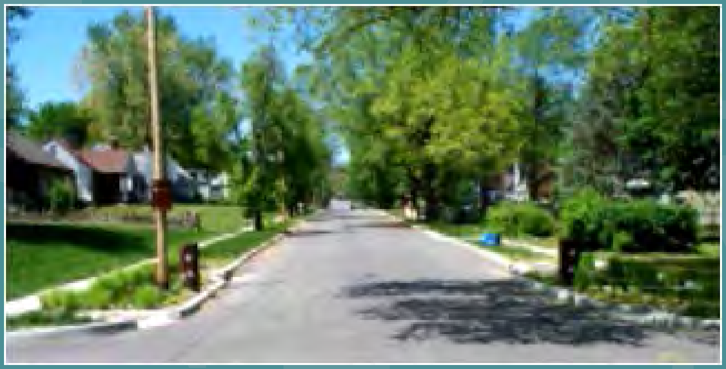
EPA/600/R-16/085 | August 2016 | www.epa.gov/research

United States
Environmental Protection
Agency

EPA's Summary Report of the Collaborative Green Infrastructure Pilot Project for the Middle Blue River in Kansas



Office of Research and Development
National Risk Management Research Laboratory
Water Supply and Water Resources Division

EPA/600/R-16/085
August 2016

EPA's Summary Report of the Collaborative Green Infrastructure Pilot Project for the Middle Blue River in Kansas City, MO

Compiled by:

Michelle Simon
National Risk Management Research Laboratory
Water Supply and Water Research Division
U.S. Environmental Protection Agency
Cincinnati, OH 45268

EPA/600/R-16/085
August 2016

Notice/Disclaimer

The United States Environmental Protection Agency, through its Office of Research and Development, funded and conducted the research described herein under an approved Quality Assurance Project Plan (Quality Assurance Identification Number W-10162). This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Any mention of trade names or commercial products does not constitute endorsement or recommendation for use.

EPA/600/R-16/085
August 2016

Foreword

The United States Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, US EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) within the Office of Research and Development (ORD) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments, and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

Cynthia Sonich-Mullin, Director
National Risk Management Research Laboratory

Abstract

The United States Environmental Protection Agency evaluated the performance of a hybrid green-gray infrastructure pilot project installed in the Marlborough Neighborhood by the Kansas City Water Services Department. Within the consent decree signed in 2010, Kansas City Water Services Department committed to completing pilot projects to construct distributed green infrastructure in select areas. Kansas City installed 135 vegetated storm control measures including 24,490 square feet (~2.275 m^2) of porous or permeable pavement and 292,000 gallons (1,100 cubic meters) of underground storage. Collectively these green and hybrid green-grey infrastructure solutions received drainage from about 54% of a total the 100 acres (40.5 hectare) that made up the pilot study area. The United States Environmental Protection Agency (EPA) evaluated the monitoring of the performance of this stormwater management pilot project. Independently, both the EPA and Kansas City determined that the green-gray combined infrastructure reduced the sewer flow volume in the combined sewer by approximately 30% after the installation of green infrastructure for the study area.

EPA studied nine individual storm control measures to evaluate hydraulic flow rates. A subset of four sites were also studied for water quality parameters. Inlet water pH ranged from 5.0-10.2, outlet water pH ranged from 6.5-7.9. Fecal coliform concentrations were unexpectedly high, with concentrations often above the upper detection limit of 6 million colony forming units per 100mL for both inlet and outlet water. Analyzed influent samples ranged from 5-31 µg/L total copper, <25-151 µg/L total zinc, and <50-61 µg/L total lead. Only one outlet sample produced enough water to make a total copper measurement which was 15 µg/L. Dissolved metal concentrations were below detection limits (<5 µg/L copper, <25 µg/L zinc, and <50 µg/L lead) for inlet and outlet water samples.

The measured soil infiltration rate was greater than the design rate (1.0 inch/hour; 2.54 cm/hour) resulting in very little overflow from the individual stormwater runoff control measures. There were eight effluent flow events of sufficient volume at one location to allow comparisons of inlet and outlet water quality. On average, there was a decrease in concentration from influent to outlet, for turbidity (37%), total suspended solids concentration (52%) and mean particle average diameter (21%). There was only one storm event at this location of great enough magnitude to compare inlet versus outlet nitrate and phosphate values. The nitrate and phosphate concentrations decreased by 52% and 56.5%, respectively for that storm.

Acknowledgements

The primary contributors and/or authors of this work are:

Michelle Simon, Ph.D., P.E., EPA
Brenda Groskinsky, EPA
Richard Field, P.E., EPA
Dustin Bambic, P.H., Tetra Tech
Deborah O'Bannon, Ph.D., P.E., University of Missouri, Kansas City
Robert Pitt, P.E., Ph.D., D.WRE, University of Alabama, Tuscaloosa
Scott Struck, Ph.D., P.E., formerly of Tetra Tech
Jason Wright, P.E., Tetra Tech

This project is the culmination of efforts of many contributors. Mr. Richard Field was the original EPA Project Officer of this study from 2008 to 2012 and Dr. Michelle Simon became EPA Project Officer from 2012-2015.

Dr. Michael Ports of Mid-America Regional Council was instrumental in initiating and interpreting this project since 2008.

Many capable Tetra Tech Staff members worked on this endeavor, notably Dr. Scott Struck, Tetra Project Manager from 2009 to 2012, and Messrs. Dustin Bambic and Jason Wright from 2012 to 2013.

Professor Deborah O'Bannon of the University of Missouri – Kansas City, and Professor Robert Pitt of the University of Alabama – Tuscaloosa, and their students were instrumental in the project from 2012-2014. Dr. Leila Talebi of the University of Alabama, provided invaluable analyses of the stormwater hydrology and runoff calculations.

Mr. Francis Reddy and Ms. Padmavathi (Pria) Iyengar of the Kansas City Water Services Department provided crucial information on the Kansas City green infrastructure plans and implementation. Mr. David Dods of the URS Corporation (AECOM) and several staff members of Burns and McDonnell, contractors to the Kansas City Water Services Department, provided critical information on the design and construction of the green and gray infrastructure of this project.

Mses. Kerry Herndon, Mandy Whitsitt, and Brenda Groskinsky of EPA Region 7 provided valuable facilitation and coordination of the project. The EPA Region 7 analytical laboratory performed the metal and nutrient analyses on the stormwater samples. Other water quality analyses were performed by the University of Missouri – Kansas City and Alabama – Tuscaloosa.

Mses. Josephine Gardiner and Marilyn Dapper assisted in manuscript preparation.

Table of Contents

Appendix B - National Demonstration of Integration of Green and Gray Infrastructure in Kansas City, Missouri – A Pre-performance Summary Report September 2011.

Appendix C - Advanced Drainage Concepts for Using Green Solutions for CSO Controls 2012 Summary Report.

List of Figures

List of Tables

Acronyms and Abbreviations

AVG	Average
BMP	Best Management Practices
CF	Cubic feet
CFU	Colony Forming Unit
CFS	Cubic feet per second
CSO	Combined Sewer Overflow
CSS	Combined Sewer System
DOI	Digital Object Identifier
EPA	U.S. Environmental Protection Agency
GI	Green Infrastructure
KCMO	Kansas City, Missouri
KCMOWSD	Kansas City Water Services Department
MAX	Maximum value
MIN	Minimum value
N	Number of samples
NRMRL	National Risk Management Research Laboratory
NTU	Nephelometric Turbidity Units
OCP	Overflow Control Plan
ORD	EPA's Office of Research and Development
pH	negative logarithm of the hydrogen ion
Region 7	U.S. EPA, Region 7
Rv	inch runoff/inch rain
SCM	Storm Control Measures
SSC	Suspended Solids Concentration
SSO	Sanitary Sewer Overflow
SSS	Sanitary Sewer System
SU	Stand Units for pH
SUSTAIN	System for Urban Stormwater Treatment and Analysis INtegration
SWMM	StormWater Management Model
TSS	Total Suspended Solids
Tt	Tetra Tech, Inc.
UA	University of Alabama - Tuscaloosa
UMKC	University of Missouri – Kansas City
URS	URS, Inc.
WinSLAMM	Source Loading and Management Model for Windows
WQ	Water Quality
WSD	Water Services Division
WWF	Wet Weather Flow

Executive Summary

In 2010, Kansas City, Missouri signed a consent decree with the United States Environmental Protection Agency (EPA) on combined sewer overflows (CSOs). Kansas City proposed to use adaptive management to implement green infrastructure (GI), in lieu of, and in addition to gray structural controls. Kansas City installed 135 stormwater control measures (SCMs) — primarily bioretention units—in a 100-acre pilot area, the Kansas City Middle Blue River Green Infrastructure Pilot Project, plus an additional 292,000 gallons (1,100 m^3) of underground storage. The EPA and Kansas City each independently determined that the green-gray combined infrastructure reduced the volume of runoff in sewer flow by approximately 30% in the combined sewer after the installation of GI (Talebi 2014). EPA Office of Research and Development evaluated the installation and performance of the KC GI from 2009-2013.

From 2009 to 2013, 112 storm events were monitored for hydrologic and hydraulic performance. Originally, it was planned to compare the 100-acre pilot area to an adjoining 83-acre control area under the same storm conditions but problems with measurement of sewer flows in the 83-acre control area precluded analyzing these flows. Therefore, sewershed flows measured before SCM construction were compared with flows post-construction at the 100-acre site from 2010 to 2011. An additional complication to this study was the fact that Kansas City suffered a drought in the summer of 2012.

Only about half of the total area was directed to the retrofitted bioretention units due to unexpected difficulties in constructing SCMs in many of the proposed locations. For example, many relief sewers were extended to backyard areas to solve local flooding and ponding problems. These inlets were located on private property and we could not access the inlets to install SCMs during this program. Other locations hindered construction of SCMs because of interferences due to driveways and large trees.

Nine of the 135 public right-of-way bioretention devices were monitored for water flows during the project. Precipitation, inflow, and outflow values were used to calibrate the empirically based WinSLAMM (Source Loading and Management Model for Windows, version 10.0; Pitt 1986) water quality model. Many of the details of the work performed by EPA and contractors can be found in Appendices B and C. The soil infiltration rate measured was more (1.0inch/hour) than expected for the soils and these individual storm control measures had very little overflow. WinSLAMM modeled, performed by the EPA team, and XPSWMM Modeling by the Kansas City Team both indicated that the total sewershed flow was reduced by 30% by the addition of the GI.

Four of the nine SCMs were sampled for water quality parameters. Inlet water pH ranged from 5.0-10.2, outlet water pH ranged from 6.5-7.9. Fecal coliform concentrations were unexpectedly high, with concentrations often above the upper detection limit of 6 million colony forming unit per 100mL for both inlet and outlet water. Analyzed influent samples ranged from 5-31 µg/L total copper, <25-151 µg/L total zinc, and <50-61 µg/L total lead. Only one outlet was sampled for total copper (15 µg/L). Dissolved metal concentrations were below detection limits (<5 µg/L copper, <25 µg/L zinc, and <50 µg/L lead) for inlet and outlet water samples.

There was very little overflow from these four SCMs. Only eight storm events, at one location produced effluent underdrain discharges of sufficient volume to allow comparisons of inlet and outlet water quality. For the eight storms that that produced inflow and outflow that was measured, there was a decrease in concentration from influent to outlet: for Nephelometric Turbidity Units (37%), total suspended solids (52%) and average diameter particle size (21%). There was only one storm event of great enough magnitude where inlet versus outlet nitrate and phosphate could be compared at this location. The nitrate concentration was reduced by 52% and phosphate concentration reduced by 56.5% for that storm.

Preface

The United States Environmental Protection Agency's (EPA) Office of Research and Development's (ORD) Aging Water Infrastructure Research Program was initiated in 2007 and focused on the advancement and demonstration of innovative technologies and techniques; the goal was to reduce cost, while providing improvement in the effectiveness of operation, maintenance, and replacement of aging and failing drinking water and wastewater infrastructure (Murray 2009). A strategy within the research program was to leverage outside entities such as municipalities, universities, and associations, utilizing their technical expertise and facilities, thereby enhancing the program's research capabilities and investments through cooperation and collaboration.

In the late 1900's, it was well known that wet-weather flow (WWF), or the storm-induced discharges from nonpoint sources, such as combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs), were a leading cause of water quality impairment in the United States' rivers and streams (EPA 1999). As such, improving the Agency's ability to control the overflow continues to be an EPA priority. Municipalities need low-cost, innovative technology to reduce the overflow events. One such innovation is the use of green infrastructure (GI). GI mimics natural processes by directing stormwater to areas that allow storage, infiltration, and evapotranspiration.

Critical research questions that continue to be current are:

1. How do we integrate green and gray infrastructure approaches?
2. How do we determine what locations are best suited for GI?
3. How are GI practices evaluated?
4. Are the GI costs beneficial when compared to gray approaches?
5. And finally, what are the operational and maintenance requirements of using GI?

EPA's Collaborative Green Infrastructure Pilot Project for the Middle Blue River in Kansas City, MO

1.0 Background

On April 19, 2007, United States Environmental Protection Agency (EPA) Administrator Stephen Johnson signed a "Statement of Intent" with state, environmental, and wastewater utility groups to formalize the use of green infrastructure (GI) for water management. In support of the agreement, several nationally focused research projects were initiated by EPA's Office of Research and Development (ORD), including a pilot GI study located in Kansas City, MO. Notably, Kansas City had, and continues to have, a strong commitment focused on the use of GI as a solution for stormwater management (EPA 2007). The city council for Kansas City adopted a resolution in 2007, "establishing the policy of the City to integrate green solutions protective of water in our City planning and development processes in a comprehensive Wet Weather Solutions Program" (KCMO 2007, 2008).

The goal of the collaboration between ORD, Region 7, Kansas City, and their partners, was to implement a pilot project to demonstrate the efficacy of integrated GI-based solutions to wet weather flow (WWF) and resulting pollution problems in combined sewer systems (CSS) located in a suburban neighborhood of Kansas City. This included the demonstration and assessment of multiple "green" practices, monitoring quality and quantity of flows, modeling efficacy at multiple scales of implementation, and conducting economic analyses comparing traditional (i.e., gray) with green approaches. ORD, Region 7, and Kansas City were also interested in the facilitation of local and regional resources for implementation of the project, including development of an approach to identify and prioritize green solutions, development of partnerships at neighborhood, watershed, and regional levels, and the provision of community outreach and coordination.

2.0 The Project

The Kansas City, MO Water Services Department (KCMOWSD) provides wastewater treatment and stormwater services for 653,000 customers and 27 different communities that cover a total of 420 square miles (KCMOWSD 2009). The area serviced by KCMOWSD includes both sanitary sewer systems (SSS) and CSS with the CSSs covering 58 square miles. The city has 90 CSS discharge locations with overflows into the Blue River, Brush Creek, Kansas River, and Missouri River. CSOs in the Blue and Missouri Rivers resulted in water quality impairments from increased bacteria levels. In 2009, the KCMOWSD developed an Overflow Control Plan (OCP) for the combined sewer overflow (CSO) with an extensive overhaul of the sewer and stormwater systems with anticipated completion in twenty-five years and $4.5 billion cost in 2008 dollars (KCMOWSD 2009). An overall goal established in the 2010 CSO consent order with the EPA was to capture seven overflow events per year, which equate to capture of about 88% of a typical year wet weather flow through the sewer system. Prior to these new controls, a typical wet weather overflow volume was 11.64 billion gallons/year (44 million cubic meters) for Kansas City. The overflow volume of the new system is required to be 1.4 billion gallons/year (5.3 million cubic meters).

KCMOWSD planned to install a two-million-gallon storage tank with a 1.4 million gal/day pumping station, a 51 million gallon/day screening treatment plant, and to replace tens of thousands of linear feet of sewer pipe for a cost of $30.6 million in the Marlborough Neighborhood. KCMOWSD later determined that GI implementation in the Middle Blue River basin could result in a more cost effective mechanism to achieve overflow control than the originally planned approach. Because KCMOWSD's analysis revealed potential benefits of GI and there was strong interest expressed by the neighborhood, Kansas City selected the Marlborough neighborhood, on the eastern side of Troost Avenue, as a location to install the pilot GI project.

In 2009, as the first course of action, KCMOWSD relined the aging and leaking sewer pipe infrastructure. Approximately 17,000 linear feet of damaged and leaking CSSs were rehabilitated and more than 70 manhole structures were repaired or replaced within the pilot project area. Prior to the pilot, the neighborhood did not have curbs or gutters. As part of negotiation for the implementation of pilot project in their neighborhood, residents requested KCMOWSD repave the streets and put in curbs and gutters. This increased the volume of stormwater runoff entering the CSS, especially since the newly relined sewer pipes were no longer leaking (Simon et al. 2014).

In 2010-2012, KCMOWSD installed a distributed GI system in the public right-of-ways within the Marlborough neighborhood. KCMOWSD installed 135 vegetated storm control measures (SCMs), 24,490 square feet of porous or permeable pavement, and 292,000 gallons (1,100 cubic meters) of underground storage space in the residential neighborhood (KCMOWSD 2013). Originally, KCMOWSD planned to install storage for 360,000 gallons (1,500 cubic meters) of stormwater, but were unable to do so due to physical limitations of the site.

The installed SCMs included:

- 81 Rain Gardens
- 53 Bioretention units
- 1 Bioswale (2,000 ft^2 or ~186 m^2)
- 24,490 ft^2 (~2.275 m^2) of porous concrete sidewalk
- 5,070 ft^2 (~471 m^2) of permeable paver sidewalk installed on Troost Avenue next to the Marlborough Neighborhood.

3.0 Methodology

ORD's study objective was to quantify the sewer flow of the system before and after installation of SCMs and underground storage. KCMOWSD contemplated a "green only" project to replace the tank, pipe, and other traditional gray structures but XPSWMM modeling indicated additional storage was needed to manage storm events.

XPSWMM (http://xpsolutions.com/software/xpswmm/) is a commercial software package based on EPA's public domain model SWMM (Stormwater Management Model https://www.epa.gov/water-research/storm-water-management-model-swmm). Therefore, a hybrid green and gray infrastructure project was installed. The area of study included two CSO outfalls (069 and 059) that drained a 744-acre area (KCMOWSD 2013).

ORD along with Tetra Tech, Inc. (Tt), the University of Missouri-Kansas City (UMKC), and the University of Alabama (UA), monitored the sewershed flow for the 100-acre GI pilot area in SE Kansas City, MO, and compared its flow both before and after the GI was installed. ORD intended to compare volumetric flow in the 100-acre pilot area sewershed to a nearby 83-acre sewershed that would have the same weather conditions (Talebi 2014).

Sewershed flow was measured for both areas using an ISCO 2150 area-velocity sensor (Teledyne-ISCO Lincoln, NE). Per ISCO's webpage (http://www.isco.com/products/products3.asp?PL=2021010): "The 2150 Flow Module uses continuous wave Doppler technology to measure mean velocity. The sensor transmits a continuous sound wave, then measures the frequency shift of returned echoes reflected by air bubbles or particles in the flow." However, low flow levels and high particulate concentrations in these sewers lead to multiple sensor failures during the sampling period (2009 to 2013). These compromised data in the three control areas rendered them unusable.

GI installation was completed in 2012, but during that summer, Kansas City, and much of the surrounding region, suffered a drought (Appendix B). Therefore, it was necessary for ORD to extend the monitoring period for another year, beyond the original intent, to obtain adequate data.

Because compromised sewer flow data in the 83-acre control area could not be used, it was decided to compare at the pilot study area sewer flow volumes before installation of GI to those after installation. The before flows from 69 storm events (3/23/2009 - 6/16/2010) were compared to the after GI installation flows (37 storm events; 04/07/2013 - 10/31/2013). Between June 2010 and June 2012, sewers were relined in the pilot study area, but only six storms produced enough data for analyses. The technical team realized the before and after flow data had significant overlap and were not statistically different. Thus, they were combined and used to represent the baseline value for a total of 75 storm events. The runoff for the pilot site was estimated from calibrated WinSLAMM (http://winslamm.com/) results.

Runoff for the pilot watershed was calculated to be 0.18 in stormwater runoff per inches of rain. This represents a 32% reduction in runoff when compared to before installation of GI. The result is consistent with the estimated 36% reduction reported by KCMOWSD from XPSWMM modeling (KCMOWSD 2013). A detailed description of these WinSLAMM analyses can be found in Talebi (2014).

4.0 Stormwater Runoff Modeling Background

Stormwater runoff modeling using WinSLAMM was performed by UA as a subcontractor to Tetra Tech. WinSLAMM is the windows application of the SLAMM (Source Loading and

Management Model) model. WinSLAMM empirically correlates stormwater runoff for SCMs under various conditions. The output parameter of WinSLAM is Rv, the ratio of an inch of runoff from an area to an inch of rainfall that falls onto it.

Table 1 Summary of Statistical Comparisons of Before and After GI Facility Construction Pilot Area (from Talebi (2014)).

Monitoring Period	Dates Corresponding to Monitoring Period	Number of Monitored Storms in each Monitoring Period	Flow Weighted Rv values Rv = inch runoff/inch rain	Percent Change between First Monitoring Period and the Second
Initial Baselining and After Relining	3/23/2009-6/16/2010 and 2/24/2011-3/192011	75	0.26	-32.3% ($p<0.001$)
After Construction	4/7/2013-10/31/2013	37	0.18	

(p from Mann-Whitley Rank Sum Test)

The key finding of the WinSLAMM analysis is that installing GI reduced the total flow from the 100-acre pilot test reduced by 30%, in spite of the repair of the leaking sewer pipe and the installation of the curb and gutters, which made drainage in the watershed more efficient. This result is consistent with the XPSWMM modeling performed by KCMOWSD. KCMOWSD's XPSWMM modeling indicated that the peak flow would decrease by 76% (KCMOWSD 2013), which may be adequate to reduce the CSO flows from this area. It was not possible for EPA to record CSO volume from the 100-acre pilot area during this study period.

Table 2 KCMO XPSWMM Results (from KCMOWSD (2013)

	Pre-existing Conditions XP SWMM Model		Calibrated BMP Model		Difference	
Location	Peak Flow (cfs)	Total Volume (cf)	Peak Flow (cfs)	Total Volume (cf)	Peak Flow (%)	Total Volume (%)
Pilot Area Outlet	12.1	108,000	2.9	69,000	-76.0	-35.9
CSO 069	45.0	184,000	30.9	133,000	-32.2	-27.8

EPA studied the hydrology of nine locations: 1324 East 76th Street, 1325 East 76th Street, 1419 East 76th Street, 1612 East 76th Street, 1336 East 76th Street, 1141 East 76th Terrace Street, 1222 East 76th Terrace, and 1112 East 76th Terrace. It was planned to measure a tenth location, but the equipment was accidently removed before measurements could be taken. The precipitation, inflow, and outflow volumes are presented in Appendix B. Talebi modeled these individual storm control measures using WinSLAMM (Talebi 2014).

5.0 Land Use and Subcatchment Drainage Area Determination

In order to use the WinSLAMM modeling environment, several data sets needed to be collected, which include characterization of land use, soil infiltration, and meteorology. ORD/UA/UMKC identified land use of specific parcels in the 100-acre pilot area with surveys of each of the 600 residential plots and the commercial areas. The land was characterized based on each of three traits: 1) commercial or residential, 2) pervious or impervious, and 3) vegetated or non-vegetated, so that their respective runoff characteristics could be established (Figure 1). Detailed information concerning roof drains and paved area connections were included in the on-site surveys conducted by UMKC graduate students during the summer of 2011. Soil infiltration tests were conducted throughout the area during this period. In addition to an extensive study of land-use for the Middle Blue River, Tt and UA did topographical surveys to determine the drainage area of each individual SCM (Figure 2). Illustrated in Figure 3 are the specific SCMs utilized (e.g., bioretention, porous pavement, bioswale, rain garden) and their respective drainage acreage. KCMOWSD placed as many SCMs as possible due to the physical constraints of the neighborhood. Approximately 54% of the area was tributary to SCMs.

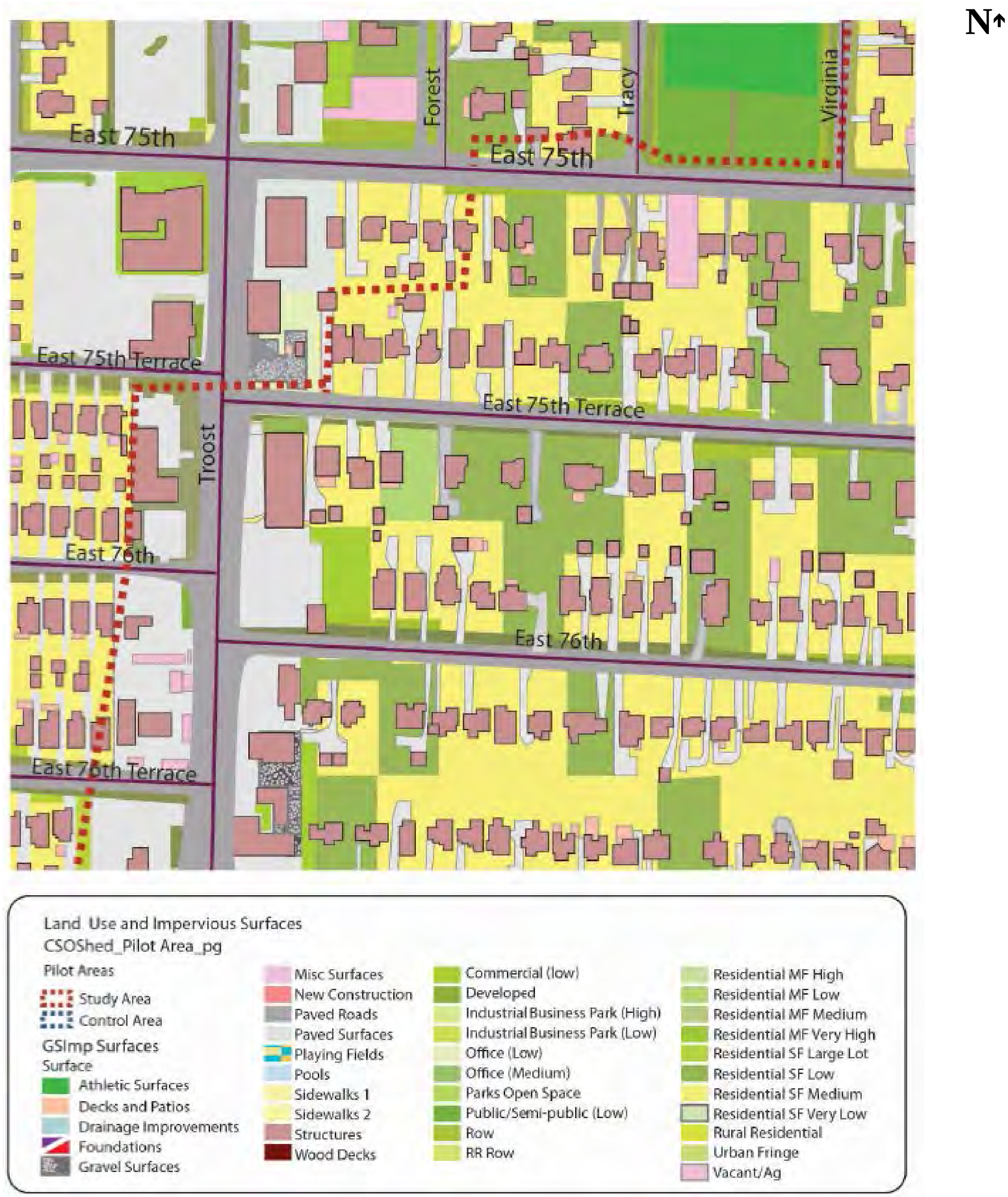


Figure 1 - Land Use Map

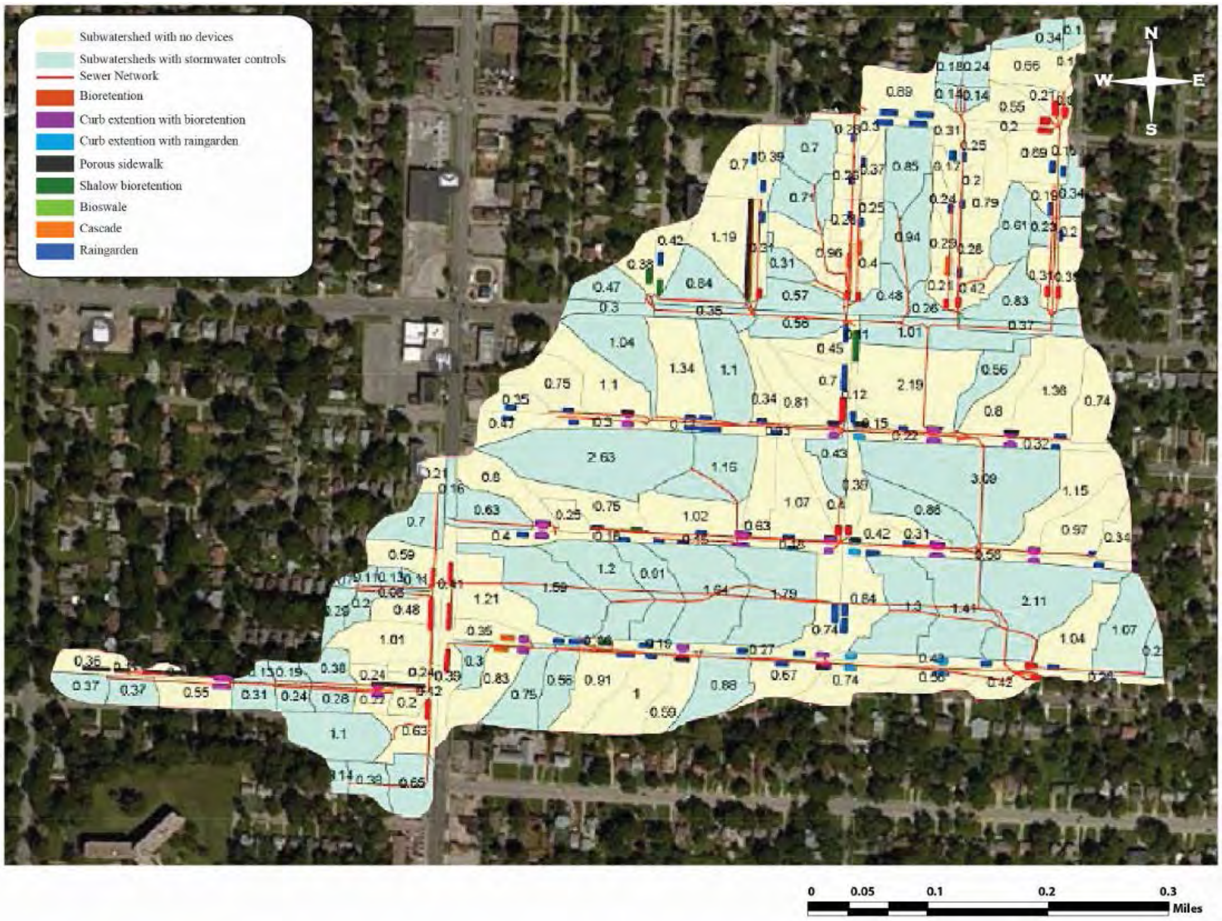


Figure 2 - Drainage Area Determination.

6.0 Soil Infiltration

UMKC measured soil infiltration rates in triplicate at six locations, for 18 individual infiltration tests. The details of the soil infiltration methods are presented in Talebi (2014). The measured infiltration rate plots are presented in Figure 3. Each symbol in Figure 3 represents a specific location in the Marlborough neighborhood. The saturated infiltration rates were higher than expected, approximately 1.0 inch/hour (Figure 3). The original estimate for soil infiltration in the initial CSO XPSMM modeling was measured to average 0.3 inch/hour.

Originally, the majority of the residential streets in the neighborhood did not have curbs and gutters. Some residents complained of standing water in many locations due to poor drainage. As such, sewer relining, along with the installation of curbs and gutters, helped to prevent problems of standing water. It was encouraging to note that the overall runoff volume decreased after the GI practices were installed, as the increased drainage efficiencies that were associated with the installation of the sewer pipe relining and new curbs and gutters were expected to increase runoff volume.

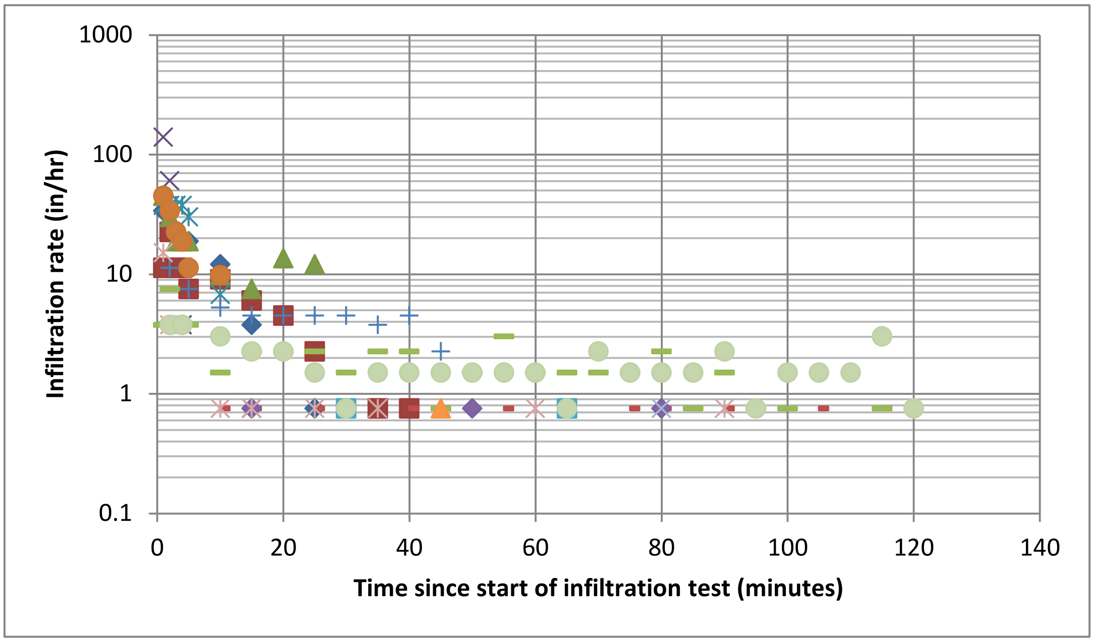


Figure 3 - Soil Infiltration Rates - Each symbol represents a location in the Marlborough Neighborhood

7.0 Water Quality

EPA measured water quality parameters at four public right-of-way locations: 1222 East 76th Terrace, 1324 76th Street, 1325 East 76th Street, 1419 East 76th Street. A 3700 series ISCO automatic sampler (http://www.isco.com/products/products3.asp?PL=201101030) was placed at each of these four locations. A broad set of stormwater quality parameters (pH, turbidity, fecal coliform, total nitrogen, nitrate, total phosphorous, phosphate, copper, zinc, lead, total suspended solids (TSS), suspended sediment concentration (SSC), median particle size (d_{50})) were measured in SCM inlet and underdrain outlet flows at four GI curb bump-out bioretention devices. Fifteen storm events produced enough water to be monitored for inflow water quality in at least one of the four bioretention devices during the 2012-2013 calendar years. The storms ranged from 0.4 to 2.6 inches total event rainfall depth.

UMKC, UA, and EPA's Region 7 Laboratories performed water quality analyses. Appendix A contains water quality data results, analytical methods and the laboratory performing the analysis. Often, there was not enough water collected to perform all analyses. In general, water quality data are very consistent among the four locations, probably due to their close spatial proximity and consistent land use. However, pH results do show some variance (Table 3). All data were submitted to the International BMP Database (http://www.bmpdatabase.org/).

Most of the stormwater infiltrated with very little overflow or underdrain flow from any of the SCM devices studied. At only one location, (1222 East 76th Street, and during eight of the 15 storms where water samples could be collected), was there flow in the underdrain available to compare with the inlet water quality with any statistical rigor. There were three storm events at 1419 East 76th Street and one storm at 1324 76th Street where there was an outflow. The fact that only 53% of the storm events produced any measureable discharge at this location is likely because the individual bioretention devices were effective at infiltrating and storing the wet weather flow (i.e., seven storm events generated rainfall totals that exceeded the design storm size of 1-inch).

The pH of the inlet water ranged from 5.0 to 10.2 and the outlet water ranged from 6.5 to 7.8. Fecal coliform concentrations were unexpectedly high, with concentrations often above the upper detection limit of 6 million CFU of organisms/100mL. Nitrate as N concentrations for all locations were very low, less than 7 mg/L, and most were below the detection limit of 1 mg/L. All phosphate concentrations for all locations were very low, less than 2 mg/L and most were below the detection limit of 1 mg/L (Table 5). All dissolved copper concentrations were below 5µg/mL detection limit. All dissolved zinc concentrations were below the detection limit of 25 µg/L. All dissolved lead was below the detection limit of 50 µg/L. Statistics were calculated assuming that value was equal to the detection limit, whether it was upper or lower.

8.0 Conclusions

In 2010, Kansas City, MO signed a consent decree with EPA to resolve combined sewer overflows. The City proposed to use an adaptive management approach in order to utilize GI in lieu of, and in addition to, gray structural controls. KCMO installed 135 GI stormwater control measures—primarily bioretention units—in a 100-acre pilot project named the Kansas City Middle Blue River Green Infrastructure Pilot Project. This pilot is one of the largest retrofitted GI areas in the United States. ORD and EPA Region 7 collaborated with the KCMOWSD to conduct long term monitoring efforts to quantify (GI) performance at two scales: site scale (individual SCMs) and pilot project (100-acre) scale.

EPA collected sewershed flow data before and after installation of GI, and performed evaluations of land use, soil infiltration, area served, and individual bioretention unit performance. Site-scale elements of the GI project included stormwater monitoring systems at nine individual SCMs (rain gardens and bioretention cells with underdrains) dispersed throughout the pilot area. Parameters measured included inflow, infiltrated volume, bypassed flow, and drawdown times. In addition, a subset of SCMs were monitored for water quality parameters including particle size distribution, bacteria counts, nutrient concentration, and metal concentration.

Only about half of the total flows were tributary to the bioretention GI devices due to property restrictions and other interferences. Including these devices at the time of original development, or redevelopment, would be much more effective as they could be designed as an integral part of the drainage system rather than a retrofit. Even with the reduced treatment of the total area flows, WinSLAMM model results for the pilot area estimate a 30% decrease in Rv ratios after GI installation. The flow reductions are consistent with the XPSWMM model results presented by KCMOWSD. KCMOWSD’s modeling also predicted installation of SCMs would reduce peak flows by 76%. Few data were available for direct observation of water quality improvements due to the large amount of infiltration at the test locations.

Nine individual storm control measures were studied for hydraulic flow rates and water quality parameters. The soil infiltration rate was measured to be higher (1.0 inch/hour) than expected and these individual storm control measures produced very little overflow. There were eight storm events at one location that produced effluent discharges of sufficient volume to allow comparisons of inlet and outlet water quality. Inlet water pH ranged from 5.0-10.2, outlet water pH ranged from 6.5-7.9. Fecal coliform concentrations were unexpectedly high, with concentrations often above the upper detection limit of 6 million CFU 100mL for both inlet and outlet water. On average, there was a decrease in concentration from influent to outlet, for national turbidity units (37% +/-15%), total suspended solids (52% +/-34%), suspended solid concentration (51% +/-24%), and average diameter particle size drop (21% +/-43%). There was only one storm event of great enough magnitude where inlet versus outlet nitrate and phosphate could be compared. The nitrate concentration was reduced by 52% and phosphate concentration reduced by 56.5% for that storm. Analyzed influent samples ranged from 5-31 µg/L total copper, <25-151 µg/L total zinc, and <50-61 µg/L total lead. Dissolved metal concentrations were below detection limits (<5 µg/L copper, <25 µg/L zinc, and <50 µg/L lead) for inlet and outlet water samples.

In conclusion, GI caused a reduction in volume of water flow into the combined sewers that should result in a reduction in contaminant mass flow into the combined sewers.

References

EPA. 1999. Preliminary Data Summary of Urban Storm Water Best Management Practices http://www.epa.gov/sites/production/files/2015-11/documents/urban-stormwater-bmps_preliminary-study_1999.pdf.

EPA. 2007. Green Infrastructure Statement of Intent. https://www.epa.gov/sites/production/files/2015-10/documents/gi_intentstatement.pdf

EPA – Kansas City Consent Decree. 2010. https://archive.epa.gov/region07/enforcement-compliance-archive/web/pdf/kcmo_ocp_cd.pdf

EPA. 2011. Report of Enhanced Framework (SUSTAIN) and Field Applications for Placement of BMPs in Urban Watersheds. EPA/600/R-11/144. http://nepis.epa.gov/Exe/ZyNET.exe/P100DEWI.TXT?ZyActionD=ZyDocument&Client=EPA&Index=2011+Thru+2015&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C11thru15%5CTxt%5C00000004%5CP100DEWI.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=p%7Cf&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL

International BMP Database http://www.bmpdatabase.org/.

Kansas City, MO (KCMO) 2007, Rooftops to Rivers. http://www.nrdc.org/water/pollution/rooftopsII/files/RooftopstoRivers_KansasCity.pdf

Kansas City, MO (KCMO) Resolution No. 070830. 2008. http://www.cleanairinfo.com/sustainableskylines/documents/Presentations/Track%205/Session%204%20-%20Stormwater%20Mitigation%20Issues%20and%20Strategies%20Part%201/03%20-%20Scott%20Cahail%20EPA%20Dallas%203-10-09.pdf

Kansas City Water Services Department (KCMOWSD). 2009. Overflow Control Plan. Revised 2012. https://www.kcwaterservices.org/wp-content/uploads/2013/04/Overflow_Control_Plan_Apri302012_FINAL.pdf

https://www.epa.gov/sites/production/files/2013-09/documents/independence-cd.pdf

Kansas City Water Services Department (KCMOWSD). 2013. Final Report Kansas City Overflow Control Program Middle Blue River Green Solutions http://www.burnsmcd.com/projects/kansas-city-overflow-control-program-management

Murray, D.J. (2009) EPA Aging Water Infrastructure Research Program: State of the

Technology for the Condition Assessment and Rehabilitation of Wastewater Collection Systems. World Environmental and Water Resources Congress 2009: pp. 1-7. doi: 10.1061/41036(342)107

Simon, M.A.; J.G. Lee; D. O'Bannon; R. Pitt; J. Wright; D. Bambic. "Update on Kansas City Middle Blue River Green Infrastructure Pilot Project" – presented to EWRI Portland, OR, June 5, 2014.

Talebi, Leila. Assessment of Integrated Green Infrastructure-Based Stormwater Controls in Small to Large Scale Developed Urban Watersheds. Ph.D. dissertation. Department of Civil, Construction, and Environmental Engineering. The University of Alabama, 2014. 620 pgs. http://unix.eng.ua.edu/~rpitt/Publications/11_Theses_and_Dissertations/Leila_Dissertation.pdf

Tertra Tech. 2011. National Demonstration of the Integration of Green and Gray Infrastructure in Kansa City, Missouri. A Pre-performance Summary Report. 9/30/2011. 98 pages.

Tetra Tech. 2013. Advanced Drainage Concepts for Using Green Solutions for CSO Control. 2012 Summary Progress Report. 63 pages.

You-tube web sites for further reference

https://www.youtube.com/watch?v=pi7WHysURGs
https://www.youtube.com/watch?v=PAxq7i1Df6s

Appendix A

Summary of Water Analyses from Individual Storm Control Measures (2012-2013)

Summary of Water Analyses from Individual Storm Control Measures (2012-2013)

EPA followed EPA Quality Assurance Plan Number W-10162 for the water analyses. EPA measured water quality parameters at four public right-of-way locations: 1222 East 76th Terrace, 1324 76th Street, 1325 East 76th Street, 1419 East 76th Street. Each of these locations contained a 6712 series ISCO automatic sampler. Stormwater quality parameters (pH, turbidity, fecal coliform, total nitrogen, nitrate, total phosphorous, phosphate, copper, zinc, lead, total suspended solids (TSS), median particle size (d_{50})) were measured in SCM inlet and underdrain outlet flows at four GI curb bump-out bioretention devices.

Table 3 Analytical Laboratories and Methods

Parameter	Analytical Reference Method	Method Detection	Laboratory
pH	YSI Meter	0.05 SU	UMKC
Turbidity	YSI Meter	0.1 NTU	UMKC
Fecal Coliform	SM 922B	100 CFU /100mL	UMKC
Nitrogen as N	SM 4500-N_{org} C	0.01 mg/L	UMKC
Phosphate as P	EPA 365.2	Total Suspended Solids	UMKC
Total Copper, Zinc, Lead	EPA 300.0	0.7 µg/L	EPA Region 7
Filtered Copper, Zinc, Lead	EPA 200.7	0.7 µg/L	EPA Region 7
Total Suspended Solids	SM 2540	1 mg/L	UMKC
Particle Size	Coulter Counter	NA	UA

Table 4 pH Analytical Results

Location	Inlet Water (SU)			Outlet Water (SU)		
	N	Min	Max	n	Min	Max
1222 East 76th Terrace Street	15	6.1	7.6	8	6.9	7.8
1324 East 76th Street	12	5.0	7.2	1	6.5	6.5
1325 East 76th Street	13	5.4	7.1	0		
1419 East 76th Street	15	6.0	10.2	3	7.2	7.7

Table 5 Turbidity Analytical Results

Location	Inlet Water (NTU)				Outlet Water (NTU)			
	n	Avg.	Min	Max	n	Avg.	Min	Max
1222 East 76th Terrace Street	14	27	6	69	8	19	6	45
1324 East 76th Street	12	27	11	62	1	93.5		
1325 East 76th Street	12	22	7	53	0			
1419 East 76th Street	15	27	7	66	3	9	3	16

Table 6 Fecal Coliform Analytical Results

Location	Inlet Water (CFU/100mL)			Outlet Water (CFU/100Ml)		
	n	Min	Max	n	Min	Max
1222 East 76th Terrace Street	10	<2 x 10^4	>6 x 10^6	3	<4 x 10^4	<2 x 10^5
1324 East 76th Street	9	<4 x 10^4	>6 x 10^6	1	>6 x 10^5	
1325 East 76th Street	10	<2 x 10^4	>6 x 10^6	0		
1419 East 76th Street	11	1.7 x 10^4	>6 x 10^6	2	<4 x 10^4	1.8 x 10^5

*6 x 10^6 CFU/100 mL was the laboratory maximum for Fecal Coliform analyses. All of the sampling locations had values above this range.

Table 7 Nitrogen as N Analytical Results

Location	Inlet Water (mg/L)				Outlet Water (mg/L)			
	n	Avg.	Min	Max	n	Avg.	Min	Max
1222 East 76th Terrace Street	14	1.9	<1	7	7	1	<1	1
1324 East 76th Street	11	1.1	<1	2	1	1	1	1
1325 East 76th Street	11	1.4	<1	5	0			
1419 East 76th Street	13	1.3	<1	5	1	1	<1	1

Table 8 Phosphate as P Analytical Results

Location	Inlet Water (mg/L)				Outlet Water (mg/L)			
	n	Avg.	Min	Max	n	Avg.	Min	Max
1222 East 76th Terrace Street	12	1.2	<1	2	7	2	1	3
1324 East 76th Street	10	1.1	<1	2	1	1	1	1
1325 East 76th Street	9	0.9	0.5	1	0			
1419 East 76th Street	12	1.1	0.5	2	3	4	<1	10

Table 9 Total Copper Concentrations Analytical Results

Location	Inlet Water (µg/L)				Outlet Water (µg/L)			
	n	Avg.	Min	Max	n	Avg.	Min	Max
1222 East 76th Terrace Street	2	20	9	31	1	15		
1324 East 76th Street	4	16	12	21	0			
1325 East 76th Street	3	13	7	22	0			
1419 East 76th Street	3	9	5	16	0			

Table 10 Total Zinc Concentrations Analytical Results

Location	Inlet Water (µg/L)				Outlet Water (µg/L)			
	N	Avg.	Min	Max	n	Avg.	Min	Max
1222 East 76th Terrace Street	2	144	136	151	1	<25		
1324 East 76th Street	4	67	<25	139	0			
1325 East 76th Street	3	69	34	130	0			
1419 East 76th Street	3	45	25	71	0			

Table 11 Total Lead Concentrations Analytical Results

Location	Inlet Water (µg/L)				Outlet Water (µg/L)			
	n	Avg.	Min	Max	n	Avg.	Min	Max
1222 East 76th Terrace Street	2	56	50	61	1	<50		
1324 East 76th Street	4	50	<50	50	0			
1325 East 76th Street	3	50	<50	50	0			
1419 East 76th Street	3	50	<50	50	0			

Table 12 Total Suspended Solids (TSS) Analytical Results

Location	Inlet Water (mg/L)				Outlet Water (mg/L)			
	n	Avg.	Min	Max	n	Avg.	Min	Max
1222 East 76th Terrace Street	15	187	30	678	7	46	14	92
1324 East 76th Street	12	215	34	825	1	149		
1325 East 76th Street	13	250	26	1128	0			
1419 East 76th Street	15	150	55	301	3	46	8	69

TSS values were the average of two duplicates.

Table 13 Particle Size

Location	Inlet Water 9 (µm)				Outlet Water (µm)			
	n	Avg.	Min	Max	n	Avg.	Min	Max
1222 East 76th Terrace Street	13	80	15	255	7	27	15	50
1324 East 76th Street	12	40	50	711	1	12		
1325 East 76th Street	12	77	15	300	0			
1419 East 76th Street	12	77	20	300	3	165	30	400

Only one outlet sample from 1222 East 76th Street on May 27, 2013, produced enough water to measure the complete suite of parameters:

Table 14 Outlet Water Analysis from 1222 East 76th Street, collected on May 27, 2013

Parameter, units	Value
pH, SU	7.25
Turbidity, NTU	6.4
Fecal Coliform, CFU/100mL	<200,000
Total Nitrogen as N, µg/L	2530
Nitrate as N, mg/L	<1
Total Phosphate as P, µg/L	700
Phosphate as P, mg/L	3
Total Copper, µg/L	15
Dissolved Copper, µg/L	6
Total Zinc, µg/L	<25
Dissolved Zinc, µg/L	<25
Total Lead, µg/L	<50
Dissolved Lead, µg/L	<50
Total Suspended Solids, mg/L	14
Suspended Sediment Concentration, mg/L	52
Particle Size, d_{50}, µm	35

Here are the percent removals for the parameters that were measurable.

Table 15 Percent Removals per Parameter from 1222 East 76th Street

Parameter, units	n	Avg.	Minimum	Maximum
Turbidity, NTU	37	8	4	57
Total Nitrogen as N, µg/L	52	1		
Total Phosphate as P, µg/L	56.5	1		
Total Suspended Solids, mg/L	52	7	-29	97
Suspended Solids Concentration, mg/L	51	7	-3.5	87
Particle Size, D_{50}, µm	21	6	-67	94

Table 16 Comparison of Inlet versus Outlet pH, SU

Location	Date	Inlet pH	Outlet pH
1222 East 76^{th} Street	9/13/2012	6.4	7.05
1222 East 76^{th} Street	4/7/2013	6.8	7.4
1222 East 76^{th} Street	4/9/2013	6.1	6.9
1222 East 76^{th} Street	5/2/2013	6.2	7.5
1222 East 76^{th} Street	5/27/2013	6.75	7.25
1222 East 76^{th} Street	5/30/2013	7.2	7.8
1222 East 76^{th} Street	6/5/2013	6.6	7.7
1222 East 76^{th} Street	6/9/2013	8.0	7.35
1324 East 76^{th} Street	5/31/2013	6.0	6.8
1419 East 76^{th} Street	8/31/2012	6.3	7.2
1419 East 76^{th} Street	11/11/2012	6.1	7.2
1419 East 76^{th} Street	4/23/2013	7.4	7.7

Table 17 Comparison of Inlet versus Outlet Fecal Chloroform, CFU/100 mL

Location	Date	Inlet Fecal Chloroform	Outlet Fecal Chloroform
1222 East 76th Street	4/9/2013	<20,000	<40,000
1222 East 76th Street	5/2/2013	>120,000	40,000
1222 East 76th Street	5/27/2013	>600,000	<200,000
1222 East 76th Street	5/30/2013	400,000	<200.000
1419 East 76th Street	11/11/2012	390,000	180,000
1419 East 76th Street	4/23/2013	<40,000	<40,000

Appendix B

National Demonstration of Integration of Green and Gray Infrastructure in Kansas City, Missouri –
A Pre-performance Summary Report September 2011.

National Demonstration of the Integration of Green and Gray Infrastructure in Kansas City, Missouri

A Pre-performance Summary Report

This page intentionally left blank

National Demonstration of the Integration of Green and Gray Infrastructure in Kansas City, Missouri

A Pre-performance Summary Report

by

Scott D. Struck, Ph.D.[1]
Robert Pitt, P.E., Ph.D., D.WRE[2]
Deborah O'Bannon, P.E., Ph.D.[3]
Michael Ports P.E., P.H., D.WRE[4]
Ginnerva Moore, J.D.[5]
Tom Jacobs[5]
Kerry Herndon[6]
Mandy Whitsitt[6]

[1]Tetra Tech, Inc., Fairfax, VA
[2]University of Alabama, Department of Civil, Construction, and Environmental Engineering, Tuscaloosa, AL
[3]University of Missouri – Kansas City, Department of Civil and Mechanical Engineering, Kansas City, MO
[4]Private consultant, Jacksonville, FL
[5]Mid-America Regional Council, Kansas City, MO
[6]EPA Region 7, Kansas City, KS

In support of

EPA contract no. EP-C-05-061

Project Officer
Richard Field, P.E., BCEE, D.WRE
Urban Watershed Management Branch
Water Supply and Water Resources Division
2890 Woodbridge Avenue (MS-104)
U.S. Environmental Protection Agency
Edison, NJ 08837

National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268

September 2011

Disclaimer

The work reported in this document was funded by the U.S. Environmental Protection Agency (EPA or the Agency) under Task Order 78 of contract no. EP-C-05-061 to Tetra Tech, Inc. Through its Office of Research and Development, EPA funded and managed, or partially funded and collaborated in, the research described herein. This document has been subjected to the Agency's peer and administrative reviews and has been approved for publication. Any opinions expressed in this report are those of the authors and do not necessarily reflect the views of the Agency; therefore, no official endorsement should be inferred. Any mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Foreword

The EPA is charged by Congress with protecting the nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To help meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building the science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL or the Laboratory) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments, and groundwater; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with public and private sector partners to both foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Sally Gutierrez, Director
National Risk Management Research Laboratory

Executive Summary

Combined sewer systems are designed to collect rainwater runoff and domestic and industrial wastewater in the same pipe. Approximately 742 cities in the U.S. have combined sewer systems. Most of the time, these systems transport all of the wastewater to a wastewater treatment plant, where it is treated and then discharged to a water body. During intense storm events, resulting high flows can overwhelm certain parts of the sewer system and treatment process, causing combined sewer overflows (CSOs). In some cases, where pipes are undersized because of population growth and/or where there is increased runoff volume from connected roof leaders and directly connected impervious areas, even small rainfall events can result in overflows. Municipalities are responsible for developing comprehensive long-term control plans (LTCPs) that recognize and control the site-specific nature of CSOs and their impacts on receiving water bodies. Many of the more recent plans include sections for "Green Infrastructure" and similar source controls that are a part of advanced design concepts. Green infrastructure includes practices and site-design techniques that store, infiltrate, evaporate, or detain stormwater runoff and in so doing, control the timing and volume of stormwater discharges from impervious surfaces (e.g., streets, building roofs, and parking lots) to the sewer system. These techniques are currently being encouraged by EPA as a management practice to contain and control stormwater at the lot or parcel level However, strategic application of green infrastructure and source controls is required to most cost effectively consider the site-specific nature of CSOs to control them.

The Kansas City Water Services Department (WSD) provides wastewater collection and treatment for approximately 650,000 people, located within the City and in 27 tributary or "satellite" communities. Approximately 56 square miles within Kansas City, south of the Missouri River, are served by combined sewers. The City's combined sewers overflow to a number of receiving streams, including the Kansas River, the Missouri River, the Blue River and Brush Creek. The City of Kansas City, Missouri has developed a project to demonstrate the application of green infrastructure for combined sewer overflow (CSO) control in the Middle Blue River.

Kansas City's WSD has designed and begun construction on a 100 acre retrofit of an aging neighborhood that has included sewer rehabilitation and implementation of Green Infrastructure along with some subsurface storage to provide a hybrid approach.

This project evaluates integrated, green infrastructure-based solutions on wet-weather flow pollution problems. The project focuses on an urban core neighborhood sub-watershed drained by a combined sewer system. Objectives of this project are:

- To measure the effects of larger-scale application of LID practices on a CSS
- Monitor the following impacts on a CSS from wet weather flows prior to implementation:
    - rainfall
    - peak system flow
    - total system flow volume
    - land characteristics
    - Infiltration properties

In partnership with the Kansas City, Missouri Water Services Department, The University of Missouri - Kansas City and the Mid America Regional Council the project team monitored pre-implementation conditions and modeled proposed designs. In conjunction with the implementation of LID practices, sewer rehabilitation was also completed for those areas in need of repair. Public rights-of-way are targeted for practice implementation with education and outreach occurring in private areas to encourage participation.

EPA's Office of Research and Development has the goal to provide detailed guidance and information on methodologies for selection, placement, and cost effectiveness and to document the benefits of green infrastructure applications in urban watersheds for new development, redevelopment, and retrofit situations. This project report provides detail on the approaches taken, monitoring data collected, models completed, implementation of private rain gardens and rain barrels, and the outreach and education that has occurred to date.

Contents

List of Tables

List of Figures

List of Acronyms and Abbreviations

BG	Billion gallons
BMPs	Best Management Practices
CFS	Cubic feet per second
COD	Chemical oxygen demand
CSO	Combined sewer overflow
CSS	Combined sewer system
DCIA	Directly connected impervious area
DO	Dissolved oxygen
EMCs	Event Mean Concentrations
FWS	Flood warning system
GI	Green infrastructure
HRU	Hydrologic response unit
In	Inch
I/I	Inflow and infiltration
KCMO	Kansas City, Missouri
MARC	Mid-American Regional Council
MBR	Middle Blue River Basin, Kansas City, MO
MG	Million gallons
MTD	Manufactured Treatment Device
NCDC	National Climatic Data Center
O&M	Operation and maintenance
OCP	Overflow Control Plan (Kansas City)
OWTs	Onsite wastewater treatment systems
PSD	Particle size distribution
RCP	Reinforced concrete pipe
ROW	Rights-of-way
SSO	Sanitary sewer overflow
SSS	Separate Sanitary Sewer System
SUSTAIN	System for Urban Stormwater Treatment and Analysis Integration
TKN	Total Kjeldahl nitrogen
TP	Total phosphorous
TSS	Total suspended solids
UGBF	Urban Green Biofilter
WSD	Water Services Department, Kansas City, MO
WWF	Wet-weather flow
WWSP	Wet-weather Solutions Program
UMKC	University of Missouri Kansas City
USEPA	U.S. Environmental Protection Agency

1. Introduction

In 2009, Kansas City, Missouri began implementing green infrastructure (GI) demonstration projects to determine the pollutant and volume control benefits in abating combined sewer overflows (CSOs) due to wet-weather flow (WWF). Those projects have included the participation of local and regional efforts to identify and prioritize stormwater runoff control projects, and to develop strong partnerships at the neighborhood, watershed, and regional levels. One of the city's pilot projects has specifically been designed to evaluate the performance of GI to control CSO discharges. The GI project will be compared with the alternate control measure considered for this area—a conventional CSO storage facility. This project will aid in the comparison of costs and benefits using the different technologies. The U.S. Environmental Protection Agency (EPA), through the efforts documented in this report, is monitoring and evaluating the performance of GI implemented at the sewershed scale. Previous understanding of GI applied at this scale was largely dependent on model analysis. This study will explore the performance of an actual implemented system. This report outlines the efforts of the EPA study that have been completed to date. These efforts are intended to, (1) determine the potential benefits of GI through modeling, (2) provide an understanding of the monitoring implemented to determine the performance of selected GI and manufactured treatment devices (MTDs), (3) detail results to date from flow and rainfall monitoring, (4) review the site and system benefits of rain gardens from demonstration projects, and (5) discuss the education and outreach efforts and benefits of these efforts.

1.1. Green Infrastructure

Advanced drainage concepts such as GI (or upland runoff and source control techniques) are currently encouraged by EPA as a management practice to contain and control stormwater at the lot to neighborhood scale. GI techniques increase retention at the runoff source, thereby decreasing the runoff volume entering the drainage system and the demand on a drainage system. Because GI is often employed at smaller scales and provides water quality and quantity benefits, it is applicable to all drainage systems—including separate sanitary sewer collection systems (SSS), and storm sewer systems or combined sewer systems (CSS).

The increased volume and rapid runoff that results from highly impervious urban areas is a direct contributor to the amount of CSO discharge. GI works to replicate natural hydrologic processes and reduce the disruptive effects of urban development and runoff. GI generally focuses on distributed controls that capture and retain runoff near the source and enhance infiltration, percolation, and evapotranspiration; reduce pollutant discharges to surface water; and encourage groundwater recharge. Some common examples of GI include bioretention/biofiltration, rain gardens, porous pavement, grass swales, infiltration basins, and disconnection of paved areas and roof tops.

Although GI techniques are increasingly used across the country, there is currently an absence of information regarding their performance when incorporated within CSSs, either as a single practice or in combination with more traditional gray storage. Thus, an objective of this project is to measure the effects of retrofitting and adding GI techniques to an urban drainage area—specifically to demonstrate a reduction in the peak flow rates, total flow volumes, and pollutant loadings of storm-generated flows at a larger scale. If this is effective, the Kansas City, Missouri Water Services Department (KCMO WSD) may consider GI retrofits as an approach to reduce smaller storm contributions to the CSS, as well as the benefits associated with reduced loading to impaired waters.

Incorporating GI techniques in the sewershed to capture, retain, or reduce stormwater before it enters the piped drainage system may be an attractive and practical alternative for many developed areas. Both developed storm and combined sewersheds can benefit from added storage, detention, and volume reduction from areas retrofitted with bioretention cells, pervious concrete, rain gardens, or other "micro" best management practices (BMPs), such as catch basin retrofits or additional tree plantings. Such practices can reduce stormwater runoff volume and pollutant mass loading, as well as the frequency of CSOs, sanitary sewer overflows (SSOs), and stormwater with discharges typically occurring only during larger, less frequent storm events.

1.2. Project Background

The KCMO WSD provides wastewater treatment and stormwater services for 653,000 people in the city and 27 different communities that cover a total of 420 square miles (WSD 2009). The area serviced by the WSD includes both SSSs and CSSs, with CSSs comprising 58 square miles of this area (Figure 1-1). The total sewer system service area is 318 square miles and there are approximately 2,700 miles of sewer in the system. The CSS area is predominately in older portions of the city. During rain events, stormwater enters into the collection systems leading to CSOs. The city has 90 combined sewer discharge locations that overflow to the Blue River, Brush Creek, Kansas River, and the Missouri River. CSOs in the Blue and Missouri rivers result in water quality impairments from increased bacteria levels. The Blue River is on Missouri's 303(d) list as impaired for *Escherichia coli* (WSD 2009). Through the use of computer modeling, the city estimates the CSO discharged volume to be nearly 6.4 billion gallons (BG) per year. The average overflow frequency is approximately 18 times per year (WSD 2009).

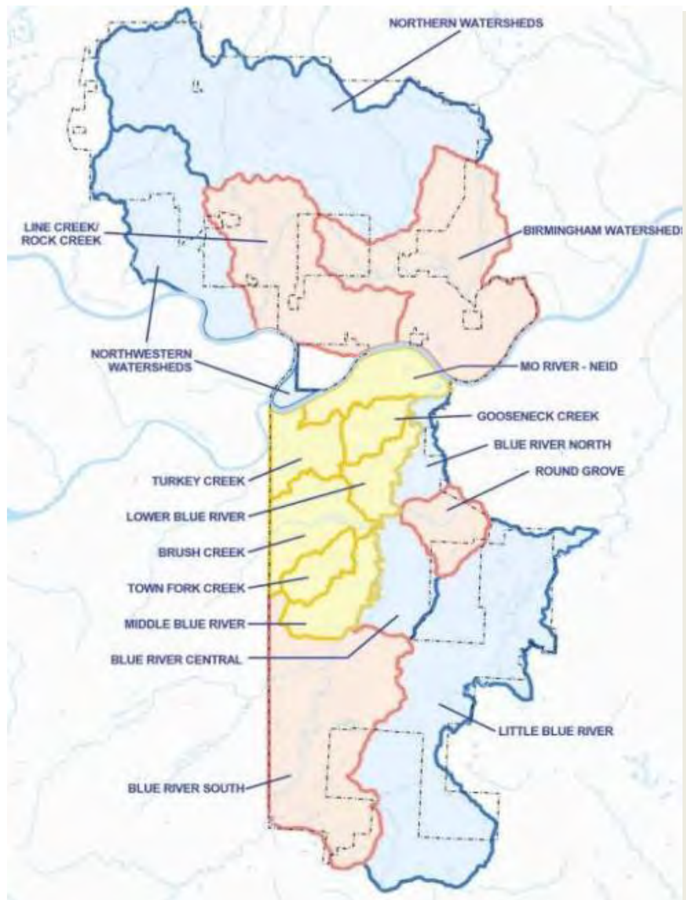


Figure 1-1: Kansas City, Missouri SSS and CSS basins.

The city began evaluating CSOs in the early 1980s. Those early efforts included various studies, CSO management plans, modeling efforts, and assessing the implementation of EPA's Nine Minimum Controls requirement for (EPA 1995). In 2003 the WSD began a comprehensive Wet Weather Solutions Program (WWSP), which was developed to address flood control and water quality issues. Two principal plans were developed to work together to achieve the goals of the WWSP— the Overflow Control Plan (OCP) and the Kansas City Stormwater Management Plan (KC-One Stormwater Management Plan and Waterways Program). Once complete, the OCP will reduce the average annual CSOvolume to 1.4 BG that will be attained by capturing 88 percent of WWF in the CSS area, and which will reduce the overflow events by 65 percent (Leeds 2009).

The city embraced the concept of GI as part of its WWSP. The acknowledgment of GI as a desirable component of the plan was made at a political and policy level. As part of incorporating the concept and the plan, the city established several committees to address CSOs and city-wide GI solutions. For example, the Green Solutions Committee was organized in 2007 to address GI for wet-weather solutions. The committee created a *Green Solutions Position Paper* in which it endorsed a formal policy on wet-weather solutions. The resolution includes four specific strategies—public education and outreach including regional partnerships, adjusting regulations to promote GI, creating incentives for GI, and investing public funding for GI—and was approved in August 2007 (WSD 2009).

The city proposed the inclusion of funding specific for GI in the OCP. It was anticipated that these resources would be directed at urban lakes, streamside protection, demonstration projects, CSS areas planned for separation, and as part of a Blue River Watershed Management Plan (Leeds 2009). In order to better understand the implication and economics of GI, preliminary analyses were conducted on three watersheds that investigated the potential cost impact of combining green and gray infrastructure. These studies were centered on capital cost and did not include lifecycle analysis. The technologies originally considered included catchbasin retrofits in city rights-of-way (ROW), curb extension swales, street trees, permeable pavement, green roofs, and stormwater planters. The analyses considered a *desktop* level study that did not include detailed modeling or monitoring, due to cost and time constraints. The evaluations included Brush Creek and Town Fork Creek watersheds, and OK Creek. Two additional storage projects within the Middle Blue River (MBR) Basin were also considered.

The findings from the Brush Creek and Town Fork Creeks studies concluded that integrating gray infrastructure and GI would exceed the cost of gray infrastructure alone to meet the required level of control (total volume of overflow). In order to make the strategy justifiable to the city's ratepayers, it was determined that significant private investment would be required. The findings for OK Creek were similar to the Brush Creek and Town Fork Creek findings, drawing the conclusion that meeting the required level of overflow control when considering capital cost alone; GI alternatives were more costly than gray infrastructure on a per volume basis.

As noted previously, the city evaluated two projects within the MBR Basin (outfalls 059 and 069) for the application of GI. The city determined that planned storage tanks could be cost-effectively replaced with distributed GI to achieve the desired level of control. The City then revised the MBR Basin Plan to incorporate GI and some associated traditional gray controls to provide the necessary storage to meet the goal of six or less overflows per year. The original gray infrastructure plan and the green/gray plan were estimated at $51 million (or $17 per gallon of storage provided) and $46 million for 3 million gallons (MG) of storage, respectively (Leeds 2009). KCMO WSD then decided to include one of the Middle Blue River projects (outfall 069) as a demonstration opportunity and included this project within their OCP to meet CSS control requirements. The amount of GI to be installed in future phases of the City's OCP implementation will be determined on the basis of demonstration programs and monitoring results. The EPA study of the MBR demonstration project will support the City's efforts and the body of knowledge by performing evaluation monitoring and assessing the results of the project when completed. In that assessment, the EPA study goals are the following:

- Demonstrate individual and collective system performance of GI retrofits in the MBR demonstration project by measuring the changes in the peak flows, total volumes, and pollutant loadings of the WWFs entering the CSS before and after GI implementation

- Compile data from other public and private flow control opportunities to demonstrate the effects of GI on different scales
- Use models to demonstrate GI and gray infrastructure integration and performance (volume and number of overflow events) on a larger scale within the CSS, and to calculate or predict the benefit of the reduction in volume, pollutant load, and number of overflow events
- Provide information on socio-economical-political barriers of green infrastructure acceptance
- Gather information for understanding outreach and education benefits to the local community
- Develop life-cycle cost comparison between conventional CSO control and green infrastructure control

The EPA Study was originally started in 2008 with the expectation that GI practices would be implemented by the city by fall of 2009 to allow for post-construction monitoring. Because of unexpected delays in design and construction, actual construction of GI practices was not started until spring of 2011. As a result, the scope of this report is limited to work performed through July 2011. The contents of this report include an overview of the modeling and data assessment conducted to date, performance of private rain gardens, initial planning and design of MTDs, and public outreach for the project.

1.3. GI Pilot Project Site Description

KCMO WSD determined through the desktop analyses of GI opportunities that GI implementation in the MBR basin would be a cost-effective option to achieve the desired level of overflow control compared to traditional storage tanks (gray infrastructure). The MBR demonstration project is part of a larger adaptive management approach to incorporate GI into the Kansas City OCP. The project involves local and regional efforts to provide the "basis-for-success" of the implementation of GI and stormwater management at the neighborhood, watershed, and regional levels. The EPA project accepts the MBR demonstration project location and intends to evaluate the feasibility of the strategy methodology and performance, including model support for sewershed performance of GI implementation within Kansas City, Missouri.

The following components are included in the EPA GI demonstration project:

- Data collection and surveys
- Modeling of conceptual design of GI distributed storage
- Post construction monitoring and green solutions operation and maintenance (O&M)

The pilot project is within the MBR watershed and targets the area draining to outfall 069, which is a total of 475 acres. The demonstration project includes a 100-acre area where GI implementation will occur in the first phase of construction. An adjacent 86-acre area is being used as a control area to compare system response to rainfall with and without GI implementation. No GI will be incorporated into this control area for the duration of the post construction monitoring program (Figure 1-2). The demonstration project and control areas are both fully developed with approximately 34 percent impervious area, and include mostly residential with some commercial land uses. Demonstration project opportunities within the drainage basin have been evaluated based upon

Figure 1-2: Middle Blue River outfall 069.

- The possibility of siting multiple practices to create the opportunity for a more measurable effect at the overflow locations
- Locations without large upstream contributions of flow; good monitoring location availability for targeted drainage areas
- Potential involvement by site owners, both public (e.g., public entities) and private (e.g., commercial property owners and private homeowners)
- Sufficient area for a number and variety of locations for the stormwater controls
- Reasonably representative of local conditions
- Available site information including detailed topographic maps, age of development, aerial photographs, and maps showing existing storm drainage system
- Permeability of soils (where appropriate for infiltrating practices)
- Area available between sidewalks and streets
- Depth to groundwater at least 10 feet
- High downspout connection possibilities where current downspouts are directly connected to impervious areas

The pilot watershed and location of selected BMPs are shown in Figure 1-3. The site selection for each type of control practice was developed from the modeled results predicting the amount of rainfall runoff draining to a catchbasin and the potential for capturing the volume in GI systems to apture the runoff before entering the catchbasin.

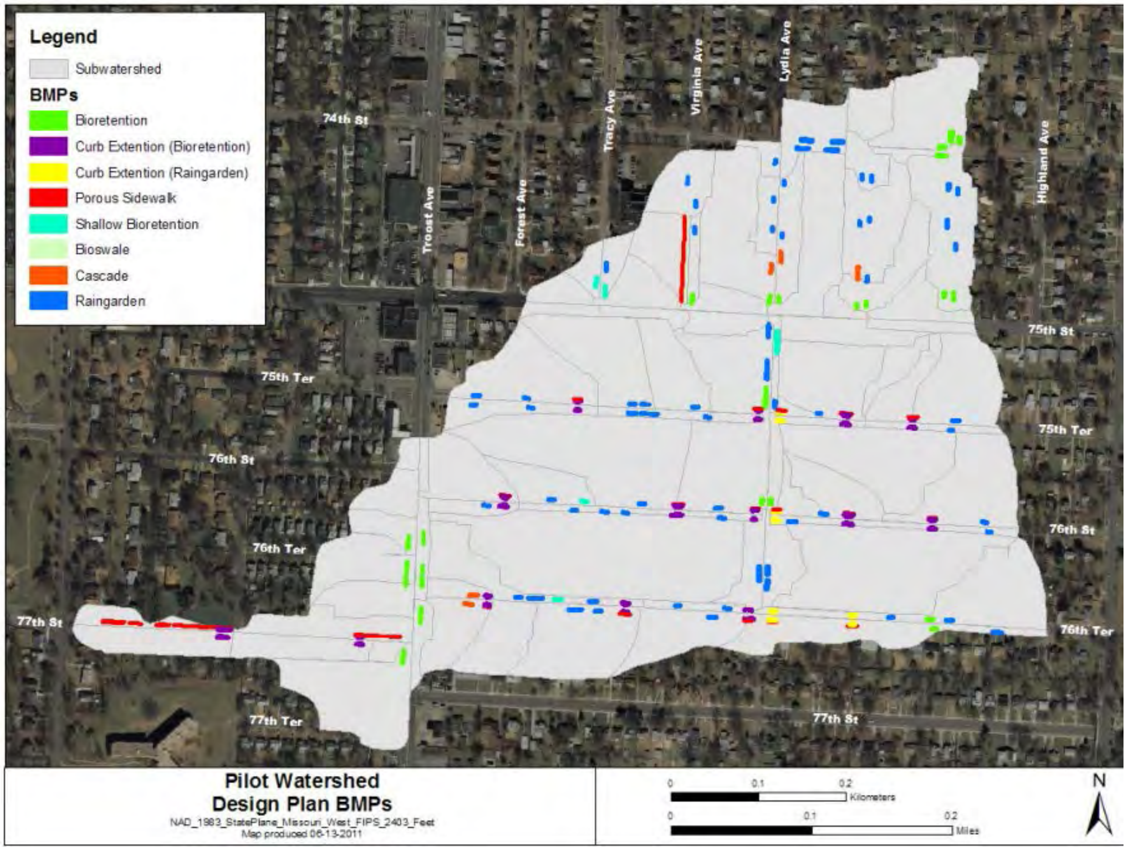


Figure 1-3: Selected BMP locations for pilot study area (based on KCMO WSD designs).

2. Monitoring to Determine Performance of GI

The monitoring design for this study meets multiple objectives. First, it describes a monitoring protocol that specifies locations and monitoring plans for broader, watershed monitoring and smaller scale management practice monitoring. This provides information at multiple scales allowing for better interpretation of scaling-up issues. Secondly, the design uses multiple comparative approached to determine whether results are statistically significant. A statistical approach is required to justify the allocation of limited resources and to demonstrate the validity of results. One way to reduce the overall number of samples collected is to establish control samples that are independent of watershed changes and that can easily be compared to data dependent on designed changes to the watershed. This study combines two approaches—a control versus test sample approach, and a before versus after approach. These approaches are discussed in further detail below.

To establish a statistically valid sampling protocol, knowledge of the actual watershed and sewer conditions is essential. Often a phased sampling approach is recommended, allowing some information to be collected initially to generate preliminary estimates of the sampling effort and expected ranges of data needed to subsequently reduce the required number of samples and analytical parameters. However, not developing a monitoring plan early in the process can result in haphazard sample collection and ultimately require much more time and resources than actually needed.

The pilot project sampling will occur within the 100-acre project watershed tributary to the combined sewer outfall 069. Samples will also be collected from the adjacent 86-acre control watershed. The land use within both of these areas is predominantly residential with some commercial along Troost Avenue.

Two scales of sampling objectives were selected for experimental design to achieve desired objectives, large-scale and small-scale watershed monitoring. First, large-scale watershed monitoring of flow was completed in both the pilot and control watersheds to establish typical baselines. Pre-construction flow monitoring was used to calibrate the models WinSLAMM and SUSTAIN (System for Urban Stormwater Treatment and Analysis INtegration) that were selected for use this project. The process to calibrate WinSLAMM for the test area, including the control practices, is discussed in Chapter 3. It is described further, along with the calibration results, in a supplemental WinSLAMM modeling report prepared as part of this project. An analogous process was used to calibrate SUSTAIN for the same area.

Post-construction watershed monitoring in both the test and control locations) will be used to verify the calibration and validate modeling results at this larger scale. Post-construction results will be monitored to determine the changes attributable to GI controls in the pilot area. Monitoring stations will be located at discharge locations of several subwatersheds. This monitoring approach will establish a paired test, using comparable data collected from the pilot and control locations. Note that before and after results can also be compared providing another monitoring approach.

2.1. Land Characteristics Survey in Kansas City Test Watershed

For modeling and a general understanding purposes, and to obtain a general understanding of the development characteristics that affect stormwater quality and quantity, land use characterizations of each parcel within the pilot watershed were inspected and evaluated for land use characterization, including the following address; property type; date of construction; dwelling type; building condition/maintenance; number of stories; percent of roof draining to pervious, impervious, or underground; roof type; potential sediment sources; whether treated wood is present (source of heavy metals), landscaping coverage; landscaping type; landscaping maintenance, percent of connected sidewalk; percent of connected driveway; driveway type; driveway condition; driveway texture (smooth or rough); and BMP potential.

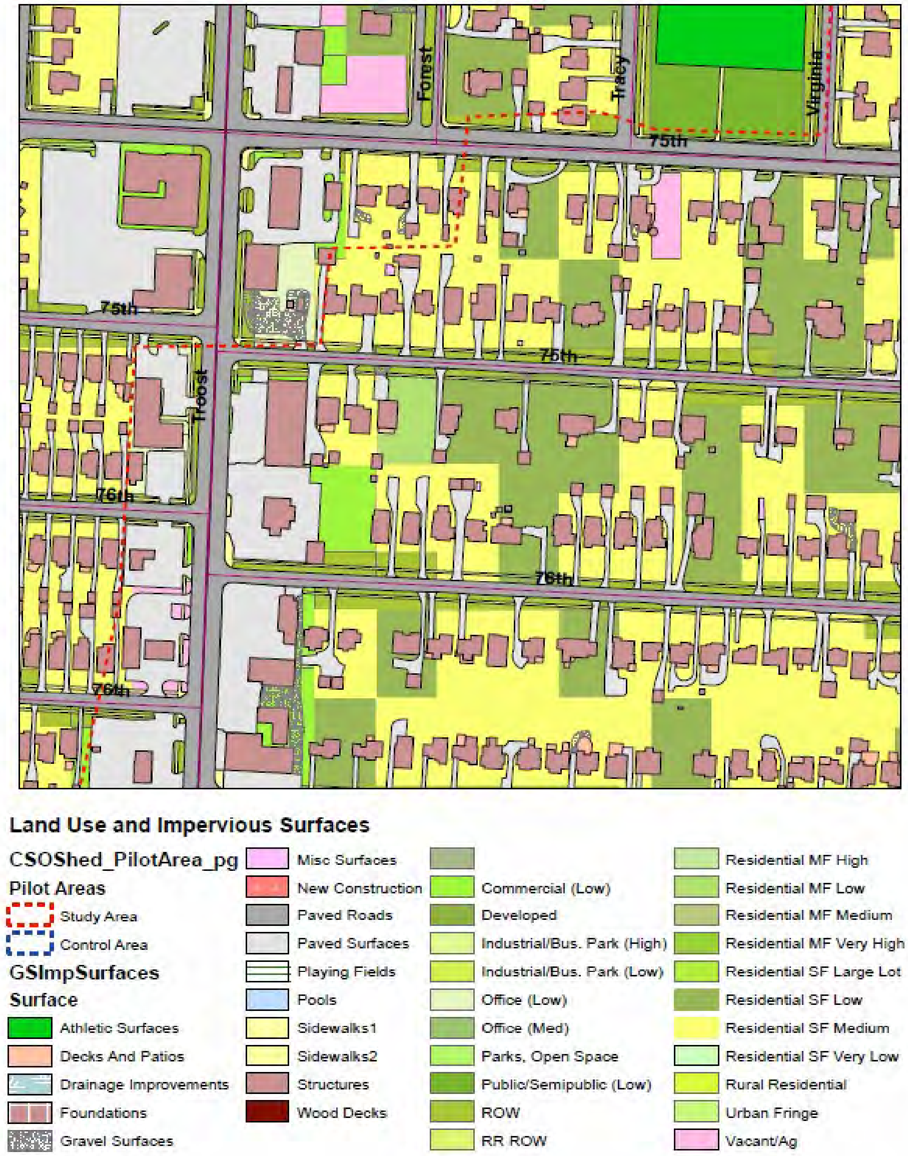


Figure 2-1. Detailed GIS coverage showing land cover components of different land uses in the Kansas City pilot watershed.

In many areas, detailed aerial coverage with GIS data sets are becoming available, showing and quantifying the finer elements of an area. Figure 2-1 is an example of a geographic information system (GIS) map from Kansas City, Missouri, showing a portion of the study area. Although this high resolution GIS data shows all of the main elements, field surveys were still needed to verify the drainage pattern for each impervious element in the test watershed, and to identify many other site elements used in stormwater quality modeling.

Dr. O'Bannon and her graduate students at the University of Missouri, Kansas City (UMKC) conducted a detailed survey of the development characteristics in the study area. This information was used in conjunction with the overall GIS information describing each land element to identify the specifics needed for the continuous modeling. They surveyed a total of 576 homes in the 100-acre area, of which 90.6 acres were residential (housing density of about 6.4 homes per acre).

2.1.1. Flow and Rainfall Monitoring

SSOs and CSOs are often a result of heavy rainfall events when the combined flow of wastewater and stormwater can exceed the capacity of the sewer system. During such events, the excess flow is discharged at a designed overflow point and released into local waterways to prevent flooding in homes, businesses, and streets. Because of this, flow in the system as well as rainfall amounts are important parameters to measure. Accuracy in these measurements assists in improving the development of models and their ability to predict flows in the combined system as well as surface flooding. Therefore, flow, and concurrent rainfall are the primary parameters for monitoring for this study. In this regard, data should be collected for every qualified event that occurs during the monitoring period. A qualified event is anticipated rainfall > 0.15 inch per day, as determined by forecasting and multiple spatially varied rainfall gages.

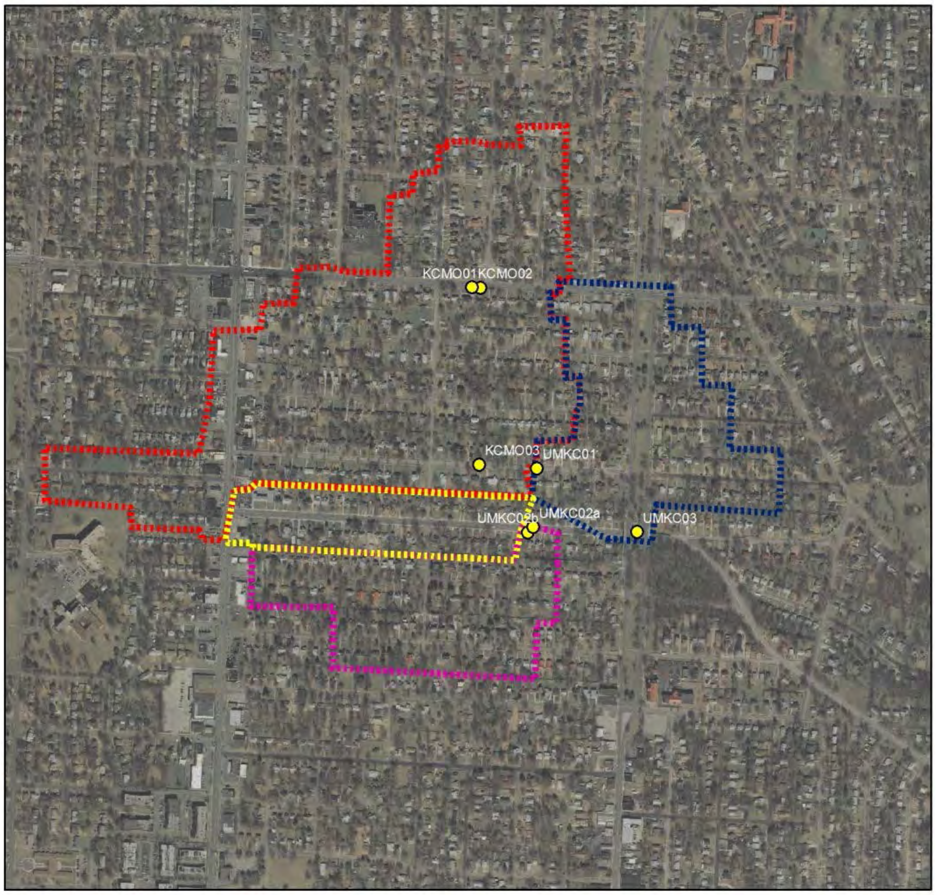


Figure 2-2: Pilot (UMKC01) and control watersheds (UMKC02a, UMKC02b, and UMKC03).

In general, large-scale monitoring is much more challenging than small-scale monitoring, as the benefits of using such devices in the drainage area will have less of a benefit than the individual monitoring described above. With about 50 events occurring each year that can produce measureable flows in the combined sewers, data from all of the events during the monitoring program might result in about 100 total events during a 27-month monitoring period. With a larger coefficient of variation (COV) expected (about 1.0), Site investigations were conducted in the pilot project area and flow meters were located at four monitoring sites for which the flow data was recorded. The areas draining to each of the monitoring site locations are shown in Figure 2-2. The drainage area contributing to the monitoring site UMKC01 depicts the pilot watershed where GI implementation will take place and the drainage areas contributing to the monitoring sites UMKC02a, UMKC02b, and UMKC03 indicate the control watersheds. Drainage areas for these catchments are summarized in Table 2-1.

Table 2-1. Pilot and control drainage areas

Monitoring Location		Drainage Area (Acres)
Pilot	UMKC01	99.7
Control	UMKC02a	41.4
	UMKC02b	27.6
	UMKC03	17.6

2.2. Flow Sampling and Rain Gauge Monitoring Equipment

For all flow monitoring an ISCO 2150 type flow sensor with a model 6700 controller was installed in the pipe using an expansion ring or concrete screws to hold the meter in place. An ISCO model 674 tipping bucket rain gauge was deployed at the border between the pilot and control watersheds during non-freezing temperatures to record rainfall quantities. Rainfall-runoff hydrographs were developed at the metering points of the control and the pilot basins.

2.3. Large-Scale Flow Monitoring Locations and Descriptions

UMKC 01: The monitoring site is located at 1461 East 76th Terrace on a grass easement. The manhole is constructed with brick and shows evidence of surcharge. The average depth of flow observed was 1.25 inches, with an average velocity of 3 feet per second (fps). An ISCO 2150 type flow meter was installed in the 42-inch reinforced concrete pipe (RCP) entering into the manhole. Figure 2-3 shows the general location of the UMKC 01 monitoring station (left) and the location of the manhole relative to the street (right).

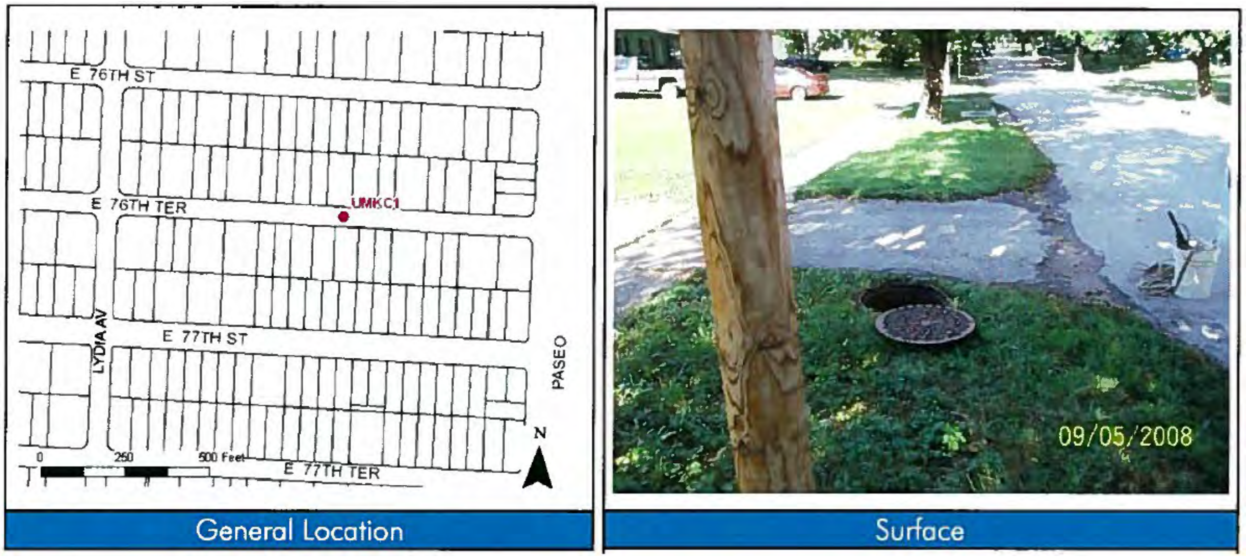


Figure 2-3: Flow monitoring site UMKC01.

Because the control site was downstream of the pilot site and given the potential error and difficulty of trying to subtract flows at one location from another (adding flow data is generally more accurate), three locations were selected for the control watershed.

UMKC 02a: The monitoring site is located at 1451 East 77th Street in the middle of the road. The manhole is constructed with brick and no evidence of surcharge was observed. The average depth of flow observed was 0.50 inches, with an average velocity of 0.50 fps. An ISCO 2150 type flow meter was installed in the 30-inch RCP sewer pipe entering into the manhole. Figure 2-4 indicates the general location of the UMKC 02a monitoring station (left) and shows the location of the manhole relative to the street (right).

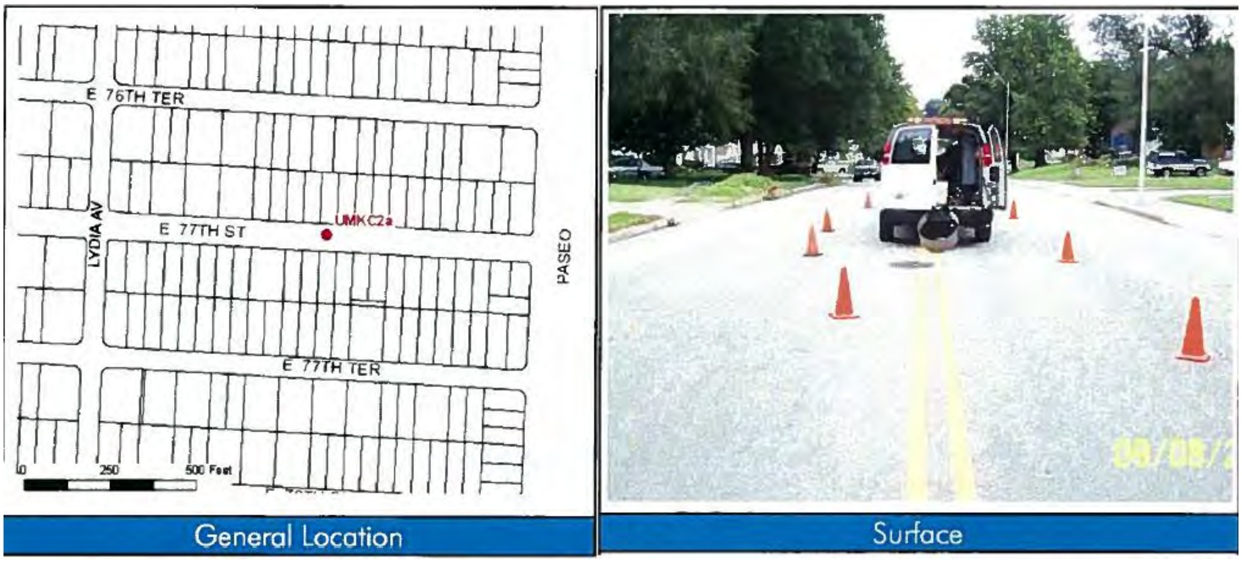


Figure 2-4: Flow monitoring site UMKC02a.

UMKC 02b: The monitoring site is located at 1451 East 77th Street on a sidewalk. The manhole is constructed with brick and no evidence of surcharge was observed. The average depth of flow observed was 0.50 inches, with an average velocity of 1.25 fps. ISCO 2150 type flow meter was installed in the 24-inch RCP sewer pipe entering into the manhole. Figure 2-5 indicates the general location of the UMKC 02b monitoring station (left) and shows the location of the manhole relative to the street (right).

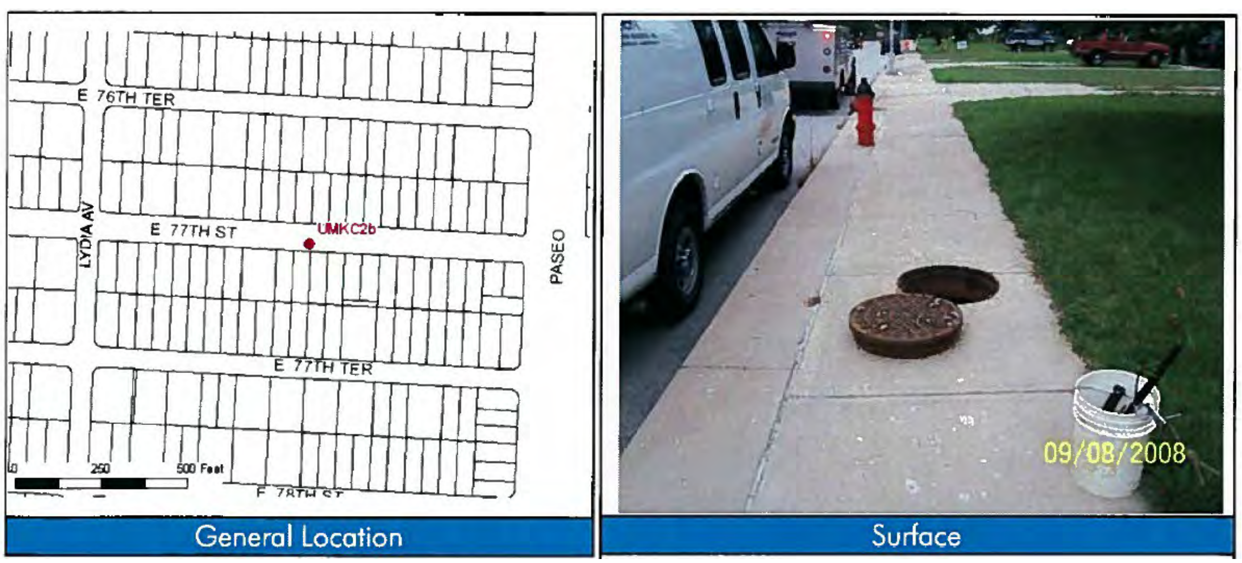


Figure 2-5: Flow monitoring site UMKC02b.

UMKC 03: The monitoring site is located at East 77th Street at Paseo Boulevard on a paved sidewalk. The manhole is constructed with brick and 5.5 feet of surcharge was observed. The Average depth of flow observed was 1.00 inches, with an average velocity of 1.50 fps. ISCO 2150 type flow meter was installed in the 30-inch RCP sewer pipe entering into the manhole. Figure 2-6 indicates the general location of the UMKC 03 monitoring station (left) and shows the location of the manhole relative to the street (right).

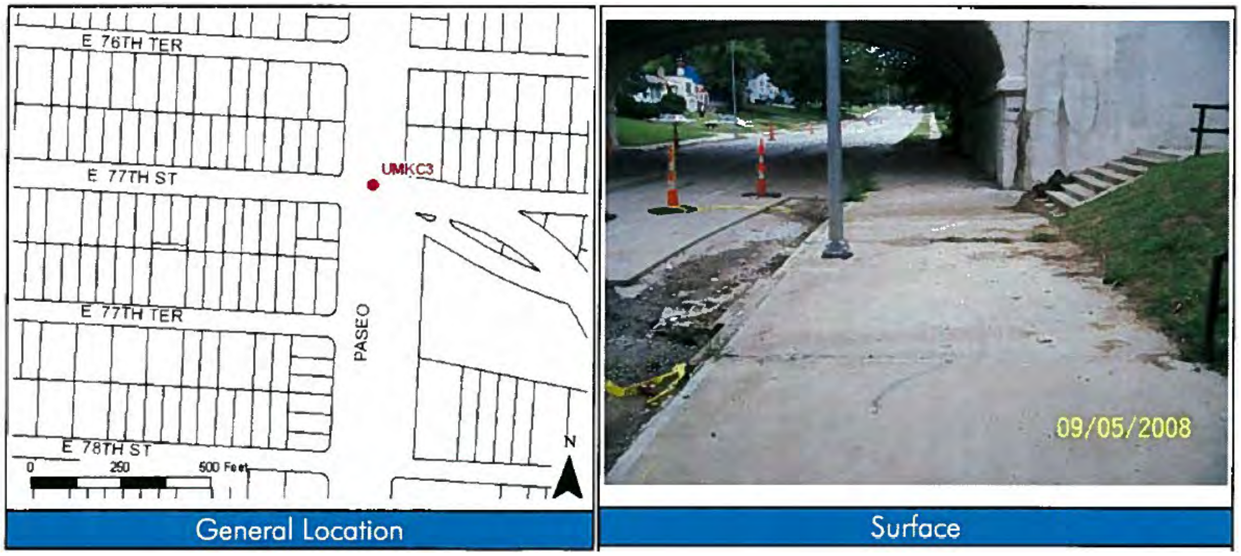


Figure 2-6: Flow monitoring site UMKC03.

2.4. Small-Scale Flow Monitoring Locations and Descriptions

Small-scale monitoring of individual GI practices will determine the performance of single systems. Several pairs of monitoring stations will be established to determine the direct benefits. These will be paired analyses with concurrent influent and effluent monitoring of flows and pollutants. Stratified random sampling will be used to separate the data into groups corresponding to different rain depths per season. Although initial modeling of the area will be used to identify rain categories for the stratifications, prior experience suggests the following rain depth strata: < 0.5, 0.5 to 3, and > 3 inches. In addition, seasonal variations (relating to soil moisture and other antecedent period factors) will be examined for appropriate strata. The desired number of events in each strata will depend upon the expected variability of the monitored factors and the data quality objectives. Most stormwater constituent coefficient of variances range from a value of about 0.5 to 1. If performance levels (treatment benefits) defined by percentage reductions of about 25 percent are desired to be statistically identified, with confidence levels of 0.95 and power of 0.8, then approximately 75 pairs of samples may be needed. With a multi-year project, about 30 or more events per year should be targeted for evaluation. Flows are relatively inexpensive to monitor after the equipment is installed, so data should be collected for almost every rain event. Because water quality evaluations are secondary for this project however, less demanding data quality objectives may be warranted. If 50 percent differences are a suitable goal, then only about 25 pairs of samples will be needed. When the data is obtained, it will be separated into different seasonal and rain depth strata for comparison testing are obtained. In the past, this approach has resulted in a more complete understanding of device performance and better quality data than simply grouping all data together. Further details of the individual GI types and locations are provided below.

2.5. BMP Monitoring and Locations

The MBR demonstration project offers several opportunities to incorporate specific practices located within existing ROW. Individual practices will typically be situated between existing curbs or edges of pavement and the sidewalk, or possibly under the sidewalk where there is insufficient ROW for additional storage. The individual practices consist of the following five primary types: rain gardens, bioretention cells (with pipe storage), curb extensions bioretention, cascading bioswales, and porous sidewalk systems. Some of these primary types also have subtypes of practices.

Simple designs typically require less complex monitoring strategies. As such, the EPA project team has focused on the less intricate systems in the design drawings. With these systems, it is possible to potentially monitor influent, effluent, and bypasses/overflows at the one or two locations where these exist rather than the many locations associated with more complex designs. Calculated use of monitoring equipment for one or two systems provides the opportunity to gather greater data in one location and will likely result in significant data and allow for better overall comparison. Based on the final plans, two types of systems have been selected for monitoring—curb-extension biofilters/bioretention and rain gardens. The locations of each are described below.

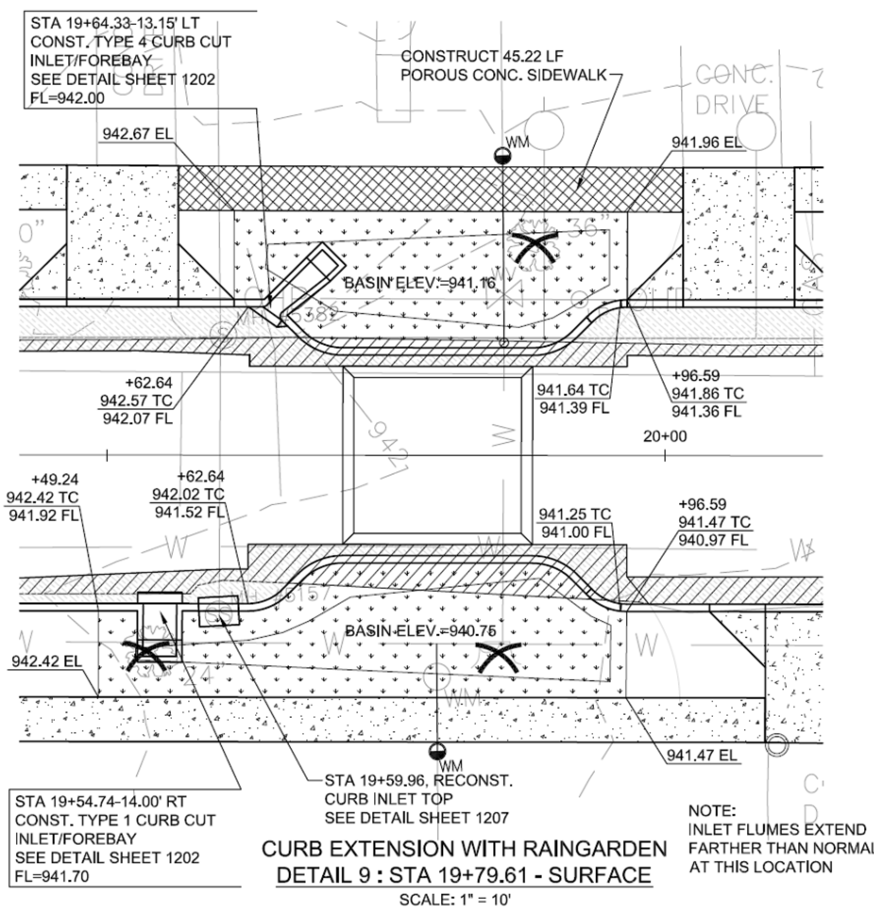


Figure 2-7: Curb-extension bioretention detail on 76th Street.

2.5.1. Curb-extension Biofilters/Bioretention

Location: East 76th Street at Station 19 + 79.61 in design plans (Figure 2-7)
This location has about 10 homes upgradient along the street and it does not have any complex underground pipe storage. Overflow continues east along East 76th Street. This site has feasible inflow and overflow monitoring.

2.5.2. Rain Gardens

Location: East 76th Street at Station 25 + 2.89 in design plans (Figure 2-8).
This location has about 2 or 3 homes upgradient. This is a very simple rain garden with no complex subsurface storage, making flow monitoring feasible for inflow and overflow.

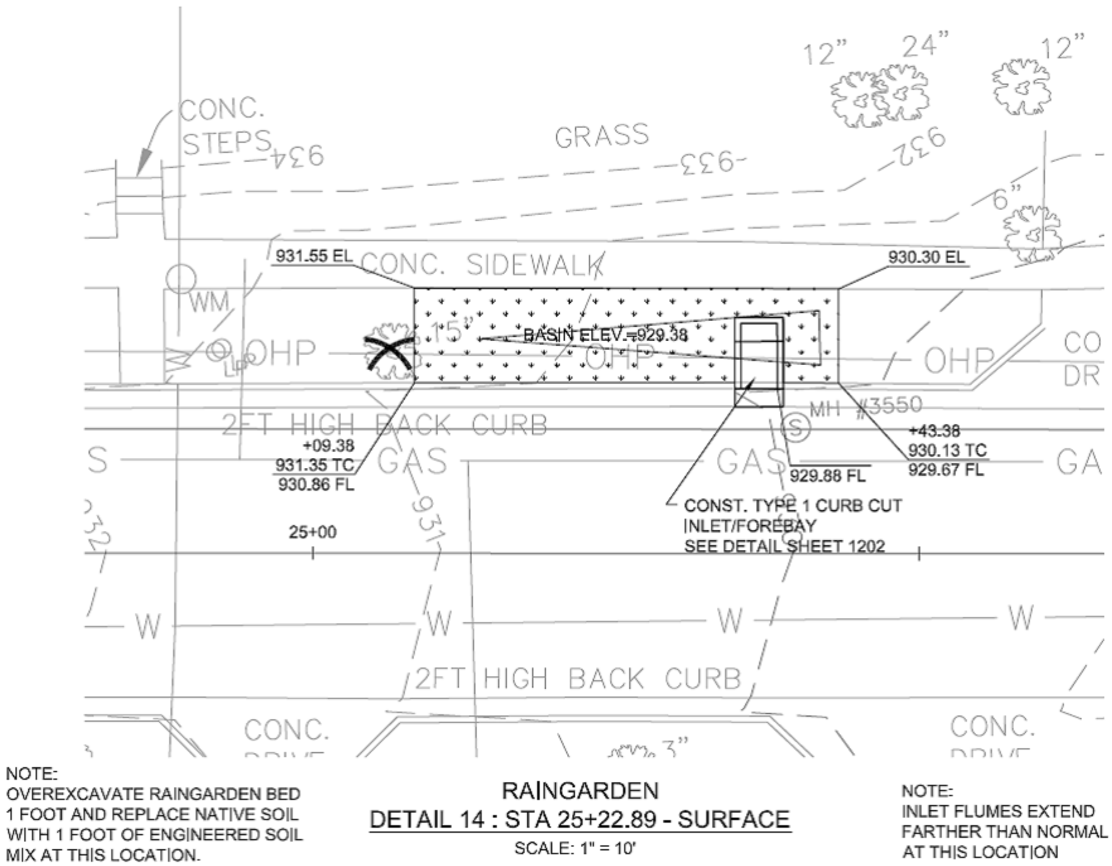


Figure 2-8: Rain garden plan detail.

2.6. Small-Scale Flow Monitoring Techniques

Flow monitoring is critical for this project and accurate inflow and overflow rates will need to be continuously measured. Because of the closeness of the inlets to the biofilters and rain gardens, there is insufficient distance to install many types of throated flow monitoring flumes. However, it is likely that small H flumes, a pre-fabricated flume with calibrated depth used for accurately measuring flow rate and volume, will be used.

The 0.50H flume requires an approach channel length of 2.5 feet. It is 0.95 feet wide and 0.675 feet tall. The flow range for this flume is 0.0004 to 0.35 cubic feet per second (cfs). For most of the drainage areas noted above (about 1 acre, or less), this size flume can be used to monitor flows during heavy rains having peak intensities of at least 1 inch per hour, though they can also measure flows during lighter rains down to 0.1 inch total, or less.

The H flume will be installed level with the approach length. The total length of the approach and H flume would be about 3 or 4 feet. Notably, this required a modification of design to extend the length of the flumes beyond that for which they were originally designed. If a narrower entry is required for the H flume, an aluminum sheet will be bolted in place over the concrete flume to allow runoff to be directed into the flume. Figure 2-9 shows a typical inlet and the lengthened flume with estimated location for the H flume. A stilling well and level recorder will also be needed for the influent H flume, and one will also be needed in a standpipe in the biofilter to record the water depth. Overflow/bypass water volumes would be estimated from the rain garden/biofilter ponded water depth. This level will indicate when the flume is flooded and water is bypassing the entrance to the device. The effluent from the H flume can be directed into the forebay box, which may require a slight construction change to locate it further into the biofilters. The water sampler intake should also be located where the cascading water from the H flume can fall onto the inlet, in the forebay.

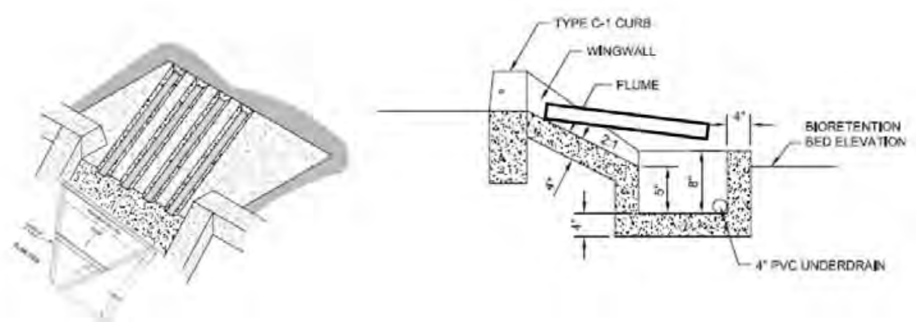


Figure 2-9: Inlet design modified with the H-Flume for inflow monitoring.

Most of the outlets will be monitored by using depth meters calibrated to the outlet (treated as a broad crested weir) to determine the depth (and therefore volume in the system) and time of overflow/effluent flow (Figure 2-10).

Figure 2-10: Outlet depth meter measuring outflow based on stage.

2.7. Analytical Parameters of Interest

The local WSD laboratory, along with UMKC, will provide most of the analyses, while particle size distribution will be analyzed at the University of Alabama, Tuscaloosa. The other parameters of interest are discussed below.

2.7.1. *E. coli*

Escherichia coli (*E. coli*) bacteria are the commonly-used bacterial indicator of sanitary quality of foods and water. They are rod-shaped Gram-negative non-spore forming organisms that ferment lactose with the production of acid and gas when incubated at 35 to 37 °C. *E. coli* bacteria are abundant in the feces of warm-blooded animals, but can also be found in the aquatic environment, in soil, and on vegetation. *E. coli* are easy to culture and their presence is used to indicate that other pathogenic organisms of fecal origin might be present. For this study, *E. coli* bacteria will be monitored during the initial stages of the study to evaluate presence or absence.

2.7.2. Basic Chemistry

Total suspended solids is a common water quality measurement usually abbreviated TSS. It is listed as a conventional pollutant in the Clean Water Act. Chemical oxygen demand (COD) is a common test used to indirectly measure the amount of organic compounds in water. Most applications of COD determine the amount of organic pollutants found in surface water (e.g., lakes and rivers), making COD a useful measure of water quality. Turbidity is the cloudiness or haziness of a fluid caused by individual particles (suspended solids) that are generally invisible to the naked eye. The measurement of turbidity is another key test of water quality. TSS, COD, and turbidity are are the basic chemical constituents of interest in this project.

TSS analytical procedures will include filtration through a 0.45 μm filter paper and comparing pre-weighed dry paper with filtered and oven dried filter paper using an analytical balance (A&D Company Limited, U.K.; model HA-202M, range < 42 g, accurate to 0.01 mg). Turbidity will be measured with a Hach turbidity meter (Hach Company, Loveland, Colorado; model 2100 AN, range 1–10,000 NTU) and in-situ using the optic port of a YSI water quality sonde (Yellow Springs Instruments, Yellow Springs, Ohio; model 6920). The YSI sondes will be used to monitor water column chemistry continuously within a BMP installation during the course of a storm event. Collectively, these instruments will measure the following water quality parameters:

- Dissolved oxygen (DO)
- Conductivity
- Temperature
- pH
- Turbidity

2.7.3. Particle Size Distribution

Suspended sediments are defined as solid particles transported in a fluid media or found in deposit after transportation by flowing water, wind, glacier, and gravitational action. Suspended sediments play a key role in shaping the characteristics of a body of water.

Particle size distribution (PSD) is an estimation of the relative amounts of particles present, sorted according to size. The PSD of a material can be important in understanding its physical and chemical properties. It affects the treatability of the stormwater and affects the maintenance and clogging of media. It can also affect the reactivity of solids participating in chemical reactions.

2.7.4. Nutrients and Metals

Nutrient pollution, such as the release of sewage effluent and runoff from lawn fertilizers or agricultural lands into natural waters, can cause eutrophication (i.e., nutrient over-enrichment). Eutrophication generally promotes excessive plant growth and decay, favors certain weedy species over others, can produce excessive or harmful algal blooms, and is likely to cause severe reductions in water quality.

Heavy metal pollution can arise from many sources but often is deposited through rainfall or associated with automotive (e.g., brake pads) or industrial runoff. Through precipitation of their compounds or by ion exchange into soils and clays, heavy metal pollutants can localize or remain inactive. Unlike organic pollutants, heavy metals usually do not decay and thus pose a different kind of challenge for control in stormwater. The following constituents of interest in this project are:

- Total phosphorous (TP)
- Phosphate (PO_4)
- Total Kjeldahl Nitrogen (TKN)
- Total ammonium (TNH_4)
- Dissolved nitrate/nitrite (NO_3/NO_2)
- Total and dissolved copper (Cu), zinc (Zn), and lead (Pb)

2.7.5. Analytical Methods

The analytical techniques used for evaluating each parameter of interest are shown in Table 2-2.

Table 2-2: Analytical methods for targeted parameter analyses

Target Parameter	Analytical Reference Method	Minimum Detection Limit
E. coli	Standard Methods* (SM) 9222B	100 **colony forming units**/100 mL
TP	EPA† 365.2	0.001 mg/L
PO_4	EPA 365.2	0.001 mg/L
TKN	SM 4500-N_{org} C	0.214 mg/L
TNH_4	SM 4500-NH_3 F	0.006 mg/L
Dissolved NO_3	EPA 300.0	0.002 mg/L
Dissolved NO_2	EPA 300.0	0.001 mg/L
TSS	SM 2540 D	0.1 mg/L
COD	SM 5220C	--
Filtered Cu, Zn, Pb	EPA 200.7	--
Total Cu, Zn, Pb	EPA 200.7	--
Major ions and cations	EPA 300.0	--

* Clesceri et. Al (1998) American Public Health Association Standard Methods
† EPA (1983)

3. Modeling of Pilot Project Areas

The evaluation of GI cost, technologies, and prioritization of locations is discussed in this chapter. Relatively simple desktop studies as well as complex monitoring and modeling efforts have been conducted to assess the potential for GI implementation and project location. Several modeling activities were performed by both the KCMO WSD, under the parallel EPA study or as part of this project. These modeling efforts were performed at various points in time and with different objectives specific to each study. The monitoring data available for use in these modeling efforts also changed over time. Additional monitoring data provided new hydrologic information which resulted in updated model representation of the system. This section provides (1) a brief background description of those efforts, (2) a description of each model applied, and (3) a summary of the conclusions of each evaluation.

The following modeling efforts were conducted:

- An XP-SWMM sewershed model that was developed by KCMO WSD as part of the OCP (WSD 2009);
- Desktop analysis conducted by KCMO WSD to highlight BMP opportunity and cost estimates within the study area;
- SUSTAIN modeling performed under parallel EPA study to evaluate the application of the SUSTAIN model when evaluating GI versus gray infrastructure from a cost optimization perspective; and
- WinSLAMM used for the opportunities and potential benefits of BMPs on private properties.

3.1. Storage Volume Analysis for 069 Sewershed

The KCMO WSD developed the OCP to provide guidance for managing CSOs (WSD 2009). In lieu of a continuous simulation of rainfall record and runoff in the city, a set of eight rainfall design events was constructed to characterize city rainfall for a typical year (WSD 2009). The development of the design storms was based on previously conducted continuous simulation hydrologic models. Eight separate events that resulted in a frequency of overflows were selected.

In a typical year, the city experiences an average of 78 rainfall events. A histogram showing the typical distribution of storm events by rainfall depth intervals is presented in Figure 3-1.

As part of that effort, an XP-SWMM model was developed as an evaluation tool. The primary modeling objective was to determine the amount of overflow from the existing sewer system and size controls to reduce CSO discharges. As applied in the 069 sewershed, the model was used to quantify the required storage capacity to achieve various levels of control of CSO discharges. Because it was developed as an event-based model, it is not intended for long-term continuous simulation.

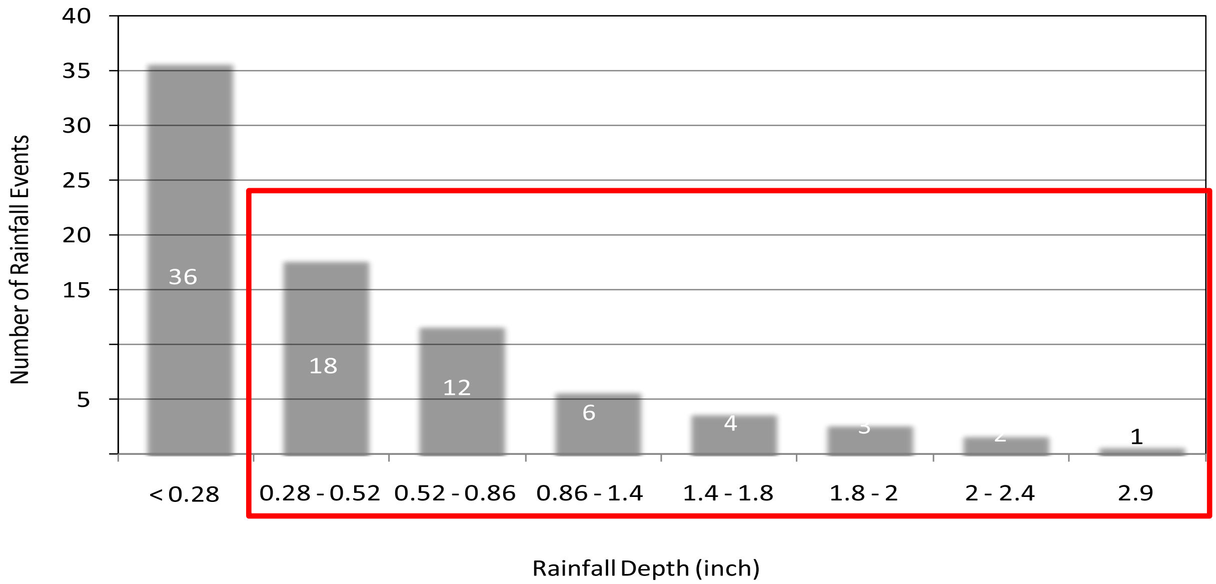


Figure 3-1. Storm size distribution for a typical Kansas City, Missouri meteorological year.

3.1.1. Overview of XP-SWMM Model

XP-SWMM (XP Software, Inc., Portland, Oregon) is a dynamic model based on EPA-SWMM. It is applicable in single events and continuous simulations accounting for all important components of time-varying rainfall, runoff, and flow routing cycle in a watershed. Flows from both piped collections systems and natural drainage channel networks can be modeled (routed) in XP-SWMM.

Both design or actual rainfall events can be used in XP-SWMM. A set of rainfall patterns including SCS types, Huff distributions, Chicago storm, and several other user-defined distributions were included in the software's library from which design storms for any duration and return period can be created. Numerous methods are available for computing storm runoff for event and continuous simulations, including non-linear runoff routing (EPA runoff method), Soil Conservation Service (SCS) unit hydrographs, Kinematic wave, Rational method, EPA R,T,K unit hydrograph (R parameter is the fraction of rainfall volume entering the sewer system as infiltration and inflow, T is the time to peak, and K is the ratio of time of recession) for rainfall dependent inflow and infiltration (RDII) , as well as several other unit hydrographs.

The EPA-SWMM non-linear runoff method (SWMM runoff) is the primary runoff hydrograph generation method used in XP-SWMM (Figure 3-2). Overland flow hydrographs are generated by a routing procedure using Manning's equation and a lumped continuity equation. The catchment is further described by surface roughness and depression storage for pervious and impervious area parameters. Unit hydrograph methods such as SCS, Rational, etc., are used for single event simulations. Unsaturated zone infiltration can be simulated in XP-SWMM with a number of methods including SCS, Hortons equation, and the Green-Ampt equation.

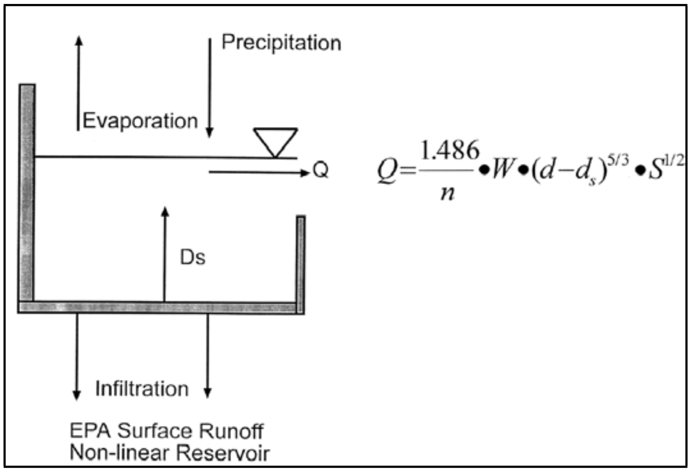


Figure 3-2: Runoff conceptualization in XP-SWMM.

In XP-SWMM, sanitary flows can be loaded using hourly and daily variation factors and peaking factors to produce unique loads to each node using direct flow, unit flow rate, or census-based methods.

3.1.2. XP-SWMM Modeling Approach and Results for 069 Sewershed

As part of WSD's efforts to evaluate existing CSO discharges and alternatives for controls, a statistical analysis was performed to characterize the storm distribution for a typical meteorological year within the study area.

The XP-SWMM model was developed for the entire combined sewer system. The land simulation component of the model was initially developed for planning level sizing of the CSO control alternatives. The model assumed that only runoff from directly connected impervious area (DCIA) reached the CSO network. For that reason, the model was primarily calibrated by adjusting the ratio of DCIA per subwatershed. The initial model representing the 100-acre pilot watershed was a component of the overall city model.

The model was calibrated using 2008 metering and rainfall data. The response of the CSOs to the series of design rainfall events was then determined using the XP-SWMM model. This rainfall distribution was applied in the 069 sewershed area. As modeled, rainfall depths of greater than 1.28 inches resulted in CSOs at outfall 069. The results were aggregated to estimate the overall volume of CSOs in a typical year. The calibrated model was used to estimate overflow volume to be controlled at outfall 069 for Design Storm D of 1.4 inches (16-hour duration). This design storm corresponds to a frequency of six overflow events per year.

The original outcome of the modeling concluded that 500,000 to 700,000 gallons of storage was required to mitigate the CSO in 069 sewershed. The model was updated by the city based on updated outfall design information. This resulted in a reduction of calculated storage to approximately 300,000 gallons or 56 percent of the runoff generated from Design Storm D.

3.2. Green Alternatives for 069 Sewershed

KCMO WSD conducted a desktop analysis and subsequently published a technical memorandum, *Green Infrastructure Alternatives for Outfalls 059 & 069* (WSD 2008), which quantifies the costs associated with modifying the CSO controls presented in the May 6, 2008 draft OCP summary for two outfalls in the MBR basin. Approximately 460 acres of outfall 069 drainage area within the MBR basin was selected for the desktop study (Figure 3-4). That study included considerations for incorporating both conventional gray infrastructure (i.e., underground storage tanks) and GI technologies for mitigating CSOs. Modeling results indicated that areas tributary to these two outfalls were likely to be improved through implementation of GI.

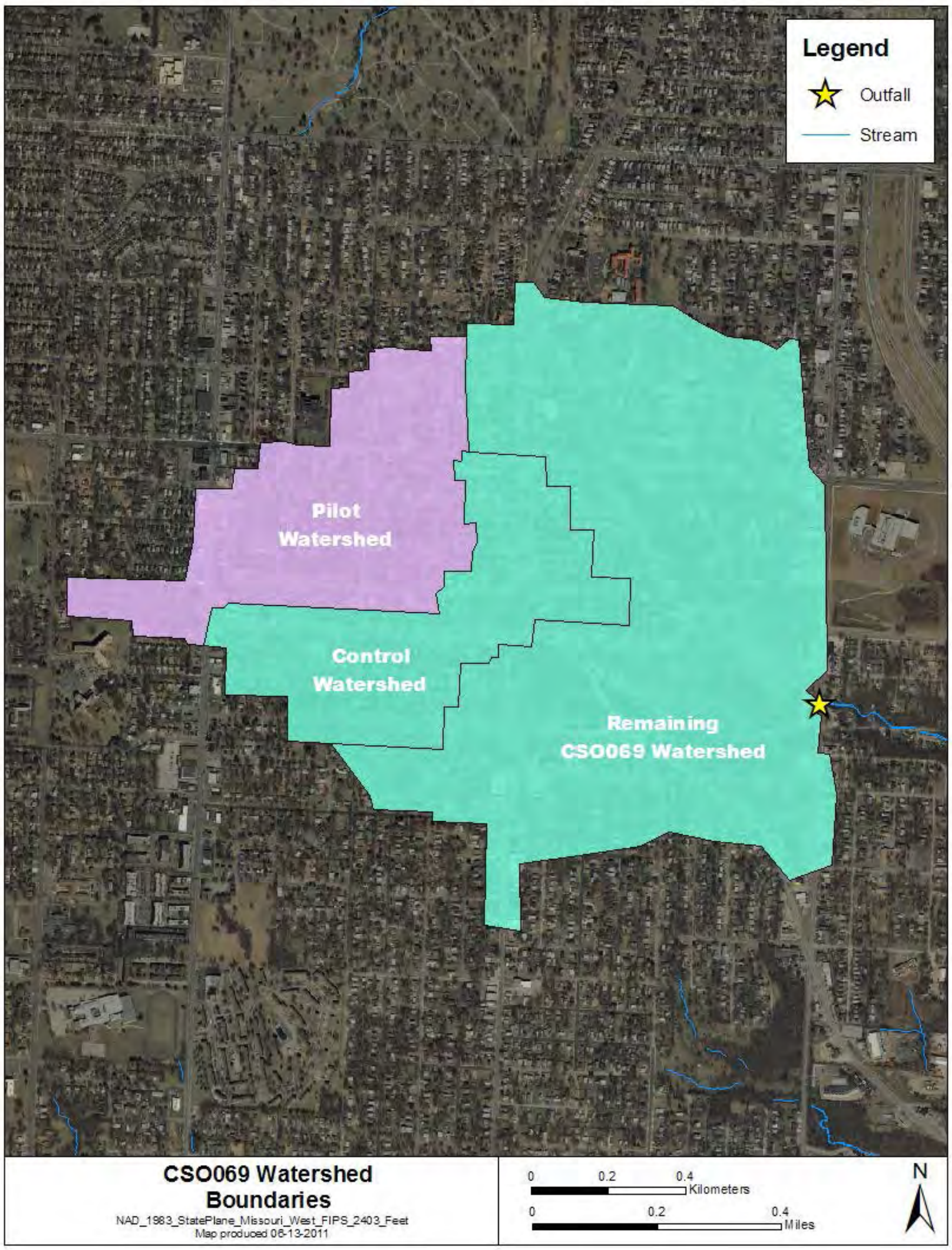


Figure 3-3: Location of pilot and control areas within the 069 sewershed.

This analysis was conducted without the benefit of detailed modeling of the system, which to properly represent the distributed green storage anticipated, would be a relatively expensive and time-consuming effort. Relating to this, an assumption was made in this study that the volume of storage in green solutions would result in an equal reduction in the volume of storage in gray components. The gray controls included storage tanks with screening facilities and outflow pumping stations. The size of the storage tank was selected to capture existing CSO volume resulting from the Design Storm D.

Table 3-1: Gray infrastructure CSO controls for outfall 069

Control Component	Total Estimated Capital Cost (million dollars)	Storage Provided (MG)	Capital Ccost per Gallon Stored (dollars)
2-million gallon storage tank 1.5-MGD pumping station 51-MGD screening 100-foot, 48-inch sewer 500-foot, 12-inch force main Odor control	$30.6	2.0	$15.30

Considering the potential benefits and cost savings associated with GI, several green technologies were considered in this desktop study. The green solutions considered and their estimated capital cost per gallon stored is as follows:

- Catchbasin retrofits in road and street ROW
- Curb extension bioretention
- Cascading swales
- Replacing sidewalks in road and street rights-of-way with permeable pavement
- Replacing pavement outside of road and street rights-of-way with permeable pavement
- Converting roof areas to green roofs

For complete elimination of the storage tanks and related facilities, it was assumed that GI would provide storage in the watershed along with potential infiltration. To demonstrate the selection of GI over gray infrastructure, these two GI processes must offset the volume stored in the tanks, as well as the volume pumped from the tanks during the most intense part of the design storm event.

Other considerations must be taken into account when comparing the cost-benefit of GI versus gray infrastructure. For example, the gray infrastructure solution presented in Table 3-1 requires 2.0 MG of storage volume, which assumes that pumping from storage occurs during the most intense 6 hours of the design storm. A GI solution must provide storage volume *greater* than 2.0 MG because of the additional pumping capacity otherwise represented in the gray storage tank. Accounting for the additional pumping capacity, the required storage volume of GI must equal that of gray infrastructure storage plus 6 hours' pumping volume (an additional 0.375 MG), which results in a total GI storage capacity of 2.375 MG (WSD 2008). According to the original desktop analysis results, the estimated capital cost to develop 2.375 MG of GI storage in the area tributary to outfall 069 is approximately $24.6 million—a $6 million dollar (≈ 20 percent) savings (WSD 2008). It is important to note that the cost information published in this study represents capital costs only and no O&M costs were included.

In January 2009, the KCMO WSD released the full text of its OCP. The plan cites some uncertainty associated with the performance of GI in mitigating overflow volumes at the outfalls. As a result, the GI capital budget proposed by the desktop analysis was increased by approximately 30 percent, bringing the original estimate of $24.6 million up to $32 million (WSD 2009). Following the adjustment, the updated plan suggests that gray infrastructure might be a more cost-effective solution when considering capital cost alone. Nevertheless, while the full cost of gray infrastructure represents a major public expense, GI offers the possibility for cost sharing through public-private partnerships. In addition, GI provides other benefits (e.g., reduced heat island effect, carbon sequestration, interception, aesthetic beauty) not offered by gray infrastructure. The OCP also proposed an annual budget of $2 million for O&M costs associated with GI upstream of outfalls 059 & 069.

Another result of the desktop study was the selection of the 100-acre pilot study catchment. The desktop study recommended further investigation of GI placement opportunity and associated costs, as well as a quantification of GI benefits. Further, the pilot study site was targeted to receive the first phase of implementation activity for which significant pre- and post-implementation monitoring would be performed.

3.3. SUSTAIN Case Study

Selection and placement of management practices form an integral part of the GI. SUSTAIN is a tool that was used in a companion/parallel study by EPA. The case study of the MBR project area was intended to provide an opportunity to further explore the decision-making process for selection and placement of GI practices by building on past or ongoing complementary efforts, including (1) cost data for local GI practices, (2) pre- and post-implementation monitoring data, and (3) GI performance modeling efforts in the watershed.

SUSTAIN was developed as a part of an EPA-initiated research project in 2003 to develop a fully integrated decision-support framework for the selection and placement of stormwater BMPs at strategic locations in urban or developing watersheds. Specifically, SUSTAIN was developed by combining publicly available modeling techniques, costs of management practices, and optimization tools in a geographically based framework to achieve design objectives, in turn facilitating the objective analyses of multiple water quality management alternatives while enabling consideration of interacting and competing factors such as location, scale, and cost.

The available data from this study was used to support the parallel SUSTAIN analysis. Products of this work that supported the SUSTAIN analysis included baseline watershed characterization, GI design specifications and siting analysis, pre-implementation monitoring data, and the site-specific GI performance modeling of private and public land areas using WinSLAMM.

SUSTAIN can be used for different watershed applications, including

- Developing total maximum daily load (TMDL) implementation plans
- Identifying management practices to achieve pollutant reductions in an area under an MS4 (municipal separate storm sewer systems) stormwater permit
- Determining optimal GI strategies for reducing volume and peak flows to CSO systems
- Evaluating the benefits of distributed GI implementation on water quality (as they may impact urban streams)

SUSTAIN is built on a base platform interface using ArcGIS, providing the user an access to the following framework components: a BMP siting tool, a watershed runoff and routing module, a BMP simulation module, a BMP cost database, a post-processor, and an optimization module (Figure 3-5).

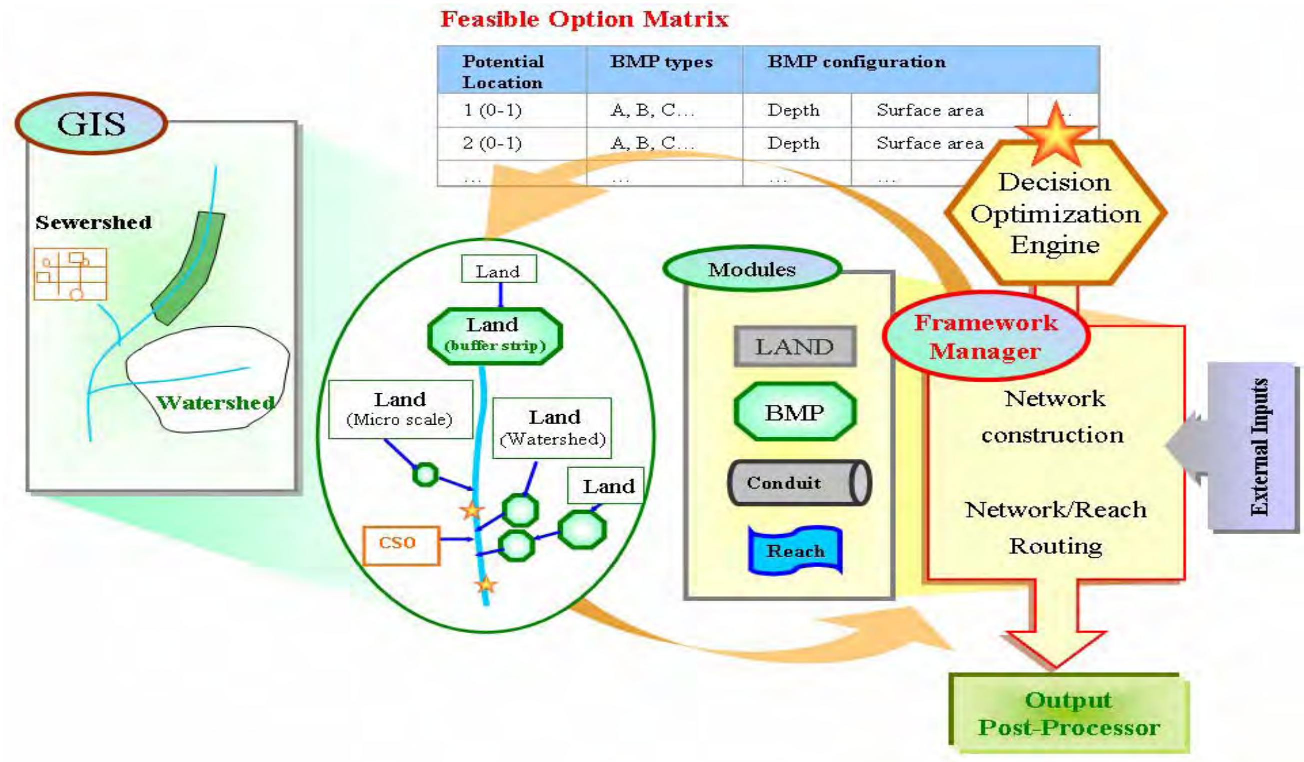


Figure 3-4: Conceptual diagram of SUSTAIN.

Each module in SUSTAIN serves its own specific function. Usually the applications begin with the use of BMP siting tool that determines the site suitability for various BMP options based on the user guided rules. The land segment module generates runoff time series data while the conveyance module provides routing capabilities between land segments or BMPs or both. Simulation of management practices by using a combination of processes for storage retention, open-channel controls, filtration, biological purification, and mechanical structure facilitated separation are provided by the process-based BMP module. The cost database is organized according to BMP construction components and populated with unit costs for each component. Results from other modules in the framework are used by the optimization module to evaluate and select a combination of BMP options that achieve a pollutant-reduction goal at minimum cost. Finally, the optimization results are presented by the post-processor as part of a cost-effectiveness curve (Figure 3-6).

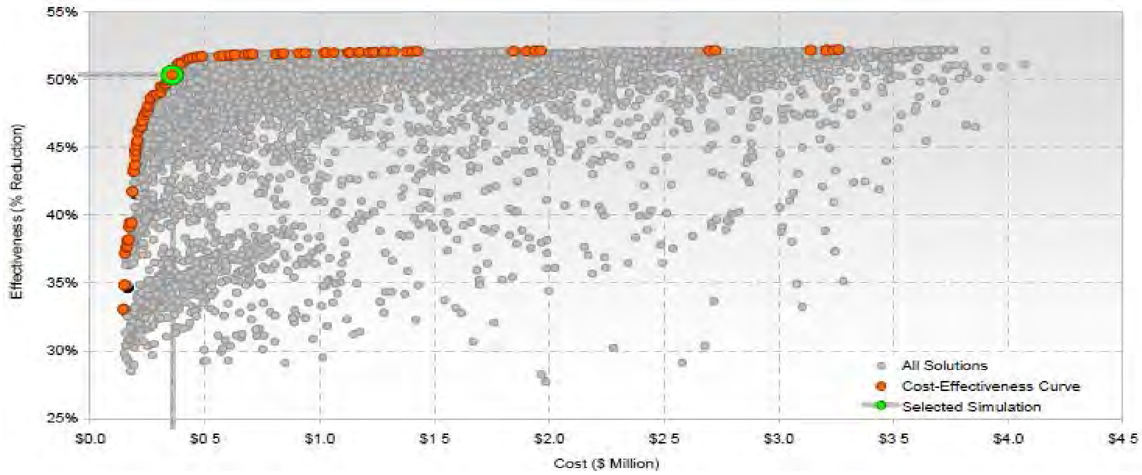


Figure 3-5: Sample of a cost-effectiveness curve from SUSTAIN post-processing.

3.4. Application of SUSTAIN Framework

For this study, GI was modeled in (ROW) areas to illustrate the cost-benefit relationships associated with introducing GI in conjunction with gray infrastructure. SUSTAIN was then applied to the rest of the outfall 069 area using the existing designs for the 100-acre pilot area to determine benefits of GI application for the entire watershed. As a part of the SUSTAIN application, criteria for management practice placement based on cost-effectiveness were identified. The impacts of implementing practices that enhance volume reduction at the private parcel scale (i.e., residential and commercial areas), in conjunction with public ROW GIs, were also studied. GI designs included in the SUSTAIN analyses were porous pavement and bioretention and rain garden systems. Rain barrels were modeled as appropriate private parcel GI practices. Table 3-2 summarizes the available information sources and describes how each source was used as part of the SUSTAIN application.

Table 3-2: Information sources and uses in the SUSTAIN application

Source	Key Information	Potential Use in SUSTAIN Application
Desktop analysis	Green options and related cost estimate; gray control option (i.e., storage tank) and its cost estimate	The estimated cost data will be used to quantify economic benefits and impacts of selected controls
GI design plan	Detailed BMP design and locations for the 100-acre pilot watershed together with estimated GI costs	The GI specifications and estimated cost were represented in SUSTAIN
Pre-construction monitoring data	15-minute rainfall data at two locations on the northwest and southeast borders of the pilot area; in-pipe flow data at seven locations	Used for model calibration and validation

SUSTAIN provides the user an option to link to an existing sewershed model using unit-area time series for each land unit, or hydrologic response unit (HRU), for boundary conditions. HRUs were developed in SUSTAIN based on a unique set of physical features, (1) impervious elements, (2) hydrologic soil type, and (3) slope. These elements affect the hydrology and help in characterizing the rainfall runoff response. Because HRUs are a unique combination of a selected set of physical features, they can be used consistently in analyzing areas outside the pilot study.

The external land use time series option in SUSTAIN was used to represent the watershed land-based runoff boundary condition. In addition, the aggregate GI methodology was used to derive land-use-associated sizing criteria for GI components within the network. The aggregate GI approach provided a means for extrapolating or projecting expected GI performance to areas outside the modeled study area. Because GI components with a SUSTAIN aggregate BMP network are sized according to contributing land use distribution, it provides a means for projecting expected responses to nearby areas with similar land use characteristics. The aggregate BMP methodology was also used to project or extrapolate the model results from this task to others in the 475-acre drainage area, and to outfall 069 to estimate GI-related costs and water quality benefits at a larger scale.

The city's criterion for GI practices is to locate them in the ROW. Thus, in the SUSTAIN application, it was assumed that all GI units would be located within the existing ROW of the public streets. As described above, GI units are typically located between the curb or edge of pavement and the sidewalk or under the sidewalk on streets where insufficient ROW behind the curb exists. GI opportunities were also identified in currently paved surfaces as bioretention and rain garden curb extensions.

Several factors or site conditions that limited the type, number, and cost of locating green solutions within the existing street ROW were considered, including the following:

- Slope – important factor that affects the length and storage capacity of a GI system or unit
- Surface and underground utilities – can restrict the type, size, and depth of GIs that can be used
- Soils and geology – primary limitations are depth to bedrock and permeability of native or disturbed soils
- Other obstructions – include paved driveways, parking, and walkways, sign posts, and large trees
- Property owner acceptance – anticipate improvements will be viewed as community amenities

After the HRUs were developed, a calibration process was performed to identify a unique set of parameters for each HRU that remain constant for all instances of that HRU within the study area, such that the spatial variation of the watershed response becomes only a function of the HRU distribution within each subarea. To characterize the model performance for a wider range of storm conditions, 10 storms of various sizes from the years 2008, 2009, and 2010 were selected. Some of the calibrated storms had rainfall volumes that were higher than the critical condition design storm, while others had comparable peak intensities. Calibration parameters were adjusted during the process until an acceptable match of benchmark calibration metrics was achieved. Some of the key parameters were those associated with depression storage and overland flow, infiltration, and DCIA.

3.5. BMP Optimization Considerations for CSO Control

Several exploratory management alternatives were considered during this pilot study in order to depict the degree of management that would be required to achieve CSO control throughout the entire 069 sewershed. These included (1) extending the proposed GI design plan (GI on public ROW) to the remainder of the 069 sewershed, (2) expanding the scope of GI to include implementation of certain practices on private land, and (3) exploring gray infrastructure options for supplemental CSO storage at the regulator outlet. The objectives for optimization are to both maximize runoff volume control, and minimize the total capital cost of implementation, as needed, to satisfy the set criteria of capturing 56 percent of Design Storm D.

Because model testing showed that the aggregate GI configuration was valid and representative for subwatersheds around 100 acres in size, the remainder of the area within CSO 069 was delineated into subwatersheds of similar size. Next, the aggregate BMP rules were applied and the simulation was completed for the remaining area of 069 watershed to evaluate the options of meeting the set CSO control criteria of capturing 56 percent of Design Storm D.

3.5.1. GI Cost Representation

Contractor bid data provided by KCMO WSD for the Middle Blue River Green solutions pilot project was used to analyze GI costs. Both general site preparation and specific site GI costs associated with construction were collected from contractor bid data.

The general cost components included

- Preconstruction costs (mobilization, traffic control, erosion and sediment control, surveying, and construction staking)
- Tree removal and utilities relocations
- Street and sidewalk improvements
- Landscape restoration
- Mulch, plants, and other miscellaneous landscape materials

The specific GI-associated costs included the following items:

- Below-grade storage system structures and general backfill
- GI construction for various surface GI types (rain gardens, shallow bioretention, pervious pavement, cascades, bioretention, and grass swale)

The costs were proportionally distributed among the GI units according to total number of GI units in design plan, and the GI-specific cost items were averaged by GI type to derive a unit cost of each GI type (Table 3-3).

Table 3-3: GI capital costs for the 069 sewershed

GI types		GI Costs Site Preparation	GI-specific Costs	Total Cost per Unit
Bioretention	Other	$19,616	$1,938	$21,554
	Shallow	$19,616	$3,247	$22,863
Bioswale		$19,616	$2,923	$22,539
Cascade		$19,616	$3,383	$22,999
Porous Sidewalk		$16,163	$13.1 /ft^2	*Varies by surface area*
Porous Pavement on Cube		$16,163	$10.7 /ft^3	*Varies by volume*
Rain Garden		$19,616	$1,249	$20,865
Storage		$19,616	$59,048	$75,210

GI costs for private parcels were derived from local applications and literature sources (Table 3-4). Schueler et al. (2007) published a manual through the Center for Watershed Protection. The manualprovided construction cost estimates for rain garden and rain barrels retrofits, and design and engineering cost estimates of 5 to 40 percent of the construction cost. However, local values were used wherever possible.

Table 3-4: Cost estimation for private parcel retrofit GI

	GI Cost ($ per Gallon of Treated Runoff)			
	Construction Cost			
BMP Type	Literature Range	Median	Design and Engineering (40% of Construction Costs)	Total Cost
Rain garden	$0.40–$0.67	$0.53	$0.21	$0.75
Rain barrel	$1.67–$5.35	$3.34	Not applicable	$2.81

3.5.2. Gray Infrastructure Costs

As per the OCP, the total capital cost for the 2-MG storage facility for sewershed 069 was estimated at $30.6 million. The estimated capital costs included an allowance of 25 percent of the total estimated construction cost for planning, engineering, and design, as well as an additional contingency cost of 25 percent. This cost estimate was based on 2006 data and has been updated for this case study using a multiplier of 1.163 (20 city Engineering News Record index value of March 2011/2006 Annual Average) to reflect a 2011 cost of $35.6 million. An initial fixed cost of $11.63 million (about one-third of the literature-based cost value, or $10 million × 1.163) was approximated to be a reasonable amount on the basis of inference from local contractor bids for certain components. The remainder of the gray infrastructure costs was approximated by back-calculating the rate as a linear function of storage capacity. Calculations demonstrating this are provided below:

$$\text{Storage cost} = (\$35{,}600{,}000 - \$11{,}630{,}000) \div 2\ \text{MG} = \$12/\text{gallon} = \$89.76/\text{ft}^3$$

$$\text{Total capital cost } (\$) = \$11{,}630{,}000 + \$89.76 \times (\text{storage volume in ft}^3)$$

3.5.3. Exploratory Management Scenarios

Three exploratory management scenarios were developed to evaluate the cost-benefits associated with gray and GI controls. Cost-effectiveness curves were plotted for each scenario towards achieving the set management goals of minimizing costs and capturing 100 percent of Design Storm D, but had an assumed GI design capture of about 50 percent of Design Storm D objective.

Table 3-5: Summary and description of baseline and exploratory optimization scenarios

Optimization Scenario		Description
Baseline	Public green (pilot area)	Full adoption of the GI design plan within the 100-acre pilot study area
Exploratory	Gray only	Baseline + supplemental gray storage at the 069 regulator outlet
	Public green + gray	Baseline + public green expanded to other 069 areas + gray supplemental storage
	Public + private Green + gray	Baseline + public Green expanded to other 069 areas + private green opportunity + gray supplemental storage

The optimization scenarios were run using average antecedent moisture conditions for the Design-Storm D time series and a comparison of overflow compliance costs associated with the three exploratory management scenarios.

Among the exploratory optimization scenarios, proposed GI options for both public and private land were maximized, with the exception of the gray only scenario, in which GI was not considered. For the scenarios containing GI, the difference in cost is attributable to the size of the gray supplemental storage associated with meeting the optimized target.

3.6. SUSTAIN Optimization Summary and Conclusions

The optimization conclusions for GI opportunity for CSO mitigation in 069 sewershed can be summarized in terms of implications for planning and management decisions. Post processing results are shown in Figure 3-7.

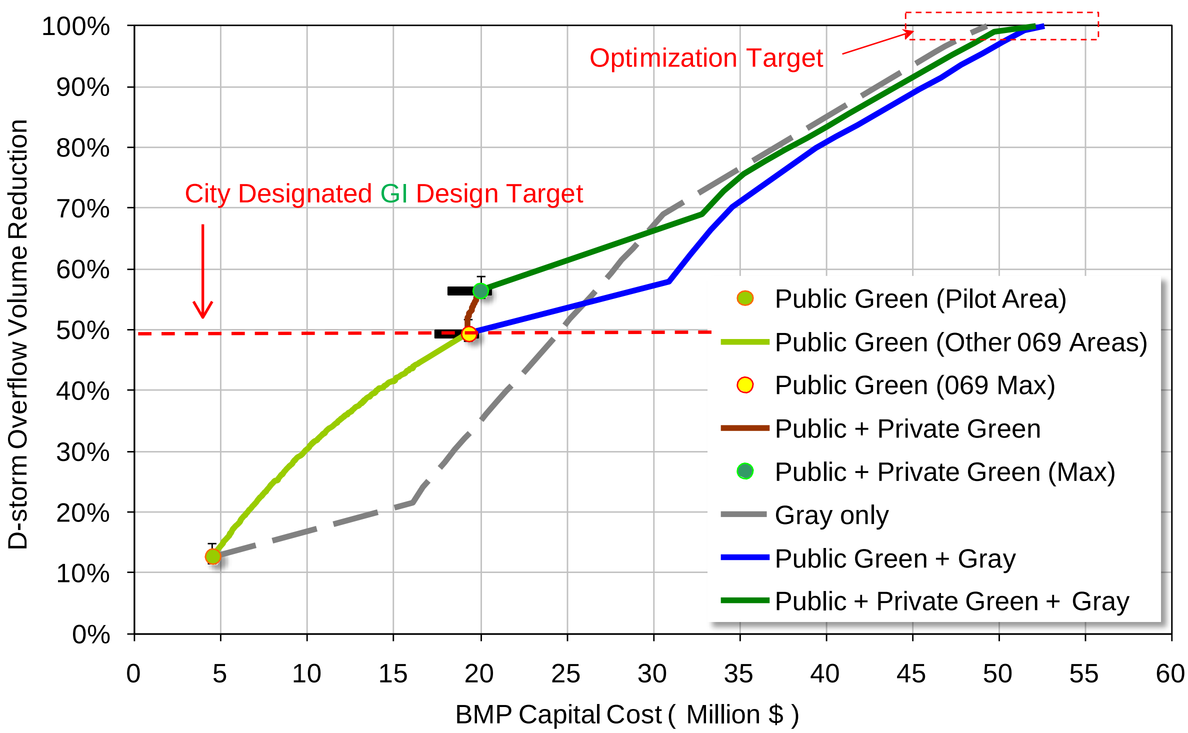


Figure 3-6: Cost-effectiveness junctions and trajectories for exploratory optimization scenarios.

Optimization for the outfall 069 sewershed used the design plan from the 100-acre pilot study site and applied proportionally the design controls to the remainder of the watershed (335 acres). The Design Storm D was used for optimization, because controlling this event was expected to attain the CSO mitigation objective as defined by the city. The modeling performed in this pilot study only considered GI implementation in public ROW as per the design plans. The cost-benefit analysis did not include O&M costs and is limited to the capital cost of construction, contingencies, and design fees. Considering the city-designated GI design target (which is approximately 56 percent volume reduction of the Design Storm D), implementation of GI on public areas and private parcels can be cost-effective in achieving the volume objective. Therefore, the target set by the city as the goal for volume reduction is met by this scenario. However, if 100 percent capture of Design Storm D is required, the current design of GI will be insufficient to capture all flows and will require additional gray storage to achieve that goal. In this case, the generalized city stated CSO mitigation objectives (100 percent capture of Design Storm D) could not be achieved by only implementing GI on public ROW, as defined by the design plan. In fact, more capture is needed.

Adding GI on private parcels provided an additional 6 to 8 percent volume reduction. When considering the costs portion of the optimization analyses the retrofit GI alternatives proposed for the study are likely to be more expensive than new GI construction costs because of significant overhead costs associated with site preparation, reconstruction of curbs and sidewalk system, and the traffic control measures needed during construction. Similarly, as this is a pilot project, the present cost considerations, which used the actual bid price, likely contain undue costs based on the uncertainty and risk with constructing the GI in this area. Therefore, these bid cost are likely to be higher than if this were a regular practice within Kansas City. Table 3-6 shows the component sizes and costs from the exploratory optimization scenarios that were based on bid costs.

Table 3-6: Management component size and costs for exploratory optimization scenario

Scenario	Management Component		Total Storage Capacity (Gallons)	Total Cost ($)	Unit storage volume cost ($/Gallon)
Public green	Bioretention	Other	520,023	$4,310,671	$8.29
		Shallow	82,109	$519,610	$6.33
	Bioswale		44,313	$102,447	$2.31
	Cascade		64,188	$522,682	$8.14
	Porous sidewalk		59,301	$381,698	$6.44
	Porous pavement on cube		11,404	$180,020	$15.79
	Rain garden		474,081	$6,069,606	$12.80
	Pipe storage		915,905	$7,178,998	$7.84
Private green	Rain barrels		14,662	$41,480	$2.83
	Rain gardens		950,443	$706,000	$0.74
Gray	Gray only		2,778,994	$38,607,040	$13.89
	Public green + gray		1,819,754	$28,731,790	$15.79
	Public + private green + gray		1,718,747	$27,692,290	$16.11

Furthermore, additional GI benefits such as esthetic improvement, community educational opportunity, increased property value, volume reduction of treatment plant inflow, carbon sequestration, and possible reduction in heat island effects, can be considered as potential factors to consider for implementing GI. GI implementation and maintenance could possibly provide a means for creating employment opportunities for a municipality (e.g., green jobs), which can ultimately contribute to sustaining a local economy.

3.7. WinSLAMM Modeling for Private Residential GI

As a parallel effort, WinSLAMM was used to evaluate the water quality and quantity improvement benefits of a large-scale application of GI control practice retrofits in the pilot watershed. WinSLAMM effort focused on BMP practices for private property as supplementary management to the practices designed in the public ROW. The WinSLAMM model was applied using a long-term, continuous simulation approach, which generated time series of flow for various types of upland controls on private parcels. The goal of the WinSLAMM study was to quantify individual private parcel GI performance.

3.7.1. WinSLAMM Background Information

WinSLAMM was developed to evaluate stormwater runoff volume and pollutant loadings in urban areas using continuous small storm hydrology, in contrast to single event hydrology methods that have been traditionally used for much larger drainage design events. WinSLAMM determines the runoff based on local rain records and calculates runoff volumes and pollutant loadings from each individual source area within each land use category for each rain event. Examples of source areas include roofs, streets, small landscaped areas, large landscaped areas, sidewalks, and parking lots.

3.8. Stormwater Controls and Calculations in WinSLAMM

WinSLAMM was used to examine a series of stormwater control practices applied to private property including rain barrels, water tanks (cisterns), and absorbent lawns and landscaping. While WinSLAMM has the capability of evaluating other controls such as infiltration or biofiltration practices, street cleaning, wet detention ponds, grass swales, porous pavement, catch basins, and selected combinations of these practices, for the current application, it was limited to applications on private property. The model evaluates the practices through calculations of the unit processes based on the actual design and size of the controls specified and determines how effectively these practices remove runoff volume and pollutants. The following summarizes the WinSLAMM modeling results that are further described in the WinSLAMM project report.

WinSLAMM does not use a percent imperviousness or a curve number to generate runoff volume or pollutant loadings. Rather, the model applies runoff coefficients to each “source area” within a land use category. Each source area has a different equation based on factors such as slope, type and condition of surface, and soil properties to calculate the runoff expected for each rain event. Custom equation coefficients are developed using monitoring data from typical examples and specific local conditions.

Each source area is also assigned a unique pollutant concentration (event mean concentrations or EMCs) and a probability distribution. The EMCs for a specific source area vary depending on the rain depth. The source area’s EMCs were developed from decades of extensive monitoring conducted by the U.S. Geological Survey, Wisconsin Department of Natural Resources, , the University of Alabama, and other groups. These monitoring efforts isolated source areas (roofs, lawns, streets, etc.) for different land uses and examined long-term data on the runoff quality. The pollutant concentrations are also continuously updated as new research data become available.

For each rainfall event in a data set, WinSLAMM calculates the runoff volume and pollutant load (EMC × runoff volume) for each source area. The model then sums the loads from the source areas to generate a land use or drainage basin subtotal load. The model continues this process for the entire rain series described in the rainfall file. It is important to note that WinSLAMM does not apply a "unit load" to a land use. Each rainfall produces a unique load from a modeled area based on the specific source areas in that modeled area.

The model's output is customizable, and typically includes the following:

- Runoff volume, pollutant loadings, and EMCs for a period of record and/or for each event
- Pre- and post-data for each stormwater management practice
- Removal by particle size from stormwater management practices applying particle settling
- Other results that can be selected related to flow-duration relationships for the study area, impervious cover model expected biological receiving water conditions, and life-cycle costs of the controls.

3.9. Model Calibration and Verification

WinSLAMM was originally calibrated using site specific data obtained from site measurements (Section 2.1 and Section 6.4) and the use of the local rainfall data. Test watershed site soil infiltration data (Section 6.5) was also used to quantify the soil responses for the modeling. In addition, regional stormwater quality data, as contained in the National Stormwater Quality Database, and more recent data from Lincoln, Nebraska were used to develop calibrated regional parameter modeling files for use in Kansas City. Verification of the model is ongoing as additional site monitoring data becomes available. Currently, the test and control watershed flow monitoring and rainfall data for the last 2 years was used to verify the model calculations under current conditions for the complete drainage areas.

In addition, rain garden monitoring data has been collected in the test watershed and those observations have been used to verify the model predictions on rain garden performance. Additional verification will occur as individual practice data becomes available during the coming project phase, while the test and control watershed flow (and rain) data will be used to verify the performance of the large-scale implementation of the GI controls throughout the area. Future use of the calibrated and verified model will be used to examine stormwater conditions for other land uses in the Kansas City area, and to calculate the benefits of alternative stormwater control programs for those areas.

3.10. Land Development and Urban Soil Characteristics

The pilot and control areas are comprised of mostly medium density residential land use, constructed prior to 1960, with a small amount of strip commercial area along Troost Avenue. Detailed inventories were made of each of the approximately 600 homes in the area by graduate students from UMKC. The breakdown of the different land surface components in the test watershed for the residential areas is shown in the results section within Chapter 6.

In addition to the site surveys, site-specific soils information was also collected for the area (Section 5-6). Disturbed urban soils have infiltration rates that are usually substantially less than rates based on general county soil maps. For the Kansas City project, small-scale infiltrometers were used to measure infiltration rates in the disturbed urban soils of the test watershed area. Infiltration rates were monitored at several locations near the streets throughout the project area. Figure 3-8 shows the average infiltration responses from 3 sets of measurements at 6 locations, representing 18 individual infiltration tests for different storm durations. Initial infiltration rates were several inches per hour, but were reduced to about 1 inch per hour after about 1 hour, as also shown on Figure 3-8. Although initial modeling efforts assumed sustained infiltration rates of about 0.3 inches per hour, more recent measurements and deeper soil profiles indicated that this may even be too large for the site. Therefore, for the shallow rain gardens considered in this analysis, infiltration rates of 0.2 inches per hour were used as a conservative approach.

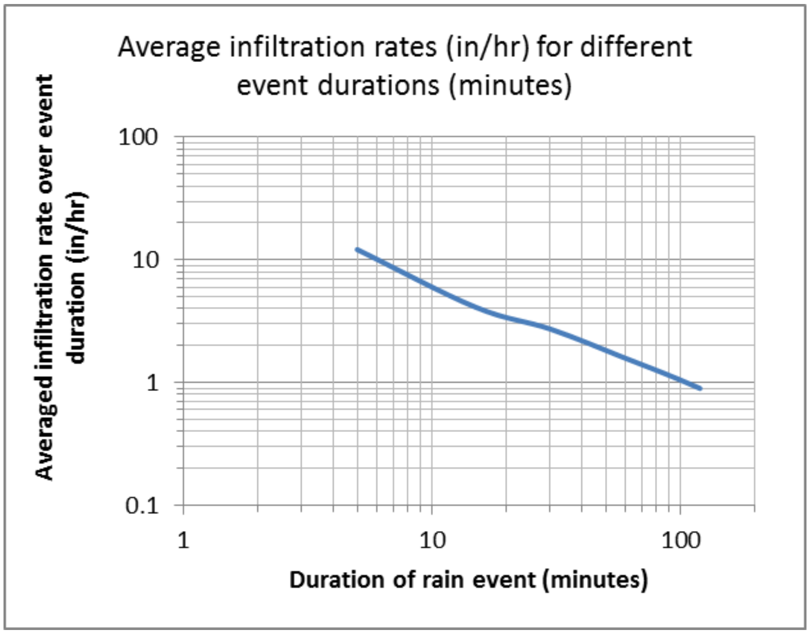


Figure 3-7: Soil infiltration characteristics for Kansas City test area.

3.11. Sources of Flow and Pollutants

The study watershed stormwater sources change for different rain depths. For the smallest rains (< 1.25 inches of rain), most of the runoff originates from the directly connected impervious areas, such as directly connected roofs, paved parking, driveways, sidewalks, and streets. After about 0.25 inches of rain for the higher intensity short duration events, the small landscaped areas contribute about half of the runoff—a relatively large fraction due to lower infiltration capabilities. Generally, streets contribute about half of the remaining flows, followed by driveways and roofs.

3.12. Evaluation of On-site Controls

Modeling was used to examine the benefits of using rain gardens, rain barrels/tanks, and roof disconnections in the Kansas City test area for the reduction of volume contributions that would contribute to CSOs. Performance plots were prepared comparing the size of the rain gardens to the size of the roof versus percent flow reductions (Figure 3-9). Rain gardens with a size of about 20 percent of the roof area are expected to result in about a 90 percent reduction in total annual flow compared to directly connected roofs. This area is about 200 ft^2 per house that could be comprised of several smaller rain gardens so they can be located at each downspout. Fifty percent reductions in the total annual flows could be obtained if the total rain garden area per house was about seven percent of the roof area. The 200 ft^2 rain garden area per house is also expected to completely control the runoff from the regulatory Design Storm D of 1.4 inches.

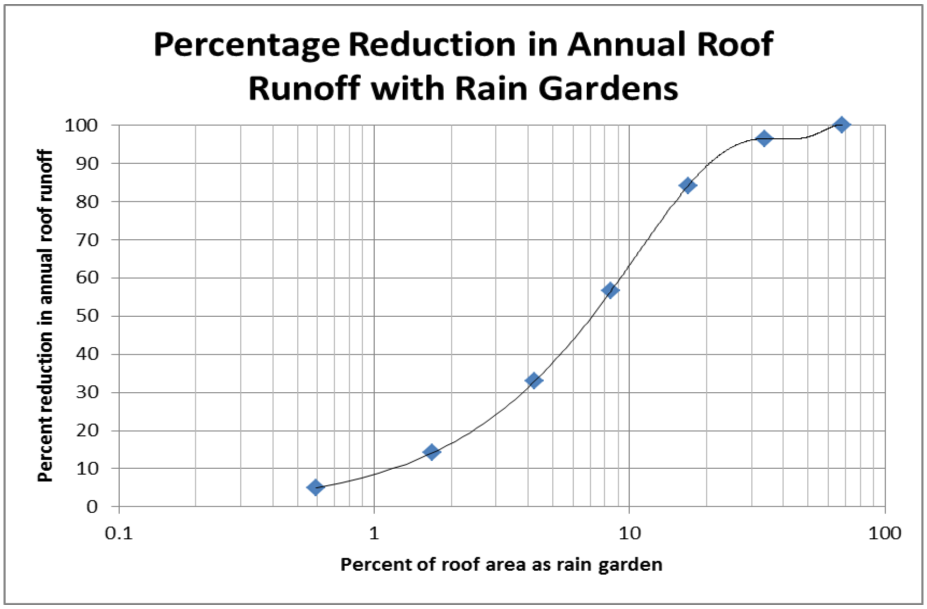


Figure 3-8: Production function for roof runoff rain gardens.

The water harvesting potential for the retrofitted rain gardens and water tanks was calculated based on supplemental irrigation requirements for the basic landscaped areas. The irrigation requirements were determined to be the amount of water needed to satisfy the evapotranspiration rates of typical turf grasses, after normal rainfall, and is shown in Figure 3-10.

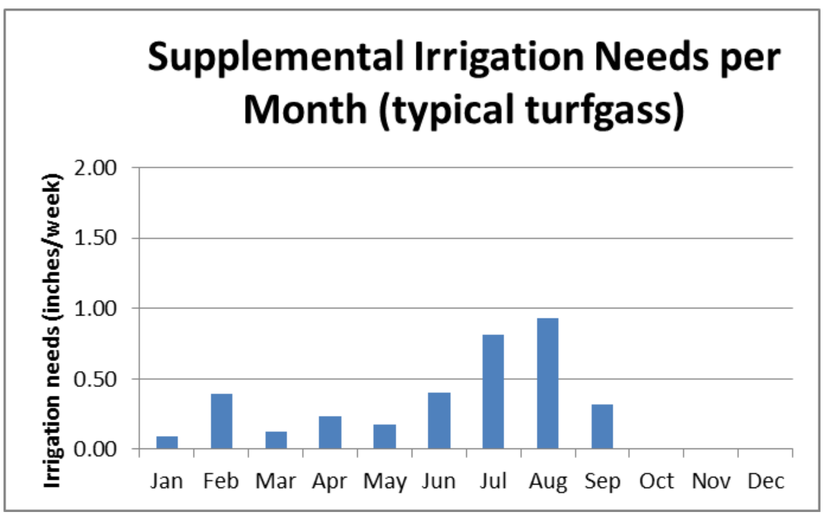


Figure 3-9: Monthly irrigation requirements to match evapotranspiration.

Rain barrel effectiveness is related to the water balance between the need for supplemental irrigation and rainfall amount for each season. The modeling simulations used a typical 1-year rainfall series and average monthly evapotransipration values for varying amounts of roof runoff storage. As shown on Figure 3-11, a single 35-gallon rain barrel (typical size) is expected to reduce the total annual runoff by about 24 percent compared to directly connected systems if the water balance is closely regulated to match the irrigation requirements. If four 35-gallon rain barrels were used (such as one on each corner of a house assuming four separate roof downspouts exist), the total annual volume reductions from the roof area could be as high as about 40 percent. Larger storage quantities result in increased beneficial usage, but likely require larger water tanks.

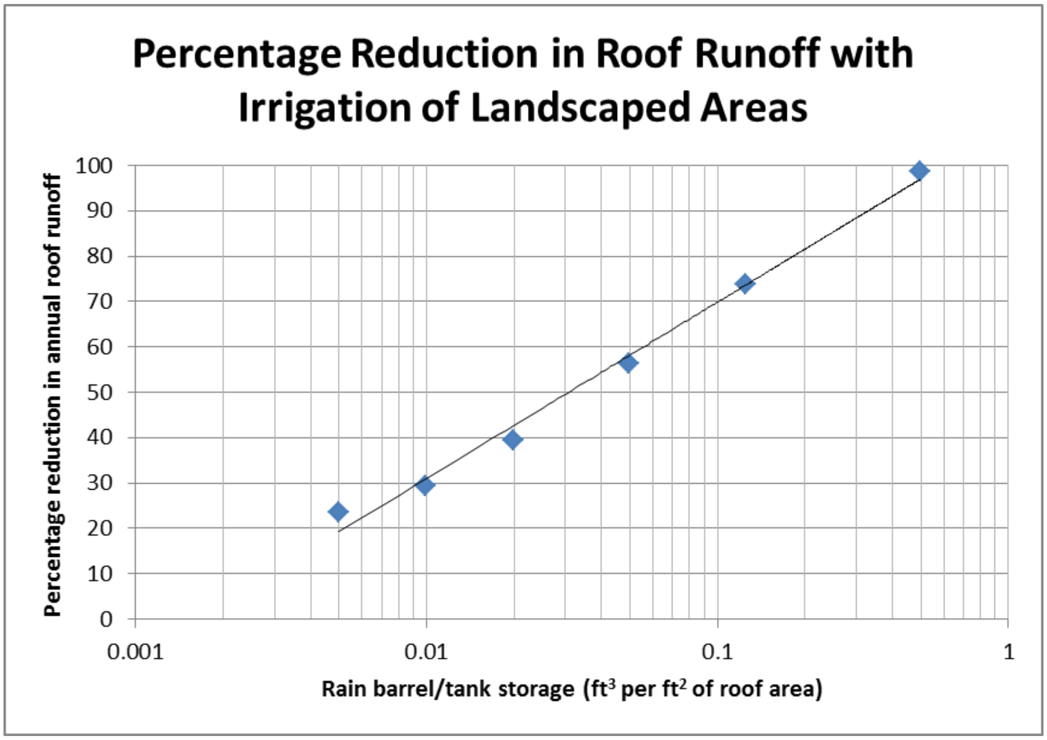


Figure 3-10: Production function of water cistern/tanks storage for irrigation to meet evapotranspiration.

Figure 3-12 illustrates expected benefits of pavement or roof disconnection practices for different individual rains, up to 4 inches in depth. The volumetric runoff coefficient (Rv; the ratio of runoff volume to rainfall volume falling on an area) is seen to increase with increasing rain amounts. For directly connected pitched roofs, the Rv is about 0.7 for 0.1 inch rains, and is quite close to 1.0 for rains larger than about 2 inches in depth. When disconnected to clayey soils, runoff is not expected until the rain depth is greater than 0.1 inches, and the Rv starts to climb steeply with rains larger than several inches in depth. Rv is expected to be very large for very large and unusual rain events that can cause severe flooding, regardless of whether they are disconnected or not. However, the benefits of pavement or roof disconnection practices for small and intermediate rains are large.

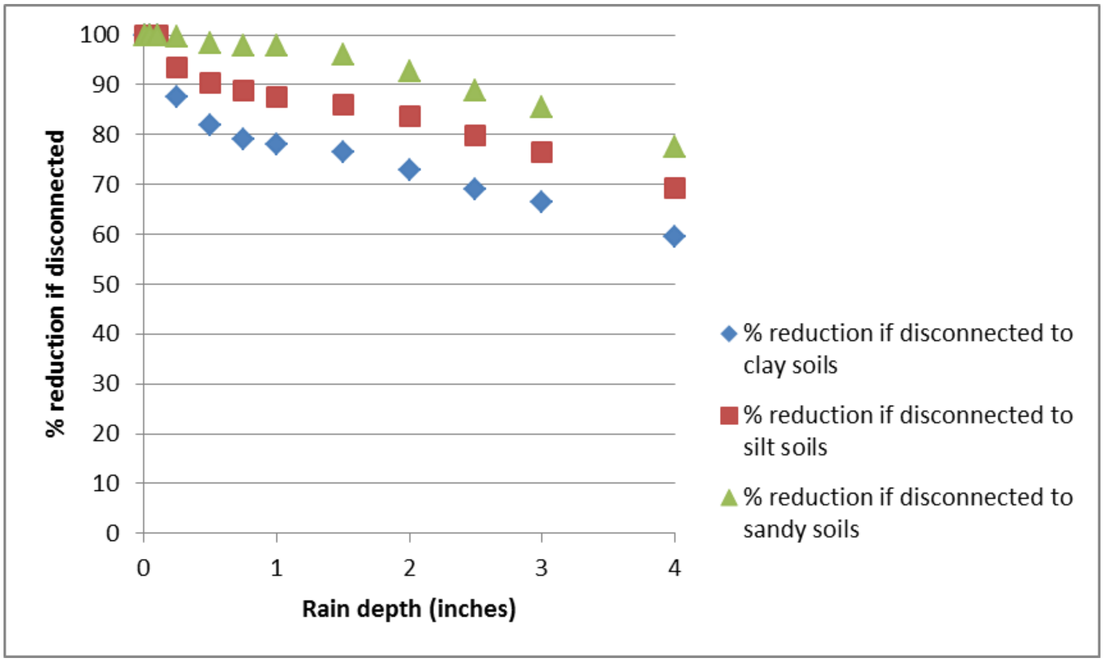


Figure 3-11: Effectiveness of roof disconnections for different soil characteristics.

3.13. Preliminary Evaluation of other Land Use Controls

A recent comprehensive evaluation of stormwater controls was conducted by Pitt (2011) for many land use categories in Lincoln, Nebraska as part of their stormwater management plan. The following example is taken from the Lincoln report and is very likely based on comparative data that can closely represent conditions similar to the pilot and control watersheds in Kansas City, Missouri.

A total of 28 alternative control options were examined by Pitt (2011) for this medium density residential area and are compared to the base conditions (Figure 3-13). Notably, that analysis used data from the batch processor in WinSLAMM that enables many attributes of each control alternative to be examined, including life-cycle costs, land requirements, maintenance requirements, expected biological conditions in the receiving waters, and runoff and pollutant characteristics. The performance characteristics and the total annual costs were included onscatterplots to enable the most cost-effective alternative to be identified for different levels of performance. Based on that evaluation, the most cost-effective stormwater control programs (i.e., the alternatives with the least cost at the highest potential control benefits) are the following:

- Curb-cut biofilters along 20 percent of curb line (37 percent runoff annual volume reductions)
- Curb-cut biofilters along 40 percent of curb line (54 percent runoff annual volume reductions)
- Small wet pond and curb-cut biofilters along 40 percent of curb line (54 percent annual runoff volume reductions; same volume reduction as above alternative, but higher cost due to small pond for increased particulate pollutant control)
- Small wet pond, rain gardens (15 percent of roof area), and curb-cut biofilters along 40 percent of curb line (66 percent annual runoff volume reductions; increased volume

reduction due to rain gardens added to curb-cut biofilters, small pond added for increased particulate pollutant control)

- Curb-cut biofilters along 80 percent of curb line (75 percent annual runoff volume reductions; though it would be clearly challenging to install this high level of curb-cut biofilters in an area that is already developed)

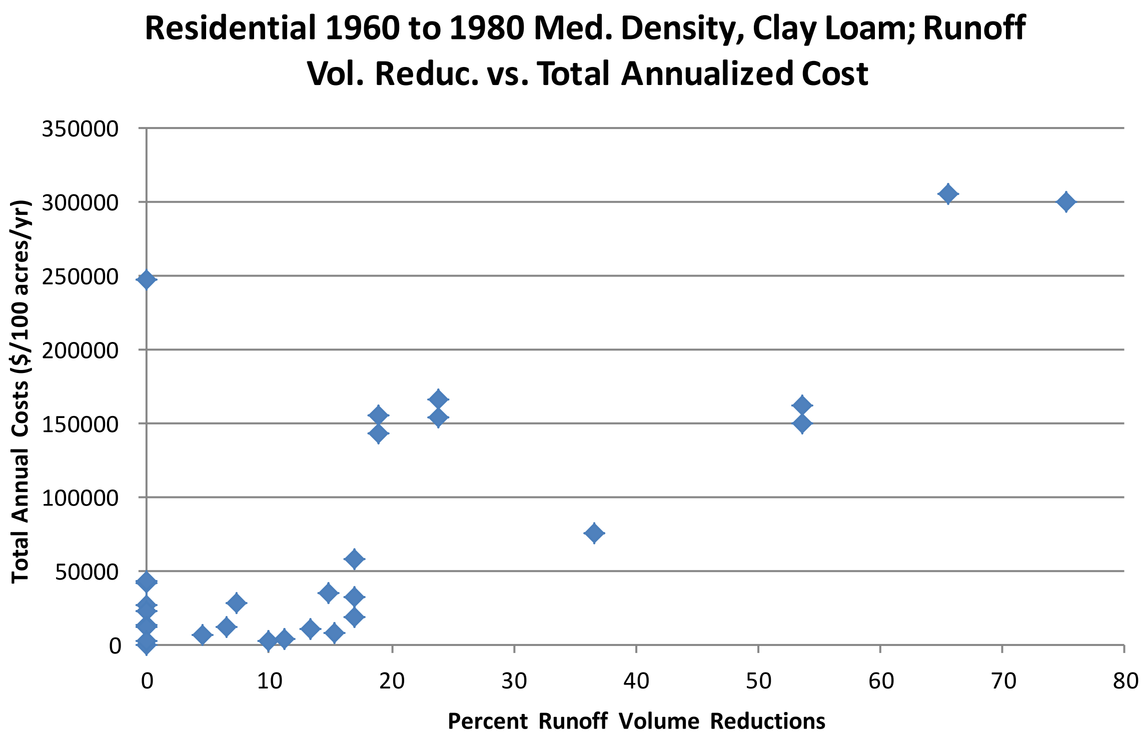


Figure 3-12: Cost-effectiveness of alternative stormwater management programs.

In addition to the above medium density residential land use analyses by Pitt (2011), similar analyses were conducted for other Lincoln area land uses that are similar to land uses found in the Kansas City area. The following is a brief discussion of the findings for these areas.

For runoff volume controls, each land use group had similar "most cost-effective" controls, as shown on the following list for the controls having at least 25 percent levels of runoff volume reduction potential in areas having clay loam soils in the infiltration areas. Although other control options have similar potential levels of control, the others were likely more costly. These are listed in order with the first control having the lowest level of maximum control (the approximate percentage of runoff reduction is shown) and with the best unit cost-effectiveness, while the last control listed having the highest level of maximum control, but the worst expected unit cost-effectiveness. Therefore, if low to moderate levels of control are suitable, the first control option might be best, but if maximum control levels are needed, then the last control option listed would be needed.

- Strip mall and shopping center areas:
    - Porous pavement (in half of the parking areas), 25 percent annual volume reductions

- Curb-cut biofilters (along 80 percent of the curbs) for strip malls or biofilters in parking areas (10 percent of the source area) for shopping centers, 29 percent annual volume reductions
- Biofilters in parking areas (10 percent of the source area) and curb-cut biofilters (along 40 percent of the curbs), 42 percent annual volume reductions

- Light industrial areas:
    - Curb-cut biofilters (along 40 percent of the curbs), 26 percent annual volume reductions
    - Roofs and parking areas half disconnected, 32 percent annual volume reductions
    - Roofs and parking areas all disconnected, 61 percent annual volume reductions
- School, church, and hospital institutional areas:
    - Small rain tank (0.10 ft^3 storage per ft^2 of roof area) for schools and churches; rain tank (0.25 ft^3 storage per ft^2 of roof area) for hospitals, 26 percent annual volume reductions
    - Roofs and parking areas half disconnected, 31 percent annual volume reductions
    - Roofs and parking areas all disconnected, 67 percent annual volume reductions
- Low and medium density residential areas:
    - Curb-cut biofilters (along 20 percent of the curbs), 36 percent annual volume reductions
    - Curb-cut biofilters (along 40 percent of the curbs), 53 percent annual volume reductions
    - Curb-cut biofilters (along 80 percent of the curbs), 75 percent annual volume reductions

3.14. WinSLAMM Analysis Summary and Considerations

Pre- and post-control installation monitoring of the CSOs of the drainage area below where the stormwater management controls are being installed will enable direct measurements of the benefits of the GI options. In addition to large-scale monitoring, individual controls were also monitored to quantify their performance under a variety of runoff conditions. The stormwater management controls in the demonstration area drain to the municipal combined sewer drainage system in the MBR watershed. The drainage pattern allowed isolation of the benefits of the green infrastructure stormwater controls with no flows coming from outside areas. The watershed model (WinSLAMM) and the sewerage model (SWMM) have been calibrated for this area using the pre-construction flow and water quality data. The calibrated models have been used to predict the benefits of the controls, and these predictions will be verified as the controls are installed. The calibrated and verified models can also be used to predict the benefits of wider applications of the upland controls across the city during later project phases. Specifically, the models will predict the decreased runoff volumes and peak runoff rates associated with stormwater controls to alleviate problems in the combined sewer system.

Water quality benefits associated with stormwater pollutant discharge reductions of wet-weather flow particulates (including particle size distributions), nutrients, (fecal indicator) bacteria, and heavy metals were also quantified using WinSLAMM. The model was also used to calculate the stormwater contributions to the combined sewerage system during wet-weather by providing a time series of flows and water quality conditions, for various types of upland controls, while SWMM, with its detailed hydraulic modeling capabilities, will focus on the interaction of these time series data with the sewerage flows and detailed hydraulic conditions in the drainage system. Both models were used interactively emphasizing their respective strengths. For example, the detailed analyses of site-specific designs of the study area stormwater controls conducted using WinSLAMM were used to optimize the control performance components contained in SUSTAIN. The strength of using a combination of models is in increasing the weight of evidence supporting the green infrastructure approach.

Suitable care is needed in the construction of stormwater controls and interpreting modeling results, as other critical factors may dramatically affect their success. Certain site conditions might restrict the applicability of some controls. The designs of infiltration devices need to be checked based on their clogging potential. As an example, a relatively small and efficient biofilter (such as in an area having a high native infiltration rate) can capture a large amount of sediment. Having a small surface area, this sediment would accumulate rapidly, possibly reaching a critical clogging load early in its design lifetime. Infiltration and bioretention devices can show significantly reduced infiltration rates after about 2 to 5 lb/ft^2 (10 to 25 kg/m^2) of particulate solids have been loaded, especially during a short (several years) period of time.

4. Performance of Selected Manufactured Treatment Devices

Two types of manufactured treatment devices (MTDs) were planned to be examined as part of the demonstration project for this study. Two Up-Flow filters by Hydro International and one UrbanGreen BioFilter by Contech Construction Products were considered for the City Fleet Maintenance Facility on 18th and Vine streets. Performance and water quality data of these MTDs, and the project description, are provided below.

4.1. Up-Flo Filter by Hydro International

The Up-Flo Filter by Hydro International (Figure 4-1) is a compact stormwater filtration technology that removes trash, fine suspended sediments, phosphorus, heavy metals, and polycyclic aromatic hydrocarbons from runoff. In brief, stormwater enters the system through an inlet pipe. Debris and sediment settle out, and floatables and oil float to the top. The flow is directed upwards through a screen before flowing across a filter media. The filtered water is then conveyed to an outlet pipe. During times of excessive flow, water bypasses the filtration media but oils and floatables are prevented by a floatables baffle. After the storm event, the filtered water drains out through a patented drain down port that also provides a light backwash for the media. Upflow filtration, as opposed to conventional downward flow filtration, was developed to overcome clogging and therefore minimize bypass (Khambhammettu et al. 2006).

Figure 4-1: Up-Flo filter by Hydro International.

Controlled tests of the Up-Flo filtration system indicate a suspended solids removal efficiency of 85 to 90 percent (with a 50 percent removal for particles, 0.45 to 30 μm, and a 95 to 100 percent removal for particles larger than 30 μm) (Khambhammettu, et al. 2006). Figure 4-2 shows the performance for mixed media for suspended solids at influent concentrations of 500mg/L, 250 mg/L, 100 mg/L and 50 mg/L

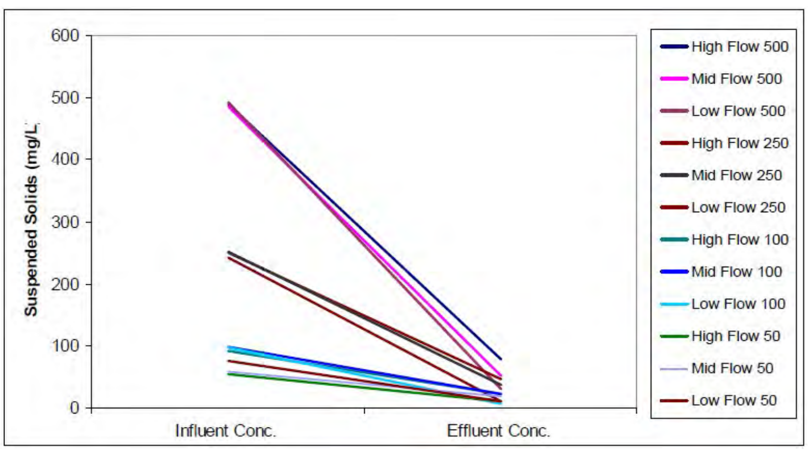


Figure 4-2: Performance for mixed media for suspended solids (Source: Khambhammettu et al., 2006).

(Khambhammettu et al. 2006). Further laboratory testing indicates the Up-Flo filter removes more than 80 percent of experimental silica sand with hydraulic loading rates around 20 gallons per minute (gpm)/ft^2 (Andoh et al. 2009). TSS test results are presented in Figure 4-3 (Andoh 2009). Laboratory testing also indicates that the Up-Flo filter is capable of higher hydraulic loading rates (around 18.2 gpm/ft^2) when compared to typical filters (around 2 gpm/ft^2). To achieve that improvement, the system requires “20 in. of driving head above the filter” with the Hydro Filter Sand media (Andoh 2009).

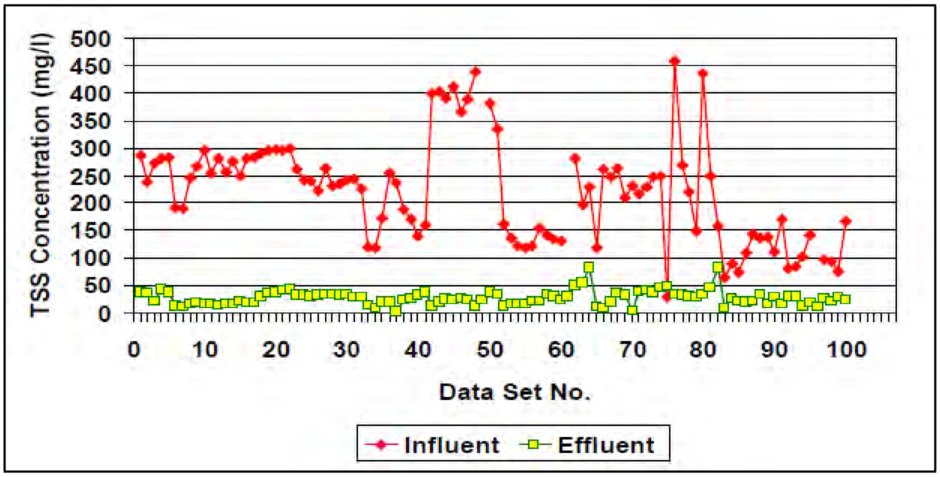


Figure 4-3: TSS test data for the Up-Flo filter (Source: Andoh et al. 2009).

Khambhammettu et al. (2006) also evaluated the performance of the Up-Flo filter during actual storm events in Alabama. The filter demonstrated improved percent reductions with increased influent concentrations. Effluent suspended solids were found to be under 30 mg/L for influent concentrations < 100 mg/L, and were under 100 mg/L for influent concentrations < 600 mg/L. When influent concentrations exceeded 90 mg/L, the percent reductions were > 70 percent. A summary of the storm event monitoring data for turbidity, suspended solids, total solids, ammonia, *E. coli*, and total coliforms (a broader group of fecal indicator bacteri that includes *E. coli*) is presented in Table 4-1. The performance tests indicate the Up-Flo filtration system is more effective at reducing particulate matter than dissolved constituents.

Table 4-1. Summary of Up-Flo filter storm event monitoring results (Source: Khambhammettu et al. 2006).

Parameter	**Average Influent Concentrations** (all mg/L, except for Bacteria that are #/100 mL and Turbidity that is NTU) (COV)	**Average Effluent Concentrations** (all mg/L, except for Bacteria that are #/100 mL and Turbidity that is NTU) (COV)	**Probability that Influent ≠ Effluent** (Nonparametric Sign Test) (A = 95% Level)
Turbidity	41 (2.5)	15 (1.4)	> 99% (significant reduction)
Suspended solids	64 (2.9)	19 (1.6)	> 99% (significant reduction)
Total solids	137 (1.7)	94 (1.2)	> 99% (significant reduction)
Ammonia	0.44 (1.47)	0.24 (1.30)	> 97% (significant reduction)
E. coli	4,750 (0.8)	2,710 (0.8)	> 99% (significant reduction)
Total coliforms	12,600 (1.0)	6,700 (0.7)	> 99% (significant d ti)

4.2. UrbanGreen BioFilter by Contech Construction Products

The UrbanGreen BioFilter (UGBF) by Contech Construction Products is a small-scale stormwater runoff treatment system that provides bioretention and filtration (Figure 4-4). The UGBF is a tree box treatment system that can be used in small drainage areas (< 2 acre) or can be expanded to include subsurface infiltration for reduced runoff. The UGBF can be installed with a curb inlet and can treat runoff from parking lots, roads, roofs, and other surfaces that produce runoff. The soil media is specified to provide high levels of "pollutant removal, hydraulic conductivity and biological vitality" (Contech 2011).
The stormwater runoff is filtered through the optimized soil media during each storm event, where pollutants are absorbed by the soil and vegetation. The system has two bypass paths. The first bypass contains a filtration cartridge (Figure 4-5) and is utilized after the biofiltration bay has reached capacity. The filter cartridge allows for an increase in treatment capacity. The second is an internal bypass for high flow which is directed downstream. The discharge can be sent to the municipal conveyance system or can be combined with an infiltration system.

Figure 4-4: UrbanGreen BioFilter
(Source: Contech Construction Products.).

Overall, the system provides evapotranspiration for small storm events and dry weather runoff (about 10 percent of annual runoff) and biofiltration for medium sized storm events (about 30 to 60 percent of annual runoff), the remaining flow can be treated through the filter cartridge (about 20 to 50 percent of annual runoff), and any excess stormwater is bypassed (less than 20 percent of annual runoff) (Contech 2011).

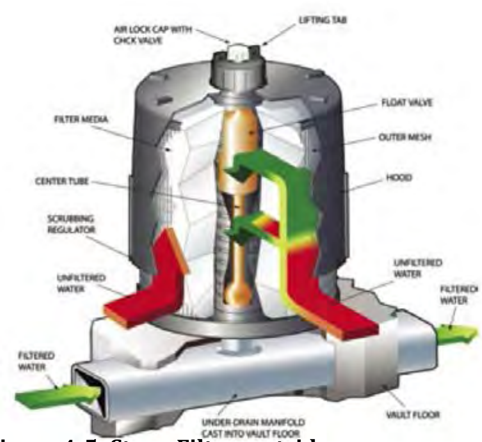


Figure 4-5: StormFilter cartridge
(Source: Contech Construction Products).

Test results show a solids removal capability of > 95 percent for a mean particle size of 25 µm. Hydraulic tests also show no scour for flows of 2 ft^3/s or less (Contech 2011). The hydraulic loading characteristics are shown in Figure 4-6. The system treats stormwater with a 50 inch/hour rate and 12 inches of driving head. Because the soil is able to provide high conductivity, the hydraulic loading rate can be provided with a lower driving head.

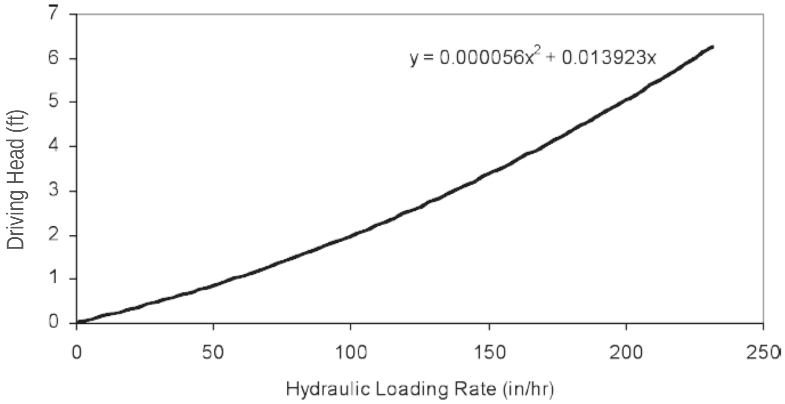


Figure 4-6: Hydraulic loading characteristics of UrbanGreen BioFilter
(Source: Contech Construction Products).

4.3. Site Location and MTD Design

The MTDs were examined for potential application at the City Fleet Maintenance Facility. This site contains two drainage areas (Figure 4-7) that could accommodate both manufactured devices in secure environments. The potential location for the UGBF was at the end of Olivia Street (drainage area A) while the Up-Flo filter was at the end of Wabash Street (drainage area B).

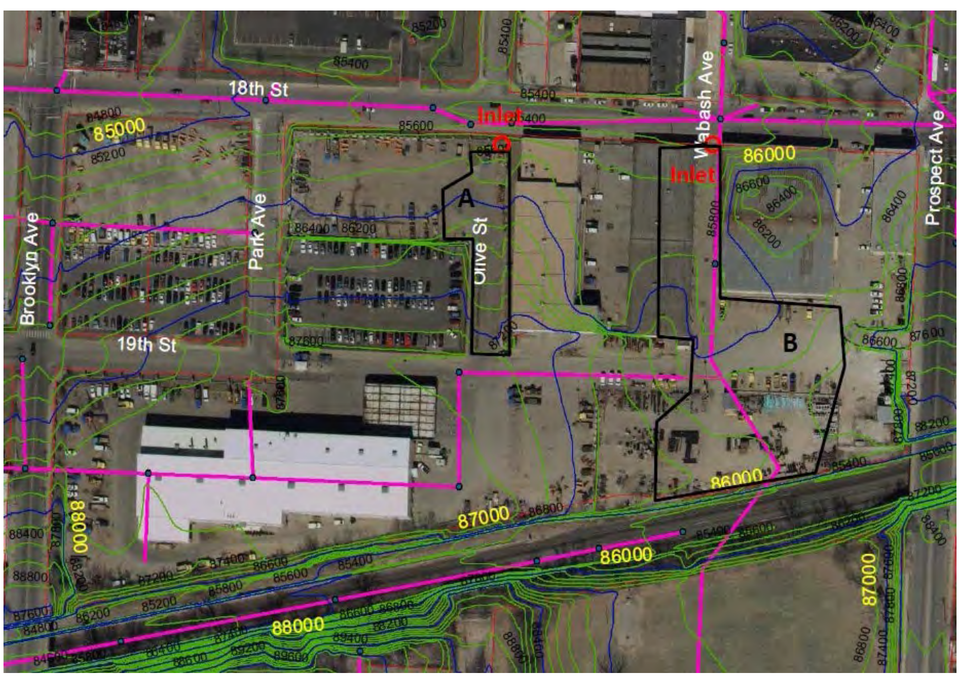


Figure 4-7: Drainage areas at the City Fleet Maintenance Facility (aerial of 18th and Prospect streets).

Both systems will be subject to performance evaluations over the course of multiple storm events based upon water quality data collected using automated sampling equipment. Influent and effluent water quality will be assessed for solids, phosphorus, metals, and nutrients. The sampling will include collection of a first flush sample as well as flow-paced discrete and field composite samples by the automated sampling equipment over the course of a precipitation event. Individual influent and effluent discrete samples will be combined according to the event hydrograph to create bulk influent and effluent stormwater composite samples that represent the mean influent and effluent water quality. First flush samples will be processed using the specified subsampling equipment and submitted to the analytical laboratory for testing. Subsamples will be taken from the bulk composite samples using the specified subsampling equipment for subsequent analysis. Field samples will be analyzed without additional processing.

Figure 4-8: Drainage area A (in orange) for the UGBF.

Drainage area A at Olivia Street (Figure 4-8) is relatively small (19,068.9 ft^2), includes part of the road and parking area, and contains two inlets. During site visits in 2010, it appeared that the inlets in drainage area A were used as temporary staging for heavy equipment and had large amounts of debris accumulated near the inlet (Figures 4-9 and 4-10).

Figure 4-10: Drainage area A site visit image.

Figure 4-9: Drainage area A site visit image (close-up).

The survey results for drainage area A and the potential location of UGBF are shown in Figures 4-11.

Notably, drainage area B at Wabash Avenue (Figure 4-12) is larger than drainage area A and includes part of the road, a parking area, pavement storage area, and half of a roof top, and only has one inlet. The drainage area for the Up-Flo filter system is estimated to be 1.72 acres (74, 761 ft^2), which assumes partial rooftop drainage. During site visits in 2010, it appeared that the inlet in drainage area B had significant sediment build-up (Figure 4-13).

Figure 4-11: Survey results for 18th and Olive streets for UGBF location.

The survey results for drainage area B and the location of the Up-Flo filter are shown in Figure 4-14. For this installation example, the runoff would enter the devices through the curb inlet and would be conveyed to the sump under the inlet. An adjustable weir has been provided and acts as a floatables trap that prevents floating items from being washed out during less frequent storm events. Flow beyond 300 gpm will pass through the bypass and directly into the municipal collection system.

Figure 4-12: Drainage area for Up-Flo filter system (in orange).

Figure 4-13: Drainage B site visit images.

Figure 4-14: Survey results for 18th and Wabash streets for Up-Flo location

5. Site and System Benefits of Rain Gardens

The pilot project is intended to provide information and experience that will allow for widespread implementation of GI projects throughout Kansas City, Missouri. This section provides an overview of the currently installed demonstration technologies, including 6 rain gardens, 20 planned downspout disconnections, and 20 planned rain barrel installations. All of these pilot projects are located on private residential properties. One of the rain garden installations (Thomas' rain garden) has detailed pre- and post-construction monitoring results. The other rain gardens include design details and pre- and post-construction images.

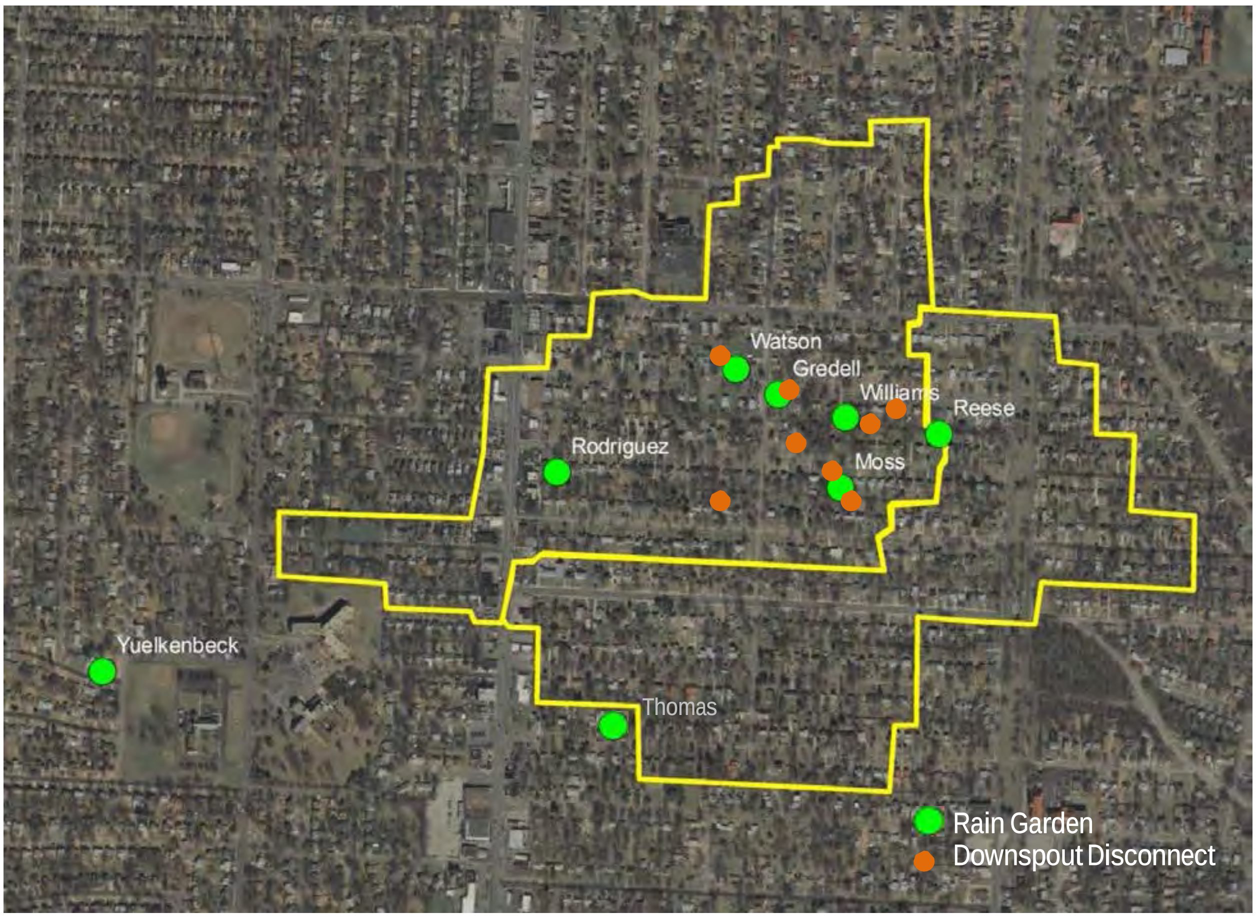


Figure 5-1. Locations of currently constructed rain gardens and downspout disconnections.

Rain gardens are designed to capture smaller volumes of runoff, particularly those associated with smaller storm events, from impervious surfaces and allow infiltration of stormwater runoff into the ground. They are well suited for pollutant removal. The rain garden pilot projects are shallow vegetated, depressed areas that use soil- and plant-based filtration to remove pollutants and infiltrate runoff. The depressed area was planted with small- to medium-sized vegetation that can withstand urban environments and tolerate periodic inundation and dry periods. The design storm for all of the pilot rain gardens is 1.37 inches with soil infiltration rates based on infiltration tests.

5.1. Thomas Rain Garden

As a part of this study a private rain garden was constructed on Ms. Thomas' property and its performance is being monitored and evaluated for potential stormwater reduction benefits. The rain garden is designed based on the soil type, moisture content, design rainfall depth, and plants adaptable to the physiographic region. The steps involved in the construction of the rain garden are shown in Figure 5-6 through Figure 5-10. Soils data for the Thomas property is summarized in Table 5-1 below:

Table 5-1. Soils report for Thomas rain garden absorption area

Thomas Rain Garden		
Field soil texture and visual description:	Silty clay loam, brown	
Particle size distribution	Sand retained on No. 10:	0.2%
	Sand retained on No. 200:	2.3%
	Silt (0.005-0.074 mm):	53.3%
	Clay (< 0.005 mm):	44.3%
Soil classifications	USDA	Silty clay
	AASHTO	A-7-6
	USCS	Lean clay
Atterberg limits	Liquid limit:	44
	Plastic limit:	21
	Plasticity index:	23
Sand-cone density (date of test: 8-18-10)	Density (dry):	1.507 g/cm^3 (1507g/L)
	Density (wet):	1.934 g/cm^3 (1934 g/L)
		28.3%
Specific gravity of soil solids		2.69

5.1.1. Infiltration Tests

Two Full-inundation infiltration tests of the rain garden were conducted on September 6, 2011 and October 28, 2011. These tests measure the actual capacity of the rain garden to infiltrate stormwater runoff. Measurements of the depth of ponding in the rain garden absorption area with respect to the time were recorded using a stop watch and staff gauge. Measurements were recorded every minute for first 5 minutes of the test following the initial filling of rain garden, then in 5-minute increments for the remainder of the test.

Infiltration tests were conducted in and around the potential site, because infiltration of water into the surface soil is responsible for the largest abstraction of stormwater in natural areas. Turf- Tec Infiltrometers (Figure 5-1) were used to measure the infiltration rates. These devices have an inner and outer ring. Both the inner and outer compartments are filled with clear water by first filling the inner compartment and allowing it to overflow into the outer compartment. As soon as the measuring point reaches the beginning of scale, the timer is started and readings are taken every 5 minutes for a duration of 2 hours or until a constant infiltration is observed. The incremental infiltration rates were calculated by noting the change in water level in the inner compartment over the 5-minute period.

Figure 5-2: Turf-Tec Infiltrometer.

Table 5-2 and Figure 5-2 show the results of the first infiltration test.

Table 5-2. Turf-Tec Infiltration Results – Test 1

Infiltration Test with Turf-Tec Infiltrometer	
Test #:	1
Date of test:	8-18-10
Test site location:	Private rain garden – Thomas' property
Locations of test:	South side of garden, ~2 ft from berm, located near center east-west East side of garden, ~2 ft. from east berm, ~2 ft. from south berm North side of garden, ~1 ft. from north berm, located near center east-west
Rain gauge site ID:	UMKC rain gauge no.1 – Paseo
Last rainfall event:	8-17-10: 0.08 inches
Moisture content (%):	26.5
In-place dry density (g/l):	1,507

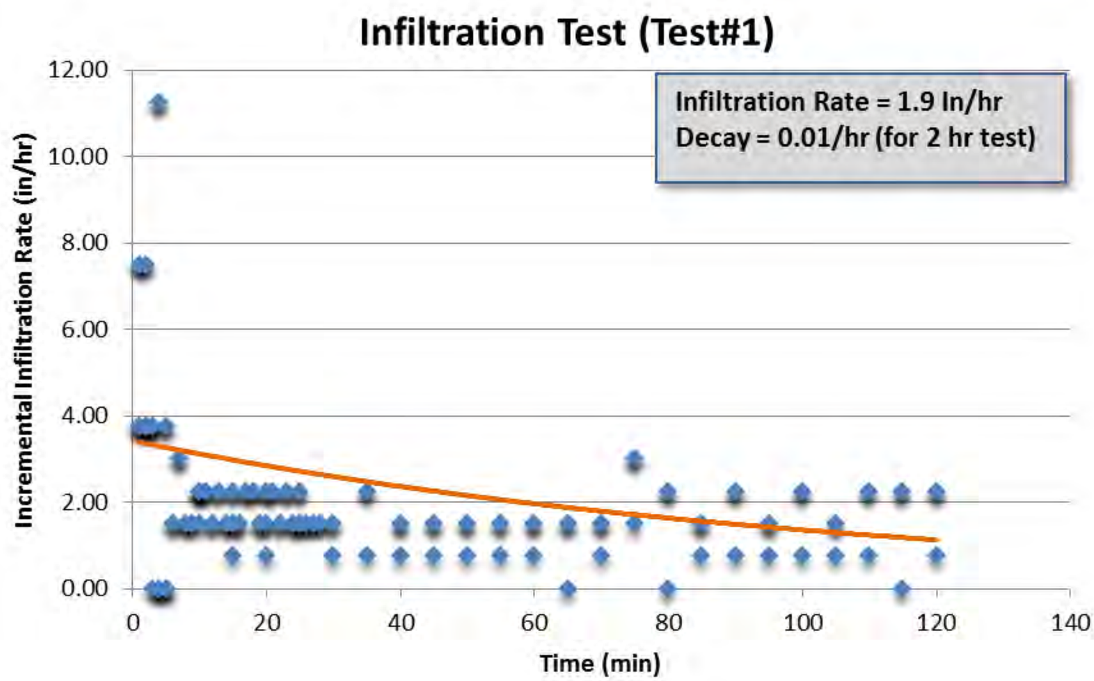


Figure 5-3: Turf-Tec infiltration test.

5.1.2. Full Inundation Infiltration Test

Full inundations tests were also completed for the Thomas rain garden. These tests measure the effects of macro-features of the absorption area that allow additional storage and direct access to additional soil surface area, which increases the effective area of the rain garden absorption area. While infiltrometers are effective at measuring the infiltration at the surface of the soil, full inundation testing provides information on the entire rain garden and includes lateral flows and macro-features that can increase infiltration rates. The full inundation tests demonstrate that the macro-features in the soil have a strong influence on the effective infiltration rate of absorption area (Table 5-3, Table 5-4, Figure 5-3, and Figure 5-4).

Table 5-3. Full inundation test on 9/2/10 for Thomas rain garden

Full Inundation Test	
Test #:	1
Date of test:	9-2-10
Test site location:	Private rain garden – Thomas property
Exact location of test:	Full inundation infiltration test
Rain gauge site ID:	UMKC rain gauge no.1 – Paseo
Last rainfall event:	8-31-10: 0.62 in, 9-1-10: 0.42 inches
Moisture content (%):	Southeast corner of absorption area: 28.3 Southwest corner of absorption area: 32.4
In-place dry density (g/L):	1,507

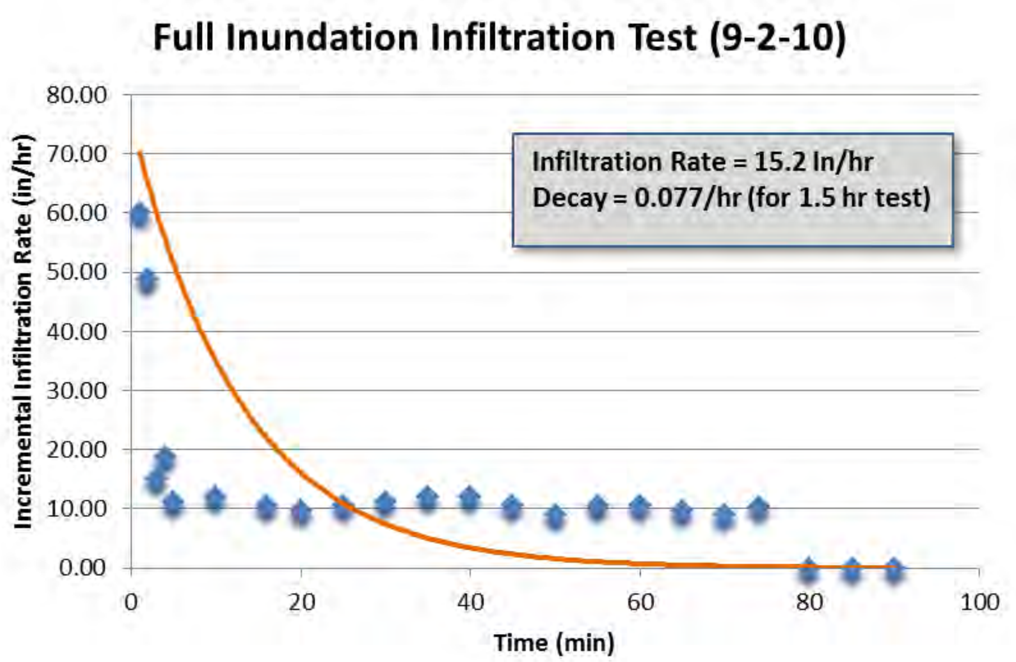


Figure 5-4: Full inundation test (9-2-10).

Table 5-4. Full inundation test on 10/28/10 for Thomas rain garden

Full Inundation Test	
Test #:	2
Date of test:	10-28-10
Test site location:	Private rain garden – Thomas property
Exact location of test:	Full inundation infiltration test
Rain gauge site ID:	UMKC rain gauge no.1 – Paseo
Last rainfall event:	10-22-10: 0.21 inches
Moisture content (%):	North center of absorption area: 26.5 South center of absorption area: 40.4
In-place dry density (g/L):	1,507

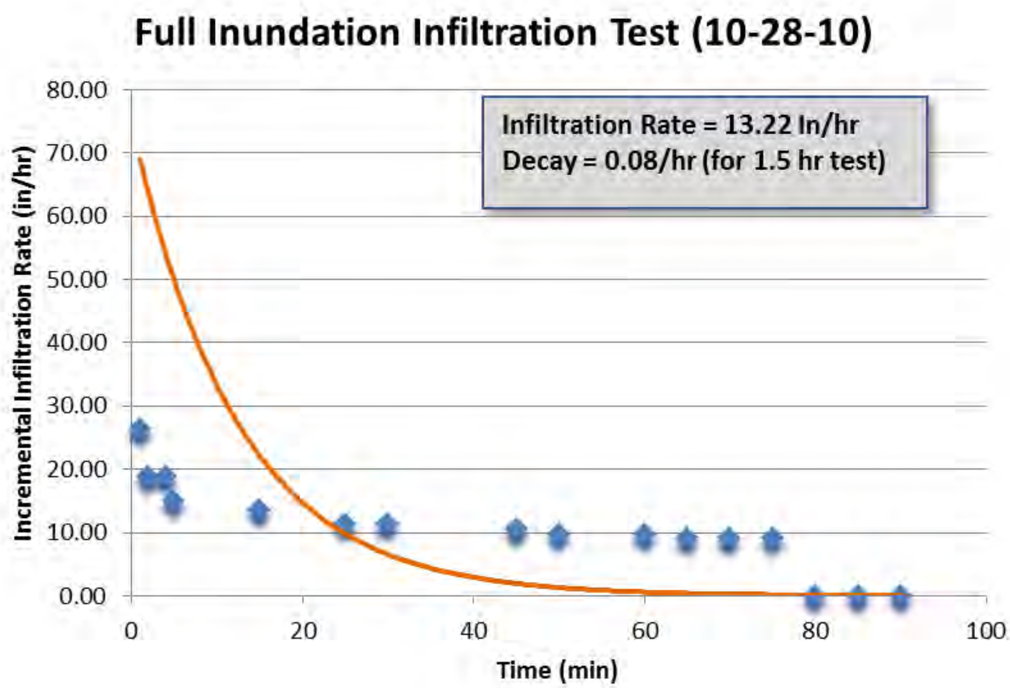
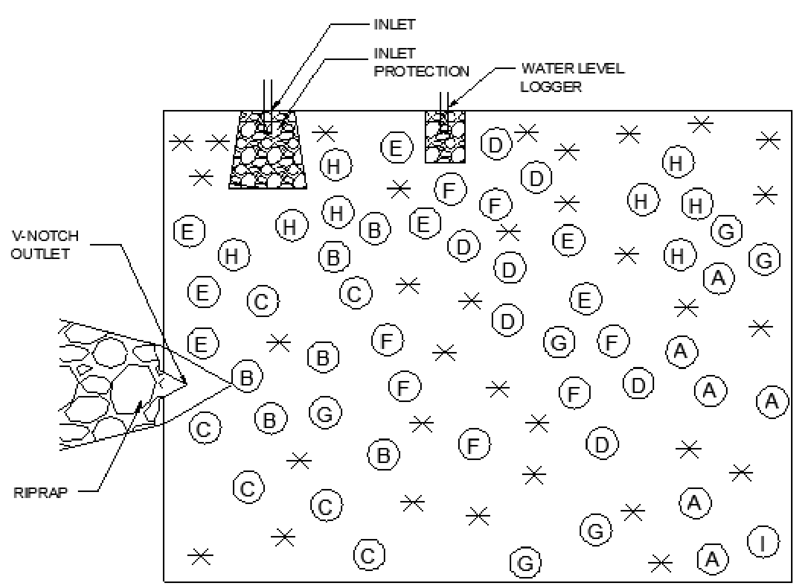


Figure 5-5: Full inundation test (10-28-10).

5.1.3. Thomas' Property Rain Garden Construction

Construction and planting of the Thomas rain garden was completed entirely by volunteers and student labor. Figure 5-5 indicates the planting scheme of the rain garden while Figure 5-6 and Figure 5-7show the clearing and planting phases, respectively.



PLANT LAYOUT		
PLANT LIST SYMBOL	COMMON NAME	QUANTITY
A	COPPER IRIS	8
B	SMOOTH PENSTEMON	8
C	PURPLE POPPY	8
D	PURPLE CONEFLOWER	7
E	PRAIRIE BLAZINGSTAR	7
F	YELLOW CONEFLOWER	7
G	FALSE ASTER	8
H	GOLDEN ROD	8
I	SOFT RUSH	1
*	BROWN FOX SEDGE	33

Figure 5-6. Plan view of Thomas property rain garden plant layout.

Figure 5-7: Sod removal in stormwater absorption area of the rain garden. Perimeter of the rain garden is marked by the rope (6/10/10).

Figure 5-8: Planting additional vegetation (left) and rain garden looking east (right) (7/21/10).

As discussed in the monitoring chapter (2), monitoring of flow is essential and one of the most important aspects of evaluating these GI systems. Figure 5-9shows the calibrated weir that was constructed to determine outflow of the Thomas rain garden. Figure 5-10 shows the disconnected roof leader and measurement barrel, while Figure 5-11 and Figure 5-12 show the completed rain garden and an educational sign for the rain garden, respectively.

Figure 5-9: Raingarden weir installation (9/23/10).

Figure 5-10: Disconnected roof leader and view of flow measurement barrel connected to pipes, looking northeast (9/28/10).

Figure 5-11. Installed rain garden on Thomas property.

Figure 5-12: Educational sign for rain garden.

5.1.4. Installation and Instrumentation of Flow Monitoring Devices and Structures

Two roof leaders were connected to a flow monitoring device to measure real time inflow to the rain garden, which consisted of a 55-gallon high-density polyethylene drum for stormwater collection and an orifice plate for controlled discharge from the barrel to the rain garden. A Global Water WL16U Water Level Logger (Figure 5-12) was installed to measure and record the depth of the water in the barrel, which is correlated with the theoretical discharge from the barrel outlet orifice. Any discharge from the rain garden was measured by a 1/8" thick stainless steel 22.5 degree sharp-crested v-notch weir at a protected outlet. Head above the crest is measured in the pool of the rain garden by a second water level logger in a perforated PVC casing. The logger also measures rain garden ponding depth and infiltration response of the absorption area to various hydraulic loadings and recurrence intervals.

Figure 5-13: Global Water Level Logger WL16 for data collection.

The water loggers have a storage capacity of 81,759 stamped data points and are programmed to sample depth on a 1-second interval. When storage space is exceeded, the collected data in the logger is wrapped, replacing the oldest data sequential in chronological order with the new data samples. The available storage capacity of the water level loggers required that data be collected within approximately 22.5 hours of the beginning of a precipitation event to record the entire rain garden inflow hydrograph and rain garden ponding depths.

5.1.5. Rain Garden Flow Monitoring Results

Installation of the flow monitoring devices and fabrication of orifice-controlled barrel flow monitoring device and outlet weir allowed flow monitoring to commence late September 2010. The first precipitation event was recorded on October 11, 2010 and the last on November 12, 2010. The latter measured event was prior to winterization of the flow monitoring device and restoration of the roof leaders on the residential property to discharge directly to rain garden.

The capacities of the rain garden to react to the precipitation events of varying intensities are durations were demonstrated in Figures 5-13 through Figure 5-16. Because the events shown had smaller discernable events that preceded the time span shown in the figures, or immediately followed the time span shown in the figures, the precipitation event durations were shortened to show a meaningful visual representation of the full event.

The reaction of the pooling depths of the rain garden to the inflow hydrograph was consistent and reflective of the peak inflow and duration of the precipitation event. The infiltration of the absorption area was estimated during the periods of low inflow to the rain garden, and the infiltration rate for this event was maintained following the peak inflow at about 7.4 inches/hour.

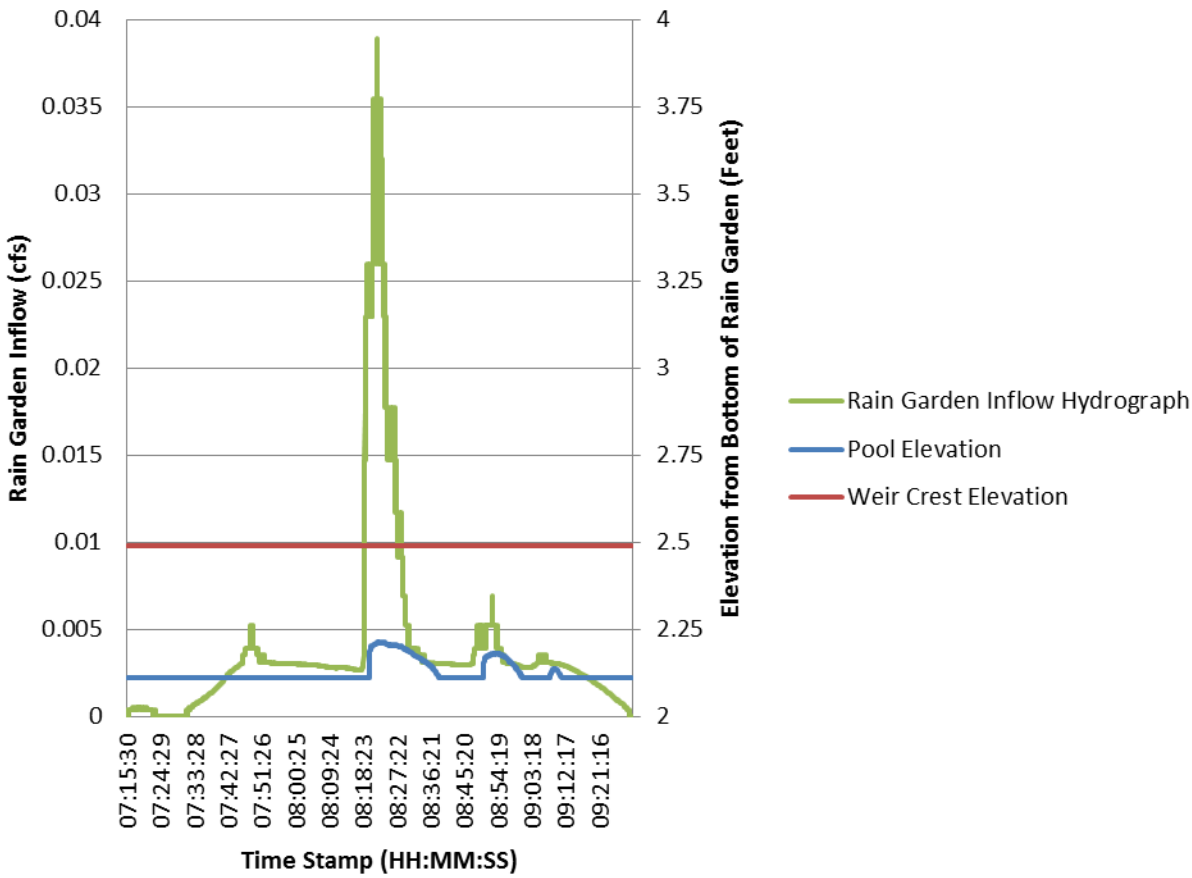


Figure 5-14: Rain garden response to precipitation event on October 11, 2010.

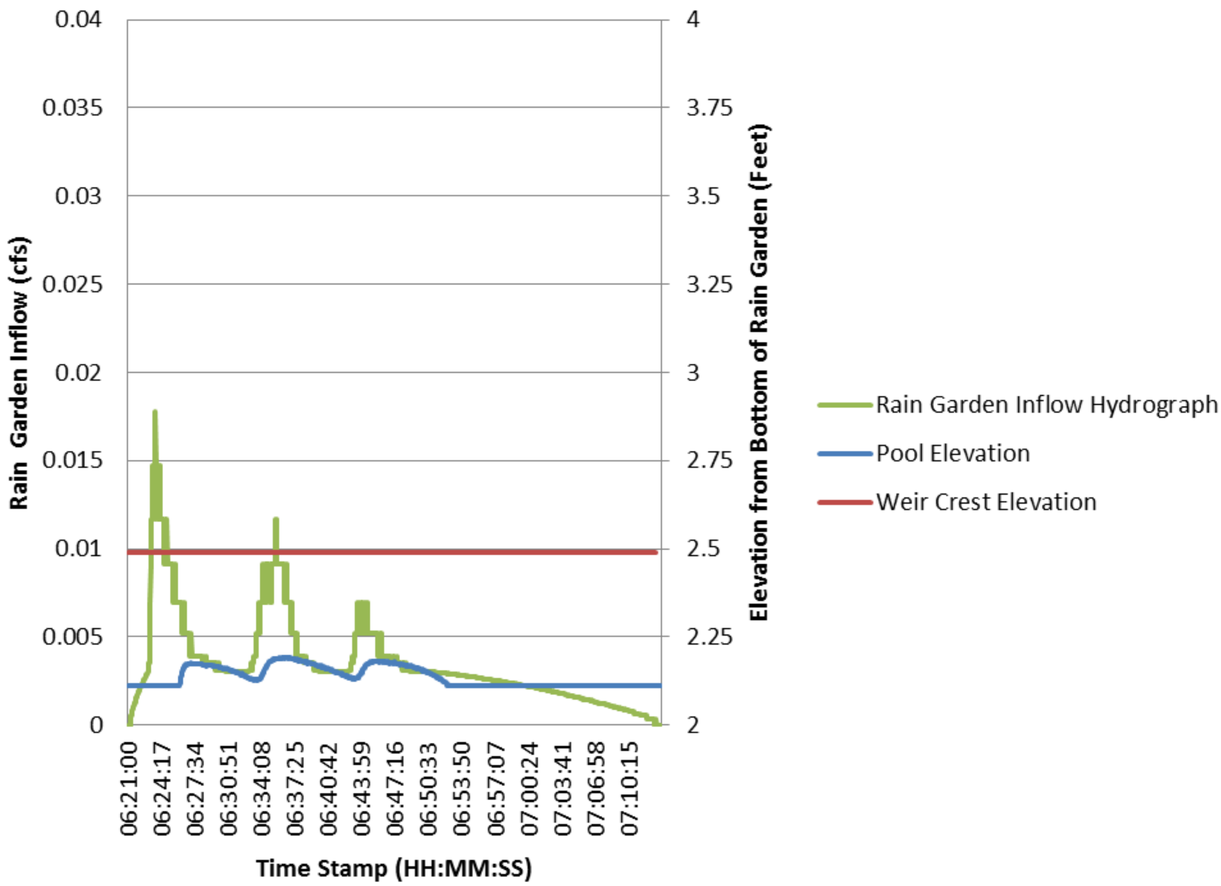


Figure 5-15: Rain garden response to precipitation event on October 12, 2010.

For the event on October 12, 2010, there was a slight delay between the beginning of the first peak of the inflow hydrograph and the beginning of the pooling depth peak, which was attributed to the infiltration rate of the rain garden initially exceeding the inflow rate. An infiltration rate between 7.0 and 8.5 inches/hour was maintained through the duration of this event.

The inflow hydrograph for the precipitation event shown in Figure 5-15 was higher in intensity and of shorter duration compared to the events shown in Figure 5-13 and Figure 5-14. The infiltration capacity of the absorption area significantly exceeded the rate of inflow, which resulted in a zero change in pooling depth.

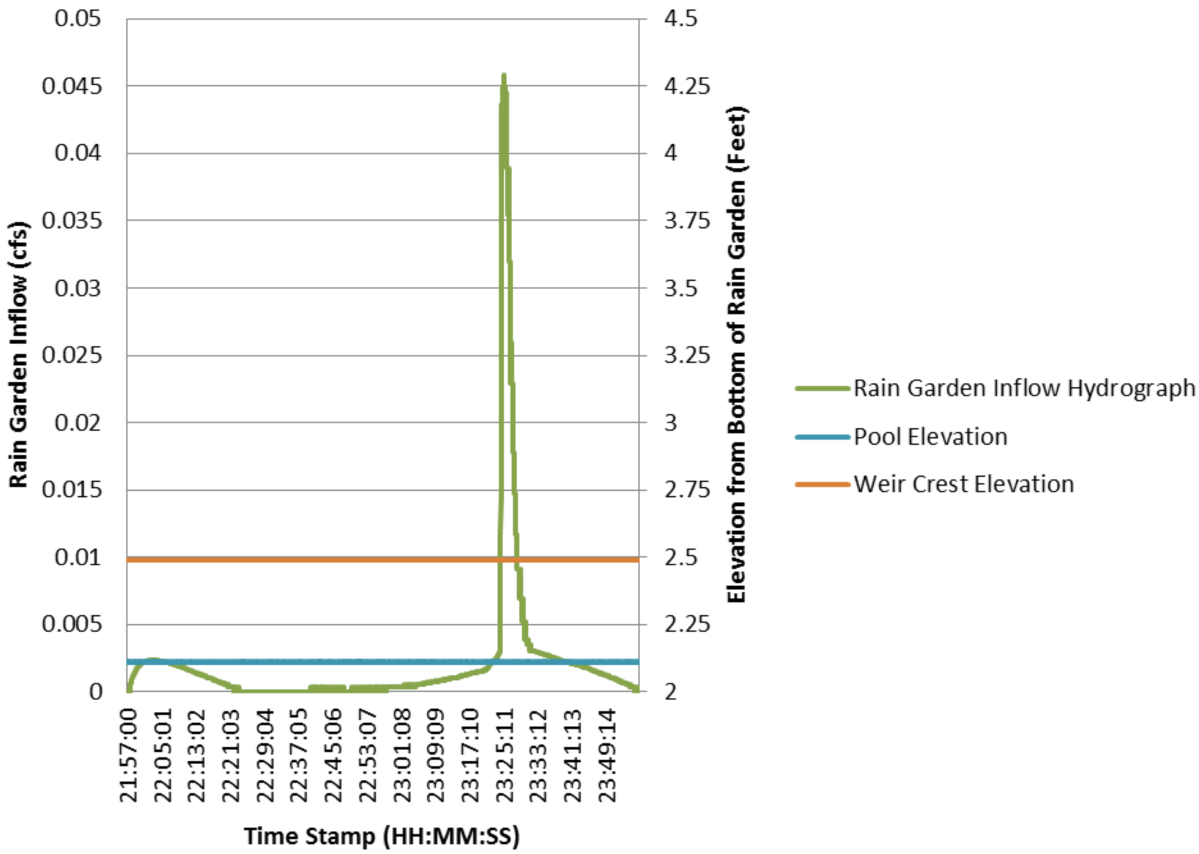


Figure 5-16: Rain garden response to precipitation event on October 22, 2010.

Figure 5-16 shows the largest precipitation event recorded at the rain garden in 2010, which had a total depth of about 1.63 inches, resulting in a total discharge volume to the rain garden of approximately 134 cubic feet. During this extended event, the pooling depth of the rain garden had not exceeded the height of the crest of the weir and the rain garden maintained an infiltration rate of greater than 5.0 inches/hour with high peak flow discharges to the rain garden.This private rain garden demonstrated effectiveness in peak flow reduction and its ability on intercept and infiltrate the run off volume during the few precipitation events that were recorded in 2010. It is important to note that this rain garden was installed in clayey soils that would typically be considered unsuitable for an infiltration (micro) BMP without the installation of an underdrain to assist in draining captured run off from under the infiltration surface. Thus, the infiltrative capacity of the absorption area at this particular site may be attributable to an intact soil matrix that was not disturbed and remolded during construction of the house on this lot, and because the minimally disruptive construction techniques did not cause typical compaction of the upper 6 to 12 inches of the soil in the absorption area that can be caused by even light excavation equipment.

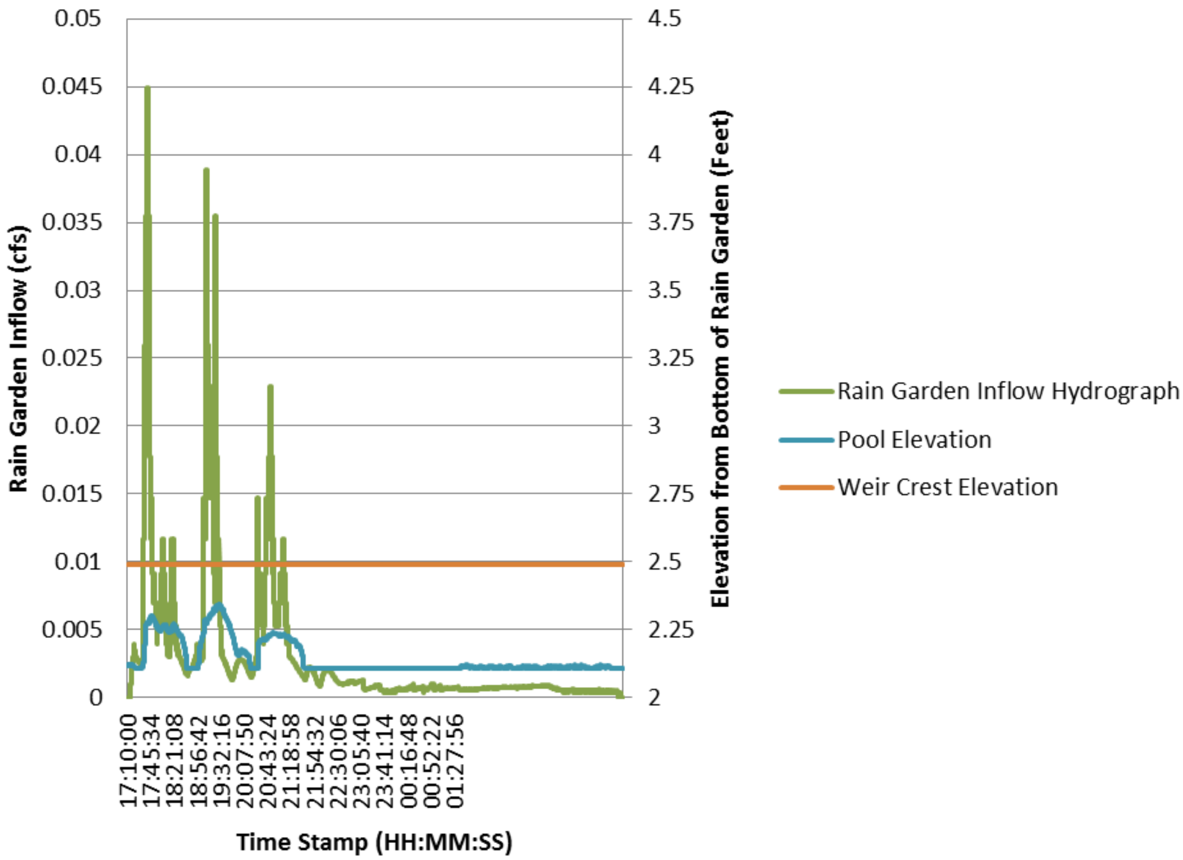


Figure 5-17: Rain garden response to precipitation event on November 12, 2010.

The higher than expected infiltration rates for this rain garden installation suggest that individual site investigations for each rain garden be conducted rather than relying on soil maps exclusively.

5.2. Other Private Property Rain Garden Projects

Several other private rain gardens were built as part of a related EPA Region 7 effort. Figures 5-17 to Figure 5-36 and Tables 5-5 to Table 5-11 provide information on each of these other private systems. Notably, the Moss rain garden (see Table 5-6 and Figure 5-22) garden will likely be monitored in future efforts.

Table 5-5: Design details of Gredell rain garden

Gredell Rain Garden	
Rooftop Contributing Area	0.008 acres (351 ft^2)
BMP Design Target (runoff capture)	100% of KCMO WSD Design Storm D
Design Volume	299.74 gallons (40.07 ft^3)
BMP Design	Bioretention (30% porosity assumed)
Soil Type	Group A with 0.025 (ft/hr) saturated infiltration rate
Average Infiltration Rate	0.27 ft/hr
BMP Sizing	Length: 12 feet Excavation Depth: 10.8 inches Rain Garden Depth: 6 inches

Gredell Rain Garden	
Rooftop Contributing Area	0.008 acres (351 ft^2)
	Width: 5 feet
Total Soil/Mulch Amendment Depth (storage depth)	0.5 ft
Mulch depth	0.17 ft
Soil depth	0.33 ft
Sand	50%
Topsoil	40%
Compost	10%
Vegetation	55 plants
Total Effective Depth	0.55 ft
Construction Time	6 hours (2 volunteers)
Planting Time (total labor hours)	2 hours (3 volunteers)
Total Materials Cost	$97.37
Unit Cost / Gallon Managed	$0.32 / gallon

Figure 5-18: Construction of the Gredell rain garden.

Figure 5-19: Rain garden area with outlet protection.

Figure 5-20: Installed rain garden on Gredell property.

Table 5-6: Design details of the Moss rain garden

Moss Rain Garden	
Rooftop Contributing Area	0.006 acres (282 ft^2)
BMP Design Target (runoff capture)	100% of KCMO WSD Design Storm D
Design Volume	240.8 gallons (32.19 ft^3)
BMP Design	Bioretention (30% porosity)
Soil Type	Group C with 0.0083 (ft/hr) saturated infiltration rate
Average Infiltration Rate	0.014 ft/hr
BMP Sizing	Length: 13 feet Excavation Depth: 0.9 ft Rain Garden Depth: 0.5 ft Width: 7 feet
Total Soil/Mulch Amendment Depth (storage depth)	0.5 ft
Mulch depth	0.17 ft
Soil depth	0.33 ft
Sand	50%
Topsoil	40%
Compost	10%
Vegetation	91 plants
Total Effective Depth	0.55 ft
Construction Time	8 hours
Planting Time	2 hours
Total Materials Cost	$152.64
Unit Cost / Gallon Managed	$0.63 / gallon

Figure 5-21: Soil excavation from rain garden absorption area.

Figure 5-22: Rain garden with installed media and outlet protection.

Figure 5-23: Installed rain garden on Moss property.

Table 5-7: Design details of the Reese rain garden

Reese Rain Garden	
Rooftop Contributing Area	0.007 acres (324 ft^2)
BMP Design Target (runoff capture)	100% of KCMO WSD Design Storm D
Design Volume	276.7 gallons (36.99 ft^3)
BMP Design	Bioretention (30% porosity)
Soil Type	Group A with 0.025 (ft/hr) saturated infiltration rate
Average Infiltration Rate	0.25 ft/hr
BMP Sizing	Length: 13 feet Excavation Depth: 0.9 ft Rain Garden Depth: 0.5 ft Width: 4 feet
Total Soil/Mulch Amendment Depth (storage depth)	0.5 ft
Mulch depth	0.17 ft
Soil depth	0.33 ft
Sand	50%
Topsoil	40%
Compost	10%
Vegetation	56 plants
Total Effective Depth	0.55 ft
Construction Time	4 hours
Planting Time	2 hours
Total Materials Cost	$84.44
Unit Cost / Gallon Managed	$0.31 / gallon

Figure 5-24: Rain garden absorption area with outlet protection.

Figure 5-25: Rain garden with installed media.

Figure 5-26: Installed rain garden on Reese property.

Table 5-8: Design details of the Rodriguez rain garden

Rodriguez Rain Garden	
Rooftop Contributing Area	0.004 acres (205 ft^2)
BMP Design Target (runoff capture)	100% of KCMO WSD Design Storm D
Design Volume	175.0 gallons (23.4 ft^3)
BMP Design	Bioretention (30% porosity)
Soil Type	Group A with 0.025 (ft/hr) saturated infiltration rate
Average Infiltration Rate	0.042 ft/hr
BMP Sizing	Length: 9 feet Excavation Depth: 0.9 ft Rain Garden Depth: 0.5 ft Width: 4 feet
Total Soil/Mulch Amendment Depth (storage depth)	0.5 ft
Mulch depth	0.17 ft
Soil depth	0.33 ft
Sand	50%
Topsoil	40%
Compost	10%
Vegetation	46 plants
Total Effective Depth	0.55 ft
Construction Time	4 hours
Planting Time	2 hours
Construction Time	3.5 hours
Planting Time	1.5 hours
Total Materials Cost	$53.11
Unit Cost / Gallon Managed	$0.30 / gallon

Figure 5-27: Construction of Rodriguez rain garden.

Figure 5-28: Installed rain garden on Rodriguez property.

Table 5-9: Design details of the Watson rain garden

Watson Rain Garden	
Rooftop Contributing Area	0.010 acres (432 ft^2)
BMP Design Target (runoff capture)	100% of KCMO WSD Design Storm D
Design Volume	368.9 gallons (49.32 ft^3)
BMP Design	Bioretention (30% porosity)
Soil Type	Group A with 0.025 (ft/hr) saturated infiltration rate
Average Infiltration Rate	0.288 ft/hr
BMP Sizing	Length: 10 feet Excavation Depth: 0.9 ft Rain Garden Depth: 0.5 ft Width: 7 feet
Total Soil/Mulch Amendment Depth (storage depth)	0.5 ft
Mulch depth	0.17 ft
Soil depth	0.33 ft
Sand	50%
Topsoil	40%
Compost	10%
Vegetation	70 plants (estimated)
Total Effective Depth	0.55 ft
Construction Time	6
Planting Time	2
Total Materials Cost	$119.02
Unit Cost / Gallon Managed	$0.32 / gallon

Figure 5-29: Soil excavation for rain garden absorption area.

Figure 5-30: Rain garden media installation.

Figure 5-31: Installed rain garden on Watson property.

Table 5-10: Design details of the Williams rain garden.

Williams Rain Garden	
Rooftop Contributing Area	0.009 acres (413 ft^2)
BMP Design Target (runoff capture)	100% of KCMO WSD Design Storm D
Design Volume	352.7 gallons (47.15 ft^3)
BMP Design	Bioretention (30% porosity)
Soil Type	Group A with 0.025 (ft/hr) saturated infiltration rate
Average Infiltration Rate	0.029 ft/hr
BMP Sizing	Length: 10 feet Excavation Depth: 0.9 ft Rain Garden Depth: 0.5 ft Width: 7 feet
Total Soil/Mulch Amendment Depth (storage depth)	0.5 ft
Mulch depth	0.17 ft
Soil depth	0.33 ft
Sand	50%
Topsoil	40%
Compost	10%
Vegetation	77 plants
Total Effective Depth	0.55 ft
Construction Time	8 hours
Planting Time	2 hours
Total Materials Cost	$105.31
Unit Cost / Gallon Managed	$0.30 / gallon

Figure 5-32: Construction of Williams rain garden.

Figure 5-33: Rain garden with installed media and outlet protection.

Figure 5-34: Installed rain garden on Williams property.

Table 5-11: Design details of the Yuelkenbeck rain garden

Yuelkenbeck Rain Garden	
Rooftop Contributing Area	0.014 acres (600 ft^2)
BMP Design Target (runoff capture)	100% of KCMO WSD Design Storm D
Design Volume	512.4 gallons (68.5 ft^3)
BMP Design	Bioretention (30% porosity)
Soil Type	Group B with 0.167 (ft/hr) saturated infiltration rate
Average Infiltration Rate	0.018 ft/hr
BMP Sizing	Length: 11 feet Excavation Depth: 0.9 ft Rain Garden Depth: 0.5 ft Width: 11.5 feet
Total Soil/Mulch Amendment Depth (storage depth)	0.5 ft
Mulch depth	0.17 ft
Soil depth	0.33 ft
Sand	50%
Topsoil	40%
Compost	10%
Vegetation	94 plants
Total Effective Depth	0.55 ft
Construction Time	12 hours
Planting Time	2 hours
Total Materials Cost	$205.36
Unit Cost / Gallon Managed	$0.40 / gallon

Figure 5-35: Construction of Yuelkenbeck rain garden.

Figure 5-36: Soil excavation for rain garden absorption area.

Figure 5-37: Installed rain garden on Yuelkenbeck property.

5.3. Rain Barrel Properties

Collecting rainwater in containers or other depositories for future use during drier periods is an ancient and common practice. With the rising price of municipal water, widespread drought restrictions, and benefits for flow and volume control, homeowners are increasingly turning to the harvesting of rainwater to both save money and protect this precious natural resource.

Rain barrels (or cisterns) are containers that can capture rooftop runoff and store it for future use. Often, the captured rainwater is used for irrigation of vegetation, including lawns and gardens, or it can be used for alternative gray water uses such as laundering clothes. Rain barrels for private residences are generally smaller systems, typically holding < 100 gallons. The collection of rooftop runoff in rain barrels is a useful method of reducing stormwater runoff volumes in urban areas where site constrains might limit the use of other GI practices.

A total of 20 rain barrels were installed as part of the pilot project. The rain barrels were often installed along with downspout disconnection (discussed in the following section) or rain gardens. As was shown in the modeling section, rain barrels can result in a reduction of runoff to the CSS—especially in instances where the downspouts were previously connected directly to the sewer system.

5.4. Downspout Disconnection Properties

Older neighborhoods often have downspouts that are directly connected to the CSS. Therefore, any rooftop runoff is directed straight to the CSS, contributing to CSOs following precipitation events. The pilot project area includes a number of homes that have directly connected downspouts as identified through smoke testing (Figure 5-38). As part of the pilot project, 20 houses will have their downspouts disconnected from the CSS, reducing the burden on the sewer system capacity. The disconnections will target the heaviest flows from the homes shown in Figure 5-38.

Figure 5-38: Homes with directly connected downspouts (blue indicates pilot project area).

6. Results to Date

This chapter presents the results of monitoring efforts and land use characterization to date for this project. It includes an overview of rainfall and flow monitoring data in MBR Basin and historical rainfall data from the greater Kansas City area. It also discusses the impacts of sewer rehabilitation in the MBR pilot study. The rainfall and flow monitoring data in the MBR watershed has been collected at both the pilot and control sites to allow for comparison and verify effects of the installed BMPs (following implementation). Much of this data was also used in the preceding modeling chapter (3).

6.1. Rainfall and Flow Monitoring

Rainfall and flow data has been collected both in the pilot and control areas to monitor and evaluate the pre- and post- construction stormwater controls. Both the dry and wet-weather data are obtained for the pilot sewershed. Pre-construction flow and water quality data are used to calibrate the watershed model (WinSLAMM) and sewerage model (SUSTAIN). These models are used to predict the benefits of stormwater controls, and these predictions will be verified once the controls are installed. For the purpose of monitoring, flow data has been collected at four different monitoring sites; site 1 being the pilot/test watershed while sites 2a, 2b and 3 are within the control watershed.

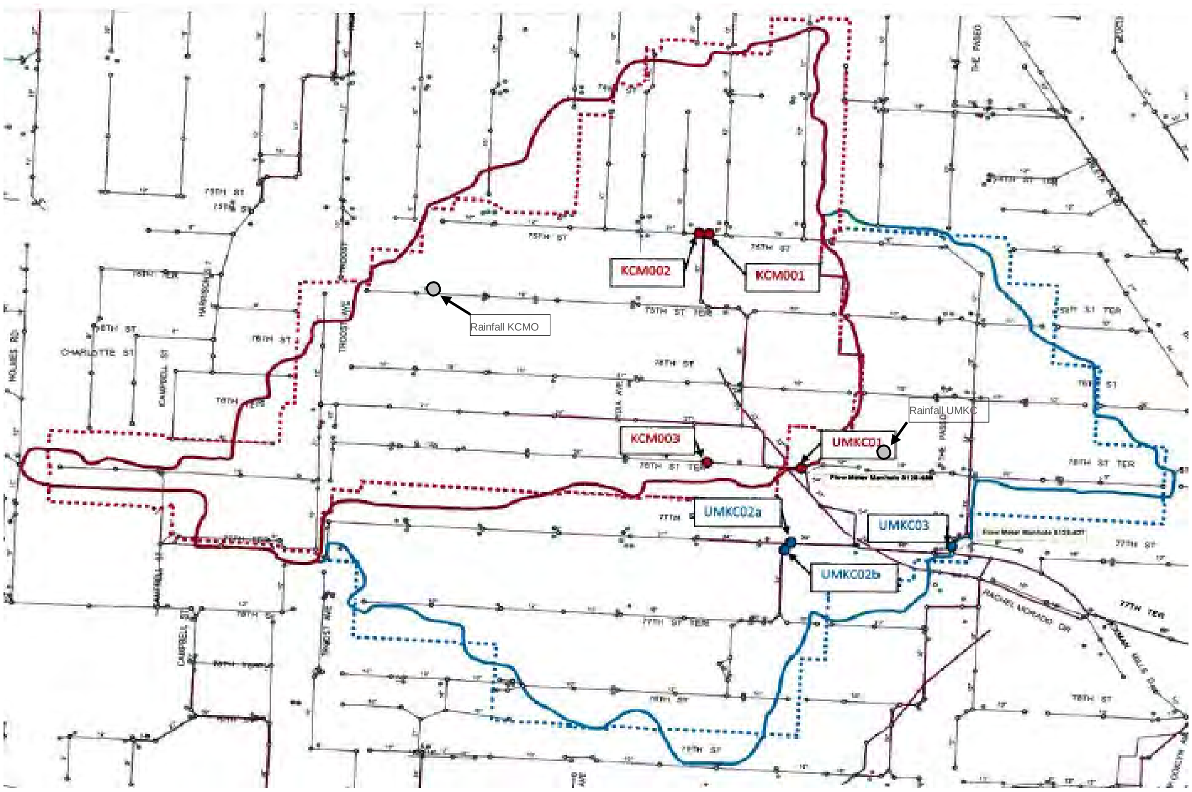


Figure 6-1: Rainfall and flow monitoring locations.

6.2. Rainfall Data

Historically, KCMO WSD has been collecting rainfall data for several years to provide flood warnings, evaluate infiltration and inflow (I/I) in sanitary sewer system areas, prepare master plans for citywide collection system improvements, and to conduct previous wet-weather control studies. Continuous long term data are available from two primary sources—the National Climatic Data Center (NCDC) for the Charles B. Wheeler Downtown Airport (Downtown Airport) and the Kansas City International Airport (MCI). Both sources provide 56 years of continuous and complete hourly precipitation data, with a precision of 0.01 inches. In addition to the historical airport rainfall data sets, recent real-time precipitation data are available for the Kansas City metropolitan area from the Flood Warning System (FWS), which uses automated technology to transmit environmental data to a central computer in real-time. The system includes 441 defined sensors from 108 rain gauges, 83 water level sensors, 11 weather data stations, and 113 battery sensors. The FWS sensors are designed to record rainfall in increments of 0.04-inches (1 mm). In this pilot study, for a finer resolution and to maintain accuracy (proximity to the study site), rainfall data has been collected from a rain gage located in the grassy center of Paseo Boulevard at the intersection with 77th Street. Rainfall has been recorded for the years 2009, 2010, and 2011 in 5-minute intervals. The history and availability of localized data are summarized in Table 6-1.

Table 6-1: Summary of rainfall data collection.

Year	Rainfall Data Collection		Missing Data	Number of Rain Events
	Start Date (Time)	End Date (Time)		
2009	9-4-09 (9:43)	11-23-09 (11:40)	10/29/09 23:25 to 11/4/09 14:35	12
2010	4-1-10 (10:43)	10-12-10 (10:41)		25
2011	4-05-11 (13:55)	Present		

6.3. Flow Data

Flow meters were installed at four monitoring sites (UMKC001, UMKC002a, UMKC002b, and UMKC003) as shown in Figure 6-1. For the purpose of analyzing the flow data for the control site, two lateral monitoring sites (UMKC002a and UMKC002b) and one outfall monitoring site (UMKC003) were selected. This will provide a clear idea of how each individual subwatershed is contributing to outfall and help in eliminating any discrepancies in flow data that might occur due to improper data collection by the flow monitoring devices. The availability of flow data is summarized in Tables 6-2 through Table 6-5. Flow data was recorded in 5-minute intervals for sites UMKC001, UMKC002a, and UMKC003, and in 15-minute intervals for site UMKC002b. Because the data was collected in smaller time intervals for sites UMKC001, UMKC002a, and UMKC003, these results were aggregated into 15-minute intervals, including the control watershed.

Table 6-2: Summary of flow data for site 1 (UMKC001)

Year			
2008	11-22-08	12-31-08	-
2009	1-1-09	12-31-09	3-18-09 (12:25) to 3-18-09 (13:25) 5-22-09 to 6-17-09[1]
2010	1-1-10	12-31-10	3-19-10(13:10) to 3-19-10 (14:05) 5-5-10 to 5-14-10[2] 6-19-10 to 11-7-10 (4:00)[3]
2011	1-7-11 (16:25)	3-10-11 (10:40)	-

1. Meter fouled 2. Meter removed for repair 3. Meter removed for sewer relining

Table 6-3: Summary of flow data for site 2a (UMKC002a)

Year	Start Date (Time)	End Date (Time)	Missing Data
2008	11-23-08 (4:50)	12-31-08	--
2009	1-1-09	12-31-09	5-22-09 to 5-31-09[1]
2010	1-1-10	12-31-10	1-19-10 to 1-21-10[2] 2-3-10 to 3-4-10[3] 3-19-10 (12:45) to 3-19-10 (13:40) 10-14-10 (12:05) to 10-29-10 (2:40)[4]
2011	1-7-11 (16:25)	3-10-11 (10:40)	--

1. Meter became unattached; reattached on 5-31-09 2. Meter fouled 3. Meter removed for replacement
4. Meter removed for calibration

Table 6-4: Summary of flow data for site 2b (UMKC002b)

Year	Start Date (Time)	End Date (Time)	Missing Data
2008	11-23-08 (4:50)	12-31-08	--
2009	1-1-09	12-31-09	3-18-09 (11:30) to 3-18-09 (12:30) 5-22-09 (12:00) to 6-1-09 (1:00)[1]
2010	1-1-10	12-31-10	3-19-10 (12:30) to 3-19-10 (13:15) 10-14-10 (12:05) to 10-29-10 (2:40)
2011	1-7-11 (16:25)	3-10-11 (10:40)	--

1. Meter fouled

Table 6-5: Summary of flow data for site 2c (UMKC002c)

Year	Start Date (Time)	End Date (Time)	Missing Data
2008	11-23-08 (4:50)	12-31-08	--
2009	1-1-09	12-31-09	2-16-09 to 2-16-09 (13:30) 5-22-09 to 6-17-09[1]
2010	1-1-10	12-31-10	3-19-10 (12:10) to 3-19-10 (13:05) 4-9-10 (11:00) to 4-9-10 (11:10)
2011	1-7-11 (16:25)	3-10-11 (10:40)	--

1. Meter removed for replacement

Table 6-5: Summary of flow data for site 3 (UMKC003)

6.4. Flow Analysis

For the purpose of analyzing the flow data to calculate different aspects of flow during storm events such as peak flow, total flow, average flow, etc., a dry weather base line flow is established from the available flow data for the years 2009, 2010, and 2011. This base line flow is calculated by taking an average flow over a 7-day dry period. After the base line flow is calculated, the flow during storm events was determined by subtracting the base line flow from the total flow. An example of an event from the control and pilot watersheds is shown in Figure 6-2.

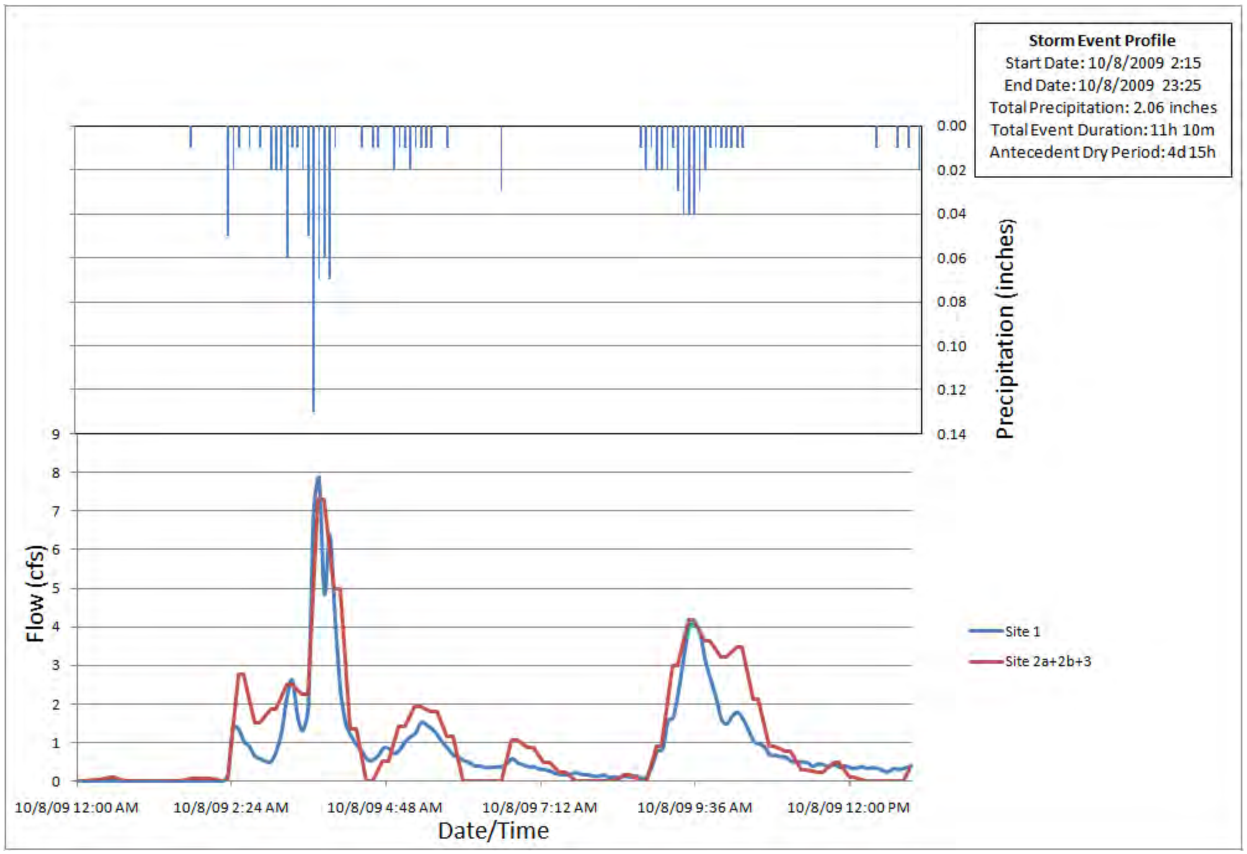


Figure 6-2: Hydrograph of a wet-weather event with its respective hyetograph for pilot and control sites.

Detailed land development and land use information for the test and control watersheds will enable the calibration of watershed stormwater quality models using site rainfall and runoff data. The observed rainfall and runoff data and calculated rainfall and runoff conditions for test and control watersheds are shown in Table 6-6 and Table 6-7, respectively.

Table 6-6: Example observed rainfall and runoff conditions

Rainfall							Pipe Flow								
Event Number	Start Date[1]	Start Time	End Data	End Time	Total (In)	5-Minute Peak Intensity (In/Hr)	Site/ Watershed	Area (Ac)	Start Date	Start Time	End Data	End Time	Total Discharge Volume (Ft^3)[2]	Peak Discharge Rate (Cfs)[2]
1	4-5-10	7:25	4-7-10	19:40	1.46	2.64	Pilot	100	4-5-10	7:30	4-11-10	5:15	638,316	39.5
							Control	86	4-5-10	7:30	4-11-10	5:30	329,237	33.7
2	4-16-10	5:15	4-16-10	9:15	0.11	0.12	Pilot	100	4-16-10	6:00	4-16-10	7:30	1,844	0.68[3]
							Control	86	4-16-10	6:30	4-16-10	8:30	3,203	0.89
3	4-22-10	10:15	4-27-10	5:45	3.36	1.08	Pilot	100	4-22-10	10:30	4-29-10	0:00	1,016,906	19.1
							Control	86	4-22-10	10:30	4-29-10	9:30	485,674	9.8
4	4-29-10	10:00	5-3-010	11:00	0.82	1.2	Pilot	100	4-30-10	7:00	5-3-10	4:45	123,915	23.1
							Control	86	4-29-10	10:00	5-3-10	11:15	102,261	10.99
6	5-19-10	11:30	5-21-10	2:00	1.34	0.96	Pilot	100	5-19-10	11:30	5-24-10	0:00	532,394	19.61
							Control	86	5-19-10	14:15	5-21-10	1:30	182,745	10.68
7	6-1-10	13:00	6-2-10	7:45	0.75	1.92	Pilot	100	6-2-10	6:45	6-2-10	9:45	58,305	16.12
							Control	86	6-2-10	6:30	6-2-10	8:30	23,959	8.27

[1] The rainfall data are obtained from a rain gauge at the site location
[2] The discharge volumes and flow rates have dry weather base flow value subtracted
[3] This event had suspect data for UMKC001 flow meter

Table 6-7: Example calculated rainfall and runoff conditions (based on observed conditions)

Event Number	Rain Start Date	Antecedent Dry Days	Rainfall Duration (Hr)	Average Rainfall Intensity (In/Hr)	Site	Pipeflow Duration (Hr)	Total (In)	Rv	Pipeflow/Rain Duration Ratio	Peak/Avg Pipeflow Rate Ratio
1	4-5-10	N/a	60.25	0.024	Pilot	141.75	1.75	1.19	2.35	31.6
					Control	142	1.05	0.72	2.35	51.9
2	4-16-10	8.4	4	0.027	Pilot	1.5	0.005	0.04	0.375	2.34[1]
					Control	2	0.01	0.09	0.5	2.26
3	4-22-10	6.04	115.5	0.029	Pilot	157.5	2.8	0.83	1.36	10.68
					Control	167	1.55	0.46	1.44	12.18
4	4-29-10	2.18	97	0.0085	Pilot	69.75	0.34	0.41	0.72	47
					Control	97.25	0.33	0.40	1.00	37.7
6	5-19-10	2.03	38.5	0.034	Pilot	108.5	1.46	1.09	2.82	14.43
					Control	35.25	0.58	0.43	0.91	7.47
7	6-1-10	11.46	18.75	0.04	Pilot	3	0.16	0.21	0.16	3.23
					Control	2	0.077	0.10	0.10	2.8

[1] This event had suspect data for UMKC001 flow meter

6.5. Effect of Sewer Rehabilitation

As part of the KCMO sewer improvements in 2010, sewers of small diameter (≤ 12 inches) in diameter were repaired and rehabilitated to reduce the quantity of flow entering the system and improve service by reducing the frequency and severity of basement backups. During this process several pipes in the pilot subwatershed were rehabilitated (including the lining of sewer pipes) in 2010. During this period the flow monitor at site 1 was removed, which accounts for the missing flow data for Site 1 (6-19-10 to 11-7-10 [4:00]) in Figure 6-2. A baseline hydrograph is plotted in Figure 6-3 showing the base line flow for Sites 1 (pilot) and 3 (control) from the available 2009 to 2011 data.

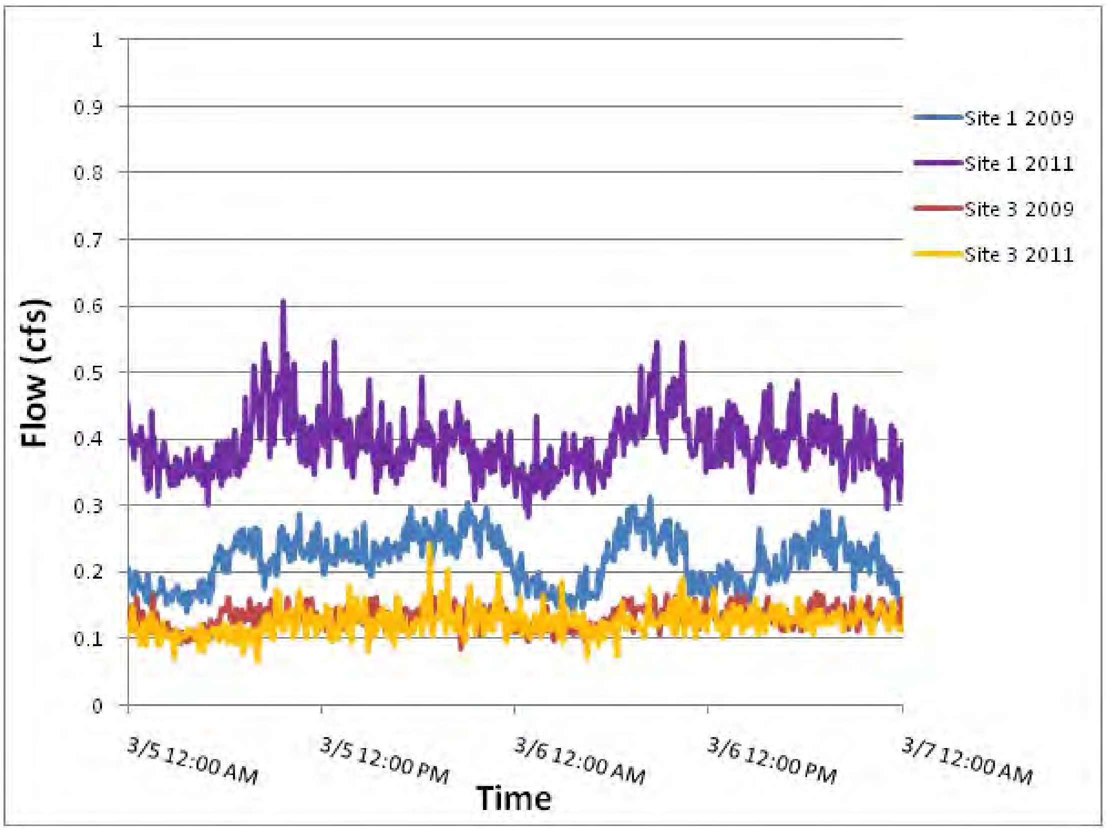


Figure 6-3: Comparison of base line (dry weather flow) for sites 1 and 3 before and after sewer rehabilitation.

Figure 6-3 also shows that the base line flow for site 3 remains relatively unchanged from 2009 to 2011, whereas significant change is observed in the base line flow for site 1 from 2009 to 2011. The results (i.e., an increase in base line flow for site 1) are likely linked to rehabilitation maintenance of the sewers by lining the cured-in-place pipe technology. Lining the sewers would not only prevent inflow/infiltration from wet-weather events (the objective for lining the sewers) but would also prevent any exfiltration from the sewer lines. If the exfiltration does not occur during dry weather, the base line flow would increase. That change can have a significant impact to the area, including potential for basement flooding or a greater number of CSOs.

6.6. Land Use Characterization

Land use characterization plays a major role in selection and implementation of GI. Information regarding different aspects—including type of land use (high-density residential, commercial, industrial, institutional, and etc.), pervious and impervious areas (sidewalks, streets), soil type, slope, and roof top drain discharges—were collected. These elements affect the site hydrology and water quality characteristics. Because infiltration of water into the surface soil is responsible for the largest abstraction of storm water in natural areas, infiltration tests were conducted in study area to evaluate the potential for the placement of storm water infiltration controls.

Table 6-8 and Table 6-9 show the original GIS information for the test watershed from KCMO WSD city sources along with the detailed site data.

Table 6-8: Original GIS measurements by KCMO WSD for test watershed

Type Of Land Use	Decks and Patios	Gravel Surfaces	Paved Roads	Paved Parking/ Storage	Sidewalks	Roofs	Pools	Pervious Areas	Sum
All Commercial:									
acres	0.00	0.14	1.92	3.41	0.24	1.36	0.00	1.25	8.32
%	0.00	1.68	23.10	40.93	2.87	16.37	0.00	15.06	100.00
All Office									
acres	0.00	0.00	0.00	0.26	0.03	0.17	0.00	0.11	0.58
%	0.00	0.00	0.00	45.86	5.80	29.72	0.00	18.63	100.00
All Institutional									
acres	0.00	0.00	0.31	0.01	0.04	0.00	0.00	0.19	0.56
%	0.00	0.00	56.07	2.59	6.36	0.00	0.00	34.98	100.00
All Residential									
acres	0.94	0.25	8.08	8.17	2.03	11.72	0.02	59.35	90.56
%	1.04	0.27	8.93	9.02	2.24	12.94	0.02	65.54	100.00
All Combined									
acres	0.94	0.39	10.32	11.85	2.34	13.25	0.02	60.91	100.02
%	0.94	0.39	10.32	11.85	2.34	13.25	0.02	60.89	100.00

Although the major categories for the site agreed between the GIS information and the site surveys, the site surveys were able to distinguish the different categories of pervious surfaces and quantify how much of the impervious areas were directly connected to the drainage system. This additional information can have dramatic effects on the actual stormwater quality and quantity, especially for the small and intermediate storms that produce most of the annual site runoff, and even for the 1.4-inch design storm used for the CSO evaluations. As an example, only about 15 percent of the residential roofs are directly connected to the CSS. If all were assumed to be connected, large errors in the roof runoff contribution calculations would occur. Similarly, if roof runoff stormwater controls were located at all properties, those located where the roofs were already disconnected would have much lower effects in decreasing the runoff reaching the combined system. Therefore, even though the detailed GIS information is very informative, the area requires site surveys.

Table 6-9: Medium density residential areas

Impervious Condition	Roofs	Driveways	Sidewalks	Parking/ Storage (Ac)	Streets	Landscaped	Isolated	Total Area
Impervious:								
Directly connected (ac)	1.87	4.12	1.15					
(%)	(15%)	(46%)	(46%)	1.59	9.35			18.07
Disconnected (ac)	10.57	4.03	1.34					
(%)	(85%)	(45%)	(54%)					15.95
Pervious:								
Unpaved (ac)		0.81						0.81
(%)		(9%)						
Landscaped						65.13		65.13
Isolated (swimming pools)							0.05	0.05
Total residential area	12.44	8.95	2.49	1.59	9.35	65.13	0.05	100.00

Similar to the rain garden methodology and reporting above, Turf-Tec Infiltrometers were used for infiltration testing in various locations across the pilot study area. Table 6-10 summarizes the data collected across the pilot watershed.

Table 6-10: Infiltration rates across the pilot watershed

Test Number	Date of Test	Address	Description of Site Location	Previous Rainfall Event	Measured Precipitation (In)	Moisture Content – Two Locations (%)
1-A	4-8-09	7444 Lydia	Between curb and sidewalk	4-2-09	0.12	26.6, 25.7
1-B	4-8-09	7428 Lydia	Between curb and sidewalk	4-2-09	0.12	23.5, 27.8
1-C	4-8-09	845, 77th Street	Near curb	4-2-09	0.12	24.5, 27.5
2-A	4-15-09	76th Terrace	Near UMKC Flow Meter MH 01	4-8-09–4-13-09	1.30	41.5, 37.8
2-B	4-15-09	1480, 76th Ter	Between sidewalk and edge of road	4-8-09–4-13-09	1.30	27.8, 25.6

The infiltration rates for the investigated sites ranged from 0.17 inches/hour to 17.83 inches/hour (Figure 6-4 through Figure 6-8) indicating the soils fall under hydrological soil groups A (sand, loamy sand, or sandy loam) and B (silt loam, or loam) with low runoff potential and moderate to high infiltration rates. These results indicate that the pilot area is well suited for GI implementation.

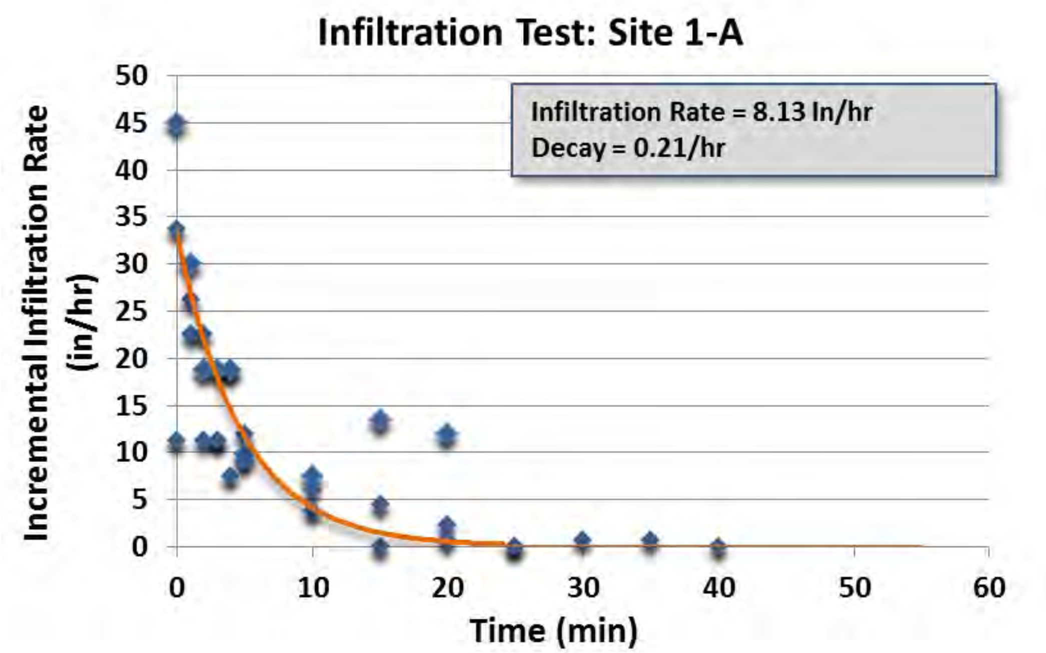


Figure 6-4: Turf-Tec Infiltrometer test results for site 1-A.

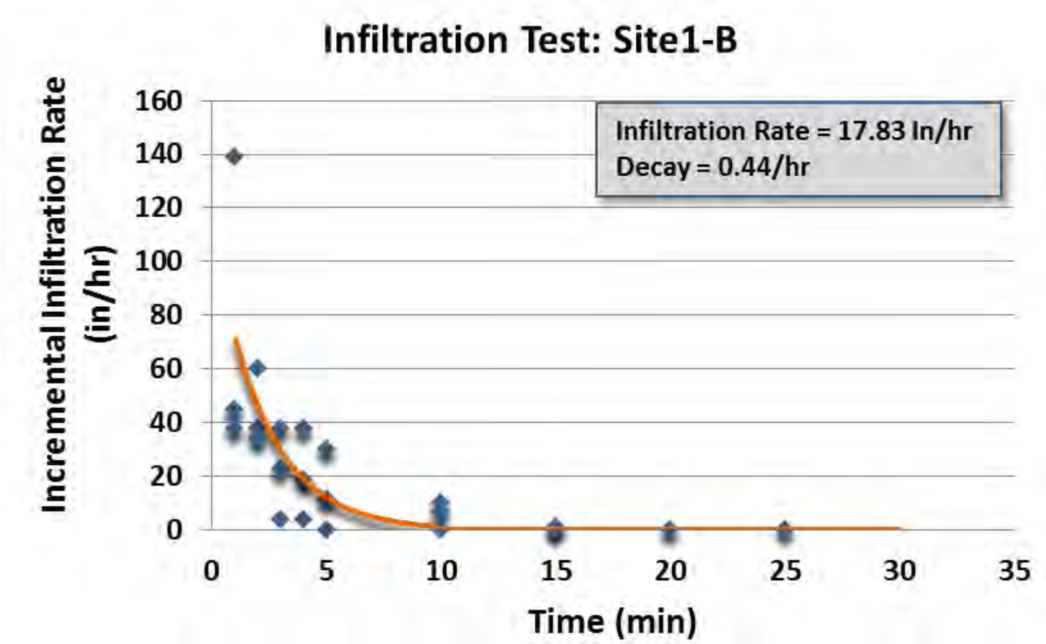


Figure 6-5: Turf-Tec Infiltrometer test results for site 1-B.

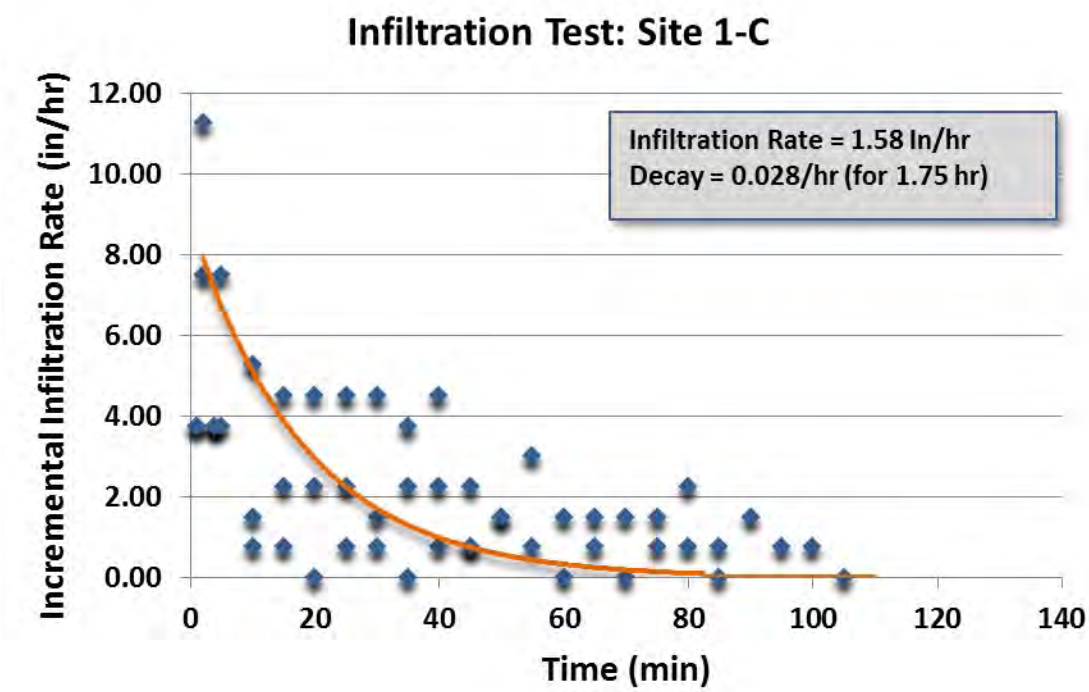


Figure 6-6: Turf-Tec Infiltrometer test results for site 1-C.

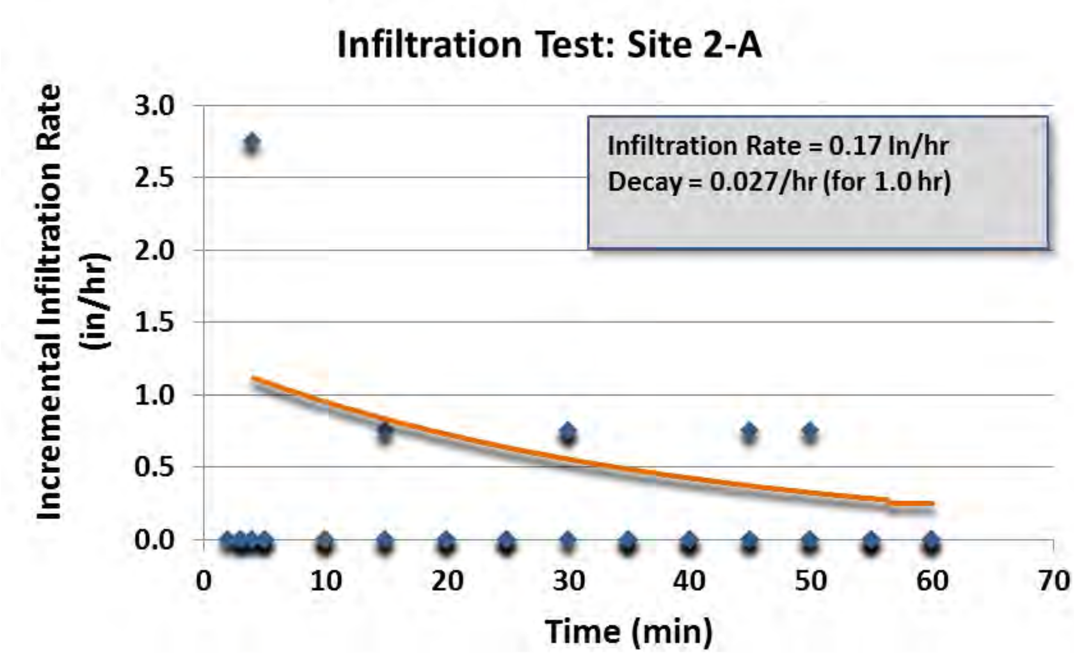


Figure 6-7: Turf-Tec Infiltrometer test results for site 2-A.

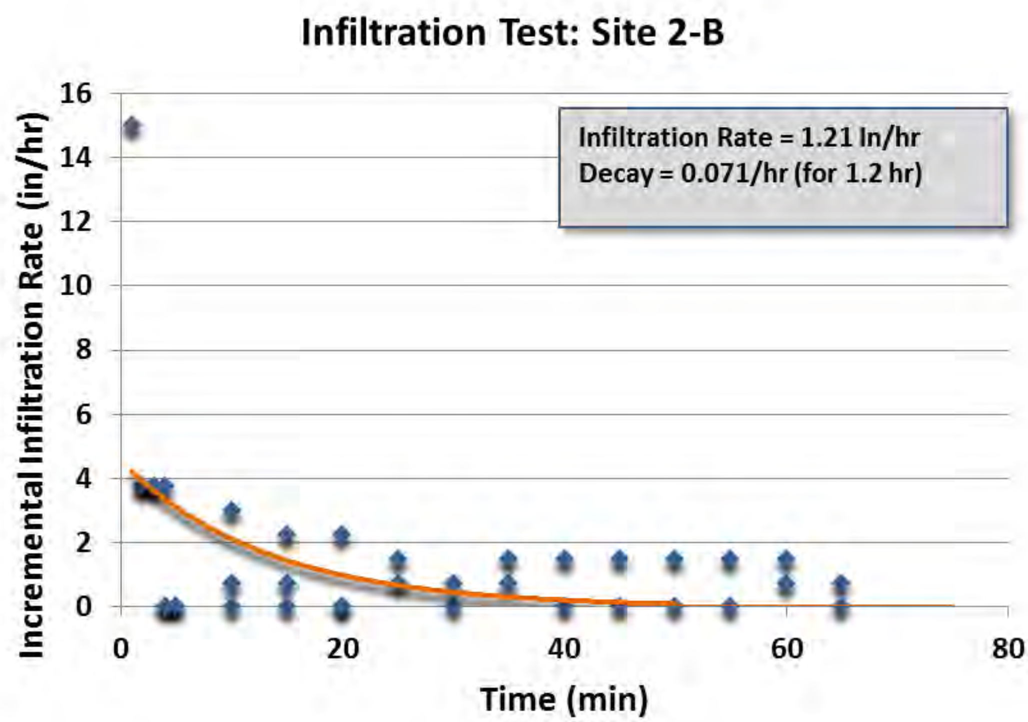


Figure 6-8: Turf-Tec infiltrometer test results for site 2-B.

7. Community Education and Outreach

An extensive effort went into community education and outreach activities because they were considered to be critical to project success. This chapter describes many of these efforts, including meeting, surveys, and other outreach events, to connect with the local community.

7.1. Background

In 2008, KCMO WSD initiated a green solutions project in the MBR Basin in Kansas City, Missouri (the "pilot project"), which was intended to evaluate the effectiveness of green solutions as an alternative to traditional CSO controls. The city selected an area of approximately 100 acres, extending from 73rd Street to 77th Terrace and Holmes Road to Paseo Boulevard in south-central Kansas City. This project area lies mostly within the borders of the Battleflood Heights Neighborhood Association, which in turn is a part of the Marlborough Community Coalition that is a non-profit organization focused on neighborhood improvements in this general area of the city. Lessons learned from KCMO WSD's pilot project will be used in the city's future planning for widespread use of green solutions—not just in the city's combined sewer area, but throughout the city; *see* map, Attachment A.

The National Demonstration of Advanced Drainage Concepts Using Green Solutions for CSO Control Project ("ADC Project"), funded through the EPA and managed by Tetra Tech, is partnering with the city to measure the effects of larger-scale application of stormwater management practices on CSOs. The ADC Project will help demonstrate larger scale implementation of green solutions practices as part of an overall adaptive management approach to combined stormwater and sewerage system needs and to control CSO.

As noted above, critical to the success of incorporating green solutions into KCMO WSD's CSO control plan is the support and involvement of the local community. This chapter documents community engagement and participation efforts that were implemented during the time period prior to, and at the commencement of, actual construction of green solutions by KCMO WSD. As such, these efforts were the result of significant collaboration between those involved with the ADC Project and KCMO WSD's pilot project.

It became clear early on that effective communication and collaboration between the ADC Project team and KCMO WSD was as important to the success of the ADC Project as communicating and engaging with residents in the pilot project area. The city relied on two consulting firms to develop and deliver its messages to the community, in addition to city staff and other consultants who were overseeing the technical aspects of the pilot project. The ADC Project team and the city both understood that because the local community would not differentiate between the ADC Project and the MBR pilot project, outreach efforts on the part of both groups needed to be consistent and collaborative. Coordination among all parties involved in these projects required frequent meetings and follow-up activities.

The ADC Project team began meeting with the city in the summer of 2008. The initial focus of these meetings was to seek an improved understanding of the scope and time frame for the MBR pilot project, since it was the driver for the ADC Project team's efforts in the pilot project area. By the late fall of 2008/early 2009, bi-weekly conference calls were established between the ADC Project team and the city and its consultants to share progress and other information related to both the technical work and communications and outreach developments. In addition, a SharePoint website was established in early 2009, and which has served as a useful information-sharing tool, used by both the ADC Poject team and the city and its consultants. The ADC Project team also developed a flyer that while somewhat technical in nature, could explain to interested parties the research that the team would be conducting; *see* Attachment B.

Planning for the community outreach and engagement activities began early in the development of the ADC Project. The planning team was comprised of staff and consultants representing KCMO WSD and the local members of the ADC Project team, which in turn included staff from EPA Region 7 and from MARC. As mentioned earlier, the planning team recognized that the community would not understand or appreciate that there were two separate projects occurring in the pilot area, KCMO WSD's pilot project and the ADC monitoring and evaluation project. For that reason, the team developed an overall approach to community outreach and engagement activities that was applicable to both projects.

Key Messages:

Green solutions benefit people and their environment

Green solutions can improve property values, provide jobs, offer health benefits, and add beauty

Neighbors working in partnership with each other and the city can enhance and amplify all project goals

These projects offer residents opportunities to contribute to one of the largest green infrastructure projects in the United States

7.2. Outreach Goals Established

An initial set of goals for community engagement and participation were established at the beginning of the process to support and enhance both projects. The goals will carry through the completion of the city's pilot project, which includes not only the construction of GI on city right-of-way property throughout the project, but also includes other activities and possible incentive programs to be implemented by the city during and after construction.

The ADC Project team and KCMO WSD staff and consultants also recognized the need for consistency and to avoid repetition in presenting information to the community. For that reason, a set of key messages and communication strategies were developed that served as the basis for communications tools and activities.

Goals:

- **Engage, educate, encourage, and excite residents and business owners in the MBR pilot project area to support the city's ADC project by installing green solutions on their property**
- **Collect and interpret data on which communication and engagement techniques result in the greatest positive response to programs and incentives offered**
- **Install a variety of green solutions on strategically located private property**
- **Collect and interpret effectiveness of green solutions on private property**

Once both teams understood each project and common goals for community education and outreach efforts were established, the ADC Project team then developed its own Communications and Public Engagement Plan (Communications Plan), designed to achieve the goals established through the joint planning process with KCMO WSD staff and consultants. A copy of the Communications and Public Engagement Plan is included (*see* Attachment C) to this report. The team used basic demographic information about the neighborhood as a starting point for development of the Communications Plan's strategies and tasks.

Battleflood Heights Demographic Information
(Based on 2000 Census Data)

Population	**3,962**
Gender	Male: 43.1%; Female: 56.9%
Race	76.4% African American
Unemployment (age 16 and over)	8.88%
Household Income	75% of households less than $75,000 annually
Age	50% age 30 and older

Based on the demographic information, the ADC Project team laid out the following tasks in its Communications Plan:

- Prepare and disseminate communications tools
- Organize and participate in meetings
- Identify interests and skills of property owners and residents
- Provide training to residents and business owners on installation, operation, and maintenance of green solutions on private property
- Install demonstration Projects on private property
- Celebrate success

7.3. Community Education and Outreach – On the Ground

The community education and outreach work began in earnest in early 2009 with a community meeting that took place on January 26, 2009 at the United Believers Church, 7546 Troost Avenue, Kansas City, Missouri. The meeting was hosted by KCMO WSD with support from the ADC Project communications team. Despite falling snow and ice, over 100 people attended the meeting. The focus of which was to inform residents of the Battleflood neighborhood about the city's pilot project and to begin educating residents about the benefits of rain gardens, rain barrels, and downspout disconnects. The city provided a survey to residents at the meeting, pertaining to the neighborhood in general, problems/concerns of neighborhood residents, communication techniques, and baseline knowledge of green solutions. Twenty responses to the survey were collected.

7.4. On the Ground – Street Meetings

The spring and summer of 2009 found the city still in initial stages of project planning and design, as well as the procurement of consultants. Regular meetings and conference calls between the city's staff and the ADC Project team continued throughout this period. Although a decision was made to not to move forward aggressively on public outreach until the city had some initial designs prepared for public input, ADC Project team members did attend meetings of the Battleflood Heights Neighborhood Association to continue to develop relationships with neighborhood leaders and interested residents. During this time, the Battleflood Heights Neighborhood Association also became active in the Marlborough Community Coalition.

By the fall of 2009, KCMO WSD had some very preliminary renderings of potential green solutions available for public review. The city and the ADC Project staff teamed up to host a series of street meetings for residents in the city's pilot project area in the fall of 2009. The street meetings were held on two consecutive Saturdays in October (10-24-09 and 10-31-09). Prior to the meetings, the city and the ADC Project team employed several methods to inform residents about the street meetings, including yard signs, press releases, letters to residents, attending neighborhood meetings, email to interested individuals, and posting on the city's website and newsletters.

In an effort to avoid confusion over the two separate projects, the ADC Project team's strategy was to allow the city to take the lead in developing and disseminating flyers to invite residents to the street meetings. A copy of the flyer developed for this purpose is included as Attachment G. Both the ADC Project team and the city participated in distributing the flyers by making them available at a local community center, through door-to-door canvassing and by placing flyers in local public library locations.

The October 24, 2009 street meeting took place in the front yard of the house at 7444 Lydia Avenue, Kansas City, Missouri (Figure 7-1). This location was chosen because it is clearly visible from a relatively main thoroughfare in the neighborhood. The October 31, 2009 street meeting was held at 1123 East 76th Street. Both addresses were within the pilot project area.

Figure 7-1: October 24, 2009 street meeting.

The street meetings served multiple purposes. First, the meetings afforded both the ADC Project team and the city an opportunity to begin to inform those who lived in the pilot project area about the imminent work that was going to be taking place in their neighborhood. It was also important to the city in particular that residents have some opportunity to provide input into the design and location of the green solutions that the city would be installing.

From the perspective of the ADC Project team, these meetings also served as a chance for the team to inform citizens about the monitoring aspect of the Project, so that residents might have a better understanding of and less concern about, the presence of people from outside of their neighborhood. The street meetings also provided the ADC Project team a chance to educate residents generally about rain gardens, rain barrels, and other best practices for managing storm water runoff on their property (Figure 7-2).

Finally, the street meetings gave both teams the opportunity to learn more about the residents within the pilot area, their interest in gardening in general, and their openness to installing rain gardens and/or rain barrels on their property in particular.

The city distributed a second written survey, jointly developed by the city and the ADC Project communications teams, which was focused on understanding neighborhood habits, including traffic patterns, and best practices for disseminating information to residents in the pilot area. The city's intent was to use the information to help develop the best ways of communicating important information to residents during the construction of the green solutions. The city also collected information that would assist in determining how best to minimize the disruption to residents while the sewers in the area were upgraded and during installation of the green solutions.

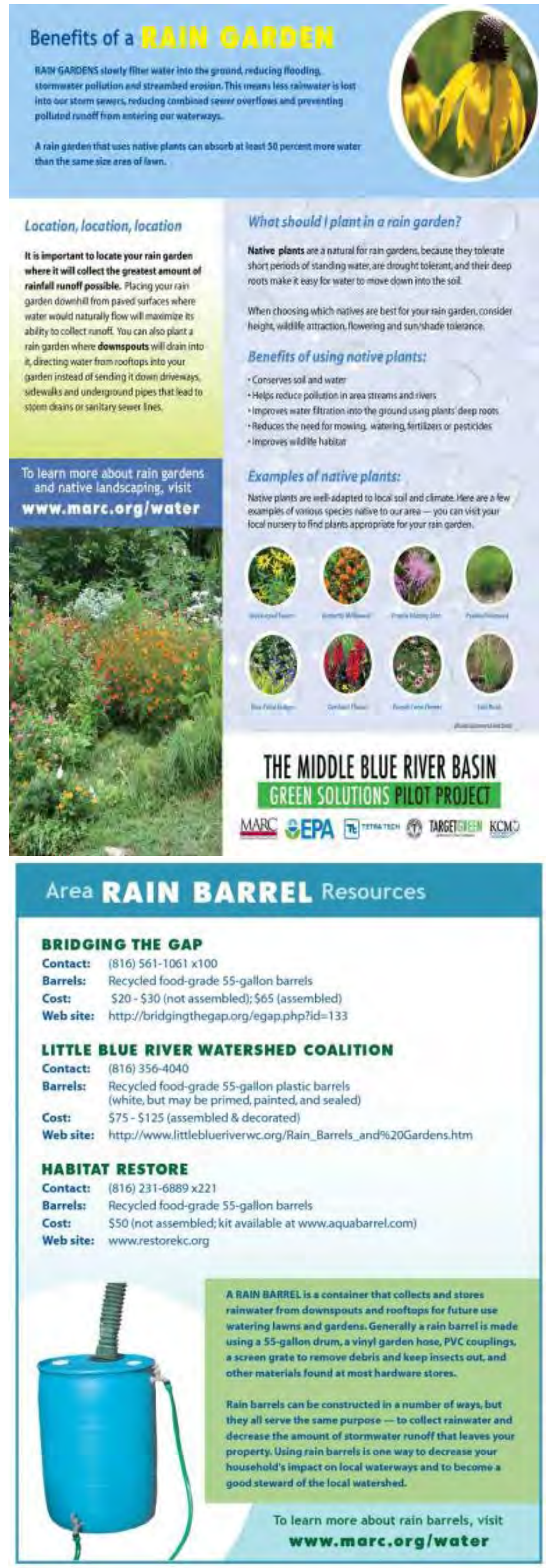


Figure 7-2: Examples of rain garden (top) and rain barrel (bottom) outreach material.

In contrast, the ADC Project team's focus was to educate and provide incentive for residents to install rain gardens, rain barrels, and best practices in managing storm water on their property. For this reason, during the street meetings the ADC Project team focused greater attention on educating residents about rain gardens and other storm water retention practices. To this end, the ADC Project team purchased native plants to donate to residents and also provided a rain barrel and the assistance of a knowledgeable individual who installed the rain barrel on a resident's property. The ADC Project team also used informative flyers and posters depicting rain gardens and rain barrels and their usefulness. As a result of both street meetings, the ADC Project team compiled a list of residents who indicated an interest in having a rain garden or rain barrel installed on their property.

7.5. Ongoing Outreach – Maintain Public Enthusiasm

Installation by the city of its green solutions was delayed for a year. This presented challenges not just to the technical work to be conducted by the ADC Project team, but also regarding ongoing communications. There was clearly a need to keep residents interested and engaged in the prospect of rain gardens and other green solutions during the interim before green solutions were actually going to be installed by the city. There was also a need for residents to see what an installed and operational rain garden looked like. One particular resident, Ms. Brenda Thomas, who lives at 1312 East 79th Street, had been particularly excited about having a rain garden in her yard, so the ADC Project team decided to find a way to construct the first residential rain garden in the area. MARC provided funding for soil amendments and plants, while UMKC students designed the rain garden and a monitoring program that would be conducted on this first installation. Volunteers from the ADC Project team then dug, tilled, and planted the garden in July of 2010 in the front yard of Ms. Thomas' home. One of the roof drains was connected to an inlet in the rain garden.

Figure 7-3: Constructing Ms. Thomas' rain garden.

Figure 7-4: Completed Thomas rain garden.

By September of 2010 the garden was a showcase for the neighborhood and doing an exceptional job of capturing and infiltrating all the rain water it received. Not long after, other community members began to ask when they could get some assistance to install one of the green solutions. Clearly, installation of Ms. Thomas' rain garden was instrumental in attracting and keeping residents' interest in green solutions during the 2010 year while there was a lull in KCMO WSD's pilot project schedule.

The ADC Project team had known since the initiation of the project that few resources were available to install rain gardens and rain barrels on the property of interested city residents. The ADC Project team addressed this challenge in two ways. First, the team continued its education and outreach work by attending Marlborough Community Coalition meetings during the spring and summer of 2010, and by staffing booths at community events during the 2010 year. Second, the ADC Project team explored additional funding opportunities through existing programs in Kansas City, including a program sponsored by the city's Fair Employment Council for summer employment. The team also applied for a federal grant, though neither of these leads came to fruition.

Concurrently, EPA Region 7 team members looked for funding within EPA and late in the fiscal year of 2010 some funds within their Water Division became available. Next, Region 7 issued a Request for Proposals for the installation of approximately 8 demonstration rain gardens and 20 rain barrels, and for services to disconnect 20 roof drains from the CSS—all on private property within the pilot project area. The Kansas City office of Tetra Tech was selected to conduct this work.

7.6. Green Solutions on the Ground

7.6.1. Residential Property Demonstrations Installed

In the early months of 2011 persons who had expressed an interest in having green practices installed on their property during street meetings or subsequent meetings of the Marlborough Community Coalition were contacted for follow up assessment. Their interest was confirmed and access agreements signed. Site visits were scheduled to determine whether the topography, yard size, and downspout locations would accommodate the selected practices. With these criteria and time constraints in mind, the team was able to identify seven properties to place demonstration rain gardens. The team then worked with each resident to design and locate the rain gardens and select the plants to be installed. The plan was to begin installation of rain gardens in March 2011, but an unusually long winter and wet spring delayed the installations until May and into the first week of June.

The team also attended and made presentations at events scheduled by the Marlborough Community Coalition. The first was a presentation at the Marlborough Community Coalition's regular monthly meeting, in order to explain the residential program and its place in the larger combined ADC pilot project. As a result, the team was also asked to make a small presentation at a dedication ceremony for a bridge that was constructed in the area. This provided an opportunity to address the broader general public about the green infrastructure work being conducted in the Marlborough area.

Volunteer labor was used to install rain gardens. Priorto beginning the installations, the team conducted 3 rain garden training sessions for a total of 11 volunteers. These volunteers consisted of UMKC students, high school students, and other interested community members. The volunteer team, led by a Tetra Tech team leader, dug the depressions, incorporated soil amendments, and planted the gardens. All seven demonstration rain gardens were installed within a few blocks of each other. After installation, the team followed up with each homeowner to answer any questions they had and provided a guidance document outlining suggested rain garden maintenance. The team will also make follow-up visits at 1-month and 4-month intervals to assure that the gardens are functioning well and plants are thriving.

Although six of the seven properties that received demonstration rain gardens also volunteered to have a rain barrel installed at their residence, none had downspouts directly connected to the sewer system. Therefore, the team then reviewed the results of the city's smoke tests of the sewers to target homes with downspouts connected to the CSS in order to identify candidate properties for downspout disconnections and rain barrel installations.

Figure 7-5: Installed rain barrel (left) and rain garden (right).

Before beginning rain barrel installations, the team coordinated with a local non-profit organization (Bridging the Gap) to hold a rain barrel construction and installation training. Three residents and six volunteers participated in the training. Because of connections formed with the neighborhood, the team was able to hold the training at a church in the neighborhood, with assistance by the Marlborough Community Coalition. By the end of the training, the group had constructed 20 rain barrels to be installed at residential properties.

All 20 rain barrels were installed by the team and volunteers, 1 per property. Three additional rain barrels were installed that were purchased by homeowners. Ten of the 20 properties with rain barrels also had connected downspouts that were disconnected. In total, 23 rain barrels on 20 properties were installed, and 17 roof drain downspouts on 10 properties were disconnected. The team plans to include several of these installations in their overall monitoring program to quantify contributions from various kinds of green solutions, as well as to quantify the benefits of having residential property installations.

7.7. KCMO Begins Construction of Green Solutions

In May 2011, the city also broke ground on their pilot project. The city sponsored a community-wide event held at South Broadland Presbyterian Church on Saturday, May 21, 2011, beginning with a pancake breakfast. Mayor Sly James welcomed everyone to the event. He was followed by councilpersons representing the residents of the pilot project area, officials from the KCMO WSD, and representatives of the various contractors who would be involved in the city's construction of green solutions. Each explained their role, introduced their representatives (whom residents could call with questions or concerns), and talked about the pilot project and schedule. Additionally, representatives of the various utilities (gas and power) talked about assistance they could provide, and various organizations that provide social and financial services had tables where community members could learn about available assistance. At least 60 community members participated. This event bolstered community spirits—the long awaited pilot project was finally happening.

7.8. Celebrating Residential Green Solutions

From the time funds became available for the residential demonstration of green solutions project, the ADC Project team had planned to hold a celebration when the demonstration projects were completed. EPA Region 7 agreed to take the lead, and started the planning process by meeting with the Marlborough Community Coalition to introduce the idea and get their input on the approach and timing of the celebration. While EPA provided leadership, the ADC Project team and Coalition were involved in all phases of planning and hosting the celebration event.

The Marlborough Community Coalition proposed July 22, 2011 as the event date. Initially the group wanted to have two events, one on Friday (7-22-11) for elected officials and the media and one the next day (Saturday 7-23-11) for residents. The ADC Project team and Marlborough Community Coalition members decided jointly that a bus tour of the rain gardens and a press conference to announce the completion of the demonstration projects would be ideal for Friday. Ms. Thomas volunteered to host the press conference on the front lawn of her residence with her rain garden in the background. The Coalition also suggested that some young student from the Benjamin Banneker Charter Academy of Technology participate in the celebration. They arranged for an art teacher to work with some of her students to paint several rain barrels that would be on display during the press conference. Ideas discussed for the Saturday event included a picnic, a festival with booths at one of the area schools, self-guided home tours where green solutions have been installed, and some demonstrations on rain garden and rain barrel maintenance. In the end, the Coalition determined that the summer schedule was already booked for key participants and the amount of construction in the neighborhood made planning of tour routes difficult. Thus, the Marlborough Community Coalition decided it best to postpone the ideas for a Saturday event to future date.

Ultimately, the heat wave that occurred around July 22, 2011 made everyone pleased that additional outside activities had not been planned. However, the Friday bus tour at 11:15 a.m. and the subsequent noon press conference, even with temperatures close to 100 degrees, was a superb event, with approximately 75 people present.

Figure 7-6: Ms. Brenda Thomas addresses the community about rain garden (left). Ms. Cindy Circo (former City Council member and Mayor Pro Temp at the press conference) and Ms. Thomas display a painted rain barrel (right).

Figure 7-7. Students at the press conference displaying rain barrels they painted.

Ms. Thomas opened the press conference with a welcome to her home and neighborhood. She talked about her rain garden, the flora and fauna that live there, and how much she enjoyed maintaining her rain garden. Next, Mark Hague, Acting Deputy Regional Administrator for EPA spoke about how the rain garden and rain barrel installations resulted from the successful partnering of many groups. Cindy Circo, Kansas City Mayor Pro Tem, spoke about the value of the pilot project to the revitalization of the Marlborough Neighborhood. Ms. Thomas closed the event by helping the student group present one of the painted rain barrels to Ms. Circo for a display at City Hall. Several local television stations shot footage and a reporter from the Kansas City Star was present to develop a story that was in the local newspaper. The local public television station, KCPT, conducted interviews and information for a segment in a series called Imagine KC, which will air at a later date.

7.9. Lessons Learned

Many lessons were learned throughout the multi-year project, though this report will only attempt to describe three. The first was the value of community celebrations. Each of the events that have occurred in the Marlborough area during the last year (Ground-breaking for City's Green Solutions Project in May, and the Residential Rain Garden Press Conference and Tour in July) have brought positive attention to the neighborhood. This visibility has resulted in a growing sense of pride as well as a willingness on the part of residents to become more active in overall community revitalization efforts.

Another lesson learned was that during the 3 years of community engagement work that the ADC team, the city, and the city's consultants, did in the project area had a secondary benefit—it supported the formation of the Marlborough Community Coalition. With both projects needing community support, this need stimulated community leaders to organize themselves to respond, not only to environmental concerns, but also housing, community policing, and the need for neighborhood revitalization.

A final lesson learned was the value of working with a local champion. Ms. Brenda Thomas became the highly visible and outspoken champion for green solutions at the neighborhood level. She was the first implementer GI and always willing to talk to others about her rain garden. She was an organizer who had many contacts inside and outside of the community and was willing to help the ADC team engage people. She also brought neighbors together to participate. She was also involved with the Marlborough Community Coalition and helped the team connect with a group that was gaining strength as an organization that mattered in local decision-making.

7.10. Future Opportunities

The ADC team and city both realize that public engagement will continue to be a priority as installation and monitoring of local green solutions occur. It is vital to continue to nurture the early implementers of green solutions with information and additional ideas for ensuring that their demonstration projects remain successful. We also need to continue to find ways to celebrate success for both public and private investments. Lastly, we need to assist the Marlborough Community Coalition in organizing and hosting their postponed Saturday festival sometime this fall.

8.References

Andoh, R., R. Pitt, N.. Togawa, and K. Osei. 2009. *The Up-Flo Filter – An Advanced Novel High-Rate Filtration System for Stormwater Treatment.* Stormwater 2009, Australia.

Contech Construction Products, Inc. 2011. *UrbanGreen™ BioFilter*. <http://www.contech-cpi.com/Products/Stormwater-Management/Treatment/UrbanGreen-BioFilter.aspx>. Accessed June 23, 2011.

Clesceri, L.S., A.E. Greenberg, and A.D. Eaton (ed.). 1998. Standard methods for the examination of water and wastewater, 20th ed. American Public Health Association, Washington, D.C.

Khambhammettu, U., R. Pitt, R. Andoh, and S. Clark, S. 2006. Performance of Upflow Filtration for Treating Stormwater. World Environment & Water Resources Congress, ASCE/EWRI. Omaha, Nebraska. May 21-26, 2006.

Leeds, T. 2009. *Kansas City's Green LTCP & Pilot Programs*. Water Services Department, Kansas City, MO.

Pitt, R. 2011. *WinSLAMM Calibration, Pollutant and Flow Sources, and Performance of Stormwater Control Programs for the Marlborough Neighborhood Test and Control Watersheds*. Kansas City, MO.

USEPA (U.S. Environmental Protection Agency). 1983. Methods for Chemical Analysis of Water and Wastes, 3rd edition. EPA report number 600479020. Washington, DC.

USEPA (U.S. Environmental Protection Agency). 2009. *SUSTAIN – A Framework for Placement of Best Management Practices in Urban Watersheds to Protect Water Quality.* EPA/600/R-09/095. U.S. Environmental Protection Agency, Office of Research and Development..

WSD (Water Services Department). 2008. *Green Alternatives for Outfalls 059 & 069*. Water Services Department, Kansas City, MO.

WSD (Kansas City, Missouri, Water Services Department). 2009. *Overflow Control Program. January 30, 2009*. Water Services Department, Kansas City, MO.

XP Software. 2010. *XP-SWMM Technical Description 2010*. <http://www.xpsoftware.com/wp-content/uploads/xpswmm-techdesc.pdf> Accessed [June 27th, 2011].

Appendix C

Advanced Drainage Concepts for Using Green Solutions for CSO Controls 2012 Summary Report

Advanced Drainage Concepts for Using Green Solutions for CSO Control

2012 Summary Progress Report

(modified by Michelle Simon and published in 2016)

This page intentionally left blank.

Advanced Drainage Concepts for Using Green Solution for CSO Control

2012 Summary Progress Report

by

Dustin Bambic, P.H.[1]
Jason Wright, P.E.[1]
Robert Pitt, P.E., Ph.D., D.WRE[2]
Deborah O'Bannon, P.E., Ph.D.[3]

[1]Tetra Tech, Inc., Fairfax, VA
[2]University of Alabama, Department of Civil, Construction, and Environmental Engineering, Tuscaloosa, AL
[3]University of Missouri – Kansas City, Department of Civil and Mechanical Engineering, Kansas City, MO

In support of:

EPA contract no. EP-C-11-009
Work Assignment 1-04

Project Officer:
Michelle Simon, Ph.D., P.E.
Urban Watershed Management Branch
Water Supply and Water Resources Division
2890 Woodbridge Avenue (MS-104)
U.S. Environmental Protection Agency
Cincinnati, OH 45268

National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268

December 2012

Disclaimer

Executive Summary

Green infrastructure includes practices and site-design techniques that store, infiltrate, evaporate, or detain stormwater runoff and in so doing, control the timing and volume of stormwater discharges from impervious surfaces (e.g., streets, building roofs, and parking lots) to the stormwater collection systems. EPA's Office of Research and Development has the goal to provide detailed guidance and information on methodologies for selection, placement, and cost effectiveness and to document the benefits of green infrastructure applications in urban watersheds for new development, redevelopment, and retrofit situations.

The Kansas City Water Services Department (KCWSD) provides wastewater collection and treatment for approximately 650,000 people, located within the City and in 27 tributary or "satellite" communities. The City of Kansas City, Missouri has developed a project to demonstrate the application of green infrastructure for combined sewer overflow (CSO) control in the Middle Blue River. KCWSD has recently completed construction of a 100-acre retrofit of an aging neighborhood that has included sewer rehabilitation and implementation of over 100 green infrastructure (GI) solutions. This project is one of the largest in the United States and provides a unique opportunity for USEPA ORD to quantify the benefits of GI solutions on large scales (overall pilot project area) and small scales (individual GI solutions) and meet its GI-related goals.

This progress summary report describes efforts completed during the 2012 calendar and presents preliminary results from monitoring efforts to date. The ADC project made significant progress during the 2012 calendar year, including the following technical achievements:

- Installation of water quality and/or hydraulic monitoring equipment at eight individual GI solutions
- Hydraulic monitoring of 12 storm events at the individual GI solutions
- Water quality monitoring of 9 storm events at the individual GI solutions for a total of 29 water quality samples
- Continued collection and download of hydraulic monitoring data from the four large-scale flow meters and rainfall gage
- Continued collection and download of hydraulic monitoring data from two private rain gardens
- Modeling of the pre- and post-construction hydrology of the pilot project area versus the control area
- Extensive efforts to compile and analyzed hydraulic and water quality monitoring data collected to date (both large-scale and small-scale)

The achievements listed above do not include the many non-technical achievements including fostering of collaboration and information exchange among EPA ORD and KCMWD and efforts by Region 7 staff to increase community awareness regarding the benefits of green infrastructure.

The lengthy construction timeline for the MBRGS pilot project and severe drought conditions have led to the project being extended into the 2013 calendar year. The following efforts are expected to be completed in 2013:

- Continued hydraulic and water quality monitoring at in the individual GI solutions, with an emphasis on water quality sampling of larger (>1-inch) storm events that generate effluent from the GI solutions
- Additional modeling efforts including SWMM or SUSTAIN modeling
- Additional statistical analyses to support quantification of the performance of individual GI solutions
- Additional analyses to quantify the post-construction performance of the MBRGS pilot project area versus the control area
- Completion of a final report that can serve as a national reference regarding the performance of GI solutions at multiple scales
- Training of KCMWD staff regarding the water quality monitoring protocols to encourage long-term monitoring of the GI solutions
- Transition of monitoring responsibility for the four large-scale flow meters to KCMWD (which owns the flow meters)

The ADC project is on track to support the GI-related goals of EPA ORD and significantly benefit the national community of agencies associated with managing stormwater and CSO impacts.

Contents

List of Tables

List of Figures

1. Background

In 2012, Kansas City, Missouri Water Services Department (KCWSD) completed construction of the Middle Blue River Green Solution (MBRGS) pilot project, which is a 100-acre area where green infrastructure (GI) solutions have been implemented to demonstrate their volume control benefits for abating combined sewer overflows (CSOs) due to wet weather flows. The MBRGS pilot project is a landmark component of the KCWSD's Overflow Control Program and will be used to assess the implementability of GI solutions across the entire CSO service area (Figure 1) including constructability, cost-effectiveness, maintenance requirements, and community acceptance. Nationally, the MBRGS pilot project is one of the largest GI retrofits to date in the United States.

Since the initial conception of the MBRGS pilot project, EPA's Office of Research & Development (EPA ORD) has been collaborating with KCWSD to [1] support KCWSD's GI implementation efforts and [2] utilize the pilot project as an opportunity to nationally demonstrate the effectiveness of GI solutions for volume and pollutant control. Efforts to support KSWSD have including monitoring of pre-implementation conditions and modeling of proposed designs. The MRRBGS pilot project is considered a national demonstration opportunity for Advanced Drainage Concepts because EPA ORD has the goal to provide detailed guidance and information on methodologies for selection, placement, and cost effectiveness of GI solutions. Further, ORD has the goal to document the benefits of green infrastructure applications in urban watersheds for new development, redevelopment, and retrofit situations.

Several Advanced Drainage Concepts work plans have been implemented by EPA ORD over the course of the design and construction of the MBGRS pilot project (EPA ORD, 2009; EPA ORD, 2011a; EPA ORD, 2011b), with goals including the following:

- Measure small- and large-scale system performance of GI retrofits in the MBR demonstration project by monitoring the changes in the peak flows, total volumes, and pollutant loadings before and after GI implementation
- Use models to demonstrate GI and gray infrastructure integration and performance (volume and number of overflow events) on a larger scale within the CSS, and to calculate or predict the benefit of the reduction in volume, pollutant load, and number of overflow events
- Provide information on socio-economical-political barriers of green infrastructure acceptance
- Gather information for understanding outreach and education benefits to the local community
- Develop life-cycle cost comparison between conventional CSO control and green infrastructure control

This report summarizes the activities during 2012 and highlights the preliminary results of monitoring efforts. These monitoring efforts will continue into 2013, after which a comprehensive final report will be developed. A modeling report with the same submittal date accompanies this progress report (EPA ORD, 2012).

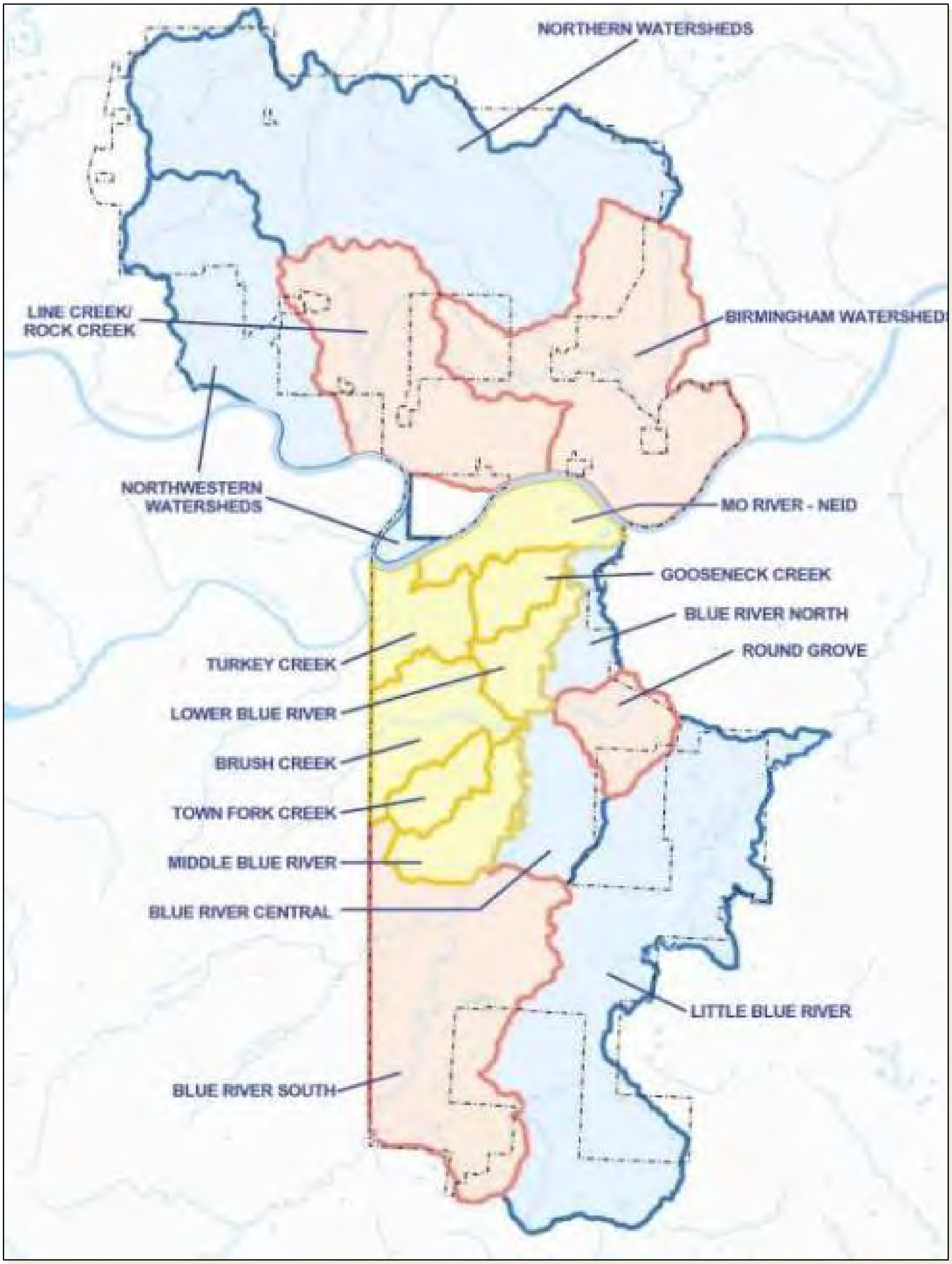


Figure 1. KCWSD Service Area with Sanitary Sewer and Combined Sewer Basins

2. Overview of 2012 Activities

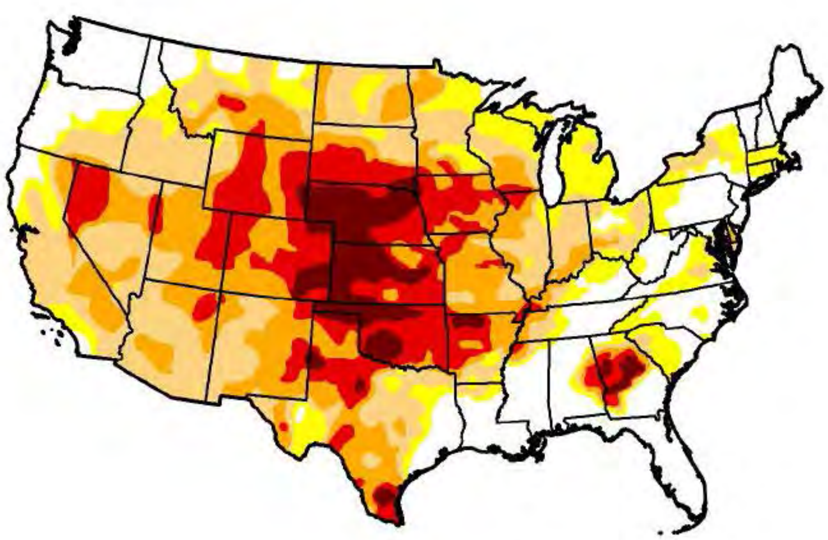
This section describes the activities completed during 2012. Previous reports provide many additional details on details on the design of GI solutions, site selection, rationale for selected field and laboratory methods, and pre-performance data analyses.

A historic drought during 2012 affected all activities associated with this project, including pilot project construction and monitoring. As shown in **Figure 2**, a vast majority of the state (84%) was under Severe Drought conditions in September 2012, with 17% being under Extreme Drought conditions. These drought conditions reduced the survival rate for many plantings in GI solutions, and limited the number of wet weather flow events that could be monitored. Ultimately, the drought conditions have led to the continuation of monitoring activities into 2013, in order to allow for collection of additional data from wet weather flows.

Figure 2. Missouri Drought Conditions as of December 2012 (table) **and September 2012** (map) (Source: U.S. Drought Monitor)

Drought Conditions (Percent Area)

	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	0.00	100.00	94.68	29.09	0.00	0.00
Last Week (12/11/2012 map)	0.00	100.00	94.68	29.09	0.00	0.00
3 Months Ago (09/18/2012 map)	0.00	100.00	100.00	84.55	16.90	0.00
Start of Calendar Year (12/27/2011 map)	95.48	4.52	0.00	0.00	0.00	0.00
Start of Water Year (09/25/2012 map)	0.00	100.00	100.00	84.50	16.90	0.00
One Year Ago (12/13/2011 map)	72.39	27.61	1.27	0.00	0.00	0.00



2.1. MBRGS Pilot Project Construction

The active construction period for the MBRGS pilot project was from May 2011 to July 2012. Shown in **Figure 3** is an example street view during construction. More than 100 individual GI solutions were constructed and planted. In order to allow KCWSD to assess the implementability of different GI designs, multiple types of GI solutions were constructed including rain gardens, bioretention areas, bioswales, porous sidewalks, and cascading swales. For most types of GI solutions, several different types of underground features are represented (under-drains, Smart Drains, subsurface storage, etc.).

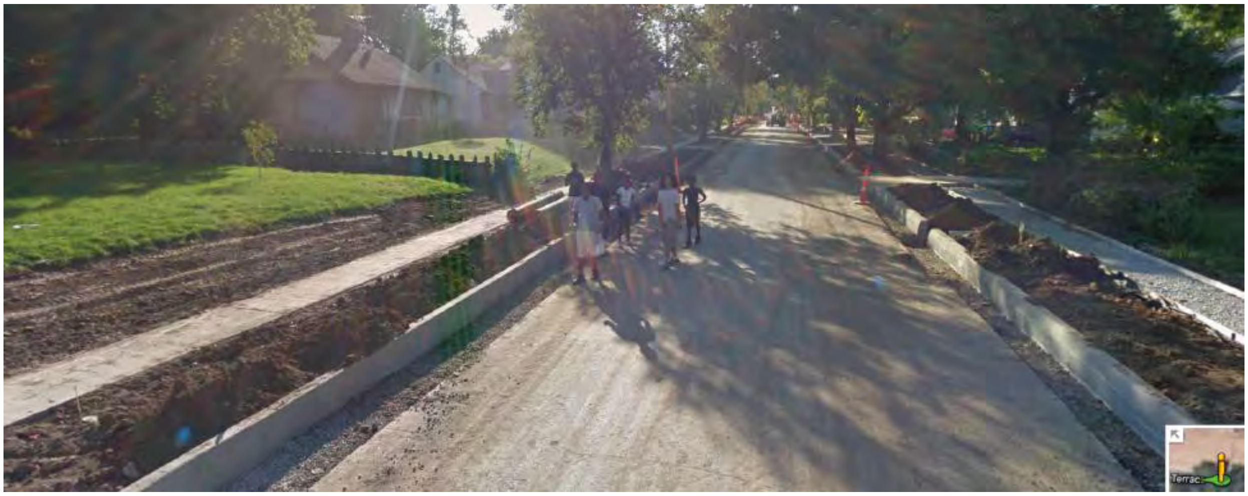


Figure 3. Google® Street View of a Street within the MBRGS Pilot Project during Construction

By spring 2012, a majority of the individual GI solutions were near completion including plantings. From spring 2012 to July 2012, much of the construction effort involved completion of plantings, which was challenged by the worsening drought conditions. During this period, many of the inlets to the individual GI solutions were sandbagged to avoid siltation due to upstream construction activities. By late July 2012, the roads in the MBR neighborhood were repaved and all sandbags had been removed, which marked KCMWD's completion of construction.

Shown in **Figure 4** is the MBRGS pilot project area and individual GI solutions constructed within the watershed. Also shown are the approximate micro-drainage areas to the individual GI solutions (yellow-shaded areas) and the areas do not drain to GI solutions (mostly yards and areas not directly connected to the street scape). Approximately half of the 100-acre pilot project area drains directly to a GI solution.

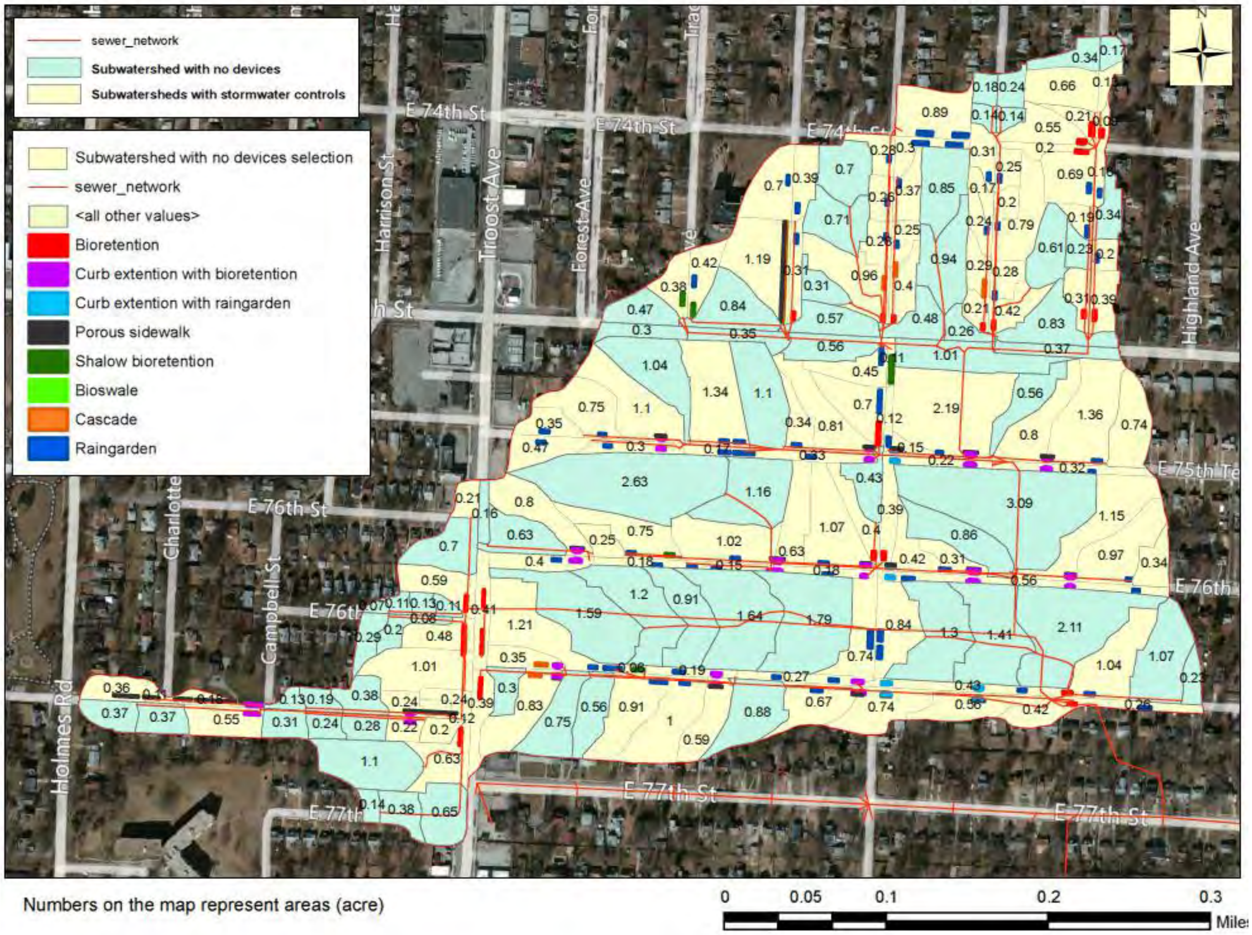


Figure 4. MBRGS Pilot Project Area, Individual GI Controls, and Micro-drainage Areas

2.2. Flow and Water Quality Monitoring Efforts

This sub-section describes the monitoring activities conducted during 2012, organized by large-scale and small-scale investigations.

2.2.1. Large-scale Flow Monitoring of Pilot Project and Control Areas

The 100-acre pilot project is within the MBR watershed and captures wet weather flows from a sub-drainage to CSO Outfall 069, which is a total of 475 acres. An adjacent 86-acre area is being used as a "control" area to compare system response to rainfall with and without GI implementation (**Figure 5**). No GI will be incorporated into this control area for the duration of the post construction monitoring program. The demonstration project and control areas are both fully developed with approximately 34 percent impervious area, and include mostly residential with some commercial land uses.

Figure 5. Outfall 069 Watershed including Pilot Project Area and Adjacent Control Area

As shown in **Table 1** and **Figure 6**, a total of four locations have been monitored for the large-scale flow assessment: UMKC01, UMKC02a, UMKC02b, and UMKC03. These sites have been monitored since November 2008. During 2012, flow monitoring efforts involved downloading data from these sites' data loggers on a monthly basis. For all flow meter sites, an ISCO 2150 type flow sensor with a model 6700 controller is installed in the pipe using an expansion ring or concrete screws to hold the meter in place. While monitoring has occurred over a 4-year period, gaps in the record for each meter are common. Notable gaps in the record include the following:

- **Gaps in UMKC01 Record:**
  - June 28, 2010 to November 7, 2010 (due to sewer line rehab)
  - March 30, 2011 to November 20, 2011 (unknown reason)
  - November 20, 2011 to September 7, 2012 (level sensor failure)
- **Gaps in UMKC02a Record:**
  - March 30, 2011 to May 28, 2011 (unknown reason)
  - September 12, 2011 to February 15, 2012 (unknown reason)
- **Gaps in UMKC02b Record:**
  - No gaps longer than 2-weeks reported
- **Gaps in UMKC03 Record:**
  - March 30, 2011 to July 5, 2011 (unknown reason)
  - September 12, 2011 to November 21, 2011 (unknown reason)

In order to calculate volumes discharged from the control area, the volumes measured by the three control area flow meters are added (UMKC02a, UMKC02b, and UMKC03; see **Figure 7**). Flows from the pilot project area and control area are independent of on another Data analysis efforts, including efforts to "patch" some of the data gaps, are described in Section 3.

Table 1. Large-Scale Flow Monitoring Locations

Equipment Type	Area Type	Model	Address	Design Station	Date Installed	Drainage Area (acres)
Rain gauge	Both Pilot and Control	RainWise tipping bucket	77th St & Paseo	N/A	7/22/09	N/A
UMKC1 flow meter	Pilot	ISCO 2150	Near 1461 E 76th Terr	S128-498	11/7/08	99.7
UMKC2a flow meter	Control	ISCO 2150	Near 1451 E. 77th St	S128-422	11/7/08	41.4
UMKC2b flow meter	Control	ISCO 2150	Near 1451 E. 77th St	S128-420	11/7/08	27.6
UMKC3 flow meter	Control	ISCO 2150	77th St & Paseo Overpass	S128-426	11/7/08	17.6

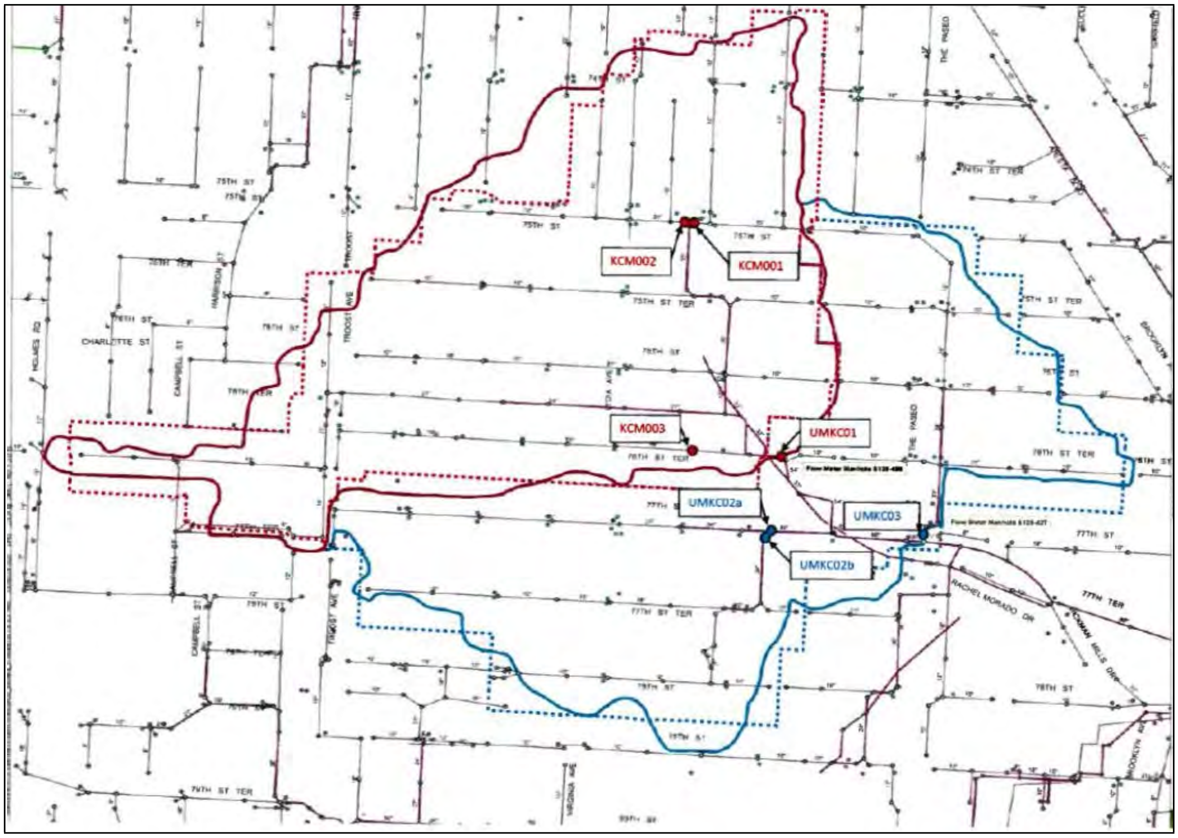


Figure 6. Pilot Project (red) and Control Area (blue) Flow Monitoring Locations
(Source: GBA, **note**: sites KCM002, KCM002, and KCM001 were not monitored for this project)

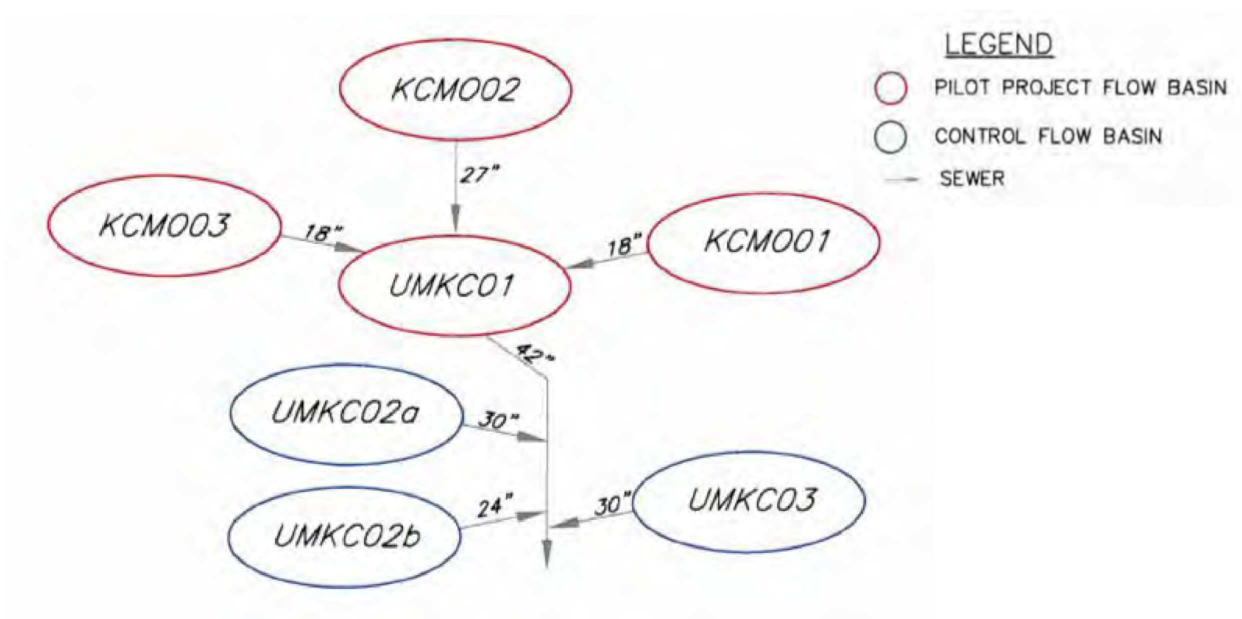


Figure 7. Flow Path Diagram for Large-Scale Flow Meter Sites (Source: GBA)

2.2.2. Small-Scale Monitoring of Individual GI Solutions

A total of 10 individual GI solutions have been monitored for this ADC project (Table 2 and **Figure 8**). Photographs, drainage information, and as-built schematics of monitoring installation at these 10 sites are shown in **Figure 9** through **Figure 26**. Four of these GI solutions were monitored for flow rate and water quality (GI Solutions #1-3 and #7), and six GI solutions were monitored for flow rate only (GI Solutions #4-6 and #8). The private rain gardens (GI Solutions #9 and #10) have been monitored since late September 2010. The private rain garden monitoring sites were decommissioned in November 2012, and will no longer be monitored. For all other individual GI solutions (GI Solutions #1 thru #8), monitoring equipment was installed in spring and early summer 2012 (May or June for most sites), and will continue into 2013.

2.2.2.1. Hydraulics Monitoring Methods

For all individual GI solutions, continuous flow rate monitoring includes inflow and outflow using either an ISCO bubbler (inlets of sites with water quality monitoring) or Global Water WL16 Water Level Loggers (all outlets and also inlets of sites without water quality monitoring). Private rain gardens were monitored using a 1-minute time step, while all other individual GI solutions were monitored with a 5-minute time step. Flow rates at GI Solutions #1 thru #8 were monitored using H-flumes at the inlets and V-notch weirs at the outlets, and in-garden water levels were measured using Global Water Level Loggers placed within the garden. Flow data were downloaded approximately monthly from the data loggers.

2.2.2.2. Water Quality Sample Collection Methods

Three curb extension rain gardens and one rain garden extension were monitored for water quality between June and November 2012. The water quality monitoring installation consists of two ISCO samplers housed in an equipment box (see **Figure 9** for a typical set-up). All inlet samples were collected using flow composite methods using a pre-set volume pacing. The curb extension rain gardens have overflow outlets with no underdrain, and outlet samples were triggered using a Liquid Level Actuator (if the water level reaches the height of the actuator, which corresponds to the height of the outlet structure, then the outlet ISCO is triggered and aliquots were filled every 15 minutes). The rain garden extension has a Smart Drain underdrain and outlet samples were triggered using a tethered cable on a time delay of 15-minutes after inflow to the rain garden was detected (after this 15-minute delay, aliquots were collected every 15-minutes if flow was present). Samples were collected during rainfall events that produced sufficient runoff volume, as described in Section 3.

At the onset of the 2012 monitoring effort, five individual GI solutions were equipped for water quality monitoring. The fifth GI solution equipped for water quality monitoring was a rain garden with Smart Drain (similar to Solution #8) at 1140 East 76th Terrace. However, in June 2012 the equipment box containing two ISCO samplers from this site was destroyed by the local municipal solid waste agency. The solid waste crew reportedly mistakenly identified the equipment box as trash that has been disposed curb-side and extracted it using a truck-mounted crane. The box was disposed at the local landfill and was never recovered. Therefore, water quality data was collected from four individual GI solutions (not five).

Table 2. Individual GI Solutions Monitored for Flow and/or Water Quality for the ADC Project

No	BMP Type	Address	Design Station	No. Flow Probes Installed?	Water Quality Sampling?	Outlet ISCO Triggered via Cable or LLA?
1	Curb Extension	1324 East 76th St.	19+79.61	1	Yes	LLA
2	Curb Extension	1325 East 76th St.	19+79.61	1	Yes	LLA
3	Curb Extension	1419 East 76th Terr.	26+51.65	1	Yes	LLA
4	Rain Garden Extension	1612 East 76th St.	31+31.12	2	No	---
5	Rain Garden Extension	1336 East 76th St.	21+29.95	2	No	---
6	Rain Garden Extension	1141 East 76th Terr.	16+10.10	2	No	---
7	Rain Garden w/ Smart Drain	1222 East 76th St.	16+28.15	1	Yes	Cable
8	Cascade Swale	1112 East 76th Terr.	12+22.24	2	No	---
9	Private rain garden	1312 East 79th St.	Mrs. Thomas	2	No	---
10	Private rain garden	1505 East 76th St.	Mrs. Moss	2	No	---

2.2.2.3. Water Quality Analytical Methods

For monitored storm events, water quality samples were analyzed by up to three laboratories, as follows (**Table 3**):

- **University of Missouri-Kansas City** (UMKC)**:** the laboratory of Dr. Deborah O'Bannon analyzed samples for pH, turbidity, total suspended solids, nutrients, and/or fecal coliform.
- **University of Alabama** (UA)**:** the laboratory of Dr. Robert Pitt analyzed samples for total suspended solids, suspended solids concentration, and particle size distribution.
- **Region 7 EPA** (Region 7 Lab)**:** the laboratory of Gary Welker analyzed samples for nutrients and/or metals.

All samples were flow-weighted composites, processed by UMKC including combing bottles from ISCO samplers, creating sub-samples for individual laboratories using cone filter, filtering, preservation, and shipping. In some cases, limited sample volume was available, and not constituents could be analyzed. In this case, the order of priority was generally from the top row to the bottom row in **Table 3**.

Figure 8. Locations of Individual GI Solutions Monitored during the ADC Project

Table 3. Laboratory Analyses for Monitoring of Small-Scale GI Solutions[1]

Pollutant Class	Analyte	Lab	Unfiltered Samples	Filtered Samples
General	pH	UMKC	√	
	Turbidity	UMKC	√	
Bacteria	Fecal coliform	UMKC	√	
Nutrients	Total nitrogen	R7	√	
	Nitrate	UMKC	√	
	Total phosphorous	R7	√	
	Phosphate	UMKC	√	
Metals	Copper	R7	√	√
	Zinc	R7	√	√
	Lead	R7	√	√
Solids	TSS	UMKC & UA	√	
	SSC	UA	√	
	Particle size distribution	UA	√	

1 – If sample volume was limited (less than 4-liters), then the order of priority was generally from top to bottom row.

Only receives flows from W along E 76th St (from driveway up)

No underdrain.

Figure 9. Pictures from Individual GI Solution #1 at 1324 East 76th Street (Curb Extension)

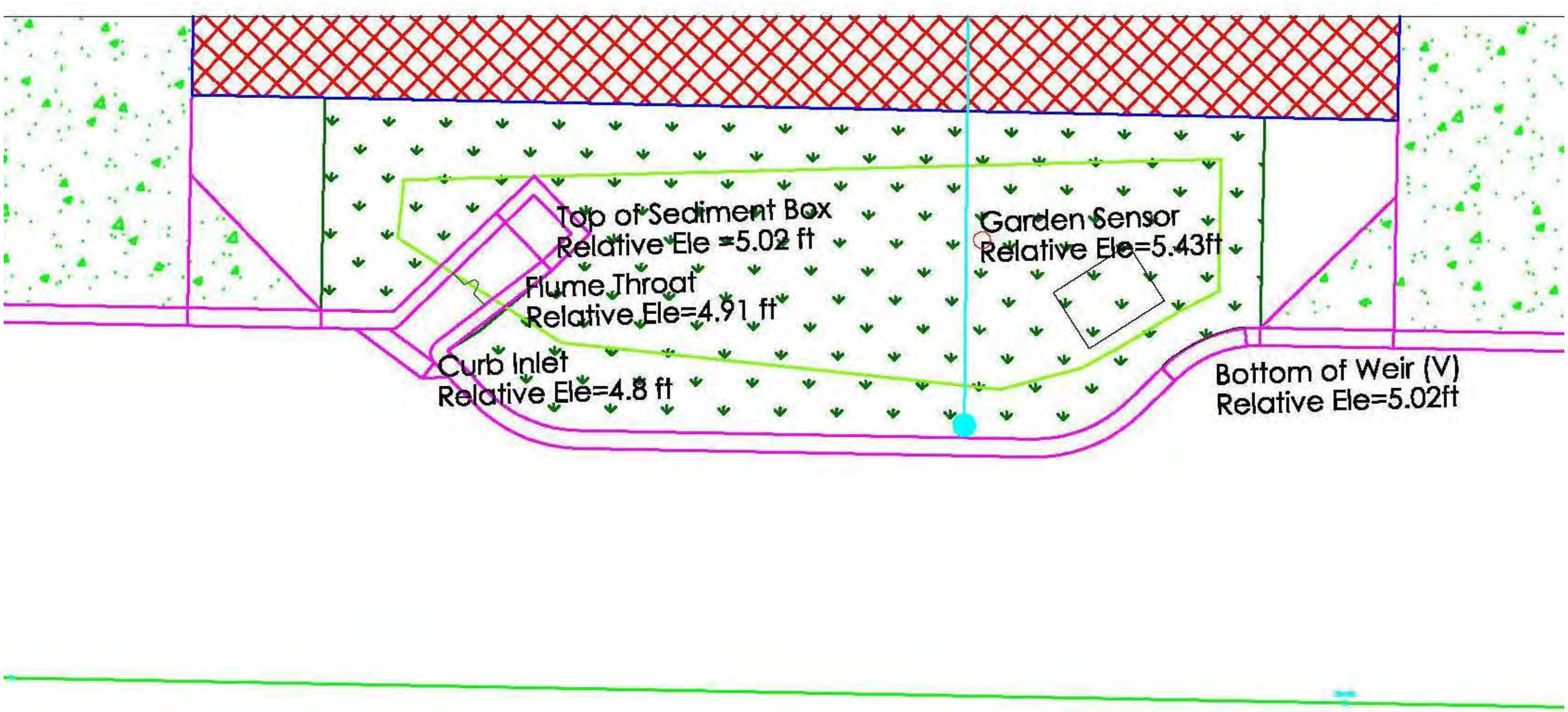


Figure 10. As-built Schematic of Monitoring Installation at Individual GI Solution #1 at 1324 East 76th Street (Curb Extension)

Drains from street centerline to far side of sidewalk to centerline of Troost

Looking upgradient towards Troost (most of lawns and homes slope south away from this location)

2 samples from small rain in morning of Oct 25, 2012

Figure 11. Pictures from Individual GI Solution #2 at 1325 East 76th Street (Curb Extension)

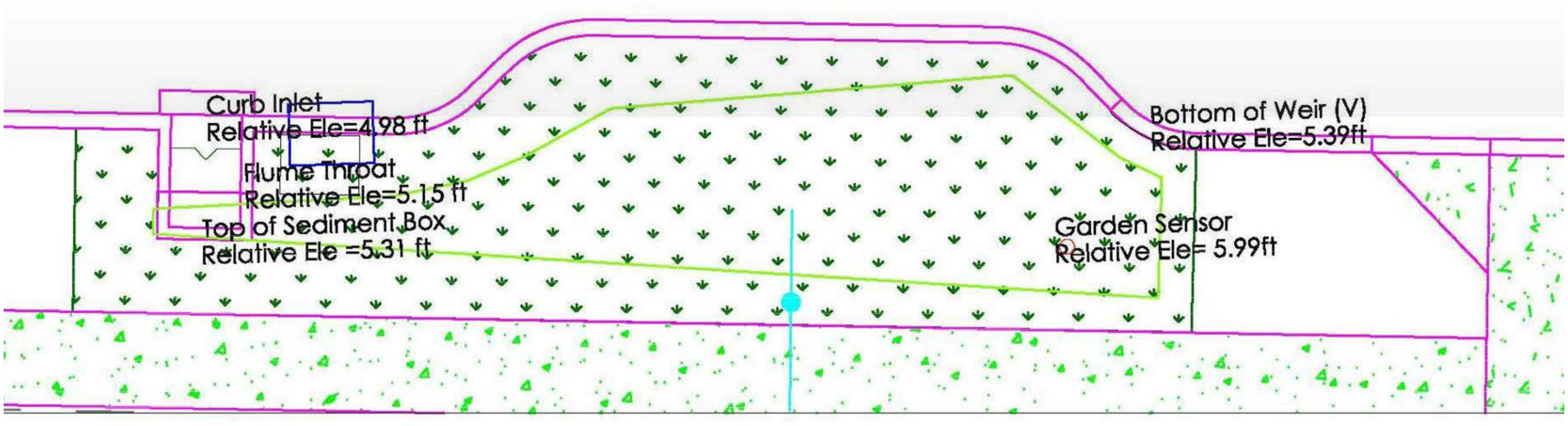


Figure 12. As-built Schematic of Monitoring Installation at Individual GI Solution #2 at 1325 East 76th Street (Curb Extension)

Figure 13. Pictures from Individual GI Solution #3 at 1419 East 76th Street (Curb Extension)

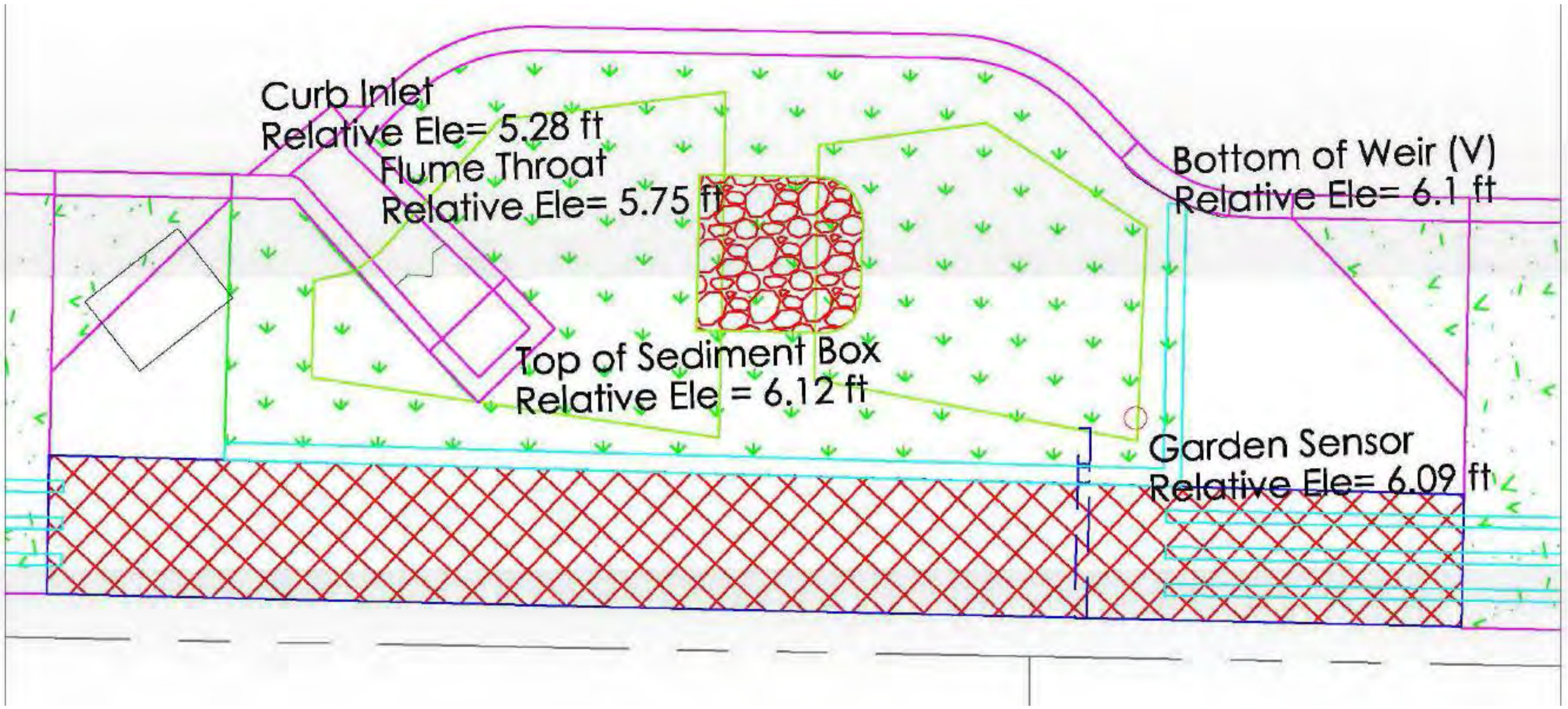


Figure 14. As-built Schematic for Monitoring Installation for Individual GI Solution #3 at 1419 East 76th Street (Curb Extension)

No samplers but two level recorders (inlet and bottom of garden) towards East (upgradient)

Towards West (also upgradient) (treated wood pole in rain garden)

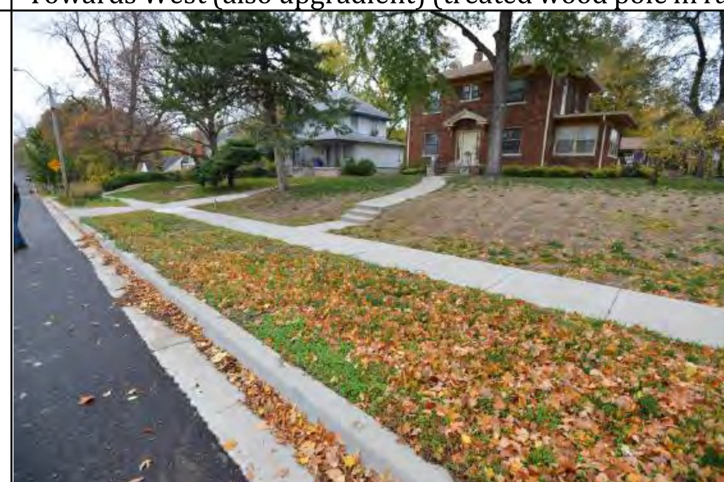


Figure 15. Pictures from Individual GI Solution #4 at 1612 East 76th Street (Rain Garden Extension)

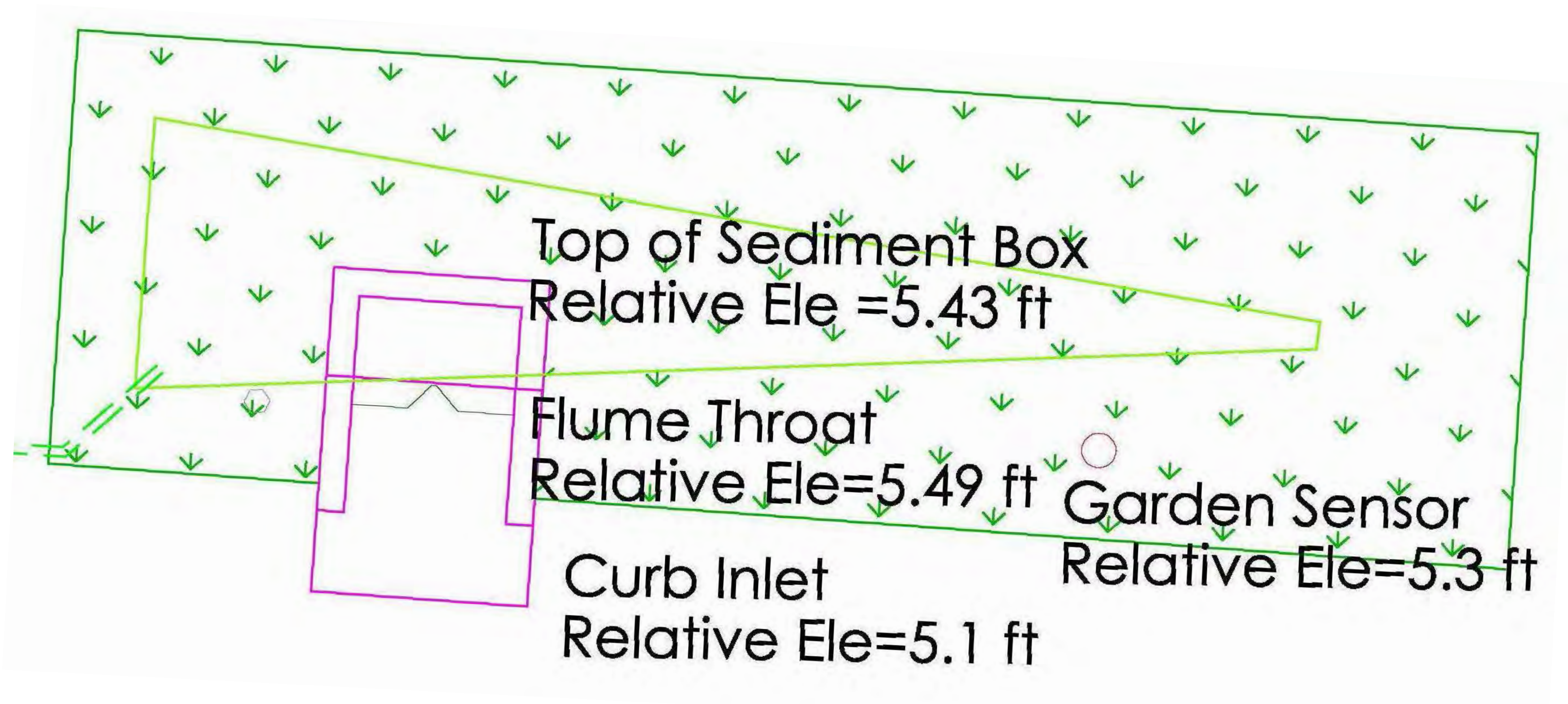


Figure 16. As-built Schematic For Monitoring Installation at Individual GI Solution #4 at 1612 East 76th Street (Rain Garden Extension)


No samplers, 2 level recorders (inlet and bottom of rain garden)


Upgradient from rain garden

Figure 17. Pictures from Individual GI Solution #5 at 1336 East 76th Street (Rain Garden Extension)

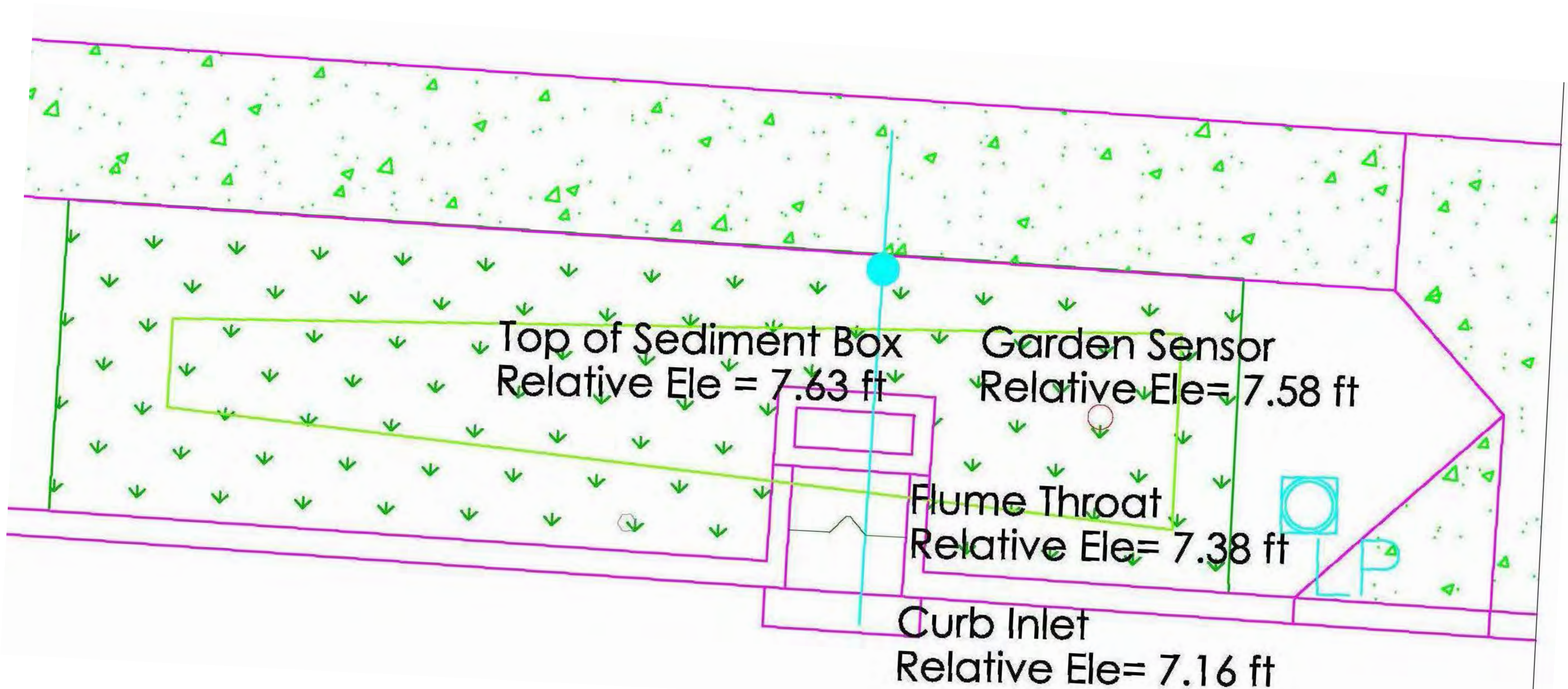


Figure 18. As-built Schematic for Monitoring Installation at Individual GI Solution #5 at 1336 East 76th Street (Rain Garden Extension)

Towards E showing sloping driveway from rain garden; only half of street and a bit of yard to system (near top of street slope)

Very small drainage area; large inlet right below rain garden

Yard slopes away from rain garden; sidewalk to street center

Driveway slopes away from rain garden towards yard inlets

Figure 19. Pictures from Individual GI Solution #6 at 1141 East 76th Terrace (Rain Garden Extension)

AS BUILT NOT AVAILBLE

Figure 20. As-built Schematic for Monitoring Installation at Individual GI Solution #6 at 1141 East 76th Terrace (Rain Garden Extension)

2 samplers and 2 level recorders (inlet and smartdrain underdrain)

E edge of drainage area slopes from garden (no house or driveway)

Figure 21. Pictures from Individual GI Solution #7 at 1222 East 76th Terrace (Rain Garden with Smart Drain)

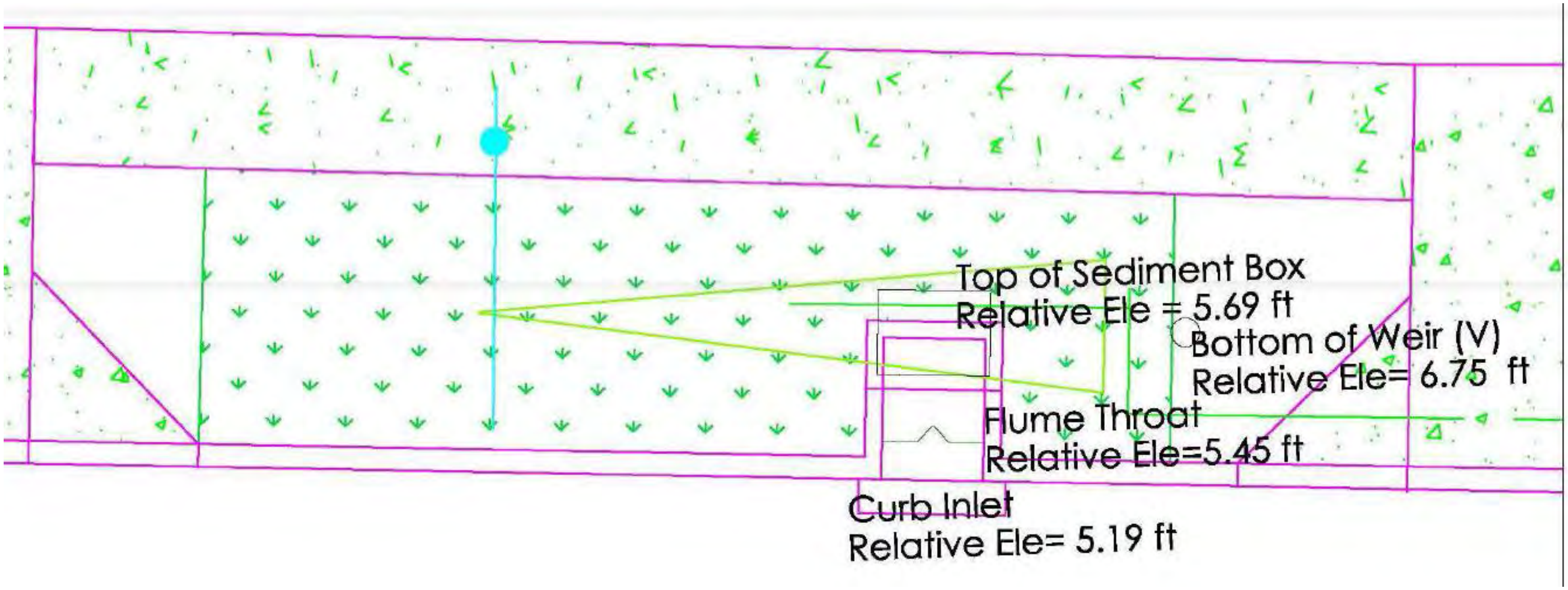


Figure 22. As-built Schematic for Monitoring Installation at I GI Solution #7 at 1222 East 76th Terrace (Rain Garden with Smart Drain)

W towards Troost and two businesses that drain to this device

Figure 23. Pictures from Individual GI Solution #8 at 1112 East 76th Terrace (Cascade Swale)

Figure 24. As-built Schematic for Monitoring Installation at Individual GI Solution #8 at 1112 East 76th Terrace (Cascade Swale)

Roof drains from half of front and half of side of home

Typical street without rain gardens

Figure 25. Pictures from Individual GI Solution #9 at 1312 East 79th Street (Mrs. Thomas Private Rain Garden)

Figure 26. Pictures from Individual GI Solution #10 at 1505 East 76th Street (Mrs. Moss Private Rain Garden)

3. Preview of Results from 2012

This section presents a preview of results based on data collected and/or compiled during 2012. Data collection will continue into 2013 and overall summary statistics, trends, and patterns are likely change by the time the final project report is generated. The final report will contain more detailed and rigorous statistical analyses.

3.1. Large-Scale Flow Monitoring

A primary goal of the large scale flow monitoring is to quantify the effectiveness of the 110 GI solutions constructed within the pilot project area. In general, the data from the four flow meter stations (**Table 1**) will support development of watershed models (e.g., WinSLAMM, SUSTAIN, and/or SWMM models). WinSLAMM modeling is described in the accompanying model report (EPA ORD, 2012) and SUSTAIN or SWMM modeling will be presented in the final report.

During the 2012 performance period, data from the four large-scale flow meters were compiled and analyzed. Analyses consisted of two primary efforts:

1. Hydrograph separation for storm events that occurred from November 2008 thru July 2012.

2. Regression analyses to patch missing water level from UMKC01 between November 2011 and September 2012

These efforts are described in the following sub-sections.

3.1.1. Hydrograph Separation

A total of 186 storm events were identified between November 2008 and July 2012. Time series analyses were used to identify these storm events and characterize storm event hydrographs. Storm hydrograph separation was performed whereby pipe-flow recorded in the time-step prior to a rainfall event was set as the base flow condition (**Figure 27**). If the flow rate dropped below the initial base flow level, the base flow rate was reset to that lower value. In addition, contemporaneous rainfall data were analyzed and associated with each storm event. For rainfall analyses, data from the ADC rainfall gage were used and, when necessary, nearby precipitation gages (5110, 5030, 5050, and 5100) where used to patch missing intervals in the ADC precipitation time series record. Storm intervals were established according to KCWSD storm criteria of 12-hour inter-event time and rainfall total >= 0.1 inches.

The distributions of rainfall events and wet weather flows for storm events between November 2008 and July 2012 are shown in **Figure 28** and **Figure 29**, respectively. Storm events with flow data available for all four large-scale flow meters are shown. If any of the four gages had a data gap during a storm event, the storm is not shown. A total of 103 storm events had data for all four flow meters. These events represent the dataset for the pre- and inter-project period, from before construction to project completion. The post-project data will be evaluated and compared to the pre-project period dataset in the final report. A preliminary analysis of the pilot project area versus the control area is presented Talebi 2014.

The median rainfall total for the 103 storm events that had available from all four flow meters was 0.4 inches, with the maximum rainfall total being 3.5-inches. The median rainfall intensity for events that had available from all four flow meters 1 inch per hour, with the maximum rainfall intensity being 4.5-inches per hour (**Figure 28**). The distribution curves for total volume and peak discharge rate are similar for the MBRGS pilot project area and control area, with the exception being the extreme decitiles (10th and 90th percentile values)(**Figure 29**). The similarity among stormwater volumes and flow rates is expected considering the pilot project and control areas have similar drainage areas (100 and 87 acres, respectively) and land uses.

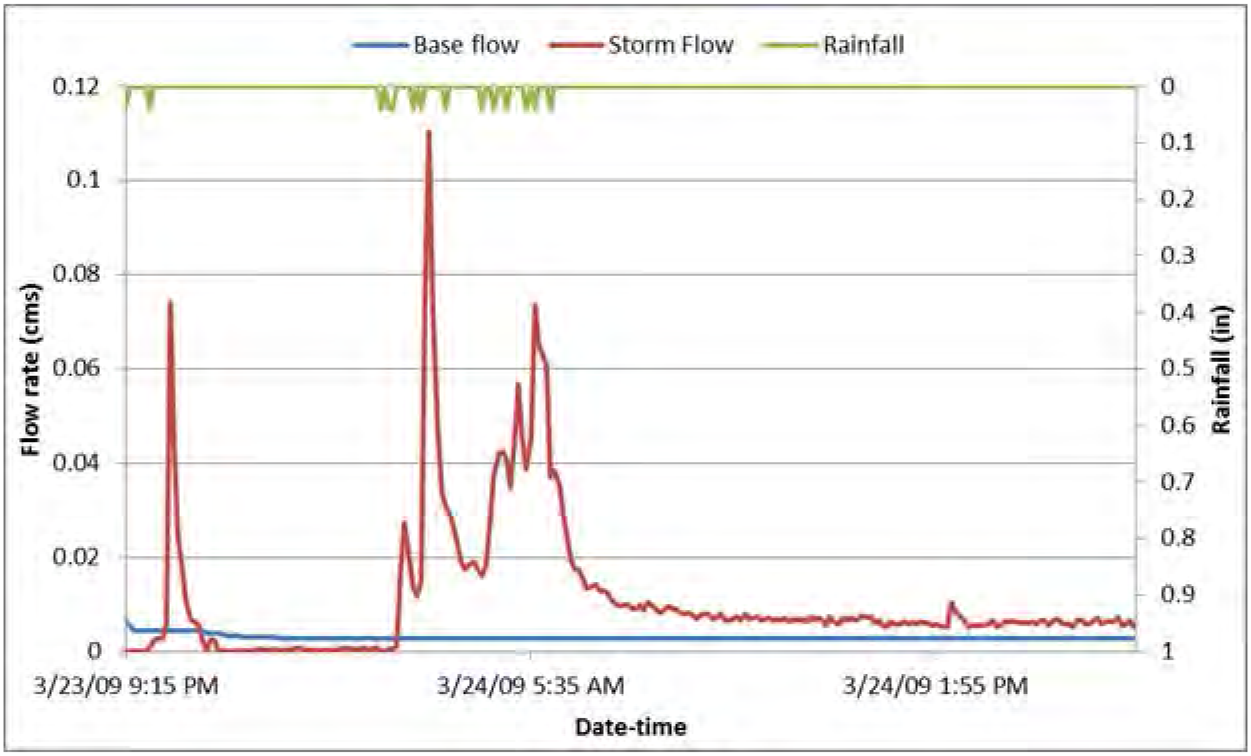
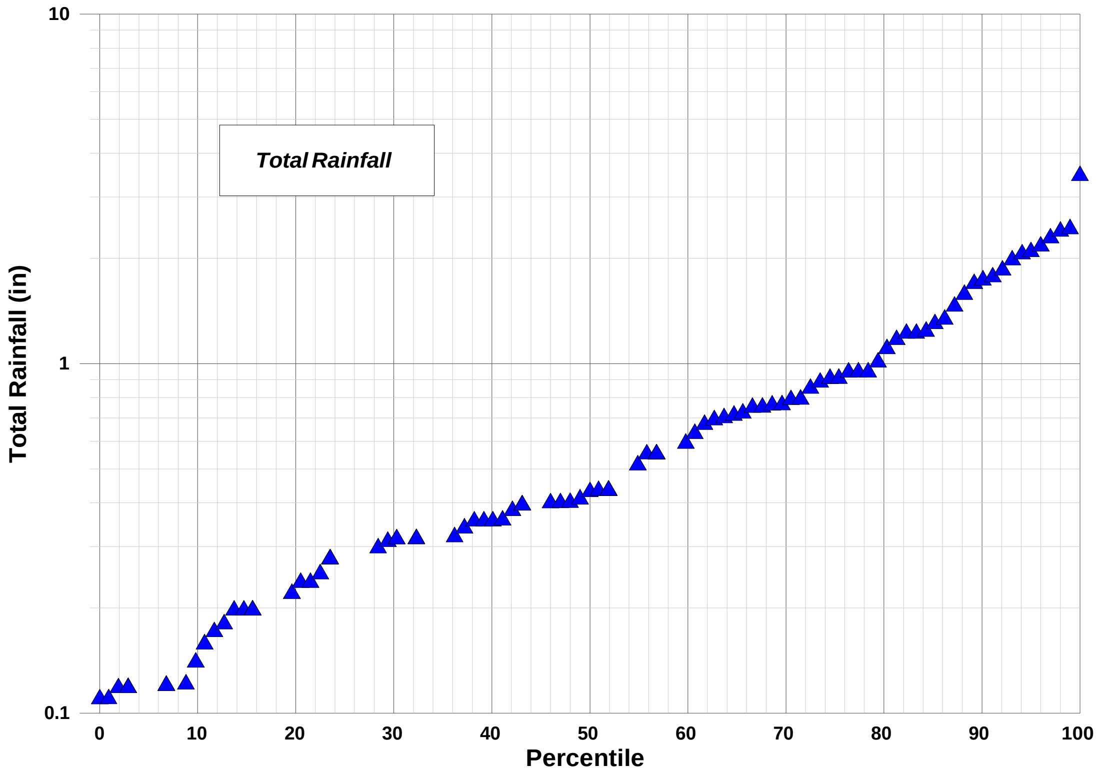


Figure 27. Example Hydrograph Separation for a UMKC01 Storm Event



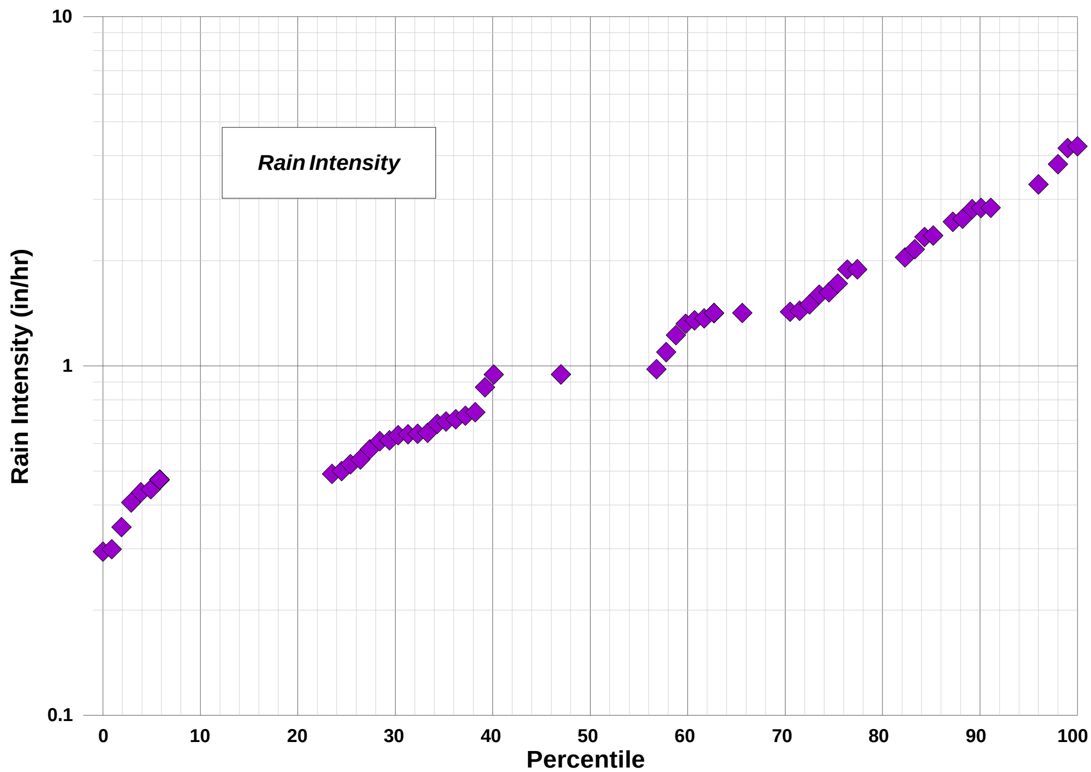
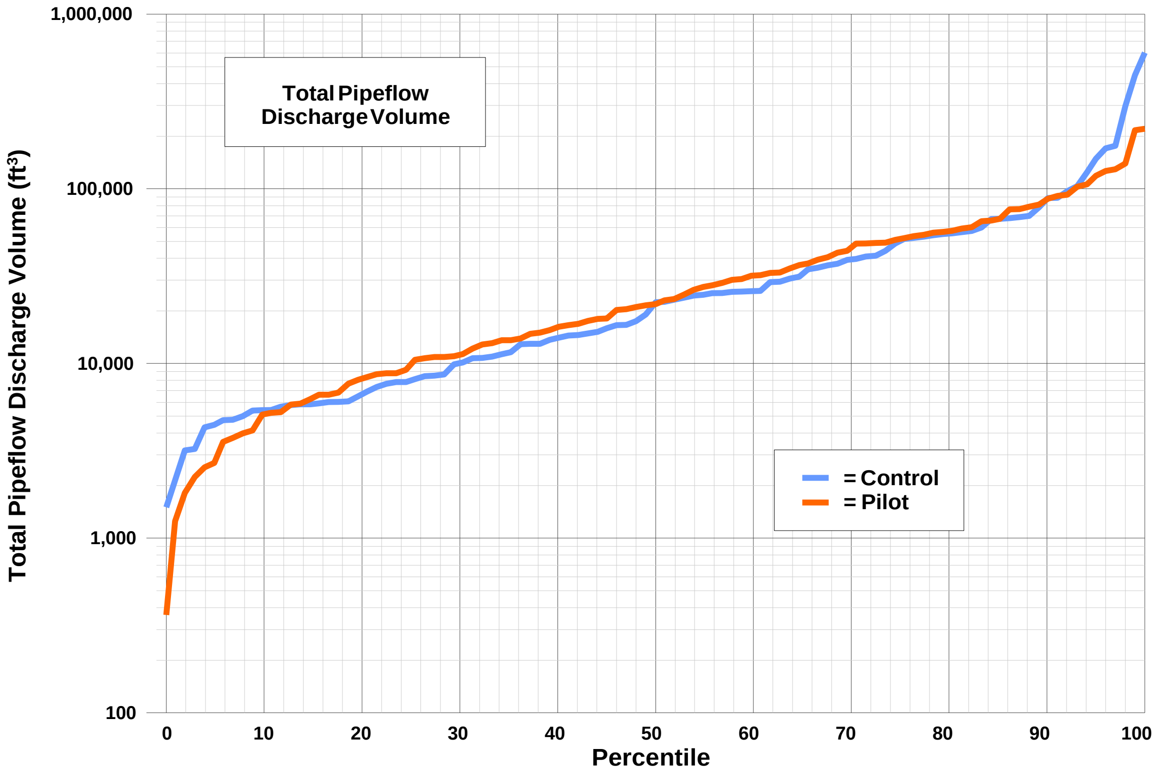


Figure 28. Total Rainfall Depth (top) and Peak 5-minute Rainfall Intensity (bottom) at the ADC Rainfall Gage during 2008 to 2011 Storm Events with Data from All Four Flow Meters



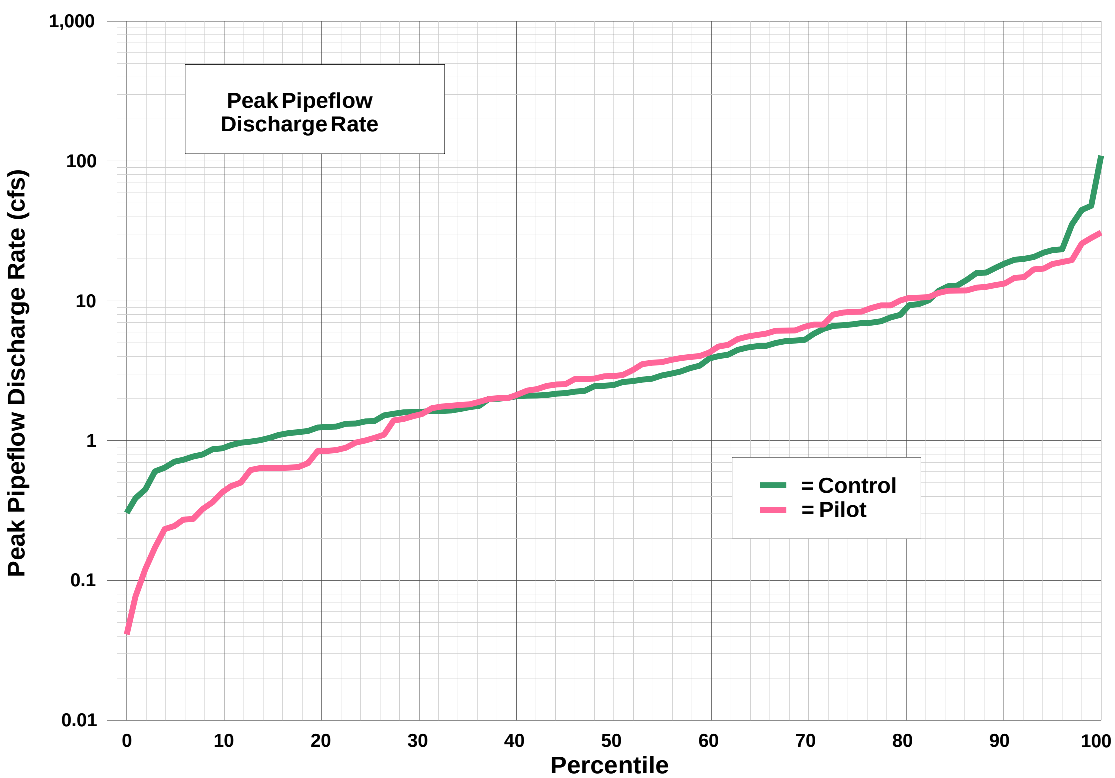


Figure 29. Total Storm Volume (top) and Peak Discharge Rate (bottom) for Wet Weather Flows from the Pilot Project Area Area Control Area during 2008 to 2011 Storm Events with Data from All Four Flow Meters

3.1.2. Regression Analyses for Patching UMKC01 Data Patching

As described in **Section 2.2.1**, between November 2011 and September 2012 the water level sensor for the UMKC01 flow meter failed. Data prior to November 2011 were used to develop a regression between measured velocity (v) and cross sectional area (A), such that flow rate (Q) could be estimated during the data gap period according to the equation $Q = v \times A$. Regression methods were based on the following:

- Missing flow values were estimated using a regression equation developed from available paired velocity and depth values under non-surcharge conditions, where depth measurements were converted to area of section flow.

- Depth measurements were transformed into area of section flow on the basis of the monitored pipe dimensions and the empirical formula:

$$\theta - cos^{-1}\left(1 - 2\left(\frac{depth}{pipe\ diameter}\right)\right)$$

Where

$$A = \frac{pipe\ diameter^2}{4}\left(1 - (cos\theta)(sin\theta)\right)$$

The polynomial regression shown in **Figure 30**, which had an R-value of 0.83, was used to estimate flow data where only velocity data were available according to for UMKC1: $Q = v \times A$. It is noted that relationships between v, Q, and *depth* were also analyzed, but the regression between v and A had a superior goodness-of-fit.

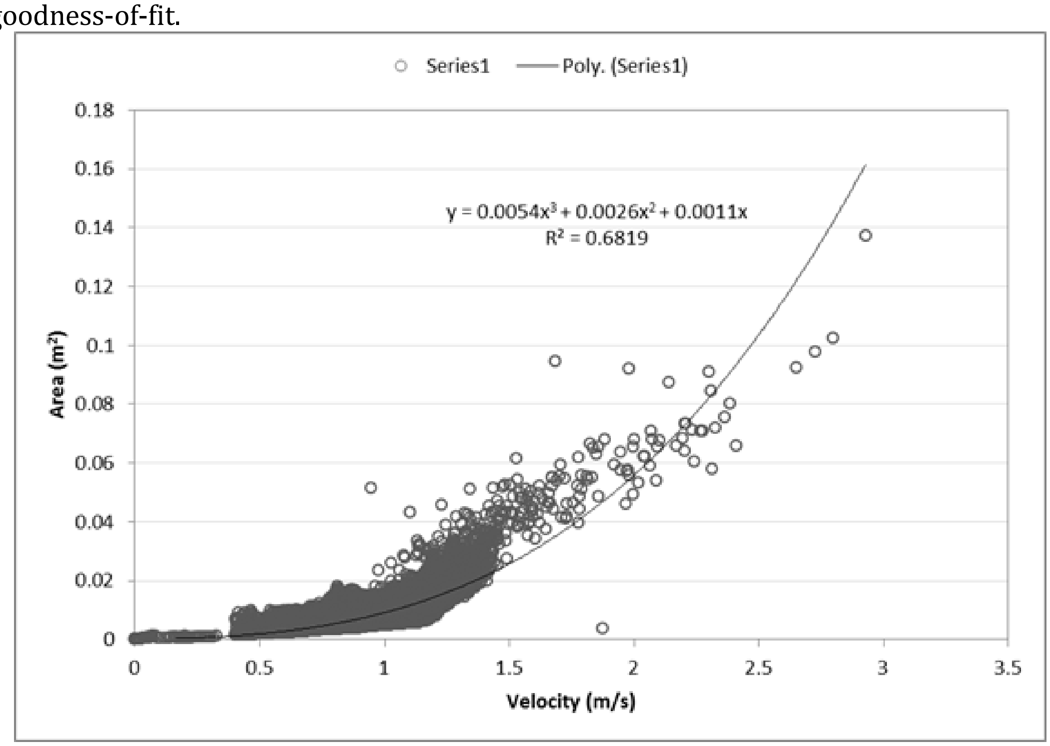


Figure 30. Cross Sectional Area (*A*) versus Flow Velocity (*v*) at UMKC01 between 2008 and 2011

3.2. Small-Scale Hydraulics and Water Quality Results

A total of 12 storm events were monitored within at least one of the individual GI solutions during the 2012 calendar year (**Table 4**). Of these 12 storms, a total of nine storms were monitored within at least one public, individual GI solution for water quality (only hydraulics data were collected for the storms that began on May 30, September 26, and December 14). Hydraulics and water quality data are presented in the following sub-sections.

Table 4. Storm Events Monitored for Hydraulics or Water Quality in Public, Individual GI Solutions

Storm Event Start Date	Total Rainfall (inches)	Individual GI Solution and Whether It was Monitored for Water Quality[1,2]							
		1	2	3	4	5	6	7	8
		Curb Extension			Rain Garden Extension			Rain Garden with Smart Drain	Cascade Swale
		1324 East 76^{th} St.	1325 East 76^{th} St.	1419 East 76^{th} Terr.	1612 East 76^{th} St.	1336 East 76^{th} St.	1141 East 76^{th} Terr.	1222 East 76^{th} St.	1222 East 76^{th} Terr.
5/30/12[a]	0.4								
6/11/12	0.8		X					X	
6/21/12	1.0	X	X	X					
7/26/12	0.5	X	X	X				X	
8/31/12	2.6		X	X[3]				X	
9/13/12	0.4		X					X[3]	
9/26/12[a]	0.2								
10/12/12	0.9	X	X	X				X	
10/17/12	??		X	X					
11/5/12	0.8			X					
11/11/12	1.5	X	X	X[3]					
12/14/12[a]	0.4								

1- During each storm event, each of the eight GI solutions was monitored for hydraulics with some exceptions.
2– For some storms/sites, the collected sample volume was limited and therefore not all constituents were analyzed.
3– Water quality sample (effluent) was also collected from the outlet structure.
a – No water quality samples were collected during this storm event, but most sites captured hydraulics data (hydraulics monitoring was continuous).

3.2.1. Hydraulics Results

For the ADC project, small-scale hydraulics data consists of flow rate measured at the inlet and outlet (if applicable) of the individual GI solutions, along with in-garden water level sensors. A total of 12 storm events were monitored for hydraulics within at least one of the public individual GI solutions during the 2012 calendar year (**Table 4)**. These hydraulics data are the foundation of all ADC analyses to quantify the performance of individual GI solutions, both in terms of volume reduction and pollutant loading reduction.

The hydraulics data collected from the eight public individual GI solutions during the 2012 calendar year are presented in **Figure 31** through **Figure 38**. For each captured storm event, water levels measured by the inlet H-flume sensors/bubblers and in-garden sensors are reported, along with estimates of total inflow volume and rainfall depth. It should be noted the water levels (units of length) from the inlet H-flumes correspond to inflow rates (units of volume per time) per standard hydraulics equations, which will be calculated and reported in the final report. Similarly, for storm events where effluent was generated through the outlet V-weirs or Smart Drain, the in-garden or in-drain water levels (units of length) correspond to outflow rates (units of volume per time), which will also be calculated and reported in the final report. Observations from the in-garden water level sensors also allow for estimates of infiltration rates (i.e., drawdown times in units of length per time), as discussed in Talebi 2014.

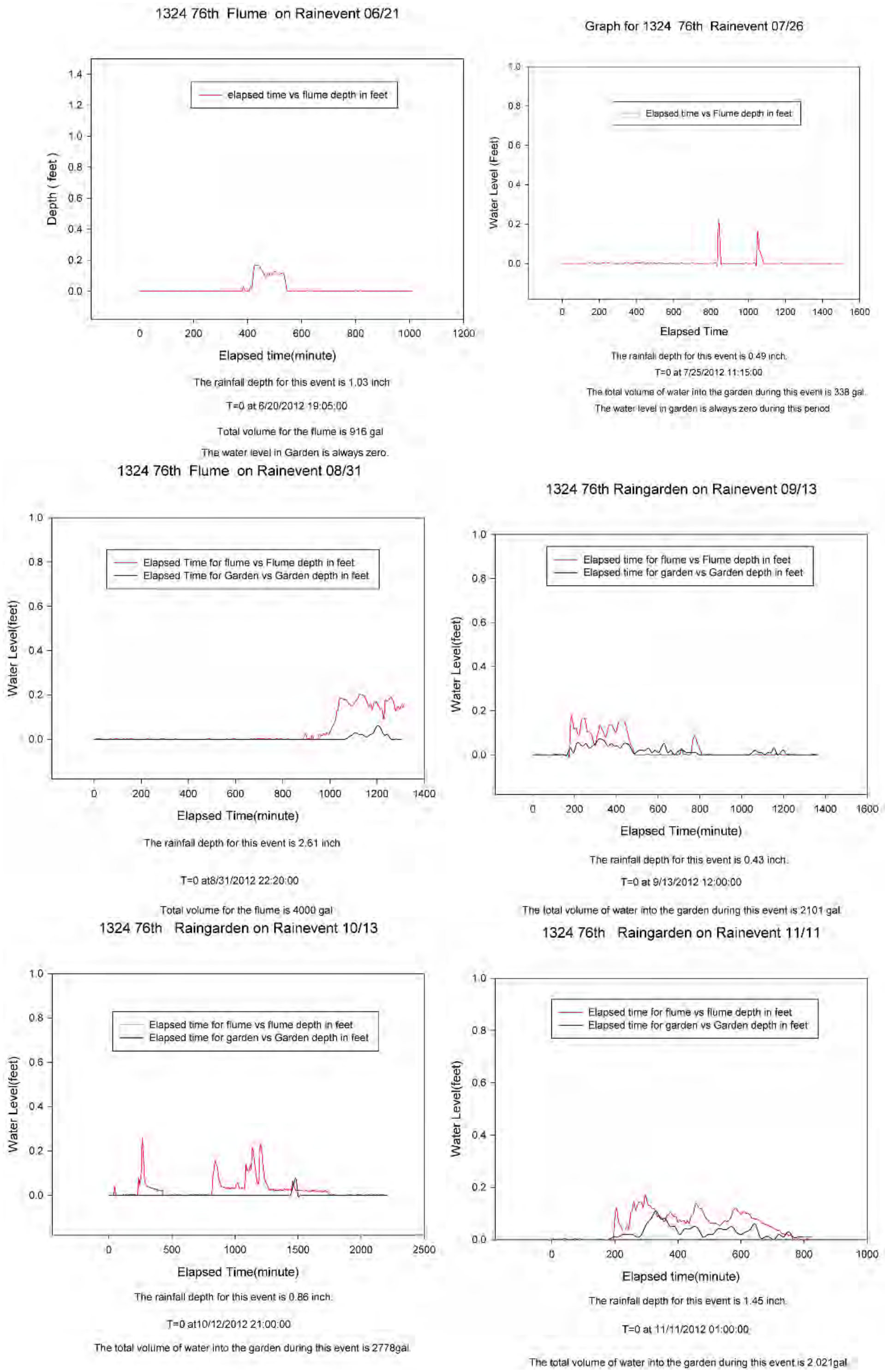


Figure 31. Storm Event Hydraulics Data for Individual GI Solution #1 at 1324 East 76th Street (Curb Extension)

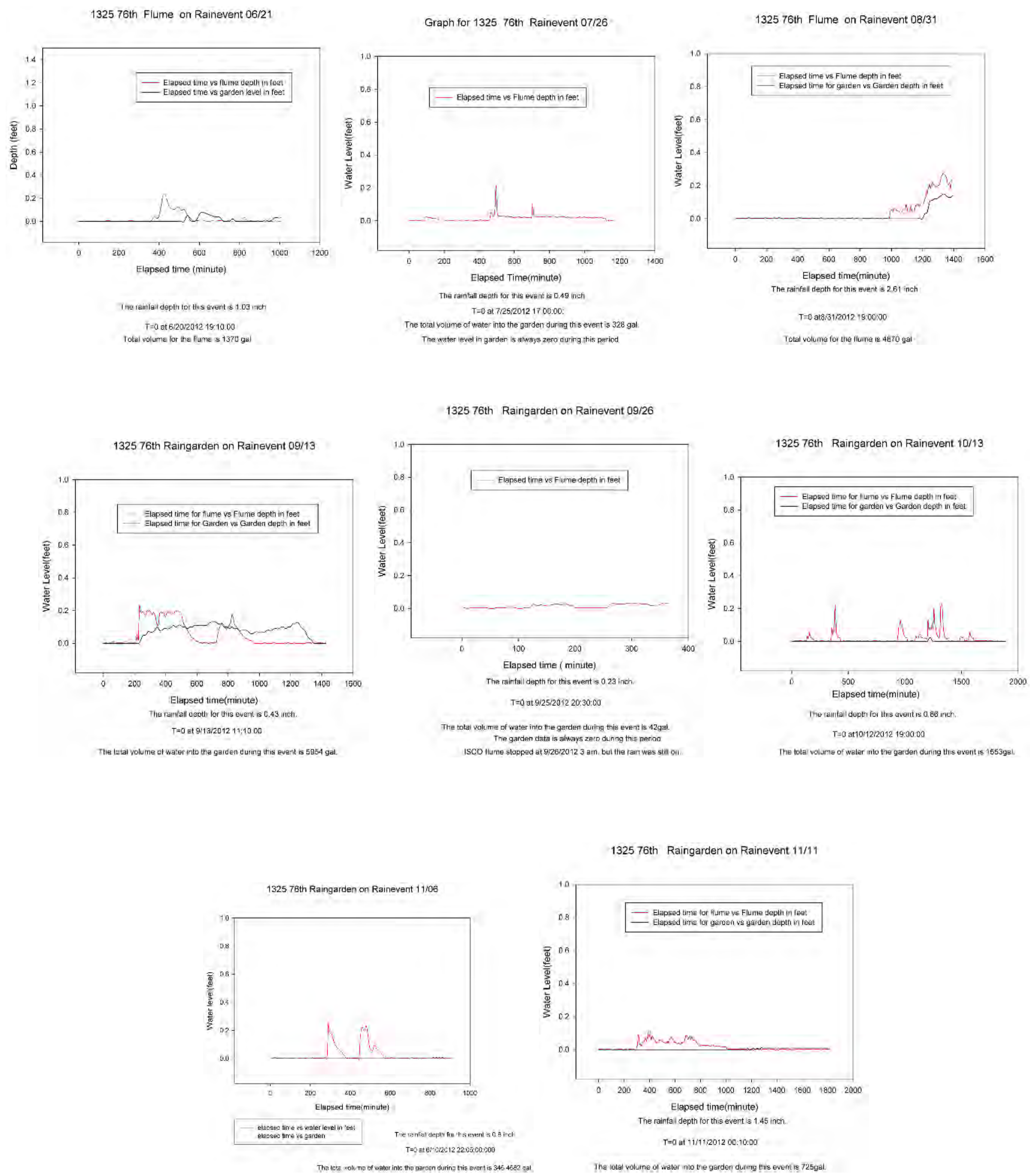


Figure 32. Storm Event Hydraulics Data for Individual GI Solution #2 at 1325 East 76th Street (Curb Extension)

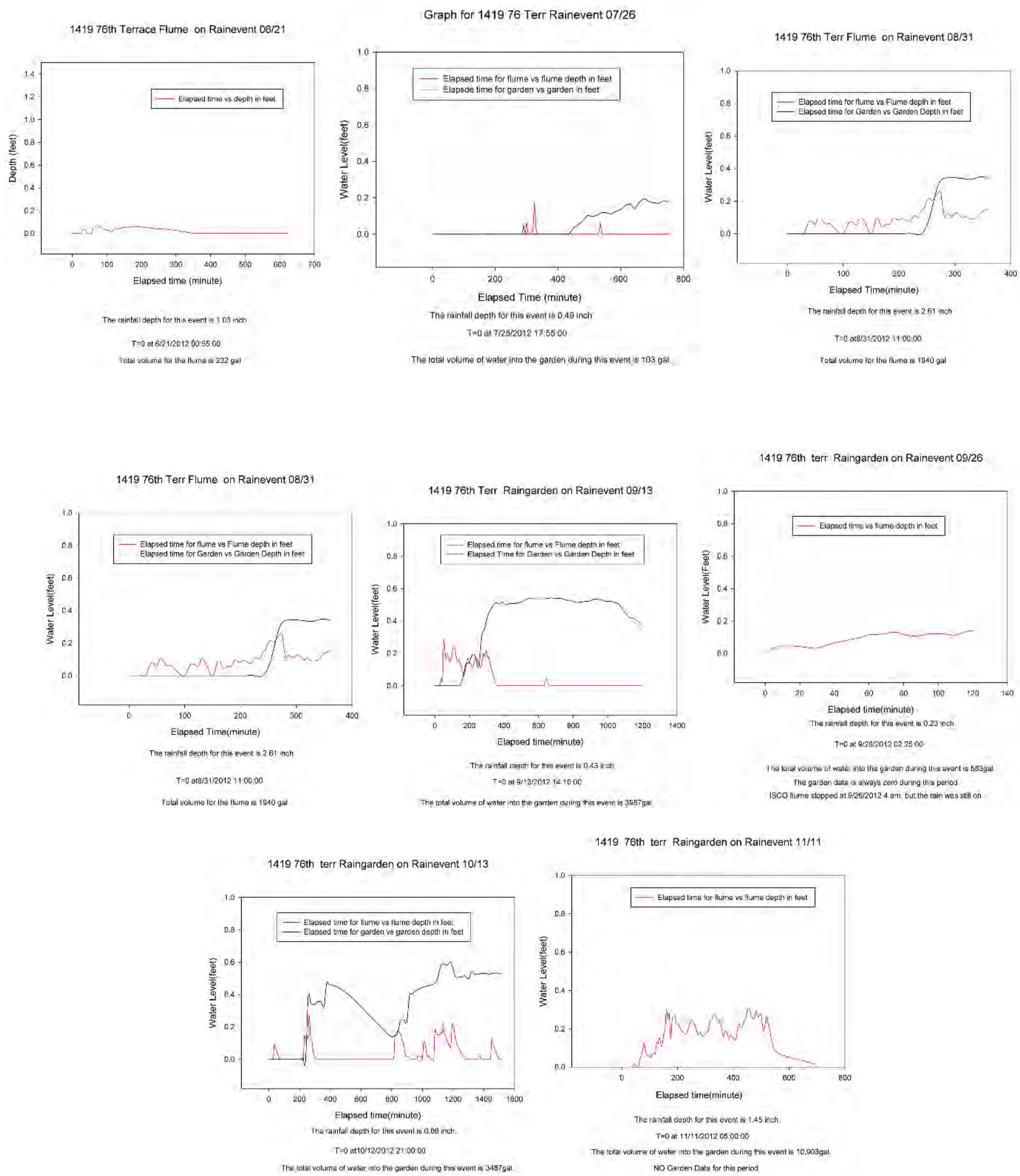


Figure 33. Storm Event Hydraulics Data for Individual GI Solution #3 at 1419 East 76th Street (Curb Extension)

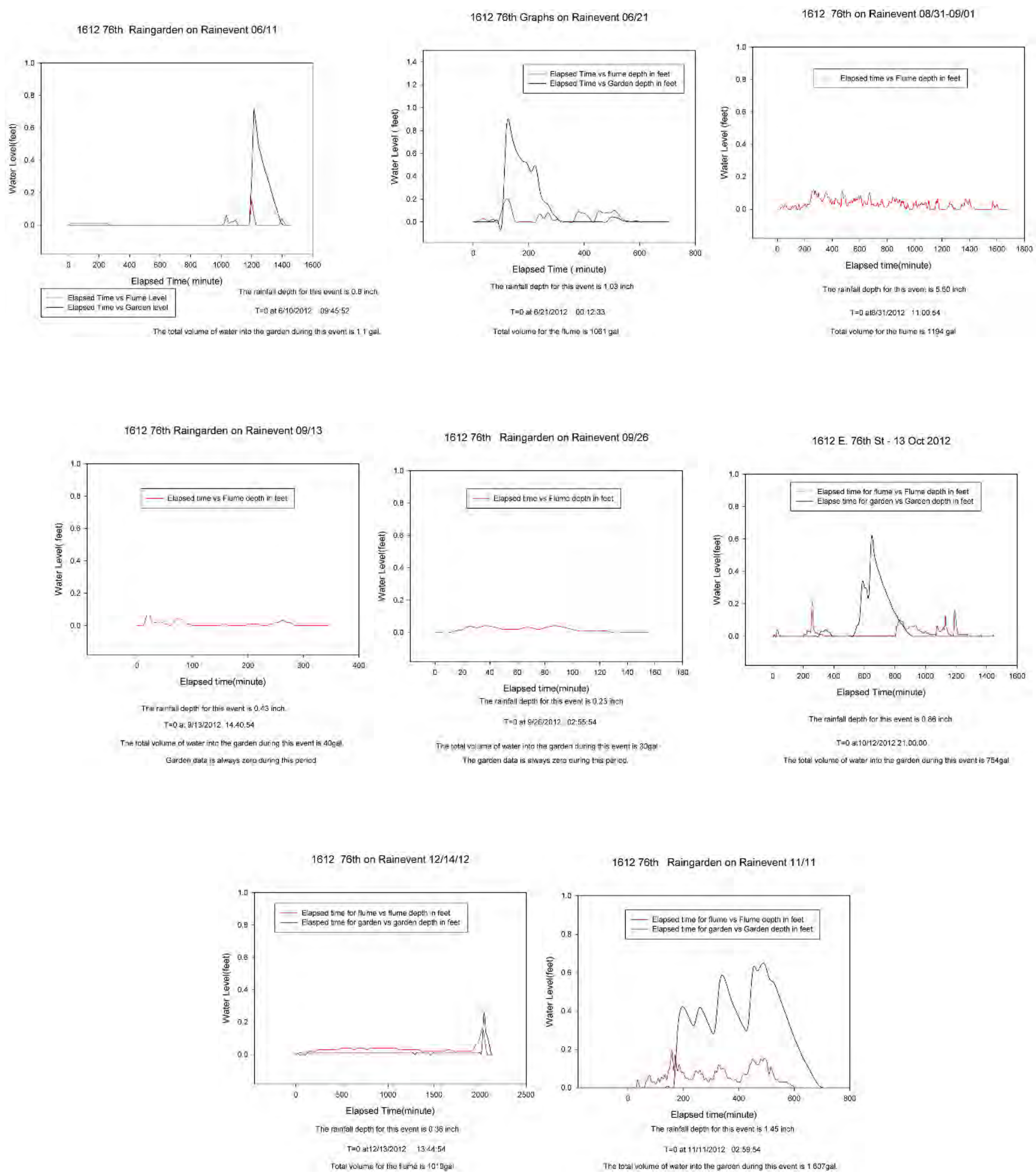


Figure 34. Storm Event Hydraulics Data for Individual GI Solution #4 at 1612 East 76th Street (Rain Garden Extension)

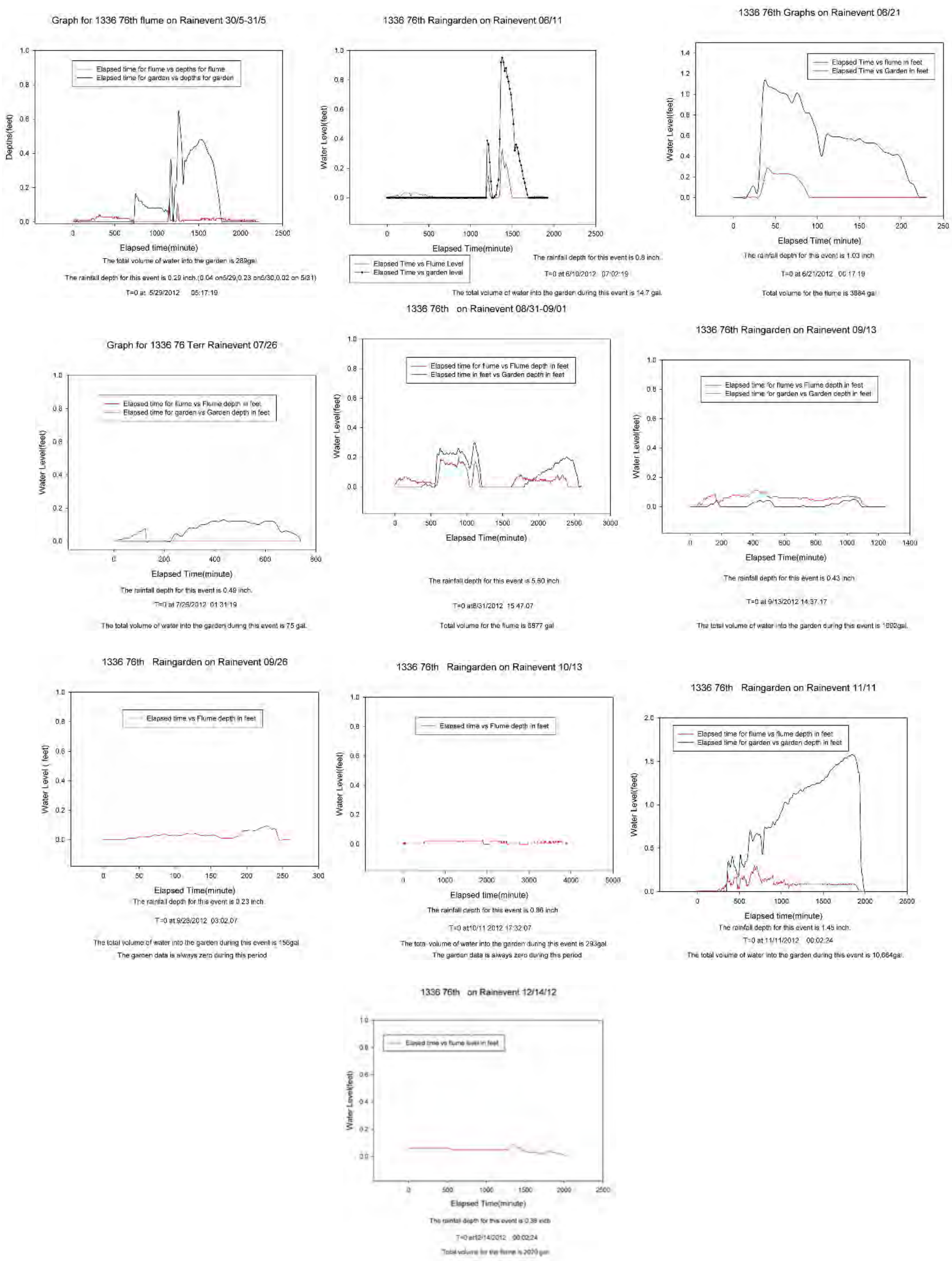


Figure 35. Storm Event Hydraulics Data for Individual GI Solution #5 at 1336 East 76th Street (Rain Garden Extension)

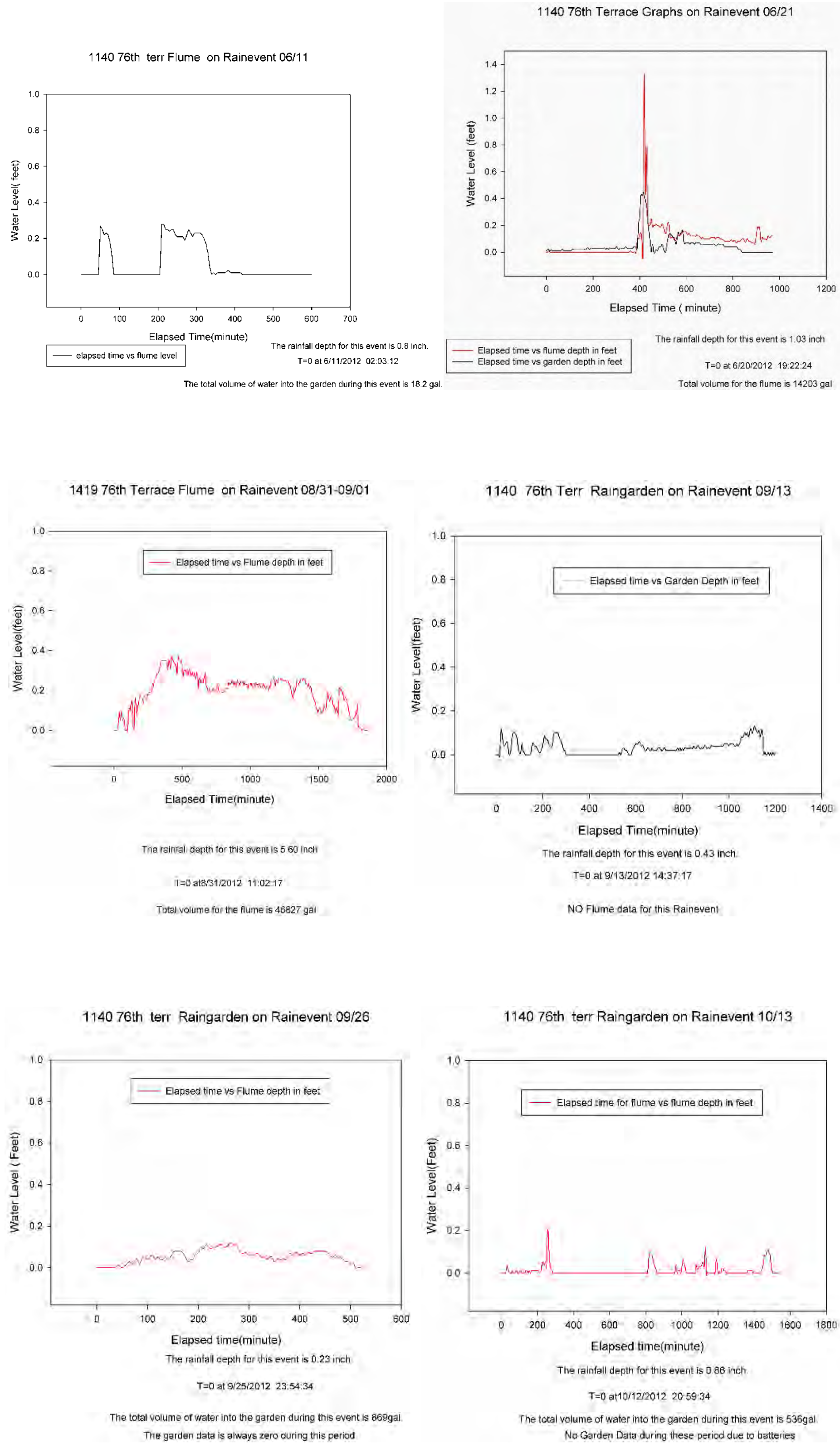


Figure 36. Storm Event Hydraulics Data for Individual GI Solution #6 at 1141 East 76th Terrace (Rain Garden Extension)

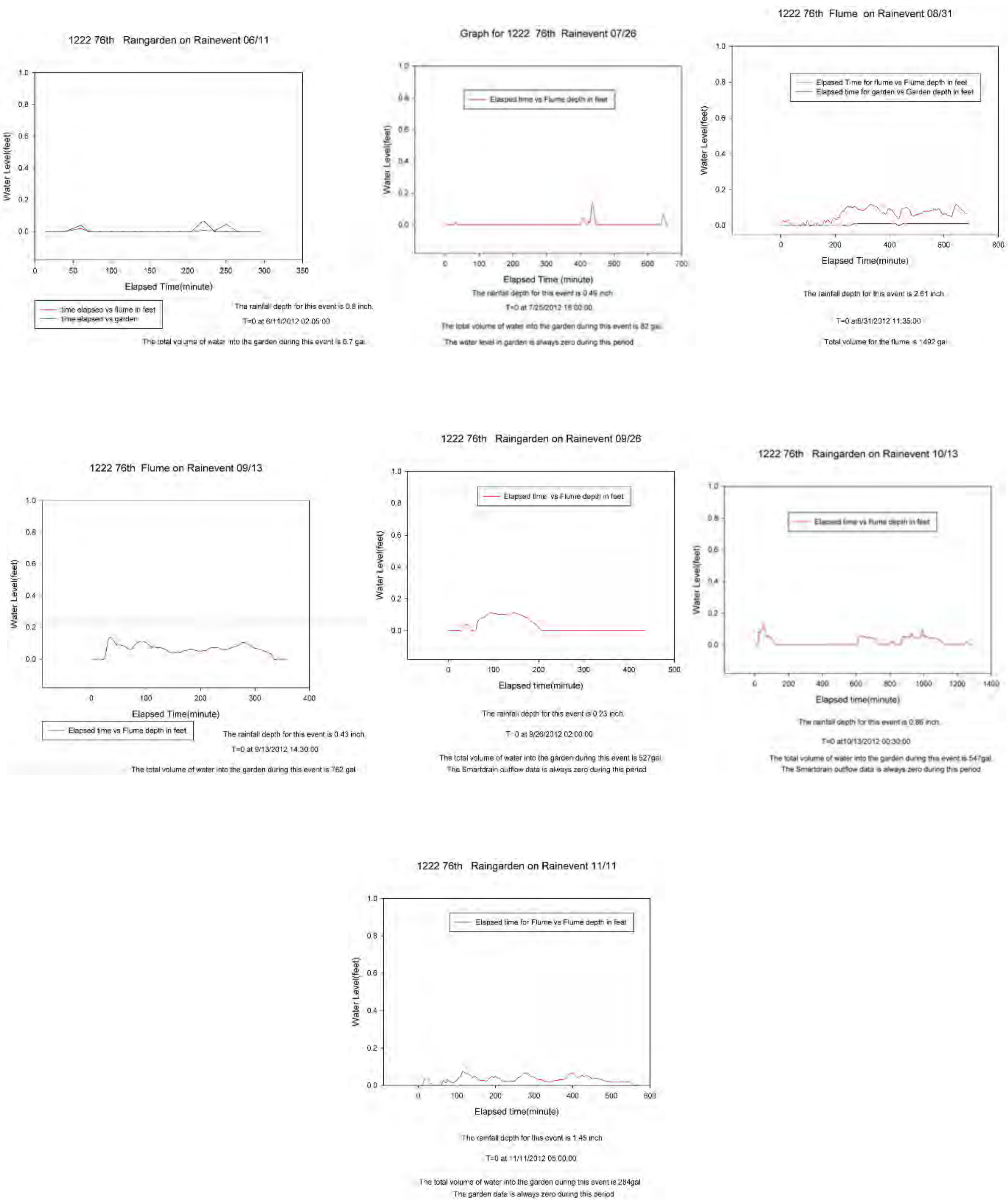


Figure 37. Storm Event Hydraulics Data for Individual GI Solution #7 at 1222 East 76th Terrace (Rain Garden with Smart Drain)

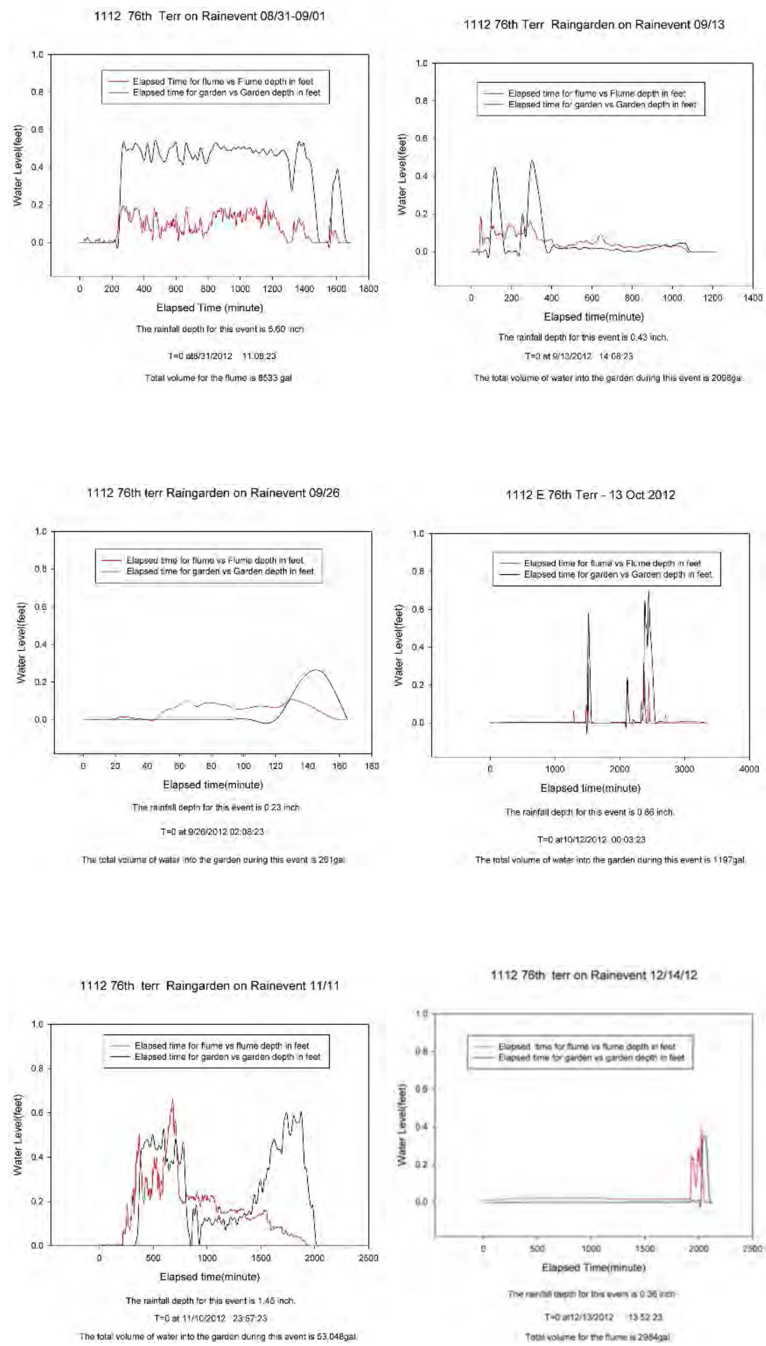


Figure 38. Storm Event Hydraulics Data for Individual GI Solution #8 at 1112 East 76th Terrace (Cascade Swale)

3.2.2. Water Quality Results

A total of 9 storms were monitored for water quality in at least one of the four GI solutions during the 2012 calendar year. Recall that four of the eight public GI solutions monitored during the ADC project have water quality monitoring installations (**Table 4**). The storms monitored for water quality ranged in total event rainfall depth from 0.4- to 2.6-inches. A total of 28 water quality samples were collected not including quality assurance/quality control samples (replicates and blanks). Of these 28 samples, only three were effluent samples collected from outlet structures (**Table 4**). The fact that such a low percentage (11%) of samples were effluent is likely due to two primary reasons: [1] the individual GI solutions were effective at retaining the wet weather flows that occurred during the monitored storms and [2] only two of the storms (August 31 and November 11) generated rainfall totals that exceeded the typical design storm size of 1-inch.

The observed concentrations of measured water quality constituents are shown graphically in **Figure 39** through **Figure 48**. Summary statistics of water quality constituents are also shown in **Table 5** through **Table 10**. Note that non-detect samples were handled as if the measured concentration was the full reporting limit. Preliminary results include the following:

- There was much overlap among sites in observed inflow concentrations, which may be expected considering the individual GI solutions are in close proximity to one another (**Figure 8**). For this reason, box plots are also shown for the "combined" dataset (all samples from all sites).
- The most striking difference among water quality measurements was influent samples (represented by boxes and whiskers) compared the effluent samples (stars). The observed concentrations of solids, nutrients, and metals solids in effluent typically fell within the lower quartile of observed concentrations for influent (i.e., stars generally align with lower whiskers of the box plots).
- TSS and SSC showed similar patterns of relative concentrations among sites.
- Fecal coliform concentrations were unexpectedly high, with concentrations often above the upper detection limit of 6 million MPN/100mL. The source of these high concentrations (whether environmental or analytical) will be investigated.
- All analyzed samples were non-detect for lead.
- Greater than 50% of measured copper was in the dissolved form in all samples tested for both dissolved and total copper (average % dissolved was 85%, ranging from 52% to 140%).
- For zinc, the median % dissolved was 44%, with two samples exhibiting % dissolved values greater 50% and two samples exhibiting % dissolved values less than 50% (average % dissolved was 44%, ranging from 18% to 71%).
- In several cases, the measured concentrations of phosphate were higher than those for total phosphorous, which is not logical. The cause of this reporting or analytical issue will be investigated.

Additional statistical analyses and comparisons of differences among sites will be performed for the final report. In addition, more robust methods for handling non-detect samples will be explored.

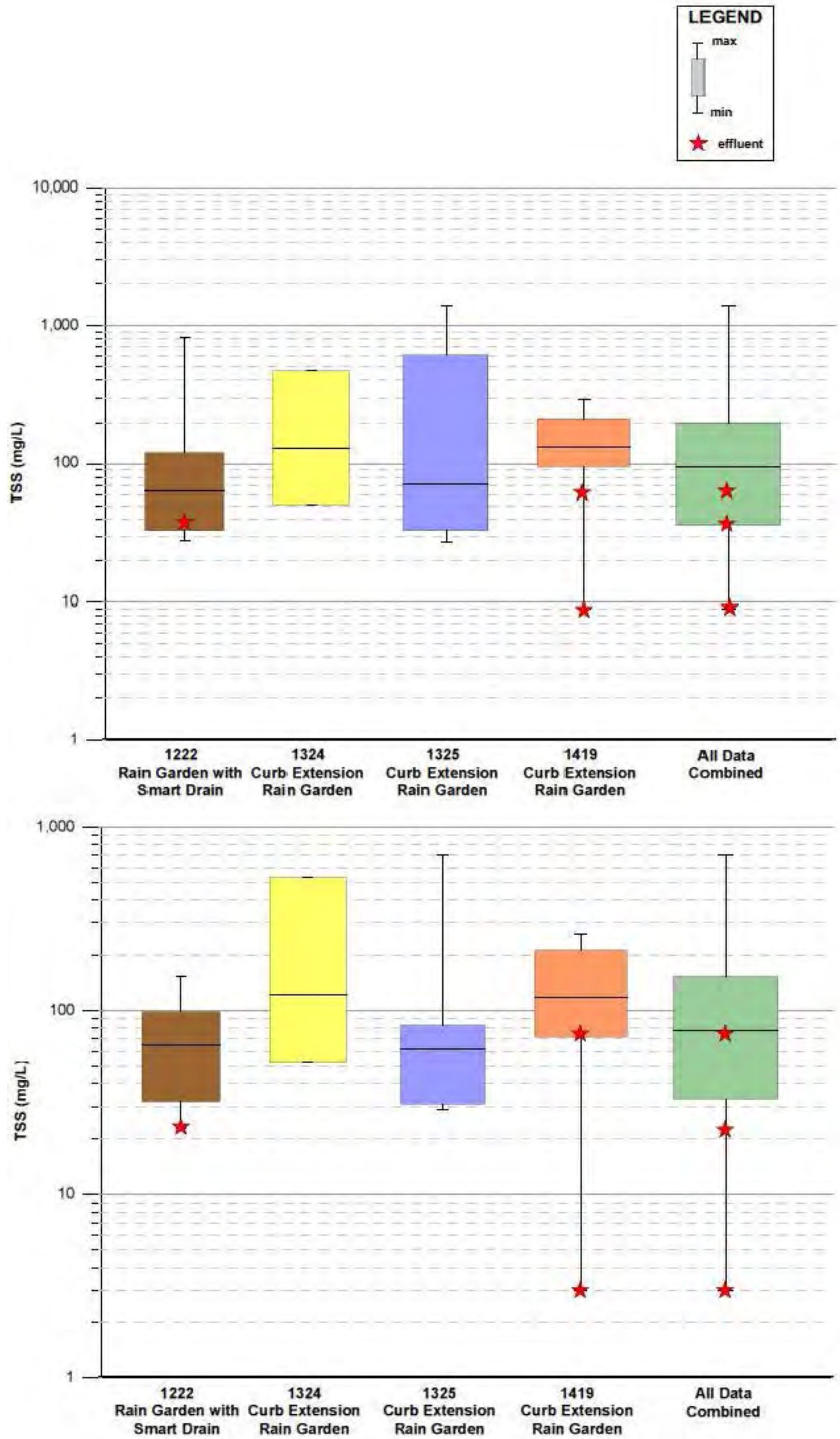


Figure 39. Measured Concentrations of TSS at Individual GI Solutions (UMKC, top; UA, bottom)

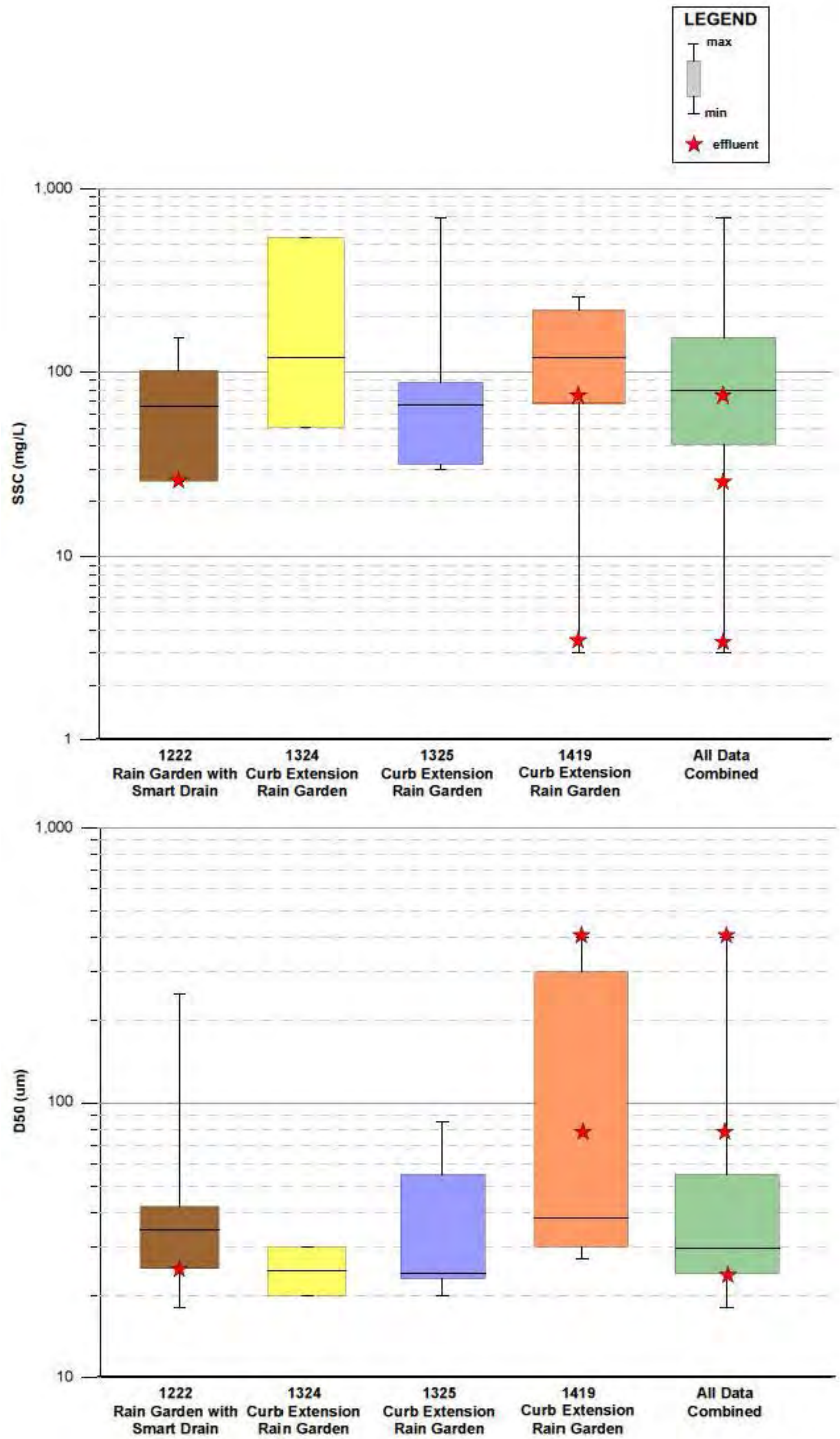


Figure 40. Measured Concentrations of SSC (top) and Median Suspended Particle Size (bottom) by UA at Individual GI Solutions

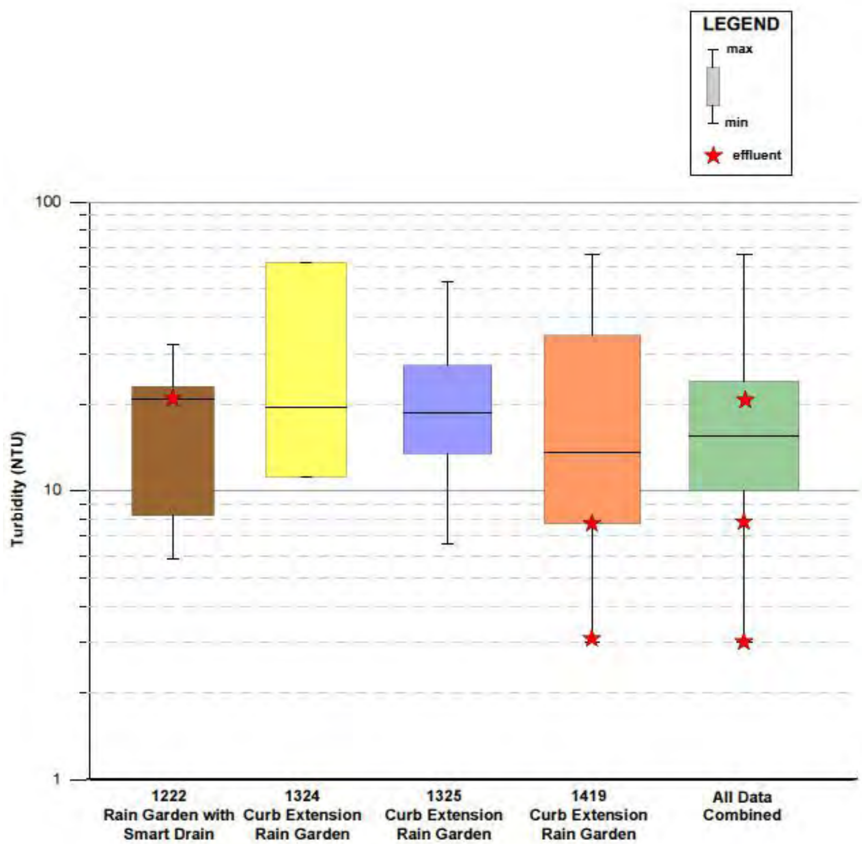


Figure 41. Measured Turbidity by UMKC at Individual GI Solutions

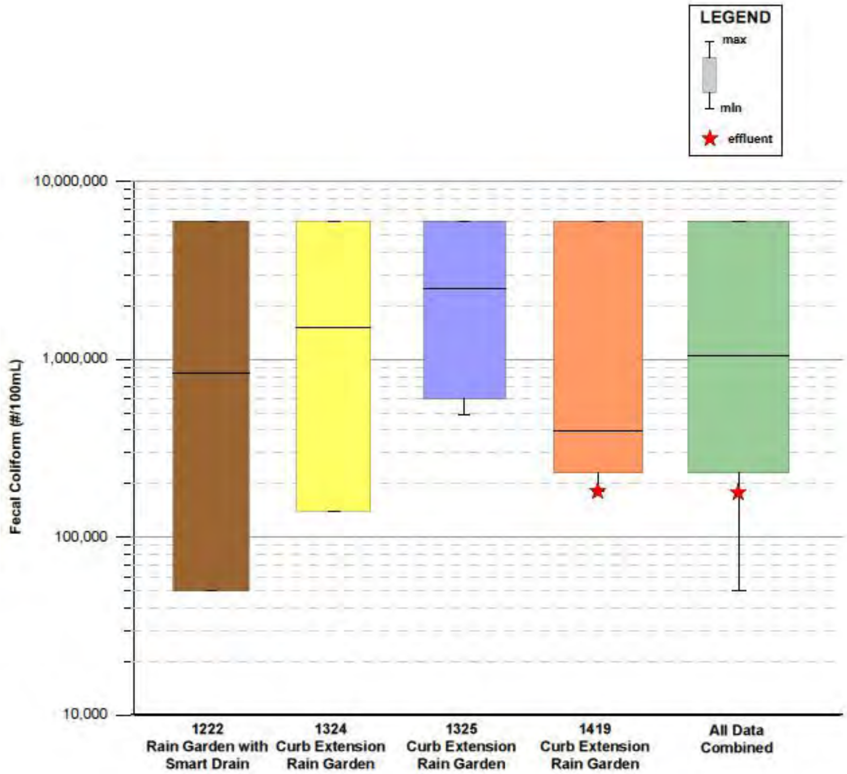


Figure 42. Measured Fecal Coliform Concentrations by UMKC at Individual GI Solutions

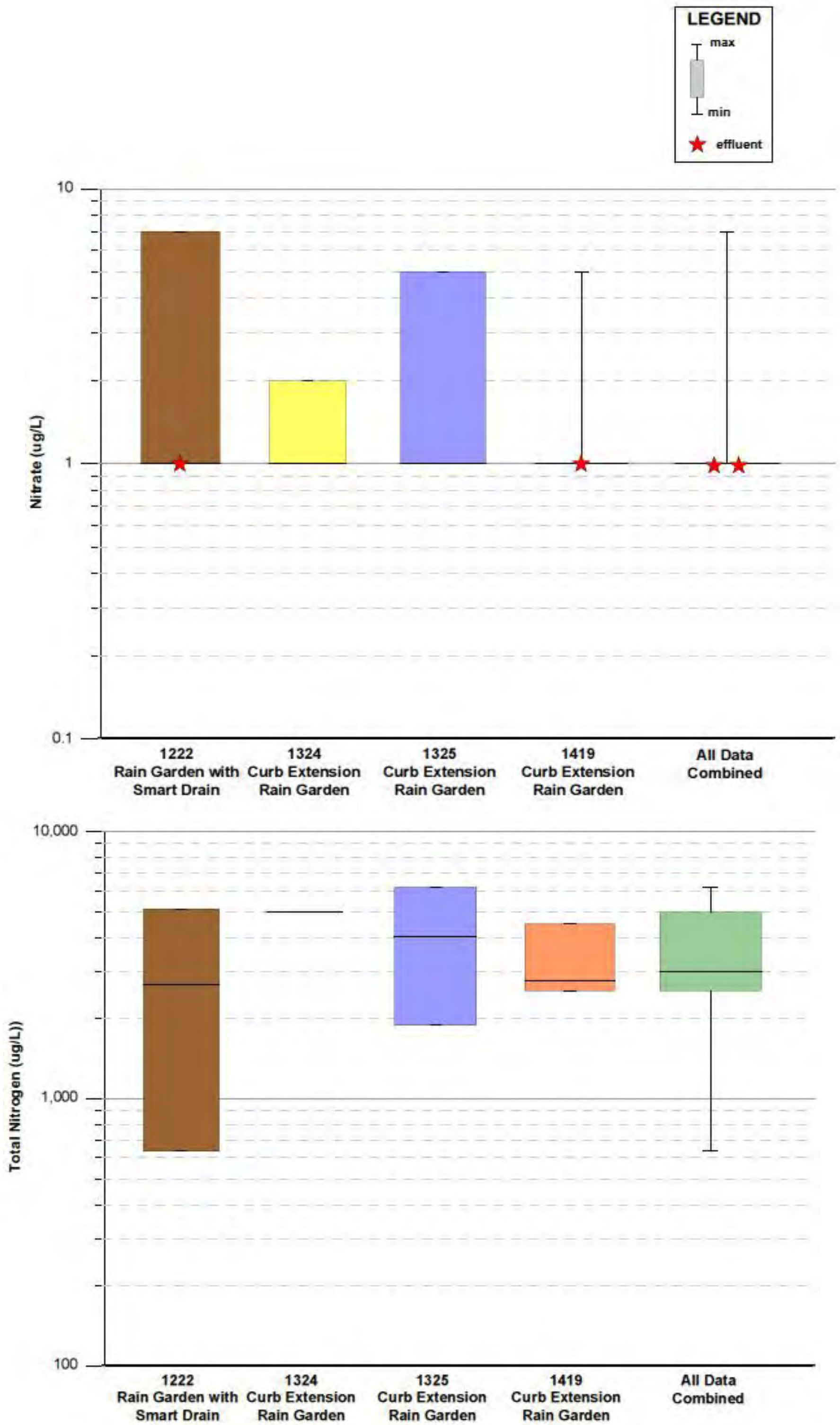


Figure 43. Measured Concentrations of Nitrate (top, UMKC) and Total Nitrogen (bottom, R7) at Individual GI Solutions

NOTE: Y-axis label for Nitrate is mg/L (not ug/L). Y-axis units for Total Nitrate will be converted to mg/L (instead of reporting as ug/L).

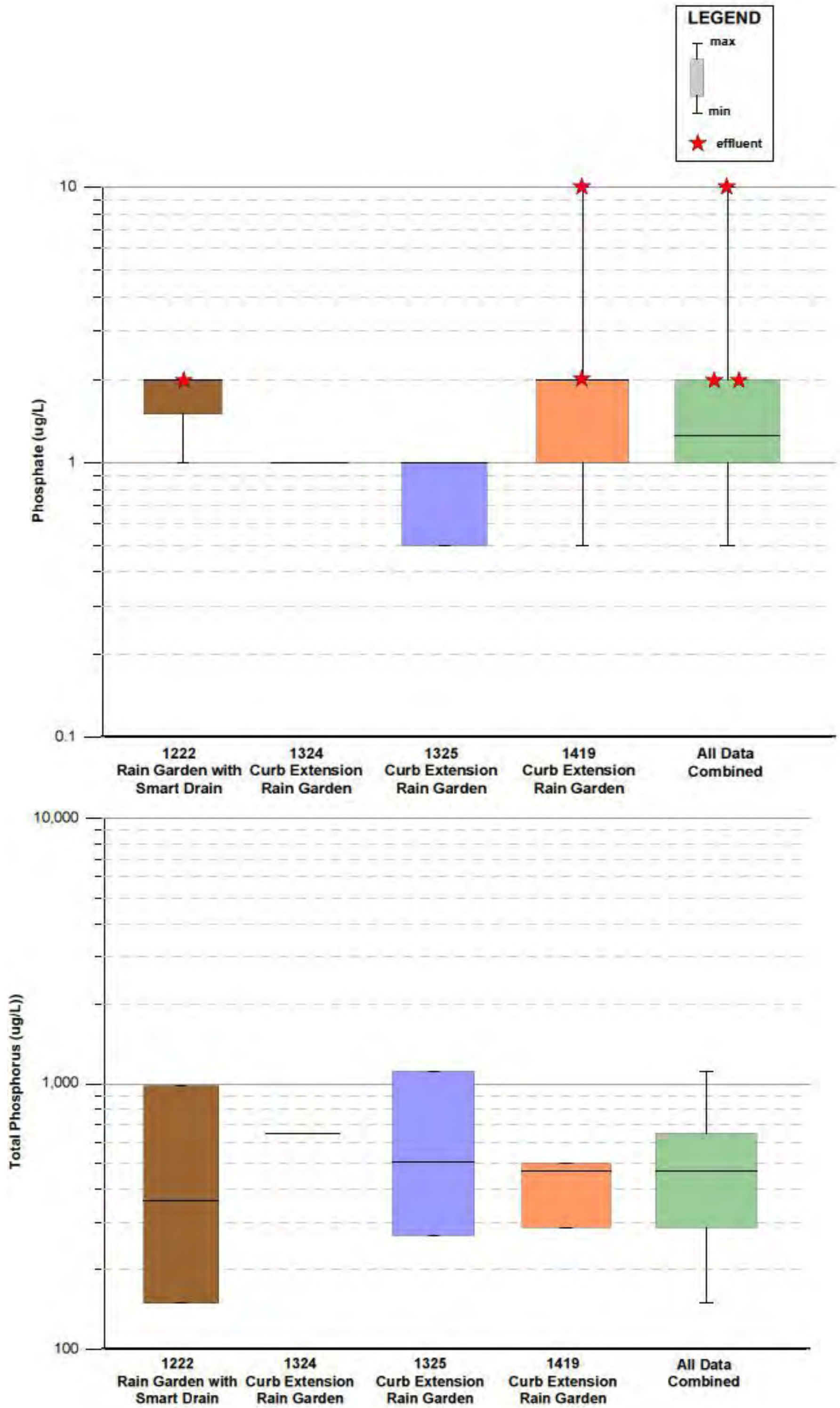


Figure 44. Concentrations of Phosphate (top, UMKC) and Total Phosphorous (bottom, R7) at Individual GI Solutions

NOTE: Y-axis label for Phosphate is mg/L (not ug/L). Y-axis units for Total Phosphorous will be converted to mg/L (instead of reporting as ug/L).

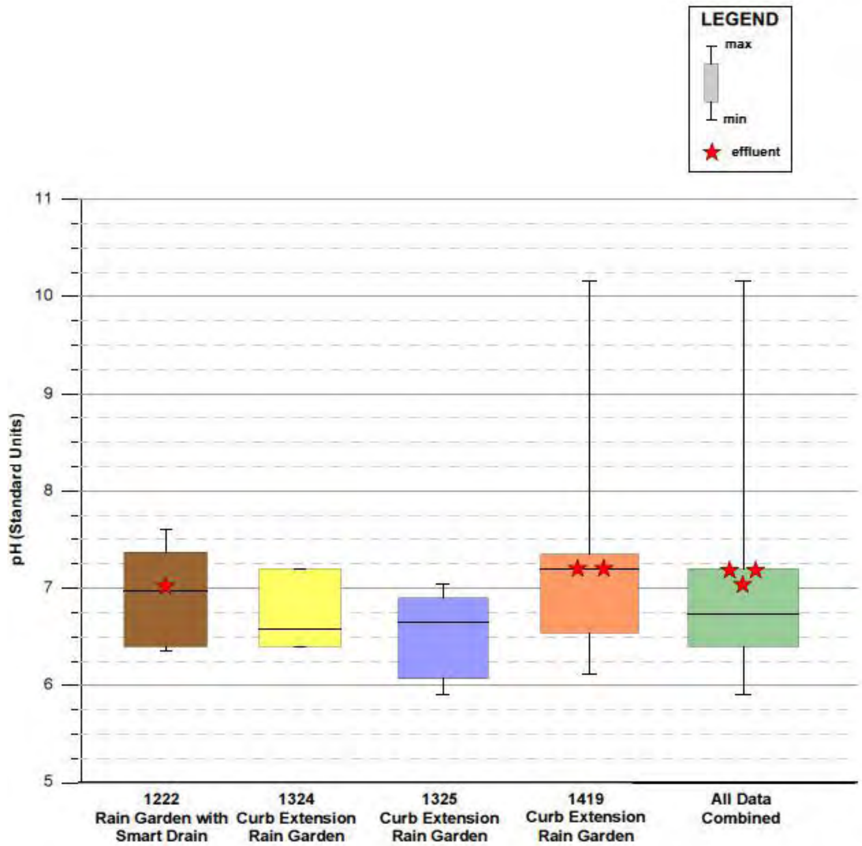


Figure 45. Measured pH at Individual GI Solutions (UMKC)

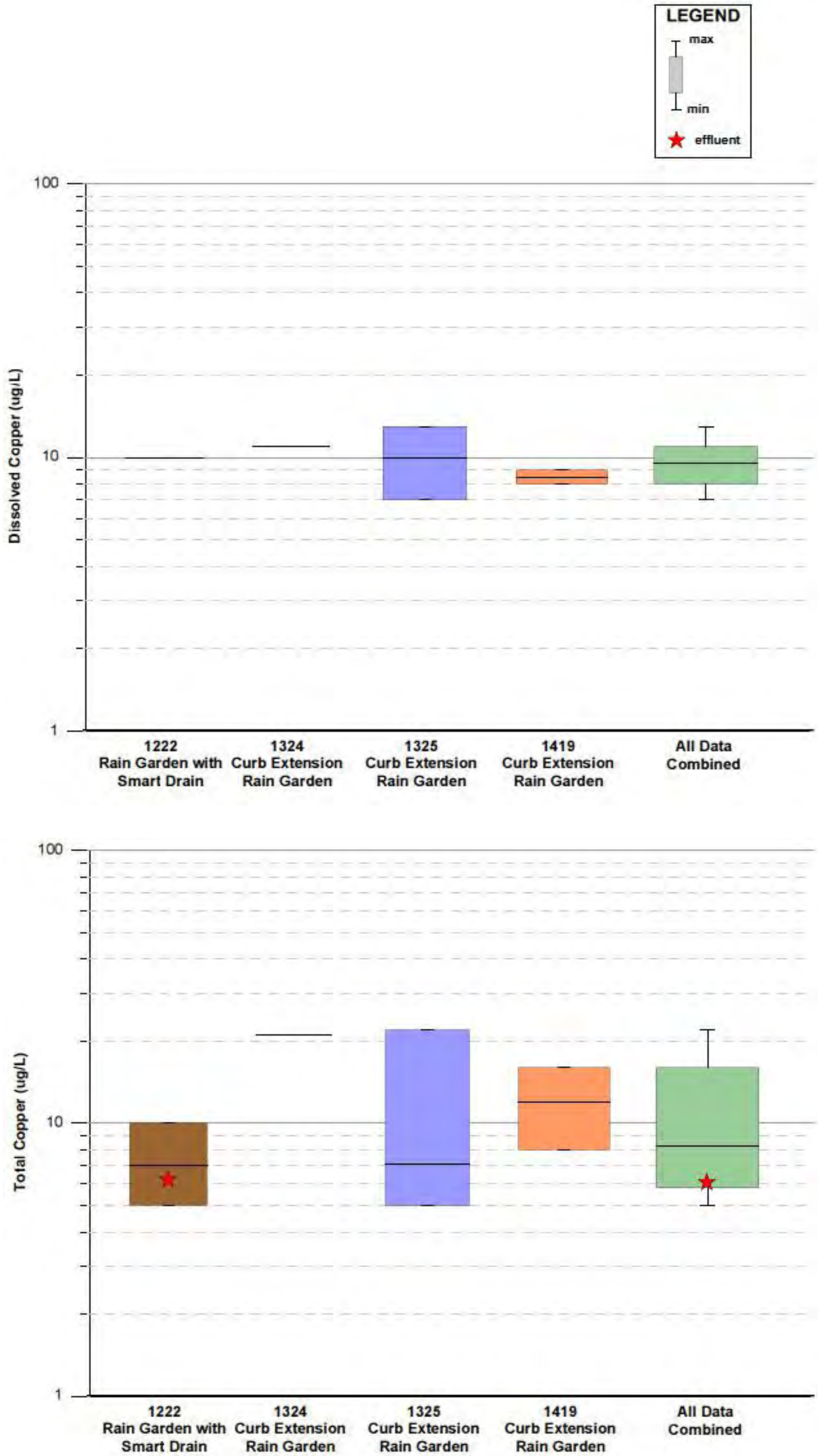


Figure 46. Measured Concentrations of Dissolved Copper (top, R7) and Total Copper (bottom, R7) at Individual GI Solutions

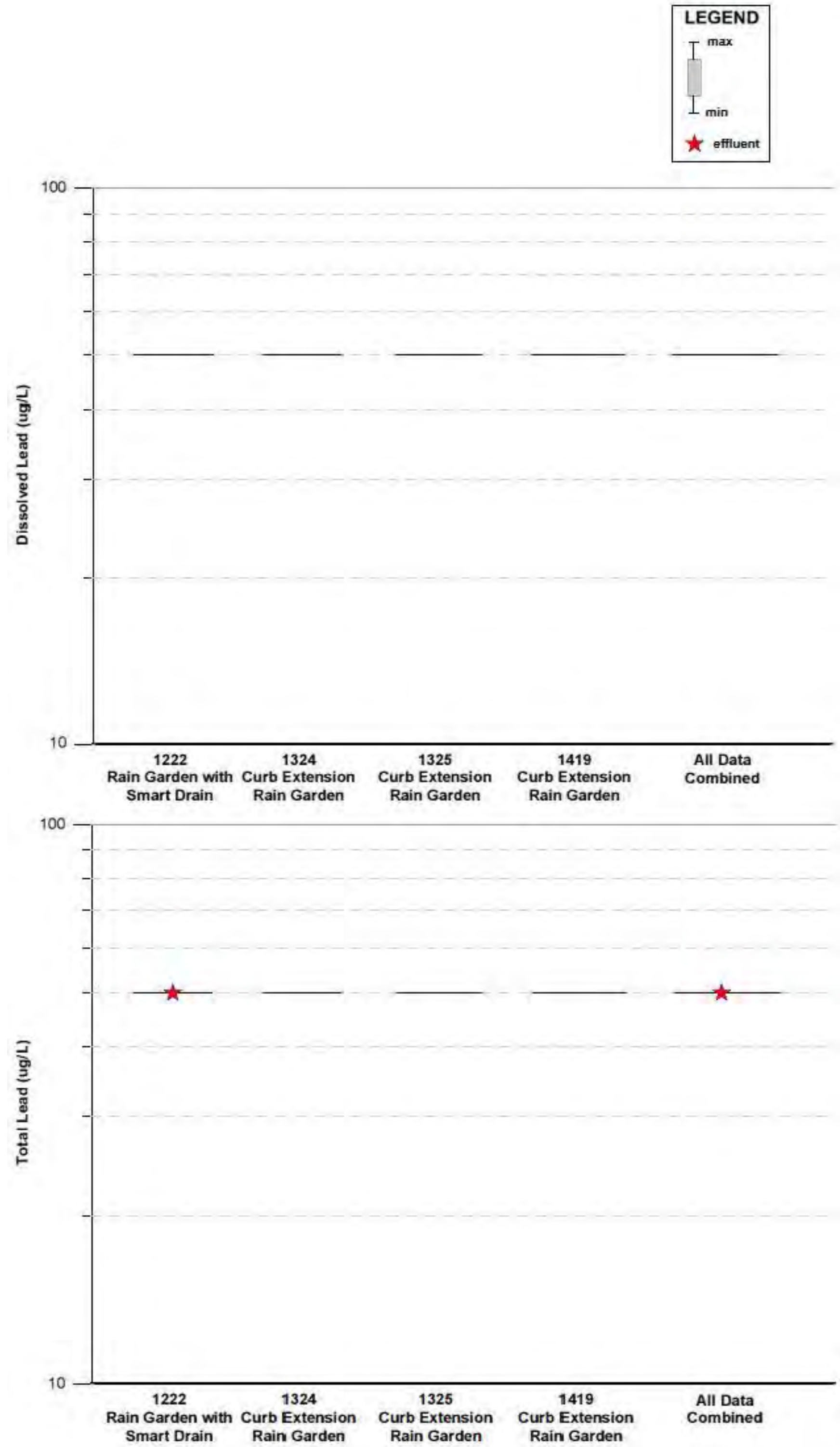


Figure 47. Measured Concentrations of Dissolved Lead (top, R7) and Total Lead (bottom, R7) at Individual GI Solutions

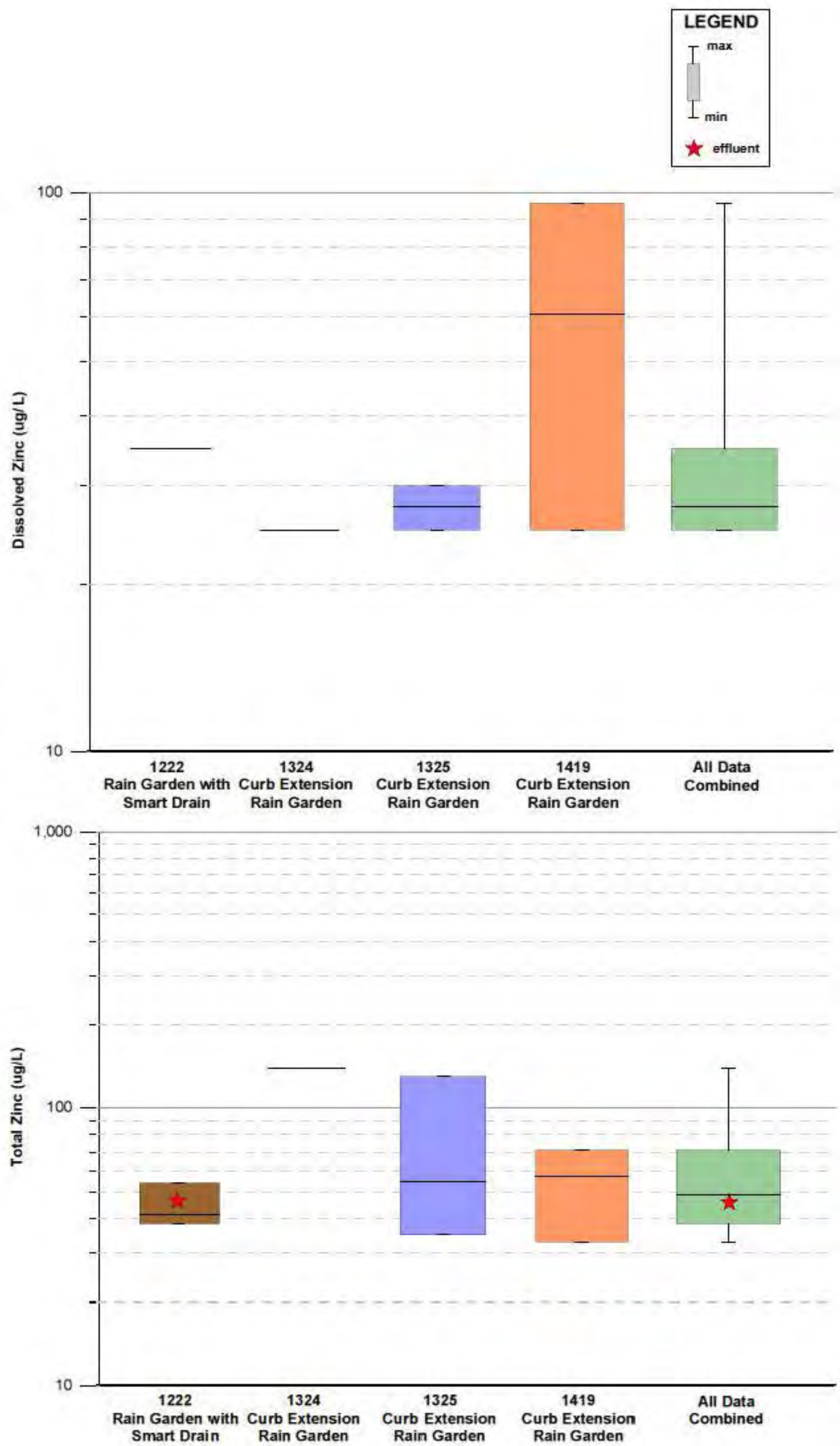


Figure 48. Measured Concentrations of Dissolved Zinc (top, R7) and Total Zinc (bottom, R7) at Individual GI Solutions

Table 5. Summary Statistics for UMKC-measured Constituents: TSS, Turbidity, Nitrate, and Phosphate

Site	BMP Type	TSS (mg/L)					Turbidity (NTU)				
		No.	Mean	Std. Dev.	Max	Min	No.	Mean	Std. Dev.	Max	Min
1324 E 76th St.	Curb Extension	4	194.75	194.52	468	51	4	28.13	23.27	62.1	11.2
1325 E 76th St.	Curb Extension	7	326	390.43	1408	27	6	22.89	16.26	52.8	6.56
1419 E 76th Terr.	Curb Extension	9	141	84.6	294	9	9	19.67	19.68	66	3.01
1222 E 76th St.	Rain Garden w/ Smart Drain	8	160	167.03	824	28	7	17.77	9.34	32.1	5.84

Site	BMP Type	Nitrate as N (µg/L)					Phosphate as P (µg/L)				
		No.	Mean	Std. Dev.	Max	Min	No.	Mean	Std. Dev.	Max	Min
1324 E 76th St.	Curb Extension	3	1.33	0.58	2	1	2	1	0	1	1
1325 E 76th St.	Curb Extension	5	1.8	1.79	5	1	3	0.83	0.29	1	0.5
1419 E 76th Terr.	Curb Extension	7	1.57	1.51	5	1	6	2.92	3.53	10	0.5
1222 E 76th St.	Rain Garden w/ Smart Drain	7	2.71	2.93	7	1	5	1.7	0.45	2	1

NOTE: NON-DETECT SAMPLES WERE HANDLED AS IF THE MEASURED CONCENTRATION WAS EQUAL TO THE REPORTING LIMIT

Table 6. Summary Statistics for UMKC-measured Constituents: pH and Fecal Coliform

Site	BMP Type	pH (SU)					Fecal Coliform (#/100mL)				
		No.	Mean	Std. Dev.	Max	Min	No.	Mean	Std. Dev.	Max	Min
1324 E 76th St.	Curb Extension	4	6.69	0.37	7.2	6.4	3	2546,667	3,067,007	6,000,000	140,000
1325 E 76th St.	Curb Extension	7	6.5	0.4	7.1	5.9	5	2,518,000	2,244,353	6,000,000	490,000
1419 E 76th Terr.	Curb Extension	9	7.2	1.19	10.2	6.1	6	2,200,000	2,944,738	6,000,000	180,000
1222 E 76th St.	Rain Garden w/ Smart Drain	8	6.9	0.5	7.6	6.4	4	1,932,500	2,806,580	6,000,000	50,000

NOTE: NON-DETECT SAMPLES WERE HANDLED AS IF THE MEASURED CONCENTRATION WAS EQUAL TO THE REPORTING LIMIT

Table 7. Summary Statistics for UA-measured Constituents: TSS, SSC, and D_{50}

Site	BMP Type	TSS (mg/L)					SSC (mg/L)				
		No.	Mean	Std. Dev.	Max	Min	No.	Mean	Std. Dev.	Max	Min
1324 E 76th St.	Curb Extension	4	206.25	221.91	528	52	4	208.50	230.62	543	51
1325 E 76th St.	Curb Extension	7	143	246	698	29	7	146	242	693	30
1419 E 76th Terr.	Curb Extension	7	127	86.4	262	3	7	129	85.9	257	3
1222 E 76th St.	Rain Garden w/ Smart Drain	6	72.8	49.8	153	23	6	73.7	51.7	155	26

Site	BMP Type	D_{50} (µm)				
		No.	Mean	Std. Dev.	Max	Min
1324 E 76th St.	Curb Extension	4	24.75	4.27	30	20
1325 E 76th St.	Curb Extension	7	37	24	85	20
1419 E 76th Terr.	Curb Extension	7	128	155	400	27
1222 E 76th St.	Rain Garden w/ Smart Drain	6	67	90	250	18

NOTE: NON-DETECT SAMPLES WERE HANDLED AS IF THE MEASURED CONCENTRATION WAS EQUAL TO THE REPORTING LIMIT

Table 8. Summary Statistics for R7-measured Constituents: Total Nitrogen and Total Phosphorous

Site	BMP Type	Total Nitrate as N (µg/L)					Total Phosphate as P (µg/L)				
		No.	Mean	Std. Dev.	Max	Min	No.	Mean	Std. Dev.	Max	Min
1324 E 76th St.	Curb Extension	1	4,967	N/A	4,967	4,967	1	650	N/A	650	650
1325 E 76th St.	Curb Extension	4	4,029.55	1,909.35	6,181	1,877.5	4	599	367.90	1113	268.4
1419 E 76th Terr.	Curb Extension	4	3,135.1	925.36	4,508	2529	4	432.98	97.77	502.5	288.3
1222 E 76th St.	Rain Garden w/ Smart Drain	3	2,805.33	2,249.36	5,126	634.8	3	497.23	431.86	980.6	149.4

NOTE: NON-DETECT SAMPLES WERE HANDLED AS IF THE MEASURED CONCENTRATION WAS EQUAL TO THE REPORTING LIMIT

Table 9. Summary Statistics for R7-measured Constituents: Total and Dissolved Lead

Site	BMP Type	Total Pb (µg/L)					Dissolved Pb (µg/L)				
		No.	Mean	Std. Dev.	Max	Min	No.	Mean	Std. Dev.	Max	Min
1324 E 76th St.	Curb Extension	1	50	N/A	50	50	1	50	N/A	50	50
1325 E 76th St.	Curb Extension	4	50	0	50	50	2	50	0	50	50
1419 E 76th Terr.	Curb Extension	3	50	0	50	50	2	50	0	50	50
1222 E 76th St.	Rain Garden w/ Smart Drain	4	50	0	50	50	1	50	N/A	50	50

NOTE: ALL SAMPLES WERE NON-DETECT

Table 10. Summary Statistics for R7-measured Constituents: Total and Dissolved Copper and Zinc

Site	BMP Type	Total Cu (µg/L)					Dissolved Cu (µg/L)				
		No.	Mean	Std. Dev.	Max	Min	No.	Mean	Std. Dev.	Max	Min
1324 E 76th St.	Curb Extension	1	21	N/A	21	21	1	11	N/A	11	11
1325 E 76th St.	Curb Extension	4	10.31	7.93	22	5	2	10	4.24	13	7
1419 E 76th Terr.	Curb Extension	3	12	4	16	8	2	8.5	0.71	9	8
1222 E 76th St.	Rain Garden w/ Smart Drain	4	7.27	2.14	10	5.01	1	10	N/A	10	10

Site	BMP Type	Total Zn (µg/L)					Dissolved Zn (µg/L)				
		No.	Mean	Std. Dev.	Max	Min	No.	Mean	Std. Dev.	Max	Min
1324 E 76th St.	Curb Extension	1	139	N/A	139	139	1	25	N/A	25	25
1325 E 76th St.	Curb Extension	4	68.43	43.10	130	35	2	27.5	3.54	30	25
1419 E 76th Terr.	Curb Extension	3	53.67	19.22	71	33	2	60.5	50.20	96	25
1222 E 76th St.	Rain Garden w/ Smart Drain	4	43.9	7.24	54	38.4	1	35	N/A	35	35

NOTE: NON-DETECT SAMPLES WERE HANDLED AS IF THE MEASURED CONCENTRATION WAS EQUAL TO THE REPORTING LIMIT

4. Conclusions and Next Steps

The ADC project made significant progress during the 2012 calendar year, including the following technical achievements:

- Installation of water quality and/or hydraulic monitoring equipment at eight individual GI solutions
- Hydraulic monitoring of 12 storm events at the individual GI solutions
- Water quality monitoring of 9 storm events at the individual GI solutions for a total of 29 water quality samples
- Continued collection and download of hydraulic monitoring data from the four large-scale flow meters and rainfall gage
- Continued collection and download of hydraulic monitoring data from two private rain gardens
- Modeling of the pre- and post-construction hydrology of the pilot project area versus the control area
- Extensive efforts to compile and analyzed hydraulic and water quality monitoring data collected to date (both large-scale and small-scale)

The achievements listed above do not include the many non-technical achievements including fostering of collaboration and information exchange among EPA ORD and KCMWD and efforts by Region 7 staff to increase community awareness regarding the benefits of green infrastructure.

The lengthy construction timeline for the MBRGS pilot project and severe drought conditions have led to the project being extended into the 2013 calendar year. The following efforts are expected to be completed in 2013:

- Continued hydraulic and water quality monitoring at in the individual GI solutions, with an emphasis on water quality sampling of larger (>1-inch) storm events that generate effluent from the GI solutions
- Additional modeling efforts including SWMM or SUSTAIN modeling
- Additional statistical analyses to support quantification of the performance of individual GI solutions
- Additional analyses to quantify the post-construction performance of the MBRGS pilot project area versus the control area
- Completion of a final report that can serve as a national reference regarding the performance of GI solutions at multiple scales
- Training of KCMWD staff regarding the water quality monitoring protocols to encourage long-term monitoring of the GI solutions
- Transition of monitoring responsibility for the four large-scale flow meters to KCMWD (which owns the flow meters)

The ADC project team very much looks forward to the 2013 efforts and anticipates the results of the project will significant benefit the national community of agencies associated with managing stormwater and CSO impacts.

5. References

EPA Office of Research and Development (2009, amended 2011). *National Demonstration of Advanced Drainage Concepts Using Green Solutions for CSO Control: Quality Assurance Project Plan, with Addenda No. 1, No.2, and No.3.* Not published.

EPA Office of Research and Development (2011a). *National Demonstration of the Integration of Green and Gray Infrastructure in Kansas City, Missouri: A Pre-performance Summary Report.*

EPA Office of Research and Development (2011b). *Report on Enhanced Framework (SUSTAIN) and Field Applications for Placement of BMPs in Urban Watersheds.* EPA 600/R-1/144 November 2011.

Talebi, Leila. Assessment of Integrated Green Infrastructure-Based Stormwater Controls in Small to Large Scale Developed Urban Watersheds. Ph.D. dissertation. Department of Civil, Construction, and Environmental Engineering. The University of Alabama, 2014. 620 pgs. http://unix.eng.ua.edu/~rpitt/Publications/11_Theses_and_Dissertations/Leila_Dissertation.pdf

Office of
Research and
Development
(8101R)
Washington,
DC 20460