# EVALUATION OF THE FARM LANE BIORETENTION RESEARCH FACILITY STORMWATER TREATMENT PERFORMANCE

By

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ABSTRACT

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Stormwater carries contaminants that pollute ground and surface waters. Decentralized treatment of stormwater using best management practices (BMPs) is the commonly accepted practice for mitigating contamination downstream. Bioretention basins provide treatment by slowing the flow of stormwater and via soil and plant associated processes. Michigan State University finished construction of a large scale bioretention basin in spring 2010. During construction numerous challenges arose which resulted in the as-built site differing from the original engineering design. Monitoring of chemical oxygen demand (COD), pH and total solids (TS) at the Farm Lane Bioretention Research Facility began in spring 2011 and is ongoing. It was concluded that little to no treatment is taking place within the bioretention basin. Numerous attempts to improve the water flow through the system have been completed, but have yielded few results. An additional study was completed evaluating the stormwater treatment performance of three plant species – *Iris virginica*, a *Carex* mix and fescue grass – in the five cells within the basin. An aerator was installed in the pond directly preceding the research cells to determine the impact of aeration on the water quality. Total nitrogen, total phosphorus, COD, pH and TS were evaluated at the influent and effluent locations. Congruent with overall monitoring of the site little to no treatment was observed in the five cells regardless of aeration. The bioretention basin is likely affected by contaminated materials used during construction. The Farm Lane bioretention basin provides an example of the importance of monitoring construction, as post construction changes are costly and challenging.

DEDICATION

I would like to dedicate this to my family who encouraged and supported me throughout this process:
Mom and Dad
Luke
Ryan

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## KEY TO SYMBOLS AND ABBREVIATIONS

| | |
|---|---|
| ANOVA | Analysis of Variance |
| BMP | Best Management Practice |
| cm | centimeter |
| COD | chemical oxygen demand |
| DI | Deionized Water |
| ft | feet |
| g | gram |
| Gal | Gallons |
| GPM | gallons per minute |
| in | inch |
| L | Liter |
| LID | Low Impact Development |
| m | meters |
| mg | milligram |
| mL | milliliter |
| n.a. | not applicable |
| s | seconds |
| sq. ft. | square feet |
| TN | total nitrogen |
| TP | total phosphorus |
| TS | total solids |

# CHAPTER 1 INTRODUCTION

Stormwater runoff frequently contains contaminants that pollute ground and surface waters (USEPA, 2000). These contaminants include oil, pathogens, metals, organic nutrients, phosphates and nitrates (Davis, 2008; W. F. Hunt, Jarrett, Smith, & Sharkey, 2006; R. Pitt, Field, Lalor, & Brown, 1995; Wu, Allan, Saunders, & Evett, 1998). As water becomes an increasingly scarce commodity, groundwater recharge and preventing water pollution have been identified as key aspects of sustainability. Consequently, the USEPA has begun to impose regulations on stormwater quality, which demands that stormwater treatment devices are implemented (USEPA, 2000). Stormwater treatment devices include dry extended detention basins, bioretention basins, constructed wetlands, infiltration trenches, wet and dry retention basins and sand filtration (Weiss, Gulliver, & Erickson, 2007).

Treatment of stormwater near its source and prior to reaching bodies of water is more economical and practical compared to collection and centralized treatment. Centralized wastewater treatment plants are not well equipped to handle the inconsistent supply of stormwater, so greater treatment can take place using stormwater treatment devices (Davis, 2007). Multiple stormwater Best Management Practices (BMPs) have been identified. BMPs target stormwater treatment by utilizing a combination of the following reduce impervious surfaces in urban areas, thus increasing groundwater recharge; increase urban plant life; slow the flow of stormwater; and reduce the demand on wastewater treatment plants (Davis, 2008). Bioretention basins are on type of BMP that are used to treat stormwater runoff. Brown and Hunt (2010) explain that bioretention basins consider several key stormwater design criteria: hydrologic, water quality and aesthetics. Hydrologic criterion is met through reduction of runoff volumes, while vegetation in the basin evapotranspire water and promote infiltration of water

into the soil. These processes also help to improve water quality (W. F. Hunt, et al., 2006; Li & Davis, 2009). Contaminants are sorped, biologically degraded, filtered and settled (Davis, Shokouhian, Sharma, & Minami, 2001).

Michigan State University installed many stormwater treatment technologies on campus to protect the Red Cedar River. The Farm Lane Bioretention Research Site finished construction in spring 2010 and is one of the largest on campus. The site has three ISCO 6700FR water samplers in place to collect stormwater samples for monitoring. Additionally, the Farm Lane bioretention basin is equipped with five parallel research cells with access points to collect water at the end of each of the cells. Following are the objectives of the study, literature review of bioretention basins, evaluation of the monitoring at the Farm Lane Bioretention Research Site and evaluation of varying plant types coupled with aeration. Lessons learned from monitoring and the five cell experiment are described throughout the document.

**Objectives**

Stormwater treatment has been identified as a key area of emphasis for sustainable development to mitigate the effects of urbanization. The Michigan State University Farm Lane Bioretention Research Facility is expected to improve the water quality of stormwater runoff within the 12.8 acre watershed. Bioretention basins are one practice to remove contaminants from stormwater. This study aims to:

- Monitor water quality impacts of an existing bioretention basin on campus
- Evaluate performance of three recommended plant species for Michigan in a field study of bioretention basins
- Analyze impact of aeration as a retrofit to improve treatment in bioretention basins

- Identify lessons learned from the bioretention basin to improve future stormwater technology installations

# CHAPTER 2 BIORETENTION BASIN LITERATURE REVIEW

Bioretention basins are a sustainable practice to manage stormwater runoff that use natural processes to remove contaminants from water. These processes require land for implementation, but use solar radiation as a renewable source of energy for treatment. The carbon footprint for natural treatment systems is significantly less than traditional wastewater treatment systems, which typically rely on highly controlled, fossil fuel intense processes. Bioretention basins can also be used to provide groundwater recharge (Schuster, Gehring, & Gerken, 2007).

Although bioretention basins show promise for being a sustainable approach to urban stormwater management, their adoption remains limited (Chapman & Horner, 2010). Numerous low impact development (LID) manuals detail design, construction and uses of bioretention basins ("Low Impact Development Manual for Michigan: A Design Guide for Implementers and Reviewers," 2008; Prince George's County, 1993). Analyzing current bioretention basin recommended design standards and the existing literature has identified gaps in knowledge. This section will evaluate existing literature on maximizing the effectiveness of stormwater treatment using bioretention basins.

Recommendation guides describing bioretention basin construction in the United States are abundant ("Low Impact Development Manual for Michigan: A Design Guide for Implementers and Reviewers," 2008; Prince George's County, 1993); however, the information presented in these guidelines is often based on anecdotal knowledge and assumptions. Broad statements regarding construction, types of vegetation and soils to use, treatment efficiencies and hydraulic performance have been made, but not all are scientifically validated. Design recommendations need to be justified and understood to ensure the viability and sustainability of bioretention

basins (Davis, Hunt, Traver, & Clar, 2009). Using knowledge gained from reviewing current literature, future research focusing on experiments that will improve the efficiency of bioretention basins in treatment of stormwater runoff will be proposed.

Recent research shows bioretention basins are effective systems that reduce most stormwater contaminants including total suspended solids, oils and grease, metals, pathogenic bacteria and nutrients (W. F. Hunt, Smith, Jadlocki, Hathaway, & Eubanks, 2008). Efficiencies in ammonia, nitrate, orthophosphorus and total phosphorus are varied. Mean reported nitrogen removal rates of 54.2% from bioretention basins suggest that they are more effective at removing nitrogen than green roofs, -67% removal rate and traditional stormwater devices, including dry ponds and wet ponds (Collins et al., 2010). Phosphorus removal appears to be closely related to the type of soil media used in construction (Ballantine & Tanner, 2010; Collins, et al., 2010). Heavy metal treatment has been shown to be very effective and closely related to the type of media used in bioretention basins (Blecken, Zinger, Deletic, Fletcher, & Viklander, 2009; Bratieres, Fletcher, Deletic, & Zinger, 2008; Davis, et al., 2001). Water quality treatment by bioretention basins is described in more detail in the following section.

Bioretention basins are typically composed of 0.7-1.0 m of a porous soil mixture, a thin mulch layer and a vegetation layer. An underdrain may be installed to direct the infiltrated water to a desired location or infiltrated water can percolate into the subsoil to recharge groundwater. The vegetation layer differentiates bioretention basins from infiltration practices and contributes to stormwater treatment by evapotranspiration, pollutant uptake and enhancing biological treatment (Davis, 2008).

A wide variety of guidelines for bioretention basins exist including varied recommendations for drawdown time, infiltration rates, permeability rates and soil media mix

(Carpenter & Hallam, 2010). Carpenter and Hallam (2010) compiled information from published design guides for bioretention basins and found wide variability in design recommendations for ponding depth, rate of decrease in water level, infiltration and permeability rates and soil media mixture (Carpenter & Hallam, 2010). As the design manuals were created for specific geographic areas, this variability in the proposed treatment area is expected. However, most design guidelines do not include specific recommendations for treatment of individual stormwater contaminants or optimized treatment efficiency. Instead the manuals typically include a list of native plants, with unknown treatment abilities and a broad range of soil media recommendations. Davis et al. completed a comprehensive review of bioretention basin technology in 2009 and identified numerous gaps in understanding bioretention technology, including ideal depth of soil media, underdrain configuration and plant selection (Davis, et al., 2009).

Understanding treatment mechanisms for specific contaminants will allow effective design of bioretention basins to improve stormwater quality in individual watersheds. The land use and number of point sources in a watershed determine contaminant concentrations in stormwater. Consequentially, the design of bioretention basins should be specific to the individual stormwater contaminants of concern identified in the downstream river. Stormwater treatment efficiencies can be increased using plants with high evapotranspiration rates, larger and deeper root mass and with strong phytoremediation traits including phytoextraction and phytosequestration (Gahoonia & Nielsen, 1998). Soil media mixes can be designed to increase phosphorus sorption, treatment of heavy metals and create anoxic areas to enhance denitrification processes (Blecken, et al., 2009; Carpenter & Hallam, 2010; W. F. Hunt, et al., 2006). Taking advantage of bioretention's multiple treatment mechanisms and evaluating

stormwater treatment from a watershed perspective will develop successful stormwater treatment practices that are effective and sustainable.

**Water Quality Treatment**

Treatment of stormwater using bioretention basins will improve effluent water quality. Typically constructed in urban areas, runoff contaminants include metals, oil and grease, bacteria, nutrients—such as phosphorous and nitrogen—and total suspended solids. Typical concentrations of select stormwater contaminants are shown in Table 1, however contaminant concentrations will likely vary substantially between watersheds.

Table 1 Standard Concentrations Of Select Contaminants In Stormwater (USEPA, 1983)

| Contaminant | Concentration (mg/L) |
|---|---|
| Total solids | 67-101 |
| Chemical oxygen demand | 40-73 |
| Total Kjeldahl Nitrogen | 0.43-1.0 |
| Total Phosphorus | 0.67-1.66 |

This section will discuss reported treatment efficiencies of bioretention basins for nutrients, total suspended solids and metals.

*Nutrient Removal*

Total nitrogen and total phosphorus load reductions in bioretention basins for laboratory and pilot-scale projects were compiled and reported by Davis (Davis, et al., 2009). Load reductions for total nitrogen were reported between 30 and 95 percent, although much of this is due to reduction in water volume and not contaminant removal. Data on the amount and type of vegetation in the bioretention basins were not evaluated (Davis, et al., 2009), but could explain this large variation. Recent research has linked nitrogen treatment efficiencies to plant selection. The variation in nitrogen removal was further reported by Hatt et al. Total nitrogen ranged from actually increasing from the effluent concentrations to 70 percent treatment (Blecken et al., 2007;

Hatt, Fletcher, & Deletic, 2009a). Cold temperatures further impact nitrogen removal. After conducting a column study, Blecken reported that cold temperatures influenced the ability of bioretention basins to treat nitrogen runoff. Additional experiments related to vegetation species selection and nutrient uptake will allow for more effective design and increased vegetation treatment efficiencies.

Another proposed solution that potentially reduces nitrogen is to install an anaerobic zone in bioretention basins. After testing, this hypothesis numerous studies have produced mixed results that are not statistically significant (Davis, 2008; W. F. Hunt, et al., 2006; Kim, Seagren, & Davis, 2003). A field study by Davis analyzed two bioretention cells. One cell was designed as described above; the other cell incorporated an anoxic zone at the bottom to promote denitrification (Davis, 2008). This zone was composed of a ratio of 17 kg newspaper per kg of sand following the recommendations of Kim et al. (Davis, et al., 2001; Davis, Shokouhian, Sharma, & Minami, 2006; Davis, Shokouhian, Sharma, Minami, & Winogradoff, 2003; Kim, et al., 2003). Although effluent water from this cell did not achieve increased denitrification, it did reduce flow peaks by 33% compared to the standard bioretention design. This is likely due to the added depth the anoxic zone provided (Davis, 2008).

Research conducted in Melbourne, Australia demonstrated that two species, *Carex appressa* and *Melaleuca ericiflolia* were the only species able to achieve nitrogen removal ranging from 46-71%, *Microleana stipoides, Dianelle revolute and Leucophyta brownii* demonstrated a generation of nitrogen ranging from 151-241% (Bratieres, et al., 2008). Another study conducted by Read with Australian vegetation showed significant variation in contaminant removal of nutrients per root mass, specifically in relation to nitrate and ammonia forms of nitrogen (Read, Wevill, Fletcher, & Deletic, 2008). Read continued to demonstrate that root plant

traits were correlated to N and P removal based on the length of the longest root, rooting depth, total root length and root mass (Read, Fletcher, Wevill, & Deletic, 2010). This information strongly suggests that species of plants with large root masses and finer root systems may increase treatment of stormwater runoff in bioretention basins.

When studying nitrogen removal more information on methods and measurements need to be documented and reported to allow for a more thorough comparison of available information. Further research is needed to improve the removal of dissolved nitrogen (Taylor, Fletcher, Wong, Breen, & Duncan, 2005).

In regard to phosphorus, Davis' study reported load reductions were varied from a net gain to 99 percent load reduction. This range was explained by the initial phosphorus content present in the bioretention soil media, in general the lower the initial phosphorus index the higher the removal rate (Davis, et al., 2009). However, this conclusion was not further analyzed. Phosphorus uptake in plants has been linked to root mass and growth in many studies (Pang et al., 2010). Phosphorus in the soil mixture is transported to roots through diffusion. Therefore, vegetation with increased root length, root mass and fine root hairs will have better access to take up phosphorus than vegetation with smaller root length, mass and fine root hairs (Gahoonia & Nielsen, 1998; Novak & Chan, 2002; Roumet, Lafont, Sari, Warembourg, & Garnier, 2008; Sharma & Sahi, 2005). In addition, temperature plays an important role in most plant root growth (Sharma & Sahi, 2005), with increasing root mass with increasing temperature.

Sharma conducted laboratory research to evaluate legume, vegetable and herb crops for increased phosphorus uptake (Sharma, Starnes, & Sahi, 2007). Sharma reported that sunflowers, cucumber and yellow squash accumulated phosphorus in their shoots with cucumber and yellow squash reporting over one percent of total phosphorus by mass in the shoots of the plant.

Phosphorus treatment in bioretention basins by vegetation is typically conducted through phytoextraction. Phosphorus accumulation between 3,000 and 6,000 mg/kg plant tissue has been reported (*Phytotechnology Tehcnical and Regulatory Guidance and Decision Trees, Revised*, 2009). The potential for increased total phosphorus by mass was also reported by Hunt et al. Analyzing three bioretention systems in North Carolina it was reported that one of the basins actually showed an increase in total phosphorus (W. F. Hunt, et al., 2006). Phosphorus is frequently in soil initially, which reduces the amount of phosphorus that can be sorped to the soil media. Consequently, current design recommendations limit media phosphorus index to range from 10 to 30 when concerned with phosphorus removal (W. Hunt).

*Suspended Solids*

Performance of bioretention basins to treat total suspended solids removal is well documented. Treatment occurs by trapping particles as they filter through the vegetation and soil media and localized settling. Hatt et al. found in a laboratory study that total suspended solids were reduced by 96 percent (Hatt, et al., 2009a). Phosphorus and total suspended solids are related since phosphorus present in the soil mixture often is leached into the water (W. F. Hunt, et al., 2006). Total suspended solid load reductions in bioretention basins for laboratory and pilot-scale projects were compiled and reported by Davis. Traditional efficiencies are approximately 95 percent with a few results reported around 55 percent mass removal. Stormwater with heavy total suspended solids contamination is prone to block or plug the filter media (Davis, et al., 2009). Hatt recommended that the top 2 to 5 inches of soil media be removed to maintain permeability rates in high suspended solids and heavy metal situations (Hatt, Fletcher, & Deletic, 2008).

*Metals*

Metals, present on roads from automobile exhaust, wearing of tires and brakes and from salts used for de-icing in winter, are common stormwater contaminants. Removal is attributed primarily to sedimentation and filtration (Ladislas, Gerente, Chazarenc, Andres, & Brisson, 2010); however, plants can contribute to the removal. Plants can immobilize metals in their rhizosphere. For example, arbuscular mycorrhizal plants, including lettuce, immobilized cadmium in the rhizosphere (Janouskova & Pavlikova, 2010). Introduction of vegetation increases the sorption lifespan of the soil if a rhizosphere can be developed (W. C. Lucas & Greenway, 2008).

In addition to immobilization many plants, hyperaccumulators, are capable of accumulating high concentrations of metals from soils into their biomass. For example, *Eupatorium capillifolium* (dog fennel) can accumulate 12.3 – 16.4 mg of Cd per kg of above-ground plant biomass when grown in soils containing 1.9 mg/kg Cd (*Phytotechnology Tehcnical and Regulatory Guidance and Decision Trees, Revised*, 2009), indicating that the metal concentration was 25 times greater in above-ground biomass than in the soil. However, hyperaccumulation is species-specific. For example, at non-inhibitory concentrations, accumulation of cadium by roots of four emergent wetland species varied from 0.2 g/g for *Baumea juncea* to 0.63 g/g for *Juncus subsecundus* (Z. H. Zhang, Rengel, & Meney, 2010). Translocation from roots to shoots also varied, resulting in shoot concentrations ranging 1.08 g/g for *S. validus* to 1.93 g/g *for J. subsecudus*. Phytoextraction and hyperaccumulation has also been observed for copper, lead and zinc (*Phytotechnology Tehcnical and Regulatory Guidance and Decision Trees, Revised*, 2009).

The removal effectiveness of cadmium, nickel and zinc by two types of macrophytes—*Juncus effuses* and *Carex riparia*—were tested by Ladislas et al. (Ladislas, et al., 2010). The results showed that cadmium and nickel were removed from the water and held in the roots of the plants, while, zinc was collected in the roots of *C. riparia* and the plant tissues of *J. effuses*. Additionally *J. effuses* was more effective in removing the metal ions from water (Ladislas, et al., 2010). Repeating the experiments with additional plants could identify vegetation with greater removal efficiencies or additional options of vegetation that can be used in bioretention basins to uptake metal.

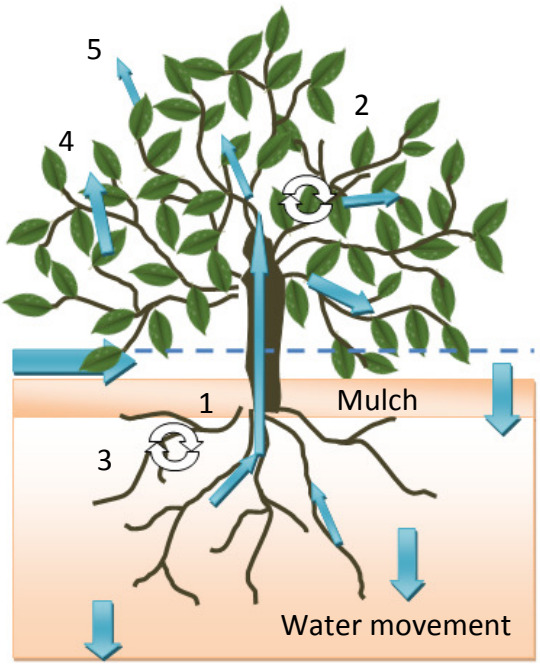
**Vegetation Options within Bioretention**

This section discusses recent research in vegetation used in bioretention cells. Data concerning native versus nonnative vegetation will also be covered.

Vegetation used in bioretention basins varies based on the geographic location, land use functions and aesthetic preference. Several factors affect vegetation treatment efficiency including the plants' ability to thrive in the environment, nutrient or contaminant uptake capacity and effect on soil microbial populations through rhizosphere interaction. Several guidance documents suggest that native plants are more effective than traditional landscaping plants due to increased root depth and their proven ability to thrive in the local environment ("Low Impact Development Manual for Michigan: A Design Guide for Implementers and Reviewers," 2008; William C. Lucas, 2005; Prince George's County, 1993). However, information on the effectiveness to treat individual stormwater contaminants in specific geographic areas, outside of Australia, is not readily available (Read, et al., 2010; Read, et al., 2008).

Figure 1 Phytoremediation Processes in a Bioretention Basin (1) Phytosequestration, (2) Phytodegradation, (3) Rhizodegradation, (4) Phytovolatilization, (5) Evapotranspiration.

For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this thesis.




Phytoremediation is the technology of using plants to remove contaminants in soil or water (McCutcheon & Schnoor, 2003). Treatment pathways include the plant utilization, stabilization, degrading and transferring contaminants and providing an environment for microorganisms to complete the same processes. Detailed, mechanistic understanding of all phytoremediation process occurring in bioretention basins is complex due to the numerous interactions between phytoremediation and other physical, chemical and biological processes. However, studies demonstrate that phytoremediation processes improve treatment with bioretention basins. Phytoremediation mechanisms are identified in Table 2 as described in the Phytotechnology Technical and Regulatory Guidance (*Phytotechnology Tehcnical and Regulatory Guidance and Decision Trees, Revised*, 2009) to limit uncertainties in terminology.

Table 2 Summary of Phytotechology Mechanisms, Phytotechnology Technical and Regulatory Guidance (*Phytotechnology Tehcnical and Regulatory Guidance and Decision Trees, Revised*, 2009)

| Mechanism | Description | Remediation Method |
|---|---|---|
| Phytosequestration | Plants sequester contaminants in the rhizosphere by releasing a photochemical substance and via transport of proteins on root system | Containment |
| Rhizodegradation | Microbial degradation in the rhizoshpere by exuded phytochemicals | Remediation by destruction |
| Phytohydrauics | Capture and transpiration of water by plants | Containment by controlling hydrology |
| Phytoextraction | Taking up of contaminants by plants via the transpiration stream | Remediation by removal of plants |
| Phytodegradation | The take up and break down of contaminants by plants via the transpiration stream by oxidation/reduction and enzymatic processes | Remediation by destruction |
| Phytovolatilization | Taking up, translocation and transpiration of volatile contaminants | Remediation by removal through plants |

Phytoextraction and phytosequestration are the two main phytoremediation mechanisms utilized in bioretention basins to treat phosphorus and metals, while phytoextraction and rhizodegradation are the two main phytoremediation mechanisms utilized to treat nitrogen.

The LID manual for Michigan suggests using native floodplain or wet meadow plant species including Cardinal Flower (*Lobelia cardinalis*), Blue Lobelia (*Lobelia siphiliticaI*), New England Aster (*Aster novae-angliae*) and Brown Fox Sedge (*Carex vulpinoidea*) ("Low Impact Development Manual for Michigan: A Design Guide for Implementers and Reviewers," 2008). Recent research conducted in Australia suggests that plant selection will significantly influence the effectiveness of nutrient removal efficiencies in bioretention basins (Read, et al., 2010) as discussed below. However, data on viability, reproduction and pest vulnerability of selected vegetation are needed. Information on native versus nonnative species selection is currently lacking and can be important in design and vegetation species selection. Finally, data on hyperaccumulators for effective treatment of specific stormwater constituents are not available.

*Native vs. Non-Native*

Vegetation species selection for use in bioretention basins are loosely correlated to research data. The assumption that native plants will perform more efficiently is based on their proven ability to thrive in the existing environment. Another hypothesis is the amount of soluble nutrient uptake will increase with the rooting depth of the crop. While this has been shown by Read, this study was conducted using native plants in Australia (Read, et al., 2008). A field study in North Carolina showed that grass biofilters were as effective in nutrient removal as bioretention basins planted with native vegetation (Passeport, Hunt, Line, Smith, & Brown, 2009). To confirm current recommendations additional testing is required to determine if native vegetation is more effective in stormwater treatment than nonnative vegetation.

**Bioretention Soil Media**

Soil media used in bioretention basins can directly influence the effectiveness of stormwater treatment, as well as the constructability which will influence application of bioretention basins by the general public. Information on soil media used for bioretention cells is varied. Carpenter conducted a national review of bioretention design standards and reported that most regulatory agencies recommend a specific mix of 30 to 60 percent sand, 20-40 percent compost and 20-30 percent topsoil (Carpenter & Hallam, 2010). The LID Manual for Michigan suggests a composition of 20 to 30 percent compost; 20 to 30 percent top soil with a clay content of less than 12 percent; and 50 percent clean sand. It is important that the soil mix meet the needs of the selected vegetation and treat the contaminant of concern (Davis, et al., 2009). Recent research conducted by Carpenter evaluated two full scale bioretention basins using a soil mix by volume of 20:30:50 compost, topsoil sand mix and 80:20 sand to topsoil mix. He concluded that the 80:20 soil mixture exhibited better treatment efficiencies for large storm events for all

measured contaminants. The 80:20 soil mix experienced short circuiting that minimized treatment during smaller storm events that did not completely flood the bioretention cell. For this experiment, large rainfall events were those that exceeded 2.3 cm in 1 hour (Carpenter & Hallam, 2010). Implementation of a small check structure or weir at the outlet of the bioretention basin allowed small storm events to pool up and eliminate short circuiting using this soil mixture to construction bioretention basins.

Davis completed a comprehensive analysis of technical information related to bioretention soil mix media and reported that bioretention basins performed similarly in treatment of particulates, metals, phosphorus and oil and grease regardless of the soil mixture (Davis, et al., 2009; Hsieh & Davis, 2005). One study analyzed by Read tested sand, soil and mulch to determine that treatment efficiencies for total suspended solids, lead and oil and grease did not differ based on soil media type (Hsieh & Davis, 2005). Treatment effectiveness of heavy metals and nutrients, specifically dissolved phosphorus and nitrate nitrogen species, were closely related to the soil mix used in the bioretention basin (Davis, et al., 2001; Hsieh & Davis, 2005). Soil mixes with existing high total phosphorus concentrations tended to leach phosphorus from the soil media mix during operation (Hatt, Fletcher, & Deletic, 2009b). The release of phosphorus from the soil mix could be increased if conditions in the bioretention basin become anaerobic. Treatment of nitrate nitrogen is effected by the soil mix through soil microbial interaction and the nitrification / denitrification processes (Brown & Hunt, 2011b).

The most effective treatment process in bioretention basins for total suspended solids, heavy metals and organic particulates is soil filtration. Soil filtration has been shown to be effective in removing total suspended solids (> 96%), particulates and oil and grease (>96%) (Hsieh & Davis, 2005).

Lucas completed a study in 2008 that evaluated different soil mixture types for bioretention treatment of total nitrogen and total phosphorus. Loam soil was more effective at removing total phosphorus than sand or gravel. On average, non-vegetated loam soil removed between 78 and 97 percent of the total phosphorus. Non-vegetated sand removed between 50 and 90 percent of the total phosphorus and non-vegetated gravel between 21 and 34 percent of total phosphorus (W. C. Lucas & Greenway, 2008). These results indicate that the effectiveness of the soil filter in removal of total phosphorus will decrease with time and volume of water treated. Therefore, the majority of phosphorus treatment can be attributed to soil sorption.

Non-vegetated loam soil was more effective in removing total nitrogen than sand or gravel. Non-vegetated loam soil removed between 14 and 40 percent of the total nitrogen. Non-vegetated sand removed between 16 and 25 percent of the total nitrogen while gravel removed between 7 and 15 percent. Unlike total phosphorus removal, total nitrogen removal efficiencies increased with time indicating that a soil microbial component may be driving total nitrogen removal efficiencies. This data suggest that soil microbial interaction is driving the nitrogen process in the media and effecting total nitrogen removal efficiencies (W. C. Lucas & Greenway, 2008).

Blecken evaluated modifying the soil mixture to include an organic carbon source and flooded zone to enhance heavy metal removal (Blecken, et al., 2009). The laboratory study determined that saturated zones and a cellulose carbon increased treatment of copper, zinc and lead; however, zinc and lead already achieve significant and adequate reductions in standard bioretention basins, so modification of the soil is not recommended due to the added cost unless copper is a contaminant of concern. Producing wet and dry areas in the bioretention basin has shown to increase heavy metal treatment efficiencies as well as produce microclimates to

enhance denitrification (Blecken, et al., 2009; Dietz, 2007; Dietz & Clausen, 2006; W. F. Hunt, et al., 2006).

Increased percentage of clay in the top soil will decrease the infiltration or permeability rate of the bioretention basins and increase the soils ability to adsorb contaminants. Table 3 shows suggested soil media mix's based on individual stormwater contaminants.

Table 3 Suggested Soil Media Mix based on Stormwater Contaminant

| Stormwater Contaminant | Suggested Soil Media Requirements | Reference |
|---|---|---|
| Total Suspended Solids | Sandy soils with high infiltration rates | (Carpenter & Hallam, 2010; Davis, et al., 2009) |
| Copper | Soil media with available carbon source | (Blecken, et al., 2009) |
| Lead | Soil media with available carbon source | (Blecken, et al., 2009) |
| Zinc | Soil media with available carbon source | (Blecken, et al., 2009) |
| Ammonia | Soil media mix with high cation exchange capacity | (Blecken et al., 2010; Perryman, Rees, Walsh, & Grace, 2011) |
| Nitrate | Wet and dry areas within the soil profile to facilitate nitrification/denitrification process | (Blecken, et al., 2009; Cho, Song, Cho, Kim, & Ahn, 2009; Collins, et al., 2010; Davis, et al., 2006) |
| Orthophosphorus | Soil media mix that will absorb phosphorus (limestone, shells, treebark, etc.) | (Ballantine & Tanner, 2010; Carpenter & Hallam, 2010; Hatt, et al., 2008; L. A. Zhang, Hong, He, Gan, & Ho, 2011) |
| Total Phosphorus | Sandy soils with high infiltration rates | (Ballantine & Tanner, 2010; Carpenter & Hallam, 2010; Hatt, et al., 2008; L. A. Zhang, et al., 2011) |

*Infiltration and Ponding*

Bioretention basin design standards typically suggest 6 to 12 inches for ponding depth and between 24 to 72 hour ponding retention times (Carpenter & Hallam, 2010). Reported design standards have not been associated with improved efficiencies of contaminants of concern (Carpenter & Hallam, 2010). Research conducted in Australia by Hatt evaluated the clogging potential of biofilter soil media (Hatt, Siriwardene, Deletic, & Fletcher, 2006). Their laboratory

findings indicate that the first two to five inches of soil are the most effective at removing the suspended solids and particulate contaminants. However, this upper section of the soil profile may become clogged and ineffective with time. Hatt (2006) suggested removing the first two to five inches of soil every year and replacing it with clean media (Hatt, et al., 2006). Based on the vegetation type selected this may be infeasible without replanting every year.

**Hydrologic Impacts and Effects**

Low impact development (LID) is a key area of emphasis for construction and sustainability. LID hydrologic goals for stormwater include:

- Hydrologic storage compensation
- Stream channel preservation
- Mimic existing hydrologic flow process by maintaining existing watershed outflow characteristics (McCuen, 2003).

Davis used existing hydrologic data in watersheds in construction and making recommendations for sizing bioretention basins (Davis, 2008). Information related to erosion and hydrologic modification is readily available and covered in the next section. However, treatment efficiencies of bioretention basins related to ponding volume and retention time in relation to vegetation species and soil media is lacking.

Treatment pathways discussed above can be enhanced or minimized based on the hydraulic design of bioretention basins. Concerns with minimum ponding time and maximum infiltration are discussed in existing literature, but not in context with maximizing treatment of contaminants of concern in specific watersheds. Over infiltration can lead to contamination of groundwater and has been noted as a potentially harmful impact of bioretention basins (Clark & Pitt, 2007; Robert Pitt, Clark, & Field, 1999; Schuster, et al., 2007). However, bioretention

basins have also been shown to clean contaminated groundwater in shallow areas during dry periods (Schuster, et al., 2007). In addition, bioretention basins allow sedimentation to take place, which decreases the threat of groundwater contamination by trapping larger contaminants or contaminants sorbed onto soil particles (Clark & Pitt, 2007; Robert Pitt, et al., 1999).

*Flood and Flow Duration Control and Erosion Control*

Treatment efficiencies of stormwater constituents can be influenced by the ponding depth, wetted time, as well as the volume of infiltration vs. flow through to the outlet of the bioretention cell. The hydrologic performance of two bioretention cells was tested by Davis (Davis, 2008). This test yielded results averaging 49% and 58% reduction in peak flows for each cell, respectively (Davis, 2008). Sansalone and Teng had previously determined that bioretention basins achieve optimum performance for small storm events (J. Sansalone & Teng, 2004; J. J. Sansalone & Teng, 2005). The short circuiting experienced by Carpenter was not an issue in the research conducted by Sansalone and Teng due to different soil media mixtures and construction of the bioretention cells allowed for a pooling depth prior to discharge. Typically less than 1/4 of the input volume flowed out of the cells within 24 hours of the start of a storm. This demonstrates that bioretention basins effectively manage stormwater to reduce peak flows and discharge that may be responsible for flooding (Davis, 2008). Bioretention basins are able to capture the stormwater flows and slowly release runoff, imitating undeveloped land behavior and reducing peak flows. Reduction in peak flows also decreases erosion, scour and transport of sediments (Davis, 2008). Monitoring during this study revealed that peak flow was reduced on averaged by a factor of two (Davis, 2008). In a field study of three bioretention sites in North Carolina it was observed that the outflow to runoff ratio is higher during winter seasons, compared to spring, summer and fall. The difference in ratio demonstrates that the plants are

likely using less water during winter months, potentially decreasing the three basins' performance (W. F. Hunt, et al., 2006).

**Literature Review Conclusions**

The use of bioretention basins to treat stormwater runoff has increased in popularity over the last ten years. Current design guides and regulations are frequently based on empirical knowledge over a short time span, additional studies need to take place monitoring older bioretention basins over significant periods of time (Davis, et al., 2009). Recent research indicates that the vegetation used in bioretention basins will have a significant impact on treatment of nutrients in bioretention basins. In addition, designing the soil media to match the stormwater contaminants of concern will potentially increase treatment efficiencies in bioretention basins. Further research is required to provide technical design information for stormwater treatment using bioretention basins within specific geographic areas. Design objectives need to be fully understood to ensure the sustainability of bioretention basins.

Bioretention basins manage stormwater runoff sustainably by using natural processes for treatment. Natural treatment processes typically have a lower carbon footprint than traditional wastewater treatment systems. While many aspects of bioretention basin design and treatment pathways have yet to be studied adequately to maximizing treatment efficiency, bioretention basins are an effective process to treat stormwater runoff and offer a sustainable method of stormwater treatment.

# CHAPTER 3 MATERIALS AND METHODS

## Bioretention Basin Setup

The Michigan State University Farm Lane Bioretention Research Site is located on the university's main campus near the intersection of Farm Lane and Service Roads. The watershed that feeds the bioretention basin is 12.8 acres and is 40% impervious. Stormwater is collected and retained from a road underpass, which is the lowest point in the area. The collected water is stored in a large tank. Water is pumped to the site once it has reached the preprogrammed level of 11,016 gallons by triggering a float switch and three 700 gallon per minute (GPM) pumps. Consequently, sample collection typically did not coincide with a storm event. Thereafter, it is funneled past the influent sampler and into the main bioretention basin. Underdrains are installed throughout each of the five research cells to carry the treated water to the effluent sampler. The water then the water enters the MSU stormwater conveyance system. Figures 2-9 shows each major component of the bioretention basin to better describe each of the components. Challenges involving these components are addressed and referred to throughout chapters 3-6.

Figure 2 Plan view of Farm Lane bioretention basin and surrounding area

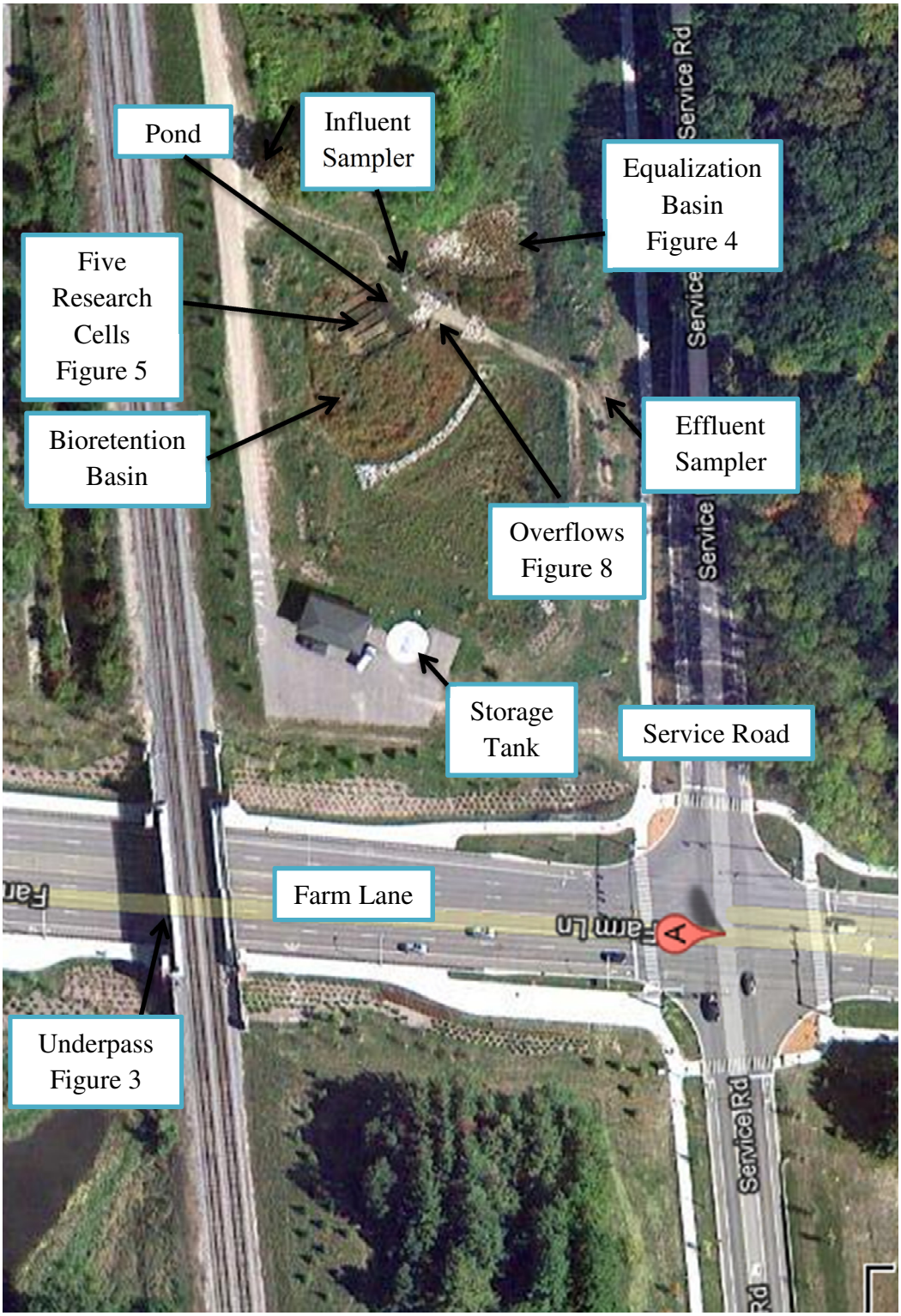


Figure 3 Farm Lane Underpass

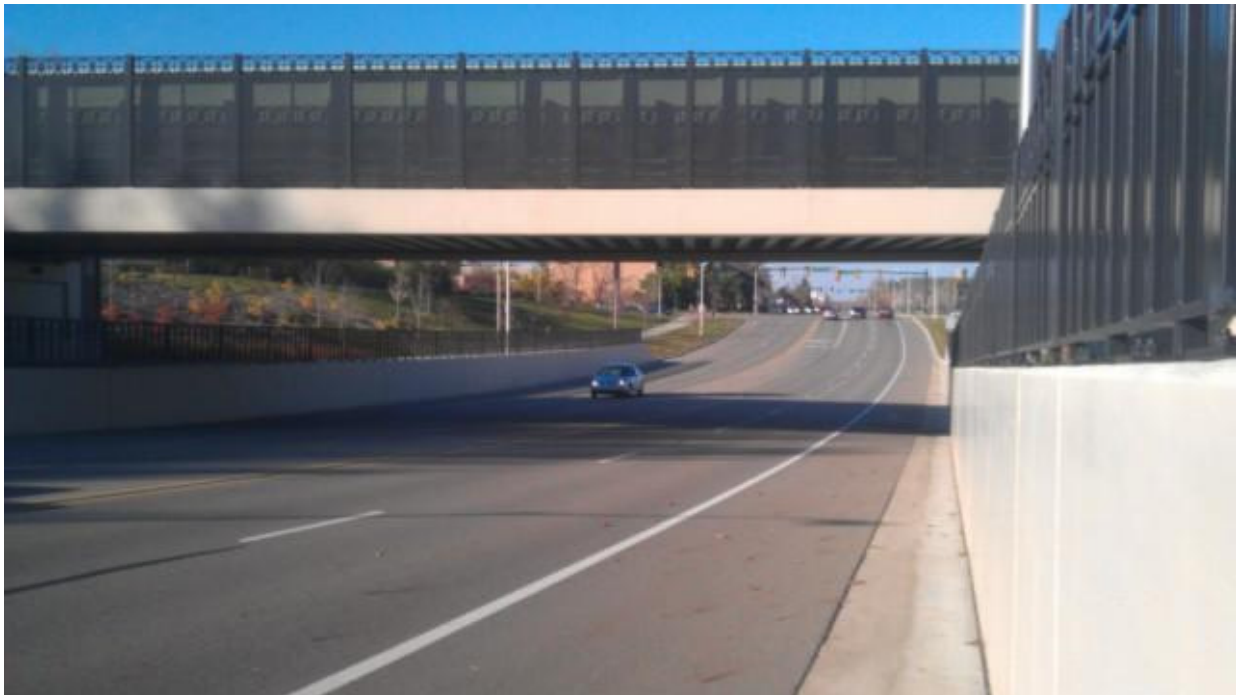


Figure 4 Rocky equalization basin where water first enters, pipe inlet at bottom left of picture leads to bioretention basin and influent sampler

Figure 5 Five research cells and ponded area in summer 2011 with overgrowth

Figure 6 Bioretention Basin two Weeks after 5 Cells were Planted (Summer 2011)

Figure 7 Flooding at Bioretention Basin

Figure 8 Overflows from Rock Basin to Bioretention Basin

Figure 9 View of Farm Lane Bioretention Basin, from Left to Right, Equalization Basin, Influent Sampler, Ponded Area, 5 Research Cells, Main Bioretention Basin, Effluent Sampler, Service Road is Shown in the Background

The Farm Lane Bioretention Basin does not behave as a traditional bioretention basin. The basin is fed both by ground and surface waters (only surface water volume was considered during the design process). The bioretention basin is approximately 2500 sq. ft., based on the amount of water pumped to the site during the first two years of sampling the site is approximately 900 sq. ft. undersized ("Low Impact Development Manual for Michigan: A Design Guide for Implementers and Reviewers," 2008). The ground water that feeds the bioretention basin is intruding the storage tank from which water is pumped. The storage tank is not fully sealed and the local water table is above the level of the tank. The volume of water and

frequency that water is delivered to the site seldom allows the basin to drain completely. Thus, what was originally designed to act as a spreader in front of the five research cells has transformed into a pond (Figure 5). The ponded area only dried at the end of fall 2011. Because water is pumped to the site quickly the water washes quickly into the ponded area. The ponded area and main bioretention basin are lower than the equalization basin, so water quickly flows through the equalization basin and little treatment takes place. Due to the location of the inlet pipe the two eastern cells receive significantly more water than the three western cells. Because the two eastern cells receive more water, the soil in those cells washes out more quickly than the other three cells; however, soil washes out of the front of each of the 5 cells during high flows. Regrading the cells is necessary twice annually to raise the level of each of the cells. Additionally, preferential flow paths are formed within the bioretention basin and water ponds behind the two eastern cells. To ensure that the cells received equal water, the channels were trenched in May 2012 to direct water out to the main bioretention area (Figure 13). The plastic pylons that separate the cells extend all the way to the clay sub-layer at the bottom of the basin, which prevents mixing of water between the cells. Additionally, the clay sub-layer prevents groundwater under the bioretention basin from infiltrating into the remainder of the basin. Water exits the bioretention basin by evapotranspiration or via the effluent underdrain (Figure 11).

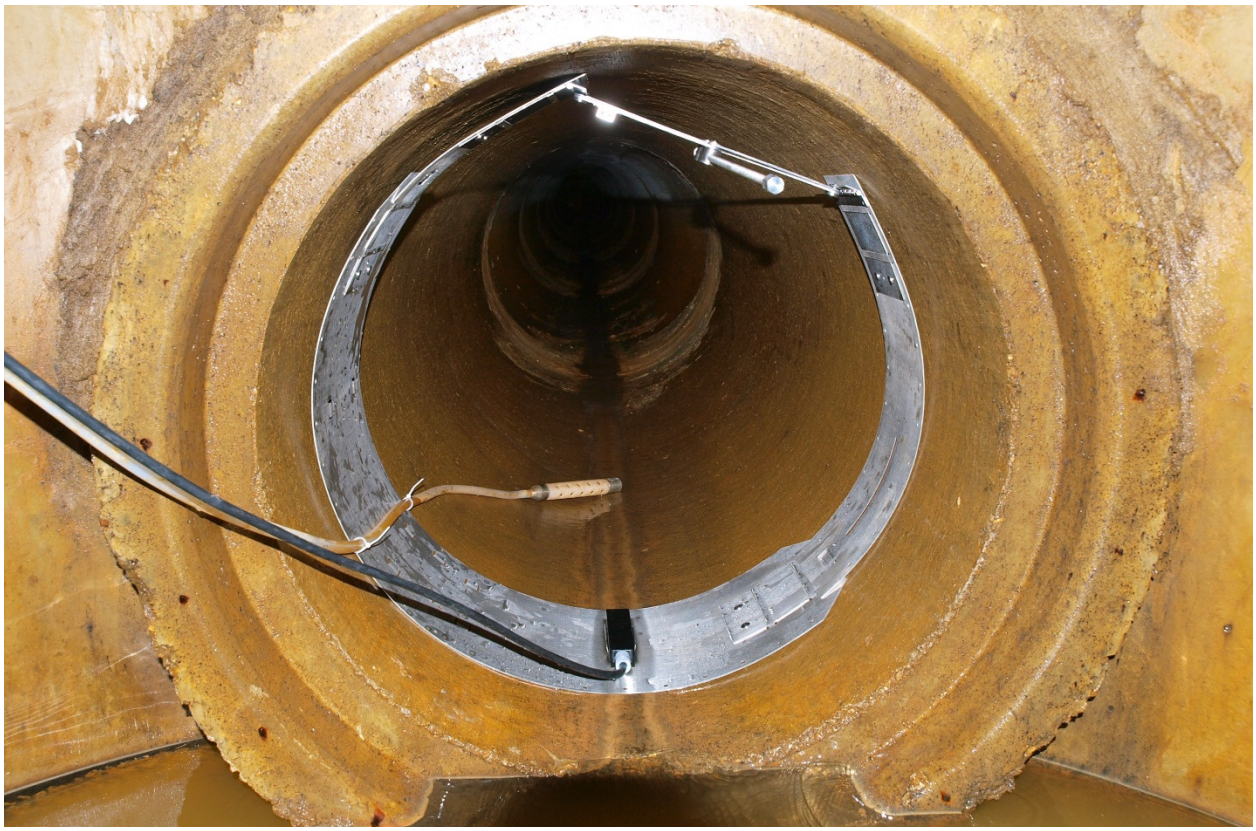
Samples were collected April 2011-October 2011. Sampling stopped in November since the bioretention basin had become mostly dry and precipitation primarily came in the form of snow. Sampling was also stopped to protect the water sampling equipment. Sampling resumed March 2012 and continued throughout the summer. The changes made to the main bioretention basin have focused on routine maintenance. The impacts of the changes mid-sampling season have not been noticed during the first two years of sampling. The channeling of the site took

place to aid in the five cell experiment, but did not change the flow rates measured at the influent and effluent samplers.

**Farm Lane Monitoring Sample Collection**

Samples were collected using ISCO 6700FR samplers with the 24 bottle configuration. Samplers are refrigerated to preserve the samples. The samplers are mounted with the option to trigger samples based on flow, using Area Velocity Flow 750 Modules (Figure 10).

Figure 10 Area 750 Velocity Flow Sensor at the Bioretention Basin



The samplers were programmed to take the first sample when flow was greater than 0.01 cubic feet per second, the lowest rate that the area velocity sensor can measure. This was selected since water is not present in the influent pipe unless water has been recently pumped the site and the flow of water through the effluent is typically slower than this rate. Tables 4 and 5 show the

collection times for 2011 and 2012. Collection times were selected to capture a typical storm hydrograph and were based off current literature (Davis, 2007).

Table 4 Summary of 2011 time samples were collected with time zero equal to when flow was detected

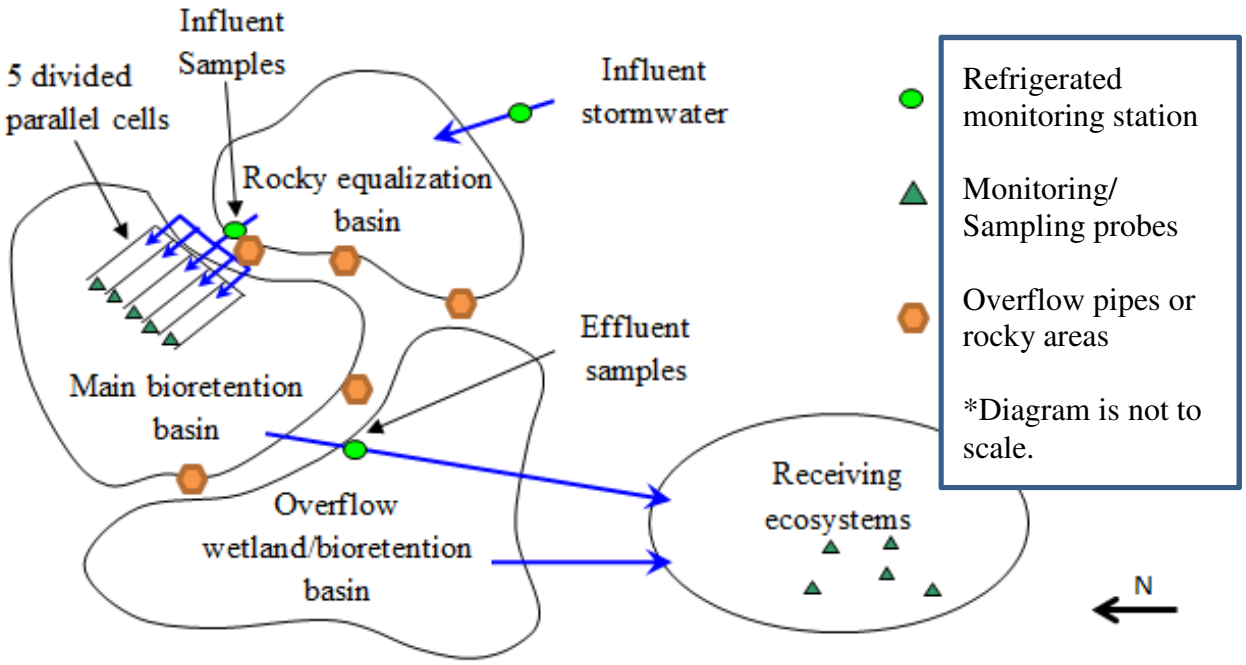
| Sample Number | Time (min) |
|---|---|
| 1 | 0 |
| 2 | 15 |
| 3 | 45 |
| 4 | 105 |
| 5 | 225 |
| 6 | 465 |
| 7 | 480 |

Table 5 Summary of 2012 time samples were collected with time zero equal to when flow was detected

| Sample Number | Time (min) |
|---|---|
| 1 | 0 |
| 2 | 15 |
| 3 | 30 |
| 4 | 45 |
| 5 | 60 |
| 6 | 90 |
| 7 | 120 |
| 8 | 240 |

The samplers are located at three locations at the bioretention site. Figure 11 shows a plan view of the site with sampler locations and general flow of water through the basin. The precipitation buckets were mounted to the enclosures that contained the samplers two feet above the roof. The buckets were cleaned of debris and dust monthly during sample collection. Flow modules were installed in manholes near each sampler.

Figure 11 Plan view of Bioretention Basin with Sampler Locations




**5 Cell Experimental Setup**

*Iris virginica*, a *Carex* mix – composed of *Carex stricta* and *Carex stipata* and fescue grass were planted in three of the cells, shown in Figure 12, in July 2011. The *Iris virginica* and *Carex* mix were purchased in quart containers from The Native Plant Nursery LLC in Ann Arbor, MI and planted on June 22, 2012. The plants were allowed to grow until May 2012 to establish a full root system when tests began. The cells were weeded weekly for the first month after the plants were planted, and then weekly again during sampling. The fescue grass was grown from seed. The other two cells were used as controls as standing water was frequently present in the two eastern cells. The site was regraded and the basin channeled after the cells to minimize flooding (Figure 13). The regrading took place at the end of the five research cells, so as to not disturb the experimental plants. After regrading, ponding in the two eastern cells was decreased substantially.

Figure 12 Location of Plants in 5 Research Cells


Figure 13 Channeled Flow to Minimize Ponding at the End of the 5 Research Cells

A Vertex, Pond-Lyfe 1 aerator was installed in the ponded area before the cells and started functioning on June 12, 2012 to determine if improved COD treatment would occur (Figure 14). The aerator was turned off on July 5, 2012 to obtain to obtain samples for comparison.

Figure 14 Vertex, Pond-Lyfe 1 Aerator

For the five research cell experiment samples were collected at the influent pipe, at five points throughout the ponded area and in the access points at the end of the five research cells. The access points collect water from an underdrain that runs through the each cell. Figure 15 shows the access points at the end of each of the five research cells.

Figure 15 Access Points at End of 5 Research Cells in August 2012

**Laboratory Tests**

More detailed descriptions of laboratory tests are included in Appendix A.

*Chemical Oxygen Demand*

Chemical oxygen demand (COD) was measured following USEPA Reactor Digestion Method 8000. Low-range COD vials (0-150 mg/L) were initially used. However, stormwater samples were too contaminated and fell outside of the range, thus, mid-range vials (0-1500 mg/L) were used. Each time COD was measured a random sample was duplicated to quantify reproducibility. Solids present in the samples led to poor reproducibility. Thus in September the process changed and samples were filtered through a 45 micron filter before measuring the 2 mL of water into the COD vials. During the two months when samples were filtered, soluble COD was measured instead of total COD. Beginning in spring 2012, samples were instead mixed in a

blender to reduce impact of solids. One duplicate for every 20 samples was run along with a standard that was within the expected range of samples.

*Total Solids*

Total solids were evaluated following USEPA accepted HACH Method 8271. Aluminum dishes were labeled and weighed to four decimals. Next, 50 mL of each stormwater were measured and poured into labeled aluminum dishes. The samples were then placed in a preheated oven set to 105 degrees C for approximately eight hours, until samples reached a constant weight. Samples were then removed from the oven, allowed to cool and weighed. Each stormwater sample was tested in triplicate and the average of the three measures was used as the amount of total solids. TS were measured as the amount of solids in 50 mL of water. TS was converted by multiplying by conversion factors and the flow of water at time of sample and presented as mass to follow industry norms.

*pH*

The pH of stormwater samples was measured using a Denver Instrument Ultra Basic-10pH probe. Before each use, the pH probe was calibrated using 4, 7 and 10 pH standards. The pH probe was inserted into each sample and once the reading equilibrated the pH was recorded. The probe was rinsed with deionized water between each sample.

*Total Nitrogen Analysis*

Low Range Test 'N Tube (0.0 to 25.0 mg/L N) Hach vials were used to measure total nitrogen following Method 10071. One sample was run in duplicate daily, along with a standard.

*Total Phosphorus Analysis*

USDA Method 8190 Low range Total Phosphorus Hach vials were used. One sample was run in duplicate daily, along with a standard.

*Dissolved Oxygen*

Dissolved oxygen was measured using a WTW Multi 3500i probe calibrated per specifications. The probe was lowered into the ponded area and held in place, for approximately one minute, until the reading steadied out.

*Soil Sample Analysis*

Soil samples were collected in May 2012 and again in August 2012 from each of the five research cells. Soil samples were taken halfway through the each cell, at 1 m, 0.5 m and 0.15 m. Soil samples were analyzed by the Michigan State University Plant and Soil Sciences Laboratory for bray phosphorus (USEPA Method 365.1), organic matter (J.R. Brown, 1998), total nitrogen (The Kjeldahl Method for Organic Nitrogen), nitrate-n (Huffman, S.A. and K.A. Barbarick, 1981), ammonium-n (Nelson, Darrell W., 1983).

*Statistical Analysis*

Statistical analysis was completed using Sigma Plot 11.0 statistical analysis software. Effluent concentrations for each of the water quality parameters – TN, TP and COD – were not normally distributed. Normality was tested using the Shapiro Wilk test. After data was transformed logarithmically, reciprocally and by taking the square root, data was still not normal. The same was repeated for removal rate data for each of the water quality parameters. Removal rate (removal rate=(effluent concentration-influent concentration)/influent concentration) data was analyzed statistically instead of effluent concentrations, since treatment performance in the bioretention basin is the focus of the experiment. Since raw and transformed data was not normally distributed the data was analyzed using analysis of variance (ANOVA) on ranks, which does not require normally distributed data. Dixon's Q test was used to identify outliers. No more than three outliers were identified per dataset.

Kruskal-Wallis ANOVA on ranks is typically used when comparing non normal data and was used for statistical analysis to determine if plant species impacted treatment. Using ANOVA on ranks each of the plant species were compared to the others separately for aerated and not aerated data for the three water quality parameters. If no significant difference was noted between plant species all of the aerated was compiled into one dataset, which was compared to the compiled not aerated dataset using the rank sum test, since the compiled data was not normally distributed. Significance between data sets was recorded if the p-value was less than 0.05. All data was analyzed numerically. The Mann Whitney rank sum test was used to compare data when only two datasets existed. This test does not require normal data. The main assumption of this test is that the two groups are independent of each other. The rank sum test was used to compare aerated and not aerated data in the five cell experiment and influent and effluent data in the monitoring.

# CHAPTER 4 FARM LANE BIORETENTION MONITORING AND LESSONS LEARNED

Since construction was concluded in 2010, qualitative and quantitative monitoring has taken place on the site. Water is pumped to the site at least once daily which prevents the basin from fully draining and creates anaerobic conditions in the soil. Changes have been made to the site in attempt to correct this as-built condition. Water quality improvements in terms of COD and TS are not statistically significant. Until major improvements of the site are completed the Farm Lane Bioretention Research Facility will not function as intended. Lessons learned from the bioretention basin have been compiled to guide practitioners and lead to more successful low impact development implementations.

## History and Site Problems

During construction numerous problems arose. The soil was over compacted with permeability test results of 0.2" in19 hours. Additionally the soil did not meet the specifications of 85% sand, 12% fines and 3% organic matter, as 40% of a clayey topsoil had been added the soil mixture. The base layer was designed to be gravel, but road aggregate was installed instead. The soil design was changed to 85% sand, an increase of topsoil to 12% and 3% compost, to be installed with minimal compaction. The permeability of the new soil mixture was 5 in./hr. Additionally, the gravel type surrounding the underdrain changed from 21AA, compacted road base, to 6A or pea stone to have larger voids and increase drainage.

There were strong proponents to use MSU farm compost, derived largely from animal waste, in the bioretention media. The bioretention media installed was 85% clean sand, 12% top soil and 3% compost. Based on estimates of phosphorus concentrations of 80-180 ppm phosphorus in the compost, it was specified that the remaining soil mixture contain less than 26 ppm to ensure that the maximum phosphorus concentration in the bioretention media was less

than 50 ppm. However, the contractor was unable to procure sufficient cured compost from MSU during installation, so an unknown portion of the compost added to the bioretention media was uncured, thereby introducing raw manure into the bioretention site. Additionally, the 12% top soil that was used was not tested to determine initial phosphorus concentrations to make sure the soil was within specifications.

Further, installation of the outflow pipe was modified from specifications due to site constraints. In the initial design, the pipe was laid under Service Road, connecting with the stormwater sewer. However, steam tunnels under Service Road prevented this. The outflow pipe was instead laid parallel to Service Road, connecting with the stormwater sewer pipe along Farm Lane. This increases the length of pipe by 280 feet, with an elevation change of only 8-9 inches. The resulting slope is extremely gradual, 0.002 ft./ft. The elevation of the outflow pipe implies that the slope of the pipe is extremely small. Additionally, the outflow pipe was constructed of 6 inch corrugated flexible PVC instead of rigid pipe. When drainage problems at the site persisted after the new bioretention media had been installed, the outflow pipe was jetted to remove any potential debris. During jetting, it was revealed that the outflow pipe was approximately two to three times longer than expected, indicating that presence of numerous and/or large bends in the pipe. With the slight slope to the effluent pipe the bends likely make a large impact on the drainage of water out of the bioretention basin. This likely contributes to the slow draining that is observed at the site.

The site was initially designed to treat the water draining into an underpass north of Farm Lane and Service Road. Water is pumped from below the underpass to the top of the first cell of the bioretention basin. It was subsequently recognized that a substantial portion of the pumped influent was actually groundwater that intruded into the pumping station. This leads to unique

challenges since water is fed to the site more frequently than if only storm events triggered flow (e.g. twice daily). Pump and piping design for the influent was based on flooding concerns. Water is stored in a large storage tank and then pumped to the site through a 24" forced main pipe using three 700 GPM pumps. The large pumps trigger when the storage tank contains 11,016 gallons of water. The pumps force water to the site too quickly to allow sampling at the first ISCO sampler. The quick flow of water also washed out portions of the two overflows initially installed between the first basin and the main bioretention basin. This created preferential flow paths, decreased the retention time of the first cell and prevented water from flowing through the pipe that feeds the influent sampler. The overflows were repaired in fall 2011. After the repairs the retention time in the equalization basin remained low and little treatment occurs in this basin. Consequently, despite an initial intent to have the first basin act as a settling basin, it mainly performs the functions of equalization and decreasing the flow rate of the influent water.

Plants in the main area of the basin were selected by Dr. Robert Schutzki (MSU Horticulture), but the 5 research cells were left unplanted to allow for research on individual plant treatment, see chapter 5. The plants were a mix of woody shrubs and plug perennials. The bioretention basin was left un-weeded and maintained for almost one year and became overgrown with weeds, with Smartweed being most prevalent. Most of the woody shrubs and perennials also returned. During fall 2011, and again in summer 2012, the weeds were removed.

**Sampling and Methods**

Three ISCO 6712FR samplers were installed to capture storm events. The first is located in line before water reaches the bioretention area. The second is located between the equalization basin and the main bioretention basin. The third is supplied water via an underdrain

in the bioretention basin and collects effluent water before it is reaches the stormwater sewer. Instead the second sampler captures the influent flow after water has been slowed by flowing through a rocky equalization basin. The samplers are programmed using the extended programming feature and trigger sampling at water velocities greater than 0.010 feet per second. While the influent sampler is triggered daily, the effluent sampler only triggered approximately once per week during the first season of sampling, corresponding with continuous saturation of the bioretention basin. Consequently, the effluent pipe was snaked and scoped with a camera in fall 2011, but no clogs were observed. The amount of effluent samples did increase in 2012.

Water samples were collected to be analyzed within 24 hours of being taken. The water samples were analyzed for COD, TS and pH each time and occasionally nutrient concentrations in the samples were measured. Table 6 describes the methods used in analysis.

Table 6 Methods to Monitor Water Quality at the Farm Lane Bioretention Basin

| Test | Method | Maximum Storage Time (hrs) |
|---|---|---|
| COD | USEPA Reactor Digestion Method 8000 | 24 |
| TS | HACH Method 8271 | 48 |
| pH | pH probe: Denver Instrument Ultra Basic-10 | 24 |

Samples were stored in the refrigerated samplers or refrigerators in the laboratories to preserve water quality.

**Water Flow Problems**

The quantity of water that enters the bioretention basin greatly exceeds the designed expectations and precipitation within the watershed. Table 7 shows the monthly volume of water that was pumped to the bioretention basin. Total precipitation within the drainage area was 6.72 M gallons in 2010, 10.1 M gallons in 2011 and 5.78 M gallons from January to October in 2012 (Enviro-weather). Since the water fed to the site greatly exceeds the precipitation in the drainage

area, most of was groundwater that has intruded the storage tank. Additionally, of the 12.8 acre drainage area, only 40% impervious so it is unlikely that the entirety of the precipitation within the watershed reaches the stormwater conveyance system that feeds the bioretention basin.

Table 7 Volume of Water (in Millions of Gallons) Pumped to the Farm Lane Bioretention Basin Monthly

| | 2010 | 2011 | 2012 |
|---|---|---|---|
| Month | Total Pumped Per Month | Total Pumped Per Month | Total Pumped Per Month |
| January | N/A | 0.79 | 0.00 |
| February | N/A | 1.30 | 1.61 |
| March | N/A | 2.38 | 2.26 |
| April | 2.04 | 2.29 | 2.16 |
| May | 2.25 | 2.34 | 2.50 |
| June | 2.26 | 1.70 | 2.23 |
| July | 1.44 | 1.88 | 1.72 |
| August | 1.08 | 1.97 | 2.16 |
| September | 1.85 | 1.85 | TBD |
| October | 1.09 | 1.99 | TBD |
| November | 1.32 | 1.89 | TBD |
| December | 1.22 | 2.40 | TBD |
| Annual Total | 14.6 | 22.8 | 14.6* |
| Annual Precipitation | 6.72 | 10.1 | 5.78* |

*Total volume of water/precipitation through August 2012

Based on present flow of water to the site, the Farm Lane bioretention basin is 35% undersized ("Low Impact Development Manual for Michigan: A Design Guide for Implementers and Reviewers," 2008).

The first water flow challenge encountered at the site was scouring in the first cell (e.g., settling or equalization basin) due to the high flow rates at which the water is pumped into the site. Additional soil and rocks were installed and large rip rap placed along the sides of this cell to prevent erosion. Consequently, the first cell functions more like an equalization basin than a

settling basin. Another physical flow challenge was encountered when the soil surrounding the overflows (Figure 8) from the first cell were washed out due to high flow during summer 2011. Additional large rocks were added to the overflow, along with landscape fabric. This was completed in fall 2011.

Water ponds at the beginning of the second cell (e.g., first bioretention basin), subsequently, the bioretention pond does not drain completely of water during spring, summer and fall months. The effluent pipe taking water from the bioretention system to the stormwater sewer is made of flexible pipe, which changes grade positively along the path to the pipe exit. To increase flow of water through the system numerous attempted fixes have been made.

- Pea gravel was added to the front of each of the research cells to distribute water more evenly and quickly within the cells.
- Originally only 2-5 holes were drilled in the front of the cell walls to allow water to enter main bioretention area. Twenty additional 1” holes were drilled. The concern was that the pylons made it too difficult for water to flow from the ponded area to the research cells, and the pea gravel combined with the additional access holes would mitigate the ponding challenge. However, no noticeable impact was noticed.
- The ponded area was pumped out and accumulated solids removed monthly during sampling seasons.
- To reduce water entering the main bioretention basin the overflow pipe between the equalization basin and the overflow area was opened; originally the pipe had been sealed. This allows water to flow into the designed overflow area on the southwest side of the site and reduced the high water levels, but did not solve the ponding issue.

- During summer 2011, soil was moved within the research cells to fill the lower washed out cells. However, the fill soil was washed out, and ponding still occurs in the two easternmost cells. Further, water washes around the back of the research cells and was fed from the back into the eastern research cells. The site was regraded again in summer 2012. The bioretention basin was also then sloped to direct water out of the cells through the bioretention basin. This has helped to direct water, but has not completely solved the problem.
- Sump pump was installed to increase elevation drop between effluent pipe inlet and outlet in September 2012. The impact is still undetermined.
- Recommendation: if road repairs are completed in the future, redirect effluent pipe to stormwater sewer on south side of Service Road through the steam tunnels, as was the original design.

**Water Quality**

Water samples were collected twice weekly, when available, and analyzed for total TS, COD and pH. While influent samples are available when water is fed to the site daily, effluent samples were only available at most once per week the first year (2011) of sampling. Thus, the number of influent events tested greatly exceeds the number of effluent events. Water quality monitoring during 2011-2012 revealed that little to no treatment was taking place.

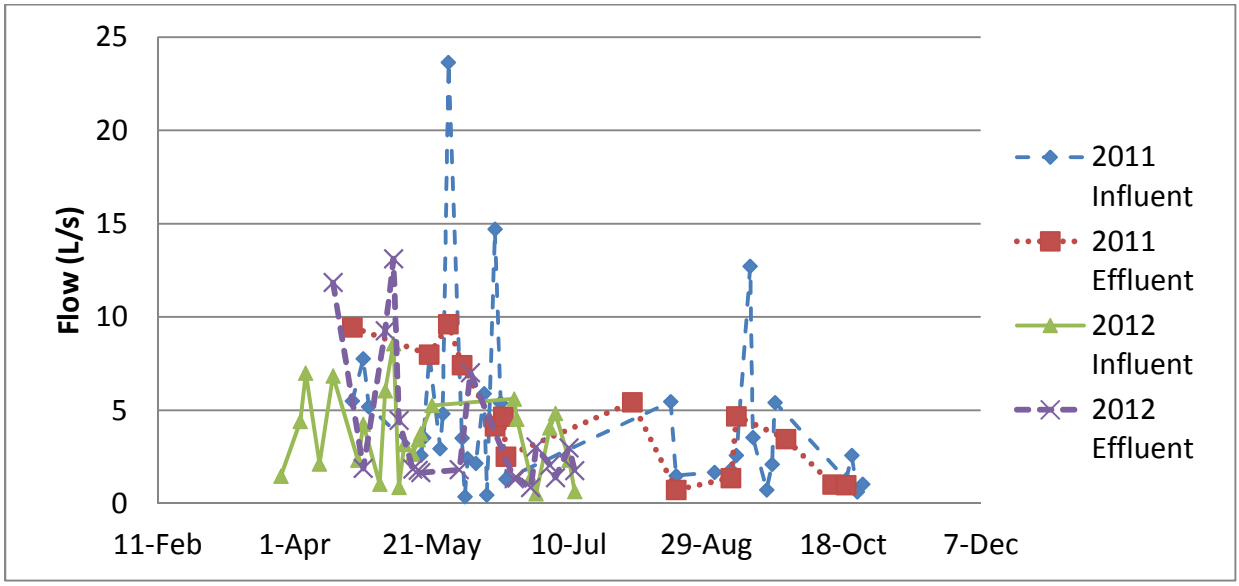
Samples were collected over four hours, as described in chapter 3, to catch the entire hydrograph that typically exists with stormwater runoff. Since the sampling events are not true storm events a peak in contamination did not exist. Thus, data for each sampling date was averaged to better see seasonal trends. Table 8 shows the amount of samples collected and number of sampling events for 2011 and 2012.

Table 8 Number of Samples Analyzed for 2011-2012 Monitoring at the Farm Lane Bioretention Basin

| | 2011 Samples | | 2012 Samples | |
|---|---|---|---|---|
| | Influent | Effluent | Influent | Effluent |
| Number of total samples | 215 | 85 | 164 | 108 |
| Number of sample events | 38 | 14 | 30 | 20 |

Water flow for 2011 and 2012 through the bioretention basin is shown in Figure 16.

Figure 16 Flow at bioretention basin samplers at time of sample collection




Water flowing through the bioretention basin is thus far not being treated as expected in a traditional bioretention basin. This is likely due to the amount of water entering the site, the contaminated media used in construction and the atypical anaerobic conditions that take place when the basin is ponded and saturated. Following are graphs and data displaying COD and TS data. Lower values for effluent water for COD and TS imply treatment. In 2011 the geometric mean COD for influent stormwater was 400 mg COD/s and for effluent stormwater 386 mg COD/s over a 7 month span. Geometric mean TS for influent stormwater was 4.4 mg/s and for effluent stormwater 4.1 mg/s over the same 7 months. Evaluating the graphs it is evident that

little to no treatment is taking place in the basin. A reduction in geometric mean COD and TS discharge of 4 and 7% is substantially less than expected for bioretention. Bioretention basins are estimated to be able to reduce total solids by 70-90 percent ("Low Impact Development Manual for Michigan: A Design Guide for Implementers and Reviewers," 2008). Additionally, due to high variability between samples and the limited number of effluent samples, the data does not indicate a statistically significant reduction in COD or TS.

Figure 17 2011 Average COD (mg/s) per Sampling Event at the Farm Lane Bioretention Site

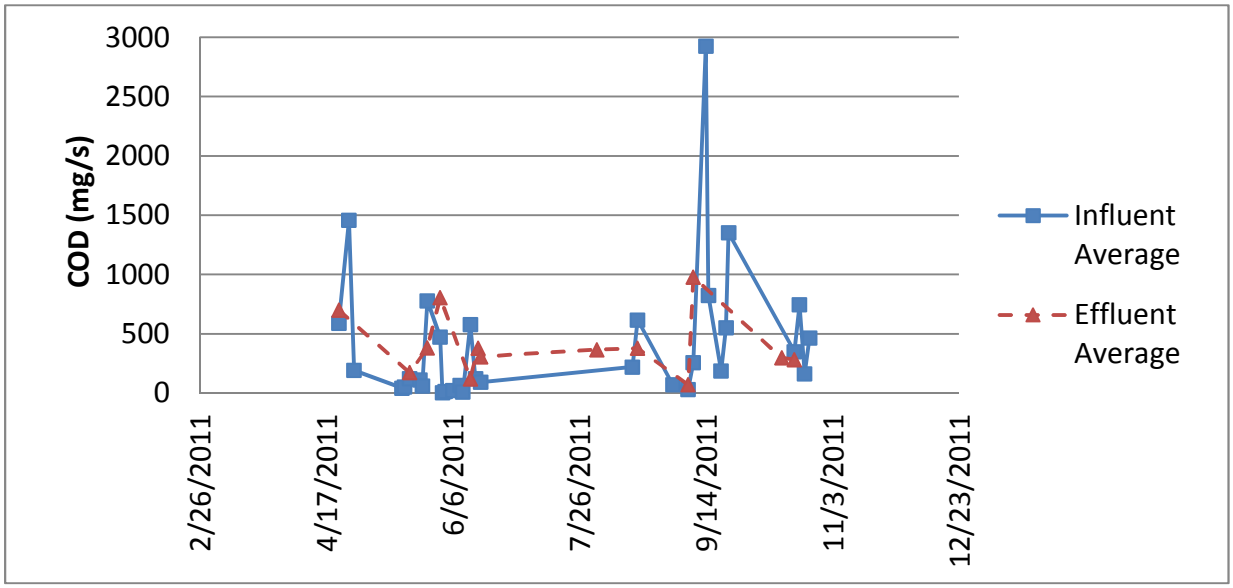
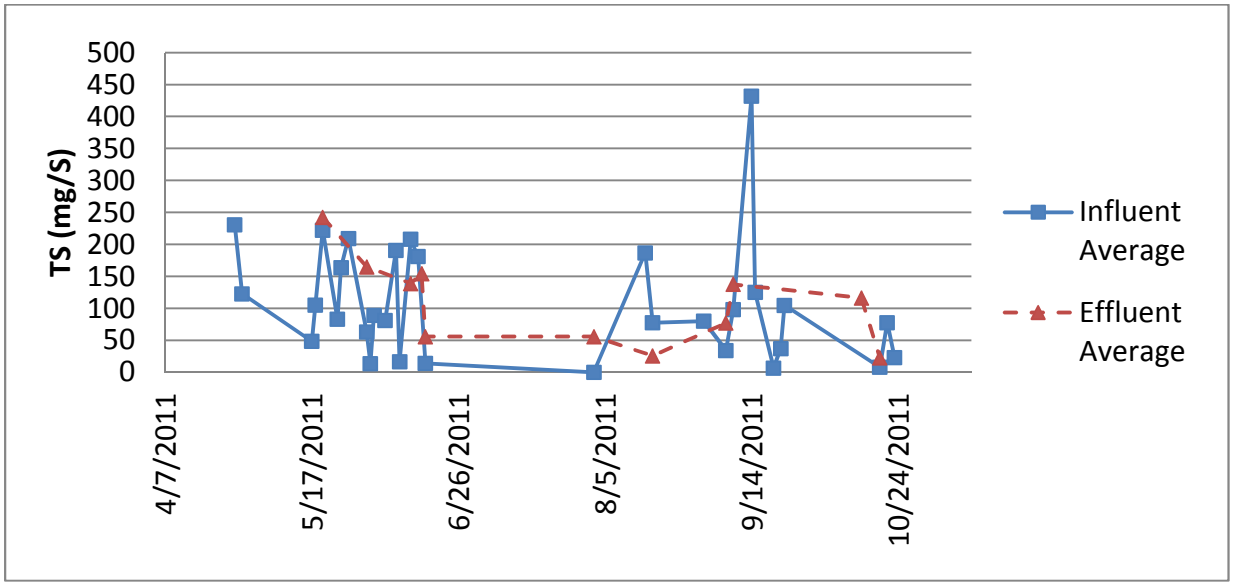


Figure 18 2011 Average Total Solids (mg/s) per Sampling Event




Sampling in 2012 revealed similar conclusions that the bioretention basin is providing little to no treatment. In 2012, the geometric mean COD for influent stormwater was 626 mg COD/s and for effluent stormwater 218 mg COD/s over a six month span. COD of influent and effluent samples were compared statistically using the Mann-Whitney Rank Sum Test and determined to not be statistically different (2011 p=0.225; 2012 p=0.207; 2011-2012 p=0.984). However, the difference between the two values is large enough to identify that COD is decreasing as water flows through the bioretention basin. Average TS for influent stormwater was 4.88 mg TS/s and for effluent stormwater 4.30 mg TS/s over the same six months. TS influent and effluent samples were also compared statistically using the Mann-Whitney Rank Sum Test and were also found to have no statistical difference (2011 p=0.485; 2012 p=0.607; 2011-2012 p=0.480). The geometric means for influent and effluent samples of each event was determined for TS and COD and are shown in Figures 19-22, below. A reduction in geometric mean for TS and COD discharge was 12% and 65%, respectively for 2012. This was

significantly improved from 2011 samples, but the treatment is still not as expected for a bioretention basin.

Figure 19 COD Geometric Mean per 2012 Sampling Event

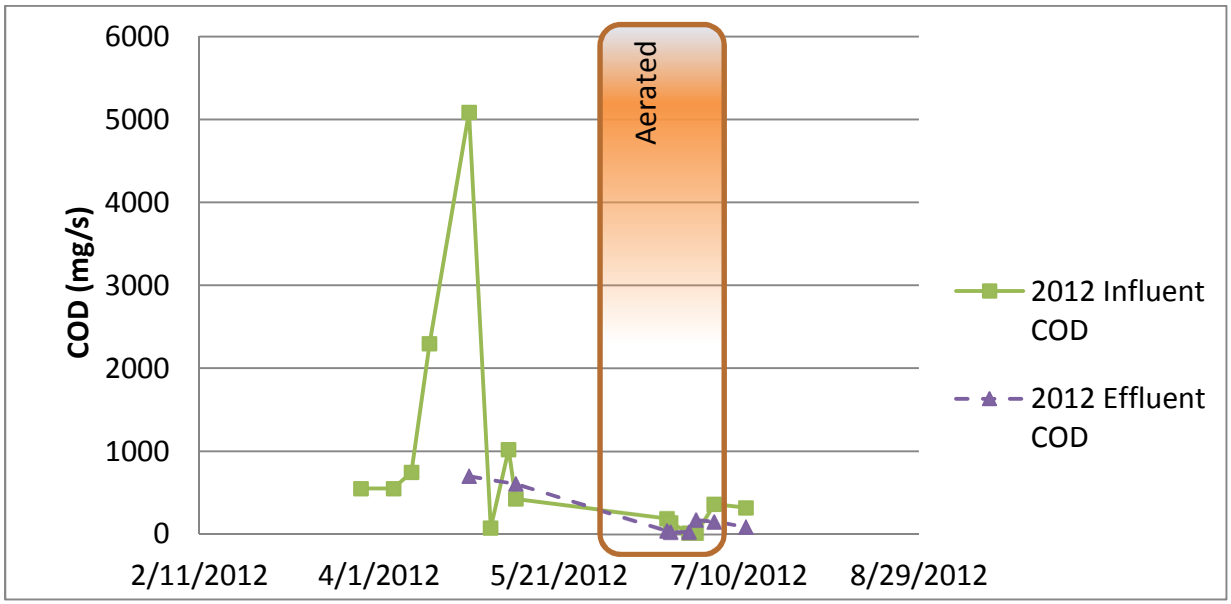
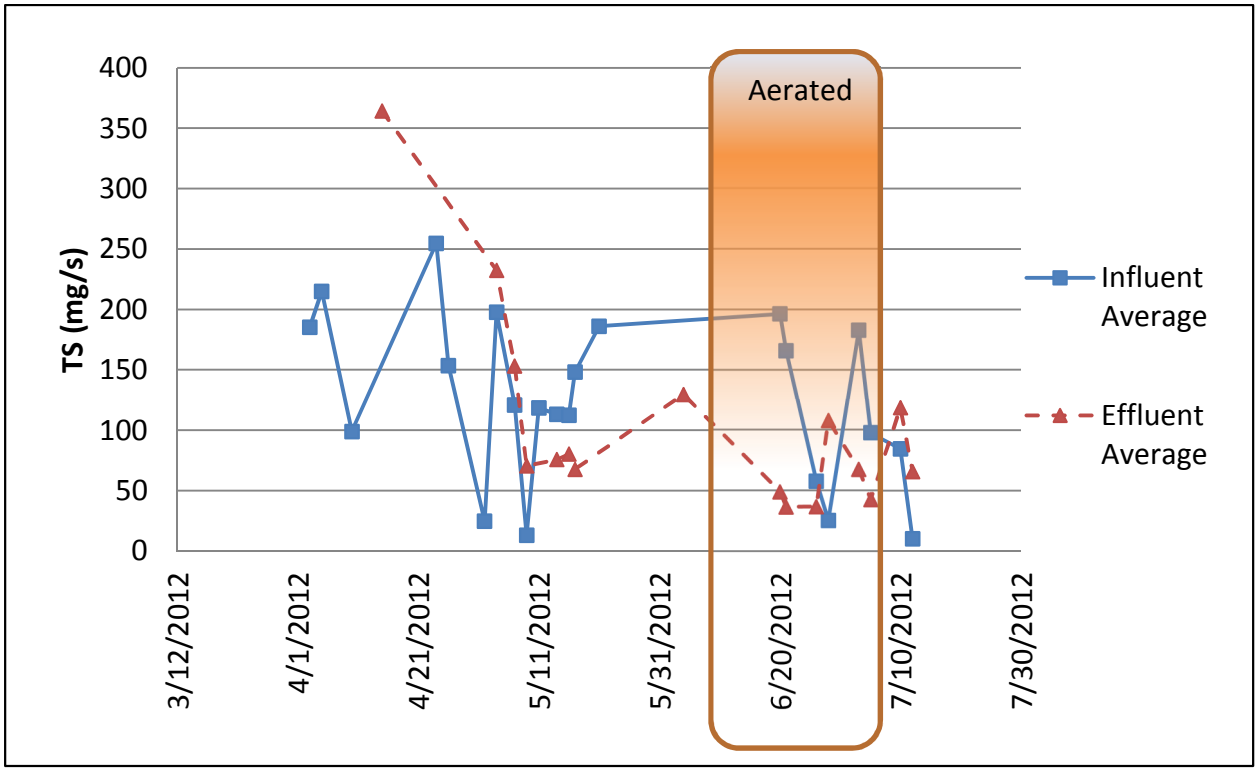



Figure 20 2012 Farm Lane Bioretention Basin TS Geometric Mean per Sampling Event



Results are also summarized for TS and COD in Tables 9-12, below. The data are presented in both mg/S and mg/L to help distinguish the impact of the flow on the determined mass of COD or TS.

Table 9 Summary of 2011-2012 COD (mg/S) Measured at the Farm Lane Bioretention Basin

| | 2011 data | | 2012 Data | |
|---|---|---|---|---|
| | Influent | Effluent | Influent | Effluent |
| Mean | 400 | 390 | 1100 | 570 |
| Median | 107 | 300 | 190 | 130 |
| 25% | 15 | 180 | 35 | 34 |
| 75% | 250 | 450 | 110 | 980 |
| Standard Deviation | 920 | 330 | 2100 | 890 |
| Minimum | 0.38 | 20 | 2.8 | 8.3 |
| Maximum | 7100 | 1500 | 12000 | 4400 |

Table 10 Summary of 2011-2012 TS (mg/S) Measured at the Farm Lane Bioretention Basin

| | 2011 Samples | | 2012 Samples | |
|---|---|---|---|---|
| | Influent | Effluent | Influent | Effluent |
| Mean | 112 | 111 | 122 | 107 |
| Median | 21.2 | 94.0 | 23.9 | 79.2 |
| 25% | 8.10 | 33.8 | 8.45 | 44.6 |
| 75% | 115 | 184 | 132 | 119 |
| Standard Deviation | 209 | 84.1 | 223 | 109 |
| Minimum | 0.900 | 12.4 | 0.38 | 12.5 |
| Maximum | 1280 | 338 | 1010 | 893 |

Table 11 Summary of COD (mg/L) Measured at the Farm Lane Bioretention Basin

| | 2011 Samples | | 2012 Samples | |
|---|---|---|---|---|
| | Influent | Effluent | Influent | Effluent |
| Mean | 102 | 132 | 169 | 158 |
| Median | 35.0 | 77.0 | 139 | 83.0 |
| 25% | 15.5 | 34.0 | 40.0 | 47.0 |
| 75% | 209 | 221 | 285 | 290 |
| Standard Deviation | 113 | 115 | 137 | 145 |
| Minimum | 0 | 10.0 | 10.0 | 8.00 |
| Maximum | 546 | 421 | 615 | 528 |

Table 12 Summary of TS (mg/L) Measured at the Farm Lane Bioretention Basin

| | 2011 Samples | | 2012 Samples | |
|---|---|---|---|---|
| | Influent | Effluent | Influent | Effluent |
| Mean | 37.1 | 25.6 | 33.2 | 31.5 |
| Median | 30.0 | 25.7 | 35.0 | 35.0 |
| Standard Deviation | 84.9 | 9.96 | 7.63 | 8.75 |
| Minimum | 2.37 | 2.53 | 9.85 | 8.33 |
| Maximum | 1028 | 43.3 | 50.0 | 43.3 |

The TS present in the stormwater remained relatively constant for 2011 and 2012 sampling seasons. However, COD and the standard deviation of COD increased. The COD removal for 2011 and 2012 is much lower than would be expected for stormwater samples. Potential causes for the high effluent COD include:

- Constant daily supply of water to the site keeps the bioretention basin in an anaerobic state
- Organic soil used in the site was not decomposed sufficiently before installed throughout the bioretention basin

An aerator was installed in June 2012 in the ponded portion of the bioretention basin with the goal of lowering COD concentrations. While the aerator successfully reduced influent COD concentrations, no impact on bioretention treatment over 4 weeks was observed; however, longer studies are warranted. However, Figure 19, above, potentially shows a steady decrease in COD since the aerator when the aerator was turned on.

Initial water quality studies reveal that the bioretention basin is not achieving anticipated treatment. This is in part due to the undersized system, which corresponds with previous studies (Brown & Hunt, 2011a). Contaminated soil and other construction material also likely contribute to the minimal treatment.

**Lessons Learned and Next Steps**

While the bioretention site has not been reducing stormwater contaminant concentrations, the effluent still meets regulatory standards and the site does provide aesthetic and biodiversity benefits to campus. Although numerous minor changes to the site have taken place, the Farm Lane Bioretention Research Facility is not functioning as a traditional bioretention basin. Typical bioretention basins can achieve 70-90% reduction in TS ("Low Impact Development Manual for Michigan: A Design Guide for Implementers and Reviewers," 2008). The installation of the facility did not follow the engineering design and the high perched groundwater table was not fully understood. Materials used in construction were likely already contaminated. Reducing the amount of water that is fed to the site and the speed at which it enters the site should help to improve treatment, since the system is undersized. The stormwater treatment benefits of the bioretention system could be improved by:

- Installing a second stormwater treatment device could be located on the northwest lot adjacent to the intersection of Farm Lane and Service Road, which could handle a portion of the runoff
- Converting the system to a BMP designed to treat the daily supply and large quantity of water such as a constructed wetland.
- Regrading the site frequently to prevent short circuiting and ponding in the eastern portion of the basin.

The bioretention basin is serving its purpose with regard to preventing the underpass from flooding, however, due to the high volumes and flow rates of water a different LID technology may have been more effective. The challenges encountered at the Farm Lane Bioretention Research facility demonstrate the importance of using good materials in construction and adhering to the engineering design. Appendix B contains a summary of key lessons learned.

# CHAPTER 5 FIVE CELL EXPERIMENT RESULTS AND DISCUSSION

An evaluation of three plant species treatment of stormwater in bioretention basins was completed during summer 2012. The five research cells at the Farm Lane Bioretention Research Facility were used to complete these analyses.

All data analyzed is in concentration form, not mass. Flow measurements were not able to be taken due to the set-up of the field site and available equipment. Generally, it can be assumed that each of the cells received similar amounts of water flow. Since the level at the front of the cells is equal across the basin and the dividing walls extend beyond the underdrain and clay sub layer, it is assumed that no mixing between the cells is taking place and that each of the cells receive the same amount of water.

Generally, in this section data will be separated into aerated vs. not aerated. The aerated samples include all samples taken when the aerator was turned on June 12-July 5. The not aerated samples include all samples taken with the aerator off, from May 22-June 11 and July 9-August 8. The range in pH of the water while the pond was aerated was 7.09-8.08 and when the pond was not aerated was 6.13-8.27.

## Dissolved Oxygen

Samples were collected from May 2012-August 2012. After observing little COD treatment throughout the bioretention basin, an aerator was installed in the ponded area, see Figure 19. The aerator was donated by The Pond Shop and installed on June 12, 2012 and dissolved oxygen concentrations were taken in the ponded area for the remainder of the experiment. The dissolved oxygen concentrations are shown below in Table 13.

Table 13 Dissolved Oxygen Concentrations in the Ponded Area, the Cells Highlighted in Gray are with the Aerator Turned On

| Date | D.O. (mg/L) |
|---|---|
| 12-Jun | 3.18 |
| 13-Jun | 3.16 |
| 18-Jun | 4.96 |
| 28-Jun | 6.15 |
| 4-Jul | 6.86 |
| 10-Jul | 7.55 |
| 15-Jul | 7.98 |
| 23-Jul | 8.11 |
| 26-Jul | 2.14 |
| 30-Jul | 1.17 |
| 3-Aug | 1.90 |
| 6-Aug | 1.96 |
| 9-Aug | 2.16 |

The dissolved oxygen concentrations in the pond remained high for 18 days after the aerator was turned off. Although the aerator is the main reason for the high D.O. measurements, other variables could cause the increase in D.O.:

- Rainfall during or just before D.O. was measured
- High wind velocities during or just before D.O. was measured
- The pumps had recently supplied stormwater to the site, mixing the ponded area

The time the D.O. concentrations were measured was not recorded, thus the high D.O. concentrations for the three weeks following the aerator being turned off cannot be attributed to a specific cause. During future sampling the time of measurement will be recorded along with qualitative observations.

**Chemical Oxygen Demand**

Chemical oxygen demand was measured for each of the samples collected. COD values from June 11-August 8 are included in the analysis, shown in Figure 21. Average COD and standard deviations for the five plant types, inlet and pond samples are shown in Table 14.

Figure 21 COD Concentrations For Five Cells, Inlet And Pond

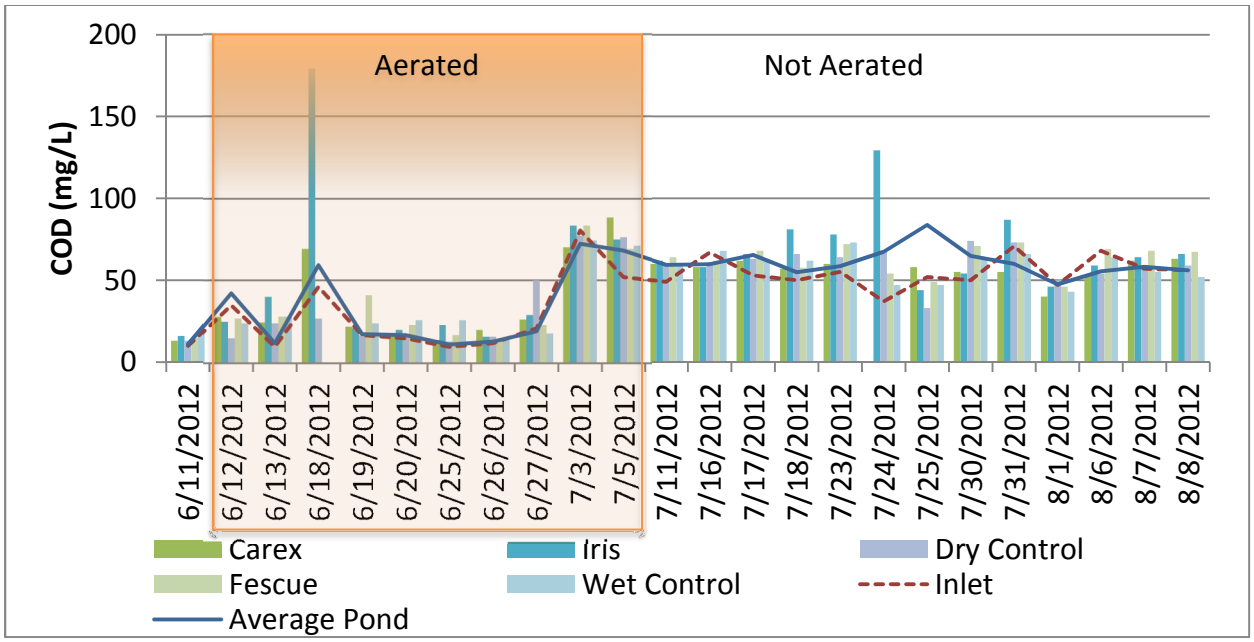


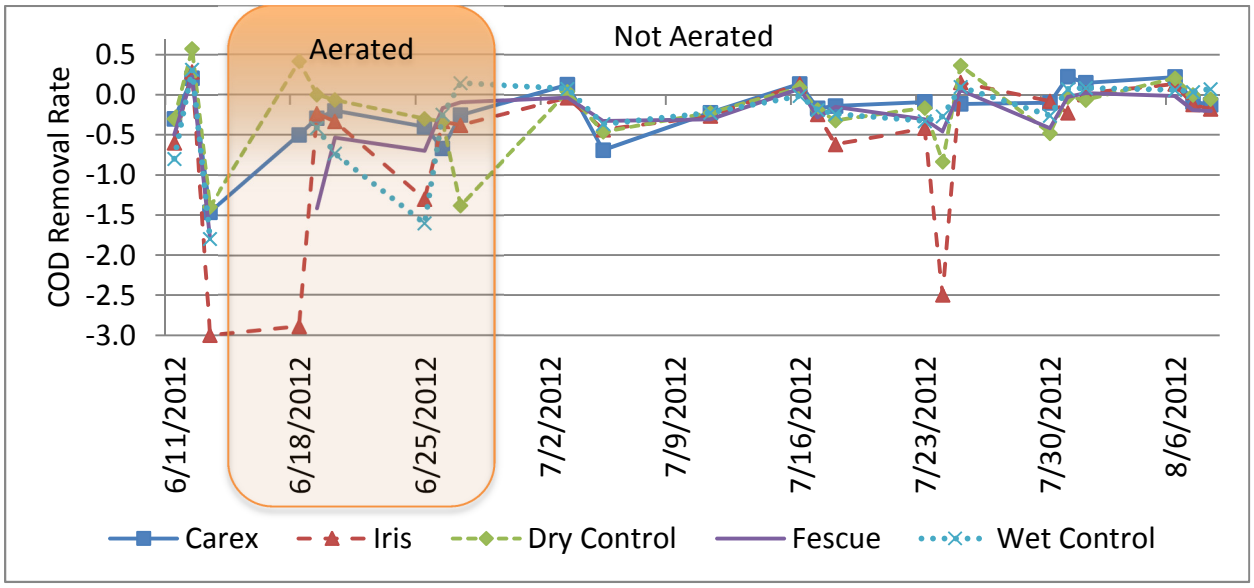

Table 14 Geometric Mean COD Concentrations and Standard Deviation of COD in 5 Cell Experiment

| | Aerated | | Not Aerated | | Aerated vs. Not Aerated |
|---|---|---|---|---|---|
| | Mean | Standard Deviation | Mean | Standard Deviation | p-value |
| Inlet | 30 | 23 | 52 | 15 | 0.453 |
| Pond | 33 | 24 | 57 | 19 | 0.008 |
| Carex | 38 | 27 | 54 | 14 | 0.259 |
| Iris | 51 | 51 | 65 | 26 | 0.114 |
| Dry Control | 33 | 25 | 57 | 16 | 0.010 |
| Fescue | 36 | 24 | 60 | 15 | 0.009 |
| Wet Control | 34 | 22 | 56 | 14 | 0.009 |

COD increased as water passed from the inlet to the pond and then the cells. This is not typical of functioning bioretention basins. Bioretention basins are designed to increase the

amount of available oxygen by delivering oxygen from the plant roots and increasing soil pore space. The five cells remained saturated and in an anaerobic state throughout the experiment, which decreases COD treatment in water throughout the bioretention basin. Chapter 4 outlines the challenges encountered with drainage, water flow and water quantity. Although changes have been made to the site, saturation of the five cells continues due to the quantity of water that flows through the basin. In addition, the uncured compost used in the soil mixture likely contributed to the increase in COD. The effect of the plants was not noticed, as COD increased in the Farm Lane bioretention basin. Additionally, the high standard deviations make it challenging to draw statistical conclusions. Removal rates are shown in Figure 22.

Figure 22 COD Removal Rates Separated by Plant Species




Using ANOVA on ranks the average COD removal rates between species was not significant for aerated samples (p=0.413). Additionally, no significance was noticed comparing species removal rates when the pond was not aerated (p=0.241), shown in figure 23 and table 15.

Figure 23 Average COD Values for Aerated and Not Aerated Samples

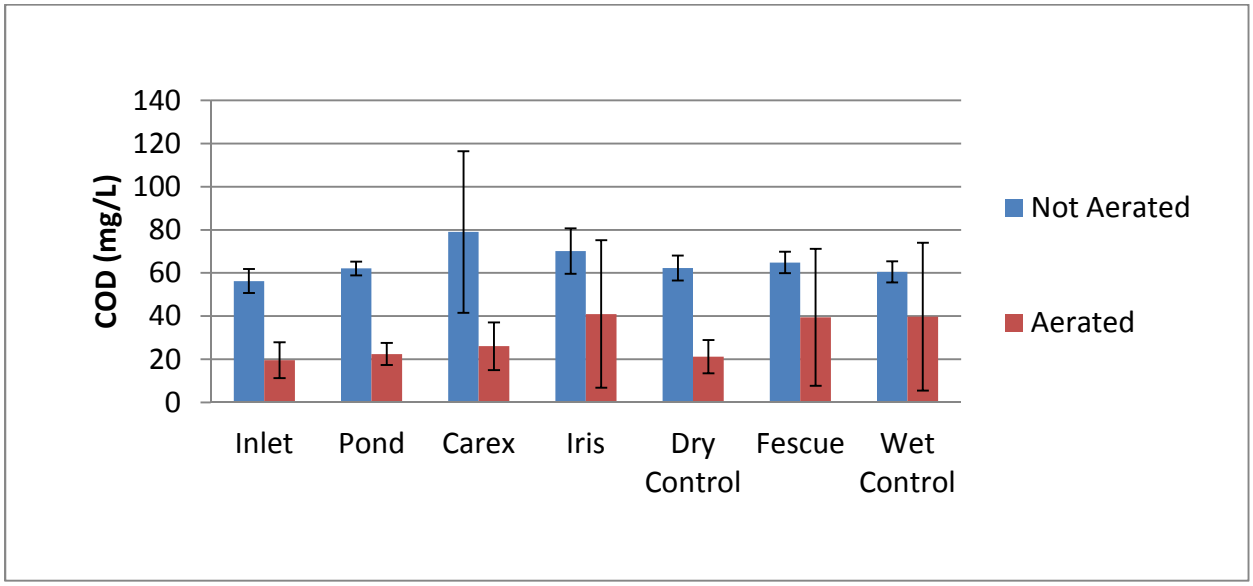



Table 15 Comparison of Impact of Aeration on COD Removal Rates Based on Plant Species

| | Aerated | | Not Aerated | |
|---|---|---|---|---|
| | Mean | Standard Deviation | Mean | Standard Deviation |
| Carex | -0.414 | 0.473 | -0.048 | 0.172 |
| Iris | -0.866 | 1.170 | -0.344 | 0.667 |
| Dry Control | -0.292 | 0.661 | -0.143 | 0.297 |
| Fescue | -0.538 | 0.671 | -0.194 | 0.195 |
| Wet Control | -0.514 | 0.746 | -0.136 | 0.248 |

Removal rates for COD were negative, implying the COD increased as water flowed through the system. Removal rates comparing not aerated data and aerated data was significant ($p<0.001$) using the Mann-Whitney Rank Sum Test. The not aerated samples increased the COD less than the aerated samples. This is potentially attributed to the temporary lowering of the COD in the aerated pond. This would then indicate that the aerator is able to aerate the entire ponded region. However, COD concentrations in general were lower when the pond was aerated, demonstrating that this study showed that aeration is beneficial in COD treatment within the pond. It would be expected that the soil (Cho, Yoon, Song, & Ahn, 2011) and plant species

would have an impact in COD removal, however, the data did not prove this statistically. This could be attributed anaerobic conditions within the cells. Another possibility is that the materials used in construction at the site were not clean, thus they are contaminating the water and did not allow for any observation of treatment by the plants.

**Total Nitrogen**

Nitrogen was frequently generated from the inlet pipe to the effluent samples. Influent and effluent concentrations are shown in Figure 24. Average concentrations and standard deviations are also shown in Table 16.

Figure 24 Total Nitrogen Concentrations in 5 Cell Experiment

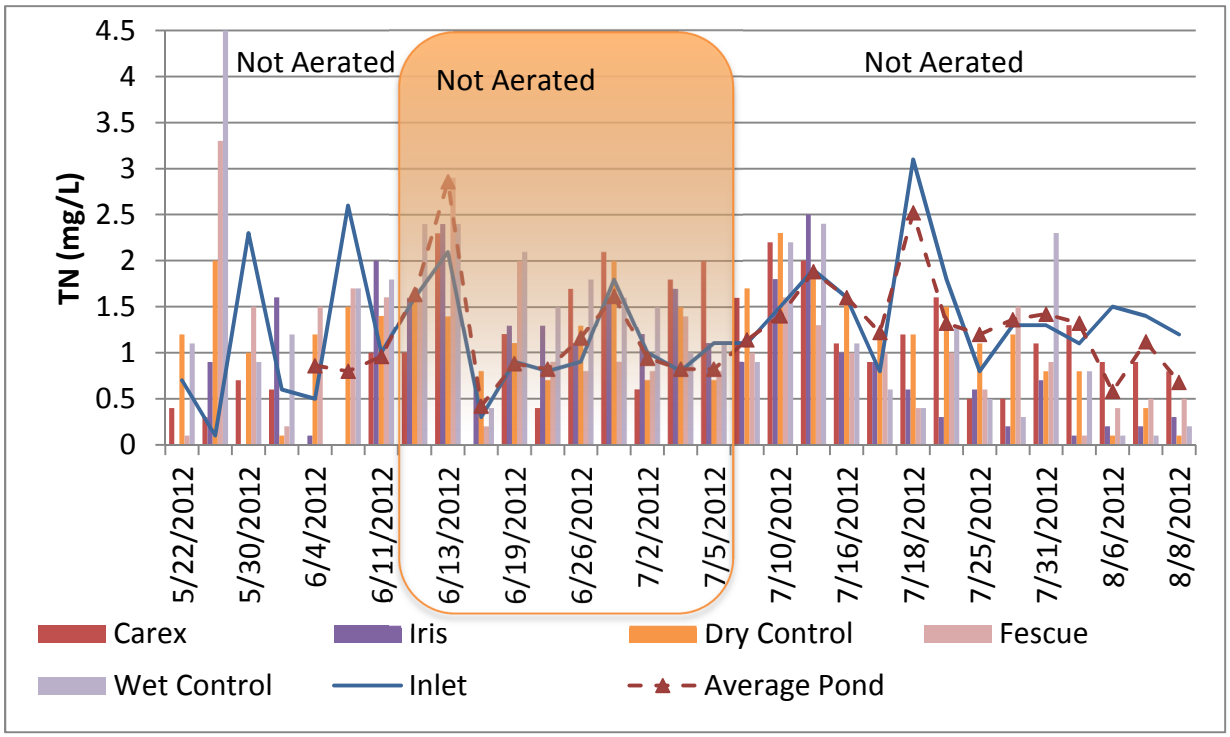


Table 16 Geometric Mean Concentration and Standard Deviation of Total Nitrogen Experiment in 5 Cell Experiment

| | Aerated | | Not Aerated | | Aerated vs. Not Aerated |
|---|---|---|---|---|---|
| | Mean | Standard Deviation | Mean | Standard Deviation | p-value |
| Inlet | 1.13 | 0.54 | 1.34 | 0.72 | 0.414 |
| Pond | 1.20 | 0.70 | 1.35 | 0.93 | 0.498 |
| Carex | 1.31 | 0.79 | 0.98 | 0.65 | 0.196 |
| Iris | 1.40 | 0.46 | 0.78 | 0.72 | 0.011 |
| Dry Control | 1.18 | 0.45 | 1.15 | 0.61 | 0.763 |
| Fescue | 1.23 | 0.77 | 0.84 | 0.74 | 0.672 |
| Wet Control | 1.58 | 0.64 | 1.16 | 1.06 | 0.087 |

Using ANOVA on ranks, plant species and the control cells were compared and determined to not be statistically different for aerated samples ($p=0.268$) and not aerated samples ($p=0.561$). This was not expected, but could likely be attributed to the contaminated soils used in construction. The saturation of the each of 5 cells could have also contributed to the similarities between the cells nitrogen effluent concentrations. A statistical difference was determined, using the rank sum test, for aerated and not aerated samples ($p<0.001$). Aerated samples had a median TN removal rate of -0.155 and not aerated samples had a median TN removal rate of 0.346. The pond was aerated TN actually increased from the inlet to the outlet, shown in Figures 25 and 26 and Table 17. Thus, samples demonstrated that adding aeration decreased nitrogen performance.

Figure 25 Average Total Nitrogen Separated by Aerated and Not Aerated

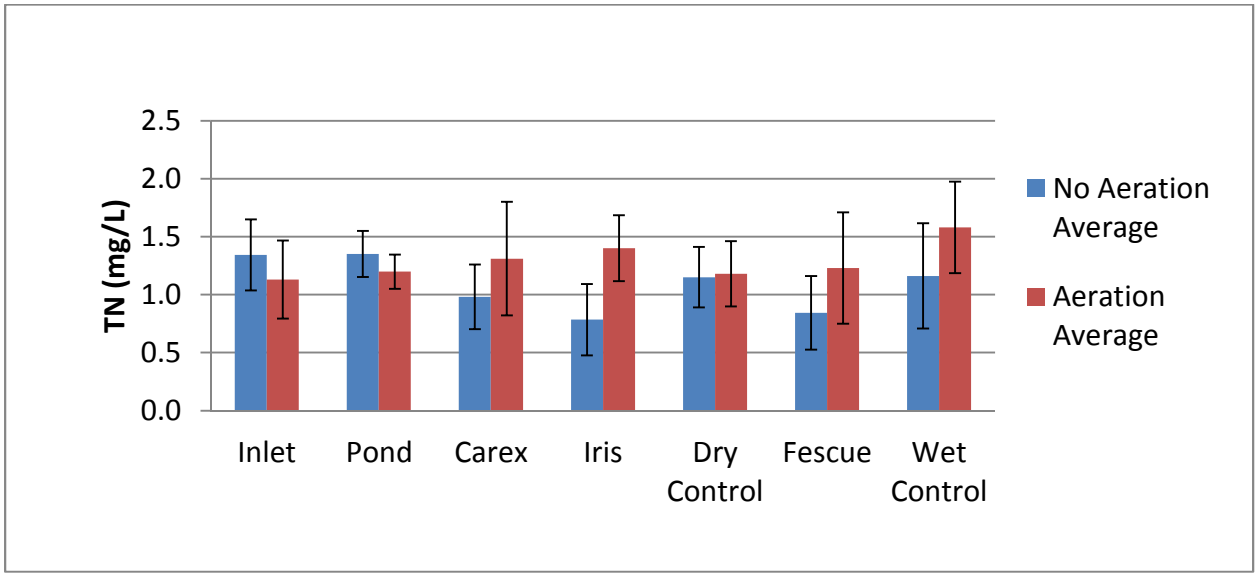



Figure 26 Removal Rate of Total Nitrogen Separated by Plant Species

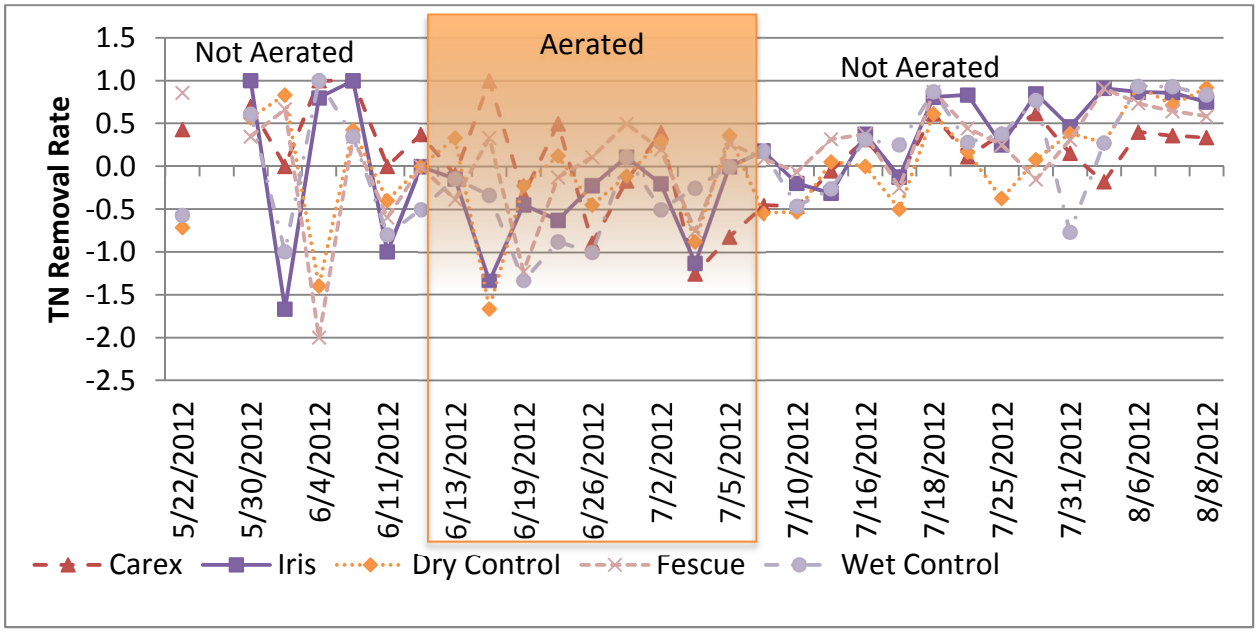


Table 17 Total Nitrogen Geometric Removal Rates and Standard Deviation Comparing Effects of Aeration

| | Aerated | | Not Aerated | |
|---|---|---|---|---|
| | Mean | Standard Deviation | Mean | Standard Deviation |
| Carex | -0.128 | 0.712 | 0.256 | 0.414 |
| Iris | -0.398 | 0.491 | 0.349 | 0.732 |
| Dry Control | -0.220 | 0.638 | 0.074 | 0.630 |
| Fescue | -0.106 | 0.537 | 0.234 | 0.659 |
| Wet Control | -0.482 | 0.462 | 0.204 | 0.639 |

The anaerobic conditions that typically exist in the bioretention basin could cause the lower TN values when the pond was not aerated. The aeration then introduced oxygen into the system, which enabled the nitrification process to take place. This likely caused the increase in TN in the effluent samples, likely in the form of nitrate. TN decreased when the pond was not aerated. However, no difference in treatment was noted based on the plants. This is likely due to the contaminated materials used in construction. Another hypothesis is that some of the organic nitrogen in the soil mixture was oxidized into soluble forms and detected while the pond was aerated. The soil analysis was inconclusive to prove these hypotheses. Although TN removal took place when the pond was not aerated the removal rates were low compared to the Michigan LID Manual estimated 40-50% removal ("Low Impact Development Manual for Michigan: A Design Guide for Implementers and Reviewers," 2008).

**Total Phosphorus**

Total phosphorus was measured each day the samples were collected using low range Hach kits. Aerated and not aerated samples were compared to determine the impact of aeration on TP. Also, each of the cells was compared to the other cells. Concentrations of TP are shown in Figure 27. Average concentrations and standard deviations for samples separated by aerated and not aerated samples are shown in Table 18.

Figure 27 Total Phosphorus Concentrations in 5 Cell Experiment

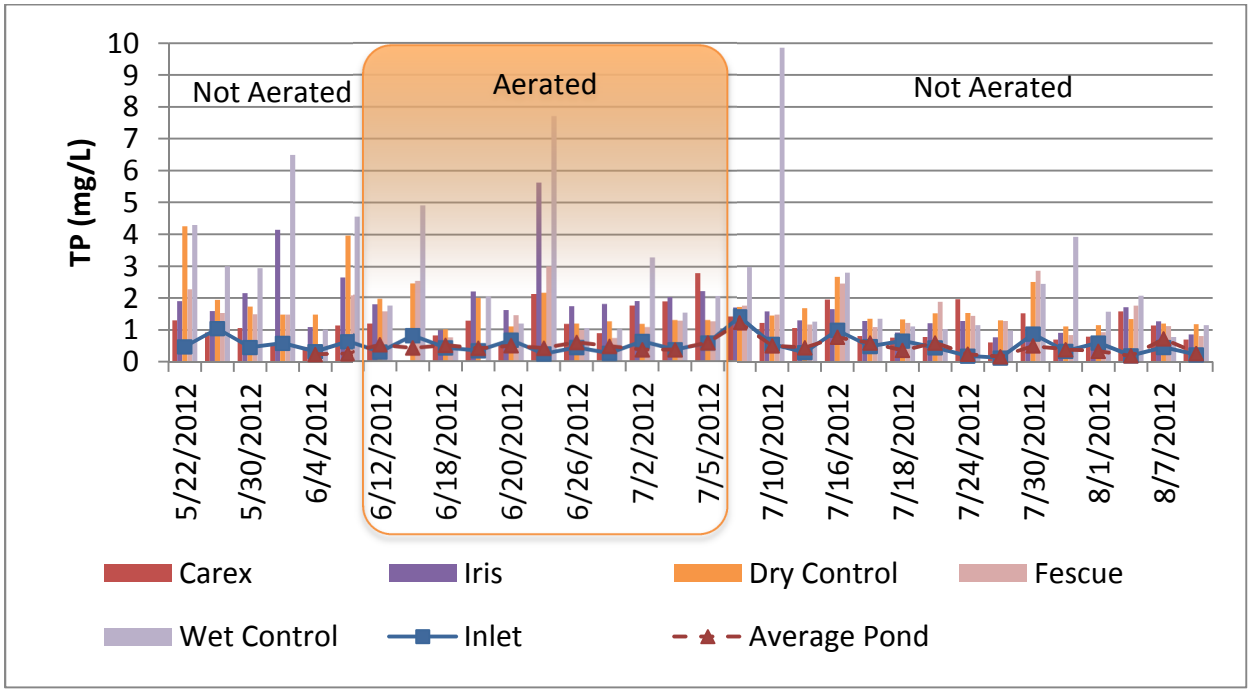



Table 18 Geometric Mean Concentration and Standard Deviation of Total Phosphorus Experiment in 5 Cell Experiment

| | Aerated | | Not Aerated | | Aerated vs. Not Aerated |
|---|---|---|---|---|---|
| | Mean | Standard Deviation | Mean | Standard Deviation | p-value |
| Inlet | 0.45 | 0.19 | 0.54 | 0.35 | 0.606 |
| Pond | 0.46 | 0.15 | 0.48 | 0.31 | 0.397 |
| Carex | 1.4 | 0.68 | 1.1 | 0.46 | 0.070 |
| Iris | 2.2 | 1.3 | 1.5 | 0.34 | 0.013 |
| Dry Control | 1.5 | 0.51 | 1.8 | 0.46 | 0.226 |
| Fescue | 1.5 | 0.76 | 1.6 | 0.58 | 0.403 |
| Wet Control | 2.5 | 2.1 | 2.7 | 2.3 | 0.766 |

Total phosphorus samples were analyzed for statistical significance using ANOVA on ranks. For aerated samples, no significant difference was noted based on plant species or control ($p=0.279$). However, the *Carex* mix cell was significantly better than the wet control cell for not aerated samples ($p=0.007$), although TP increased for each of these cells. Since the not aerated

*Carex* mix cell was statistically different than the other four cells, not aerated samples were compared to aerated samples in two sets. Aerated samples could be compiled into one dataset since no significant difference was noted between those samples. First, the not aerated *Carex* mix samples were compared to all of the aerated samples. The *Carex* mix not aerated samples were significantly better than all the aerated samples (p=0.001). Then, the not aerated samples from the other four cells (*Iris*, dry control, fescue and wet control) were compiled into one dataset and compared to the compiled aerated samples. The compiled not aerated cells, minus the *Carex* mix samples, were not significantly different than the compiled aerated samples (p=0.646).

Figure 28 shows the average TP for each of the cells separated by aerated samples and not aerated samples. Table 19 shows the geometric mean removal rates and standard deviations for each of the cells.

Figure 28 Average Total Phosphorus Separated By Aerated and Not Aerated

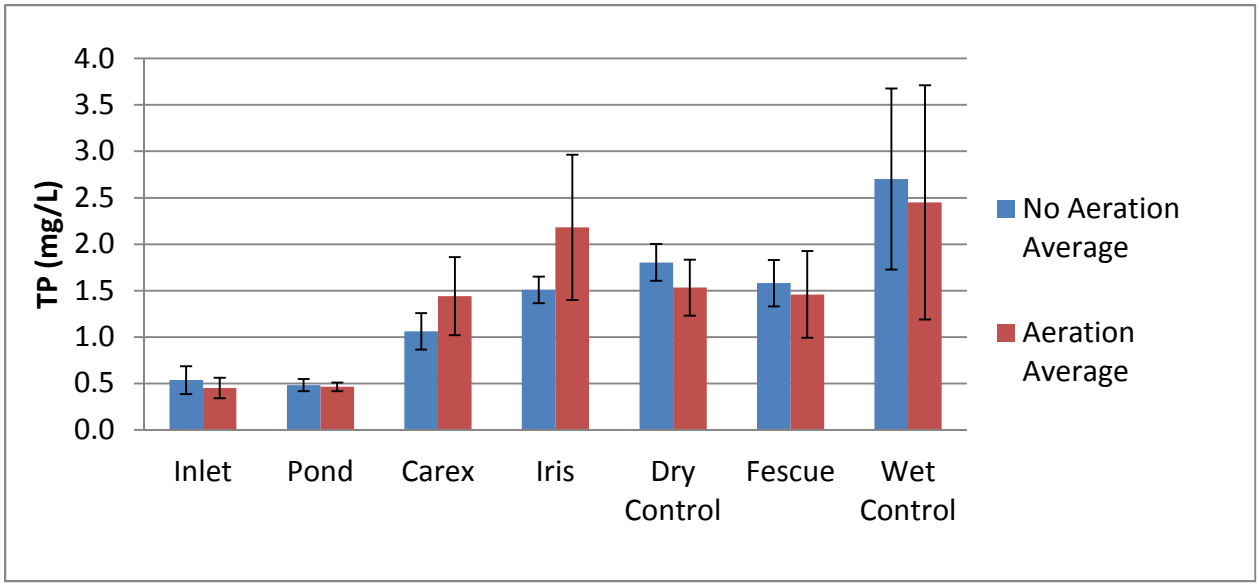


Figure 29 Removal Rate of Total Phosphorus Separated by Plant Species

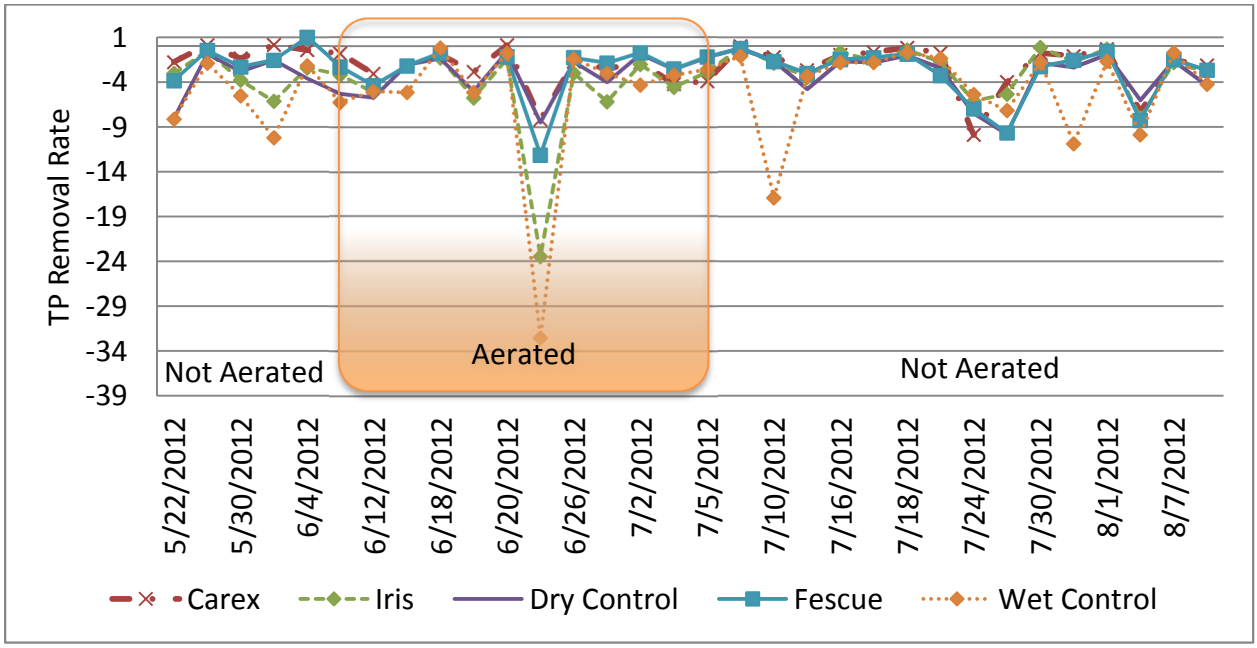



Table 19 Total Phophorus Geometric Removal Rates and Standard Deviation Comparing Effects of Aeration

| | Aerated | | Not Aerated | |
|---|---|---|---|---|
| | Average | Standard Deviation | Average | Standard Deviation |
| Carex | -2.90 | 2.25 | -1.79 | 2.50 |
| Iris | -5.57 | 6.53 | -2.64 | 2.21 |
| Dry Control | -3.07 | 2.46 | -3.36 | 2.65 |
| Fescue | -2.82 | 3.43 | -2.61 | 2.66 |
| Wet Control | -5.76 | 9.05 | -4.90 | 4.31 |

The aerated samples increased phosphorus more than the not aerated samples. However, since the cells were weeded throughout the experiment, an increase in phosphorus is not expected. Typically bioretention basins can achieve 80% removal of TP ("Low Impact Development Manual for Michigan: A Design Guide for Implementers and Reviewers," 2008). Additionally, plants remained healthy throughout the experiment, so decay of plants should not have contributed to the increase of phosphorus. Additionally, the plants may have not needed to obtain phosphorus from the stormwater since the soil already had high phosphorus

concentrations. The increase in phosphorus is potentially due to phosphorus being washed out of the uncured compost used in the soil mixture. Although the influent concentrations of TP fell within the Michigan limits for wastewater discharge, the concentrations at the effluent locations exceeded the standard of 1 mg/L (DEQ). Initial phosphorus concentrations in the soil ranged from 3-67 ppm Bray P. Although analysis of the soil did not prove this assumption to be true, see soils section below. More soil samples need to be analyzed to demonstrate this effect. Since only 3 soil samples were taken in each cell at the start and end of the experiment it is difficult to understand what is taking place with the soil throughout the cell. Another hypothesis for the increase in TP is that the aeration oxidized organic carbon in the solids, which increased the soluble phosphorus.

**Total Solids**

Total solids (TS) were analyzed for each of the samples collected. Figure 30 shows the TS concentrations with the aerated samples highlighted. Table 20 shows the geometric mean TS for aerated and not aerated samples.

Figure 30 Total Solids Concentrations (mg/L) During Five Cell Experiment

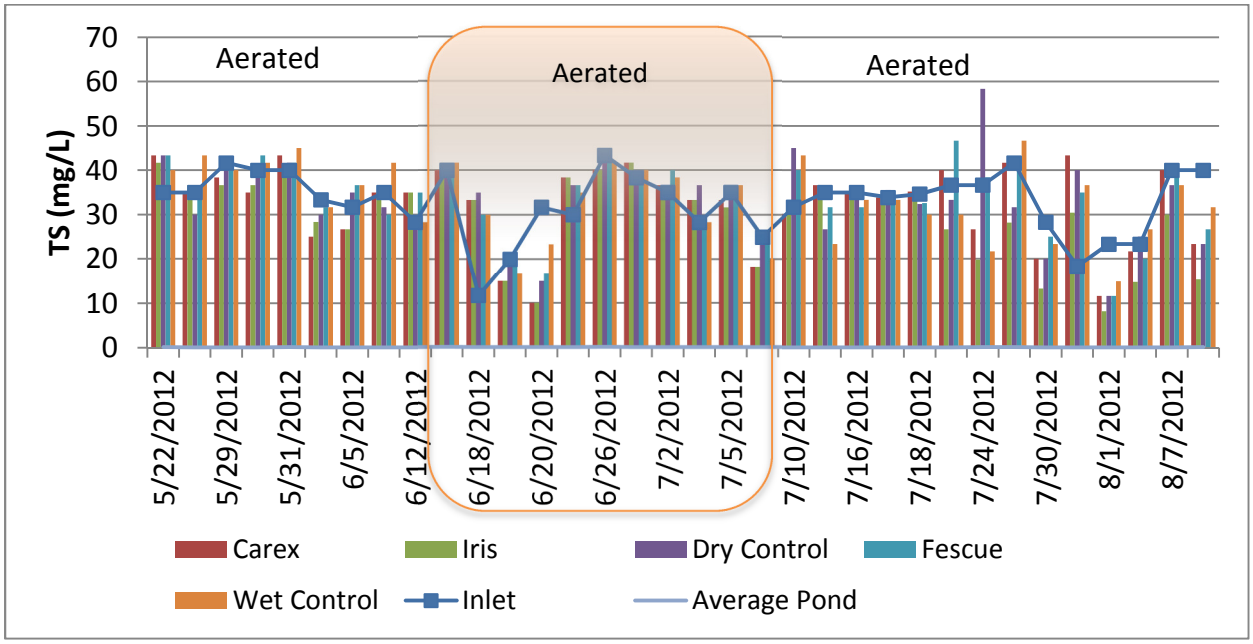



Table 20 Total Solids Geometric Mean (mg/L) for Aerated and Not Aerated Samples

| | Aerated | | Not Aerated | | Aerated vs. Not Aerated |
|---|---|---|---|---|---|
| | Average | Standard Deviation | Average | Standard Deviation | p-value |
| Inlet | 31.1 | 9.11 | 33.7 | 6.31 | 0.956 |
| Carex | 32.4 | 10.3 | 32.1 | 8.93 | 0.439 |
| Iris | 32.3 | 10.3 | 28.6 | 9.35 | 0.027 |
| Dry Control | 32.4 | 8.70 | 33.5 | 9.65 | 0.294 |
| Fescue | 33.3 | 8.13 | 33.8 | 8.33 | 0.126 |
| Wet Control | 32.7 | 8.11 | 33.6 | 8.78 | 0.439 |
| Average Pond | 31.4 | 10.0 | 33.8 | 6.44 | 0.632 |

With the exception of the *Iris virginica* cell there was no significance per sampling location regardless of aeration. However, *Iris virginica* had significantly lower TS when the bioretention basin was not aerated. The average concentrations for aerated and not aerated samples were compared and are shown graphically in figure 31.

Figure 31 Average Total Solids Concentrations Comparing Aerated and Not Aerated Samples

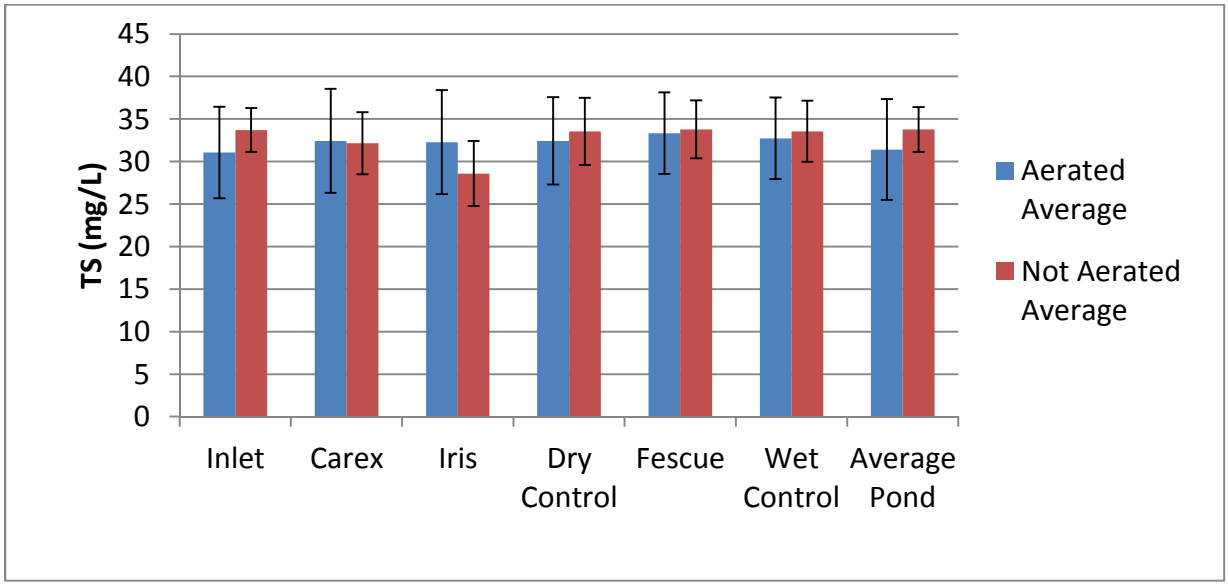



Figure 32 shows the removal rates for each of the research cells and Table 21 shows the average removal rates and standard deviations.

Figure 32 Removal Rate of Total Phosphorus Separated by Plant Species

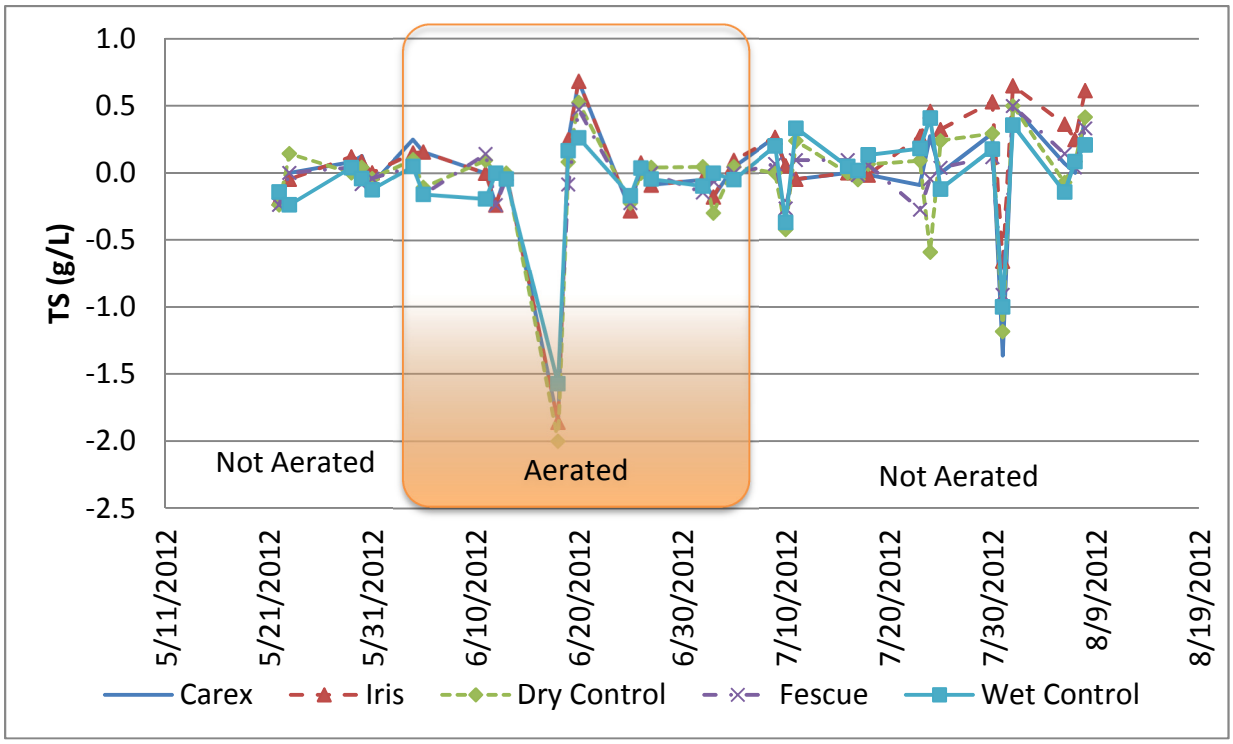


Table 21 Geometric Mean and Standard Deviation of Total Solids Removal Rates for Aerated and Not Aerated Samples

| | Aerated | | Not Aerated | |
|---|---|---|---|---|
| | Average | Standard Deviation | Average | Standard Deviation |
| Carex | -0.15 | 0.63 | 0.028 | 0.35 |
| Iris | -0.14 | 0.63 | 0.14 | 0.29 |
| Dry Control | -0.16 | 0.64 | -0.017 | 0.35 |
| Fescue | -0.17 | 0.50 | -0.013 | 0.26 |
| Wet Control | -0.14 | 0.49 | -0.013 | 0.29 |

The TS removal rates for each of the five research cells were compared using ANOVA on ranks. No statistical difference between plantings was noted for aerated ($p=0.998$) and not aerated ($p=0.268$) samples. Further, using the rank sum test, a significant difference was not noted between aerated and not aerated samples ($p=0.484$). The standard deviation is too high for the samples to determine if aeration made a statistical impact on TS treatment. The TS at each of the effluent locations were higher than the Michigan standard of 30 mg/L, however the TS concentrations are near the regulated limit (DEQ).

**Soils**

Soil samples were collected at the start and end of the five cell experiment, as described in section 2. The soils samples were analyzed by the Michigan State University Soil and Plant Nutrient Laboratory for bray phosphorus, organic matter, total nitrogen, nitrate and ammonium. Samples were taken at 0.152 m, 0.5 m and 1 m below the soil surface. Table 22 shows the change in concentration, initial minus final concentration, for each of the analyzed properties.

Table 22 Change in Soil Properties from May 2012-August 2012

| Species | Depth (m) | Bray Phosphorus (ppm) | Organic Matter (%) | Total N (%) | Nitrate-N (ppm N) | Ammonium-N (ppm N) |
|---|---|---|---|---|---|---|
| | 0.15 | -20 | 0.2 | -0.013 | 2.4 | 0.04 |
| | 0.50 | 50 | -0.6 | -0.036 | 0.24 | 0.10 |
| Carex | 1.0 | 2.0 | -0.2 | 0.005 | 1.2 | 0.83 |
| | 0.15 | 5.0 | 0 | -0.002 | 2.0 | 0.46 |
| | 0.50 | -11 | 0.3 | 0.016 | 3.4 | 1.2 |
| Iris | 1.0 | 3.0 | -0.3 | 0.002 | 2.7 | 0.86 |
| | 0.15 | -19 | 0.7 | 0.029 | 2.4 | 0.88 |
| | 0.50 | 4.0 | 0.2 | 0.005 | 0.81 | 0.42 |
| Dry control | 1.0 | 19 | -0.4 | -0.007 | -0.12 | -0.36 |
| | 0.15 | -5.0 | 0.1 | 0.027 | 2.6 | 0.87 |
| | 0.50 | 26 | -0.3 | 0.018 | 0.69 | 1.5 |
| Fescue | 1.0 | 24 | -0.6 | 0.003 | -2.4 | 1.9 |
| | 0.15 | -24 | 0.9 | 0.019 | 5.7 | 1.1 |
| | 0.50 | -54 | 0.1 | 0.001 | -0.29 | 0.38 |
| Wet Control | 1.0 | -43 | 0.3 | 0.016 | 1.9 | -0.59 |

The wet control cell had the greatest decrease in nitrate, as expected, since the cell is the most saturated it remains in an anaerobic state, which converts the nitrate to nitrogen gas. The geometric mean of each of the properties at the three soil depths was determined and shown in Table 23.

Table 23 Change in Soil Properties Geometric Mean at Three Soil Depths

| Depth (m) | Bray Phosphorus (ppm) | Organic Matter (%) | Total N (%) | Nitrate-N (ppm N) | Ammonium-N (ppm N) |
|---|---|---|---|---|---|
| 0.15 | -12.6 | 0.380 | 0.012 | 3.01 | 0.673 |
| 0.50 | 3.00 | -0.060 | 0.001 | 0.977 | 0.699 |
| 1.0 | 1.00 | -0.240 | 0.004 | 0.662 | 0.520 |
| Composite | -2.87 | 0.027 | 0.005 | 1.55 | 0.631 |

The net removal of organic matter makes sense since the cells were weeded weekly throughout the experiment. Due to the limited samples, few conclusions can be drawn from the

soil analysis. Bray phosphorus is a measurement of "available" phosphorous, so an increase is somewhat consistent with the hypothesis that aeration increased the soluble phosphorus. The organic carbon is oxidized with aeration, which impacts the availability of phosphorus. Future soil analysis is planned and could likely further explain what is taking place regarding water quality within the bioretention basin.

**Summary**

Overall little treatment was observed within the five research cells of the bioretention basin. The site is likely affected by the unclean construction materials, high flows of water and frequency that water is supplied to the site which keeps the basin operating poorly. The plants were unable to overcome the shortcomings of the site, despite other studies showing their benefits (Hatt, et al., 2009b; Hsieh & Davis, 2005; Read, et al., 2010; Read, et al., 2008). Aeration was both beneficial and detrimental to stormwater quality depending on the contaminant evaluated. Table 24 shows a summary of the impact on aeration on the tested contaminants.

Table 24 Impact of Aeration on Measured Contaminants

| Contaminant | Impact of aeration |
|---|---|
| COD | Beneficial, however net increase in COD through the system for both aerated and not aerated samples. COD increased more with aeration. |
| TN | Detrimental, TN increased with aeration and decreased without aeration |
| TP | Detrimental, TP increased both with and without aeration, but TP increased more with aeration |
| TS | Unaffected |

Since the soil was originally contaminated, TN and TP are potentially being leached out of the soil. Even though the aeration detrimentally impacted TN and TP, it is possible that the aeration is speeding up the flush out of these contaminants from the soil. In that case the aeration

would be beneficial since the soil would more quickly reach a point where it could provide treatment. However, the limited soil information collected cannot confirm this. Further analysis of the soil quality is required and will be completed with future studies.

# CHAPTER 6 CONCLUSIONS

The Farm Lane Bioretention Research Facility was constructed as a major stormwater treatment sites on campus. Collection and analysis of stormwater samples was completed during 2011 and 2012. Qualitative observations of the bioretention basin have been recorded regarding flow of water through the site, plant survival and the physical structure of the bioretention basin. Along with ordinary operations and maintenance of the site, major attempts to fix the system have been completed.

The first two years of sampling and a study in the five research cells have revealed that little to no treatment is taking place within the bioretention basin. This is attributed to contaminated materials used in construction along with a 35% undersized system. The bioretention basin was undersized since the volume of groundwater that would flow through the system was not understood during the engineering design. In 2012, it was determined that COD treatment is taking place. The soil mixture was composed of 3 percent compost. A portion of the compost was partially cured, which is contaminating water entering the site. The contaminated soil will continue to be tested, to determine the rate at which it is decomposing. It is anticipated that the soil will reach equilibrium over time and treatment within the bioretention basin will improve. Water quality monitoring will continue at the bioretention basin, and be expanded to include phosphorus and nitrogen analysis, along with further soil studies.

The five research cells at the front of the bioretention basin were used to evaluate their treatment performance three plant species – *Iris virginica*, a *Carex* mix and fescue grass – in bioretention basins. In addition, the impact of aeration in the ponded area preceding the five research cells was analyzed. No noticeable difference was determined between plant species for COD, TN and TS. Analyzing the samples based on aerated or not aerated: COD, TN, TP and TS

were all generated in the system when the aerator was turned on; and COD and TP were generated when the aerator was off. The TP increase is of particular concern since TP concentrations exceeded Michigan discharge limits for wastewater. The impact of the plants was not noticeable which is conjectured to be due to the contaminated materials. This study also demonstrated that aeration alone will not fix the Farm Lane bioretention basin to make it function properly.

Lessons learned from the bioretention basin were described with the goal of improving the performance of the Farm Lane bioretention basin and to aid in the design and construction of future bioretention basins. Knowing the correct volume of water that will enter the system is critical when sizing the bioretention basin. The results from this study highlight the importance monitoring during construction to ensure the basin is built per the engineering specifications. Although the Farm Lane Bioretention Research Facility is not treating stormwater sufficiently numerous lessons can be gained.

# APPENDICES

# Appendix A

## Laboratory Standard Operating Procedures

**Standard Operating Procedure - Total Solids (wastewater)**

For each sample running a total solids test on do 3 dishes.

First label each dish using tape and a marker. “I” for influent or “E” for effluent flowed by the sample number then a, b, or c for the duplicates (i.e. I1a, I1b, I1c, or E2a, E2b, E2c).

Next using the scale record the initial weight of each empty labeled dish.

Invert bottle approximately 3 times in order to get a good composite mixture of its sample.

Using a graduated cylinder (or 50 mL bulb) measure out 50 mL of sample and pour into its designated dish. Rinse the 50 mL bulb with next sample between samples to clean container.

Place full dishes on tray.

In addition record the initial weight of an empty dish and put it in the oven with the other samples as a blank to compare its weight after it comes out of the oven to know if there needs to be any adjustments or calibrations.

Once all the samples are poured, place tray(s) in oven.

Turn oven on to approximately 105 Degrees C.

Let cook over night.

When ready to check samples to make sure all water has evaporated, then turn off oven and let cool.

Once dishes are cooled to room temperature they can each be individually weighed again. Record the final weights into the lab book.

The difference in weight between the initial and the final will be that of the total solids.

**Standard Operating Procedure – COD (wastewater)**

For every run there will be a duplicate, blank and a standard.

So for example, 7 samples would require 10 COD vials, 8 for the samples and one blank and one standard.

Note there is a difference between high range and low range vials so make sure you know which one you are using. For stormwater low range are typically sufficient, but the conditions at the Farm Lane Bioretention Basin require high range vials.

It's important to label the caps of the vials to avoid confusion later on "I" for influent and "E" for effluent followed by the bottle number then a or b for the duplicates (i.e. I1a, I1b, E2a, E2b).

For the sake of time it is convenient to turn the preset hot bath on to let it warm up while you prepare samples. There is a COD option that is preset to the correct temperature and time.

For the blank, using a pipette add 2 mL of DI water. Invert the vial 5-10 times (until precipitates are dissolved, also important to be consistent with how many times you invert each sample).

When pipetting, dispose of used pipette tips into the sharps container and use new tips for every different sample as to not cross contaminate.

For the standard, using a pipette add 0.4 mL of DI water and then 1.6 mL of 3.00 ppm COD standard.

For samples, in order to reduce the particles in the samples they must be blended before being added to the COD vials. For each sample rinse the blender with the new sample 3 times. From here, using a pipette add 2 mL of filtered sample into the labeled COD vial. Repeat this process for the amount of samples you have, making sure to make one duplicate.

Once all samples, the blank and standard are prepared and the hot bath is up to temperature (approximately 150 degrees C) you can insert the vials into the cooker and press start. The hot bath is on a timer and will automatically turn off after 120 minutes of cooking.

Once samples have cooled they can be put into the COD meter.

Turn it on with the button on the very back.

Select "Favorite Programs". There is an option for COD HR and COD LR, select whichever vials were used.

Before inserting any vial, wipe it off with a paper towel to remove any smudge marks or finger marks that could affect the light being measure through the vial.

Start with the blank and zero the instrument.

Once it is zeroed you are good to RUN your samples and standard through it (wiping each one sufficiently before inserting). Record all the values into a lab book.

Used vials can go back in the box that they came from. Once a box is full of old samples it can be disposed of properly.

**Standard Operating Procedure- pH (wastewater)**

Calibration: It is good practice to calibrate the pH meter before using it. In order to do this you will need 3 clean beakers and fill them respectively with 4 pH, 7 pH and 10 pH buffer solutions.

Remove the cap from the tip of the pH probe and rinse it with DI water into a designated “Rinse” beaker. On the pH meter press the calibrate button. Starting with the 4 pH buffer, let the probe submerge into the solution and recognize it as the 4 pH buffer. Once it registers that you can remove the probe, rinse it and then stick it in the 7 pH buffer. Repeat for the 10 pH buffer.

Now that the meter is calibrated it is ready for samples.

To obtain a good representation of a sample, it is good to invert the sample a few times to mix it up. Then pour an arbitrary amount (enough for the pH probe to be submerged in) into a beaker. You do not need to pour into a beaker if the probe is long enough to so that its tip can be significantly submerged in the container the sample is already in.

Let the probe sit the sample until its reading is no longer changing. This may take a couple minutes for it to settle. Try to be consistent with the time you let the probe reach each sample, if given more time than others the reading may change slightly as the contents of the sample settle.

Be sure to rinse the probe with DI water between each sample to minimize cross contamination.

Record values into lab book.

**Standard Operating Procedure – Total Phosphorus**

Low Range (0-3.5 mg/L $PO_4^{3-}$ or 0-1.1 mg/L P)

For every run a duplicate of one sample was run, along with a blank and standard. Label each vial with the date and sample identifier.

First, turn on the heating block and select TP (30 minutes at 150 degrees celcius) and start the program to preheat the oven. Cut open the Potassium Perslfate Powder Pillows so there is one for each sample and pinch the sides so they are easy to pour. Do not add until sample has been added.

Remove caps and add 5 mL of the sample to each vial. For the blank, add 5 mL dionized water.

Add one pillow to each vial and tighten caps. Shake each vial for about 20 seconds, until the powder dissolves.

Place the vials in the heating block and restart the program.

After the program has run (30 minutes) remove the vials and let them cool to room temperature under the fume hood, approximately 15 minutes .

Cut open enough PhosVer3 Powder Pillows so there is one for each sample except for the blank and pinch the sides so they are easy to pour. Do not add yet.

When cool, remove all caps and add 2 mL of the 1.54N Sodium Hydroxide Standard Solution and rest caps on top of their respective vials. Tighten the cap on the blank, as it is finished.

Add one powder pillow to each vial.

Tighten the caps and shake until mixed, approximately 15 seconds.

Wait 2 minutes for the reaction to occur.

Turn on the reader and select the correct program “TP LR.” Clean the vials with the kimwipe before reading and use the blank to zero the instrument. Record the measurement in the lab notebook and place the used vials in the original container.

Once all the vials in the container have been used fill dispose of properly through ORCBS.

**Standard Operating Procedure - Total Nitrogen (wastewater)**

For every run there will be a duplicate, blank and a standard (i.e. 7 samples would require 10 COD vials, 8 for the samples and one blank and one standard)

First, turn on the heating block and select TN (30 minutes at 105°C) and start the program so when the samples are ready, the temperature will be at 105°C.

Next, label the caps of each vial and use a and b to designate the duplicates. Note there is a difference between high range and low range vials so make sure you know which one you are using. For stormwater low range are typically sufficient.

Cut open enough Total Nitrogen Persulfate Reagent Powder Pillows so there is one for each sample and pinch the sides so they are easy to pour. Remove all of the caps of the vials simultaneously and then add one "pillow" to each vial. After adding the pillow, rest the cap on each vial as a place marker.

For the low range kits (0-25 mg/L) add 2 mL of sample to each vial, 2 mL deionized water to the blank and 2 mL standard to the standard vial. For the high range kits (10-150 mg/L) add 0.5 mL of each.

Tighten the caps and shake for 30 seconds then place in the heating block and restart the program.

When the 30 minutes are up, promptly remove the vials and let them cool to room temperature under the fume hood (about 10 minutes).

Cut open enough TN Reagent A Powder Pillows so there is one for each vial and pinch sides. Remove all of the caps and place in front of the vial. Add one "pillow" to each vial. After adding the pillow, rest the cap on each vial as a place marker.

Tighten the caps and shake for 15 seconds. Wait for 3 minutes for the reaction to occur.

Cut open enough TN Reagent B Powder Pillows so there is one for each vial and pinch sides while the 3 minute reaction is occurring. When the timer goes off, remove all of the caps and place in front of the vial. Add one "pillow" to each vial. After adding the pillow, rest the cap on each vial as a place marker.

Tighten the caps and shake for 15 seconds. Wait for 2 minutes for the reaction to occur.

While the 2 minute reaction is occurring, get out the TN Reagent C Vials and label one for each sample. Remove all of the caps and when the timer goes off, using a pipette add 2 mL of each digested sample vial *to* the TN Reagent C Vials. Make sure that the sample goes as straight into the vial as possible. Rest the cap on each vial as a place marker.

Use a new tip for each sample and put the used ones in the sharps container.

Tighten all the caps and slowly invert the vials 10 times to mix (don't shake!). Be careful, because the vials will be hot. This should take about 30 seconds. Wait for 5 minutes for the reaction to occur.

Turn the reader on while the reaction is occurring and select the correct program (TN HR or TN LR under favorites) and hit start.

Wipe each vial with a kimwipe and zero the reader with the blank.

Read each sample and record the amount in the lab notebook.

Return the used vials to the boxes and store under the countertop.

When all of the vials are used, fill out an ORCBS label (there are two different ones for each box) and attach it to the box. Fill out an ORCBS pick-up form online at http://www.oeos.msu.edu/chem-waste/new.htm.

**Soil Analysis**

MSU Soil and Plant Nutrient Lab Reference Methods:

Soil Organic Matter: Recommended Chemical Soil Test Procedures for the North Central Region; J.R. Brown; North Central Regional Research Publication No. 221; Revised January, 1998.

Nitrate-Nitrogen: Huffman, S.A. and K.A. Barbarick, 1981. Soil nitrate analysis by cadmium reduction. Communications in Soil Science and Plant Analysis. 12(1): 79-89.

Ammonium-Nitrogen: Nelson, Darrell W., 1983. Determination of Ammonium in KCl Extracts of Soils by the Salicylate Method. Communications in Soil Science and Plant Analysis. 14(11) 1051-1062.

Phosphorus in water: U.S. Environmental Protection Agency, Methods for the Determination of Inorganic Substances in Environmental Samples, EPA-600/R-93/100, August 1993, Method 365.1

Total Nitrogen: Micro-Kjeldahl digestion and then analyzed on a Lachat Flow Injection Analyzer by the Salicylate Method. Bradstreet, R.G. 1965. The Kjeldahl Method for Organic Nitrogen. Academic Press, New York and London.

# Appendix B

## Key Lessons Learned from the Farm Lane Bioretention Research Facility

Lessons Learned

- Monitoring construction is critical, since post construction changes are costly and challenging
    - Stick to engineering design, if changes are made evaluate the impact of those changes to ensure
- Use clean materials in construction
    - The soil provides a substantial portion of the treatment and needs to meet bioretention design specifications and initially have a low phosphorus index
- Understand the true volume of water that is fed to site, which includes studying the seasonal local groundwater table levels and if any perched tables are present
- Supplying water to a bioretention basin en masse, as opposed to gradually during a storm event, impedes treatment

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