installation	DNO[b]	0.70	1.0	NR[c]
I-1[a]	SI-1 + Additional Staking	DNO	1.00	4.8	NR
I-2[a]	SI-1 + Underlay	DNO	0.61	2.3	NR
I-3[a]	I-2 + Additional Staking + Improved Underlay	DNO	0.94	4.6	NR
I-4[a]	I-3 + U-Staples + Improved Connections	2.0	1.13	5.9	NR
I-5[a]	I-4 + Upstream Ditch Check	NR	0.95	NR	NR
I-6[a]	I-4 + Improved Underlay	NR	0.84	NR	NR
I-7[d]	I-4 w/ Reduced Installation Diameter	5.0	1.10	10.4	9.0

Notes: [a] performed under inlet construction stage 2 condition as per originally proposed testing regime
[b] DNO: did not overtop
[c] NR: data not collected
[d] identified most feasible and effective installation (MFE-I)


(a) ALDOT standard installation
(b) ALDOT std. installation impoundment


(c) ALDOT standard installation deposition
(d) MFE-I

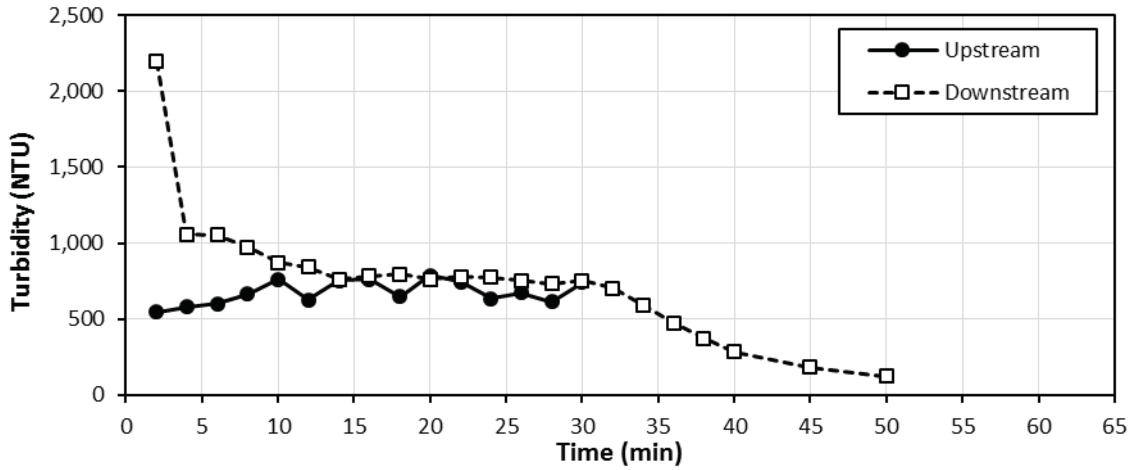
(e) MFE-I wattle abutment
(f) MFE-I sod staple installation


(g) MFE-I impoundment
(h) MFE-I post-test

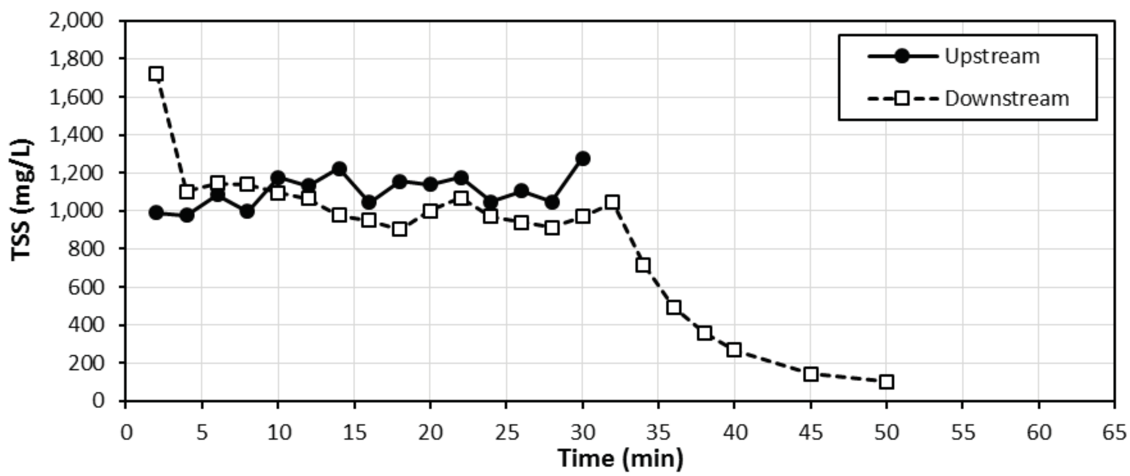
Figure 5.8 Wattle Barrier IPPs Specifications and Installations in Test Channel.

5.6.4 Wattle Barrier MFE-I Performance

The wattle barrier MFE-I, stapled and reduced diameter, was tested in Phase II testing as per the developed testing regime. Phase II testing used sediment-laden flow to evaluate the practice's ability to improve turbidity and TSS of incoming runoff. Average water quality results for the five tests performed on the aggregate barrier MFE-I are presented in Figure 5.9. The results indicate that the wattle barrier had no effect in improving turbidity, however some improvements are seen in TSS during the 30 min. test duration. Turbidity and TSS decrease during the dewatering period.



(a) turbidity



(a) TSS

Figure 5.9 Wattle Barrier MFE-I Water Quality Results.

Pre and post-test surveys of the channel were conducted to quantify the total amount of sediment retained upstream of the device. The average sediment retained upstream of the wattle barrier MFE-I for the three replicate tests was 71%. Sediment retention was reduced to an average of 49% during the longevity evaluation.

5.7 OTHER INNOVATIVE PRACTICES

Through the research and development process, two innovate IPPs were developed. The developed IPPs are based on two silt fence barriers creating a flow through system. The first developed flow configuration used rip-rap filled gabion baskets as a flow through medium. The second used hay bales as a medium between the silt fence rows.

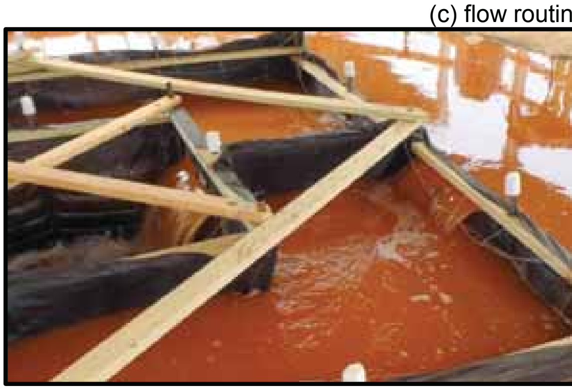
5.7.1 Gabion Flow System

A gabion flow system was developed based on a combination of silt fence barrier and gabion basket IPPs (MDE 2011). The purpose of this developed system was to create a practice that would provide an impoundment that would protect an earthen channel from erosion and promote the capture of rapidly settleable solids outside of the IPP. Once flow enters the flow through system, an elongated flow path through a medium reduces the turbulence and flow velocity to create conditions favorable to sedimentation of the smaller particle sizes. A series of tests were conducted to determine the MFE-I. Ultimately the MFE-I was developed by placing six galvanized gabion baskets around the inlet to form a square perimeter. Reinforced silt fence barriers were provided on each side of the baskets. The baskets measured 6 ft in length, 3 ft in width, and 1.5 ft in height. Baskets were filled with rip-rap stone and tied shut using galvanized wire. A routing system was developed to force flows through one weir opening, through the six baskets, and discharge via an exit weir. Dewatering boards are provided next to the entrance and exit weir to allow impounded water to recede at the conclusion of the test. Figure 5.10(a) and (b) depict the installation in the test channel. Figure 5.10(c) shows the flow routing through the system. Figure 5.10(d) shows the entrance and exit weirs during full impoundment conditions. A post-test photo is provided in Figure 5.10(e). Installation details are provided in Appendix C.

(a) test channel installation

(b) weir placement

(c) flow routing configuration

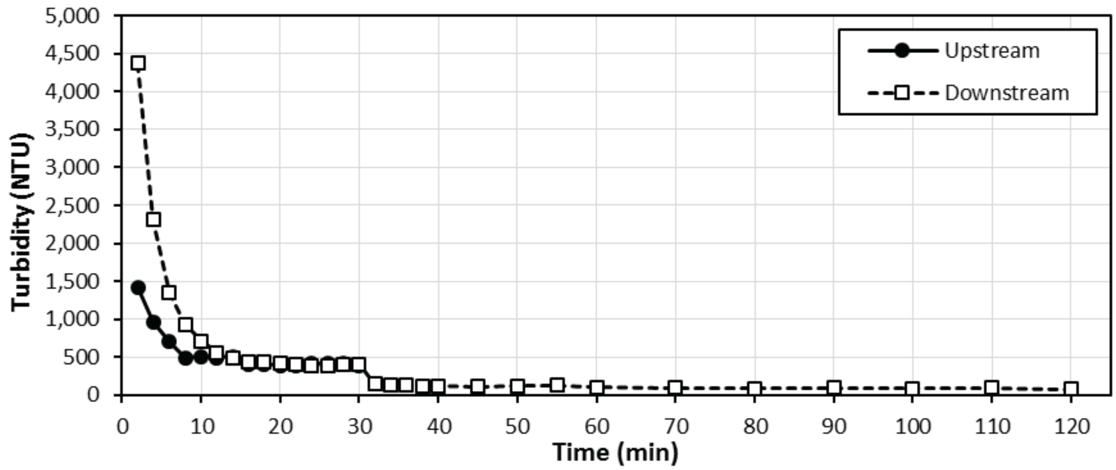


(d) weirs under full impoundment

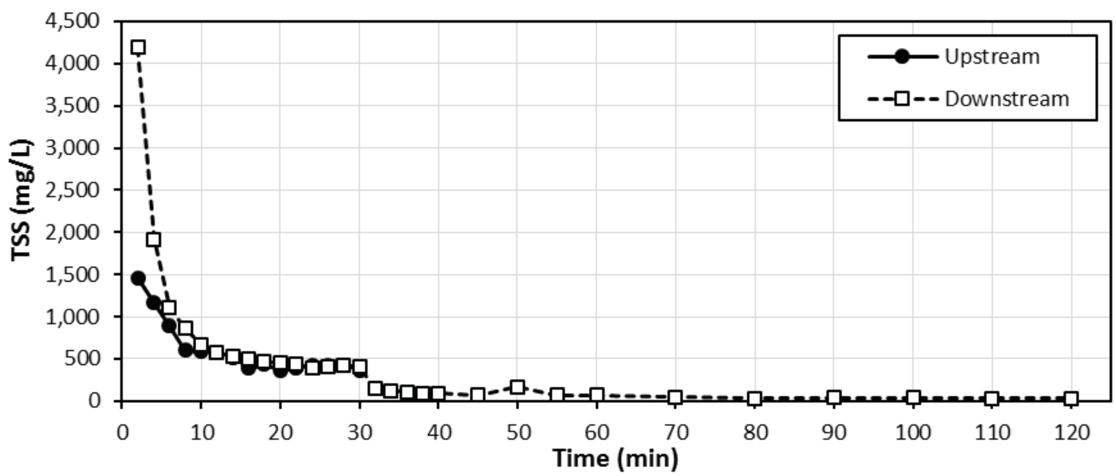
(e) post-test deposition

Figure 5.10 Gabion Basket Flow Through System.

The gabion basket flow through system was evaluated with sediment-laden flow to evaluate the practice's ability to improve turbidity and TSS. Average water quality results for the longevity test performed on the system are presented in Figure 5.11. The results indicate that the gabion basket flow through system had no effect in improving water quality during the 30 min. flow introduction period, however improvements are seen during the dewatering period.



(a) turbidity



(a) TSS

Figure 5.11 Gabion Basket Flow Through System Water Quality Results.

5.7.2 Hay Bale Flow System

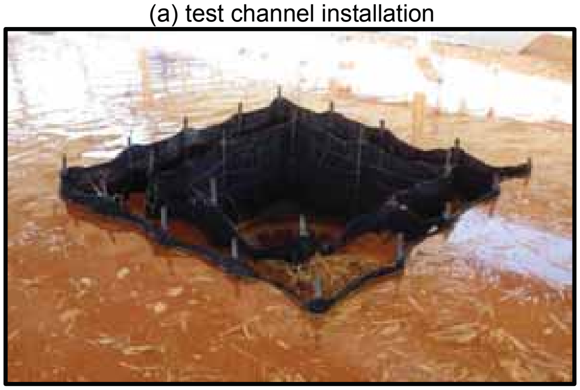
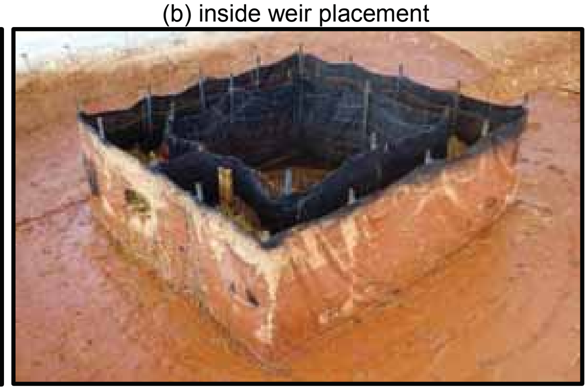
Similar to the gabion basket flow system, a hay bale flow system was developed. Rather than using riprap filled gabion baskets as a flow through medium between silt fence barriers, this system used hay bales. Two silt fence barriers were used to create a flow routing system that included entrance and exit weirs, both equipped with dewatering boards. The weirs were cut at an elevation capable of allowing flow to travel through the hay bale medium rather than allowing flow to over top the bales. Unlike the gabion system, the two silt fence barriers were not reinforced with lumber with the idea that the lower weir height would reduce the hydrostatic forces on the silt fence barriers. Complete installation details are provided in Appendix C. The test was performed under sediment-laden conditions to assess water quality improvement performance.

The hay bale flow through system has two function methods. During smaller storm events, stormwater is forced to flow through three mediums: (1) outside barrier fence, (2) hay bales, and

(3) inside barrier fence. This allows for water to be temporarily detained twice to allow for particle settlement. Furthermore, some filtration can be expected as water passes through the barriers. The second function method of the system is designed for storms that generate greater amounts of runoff. When the capacity of the outside silt fence barrier is exceeded, runoff is routed through the outside barrier weir. Overtopping flows are routed through the hay bale medium in-between the two silt fence barriers. Flows discharge via the system through the exit weir located on the inside silt fence barrier.

The test practice performed as intended. Flows primarily passed through the two silt fence barriers rather than flowing through the hay bale medium. This was expected due to the initial permeability of the filter fabric. Once the fabric began to blind with sediment and lose its capability to flow water, less flow was visible flowing through the barriers and a greater visible amount flowed through the designed hay bale flow path. Over time, the T-posts near the entrance weir deflected towards the inlet structure due to the force of the incoming flow. Although the structural integrity of the practice was not compromised, the use of lumber reinforcement would result in a more robust installation.

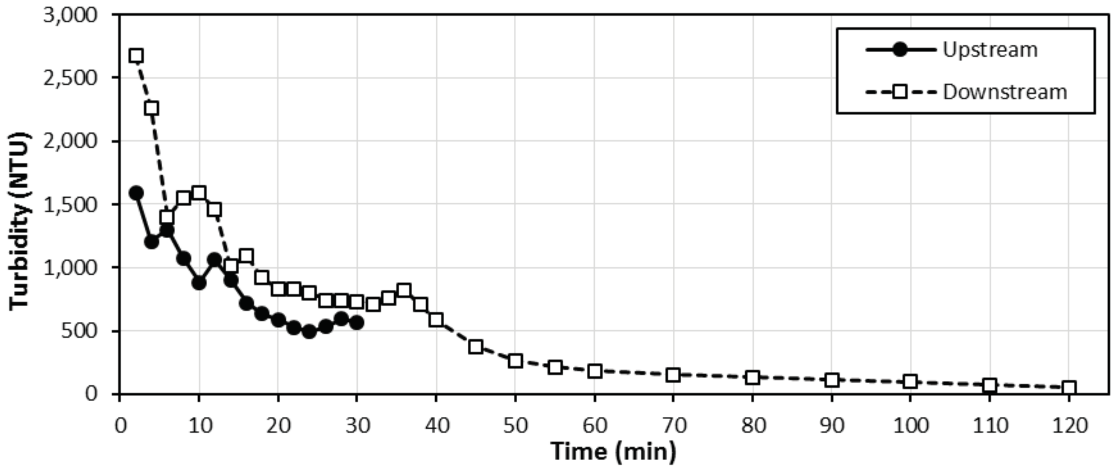

(a) test channel installation (b) inside weir placement

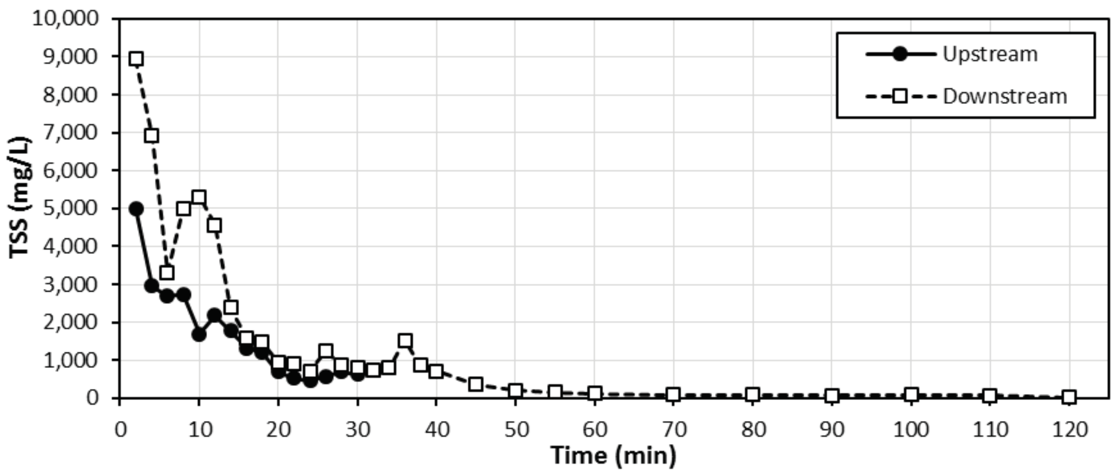
(c) impoundment (b) post-test deposition

Figure 5.12 Hay Bale Flow Through System.

The hay bale flow through system was evaluated with sediment-laden flow to evaluate the practice's ability to improve turbidity and TSS. Average water quality results for the longevity test performed on the system are presented in Figure 5.13. The results indicate that the hay bale flow through system had no effect in improving water quality during the 30 min. flow introduction period, however improvements are seen during the dewatering period.



(a) turbidity



(a) TSS

Figure 5.13 Hay Bale Flow Through System Water Quality Results.

5.7.3 Innovative Inlet Protection Summary

A summary of the two types of innovative IPPs tested is provided in Table 5.6. Complete installation details for both the gabion basket and hay bale flow systems are provided in Appendix C.

Table 5.6 Innovative IPP Evaluations

Install	Tested Configuration	Hydraulic Performance Overtopping (mins)	Ponding Height (ft)	Ponding Length (ft)	Dewatering (mins)
I-1	Gabion Baskets	3.0	1.76	19	22
I-2	Filter Fabric Wrapped Gabion Baskets	1.5	NR[a]	NR	NR
I-3	Double Silt Fence Gabion Basket Flow-Through System	4.0[b]	2.29	31[c]	90
I-4	Double Silt Fence Hay Bale Flow-Through System	7.0[b]	2.51	33[c]	110

Notes: [a] NR: data not collected
[b] overtopping time into outside weir
[c] full channel length

5.8 MANUFACTURED INLET PROTECTION PRODUCTS

An additional component of this research study was to evaluate four manufactured IPPs. The tested products included: (1) round Silt-Saver frame and filter assembly (R-100A), (2) square Silt-Saver frame and filter assembly (S-200A), (3) Grate Pyramid, and (4) Erosion Eel. As per the designed testing regime, manufactured products were tested only per the manufacturer's installation details and instructions, which are provided in Appendix B. No attempts or iterations were made to improve the product's installation in a manner that would modify the design or fabrication of the product. Currently, the Silt-Saver dome is the only approved IPP manufactured product for use by ALDOT (ALDOT 2014).

5.8.1 Silt-Saver (Silt-Saver®, Inc.) Round Frame, R-100A

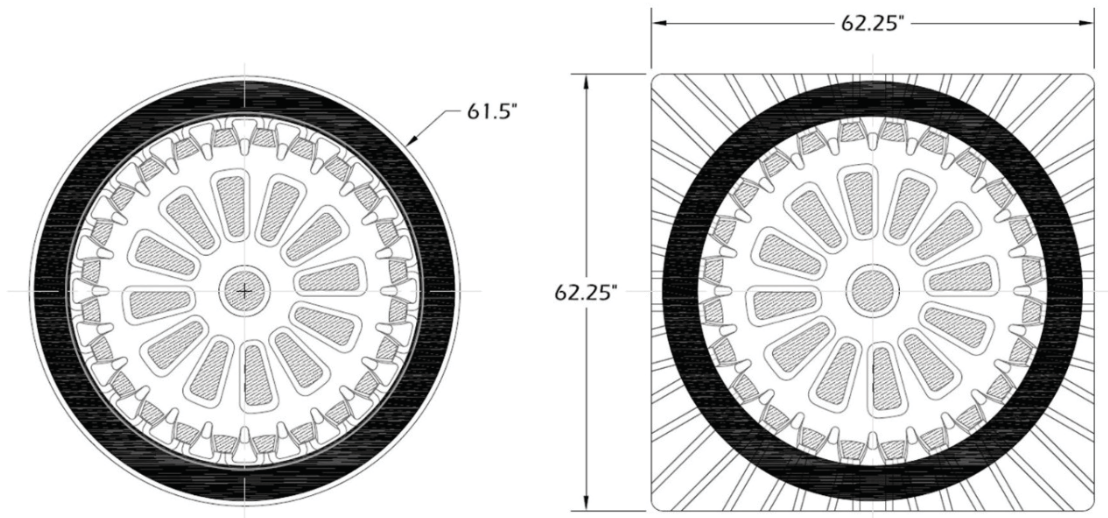
The round Silt-Saver frame and filter assembly are the more common of the two Silt-Saver products. The round design is marketed for circular inlet structures. The product was installed as per manufacturer installation literature. The dome fits over inlet structures with outside diameters up to 60 in. and is covered with a fabric sock. Pockets on the footing of the filter sock were filled with ALDOT No. 4 stone as prescribed.

As per the designed protocols, the product was tested in the test channel under the prescribed testing regimen. During testing, water quickly impounded around the device as the fabric's flow-through capacity was overwhelmed. Overtopping into the fluorescent green, high flow, section of fabric geotextile occurred after five minutes from the commencement of the test. As the ponding height increased around the dome, the device visually became disfigured under the hydrostatic pressure as pictured in Figure 5.15(b). This deformation caused the device to effectively dislodge from the rim of the inlet and provided for device short-circuiting and rapid dewatering between the bottom of the dome and the inlet structure. Although the failure was not catastrophic, the product clearly did not perform as intended.

Common field installation of the Silt-Saver domes provide stone that overflow the provided product pockets. In a subsequent investigative test, additional aggregate was added outside of the device. The evaluation was performed to appraise any possible improvements the additional aggregate placed outside the pockets and around the device may provide. However, similar to the standard installation, the device yielded under high water levels and dislodged from the inlet rim. Due to the multiple failures experienced with the round dome, further performance testing was abandoned under the prescribed testing conditions.

5.8.2 Silt-Saver (Silt-Saver®, Inc.) Square Frame, S-200A

As with the round dome, the square Silt-Saver dome is marketed for use on square inlet structures with up to 60 in. widths. The device has a larger footprint due to its square shape and therefore was tested to determine if the geometry would provide greater stability from disfigurement and dislodgement. Installed on a 60 in. diameter inlet structure, the square dome provides 7.3 ft^2 of surface area protection between the device and soil. In contrast, the round dome only provides 1.0 ft^2 of soil protection around the inlet. The gap between the edge of the dome device and concrete inlet structure measures 0.75 in. around the entire perimeter for the round configuration. Four points measuring a 1.13 in. make up the smallest gap between the square product and the concrete structure. These contact areas are depicted in the CAD drawings provided in Figure 5.14. The drawings provide a plan view perspective of the devices installed over a 60 in. round inlet structure. The ring shaded in black represents the concrete inlet structure and the gray lines are the respective Silt-Saver products.



(a) R-100A Dome Installation (b) S-200A Dome Installation

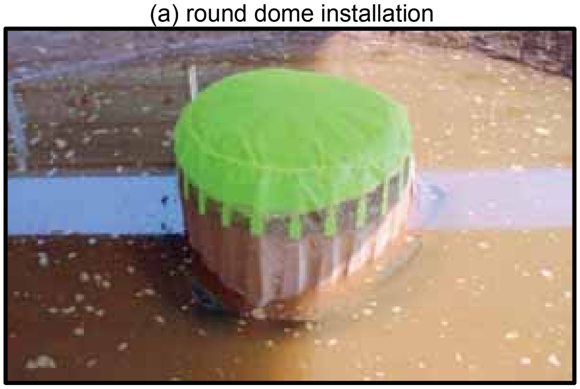
Figure 5.14 Silt-Saver Footprint on Typical Inlet Structure.

As pictured in Figure 5.15(g), the square dome was installed over the test channel inlet and the fabric pockets were filled with ALDOT No. 4 stone. During testing, the square dome impounded water past the filter fabric material on the dome and held its structural integrity throughout the duration of the test as pictured in Figure 5.15(h). However, similar to the round device, dewatering occurred within 19 minutes. A post-dewatering investigation showed that the soil underneath the device eroded causing piping, and thus short-circuiting of flow underneath the dome. This undercutting is undesirable and is considered to be a failure as it allowed flow to bypass the product. Although the geotextile sock had blinded preventing substantial flow from passing through the fabric, the undercutting allowed for a rapid dewatering time.

As with the tested IPPs, the Silt-Saver installation could be improved by providing a filter fabric underlay and possibly driving stakes, staples, or rebar through the product to affix it to the ground to minimize erosion underneath the device. However, no attempts were made to improve the product's installation and structural integrity.

(a) round dome installation

(b) round dome impoundment



(c) round dome disfigurement

(d) round dome dislodgement

(e) round dome with add'l aggregate

(f) round dome with add'l aggregate disfigurement

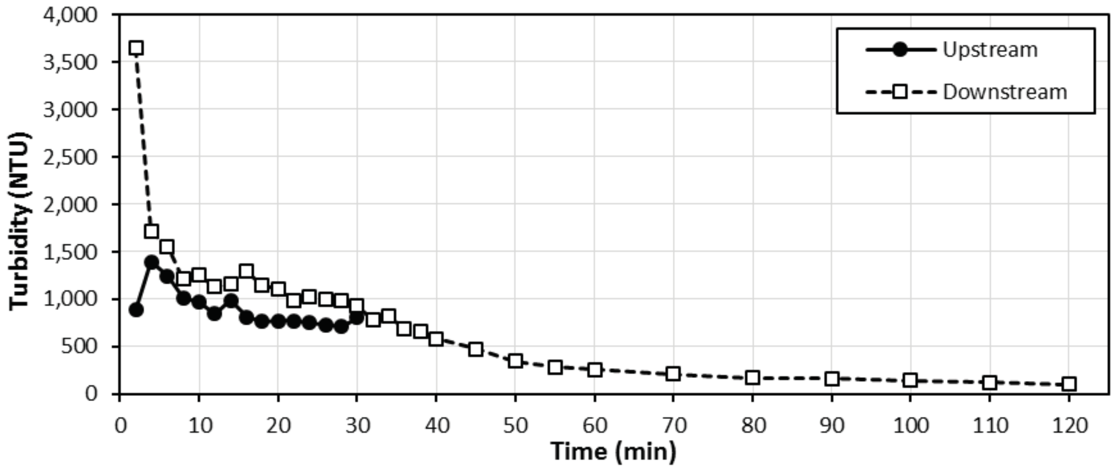
(g) square dome installation

(h) square dome impoundment

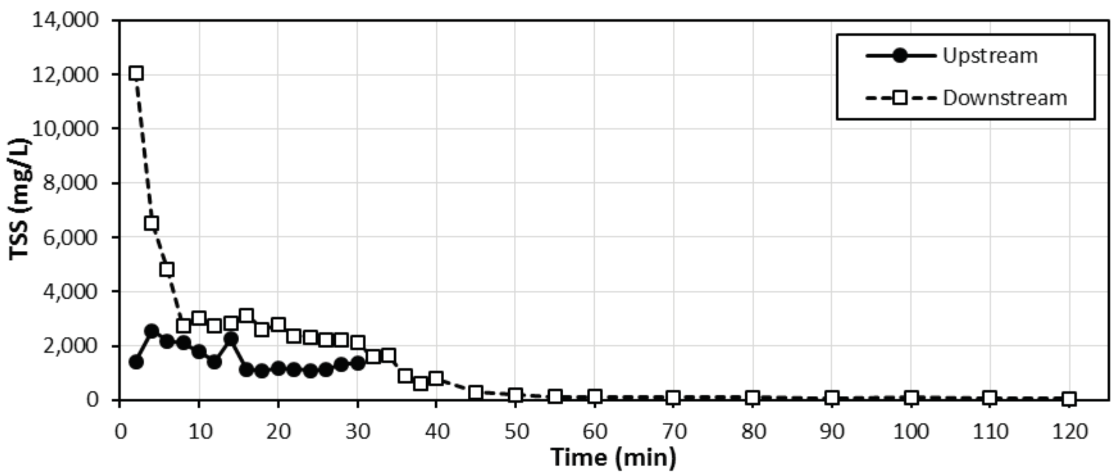
Figure 5.15 Silt-Saver Product Testing.

The Silt-Saver was tested in Phase II testing as per the developed testing regime. Phase II testing used sediment-laden flow to evaluate the practice's ability to improve turbidity and TSS.

Average water quality results for the five tests performed on the Silt-Saver are presented in Figure 5.16. The results indicate that the manufactured device had no effect in improving turbidity, however some improvements are seen in TSS during the 30 min. test duration. Turbidity and TSS decrease during the dewatering period.



(a) turbidity



(a) TSS

Figure 5.16 Silt-Saver Water Quality Results.

One pre and post-test survey was conducted during Silt-Saver testing which resulted in 42% of the introduced sediment being retained upstream of the device.

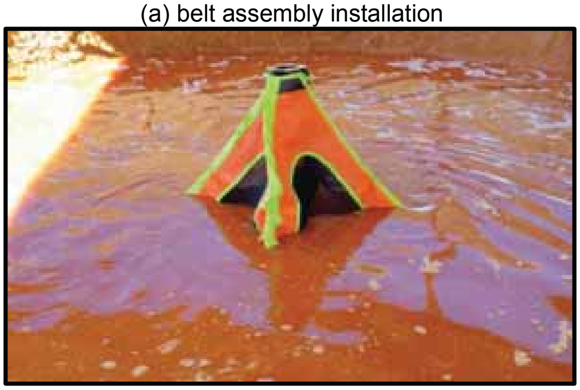
5.8.3 Grate Pyramid (ACF Environmental, Inc.)

The Grate Pyramid product was tested in the inlet test channel following manufacturer prescribed installation details. Unlike the Silt-Saver IPP products, the Grate Pyramid is affixed to the inlet structure with a galvanized steel belt as shown in Figure 5.17(a). Four round tubes connect to the belt to form a pyramid over the inlet. A fabric fits over the installed metal frame and secures along the bottom to the belt with Velcro. The complete test channel installation is pictured in Figure 5.17(b).

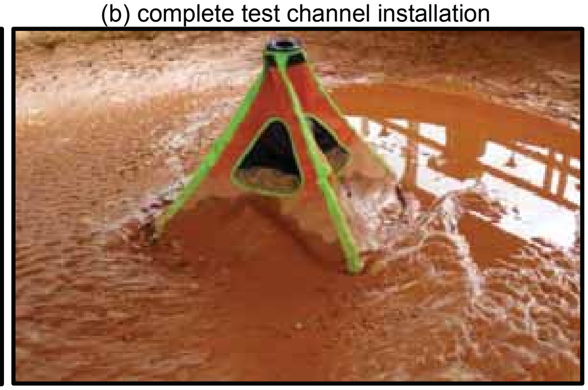
The test was performed under sediment-laden conditions to assess water quality improvement performance. The Grate Pyramid fabric is composed of a woven geotextile, which has a higher permeability than the nonwoven fabrics. Flow passed through the fluorescent orange woven fabric for 3.5 minutes prior to breaching into the overflow windows. Structurally, the product performed relatively well. Although the metal tubing twisted from its original intended position due to the force of water, the structural integrity of the system was not compromised. Higher rates of flow were visible at the tube connections located on the belt assembly. The Velcro fastener does not provide a tight seal at these four points. Unlike the other tested IPPs, a filter fabric underlay would not provide benefit to this product as undercutting is not a possible failure mode due to the device being attached to the inlet structure.

(a) belt assembly installation

(b) complete test channel installation



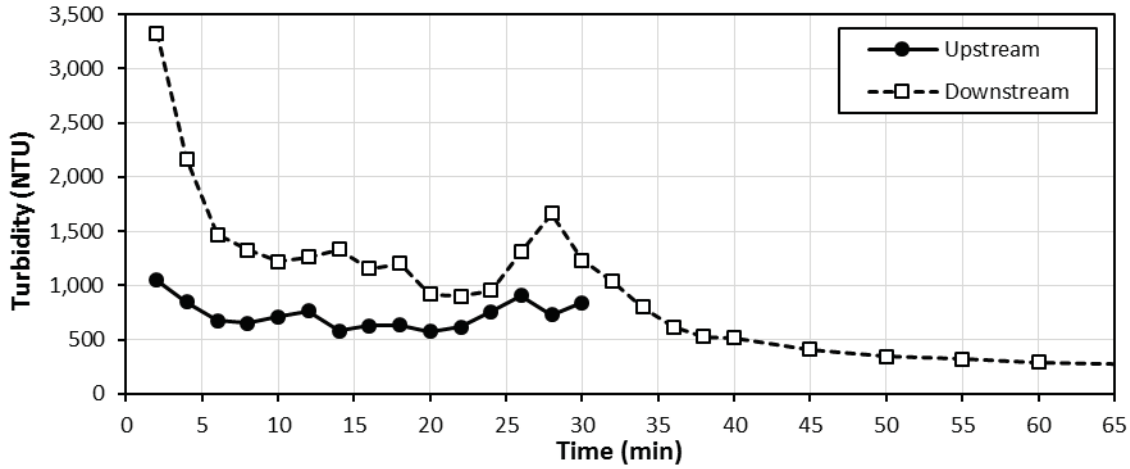
(c) maximum impoundment



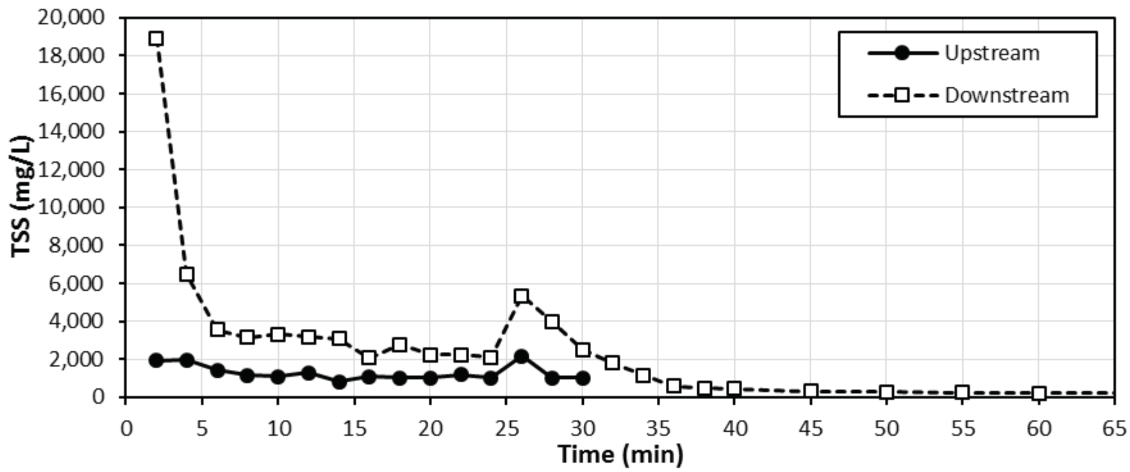
(b) post-test deposition

Figure 5.17 Grate Pyramid Product Testing.

The Grate Pyramid was tested using sediment-laden flow to evaluate the practice's ability to improve turbidity and TSS. Average water quality results for the five tests performed on the device are presented in Figure 5.18. The results indicate that the manufactured device had no effect in improving turbidity, however some improvements are seen in TSS during the 30 min. test duration. Turbidity and TSS decrease during the dewatering period.



(a) turbidity



(a) TSS

Figure 5.18 Grate Pyramid Water Quality Results.

5.8.4 Erosion Eel (Friendly Environment)

The fourth manufactured product tested was the Erosion Eel. This product is a synthetic wattle barrier composed of chopped recycled rubber tires. The products were installed using manufacturer published installation details for IPP applications. As shown in Figure 5.19(a), the Erosion Eels are arranged in a square configuration around the inlet structure. No staking is provided with the idea that the weight of the rubber filled wattles is sufficient to hold the product down. The installation details include the use of a flocculant infused coir underlay jammed underneath the wattles. For the purposes of replicability between manufactured devices, an untreated coir underlay provided by the manufacturer was used during evaluations.

During a clean water test, the wattles were unable to withstand the hydrostatic force of the impounded water, which dislodged the Erosion Eels from their installed positions as seen in Figure 5.19(b)-(d). This dislodgment pushed the wattles up to the inlet structure and allowed water to flow underneath the device. Due to this catastrophic failure, the prescribed installation method is not recommended for use under the tested flow conditions. As shown with the straw wattle IPP testing, the device could be greatly improved by providing staking and a filter fabric underlay.


(a) test channel installation

(b) product dislodgement during testing


(c) undercutting flows

(d) post-test deposition pattern

Figure 5.19 Erosion Eel Product Testing.

5.8.5 Manufactured Inlet Protection Products Summary

As shown through testing, the major failure mode of the manufactured products was through device dislodgment. Consideration should be taken when specifying such products to ensure the susceptible flow rates do not overburden the devices. Furthermore, device staking and the use of a filter fabric underlay would reduce undercutting. The four tested manufactured products are summarized in Table 5.7. Complete installation details for the products are provided in Appendix B.

Table 5.7 Manufactured IPP Evaluations

Install	Tested Configuration	Hydraulic Performance				Product Cost
		Overtop. (mins)	Ponding Height (ft)	Ponding Length (ft)	Dewater. (mins)	
SI-1	Silt-Saver Round Frame, R-100A	NR[a]	NR	NR	NR	$340
I-2	Silt-Saver Round Frame, R-100A, w/ Additional Aggregate	5.0	1.73	NR	6.5	$356
SI-2	Silt-Saver Square Frame, S-100A	6.0	1.43	20.0	15.0	$345
SI-3	Grate Pyramid	3.5	1.38	17.8	72.0	$295
SI-4	Erosion Eel	2.0	0.60	6.6	4.0	$228

Notes: [a] NR: data not collected

5.8.6 SUMMARY

This chapter provided the testing results for providing improvements to four standard IPPs (Aggregate Barrier, Sandbag Barrier, Silt Fence Barrier, and Wattle Barrier), two innovative practices (Gabion Basket and Hay Bale Flow Systems, and evaluating four manufactured products (Silt Saver R-100A, Silt Saver S-200A, Grate Pyramid, and Erosion Eel). The development of these

MFE-Is will be used to provide performance based evaluations in future testing efforts. Furthermore, the developed MFE-Is will provide designers and installers with practices that can structurally withstand the hydrodynamic and hydrostatic loads from typical 2-yr, 24-hr flow rates.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

The selection of proper erosion and sediment controls is necessary to ensure practices and products perform to their intended design. IPPs are used at storm drain inlets during un-stabilized conditions to prevent sediment from entering the stormwater utilities and ultimately from leaving the construction site. These practices are critical components of an effective SWPPP to provide a location for sediment to be retained prior to offsite discharge. The presented research focused on developing a large-scale testing methodology to apply towards the evaluation of IPPs in roadway median conditions.

This research was undertaken to provide deeper understanding on the performance of IPPs and to improve the performance of current standard designs. This work will ultimately become useful for providing improved practices that can help site operators conform to increasing erosion and sediment control regulations and permitting requirements.

6.1.1 RAINFALL ANALYSIS

To satisfy the first research objective, a hydrologic analysis method was developed to categorize the state based on typical IPP drainage basins. Rainfall and soil hydrologic parameters were determined using GIS techniques to establish testing flow rate and sediment rate introduction parameters that are representative of typical in-field conditions. This GIS method enabled the fulfillment of the second objective of developing a large-scale testing methodology, protocols, and testing apparatus that mimicked expected in-situ conditions. Based on the GIS analysis, it was concluded that using a 1.25 ft^3/s test flow rate for a 30 minute duration provides for replicable controlled testing conditions representing flow rates of a 2-yr, 24-hr storm for a 1.0 ac contributory area in the state of Alabama. Furthermore, the analysis conducted provides guidance on expected stormwater runoff flow rates based parameters on a statewide level. Similar analysis could be conducted for the design and selection of various erosion and sediment control practices.

6.1.2 LARGE-SCALE TESTING METHODOLOGY

The second objective of this research was to develop a large-scale testing methodology, protocols, and testing apparatus for large-scale performance-based testing of IPPs. This objective was met by performing a literature review of past and current IPP testing experiments and standards to help develop a method that would be suitable for the prescribed experimental needs. Furthermore, water and sediment introduction systems were designed and constructed to achieve the desired introduction rates that were determined through the GIS analysis. Data collection procedures and analysis were developed for both clean water installation improvement testing and the performance based testing.

The developed method was then used in the next step of the research to evaluate the MFE-Is under sediment-laden flows to assess performance. These evaluations lent to the comparison between developed MFE-Is and various manufactured products.

6.1.3 INSTALLATION EVALUATIONS AND IMPROVEMENTS

The third research task was to identify installation deficiencies and provide structural improvements to develop MFE-Is for each of the tested practices. This objective was achieved by conducting large-scale experiments following the developed protocols and regime to establish the MFE-I for the tested IPPs. Four typical IPPs were tested: (1) Aggregate Barriers, (2) Sandbag Barriers, (3) Silt Fence Barriers, and (4) Wattle Barriers. In addition, two innovative practices were developed and tested: (1) Gabion and (2) Hay Bale flow through systems. To provide comparisons to IPP products, four manufactured devices were evaluated: (1) round Silt-Saver frame and filter assembly (R-100A), (2) square Silt-Saver frame and filter assembly (S-200A), (3) Grate Pyramid, and (4)

Erosion Eels. Improvements were provided to deficiencies in the standard practices primarily by providing structural enhancements to withstand hydrodynamic and hydrostatic loads. Materials typical to the construction industry were used throughout installation iterations. Ease of installation was also taken into consideration.

Installations followed manufacturer specifications to evaluate the structural design of the selected products. The practices and products were evaluated on their ability to structurally withstand the hydrodynamic and hydrostatic loads, prevent scouring, undercutting, and short-circuiting, provide detention volume to promote deposition, and in their capability to efficiently dewater. Through this research, MFE-Is were identified for each of the four tested standard practices. These MFE-Is were then used to conduct sediment-laden experiments to provide performance based comparisons in an extension of this research.

6.1.4 INLET PROTECTION RECOMENDATIONS

The results of this study show how large-scale testing was conducted to improve current standard design and installation practices for typical IPPs. Installation improvements provided structural enhancements to IPPs for withstanding design flow rates. Improved practices were designed to maximize impoundment volumes and provide efficient dewatering.

Impoundment volume can be contributed to the installed height of the device coupled with the structural rigidity to withstand flow conditions. Dewatering time becomes a function of overall porosity or additional dewatering mechanisms of the IPP. To maximize the protected channel length from erosion and to provide the largest detention volume for sedimentation, IPP's should be installed with reasonable maximum height. Furthermore, IPPs should be installed in sump areas where adequate storage exists to detain impounded stormwater. With the design of all IPPs, overflow considerations must be taken into account to minimize risk of flooding and property damage. IPPs are only as resilient as the weakest point in the device or installation, as observed during testing. Once the weakest point of the IPP failed, it typically triggered a larger, catastrophic failure. For this reason, special attention should be placed on all individual components that make up the structural integrity of an IPP (i.e., sandbags, concrete blocks, T-posts, wire backing, etc.).

Sediment retention averaged 77% for replicate tests. Retention ranged between 49% for the wattle barrier up to 84% for the silt fence barrier longevity test. A summary of hydraulic performance characteristics, sediment retention, and estimated cost data for the four improved practices or MFE-Is are provided in Table 6.1.

Table 6.1 Characteristics and Costs of Developed MFE-I IPPs

Inlet Protection Practice	Hydraulic Performance			Sediment Retention		Material Costs[a]
	Impoundment Length (ft)	Dewatering Time (min)	Ponding Height (ft)	Replicates	Longevity	
Aggregate MFE-I	18.1	13	1.24	76%	71%	$135
Sandbag MFE-I	14.5	120	1.08	71%	59%	$85
Silt Fence MFE-I	31.0	90	2.3	91%	84%	$95
Wattle MFE-I	10.4	9	1.10	71%	49%	$107

Notes: [a] cost per installation, does not account for labor and equipment costs

The results of this research can be used to provide IPP performance guidance to designers, contractors, and inspectors. Furthermore, developed IPP improvements can be used to provide enhanced in-field installations.

6.1.5 TRAINING AND OUTREACH

The fourth and final objective of this research was to provide guidance on proper design and installation techniques. This objective ensures that the lessons learned through large-scale testing can be used and applied by the erosion and sediment control industry. Beyond professional research presentations, formal training was developed and provided through a two-day training event that was held through the Alabama Technology Transfer Center (T^2) in partnership with the

International Erosion Control Association (IECA) University Partners Program. The two-day event was held on May 29 - 30th, 2014 and was divided into classroom and outdoor field instructional sessions. The event showcased research being performed by various universities in the southeast geared towards solving erosion and sediment control problems in the construction sector. The primary goal of this training event was to provide industry participants exposure to innovative research being performed on commonly employed erosion and sediment control practices in both horizontal and vertical construction.

IPP research was showcased both in the classroom and during the field day. The field instructional session was held at the AU-ESCTF and provided attendees with a hands-on opportunity to: (1) learn proper installation techniques on various erosion and sediment controls to achieve improved performance, (2) observe full-scale, channelized flow testing demonstrations, and (3) interact with vendors and manufacturers of current erosion and sediment control products.

In preparation for the IPP field day session, six drop inlet structures were acquired and installed at the facility as mock inlets. IPPs that have been improved and developed through this research effort were installed around the mock inlets. Field day participants were able to see, in person, the proper installation techniques for the IPPs. In addition to the mock inlets, an improved silt fence barrier was installed and demonstrated in the test channel.

(a) IPP research presentation

(b) installation of mock inlet structures

(c) installed IPPs in mock inlets

(d) field day IPP station

Figure 6.1 IPP Training and Outreach.

Select participant comments received in course review materials included:

- *"Best session ever attended. Research is very applicable to the real world; long-time needed."*
- *"Overall a very good and very informative program with experienced persons providing lectures and demonstrations."*
- *"Best class I have attended."*
- *"Very good presentation, great location, well organized, great work by students!"*

A second field day focused on field installations and demonstrations was held on November 3, 2014 at the AU-ESCTF.

6.1.6 LIMITATIONS AND RECOMMENDED FURTHER RESEARCH

This presented IPP research is a component of a larger on-going comprehensive ALDOT study. In continuation of this effort, sediment-laden tests performed on the MFE-Is as part of this research will be used to assess the performance of manufactured products submitted for review and consideration for inclusion on ALDOT's approved products list. This performance based testing of manufactured products will allow researchers to identify performance characteristics of these practices in comparison to standard, MFE-I practices. Effective performance parameters should identify a P-factor that could be applied to the universal soil loss models (RUSLE or MUSLE). This would allow designers to estimate sediment loss reductions by implementing various IPPs.

Upon completion of the current ALDOT IPP study, the test channel could be easily modified to provide for IPP testing on curb and gutter inlet configurations (i.e., ALDOT Type IV configuration). This testing would allow for a large variety of practices and products that are geared and marketed directly for curb and gutter applications. Flow and sediment introduction rates will have to be recalculated for this setup as curb and gutter inlets typically have smaller contributory areas than drop inlets in roadway medians. ALDOT along with several other DOTs, maintain standard IPP drawings and specifications for curb and gutter inlet structures. There are also a myriad of manufactured products that would be suitable for testing.

This research focused on one flow rate that was target to represent the 2-yr, 24-hr storm event on the maximum drainage basin applicable to IPPs. Through the experiment conducted, it was evident that this design quickly overwhelmed any installed IPP. Testing could be performed to evaluate performance under more common and less intense storm events. For example, USEPA and many counties suggest and use 85th, 90th and 95th percentile daily rainfall for stormwater water quality control facilities in order to maintain and restore the pre-development site hydrology to the maximum extent technically feasible. Shrestha et al. (2013) shows that 95th percentile daily rainfall is typically less than 1-yr, 24-hr storm (definitely less than 2-yr, 24-hr storm); for example, the 95th percentile daily rainfall at Montgomery is 2.1", but 1-yr and 2-yr, 24-hr storms are 3.7 and 4.3" (from Atlas 14), respectively. A future study using other representative rainfall depths would be beneficial in categorizing practices and products for various flow conditions.

An attempt made with each developed MFE-I was to provide a dewatering mechanism to reduce the detention time collected stormwater around the storm drain inlet. Extended periods of stormwater detention increases the risk of flooding to adjacent roadways and property, but reducing the detention time would not allow certain-size sediments to settle instead of discharging into the downstream receiving waters. The optimal detention time for each IPP was not quantified as part of this study. The dewatering mechanisms developed removed stormwater from the entire water column. Sediment basin research has shown that floating skimmers are more effective in minimizing sediment discharge by providing dewatering from the top of the water column. Similar techniques, on a smaller scale, could be developed to provide a surface dewatering mechanism to be used for IPPs.

A hypothesis that has been developed through this research effort is that an IPP's ability to reduce sediment transport is directly related to its capability in impounding water. By creating large impoundments, suspended sediments are able to settle out of the stormwater prior to entering the inlet. The ability to impound water is primarily a function of the IPPs height. A study could be performed to analyze the relationship between impoundment depth and sediment deposition. These results could be useful to aid designers in selecting practices and products that provide the optimum height to impound sufficient runoff to create a favorable condition for sediment deposition.

The large-scale testing efforts of this research focused on an IPP's ability in reducing sediment discharge. Although sediment is the target pollutant associated and measured with construction stormwater regulations, other pollutants may be monitored for construction activities within sensitive or TMDL controlled watersheds. Other target water quality parameters such as: dissolved oxygen, nitrate, phosphate, and heavy metals could be monitored to determine an IPP contribution in their reduction. For example, products made up of agricultural material (i.e., straw, wheat) may be introducing nitrogen into runoff that would be undesirable for water bodies with eutrophication concerns. Another such example stems from products that contain recycled materials (i.e., carpet and tires). These products could potentially leach heavy metals which would make their way into receiving water bodies. Studies have shown that tire dust carries multiple heavy metals including: iron, zinc, chromium, and lead, which could be detrimental to aquatic organisms.

The test channel and protocols used in this study had the advantage of evaluating practices on a controlled environment (i.e., soil preparation, runoff quantity, sediment concentration, etc.). Investigations should be performed to assess the feasibility of IPP installations and performance on actual construction sites, which are susceptible to a wider range of unknown parameters. A field installation study could provide insights on the performance of practices across a wide variety of rainfall scenarios and sediment loads. Furthermore, a field study may highlight the importance of proper installation to achieve designed performance from a practice or product. The recommended study will also provide data on practice degradation and maintenance needs. Remote sampling equipment could be used to capture water quality samples during actual storm events.

Observations presented in this study show that IPPs can provide retention of rapidly settable solids in sediment-laden runoff. However, negligible improvements were observed in water quality (TSS and turbidity). Further research should be conducted on the developed enhanced practices (MFE-I) to study the performance of IPPs with the addition of flocculent aids.

This research developed a GIS method of analyzing stormwater runoff rates across the state of Alabama for the designed storm drain inlet drainage basin. A similar study could be performed to develop models for the southeastern US and the entire country. Updated rainfall data at different return periods (i.e., Atlas 14) could also be analyzed for comparison.

IPPs are commonly used in conjunction with other upstream and downstream erosion and sediment controls. Larger scaled research could be performed to evaluate field-scale conditions where a treatment-train approach would be investigated to evaluate the sediment capture efficiency of a completely protected construction site.

6.1.7 ACKNOWLEDGEMENTS

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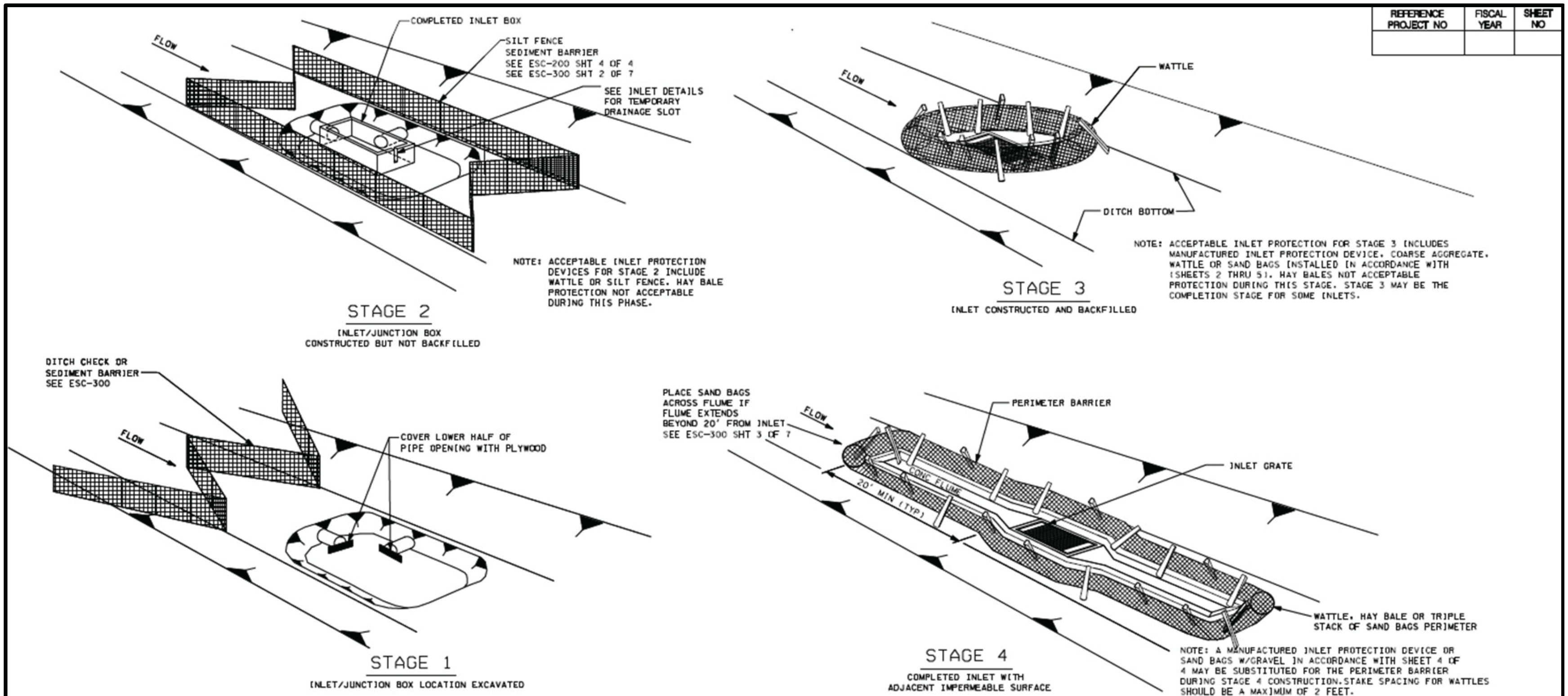
APPENDIX A

ALDOT SPECIAL AND STANDARD HIGHWAY DRAWINGS FOR EROSION AND SEDIMENT CONTROLS (ESC-400)

REFERENCE PROJECT NO	FISCAL YEAR	SHEET NO



DITCH INLET CONSTRUCTION STAGES

NOTES:

1. FOUNDATION BACKFILL SHOULD BE PLACED IN STAGE 1 IMMEDIATELY AFTER PIPE INSTALLATION. INLET CONSTRUCTION SHOULD COMMENCE AS SOON AS POSSIBLE AND BE CONTINUOUS THROUGH COMPLETION.
2. CONFIGURATIONS MAY BE ADJUSTED WITH APPROVAL OF THE ENGINEER FOR TRAVELWAY SAFETY, WATER FLOW, SOIL OR INSTALLATION CHALLENGES.
3. DURING STAGE 1 AND STAGE 2, SILT FENCE MAY BE REQUIRED UPSLOPE OF THE INLET EXCAVATION AS DIRECTED BY THE ENGINEER.
4. IF SILT FENCING IS INSTALLED AROUND THE INLET EXCAVATION IT SHOULD BE PLACED IN A CONFIGURATION THAT WILL ALLOW INLET CONSTRUCTION.
5. FOR CURB INLET PROTECTION SEE SHT 3 OF 4 AND SHT 4 OF 4.
6. FOR MANUFACTURED INLET PROTECTION DEVICES SEE ALDOT LIST II-24.

--SPECIFICATIONS--
CURRENT ALABAMA DEPARTMENT OF TRANSPORTATION

REVISIONS

ALABAMA DEPARTMENT OF TRANSPORTATION
1409 COLISEUM BOULEVARD
MONTGOMERY, AL 36130-3050

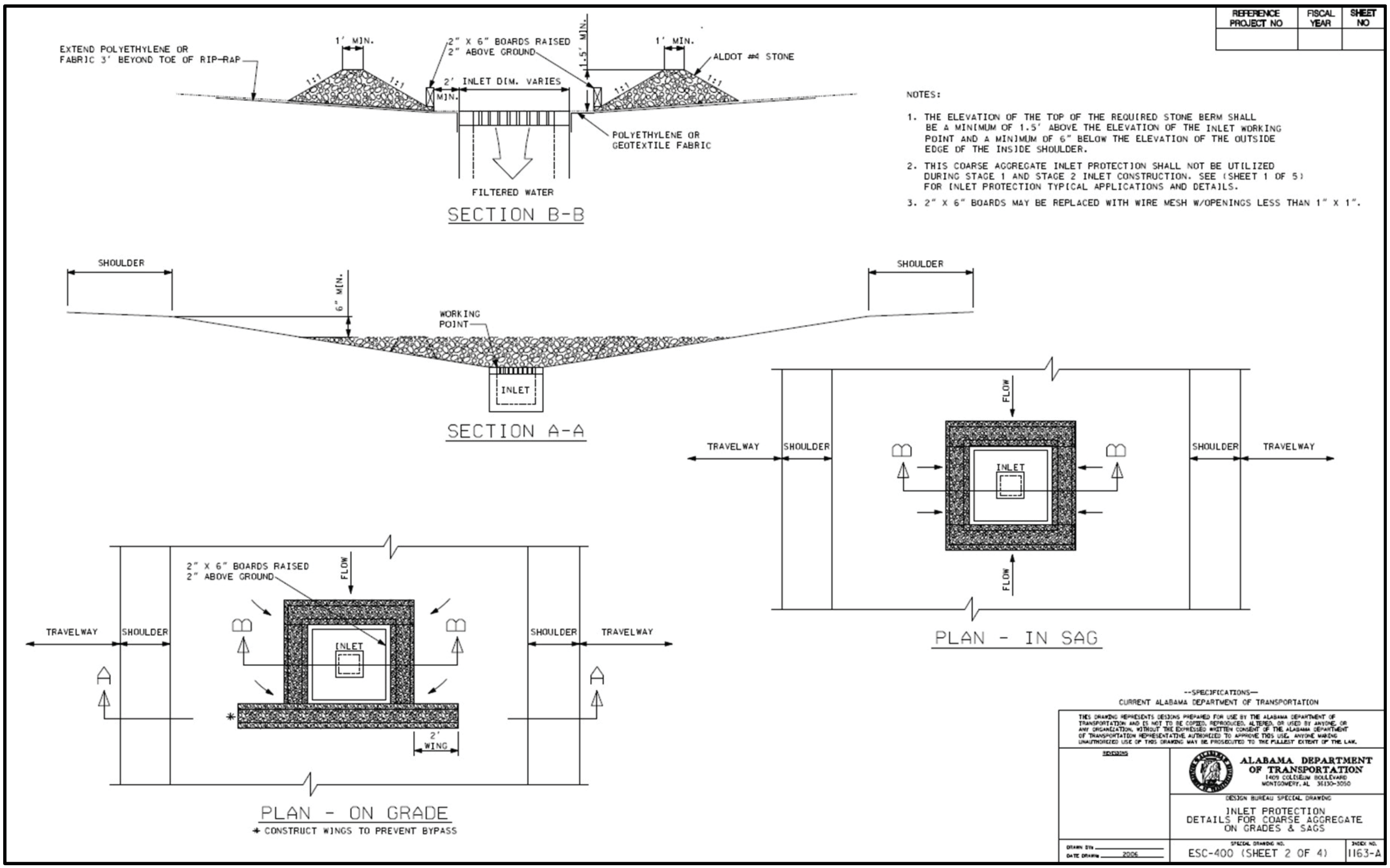
DESIGN BUREAU SPECIAL DRAWING

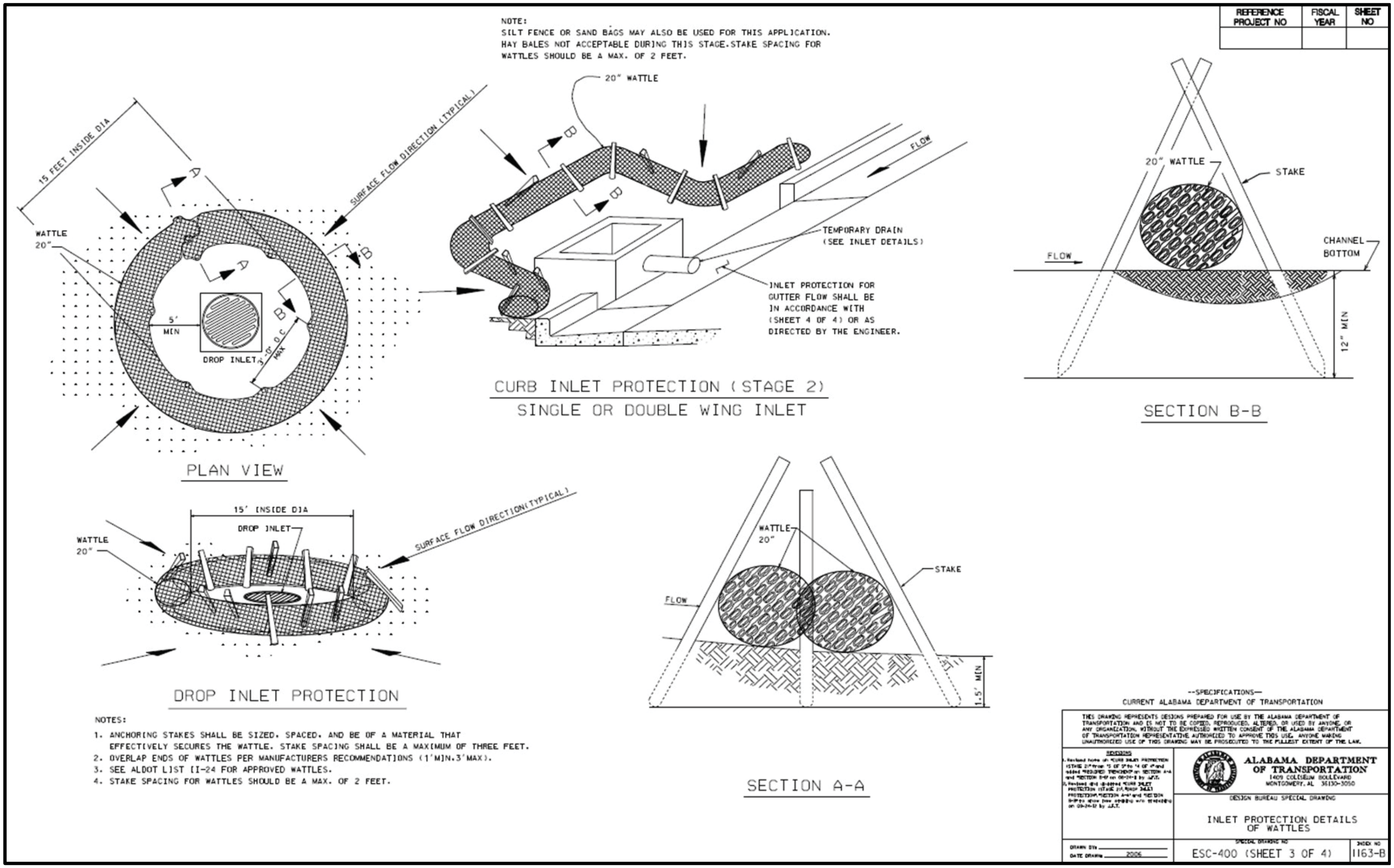
INLET PROTECTION
TYPICAL APPLICATIONS AND DETAILS

DRAWN BY:
DATE DRAWN: 2006

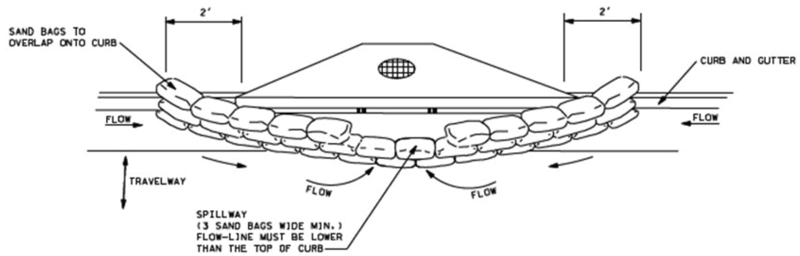
SPECIAL DRAWING NO: ESC-400 (SHEET 1 OF 4)

INDEX NO: 1163

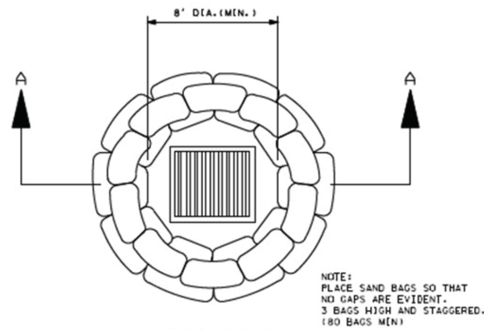

REFERENCE PROJECT NO
FISCAL YEAR
SHEET NO
EXTEND POLYETHYLENE OR FABRIC 3' BEYOND TOE OF RIP-RAP
1' MIN.
2" X 6" BOARDS RAISED 2" ABOVE GROUND
1.5' MIN.
1' MIN.
ALDOT #4 STONE
1:1
2' MIN.
INLET DIM. VARIES
POLYETHYLENE OR GEOTEXTILE FABRIC
FILTERED WATER
SECTION B-B
NOTES:
1. THE ELEVATION OF THE TOP OF THE REQUIRED STONE BERM SHALL BE A MINIMUM OF 1.5' ABOVE THE ELEVATION OF THE INLET WORKING POINT AND A MINIMUM OF 6" BELOW THE ELEVATION OF THE OUTSIDE EDGE OF THE INSIDE SHOULDER.
2. THIS COARSE AGGREGATE INLET PROTECTION SHALL NOT BE UTILIZED DURING STAGE 1 AND STAGE 2 INLET CONSTRUCTION. SEE (SHEET 1 OF 5) FOR INLET PROTECTION TYPICAL APPLICATIONS AND DETAILS.
3. 2" X 6" BOARDS MAY BE REPLACED WITH WIRE MESH W/OPENINGS LESS THAN 1" X 1".
SHOULDER
6" MIN.
WORKING POINT
INLET
SHOULDER
SECTION A-A
FLOW
TRAVELWAY
SHOULDER
B
INLET
B
SHOULDER
TRAVELWAY
FLOW
PLAN - IN SAG
2" X 6" BOARDS RAISED 2" ABOVE GROUND
FLOW
TRAVELWAY
SHOULDER
B
INLET
B
SHOULDER
TRAVELWAY
A
A
*
2' WING
PLAN - ON GRADE
* CONSTRUCT WINGS TO PREVENT BYPASS
--SPECIFICATIONS--
CURRENT ALABAMA DEPARTMENT OF TRANSPORTATION
THIS DRAWING REPRESENTS DESIGNS PREPARED FOR USE BY THE ALABAMA DEPARTMENT OF TRANSPORTATION AND IS NOT TO BE COPIED, REPRODUCED, ALTERED, OR USED BY ANYONE, OR ANY ORGANIZATION, WITHOUT THE EXPRESSED WRITTEN CONSENT OF THE ALABAMA DEPARTMENT OF TRANSPORTATION REPRESENTATIVE AUTHORIZED TO APPROVE THIS USE. ANYONE MAKING UNAUTHORIZED USE OF THIS DRAWING MAY BE PROSECUTED TO THE FULLEST EXTENT OF THE LAW.
REVISIONS
ALABAMA DEPARTMENT OF TRANSPORTATION
1409 COLISEUM BOULEVARD
MONTGOMERY, AL 36130-3050
DESIGN BUREAU SPECIAL DRAWING
INLET PROTECTION
DETAILS FOR COARSE AGGREGATE
ON GRADES & SAGS
DRAWN BY:
DATE DRAWN: 2006
SPECIAL DRAWING NO.
ESC-400 (SHEET 2 OF 4)
INDEX NO.
1163-A


REFERENCE PROJECT NO
FISCAL YEAR
SHEET NO
NOTE:
SILT FENCE OR SAND BAGS MAY ALSO BE USED FOR THIS APPLICATION. HAY BALES NOT ACCEPTABLE DURING THIS STAGE. STAKE SPACING FOR WATTLES SHOULD BE A MAX. OF 2 FEET.
15 FEET INSIDE DIA
SURFACE FLOW DIRECTION (TYPICAL)
WATTLE 20"
A
B
5' MIN
DROP INLET
2' O.C. MAX
PLAN VIEW
20" WATTLE
B
FLOW
TEMPORARY DRAIN (SEE INLET DETAILS)
INLET PROTECTION FOR GUTTER FLOW SHALL BE IN ACCORDANCE WITH (SHEET 4 OF 4) OR AS DIRECTED BY THE ENGINEER.
CURB INLET PROTECTION (STAGE 2)
SINGLE OR DOUBLE WING INLET
20" WATTLE
STAKE
FLOW
CHANNEL BOTTOM
12" MIN
SECTION B-B
15' INSIDE DIA
DROP INLET
WATTLE 20"
SURFACE FLOW DIRECTION (TYPICAL)
DROP INLET PROTECTION
WATTLE 20"
FLOW
STAKE
1.5' MIN
SECTION A-A
NOTES:
1. ANCHORING STAKES SHALL BE SIZED, SPACED, AND BE OF A MATERIAL THAT EFFECTIVELY SECURES THE WATTLE. STAKE SPACING SHALL BE A MAXIMUM OF THREE FEET.
2. OVERLAP ENDS OF WATTLES PER MANUFACTURERS RECOMMENDATIONS (1'MIN.3'MAX).
3. SEE ALDOT LIST II-24 FOR APPROVED WATTLES.
4. STAKE SPACING FOR WATTLES SHOULD BE A MAX. OF 2 FEET.
--SPECIFICATIONS--
CURRENT ALABAMA DEPARTMENT OF TRANSPORTATION
THIS DRAWING REPRESENTS DESIGNS PREPARED FOR USE BY THE ALABAMA DEPARTMENT OF TRANSPORTATION AND IS NOT TO BE COPIED, REPRODUCED, ALTERED, OR USED BY ANYONE, OR ANY ORGANIZATION, WITHOUT THE EXPRESSED WRITTEN CONSENT OF THE ALABAMA DEPARTMENT OF TRANSPORTATION REPRESENTATIVE AUTHORIZED TO APPROVE THIS USE. ANYONE MAKING UNAUTHORIZED USE OF THIS DRAWING MAY BE PROSECUTED TO THE FULLEST EXTENT OF THE LAW.
REVISIONS
ALABAMA DEPARTMENT OF TRANSPORTATION
1409 COLISEUM BOULEVARD
MONTGOMERY, AL 36130-3050
DESIGN BUREAU SPECIAL DRAWING
INLET PROTECTION DETAILS OF WATTLES
DRAWN BY
DATE DRAWN 2006
SPECIAL DRAWING NO
ESC-400 (SHEET 3 OF 4)
INDEX NO
1163-B

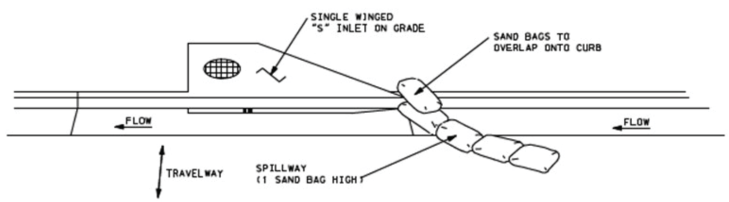
REFERENCE PROJECT NO	FISCAL YEAR	SHEET NO



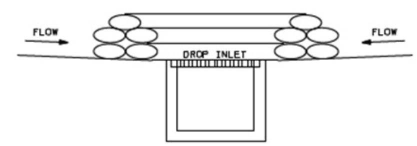
TYPICAL (SAND BAG) PROTECTION FOR INLET IN SAG



DROP INLET
PLAN VIEW



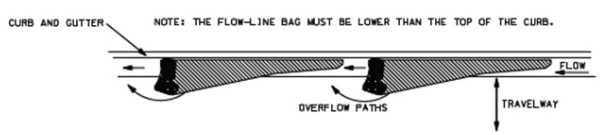
TYPICAL (SAND BAG) PROTECTION FOR INLET ON GRADE



SECTION A-A
SAND BAG BARRIER

CURB INLET PROTECTION NOTES:

1. CURB INLET PROTECTION CAN ALSO BE USED AT OTHER EDGE-OF-PAVEMENT TYPE INLETS SUCH AS TYPE "E" INLETS AT MEDIAN BARRIER LOCATIONS.
2. SEE SHT 3 OF 4 FOR INLET PROTECTION WHERE INLET CONSTRUCTION HAS NOT BEEN COMPLETED.
3. THIS CURB INLET PROTECTION METHOD CAN BE USED DURING ANY STAGE OF BASE AND PAVEMENT CONSTRUCTION.
4. BAG HEIGHT AND NUMBER OF BAGS SHOULD BE BASED ON CURB HEIGHT AND USE OF TRAVELWAY.
5. SEDIMENT SHOULD BE CONTROLLED PRIOR TO ENTERING GUTTER. GUTTER CHECKS AND INLET PROTECTION ARE FOR SECONDARY CONTROL.
6. REMOVE ACCUMULATED SEDIMENT AFTER EVERY RAINFALL. SWEEP SEDIMENT FROM HARD SURFACES AND DISPOSE OF APPROPRIATELY AWAY FROM INLETS AND/OR WATER BODIES.
7. IF DENUDED AREAS EXIST BEHIND THE INLET. A SEDIMENT BARRIER SHOULD BE INSTALLED AROUND IT'S PERIMETER TO CONTROL SEDIMENT. SEE SHT 3 OF 4.
8. PAYMENT FOR CURB INLET PROTECTION FOR WORK REQUIRED BEYOND STAGE 2 (SEE SHT 3 OF 4) WILL BE MADE AS APPROPRIATE FOR ITEMS USED.



CURB AND GUTTER SEDIMENT
CONTAINMENT SYSTEM

--SPECIFICATIONS--
CURRENT ALABAMA DEPARTMENT OF TRANSPORTATION

REVISIONS
1. Changes Notes No's 2, 7, and 8 from "SHT. 3 OF 5" to read "SHT. 3 OF 4" on 08-23-11 by A.F.T.

ALABAMA DEPARTMENT OF TRANSPORTATION
1409 COLISEUM BOULEVARD
MONTGOMERY, AL 36130-3050

DESIGN BUREAU SPECIAL DRAWING

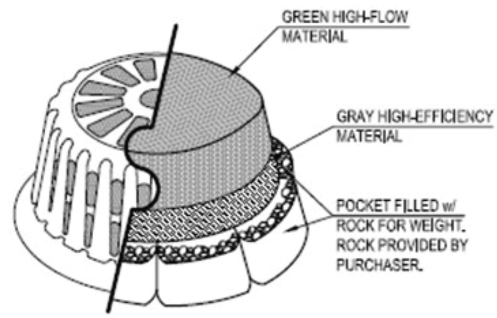
INLET PROTECTION
DETAILS OF SAND BAG

DRAWN BY: ____
DATE DRAWN: 2006

SPECIAL DRAWING NO. ESC-400 (SHEET 4 OF 4)
INDEX NO. 1163-D

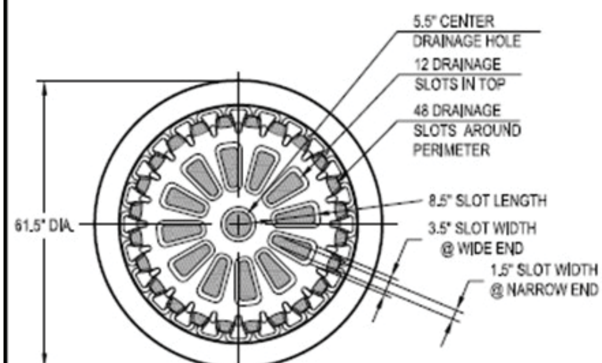
APPENDIX B

MANUFACTURER'S SPECIFICATIONS FOR INSTALLATIONS USED DURING EXPERIMENTATION

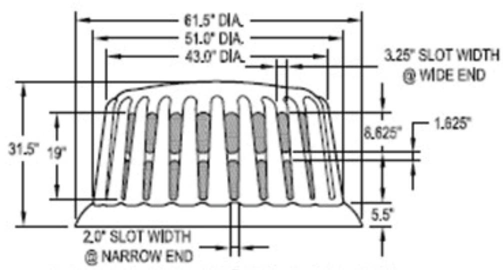


ISOMETRIC VIEW

SHOWN WITH ROADWAY PROJECTS FILTER HAT



PLAN VIEW



ELEVATION VIEW

REPLACEMENT FILTERS: MODEL # R-140

FILTER OPTIONS

FILTER HAT IS AVAILABLE IN THREE OPTIONS:

1) ALL HIGH-FLOW MATERIAL
2) ALL HIGH-EFFICIENCY MATERIAL
3) HIGH-FLOW MATERIAL ON TOP HALF OF HAT, HIGH-EFFICIENCY MATERIAL ON BOTTOM HALF (THIS FILTER COVER IS RECOMMENDED FOR ALL ROADWAY PROJECTS.)

IT IS THE PURCHASERS RESPONSIBILITY TO PURCHASE APPROPRIATE FILTER HAT. PURCHASER SHALL PROVIDE ROCK FOR FILTER POCKETS.

FILTER HAT INSTALLATION

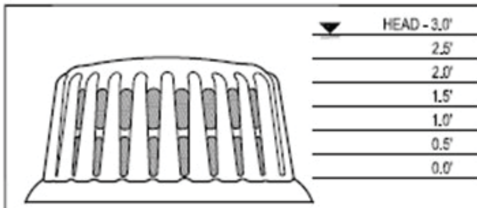
FILTER HAT SLIDES DIRECTLY OVER FILTER FRAME. TO KEEP FILTER FRAME IN PLACE OVER STORM STRUCTURE, ROCK POCKETS ARE SEWN DIRECTLY INTO FILTER HAT MATERIAL. EVERY FILTER HAT COMES IN ONE PIECE FOR EASY INSTALLATION.

MAINTENANCE

ALL TEMPORARY EROSION, SEDIMENTATION, & POLLUTION CONTROL PRACTICES SHOULD BE INSPECTED DAILY. CONTRACTOR SHALL REMOVE SEDIMENT AND DISPOSE OF IN A PROPER MANNER. INSPECT R-100A DAILY FOR CUTS, ABRASIONS, AND PROPER INSTALLATION. REPLACE OR REPOSITION AS NECESSARY.

SPECIFICATIONS

FILTER FABRIC SILT-SAVER HAT SHALL BE BASED ON DESIGN PROFESSIONAL'S SPECIFICATIONS.



FRAME & FILTER DISCHARGE ANALYSIS

HEAD (FT)	EQUATION USED	OPENING AREA (SF)	FRAME FLOW (CFS)	FILTER AREA (SF)	FILTERED FLOW (CFS)
0.5	O	2.1	7	6	2
1.0	O	3.9	19	12	3
1.5	O	7.0	41	18	5
2.0	O	8.0	54	24	7
2.5	O	9.2	70	30	9
3.0	O	9.2	77	—	77

DUE TO NARROW SLOT, A TRANSITION WILL OCCUR BETWEEN WEIR AND ORIFICE CONDITIONS. ORIFICE FLOW WILL PROVIDE A MORE CONSERVATIVE ESTIMATE OF FLOW, THEREFORE THE LESSER OF THE ORIFICE AND WEIR FLOWS WILL BE USED FOR EACH STAGE CALCULATION.

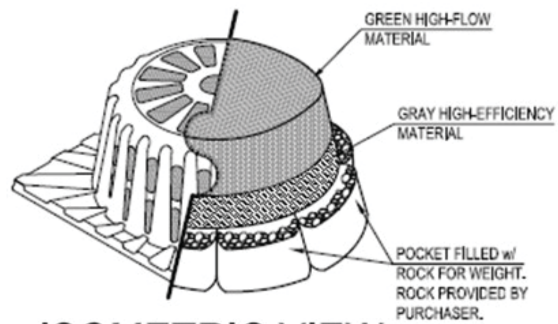
FILTER MATERIAL ALLOWS 129 gpm/SF OR 0.29cfs/SF
ORIFICE EQUATION (O) = Q=0.6A(2gh)^0.5
P = FEET PERIMETER
h = HEAD IN FEET
Q = CAPACITY IN cfs
A = FREE OPEN AREA OF FRAME
g = 32.2 FEET-PER-SECOND/SECOND

SILT-SAVER Sediment Control Products

ROUND FRAME & FILTER ASSEMBLY
Model # R-100A

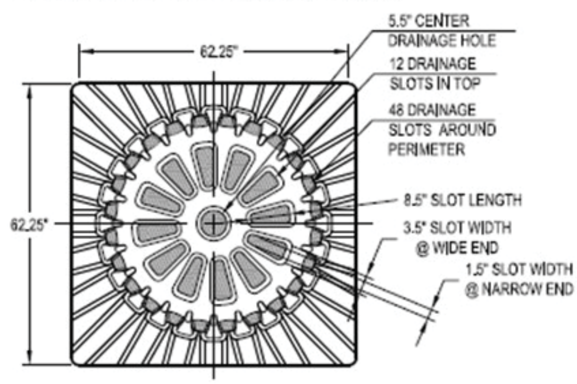
FRAME MATERIAL: BLACK 0.25" HMWPE
FILTER FABRIC MATERIAL: REFER TO SPEC
SCALE: NOT TO SCALE
LAST UPDATED: APRIL 2010

SILT-SAVER, INC. 1094 CULPEPPER DRIVE, CONYERS, GA 30094 PHONE: (770) 388-7818 FAX: (770) 388-7640 TOLL FREE: 1-888-382-SILT (7458) www.siltsaver.com

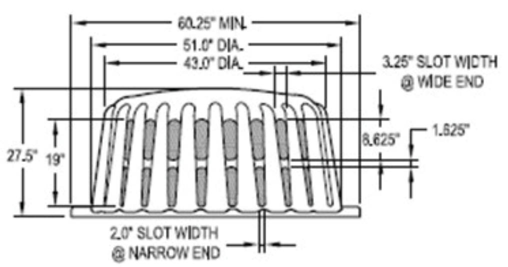


ISOMETRIC VIEW

SHOWN WITH ROADWAY PROJECTS FILTER HAT



PLAN VIEW



ELEVATION VIEW

REPLACEMENT FILTERS: MODEL # S-240

FILTER OPTIONS

FILTER HAT IS AVAILABLE IN THREE OPTIONS:

1) ALL HIGH-FLOW MATERIAL
2) ALL HIGH-EFFICIENCY MATERIAL
3) HIGH-FLOW MATERIAL ON TOP HALF OF HAT, HIGH-EFFICIENCY MATERIAL ON BOTTOM HALF (THIS FILTER COVER IS RECOMMENDED FOR ALL ROADWAY PROJECTS.)

IT IS THE PURCHASERS RESPONSIBILITY TO PURCHASE APPROPRIATE FILTER HAT. PURCHASER SHALL PROVIDE ROCK FOR FILTER POCKETS.

FILTER HAT INSTALLATION

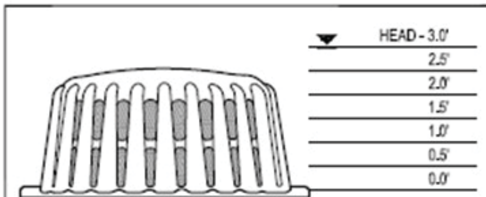
FILTER HAT SLIDES DIRECTLY OVER FILTER FRAME. TO KEEP FILTER FRAME IN PLACE OVER STORM STRUCTURE, ROCK POCKETS ARE SEWN DIRECTLY INTO FILTER HAT MATERIAL. EVERY FILTER HAT COMES IN ONE PIECE FOR EASY INSTALLATION.

MAINTENANCE

ALL TEMPORARY EROSION, SEDIMENTATION, & POLLUTION CONTROL PRACTICES SHOULD BE INSPECTED DAILY. CONTRACTOR SHALL REMOVE SEDIMENT AND DISPOSE OF IN A PROPER MANNER. INSPECT S-200A DAILY FOR CUTS, ABRASIONS, AND PROPER INSTALLATION. REPLACE OR REPOSITION AS NECESSARY.

SPECIFICATIONS

FILTER FABRIC SILT-SAVER HAT SHALL BE BASED ON DESIGN PROFESSIONAL'S SPECIFICATIONS.



FRAME & FILTER DISCHARGE ANALYSIS

HEAD (FT)	EQUATION USED	OPENING AREA (SF)	FRAME FLOW (CFS)	FILTER AREA (SF)	FILTERED FLOW (CFS)
0.5	O	2.1	7	6	2
1.0	O	3.9	19	12	3
1.5	O	7.0	41	18	5
2.0	O	8.0	54	24	7
2.5	O	9.2	70	30	9
3.0	O	9.2	77	—	77

DUE TO NARROW SLOT, A TRANSITION WILL OCCUR BETWEEN WEIR AND ORIFICE CONDITIONS. ORIFICE FLOW WILL PROVIDE A MORE CONSERVATIVE ESTIMATE OF FLOW, THEREFORE THE LESSER OF THE ORIFICE AND WEIR FLOWS WILL BE USED FOR EACH STAGE CALCULATION.

FILTER MATERIAL ALLOWS 129 gpm/SF OR 0.29cfs/SF
ORIFICE EQUATION (O) = Q=0.6A(2gh)^0.5
P = FEET PERIMETER
h = HEAD IN FEET
Q = CAPACITY IN cfs
A = FREE OPEN AREA OF FRAME
g = 32.2 FEET-PER-SECOND/SECOND

SILT-SAVER
Sediment Control Products

SQUARE FRAME & FILTER ASSEMBLY
Model # S-200A

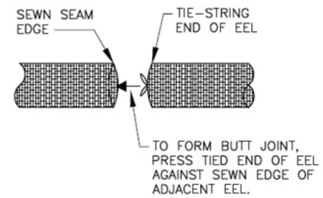
FRAME MATERIAL: BLACK 0.25" HMWPE
FILTER FABRIC MATERIAL: REFER TO SPEC
SCALE: NOT TO SCALE
LAST UPDATED: APRIL 2010

SILT-SAVER, INC. 1094 CULPEPPER DRIVE, CONYERS, GA 30094 PHONE: (770) 388-7818 FAX: (770) 388-7640 TOLL FREE: 1-888-382-SILT (7458) www.siltsaver.com

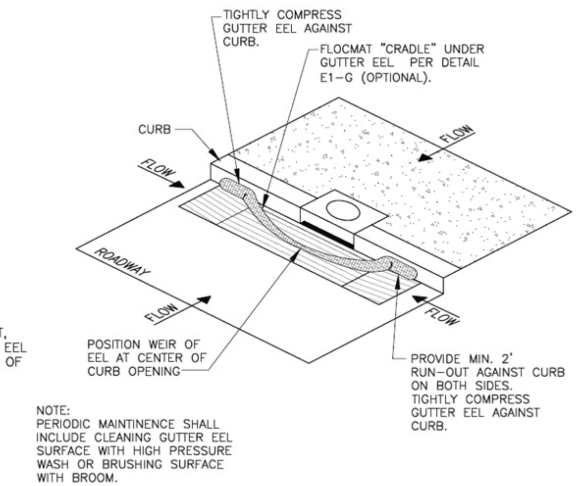
Grate Pyramid - Type B
Stormwater Filter

GENERAL NOTES

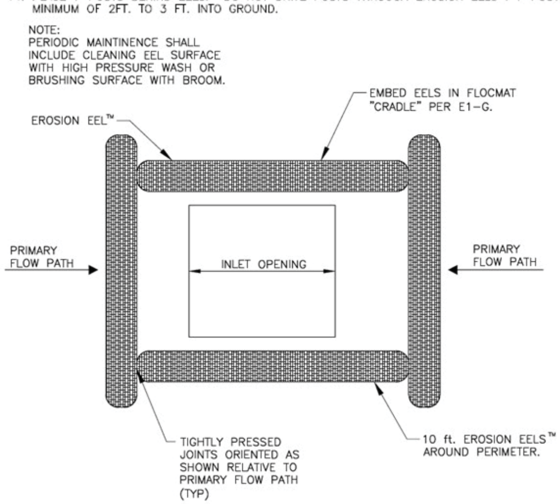
1. EROSION EELS™ SHALL BE MANUFACTURED FROM A WOVEN GEOTEXTILE COVERING WITH INTERIOR FILTER MATERIALS.
2. LENGTHS OF EROSION EELS™ SHALL BE EITHER A NOMINAL +/−10 FT. OR +/− 4.5 FT. NOMINAL DIAMETER SHALL BE +/−9.5 INCHES OR +/− 20 INCHES.
3. EROSION EELS™ CAN BE PLACED AT THE TOP, ON THE FACE, OR AT THE TOE OF SLOPES TO INTERCEPT RUNOFF, REDUCE FLOW VELOCITY, RELEASE THE RUNOFF AS SHEET FLOW AND PROVIDE REMOVAL OF SEDIMENT FROM THE RUNOFF.
4. EROSION EELS™ SHALL BE INSTALLED ALONG THE GROUND CONTOUR, AT THE TOE OF SLOPES, AT AN ANGLE TO THE CONTOUR TO DIRECT FLOW AS A DIVERSION BERM, AROUND INLET STRUCTURES, IN A DITCH AS A CHECK DAM TO HELP REDUCE SUSPENDED SOLIDS LOADING AND RETAIN SEDIMENT, OR AS A GENERAL FILTER FOR ANY DISTURBED SOIL AREA.
5. NO TRENCHING IS REQUIRED FOR INSTALLATION OF EROSION EELS™.
6. PREPARE BED FOR EEL INSTALLATION BY REMOVING ANY LARGE DEBRIS INCLUDING ROCKS, SOIL CLODS, AND WOODY VEGETATION. EROSION ELLS™ CAN ALSO BE PLACED OVER PAVED SURFACES INCLUDING CONCRETE AND ASPHALT WITH NO SURFACE PREPARATION REQUIRED.
7. RAKE BED AREA WITH A HAND RAKE OR BY DRAG HARROW.
8. DO NOT PLACE EEL DIRECTLY OVER RILL AND GULLIES UNTIL AREA HAS BEEN HAND−EXCAVATED AND RAKED TO PROVIDE A LEVEL BEDDING SURFACE. ALL SURFACES SHALL BE UNIFORMLY COMPACTED FOR MAXIMUM SEATING OF EELS IN PLACE.
9. FOR LOCATIONS WHERE EELS WILL BE PLACED IN CONCENTRATED FLOWS (SUCH AS CHECK DAMS, INLET PROTECTION) AND FOR PERIMETER CONTROLS AT PRIMARY DISCHARGE LOCATIONS, BED THE EELS IN A JUTE MESH CRADLE PER THE DETAILED DRAWINGS.
10. IF MORE THAN ONE EROSION EEL™ IS PLACED IN A ROW, THE EELS SHALL BE JOINED PER DETAIL E1−B1.
11. FOR CHECK DAM APPLICATIONS, EROSION EELS™ SHALL BE PLACED PERPENDICULAR TO THE FLOW OF THE WATER. EROSION EELS™ SHALL CONTINUE UP THE SIDES SLOPES A MINIMUM OF 3 FEET ABOVE THE DESIGN FLOW DEPTH.
12. EROSION EELS™ SHALL REMAIN IN PLACE UNTIL FULLY ESTABLISHED VEGETATION HAS COMPLETELY DEVELOPED OR UNTIL THE STORAGE CAPACITY/FUNCTIONAL LIFE OF THE EEL HAS BEEN EXHAUSTED (REQUIRING REPLACEMENT WITH NEW EELS).
13. ANCHORING POSTS FOR CHECK DAM APPLICATIONS SHALL HAVE A MINIMUM WEIGHT OF 1.25 LBS/FT STEEL T−POSTS (5 TO 7 FT. LENGTHS) ROLLED FROM HIGH CARBON STEEL. POSTS SHOULD BE HOT−DIP GALVANIZED OR COATED WITH A WEATHER−RESISTANT PAINT FOR STEEL APPLICATION. POSTS SHOULD BE EQUIPPED WITH A METAL ANCHOR PLATE. INSTALL PER DETAILS ON THIS SHEET.
14. PLACE T−POSTS BEHIND EELS. DO NOT DRIVE POSTS THROUGH EROSION EELS™. T−POSTS ARE TO BE EMBEDDED A MINIMUM OF 2FT. TO 3 FT. INTO GROUND.



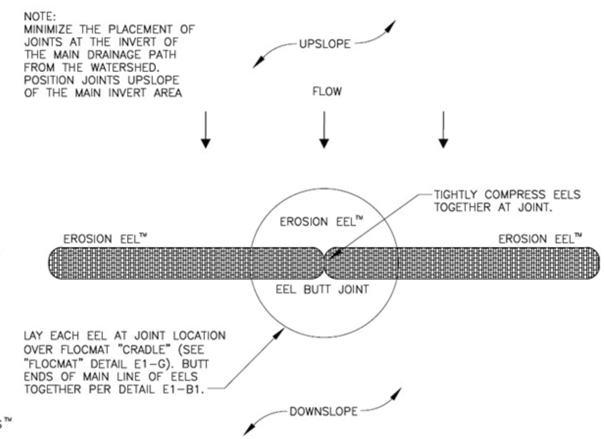
BUTT JOINT DETAIL E1−B1



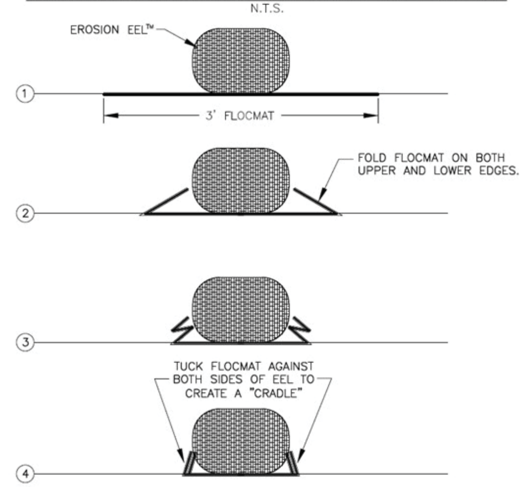
ISOMETRIC DETAIL E3−C: SMALL CURB INLET SEDIMENT TRAP − GUTTER EEL
N.T.S.



DETAIL E3−B: AREA INLET PROTECTION
N.T.S.



DETAIL E1−E: PLAN VIEW − OVERLAP/JOINT DETAIL NEAR DISCHARGE POINTS FROM WATERSHED
N.T.S.



INSTALL FLOCMAT AT MAIN DISCHARGE LOCATIONS FOR WATERSHED.

DETAIL E1−G: SECTION − FLOCMAT
N.T.S.

APPENDIX C

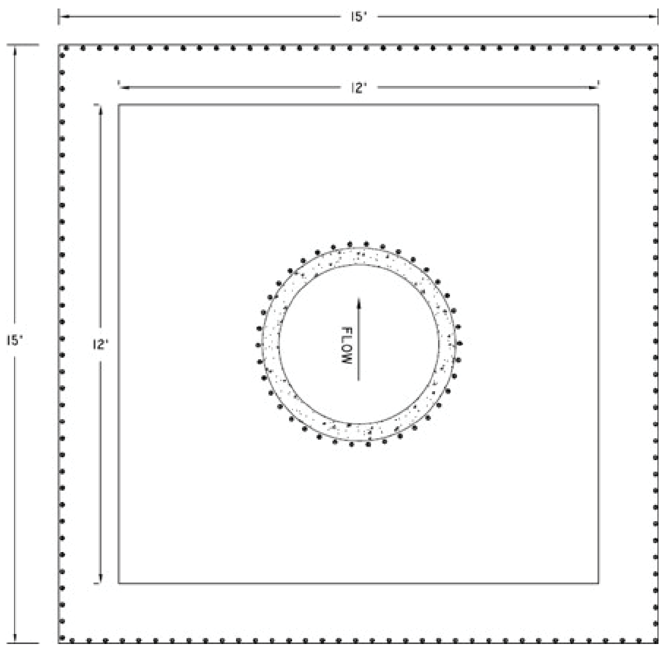
INSTALLATION SPECIFICATIONS AND PROCEDURES FOR DEVELOPED MFE-IS

AGGREGATE BARRIER MFE-I: ENHANCED BLOCK & GRAVEL

Installation Materials:

☐ 12’ x 12’ 8 oz. FF Sheet
☐ 15’ x 15’ 8 oz. FF Sheet
☐ Sod Pins
☐ (40) 8”x8”x16” Cinder Blocks
☐ 20”x12” Hardware Cloth
☐ No. 4 Stone

Installation Procedures:



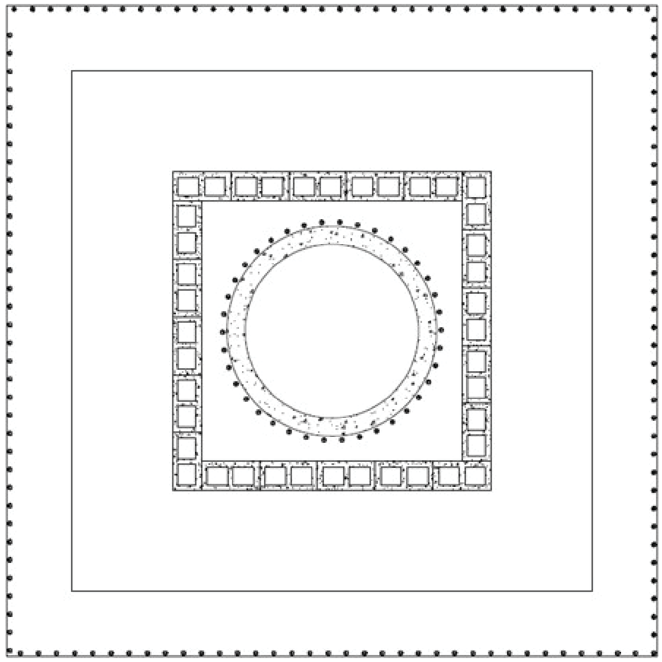
Step 1: Center down the two filter fabric layers as shown. The 12’x12’ FF layer should be on top.

Step 2: Pin the 15’x15’ FF around the outside perimeter at 5” OC.

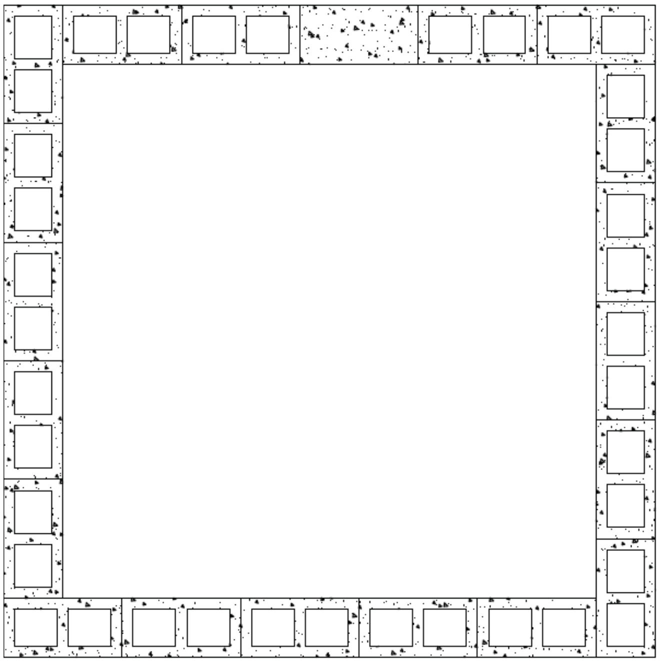
Step 3: Pin both FF layers together around inlet structure perimeter. The top FF layer should only be pinned around the inlet.

Step 4: Cut the excess FF on the inside of the inlet structure.

Note: The orientation of the channel is consistent throughout the installation guide.

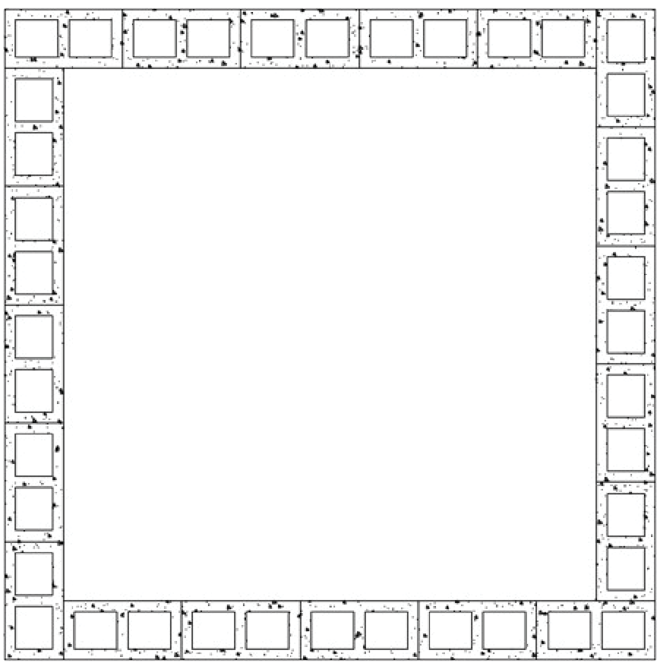


Step 5: Next install the cinder blocks as shown. Note the configuration is staggered for the first and second layer.

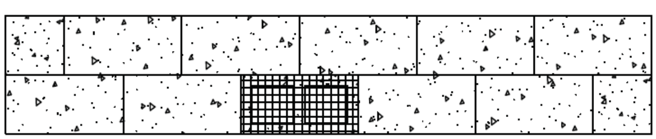


Step 5.1: Shown is the first layer of cinder blocks. The first row will take 20 blocks. With the exception of the dewatering block, all blocks should be upright. Note the location of the dewatering block.

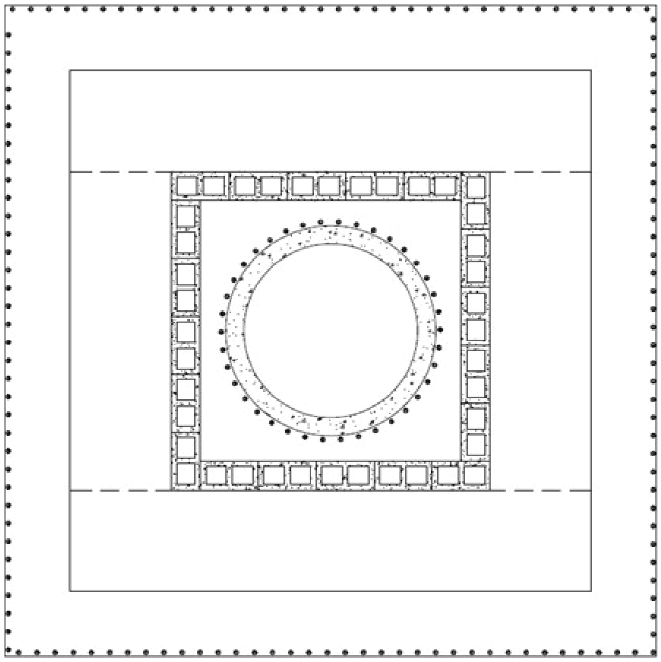
Step 5.2: Wrap the dewatering block in the hardware wire mesh before placement. The mesh should be placed on the outside face of the block.



Step 5.3: install the second row of cinder blocks. Note the orientation is staggered. All blocks on this row are up right.

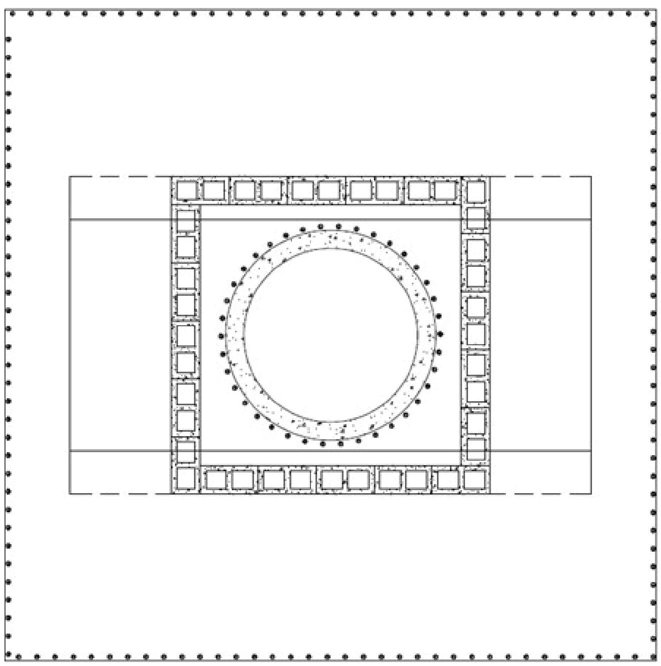


From the back face, the blocks should look like the picture to the left. The dewatering block is overturned, and wrapped in wire mesh.

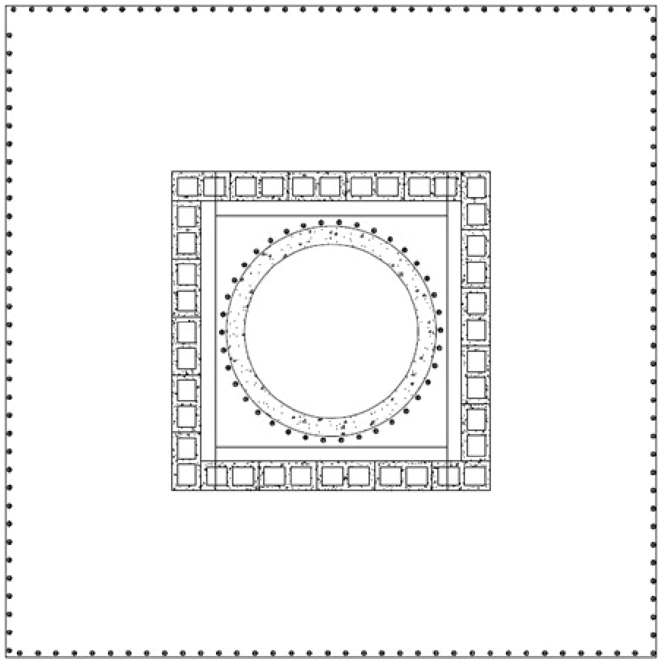


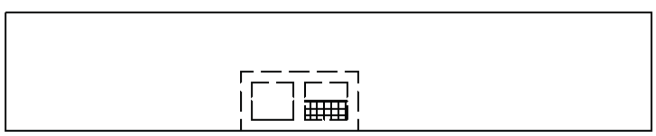
Step 6: Wrap the top FF layer over the blocks.

6.1: First wrap the front and back sections of FF over the blocks as shown.

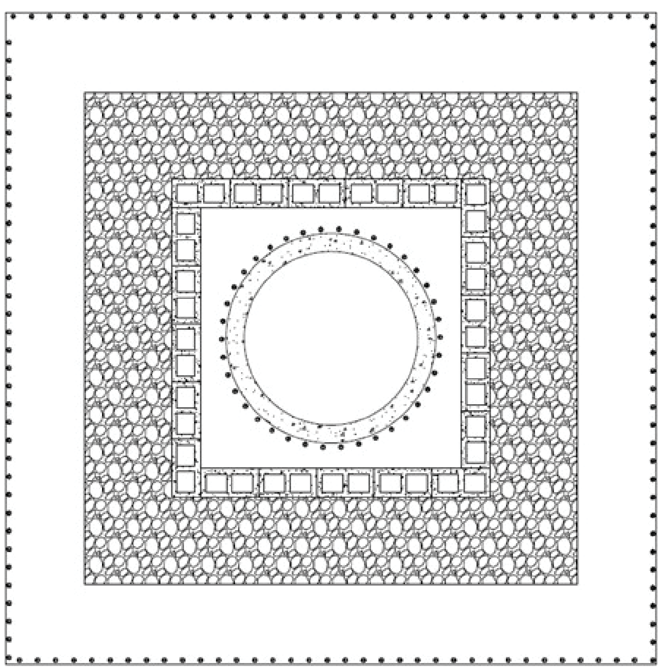


6.2: Next wrap the left and right sections of FF over the block in an envelope as shown.



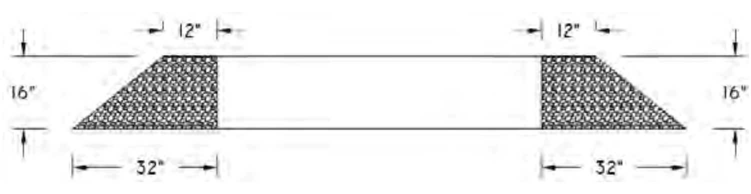


<u>Step 7:</u> Next cut a rectangular section on the right side of the dewatering block. The rectangular cut will be approximately 2.5” x 5” as shown. Only half of the right opening should be exposed.



<u>Step 8:</u> Lay ALDOT #4 stone as shown. The height of the aggregate will be 16” with a top width of 12”. The bottom width of the aggregate barrier will be 32” around the perimeter of the wall.

<u>Step 9:</u> Trim the excess filter fabric that was wrapped around the cinder blocks. The fabric should be cut flush with the top of the blocks.

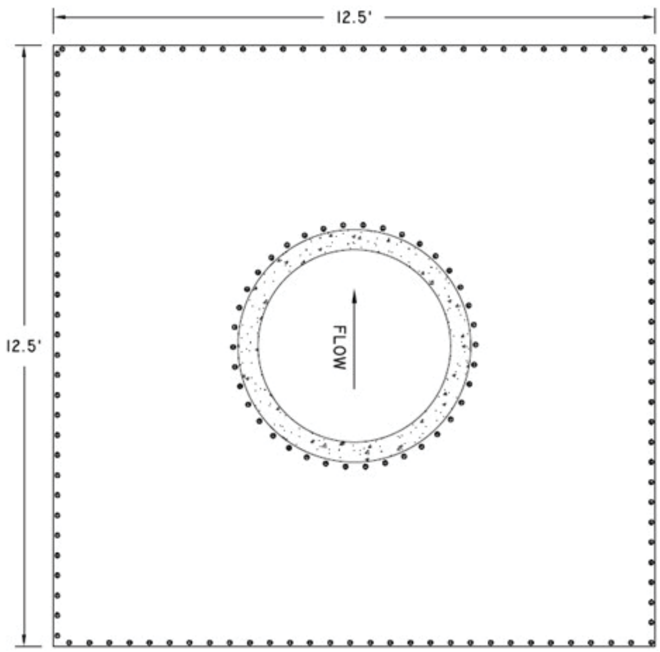


SAND BAG BARRIER MFE-I: ROTATED CONFIGURATION

Installation Materials:

☐ 12.5’ x 12.5’ 8 oz. FF sheet
☐ Bags Filled with Washed Masonry Sand

Installation Procedures:

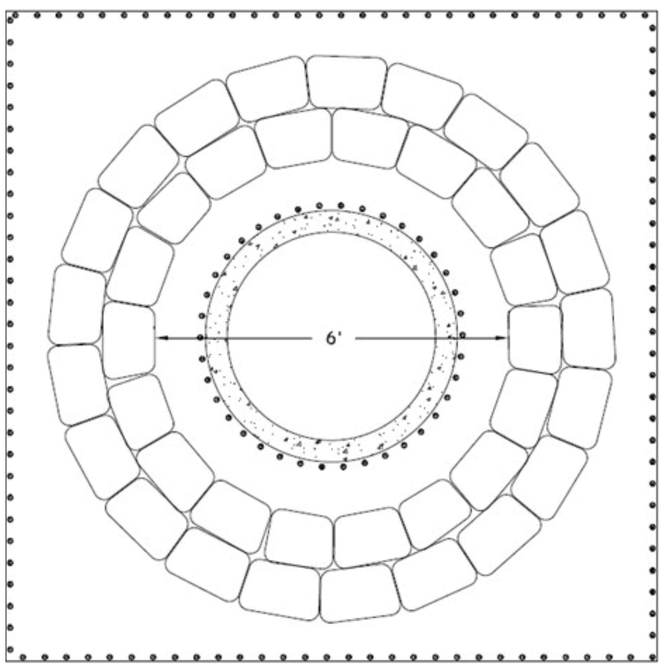


Step 1: Install 8 oz filter fabric as shown.

Step 2: Pin filter fabric around inlet structure

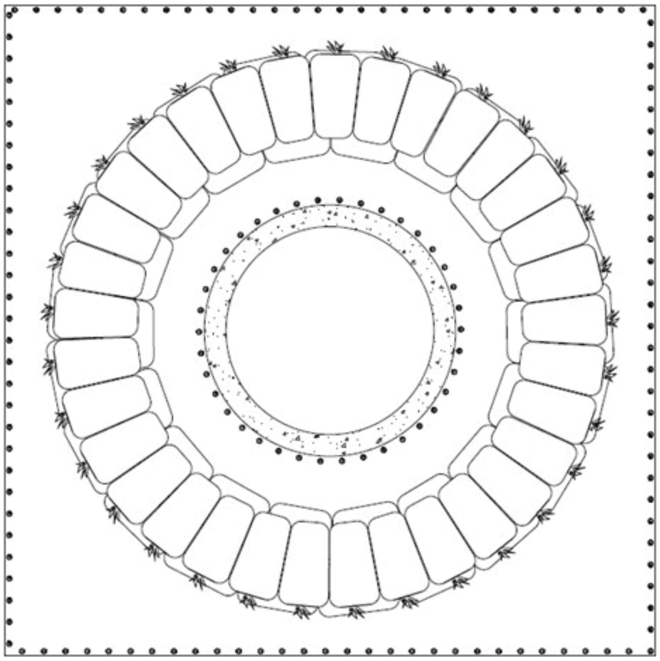
Step 3: Pin filter fabric around perimeter spacing at 5” OC.

Note: The orientation of the channel is consistent throughout the installation guide.



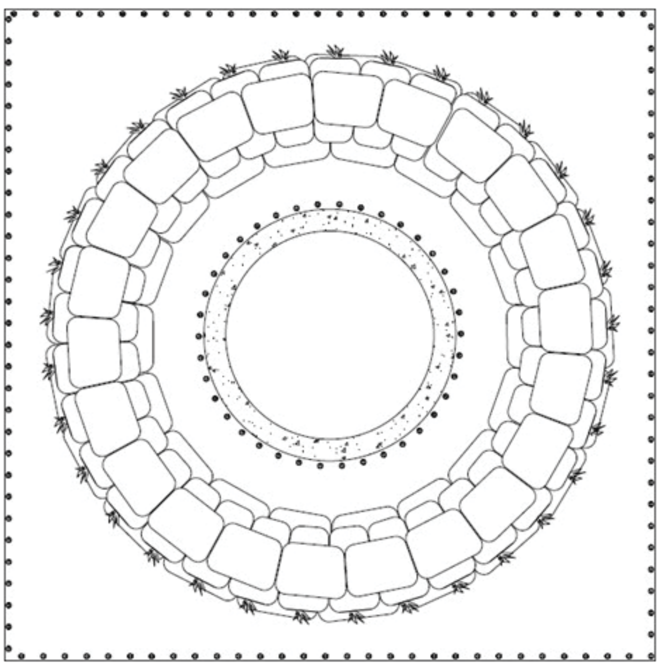
Step 4: Lay first row of sand filled bags.

- **4.1:** Create ring with 6’ inside diameter.
- **4.2:** Abut bags to create tight seams/seals.
- **4.3:** Stagger bag placement.



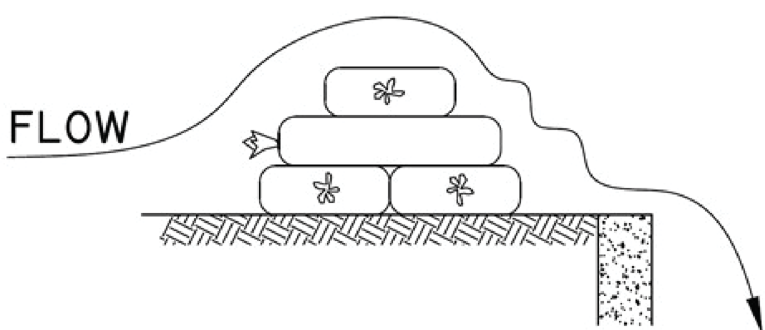
Step 5: Install second row of sand bags.

5.1: Rotate orientation to be perpendicular to first row.



Step 6: Install top row of sand bags.

6.1: Bag orientation is parallel to first row.



SILT FENCE BARRIER MFE-I: REINFORCED T-POST INSTALLATION

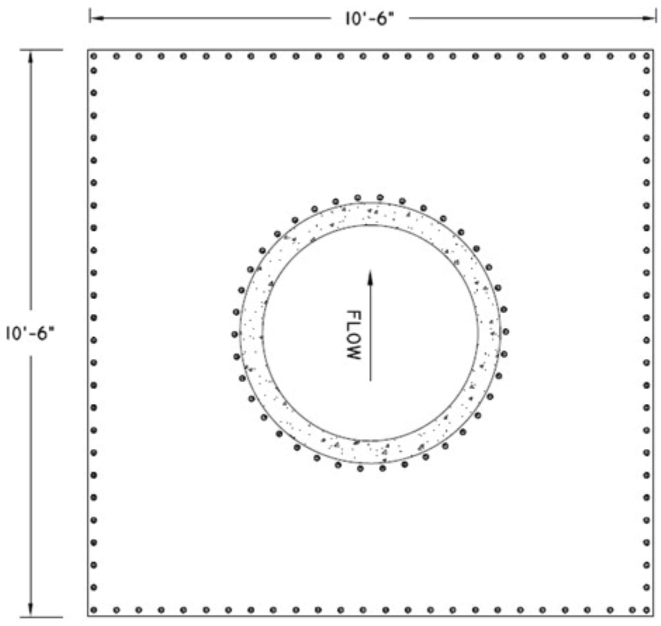
Installation Materials:

☐ 10.5’ x 10.5’ 8 oz. FF Sheet
☐ 40’ x 45”3.5 oz FF Silt Fence
☐ 38’ Wire Mesh Backing
☐ Sod Pins

Pressure Treated Lumber:
☐ 2”x4”x8’ (qty. 4)
☐ 2”x4”x12’ (qty. 2)

☐ ½” Staples
☐ Staple Gun
☐ C-Ring Staples

Installation Procedures:

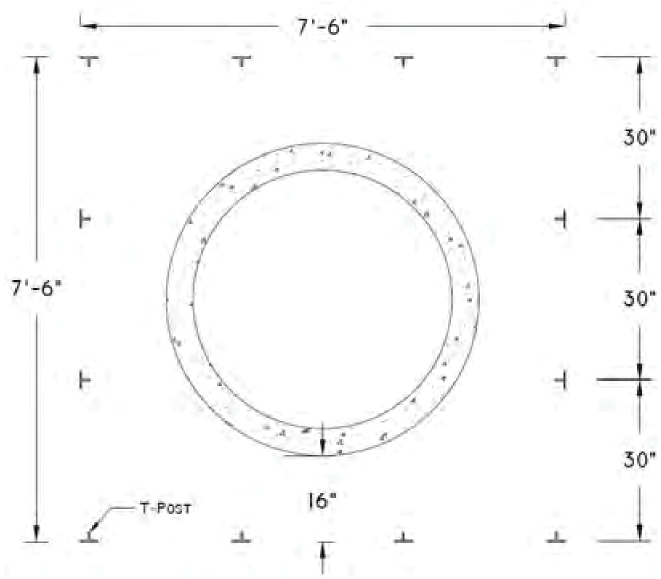


Step 1: Install 8 oz filter fabric as shown.

Step 2: Pin filter fabric around inlet structure.

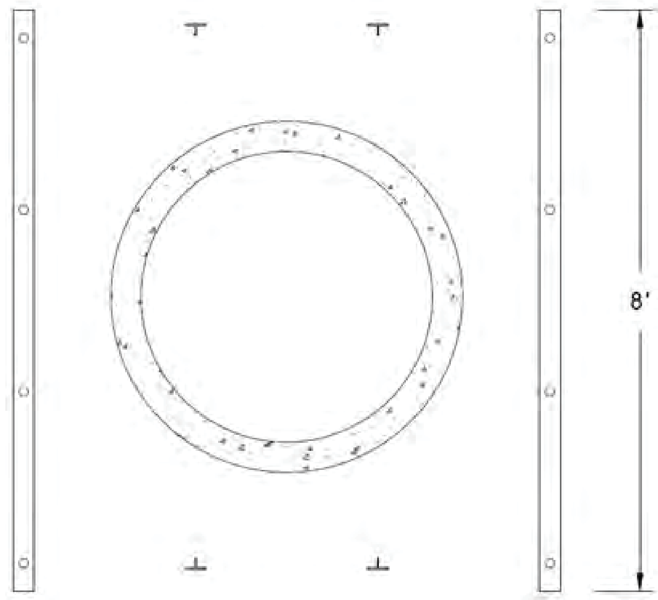
Step 3: Pin filter fabric around perimeter using a 5” spacing OC.

Note: The orientation of the channel is consistent throughout the installation guide.

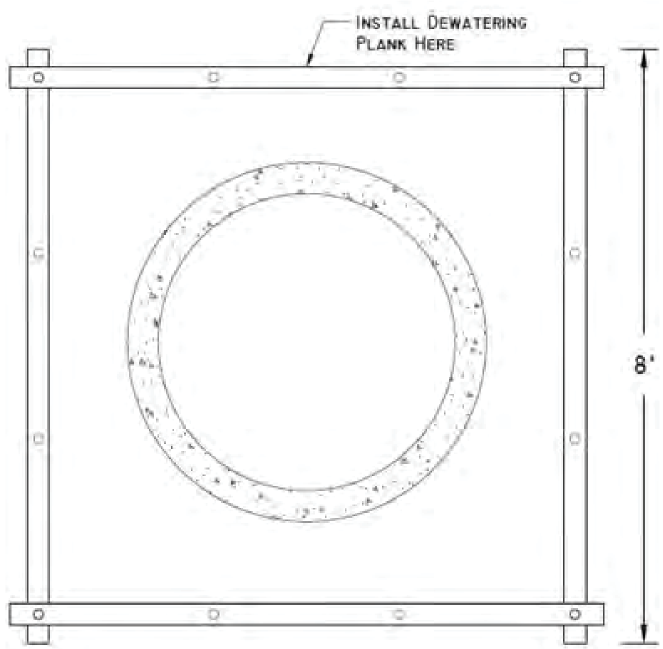


Step 4: Drive 5’ T-posts 24” into ground at shown locations.

- **4.1:** Match post orientations and locations as shown.
- **4.2:** Use a level and make an effort to keep posts plumbed vertically.
- **4.3:** 36” should remain exposed above the ground.



Step 5: install 2"x4"x96" boards as shown. Slide installed T-posts through holes in boards.



Step 6: Install the next 2 boards above the preceding board installation. Install the dewatering plank before continuing to step 7.

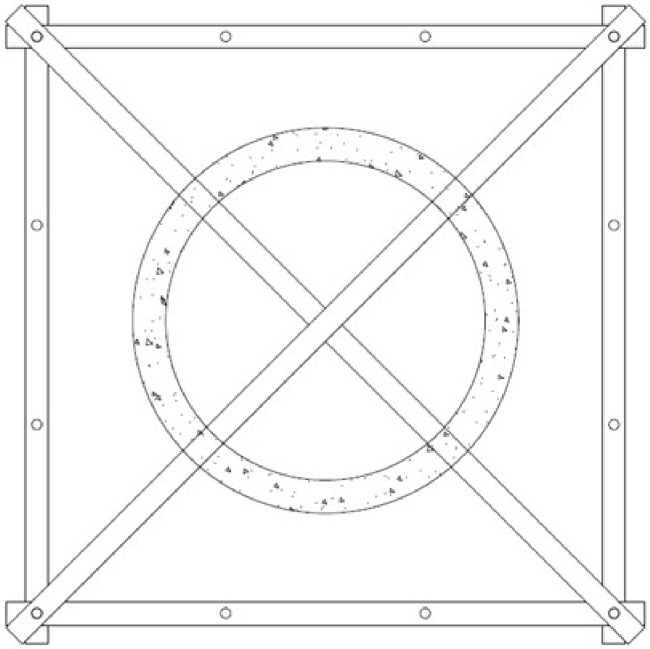
6.1: Set top of the installed boards to a height of 32" from the ground.

6.2: Use a level and make an effort to keep posts level.

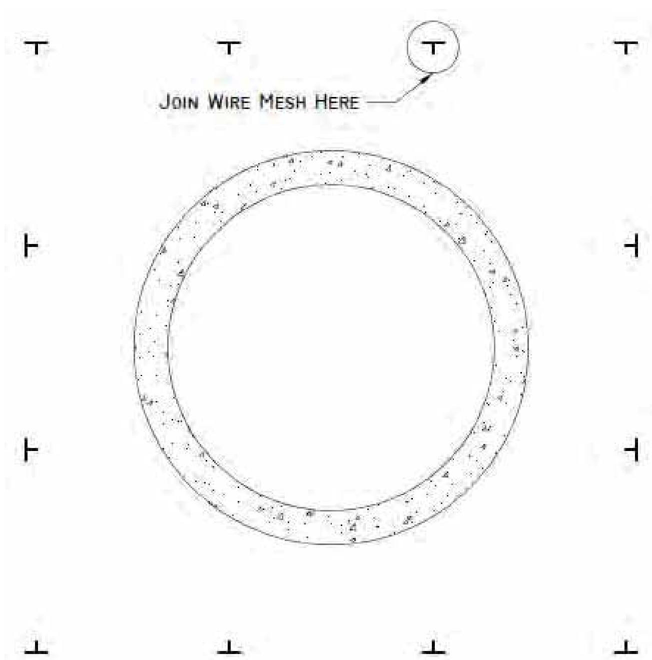
6.3: The boards installed in step 5 should sit directly below step 6 boards.

6.4: The top of the step 5 boards will be at a height of ~30.5".

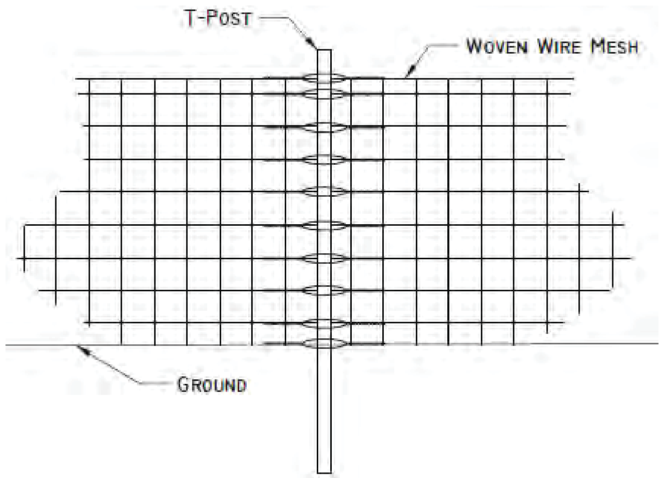
6.5: Refer to attached drawings for dewatering Plank design and installation.



<u>Step 7:</u> Install the cross boards as shown.

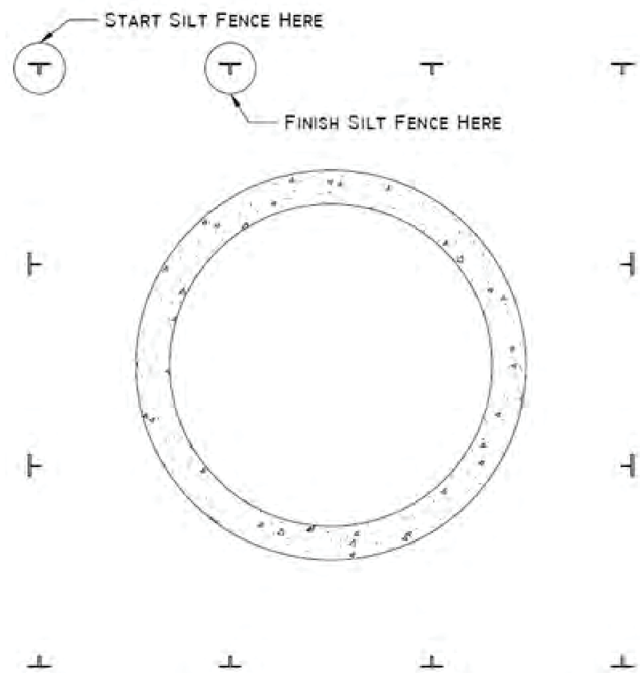


<u>Step 8:</u> Install the wire mesh. The starting and ending point should be the same post as shown. Connect ends around the post shown. Refer to diagram for connection detail.



Step 9: Staple wire mesh to 2x4 posts every 12".

Step 10: Wrap excess wire mesh over 2x4 boards.

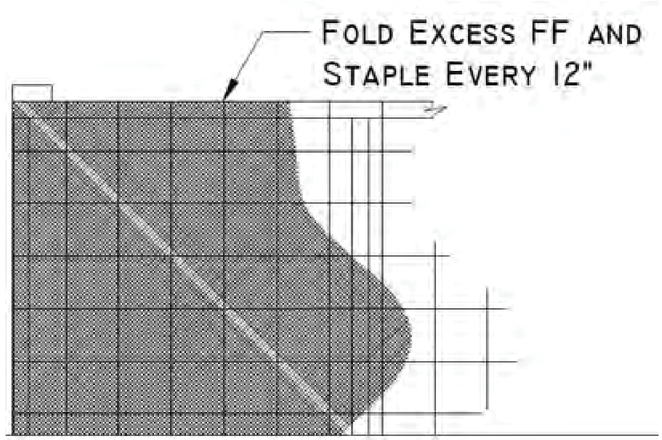


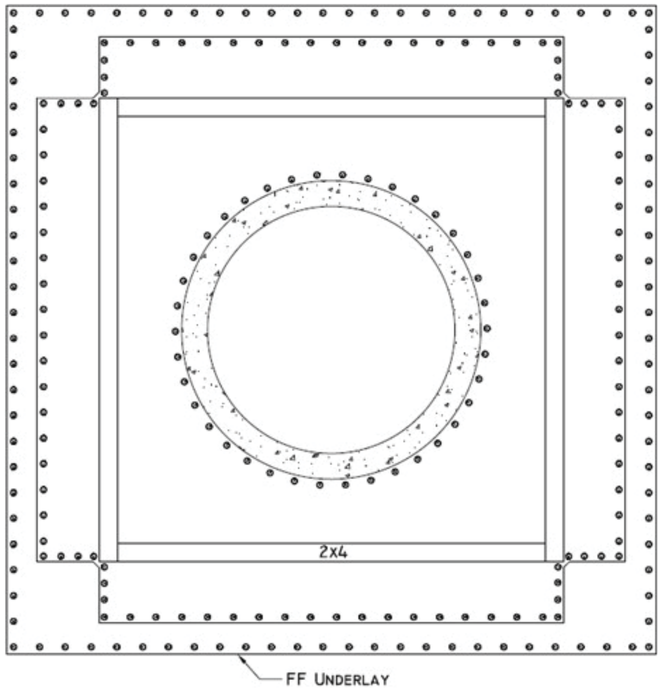
Step 11: Start the silt fence filter fabric at the shown location.

11.1: Staple FF along top side of boards every 12".

11.2: There should be approx. 10" of excess along the bottom.

11.3: Overlap end joint approx. 30" past starting point to shown T-post.





Step 12: Lay silt fence filter fabric over filter fabric underlay.

12.1: Corners will need to be notched to allow fold as shown.

12.2: Leave as much length as possible at notched cut to ensure adequate coverage.

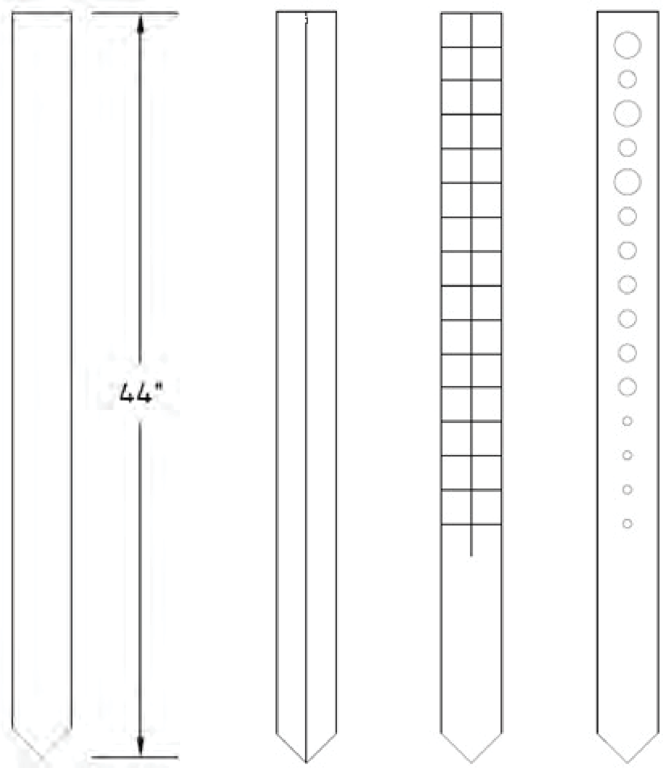
Step 13: Pin along perimeter every 5" OC.

Step 14: Staple silt fence filter fabric to the dewatering plank.

14.1: Staple to either side of holes in plank with 4" spacing on staples

14.2: cut individual cross slits on the filter fabric at the hole locations to allow water to flow through.

Dewatering Plank Design:



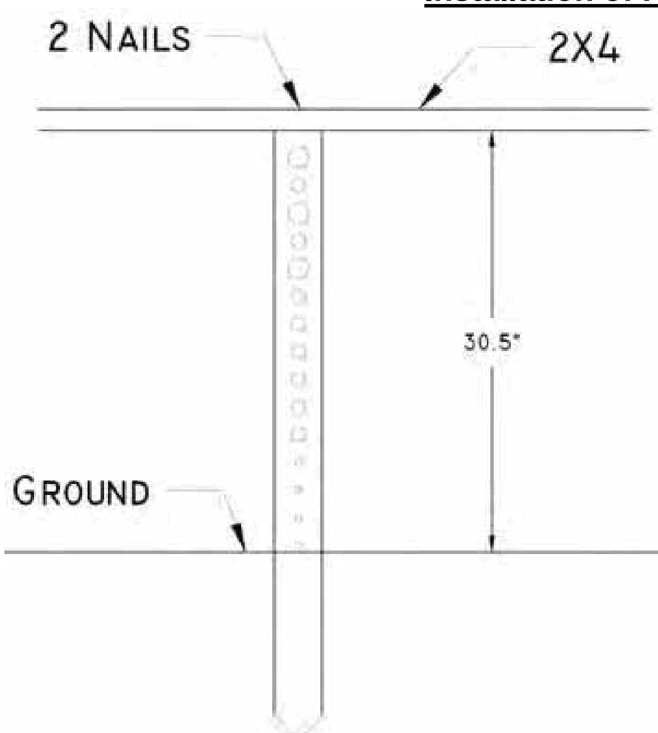
Step 1: Cut a 2x4 44” in length.

Step 2: Draw a straight line along the centerline of the 2x4.

Step 3: Draw horizontal lines at 2” intervals down the length of the board.

Step 4: Drill holes at center points. Note that there are 3 different sized holes corresponding to the required drill bit size. Small = 0.5”, Medium = 1”, Large = 1.5”

Installation of Plank:



Step 1: Drive 2x4 into ground leaving approximately 30.5” exposed above the ground. The

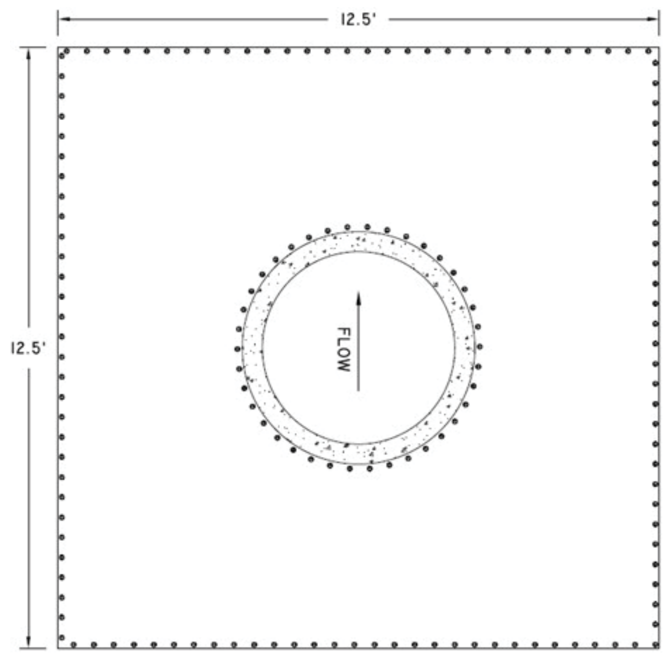
Step 2: Fasten the cross board to the dewatering plank using 2 3” nails.

WATTLE BARRIER MFE-I: TEE-PEE STAKED & STAPLED

Installation Materials:

- ☐ 12.5' x 12.5' 8 oz. FF Sheet
- ☐ 10' x 20" Wattles (qty. 3)
- ☐ Sod Staples
- ☐ Sod Pins
- ☐ 1" x 2" Wooden Stakes

Installation Procedures:

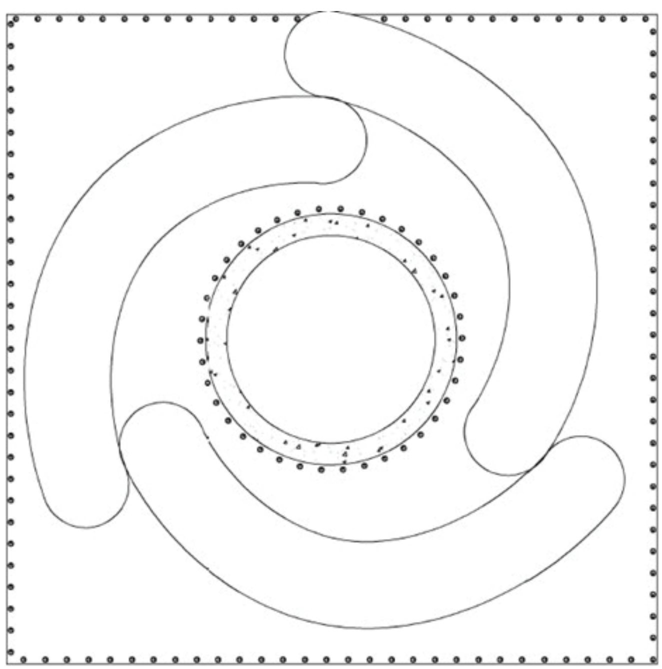


Step 1: Install 8 oz filter fabric as shown.

Step 2: Pin filter fabric around inlet structure spacing at 5" OC.

Step 3: Pin filter fabric around perimeter spacing at 5" OC.

Note: The orientation of the channel is consistent throughout the installation guide.

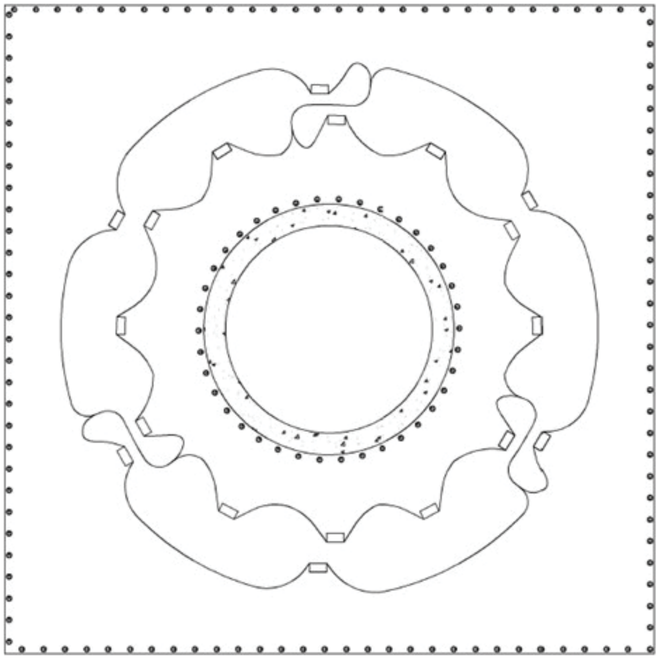


Step 4: Lay three wattles around inlet structure.

4.1: Overlap wattles as shown.

4.2: Wattle joints should not be at the face receiving concentrated flow.

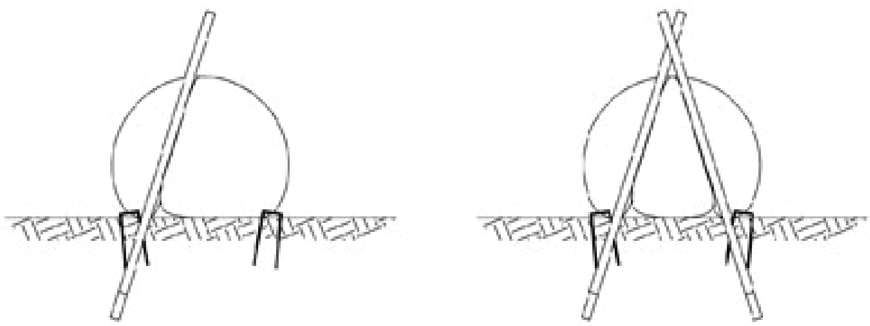
4.3: Wattles should overlap 18" at joints.

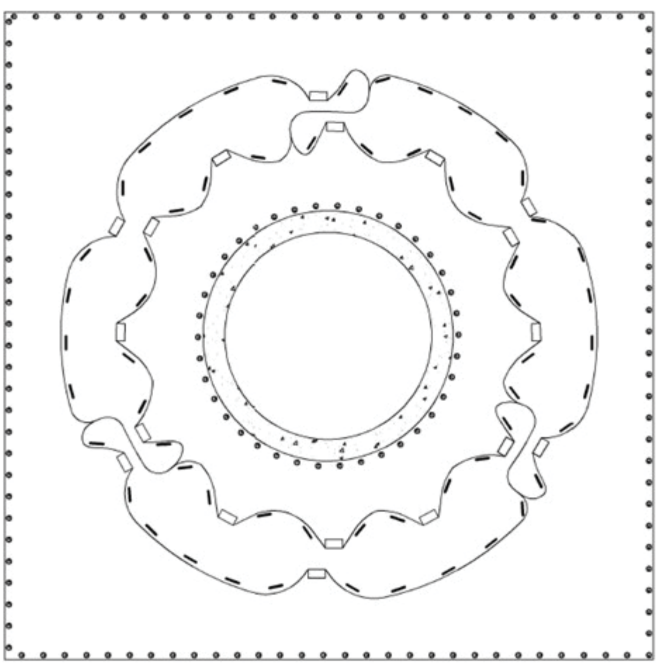


Step 5: Stake wattles as shown using tee-pee method (shown below).

5.1: Stake spacing should be ~2' OC around interior wattle face.

5.2: Stake spacing should be ~4' OC around exterior wattle face.





Step 6: Insert sod staples at 10" spacing OC around interior and exterior face of wattles.

GABION FLOW SYSTEM MFE-I

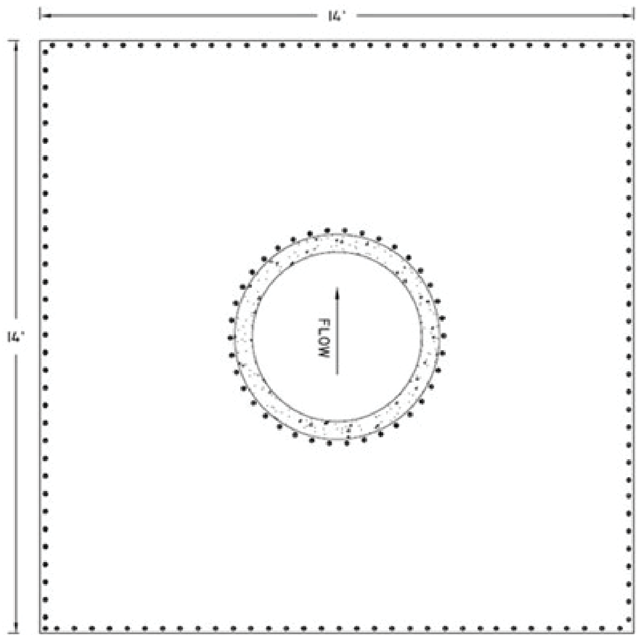
Installation Materials:

- ☐ 14’ x 14’ 8 oz. FF sheet
- ☐ 5’ T-posts (qty. 25)
- ☐ 100’ x 45” 3.5 oz FF Silt Fence
- ☐ 100’ Wire Mesh Backing
- ☐ 6’ x 3’ x 1.5’ Gab. Baskets (qty. 6)
- ☐ Class 1 Riprap (6 CY)

Pressure Treated Lumber:

- ☐ 2” x 4” x 6.5’ (qty. 4)
- ☐ 2” x 4” x 8’ (qty. 12)
- ☐ 2” x 4” x 10’ (qty. 2)
- ☐ Sod Pins
- ☐ ½” Staples
- ☐ Staple Gun
- ☐ C-Ring Staples
- ☐ Tie Wire

Installation Procedures:

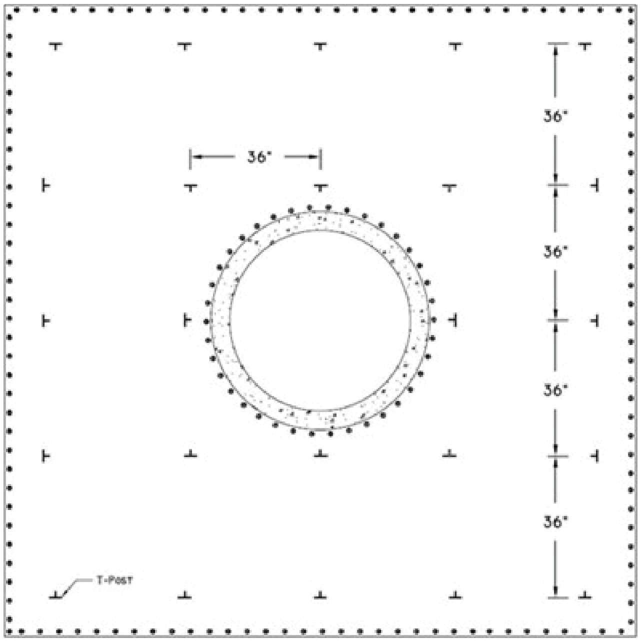


Step 1: Install 8 oz filter fabric as shown.

Step 2: Pin filter fabric around inlet structure

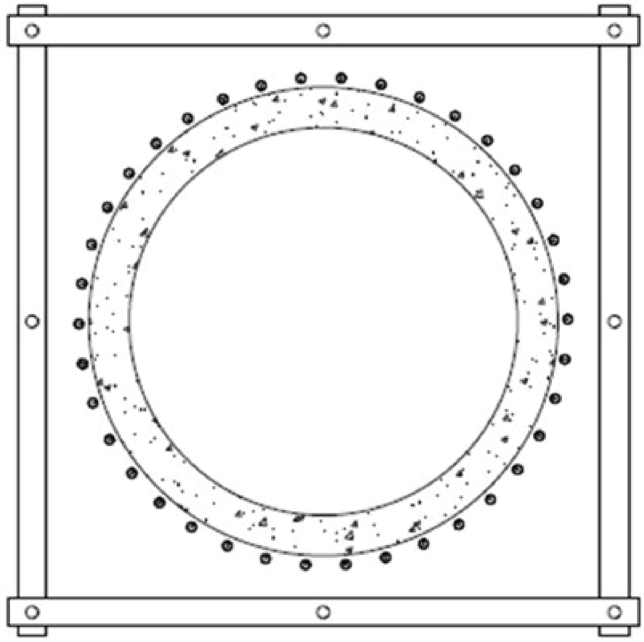
Step 3: Pin filter fabric around perimeter using with 5” spacing OC.

Note: The orientation of the channel is consistent throughout the installation guide.



Step 4: Drive 5’ T-posts 24” into ground at the 25 shown locations.

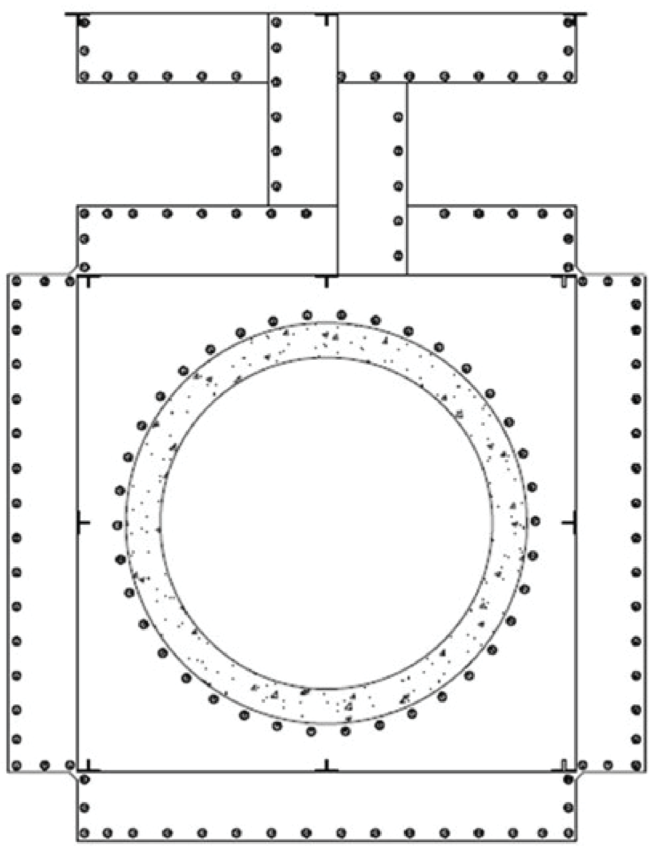
- **4.1:** Match post orientations and locations as shown.
- **4.2:** Use a level and make an effort to keep posts plumbed vertically.
- **4.3:** 36” should remain exposed above the ground.



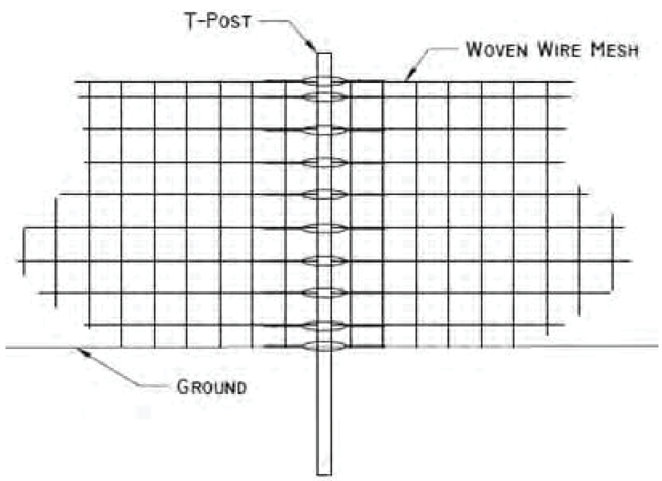
Step 5: install 2”x4”x6.5’ boards as shown. Slide installed T-posts through holes in boards.

5.1: Set top of the installed boards to a height of 32” from the ground.

5.2: Use a level and make an effort to keep posts level.



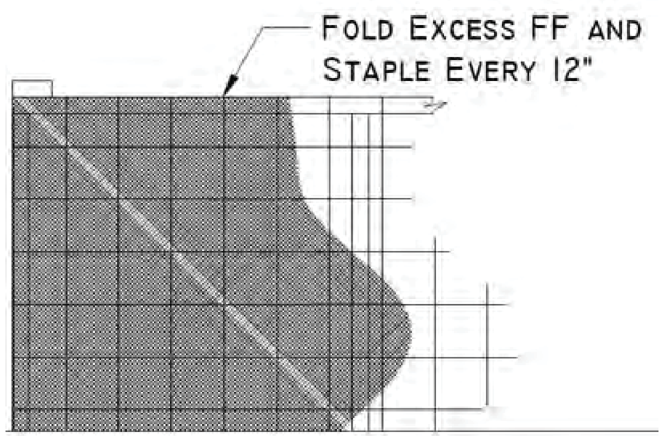
Step 6: install silt fence and backing around inside perimeter as shown and pin along base at 5” intervals OC.



6.1: Install the wire mesh.

6.2: Staple wire mesh to 2x4 boards every 12”.

6.2: Wrap excess wire mesh over 2x4 boards.

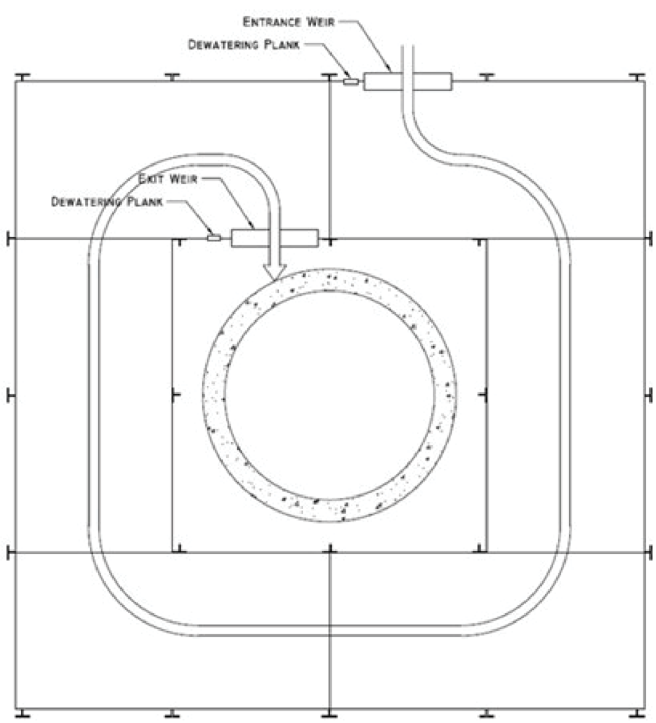


6.3: Staple FF along top side of boards every 12”.

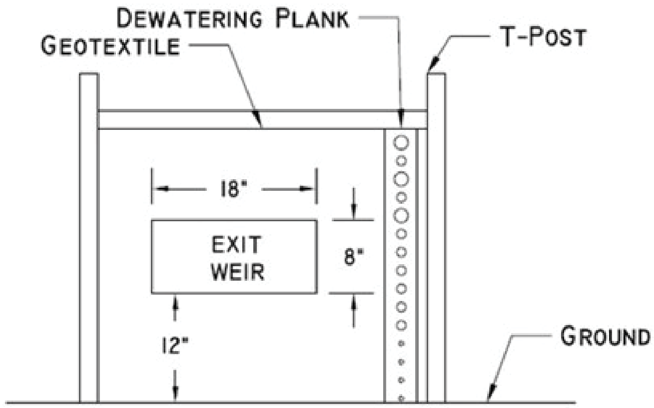
6.4: There should be approx. 10” of excess along the bottom.

6.5: Corners will need to be notched to allow fold as shown.

6.6: Leave as much length as possible at notched cut to ensure adequate coverage.

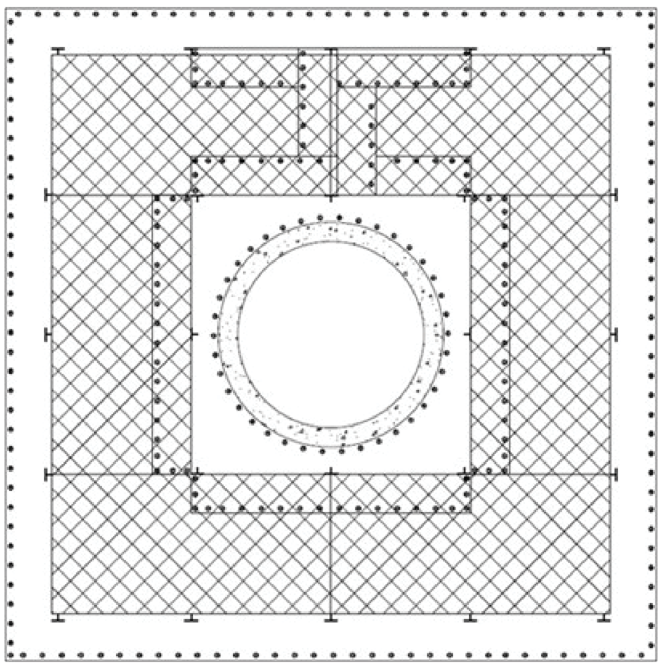


Step 7: Cut exit weir at shown location and install dewatering plank to create shown flow path



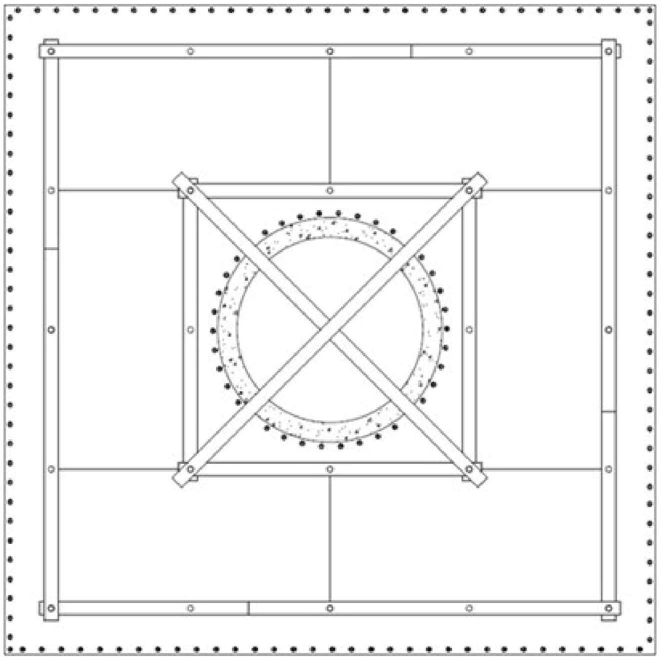
7.1: Cut FF as shown and hog ring to wire mesh backing. Do not cut wire backing.

7.2: Refer to Silt Fence Barrier MFE-I drawings for dewatering plank details.



Step 8: Place the six gabion baskets between the posts as shown.

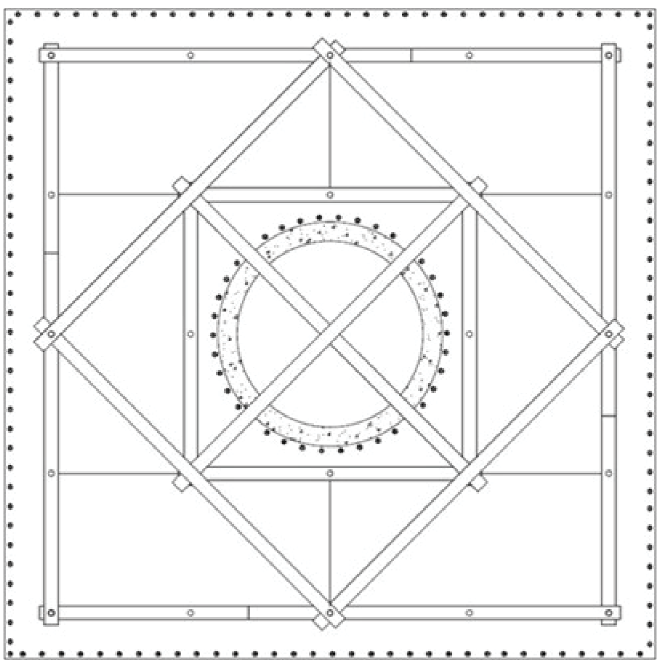
8.1: Fill the baskets with Class 1 riprap



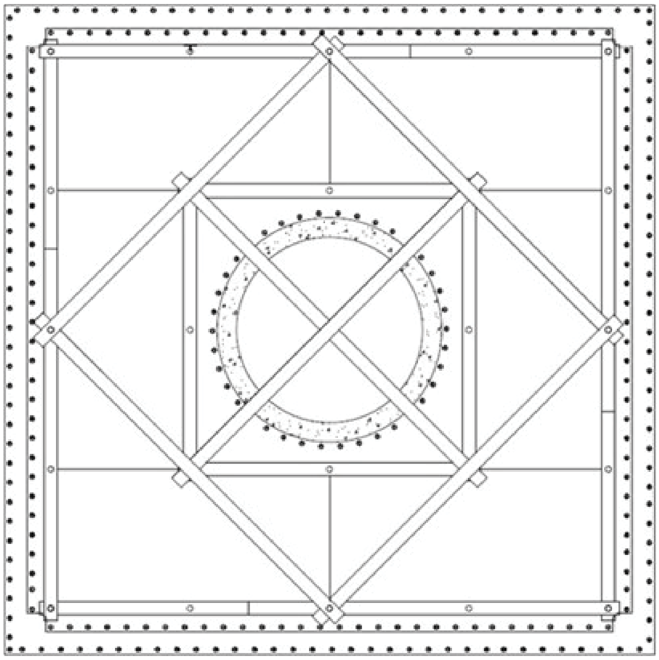
Step 9: Install cross boards along inside silt fence perimeter.

Step 10: Install 2”x4”x8’ boards around outside perimeter.

10.1: Use 2 boards per 12’ segment, overlapping ~4’ at the middle of the segment.



Step 11: Install 2”x4”x10’ cross boards for outside perimeter fence.

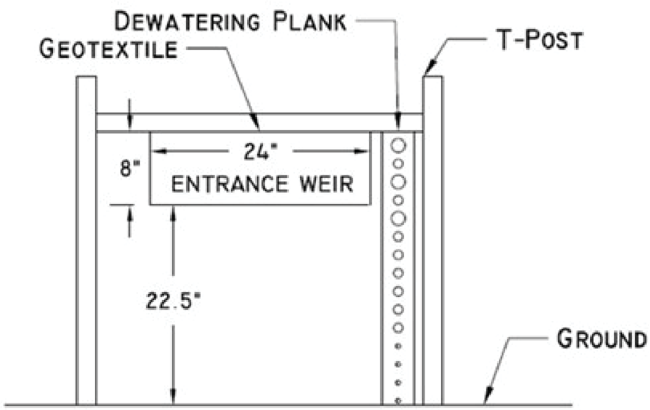


Step 12: Install outside silt fence wire and fabric as shown.

Step 13: Pin along perimeter every 5" OC.

Step 14: Staple silt fence filter fabric to the dewatering plank.

> **14.1:** Staple to either side of holes in plank with 4" spacing on staples.
>
> **14.2:** cut individual cross slits on the filter fabric at the hole locations to allow water to flow through.



Step 15: Cut entrance weir at shown location (step 7) and install dewatering plank.

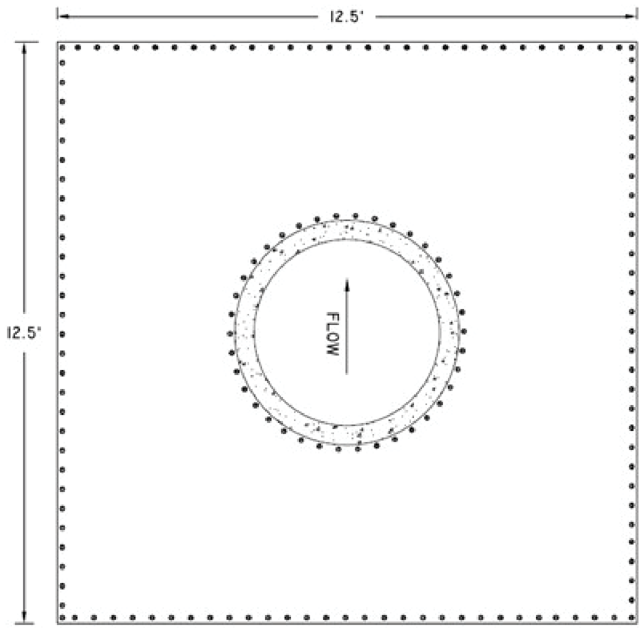
> **15.1:** Cut FF as shown and hog ring to wire mesh backing. Do not cut wire backing.
>
> **15.2:** Refer to Silt Fence Barrier MFE-I drawings for dewatering plank details.

HAY BALE FLOW SYSTEM MFE-I

Installation Materials:

- ☐ 12.5' x 25' 8 oz. FF sheet
- ☐ 5' T-posts (qty. 25)
- ☐ 100' x 45" 3.5 oz FF Silt Fence
- ☐ 100' Wire Mesh Backing
- ☐ Hay Bales (qty. 10)
- ☐ Sod Pins
- ☐ ½" Staples
- ☐ Staple Gun
- ☐ Hog Ties
- ☐ Aluminum Ties

Installation Procedures:

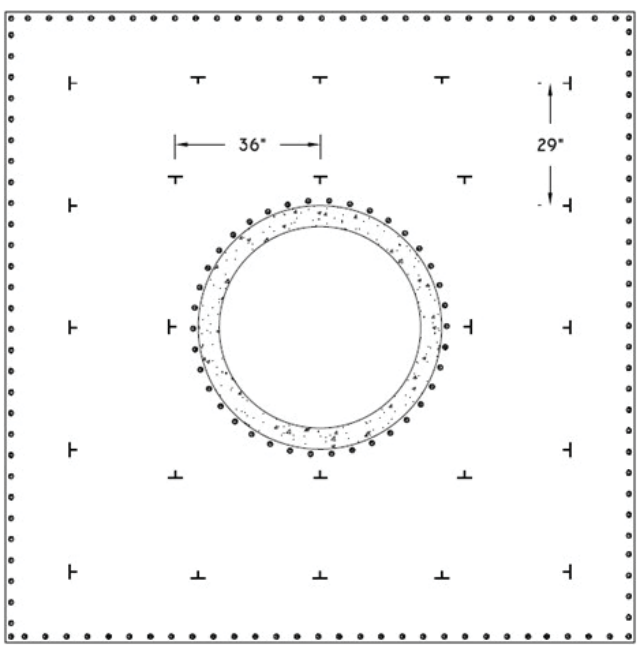


Step 1: Install 8 oz filter fabric as shown.

Step 2: Pin filter fabric around inlet structure

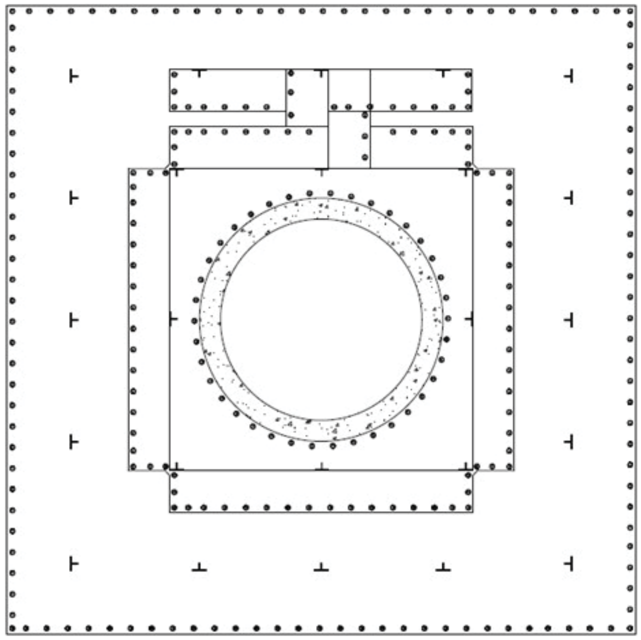
Step 3: Pin filter fabric around perimeter using with 5" spacing OC.

Note: The orientation of the channel is consistent throughout the installation guide.

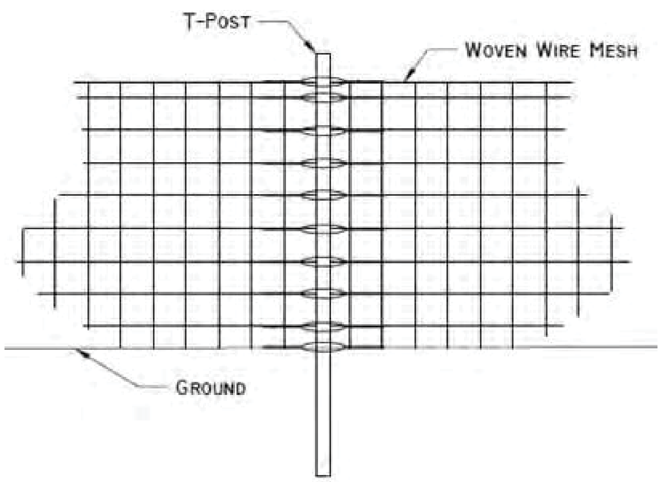


Step 4: Drive 5' T-posts 24" into ground at the 25 shown locations.

- **4.1:** Match post orientations and locations as shown.
- **4.2:** Use a level and make an effort to keep posts plumbed vertically.
- **4.3:** 36" should remain exposed above the ground.



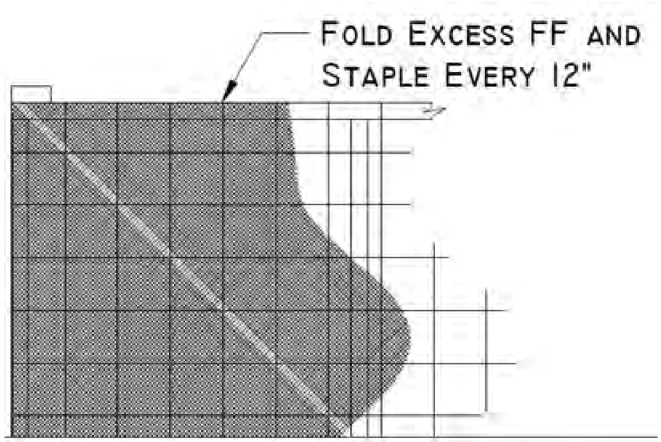
Step 5: install silt fence and backing around inside perimeter as shown and pin along base at 5” intervals OC.



5.1: Install the wire mesh.

5.2: Staple wire mesh to 2x4 boards every 12”.

5.3: Wrap excess wire mesh over 2x4 boards.

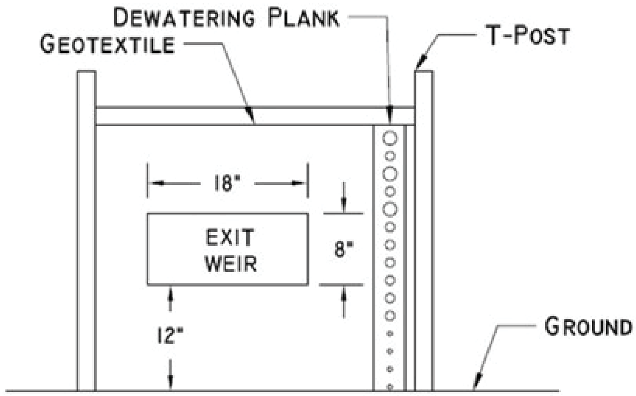


5.4: Staple FF along top side of boards every 12”.

5.5: There should be approx. 10” of excess along the bottom.

5.6: Corners will need to be notched to allow fold as shown.

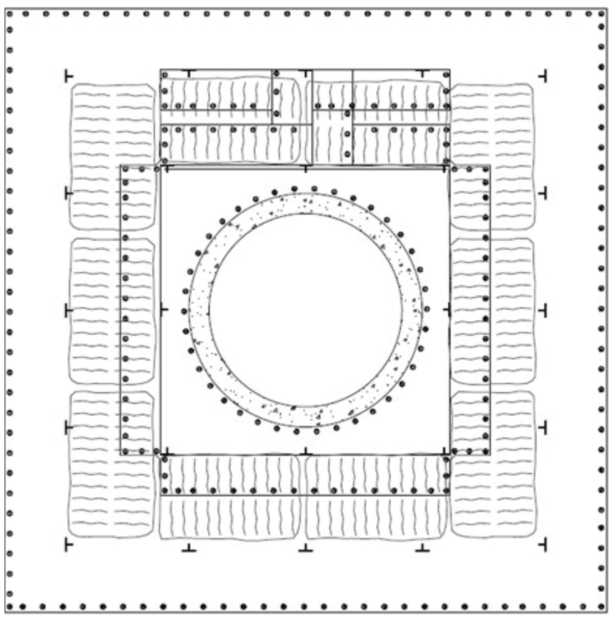
5.7: Leave as much length as possible at notched cut to ensure adequate coverage.



Step 6: Cut exit weir at shown location (step 10) and install dewatering plank to create shown flow path

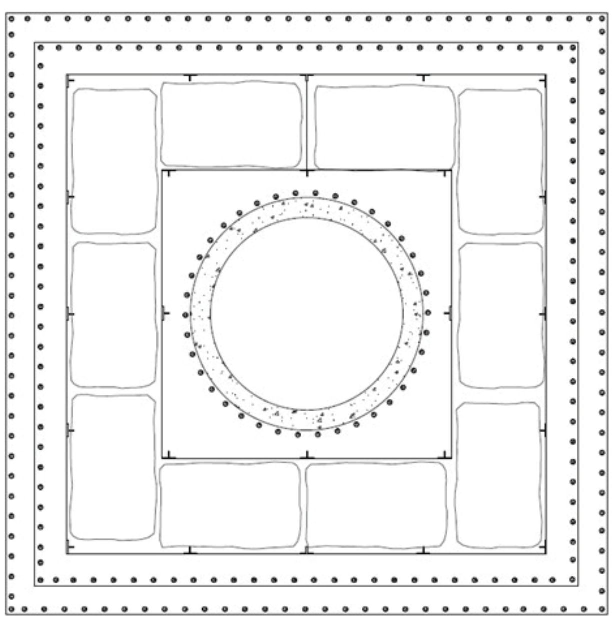
6.1: Cut FF as shown and hog ring to wire mesh backing. Do not cut wire backing.

6.2: Refer to Silt Fence Barrier MFE-I drawings for dewatering plank details.



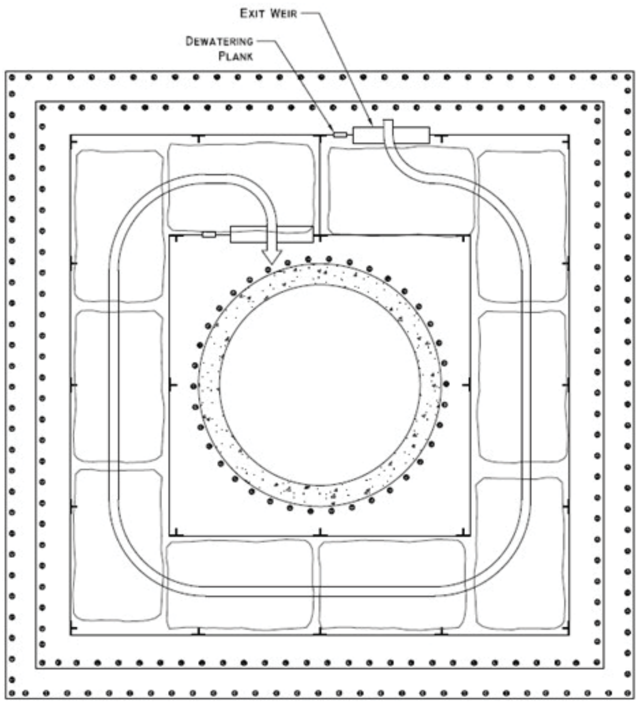
Step 7: Place the ten gabion baskets between the posts as shown.

7.1: Hay bales should tightly fit between posts and each other.



Step 8: Install outside silt fence wire and fabric as shown.

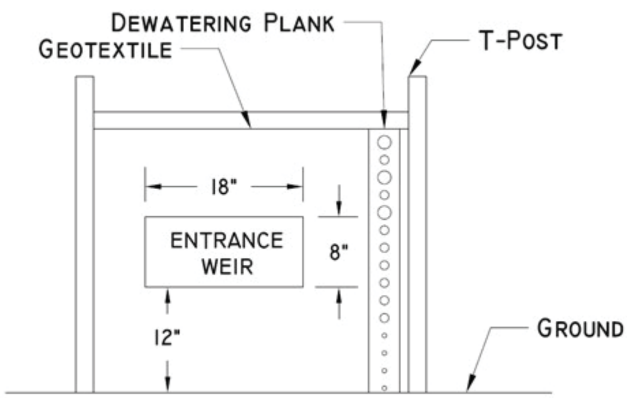
Step 9: Pin along perimeter every 5" OC.



Step 10: Staple silt fence filter fabric to the dewatering plank.

11.1: Staple to either side of holes in plank with 4" spacing on staples

11.2: cut individual cross slits on the filter fabric at the hole locations to allow water to flow through.



Step 12: Cut entrance weir at shown location (step 10) and install dewatering plank.

12.1: Cut FF as shown and hog ring to wire mesh backing. Do not cut wire backing.

12.2: Refer to Silt Fence Barrier MFE-I drawings for dewatering plank details.