

# Multi-Variate Study of Stormwater BMPs

2008 Green Building Research Fund Grants | FINAL REPORT | March 2011

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## ABOUT BNIM

With over 40 years of experience as a multidisciplinary architectural firm, Berkebile, Nelson, Immenschuh, McDowell (BNIM) has built a reputation for thoughtful and responsive design and planning, thorough technical competence and conscientious service. With offices in Kansas City, Houston, Des Moines, San Diego, and Los Angeles, BNIM has completed many significant public and private projects at both local and national levels. The firm's areas of expertise include sustainable design and community redevelopment, urban planning and design, stormwater management, educational facilities, campus master planning, and residential and corporate office spaces. BNIM is committed to restorative design, which aims to maximize human potential, productivity, and health while increasing the vitality of natural systems. For more information, contact Jim Schuessler at 816.783.1500, or visit [www.bnim.com](http://www.bnim.com).

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The U.S. Green Building Council is a nonprofit membership organization whose vision is a sustainable built environment within a generation. Its membership includes corporations, builders, universities, government agencies, and other nonprofit organizations. Since USGBC's founding in 1993, the Council has grown to more than 17,000 member companies and organizations, a comprehensive family of LEED® green building certification systems, an expansive educational offering, the industry's popular Greenbuild International Conference and Expo ([www.greenbuildexpo.org](http://www.greenbuildexpo.org)), and a network of 78 local chapters, affiliates, and organizing groups. For more information, visit [www.usgbc.org](http://www.usgbc.org).



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## TABLE OF CONTENTS

<b>1 :: INTRODUCTION .....</b>	<b>2</b>
Monitoring Goals and Objectives	
Types of Monitoring	
Precipitation	
Flow Metering	
Water Quality Sampling	
Soil Sampling	
Infiltration Testing	
Site Selection	
<b>2 :: SITE ONE: CITY UNION MISSION .....</b>	<b>14</b>
Introduction + Overview	
Project Details	
Monitoring Inventory + Analysis	
Conclusions	
<b>3 :: SITE TWO: APPLEBEE'S SUPPORT CENTER COURTYARD RAINGARDEN .....</b>	<b>40</b>
Introduction + Overview	
Project Details	
Monitoring Inventory + Analysis	
Conclusions	
<b>4 :: SITE THREE: APPLEBEE'S SUPPORT CENTER TREATMENT TRAIN .....</b>	<b>56</b>
Introduction + Overview	
Project Details	
Monitoring Inventory + Analysis	
Conclusions	
<b>5 :: SITE FOUR: THE UNIVERSITY OF KANSAS FITNESS CENTER .....</b>	<b>76</b>
Introduction + Overview	
Project Details	
Monitoring Inventory + Analysis	
Conclusions	
<b>6 :: CONCLUSIONS .....</b>	<b>94</b>
<b>7 :: APPENDIX .....</b>	<b>98</b>
How does research relate back to the concerns of USGBC?	
Design Modifications	
Soil Temperature	
Rainfall Comparison	

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## LIST OF FIGURES AND TABLES

### 1 :: INTRODUCTION

5	Figure 1.1	HOBO Data Logging Rain Gauge Data Logger
6	Figure 1.2	ISCO Portable Sampler
7	Figure 1.3	ISCO Showing Collection System
7	Figure 1.4	Water Sample
8	Figure 1.5	Soil Sample
9	Figure 1.6	Piezometer
12	Figure 1.7	Context Map

### 2 :: CITY UNION MISSION INFILTRATION BASIN [SITE ONE]

15	Figure 2.1	View of Infiltration Basin #1 from Roof (Basin #2 is in background)
17	Figure 2.2	City Union Mission Context Map
17	Figure 2.3	Project Overview
18	Figure 2.4	Basin #1
18	Figure 2.5	Basin #2
18	Figure 2.6	Basin Location Diagram
18	Figure 2.7	Water Flow Diagram
19	Figure 2.8	Basin #1 Monitoring Equipment
20	Figure 2.9	Basin Section
20	Figure 2.10	Installing the Inlet Connection Equipment
20	Figure 2.11	ISCO Collection System
21	Figure 2.12	Precipitation Summary (2009)
22	Figure 2.13	Precipitation Summary (2010)
24	Table 2.1	Soil Test Results
25	Figure 2.14	Basin #1 Rainfall, Soil and Water Depth Results (Fall 2009)
26	Figure 2.15	Basin #1 Soil and Water Depth Results (2010)
27	Figure 2.16	Basin #3 Rainfall, Soil and Water Depth Results (Fall 2009)
28	Figure 2.17	Basin #3 Soil and Water Depth Results (2010)
30	Table 2.2	Basin 1: Estimated Runoff Volumes and Water Depths in Basin
31	Figure 2.18	Prairie Cordgrass Root System
31	Figure 2.19	Vegetation after One Growing Season
32	Figure 2.20	Planting Plan
33	Figure 2.21	Basin #1 Soil Moisture (2010)
34	Table 2.3	Basin #1 Flow "In" Water Quality (2009)
34	Table 2.4	Basin #1 Flow "Out" Water Quality (2009)
35	Table 2.5	Basin #1 Water Quality in mg/L(2010)
35	Table 2.6	Basin #1 Water Quality in total lb (2010)

### 3 :: APPLEBEE'S SUPPORT CENTER COURTYARD RAINGARDEN [SITE TWO]

41	Figure 3.1	Courtyard to be Monitored
43	Figure 3.2	Applebee's Support Center Context Map
43	Table 3.1	Project Overview
44	Figure 3.3	Outlet Sampling Location
44	Figure 3.4	Raingarden Layout
45	Figure 3.5	Water Flow Diagram
46	Figure 3.6	Sidewalk Span Over Raingarden Section
46	Figure 3.7	Pavement and Raingarden Section
47	Figure 3.8	Precipitation Summary (2009)
48	Figure 3.9	Precipitation Summary (2010)
49	Figure 3.10	Planting Design and Plant List
50	Figure 3.11	Courtyard with raingarden beyond
50	Figure 3.12	Courtyard with raingarden
50	Figure 3.13	Raingarden with gutters in background
50	Figure 3.14	Equipment Connection
51	Figure 3.15	Soil Moisture Summary (2010)
52	Table 3.2	Water Quality Data into the Raingardens
52	Table 3.3	Water Quality Data out of the Raingardens
53	Figure 3.16	Bamboo along entry walk
54	Figure 3.17	Original Designed Outlet Drain

---

## 4 :: APPLEBEE'S SUPPORT CENTER TREATMENT TRAIN [SITE THREE]

57	Figure 4.1 Aerial Photo Towards BMP Treatment Train after Rough Grading
59	Figure 4.2 Site Context Map
59	Figure 4.3 Sand Filter and Sediment Forbay Photo
59	Table 4.1 Project Overview
60	Figure 4.4 Watershed and BMP Layout Diagram
60	Figure 4.5 Sediment Forbay Photo
60	Figure 4.6 Sand filter, Renner Road monitoring stations and Wetand Construction
60	Figure 4.7 Entry pipe to Sediment Forbay (from parking lots)
60	Figure 4.8 Sand Filter under Construction
61	Figure 4.10 Water Flow Diagram
62	Figure 4.11 Monitoring Equipment Location Diagram
63	Figure 4.12 Precipitation Summary (2009)
64	Figure 4.13 Precipitation Summary (2010)
65	Figure 4.14 Wetland Planting
65	Figure 4.15 Wetland Plants after One Year Establishment
66	Figure 4.16 Wetland Planting Design Diagram
66	Figure 4.17 Wetland Plant List
67	Table 4.2 Sand Filter "In" Water Quality Data
67	Table 4.3 Sand Filter "Out" Water Quality Data
68	Table 4.4 Renner Road Water Quality Data
70	Table 4.5 Wetland Water Quality Data
71	Table 4.6 Applebee's Landscape Chemical Application
72	Figure 4.18 Cattails present and drainage location
72	Figure 4.19 Washout at spillway. Weeds visible
73	Figure 4.20 Sediment entering wetland
74	Figure 4.21 Erosion from sediment trap

## 5 :: UNIVERSITY OF KANSAS FITNESS CENTER INFILTRATION BASIN [SITE FOUR]

77	Figure 5.1 Raingarden in 2009
77	Figure 5.2 Raingarden in Fall 2010
79	Figure 5.3 Site Context Map
79	Figure 5.4 Project Overview
80	Figure 5.5 Watershed - Building Roof Drainage to Detention basin
81	Figure 5.6 Water Flow
81	Figure 5.7 Raingarden Section at Pipe Outlets
82	Figure 5.8 Enlarged Detail of Level Spreader
82	Figure 5.9 Level Spreader Manhole and Outlet (2009)
82	Figure 5.10 Level Spreader Outlet (2010)
84	Figure 5.11 Monitoring Equipment
84	Figure 5.12 Section Through Outlet
85	Figure 5.13 Precipitation Summary (2009)
86	Figure 5.14 Precipitation Summary (2010)
87	Figure 5.15 Educational Signage
87	Figure 5.16 Planting Design + Plant List
88	Figure 5.17 Planting (Fall 2010)
89	Table 5.1 BMP Water Quality Data
89	Table 5.2 Roof Water Quality Data
90	Figure 5.18 Soil Moisture (2010)

## 6 :: CONCLUSIONS

## 7 :: APPENDIX

101	Figure 7.1 2010 NE Kansas Soil Temperature
102	Figure 7.2 Comparison of Rain Events at Three Sites





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## INTRODUCTION

### a) Research Grant Program

The U.S. Green Building Council (USGBC) created the grant program to spur research that will advance sustainable building practices and encourage market transformation. Our team was one of thirteen recipients out of over 250 applications for the 2008 Green Building Research Fund Grants, the first grants of their kind in the green building industry. This research topic was Priority Topic No. 2 under the category of Ecosystem and Site Design and focused on managing stormwater around sustainable building sites.

### b) Purpose of Research

This project monitors the performance of stormwater Best Management Practices (BMPs) such as raingardens, bioswales, and vegetated infiltration beds. These are systems used to capture stormwater runoff near the point of generation (e.g. - roofs, patios, parking lots, driveways), slow runoff rates, infiltrate stormwater into site soils, and remove pollutants, while also creating landscaping amenities and habitat enhancements. BMPs are used to integrate stormwater management into site landscaping amenities. Specific BMPs included in this research project are described in Section 4.

This topic affects many fields - architecture, construction, facility maintenance, engineering and, most importantly, human behavior and health. Lessons and information gathered from this report have the capacity to alter design standards, and policymaking and to significantly impact human health and productivity. This document includes thoughts related to the potential to influence building and site design as well as development policy and standards, facility operations and maintenance standards. This research yields results that can address such business and City Department concerns as dollars lost in stormwater management. Additional outcomes include reducing aquifer depletions, becoming good stewards to downstream neighbors, and abating flooding. All of these factors create better, more livable communities and neighborhoods.

Only 3% of the water in the world is fresh water (with a majority of that water held in glaciers and polar ice caps). It has been estimated that less than 1% of fresh water is available for use and consumption with no more water being produced. With increasing demand from growing populations, fresh water will become a valuable commodity (probably more so than oil). Many cities across the nation have embraced and experienced success with green solutions. BMPs should be incorporated into all facets of building, construction, design, and policy to protect water as a precious resource.

# Introduction

## MONITORING GOALS AND OBJECTIVES

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### RESEARCH TOPIC GOAL:

Develop or improve Best Management Practices (BMPs) for on-site stormwater management, including effective utilization, treatment, infiltration, and storage.

### OBJECTIVES:

#### A) Promote the use of alternative on-site sources of water.

- Outreach: Raise awareness regionally of what is possible, what is probable, what is provable, and replicable.
- Maintenance: Determine to what level maintenance standards affect the success of the systems. Explore whether sustainable design features such as soils, vegetation and layout affect the performance of the system. Identify any major issues identified that can reduce the effectiveness of the BMP, including siltation, weed growth, and irrigation usage.

#### B) Provide a process that is replicable in different climates / bio-regions.

- Availability: Use the International Stormwater BMP database with its described protocol for stormwater monitoring. Document the findings using the database forms so that the data can be shared globally.
- Design Modifications: Identify improvements to BMP design components (per different climates/bio-regions).

#### C) Documentation

- Water Quality: Document the success of removing pollutants from surface runoff from building roof and impervious surfaces with the integration of BMPs. The focus will be on the start of rain events when pollutant loading is at its highest (first flush rain events).
- Soil Infiltration Rates: Document the infiltration rate of the BMP as a measure of reducing runoff and recharge of the aquifer.
- Soil Sampling: Document the change in soil over time and within the BMP. Explore whether sustainable design features such as soils, vegetation, and layout affect the performance of the system.
- Facility Sizing: Evaluate the performance of the BMP in comparison to its size versus the drainage area.
- Performance Baseline: Compare results to preliminary hypothesis, BMP database, or previous submitted LEED Certification documentation.
- Cost: Address how BMPs can be created effectively on sites with smaller budgets but still be effective with limited budgets.

#### D) USGBC LEED Impact

- Rating System: Evaluate the success or shortcomings of the current LEED credits involving stormwater management.

Not all objectives will be evaluated for each site.

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## OVERALL HYPOTHESIS:

Stormwater flows and water quality tests were typically taken at the intake and outlet of the BMPs. Typically within 48 hours of a rain event, water samples were collected, refrigerated, and taken to the lab to test for sediments and contaminants. Flow meters recorded the amount of water entering and leaving the BMPs, documenting the success of plant and soil absorption.

1. Quantity - Stormwater quantity conveyed through monitored urban stormwater BMPs is expected to be reduced through infiltration, transpiration, and slowing water velocity. This hypothesis is supported by previous research from other organizations [Mid-America Regional Council and American Public Works Association, Manual of Best Management Practices for Stormwater Quality].
2. Quality- Stormwater is expected to show improved overall quality after passing through an urban stormwater BMP. The exact results vary between BMP types, but general cleaning takes place as water passes through vegetation and soil. It also occurs when water stands still and allows time for particles to settle.

# Introduction

## TYPES OF MONITORING

To meet the project goals and objectives, the research team installed a variety of monitoring equipment at different sites. Each type of monitoring equipment provides stand-alone data, but when combined, depict the larger story.

### PRECIPITATION

Each site integrates an Onset Data Logging Rain Gauge that measures rainfall quantity and intensity. We are using the HOB0® Data Logging Rain Gauge Data Logger, Model: RG3. This model is battery powered and integrates a tipping-bucket rain gauge that automatically records rainfall data, rates, times, and duration. (A time and date stamp is stored for each tip of the rain gauge bucket).

In addition, we compared the precipitation with local NOAA reporting station to double check accuracy of on-site precipitation data.



Installation Requirements: It was important that the gauges be located near the BMP sites in a level and elevated mounting position with minimal opportunity for interference from tall objects and wind disturbance.

Figure 1.1 HOB0 Data Logging Rain Gauge Data Logger

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## FLOW METERING

Equipment is used to measure flow rates in and out of the BMPs. Storm events are monitored with minimal labor requirements. Readings are typically taken every five minutes to provide water level data over a rain event. This information is compared to the drainage area and rainfall to double check data quality.

All monitoring locations included either a Teledyne ISCO 6700 or 6712 Portable Samplers (Teledyne ISCO, INC., Lincoln, NE) with a Teledyne ISCO 730 Bubbler Flow Module attached. Where site conditions allowed, the ISCO samplers were installed in BMP inflow and outflow pipes. This allowed us to compare water quantity measurements up and down stream of BMPs.

The bubbler flow modules use an internal air compressor to force a metered amount of air through a bubble line submerged in the flow channel. By measuring the pressure needed to force air bubbles out of the line, the water level can be calculated. The ISCO Sampler then calculates flow rate from the water levels. It is suitable for small channels and is not affected by wind, steam, foam, or turbulence.



Figure 1.2 ISCO Portable Sampler

# Introduction

## WATER QUALITY SAMPLING

Equipment is used to take water samples of runoff moving through BMPs. Sample are taken automatically when water movement is present. Water samples are taken to the lab for analysis.

All monitoring locations included either a Teledyne ISCO 6700 or 6712 Portable Samplers. Typically the ISCO samplers were hooked to inflow and outflow pipes. This allowed us to compare water quality measurements before and after the BMPs.

Typically, every five minutes the equipment forces an air bubble out of the line to sense water flow. If water flow is present, the sampler is engaged and the first sample is taken. This allows a sample to be taken at the start of a rain event (first flush sample).

Samples were taken every 30 minutes throughout a rain event (for a maximum of 24 samples over 12 hours). If the bubbler did not detect water flow, the sampler was disengaged, a bottle was skipped, and ready for the next rain event.

Samples were sent to the Kansas State University (KSU) testing laboratory in Manhattan, Kansas. Depending upon the location and dry period prior to rain event, samples were typically tested for the following:

- a. Total Suspended Solids (TSS)
- b. Total Nitrogen (TN)
- c. Total Phosphorus (TP)
- d. Zinc (Zn)
- e. Chloride (Cl)
- f. Sulfur (S)
- g. pH
- h. Electrical Conductivity (EC  $\mu$ S)

Selected samples were also tested for:

- i. Fecal Coliforms (Ecoli)

Electrical conductivity (EC) was tested because it is indicative of the ability of an aqueous solution to carry an electric current. It is used as a cost-effective surrogate analysis for dissolved solids and salts. Plants are detrimentally affected, both physically and chemically, by excess salts.



Figure 1.3 ISCO Showing Collection System



Figure 1.4 Water Sample

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## SOIL SAMPLING

Soil sampling was done to test particle size distribution, pH, Zinc, bulk density, and organic matter content of the planting soil within the BMPs. These characteristics provide an indication of soil quality and compaction for the plant growing environment with correlations to water infiltration rates. As BMPs mature, the ratios of these parameters should change due to plant growth and root penetration, mulch decomposition, microorganism activity, plus the influx of sediment and pollutants to the BMPs.

ASTM F1631 Method B was used to complete the Particle Size Evaluation, and ASTM F1647 Method A was used to calculate Organic Matter.



Figure 1.5 Soil Sample



# Introduction

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## INFILTRATION TESTING

Stormwater BMPs collect stormwater runoff from hardscapes within the built environment. They function to temporarily detain runoff, slow it down, infiltrate a portion to subsoils, and create landscaping and habitat improvements. In the process, they also remove pollutants from the surface runoff. The rate that water infiltrates into the ground is a primary variable that contributes to the success of unlined BMPs.

Piezometers (small diameter wells) were installed at the City Union Mission site to help measure how well the Infiltration basins function during storm events, infiltrate water into the surrounding subsoil, and recover capacity between storm events. The wells allow for the measurement of water levels within the infiltration basins. In addition, the wells measure the time between the start of a rain event and when the storage volume exceeds capacity and overflows.

The wells consist of perforated PVC pipe that was installed in shallow auger holes advanced into the raingarden beds. The wells were installed three feet into the soil (to match the depth of engineered soil). A pressure transducer was suspended near the bottom of the each well. Pressure head readings were recorded by the transducer and converted to water level readings.



Figure 1.6 Piezometer



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### DESCRIPTION OF SITE QUALITIES AND CRITERIA

It was important for the research team to select monitoring sites as quickly as possible to start gathering data by summer 2009. The BNIM team investigated a range of sites within an acceptable drivable distance. The sites needed to be recently completed projects with minimal immeasurable variables (i.e. it was desirable to identify sites with single flows in and out with minimal sheet flow from adjacent areas). Projects focused on building projects with runoff from impervious areas (roof and parking areas). The following is a list of projects we initially investigated in the Kansas City area.

- 12th Street Streetscape (in front of City Hall), Infiltration Basin
- Bartle Hall Convention Center North Dock, Infiltration Basin
- City Union Mission, Infiltration Basin
- 6400 Pennsylvania, Streetscape BMPs
- Anita B. Gorman Conservation Discovery Center, Bioswale
- 99th and Holmes Fire Station, Raingarden
- Resurrection Cemetery Joint-Use Facility, Wet Pond and Wetland
- Applebee's Support Center, Raingardens
- Applebee's Support Center, Treatment Train
- Harmony Park, Stream Stabilization
- Coon Creek Wetland (east) and Playfield, Underground Infiltration System
- Platte Purchase Park, Bioswales
- City of Independence, Detention Pond Revegetation
- The University of Kansas, Modified Detention Basin
- Highland View Parking Lot, Bioretention Cells
- Zona Rosa, Sediment Basin/Detention System or Stream Restoration
- St. Paul's United Methodist Church, Wet Pond / Stream Restoration
- Johnson County Government Sunset Office Bldg, Bioretention
- Fire Station #3, Bioretention cells
- 39th and Coachman, Stormwater Detention Facility
- KCPL Power Plant, Welson Sough Restoration
- Shawnee Mission Lake, Wetland
- Prairie Star Parkway, Bioretention Cells

## SELECTED SITES

The research and technical team discussed this grant as having a unique niche to fill. The audience for this monitoring project includes architects, landscape architects, engineers, and property owners. The importance of retrofit BMPs was deemed important to site selection. In addition, there was an opportunity to respond to the financial side of BMPs. Less expensive BMPs were chosen to show that cost does not need to be a major factor when designing BMPs while still accomplishing great water quantity and quality results (cost-to-benefit ratio). As shown in Figure 1.7, selected sites were:

- Site #1: City Union Mission, Infiltration Basin
- Site #2: Applebee's Support Center, Raingardens
- Site #3: Applebee's Support Center, BMP Treatment Train
- Site #4: The University of Kansas Fitness Center, Modified Detention Basin/Raingarden

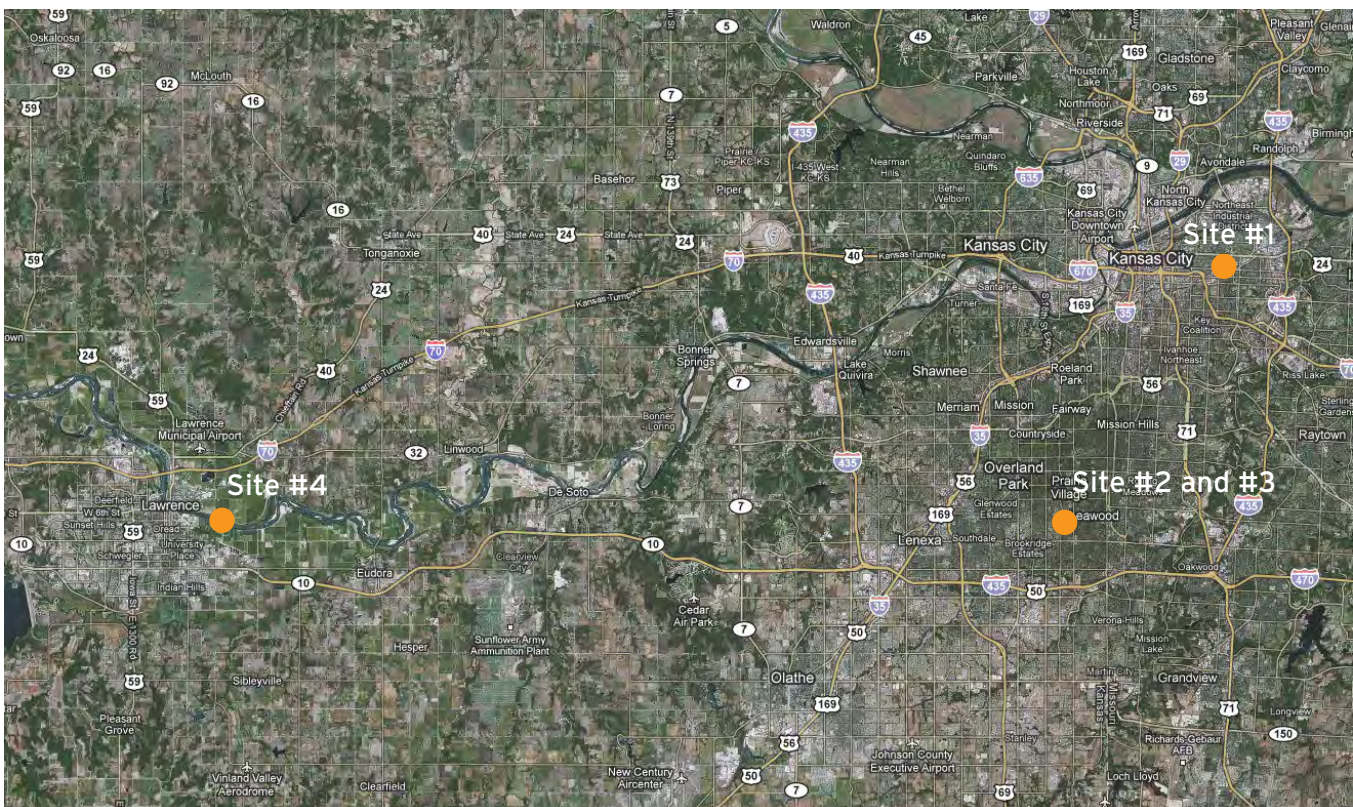


Figure 1.7 Context Map





# City Union Mission Infiltration Basins

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## INTRODUCTION + OVERVIEW

### INFILTRATION BASINS

#### GENERAL APPLICATION

As identified by the American Public Works Association (APWA) Manual of Best Management Practices for Stormwater Quality, infiltration basins typically improve water quality by capturing stormwater volume, holding this volume, and infiltrating it into the ground over a period of days as opposed to flowing into traditional stormwater systems and eventually streams. Infiltration basins frequently contain subsurface underdrains so that the water is filtered by the soils and vegetation before the water exits the system. They are commonly designed off-line and only intercept a certain volume of runoff. Any excess volume is bypassed. Infiltration basins are not designed to retain water for long periods of time.

#### ADVANTAGES

The following are the advantages of infiltration basins and the expected results.

- The runoff volume from the roof will be reduced as the water is infiltrated, evaporated and transpired. The infiltration basins are expected to show large amounts of infiltration.
- The runoff rate from the roof to the outlet will be slowed. This lag time will reduce the potential for downstream flooding and support streambank integrity.
- On certain rain events, the entire building roof runoff will be detained on site. It is anticipated that the outlet will overflow rarely. Only during large storm events will overflows take place.
- Some national jurisdictions require that the post-development runoff cannot exceed the pre-development peak flow rate. If designed appropriately, infiltration basins can reduce the detention requirements on-site and size/cost of downstream stormwater control facilities. In addition to the holding capacity in the basin, the engineered soils provide subsurface detention volume. The design will show that infiltration basins do not just clean runoff, but they can reduce the quantity of runoff, more than previously expected.
- Infiltration practices can remove fine sediment, trace metals, nutrients, bacteria, and oxygen-demanding substances (organics).

### CITY UNION MISSION INFILTRATION BASIN

#### DESIGN INTENT

The infiltration basins were designed similar to typical systems with two major differences. At City Union Mission, the inlet is subsurface and the outlet drain is elevated to create holding capacity. A level spreader dissipates the energy of the roof runoff and spreads it evenly over the infiltration basin, removing the potential for erosion at pipe outlet and need for a sediment forebay. In addition, the three infiltration basins are sequentially connected to slow the runoff and encourage infiltration, transpiration and evaporation.

#### MONITORING GOALS

- Determine the size of rain events in which an overflow from the first and third basin can be expected.
- Determine root penetration.
- Determine how soil profile changes with time.
- Assess the cost to benefit ratio.

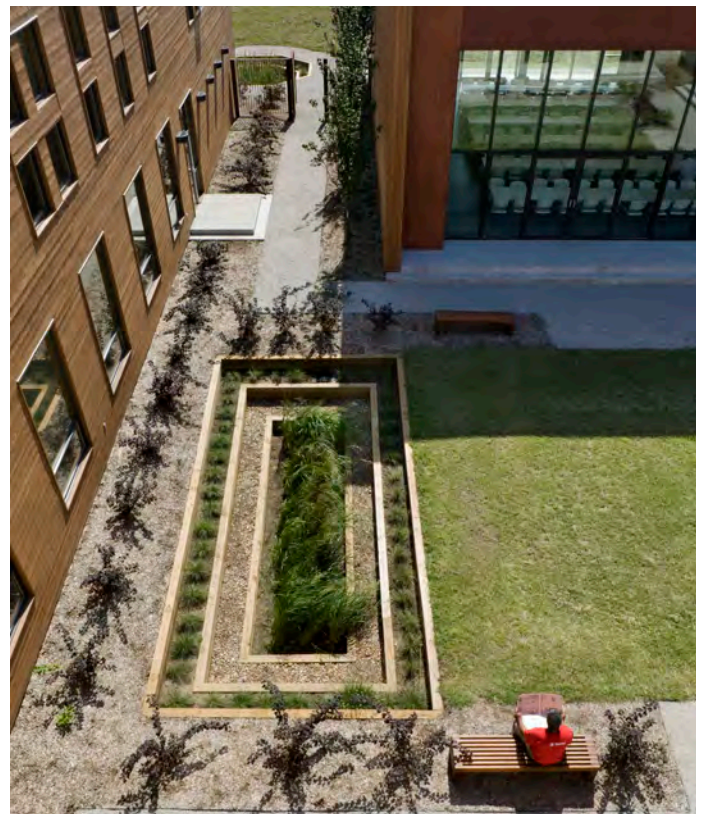


Figure 2.1 View of Infiltration Basin #1 from Roof (Basin #2 is in background)

## MONITORING OVERVIEW



### SOIL / INFILTRATION

The installed engineered soil and plants provide a good rate of infiltration while promoting healthy plant growth. All three of the basins drain well. Basins 1 and 2 never hold water for more than 24 hours. The infiltration rate is faster than expected in Basin #1 and #3 probably due to existing porous soils adjacent to the basin. These soils allow water to move laterally out of the basin, which helps the basins perform better.

### VEGETATION

*Spartina pectinata* (prairie cordgrass) and *Sporobolus heterolepis* (prairie dropseed) have proved to be great performers. Plant roots have established 30" deep in less than two years. Cordgrass is well adapted to the wet zone of the basins. Dropseed does better in drier conditions and is growing well on the edges. *Lobelia cardinalis* (cardinal flower) is slow to establish, which makes it easy for weeds to spread. If low maintenance is a priority, the cardinal flower should not be considered for this application.

### WATER QUANTITY

The infiltration basins are properly sized to successfully manage 1.37" storm events (the local water quality, or 90th percentile). Basin #1 has storage area of 368 SF (or about 5% sizing factor) and 872 CF of storage capacity.

$$7,000 \text{ SF Roof} \times \frac{1.37 \text{ in}}{12 \text{ in/ft}} = 800 \text{ CF of rainfall going to Basin \#1 in a 1.37" Storm}$$

Flow volume comparison shows that the flow volume out of the Basin was dramatically slower than flow into the basin.

### WATER QUALITY

Only one outflow from Basin #1 was recorded during 2009 and 2010. Thus all of the contaminants from rain events of less than 2.44 inches of rain were contained within the basin.

On large rain events, it appears that runoff was probably picking up and exporting pollutants such as TN, TP, S, and TSS. However, the outflow data is insufficient to verify this hypothesis.

It appears that heavy metals such as Zn were maintained within the basin.

### MAINTENANCE

- Weeds: Weeds were minimal. Spot spraying of weeds was completed in April 2010 prior to the native grass growth season.
- Irrigation: There is no irrigation on site.
- Mulch: The planters are not mulched.
- Silt: Silt from adjacent landscaped areas affected Basin #3. Erosion control measures (seeding and straw wattles) were added to control adjacent soil movement.

### COST TO BENEFIT ANALYSIS

A typical detention pond to manage stormwater runoff from a 15,000 square foot building may cost approximately \$40,000 to \$50,000. In many regions, water quality BMPs are required in addition to detention ponds. The cost of the three infiltration basins at this site was \$72,000. Monitoring at this site indicates that infiltration basins have the potential to reduce runoff volumes in addition to filtering pollutants, which could help to reduce the size, and hence cost, of required detention ponds.



PROJECT DETAILS

PROJECT DESCRIPTION

City Union Mission is a not-for-profit organization serving the base level needs of those whose lives have been disrupted in the Kansas City community. Their previous facility was inadequate to meet rising demands, and the development of a separate structure housing the Christian Life Program was created. This program nurtures the re-entry process for one hundred of the most promising men who will live and attend classes in the facility during their one-year curriculum. The resulting design supports the belief that students of the program deserve to experience the best during their course and afterward, wherever their new life leads them.

Located in a neglected neighborhood within the urban core (Figure 2.2), the creation of a safe and healthy environment was paramount. To address this goal, the facility was developed around a secure courtyard that connects the interior and exterior throughout. Programmatic spaces include a dormitory, living area, classrooms, recreation rooms, and administrative offices. A multi-purpose space is used for dining, recreation, and worship. Exterior building materials include recycled hardwood combined with brick and burnished block masonry.

The site design incorporates a variety of sustainable features and is a showcase for urban stormwater management. The small site includes three vegetated infiltration basins that accept all of the roof runoff from the building with no connection to the city’s storm sewer system. Indigenous plant materials that require minimal maintenance were integrated throughout the site. Hidden from view are the geothermal wells and the recycled water storage tanks, which hold filtered water from the showers for use in toilet flushing.

Monitoring at the City Union Mission in downtown Kansas City provided the opportunity to show how a small urban site within a blighted area could still receive substantial runoff reduction with a minimal budget.



Figure 2.2 City Union Mission Context Map

CITY UNION MISSION	
Land Use and Owner Description	City Union Mission
Completed	2008
Address	1100 E. 11th St., Kansas City, MO
Location in Watershed	Near top of watershed at approx. elev. 910 MSL
Area of Building	27,000 square feet building
Building Use	Residence Hall
LEED Certification	None
Cost of Construction	\$6.7 Mill. for Building and Site
Cost of 3 Infiltration Basins	\$72,000
Materials	6 x 6 lumber, engineered soils, and plants
Plants	Prairie Cordgrass, Prairie Dropseed, Cardinal Flower
Roof Area To Basin #1	7,000 Square Feet
Surface Area of Captured Vol when Full (Basin #1)	546 Square Feet
Infiltration Surface Area (Basin #1)	103 Square Feet
Captured Vol when Full (Basin #1)	872 Cubic Feet

Figure 2.3 Project Overview



## PROJECT DETAILS

### STORMWATER SYSTEM DESCRIPTION

A series of three interconnected vegetated infiltration basins collect roof and site runoff (Figure 2.6). Each basin consists of a shallow depression framed with wooden timbers. The basins were backfilled with permeable engineered soils and planted with grasses and flowers. Basin #1, as shown in Figure 2.4, is the first cell in the series, and is monitored for runoff quality and quantity. This cell receives about half of the roof runoff (Figure 2.7). Runoff from three roof drains enter the infiltration basin through a perforated pipe that wraps the basin and acts as a level spreader. The outlet from Basin #1 is a slotted area drain that conveys water to the second infiltration basin. The outlet from Basin #2 conveys water to Basin #3 (Figure 2.7). This system costs very little to construct and was easy to install, which makes it a very useful example of BMP design and implementation.



Figure 2.4 Basin #1



Figure 2.5 Basin #2

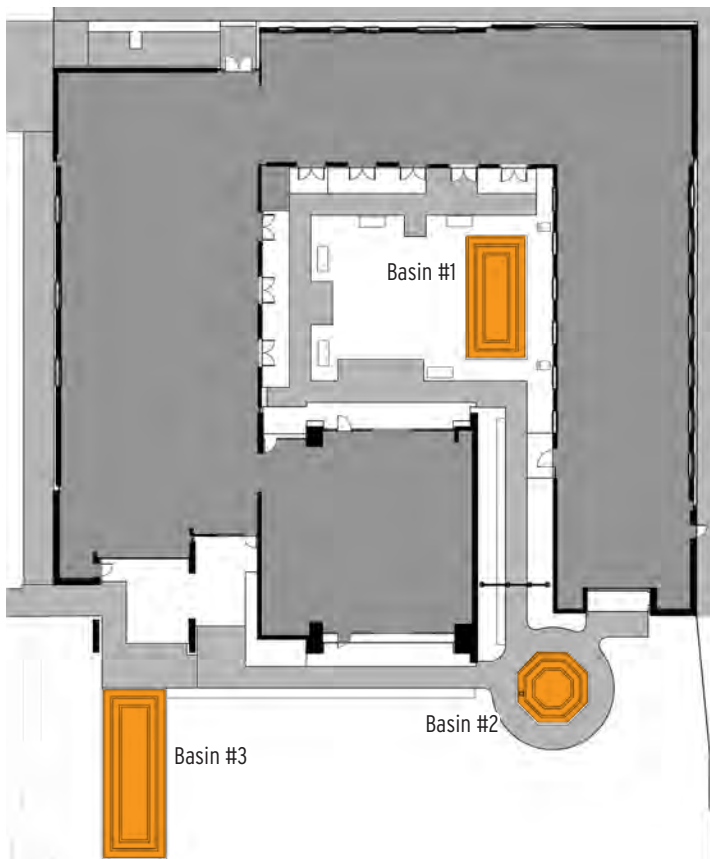


Figure 2.6 Basin Location Diagram

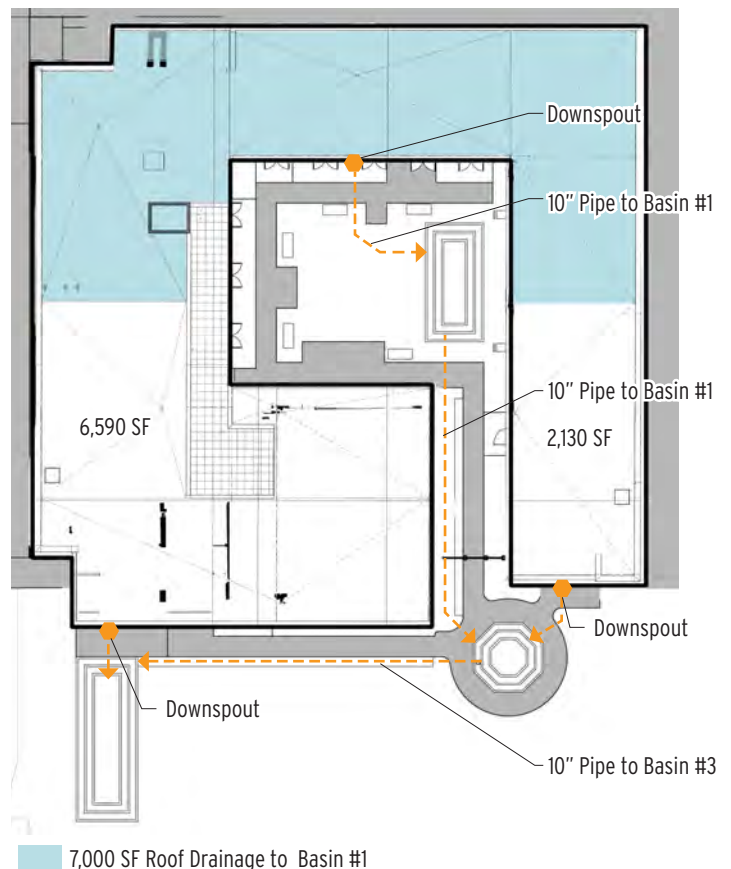


Figure 2.7 Water Flow Diagram

## PROJECT DETAILS

## STORMWATER SYSTEM DESCRIPTION

Two ISCO samplers were installed at this site, one at the inflow and one at the outflow point of Basin #1 (Figure 2.8). This configuration allowed the research team to compare water quality and quantity of water entering the infiltration to water exiting the basin. The connection point shown in Figure 2.8 is where the 1/2" ISCO sampler tube connects to the inlet or pipe to sample water. The connection point is illustrated in more detail in the Basin Section illustrated by Figure 2.9. In addition, water level monitoring wells were installed in Basins 1 and 3 to help assess infiltration rates in the basins.

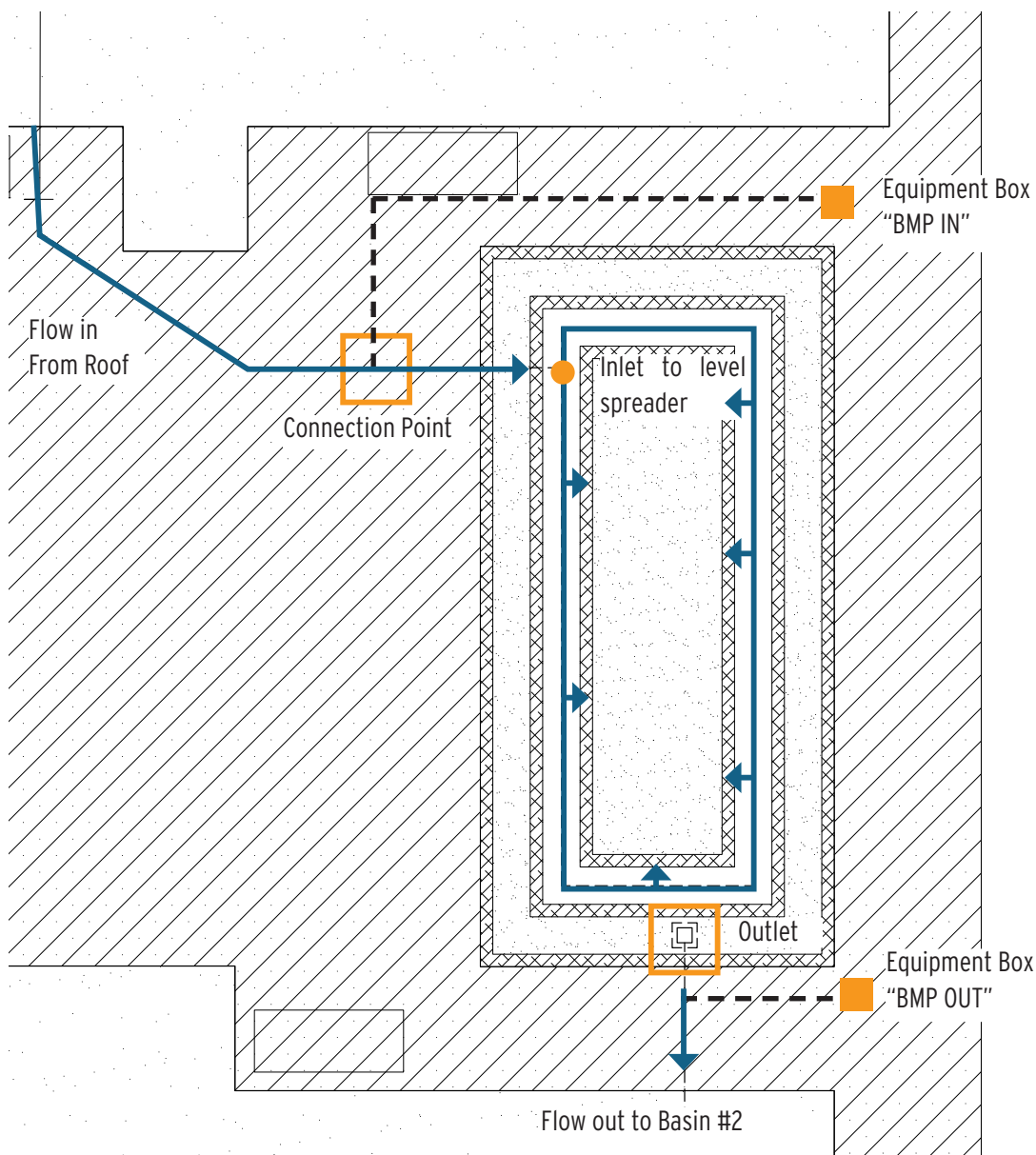


Figure 2.8 Basin #1 Monitoring Equipment

## PROJECT DETAILS

Figure 2.9 shows the inlet pipe into the level spreader. Runoff is distributed via a level spreader that distributes runoff equally around all sides of the basin. The two lower levels plus the three feet of engineered soils in Basin #1 hold approximately 872 CF of runoff. The water level monitoring well documented how water moved through the basin during and after each rain event.

Based on the design, the infiltration basin holds a 2.3 inch rain if totally full.

$$\frac{872 \text{ CF}}{7,000 \text{ SF Roof Area}} = 0.12 \text{ ft or } 1.44 \text{ inch Rain Event}$$

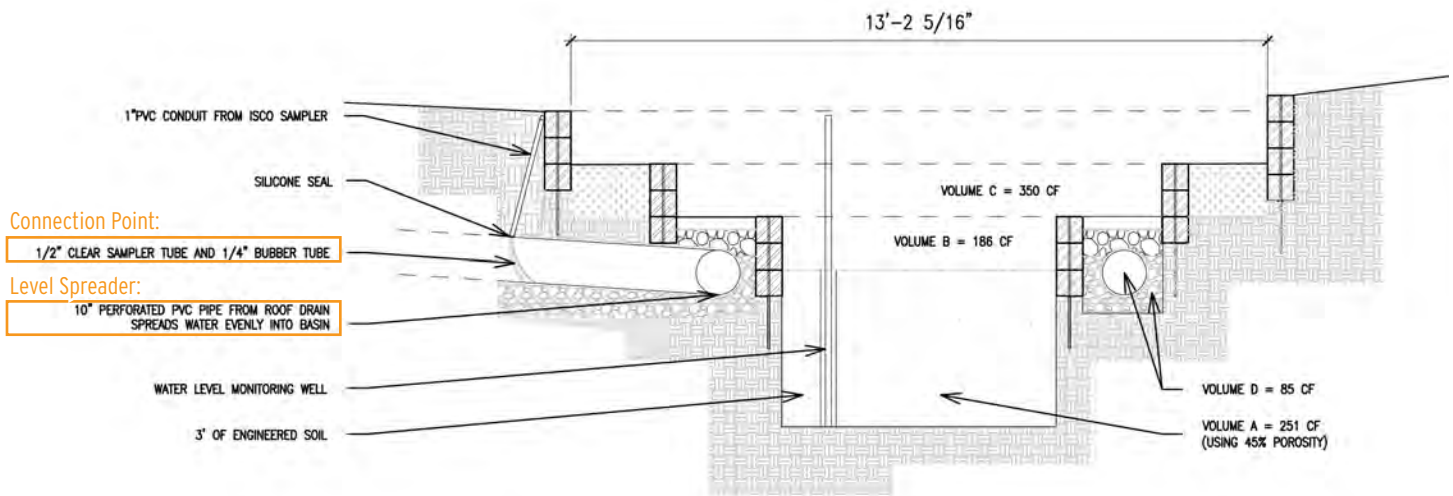


Figure 2.9 Basin Section



Figure 2.10 Installing the Inlet Connection Equipment



Figure 2.11 ISCO Collection System

## PRECIPITATION INVENTORY

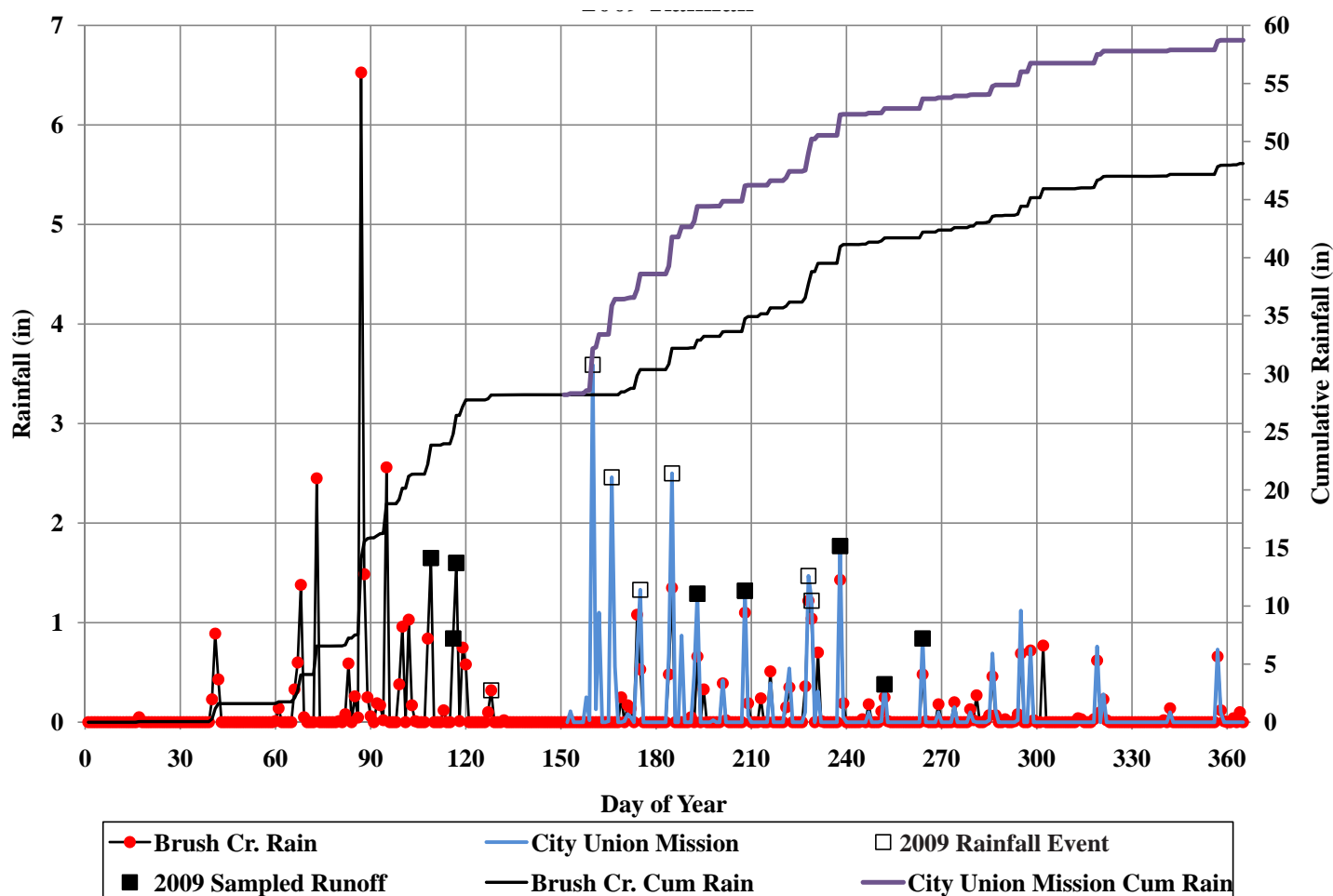


Figure 2.12 Precipitation Summary (2009)

## PRECIPITATION

The above chart shows the local precipitation and on-site monitoring data from 2009. Daily rainfall events and cumulative rainfall are shown. The closest local U.S. Geological Survey (USGS) precipitation monitoring site is about five miles away (called Brush Creek), which can account for the differences in cumulative rainfall. The largest rain event occurred near the end of March when the equipment was not yet installed. We were able to capture, however, 9 of the 15 rain events over the water quality storm event (1.37 inches, or 90%, of the average annual stormwater volume of all 24-hour storms). This rain data was compared to individual flow monitoring sites with the following results.

Of the 14 rain event samples during 2009 (see Table 2.4), one rain event was an outlet sample. Few outlet samples indicate that water rarely exits Basin #1. Field observations at the time of sampling indicate that the Basin #1 outlet sample may have been water backing up in the outlet pipe from Basin #2. (On this occasion basin #2 was full and stormwater could have been working its way back up the pipe.) Regardless of whether the sample was overflow or backflow, there was only one rain event that caused the monitoring equipment to sample outflow. This means that the basin materials and size allow sufficient water infiltration.



## MONITORING ANALYSIS

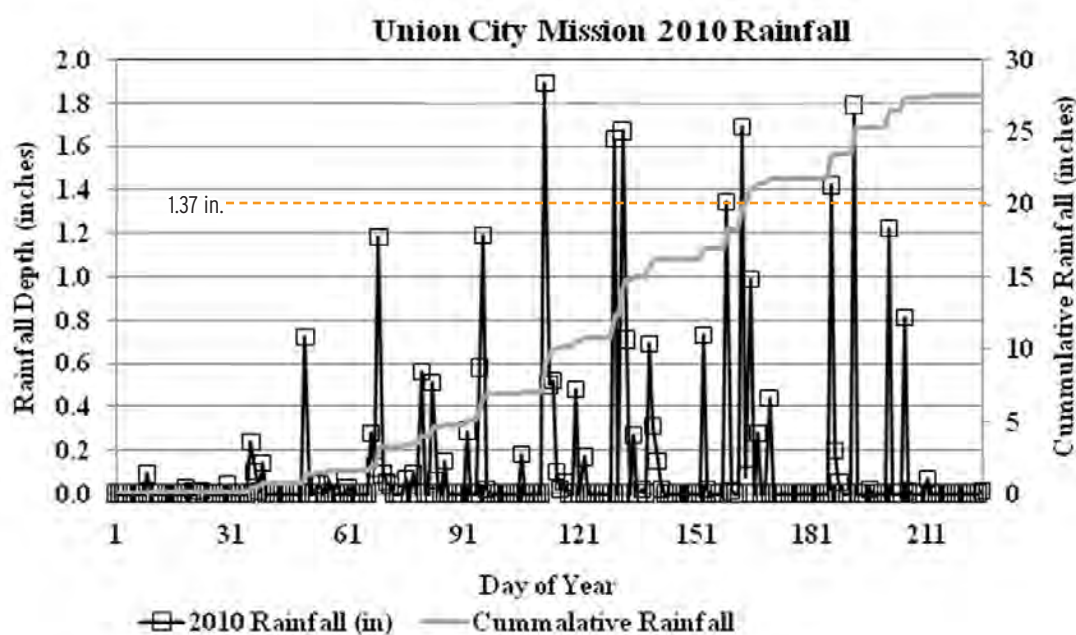


Figure 2.13 Precipitation Summary (2010)

In 2010, we had seven rain events larger than the water quality storm event (1.37 inches). The largest rain event was on 4/22 (day 112) at 1.89 inches. This followed a 15-day period without much precipitation. On 5/10, 5/12 and 5/13 (days 130-133), we received the most precipitation in a short period of time in 2010 (1.63, 1.67, and 0.71 inches respectively). This followed 9 days without much precipitation.

No outfall out of Basin #1 were recorded in 2010. All of the roof runoff was considered to be absorbed by the basin and surrounding soils.



## MONITORING ANALYSIS

### SOIL/INFILTRATION

#### SOIL TESTING

The engineered soil medium placed within each of the infiltration basins was created with a blend of topsoil, gravel and brick sand. The USDA classification is a “Sandy Loam” with a uniformity coefficient of 186.3. Samples of the soil mix were taken at the time of BMP installation, after the first year of monitoring (approximately 18 months after installation), and after the second year of monitoring (2010).

The actual USDA Particle Size Evaluation\* is as follows:

The actual USDA Particle Size Evaluation\* is as follows:

						TEXTURES			
Sample ID	Location	PH	Organic Matter % Dry Wt	ZN ppm	SO <sub>4</sub> -S ppm	Gravel 2.0 (10)	Sand 2.0 - 0.05 mm	Silt 0.05-0.002mm	Clay <0.002mm
2008 Results									
1	Cell 1 (Composite)	NR	2.28	NR	NR	10.1	58.1	29.3	12.6
2010 Results									
1	Cell 1 (0-6in)	7.4	3.00	8.4	13.4	NR	60.0	28.0	12.0
2	Cell 1 (6-12 in)	7.8	2.80	4.4	19.3	NR	60.0	26.0	14.0
3	Cell 1 (12-24 in)	7.9	3.30	6.5	23.4	NR	60.0	26.0	14.0
4	Cell 1 (24-36 in)	8.0	3.00	7.1	32.8	NR	64.0	24.0	12.0
5	Cell 1 Sub Soil	8.1	0.60	15.6	42.3	NR	18.0	56.0	26.0
6	Cell 3 (0-6in)	7.5	2.80	8.6	12.9	NR	55.0	29.0	16.0
7	Cell 3 (6-12 in)	7.7	3.40	3.8	20.4	NR	56.0	30.0	14.0
8	Cell 3 (12-24 in)	7.8	3.50	6.6	23.8	NR	52.0	30.0	18.0
9	Cell 3 (24-36 in)	8.0	3.40	7.3	34.6	NR	62.0	24.0	14.0
10	Cell 3 Sub Soil	8.0	1.20	14.7	39.7	NR	20.0	56.0	24.0
QC 1-1	Cell 1 (0-6in)	7.6	3.10	8.1	13.5	NR	NR	NR	NR

Table 2.1 Soil Test Results

\* Note: Gravel fraction was removed from the soil samples, then the particle size distribution was measured on the remaining fractions (per USDA testing protocol).

QC = Quality Check required by the EPA  
NR = Not Recorded

#### OBSERVATIONS

- The organic matter percentage increased after installation.
- There is a substantial change in soil texture between the 12-24 inch and 24-36 inch depth intervals, indicating the change from engineered to native soils.
- An infiltration test was conducted on the installed soil material yielding an infiltration rate of 0.6 inches per hour.
- SO<sub>4</sub>-S is sulfur as the sulfate form. Sulphur is an essential element for growing plants, being a component of plant proteins and having an important role in synthesis of chlorophyll. Levels between 4-10ppm are considered low; 10-20ppm are considered medium level; and 20-50ppm is considered high.

#### CONCLUSIONS

- Basin #1 and #3 subsoil has high silt and clay content. Consequently, the basins were expected to have a slow infiltration rate. However, the water infiltration documented with the water level monitoring wells show high infiltration rates. The low subsoil permeability and high infiltration rate suggest that water is infiltrating downward until it reaches the subsoil, and then infiltrating laterally through the timber walls and adjacent soils.
- Sulfur levels are normal in the engineered soil and elevated in the subsoils.
- Sand, silt and clay percentages did not change much. The organic matter percentage increased, likely due to plant root growth.

## SOIL/INFILTRATION

### BASIN #1 MONITORING RESULTS

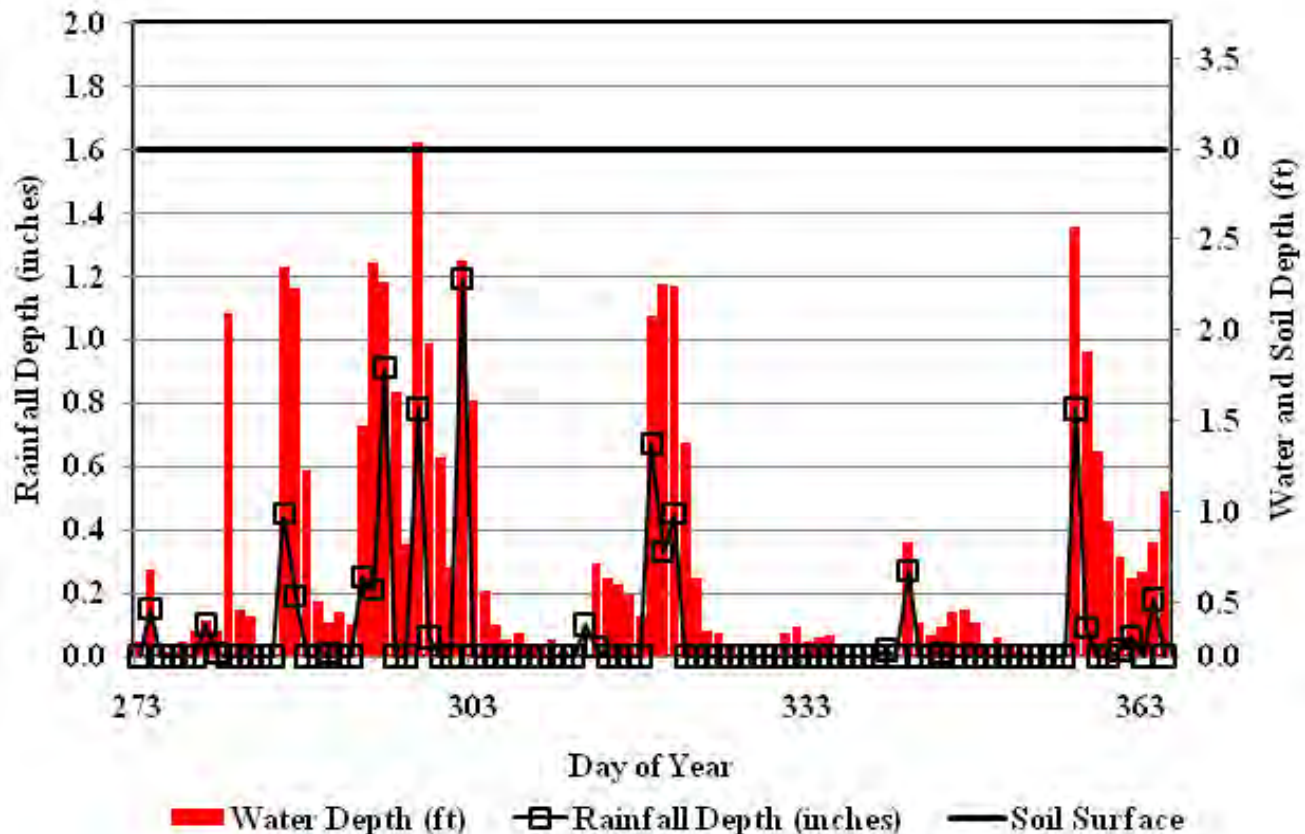


Figure 2.14 Basin #1 Rainfall, Soil and Water Depth Results (Fall 2009)

## SOIL INFILTRATION

Piezometers were added on September 29, 2009 (day 273) to the first and third infiltration basins (second half of the first monitoring year). Piezometers measure water level related to time. Figure 2.14 shows that the water level of Basin #1 was almost always eight inches or more from the soil surface. The water level reached the soil surface one time within the 90-day monitoring period in late 2009. This indicates that Basin #1 is effectively infiltrating and storing water.



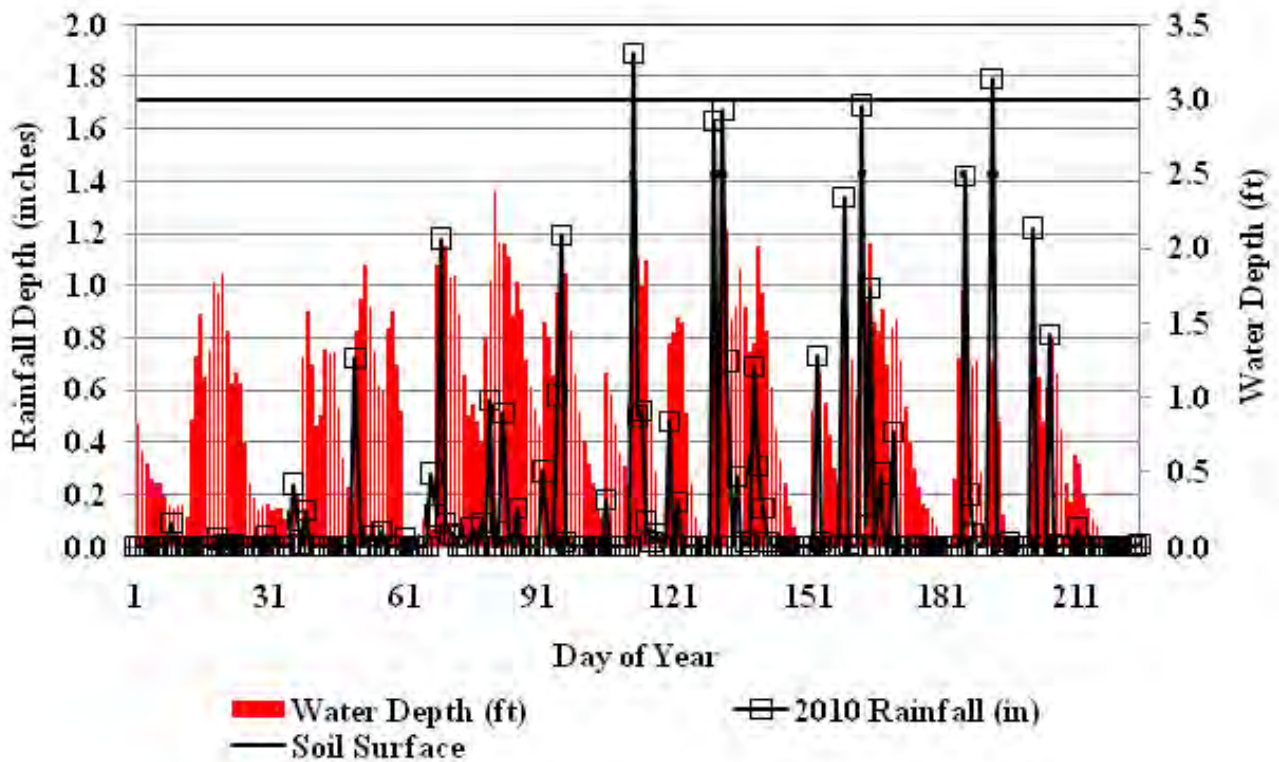


Figure 2.15 Basin #1 Soil and Water Depth Results (2010)

Figure 2.15 shows the elevation of water within Basin #1 (shown in red). Water Depth 3.0 feet represents the top elevation of the engineered soils or bottom of the basin. (The engineered soils were installed at three feet deep). According to the data, the basin did not have standing water in 2010. This is consistent with observations made by the building staff. In addition, the infiltration rate was estimated by how fast the red lines trend down from the peaks. In general, the basin was draining in 2010 at an average rate of .06 inches per hour (1.4 in. / day).

This estimated infiltration rate is consistent with what might normally be expected in soils with a high silt and clay content, such as were found beneath the infiltration basins. However, site observations suggest that water infiltrated much faster than

this rate. For example, as shown in Figure 2.15, water levels only extended above the soil surface during two storm events in 2010. This data indicates that the basin can sufficiently infiltrate and store water. Water is believed to be seeping laterally out of Basin #1 through permeable fill material at the site. The low infiltration rates may be representative of deeper native soils, but lateral infiltration through fill material may be occurring at higher water levels.

The project site was urban with development occurring for over 100 years. The site was previously developed with housing and a hotel prior to being cleared for many years. During excavation for the basin, brick, and fill materials was discovered. In addition, the downtown environment sits on a series of limestone shelves.

## SOIL/INFILTRATION

### BASIN #3 MONITORING RESULTS

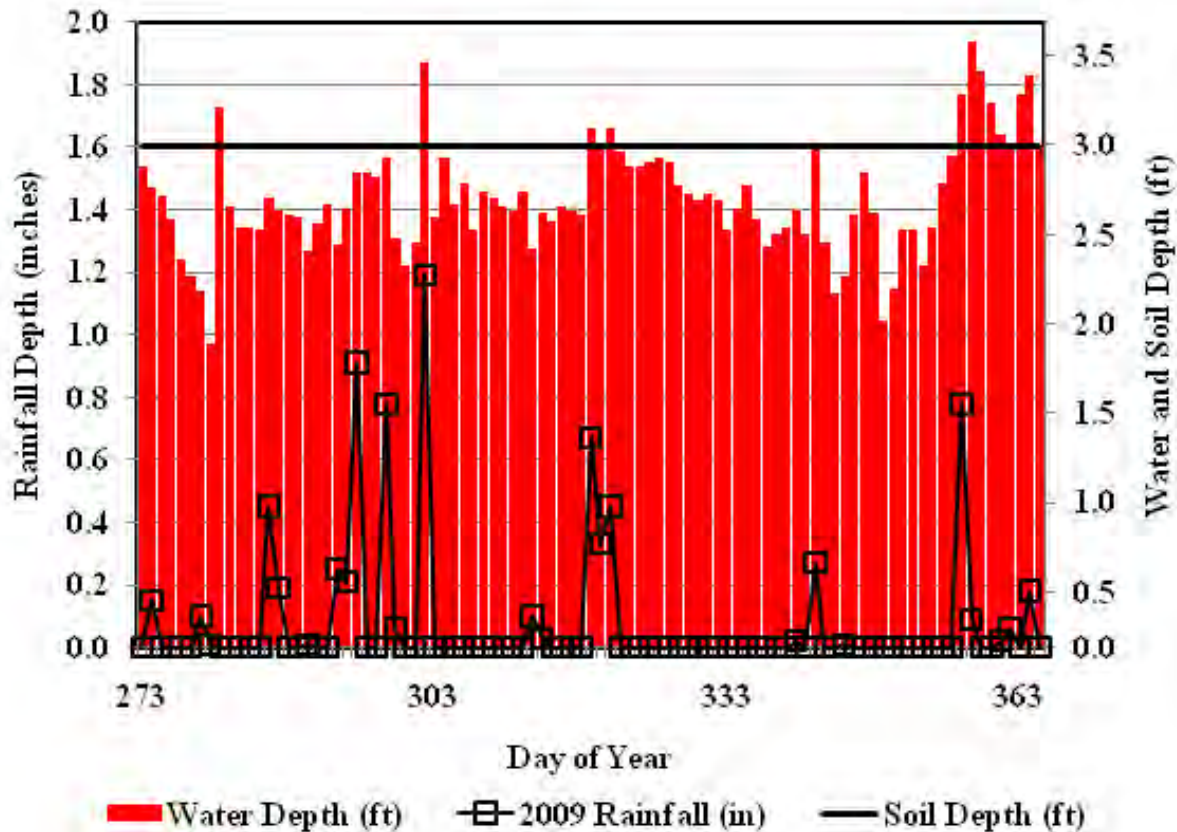


Figure 2.16 Basin #3 Rainfall, Soil and Water Depth Results (Fall 2009)

Figure 2.16 shows the elevation of water within Basin #3. The infiltration rate of Basin #3 in 2009 averaged 0.044 inches per hour (1.1 in/day). The infiltration rate in Basin #3 is slower than Basin #1. This estimated infiltration rate is consistent with expected rates for clayey soils and is likely representative of the deeper underlying soils. Site observations do suggest higher infiltration rates, given the limited number of outflow events from the basin. It is believed that at higher water levels water seeps laterally out of the basin, through the timber walls. The basin is placed in an exposed location adjacent to a sunny, southwest facing embankment. This may promote lateral exfiltration and evaporation of collected water into drier surrounding soils.

## MONITORING ANALYSIS

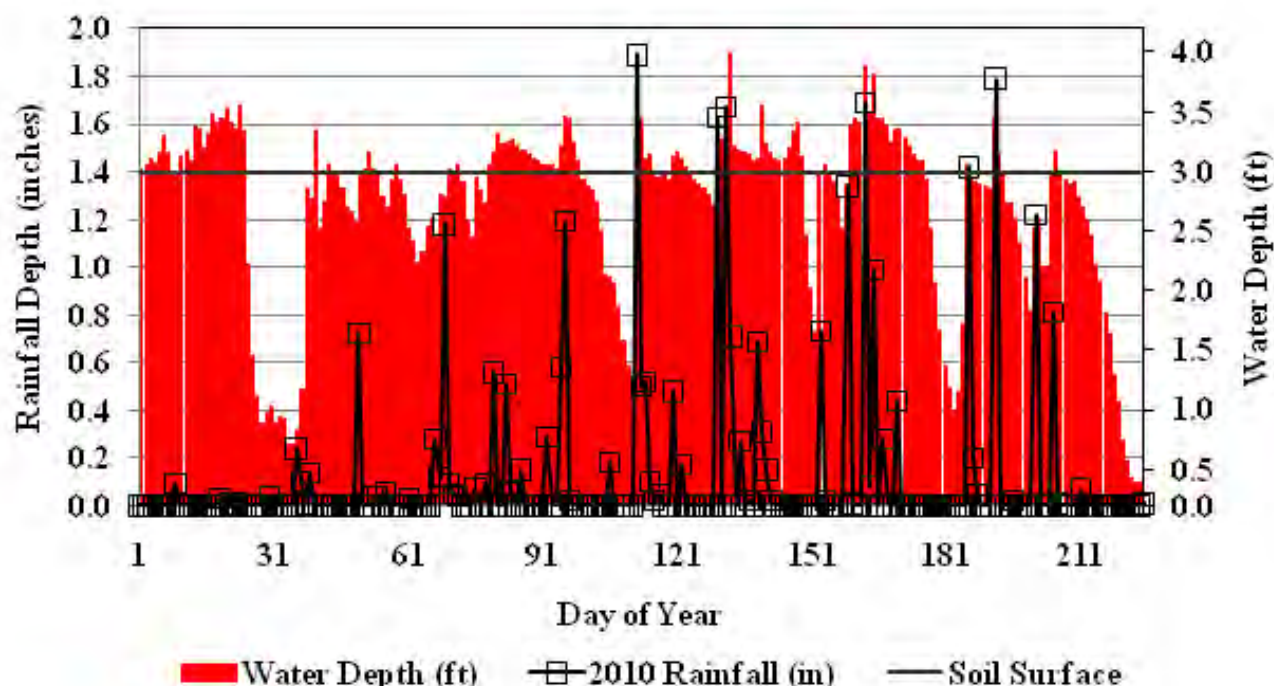


Figure 2.17 Basin #3 Soil and Water Depth Results (2010)

Figure 2.17 shows the elevation of water within Basin #3. The water elevation in 2010 trended near the top elevation of the engineered soils or bottom of basin with standing water regularly observed after rain events. This is consistent with observations made by the building staff. The infiltration rate in 2010 averaged 0.08 inches per hour (slightly higher than in 2009).

1-3/4 inches of excess water from basin #3 was removed on April 9th, 2010 (day 99) to promote growth of the cordgrass at the beginning of the growing season.

The three basins provide excellent flow volume retention and infiltration, which should also result in peak flow rate reductions.



## MONITORING ANALYSIS

### SOIL/INFILTRATION

Estimated Runoff Volume for City Union Mission Cell No. 1				
Event	Date	Rain Depth (in)	Rain Depth (ft)	Flow Volume (ft <sup>3</sup> )
1	3/24/10	0.56	0.047	327
	3/27/10	0.57	0.048	333
2	4/2/10	0.29	0.024	169
	4/6/10	0.58	0.048	338
	4/6/10	1.19	0.099	694
3	4/22/10	1.89	0.158	1103
	4/24/10	0.50	0.042	292
	4/24/10	0.52	0.043	303
4	5/10/10	1.63	0.136	951
	5/12/10	1.67	0.139	974
	5/13/10	0.71	0.059	414
	5/19/10	0.69	0.058	403
5	6/2/10	0.73	0.061	426
6	6/8/10	1.34	0.112	782
7	6/12/10	1.69	0.141	986
	6/14/10	0.99	0.083	578
8	7/5/10	1.42	0.118	828
9	7/11/10	1.79	0.149	1044
10	7/20/10	1.22	0.102	712
	7/24/10	0.81	0.068	473

Table 2.2 Basin 1: Estimated Runoff Volumes and Water Depths in Basin

The infiltration rates in Basin #1 were higher than expected, so we compared calculated runoff flow volumes generated from the roof area (7,000 SF) compared to documented flow rates. As shown, the estimated volume of water within the basin (shown in blue) was higher than storage capacity at 872 CF. According to this calculation, we should have had standing water more frequently and overflows occurring 5 of 20 times in 2010.

### CONCLUSION

- The data shows that Basin #1 was constructed to handle the water quality storm event (1.37 inches) without outfall.
- Because of the pre-existing conditions and construction debris such as bricks, the basin is infiltrating faster than expected.



## VEGETATION

Vegetation was selected for its ability to withstand wet weather, drought, and short periods of ponding. The basins were planted with a simple plant palette of *Spartina pectinata* (prairie cordgrass), *Sporobolus heterolepis* (prairie dropseed), and *Lobelia cardinalis* (cardinal flower). Prairie Cordgrass was planted in the lower section of the basin. Its tolerance of wet conditions made it a suitable plant for the basin bottom. Prairie Dropseed was planted on higher elevations because of its preferred drier conditions (Figure 2.20).

As documented in Figure 2.18, the Prairie Cordgrass root system reached 30 inches deep after three growing seasons within Basin #1 (6 inches above the bottom of the basin engineered soils). The root growth within Basin #3 was slower, which could be associated with available water. Since basin #1 was drier with less periods of standing water, the root growth was more prolific. In addition, the infiltration rates were higher. As the roots grow in basin #3, the infiltration rate is expected to improve.

## CONCLUSION

- Prairie Cordgrass has proved to be a great performer as well as adapted to the wet zone of the basins.
- The cardinal flower was difficult to establish. A different plant material should be considered.



Figure 2.18 Prairie Cordgrass Root System



Figure 2.19 Vegetation after One Growing Season



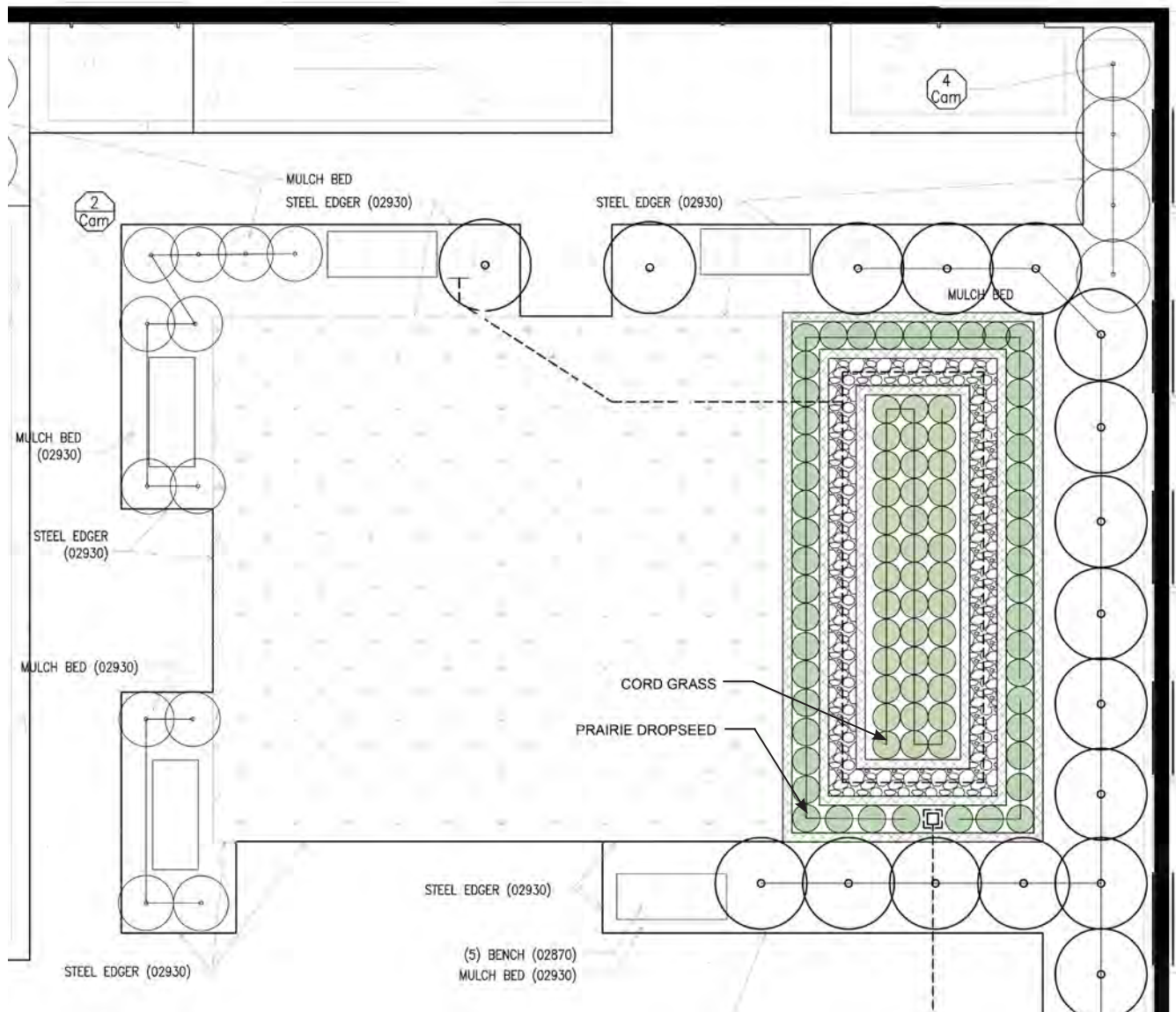


Figure 2.20 Planting Plan

## WATER QUANTITY

## SOIL MOISTURE

Figure 2.21 shows the soil moisture within Basin #1. Eight soil cores were taken over the course of 2010. Samples were collected every 12 inches for the full 3 feet of engineered soil. A composite soil moisture test was conducted (as shown by the black boxes). The black horizontal line (shown at 6 inches) represents soil moisture at 1/3 bar (not quite full saturation). The blue line represents the results from the Modified Penman Equation. This equation estimates the amount of water available for grasses. The equation takes into account temperature, humidity, wind speed, rainfall, and solar radiation (components of evapotranspiration). As the blue line nears the 1/3 bar (shown as the thickened line at 6 inches), the basin is considered saturated, and runoff is expected.

## CONCLUSION

- In 2010 we could have anticipated about 2 periods of standing water within the basin (shortly after rain events on 5/12 and 6/12). According to the monitoring well data, this did not occur, nor were any outflows from Basin #1 observed. This is likely due to lateral filtration of water to fill material around the basin.
- The moisture levels were consistent throughout the year. In general, the soil held moisture nicely providing a good growing environment. Conditions were seldom near the wilting point nor overly saturated.

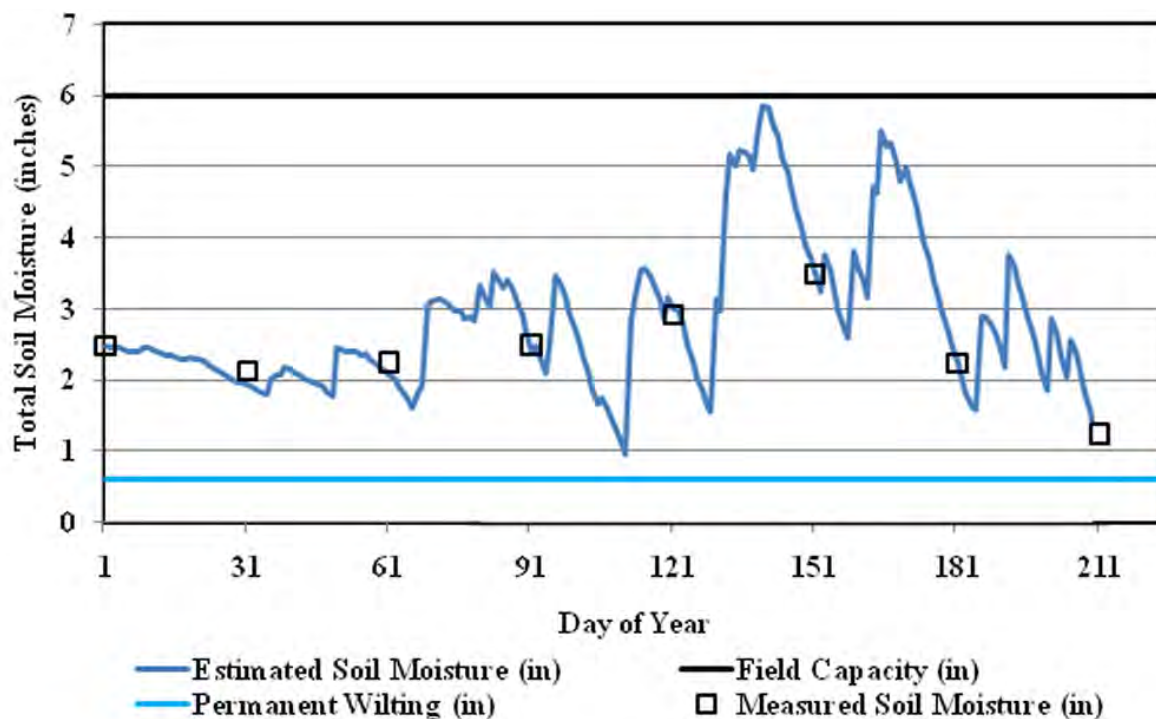


Figure 2.21 Basin #1 Soil Moisture (2010)

## WATER QUALITY

City Union Mission Flow 'In'								
Date	Flow Vol.	Precip (in)	TN ppm	TP ppm	Zn ppm	Cl ppm	S ppm	TSS
4/19/2009	226.4	1.7	2.0	0.03	0.02	2.5	ND	ND
4/27/2009	348.3	2.4	0.9	ND	1.36	1.3	ND	ND
5/8/2009	21.1	0.3	No Sample					
7/12/2009	221.3	1.3	0.9	0.04	ND	1.2	ND	15
7/27/2009	226.4	1.3	0.5	0.02	ND	0.7	ND	6
8/17/2009	170.4	1.2	No Sample					
8/26/2009	207.5	1.8	0.9	ND	0.02	0.1	ND	ND
9/9/2009	54.3	0.4	ND	ND	0.03	1.5	ND	ND
9/21/2009	153.7	0.8	0.6	0.02	0.03	1.6	ND	ND

Table 2.3 Basin #1 Flow "In" Water Quality (2009)

City Union Mission Flow 'Out'								
Date	Flow Vol.	Precip (in)	TN ppm	TP ppm	Zn ppm	Cl ppm	S ppm	TSS
4/27/2009	38.4	2.44	2.2	1.13	ND	1.3	0.9	11

Table 2.4 Basin #1 Flow "Out" Water Quality (2009)

### Legend

Rain (in)  
 Flow Vol. (ft<sup>3</sup>)  
 TN Total Nitrogen (ppm)  
 TP Total Phosphorus (ppm)  
 Zn Zinc (ppm)  
 Cl Chlorides (ppm)  
 S Sulfur (ppm)  
 TSS Total Suspended Solids (mg/l)  
 ND = Not detectable (less than .01 mg/l Zn, S, Cl, TN and TP)  
 ppm = parts-per-million (equal to mg/l)

### CONCLUSIONS:

- The flow volumes out of Basin #1 were significantly less than the flows into the basin. In fact, only one outflow event was recorded, indicating that the basin significantly reduced stormwater flows from the site.
- The monitoring results from the one discharge event indicated that during large flows it may be possible for runoff to export TN, TP, S, and TSS from the basin. However, the field staff conducting the sampling observed that water may have been backed up in the discharge pipe from the next downstream basin, so the results are somewhat suspect. It does appear that heavy metals such as Zn were retained in the basin.

## MONITORING ANALYSIS

### WATER QUALITY

City Union Mission Basin 1 Water Quality Inflow [Concentration]							
Date	Event	Total N (mg/L)	Total P (mg/L)	Zn (mg/L)	Cl (mg/L)	S (mg/L)	TSS (mg/L)
3/24 - 3/27/2010	1	1.61	0.07	0.02	0.15	1.13	12
4/2 - 4/6/2010	2	1.01	0.02	0.01	0.34	0.16	58
4/22 - 4/24/2010	3	1.12	0.05	0.03	0.39	0.54	62
5/10 - 5/19/2010	4	0.67	0.03	0.01	0.16	0.04	39
6/2/2010	5	0.56	0.04	0.04	0.21	0.11	44
6/8/2010	6	0.67	0.04	0.02	0.17	0.12	57
6/12 - 6/14/2010	7	0.51	0.05	0.03	0.64	0.23	41
7/5/2010	8	0.34	0.05	ND	1.1	0.33	32
7/11/2010	9	0.89	0.08	0.03	0.73	0.48	69
7/20 - 7/24/2010	10	0.91	0.07	0.04	0.79	0.16	52

Table 2.5 Basin #1 Water Quality in mg/L(2010)

City Union Mission Basin 1 Water Quality Inflow [Mass]							
Date	Event	Total N (lb)	Total P (lb)	Zn (lb)	Cl (lb)	S (lb)	TSS (lb)
3/24 - 3/27/2010	1	0.033	0.001	0.000	0.003	0.023	0.24
4/2 - 4/6/2010	2	0.025	0.000	0.000	0.008	0.004	1.42
4/22 - 4/24/2010	3	0.039	0.002	0.001	0.013	0.019	2.14
5/10 - 5/19/2010	4	0.028	0.001	0.000	0.007	0.002	1.63
6/2/2010	5	0.015	0.001	0.001	0.005	0.003	1.14
6/8/2010	6	0.032	0.002	0.001	0.008	0.006	2.72
6/12 - 6/14/2010	7	0.024	0.002	0.001	0.030	0.011	1.96
7/5/2010	8	0.017	0.003	ND	0.056	0.017	1.62
7/11/2010	9	0.057	0.005	0.002	0.047	0.031	4.40
7/20 - 7/24/2010	10	0.033	0.003	0.001	0.029	0.006	1.88

Table 2.6 Basin #1 Water Quality in total lb (2010)

#### Legend

- Rain (in)
- Flow Vol. (ft3)
- TN total nitrogen (mg/l)
- TP total Phosphorus (mg/l)
- Zn zinc (mg/l)
- Cl chlorides (mg/l)
- S sulfur (mg/l)
- TSS total suspended solids (mg/l)
- ND = Not detectable (less than .01 mg/l Zn, S, Cl, TN and TP)
- N/A = Not Applicable

Table 2.6 shows the same data as Table 2.5 converted to total pounds of pollutant. The pollutants from the roof were relatively modest, but because of the 100% infiltration in 2010, all were removed from the stormwater runoff.

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## MONITORING ANALYSIS

### MAINTENANCE

- Weeding: Weeding operations occurred twice during the growing season. The cordgrass within the bottom of the planters established well and out-competed the weeds. A few stems of Johnson Grass were observed and mechanically removed. Additional spreading weeds and clover were observed within the Prairie Dropseed planter zone in Basins #1 and #2. Within the Cardinal Flower planting area in Basin #3, the most weeds were observed. This plant species spreads slowly. Weeding was required monthly in this zone.
- Chemicals: No chemicals or pre-emergent was needed.
- Irrigation: No supplemental watering was provided.
- Pumping: 1-3/4 inches of excess water from Basin #3 was removed on April 9th, 2010 to promote growth of the Cordgrass at the beginning of the growing season.
- Mulch: No hardwood or mineral mulch was applied.
- Sedimentation: Sediment accumulation is minimal. Establishment of adjacent landscape material (at Basins #1 and #2) and erosion filter sock around Basin #3 was important. The filter sock was removed at the end of 2010 with the establishment of the adjacent landscaped area.

## CONCLUSIONS

### COST TO BENEFIT ANALYSIS

- A typical detention pond to manage stormwater runoff from a 15,000-square foot building may cost approximately \$40,000 to \$50,000. In many regions, water quality BMPs are required in addition to detention ponds. The cost of the three infiltration basins at this site was \$72,000. Monitoring at this site indicates that infiltration basins have the potential to reduce runoff volumes in addition to filtering pollutants, which could help to reduce the size, and hence cost, of required detention ponds.
- The basins are creatively incorporated into the courtyard and surrounding landscape adjacent to building entries showcasing the on-site stormwater management strategies. Integrating stormwater controls into site landscaping provides additional opportunities to reduce overall site costs.



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## LESSONS LEARNED

- Site characterization is an important part of BMP design. The bricks and porous fill material at Basin #1 could have been a problem if the building had a basement, by providing a preferential pathway for water movement into the building. It was not an issue here because of the building design, but provides a good reminder for other sites.
- Organic material added to the soil mix helped maintain soil moisture during dry periods.
- Plant selection is important. Each BMP is different, so plants should be matched to the soil and water conditions created at each site.
- Some plants grow very deep root systems which helps BMP performance as plants mature. Infiltration rates into soils are expected to improve over time as the roots grow larger and deeper.
- The planters were built with simple materials for low cost, yet they look quite nice and fit the surroundings. All BMPs do not have to be expensive.
- The greatest benefit of the BMPs at this site is reducing the amount of stormwater runoff that leaves the site. The site is located in an urban neighborhood of Kansas City, and the BMPs help reduce flows to the local sewer system. In this location, the water quantity benefits of BMPs are more important than the water quality benefits. Design objectives will be different at every site, and the BMP designs can be customized to the site-specific objectives.

## INFILTRATION BASIN DESIGN RECOMMENDATIONS

- It is very important to complete soil testing prior to installation. Testing and observation of excavation will inform the design. Site characteristics such as fill material and drainage are important to the success of the BMP.
- Use level spreaders. The use of a level spreader helps prevent incoming flow velocities from reaching erosive levels.
- During vegetation establishment, protect BMP structures from receiving sediment runoff. Some siltation was observed in Basin #3 that required hand removal of sediment. This likely happened because the BMP structure was not protected during and following construction. Without total replacement of rock and soils, the basin will always infiltrate a little slower than the other basins.
- Consider the planned microclimate, wetness zone, aesthetics, and weed control when selecting plants. Plant selection is very important.
- Plant slow growing species such as *Lobelia cardinalis* (cardinal flower) in combination with other plant materials. When planted with species that establish quickly, the planter bed will be less likely to be overcome by weeds.
- The typical design standard calls for a recommended 3:1 maximum side slope. The designer created a smaller footprint by installing small walls made out of treated lumber. The height of the walls at City Union Mission were maintained at a maximum of 18 inches to provide easy access and better public safety.
- A variance from most BMP Design Standard, a length-to-width ratio of 3:1 or greater is not required if you integrate a level spreader to dissipate flow and velocity.
- Grade the bottom of the basin flat to provide uniform ponding.
- Provide a maximum water depth of 1 to 2 ft to promote the survival of vegetation. Few plant species will tolerate greater ponding depths plus drying between storm events.
- Create an emergency spillway capable of passing runoff from larger storms without damage to adjacent structures. An overflow drain was installed in Basins #1 and #2, and the site (especially the interior courtyard) was graded to overflow away from the structures (out of the interior courtyard).
- A forebay was not needed here due to low sediment loads from the roof.





# Applebee's Courtyard Rain Garden

USGBC | BNIM | URS | KANSAS STATE UNIVERSITY. | 40

## INTRODUCTION + OVERVIEW

### RAINGARDENS

#### GENERAL APPLICATION

Raingardens typically improve water quality by collecting the first flush of stormwater runoff in a shallow pond (typically about 4"-8" holding capacity) and allowing it into infiltrate in the ground. Raingardens are fairly inexpensive and do not have specialty soils nor subdrainage piping. They are intended to drain down in 24-48 hours.

#### ADVANTAGES

- The runoff volume from the roof will be reduced as the water is infiltrated, evaporated, and transpired.
- The runoff rate from the roof to the outlet will be slowed. This time of concentration will reduce the potential for downstream flooding and stream bank erosion.
- Nationally, some jurisdictions require that the post-development runoff cannot exceed the pre-development peak flow rate. If designed appropriately, raingardens can help reduce the detention requirements for individual sites. Raingardens do not just clean runoff, but they can reduce the quantity of runoff.

### APPLEBEE'S COURTYARD RAINGARDEN

#### DESIGN INTENT

Applebee's Courtyard raingardens were integrated into the entire courtyard design. The raingardens are oriented as long narrow swales, filtering water as it runs down the planted swales towards the outlet structure. The raingardens have a large pervious zone and are heavily planted with wet-mesic plants to maximize infiltration and transpiration. The raingarden functions not only to clean runoff from each rain event, but also as a public amenity. The Applebee's courtyard raingarden is designed to create beautiful public space for people to enjoy and engage in informal business meetings. The raingarden manages stormwater well and helps create an outdoor environment for people to enjoy.

#### MONITORING GOALS

- Define the appropriate ratio of raingarden area compared to the size of watershed (The drainage area of the roof).
- Determine the size of rainfall event when runoff will occur.

#### MONITORING CONCERNS

Monitoring Concerns: 1) The courtyard is typically irrigated. 2) There are four roof downspouts, and thus, we will not be able to measure inflow hydrographs at all inlet flows (due to limited equipment); however, we should be able to calculate total runoff volumes from the roof drainage area. 3) The raingarden design acts like a bioswale with little holding capacity, but the design encourages substantial infiltration and evapo-transpiration opportunities.



Figure 3.1 Courtyard to be Monitored

## INTRODUCTION + OVERVIEW

### MONITORING OVERVIEW



#### SOIL / INFILTRATION

The design with long, nearly flat raingardens provides good infiltration rates, but does not provide much storage capacity. The raingarden does not have enough holding capacity to capture a 1.37" storm event. Although undersized for storage capacity, the garden is not washing out due to the distribution of water, swale size, use of rock, and native vegetation. If the BMP was dry then there was about thirty-eight minutes before runoff occurred from courtyard. The raingardens can infiltrate about 1/3 inch rain event.

#### VEGETATION

Except for the *Equisetum hyemale* (horsetail) which was planted in a shady corner, all of the plants within the raingardens established well including Tussock sedge, Blue lobelia, Cardinal flower, Karl Foerster feather reed grass, Brown-eyed Susan, Two row Stonecrop sedum, and bamboo). The bamboo is spreading as expected within the east/west raingarden. Protected with a sidewalk on one side and concrete curb on the other, this plant species is establishing well. As expected, bamboo planted within Plant Hardiness Zones 5a/5b, have issues with winter tip freeze.

#### WATER QUANTITY

This courtyard has minimal storage capacity; however it was observed that rain events of 1/3 inch or less do not reach the outlet structure.

#### WATER QUALITY

The raingarden did not show significant pollutant removal rates, and in some cases exported some constituents, although at fairly low levels. This is likely due to being undersized.

The contaminant loading off the roof was low:

Total Nitrogen (TN):	2.5 ppm
Total Phosphorus (TP):	0.2 ppm
Total Suspended Solids (TSS):	40.3 mg/l

The raingarden was successful in extracting soil nutrients from runoff:

56% Reduction of TN  
50% Reduction of TP

The raingarden exported Chloride (Cl), Sulfur (S) and Total Suspended Solids (TSS)

#### MAINTENANCE

- Weeds: Weed grass is very minimal. Some cattails have tried to establish and required pulling. Jute netting (which was installed as an erosion control blanket) was successful in reducing erosion during the establishment period.
- Irrigation: The irrigation system ran in 2009 but was disengaged during 2010 growing season.
- Mulch: Mulch was observed clogging the outlet grate during some larger rain events and was not applied in 2010.



PROJECT DETAILS

PROJECT DESCRIPTION

The Applebee’s Restaurant Support Center was designed to house more than 500 associates that provide assistance to approximately 2,000 Applebee’s Restaurants worldwide. The Center’s design responds directly to the needs of Applebee’s Services, Inc. with a focus on associate satisfaction, productivity, food innovation, and development of the land and facility in ways that minimize negative environmental impact. The project received a LEED Silver Certification by the USGBC in 2008.

The two-story building is nestled into the sloped terrain and organized along a curved circulation system - with public entries above on a prairie level and private access below at lake level. Four open-office wings extend out from the circulation spine like “fingers,” and are separated by three atria and exterior landscaped courtyards that connect down to the lake and trail system. The courtyards each have a unique design and extend the uses in each atrium. To showcase the company’s focus, the Culinary Center is located on center stage directly off of the main entry in the first grand atrium. The building enclosure is energy efficient with increased thermal insulation and reflective roofing materials.

The restorative site design incorporates native landscape with water-efficient and low-maintenance prairie grasses, wildflowers, and storm water BMPs. Stormwater management is an integral part of the site design. All on-site stormwater, as well as a percentage of off-site water, is either absorbed or routed and cleaned within a treatment train of BMPs that include native vegetated swales, raingardens, rock sediment forebay, a sand filter, and a wetland prior to reaching the existing neighboring lakes. Each of the courtyards includes a series of raingardens that treat roof runoff.



Figure 3.2 Applebee's Support Center Context Map

APPLEBEE'S SUPPORT CENTER	
Land Use and Owner Description	Applebee's International, Inc.
Completed	2007
Address	11202 Renner Blvd, Lenexa, KS
Location in Watershed	Near bottom of watershed, approx. elev. 1033 MSL
Site Area	30.72 Acre, 610 Parking Stalls
Building Area	178,000 Square Feet Building
Building Use	Office
LEED Certification	Silver
Cost of Construction	\$29.8 Million for Building and Site
Cost of Raingardens	\$9,000
Materials	Native soils, jute netting and plantings
Plants	Tussock Sedge, Blue Lobelia, Cardinal Flower, Karl Foerster Feather Reed Grass, Native Bamboo, Etc
Roof Area to Raingardens	15,750 Square Feet
Surface Area of Captured Volume when full	1,266 Square Feet
Infiltration Surface Area	1,266 Square Feet

Table 3.1 Project Overview



## PROJECT DETAILS

### STORMWATER SYSTEM DESCRIPTION

The third (southern) courtyard was selected for stormwater monitoring. Figure 3.4 illustrates the layout of the raingardens in relationship to the courtyard design. Roof runoff from four downspouts runs through a series of interconnected linear raingardens across the courtyard to the north and then east toward the outlet grate. The courtyard provides three intimate gathering areas for outdoor meetings, each separated by a berm with native ornamental grasses. The raingardens are an integral component of the courtyard landscaping, and they serve an important role in cleaning the runoff before it is directed to the storm sewer system.

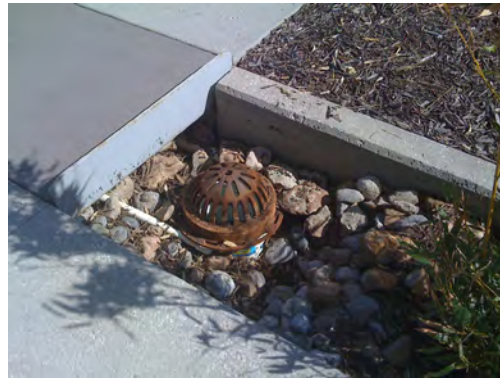


Figure 3.3 Outlet Sampling Location



Figure 3.4 Raingarden Layout

## PROJECT DETAILS

### STORMWATER SYSTEM DESCRIPTION

Runoff from the roof is collected in four roof drains, which then directs water flow into the raingardens. The blue area in Figure 3.5 represents the roof area draining to the courtyard. Water flows north through the linear raingardens, and then east towards the outlet grate (Figure 3.5). Two ISCO monitoring stations are installed. The "Courtyard In" monitoring station measures runoff from one of the roof gutters before the water is cleansed through the raingarden. The "Courtyard Out" monitoring station measures runoff that has flowed through the series of linear raingardens.

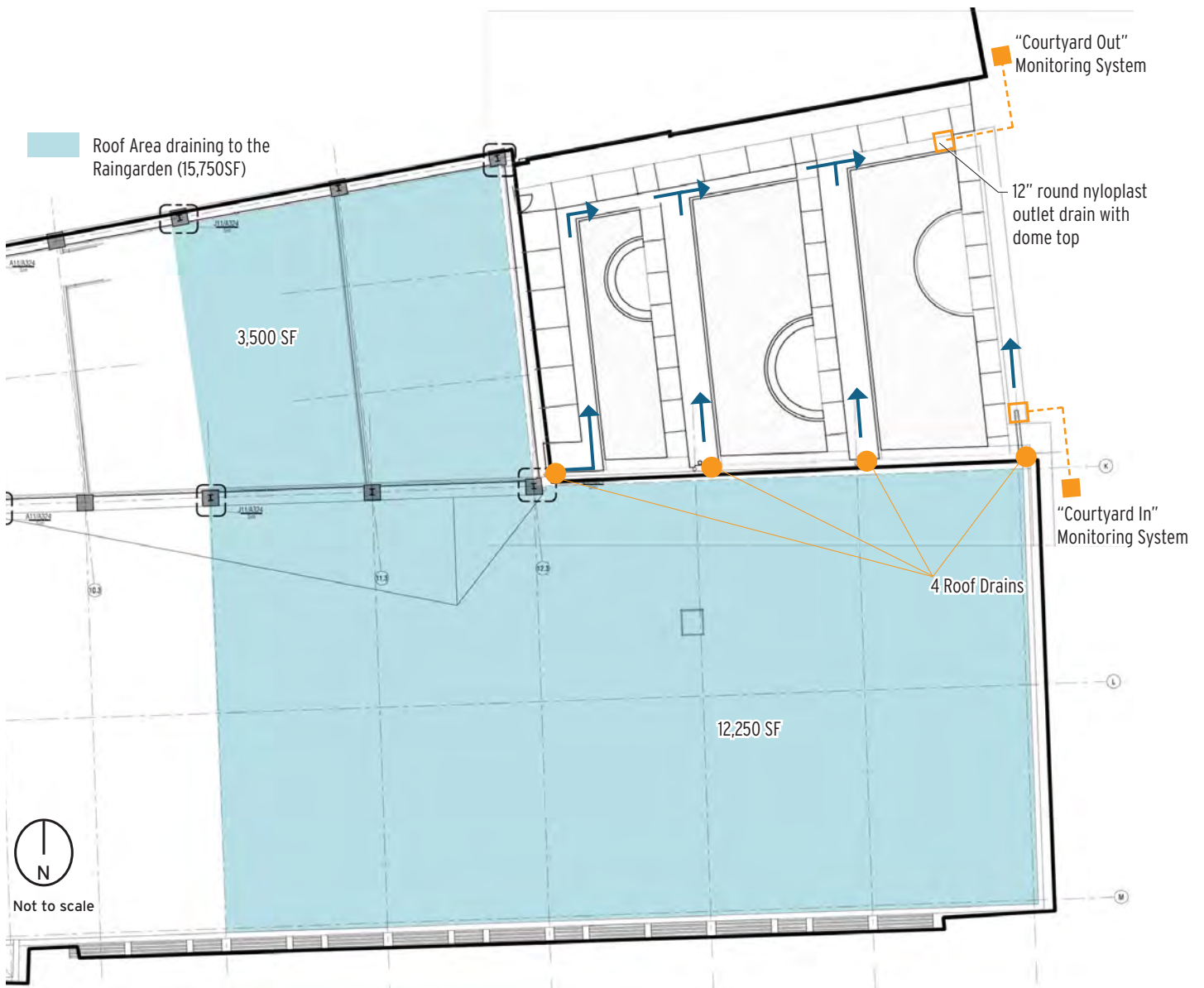


Figure 3.5 Water Flow Diagram

## PROJECT DETAILS

### STORMWATER SYSTEM DESCRIPTION

This site drainage within the courtyard demonstrates cost-effective site design approaches. For example, there are no underdrains or engineered soils. Figure 3.7 illustrates a typical section of the sidewalk adjacent to the depressed raingarden and the landscape berm. The raingarden is planted with a mix of native Kansas plants and cultivars in 8-inches of planting soil mix. The linear raingardens are graded to let water flow without using underdrains. Figure 3.6 shows one instance of how the raingarden allows water flow under the sidewalk.

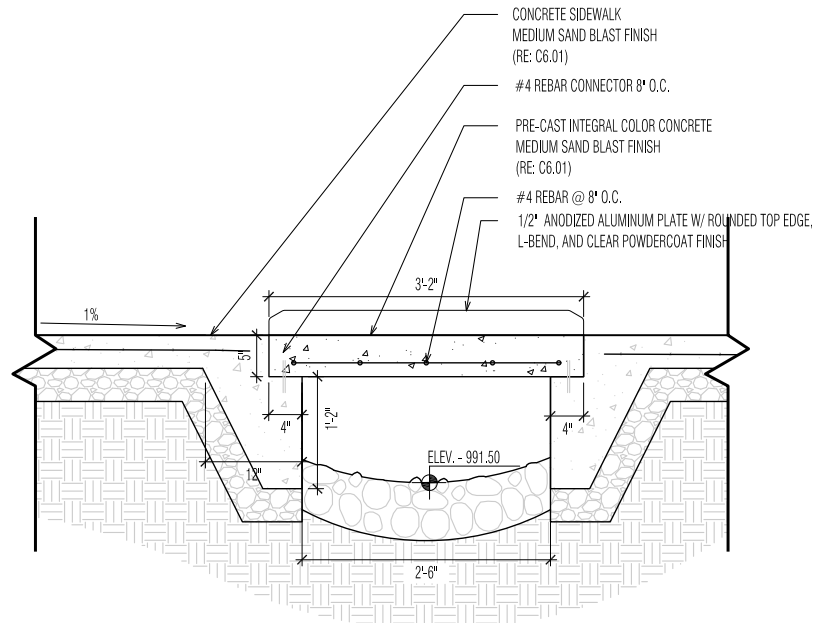


Figure 3.6 Sidewalk Span Over Raingarden Section

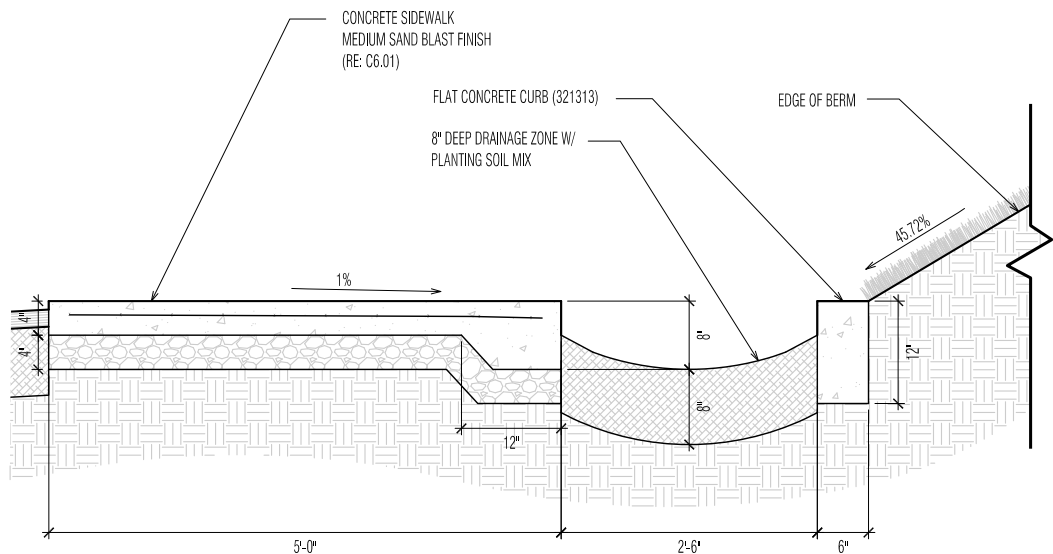


Figure 3.7 Pavement and Raingarden Section

### PRECIPITATION INVENTORY

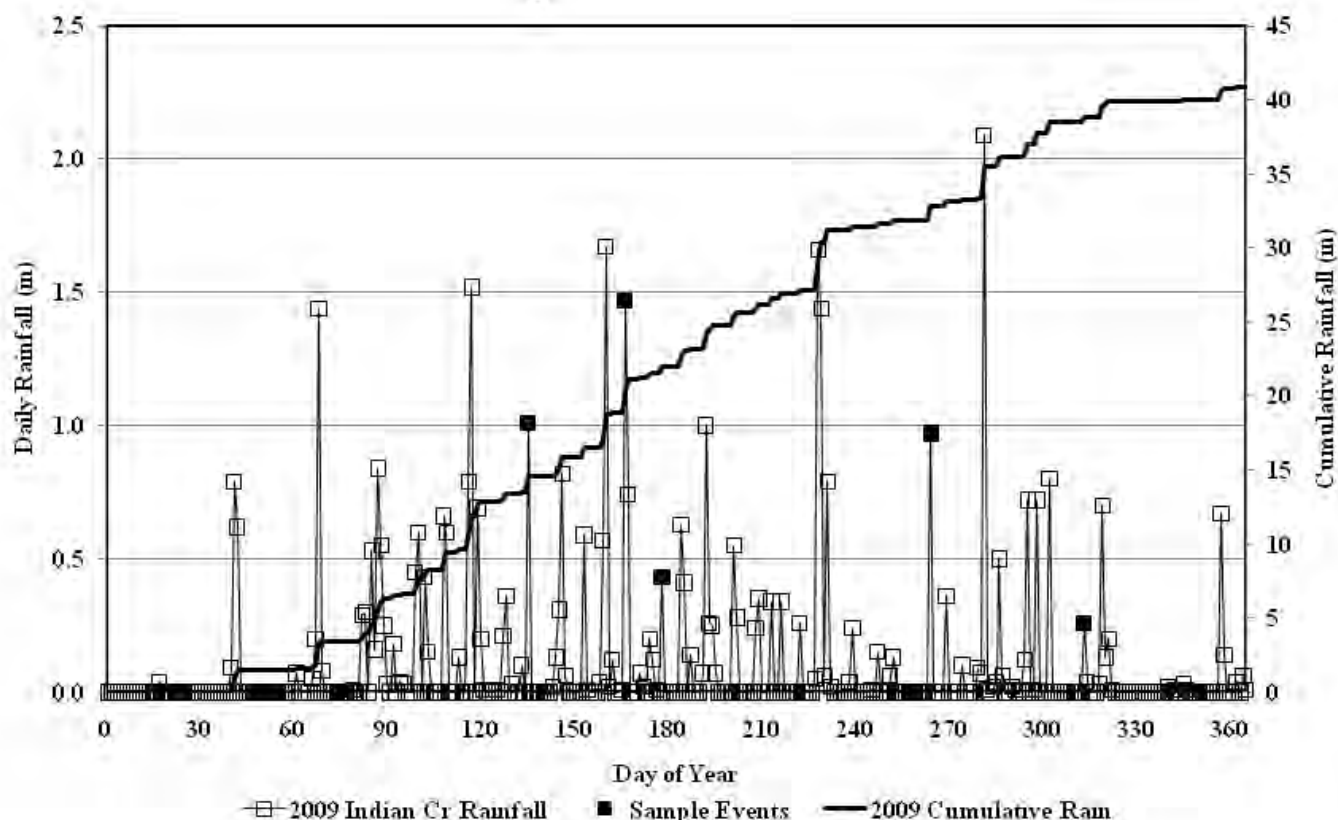


Figure 3.8 Precipitation Summary (2009)

### PRECIPITATION

The above figure shows the local precipitation and on-site monitoring data for 2009 sampled events. The equipment was installed on May 14th (Day 134). In 2009 we had 5 rain events larger than the water quality storm event (1.37-inches or 90% of the average annual stormwater volume of all 24-hour storms). We were able to capture 5 rain events following a variety of different storm sizes. The cumulative rainfall recorded at the Applebee's site is also shown.

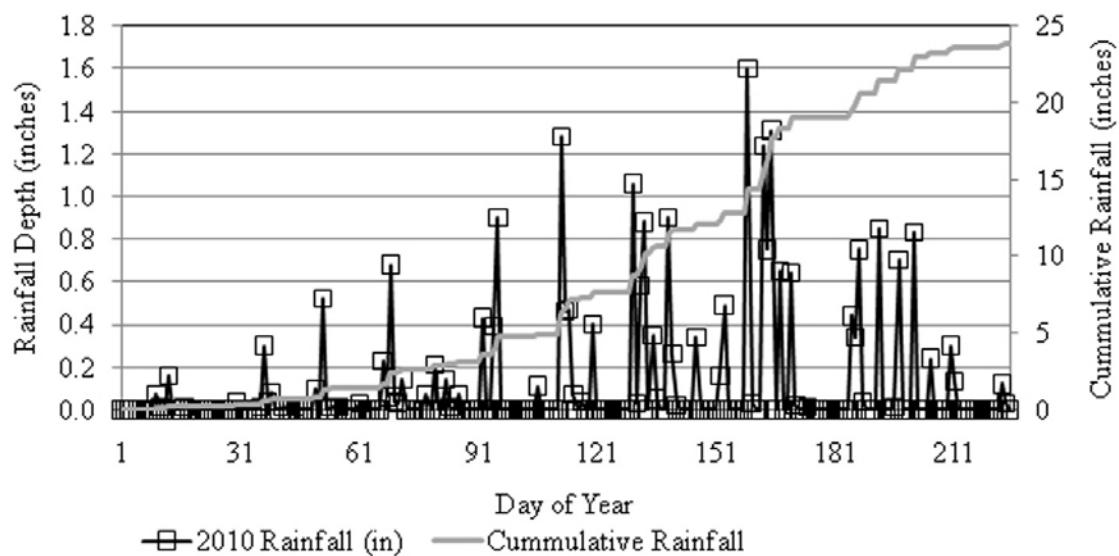


Figure 3.9 Precipitation Summary (2010)

In 2010 we had 1 rain event larger than the water quality storm event. Of the 12 rain events sampled, nine occasions of discharge were recorded from the courtyard. Field observations indicate a tenth discharge also occurred on 4/6. (Mulch was removed from the outlet grate referencing flow.) Based on this data, it was identified that a rain event larger than a 1/3-inch rain event was needed for an outflow to occur.



VEGETATION

The courtyard was planted with a mix of native Kansas plants and regionally popular ornamentals requiring minimal maintenance once established. A majority of the plants have established well (after 3 growing seasons). In some areas with extensive shade along the north facing wall, the Prairie Dropseed is slow to propagate. The designer experimented with a spreading bamboo in the east-west raingarden. The Horsetail planted in the southwest corner did not establish because of the extensive shade and was replaced with Tussock Sedge. Also in the southwest corner, some moss was present in this shaded environment.

SHRUBS AND GRASSES

SYMB.	BOTANICAL NAME	COMMON NAME	SIZE	SPACING
Cab	Cornus alba var. Bailhala	Ivory Halo Dogwood	3 gal.	per plan
Eal	Euonymus alatus var. Compactus	Dwarf Winged Burning Bush	3 gal.	per plan
Vju	Viburnum x juddii	Judd Viburnum	3 gal.	per plan
Brnw	Buxus microphylla var. Wintergreen	Wintergreen Boxwood	3 gal.	per plan
Jch	Juniperus chinensis var. Sea Green	Sea Green Juniper	3 gal.	per plan
Vmi	Vinca minor	Periwinkle	36/Flat	18" O.C.
Msi	Miscanthus sinensis	Dwarf Maiden Grass	3 gal.	per plan
Pal	Pennisetum alopecuroides	Dwarf Fountain Grass	3 gal.	per plan
Pvh	Panicum virgatum var. Heavy Metal	Heavy Metal Switchgrass	3 gal.	per plan
Lsp	Liatris spicata	Marsh Blazing Star	2 qt	5' O.C.
Epu	Echinacea purpurea	Purple Coneflower	DCP	18 in O.C.
Ive	Iris versicolor	Blue Flag Iris	DCP	18 in O.C.
Rmi	Rudbeckia missouriensis	Missouri Black-eyed Susan	2 qt	18 in O.C.
Cac	Calamagrostis x acutiflora	Feather Reed Grass/Karl Foerster*	3 gal.	per plan
Efc	Euonymus fortunei var. Coloratus	Wintercreeper Euonymus	1 gal.	per plan
Pos	Phyllostachys aereosulcata spectabilis	Spectabilis Bamboo	2-3 gal.	per plan
Ssp	Sedum spurius	Two Row Stonecrop	1 gal.	per plan
Pee	Pennisetum setaceum var. Compactus	Dwarf Purple Fountain Grass	1 gal.	per plan

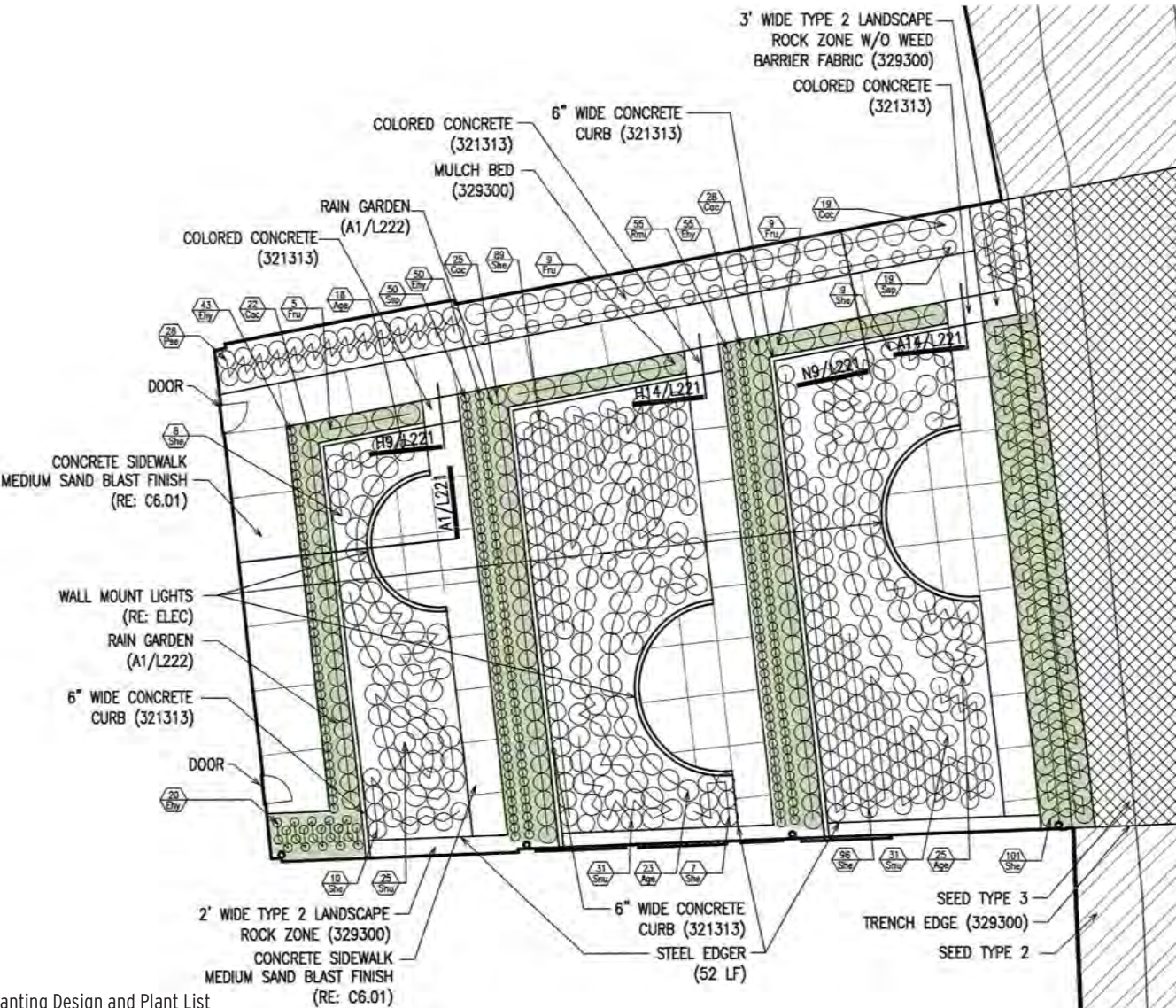


Figure 3.10 Planting Design and Plant List



## MONITORING ANALYSIS



Figure 3.11 Courtyard with raingarden beyond



Figure 3.12 Courtyard with raingarden



Figure 3.13 Raingarden with gutters in background



Figure 3.14 Equipment Connection

WATER QUANTITY

SOIL MOISTURE

The following figure shows the soil moisture within the raingarden. A soil core was taken during 2010 on 8 occasions. A soil moisture test was conducted from the top 12 inches of soil (as shown by the black boxes). The black horizontal line (shown around 7.25 inches) represents soil moisture at 1/3 bar (not quite full saturation). The blue line represents the results from the Modified Penman Equation. This equations estimates the amount of water available for grasses. The equation takes into account temperature, humidity, wind speed, rainfall, and solar radiation (components of evapotranspiration). As the blue line nears 1/3 bar, the basin is considered saturated, and runoff is expected. Shown below runoff was expected to occur during six periods throughout the summer of 2010.

CONCLUSION

As indicated, the soil moisture within the raingardens was consistent throughout the year, providing a good environment for plant growth. The irrigation system was de-activated during the 2010 testing period, and the soils maintained moisture levels never drying out. The soils were traditional planting soils with a combination of topsoil and compost. No sand or aggregates were added.

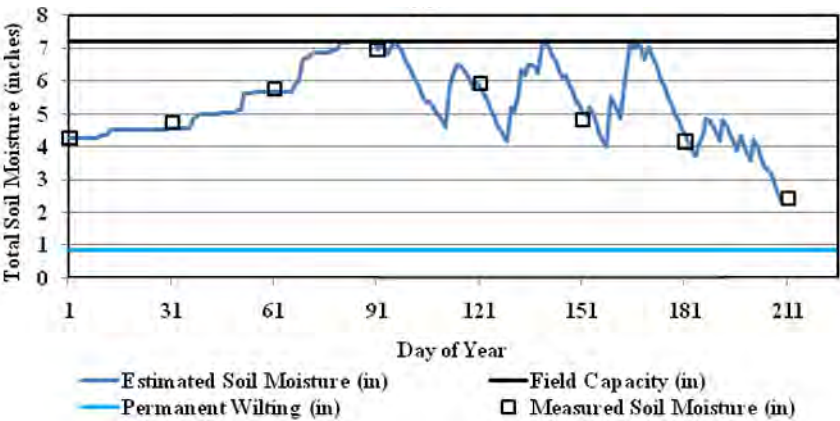


Figure 3.15 Soil Moisture Summary (2010)



## MONITORING ANALYSIS

### WATER QUALITY

Applebee's Courtyard "In"											
Rain Event	Event	Location	Precip	TN ppm	TP ppm	Zn ppm	Cl ppm	S ppm	pH	EC µS	TSS
5/15/2009		First Flush	1.01	3.91	0.11	0.11	5.46	ND	6.8	85	11
6/15/2009		First Flush	1.47	5.3	0.06	0.14	2.94	1.00	6.8	74	19
6/27/2009	1	First Flush	0.48	4.33	1.07	0.02	ND	ND	6.8	46	97
4/2/2010			0.43	No Sample							
5/12/2010	3		0.58	No Sample							
5/26/2010	4	First Flush	0.34	1.14	0.06	ND	0.23	0.24	7.33	23	43
5/26/2010		First Flush	0.34	1.54	0.07	ND	0.15	0.72	7.40	46	68
6/2/2010	5	First Flush	0.49	1.46	0.06	ND	0.15	0.31	7.38	25	4
6/8/2010	6	First Flush	1.60	1.26	0.04	ND	0.19	0.48	7.29	20	20
6/14/2010		Bottle 1	1.31	No Sample							
6/14/2011	7	Composite	1.31	0.71	0.04	ND	0.15	ND	7.00	18	36
6/14/2011		First Flush	1.31	0.69	0.06	ND	0.15	ND	7.25	13	60

The average first flush contaminant load off the roof was low:

Total Nitrogen (TN): 2.5 ppm

Total Phosphorus (TP):  
0.2 ppm

Total Suspended Solids (TSS):  
40.3 mg/l

Table 3.2 Water Quality Data into the Raingardens

Applebee's Courtyard "Out"											
Rain Event	Event	Location	Precip	TN ppm	TP ppm	Zn ppm	Cl ppm	S ppm	pH	EC µS	TSS
6/27/2009	1	First Flush	0.48	1.39	0.06	0.08	0.77	1.87	7.2	95	112
5/10/2010	2		1.06	No Sample							
5/12/2010	3	First Flush	0.58	1.03	0.10	0.04	13.70	1.53	7.28	73	48
5/13/2010			0.88	No Sample							
5/26/2010	4	First Flush	0.34	2.09	0.10	0.02	1.74	1.74	7.40	72	116
6/2/2010	5	Composite	0.49	1.43	0.08	ND	1.33	2.35	7.72	73	44
6/2/2010		First Flush	0.49	1.43	0.08	ND	0.37	1.07	7.73	52	16
6/8/2010	6	First Flush	1.60	0.96	0.04	0.02	0.21	2.90	7.92	115	72
6/8/2010		First Flush	1.60	1.53	0.07	ND	0.78	1.67	7.42	76	48
6/14/2010			1.31	No Sample							
6/14/2010	7	Composite	1.31	1.12	0.05	ND	0.23	0.94	7.44	79	60

Table 3.3 Water Quality Data out of the Raingardens

#### Legend

Precipitation (in)

TN total nitrogen (ppm)

TP total Phosphorus (ppm)

Zn Zinc (ppm)

Cl Chloride (ppm)

S Sulfur (ppm)

EC Electro Conductivity (µS)

TSS total suspended solids (mg/l)

ND = Not detectable (less than .01 mg/l Zn, S, Cl, TN and TP)

ppm = parts-per-million (equal to mg/l)

#### CONCLUSION

The raingarden provided modest pollutant removal rates for nitrogen and phosphorus, and in some cases exported some constituents, although at fairly low levels. This is likely due to being undersized for the contributing drainage area.

The raingarden was successful in extracting soil nutrients from runoff:

56% Reduction of TN

50% Reduction of TP

The raingarden exported Chloride (Cl), Sulfur (S) and Total Suspended Solids (TSS). It is believed that the increased Chloride and Sulfur loads were associated with snow melt salts being applied to surrounding walks throughout the winter.

## MONITORING ANALYSIS

### MAINTENANCE

- **Weeding:** Weeding operations occurred minimally throughout the growing season with one intensive weeding operation occurring in July. Most of the weeds were taken out of the adjacent mulched landscaped area (not from within the raingardens). Within the raingardens, one zone of cattails was observed and mechanically removed.
- **Chemicals:** It is expected that the cattails will return in 2011 and may require removal. No chemical or pre-emergents were applied in 2009 and 2010.
- **Irrigation:** The permanent irrigation system within this courtyard was turned off during 2010. No supplemental watering was provided.
- **Pumping:** There is no opportunity for standing water, thus no pumping is required.
- **Mulch:** The original design did not mulch the raingardens. A jute net was applied at the time of planting to protect against erosion. The adjacent plantings were mulched with hardwood mulch in 2009. Throughout the monitoring stage, mulch would float into the raingardens and collect at the overflow requiring hand removal after larger rain events. No hardwood or mineral mulch was applied in 2010 within either the raingardens or adjacent planters. Future mulching should be minimized with each additional establishment year.
- **Sedimentation:** Beyond the mulch movement, no erosion was observed. Sediment accumulation is minimal as the only sediment entering the courtyard is from the roof or adjacent landscaped areas.

### SIZE TO RAINGARDEN RATIO

- The raingarden is somewhat undersized relative to the drainage area of the roof. The raingarden surface area is approximately 1,266 SF, compared to the roof area of 15,750 SF. This is a ratio of about 8%, which is within design guidelines in some areas of the country. However, the runoff volume from the roof for the local water quality storm event (1.37 inches) is approximately 1,560 CF. The capture volume for the raingarden is approximately 800 CF, so it can hold approximately half of the water quality storm event. So in some respects, the raingarden acts much like a bioswale, i.e. a conveyance device, as much as an infiltration device.
- A 100-foot-long swale at 1.1% slope flowing 1 inch of water has a contact time of 5 minutes. The length of raingarden runs are 124 feet, 100 feet, 75, and 60 feet. A 5-minute contact time meets some regional BMP standards, while a 10-minute time is the requirement for other regions. Longer runs would promote greater contact time allowing for more pollutant removal.
- Even though the raingarden is somewhat undersized, the plants are growing well, and it has been subject to minimal erosion. This is a function of good design which distributes water uniformly throughout the garden and minimizes concentrated flows in any single location.



Figure 3.16 Bamboo along entry walk

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## CONCLUSIONS

### LESSONS LEARNED

- The design does not have to be complicated to be attractive.
- BMPs can provide benefit even if their size is not ideal. However, undersizing BMPs makes them susceptible to erosion, so designs need to consider how larger storm events will pass through them without damage.
- Distributing water from the roof throughout the raingarden (four entry points) likely helped limit erosion and plant disturbance. The layout of the raingarden also mimics tributary streams leading to a larger stream, providing a replication of stream forms found in nature.
- Undersized BMPs will likely have limited pollutant removal performance.
- We might be able to improve the performance of the raingarden/bioswale somewhat by the addition of mulch and periodic rock checkdams to help hold sediment and mulch in place.
- Native plants are often recommended for use in BMPs due to their adaptation to local conditions and habitat enhancement value. However, some horticultural favorites also perform well if personal tastes lean towards cultivars. Plant selections do not need to be rigid, however, potentially invasive species should not be considered.

### RAINGARDEN DESIGN RECOMMENDATIONS

- Create near flat slopes to promote infiltration and absorption by plants.
- Evaluate the elevation of the outlet structure, taking into account mulch and debris buildup. During the first year of establishment, erosion was occurring at the eastern edge of the raingarden. It was observed that the outlet was covered with mulch and set too low (Figure 3.17). The outlet structure was raised with a perforated riser to resist clogging and provide better drainage during larger rain events (Figure 3.3).
- Consider irrigating new raingarden installations with permanent or temporary systems until plants are established.
- Consider check dams to add storage capacity to raingardens.



Figure 3.17 Original Designed Outlet Drain







## Applebee's Treatment Train

## INTRODUCTION + OVERVIEW

### TREATMENT TRAINS

#### GENERAL APPLICATION

Treatment trains are typically a series of BMPs and/or natural features, each planned to treat a different aspect of stormwater runoff and potential pollution, that are implemented in a linear fashion to maximize pollutant removal. At this site, the first stage in the treatment train is preservation and promotion of natural hydrology. The second stage is engineered sedimentation and filtration systems at or near the source of runoff. The final stage of a treatment train is on-site detention and treatment.

#### ADVANTAGES

- Treatment Trains are the preferred approach for water quality improvement because a single BMP may not suffice to meet the stormwater management objectives.
- Treatment trains include site development strategies, management practices and engineered solutions like structural BMPs. Therefore, planning for treatment trains early in the site design process is the most beneficial strategy in implementing best management practices.
- Treatment train practices can efficiently infiltrate site generated runoff, especially in small rain events, which results in a reduced peak runoff rate. This reduces the demands and stress on downstream control facilities.
- During large rain events, detention basins can help effectively manage and release stormwater.

### APPLEBEE'S TREATMENT TRAIN

#### DESIGN INTENT

The design of the system includes a series of native plantings in sheet flow drainage areas, bioswales, raingardens, bioretention areas, sediment forbays, a sand filter, and a wetland. These BMPs in linear configurations maximize pollutant removal for the parking areas and most of the site driveways.

#### MONITORING GOALS

- It was anticipated that the quality of runoff after processing through the BMP Treatment Train would be substantially cleaner than the runoff from the adjacent public street (or traditional street/parking lot design).
- Compare the LEED documents submitted for the LEED Silver Certification application to the actual findings observed and prove the appropriate complete stormwater credits were met.

#### MONITORING CONCERNS

The outlet structure from Renner Boulevard is near the high water elevation for the wetland. During times when the wetland is filled, stormwater monitoring will not be available.



Figure 4.1 Aerial Photo Towards BMP Treatment Train after Rough Grading

## MONITORING OVERVIEW



### SOIL / INFILTRATION

Inspection of site soils indicates heavily disturbed areas due to construction activities. Topsoil was removed, and remaining soils consist of a mix of disturbed and compacted subsoil, rock, and fill material. This contributed to erosion, sediment runoff, and slow establishment of vegetation.

Minimal infiltration can be expected within the sediment forebays/sand filter and was not monitored.

### VEGETATION

The lack of established vegetation along the berm between the west forebay and wetland contributed to erosion and sediment runoff into the wetland.

The substantial landscaping project near the main entry to the building in June of 2010 contributed to erosion and sediment runoff into the eastern sediment forebay.

**Wetland** - The wetland experienced its first growing season in 2010. Substantial growth occurred within the first year, however additional time is required for emergent plants to establish.

### WATER QUANTITY

In general, the flow data collected is not consistent. Therefore, it is difficult to gage if less water per acre flows off the treatment train or off Renner Road.

**Sediment Forbays** - The quantity of water on the north forebay and lack of elevation of the berm allowed the berm to be compromised during large rain events.

**Sand Filter** - The sand filter experiences surface erosion in larger storm events. Overflow from the sand filter caused erosion on the banks and spillway at that feature

**Wetland** - The wetland may be undersized for the size of the combined on-site and off-site drainage areas leading to it. The combined site drainage areas are 18.2 acres. The wetland is 0.5 acres, making it 2.8% of the drainage area.

The erosion problems at the sediment forebay and sand filter highlight the benefits of locating BMPs near the source of runoff rather than at the “end of pipe.”

### WATER QUALITY

Comparison to Renner: Water quality off Renner Road appears a little better than that coming off the parking/site. This is likely due to the site being under construction during the summer of 2010, which caused upstream erosion and more sediment buildup than normal in the treatment train.

Other than the sand filter, the treatment train did not improve water quality. In fact, a number of water quality parameters worsened by the end of the system. Without a good explanation, there were elevated sulfate and chloride levels discharging from the sand filter. Major causes of water quality issues are likely site erosion, lack of dense vegetation, and the attraction of geese to the wetland.

**Sediment Forebay/Sand Filter** - As expected, the sand filter removes sediment and associated particulate pollutants such as metals and phosphorous. As expected, the sand filter has not shown to affect dissolved constituents.

**Wetland** - The geese and duck populations were problematic for a first-year wetland establishment. Until the vegetation is established, water quality will be polluted by water fowl.

The water quality issues highlight the importance of stabilizing the site prior to BMP start-up.

### MAINTENANCE

**Sediment Forbays** - The trap is anticipated to slowly fill with silt over the next 5-10 years. Some weeds and cattails might establish over the years.

**Sand Filter** - Some weeding was required within the 3” mineral mulch layer above the filter fabric/sand layer. After large rain events, the 3” rock mulch layer over the sand filter may need to be raked back into place should strong flows occur out of the inlet pipes or over the spillway.

**Wetland** - Weeding operations were not needed. Some mowing of spot weeds was conducted monthly. One zone of cattails was observed below the building drain tile pipe outlet within the wetland side slope and mowed monthly.



PROJECT DESCRIPTION

See site two - description above



Figure 4.2 Site Context Map

APPLEBEE'S SUPPORT CENTER	
Land Use and Owner Description	Applebee's Corporation
Completed	2009
Address	11202 Renner Blvd, Lenexa, KS
Location in Watershed	Near bottom of watershed, approx. elev. 1033 MSL
Size of Watershed Treated	13 Acres + 5.2 Acres (Renner)
Site Area	30.72 Acre, 610 Parking Stalls
Building Area	178,000 Square Feet Building
Building Use	Office
LEED Certification	Silver
Cost of Construction	\$29.8 Mill. for Building and Site
Cost of BMP Construction	\$109,000
Materials	4" Rock, Sand, Underdrainage piping, Oufall structure, and Native Plants
Wetland Plants	Wet-Mesic Plants (See Figure 4-17)
Sediment Forebay Size	585 Square Yards
Sand Filter Size	877 Square Yards
Wetland Size	1,670 Square Yards

Table 4.1 Project Overview



Figure 4.3 Sand Filter and Sediment Forebay Photo



## PROJECT DETAILS

### STORMWATER SYSTEM DESCRIPTION

At the Applebee's site, a series of BMPs occur in sequence, providing a multi-BMP "treatment train." At this location, there are two watersheds being monitoring and compared (Figure 4.4). The Renner Road Watershed is 5.2 acres of public street right-of-way. Runoff from this watershed is sampled before it is treated by any type of BMP. The Parking Lot Watershed is 13 acres of internal drive/parking areas. Runoff from this watershed is sampled before it enters on of the sediment forebays.



Figure 4.4 Watershed and BMP Layout Diagram



Figure 4.5 Sediment Forbay Photo



Figure 4.7 Entry pipe to Sediment Forbay (from parking lots) Runoff appears to be carrying sediment from upstream BMPs and landscape construction project.



Figure 4.8 Sand Filter under Construction



Figure 4.6 Sand filter, Renner Road monitoring stations and Wetand Construction

## PROJECT DETAILS

### STORMWATER SYSTEM DESCRIPTION (CONT.)

As diagramed in Figure 4.10, the runoff from Renner Road Watershed is piped under the parking lot to a monitoring station, which samples the water before it is released to the wetland. The Runoff from the Parking Lot Watershed flows through a series of BMPs before it is sampled. Within the Parking Lot Watershed, the terraced 610 parking stalls are separated by broad vegetated swales located in landscape islands that treat the stormwater runoff where it falls by directly intercepting it from the paved surfaces. Once intercepted, the runoff flows perpendicular to the slope of the parking lot through turf vegetated swales. The mild

slopes and vegetation in the swales slow the time of concentration, allowing the Blue Flag Iris, Switchgrass, and other native plantings more time to absorb the runoff and maximizing the contact time of the runoff with the soil before being intercepted by area inlets. From the inlets, the stormwater is discharged into two separate sediment forebays feeding a surface sand filter for additional cleansing. The sand filter is located upstream of a nearly one-half-acre constructed wetland flanking the north side of the building.



Figure 4.10 Water Flow Diagram



## PROJECT DETAILS

The wetland was sized to treat the stormwater runoff volume of a 2-year (50%) storm event from the 5.2 acres of off-site public street right-of-way and commercial development, in addition to the runoff from the Applebee's parking lot (Figure 4.10). A 42-inch storm sewer line from Renner Road connects to a junction manhole near the wetland. Within the manhole is a 2-foot tall divider wall that sends water toward the wetland during smaller rain events (up to the 2-year event). Flows are conveyed to the wetland via a 12-inch concrete pipe.

Commercial business parks typically have large expanses of parking lots, driveways, and roads, all of which generate significant amounts of stormwater runoff. The Applebee's site is not a typical inflow-outflow study of a single BMP, but a comparison of the runoff characteristics from two different design approaches. Two monitoring systems (Renner Road Monitoring Station and the Sand Filter Monitoring Station) have been installed in the storm sewer outlet pipes allowing a side-by-side comparison of a conventional drainage system verses an integrated BMP treatment train (Figure 4.11). In addition, a third location is being monitored that compares runoff after filtration through a sediment forebay and sand filter.

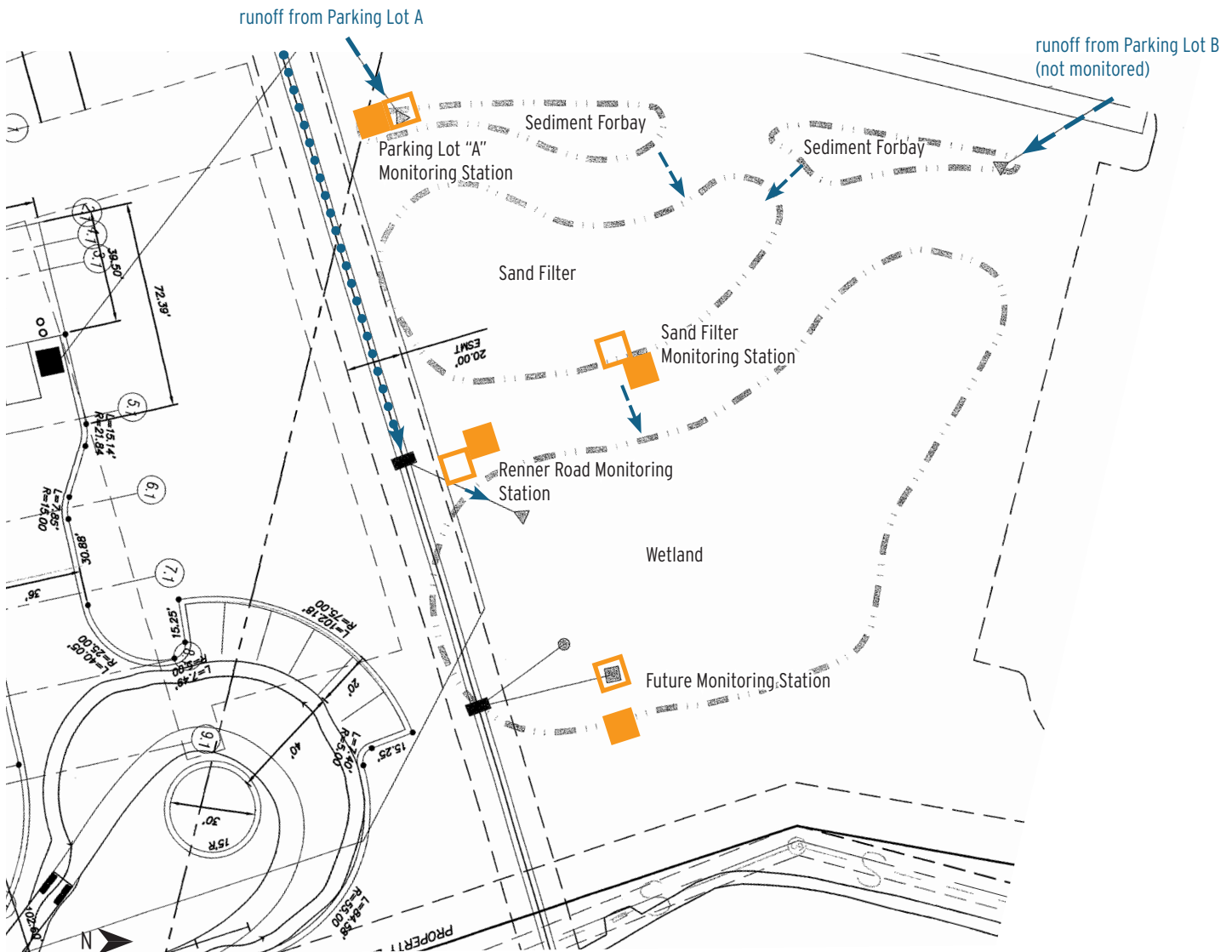


Figure 4.11 Monitoring Equipment Location Diagram

## MONITORING ANALYSIS

### PRECIPITATION

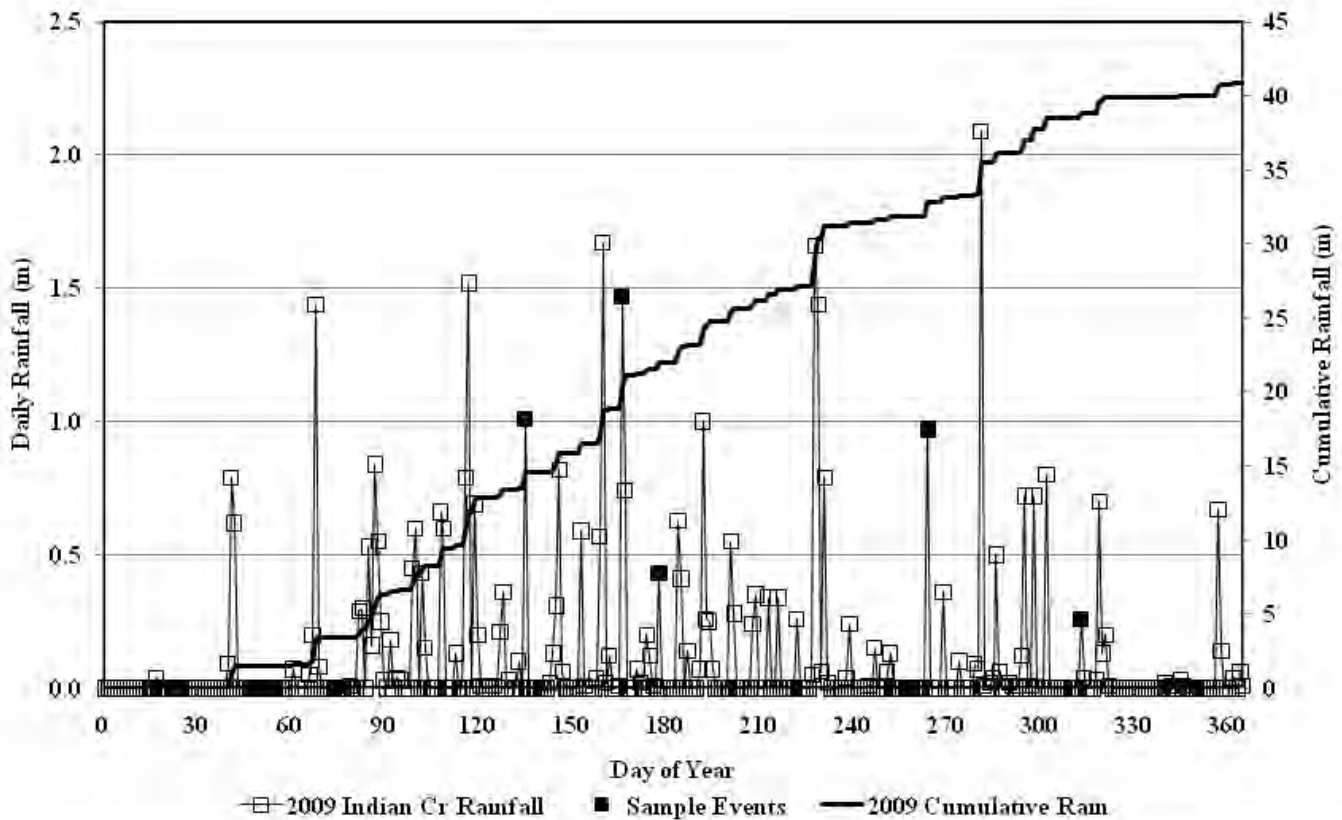


Figure 4.12 Precipitation Summary (2009)

### PRECIPITATION

The above figure shows the regional precipitation (outlined squares) and on-site monitoring data (black squares) for 2009 sampled events. The equipment was installed on May 14th (Day 134). In 2009 we had 5 rain events larger than the water quality storm event (1.37-inches or 90% of the average annual stormwater volume of all 24-hour storms). We were able to capture 5 rain events following a variety of different storm sizes. The cumulative rainfall recorded near the Applebee's site is also shown.

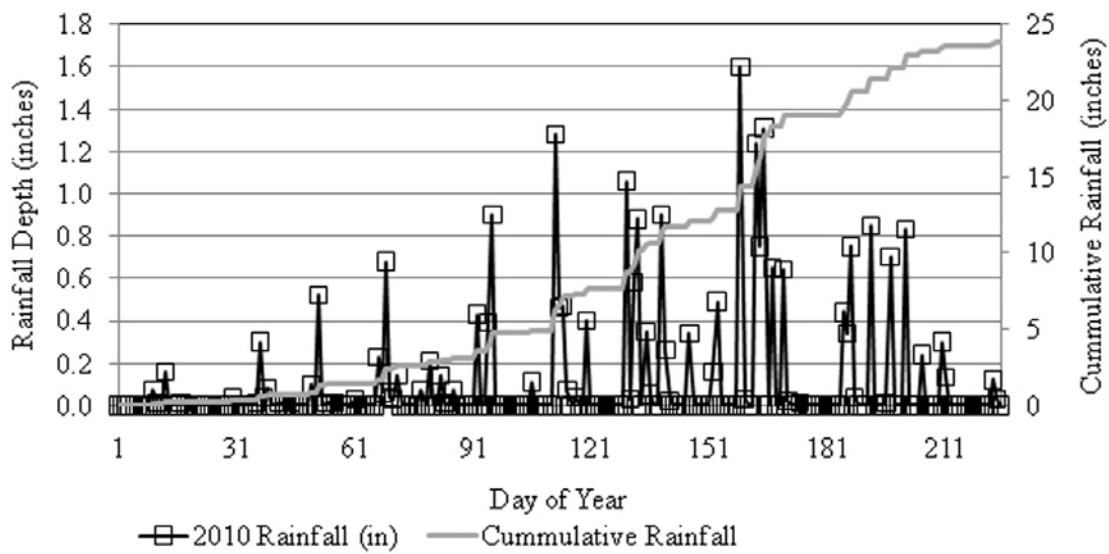


Figure 4.13 Precipitation Summary (2010)

In 2010 we had one rain event larger than the water quality storm event.



## MONITORING ANALYSIS

### VEGETATION

In the fall of 2009 after the first summer of monitoring, the wetland was planted. The area was seeded with two wet-mesic seed mixes, erosion blanket applied, and area plugged with deep cell plugs at 24 inches on center. Monitoring was added in Spring 2010 to document how the wetland performed during its first year of growth. Below is a list of the wetland plants installed.

### CONCLUSIONS

The upland plants started to establish well in the first year. There was not much plant material establishing within the wetland pod shelf zone. The first year, the wetland functioned more like a retention pond than a wetland.

The planting method appears to be successful on the uplands, although some of the wildlife was observed pulling up the planted plugs.



Figure 4.14 Wetland Planting



Figure 4.15 Wetland Plants after One Year Establishment





Figure 4.16 Wetland Planting Design Diagram

EDGE PLANTING		SHALLOW SHELF PLANTING		DEEP SHELF PLANTING	
BOTANICAL NAME	COMMON NAME	BOTANICAL NAME	COMMON NAME	BOTANICAL NAME	COMMON NAME
<i>Sorghastrum nutans</i>	Indiangrass	<i>Spartina pectinata</i>	Prairie Cordgrass	<i>Eleocharis palustris</i>	Creeping Spikerush
<i>Panicum virgatum</i>	Switchgrass	<i>Carex vulpinoidea</i>	Fox Sedge	<i>Scirpus fluviatilis</i>	River Bulrush
<i>Rudbeckia triloba</i>	Brown Eyed Susan	<i>Carex hystericina</i>	Bottlebrush Sedge	<i>Scirpus atrovirens</i>	Green Bulrush
<i>Aster novea-angliae</i>	New England Aster	<i>Acorus calamus</i>	Sweet Flag	<i>Scirpus validus</i>	Soft-Stemmed Bulrush
<i>Echinacea purpurea</i>	Purple Coneflower	<i>Iris virginica</i> var. <i>shrevei</i>	Blue Flag Iris	<i>Scirpus fluviatilis</i>	River Bulrush
<i>Echinacea paradoxa</i>	Yellow Coneflower	<i>Alisma subcordatum</i>	Water Plantain	<i>Juncus effusus</i>	Soft Rush
		<i>Asclepias incarnata</i>	Swamp Milkweed	<i>Sagittaria latifolia</i>	Broadleaf Arrowhead
		<i>Scirpus atrovirens</i>	Green Bulrush		

Figure 4.17 Wetland Plant List

## WATER QUALITY - SAND FILTER

Applebee's Sand Filter "In"											
Rain Event	Event	Note	Precip	TN ppm	TP ppm	Zn ppm	Cl ppm	S ppm	pH	EC µS	TSS
6/27/2009		First Flush	0.48	3.17	0.29	0.04	42.95	16.26	7.4	315	47
9/21/2009		First Flush	0.97	5.02	0.32	0.09	21.37	11.57	7.3	282	45
4/2/2010			0.43	No Sample							
4/23/2010	2	First Flush	0.46	1.10	0.07	ND	62.40	15.78	7.36	348	116
4/23/2010		First Flush	0.46	1.10	0.07	ND	112.70	13.61	7.41	449	48
4/24/2010	3	First Flush	0.47	2.37	0.05	0.02	148.30	28.92	7.14	654	48
5/10/2010	4	First Flush	1.06	3.53	0.12	0.02	143.40	32.62	7.62	695	160
5/10/2010		First Flush	1.06	1.63	0.07	ND	64.30	11.23	7.51	312	172
5/12/2010	5	First Flush	0.58	1.13	0.05	ND	47.90	9.26	7.51	267	444
5/13/2010			0.88	No Sample							
5/15/2010			0.35	No Sample							
5/19/2010	6	First Flush	0.9	1.12	0.02	0.02	100.50	18.25	7.43	489	90
5/20/2010	7	First Flush	0.26	2.07	0.27	ND	22.10	4.19	7.21	149	480
5/26/2010	8	First Flush	0.34	2.99	0.24	ND	26.53	19.72	7.79	337	168
6/1/2010	9	First Flush	0.16	2.09	0.13	ND	12.87	7.70	8.02	201	196
6/2/2010	10	First Flush	0.49	3.69	0.23	ND	57.57	25.38	8.28	499	136
6/2/2010		Bottle 6	0.49	2.73	0.36	ND	48.25	7.05	8.17	235	480
6/8/2010	11	First Flush	1.60	3.02	0.10	ND	20.73	15.12	7.90	514	128
6/8/2010		First Flush	1.60	2.43	0.50	ND	40.47	8.44	7.92	257	752
6/14/2010			1.31	No Sample							
6/14/2010			1.31	No Sample							
7/11/2010			0.85	No Sample							
7/11/2010			0.85	No Sample							
7/16/2010	12	First Flush	0.7	0.97	0.04	ND	2.70	0.33	7.55	18	32
7/16/2010			0.7	No Sample							
7/20/2010		First Flush	0.83	0.75	0.03	ND	2.60	0.30	7.33	18	40

Table 4.2 Sand Filter "In" Water Quality Data

Applebee's Sand Filter "Out"											
Rain Event	Event	Notes	Precip	TN ppm	TP ppm	Zn ppm	Cl ppm	S ppm	pH	EC µS	TSS
6/27/2009		First Flush	0.48	2.92	0.07	0	63.92	17.57	7.5	442	12
4/2/2010	1	First Flush	0.43	3.77	0.22	ND	208.00	56.87	7.52	940	80
4/23/2010	2	First Flush	0.46	0.56	0.06	ND	91.20	9.85	7.42	361	20
4/23/2010			0.46	No Sample							
4/24/2010	3		0.47	No Sample							
5/10/2010	4	First Flush	1.06	0.65	0.06	0.01	81.30	9.16	7.37	343	108
5/12/2010	5		0.58	No Sample							
5/26/2010	8	First Flush	0.34	3.46	0.06	ND	631.90	69.06	7.85	2590	24
5/26/2010	8	Composite	0.34	1.62	0.07	ND	97.96	16.41	7.54	496	36
5/26/2010		First Flush	0.34	1.98	0.09	ND	118.36	18.66	7.62	578	72
6/2/2010	10	First Flush	0.49	1.29	0.09	ND	59.44	10.78	8.06	343	44
6/8/2010	11	First Flush	1.60	1.36	0.08	ND	68.76	14.69	8.08	489	60
7/11/2010			0.85	No Sample							
7/11/2010			0.85	No Sample							
7/16/2010			0.7	No Sample							
7/16/2010			0.7	No Sample							
7/20/2010	13	Grabbed	0.83	1.13	0.09	ND	42.30	8.87	7.46	324	15

Table 4.3 Sand Filter "Out" Water Quality Data



## WATER QUALITY - RENNER ROAD

Applebee's Renner												
Rain Event	Event	Notes	Precip	TN ppm	TP ppm	Zn ppm	Cl ppm	S ppm	pH	EC µS	TSS	EColi
10/9/2009		First Flush	0.26	2.15	0.13	0.08	45.07	13.58	7.4	318	66	54
4/2/2010			0.43	No Sample								
4/5/2010			0.39	No Sample								
4/5 - 4/6			0.9	No Sample								
4/16/2010		First Flush	0.11	0.59	0.05	ND	23.10	3.10	7.29	130	4	0
4/22/2010		First Flush	1.28	2.64	0.10	ND	43.70	7.66	7.13	275	12	0
4/23/2010	2	First Flush	0.46	2.46	0.12	ND	27.30	5.26	7.46	209	116	0
4/24/2010		First Flush	0.47	1.10	0.06	0.02	48.70	7.60	7.54	253	28	0
5/12/2010	5		0.58	No Sample								
5/26/2010	9		0.34	No Sample								
6/1/2010			0.16	No Sample								
6/1/2010	10	First Flush	0.16	2.10	0.12	0.02	12.33	4.52	7.66	175	156	1027
6/2/2010	11	Composite	0.49	3.21	0.13	0.02	35.50	10.89	7.94	284	48	2002
6/2/2010		First Flush	0.49	1.90	0.05	0.02	65.93	14.46	8.13	479	48	2016
6/8/2010	12	Composite	1.6	1.85	0.17	ND	63.88	12.78	8.04	477	172	1741
6/8/2010		First Flush	1.6	1.68	0.11	ND	31.55	4.69	8.00	227	68	428
6/14/2010			1.31	No Sample								
7/5/2010			0.34	No Sample								
7/5/2010			0.34	No Sample								
7/11/2010			0.85	No Sample								
7/11/2010			0.85	No Sample								
7/16/2010		First Flush	0.7	1.32	0.11	ND	12.40	4.36	7.88	141	126	43
7/16/2010		Composite	0.7	2.15	0.16	0.03	48.10	11.83	7.90	381	154	78

Table 4. 4 Renner Road Water Quality Data

### Legend

- Rain (in)
- Flow Vol. (ft<sup>3</sup>)
- TN total Nitrogen (ppm)
- TP total Phosphorus (ppm)
- Zn Zinc (ppm)
- Cl Chloride (ppm)
- S Sulfur (ppm)
- EC Electro Conductivity (µS)
- Ecoli (colonies/100 ml)
- TSS total suspended solids (mg/l)
- ND = Not detectable (less than .01 mg/l Zn, S, Cl, TN and TP)
- ppm = parts-per-million (equal to mg/l)

### CONCLUSIONS

Water quality from Renner Road (as shown in Table 4.4) was similar or better quality than the water into the Sediment Forebay (as shown in Table 4.2). After construction was started in May 2010, the water quality into the forebay worsened. The TSS average rose from 98 mg/l to 224 mg/l during the construction processes.

The sediment forebay/sand filter removed on average 117 mg/l of TSS, reduced TN and TP levels (when comparing Table 4.2 and Table 4.3), and produced a better water quality than water directly from Renner Road (excluding Cl and S).

#### De-Icing Salts.

The client applied high levels of snow removal salts over the winter of 2009 and 2010. Large areas of fescue immediately adjacent to parking lot areas needed to be replaced in Spring 2010. Chloride levels were documented higher than normal after rain events on 4/21 (1.28" rain event) and 5/10 (1.06" rain event). It is assumed that it took a large rain event for the extra chloride to reach the sediment forebay. These chloride levels were not removed by the sediment forebay and sand filter.



## WATER QUALITY - WETLAND

### WETLAND ECOLI LEVELS

The Ecoli levels were documented to be very high (Table 4.5). These levels were not documented by the sampling stations for Renner Road and the Sand Filter Out. The lack of ecoli coming off of Renner Road and the Sand Filter indicates that the Ecoli entered into the system at the wetland. Because the plants were not established, the bacteria was not absorbed or processed.

We compared these results to a more established wetland monitored by our partner, Johnson County Public Works, Stormwater Management Program. Prior to Lake Lenexa (also in Lenexa, Kansas), two stormwater wetlands were sampled from June 2007 to October 2008. Based on comparable, established wetland, we might anticipate that water quality in the wetland will improve over time as vegetation establishes, and upstream erosion is corrected.

At these comparative wetlands (referred to as the south and northeast cells), with the exception of a large rain event on 06/05/08 (3.07" rain), the south wetland removed greater than

90% of TKN, TP, and TSS by mass. The data for the northeast cell was more unpredictable, particularly in 2007. However, after the dredging, this cell began removing higher levels of TKN, TP, and TSS.

Waterfowl prefer open lines of sight to be able to observe potential predators, so tall dense vegetation at pond edges and narrow widths of open water tend to discourage them. As vegetation further establishes in the wetland, waterfowl use may decline.

Wetland performance is a function of more than just adequate sizing. Upstream site stabilization, erosion control, vegetation establishment, and maintenance all contribute to hydraulic and

Applebee's Wetland												
Rain Event	Event	Notes	Precip	TN ppm	TP ppm	Zn ppm	Cl ppm	S ppm	pH	EC µS	TSS	EColi
4/22/2010	1	Composite	1.28	1.37	0.08	ND	308.30	31.14	7.44	1040	52	0
4/24/2010	2	Composite	0.47	1.47	0.07	ND	166.80	23.46	7.32	712	48	0
4/30/2010	3	First Flush	0.40	1.87	0.04	ND	362.50	49.61	7.53	139	96	8
5/10/2010	4	First Flush #9	1.06	2.57	0.10	ND	306.80	44.47	7.70	1180	96	10
5/12 - 5/13			0.58	No Sample								
5/19/2010	5	Composite	0.90	2.38	0.05	ND	262.90	38.33	7.55	109	116	25
5/26/2010	6	Composite	0.34	2.57	0.35	ND	109.07	21.69	7.67	596	688	1921
5/26/2010	6	First Flush #1	0.34	5.03	1.28	ND	134.94	27.99	7.80	720	2552	3842
6/1/2010	7	First Flush #1	0.16	2.69	0.28	ND	67.32	14.61	8.04	429	420	2180
6/2/2010	8	Composite	0.49	1.79	0.18	ND	44.18	9.36	7.74	259	180	4045
6/2/2010		First Flush	0.49	2.09	0.14	ND	171.35	29.17	7.78	851	200	2757
6/8/2010	9	Grab Sample	1.60	0.97	0.12	ND	101.85	10.56	8.18	326	188	1659

Table 4.5 Wetland Water Quality Data

### Legend

- TN total Nitrogen (mg/l)
- TP total Phosphorus (mg/l)
- Zn Zinc (mg/l)
- Cl Chloride (mg/l)
- S Sulfur (mg/l)
- EC Electro Conductivity (µS)
- Ecoli (colonies/100 ml)
- TSS total suspended solids (mg/l)
- ND = Not detectable (less than .01 mg/l)
- Zn, S, Cl, TN and TP)

## MONITORING ANALYSIS

### CHEMICAL APPLICATION

Date Applied	Next Rain Event	Chemicals Applied	Rate	Total Weight	Notes
4/14/2010	4/16/2010	Primera Triplet EPA 228-312	1.3/1000 sf	103 Lbs between 2	Turf fertilizer, spot treatment of broadleaf weeds
		Barrage HF EPA5905-529	0.35oz/1,000sf		
		Barricade4FL EPA 100-1139	Spot Spray		
4/15 & 4/19/2010	4/22/2010	Battleship III EPA 228-453-5905	1.1 oz/1000sf	485 Oz	Treat buffalo grass areas & fescue areas
		Barricade 4FL EPA 100-1139	0.5oz/1,000sf	221 Oz	

Chemical Name	Active Ingredients	% of A. I.
Primera Triplet	Dicamba, dimethylamine salt	2.77
	Dimethylamine (R)-2-(2-methyl-4-chlorophenoxy)propionate	8.17
	Dimethylamine 2,4-dichlorophenoxyacetate	30.56
Barrage HF	Acetic acid, (2,4-dichlorophenoxy)-, 2-ethylhexyl ester	78.10
Barricade 4FL	2,4-Dinitro-N3,N3-dipropyl-6-(trifluoromethyl)-1,3-benzenediamine (Note: N3 = N superscript 3)	40.70
Battleship III	1-Methylheptyl ((4-amino-3,5-dichloro-6-fluoro-2-pyridinyl) oxy) acetate	4.45
	Dimethylamine 2-methyl-4-chlorophenoxyacetate	37.84
	Triethylamine triclopyr	4.07

Table 4.6 Applebee's Landscape Chemical Application

These chemical were applied throughout the Applebee's campus in 2010. The team reviewed the sampling data of the runoff into the sediment trap immediately after the application of chemicals. In general there was no perceived increase of monitored constituent when comparing before and after rain events.

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## MONITORING ANALYSIS

### MAINTENANCE

#### Sediment Forebays

- Chemicals: None
- Irrigation: None
- Weeding: None
- Erosion: The berm around the northern sediment forebay was compromised in three locations and requires restoration. The elevation of the berm compared to the elevation of the spillway appears to be within 12 inches of the spillway elevation. Combined with the erosive nature of the soils and lack of established vegetation, the berm failed.
- Adjustment: At the northern sediment forebay, the velocity of runoff from the 30" diameter storm pipe displaced the riprap at the pipe outlet requiring hand replacement once during 2010.
- Eventually the sediment forebay will become clogged with sediment and will require cleaning. It was the design team's expectation that the sediment forebay will be successful for approximately 5 to 10 years.

#### Sand Filters

- Chemicals: None
- Irrigation: None
- Weeding: Some weeds were pulled near spillway on one occasion during 2010 (See figure 4.19).
- Sedimentation: Some erosion was observed along the northern side of the sand filter. This erosion resulted from the berm along the northern sediment basin failing. The sediment was shoveled off the top of the sand filter within a 100sf area.
- Adjustment: After a few large rain events, the top layer of the sand filter was displaced by the energy of the runoff from the vegetated spillway. The top layer of the sand filter needed to be shoveled/regraded a couple times a year.
- The sand filter is not expected to require replacement for many years as long as regular maintenance and surface cleaning is conducted. The filter fabric within it is a potential clogging point and will continue to be monitored. A more efficient inlet level spreader would also enhance performance.



Figure 4.18 Cattails present and drainage location



Figure 4.19 Washout at spillway. Weeds visible



## CONCLUSIONS

### MAINTENANCE (CONT)

#### Wetland

- Maintenance for the first year of planting was minimal.
- Chemicals: None in 2010.
- Irrigation: No supplemental watering was provided.
- Weeding: Weeding operations were not needed. Some spot mowing of weeds was conducted monthly. One zone of cattails was observed below the building drain tile pipe outlet within the wetland side slope and mowed monthly. It is expected that in 2011, a spot herbicide application will be required in this isolated area.
- Erosion Control Blankets: The biodegradable netting from the installation of the plants stayed intact throughout the growing season.
- Sedimentation: Substantial sedimentation occurred because of the sediment trap berm compromise. The berm will require repair in 2011.

### LESSONS LEARNED

- The larger, more complex nature of this site required more care and time for BMP establishment.
- The larger the area of the site that is disturbed, the more effort it takes to restore vegetation and control erosion. Site development significantly disturbs site soils. Greater effort needs to be placed on restoring soil structure and organic matter before sites are vegetated, in order to help establish healthy, dense vegetation, limit weeds and erosion, and reduce the need for herbicide applications.
- Erosion at the site, both upstream of the BMPs, and around the BMPs, was a significant problem in performance of the system. Ideally, the BMPs at the site would have been installed and established from upstream to downstream, with the wetland established last after the rest of the site was fully stabilized and vegetated. It could have been used as a temporary sediment pond during that time.
- "End of Pipe" treatment systems can make it difficult to manage larger storm events. The BMPs are generally designed to treat the first flush of stormwater runoff from the site, yet flows from large storms must be safely conveyed through or bypassed around the BMPs. Managing erosion from larger storms appears to be a challenge at the sediment forebay and sand filter.
- The wetland seems to be undersized for the site. Large flows will pass through it with minimal residence times, reducing treatment efficiency. Capacity has been further reduced by sedimentation. Correction of upstream erosion problems and dredging the wetland would help improve its performance.
- Geese can be controlled by landscaping practices. Geese prefer open lines of sight to be able to observe potential predators. Tall, dense vegetation around the edges of ponds and wetlands and narrow widths of open water tends to discourage them. Additional plantings of tall emergent vegetation around the edge of the wetland and additional plantings on the shoreline would help reduce geese at the wetland.



Figure 4.20 Sediment entering wetland

## DESIGN RECOMMENDATIONS

### Sediment Forebay

- Size berms and conveyance features of sediment forebays appropriately to hold and convey large rain events without deterioration. The southern forebay berm height of 24-inches taller than the top of the overflow channel was successful. The northern sediment forebay berm height of 12-inches higher than the overflow channel was undersized.
- Evaluate the size of rock at the sediment forebay inlet to reduce erosion potential. Even though the sediment forebay was 3' deep of 6-12 inch diameter rock, larger rock should have been installed at the outlet from the 30" storm sewer pipe.

### Sand Filter

- Dissipate runoff and ensure slow runoff velocities into sand filters. Vegetated spillways still allow a substantial velocity of runoff. The entry points to sand filters should be reinforced to dissipate runoff velocities. A different level spreader configuration with a vegetated surface over the sand filter could resist displacement due to flow velocities.

### Wetland

- Discourage water fowl from entering an establishing wetland. If land is available, consider a 10' wide vegetated low water buffer (of approximately 12" deep water) to discourage water fowl from occupying an establishing wetland.
- Dissipate runoff flow at entry points to wetland to control erosion at inlet points.



Figure 4.21 Erosion from sediment trap

## LEED SUBMISSION

This project received SScr 6.2 Stormwater Design: Quality Control credit using LEED-NC 2.2. The credit requires 80% of the total suspended solids (TSS) to be removed. The following information was provided by the LEED submission.

- Non-structural BMP practices included Vegetated swales, Rain gardens and Native Vegetation (17+ acres).
- Structural BMP practices included sediment forebay, sand filter and constructed wetland. The wetland was sized for 15 acres of impervious area.
- The credit was achieved by sending 93% of the site runoff through at least one of the listed non-structural or structural controls.

Erosion from un-established site areas has led the site to NOT meet the criteria in 2010. The framework is in place to meet this criteria within a couple years assuming the following parameters are met:

- existing erosion is corrected
- plants continue to establish across the site.
- emergent plants within the wetland propagate.
- no additional landscape construction projects are undertaken

The design team worked hard to build/establish the treatment train in sequence. This system is complex, containing numerous conveyance and treatment elements. The design team waited for upstream plants to establish prior to mucking out and planting the wetland. With additional time, emergent plants should establish in the wetland, reducing waterfowl use, and improving pollutant removal capacity.





# University of Kansas Detention Basin

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## INTRODUCTION + OVERVIEW

## DETENTION BASIN DESCRIPTION

## GENERAL APPLICATION

Detention basins are stormwater ponds typically designed to protect against flooding and downstream erosion by storing water for a limited period of a time. These basins are also called “dry ponds,” “holding ponds,” or “dry detention basins” when they are designed to dry out between storm events. In its basic form, a dry detention basin is used to manage water quantity while having a limited effectiveness in protecting water quality.

Raingardens typically improve water quality by collecting the first flush of stormwater runoff in a shallow pond (typically about 4”-8” holding capacity) and allowing it into infiltrate in the ground. Raingardens are fairly inexpensive and do not have specialty soils nor subdrainage piping. They are intended to drain down in 24-48 hours.

## ADVANTAGES

The following are the advantages of raingardens in connection with a detention basin and the expected results.

- In this environment a conventional detention basin was modified with a raingarden installed at the points of contact with the roof runoff. The runoff is distributed evenly, slowed, filtered of pollutants and encouraged to infiltrate.
- The runoff rate from the roof to the outlet will be slowed. This lag time will reduce the potential for downstream flooding and stream bank erosion.



Figure 5.1 Raingarden in 2009

## KU MODIFIED DETENTION BASIN WITH RAINGARDEN PRE-TREATMENT

## DESIGN INTENT

The design includes a pre-treatment system of level spreaders, 12 inches of engineered soils and a two-tiered raingarden that distributes runoff over a large area promoting infiltration and transpiration prior to sheet flow across a fescue planted detention basin and outlet structure. In accordance with the APWA BMP Manual, the outlet structure was located at least 10 feet away from building foundations, shredded hardwood mulch (not pine or woodchips) was applied at installation, and native plants were selected for drought and wet conditions. In addition, the raingarden was designed to handle the acre of roof runoff. (This is above the APWA BMP Manual recommended watershed size).

## MONITORING GOALS

- On small rain events, it is expected that overflows out of the detention cell will not occur.
- Nationally, some jurisdictions require that the post-development runoff cannot exceed the pre-development peak flow rate. If designed appropriately, pre-treatment can help reduce the detention requirements for individual sites. The design will show that raingardens do not just clean runoff, but they can reduce the speed and concentration of runoff, more than expected.
- Further definition of the appropriate ratio of pretreatment area compared to the size of watershed.

## MONITORING CONCERNS

- As water is distributed between multiple inlet pipes, it will be hard to quantify water quantity into the project area.



Figure 5.2 Raingarden in Fall 2010



## MONITORING OVERVIEW



### SOIL / INFILTRATION

- The level spreader and limestone boulder were constructed to slow runoff, reduce erosion, and support infiltration.
- With additional growth, it is anticipated that the plants should improve infiltration into the subbase (beyond the improved engineered soil subbase).
- The raingardens incorporate 12 inches of bioretention soil mixture surrounded by limestone boulders.
- The soil moisture data shows that the moisture conditions in the soil vary widely over the course of the year. This is likely due to the elevated garden beds in an open location being exposed to sun and wind, plus the engineered soils. Evapotranspiration is likely occurring, as is infiltration.
- It appears that the KU BMP can infiltrate about a 0.40 inch rain event if the BMP is dry.

### VEGETATION

- The plants were installed in May 2009 and appear to be thriving.

### WATER QUANTITY

- The design of the raingarden is successful at distributing flows from the roof across multiple locations in the garden.
- When the raingarden is dry there is about an hour and twenty minutes before runoff occurred from the BMP a significant reduction over expected travel times through pipes!.

### WATER QUALITY

Runoff from the control roof was low and averaged the following properties:

Total Nitrogen (TN) =	2.3 ppm
Total Phosphorus (TP) =	0.2 ppm
Chloride (Cl) =	0.2 ppm
Sulfur (S) =	0.7 ppm
Total Suspended Solids (TSS) =	56 mg/l

The raingarden was successful in extracting the following nutrients from the runoff:

**40%** Reduction TN  
**50%** Reduction of TP

TSS levels were relatively modest, averaging 50-60 ppm, and were generally unchanged by the raingarden.

Runoff did export the following constituents, at low levels:

Chloride (Cl) = 3.1 ppm (+ 2.9 ppm)  
Sulphur (S) = 0.9 ppm (+ 0.2 ppm)

### MAINTENANCE

- Weeds: Weeding was required monthly with a major weeding operation occurring in August 2010.
- Irrigation: The area was hand-irrigated to assist with plant establishment during dry periods.
- Mulch: The landscape area is being mulched every spring.

PROJECT DESCRIPTION

The University of Kansas Fitness Center was built on the southern end of campus and originally opened in 2003. The facility provides a multitude of recreational opportunities including Aerobics Studio, weight room, six basketball courts, locker rooms, suspended three lane track, welcome center, etc. Later, in 2008, the University expanded the complex with a new 100,000 square foot facility which houses four basketball courts, two racquetball courts, extended running track, and Martial Arts Studio.

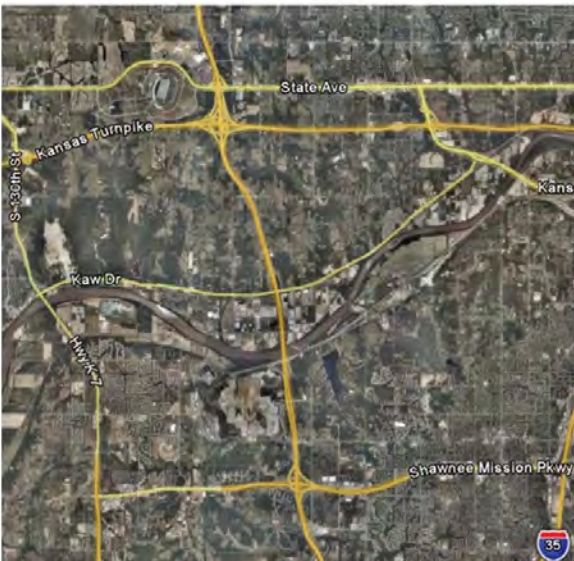


Figure 5.3 Site Context Map

THE UNIVERSITY OF KANSAS FITNESS CENTER	
Land Use and Owner Description	The University of Kansas
Address	Lawrence, KS
Location in Watershed	Low in the Watershed
Building Use	Multi-Use Fitness Center
LEED Certification	None
Cost of Construction	\$17 Mill. for Building and Site
Cost of Raingarden Installation	\$51,000
Cost of Raingarden Plants	\$12,500
BMP Type and Description	Modified Detention Basin/Raingardens
Materials	Limestone Boulders, Engineered Soil, Turf Grass, and Native Plantings
Size of Roof Watershed (to Raingarden)	44,000 Square Feet
Surface Area of Captured Volume when full	4,980 Square Feet
Infiltration Surface Area	4,980 Square Feet
Capture Volume when Full (assuming 45% pore space in engineered soils)	2,241 Cubic Feet

Figure 5.4 Project Overview

## PROJECT DETAILS

### STORMWATER SYSTEM DESCRIPTION

Monitoring equipment at the KU site is set up to sample water from two watersheds. The BMP watershed includes water that falls on the roof, and water that falls on and flows through the rain garden and detention basin (Figure 5.5). This system is retrofitted to divert runoff from the building into nine level spreaders that direct runoff into a stepped rain garden and then to an adjacent detention basin. The roof watershed includes only water that falls and the roof. The outlet for both watersheds ties into the storm sewer (Figure 5.6).

Two ISCO samplers are installed near the outlet to monitor runoff quality. One ISCO machine samples water from the BMP watershed, and one ISCO machine samples water from the roof watershed.

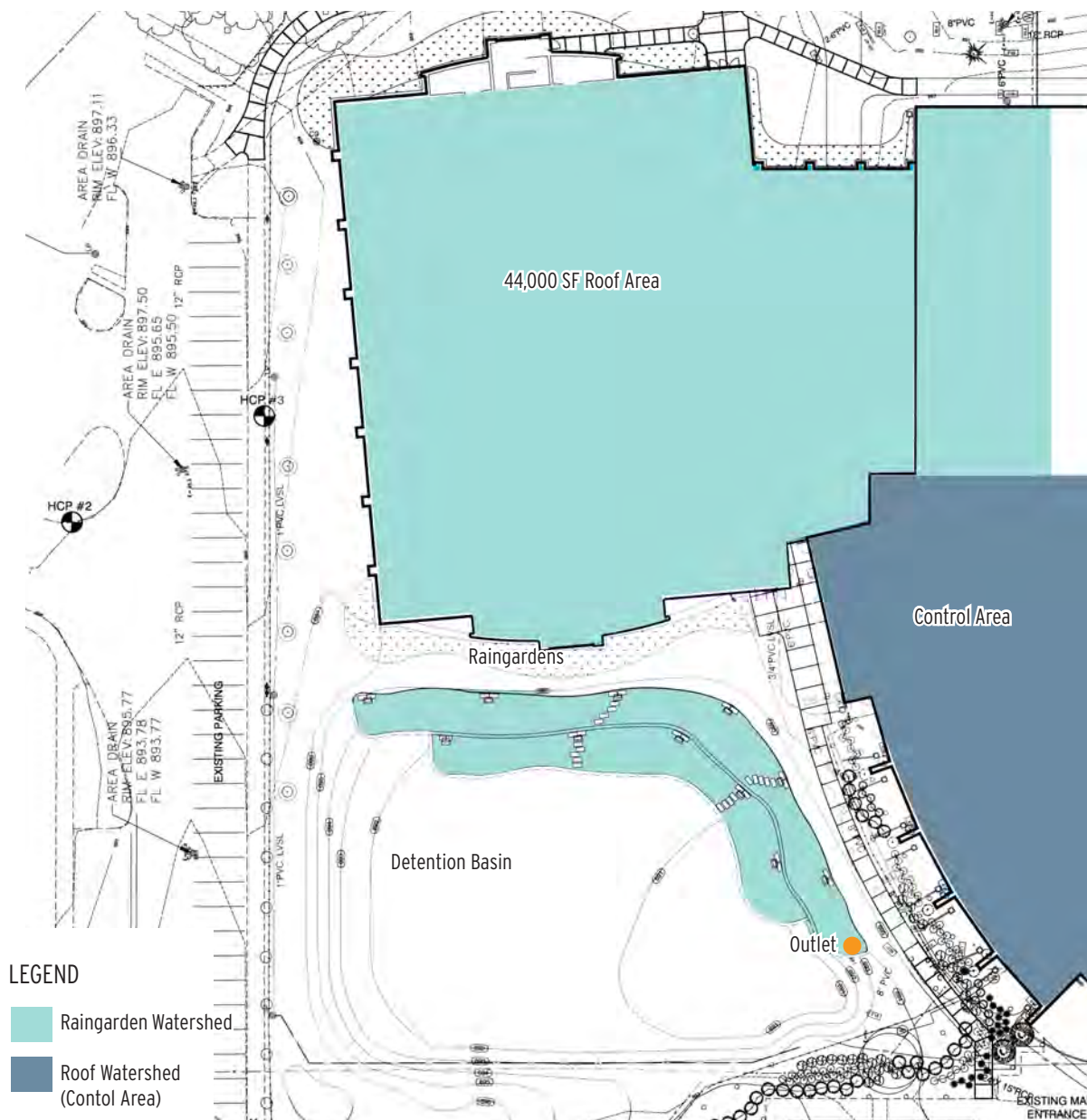


Figure 5.5 Watershed - Building Roof Drainage to Detention basin



## PROJECT DETAILS

## STORMWATER SYSTEM DESCRIPTION (CONT.)

Figure 5.7 illustrates how water flows through the site to end up at the outlet near the southeast corner of the site. In the BMP watershed, runoff from the roof flows through 8-inch drain pipes into nyloplast manhole structures. These structures are level spreaders which disperses water to eleven (11) outlet points

within the rain garden. To help reduce erosion, stones at each pipe outlet slow water flow. As shown in Figure (5.9), the nine-inch stones buffer views of the outlet pipes, and help dissipate energy of water flow. Dispersing the water over a large area also reduces the possibility of erosion and increases opportunity for infiltration.

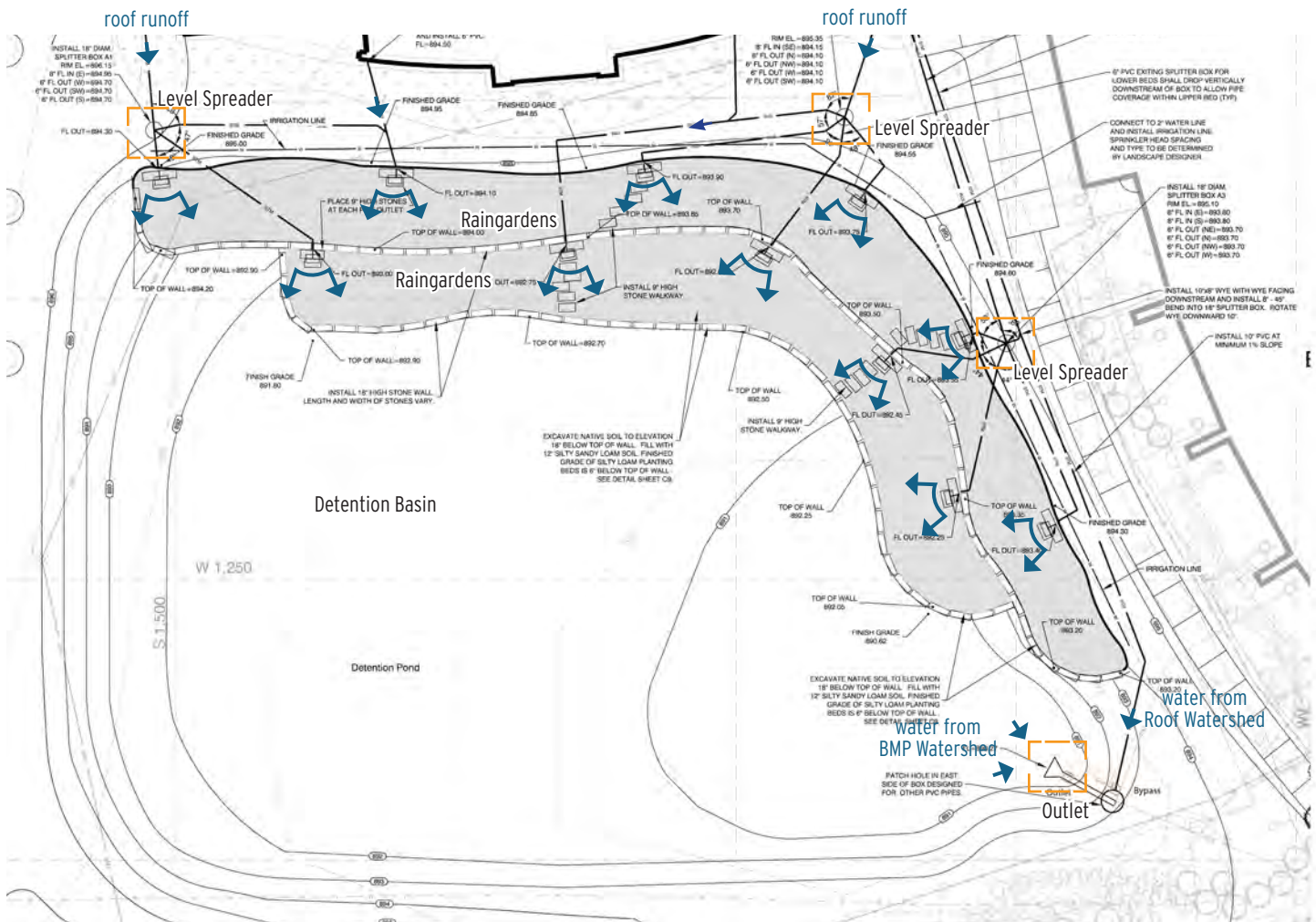


Figure 5.6 Water Flow

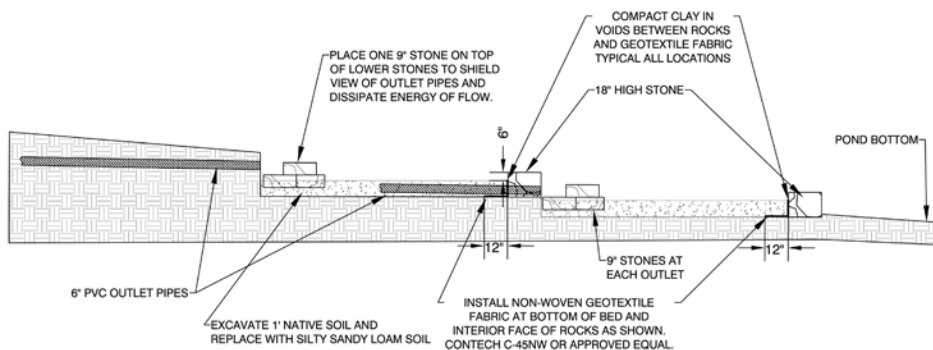


Figure 5.7 Rain garden Section at Pipe Outlets

Figure 5.8 shows the 8-inch drain pipe connecting to the nyloplast manhole structure [level spreader]. The manhole disperses runoff into four separate 6-inch PVC pipes towards different locations within the raingarden. Figure 5.9 and 5.10 show the system successfully installed.

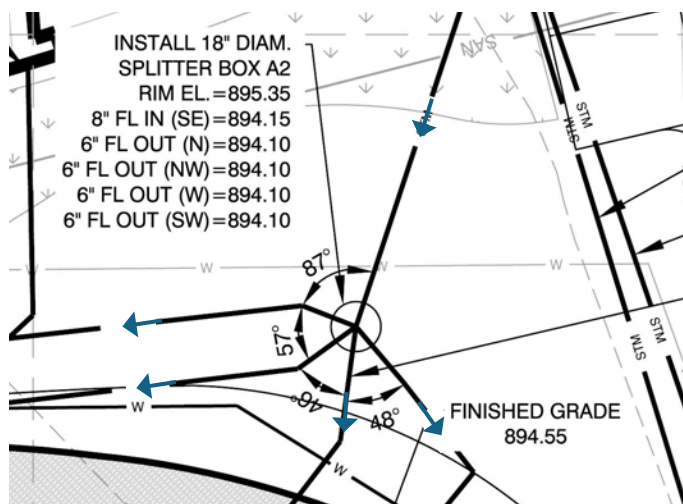


Figure 5.8 Enlarged Detail of Level Spreader

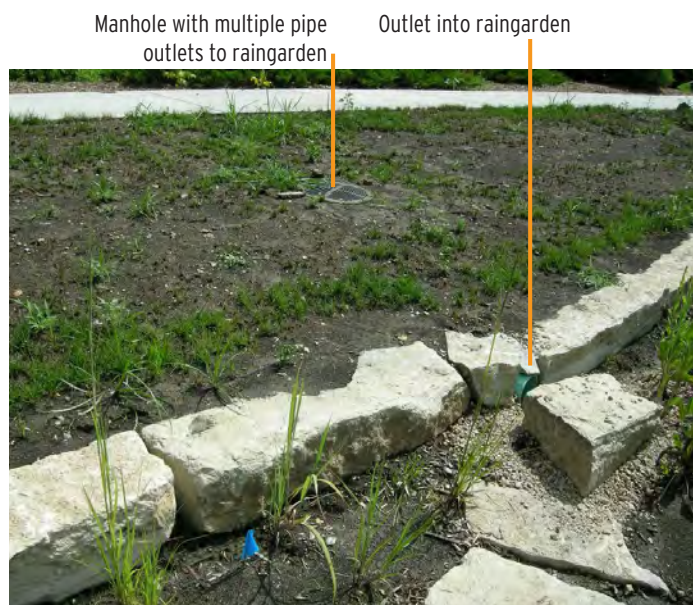


Figure 5.9 Level Spreader Manhole and Outlet (2009)



Figure 5.10 Level Spreader Outlet (2010)





## PROJECT DETAILS

### STORMWATER SYSTEM DESCRIPTION (CONT.)

Figure 5.11 locates the two ISCO samplers near the outlet to the storm sewer. One ISCO monitoring station takes samples of water from the BMP Watershed; the other ISCO station samples water from the roof watershed. A detailed section of the outlet

shows how the ISCO monitoring stations are attached to the outlet to obtain the necessary water samples (Figure 5.12). The Tipping Bucket shown in Figure 5.11 is a rain gauge that automatically records rainfall data, rates, times, and duration.

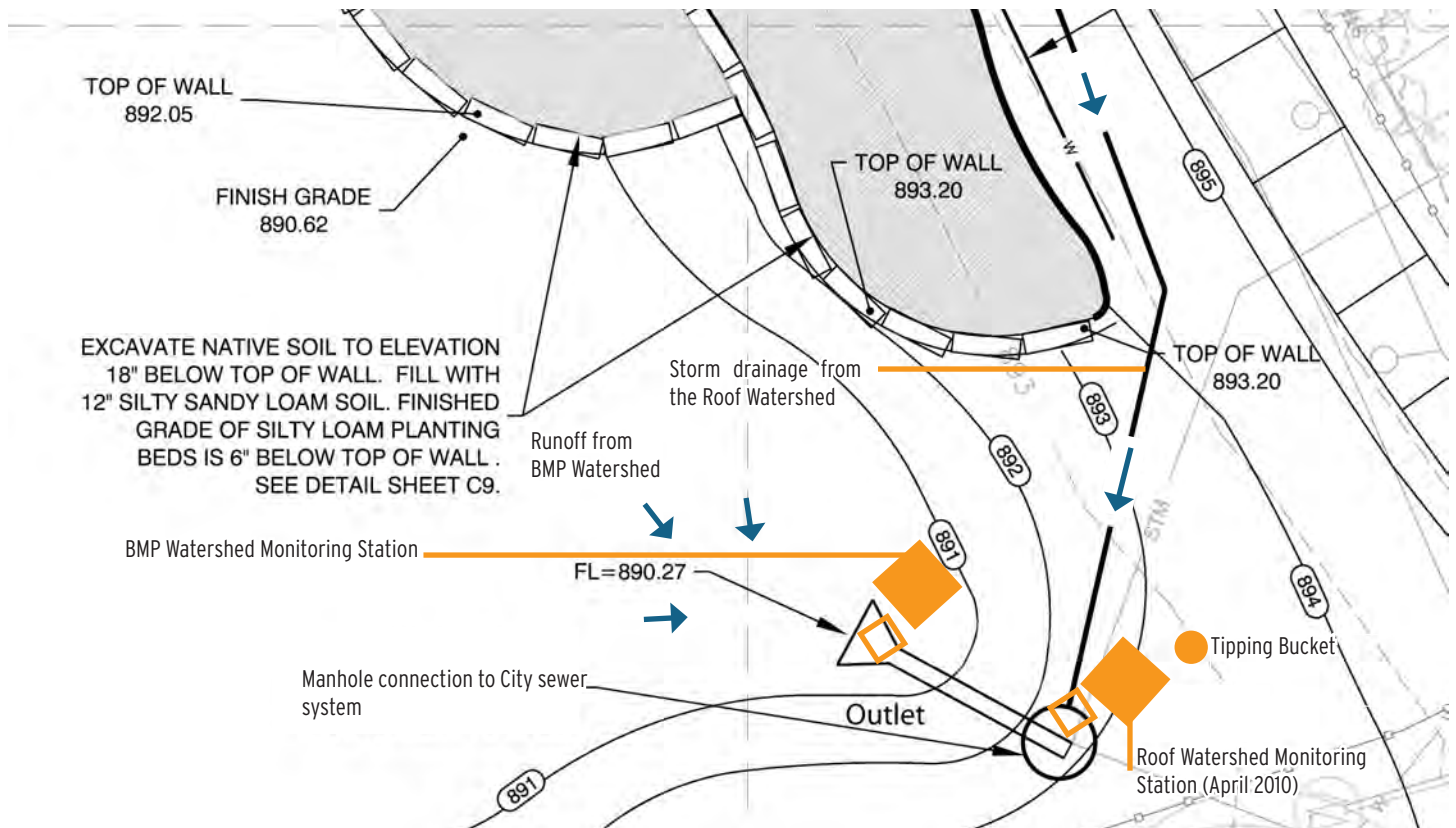


Figure 5.11 Monitoring Equipment

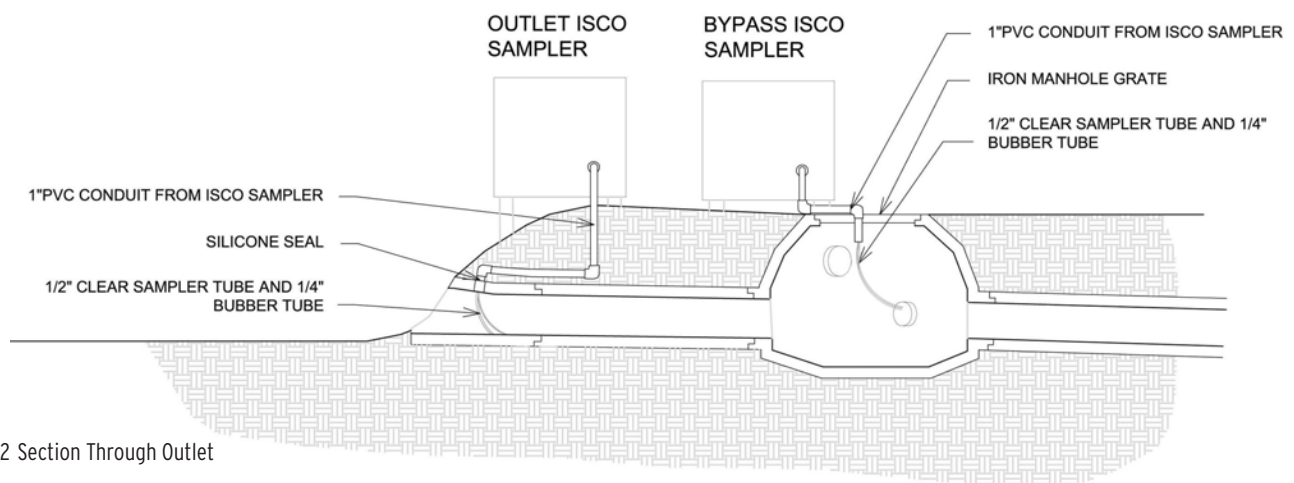


Figure 5.12 Section Through Outlet

## PRECIPITATION

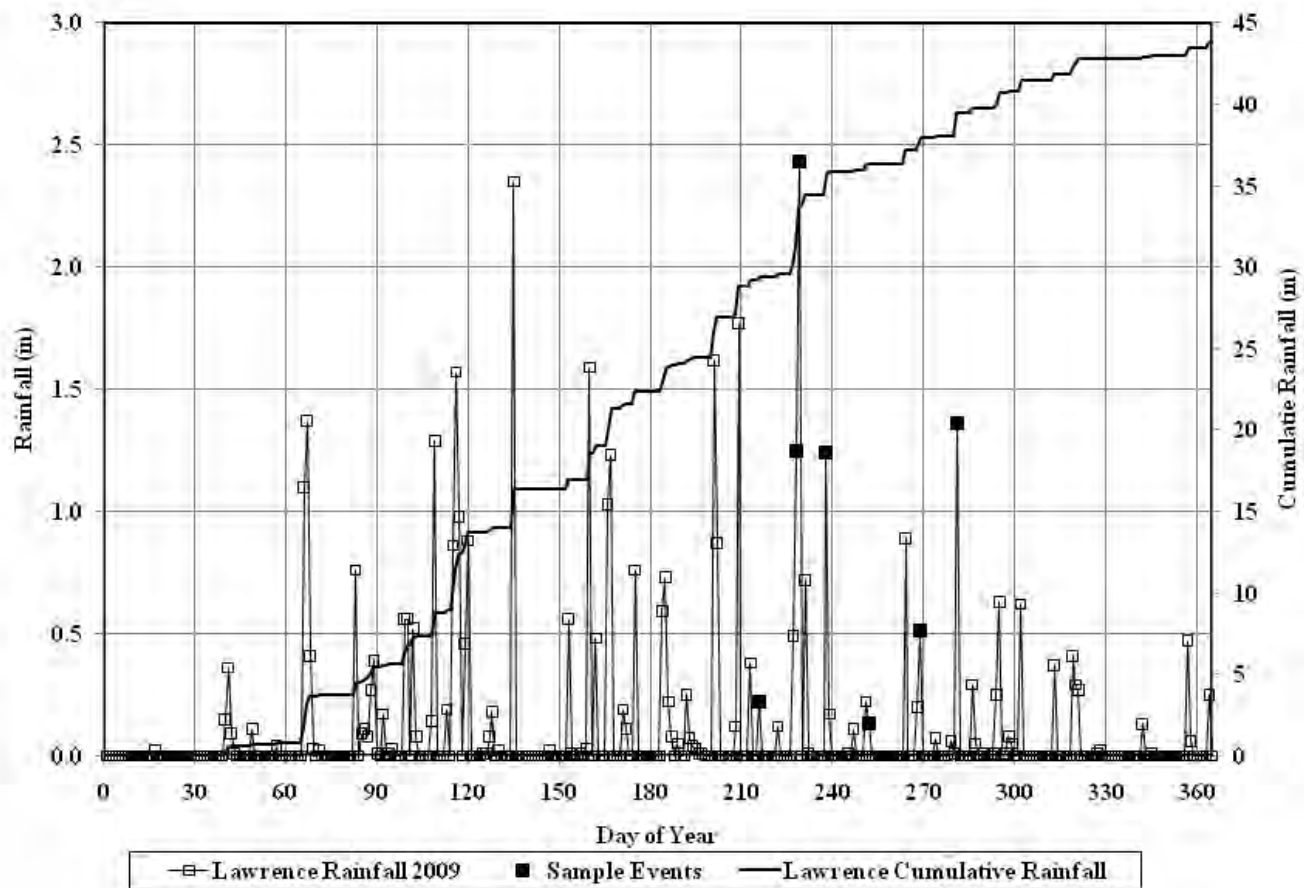


Figure 5.13 Precipitation Summary (2009)

Daily rainfall events and the cumulative rainfall recorded at the Lawrence, Kansas site are shown in Figure 5-45. Rainfall events during which samples were collected are highlighted.

## PRECIPITATION

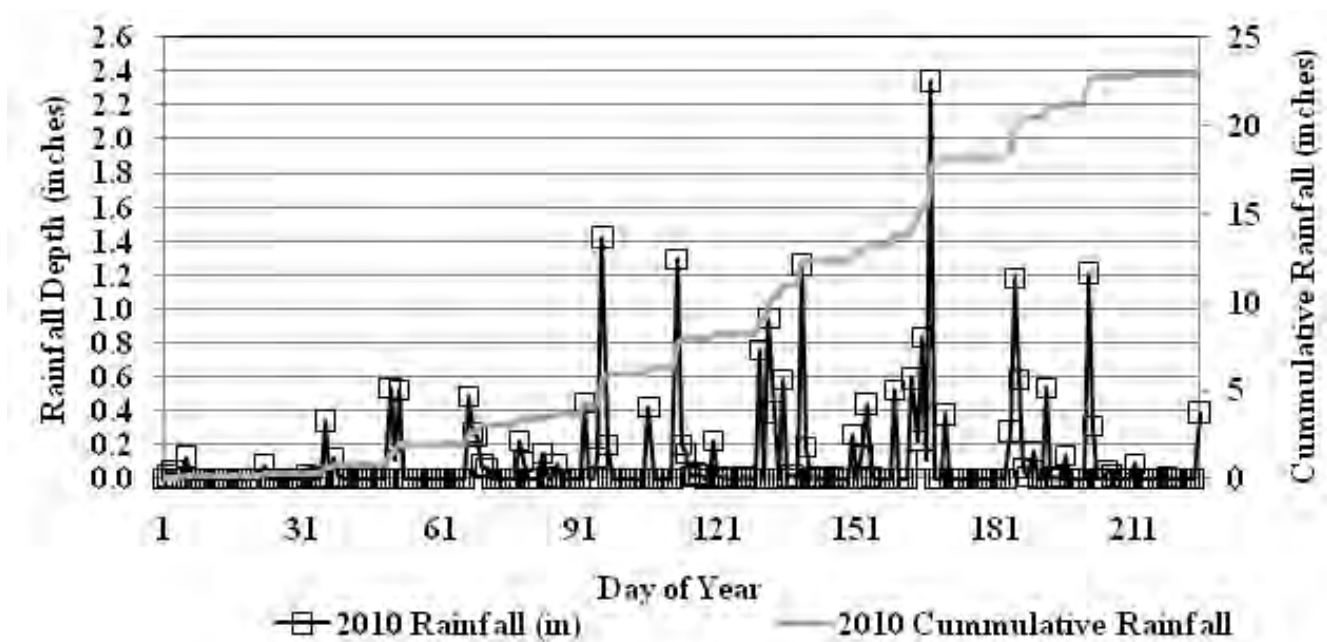


Figure 5.14 Precipitation Summary (2010)

## SOIL/INFILTRATION

The raingardens incorporate 12 inches of bioretention soil mixture surrounded by limestone boulders. The infiltration rate is about 0.40 inches per hour when the raingardens started out dry.

The general effect of the raingarden on slowing runoff from the site was estimated by reviewing rainfall and sampling records and comparing the time rainfall started to the time water discharged from the raingarden. When the raingardens were dry, there was a lag time of about an hour and twenty minutes between the start of rainfall and the time water discharged from the raingarden. When

there had been an inch or more of precipitation the prior day and site soils were wet, the time to runoff was 50 to 70% shorter. The results suggest that raingardens and similar BMPs can significantly slow the stormwater runoff from a site such as this, compared to conventional infrastructure. Travel times over a similar distance through pipes would likely have taken minutes, rather than over an hour.

## VEGETATION

The 5,200-square-foot rain garden has 18 native species planted on two terraces bounded by large cut stone. The native plant species were chosen for their adaptability to the site. The vegetation was planted in 2009. After two growing seasons, the plants are well established. These plants have a deeper root depth when compared to the fescue planted detention, which suggests they will help improve infiltration over time as their root systems continue to expand.

Plant selection was critical. The plants needed to be able to withstand drier conditions than traditional raingardens (where water ponding is possible).

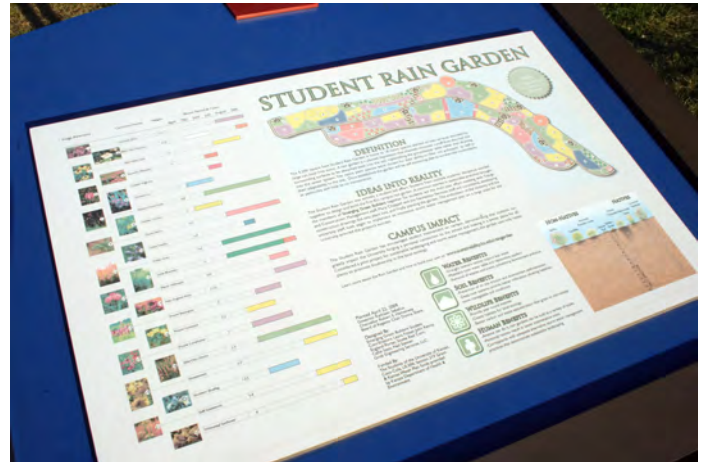


Figure 5.15 Educational Signage

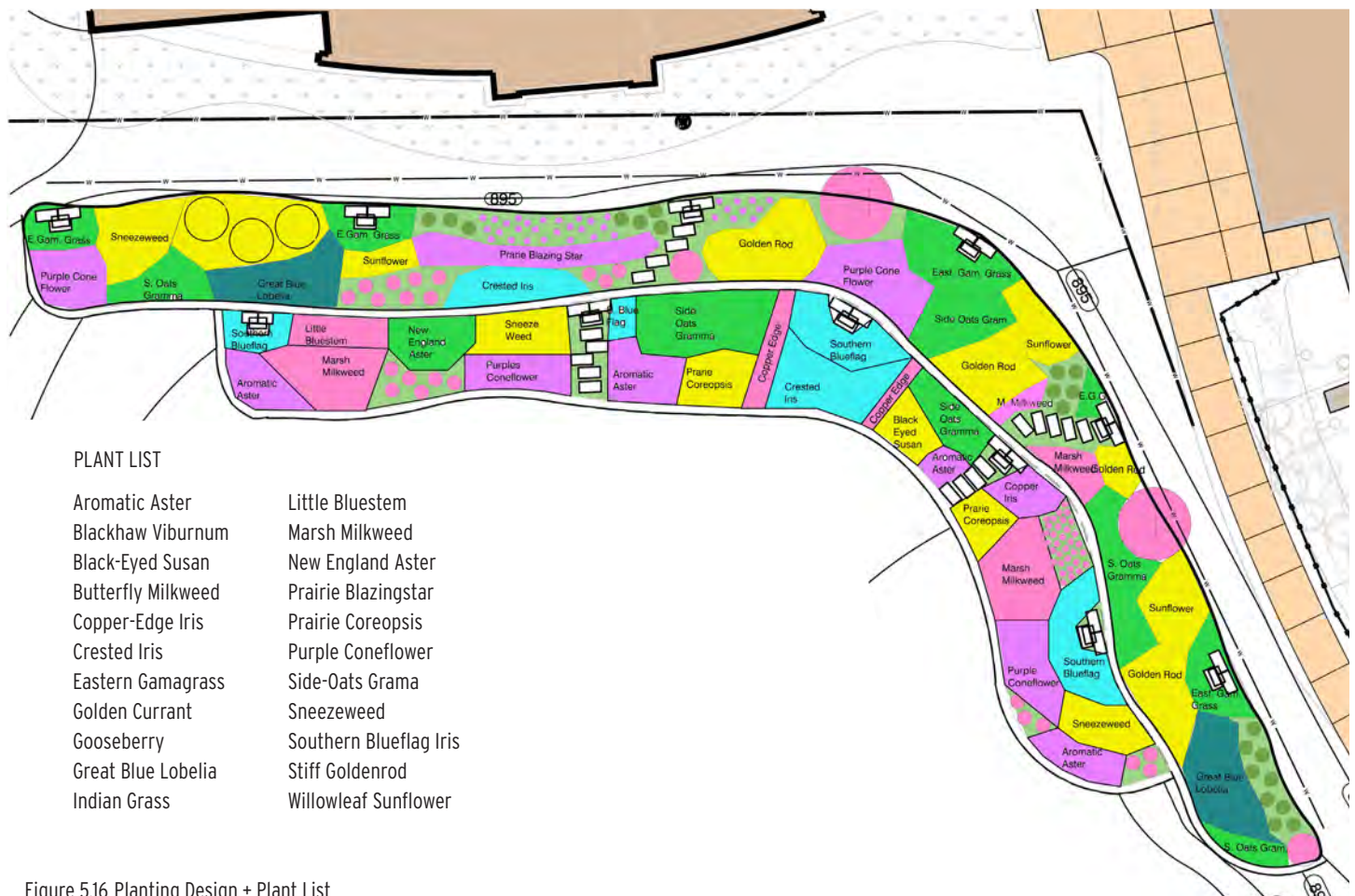


Figure 5.16 Planting Design + Plant List



## MONITORING ANALYSIS

### VEGETATION



Figure 5.17 Planting (Fall 2010)

## MONITORING ANALYSIS

### WATER QUALITY

University of Kansas BMP												
Rain Event	Event	Notes	Precip	TN ppm	TP ppm	Zn ppm	Cl ppm	S ppm	pH	EC µS	TSS	EColi
8/4/2009			2.11	0.48	1.07	0.01	7.7	ND	7.3	149	34	0
8/18/2009			3.68	1.12	0.18	ND	1.2	ND	6.7	72	59	0
8/18/2009			3.68	0.93	0.008	0.05	1.1	ND	6.6	33	9	0
8/26/2009			1.24	0.72	0.05	ND	1.6	ND	7.5	172	34	0
9/9/2009			0.35	3.1	0.09	ND	0.8	0.77	6.7	85	47	0
9/26/2009			0.51	0.82	0.2	ND	2.5	ND	7.4	107	23	0
10/8/2009			1.36	0.27	0.09	ND	0.8	ND	7.4	112	38	0
4/2/2010	1	First Flush	0.45	1.29	0.04	ND	8.3	0.42	7.74	29	128	0
4/27/2010	2	First Flush	0.04	1.37	0.07	ND	5.30	5.13	7.45	132	4	0
5/13/2010	3	First Flush	0.39	2.70	0.19	ND	7.10	2.49	7.36	116	28	17
5/19/2010	4	Not in Journal	1.26	2.77	0.08	ND	6.90	4.21	7.49	128	214	56
6/1/2010	5	First Flush	0.13	2.71	0.21	ND	0.72	0.35	7.82	191	180	229
6/2/2010	6	First Flush	0.44	1.12	0.05	ND	0.15	1.44	7.62	119	36	6
6/8/2010	7	Composite	0.52	1.16	0.09	ND	0.26	1.16	7.51	83	24	0
6/16/2010	8		2.34	No Sample								
7/4/2010		Composite	1.18	0.86	0.05	ND	2.70	3.44	7.64	126	183	859
7/8/2010		Composite	0.16	2.29	0.15	0.03	7.50	0.67	7.22	31	31	172
7/11/2010		Composite	0.53	2.39	0.28	0.05	6.40	0.58	7.05	24	47	0
7/21/2010	9	Composite	0.31	1.85	0.15	ND	2.60	1.31	7.51	74	24	15

Table 5.1 BMP Water Quality Data

University of Kansas Roof												
Rain Event	Event	Notes	Precip	TN ppm	TP ppm	Zn ppm	Cl ppm	S ppm	pH	EC µS	TSS	EColi
4/5/2010			0.68	1.55	0.06	0.03	8.30	0.42	7.74	29	128	0
4/27/2010	2	KU Roof	0.04	1.39	0.06	0.01	8.50	0.13	7.13	28	52	0
5/13/2010	3		0.39	2.15	0.10	0.02	7.20	0.64	7.10	36	36	140
5/19/2010	4		1.26	2.42	0.06	0.03	7.30	0.58	7.08	31	73	286
6/1/2010	5	Composite	0.13	3.63	0.24	0.02	0.17	1.23	7.32	63	116	2022
6/2/2010	6		0.44	No Sample								
6/8/2010	7	Composite	0.52	1.67	0.12	0.01	0.17	0.62	7.04	63	28	1002
6/16/2010	8	Composite	2.34	1.73	0.09	0.01	0.16	0.13	6.44	20	24	372
7/21/2010	9	Composite	0.31	No Sample								

Table 5.2 Roof Water Quality Data

\* Note: the roof monitoring site will be activated in April 2010.

#### Legend

Precipitation (in)  
 TN total Nitrogen (mg/l)  
 TP total Phosphorus (mg/l)  
 Zn Zinc (mg/l)  
 Cl Chloride (mg/l)  
 S Sulfur (mg/l)  
 EC Electro Conductivity (↔S)  
 TSS total suspended solids (mg/l)  
 ND = Not detectable (less than .01 mg/l Zn, S, Cl, TN and TP)

#### CONCLUSION

The raingarden reduced TN and TP levels. TSS levels were relatively low coming off the roof and were generally unchanged by the raingarden. Runoff did export low levels of chloride and sulfur.



## WATER QUANTITY

### SOIL MOISTURE

The following figure shows the soil moisture within the raingarden. A soil core was taken for the entire 12-inch depth of engineered soil. A moisture test was conducted approximately monthly (as shown by the black boxes). The black horizontal line represents soil moisture at 1/3 bar (not quite full saturation). The blue line represents the results from the Modified Penman Equation. This equation estimates the amount of water available for grasses. The equation takes into account components of evapotranspiration. As the blue line nears the 1/3 bar, the basin is considered saturated and runoff is expected. Overflows out of the raingarden were expected from about day 61 (March 1st) through about day 171 (June 20th).

### CONCLUSIONS

The design of the raingardens with elevated terraces separated by limestone boulders could allow water to be released through the rock walls after stormwater events pass. Plant selection is critical for this site, which is drier than more traditional raingardens (where water ponding is possible).

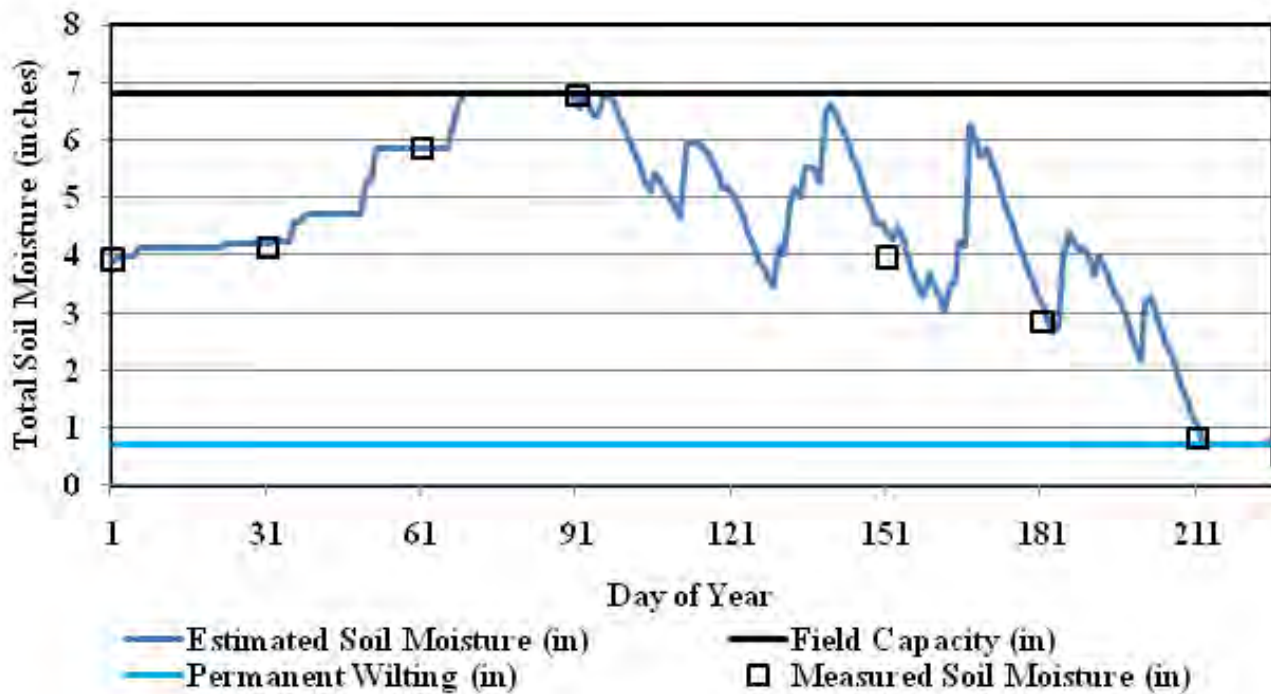


Figure 5.18 Soil Moisture (2010)

## MONITORING ANALYSIS

## MAINTENANCE

- Weeding: Weeding operations occurred monthly during the growing season with a substantial weeding operation occurring in August 2010.
- Chemicals: No chemicals or pre-emergent was needed.
- Irrigation: Supplemental watering was provided during drier conditions. Water was provided by hand watering from adjacent quick couple locations.
- Plants: Additional plugs were planted in the Spring of 2010 to replace the plants that did not survive the first fall and winter.
- Mulch: The project was mulched with hardwood in the Spring of 2010.
- Sedimentation: Sediment accumulation was minimal since the runoff was from roof surfaces. An adjacent construction project occurred in 2010 and a silt fence was maintained to prevent sedimentation of the raingardens.
- Reseeding: The detention basin was aerated and reseeded in August of 2009.

## COST TO BENEFIT ANALYSIS

- A landscape contractor constructed the raingarden in Spring 2009 for a cost of \$51,000. Their scope included providing and connecting all the drainage piping, all site work, providing and placing the rock walls, providing the soil mix and turf seeding around the rain garden.
- The cost of the plants was \$12,500. All the planting was done by volunteers.
- The plants and design provide educational opportunities (including the installed signage).
- The opportunities for erosion were reduced with the distribution of runoff (mimicking nature) from five building downspouts across eleven outlets.
- As noted previously, the time of concentration (or water flow time across the site) was greatly enhanced by the raingarden. BMPs such as this are generally installed for water quality benefits, but these results suggest that they may be able to provide flow volume or rate reductions as well. Additional monitoring and modeling would be needed to quantify such effects at this site, but the results suggest that BMPs may be able to help reduce the size and cost of conventional detention ponds when used in an integrated site design.
- Native landscaping such as used at this site can also help reduce long term site maintenance costs and site greenhouse gas emissions. Turf grass lawns in this region typically require mowing every 7 to 10 days during the growing season, plus biannual fertilizer applications.

## SIZE TO RAINGARDEN RATIO

- The roof area of at 44,000 SF compared to the infiltration area of 4,980 SF is a ratio of 11.3%. This is a good ratio for pollutant removal. Additional ponding within the raingardens would have improved the performance of the raingardens.

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## CONCLUSIONS

### LESSONS LEARNED

- Raingarden soils dry out between storm events and the design of the raingardens affects how quickly they dry out, so plants need to be selected accordingly. Raingardens are not wetlands.
- The raingarden is planted mostly with flowers. When they are in bloom it looks quite nice. Other times of the year it could potentially look somewhat weedy. Additional tall grasses might provide a more ornamental look in situations such as this.

### DESIGN RECOMMENDATIONS

- Allow a ponding depth of 4-8 inches (APWA BMP Manual). This design did not allow for significant storage of water. Additional storage of water would allow additional pollutants to settle out of runoff.
- As installed, locate BMP at least 10 feet away from building foundations (APWA BMP Manual).
- As installed, use shredded hardwood mulch (not pine or woodchips). Application of a this layer of hardwood mulch helps maintain soil moisture and also absorbs pollutants.
- 12-inch engineered soils were successful in providing a good planting medium for establishment of plants. Deeper depths of engineered soils are not expected to provide additional benefit at this site.
- This series of raingardens was designed to treat a larger drainage area than the standard which suggests a maximum of an acre runoff to the raingarden. Because the water was distributed evenly across the terraced gardens, erosion and blowout of the soils was not observed.
- As installed, compaction of surrounding soil should be minimized.

Note: To continue the development of a treatment system, the fescue detention basin should be considered being modified to a raingarden or bioretention cell with an elevated outlet structure and replacement of a portion of the fescue to wet-mesic plants.





# Conclusions

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# Conclusions

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## OVERALL RECOMMENDATIONS AND LESSONS LEARNED

- Preserve the existing landscape. The less site disturbance the better. It is easier to maintain the existing landscape than to rebuild it.
- Site development significantly disturbs site soils. Minimize site disturbance to the maximum extent possible. Greater effort also needs to be placed on restoring soil structure and organic matter before sites are vegetated, in order to help establish healthy, dense vegetation, limit weeds and erosion, and reduce the need for herbicide applications. This can be done through deep tilling/ripping, plus addition of organic matter in the form of compost, a sustainable, recycled product. This will also improve soil moisture retention for plant health, promote healthy root growth in plants, and promote stormwater infiltration across the site.
- Keep designs simple, especially in areas where BMPs are new techniques and have not been widely constructed or maintained yet. Simple designs can still be attractive and elegant. Complex designs are more difficult to build and likely will not be fully maintained.
- Off-line designs limit flow velocities through BMPs, erosion, washing out, and pollutant export. Where water flows through BMPs ("in-line" designs), distribute flows to minimize erosion.
- BMPs are most effective when they are located near the source of stormwater runoff and treat small drainage areas (less than one acre). Such an approach more closely replicates ecological form and function of the natural landscape and replicates hydrology of the natural landscape. End-of-pipe systems are more susceptible to erosion and bypass in large storm events and are less effective in replicating the hydrology and function of the natural environment. This is part of the philosophy of Low Impact Development (LID) and it is totally applicable to sustainable site design approaches as well.
- Size matters. Undersized systems will have problems. BMP design guidelines in many parts of the country recommend that BMPs be designed to capture the "Water Quality Storm Event," which is often the 90th percentile storm event. That means, over the long-term average, 90 percent of storm events are that size or smaller. This ranges from about  $\frac{3}{4}$  to  $1\frac{1}{2}$  inches in various regions of the country. At the same time, conveyance features in, out, and around BMPs need to be sized to safely pass larger storm events without damage or erosion.
- Design objectives will be different at every site, and the BMP designs can be customized to the site-specific objectives. At some sites, water quantity control (runoff volumes and rates) may be more important than water quality control. In those cases, infiltration BMPs would be preferred. In other locations, water quality issues may be more important, so the designs should be developed with pollutant removal objectives in mind.
- BMP designs can be customized to promote removal of specific types of pollutants. Some pollutants exist in particulate forms, others in dissolved forms. Pollutant removal mechanisms vary with the type of pollutant, and include sedimentation, precipitation, filtration, adsorption, biodegradation, and photodegradation. Depending on the pollutant of most concern, certain removal mechanisms can be enhanced by the design.
- Site characterization is a critical part of the design effort. Soil types and compaction, the presence of fill material, depth to bedrock and groundwater, and the presence of subsurface utilities should all be taken into account in the BMP design process.

- 
- Plant selection is important. Each BMP is different, so plants should be matched to the soil and water conditions created at each site. Take into account how long water will pond in the BMP, how deep the water will stand in the BMP, and how rapidly it will dry out. Native plants are available that are adapted to a wide range of environmental conditions; pick the plants for the conditions created at each site.
  - Some plants grow very deep root systems, which help BMP performance as plants mature. Infiltration rates into soils can improve over time as the roots grow larger and deeper.
  - BMPs do not have to be expensive to be effective. Low cost and locally available native materials can be used to create attractive and functional designs.
  - Till establishment nuisance species of plants are probable based on their quick growing cycle and lack of rooting systems. Additional maintenance should be expected to remove nuisance species until the selected plant species have established.
  - Lastly, BMPs can provide additional wildlife habitat compared to traditional mowed detention facilities.





# Appendix

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## APPENDIX A - HOW DOES RESEARCH RELATE BACK TO THE CONCERNS OF USGBC?

### SS Credit 6.1 Stormwater Design - Quality Control

#### Option 1 - Less than 50% net imperviousness

The requirement for this point has changed very little over the last decade. Version 2.0 required a no net increase in rate and quantity of stormwater runoff from existing to developed conditions. Version 2009 changes the terminology to pre-development and post development and documents the design storms required for calculations at 1- and 2-year 24-hour storms.

#### Option 2 - Greater than 50% Net Imperviousness

The requirement for this point has changed very little over the last decade. Version 2.0 required a 25% decrease in rate and quantity of runoff, where Version 2009 now ONLY requires the volume of runoff to be reduced by 25% from the 2-year, 24-hour storm (not rate).

### SS Credit 6.2 Stormwater Design - Quality Control

#### Option 1 - Less than 50% net imperviousness

The requirement for this point changed dramatically over the last decade. Version 2.0 required a treatment system to remove both 80% of the average annual post development total suspended solids (TSS) and 40% of the average annual post development total phosphorous (TP). Version 2009 deleted the requirement for phosphorous removal. In addition, the requirement was modified to require treatment of 90% of the average annual rainfall.

#### Option 2 - Performance monitoring

This option was added in Version 2009 to allow for monitoring data (conforming to accepted protocol) demonstrating compliance with the criteria.

A) The research agrees that the removal of the total phosphorous was appropriate. Some Best Management Practices such as bioswales allow runoff to pickup phosphorous and carry it if they are undersized for the drainage area.

B) Table 2 on page 104 of Version 2009 LEED Reference Average and Probably ranges of TSS Removal. Based on this report's findings, the following the sand filter matched the range and average removal rates for TSS (Average 80%, Range 60-90%). The wetland results are expected to improve as the site is stabilized.

C) Future LEED Credits should focus on the successes of Best Management Practices. Quantity and quality of runoff can dramatically be improved at the typical storm events. If the volume of runoff is maintained based on 90% rain events, the quality of water will be improved and ultimately the natural hydrology maintained.

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## APPENDIX B - DESIGN MODIFICATION

The following is a summary of design modifications as determined from this research.

- a. Performance of a BMP can be improved by restoring compacted site soils, specifically adjacent to the BMP facilities. Uncompacted area allow for improve subsurface water movement and infiltration.
- b. Best Management Practices can be designed for easy installation of monitoring equipment. BMPs that require sheet flow across large areas are hard to monitor and require weirs and other structural additions. Simple pipes in and out of BMPs allow runoff to be easily monitored.
- c. BMPs that are interconnected and tied together in sequence perform substantially better than individual BMPs. The connected sediment forebay and sand filter improved water quality. (Once the wetland is established with emergent plants, it is expected that the third level of filtration will be improved.)
- d. The cost for BMPs doesn't have to be substantial or take away from usable land or public space.
- e. Most BMP sites are not designed for stormwater monitoring. Design of BMPs should consider the Inlet and Outlet elevations to prevent water from pooling within pipes. If water backs up in the pipes, it muddles the monitoring data.
- f. Design of BMPs with Inlet and Outlet orientations in horizontal configurations (such as culvert and storm sewer piping) provide easy access to monitoring equipment at tie in locations. Vertical drops in water flow can cause turbulence, making it tough to record actual water flow volume.
- g. Materials - Mulch is prone to floating, clogging outlet structures and sampling tubes. Coarse, shredded mulch will float less than chips or nuggets. Small check dams may be used to help keep mulch in place.

There were some potential problems observed, but they were corrected where feasible. They included:

- a. Leaf debris created a blockage at the Sediment Trap IN location. To reduce the opportunity for this a strainer was added.
- b. For smaller drainage/roof areas, the time of concentration could be less than five minutes. This means that the first flush of runoff can reach the sampling location prior to the collection of the first sample. Thus, it is possible to miss some of most contaminated runoff, which is assumed to occur within the first flush.
- c. Even under the best circumstances, the accuracy of flow measurements can have an estimated +/- 10% accuracy.
- d. Common maintenance problems such as detached tubing, dead battery, or clogged sensor can result in loss of data. This is also one of the reasons we compare flow/drainage area/rainfall data to isolate or reduce discrepancies.

## APPENDIX C - SOIL TEMPERATURE

The following figure shows the soil temperature as monitored in northeast Kansas (about 90 minutes from the Kansas City metropolitan area). The below soil moisture was measured at a depth of two inches. Around day 91 (April 1st) the soil temperatures rise to 60 degrees and warm season plants start to grow.

### Summary

For the first three months and last two months of the year, warm season grasses and wildflowers are not actively growing, so transpiration will be limited during those time periods. However, water will still infiltrate into site soils through the root zones, and organic matter in soils, vegetation, and mulch will still adsorb and filter pollutants. Consequently, vegetated BMPs will perform best during active growing seasons, but can help reduce stormwater flows and filter pollutants all year.

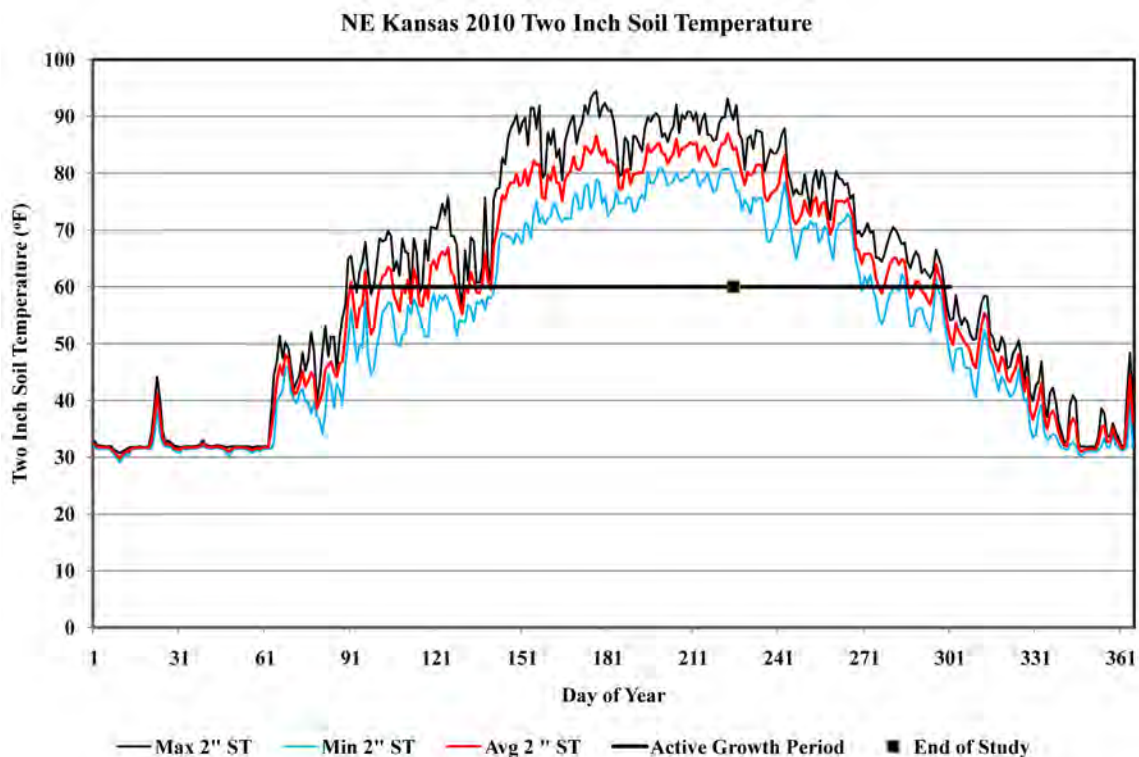


Figure 7.1 2010 NE Kansas Soil Temperature



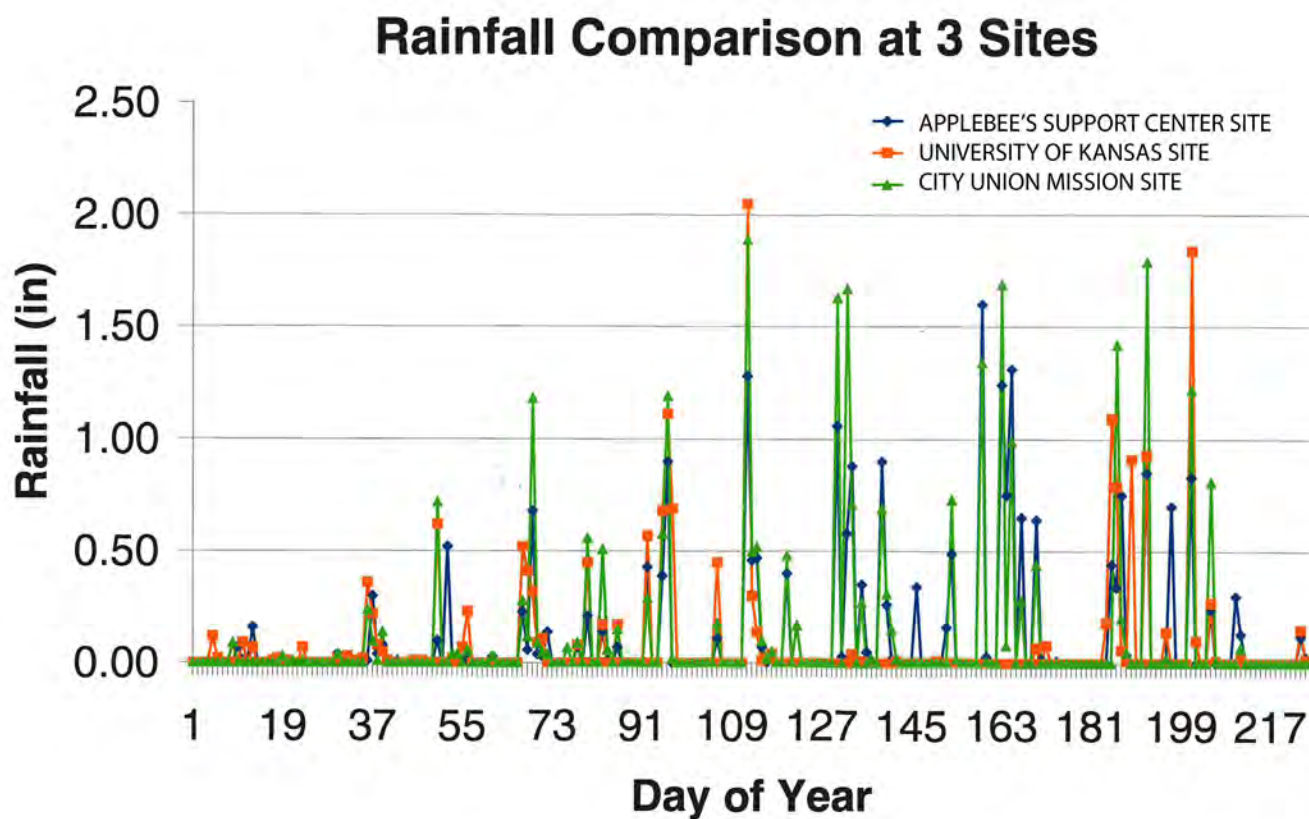


Figure 7.2 Comparison of Rain Events at Three Sites

This shows a comparison of the rain events occurring in 2010 from the different sites. All of the sites are within a 50 minute drive of each other. The chart illustrates how rainfall intensities can vary across even small areas during common storm events.