UNIVERSITY OF MINNESOTA

ST. ANTHONY FALLS LABORATORY
Engineering, Environmental and Geophysical Fluid Dynamics

Project Report No. 586

Capture of Gross Solids and Sediment by Pretreatment Practices for Bioretention

Final Report for the Project:
Field performance assessment of sediment and gross solids removal from surface inlet pretreatment practices for bioretention

by

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Prepared for
University of Minnesota Water Resources Center,
Minnesota Stormwater Research Council
and
Anoka Conservation District

January 2019
Minneapolis, Minnesota

This project was supported by the University of Minnesota Water Resources Center and by the Minnesota Stormwater Research Council with financial contributions from

- Capitol Region Watershed District
- Mississippi Watershed Management Organization
- Ramsey-Washington Metro Watershed District
- South Washington Watershed District
- Valley Branch Watershed District, and
- City of Edina

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EXECUTIVE SUMMARY

The purpose of this project was to measure the performance of several pretreatment practices for bioretention, both proprietary and non-proprietary, commonly used in Minnesota using field-based performance testing. Five pretreatment practices for bioretention were assessed for capturing sediment and gross solids with field testing.

Most bioretention practices in Minnesota are designed to store the volume of runoff from a 1-inch rainfall event. Design volume tests involved measuring performance at the design storage volume (full storage volume before bypass) of the bioretention practice and were completed for four pretreatment practices. For this testing, the full design storage volume was added from a fire hydrant to the pretreatment and bioretention within 40 minutes (low intensity) or within 20 minutes (high intensity). The pretreatment and bioretention practices were not allowed to overflow or bypass during the design volume tests. Four pretreatment practices were tested, including:

- grass lined inlet (i.e., grassed buffer strip),
- Rain Guardian Bunker proprietary device,
- Rain Guardian Turret proprietary device,
- rock lined inlet (i.e., riprap).

A fifth pretreatment practice, an in-line shallow sump grit chamber, was tested for performance when the design storage volume was added in 30 minutes (low intensity) and 15 minutes (high intensity). The shallow sump grit chamber was also with bypass conditions, which involved adding approximately two and a half times the design volume to the pretreatment and bioretention practice, causing the system to overflow and bypass some water and solids to the downstream conveyance system. The goal of this testing was to determine the performance of an in-line shallow sump grit chamber under bypass conditions.

Prior to testing each pretreatment practice was thoroughly cleaned. Three sediment sizes including a coarse sediment (D_{50} = 1.17mm), a medium sediment (D_{50} = 0.41mm), and a fine sediment (D_{50} = 0.12mm) and three types of gross solids (plastic forks, synthetic leaves, and wood dowels) were added to water from a fire hydrant throughout the duration of each test. After testing was complete, sediment and gross solids were collected and then analyzed at St. Anthony Falls Laboratory to determine capture performance.

Summary of Results

All five pretreatment practices captured greater than 88% of the total sediment and greater than 65% of the fine sediment fraction (D_{50} = 0.12mm) in the low intensity tests, from an initially clean condition. During the high intensity tests, all practices captured greater than 70% of the total sediment mass and greater than 30% of the fine sediment fraction, similarly from an initially clean condition. Four of the five pretreatment practices captured 75% of the gross solids during low intensity tests and more than 55% of the gross solids during high intensity tests. The grass lined inlet captured the least gross solids; 20% during low intensity and 30% during high intensity. The performance for several sequential tests and maintenance needed for long-term operation of these pretreatment practices was not measured in this project.

Bypass tests were conducted to determine the performance of an in-line shallow sump grit chamber under bypass conditions. During these tests, overall sediment captured decreased from 95% during low intensity design volume tests down to 80% capture during high intensity bypass tests. Gross solids capture decreased from greater than 80% to below 40%. Thus, bypass at these

flow rates had minimal effect on the sediment, but measurable effect on the gross solids performance.

Though at least four of the five pretreatment practices performed similarly in terms of sediment and gross solids capture, only three out of the five appear to be simple to inspect and maintain. When maintenance is required, the grass lined inlet and rock lined inlet likely require the same amount of effort and cost to maintain them as would be needed to install them. In addition, the grass lined inlet and rock lined inlet would likely become filled with sediment within a few storm events. Of the pretreatment practices tested in this study, the grass lined inlet and rock lined inlet are among the most difficult and costly to maintain.

To maintain the Rain Guardian Bunker, Rain Guardian Turret, and shallow sump, one would need to remove the top grate and either shovel or hydro-vac the collected sediment and gross solids from within the collection chamber. The Bunker and Turret are both easily visible from the street so visual inspections of accumulated sediment depth are simple. The shallow sump is hidden underground, which makes assessing sediment accumulation depth more challenging. The Bunker, Turret, and shallow sump appear to have ample storage volume for collection and retaining sediment and gross solids. Of the pretreatment practices tested in this study, the Bunker and Turret are among the easiest to maintain, and the shallow sump is moderately easy to maintain.

Partnerships

This project was funded by the Minnesota Stormwater Research Council with additional funding and in-kind support provided by Anoka Conservation District. St. Anthony Falls Laboratory conducted the field testing and laboratory analysis; Anoka Conservation District provided staff and materials to install pretreatment practices to be consistent with industry standards.

ACKNOWLEDGEMENTS

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In addition, this project was supported by the Anoka Conservation District (ACD). The authors wish the thank the Water Resources Center and the Minnesota Stormwater Research Council and affiliated entities for provided funding to support this project. In addition, the authors wish to thank the ACD for provided funding and in-kind match (labor and materials) for this project.

Support and assistance from several organizations and individuals are listed below and is greatly appreciated. Support and assistance for the contracting process was provided by Jeff Peterson, John Bilotta, Ann Lewandowski, Cheryel Konate, Jenni Larson, Chris Lord, and Jared Wagner. In addition, Chris Lord, Jared Wagner, Mitch Haustein, and Jackson Miller (MN Conservation Corps Apprentice) provided in-kind support via labor and materials throughout testing conducted in Anoka. Support provided by St. Anthony Falls Laboratory (SAFL) staff and students include Rob Gabrielson, Peter Olson, Ben Erickson, Jim Tucker, Rikita Patel, Camila Merino-Franco, and Parker Brown.

The Cities of Anoka and Bloomington, MN provided staff, access to fire hydrants, and supplied water meters and hose for use in field testing. The authors wish to thank Marcus Mihelich from the City of Anoka, and Steve Gurney, Pat Conrad, and Ben Whitcomb from the City of Bloomington for their assistance. The City of Anoka donated 12,939 cubic feet of water and the City of Bloomington donated 1,560 cubic feet of water for field testing. In addition, owners of the property on which the rain gardens were located cooperated with field testing and supplied garden hose and donated water for field testing.

TABLE OF CONTENTS

FIGURES

TABLES

ACRONYMS AND ABBREVIATIONS

ACD = Anoka Conservation District

BBP = Bloomington Bypass (Shallow sump grit chamber, nonproprietary, City of Bloomington design)

BDV = Bloomington Design Volume (Shallow sump grit chamber, nonproprietary, City of Bloomington design)

BP = Bypass

cfs = cubic feet per second

GLI = Grass Lined Inlet

MSRC = Minnesota Stormwater Research Council

RGB = Rain Guardian Bunker

RGT = Rain Guardian Turret

RLI = Rock Lined Inlet

RPD = Relative Percent Difference

SAFL = St. Anthony Falls Laboratory

TD = Total Duration

UMN = University of Minnesota

CHAPTER 1: INTRODUCTION

Bioretention practices, often called rain gardens, have become an increasingly common stormwater treatment option in Minnesota. Beyond stormwater treatment, bioretention areas have aesthetic and other benefits and may be designed in a variety of ways to fit the characteristics of a given site. A primary purpose for these practices, however, is to capture sediment from stormwater while it infiltrates into the bioretention media. This sediment can accumulate over time and eventually clog a bioretention cell. Thus, pretreatment of incoming stormwater is an integral part of the treatment process and is required for bioretention by the Minnesota Stormwater Manual, as described in "Design Criteria for Bioretention:"

> *"Warning: To prevent clogging of the infiltration or filtration system with trash, gross solids, and particulate matter, use of a pretreatment device such as a vegetated filter strip, vegetated swale, small sedimentation basin (forebay), or water quality inlet (e.g., grit chamber) to settle particulates before the stormwater discharges into the infiltration or filtration system is REQUIRED." (MPCA 2017a)*

The Minnesota Stormwater Manual also describes criteria for pretreatment (settling devices, screens, and vegetative filter strips), and provides performance recommendations:

> *"It is recommended that pretreatment practices be designed for easy maintenance and capture a minimum of 25 percent of the sediment from runoff. Pretreatment practices capture solids that are quickly settled or screened, including gross solids and most sand particles (roughly 100 microns (µm) and larger), although some pretreatment practices also capture floatables. In many watersheds, this material accounts for a large portion of the total pollutant load." (MPCA 2017b)*

Actual data on the effectiveness of pretreatment practices, whether from field studies or laboratory or field testing, is limited or varies widely in method and results. This is of limited value to designers tasked with striking the right balance of effectiveness, initial construction costs, and long-term maintenance costs for the pretreatment and treatment practice system. The performance effectiveness of small and simple above-ground pretreatment practices for bioretention is a significant knowledge gap for industry professionals.

This project encompassed field-based performance testing of several pretreatment practices, both proprietary and non-proprietary, commonly used in Minnesota. The goal of the project is to gather performance data that will assist project designers, local government maintenance forces, and others by:

- Providing a quantitative measurement of effectiveness of several pretreatment practices;
- Offering a common point of comparison for different practices, by using the same test method;
- Informing assumptions about maintenance frequency of the pretreatment practice, and the bioretention practice;
- Improving understanding of how these practices function;
- Prompting innovations or design improvements based on measured data;
- Demonstrating a test method that can be applied in other locations and to other pretreatment practices.

This final report is organized into several chapters that describe the site locations (Chapter 2), the pretreatment practices (Chapter 3), the field methods (Chapter 4), the results and discussion (Chapter 5), the conclusions (Chapter 6) and lessons learned from this project as well as suggestions for future research (Chapter 7) that would continue data collection started with this project.

CHAPTER 2: SITE LOCATIONS

Site selection is critical to the success of field testing and monitoring. For this project, criteria used for site selection included safe roadway access, a nearby water source (fire hydrant), low traffic on nearby streets, adequate retention volume for longer tests, and a nearby storm sewer. Anoka Conservation District (ACD) suggested a site in the City of Anoka for testing of the Rain Guardian Bunker. The site characteristics also allowed for testing of a grass lined inlet, Rain Guardian Turret, and rock lined inlet with modification of the pretreatment entrance, thus allowing comparison of performance within the same bioretention practice and under the same test conditions for four practices. An additional non-proprietary in-line shallow sump grit chamber that has been designed and constructed in several locations within the City of Bloomington was also recommended for testing by industry professionals. The site in Anoka could not be modified to accommodate this practice, so another site in the City of Bloomington was selected for testing this practice. The sites used for testing as part of this project are described in detail within this chapter.

2.1 ANOKA SITE

ACD identified a newly-constructed bioretention facility in the city of Anoka, Minnesota at the northeast corner of 38th Lane N and 8th Lane (Figure 1 and Figure 2) which met the desired site characteristics described above. In addition, this site was constructed in 2017 and little of the planned vegetation was installed prior to testing, allowing testing to occur without interference from or interfering with the vegetation.

Figure 1. Photo of the Anoka site in May 2018, prior to testing. Gutter flow along 38th Lane is from right to left in the photo, encountering the basin inlet before the large catch basin nearest the fire hydrant.

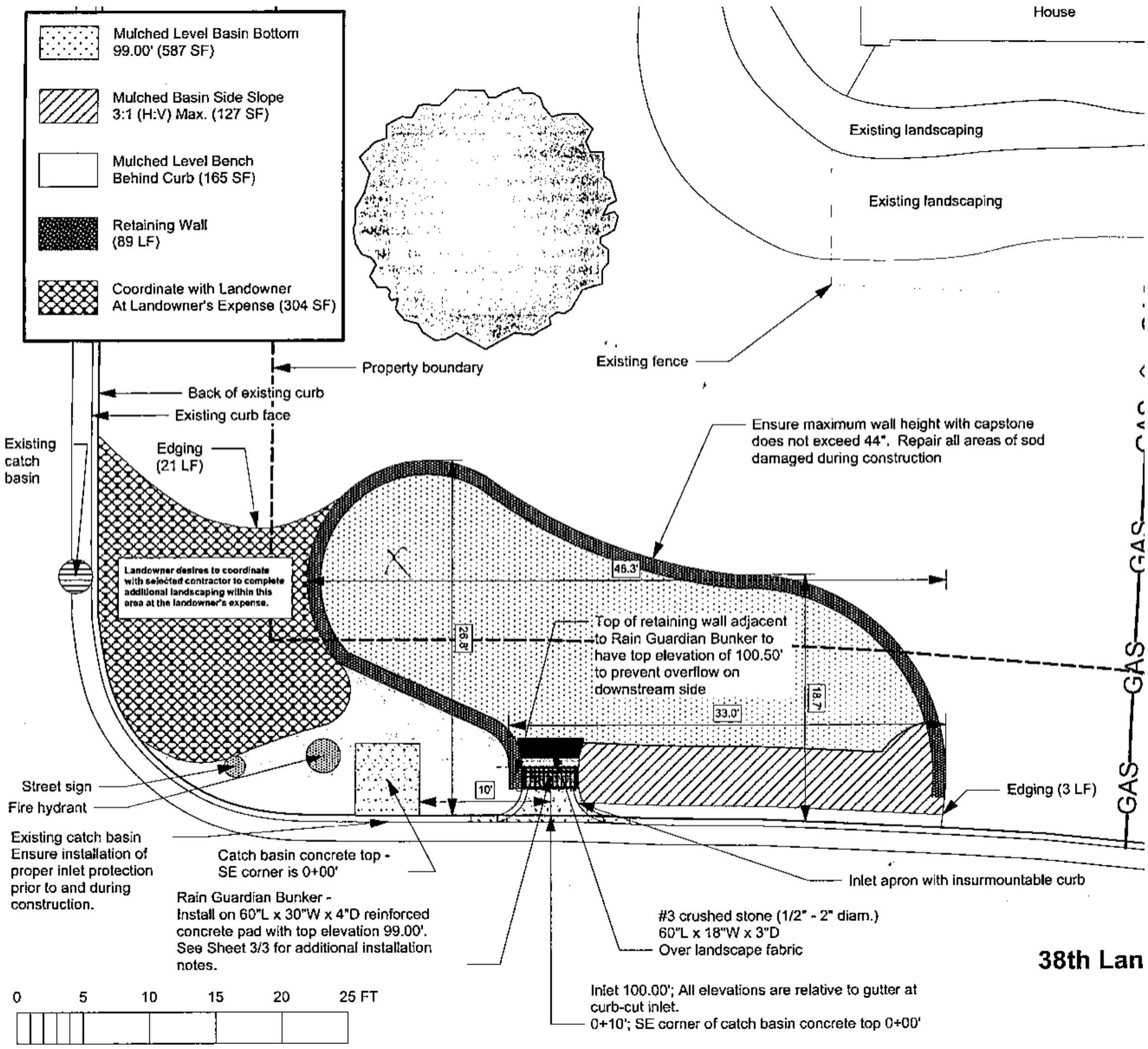

Figure 2. Site plan of the Anoka field site. (courtesy of Anoka Conservation District)

The design volume for the bioretention was 600 cubic feet (600 square feet x 1 ft deep). The watershed that drains to the bioretention is approximately 10.5 acres of low-density residential with little topographic elevation change, a portion of which is shown in Figure 3. Hydrologic modeling by ACD revealed that a 0.11-inch rainfall event on the contributing area would produce 600 cubic feet of runoff to the bioretention, which corresponds to the design volume of the bioretention. As is often the case, this bioretention was a “garden of opportunity” in which ACD was able to partner with the homeowner to build a bioretention on the property but was limited by the space available. It is the intention that more bioretention practices will be installed within the watershed to reduce the burden on this specific bioretention and increase the overall effectiveness of all bioretention practices. During testing, it was evident that infiltration was rapid (~25 inches/hr) at this basin. The bioretention is newly constructed and the subsoil at the site and in most of Anoka is sandy, which explains the rapid infiltration rate.

Figure 3. Aerial photo and topography in the vicinity of the Anoka field site, which is identified with a star. Image and contours from MnTOPO (https://www.dnr.state.mn.us/maps/mntopo/index.html)

This bioretention basin was designed to use a Rain Guardian Bunker pretreatment device, which included a concrete pad as the bottom of the structure. The Rain Guardian could be removed, leaving a combination of concrete and composite frame (Figure 4). With modification, a Rain Guardian Turret could be installed in this same location. With construction of a sloped surface, a rock lined inlet and grass lined inlet could also be installed in this location. Thus, the curb inlet and bioretention basin features remained the same for all testing conducted at the Anoka site.

Figure 4. At the Anoka site, the outer frame and concrete pad of the Rain Guardian Bunker device was left in place and adapted for all tests.

2.2 BLOOMINGTON SITE

The site in Anoka could not be modified to accommodate a shallow in-line sump grit chamber that was recommended for testing by industry professionals and used at several sites in the City of Bloomington, Minnesota. The City has installed numerous rain gardens and has developed several different pretreatment designs. One of the most recent designs was selected for testing because the site met the site selection criteria described above and because the design is different from the four pretreatment practices tested at the Anoka site.

A rain garden site located on Queen Avenue between 86th and 88th Street was chosen for field testing, as shown in Figure 5, featuring Bloomington's "new" pretreatment design. The rain garden, pretreatment, and street improvements were constructed in 2016 and the rain garden was reconstructed in 2017 due to lack of infiltration. The residential watershed area draining to the rain garden is estimated to be approximately 2.3 acres, which is visible but not outlined in Figure 6.

Figure 5. Queen Avenue rain garden in Bloomington, looking north. The inlet to the pretreatment device is through the furthest curb grate. The gutter low point is between the middle and bottom catch basins.

The typical bioretention design specified a storage volume of 150 cubic feet, though the actual volume of this bioretention basin including the pretreatment device sump was found to be ~119 cubic feet, assuming no infiltration. Using a similar hydrologic estimation process as was used on the Anoka site, it is estimated that a 0.1-inch rainfall event on the contributing area will produce 119 cubic feet of runoff for the site in Bloomington, which corresponds to the design volume of the bioretention. Similar to the Anoka site, this bioretention was a “garden of opportunity” in which the City was able to partner with the homeowner to build a bioretention on the property but was limited by the space available. It is the intention that more bioretention practices will be installed within the watershed to reduce the burden on this specific bioretention and increase the overall effectiveness of all bioretention practices.

Figure 6. Aerial photo and topography in the vicinity of the Bloomington field site, which is identified with a star. Image and contours from MnTOPO (https://www.dnr.state.mn.us/maps/mntopo/index.html)

It is important to note that white-colored turbidity may be visible in photos of water from the Bloomington tests (BDV, BBP, shallow sump grit chamber). This turbidity was visible during testing and was explained by City staff as lime residue from water treatment in the distribution pipes. The City of Bloomington does not flush their hydrants or water supply lines, so this residue can build up and become visible during "high flow" events such as our use during testing. This residue is very fine grain and was not visible in samples collected from Bloomington compared to samples collected from Anoka. It is not expected that this residue had any effect on the testing results.

CHAPTER 3: PRETREATMENT PRACTICES

Pretreatment practices are intended to reduce maintenance and prolong the lifespan of structural stormwater BMPs by removing trash, debris, organic materials, coarse sediments, and associated pollutants prior to entering structural stormwater BMPs (MPCA 2017b). The performance goal set forth by the MPCA is capture of gross solids and 25% of sediment greater than 100µm. In addition, proper pretreatment practices can provide a stable inlet into a bioretention practice that prevents erosion and minimizes disturbance of ground cover (e.g., mulch) within the bioretention.

Five pretreatment practices were tested as part of this study: grass lined inlet, Rain Guardian Bunker, Rain Guardian Turret, rock lined inlet, and in-line shallow sump grit chamber. The primary treatment mechanisms for stormwater pretreatment are screening, settling, and filtration and are described for each of the five practices tested in this project in Table 1.

Table 1. Pretreatment practices, brief description, and treatment mechanisms

Practice	Description	Treatment mechanisms
Grass Lined Inlet	Non-proprietary, grassed conveyance, sloped between curb cut and bottom of bioretention.	• settling among vegetation, • vegetative filtration
Rain Guardian Bunker	Proprietary rectangular chamber with top grate, concrete bottom, screened exit wall, and skimming debris wall.	• screening on top grate, • settling within the chamber, • screening by the screen wall • skimming of floatables by debris wall
Rain Guardian Turret	Proprietary cylindrical chamber with top grate, concrete bottom, screened exit wall, and skimming debris wall.	• screening on top grate, • settling within the chamber, • screening by the screen wall • skimming of floatables by debris wall
Rock Lined Inlet	Non-proprietary, rock-covered conveyance, sloped between curb cut and bottom of bioretention.	• settling among rocks
Shallow Sump Grit Chamber	Non-proprietary, shallow sump below gutter and connected to bioretention by three sub-surface PVC pipes.	• screening on top grate, • settling in shallow sump

Each practice was assigned a unique identifier for labeling samples as shown in Table 2. The Bloomington shallow sump grit chamber was tested in two different ways, first to the rain garden design volume (BDV), and then with a larger water volume, inducing bypass (BBP). To differentiate between tests and clarify labeling, a unique identifier combining the practice (3 letter identifier), flow rate (3 number fraction of one cfs), and replicate (sequential letter) was utilized. For example, the first replicate of the grass lined inlet at 0.5cfs would be labeled GLI-050-A, and the second replicate of the Rain Guardian Turret at 0.25cfs would be labeled RGT-025-B.

Table 2. Pretreatment practice, Unique identifier, storage and flow rate capacity, test flow rates and durations, and number of replicates. cfs = cubic feet per second.

Pretreatment Practice	ID	Flow rate and Storage Capacity	Test flow rate and duration (replicates)
Grass Lined Inlet	GLI	Storage capacity = minimal (depth of grass). Flow rate capacity = unknown.	0.25cfs for 40 minutes (2), 0.5cfs for 20 minutes (2)
Rain Guardian Bunker	RGB	Storage capacity = 2.85ft^3. Flow rate capacity = 6.11cfs.	0.25cfs for 40 minutes (2), 0.5cfs for 20 minutes (2)
Rain Guardian Turret	RGT	Storage capacity = 4.02ft^3. Flowr ate capacity = 3.45cfs.	0.25cfs for 40 minutes (2), 0.5cfs for 20 minutes (2)
Rock Lined Inlet	RLI	Storage capacity = minimal (pore space between rock). Flow rate capacity = unknown.	0.25cfs for 40 minutes (2), 0.5cfs for 20 minutes (2)
Shallow sump grit chamber (bypass)	BBP	Storage capacity = ~6ft^3. Flow rate capacity = unknown.	0.12cfs for 40 minutes (1), 0.25cfs for 20 minutes (1)
Shallow sump grit chamber (design volume)	BDV	Storage capacity = ~6ft^3. Flow rate capacity = unknown.	0.06cfs for 30 minutes (2), 0.12cfs for 15 minutes (2)

3.1 GRASS LINED INLET

A grass lined inlet (GLI) in a non-proprietary grassed conveyance that is sloped between the curb cut and the bottom of bioretention, as shown in Figure 7. It is also sometimes called a filter strip, buffer strip, or vegetative filter. GLIs capture sediment and gross solids by a combination of settling and vegetative filtration. As water, sediment and gross solids flow over the GLI, the vegetation both intercepts particles and gross solids (vegetative filtration) and reduces the flow velocity near the soil surface, which allows for settling of sediment. Sediment that settles on the soil within the vegetation is thus protected by the vegetation within a non-turbulent boundary layer.

Figure 7. Flow on grass lined inlet at 0.25 cfs (GLI-025-B). Curb cut entrance along bottom of the picture, exit into the bioretention practice at the top.

The width, length, and slope of the GLIs varies based on design parameters and site constraints. For this project, the dimensions of the GLI were approximately 48 inches wide, 52 inches long, and an elevation change of 10.5 inches which produced a slope of 5H : 1V, or 20%. This slope is greater than 8%, which is the maximum recommended by the Minnesota Stormwater Manual (MPCA 2017a). Extending the length to reduce the slope angle to 8% or less was considered, but experience and field observations of the authors and industry experts suggest ~20% slope is consistent with actual installations of GLIs.

3.2 RAIN GUARDIAN BUNKER

The Rain Guardian Bunker (RGB) is a proprietary, rectangular chamber with top grate, concrete bottom, screened exit wall, and skimmer beam, as shown in Figure 8. Water, sediment, and gross solids flow into the RGB from the curb inlet, first through the top grate which captures gross solids by screening. Water, sediment, and any uncaptured gross solids then fall into the rectangular chamber where sedimentation captures sediment and settleable gross solids. Water then exits the chamber through a screen exit wall, which screens additional sediment and gross solids. When the water level is near the top of the screen wall, a skimmer beam intercepts floatables. When the flow exceeds the capacity of the screen wall, water overtops the screen wall. A cross section of the RGB is shown in Figure 9. No modifications to the installation or design of the RGB were made for testing.

Figure 8. Overhead view of Rain Guardian Bunker (RGB) at 0.25 cfs during gross solids addition (RGB-025-B). Entrance from the curb cut comes into the RGB from the right of the picture; flow through the screen wall exiting the RGB in the center of the picture towards the left.

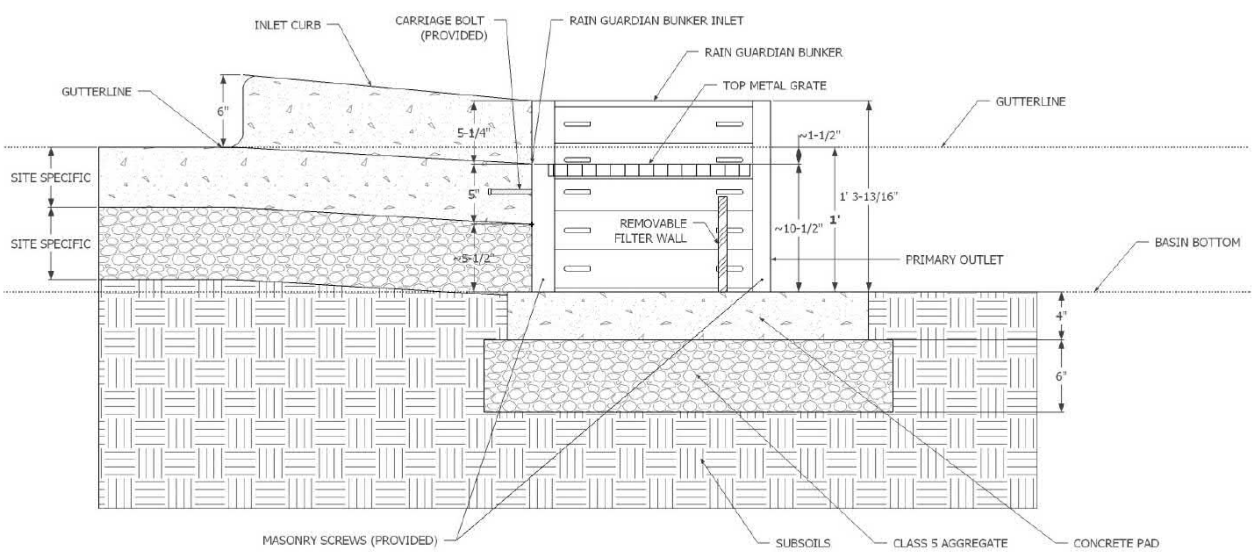

Figure 9. Cross section of Rain Guardian Bunker (flow from left to right) (http://www.rainguardian.biz/installation/downloads)

3.3 RAIN GUARDIAN TURRET

The Rain Guardian Turret (RGT) is a proprietary, cylindrical chamber with top grate, concrete bottom, screened exit wall, and skimmer beam as shown in Figure 10. Water, sediment, and gross solids flow into the RGT from the curb inlet, first through the top grate which captures gross solids by screening. Water, sediment, and any uncaptured gross solids then fall into the cylindrical chamber where sedimentation captures sediment and settleable gross solids. Water then exits the chamber through a screen exit wall, which screens additional sediment and gross solids. Compared to the Rain Guardian Bunker, the RGT has a larger grate area, larger settling chamber, and smaller screen wall area, with larger screen openings. When the water level is near the top of the screen wall, a skimmer beam intercepts floatables. When the flow exceeds the capacity of the screen wall, water overtops the screen wall. A cross section of the RGT is shown in Figure 11. To facilitate testing of the RGT, diversion plates were constructed from lightweight insulation panels (pink, shown in Figure 10) to divert flow into the opening of the RGT.

Figure 10. Rain Guardian Turret testing at 0.25 cfs (RGT-025-A). Entrance from the curb cut comes into the RGT from the right of the picture; flow through the screen wall exiting the RGT in the center of the picture towards the left.

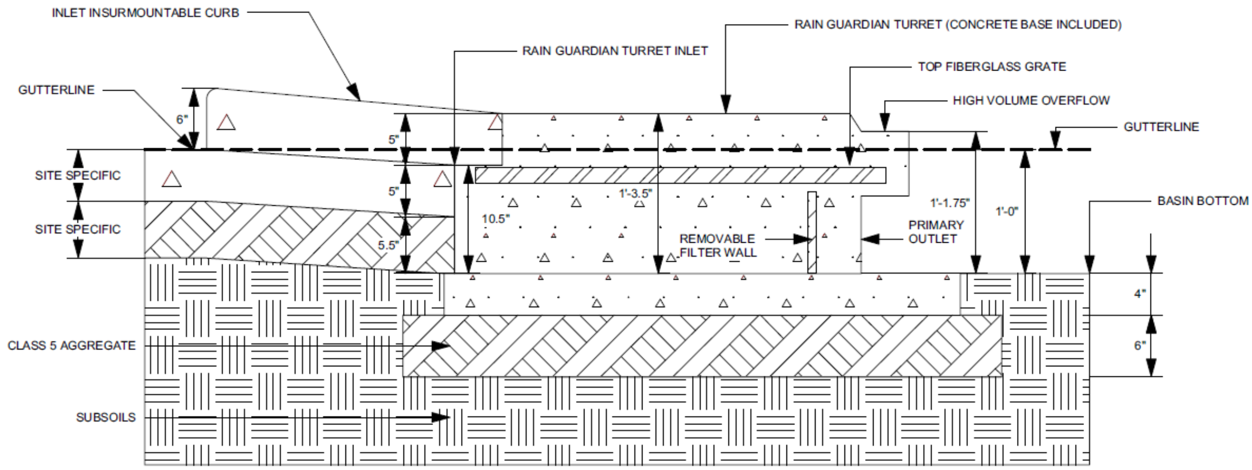

Figure 11. Rain Guardian Turret cross section (flow from left to right) (http://www.rainguardian.biz/installation/downloads)

3.4 ROCK LINED INLET

A rock lined inlet (RLI) in a non-proprietary rock-covered conveyance that is sloped between the curb cut and the bottom of bioretention, as shown in Figure 12. It is also sometimes called a riprap entrance, rock channel, or rock buffer strip. RLIs capture sediment and gross solids by settling among the rocks. As water, sediment and gross solids flow over the RLI, the rocks create roughness that intercepts sediment and gross solids and reduces the flow velocity near the rock surface, which allows for settling of sediment. Sediment that settles among the rock is thus protected by the non-turbulent boundary layer.

Figure 12. Rock lined inlet after testing at 0.50 cfs for 20 minutes. Entrance from the curb cut comes into the RLI from the right of the picture; exit into the bioretention practice at left.

The width, length, and slope of the RLIs varies based on design parameters and site constraints. For this project, the dimensions of the RLI were approximately 48 inches wide, 52.5 inches long, and an elevation change of 10.5 inches which produced a slope of 5H : 1V, or 20%. Experience and field observations of the authors and industry experts suggest ~20% slope is consistent with actual installations of RLIs.

3.5 SHALLOW SUMP GRIT CHAMBER

The in-line shallow sump grit chamber tested during this project comprises a rectangular catch basin, approximately 36 inches long by 24 inches wide with a 12-inch sump. There are five 4-inch holes in the bottom of the concrete chamber floor which allow for infiltration of water from the sump into the subsurface soils. The grit chamber is installed in-line with the gutter and has three 4-inch outlet pipes leading to the bioretention basin (Figure 13). Stormwater flows down the street gutter line and drops through the grate into the sump. When flow into the sump and through the outlet pipes is greater than the infiltration rate, the water will continue to rise in the sump and the bioretention basin simultaneously.

Figure 13. Shallow sump pretreatment with surface grate removed. This photo was taken upon arrival at the site, before cleaning the sump in preparation for testing.

When the water depth in the bioretention reaches 12 inches, the water level in the shallow sump is approximately at the elevation of the gutter (Figure 14). As the water level increases above this depth, water will begin to flow from the shallow sump grit chamber into the downstream gutter and on to the downstream conveyance. Water that flows out of the shallow sump grit chamber into the gutter is considered “bypass” because it bypasses treatment by the bioretention. During bypass conditions, water is treated by the shallow sump grit chamber and some water flows into the bioretention (assuming infiltration occurs), but sediment and gross solids may flow over the top of the grit chamber or be resuspended within the shallow sump grit chamber and allowed to flow out of the device and into the gutter. During larger rainfall and flow events, this could mobilize previously-captured sediment and release it from the shallow sump grit chamber.

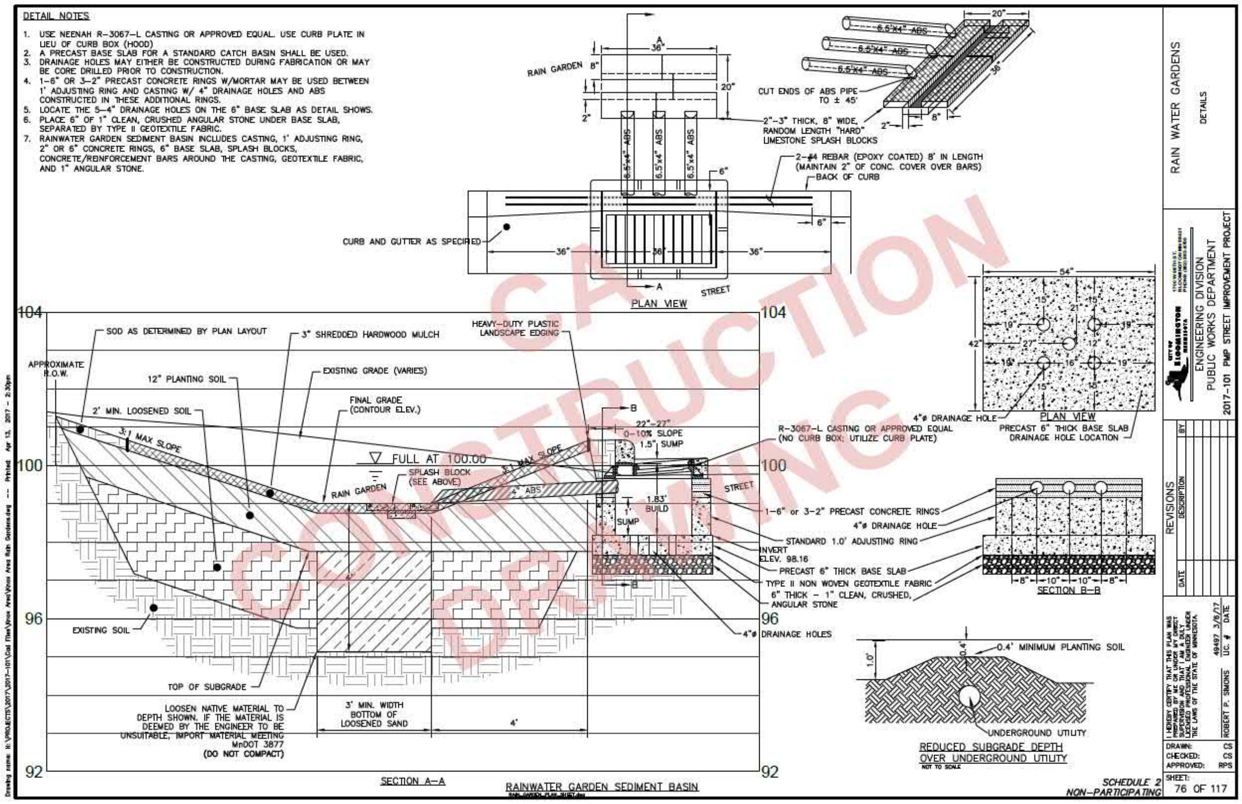

Figure 14. Shallow sump bioretention pretreatment practice design plan

CHAPTER 4: METHODS

4.1 FIELD-BASED TESTING

A field-based testing approach was used in this project because several of the available pretreatment practices are installed and easily accessible in the field. The relatively short duration of this project and the uncertainty associated with field monitoring prevented the use of long-term monitoring to measure performance. Thus, a field-testing methodology was adopted to produce repeatable results on five different pretreatment practices within a single summer season.

Field-testing allows for control of several variables associated with performance, including flow rate, volume, and duration; pollutant characteristics and amount; timing of testing during specific weather conditions; and the ability to repeat tests if results are inaccurate or errors appear. In addition, field-testing allowed for collection of all sediment captured by the pretreatment practices which were transported back to the analytical laboratory to be measured in whole. Long-term field monitoring produces sub-samples which have been shown to be inaccurate for sediment measurement (Gettel *et al.* 2011). Though field-testing was used in this study, laboratory testing can be more accurate, more cost-effective, and a better method for comparing multiple practices side-by-side under identical conditions. This is explained in more detail in Lessons Learned.

Another advantage of field testing compared to monitoring is that the testing approach is based on the design storage volume of the bioretention and is independent of the actual contributing area. As described above, both the Anoka and Bloomington sites become filled to design volume with runoff from a 0.1-inch rainfall event, which is considerably less than the recommended capture volume of a 1-inch event (MPCA 2017b). If performance was measured by monitoring, it would be evident that the bioretention (and pretreatment practices) were undersized and frequently filled beyond capacity. Field testing, however, can supply exactly the design volume in multiple replicates to measure the performance of the pretreatment practice for the volume and sediment mass for which it was designed. In general, the testing protocol was similar between both sites and all five different pretreatment practices, as follows:

1. Prepare gross solids and sediment to be used in field testing,
2. Prepare for test by gathering all field equipment and transporting it to the field site,
3. Deploy field testing equipment at the field site,
4. Prepare the site by installing the pretreatment practice to be tested,
5. Thoroughly clean the pretreatment practice prior to testing,
6. Saturate the soil of the bioretention practice prior to the first test of a testing day,
7. Conduct a test, as follows:
    a. Open gate valve at water meter to begin flow,
    b. Adjust flow until target rate is achieved,
    c. Start sediment feed and stopwatch (t = 0), and record water meter reading,
    d. Periodically feed gross solids one handful at a time,
    e. Check flow rate and make slight adjustments if necessary,
    f. Stir sediment in sediment feeder supply as needed,
    g. Periodically record water depth inside the corral area (to be defined later),
    h. Take photos and notes as needed,
    i. When test volume reaches design volume or test volume, stop sediment feed, close valve to stop water flow, and record the stop time (total duration).
8. Drain or pump out excess water from the basin,
9. Carefully collect, label, and store sediment and gross solids,

10. Set up for the next test, if applicable, until all tests for that day are complete,
11. Restore pretreatment practice to normal operating condition,
12. Collect all field equipment and transport equipment and samples back to SAFL,
13. Process collected sediment and gross solids,
14. Record and check results.

It is important to note that a clean water "rinse" was performed at the beginning of each testing day to ensure clean conditions and saturate the bioretention soils so that infiltration characteristics were similar for all tests. The testing process is described in further detail in the following sections.

4.2 SYNTHETIC STORMWATER

Field testing uses synthetic stormwater to control the rate, volume, duration, and pollutant characteristics throughout testing. For this project, the synthetic stormwater consisting of potable water from municipal fire hydrants and carefully chosen solids added to the water to achieve a solids concentration of 200mg/L. The volume, duration, and flow rate of synthetic stormwater were selected based on the size of the bioretention facility and the water supply limitations. The volume of water used for testing corresponded to the design storage volume of the bioretention practice (600 cubic feet for Anoka, 150 cubic feet for Bloomington). Two flow rates were selected based on the capacity of the fire hydrant and duration over which the flow rates could be achieved. A flow rate of 0.25 cubic feet per second (cfs) for 40 minutes and a flow rate of 0.5cfs for 20 minutes were selected for tests conducted at the Anoka site (GLI, RGB, RGT, RLI). Because the flow volume for these events are identical, they will be described as low intensity (0.25cfs for 40 minutes) and high intensity (0.5cfs for 20 minutes). Two replicates of all these tests were performed.

For Bloomington, the tests of the shallow sump grit chamber at the design volume (BDV) proposed to use flow rates of 0.06cfs for 40 minutes (low intensity) and 0.12cfs for 20 minutes (high intensity), both of which correspond to a volume of 150 cubic feet. Actual test duration and flow volume were determined in the field based on actual storage volume within the bioretention. Two replicates for these tests were performed.

Additional tests for the shallow sump grit chamber were added to measure the performance when the storage volume within the in-line sump grit chamber and bioretention practice were exceeded (i.e., experienced bypass). For these bypass tests (BBP), flow rates of 0.12cfs for 40 minutes (low intensity) and 0.25cfs for 20 minutes (high intensity) were used. These tests correspond to a volume of 300 cubic feet, which is approximately 2.5 times the design volume of the bioretention. Only one replicate for each of these tests were performed, due to time constraints and weather. A summary of recorded volumes, flow rates, and test times is shown in Table 7 in the Appendix.

4.2.1 Solids composition

A study of stormwater runoff in the Twin Cities Metropolitan Area found that the average event mean total suspended solids (TSS) concentration was 184mg/L, based on 520 measurements (Brezonik and Stadelmann, 2002). While there is substantial variability in reported TSS concentrations, this value was used as a basis for choosing the total solids concentration of 200mg/L.

Typically, gross solids (GS) refer to solids larger than 4.75 mm, including vegetation and trash, while sediment refers to sediment less than 4.75 mm. For this project, a ratio of 80% sediment and 20% gross solids by mass was used to create the total solids at a concentration of 200 mg/L. From Kalinosky (2015), recovered solids from street sweeping were classified as fine solids (assumed to be principally sediment) or coarse organics (size > 2mm). Typical of many Minnesota watersheds, the proportion of coarse organics increased significantly in the autumn (September-November), while fine sediments peaked during early spring (February to April). The overall average proportion was approximately 80% fine solids and 20% coarse organics. Thus, a total solids concentration consisting of 80% sediment and 20% gross solids by mass was selected for testing in this project, as shown in Figure 15.

Figure 15. Synthetic stormwater solids composition. The height of each labeled box (left) is mass-proportional to the amount used in testing. The picture at right shows approximately the volume used of each component.

An adequate amount of sediment and gross solids had to be used in each test to ensure any error in the sample processing (collection, drying, weighing, etc.) would be minimal compared to the total mass measured. Given a total solids concentration of 200mg/L and a ratio of 80% sediment and 20% gross solids, the mass needed for each test was calculated based on the design volume for both the Anoka (600 cubic feet) and Bloomington field sites (150 cubic feet), as listed in Table 3.

Table 3. Target mass of sediment and gross solids for total solids loading of 200mg/L.

Solids type (% of Total)	Anoka (600 ft^3 design volume)		Bloomington (150 ft^3 design volume)	
	Mass (g)	Mass (lb)	Mass (g)	Mass (lb)
Sediment (80%)	2,718.4	5.99	679.6	1.50
Coarse Sand D_{50}=1.17 mm (26.7%)	226.5	0.50	56.6	0.12
Medium Sand D_{50}=0.41 mm (26.7%)	226.5	0.50	56.6	0.12
Fine Sand D_{50}=0.12 mm (26.7%)	226.5	0.50	56.6	0.12
Gross Solids (20%)	679.6	1.50	169.9	0.37
Forks (6.7%)	1,132.7	2.50	283.2	0.62
Leaves (6.7%)	1,132.7	2.50	283.2	0.62
Dowels (6.7%)	1,132.7	2.50	283.2	0.62
Total solids (100%)	3,398.0	7.49	849.5	1.87

4.2.2 Gross solids

Three types of gross solid (GS) material were chosen for testing: artificial leaves, wood dowels, and polypropylene forks. These items were chosen because they had properties similar to documented stormwater debris as summarized by McIntire *et al.* (2012), were cleanable and re-usable for multiple tests, non-degrading in water, stable during oven drying, amenable to handling, and readily available. Several other materials were evaluated and ultimately eliminated from use in testing because they did not meet the above criteria. Actual leaves and other organic materials (grass clippings, etc.), when used in testing, break apart into smaller particles and do not remain a consistent mass between wetting and drying cycles. Thus, the materials used in testing to represent gross solids and properties thereof are listed in Table 4.

Table 4. Properties of gross solids materials used in testing.

	Artificial Leaves	Dowels	Forks
Mass per piece	0.25 g	1.2 g	2.6 g
Dimensions	3.25" x 2.75"	5/16" dia x 1.5" length	5.75" length x 1" width
Material	polypropylene	hardwood	polypropylene
Name (source)	Gresorth (Amazon.com)	Fluted wood dowel pins (McMaster-Carr)	Medium weight forks (Litin's Party Value, Minneapolis)
Observed buoyancy	Initially float until saturated, then slowly sink except when suspended by air bubbles	Initially float, become neutrally buoyant or sink when fully waterlogged	Slowly sink except where suspended by air bubbles (rare)

Artificial leaves represent vegetation and are also similar in form to plastic or paper trash. The slight surface texture, jagged leaf-like edges, buoyancy, and flexibility mimic some properties of actual leaves. Wood dowels were chosen to represent cigarette butts, small organic debris (i.e., wood sticks), and floatables. Forks represent plastic debris, trash, or waterlogged (slightly sinking) sticks. Polystyrene utensils were tested but melted during drying and thus could not be used.

Polypropylene forks were found to be flexible and oven stable. Figure 16 shows a bag of synthetic gross solids next to actual gross solids recovered from the Bloomington field site during pre-cleaning.

Figure 16. A bag of synthetic gross solids used in testing (leaves, dowels, and forks) next to actual maple leaves and a cigarette butt recovered from the Bloomington site.

4.2.3 Sediment

Pretreatment for bioretention is primarily intended to capture particles greater than 100µm, as represented in Figure 17 (MPCA 2017b). To represent this range, the sediment portion of the synthetic stormwater solids consisted of a blend of one-third of each of three sizes of silica sand (Figure 18), each having a relatively narrow particle size distribution (Figure 19). Using a blend of three distinct sizes enabled sediment removal efficiency analysis for each size class as well as overall removal efficiency. The coarse sand (Agsco 12-20, D_{50} ~1170µm) and medium sand (Agsco 35-50, D_{50} ~410µm) were purchased in 50-lb bags from Agsco Corporation, Wheeling, IL (www.agsco.com). The fine sand (Agsco 120-200, D_{50} ~120µm) was a custom blend produced by Agsco.

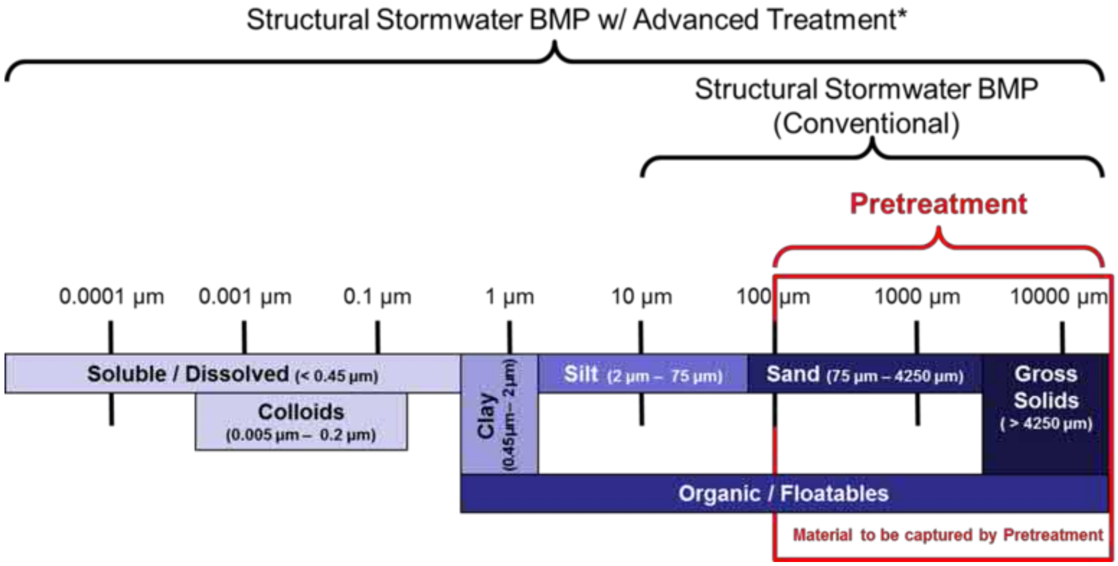

Figure 17. Pretreatment is intended to capture a portion of particles greater than 100µm (MPCA 2017b).

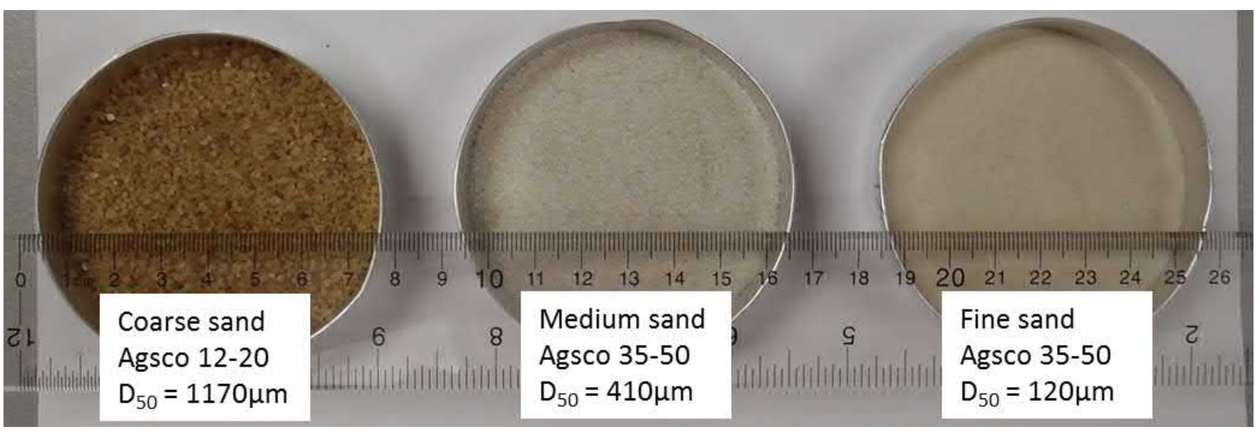

Figure 18. The three silica sands were blended in equal proportions by mass to create the sediment mix.

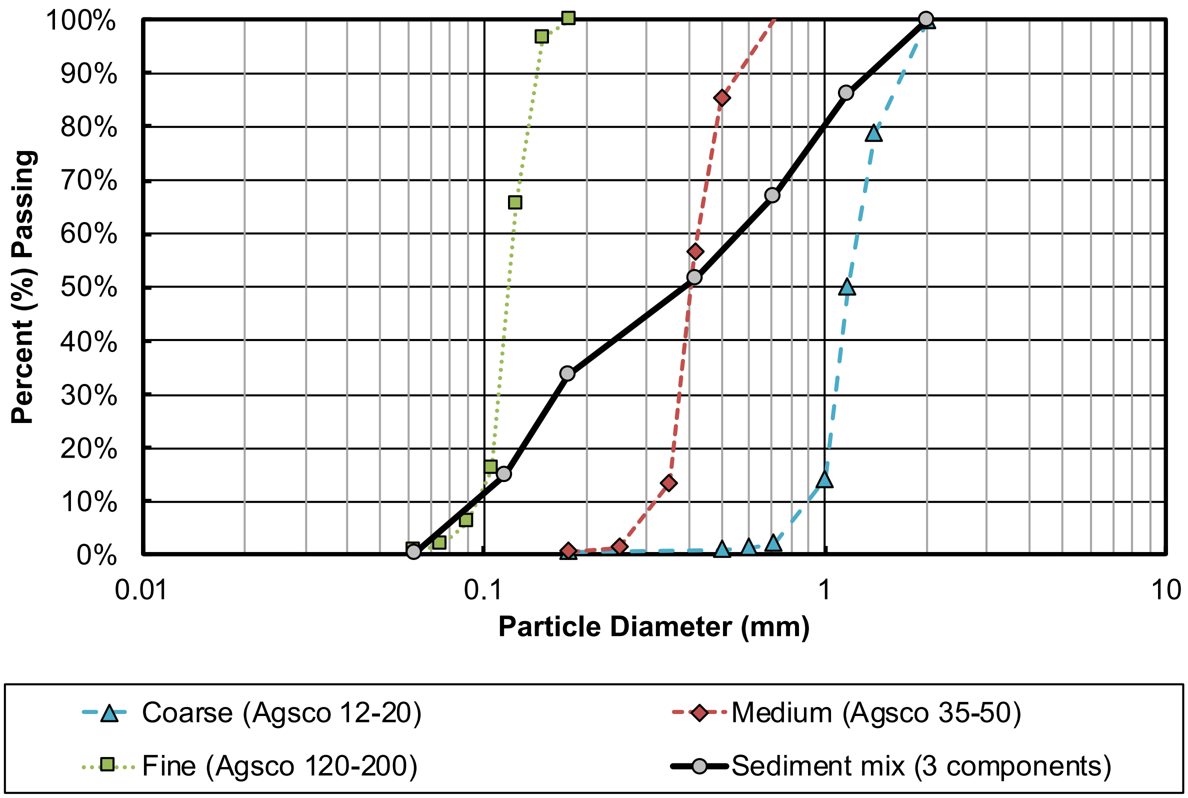

Figure 19. Particle size distribution chart of sand used in testing. Data from SAFL sieve testing.

Sieve analysis of the sediment was done at the SAFL sediment lab using standard 8-inch sieves. A Cole-Parmer Symmetry model S-PT 4202I balance with readability of 0.01g (10mg) was calibrated and used to measure mass of sediment, sieves, and gross solids. Comparison testing established there was no appreciable mass difference between oven-dry sediment and sediment taken from the supply bags, which were stored in the sediment lab. Therefore, masses for oven dry sediment taken from pretreatment devices were compared directly to initial masses taken from the stored sediment. Prior to each day of field testing, sediment was weighed and proportioned into labeled plastic zip top bags.

When sediment was collected from the pretreatment practices following testing, a sieve analysis was used to separate the coarse, medium, and fine sizes for comparison to the input values. After several trials, a set of 6 sieves was found to adequately characterize the sediment, with divisions between size classes shown in Table 5.

Table 5. Sieve analysis of whole sediment mix and division of sediment classes

US Std. Sieve #	Opening size (mm)	Percent passing	Sediment Retained
10	2.00	100.0%	Foreign material
16	1.17	86.2%	Coarse
25	0.71	67.1%	Coarse
40	0.42	51.5%	Medium
80	0.18	33.5%	Medium
(140 or 120)	0.12	14.9%	Fine
Pan	--	--	Fine

4.3 TEST EQUIPMENT

A substantial amount of equipment was needed to conduct field testing for this project, as shown in Figure 20. The equipment can be separated into several categories:

- Equipment was needed to control and deliver water to the pretreatment practice (hydrant, hose, and water meter supplied by the City of Anoka and City of Bloomington, respectively)
- Equipment to dissipate the energy from flow out of a fire hose and spread the flow evenly across the entire width of entrance into the pretreatment practice (barrel and flow spreader constructed by SAFL staff)
- Equipment to add sediment and gross solids at a constant rate throughout the duration of the tests (calibrated sediment feeder and SAFL staff adding gross solids by hand)
- Equipment to prevent sediment and gross solids from entering the bioretention practice ("corral" constructed of wire mesh and geotextile fabric, wire ties, stapler)
- Equipment to collect sediment and gross solids during grass lined inlet testing (new geotextile fabric large enough to fully capture any sediment and gross solids deposited in the corral)
- Equipment to draw water from within the bioretention cell after a test is complete (gas-powered pump, hose, intake screen, shovel and rake)
- Equipment to collect sediment and gross solids captured during tests (gas-powered generator, wet-dry vac equipped with custom-designed filter screen, garden hose and rinsing nozzles, clean buckets and tubs, custom-designed rinse rack for washing rock during rock lined inlet testing)
- Equipment to store and transport collected samples back to SAFL for analysis (clean buckets and zip top bags)
- Equipment to install and change pretreatment practice (wooden sloped frame, sod, rock, proprietary devices, battery-powered drills and screws, hammer, wrenches, stapler)
- Equipment to restore the site to operating condition (rake, shovel, hose and spray nozzle)

Figure 20. Field equipment used at Anoka field site.

4.3.1 Water supply and distribution

The City of Anoka Public Works water and sewer division supported the research by providing a hydrant flow meter, HPM model FHM03, with gate valve and a 2.5-inch hose for water supply. The City of Bloomington provided a 3-inch Sensus Omni H2/V2 water meter with gate valve and a long hose to reach from a nearby hydrant to the pretreatment practice. The hose end was secured to a hole near the top of a blue 55-gallon plastic barrel that dissipated turbulence from the high-pressure jet from the hose. At the bottom of the barrel, a 4-inch diameter pipe stub carried water to the flow distributor and level spreader. The flow distributor was constructed from wood and sheet metal to spread the incoming water to an even depth across 24 inches of width, to represent typical curb inlet flow. For tests conducted at the Anoka site, the edge of the flow distributor was located 18 inches upstream from the pretreatment practice lip and the distributor was centered in the curb inlet to the pretreatment practice. For tests conducted at the Bloomington site, the flow distributor was directed down the gutter line and into the grate (Figure 21). The flow distributor was modified to narrow the flow width to match the grate width.

Figure 21. Bloomington field site during pre-wetting flow. Flow enters the shallow sump through the curb grate and emerges into the fenced area of the rain garden through pipes, shown in a subsequent photo.

4.3.2 Sediment feeder and gross solids

A steady rate of sediment was supplied via an auger-type Accurate model 302 sediment feeder with a one-inch diameter nozzle and solid flight auger, which was powered by a small portable generator. The feed rate settings were calibrated at SAFL with the sediment mix on the basis of grams per minute. The feeder was mounted so that sediment fell in the center of the flow distributor and was carried downstream into the pretreatment practice by the flow (Figure 22). A metal plate was used in the first test to spread the falling sediment across the flow distributor, but moisture on the plate during testing begin to accumulate sediment by cohesion. Thus, the plate was rinsed and removed during the test to ensure all sediment discharged from the feeder was added to the distributor, and the pretreatment practice. The plate was not used in subsequent tests.

Figure 22. Sediment feeder and flow distributor.

Prior to each test, the sediment feeder was filled with the appropriate amount of pre-weighed and pre-mixed sediment blend. An additional 100g of sediment mix was added to the feeder to compensate for sediment remaining in the feeder and auger tube at the end of a given test. At the end of each test, sediment was carefully removed from the sediment feeder and auger tube by physically dumping it out from the top and sides of the feeder. This sediment was stored in a zip top bad and labeled "Not Fed" for analysis.

Prior to each test, the appropriate amount of pre-weighed gross solids was mixed into a bucket of clean water to allow the gross solids to become saturated and better represent gross solids that would be carried in stormwater to a pretreatment practice. Throughout the duration of each test, gross solids were carefully added by hand to the flow immediately downstream of the flow distributor.

During the field tests in Anoka, a clean geotextile fabric was placed on top of the concrete apron between the flow distributor and the pretreatment practice to ensure sediment or gross solids were not captured on the concrete apron prior to entering the pretreatment practice. The geotextile also prevented entrainment of any sediment, concrete, or gross solids that was on the apron, which would bias the results of the testing. This geotextile was observed throughout the duration of each test to ensure sediment and gross solids did not accumulate on its surface.

4.3.3 Downstream sediment and gross solids collection

To simplify cleanup and restoration, a "corral" was constructed to contain sediment and gross solids that flowed out of the pretreatment practice and into the bioretention. In addition, the corral was used to measure performance of the grass lined inlet, as described in section 4.5 below. The corral was constructed of hardware mesh with ½-inch square holes, attached to steel fence posts set into the ground. For testing in Anoka, the corral area was approximately 28 square feet, expanding from 48 inches wide at the bottom of the pretreatment practice to 67 inches wide, and was approximately 70 inches long. Geotextile fabric was clipped or clamped to the hardware mesh around the edges and weighted against floatation with clean stones at the bottom. The hardware mesh and geotextile were attached to the pretreatment practice frame so as to not allow flow through gaps.

The geotextile fabric would clog over time so that the water level inside the corral was higher than in the water level in the bioretention basin outside the corral. Thus, an overflow outlet was created in the fabric sides to prevent water from fully submerging the pretreatment practice and backing up into the curb inlet. Water levels were periodically measured inside the corral, referenced to the base slab (see Figure 4).

For the tests conducted in Bloomington, the corral was made of hardware mesh with ¼-inch openings and was approximately two feet wide and three feet long and did not include the geotextile fabric (Figure 23). This is because the bioretention was fully established with vegetation, and the corral could not be larger without impacting vegetation.

Figure 23. Gross solids containment area at Bloomington field site. Flow from the shallow sump box enters the bioretention basin through the three pipes at right.

4.3.4 Drain pump

To allow for as many tests as possible in each testing day, the water within the bioretention practice was removed using a three-inch gas-powered semi-trash pump. The pump intake was installed within a five-gallon plastic bucket that was placed in an excavated hole in the bottom of the bioretention at the Anoka site. In Bloomington, a smaller pump was used and placed directly on the bottom of the bioretention basin. Fencing was used to control the movement of floating wood mulch toward the pump, but raking was still required to redistribute the mulch after testing. A small electric submersible pump was also used during some tests to dewater the area immediately adjacent to the pretreatment practice.

4.3.5 Field collection of sediment and gross solids

Gross solids were collected by hand in all tests and transferred directly to a properly labeled storage containers. Hands were washed prior to gross solids collection, and hands and any other items contacting the gross solids and sediment were carefully rinsed after collection into the appropriate location so as not to misallocate mass.

A device was needed to collect sediment from within the pretreatment practices, but that would allow the collected sediment to be quickly and easily separated and stored for transport back to SAFL for analysis. A standard wet-dry vacuum could collect wet sediment, but fine sediment could become trapped within the filter cartridge or mesh filter screen within the vacuum. To overcome this limitation, a secondary filter bucket (Figure 24) was constructed to capture and contain collected sediment. A nozzle and green flexible hose were connected to an inlet pipe, which were attached with a gasket to the lid of a standard 5-gallon bucket. A fine screen (#270 mesh, 53µm) was wrapped around a mesh cylinder within the bucket, which also sealed to the 5-gallon bucket lid and connected to a standard 5-hp Shop-Vac wet-dry vacuum via a black outlet pipe. The lid was then attached to a clean 5-gallon bucket. When the wet-dry vacuum was running, suction would collect wet sediment through the nozzle and into the 5-gallon bucket, but the #270 mesh screen would prevent sediment from leaving the bucket or entering the wet-dry vacuum. Thus, sediment was collected within the 5-gallon bucket.

When wet sediment was difficult to collect within a pretreatment practice, a plastic squeeze bottle with clean water was used to mobilize sediment as the wet-dry vacuum collected it. In addition, this bucket-collection system was most efficient when using two pre-cleaned buckets. Once the first bucket was partially filled with a water/sediment mix, the lid with attached hoses was carefully switched to a second bucket to continue vacuuming. Meanwhile, water from the first bucket was poured through a #325 sieve (US Standard mesh, 44µm) to separate collected sediment from the water. Once all sediment water collected from the pretreatment practice, the nozzle, hose, filter, and second bucket were thoroughly rinsed into a single bucket and partly decanted through the sieve so that all sediment was captured in a single bucket. This bucket was then sealed, properly labeled, and transported back to SAFL for analysis.

Figure 24. A filter bucket was designed to trap sediment in the 5-gallon bucket (right), with suction provided by a wet-dry vac (left).

4.3.6 Sample storage

Sediment collected during field testing was stored in clean 5-gallon plastic buckets with lids, sealed with duct tape, and labeled prior to transportation back to SAFL for analysis. Gross solids were collected by hand and stored in clean, clear, zip top bags, then sealed and labeled prior to transportation back to SAFL for analysis. For tests in which geotextile fabric was used to collect sediment and/or gross solids, the fabric was carefully folded to retain solids, stored inside a large zip top bag, labeled, and placed inside a clean 5-gallon bucket for transportation.

4.4 SAMPLE PROCESSING AND ANALYTICAL METHODS

Labeled containers of gross solids and sediment, sealed zip top plastic bags or sealed 5-gallon buckets, were transported to SAFL at the end of each testing day and stored until processing could be completed. For the first few runs, sediment and foreign material was rinsed from the gross solids under running water on coarse mesh over a watertight bin (Figure 25). All water from the bins was poured through coarse (US standard #10, 2mm opening) and then very fine (US standard #325, 44μm opening) sieves (Figure 26). The #10 was chosen because the openings are larger than any sediment that was used in field testing and thus anything captured on this sieve is foreign material that was not part of the testing. Material retained on the coarse sieve such as grass blades and seeds were gently rinsed to remove any sediment, then discarded. Sediment retained on the #325 sieve was rinsed into pans for oven drying and processing. Because the #325 sieve is finer than any sediment used in testing, any material passing this sieve was discarded.

Figure 25: Rinsing gross solids on a mesh box over a watertight bin. This method was later revised (see Figure 27).

Figure 26. The rinse bin was poured carefully through a #325 sieve to retain sediment particles.

A more effective and efficient method was developed using two 5-gallon buckets (Figure 27). A bag of gross solids was emptied into a clean bucket then rinsed to remove any sediment clinging to the bag. The bucket with gross solids was filled about three-quarters full with clean water. A second clean bucket was also filled about three-quarters full with clean water. Small, loosely held handfuls of gross solids were gently swirled and shaken while underwater in the first bucket, then carefully removed and placed into the second bucket. Once all the gross solids were transferred to the second bucket, the water from the first bucket was poured through the #10 sieve to exclude foreign materials larger than 2mm and through a #325 sieve to retain test sediment. In addition, the bucket was rinsed, and rinse water was also passed through the sieves. Any sediment retained on the #325 sieve was added to a sediment drying tray and properly labeled.

Figure 27. Two bucket rinse method of cleaning sediment from gross solids. The grey mesh wastebasket (lower left) was used to dry gross solids in the oven.

Using the same submerged swirling process, gross solids were moved from the second bucket to a labeled drying bin (wire mesh wastebasket) for drying in a large sediment oven. The second bucket was then poured through the sieves, and the sediment was added to the collected sediment tray. There were typically only a few grains of sediment in the second bucket; if more was apparent, a third rinse cycle was added. After fully drying in the oven at 200°F for at least 24 hours, the gross solids were sorted and weighed by type (leaves, dowels, forks).

Captured sediment was transferred from buckets or bags to labeled metal pans for oven drying. Excess water was removed from the sediment using a #325 sieve (Figure 28). Sediment was dried in the oven at 200°F for at least 24 hours and then sieved to determine particle size distribution. When necessary, the dry captured sediment was split into several portions to be sieved sequentially. Weights were recorded on paper sheets (Figure 29), and then input into a spreadsheet for calculations of percent passing each sieve. All of the sequential portions were totaled. The pre-sieve total mass was compared to the sum of the sequential portions and samples were re-sieved if error was significant. The small amount of “not fed” sediment removed from the feeder was sieved and weighed in the same manner as the captured sediment. The average percent error for all sieved samples was 0.29% (n = 74).

Figure 28. Rinsing sediment from a sieve into a pan for oven drying.

Sieve Analysis Data Sheet
ASTM D422-63(2007)

Project Name: Pretreatment   Tested By: P.O.   Date: 6/26/18
Sample No.: Rep 6/6   Checked By: MAH   Date: 7/12/18
Sample Desc.: RLI050A - Captured

Weight of Container (g): 38.07   A
Weight of Container & Soil (g): 334.27   B
Weight of Total Dry Sample (g): 296.20   C = B - A

1st sieve J_1 = 100 - I_1, all others J_2 = J_1 - I_2.

D	E	F	G	H = G - F	I = H / C x 100	
Sieve Number	**Diameter (mm)**	**Mass of Sieve (g)**	**Mass of Sieve & Soil (g)**	**Soil Retained (g)**	**Soil Retained (%)**	**Soil Passing (%)**
10		474.13	474.38			
16		357.48	419.72			
25		406.02	494.12			
40		342.98	383.02			
80		342.78	369.46			
120		530.44	560.89			
Pan		362.97	369.53			
			TOTAL:	254.32		

Figure 29. Sample sieve analysis data sheet.

4.5 GRASS LINED INLET

4.5.1 Testing setup and cleanup

To install a GLI within the bioretention site in Anoka, a wooden frame was constructed to support the GLI, simulate infiltration of water through the GLI, and capture of sediment and gross solids on the surface of the GLI. The wood frame was constructed by ACD as a sloped plywood surface that was attached to the outer frame of the original Rain Guardian Bunker at the Anoka site (Figure 30). Several small holes were drilled along horizontally-oriented shallow grooves in the plywood (T1-11 siding) to simulate infiltration into the subsoil. The frame was constructed so that the top of the sod was approximately level with the curb inlet edge at the entrance, and approximately level with the bioretention bottom elevation at the exit of the GLI.

Figure 30. Wood frame and slope used for rock- and grass-lined inlet testing.

Commercially grown bluegrass sod was purchased and installed on the day of testing (Figure 31). The sections of sod were rolled out perpendicular to the flow direction and seams were closed as tightly as possible to prevent water flow between sections and under the sod. In addition, the sod was attached to the wooden frame with standard wood screws through the root mat (approximately 1-inch thick). Fresh sod was used for each test. After the first test, sod was wrapped up the sides of the box to minimize turbulence and lifting of the edges of the sod.

Figure 31. Preparing the grass lined inlet with fresh sod.

As described previously, sediment and gross solids are captured on the surface of a GLI. When removing this sediment after a test, however, it is likely that grass and organic soil associated with the sod would also be collected. Separating test sediment from solids contributed by the sod would be challenging and time consuming. Thus, performance was measured by comparing the influent sediment to the amount of sediment that was NOT captured by the GLI, but rather was delivered to the bioretention. Also, because fresh sod was used for each test of the GLI, a clean water rinse of approximately 300 cubic feet was passed over the GLI to wash away any loose grass clippings or soil material prior to testing.

As previously described, a “corral” was constructed to capture gross solids and sediment that flowed out of the pretreatment practices during testing. For the GLI tests, a new, seamless piece of nonwoven geotextile (Propex Geotex 801) was added to the corral for each test run. Prior to field testing, this geotextile was tested in the laboratory to ensure it allowed water to pass through but retained the sediment used in field testing. Clean rocks were used to weigh the fabric to prevent floating (Figure 32).

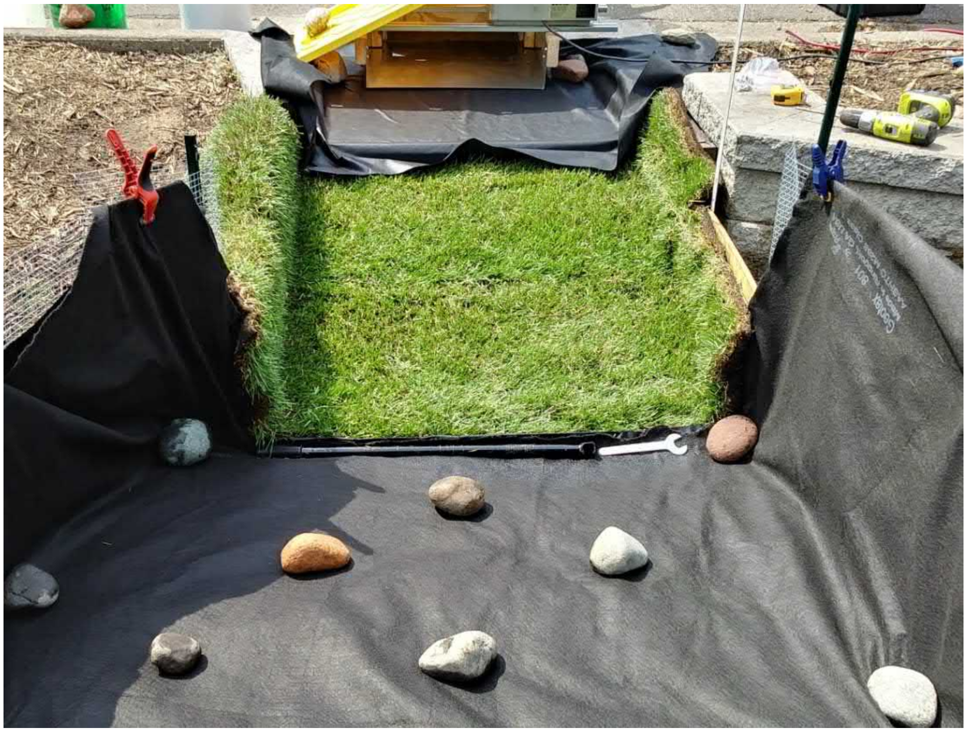

Figure 32. Grass lined inlet with fabric lined corral, after rinsing, ready for a test.

Figure 33 is a photograph taken during the GLI-025-B (grass lined inlet, 0.25 cfs flow rate, replicate B) test run. At the end of each test, the water was drained from the bioretention as described above and any gross solids resting on or in the grass were collected, properly stored, and labeled "captured." In the corral area, sediment was rinsed off the weight stones onto the geotextile. Then, excess geotextile that was clearly not touched by sediment was cut off and the remaining sediment-laden geotextile was carefully folded to retain sediment and gross solids and stored for lab processing. After all samples were collected, the site was prepared for a subsequent test or restored to an operational condition.

Figure 33. Flow on grass lined inlet at 0.25 cfs (GLI-025-B).

4.5.2 Sample processing

At the laboratory, the geotextile containing the non-captured (passing) sediment and gross solids was spread out on a plastic sheet. Gross solids were removed by hand (Figure 34) and rinsed to remove and retain sediment as described above. The geotextile was cut with a heavy scissors into pieces approximately 4 ft by 6 ft for ease of handling. Then, each piece of fabric was thoroughly rinsed with clean water over a watertight bin (Figure 34). This process required one person to hold and manipulate the fabric and one person to spray sediment down the fabric into the bin. Beyond this, samples were processed as described above.

Figure 34. For the grass lined inlet, solids passing the pretreatment and landing in the geotextile were processed and weighed. Gross solids were removed from the geotextile at SAFL (left) and sediment was rinsed from the fabric (right).

4.6 RAIN GUARDIAN BUNKER

4.6.1 Testing setup and cleanup

Testing setup for the RGB required no additional setup because the site was originally designed and constructed with an RGB. Thus, the site simply needed to be cleaned prior to testing. Figure 35 is a photo taken during RGB testing. After a test was complete, gross solids were carefully removed from the top grate by hand and sediment was rinsed from the grate into a bin and decanted through a #325 sieve. The chamber area below the grate and upstream of the screen wall (sometimes noted as pre-screen) was cleared of gross solids by hand. Then sediment was removed from the chamber using the custom filter bucket described above. Gross solids were removed from the screen wall, which was then disassembled and rinsed in a bin (Figure 36) to remove sediment from the screen, backing, and aluminum rails. ACD provided a new screen wall assembly for each of the four tests to eliminate the possibility of cross-contamination and allow for quick re-assembly of the Bunker between tests. Sediment was also collected from the small area of slab just beyond the screen wall and counted as captured because this area is also part of the surface prescribed for maintenance by ACD. All of the capture locations were combined for reporting. After all samples were collected, the site was prepared for a subsequent test or restored to an operational condition.

Figure 35. Rain Guardian Bunker at 0.5cfs test flow (RGB-050-A)

Figure 36. Rinsing the partially disassembled Rain Guardian Bunker screen wall in a bin (foreground) and vacuuming captured sediment from the bunker (background).

4.6.2 Sample processing

Sediment and gross solids were collected separately from several "captured" locations (grate, chamber, screen wall, immediately downstream of screen wall), and separate processing was maintained for each of these locations. Gross solids recovered from the corral area were cleaned and dried as described but not weighed or quantified. Beyond this, samples were processed as described above.

4.7 RAIN GUARDIAN TURRET

4.7.1 Testing setup and cleanup

The RGT is made of concrete and weights slightly over 1,000 lbs, precluding easy installation and removal at the Anoka bioretention site. Instead, ACD supplied a dimensionally accurate lightweight replica of the Turret (Figure 37) which was used for testing in conjunction with normal grates and screen wall. To form the base, a short plywood box with a top elevation the same as the Bunker concrete base slab was overlain by a piece of geotextile fabric with a 1/8th inch sheet of clear polycarbonate plastic on top. Weatherstripping on the underside of the Turret model allowed a sediment-tight seal with the clear plastic sheet. The Turret was held in place by the weight of the top grates (~160 lb) and a ratchet strap to the Bunker frame. Waterproof tape was used to seal slight gaps at the curb inlet lip transition, which was overlain by a piece of geotextile fabric positioned under the flow distributor as described above.

Figure 37. A special lightweight replica of the Rain Guardian Turret was used in testing at the Anoka site.

The test procedure as described above was followed. Figure 38 and Figure 39 show the RGT during testing. After testing, the heavy grates required two people to lift off and suspend over a bin to rinse down any attached sediment. Figure 40 is an example of the cleanout process for the RGT. Similar to the RGB, sediment was collected from the area directly in downstream of the screen wall according to manufacturer's maintenance guidance. After all samples were collected, the site was prepared for a subsequent test or restored to an operational condition.

Figure 38. Rain Guardian Turret testing at 0.25cfs (RGT-025-A).

Figure 39. Rain Guardian Turret testing at 0.50cfs at a high water level (RGT-050-B).

Figure 40. Cleanout gross solids and sediment from the Rain Guardian Turret.

4.7.2 Sample processing

Sediment and gross solids were collected separately from several "captured" locations (grate, chamber, screen wall, immediately downstream of screen wall), and separate processing was maintained for each of these locations. Beyond this, samples were processed as described above.

4.8 ROCK LINED INLET

4.8.1 Testing setup and cleanup

To install a RLI within the bioretention site in Anoka, a wooden frame was constructed to support the RLI, simulate infiltration of water through the RLI, and capture of sediment and gross solids within the RLI. This wood frame was identical to the wood frame constructed for the GLI and described in section 4.5.1 above, but installed slightly lower in elevation such that the top of the rock was approximately level with the curb inlet edge at the entrance, and approximately level with the bioretention bottom elevation at the exit of the RLI. The end of the slope extended several inches below the grade of the mulch layer on the basin floor and rocks were held in place by a short vertical piece of wire mesh with half inch openings. The frame was covered with geotextile fabric shingled horizontally at a seam and extending up the frame walls. The fabric also extended under the water distribution pan such that no sediment could escape from the system through small cracks or gaps.

Round, pre-washed cobbles 3 – 5 inches in diameter were then placed on the fabric and approximately leveled. Although an effort was made to remove unsound rocks before any testing, a number of rocks showed wear or chipped pieces in the first test. These rocks were removed from further testing and the pieces removed where possible in post-test processing. Figure 41 shows the

RLI with water beginning to flow, immediately prior to the start of sediment feed at t=0. Figure 42 illustrates the post-test condition for two tests.

Figure 41. Beginning of flow on RLI, just prior to the start of a test. Gross solids and sediment are ready to be fed.

Figure 42. Rock lined inlet after testing at 0.25 cfs for 40 minutes (left) and 0.50 cfs for 20 minutes (right).

Immediately following each test, water was drained down and gross solids were removed from the surface of the rocks and placed in a labeled container (Figure 43) for processing at the lab. Stones were then removed and thoroughly rinsed onsite (Figure 44) with a hose and sprayer over a watertight bin. The bin was periodically decanted through a #10 sieve (2mm openings) and a #325 sieve, as described above. Sediment from the sieve was then transferred to a labeled container for processing at the lab. After all rocks were rinsed, the bin was thoroughly rinsed with all rinse water passing through the sieves. After the rocks were removed, a considerable amount of sediment remained on the geotextile fabric below (Figure 45). The fabric was cut and carefully folded to contain sediment, then transferred to a labeled container for processing at the lab. After all samples were collected, the site was prepared for a subsequent test or restored to an operational condition.

Figure 43. Removal of gross solids from the rock lined inlet.

Figure 44. Rinsing rocks from the rock lined inlet.

Figure 45. Sediment remaining on geotextile when rocks were removed from RLI.

4.8.2 Sample processing

At the laboratory, the geotextile containing the captured sediment that was present under the rocks was rinsed into a water tight bin and processed as described above. Beyond this, samples were processed as described above.

4.9 SHALLOW SUMP GRIT CHAMBER (DV)

4.9.1 Testing setup and cleanup

Testing at the in-line shallow sump grit chamber in Bloomington was slightly different than testing at the sites in Anoka, as described above. In addition, some specific modifications to the practice or site were made to accommodate testing. The base slab of the shallow sump grit chamber has five (5), four-inch diameter holes designed for infiltration, which were plugged with red plumbing test plugs to limit the loss of test solids into the holes (Figure 46). During testing it was observed that water could seep into the chamber around some plugs and in the gap between the base slab and walls. It is unclear whether sediment or water were lost through these unsealed seams.

Figure 46. A wet-dry vac was used to remove sediment from the bottom of the Bloomington sump. The red plugs were inserted to seal infiltration holes in the slab to limit sediment loss.

After setting up the flow distributor along the curb line (Figure 21), the pretreatment practice and bioretention basin was flushed with water, and then pumped down. The grate was thoroughly rinsed. The connecting pipes were then sprayed out and the sump was hosed down and cleaned. For testing at this site, cleaning the sump after rinsing was necessary before every test.

For the first test at the design volume (BDV), water flow rate adjustment was done before beginning the sediment feed at t=0. However, due to the small basin volume, subsequent tests started sediment feed at t=0 as soon as water began to flow through the distributor. Flow rate was the adjusted in the first few minutes of the test. For the design volume tests (BDV), each test was run until just before overflow of water to the downstream gutter, when the water elevation was at the top of the grate. This occurred at staff gauge elevation of approximately 12 inches above the bottom of the bioretention basin. When this water elevation was reached, the sediment feeder was shut down, the water was turned off, and the stop time was recorded. Test duration was approximately 15 minutes for the 0.06 cfs flow rate and 30 minutes for the 0.12 flow rate, compared to the proposed test duration of 20 minutes and 40 minutes, respectively.

Collection of sediment and gross solids was similar to collection from the chambers of the RGB and RGT but was complicated by the presence of standing water in the sump. The first step after flow was shut off was to slowly pump the water out of the bioretention basin. The drain rate was slow enough that sediment and gross solids were not observed to move. After the water receded to the invert level of the pipes connecting the sump to the bioretention, the grate surface was gently rinsed into the sump, then raised in place and rinsed again to remove any sediment, then removed and placed out of the way. There was typically very little accumulation of gross solids and sediment on the grate. Gross solids were then removed by hand from the sump and placed in labeled containers for lab processing.

Clear water in the sump was pumped away with a suspended, small submersible pump to within about three inches of the sediment surface so as not to entrain sediment. The remaining water was vacuumed off using a wet-dry vacuum and filter bucket as described in Section 4.3.5 . This water was passed through the #325 sieve to retain any sediment. Vacuuming then continued to remove all the captured sediment (Figure 46) as described above. This was complicated by the gap between the bottom slab and wall; applying too much suction near the wall tended to draw in fine organic particles (Figure 47), which were excluded where possible. Captured sediment from the filter bucket was labeled and stored for lab processing. Any sediment in the connecting pipes was rinsed into the bioretention basin and was not counted as captured. The corral was cleaned of gross solids, which was bagged and taken to the lab for cleaning but was not counted or weighed. After all samples were collected, the site was prepared for a subsequent test or restored to an operational condition.

Figure 47. Fine organic material retained on sieve.

4.9.2 Sample processing

Samples were processed as described above.

4.10 SHALLOW SUMP GRIT CHAMBER (BYPASS)

4.10.1 Testing setup and cleanup

To measure the performance of the shallow sump grit chamber during bypass conditions, sediment and gross solids had to be collected in additional locations: in the gutter downstream of the sump and in a second downstream catch basin, which is connected to the city's storm sewer system. This was accomplished by fitting the downstream catch basin with a geotextile basket to capture solids (Figure 48), and thoroughly cleaning the 6 feet of gutter between the two catch basins by flushing and vacuuming before testing. The grate of the downstream catch basin was also thoroughly rinsed. The geotextile fabric was secured below the grate of the downstream catch basin and all gaps were sealed or covered with waterproof tape. The flow distributor was also sealed to the frame of the pretreatment practice inlet to prevent sediment or gross solids from backing up the curb line during elevated water due to bypass flows.

Figure 48. For the bypass tests of the Bloomington pretreatment practice, the downstream catchbasin was lined with a geotextile basket to capture sediment and gross solids bypassing and/or washing out of the pretreatment practice.

As previously described, the bypass tests used approximately twice the design volume to induce bypass of the pretreatment practice, as shown in Figure 49. At the highest flow rate (BBP-025), the test was stopped slightly early (test duration = 30 minutes) because the geotextile basket in the downstream catch basin was on the verge of bypassing.

At the conclusion of the test, water was shut off and the surcharged bioretention basin was allowed to drain down before being pumped out. Sediment and gross solids in the shallow sump grit chamber were collected as described above. Collection of sediment and gross solids that had bypassed the pretreatment consisted of thoroughly vacuuming the street gutter between the pretreatment inlet and the downstream catch basin and collecting the geotextile fabric basket from the downstream catch basin. The catch basin grate was rinsed down into the fabric with clean water, then the grate was raised and rinsed further before removal (Figure 50). Excess fabric was cut off and then the fabric with sediment and gross solids was carefully removed and placed in a labeled container for lab processing. After all samples were collected, the site was prepared for a subsequent test or restored to an operational condition.

Figure 49. Flow in the gutter during bypass (BBP-025-A).

Figure 50. Gross solids and slight amount of sediment captured on geotextile fabric in the downstream catch basin frame (BBP-012-A).

4.10.2 Sample processing

Samples were processed as described above.

4.11 CALCULATIONS

The calculation of solids removal is shown in the following mass balance equation and is the same for both sediment and gross solids. The captured dry mass is the material captured by the pretreatment practice that has been oven dried and weighed; and the net initial dry mass is the mass fed to the system minus any mass not fed.

$$Removal = (captured\ dry\ mass)/(net\ initial\ dry\ mass)$$

For the gross solids, the net initial dry mass was the pre-weighed amount prepared at the laboratory minus any gross solids not fed to the system. In all but one replicate, the complete amount of gross solids was fed during the tests. For the sediment, the net initial dry mass is the pre-weighed amount prepared at the laboratory minus the "not fed" amount recovered from the sediment feeder. This calculation was repeated for each sediment fraction and type of gross solid, and then combined for a grand total for each test run. The following is an example calculation for the smallest sediment size (D_{50}~120µm, designated as) for test RLI-050-A:

$$Removal\ of\ D_{50}120\mu m = \frac{captured\ dry\ mass}{net\ initial\ dry\ mass} = \frac{311.76g}{939.47g - 29.06g} = 0.342 \times 100\% = 34.2\%$$

A similar example calculation for artificial leaves, designated as part of the gross solids mix, also for test RLI-050-A:

$$Removal\ of\ leaves = \frac{captured\ dry\ mass}{net\ initial\ dry\ mass} = \frac{226.47g}{79.64g - 0g} = 0.351 \times 100\% = 35.1\%$$

An example calculation for the total of all sediment in RLI-050-A:

$$Removal\ of\ total\ sediment = \frac{2162.63g}{2818.34g - 46.56g} = 0.780 \times 100\% = 78.0\%$$

This same process is also used for the bypass tests (BBP) because the net initial dry mass and captured dry mass are measured directly. The additional mass collected as bypass is reported to illustrate the potential for resuspension.

For the GLI, the mass of solids retained within the GLI was not measured and thus the above calculation is not possible. For the GLI test data, a modified removal calculation was used:

$$Removal = \frac{net\ initial\ dry\ mass - untreated\ dry\ mass}{net\ initial\ dry\ mass}$$

The net initial dry mass is the same as above and is equal to the mass fed to the system minus any mass not fed. The untreated dry mass is the material that passed untreated through the pretreatment practice and was captured downstream in the corral and has been oven dried and weighed. An example calculation is below with data from test run GLI-050-A for the intermediate sediment, identified as D_{50}~410µm. A total of 939.47g of the intermediate sediment was placed in the feeder, 21.35g were collected from the feeder after the test as not fed, and 179.93g was collected in the corral (untreated):

$$Removal\ of\ \ D_{50}410\mu m\ = \frac{(939.47g - 21.35g) - 179.93g}{939.47g - 21.35g} = 0.804 \times 100\% = 80.4\%$$

It is important to note that the calculations for the RGB, RGT, RLI, BDV, and BBP all calculate performance efficiency directly from the mass captured within the pretreatment practice, whereas the calculation for the GLI is based on the difference between input and untreated mass. Thus, any error associated with the measurements are mathematically included in the performance of the GLI and omitted from the performance of the other pretreatment practices. In general, this would bias the performance of the GLI to be larger (i.e., better) than the actual performance by the amount of the error. The error is discussed in Section 5.3 Error and Uncertainty.

Calculations were repeated for each flow rate and replicate. Actual calculations were performed in a spreadsheet. Results are reported in CHAPTER 9: Appendix.

Precision was calculated using the Relative Percent Difference (RPD) to determine how much two or more data replicates are in agreement with each other. For this project, two replicates (A & B) were conducted for each pretreatment practice for each flow rate tested (except for the bypass tests). From this data, the Relative Percent Difference (RPD) was calculated as follows:

RPD = (A – B) ÷ ((A + B) / 2) x 100

where A is the larger of the two duplicate sample values and B is the smaller value.

CHAPTER 5: RESULTS AND DISCUSSION

5.1 ANOKA SITE: GRASS LINED INLET, RAIN GUARDIAN BUNKER, RAIN GUARDIAN TURRET, AND ROCK LINED INLET

5.1.1 Sediment Capture

5.1.1.1 Low intensity (Q = 0.25cfs for 40 minutes)

Sediment capture for the tests designed to simulate the design storage volume of the bioretention practice (600 cubic feet for Anoka) for the low intensity flow conditions is shown in Figure 51. In general, all pretreatment practices captured at least 95% of the coarse sediment fraction (D_{50} = 1.17mm) mass and the medium sediment fraction (D_{50} = 0.41mm) mass. The pretreatment practices also captured 65 – 80% of the fine sediment fraction (D_{50} = 0.12mm).

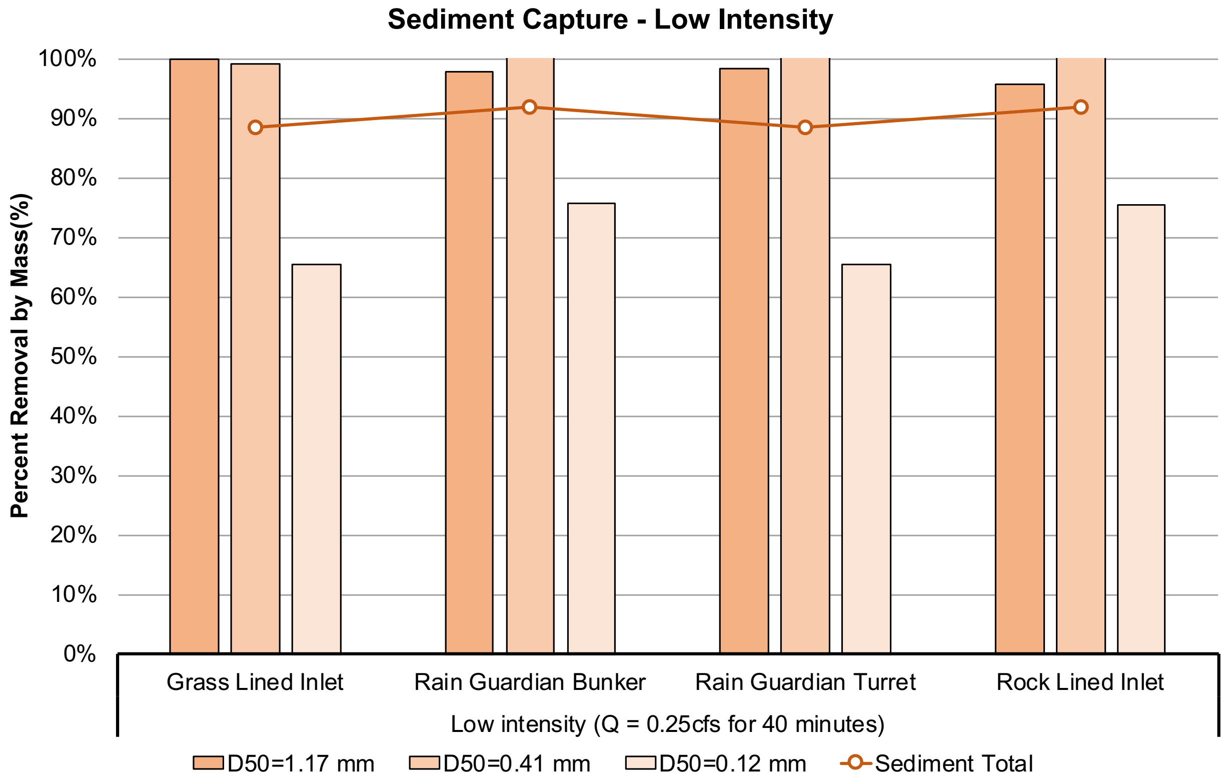

Figure 51: Sediment capture by percent for design volume low intensity tests (Q = 0.25cfs, duration = 40 minutes).

The purpose of pretreatment is to reduce the maintenance burden on primary treatment practices (i.e., bioretention) by capturing gross solids and 25% of the sediment > 100µm (MPCA 2017a). As shown in Figure 19, approximately 90% of the fine sediment fraction used in testing is between than 0.1mm (100 µm) and 0.2 mm. As shown in Figure 51, 65 – 80% of this fine sediment fraction was captured by all four pretreatment practices for low intensity tests. When all three sediment fractions are summed, 88 – 95% of the sediment mass was captured by the pretreatment practices.

Thus, these pretreatment practices exceed the goal set by the MPCA for these simulated flow conditions.

Due to the high velocity of the water, and short length and flexibility of the grass, it was unclear whether the GLI would be able to capture sediment effectively. As shown in Figure 51, over 90% of the total sediment was captured in the GLI for low intensity tests. This data was corroborated by visual observations of a significant accumulation of sediment on the grass during testing (Figure 52). This accumulation was most evident near the seam between sod sections, but sediment accumulation was observed throughout the GLI.

Figure 52. Sediment accumulation near the horizontal seam between sod sections in the GLI. Flow was right to left.

The Rain Guardian Bunker and Turret both captured approximately 90% of the test sediment, most of which was captured within the chamber of the devices (data in Appendix A). Some sediment was also captured on the surface grate in association with gross solids (primarily leaves), and some sediment was deposited downstream of the screen wall on the concrete base pad. The sediment downstream of the screen wall likely didn't flow through the screen, but rather flowed over the screen water during high water conditions and settled on the pad.

5.1.1.2 High intensity (Q = 0.50cfs for 20 minutes)

Sediment capture for the tests designed to simulate the design storage volume of the bioretention practice (600 cubic feet for Anoka) for high intensity flow conditions is shown in Figure 53. In general, all pretreatment practices captured at least 95% of the coarse sediment fraction (D_{50} = 1.17mm) mass and the medium sediment fraction (D_{50} = 0.41mm) mass, except for the grass lined inlet (GLI) which only captured 80% of the medium sediment fraction (D_{50} = 0.41mm). The pretreatment practices also captured 30 – 40% of the fine sediment fraction (D_{50} = 0.12mm).

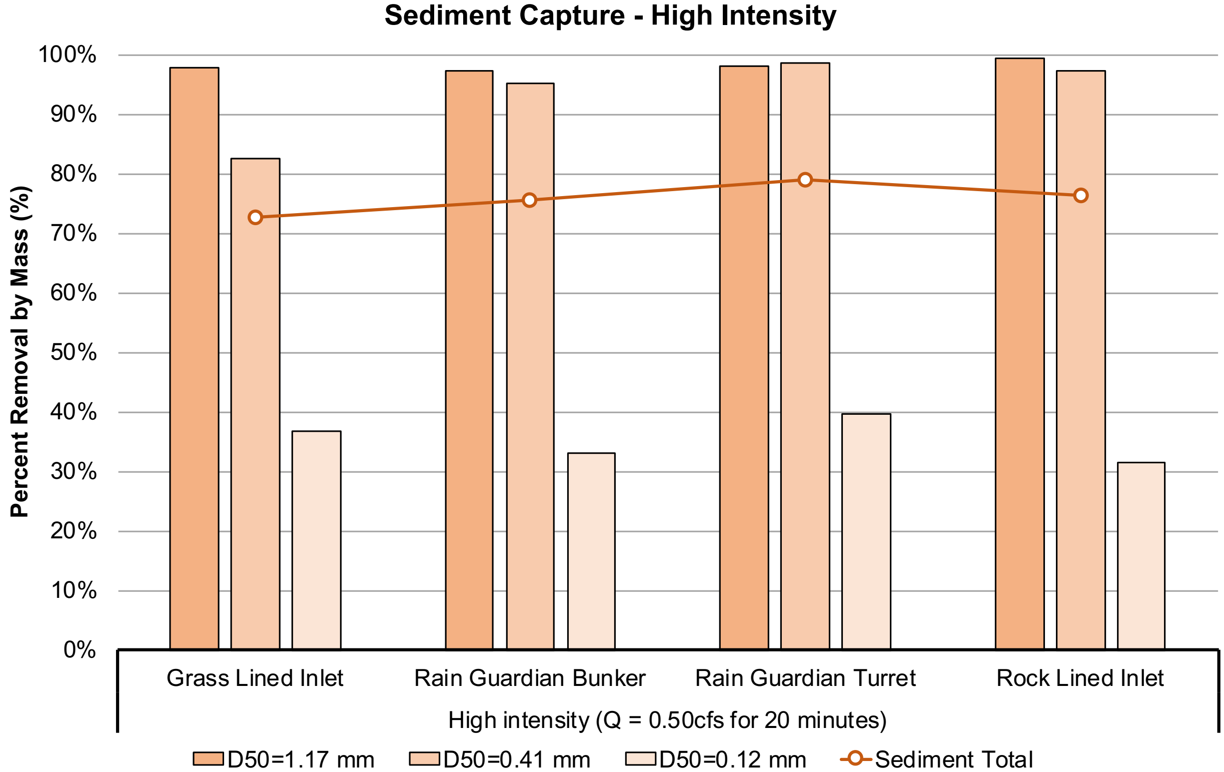

Figure 53: Sediment capture by percent for design volume high intensity tests (Q = 0.50cfs, duration = 20 minutes).

For all practices and all sediment fractions, less sediment was captured in the high intensity tests (Figure 53) compared to the low intensity tests (Figure 51). This is expected because higher flow creates more turbulence, more mixing, and shorter residence time within the pretreatment practice, and likely causes more overflow from the pretreatment practice into the primary practice (i.e., bioretention). All practices did, however, capture greater than 30% of the fine sediment fraction and at least 70% of the total sediment mass, which exceeds the goal of 25% capture of sediment > 100µm (MPCA 2017a).

5.1.2 Gross Solids Capture

5.1.2.1 Low Intensity (Q = 0.25cfs for 40 minutes)

Gross solids capture for the design volume low intensity test is shown in Figure 54. The RGB, RGT, and RLI captured over 98% of the mass of forks and leaves. The GLI, however, only captured 8% of the forks and 3% of the leaves. For the wood dowels, approximately 40% of the mass was captured by the GLI and the RGB; approximately 60% by the RGT; and over 80% captured by the RLI. Of the gross solids used in this testing, the wood dowels best represent floatables because they remained floating on the water surface throughout the duration of most tests. Overall, gross solids were captured at 20% (GLI), 80% (RGB), 85% (RGT), or 95% (RLI).

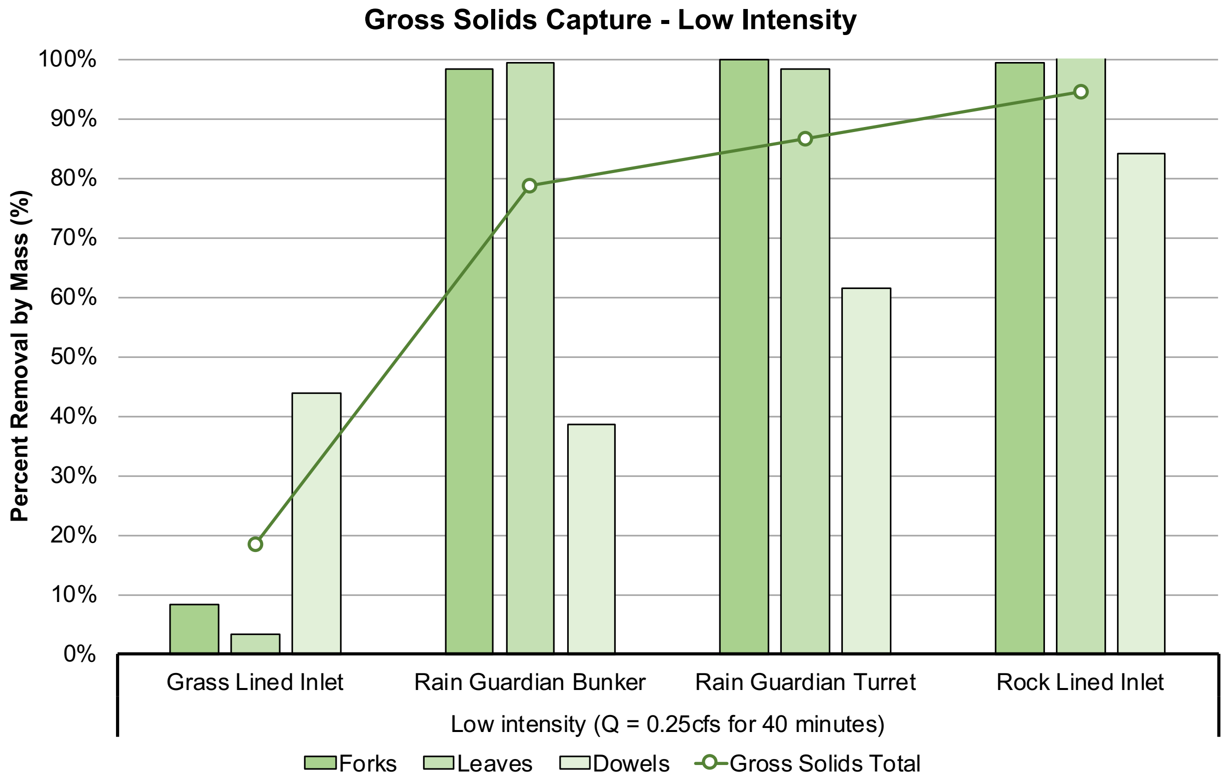

Figure 54: Gross solids capture by percent for design volume low intensity tests (Q = 0.25cfs, duration = 40 minutes).

While the GLI was shown to capture sediment (Figure 51 & Figure 53), it is evident from Figure 54 that GLIs are not effective at capturing gross solids. This is consistent with the design of GLIs in that there is no physical mechanism for gross solids to be captured. The short length and flexibility of lawn grass is not enough to capture and retain debris. While it appears from Figure 54 that the GLI captured over 40% of the wood dowels, field observations revealed that these dowels were floating on the water surface and deposited on the GLI as the water in the bioretention was drained (Figure 55). Without the corral, it is likely these dowels would have been dispersed throughout the bioretention and would not have been "captured" by the GLI.

The Rain Guardian Bunker and Turret captured 80% and 85% of the gross solids, respectively (Figure 54). Most of the gross solids were captured on the surface grate and nearly all of the remaining gross solids were captured within the chamber (data in Appendix A). A small fraction (2 – 4%) of gross solids were captured on the concrete pad downstream of the screen wall (data in Appendix A).

Figure 55: Capture of gross solids on grass lined inlet. Note wood dowels floating on water surface above the GLI near the downstream boundary with the corral. These dowels were deposited on the GLI during drawdown and counted as "captured."

5.1.2.2 High Intensity (Q = 0.50cfs for 20 minutes)

Gross solids capture by the pretreatment practices during the high intensity test is shown in Figure 56. The RGB and RGT captured over 95% of the forks, 55 – 75% of the leaves, and 30 – 45% of the dowels in high intensity tests. The RLI captured 80% of the forks, 25% of the leaves, and 65% of the dowels. The GLI captured 10% of the forks, less than 5% of the leaves, and 70% of the wood dowels. Overall, gross solids were captured at 30% (GLI), 60% (RGB and RLI), and 70% (RGT).

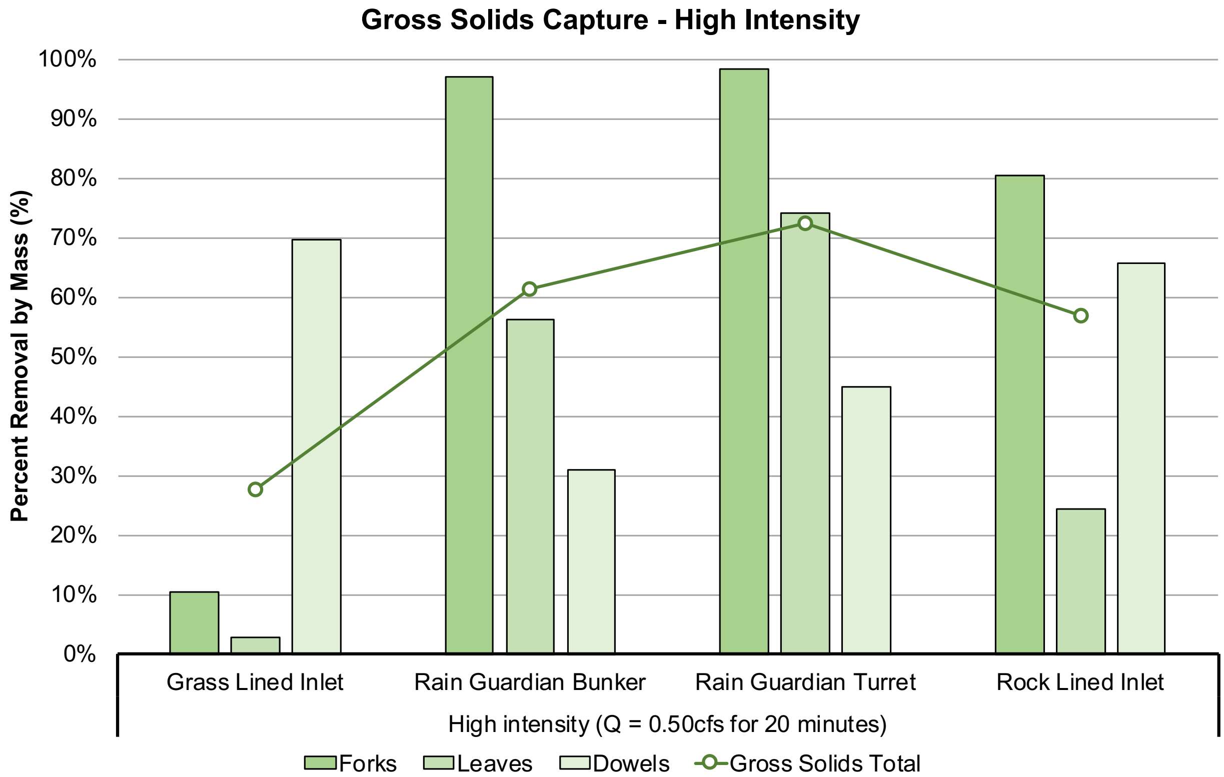

Figure 56: Gross solids capture by percent for design storage volume tests, Q = 0.50cfs, duration = 20 minutes.

In addition to the flow rate (and likely flow velocity), a primary difference between the low intensity and high intensity tests at the Anoka site (GLI, RGB, RGT, RLI) is the water depth within the bioretention cell, and subsequently the proportion of the pretreatment practice that was inundated by backwater. For the sloped practices (GLI, RLI), this meant that water, sediment, and gross solids that were carried into the practice by high velocity supercritical flow were intercepted by a standing pool at some point along the slope of the pretreatment practice. This point occurred near the bottom edge of the GLI and RLI for the low intensity tests, and near the upper edge during the high intensity tests. In other words, the GLI and RLI were mostly exposed during low intensity such that rocks and even some grass were emergent through the flow. Conversely, most of the rock and grass were fully submerged during high intensity flow. Thus, emergent rocks were able to intercept and capture gross solids during the low intensity tests but gross solids were carried further downstream during the high intensity tests, as shown in Figure 57. During the low intensity tests on the RLI, it was observed that the accumulation of gross solids (Figure 57) also created a “debris filter” that intercepted and captured sediment among the gross solids.

Figure 57. Rock lined inlet after testing at 0.25cfs for 40 minutes (left) and 0.50cfs for 20 minutes (right).

It was also observed during testing that sediment was deposited (likely by settling) in the RLI just downstream of the point of inundation, likely due to the energy dissipation caused by the pool. The effect of this inundation from backwater is further illustrated by the apparent increase in dowel capture by the GLI from the low intensity tests (45% dowel capture) to the high intensity tests (70% dowel capture). As previously discussed, dowels "captured" by the GLI were actually deposited on the GLI during the drawdown phase after the tests were complete, not as a result of the GLI physically retaining the dowels. Because more of the GLI was inundated by backwater during the high intensity tests, more dowels were deposited during drawdown.

During the high intensity tests, the Rain Guardian Bunker and Turret captured 60% and 70% gross solids, respectively. Similar to the low intensity tests, most of the gross solids were captured on the surface grate and nearly all of the remaining gross solids were captured within the chamber (data in Appendix A).

5.2 BLOOMINGTON SITE: IN-LINE SHALLOW SUMP GRIT CHAMBER

A primary difference between the Anoka and Bloomington field sites is the size of the primary treatment, the bioretention practice. In Anoka, the bioretention practice could hold approximately 600 cubic feet of runoff, whereas the bioretention in Bloomington could hold approximately 119 cubic feet of runoff. Thus, the Bloomington bioretention required a lesser flow rate (Q = 0.06cfs, duration = 30 minutes for low intensity; Q = 0.12cfs, duration = 15 minutes for high intensity) to allow for tests with a similar test duration as Anoka. Subsequently, less sediment and gross solid mass were used so that the solids concentration was similar between tests. Though every effort was made to create field tests that would be comparable between the different sites, the results from Anoka are not directly comparable to the results from Bloomington.

Field testing in Bloomington included additional tests beyond the design volume, inducing bypass of the pretreatment practice. Because the shallow sump grit chamber installed in Bloomington is constructed in-line, it is expected that performance will be affected under bypass conditions because turbulence could resuspend previously captured sediment and gross solids, allowing them to exit the pretreatment chamber and be delivered downstream. By contrast, the sites in Anoka were all designed as off-line systems such that if the flow volume exceeded the design volume, then excess water, sediment, and gross solids would simply pass by the pretreatment and bioretention without interacting with previously captured sediment or gross solids, which is an advantage of the off-line design.

Sediment capture by the shallow sump grit chamber for the design volume tests and the bypass tests is shown in Figure 58. For the design volume tests ((a) and (b) in Figure 58), the overall sediment capture decreases from 95% to 90% primarily because fine sediment (D_{50} = 0.12mm) capture decreases from 80% to 65%. As previously discussed, this is not surprising because as the intensity increases the residence time decreases and thus more sediment is carried through the pretreatment practice into the bioretention. From test (b) to (c), the flow rate remains the same, but the duration is doubled to allow in-line bypass of the pretreatment practice to occur. As noted in Figure 58, bypass began at 15 minutes after the test began and continued through the full duration (40 minutes). The performance is nearly identical between the design volume test (b) and the bypass test (c) at the same flow rate. Thus, in-line bypass of the pretreatment practice at this flow rate does not appear to affect sediment capture performance.

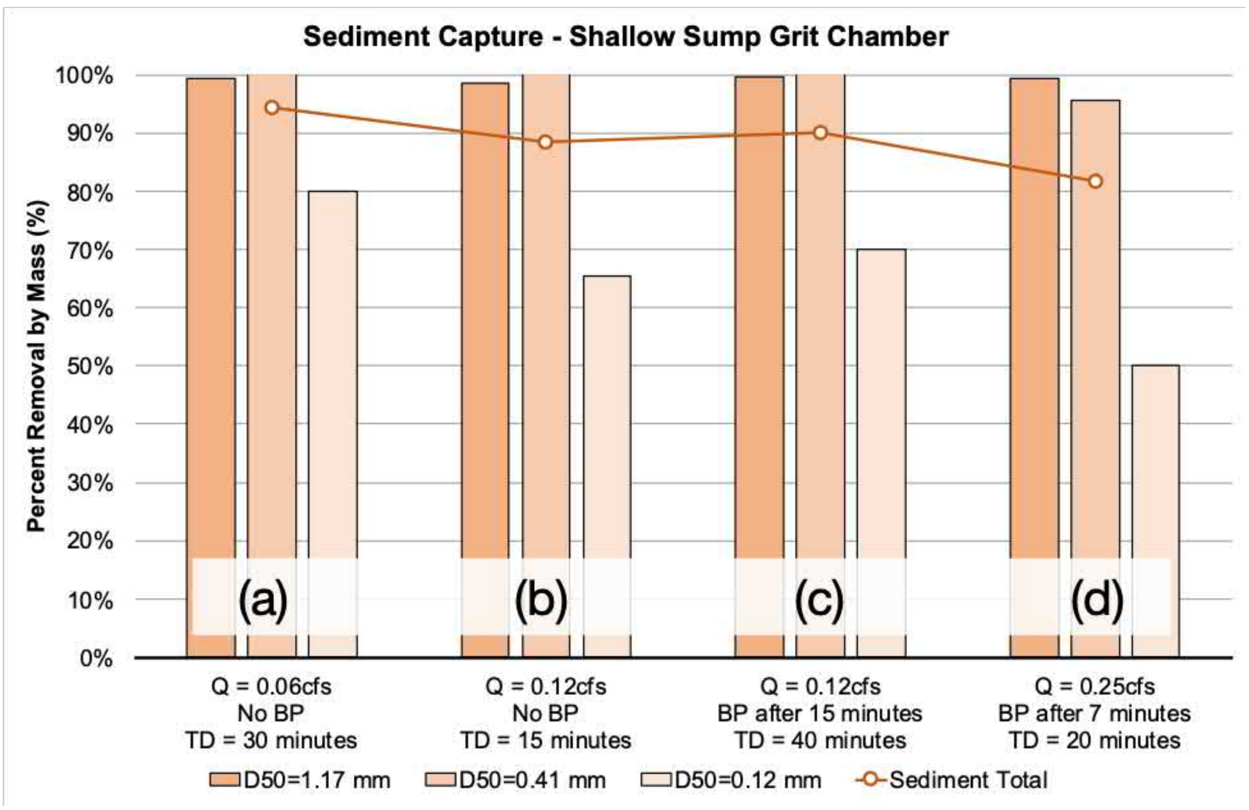

Figure 58: Sediment capture by the shallow sump grit chamber for two design volume tests* (a) *Q = 0.06cfs for 30 minutes and* (b) *Q = 0.12cfs for 15 minutes; and two bypass tests* (c) *Q = 0.12cfs for 40 minutes and* (d) *Q = 0.25cfs for 20 minutes. BP = Bypass; TD = Total Duration.

The increase in intensity from (c) to (d) resulted in a decrease in performance from 90% overall sediment capture to 80%, which can be associated with a decrease in medium sediment (D_{50} = 0.41mm) capture (100% to 95%) and fine sediment (D_{50} = 0.12mm) capture (70% to 50%). This was expected due to a reduction in residence time within the pretreatment practice and an increase in turbulence which could resuspend previously captured sediment.

Approximately 75% of fine sediment (D_{50} = 0.12mm) was either captured in the shallow sump grit chamber or not fed for the design volume and bypass tests for the same flow rate (Q = 0.12cfs) while 25% was either delivered to the bioretention or bypassed the in-line shallow sump grit chamber in the bypass test (10%), as shown in Figure 59. In the test of the shallow sump grit chamber with the highest flow rate (Q = 0.25cfs), approximately 16% of the fine sediment bypassed the in-line chamber.

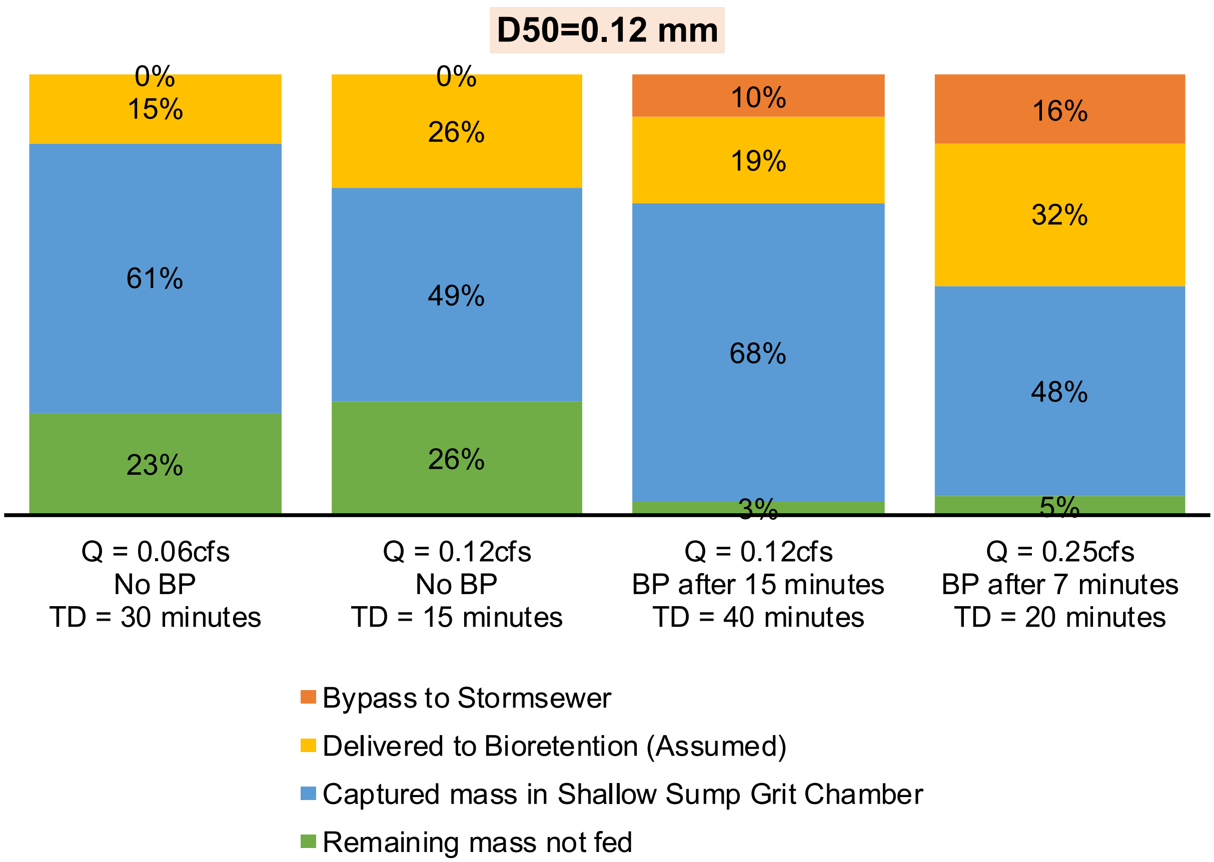

Figure 59: Fine sediment (D_{50} = 0.12mm) capture and bypass by the shallow sump grit chamber for four tests.

Gross solids capture by the shallow sump grit chamber for the design volume tests and the bypass tests is shown in Figure 60. The decrease in gross solids capture between the low and high intensity design volume tests ((a) and (b) in Figure 60) is expected due to the increase in mixing and decrease in residence time within the shallow sump grit chamber, resulting in export of gross solids from the pretreatment and into the bioretention. Capture performance for forks remained nearly the same, but leaf capture decreased from 90% to 65% and dowel capture decreased from 55% to 45%. Inducing bypass in the shallow sump grit chamber by increasing the duration but maintaining the same flow ((b) to (c)) resulted in a decrease of gross solids capture from 70% to 60%, primarily because dowel capture decreased from 45% capture in the design volume test (no bypass) to 15% in the bypass test (Figure 60). When the intensity of the bypass test was increased (test (c) to (d)), gross solids captured decreased again from 60% overall capture to below 40% capture due to reduction in capture efficiency for all three gross solids types.

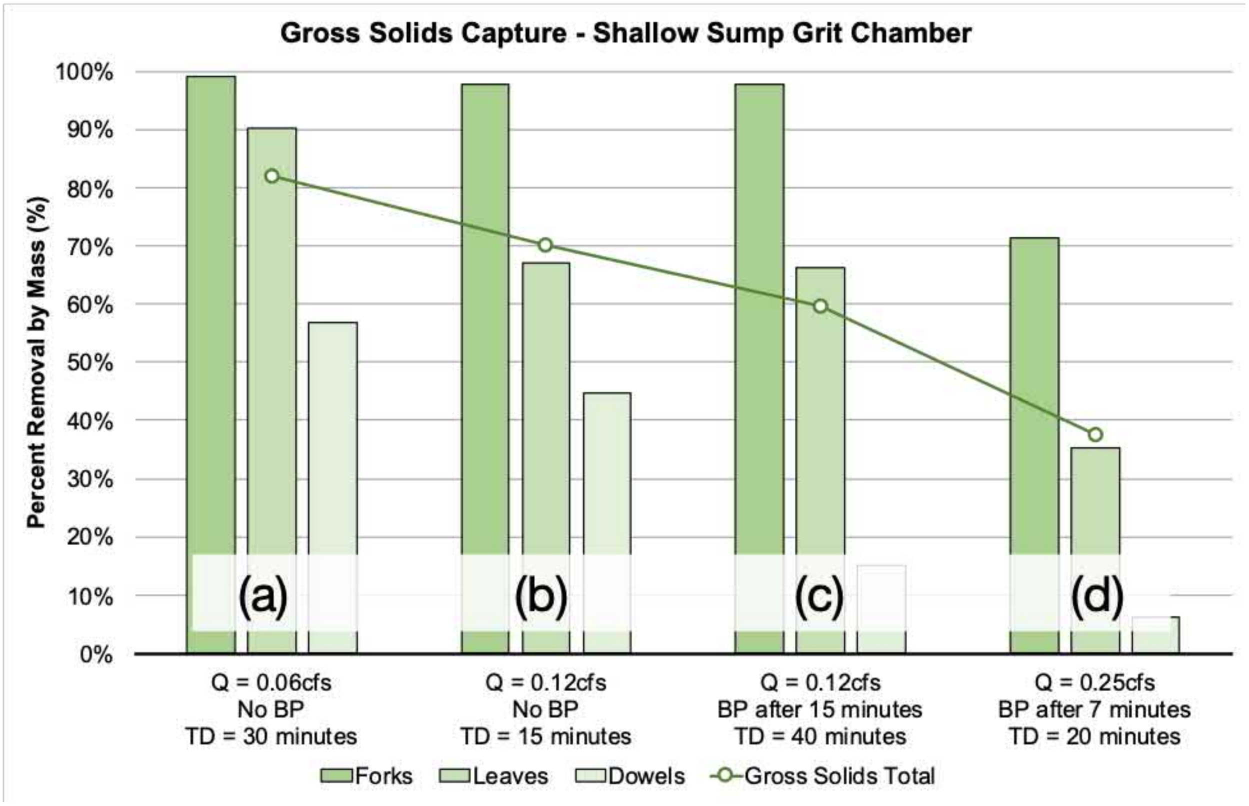

Figure 60: Gross solids by the shallow sump grit chamber for two design volume tests* (a) *Q = 0.06cfs for 30 minutes and* (b) *Q = 0.12cfs for 15 minutes; and two bypass tests* (c) *Q = 0.12cfs for 40 minutes and* (d) *Q = 0.25cfs for 20 minutes. BP = Bypass; TD = Total Duration.

Approximately 66-67% of the leaves were captured in the shallow sump grit chamber during the design volume and bypass tests for the same flow rate (Q = 0.12cfs), as shown in Figure 61. Of the remaining 33-34% of leaves that was untreated, 21% bypassed the in-line shallow sump grit chamber in the bypass test. The amount that bypassed increased to 74% for wooden dowels (data not shown) because there is no mechanism within the in-line shallow sump grit chamber to capture floatables. Thus most of the dowels flowed over the top of the grate when the water level was above the grate elevation.

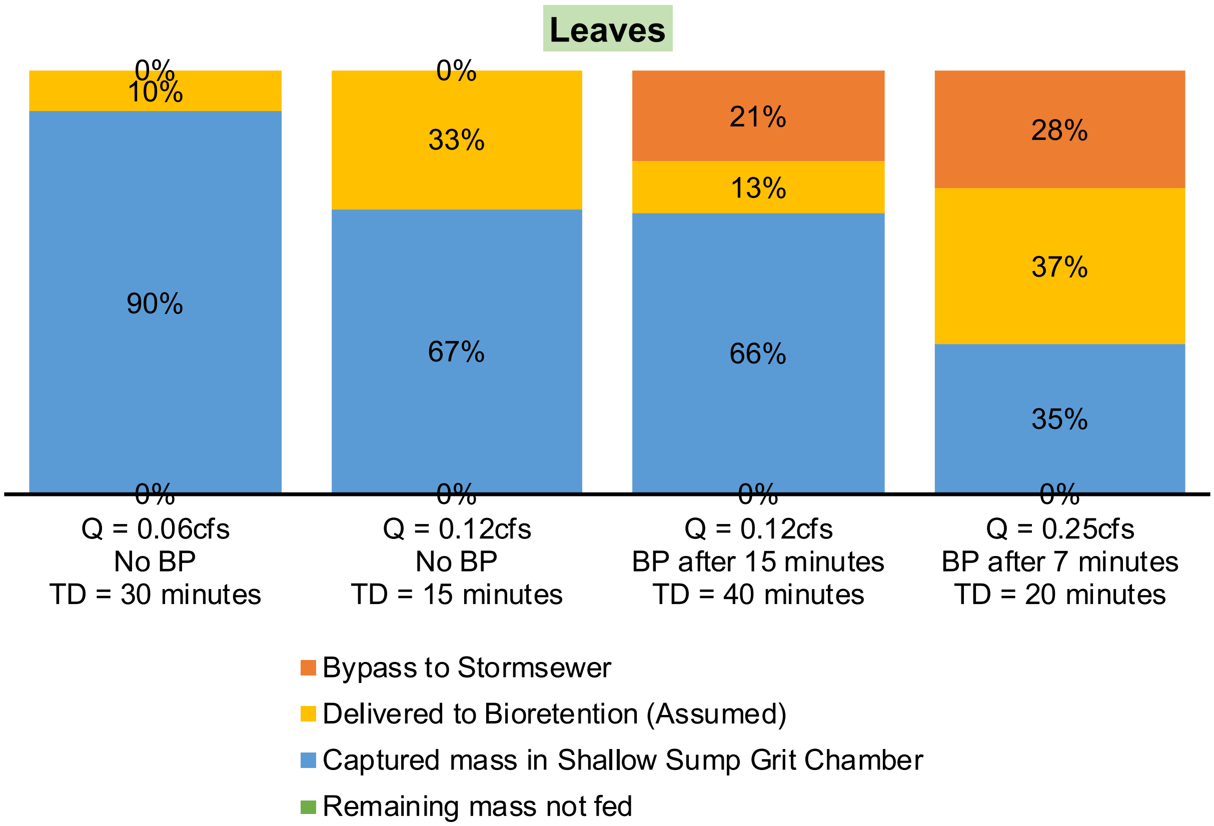

Figure 61: Leaves capture and bypass by the shallow sump grit chamber for four tests.

5.3 ERROR AND UNCERTAINTY

The nature of field testing is such that not all components or uncertainty can be measured. For this project, the sediment that was delivered to the bioretention was only quantified for tests of the GLI. However, the sediment that was captured on the GLI was not quantified, and thus a mass balance could not be completed. For all other tests, the sediment delivered to the bioretention was not quantified, and thus a mass balance could not be completed. For gross solids, the use of the corral and collection of gross solids from all locations allowed for a mass balance to be completed for some tests. Mass balance errors for gross solids were less than 5%.

In addition, precision was quantified using the relative percent difference (RPD) calculation as described above. The RPD was calculated for all tests in which two replicate tests were conducted (see Table 2). The average RPD for these ten pairs of replicates are reported for each sediment fraction and gross solids type used in testing, as shown in Table 6.

Table 6: Average Relative Percent Difference (RPD) for sediment and gross solids tests (n = 10).

	Initial Mass added to Pretreatment	Captured Mass in Pretreatment	Percent Removal
D50=1.17 mm	2.9%	3.2%	1.4%
D50=0.41 mm	2.4%	5.0%	2.8%
D50=0.12 mm	2.6%	20.4%	19.0%
Sediment Total =	2.4%	5.9%	4.6%
Forks	0.6%	22.7%	22.8%
Leaves	0.1%	24.5%	24.5%
Dowels	0.3%	26.0%	26.1%
Gross Solids Total =	0.2%	10.5%	10.4%
Sediment + Gross Solids =	1.9%	4.5%	3.6%

5.4 MAINTENANCE CONSIDERATIONS

This project was limited by time and funding to measure the sediment and gross solids capture performance of five pretreatment practices for bioretention, each at two flow intensities and two replicates for each test. To provide an adequate comparison between practices, each practice was freshly installed and cleaned prior to every test and replicate. Thus, the accumulation of sediment and gross solids from multiple sequential tests was not measured as part of this project. Further research is needed to determine the recommended maintenance frequency based on performance. However, the following observations can be made from the testing that was conducted.

5.4.1 Grass Lined Inlet (GLI)

The GLI did not capture gross solids, so maintenance to remove gross solids from the pretreatment is expected to be minimal. These gross solids are expected to accumulate within the bioretention practice, however, and maintenance would be necessary to remove them. The GLI collected a substantial amount of sediment during the tests. It is expected that this sediment would continue to accumulate, effectively increasing the soil elevation wherever sediment is deposited. If the GLI is mowed as part of maintenance, the grass height will be determined by the soil elevation, and thus the GLI is expected to increase in elevation over time as sediment accumulates. The amount of sediment that was accumulated was approximately equal to ½ of the grass height. Thus, it is possible that only a few storms could “fill” the capacity of the GLI. This phenomenon has been observed by stormwater professionals, resulting in a common design practice of including a 2 to 4-inch drop in elevation from the back of curb to the top of the GLI to allow for sediment accumulation. To maintain a GLI, the grass, sediment, and likely the topsoil will need to be removed and replaced to restore the GLI to the original design elevation. This level of maintenance is effectively the same cost as constructing a brand new GLI. Of the pretreatment practices tested in this study, the GLI is likely among the most difficult and costly to maintain.

5.4.2 Rain Garden Bunker (RGB)

The RGB collected sediment and gross solids in all tests. Collecting the sediment and gross solids to calculate performance was similar to the maintenance recommendations for the RGB, though the test sediment and gross solids were carefully collected for quantification. The accumulation of sediment and gross solids within the RGB was minimal compared to the storage capacity. Also, the chamber and screen wall design of the RGB suggest that gross solids and sediment would be protected from resuspension during high intensity flow conditions, though data to support this was not collected as part of this study.

Access to the sediment and gross solids within the RGB was simple, and accumulation of sediment and gross solids with the RGB is easily visible from the road. This is an advantage because visual inspection of the RGB is quick and could be completed by homeowners, or by staff from a vehicle. In addition, the permeable screen wall allows stored water to filter out of the bunker when runoff ceases, resulting in a dry chamber between runoff events. This prevents mosquito breeding and obnoxious odors and allows the bunker to be cleaned with a shovel by homeowners or minimally trained staff.

It is anticipated that the RGB could collect and store several storms of sediment and gross solids before maintenance is needed, though it is impossible to predict from this project how frequently maintenance will be needed and the capture performance as sediment and gross solids accumulate. Of the pretreatment practices tested in this study, the RGB is likely among the easiest to maintain.

5.4.3 Rain Garden Turret (RGT)

Similar to the RGB, the RGT collected sediment and gross solids in all tests. Collecting the sediment and gross solids to calculate performance was similar to the maintenance recommendations for the RGT, though the test sediment and gross solids were carefully collected for quantification. The accumulation of sediment and gross solids within the RGT was minimal compared to the storage capacity. Also, the chamber and screen wall design of the RGT suggest that gross solids and sediment would be protected from resuspension during high intensity runoff events, though data to support this was not collected as part of this study.

Access to the sediment and gross solids was not as simple as the RGB because the top grates of the RGT used during testing were larger and heavier than those of the RGB. Since testing, the grates used on the RGT have been replaced with fiberglass grates that are substantially less weight. Thus maintenance of the RGT is expected to be at least as simple as the RGB. Accumulation of sediment and gross solids with the RGT is easily visible from the road. This is an advantage because visual inspection of the RGT is quick and could be completed by homeowners, or by staff from a vehicle. In addition, the permeable screen wall allows stored water to filter out of the turret when runoff ceases, resulting in a dry chamber between runoff events. This prevents mosquito breeding and obnoxious odors and allows the turret to be cleaned with a shovel by homeowners or minimally trained staff.

It is anticipated that the RGT could collect and store several storms of sediment and gross solids before maintenance is needed, though it is impossible to predict from this project how frequently maintenance will be needed and the capture performance as sediment and gross solids accumulate. Of the pretreatment practices tested in this study, the RGT is likely among the easiest to maintain.

5.4.4 Rock Lined Inlet (RLI)

The RLI captured sediment and gross solids in all tests, though fewer gross solids were captured in the high intensity test. It was apparent from the field tests that the RLI does not have much capacity to store captured gross solids (see Figure 62), though sediment could accumulate in the large pore spaces between the individual rocks (see Figure 63).

Figure 62. Rock lined inlet after testing at 0.25 cfs for 40 minutes (left) and 0.50 cfs for 20 minutes (right).

Figure 63. Sediment remaining on geotextile when rocks were removed from RLI.

Sediment that is collected within the pore spaces of the RLI may be protected from high intensity storms, but the storage capacity within the pores is minimal and may become filled within a few storms. In addition, it is expected that gross solids that may be captured during low intensity storms would become mobilized and potentially washed out of the RLI during high intensity runoff events. There is no mechanism to protect collected gross solids.

Maintenance of the RLI consists of removing the rocks and either washing them onsite or installing new washed rocks as replacement. In addition, sediment and gross solids that may have accumulated within the RLI need to be removed. During testing, the rocks needed to be washed and the geotextile fabric beneath the rocks needed to be cleaned so that all the captured sediment could be quantified. Field maintenance of a RLI is anticipated to be similarly time and labor intensive. This level of maintenance is effectively the same cost as constructing a brand new RLI. Of the pretreatment practices tested in this study, the RLI is likely among the most difficult and costly to maintain.

5.4.5 Shallow Sump Grit Chamber (BDV and BBP)

The shallow sump grit chamber collected sediment and gross solids in all tests, including tests in which bypass was induced (though not as well). Collecting the sediment and gross solids to calculate performance was similar to the maintenance procedures for the shallow sump, though the test sediment and gross solids were carefully collected for quantification. The accumulation of sediment and gross solids within the shallow sump was minimal compared to the storage capacity. Though the shallow sump is relatively similar in dimension to the RGB, sediment and gross solids collected in the shallow sump are less protected compared to the off-line design of the RGB because the shallow sump is installed in-line with the gutter. Bypass tests were not conducted on both devices, so a quantitative comparison of bypass conditions cannot be made. During bypass testing of the shallow sump, however, sediment was captured while gross solids were released and delivered downstream.

Access to the sediment and gross solids within the shallow sump was simple, though the shallow sump is not easily visible from the surface and could be easily missed or forgotten. Visual inspection therefore requires access to the sump, likely removal of the surface grate, and inspection of the accumulated sediment. In addition, the saturated nature of the sump makes visual observation of the sediment depth challenging. It is possible that sediment depth could be measured with a staff gauge through the slots in the grate, though this method may be inaccurate. It is anticipated that the shallow sump could collect and store several storms of sediment and gross solids before maintenance is needed, though it is impossible to predict from this project how frequently maintenance will be needed and the capture performance as sediment and gross solids accumulate. Of the pretreatment practices tested in this study, the shallow sump is likely to be moderately easy to maintain.

CHAPTER 6: CONCLUSIONS

Though little guidance is available for pretreatment practices, many are installed throughout our urban landscapes because they are required as part of installation for many primary treatment practices. A benchmark for performance is set forth by the Minnesota Pollution Control Agency: capture of gross solids and 25% of sediment greater than 100µm. Five pretreatment practices for bioretention were assessed for sediment and gross solids capture by field testing at the design storage volume and two different intensities. Three sediment sizes, a coarse sediment (D_{50} = 1.17mm), a medium sediment (D_{50} = 0.41mm), and a fine sediment (D_{50} = 0.12mm) and three types of gross solids (plastic forks, synthetic leaves, and wood dowels) were added throughout the duration of each test.

All five pretreatment practices captured greater than 88% of the total sediment and greater than 65% of the fine sediment fraction (D_{50} = 0.12mm) in the low intensity tests (design volume filled in 40 minutes). During the high intensity tests (design volume filled in 20 minutes), all practices captured greater than 70% of the total sediment mass and greater than 30% of the fine sediment fraction, which exceeds the criterion of 25% of sediment greater than 100µm. Thus, all five pretreatment practices were able to achieve the goal when tested from a clean initial condition. The performance and maintenance needed for long-term operation of these pretreatment practices was not measured in this project.

Four of the five pretreatment practices captured 75% of the gross solids during low intensity tests and more than 55% of the gross solids during high intensity tests. The grass lined inlet captured the least gross solids; 20% during low intensity and 30% during high intensity. Inundation of the grass lined inlet during the high intensity tests resulted in floating wood dowels being deposited on the grass lined inlet surface after the test was complete. Though these are reported as “capture” as part of this study, these would likely not be captured during actual operation of a grass lined inlet.

Additional design volume and bypass tests were conducted on an in-line shallow sump grit chamber to determine if resuspension of sediment and gross solids could be measured. During these tests, overall sediment captured decreased from 95% during low intensity design volume tests down to 80% capture during high intensity bypass tests. Gross solids capture decreased from greater than 80% to below 40%. Thus, bypass at these flow rates had minimal effect on the sediment, but measurable effect on the gross solids performance.

Though at least four of the five pretreatment practices performed similarly in terms of sediment and gross solids capture, only three out of the five appear to be simple to inspect and maintain. When maintenance is required, the grass lined inlet and rock lined inlet likely require the same amount of effort and cost to maintain them as would be needed to install them (i.e., initial construction cost = maintenance cost). The grass lined inlet and rock lined inlet are likely among the most difficult and costly to maintain.

To maintain the Rain Guardian Bunker, Rain Guardian Turret, and shallow sump grit chamber, one would need to remove the top grate and either shovel or hydro-vac the collected sediment and gross solids from within the collection chamber. The Bunker and Turret are both easily visible from the street and the permeable screen wall in the bunker and the turret allows for a dry chamber between runoff events. The shallow sump grit chamber is hidden underground, which makes assessing sediment accumulation depth more challenging. Of the pretreatment practices tested in this study, the Bunker and Turret are likely among the easiest to maintain, and the shallow sump grit chamber is likely to be moderately easy to maintain.

CHAPTER 7: LESSONS LEARNED & FUTURE RESEARCH

Though the authors have conducted field testing prior to this study, the uniqueness of the practices (pretreatment for bioretention) and site conditions produced many unknowns and several lessons were learned through the field-testing process. The primary lesson learned is that compared to field testing, laboratory testing can be more accurate, more cost-effective, and a better method for comparing multiple practices side-by-side under identical conditions. Below are several reasons to support this observation:

- **Laboratory testing is not weather dependent:** field testing can only be conducted during dry-weather conditions, with an antecedent dry period prior to testing. Several opportunities for testing were lost, and results delayed due to poor weather conditions. Laboratory testing could have been completed on consecutive days, regardless of weather or season.
- **Field testing requires more pre-test preparation and post-test cleanup:** Field testing required gathering, loading, transporting, and deploying numerous pieces of equipment prior to any tests being conducted. In addition, the site needed to be prepared and cleaned prior to testing. After testing was complete, the site had to be restored to operating condition and all equipment had to be gathered, loaded, transported back to and stored at St. Anthony Falls Laboratory. The amount of time necessary for pre-test prep and post-test cleanup for field testing is equivalent to at least one additional test per test day.
- **Laboratory testing is more accurate:** Testing in the laboratory can be controlled more accurately than field testing. Water flow rate, volume, water level control, sediment and gross solid application, and sediment and gross solid collection are all more consistent and more accurate from test-to-test and device to device with laboratory testing. One key benefit of laboratory testing for this type of project is that every component of the water and pollutant mass balance can be measured effectively, accurately, and efficiently. Thus, error can be accurately assessed and reported with all measurements.
- **Laboratory testing is a more direct comparison:** Laboratory testing allows for different devices to be tested under identical conditions with the ability to conduct multiple test replicates. In addition to identical input conditions, laboratory testing allows for scaling of devices so that each device is the appropriate size in comparison to other devices.
- **Laboratory testing is more robust:** Laboratory testing is rarely limited by water supply, sediment feed rate, or gross solids application. Laboratory testing for pretreatment practices could be conducted with any number of storm events up to and exceeding the 100-year event. In addition, laboratory testing can be conducted to simulate infiltration and backwater conditions to exactly mimic field conditions but are more consistent and repeatable between tests and devices compared to field testing.
- **Laboratory testing is more efficient:** Typically in laboratory testing all the equipment is on-hand, all staff and personnel are on-site, and the analytical facilities are in-house. Thus, conducting experiments, repeating replicates, analyzing samples, and changing test conditions are all more time- and cost-efficient.

There are several specific observations from this project that may improve future field or laboratory testing of pretreatment practices:

- The gas powered three-inch semi-trash pump that was used to drain the basin was difficult to regulate because of its size, constant need to be adjusted, and intermittent flow operation for the basin that was studied.
- During testing of the grass lined inlet, grass blades and very fine soil particles made processing solids samples challenging. Pre-rinsing removed most of these organics, but

they could not be eliminated. Synthetic grass may have been more manageable, repeatable, and easier to clean.

- For the grass lined inlet and rock lined inlet testing, processing the geotextile and associated sediment and gross solids was time-consuming and challenging. It required removing, re-setting, and processing and required more labor than processing the samples from other practices.
- For the grass lined inlet testing, sediment built up near the centerline and along the seam of the sod. If the test were repeated without cleanout or replacing the sod, the settling patterns would likely be different as the capacity is filled. Between storms, roots may grow up into the deposited sediment, changing the shape of the inlet as well.
- For the rock lined inlet testing, sediment (coarse and medium) accumulated under and around the rocks. If multiple tests were performed sequentially without cleanout, the space under and between rocks would fill quickly.
- For the bypass testing, pre-cleaning and collecting sediment from the gutter, and setting up, sealing, and removing the geotextile basket in the downstream catch basin added significantly to the time required to run a test. These tests required approximately twice as much time as the other tests.

These lessons learned inform future research about field testing, laboratory testing, and pretreatment practices. While this project produced a quantitative performance comparison of pretreatment practices for bioretention, there are several other questions about the performance and maintenance of pretreatment practices that still need to be addressed, potentially as future research:

- **How frequently should pretreatment practices be maintained?** It was clear that all five pretreatment practices in this study captured sediment and gross solids. How quickly these practices fill with sediment and solids, or how performance is affected by accumulated sediment and gross solids was not measured. Thus, the optimal frequency of maintenance is still unknown. A study using several sequential "storms" could be used to determine when maintenance is most cost-effective for each practice.
- **How should pretreatment practices be designed or sized?** This study showed that all five pretreatment practices captured more than 30% of sediment greater than 100μm, but it did not determine if the sizing and design of these practices is optimal. Often, pretreatment practices are "sized" based on the space available or are a one-size-fits-all device. With an understanding of treatment mechanisms and performance, a study on various sizes and aspect ratios for several different pretreatment practices could determine optimal sizing criteria that would balance cost, storage capacity for sediment and gross solids, and maintenance frequency.
- **How do other pretreatment practices compare?** These five pretreatment practices are just a few of the most common practices in Minnesota, but there are others here and from other parts of the world. A study to compare the short and long-term performance of these various pretreatment practices could provide a robust pretreatment toolbox for stormwater professionals to use.
- **Are pretreatment practices cost-effective?** A common assumption is that pretreatment practices reduce the overall life-cycle costs of stormwater treatment practices by simplifying maintenance and reducing the maintenance needed in primary treatment practices (e.g., bioretention). While this study has shown that pretreatment practices are effective at capturing sediment and gross solids, it is unclear how the long-term life-cycle costs of maintaining pretreatment practices compares to the life-cycle costs of maintaining primary treatment practices. In addition, it is unknown how the use of pretreatment practices actually reduces the maintenance of primary treatment practices. For example, a

small pretreatment chamber that is effective at capturing sediment and gross solids may need more frequent maintenance. A study is needed to compare the estimated costs of maintaining primary treatment practices against the estimated costs of maintaining pretreatment practices in combination with primary treatment practices.

CHAPTER 8: REFERENCES

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CHAPTER 9: APPENDIX

9.1 PROCEDURE

Prep at lab

1. Pre-weigh, package, and label dry sediment and gross solids
2. Set and record sediment feeder rate
3. Ready supplies and tools and load into truck

Setup in field

1. Set up meter and hose. For the first run, find the valve setting (number of turns) to get the target flow rate.
2. Place flow distributor and break tank.
3. Set up generator and sediment feeder, fuel and test.
4. Place pre-weighed sediment in feeder, feed sediment to the tube end, set feed rate, and cover feeder, check feed rate if needed.
5. Place gross solids in clean water 5-gallon bucket to hydrate.
6. Prepare notebook, camera, video camera
7. Set up staff gauge(s)
8. Set up drain sump, pump intake, and discharge to storm drain.
9. Clean pretreatment entrance
10. For the first run of the day, run total volume of clear water to saturate the bioretention basin. (A flushing run was used after each new sod installation for the grass lined inlet).

Test Run

1. Record time when water flow begins
2. Record time when sediment begins (feeder on)
3. Feed sediment at determined rate
4. Feed gross solids by hand from bucket, approximately paced
5. Periodically check flow rate and adjust if needed
6. Periodically record depth on staff gauge
7. Take photos and/or video
8. Stop sediment feed and water at volume target (600 cubic feet in Anoka), OR maximum water level (bypass level) reached. Record time.

Cleanup in field

1. Possible sediment locations are Not Fed (in feeder or bucket or transition area between feeder and basin), Pretreatment Area (captured), Beyond Pretreatment (passed, not captured).
2. Label all collected material with date, run number, collector's initials
3. Collect floating gross solids if they are likely to move
4. Drain or pump out rain garden at a rate low enough so that materials do not move from the pretreatment device.
5. Collect accessible gross solids by hand, into clean storage container. Label storage container or bag with date, time, run number, or other identifying information.

6. Collect accessible sediment with a scoop, rinse through screen to capture gross solids, place sediment into container.
7. Use wet-dry vac with rinse water from a hose or sprayer to clean up remaining sediment, rinse vac through screen into container
8. Decant clear water from sediment storage container by tipping to side over a #325 sieve, being very careful not to lose any sediment grains.
9. Prepare for next test or restore pretreatment and bioretention basin.

<u>Processing at lab</u>

1. Carefully rinse off and collect sand from gross solids, geotextiles, bags, buckets, etc.
2. Maintain labeling through process – keep Not Fed separate from Captured in pretreatment separate from Passing
3. Transfer sediment to drying pans, place in oven overnight
4. Place screens with gross solids in oven overnight
5. Weigh gross solids batch
6. Separate and weigh gross solids components
7. Weigh sediment batch
8. Sieve and weigh sediment components
9. Label and store sediment for further analysis or discard

9.2 TEST DATA

Table 7: Raw flow, volume, and water depth data from field testing.

Designation	Date	Start Time	[1]Sediment Feed Duration (minutes)	[2]Pre-flush + Flowrate Adjustment (ft³)	Total Volume (ft³)	Average Flowrate (cfs)	[3,4]Estimated Maximum Water Depth (nearest 5mm)
GLI-025-A	6/12/18	11:21	39.57	364.2	599.6	0.253	140
GLI-025-B	6/15/18	11:25	39.97	322.4	600.0	0.250	140
GLI-050-A	6/12/18	13:57	20.10	339.9	601.0	0.498	180
GLI-050-B	6/15/18	9:29	20.18	346.0	600.6	0.496	200
RGB-025-A	6/29/18	9:58	39.45	323.0	600.5	0.254	175
RGB-025-B	7/16/18	12:09	40.03	39.7	600.0	0.250	180
RGB-050-A	6/29/18	11:56	20.97	36.2	601.1	0.478	245
RGB-050-B	6/29/18	13:41	19.72	56.9	581.5	0.492	255
RGT-025-A	7/10/18	12:45	39.27	38.9	599.5	0.254	200
RGT-025-B	7/16/18	10:04	39.45	339.7	600.3	0.254	215
RGT-050-A	7/10/18	11:02	20.22	400.7	601.1	0.496	230
RGT-050-B	7/10/18	14:27	20.70	70.5	600.4	0.483	265
RLI-025-A	5/31/18	11:37	40.33	1.5	609.2	0.252	no data
RLI-025-B	6/4/18	13:31	39.40	41.1	604.3	0.256	205
RLI-050-A	6/4/18	9:36	20.80	404.5	601.0	0.482	240
RLI-050-B	6/4/18	11:40	20.10	203.0	600.9	0.498	290
BDV-006-A	10/23/18	14:09	28.51	362.6	108.2	0.063	305
BDV-006-B	10/24/18	9:34	30.73	175.2	115.5	0.063	305
BDV-012-A	10/24/18	11:20	14.82	4.4	112.5	0.127	305
BDV-012-B	10/24/18	12:42	15.11	3.7	113.6	0.125	305
BBP-012-A	10/30/18	11:19	40.27	259.7	303.0	0.125	380
BBP-025-A	10/30/18	14:11	19.66	7.5	296.6	0.251	395

[1]Bypass (full basin) time 15.18 minutes BBP-012-A, 7.25 minutes BBP-025-A

[2]Larger flushing volumes were typical of the first test in any day to pre-wet the basin.

[3]Reference point for Anoka (RLI, GLI, RGB, RGT) is concrete base slab = basin bottom.

[4]Reference point for Bloomington (BDV, BBP) is estimated basin bottom, ~1 inch below pipe inverts.

Table 8: Raw mass data for Grass Lined Inlet (GLI) field tests

Mass data for GLI-025-A

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Untreated by Pretreatment (Captured in Bioretention) (g)	(e) Captured in Pretreatment (Assumed) (g)	(f) Percent Removal (%)
[1] D50=1.17 mm	939.39	56.33	883.06	0.95	882.11	99.9%
[2] D50=0.41 mm	939.44	33.62	905.82	2.87	902.95	99.7%
[3] D50=0.12 mm	939.39	63.74	875.65	176.37	699.28	79.9%
Sediment Total =	2818.22	153.69	2664.53	180.19	2484.34	93.2%
[A] leaves	226.61	0	226.61	218.14	8.47	3.7%
[B] dowels	226.03	0	226.03	139.57	86.46	38.3%
[C] forks	227.43	0	227.43	216.72	10.71	4.7%
Gross Solids Total =	680.07	0	680.07	574.43	105.64	15.5%
Sediment + Gross Solids =	3498.29	153.69	3344.6	754.62	2589.98	77.4%

Mass data for GLI-025-B

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Untreated by Pretreatment (Captured in Bioretention) (g)	(e) Captured in Pretreatment (Assumed) (g)	(f) Percent Removal (%)
[1] D50=1.17 mm	939.4	33.39	906.01	0.65	905.36	99.9%
[2] D50=0.41 mm	939.46	40.84	898.62	12.63	885.99	98.6%
[3] D50=0.12 mm	939.48	59.81	879.67	428.67	451	51.3%
Sediment Total =	2818.34	134.04	2684.3	441.95	2242.35	83.5%
[A] leaves	226.65	0	226.65	220.26	6.39	2.8%
[B] dowels	226.53	0	226.53	113.96	112.57	49.7%
[C] forks	225.88	0	225.88	199.28	26.6	11.8%
Gross Solids Total =	679.06	0	679.06	533.5	145.56	21.4%
Sediment + Gross Solids =	3497.4	134.04	3363.36	975.45	2387.91	71.0%

Mass data for Average of two replicates (GLI-025-A & GLI-025-B)

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Untreated by Pretreatment (Captured in Bioretention) (g)	(e) Captured in Pretreatment (Assumed) (g)	(f) Percent Removal (%)
[1] D50=1.17 mm	939.395	44.86	894.535	0.8	893.735	99.9%
[2] D50=0.41 mm	939.45	37.23	902.22	7.75	894.47	99.1%
[3] D50=0.12 mm	939.435	61.775	877.66	302.52	575.14	65.5%
Sediment Total =	2818.28	143.865	2674.415	311.07	2363.345	88.4%
[A] leaves	226.63	0	226.63	219.2	7.43	3.3%
[B] dowels	226.28	0	226.28	126.765	99.515	44.0%
[C] forks	226.655	0	226.655	208	18.655	8.2%
Gross Solids Total =	679.565	0	679.565	553.965	125.6	18.5%
Sediment + Gross Solids =	3497.845	143.865	3353.98	865.035	2488.945	74.2%

Note: ***a - b = c*** ***c - d = e*** ***e ÷ c = f***

Table 8: Raw mass data for Grass Lined Inlet (GLI) field tests (cont'd)

Mass data for GLI-050-A

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Untreated by Pretreatment (Captured in Bioretention) (g)	(e) Captured in Pretreatment (Assumed) (g)	(f) Percent Removal (%)
[1] D50=1.17 mm	939.4	26.61	912.79	35.41	877.38	96.1%
[2] D50=0.41 mm	939.47	21.35	918.12	179.93	738.19	80.4%
[3] D50=0.12 mm	939.46	42.92	896.54	546.4	350.14	39.1%
Sediment Total =	2818.33	90.88	2727.45	761.74	1965.71	72.1%
[A] leaves	226.53	0	226.53	217.11	9.42	4.2%
[B] dowels	226.9	0	226.9	76.82	150.08	66.1%
[C] forks	226.01	0	226.01	215.37	10.64	4.7%
Gross Solids Total =	679.44	0	679.44	509.3	170.14	25.0%
Sediment + Gross Solids =	3497.77	90.88	3406.89	1271.04	2135.85	62.7%

Mass data for GLI-050-B

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Untreated by Pretreatment (Captured in Bioretention) (g)	(e) Captured in Pretreatment (Assumed) (g)	(f) Percent Removal (%)
[1] D50=1.17 mm	939.39	26.57	912.82	7.39	905.43	99.2%
[2] D50=0.41 mm	939.43	22.48	916.95	138.82	778.13	84.9%
[3] D50=0.12 mm	939.5	40.35	899.15	588.9	310.25	34.5%
Sediment Total =	2818.32	89.4	2728.92	735.11	1993.81	73.1%
[A] leaves	226.5	0	226.5	223.21	3.29	1.5%
[B] dowels	227	0	227	60.52	166.48	73.3%
[C] forks	226.65	0	226.65	189.82	36.83	16.2%
Gross Solids Total =	680.15	0	680.15	473.55	206.6	30.4%
Sediment + Gross Solids =	3498.47	89.4	3409.07	1208.66	2200.41	64.5%

Mass data for Average of two replicates (GLI-050-A & GLI-050-B)

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Untreated by Pretreatment (Captured in Bioretention) (g)	(e) Captured in Pretreatment (Assumed) (g)	(f) Percent Removal (%)
[1] D50=1.17 mm	939.395	26.59	912.805	21.4	891.405	97.7%
[2] D50=0.41 mm	939.45	21.915	917.535	159.375	758.16	82.6%
[3] D50=0.12 mm	939.48	41.635	897.845	567.65	330.195	36.8%
Sediment Total =	2818.325	90.14	2728.185	748.425	1979.76	72.6%
[A] leaves	226.515	0	226.515	220.16	6.355	2.8%
[B] dowels	226.95	0	226.95	68.67	158.28	69.7%
[C] forks	226.33	0	226.33	202.595	23.735	10.5%
Gross Solids Total =	679.795	0	679.795	491.425	188.37	27.7%
Sediment + Gross Solids =	3498.12	90.14	3407.98	1239.85	2168.13	63.6%

Note: ***a - b = c*** ***c - d = e*** ***e ÷ c = f***

Table 9: Raw mass data for Rain Guardian Bunker (RGB) field tests

Mass data for RGB-025-A

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Captured on Surface Grate (g)	(e) Captured in Chamber (g)	(f) Captured on Screen wall (g)	(g) Deposited Downstream of Screen Wall (g)	(h) Captured in Pretreatment (g)	(i) Percent Removal (%)
[1] D50=1.17 mm	939.39	49.13	890.26	52.43	813.06	0	1.6	867.09	97.4%
[2] D50=0.41 mm	939.4	46.91	892.49	64.19	824.66	1.16	13.74	903.75	101.3%
[3] D50=0.12 mm	939.41	71.2	868.21	106.06	387.36	17.96	181.21	692.59	79.8%
Sediment Total =	2818.2	167.24	2650.96	222.68	2025.08	19.12	196.55	2463.43	92.9%
[A] leaves	226.58	0	226.58	144.96	80.94	0	0.24	226.14	99.8%
[B] dowels	226.66	0	226.66	41.52	34.36	1.16	15.79	92.83	41.0%
[C] forks	226.17	0	226.17	157.86	68.2	0	0	226.06	100.0%
Gross Solids Total =	679.41	0	679.41	344.34	183.5	1.16	16.03	545.03	80.2%
Sediment + Gross Solids =	3497.61	167.24	3330.37	567.02	2208.58	20.28	212.58	3008.46	90.3%

Mass data for RGB-025-B

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Captured on Surface Grate (g)	(e) Captured in Chamber (g)	(f) Captured on Screen wall (g)	(g) Deposited Downstream of Screen Wall (g)	(h) Captured in Pretreatment (g)	(i) Percent Removal (%)
[1] D50=1.17 mm	939.39	43.87	895.52	11.34	864.42	0.01	1.27	877.04	97.9%
[2] D50=0.41 mm	939.44	44.11	895.33	10.03	876.91	2.01	20.49	909.44	101.6%
[3] D50=0.12 mm	939.44	68	871.44	14.59	419.35	22.66	167.99	624.59	71.7%
Sediment Total =	2818.27	155.98	2662.29	35.96	2160.68	24.68	189.75	2411.07	90.6%
[A] leaves	226.58	0	226.58	86.43	137.83	0	0	224.26	99.0%
[B] dowels	226.14	0	226.14	10.84	20.65	18.98	31.82	82.29	36.4%
[C] forks	226.14	0	226.14	144.38	74.75	0	0	219.13	96.9%
Gross Solids Total =	678.86	0	678.86	241.65	233.23	18.98	31.82	525.68	77.4%
Sediment + Gross Solids =	3497.13	155.98	3341.15	277.61	2393.91	43.66	221.57	2936.75	87.9%

Mass data for Average of two replicates (RGB-025-A & RGB-025-B)

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Captured on Surface Grate (g)	(e) Captured in Chamber (g)	(f) Captured on Screen wall (g)	(g) Deposited Downstream of Screen Wall (g)	(h) Captured in Pretreatment (g)	(i) Percent Removal (%)
[1] D50=1.17 mm	939.39	46.5	892.89	31.885	838.74	0.005	1.435	872.065	97.7%
[2] D50=0.41 mm	939.42	45.51	893.91	37.11	850.785	1.585	17.115	906.595	101.4%
[3] D50=0.12 mm	939.425	69.6	869.825	60.325	403.355	20.31	174.6	658.59	75.7%
Sediment Total =	2818.235	161.61	2656.625	129.32	2092.88	21.9	193.15	2437.25	91.7%
[A] leaves	226.58	0	226.58	115.695	109.385	0	0.12	225.2	99.4%
[B] dowels	226.4	0	226.4	26.18	27.505	10.07	23.805	87.56	38.7%
[C] forks	226.155	0	226.155	151.12	71.475	0	0	222.595	98.4%
Gross Solids Total =	679.135	0	679.135	292.995	208.365	10.07	23.925	535.355	78.8%
Sediment + Gross Solids =	3497.37	161.61	3335.76	422.315	2301.245	31.97	217.075	2972.605	89.1%

Note: $a - b = c$ $d + e + f + g = h$ $h \div c = i$

Table 9: Raw mass data for Rain Guardian Bunker (RGB) field tests (cont'd)

Mass data for RGB-050-A

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Captured on Surface Grate (g)	(e) Captured in Chamber (g)	(f) Captured on Screen wall (g)	(g) Deposited Downstream of Screen Wall (g)	(h) Captured in Pretreatment (g)	(i) Percent Removal (%)
[1] D50=1.17 mm	939.42	5.81	933.61	7.26	866.56	0.92	34.84	909.58	97.4%
[2] D50=0.41 mm	939.42	7.81	931.61	3.43	815.62	4.81	85.67	909.53	97.6%
[3] D50=0.12 mm	939.41	28.72	910.69	10.55	194.38	31.24	99.19	335.36	36.8%
Sediment Total =	2818.25	42.34	2775.91	21.24	1876.56	36.97	219.7	2154.47	77.6%
[A] leaves	226.51	0	226.51	95.91	18.28	0	6.48	120.67	53.3%
[B] dowels	226.54	0	226.54	31.99	39.23	2.49	10.2	83.91	37.0%
[C] forks	226.93	0	226.93	158.44	52.84	0	13.08	224.36	98.9%
Gross Solids Total =	679.98	0	679.98	286.34	110.35	2.49	29.76	428.94	63.1%
Sediment + Gross Solids =	3498.23	42.34	3455.89	307.58	1986.91	39.46	249.46	2583.41	74.8%

Mass data for RGB-050-B

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Captured on Surface Grate (g)	(e) Captured in Chamber (g)	(f) Captured on Screen wall (g)	(g) Deposited Downstream of Screen Wall (g)	(h) Captured in Pretreatment (g)	(i) Percent Removal (%)
[1] D50=1.17 mm	939.39	29.68	909.71	4.96	817.57	0.85	61.72	885.1	97.3%
[2] D50=0.41 mm	939.39	30.72	908.67	3.21	681.73	6.55	151.81	843.3	92.8%
[3] D50=0.12 mm	939.42	56.82	882.6	9.69	121.11	26.33	99.59	256.72	29.1%
Sediment Total =	2818.2	117.22	2700.98	17.86	1620.41	33.73	313.12	1985.12	73.5%
[A] leaves	226.55	0	226.55	109.64	14.29	0	10.53	134.46	59.4%
[B] dowels	225.38	0	225.38	22.97	11.35	0	21.41	55.73	24.7%
[C] forks	225.55	0	225.55	145.74	53.3	0	15.87	214.91	95.3%
Gross Solids Total =	677.48	0	677.48	278.35	78.94	0	47.81	405.1	59.8%
Sediment + Gross Solids =	3495.68	117.22	3378.46	296.21	1699.35	33.73	360.93	2390.22	70.7%

Mass data for Average of two replicates (RGB-050-A & RGB-050-B)

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Captured on Surface Grate (g)	(e) Captured in Chamber (g)	(f) Captured on Screen wall (g)	(g) Deposited Downstream of Screen Wall (g)	(h) Captured in Pretreatment (g)	(i) Percent Removal (%)
[1] D50=1.17 mm	939.405	17.745	921.66	6.11	842.065	0.885	48.28	897.34	97.4%
[2] D50=0.41 mm	939.405	19.265	920.14	3.32	748.675	5.68	118.74	876.415	95.2%
[3] D50=0.12 mm	939.415	42.77	896.645	10.12	157.745	28.785	99.39	296.04	33.0%
Sediment Total =	2818.225	79.78	2738.445	19.55	1748.485	35.35	266.41	2069.795	75.6%
[A] leaves	226.53	0	226.53	102.775	16.285	0	8.505	127.565	56.3%
[B] dowels	225.96	0	225.96	27.48	25.29	1.245	15.805	69.82	30.9%
[C] forks	226.24	0	226.24	152.09	53.07	0	14.475	219.635	97.1%
Gross Solids Total =	678.73	0	678.73	282.345	94.645	1.245	38.785	417.02	61.4%
Sediment + Gross Solids =	3496.955	79.78	3417.175	301.895	1843.13	36.595	305.195	2486.815	72.8%

Note: $a - b = c$ $d + e + f + g = h$ $h \div c = i$

Table 10: Raw mass data for Rain Guardian Turret (RGT) field tests

Mass data for RGT-025-A

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Captured on Surface Grate (g)	(e) Captured in Chamber (g)	(f) Captured on Screen wall (g)	(g) Deposited Downstream of Screen Wall (g)	(h) Captured in Pretreatment (g)	(i) Percent Removal (%)
[1] D50=1.17 mm	939.4	49.6	889.8	41.89	830.44	0.06	0.4	872.79	98.1%
[2] D50=0.41 mm	939.38	42.75	896.63	53.55	850.01	0.53	1.04	905.13	100.9%
[3] D50=0.12 mm	939.45	66.17	873.28	66.26	423.99	9.86	40.05	540.16	61.9%
Sediment Total =	2818.23	158.52	2659.71	161.7	2104.44	10.45	41.49	2318.08	87.2%
[A] leaves	226.44	0	226.44	156.02	68.56	0	0	224.58	99.2%
[B] dowels	226.53	0	226.53	33.84	102.76	0	7.81	144.41	63.7%
[C] forks	226.63	0	226.63	163.25	63.34	0	0	226.59	100.0%
Gross Solids Total =	679.6	0	679.6	353.11	234.66	0	7.81	595.58	87.6%
Sediment + Gross Solids =	3497.83	158.52	3339.31	514.81	2339.1	10.45	49.3	2913.66	87.3%

Mass data for RGT-025-B

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Captured on Surface Grate (g)	(e) Captured in Chamber (g)	(f) Captured on Screen wall (g)	(g) Deposited Downstream of Screen Wall (g)	(h) Captured in Pretreatment (g)	(i) Percent Removal (%)
[1] D50=1.17 mm	939.4	39.48	899.92	37.74	847.07	0	0.04	884.85	98.3%
[2] D50=0.41 mm	939.4	50.78	888.62	40.19	853.52	0.76	2.34	896.81	100.9%
[3] D50=0.12 mm	939.43	74.66	864.77	56.32	455.93	13.98	68.81	595.04	68.8%
Sediment Total =	2818.23	164.92	2653.31	134.25	2156.52	14.74	71.19	2376.7	89.6%
[A] leaves	226.63	0	226.63	148.04	73.37	0	0	221.41	97.7%
[B] dowels	226.56	0	226.56	51.14	61.56	0	22	134.7	59.5%
[C] forks	226.74	0	226.74	195.38	31.28	0	0	226.66	100.0%
Gross Solids Total =	679.93	0	679.93	394.56	166.21	0	22	582.77	85.7%
Sediment + Gross Solids =	3498.16	164.92	3333.24	528.81	2322.73	14.74	93.19	2959.47	88.8%

Mass data for Average of two replicates (RGT-025-A & RGT-025-B)

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Captured on Surface Grate (g)	(e) Captured in Chamber (g)	(f) Captured on Screen wall (g)	(g) Deposited Downstream of Screen Wall (g)	(h) Captured in Pretreatment (g)	(i) Percent Removal (%)
[1] D50=1.17 mm	939.4	44.54	894.86	39.815	838.755	0.03	0.22	878.82	98.2%
[2] D50=0.41 mm	939.39	46.765	892.625	46.87	851.765	0.645	1.69	900.97	100.9%
[3] D50=0.12 mm	939.44	70.415	869.025	61.29	439.96	11.92	54.43	567.6	65.3%
Sediment Total =	2818.23	161.72	2656.51	147.975	2130.48	12.595	56.34	2347.39	88.4%
[A] leaves	226.535	0	226.535	152.03	70.965	0	0	222.995	98.4%
[B] dowels	226.545	0	226.545	42.49	82.16	0	14.905	139.555	61.6%
[C] forks	226.685	0	226.685	179.315	47.31	0	0	226.625	100.0%
Gross Solids Total =	679.765	0	679.765	373.835	200.435	0	14.905	589.175	86.7%
Sediment + Gross Solids =	3497.995	161.72	3336.275	521.81	2330.915	12.595	71.245	2936.565	88.0%

Note: ***a - b = c*** ***d + e + f + g = h*** ***h ÷ c = i***

Table 10: Raw mass data for Rain Guardian Turret (RGT) field tests (cont'd)

Mass data for RGT-050-A

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Captured on Surface Grate (g)	(e) Captured in Chamber (g)	(f) Captured on Screen wall (g)	(g) Deposited Downstream of Screen Wall (g)	(h) Captured in Pretreatment (g)	(i) Percent Removal (%)
[1] D50=1.17 mm	939.41	29.75	909.66	0.62	893.67	0.12	0.21	894.62	98.3%
[2] D50=0.41 mm	939.41	49.28	890.13	0.41	848.9	5.45	17.35	872.11	98.0%
[3] D50=0.12 mm	939.42	63.97	875.45	1.81	264.01	13.09	15.33	294.24	33.6%
Sediment Total =	2818.24	143	2675.24	2.84	2006.58	18.66	32.89	2060.97	77.0%
[A] leaves	226.66	0	226.66	106.01	70.33	0	0	176.34	77.8%
[B] dowels	226.01	0	226.01	68.96	48.46	0	3.69	121.11	53.6%
[C] forks	227.28	0	227.28	179.27	47.96	0	0	227.23	100.0%
Gross Solids Total =	679.95	0	679.95	354.24	166.75	0	3.69	524.68	77.2%
Sediment + Gross Solids =	3498.19	143	3355.19	357.08	2173.33	18.66	36.58	2585.65	77.1%

Mass data for RGT-050-B

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Captured on Surface Grate (g)	(e) Captured in Chamber (g)	(f) Captured on Screen wall (g)	(g) Deposited Downstream of Screen Wall (g)	(h) Captured in Pretreatment (g)	(i) Percent Removal (%)
[1] D50=1.17 mm	939.39	6.47	932.92	0.08	909.56	0.06	0.35	910.05	97.5%
[2] D50=0.41 mm	939.4	9.54	929.86	0.6	907.4	2.82	10.26	921.08	99.1%
[3] D50=0.12 mm	939.42	31.88	907.54	8.17	346.17	11.08	48.43	413.85	45.6%
Sediment Total =	2818.21	47.89	2770.32	8.85	2163.13	13.96	59.04	2244.98	81.0%
[A] leaves	226.55	0	226.55	121.14	37.82		0.69	159.65	70.5%
[B] dowels	226.5	0	226.5	58.62	10.77	1.09	11.26	81.74	36.1%
[C] forks	226.94	0	226.94	189.97	21.25		7.89	219.11	96.5%
Gross Solids Total =	679.99	0	679.99	369.73	69.84	1.09	19.84	460.5	67.7%
Sediment + Gross Solids =	3498.2	47.89	3450.31	378.58	2232.97	15.05	78.88	2705.48	78.4%

Mass data for Average of two replicates (RGT-050-A & RGT-050-B)

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Captured on Surface Grate (g)	(e) Captured in Chamber (g)	(f) Captured on Screen wall (g)	(g) Deposited Downstream of Screen Wall (g)	(h) Captured in Pretreatment (g)	(i) Percent Removal (%)
[1] D50=1.17 mm	939.4	18.11	921.29	0.35	901.615	0.09	0.28	902.335	97.9%
[2] D50=0.41 mm	939.405	29.41	909.995	0.505	878.15	4.135	13.805	896.595	98.5%
[3] D50=0.12 mm	939.42	47.925	891.495	4.99	305.09	12.085	31.88	354.045	39.7%
Sediment Total =	2818.225	95.445	2722.78	5.845	2084.855	16.31	45.965	2152.975	79.1%
[A] leaves	226.605	0	226.605	113.575	54.075	0	0.345	167.995	74.1%
[B] dowels	226.255	0	226.255	63.79	29.615	0.545	7.475	101.425	44.8%
[C] forks	227.11	0	227.11	184.62	34.605	0	3.945	223.17	98.3%
Gross Solids Total =	679.97	0	679.97	361.985	118.295	0.545	11.765	492.59	72.4%
Sediment + Gross Solids =	3498.195	95.445	3402.75	367.83	2203.15	16.855	57.73	2645.565	77.7%

Note: $a - b = c$ $d + e + f + g = h$ $h \div c = i$

Table 11: Raw mass data for Rock Lined Inlet (RLI) field tests

Mass data for RLI-025-A

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Captured in Pretreatment (g)	(e) Percent Removal (%)
[1] D50=1.17 mm	939.44	11.04	928.4	852.8	91.9%
[2] D50=0.41 mm	939.44	14.18	925.26	988.41	106.8%
[3] D50=0.12 mm	939.42	41.08	898.34	551.64	61.4%
Sediment Total =	2818.3	66.3	2752	2392.85	86.9%
[A] leaves	225.87	0	225.87	228.31	101.1%
[B] dowels	226.65	0	226.65	223.77	98.7%
[C] forks	227.32	2.71	224.61	224.7	100.0%
Gross Solids Total =	679.84	2.71	677.13	676.78	99.9%
Sediment + Gross Solids =	3498.14	69.01	3429.13	3069.63	89.5%

Mass data for RLI-025-B

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Captured in Pretreatment (g)	(e) Percent Removal (%)
[1] D50=1.17 mm	939.44	43.59	895.85	890.27	99.4%
[2] D50=0.41 mm	939.4	38.17	901.23	906.71	100.6%
[3] D50=0.12 mm	939.42	76.36	863.06	776.8	90.0%
Sediment Total =	2818.26	158.12	2660.14	2573.78	96.8%
[A] leaves	226.48	0	226.48	225.54	99.6%
[B] dowels	226.82	0	226.82	157.55	69.5%
[C] forks	227.15	0	227.15	224.5	98.8%
Gross Solids Total =	680.45	0	680.45	607.59	89.3%
Sediment + Gross Solids =	3498.71	158.12	3340.59	3181.37	95.2%

Mass data for Average of two replicates (RLI-025-A & RLI-025-B)

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Captured in Pretreatment (g)	(e) Percent Removal (%)
[1] D50=1.17 mm	939.44	27.315	912.125	871.535	95.5%
[2] D50=0.41 mm	939.42	26.175	913.245	947.56	103.8%
[3] D50=0.12 mm	939.42	58.72	880.7	664.22	75.4%
Sediment Total =	2818.28	112.21	2706.07	2483.315	91.8%
[A] leaves	226.175	0	226.175	226.925	100.3%
[B] dowels	226.735	0	226.735	190.66	84.1%
[C] forks	227.235	1.355	225.88	224.6	99.4%
Gross Solids Total =	680.145	1.355	678.79	642.185	94.6%
Sediment + Gross Solids =	3498.425	113.565	3384.86	3125.5	92.3%

Note: ***a - b = c*** ***d ÷ c = e***

Table 11: Raw mass data for Rock Lined Inlet (RLI) field tests (cont'd)

Mass data for RLI-050-A

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Captured in Pretreatment (g)	(e) Percent Removal (%)
[1] D50=1.17 mm	939.42	7.83	931.59	924.06	99.2%
[2] D50=0.41 mm	939.45	9.67	929.78	926.81	99.7%
[3] D50=0.12 mm	939.47	29.06	910.41	311.76	34.2%
Sediment Total =	2818.34	46.56	2771.78	2162.63	78.0%
[A] leaves	226.97	0	226.97	79.64	35.1%
[B] dowels	225.99	0	225.99	121.98	54.0%
[C] forks	226.31	0	226.31	194.69	86.0%
Gross Solids Total =	679.27	0	679.27	396.31	58.3%
Sediment + Gross Solids =	3497.61	46.56	3451.05	2558.94	74.1%

Mass data for RLI-050-B

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Captured in Pretreatment (g)	(e) Percent Removal (%)
[1] D50=1.17 mm	939.4	55.48	883.92	877.56	99.3%
[2] D50=0.41 mm	939.42	38.38	901.04	853.68	94.7%
[3] D50=0.12 mm	939.45	50.72	888.73	256.66	28.9%
Sediment Total =	2818.27	144.58	2673.69	1987.9	74.4%
[A] leaves	226.54	0	226.54	30.98	13.7%
[B] dowels	225.79	0	225.79	174.85	77.4%
[C] forks	224.68	0	224.68	168.46	75.0%
Gross Solids Total =	677.01	0	677.01	374.29	55.3%
Sediment + Gross Solids =	3495.28	144.58	3350.7	2362.19	70.5%

Mass data for Average of two replicates (RLI-050-A & RLI-050-B)

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Captured in Pretreatment (g)	(e) Percent Removal (%)
[1] D50=1.17 mm	939.41	31.655	907.755	900.81	99.2%
[2] D50=0.41 mm	939.435	24.025	915.41	890.245	97.3%
[3] D50=0.12 mm	939.46	39.89	899.57	284.21	31.6%
Sediment Total =	2818.305	95.57	2722.735	2075.265	76.2%
[A] leaves	226.755	0	226.755	55.31	24.4%
[B] dowels	225.89	0	225.89	148.415	65.7%
[C] forks	225.495	0	225.495	181.575	80.5%
Gross Solids Total =	678.14	0	678.14	385.3	56.8%
Sediment + Gross Solids =	3496.445	95.57	3400.875	2460.565	72.4%

Note: ***a - b = c*** ***d ÷ c = e***

Table 12: Raw mass data for Shallow Sump Grit Chamber Design Volume (BDV) field tests

Mass data for BDV-006-A

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Captured in Pretreatment (g)	(e) Percent Removal (%)
[1] D50=1.17 mm	259.91	46.19	213.72	212.4	99.4%
[2] D50=0.41 mm	259.93	48.51	211.42	221.12	104.6%
[3] D50=0.12 mm	259.99	56.15	203.84	166.19	81.5%
Sediment Total =	779.83	150.85	628.98	599.71	95.3%
[A] leaves	56.56	0	56.56	51.68	91.4%
[B] dowels	56.41	0	56.41	24.03	42.6%
[C] forks	55.79	0	55.79	55.77	100.0%
Gross Solids Total =	168.76	0	168.76	131.48	77.9%
Sediment + Gross Solids =	948.59	150.85	797.74	731.19	91.7%

Mass data for BDV-006-B

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Captured in Pretreatment (g)	(e) Percent Removal (%)
[1] D50=1.17 mm	259.91	65.02	194.89	193.53	99.3%
[2] D50=0.41 mm	259.87	66.29	193.58	199.66	103.1%
[3] D50=0.12 mm	259.99	64.99	195	152.5	78.2%
Sediment Total =	779.77	196.3	583.47	545.69	93.5%
[A] leaves	56.52	0	56.52	50.24	88.9%
[B] dowels	56.34	0	56.34	40.13	71.2%
[C] forks	56.62	0	56.62	55.58	98.2%
Gross Solids Total =	169.48	0	169.48	145.95	86.1%
Sediment + Gross Solids =	949.25	196.3	752.95	691.64	91.9%

Mass data for Average of two replicates (BDV-006-A & BDV-006-B)

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Captured in Pretreatment (g)	(e) Percent Removal (%)
[1] D50=1.17 mm	259.91	55.605	204.305	202.965	99.3%
[2] D50=0.41 mm	259.9	57.4	202.5	210.39	103.9%
[3] D50=0.12 mm	259.99	60.57	199.42	159.345	79.9%
Sediment Total =	779.8	173.575	606.225	572.7	94.5%
[A] leaves	56.54	0	56.54	50.96	90.1%
[B] dowels	56.375	0	56.375	32.08	56.9%
[C] forks	56.205	0	56.205	55.675	99.1%
Gross Solids Total =	169.12	0	169.12	138.715	82.0%
Sediment + Gross Solids =	948.92	173.575	775.345	711.415	91.8%

Note: ***a - b = c*** ***d ÷ c = e***

Table 12: Raw mass data for Shallow Sump Grit Chamber Design Volume (BDV) field tests (cont'd)

Mass data for BDV-012-A

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Captured in Pretreatment (g)	(e) Percent Removal (%)
[1] D50=1.17 mm	259.95	55.47	204.48	199.91	97.8%
[2] D50=0.41 mm	259.92	56.29	203.63	206.53	101.4%
[3] D50=0.12 mm	259.81	72.99	186.82	122.23	65.4%
Sediment Total =	779.68	184.75	594.93	528.67	88.9%
[A] leaves	56.53	0	56.53	36.83	65.2%
[B] dowels	56.16	0	56.16	25.84	46.0%
[C] forks	58.54	0	58.54	58.52	100.0%
Gross Solids Total =	171.23	0	171.23	121.19	70.8%
Sediment + Gross Solids =	950.91	184.75	766.16	649.86	84.8%

Mass data for BDV-012-B

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Captured in Pretreatment (g)	(e) Percent Removal (%)
[1] D50=1.17 mm	259.91	57.86	202.05	200.41	99.2%
[2] D50=0.41 mm	259.95	54.5	205.45	203.89	99.2%
[3] D50=0.12 mm	260.02	61.74	198.28	130.12	65.6%
Sediment Total =	779.88	174.1	605.78	534.42	88.2%
[A] leaves	56.6	0	56.6	39.02	68.9%
[B] dowels	56.87	0	56.87	24.68	43.4%
[C] forks	57.82	0	57.82	55.2	95.5%
Gross Solids Total =	171.29	0	171.29	118.9	69.4%
Sediment + Gross Solids =	951.17	174.1	777.07	653.32	84.1%

Mass data for Average of two replicates (BDV-012-A & BDV-012-B)

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Captured in Pretreatment (g)	(e) Percent Removal (%)
[1] D50=1.17 mm	259.93	56.665	203.265	200.16	98.5%
[2] D50=0.41 mm	259.935	55.395	204.54	205.21	100.3%
[3] D50=0.12 mm	259.915	67.365	192.55	126.175	65.5%
Sediment Total =	779.78	179.425	600.355	531.545	88.5%
[A] leaves	56.565	0	56.565	37.925	67.0%
[B] dowels	56.515	0	56.515	25.26	44.7%
[C] forks	58.18	0	58.18	56.86	97.7%
Gross Solids Total =	171.26	0	171.26	120.045	70.1%
Sediment + Gross Solids =	951.04	179.425	771.615	651.59	84.4%

Note: ***a - b = c*** ***d ÷ c = e***

Table 13: Raw mass data for Shallow Sump Grit Chamber Bypass (BBP) field tests

Mass data for BBP-012

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Deposited on Bypass Gutter (g)	(e) Captured in Downstream Bypass Grate (g)	(f) Captured in Pretreatment (g)	(g) Percent Removal (%)
[1] D50=1.17 mm	486.4	6.1	480.3	0.0	0.1	478.2	99.6%
[2] D50=0.41 mm	486.4	5.3	481.1	0.1	0.6	483.3	100.4%
[3] D50=0.12 mm	486.8	16.2	470.6	23.2	23.3	329.1	69.9%
Sediment Total =	**1,459.6**	**27.6**	**1,432.0**	**23.3**	**24.0**	**1,290.6**	**90.1%**
[A] leaves	113.4	0.0	113.4	0.0	24.2	75.1	66.2%
[B] dowels	113.5	0.0	113.5	0.0	83.8	17.1	15.1%
[C] forks	114.4	0.0	114.4	0.0	2.6	111.8	97.7%
Gross Solids Total =	**341.4**	**0.0**	**341.4**	**0.0**	**110.5**	**204.0**	**59.8%**
Sediment + Gross Solids =	***1,801.0***	***27.6***	***1,773.4***	***23.3***	***134.5***	***1,494.6***	***84.3%***

Mass data for BBP-025

	(a) Initial Mass (g)	(b) Mass Not Fed (g)	(c) Influent to Pretreatment (g)	(d) Deposited on Bypass Gutter (g)	(e) Captured in Downstream Bypass Grate (g)	(f) Captured in Pretreatment (g)	(g) Percent Removal (%)
[1] D50=1.17 mm	486.4	26.0	460.4	0.1	0.1	457.8	99.4%
[2] D50=0.41 mm	486.4	17.7	468.7	0.4	3.1	447.7	95.5%
[3] D50=0.12 mm	486.4	22.4	464.1	20.8	55.4	232.1	50.0%
Sediment Total =	**1,459.2**	**66.0**	**1,393.2**	**21.3**	**58.6**	**1,137.6**	**81.7%**
[A] leaves	113.2	0.0	113.2	0.0	31.6	39.9	35.2%
[B] dowels	113.7	0.0	113.7	0.0	84.1	7.0	6.2%
[C] forks	112.4	0.0	112.4	0.0	29.5	80.1	71.3%
Gross Solids Total =	**339.3**	**0.0**	**339.3**	**0.0**	**145.1**	**127.0**	**37.4%**
Sediment + Gross Solids =	***1,798.5***	***66.0***	***1,732.5***	***21.3***	***203.7***	***1,264.6***	***73.0%***

Note: $a - b = c$ $d + e = f$ $f \div c = g$