ASSESSMENT OF INTEGRATED GREEN INFRASTRUCTURE-BASED STORMWATER CONTROLS IN SMALL TO LARGE SCALE DEVELOPED URBAN WATERSHEDS

by

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A DISSERTAION

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ABSTRACT

Green infrastructure (GI) stormwater control approaches and techniques store, infiltrate, evapotranspire, and in some cases reuse stormwater to reduce runoff quantity and to improve overall environmental quality. The literature review indicates substantial benefits provided by GI stormwater controls in small scales including reduced stormwater runoff volumes, enhanced groundwater recharge, reduced pollutant discharges to water bodies, and decreased combined sewer overflow events.

The main objective of this dissertation research was to examine the benefits of individual and integrated GI stormwater control practices at small to large scales in urban watersheds. The hypothesis of this research is: "*Retrofitting integrated green infrastructure controls in large areas served by separate or combined sewers can result in significant runoff volume reductions.*" Three case studies which were extensively monitored and evaluated have been selected for this dissertation research; 1) Millburn, NJ with dry wells monitored at a small scale, 2) Kansas City, MO with various GI practices including biofilters, curb extension biofilters, cascade biofilters, porous pavement, rain gardens monitored at small scales (individual GI performance) and monitored at large scales (overall integrated GI performance and their impact on combined sewer overflows (CSOs), and 3) Cincinnati, OH with three study sites including Cincinnati State College, the Cincinnati Zoo, and the Clark Montessori High School, which have several GI stormwater control types with monitoring at large scales.

Analyses were conducted at infiltration facilities and at combined and separate sewer flow monitoring locations in the study areas to calculate the benefits of green infrastructure-based stormwater controls. The analyses conducted as part of this dissertation research were aimed at showing that monitoring results for runoff volume reductions from isolated small-scale

stormwater controls can be scaled-up for use in typical drainage area benefit predictions, but only if sufficient information is available (such as soil characteristics, land development, actual runoff treated, etc.).

The analyses at the small scales at Millburn, NJ and Kansas City, MO, indicated that there were varying levels of infiltration performance in the areas, but most dry wells and biofilters were able to completely drain within a few days. However, several had extended periods of standing water that may have been associated with high water tables, poorly draining soils (or partially clogged soils), or detrimental effects from snowmelt on the clays in the soils. At large scales at the Kansas City and Cincinnati test areas, direct measurements of flows by the in-system flow monitors in the combined or separate sewers on or adjacent to several of the green infrastructure components were used to directly measure whole system performance. The results at the large scales indicated that for most flow monitoring locations, there was a statistically significant difference ($p<0.05$) between the "after" construction period data and the "before" construction period data, which supports the hypothesis of this dissertation research. The runoff volume reductions for the large-scale studied areas ranged from 20% (for the Clark Montessori High School that has about 25% of its drainage area treated by green infrastructure controls) to about 85% (for Cincinnati State College where most of the area's runoff was treated by the treatment devices). The results showed that the green infrastructure locations and coverage in the watersheds directly affected the runoff reductions in the areas. The watersheds should have most of their flows treated by the green infrastructure stormwater control practices to result in large runoff volume reductions in the watersheds. Some of the flow monitoring results appears to be faulty and since the monitoring period has concluded and the equipment removed, it is not possible to verify the calibrations. Therefore, an important part of this dissertation research was to develop and demonstrate an effective monitoring and evaluation strategy and QA/QC process. This dissertation research also utilized a calibrated version of WinSLAMM for each study area that can be used to determine likely long-term benefits under a large variety of conditions, as well as recommendations for flow monitoring of green infrastructure stormwater controls.

DEDICATION

To

My dear husband and best friend, Alireza

My beloved parents, Eshrat Rajabi and Ramezan Talebi

LIST OF ABBREVIATION AND SYMBOLS

ac	Acre
ANOVA	Analysis of Variance
cm	Centimeter
COV	Coefficient of Variation
CSO	Combined Sewer Overflow
CSS	Combined Sewer System
f_o	Initial infiltration rate
f_c	Final (constant) infiltration rate
ft	Feet
ft^2	Square feet
hr	Hour
in	Inch
in/hr	Inch per Hour
k	First-order rate constant
L	Liter
m	Meter
mL	Milliliter
mm	Millimeter
mm/hr	Millimeter per Hour
mg/L	Milligram per Liter

N	Nitrogen
n/a	Not Available
P	Phosphorous
QA	Quality Assurance
QC	Quality Control
R_v	Ratio of runoff depth to rainfall depth
TN	Total Nitrogen
TP	Total Phosphorus
TS	Total Solids
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
vs.	Versus

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CHAPTER 1.0

INTRODUCTION

The natural hydrological cycle in urban and surrounding areas can be significantly influenced by changes in urbanization, resulting in potentially serious environmental problems such as increased runoff volume, lower groundwater recharge, accelerated erosion, and greater flooding. Increased amounts of impervious surfaces (e.g., streets, building roofs, and parking lots) due to urbanization are the most important cause of runoff increases in urban areas. In addition to the many challenges associated with the quantity aspects of urban stormwater runoff, it also causes adverse effects on urban receiving water quality (Burton and Pitt, 2002; Pitt et al., 2002; Pickett et al., 2011; Pitt et al., 2012).

There are several methods to control stormwater discharges in urban areas. The traditional method is to collect stormwater runoff in older areas through the use of combined sewer systems, which transport surface runoff, along with domestic and industrial wastes. In most newer cities, separate drainage systems are used. Under wet weather conditions, the large volumes of stormwater runoff commonly exceed the transport capacity of the combined sewer systems and the treatment capacity at the wastewater treatment facility. The excess combined stormwater and sewage overflows are discharged to adjacent water bodies at specific combined sewer overflow (CSO) discharge points. These untreated combined sewer overflows (CSOs) contaminate rivers and streams with microbial pathogens, suspended solids, chemicals, nutrients, and organic matter (Tibbet, 2005; USEPA, 2014). In many cities served by combined sewers, uncontrolled CSOs may occur during relatively small rainfall depths (sometimes less than 0.5

inches of rain). Over the past decades, much research, followed by regulations and implementation of CSO controls have been used to decrease the volume and frequency of these overflows. Several methods have been used to diminish combined sewer overflows (CSOs) in urban areas, including traditional infrastructure-based CSO control approaches that rely on structural solutions (e.g. large-scale tunneling, treatment plant expansion, etc.), emerging green infrastructure-based stormwater control practices that rely on reducing the stormwater contributions through infiltration, and changes in development practices that affect the surface hydrology and associated runoff.

Green infrastructure stormwater control practices include integrated approaches that store, infiltrate, or detain stormwater runoff before discharge to the stormwater collection systems (USEPA, 2014). These practices may be used at large scales (city or county), and small scales (site or neighborhood). The most common types of green infrastructure include bioretention facilities (and subcategories, including rain gardens, curb-cut biofilters, curb-extension biofilters, etc.), bioswales, permeable pavement, green roofs, rainwater harvesting systems, and planter boxes (Pitt et al, 2012; USEPA, 2014).

Numerous studies have evaluated the performance of different types of individual green infrastructure components at relatively small scales, indicating that these features are expected to be effective in reducing runoff volumes (important for combined and separately sewered areas) as well as enhancing the stormwater runoff quality (important for separately sewered areas). Yet, there are few demonstrations of integrated green infrastructure facilities at large scales with explicit real time evaluations of its impacts on reducing flows in combined sewers.

Although different models (such as WinSLAMM, SUSTAIN, and SWMM) predict hydrologic performance and model the water quality of green infrastructure in urban areas, it is important to study the real time pre- and post- construction flow and water quality data at multiple scales to quantify the actual benefits of the integrated green infrastructure components to better calibrate and verify the models at the different scales over which they are to be applied. Linear extrapolations of the small-scale individual facility results to larger scales containing many facilities, as typically conducted using simple spreadsheet stormwater models, may result in inaccurate predictions of the large-scale performance for the whole development or community. Typical issues that must be addressed include how the individual controls are connected. Usually, they are in series with large storm overflows from up-gradient devices directed to downstream facilities. The additional water from the up-gradient facility consumes some of the treatment capacity of the downstream device. In addition, many facilities in urban large area have widely varying drainage areas due to micro-topographic conditions, with some facilities receiving much less water than expected and others receiving more water, resulting in variable performance of the individual facilities. Finally, drainage system flow losses and gains and interactions with the groundwater also affect system-wide performance that may not be indicated during the smaller-scale monitoring at individual locations.

The main objective of this research is to examine the effectiveness of retrofitted green infrastructure stormwater controls in several small- and large-scale developed urban watersheds in areas served either by separated or combined sewer systems. At small scales, infiltration measurements from individual stormwater controls, including drywells and biofilters, were used to quantify the benefits (such as runoff volume reductions). In addition, the effects of soil types, storm event characteristics, and land development characteristics on the infiltration behavior of individual green infrastructure stormwater controls were examined. At large scales, direct measurements of flow from in-system flow monitors placed in combined or separate sewers affected by individual green infrastructure devices were evaluated. Real-time rainfall and runoff data from combined and separate sewer systems affected by GI stormwater controls in upstream areas were analyzed both before and after construction of the stormwater controls. The runoff characteristics of the pre- and post-construction conditions were then statistically compared to measure the benefits of integrated GI stormwater controls at the large scales.

This dissertation research focuses on three case studies associated with recent or on-going research at the University of Alabama, including;

a) The Township of Millburn, New Jersey

b) Kansas City, Missouri, and

c) Cincinnati, Ohio.

The Millburn, NJ project was used as a small-scale case study which used dry wells as stormwater infiltration controls. The Kansas City, MO project was one of the largest projects in the United States using extensive GI controls in a completely monitored 100-acre neighborhood that encompasses implementation of over 100 green infrastructure-based stormwater controls and sewer rehabilitation. Therefore, the Kansas City, MO case study provided an opportunity to evaluate the benefits of GI stormwater controls at small scales (using infiltration data from individual GI stormwater control monitoring), and large scales (overall impacts of all GI controls on 100-acre neighborhood and combined sewer systems compared to adjacent control watershed). The Cincinnati, OH project represented several studies at large scales that include implementation of integrated watershed based GI stormwater controls to reduce CSO volumes. In the Cincinnati case studies, the flow monitoring data obtained in the sewer lines after construction were compared to before construction conditions. During the Kansas City case study, an adjacent 86-acre sub-watershed with no stormwater controls was also examined, in addition to the before and after GI facility monitoring. This dissertation research therefore also compares several different experimental design approaches and data collection methods that were used during these projects.

In addition to the analysis of the measured data, WinSLAMM (a stormwater quality model that incorporates a wide range of sustainable infrastructure unit processes and associated controls that are tailored for site specific conditions) was calibrated using the before construction flow and GI construction data and other site conditions to model green infrastructure stormwater performance at each study area to predict the performance of control options for varying conditions.

This dissertation contains five chapters including: the literature review (chapter 2), hypotheses and methodology (chapter 3), results (chapter 4) and conclusions and recommendations (chapter 5). Extensive appendices are also included that contain the collected fundamental data and detailed statistical analyses.

The preliminary results of this dissertation research were published in association with and presented at several national and international conferences. Below is a list of these publications and presentations.

<u>PEER-REVIEWED RESEARCH REPORTS</u>

- Talebi, L., and Pitt, R., "Evaluation of Retrofitted Green Infrastructure Stormwater Controls at Cincinnati State College, the Cincinnati Zoo, and the Clark Montessori High School", Prepared for Metropolitan Sewer District of Greater Cincinnati and USEPA, 95 pages. October, 2013

- Pitt, R., Talebi, L., O'Bannon, D., Bambic, D., Wright, J. "Modeling of Green Infrastructure Components and Large-Scale Test and Control Watersheds at Kansas City, MO," Prepared for USEPA and Tetra Tech, 357 pages. December, 2013

- Pitt, R., and Talebi, L., "Evaluation and Demonstration of Stormwater Dry Wells and Cisterns in Millburn Township, New Jersey," Urban Watershed Management Branch, U.S. Environmental Protection Agency, Edison, NJ 08837. 302 pages. July, 2012

- Pitt, R., Talebi, L., Bean, R, and Clark, S., "Stormwater Non-Potable Beneficial Uses and Effects on Urban Infrastructure," Water Environment Research Foundation. WERF INFR3SG09, Alexandria, VA. 234 pages. April 2012

- Pitt, R., and Talebi, L., "Strategies and Experimental Design for Monitoring the Performance of Various Green Infrastructure Controls at Cincinnati Demonstration Project Sites - A Preliminary Strategy and Plan," Prepared for the Metropolitan Sewer District of Greater Cincinnati, Cincinnati, OH. 163 pages. September, 2011

CHAPTERS IN BOOKS (PEER-REVIEWED)

- Talebi, L., Pitt, R., "Evaluation and Demonstration of Stormwater Dry Wells and Cisterns in Millburn Township, New Jersey." In: Pragmatic Modeling of Urban Water Systems, Monograph 21. (Edited by W. James, K.N. Irvine, E.A. McBean, R.E. Pitt and S.J. Wright). CHI, Guelph, ON Canada, 2013

- Pitt, R., Talebi, L., "Modeling Green Infrastructure with Large-Scale Monitoring at Kansas City, Missouri." In: Pragmatic Modeling of Urban Water Systems, Monograph 21. (Edited by W. James, K.N. Irvine, E.A. McBean, R.E. Pitt and S.J. Wright). CHI, Guelph, ON Canada, 2013

PUBLICATIONS and PRESENTATIONS

- Talebi, L., Pitt R., Alfaqih, L., "Evaluation of Retrofitted Green Infrastructure Stormwater Controls in areas served by separate and combined sewers at large scale in Cincinnati, OH." ASCE/ EWRI 2014, World Environmental and Water Resources Congress, Portland, OR, June 1-5, 2014

- Talebi, L., Pitt R., Alfaqih, L., "Performance Results from Large-Scale System Monitoring and Modeling of Intensive Applications of Green Infrastructure in Areas Served by Separate and Combined Sewers in Cincinnati, Ohio," International Low Impact Development Symposium, August 18-21, 2013, St, Paul, Minnesota

- Pitt, R., Talebi, L., O'Bannon, D., Bambic, D., Wright, J., Simon, M., "Comparison of WinSLAMM Modeled Results with Monitored Bioinfiltration Data during Kansas City Green Infrastructure Demonstration Project," ASCE/ EWRI 2013, World Environmental and Water Resources Congress, Cincinnati, OH, May 19-23, 2013

- Talebi, L., Pitt, R., "Changes in Chemical and Microbiological Quality of Runoff with the use of Drywells; A Case Study in Millburn, NJ," WEFTEC, the 85thd Annual Water Environment Federation Technical Exhibition and Conference. New Orleans, LA, September 29 – October 3, 2012

- Pitt, R., Talebi, L., "The development of sizing and performance production functions of green infrastructure stormwater controls using WinSLAMM," 50 years of watershed modeling, Engineering Conferences International (ECI), Boulder, CO, September 24-26, 2012

- Talebi, L., Pitt, R., Clark, S., "Stormwater Reuse Opportunities and Effects on Urban Infrastructure Management; Review of Practices and Proposal of WinSLAMM Modeling," WEF Stormwater symposium, Baltimore, Maryland, July 18-20, 2012

- Talebi, L., Pitt, R., "Roof Runoff Harvesting Benefits for Regional Conditions in Low Density and Medium Density Residential Areas," ASCE/ EWRI 2012, World Environmental and Water Resources Congress, Albuquerque, NM, May 20-24, 2012

- Talebi, L., Pitt, R., Clark, S., "Stormwater Non-potable Beneficial Uses; a Review of International and United States Practices," International Low Impact Development Conference (LID): Greening the Urban Environment, Philadelphia, PA, September 25-28, 2011

- Talebi, L., Pitt, R., "Stormwater Non-potable Beneficial Uses: Modeling Groundwater Recharge at a Stormwater Drywell Installation," ASCE/ EWRI 2011, World Environmental and Water Resources Congress, Palm Springs, CA, May 22-26

POSTER PRESENTATIONS

- O'Bannon, D., Talebi, L., Ma, Y., Pitt, R., Simon, M., “Effectiveness of urban stormwater control measures in a 100-acre test site,” ASCE/ EWRI 2014, World Environmental and Water Resources Congress, Portland, OR, June 1-5, 2014

- Talebi, L., Pitt, R., “Fitting Infiltration Models to Urban Dry Well Data,” ASCE/ EWRI 2013, World Environmental and Water Resources Congress, Cincinnati, OH, May 19-23, 2013

- Talebi, L., Pitt, R., “Modeling Infiltration at Stormwater Drywell Installations; A case study in Millburn, NJ,” International Low Impact Development Conference (LID): Greening the Urban Environment, Philadelphia, PA, September 25-28, 2011

CHAPTER 2.0

LITERATURE REVIEW

2.1 Stormwater Runoff Challenges in Urban Areas

The world's population is growing rapidly, especially in urban areas, and will continue to increase in the coming decades (UNESCO, 2009). The United Nations Population Fund (UNFPA) reported an average annual increase of 1.1 percent in the world's population and estimated a global population of about 9 billion people by 2050, while the current population in 2012 is about 7 billion people (UNFPA, 2012). It is expected that more than two-thirds of the population in 2050 will be in urban areas 2050 (UNFPA, 2012). Numerous studies suggest that this shift in human habitation from rural to urban areas will cause changes in the hydrological cycle in urban and surrounding areas, along with serious environmental and social problems. The growth in urbanization also significantly accelerates environmental changes of ecosystems, especially in urban receiving waters due to dramatic changes to the local water cycle (Burton and Pitt, 2002; Pitt et al., 2002; Pickett et al., 2011; Pitt et al., 2012).

Runoff is defined as that portion of rainfall that does not infiltrate into the ground or evaporates and reaches a stream channel quickly (Booth, 1991). Increased amounts of impervious surfaces due to urbanization are the most important cause of runoff increases in urban areas (Hollis, 1975; Claytor and Schueler, 1996; Brabec et al., 2002; Pitt et al., 2002). In 1968, Leopold classified the impacts of land-use changes on watershed hydrology in four categories, including; changes in peak flow characteristics, changes in total runoff volume, changes in water quality, and changes in the hydrologic amenities. On a natural and undeveloped ground cover, the runoff may vary from 10 to 30 percent of the overall precipitation. As urban development occurs, depending on the type and degree of imperviousness, the surface runoff might increase to 55% of the total annual precipitation (Prince George's County, 1999). Figure 2.1 illustrates typical increased runoff flows (and associated decreased infiltration amounts) with increasing amounts of impervious surfaces. Despite the many challenges associated with the quantity aspects of urban stormwater runoff, such as flooding, accelerated erosion, and groundwater recharge reduction, stormwater runoff also causes adverse effects on receiving water quality (Burton and Pitt, 2002). Stormwater runoff quantity and quality greatly depends on land use characteristics (i.e. size and type) and weather conditions (i.e. wet/dry weather), therefore runoff volume, and type and the concentration of pollutants in runoff vary in different watersheds and urban areas (Booth, 1991; Burton and Pitt, 2002; Pitt et al, 2004; Butler and Davies, 2011).

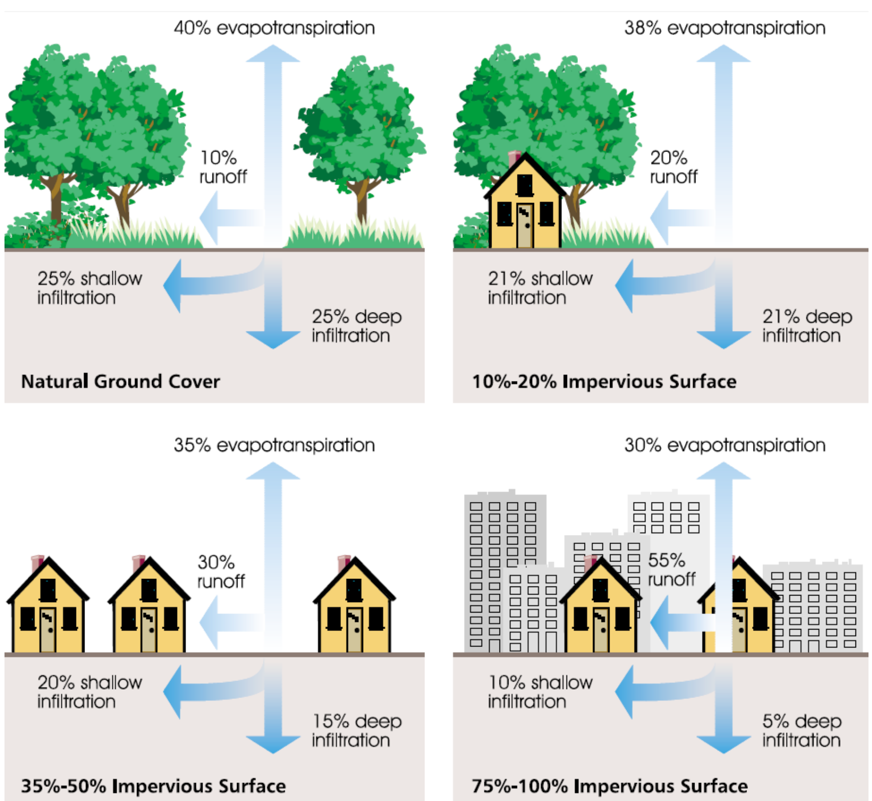


Figure 2.1. Runoff variability with increased impervious surfaces (FISRWG, 1998)

The impacts of land use characteristics and potential changes in land use on stormwater runoff volume have been quantified in numerous studies by comparing pre- and post-development hydrological conditions. In most cases, the results clearly indicate an increase in runoff volume and flood risk, along with base flow reductions due to urbanization (Arnold and Gibbons, 1996; Camorani et al., 2005; Ali et al., 2011; Jacobson, 2011; Du et al., 2012). Similarly, floods with shorter recurrence intervals are more likely to have increases in flood magnitudes than those with long recurrence intervals due to urbanization (Hirsch et al., 1990).

As the stormwater runoff moves through an urban area, it picks up and transports a large variety of natural and human-made pollutants from impervious surfaces (i.e. roads, buildings, parking lots) and compacted soils, and ultimately deposits them into water bodies such as streams and lakes. Many studies have shown contamination in stormwater collected from various catchment sources (Field et al., 1973; Hvitved-Jacobsen et al., 2010; Barbosa et al., 2012). There have been more than 350 compounds identified in stormwater runoff (Eriksson, 2002), but the most common pollutants in stormwater runoff include solids (Pitt et al., 2004; Ahmed et al., 2008), heavy metals such as copper (Cu), lead (Pb) and zinc (Zn) (Förster, 1996; Borchardt and Sperling, 1997; Brown and Peake, 2006), polycyclic aromatic hydrocarbons (PAHs) (Pitt, 1995; Förster, 1999, Brown and Peake, 2006; Zhang et al., 2008), pesticides and herbicides (Revitt et al., 1999; Zobrist et al., 2000; Clark et al., 2006), and bacteria (Lye, 2002; Ahmed et al., 2008) which directly impacts water bodies. Pitt et al. (2004) developed the National Stormwater Quality Database (NSQD) which includes more than 8,000 stormwater events covering the major land uses and most geographical areas of the country. These data were evaluated to test the validity of several commonly accepted assumptions concerning stormwater, and produced a statistical tool that can assist stormwater managers and regulators. This study shows that many of the constituents found in stormwater likely have concentrations greater than the associated numeric criteria. The most potentially problematic constituents (where the exceedences from the respective criteria are the greatest) include bacteria (total coliforms, fecal coliforms, and *E. coli.*) followed by solids and turbidity. Table 2.1 lists characteristics of the most common stormwater pollutants (Barbosa et al., 2012).

Table 2.1. Characteristics of common stormwater pollutants (modified from Barbosa et al., 2012)

Pollutant Type	Parameter	Source	Comments
Solids	Total suspended solids (TSS)	Pavement wear; construction sites or rehabilitation works; atmospheric fallout; anthropogenic wastes, etc.	60 to 80% of SS in stormwater could be less than 30 µm in diameter. Heavy metals and PAHs are preferentially bound to the smaller particles (e.g.: 100 to 250 µm)
Heavy metals	Cu, Zn, Cd, Pb, Ni and Cr	Vehicles parts and components; tire wear; fuel and lubricating oils; traffic signs and road metallic structures; building materials, especially galvanized metal; treated wood.	They are relevant because of toxic effects. Generally, the focus is on copper (Cu), zinc (Zn); cadmium (Cd) and lead (Pb). The relevance of Pb is minor in countries using unleaded gasoline.
Biodegradable organic matter	BOD_5 and COD	Vegetation (leaves and grass) and animals such as dogs, cats and birds (either fecal contributions or dead bodies)	Organic matter (o.m.) from stormwater is less biodegradable (dominated by plant material), therefore it is also less problematic for the environment than the o.m. from CSOs, but can still cause sediment anoxic conditions.
Organic micropollutants	PAHs, PCBs, MTBEs, endocrine disrupting chemicals	PAHs: incomplete fossil fuel combustion; abrasion of tire and asphalt pavement, etc. Phthalate esters: plastic materials. Pet pharmaceuticals, insecticides	Presently, a large number of compounds (over 650 identified) are discharged in trace concentrations and sometimes there is no accurate chemical determination

Pollutant Type	Parameter	Source	Comments
		and herbicides.	method available for them.
Pathogenic microorganisms	Total coliforms; *Escherichia coli*	Contributions from urban wildlife and pets; leaking sanitary sewers.	Stormwater sources are much different than domestic wastewater contribution such as from CSOs.
Nutrients	Nitrogen and phosphorous (i.e.: total Kjeldahl N; NO_2 + NO_3; total-P; soluble-P)	Fertilizers and atmospheric fallout, decomposing organic materials.	Nutrients can cause not only eutrophication problems but also water discoloration, odors, toxic releases and overgrowth of plants.
(Hvitved-Jacobsen and Yousef, 1991; Wanielista and Yousef, 1993; Burton and Pitt, 2002; Eriksson et al., 2005; Lau and Stenstrom, 2005; McCarthy et al., 2008; Hvitved-Jacobsen et al., 2010; Bjorklund, 2011).			

2.2 Urban Drainage

The conveyance of wastewater and stormwater is a vital concern in urban areas to prevent waterborne diseases and to decrease the risks of flooding (Kingma, 2012). Urban drainage systems handle wastewater from residential, industrial and other properties. In addition, some drainage systems convey stormwater in urban areas, with the aim of minimizing the problems caused by stormwater runoff (e.g. flooding) (Butler and Davies, 2011).

2.2.1 Combined Sewer Systems (CSS)

The EPA (2012) describes a combined sewer system as a system that "transports surface runoff and human domestic wastes (sewage), and sometimes industrial wastes. Wastewater and runoff in a combined sewer may occur in excess of the sewer capacity and cannot be treated immediately. The excess is frequently discharged directly to a receiving stream without treatment, or to a holding basin for subsequent treatment and disposal" (USEPA, 2014).

Combined sewer systems (CSS) were first implemented in Europe in the 1840s to facilitate stormwater drainage, to flush sanitary sewage along the conveyances, and to help dry streets to enable rapid access to transportation after rains. The cities of Hamburg and London were among the first cities that began allowing the discharge of sanitary wastewater into stormwater drainage systems with the advent of the flush toilet, resulting in early combined sewers. In the 1870s, the United States also started to study and apply European combined sewer systems on a large scale due to rapid urbanization. Brooklyn, Chicago, and Jersey City were early adopters of CSSs during the 1850s (Tarr et al., 1984; Burian et al., 1999; USEPA, 2014).

Combined sewer systems are capable of handling the region's sanitary sewage flows under dry weather conditions. While combined sewer systems are a great solution during dry weather, under most wet weather conditions, the large volume of stormwater runoff exceeds the capacity of combined sewer systems and their treatment capacity, resulting in an overflow of untreated or poorly treated sanitary wastewater with the stormwater. According to the EPA, these combined sewer overflows (CSOs) are discharged to U.S. water bodies (typically rivers, and streams) at specific CSO points, to prevent flooding in urban areas. Currently, approximately 40 million people in 772 communities throughout 32 states in the United States are served by combined sewer systems. Most of the combined sewer systems (and therefore the CSOs) are located in the Northeast and Great Lakes regions, and the Pacific Northwest (USEPA, 2014).

Since CSOs are untreated mixtures of domestic, commercial, institutional and industrial wastes, along with stormwater runoff, the diverted water from CSOs contaminate water bodies with microbial pathogens, suspended solids, chemicals, nutrients, viruses, metals, polyaromatic hydrocarbons, and organic matter that deplete dissolved oxygen, and cause many other receiving water problems (Tibbets, 2005; USEPA, 2014). Uncontrolled discharges from untreated stormwater and CSOs could be a major reason for low-quality water in water bodies (Clark et al., 2006). For instance, many studies have shown the adverse impact of CSOs on microbiological water quality of receiving water bodies due to the presence of bacteria (fecal coliform, and *E. coli*) in wastewater and animal wastes found in stormwater runoff (Ashley and Dabrowski, 1995; Marsalek and Rochfort, 2004; Rechenburg et al., 2006; Maki et al. 2007; Ham et al., 2009; Passerat et al., 2011). Table 2.2 summarizes typical pollutant concentrations in CSOs and other pollutant sources. Generally, the contaminant concentrations in CSOs are between the urban runoff and sanitary sewage concentration values. To reduce the CSOs impacts on receiving waters during the last decades, several types of practices for stormwater management have been applied, mainly by reducing runoff volumes and improving the stormwater quality (Gasperi et al., 2012).

Table 2.2 Comparison of typical values for pollutant discharges (Shu et al., 2004)

Contaminant Source	BOD_5 (mg/L)	TSS (mg/L)	COD (mg/L)	Total N (mg/L)	Total P (mg/L)	Fecal Coliform (counts/100mL)
Rainfall	1--13	<1	9--16	--	0.02--0.15	--
Treated wastewater	<5--30	<5--30	--	15--25	<1--5	<200
Urban runoff	10--250	67--101	40--73	0.4--1.0	0.7--1.7	10^3--10^7
CSO	25--100	150--400	260--480	3.0--24	1.0--10	10^5--10^7
Sanitary Sewage	100--400	100-350	260--900	20--85	4.0--15	10^7—10^9

Source: Water Environment Federation (WEF). Prevention and Control of Sewer System Overflows. (WEF, 1999)

2.2.2 Combined Sewer Policy and Guidance

CSOs are subject to section 301 (a) of the Clean Water Act (CWA) and the implementation regulations for the National Pollutant Discharge Elimination System (NPDES), since CSOs are point source discharges (USEPA, 2001). In 1989, the EPA issued the National Combined Sewer Overflow Control Strategy to address the water quality and quantity challenges associated with CSOs. According to this strategy, CSOs are “subject to NPDES permit requirements and the Clean Water Act” (USEPA, 1995). The main objectives of the National Combined Sewer Overflow Control Strategy (1989) were to ensure that CSOs only occur due to increased wet weather flows, and to minimize the impacts of CSOs on water quality, and human health. The National CSO Control Policy provides some principles to ensure that CSO controls meet the clean water act (CWA) requirements, and are cost-effective (USEPA, 1995).

In 1995, the EPA issued the “Guidance for Nine Minimum Controls” for CSOs. The nine minimum controls are technology-based controls that can address the CSO challenges without major construction costs or extensive engineering studies, prior to long-term control implementation. Municipalities served by combined systems were required to implement the nine minimum technology controls no later than January 1, 1997. The nine minimum controls included: 1) proper operation and regular maintenance programs for the sewer system, 2) maximization of storage in the collection system , 3) review and modification of pretreatment requirements to assure CSO impacts are minimized, 4) maximization of flow to the publicly owned treatment facility (POTW) for treatment, 5) elimination of CSOs during dry weather, 6) control of solids and floatable materials in CSOs, 7) pollution prevention programs to reduce contaminants in CSOs, 8) public notification program to educate public about CSOs, and 9) monitoring to effectively characterize CSO impacts and the efficacy of CSO controls.

In 1999, Congress urged EPA to develop guidance for states and Regional Offices to facilitate water quality and designated use reviews for CSO receiving waters. Therefore, in 2001, the EPA issued “Guidance: Coordinating CSO Long-Term Planning with Water Quality Standards Reviews” to address questions on integrating development of CSO long-term control plans (LTCPs) with water quality standards reviews. The main objective of this guidance was to improve the implementation of CSO Control Policy by; 1) improving the level of cooperation between CSO communities and environmental organizations, 2) integrating development of LTCP implementation of CSO controls with water quality standards, and 3) reconciling water quality standards with well-designed and operated CSO LTCPs without causing extensive economic and social impacts (USEPA, 2001).

2.3 Conventional CSO Control Strategies (Grey Infrastructure)

Numerous approaches have been historically used to minimize combined sewer overflows (CSOs) in urban areas. Traditional infrastructure-based CSO control approaches rely on structural solutions such as large-scale tunneling, transmission/storage, and treatment plant expansion to deliver the collected combined sewage to wastewater treatment plants for treatment before being discharged to water bodies (Raucher, 2009). Conventional approaches for reducing CSOs sought to increase storage or conveyance capacity within the sewer system. One of the most common traditional approaches is in-line storage systems that add storage volumes within the sewer system. Another traditional approach to reduce CSOs is to locate large underground storage tanks at CSO discharge points. These systems generally store, and in some cases pretreat, combined sewage before discharging it back to the sewer systems for treatment at the sanitary wastewater treatment facility which usually has expanded treatment flow capacities during wet weather (Montalto et al., 2007; USEPA 2014).

2.4 Green Infrastructure

Recently, there has been a shift in CSO control strategies, from the traditional grey infrastructure approach (storage/treatment) to a more integrated approach that also incorporates stormwater volume reduction before discharges to the combined sewer (green infrastructure).

CSO consent decrees have started to incorporate this integrated approach at the urging of local environmental groups and after economic analyses. There remains uncertainty with this integrated approach, especially concerning the full-scale field performance, actual costs, and required maintenance (both short-term and long-term) of the green infrastructure components. Therefore, some communities are conducting demonstration projects to obtain actual local experience that will guide them for more accurate design evaluations.

According to EAP (2013), “Green infrastructure is a cost-effective and resilient approach to our water infrastructure needs that provides many community benefits.” Tzoulas et al. (2007) indicated that green infrastructure might comprise “all natural, semi-natural and artificial networks of multifunctional ecological systems within, around and between urban areas, at all spatial scales.” A common consideration among all different definitions of green infrastructure is the emphasis on environmental, social and economic benefits, as well as supporting sustainable communities (Newell et al., 2012).

Using vegetation, soils, and natural processes (USEPA, 2014), green infrastructure manages stormwater where it falls (Dunn, 2010). Therefore, green infrastructure can have many benefits, including: reducing stormwater discharges and combined sewer overflows, mitigating flood risks, recharging groundwater, cooling urban areas by shading building surfaces, reducing air temperature, enhancing the ecological value of water for wildlife, and providing social benefits by creating green jobs (Weber et al., 2006; Montalto et al., 2007; Tzoulas et al., 2007; Dunn, 2010; Spatari et al., 2011, Larson et al., 2013; USEPA, 2014).

There are several types of green infrastructure facilities that are used at the scale of a city (or county), and neighborhood (or site). The most common types of green infrastructure includes bioretention facilities (and subcategories, including rain gardens, curb-cut biofilters, curb-extension biofilters, etc.), bioswales, permeable pavement, green roofs, rainwater harvesting systems, and planter boxes (USEPA, 2014). Other traditional stormwater volume reduction controls include dry wells, injection wells, bottomless catchbasins, infiltration trenches, and percolating ponds (infiltration ponds). In the following sections, some examples of green infrastructure are described, including rain gardens (bioretention/bioinfiltration), permeable pavements, dry wells, and rainwater harvesting cisterns.

2.4.1 Rain garden/Bioinfiltration/Bioretention

Bioretention facilities, also known as bioinfiltration cells or rain gardens, are one of the most common types of green infrastructure in urban areas. These collect and absorb runoff from adjacent impervious surfaces (i.e. rooftops, streets, parking lots, driveways, sidewalks). These infiltration practices are designed to allow stormwater runoff to infiltrate, recharge groundwater, reduce peak flows, and filter pollutants (USEPA, 2012). A typical stormwater bioretention system consists of different components including (from top to bottom); water storage zone, vegetation (usually native vegetation including various grasses, shrubs, and small trees), a layer of engineered soil media (selected for its hydraulic and water quality benefits), and a subsurface water storage layer (if an underdrain is used, making it a biofilter). During storm events, runoff from adjacent areas enters the bioretention system to be infiltrated. The vegetation layer helps to maintain soil porosity and promote biological activity. Runoff from short periods of intense storms can temporarily pond on the surface up to a certain depth (usually 15-20 cm), while an underdrain (if used) collects filtered water to a storm drain system (Davis et al., 2001; Davis, 2008). Figure 2.2 shows a schematic of a bioretention. In a combined system, the use of an underdrain may result in substantial amounts of surface runoff being redirected to the combined sewers with minimal volume losses. However, the flows to the combined sewer are usually delayed (usually by minutes to a few hours), reducing the time when the peak flows enter the treatment plant, hopefully reducing the discharge of untreated CSOs. If no underdrains are used, more of the water will infiltrate, but if the natural infiltration rates are poor, surface ponding is rapidly consumed and overflowing water is directed to the combined sewer with minimal treatment and extended ponding may cause nuisance mosquito problems.

Rain gardens are usually simplified as small bioretention devices on private property. They are usually constructed by excavating a shallow depression and possibly tilling in an organic soil amendment to the surface soils. They are vegetated with suitable plants that can withstand the frequent flooding and drying conditions. They do not have underdrains, and any surface overflows are directed to the drainage system.

Many researchers have studied the performance of bioretention devices in reducing stormwater runoff volumes (Hunt and Jarrett, 2004; Dietz and Clausen, 2005; Sharkey and Hunt, 2005; Davis, 2008; Hunt et al., 2008; Hatt et al., 2009; Brown and Hunt, 2010; DeBusk and Wynn, 2011) and for enhancing water quality (Clark and Pitt, 1999; Clark 2000; and many of the previously listed researchers), both in the laboratory and in the field. The composition of bioretention filter media, and its associated characteristics, affect the bioretention system’s performance (Davis et al., 2001; Pitt et al., 2002 and 2008; Dietz and Clausen, 2005; Hatt et al., 2009; Hunt et al., 2008). Monitored results indicate that bioretention devices are capable of removing substantial amounts of the stormwater runoff and associated pollutants. Generally, for use in an area having a combined sewage system, pollutant control for underdrain or surface overflows that discharge to the combined sewerage is not very important, as the sewage treatment plant will provide excellent pollution control. Infiltrating water that recharges the groundwater, however, benefits from treatment by the media to minimize groundwater contamination potential. Biofilters have been shown to reduce the concentrations of an extensive range of stormwater pollutants, including total suspended solids (TSS), nutrients (N, and P), heavy metals, oil/grease and bacteria, from the water treated by the engineered soil/media. However, some media (especially composts) can add significant amounts of nutrients to the treated water. The selection of the treatment media is therefore critical to provide the desired treatment while minimizing any detrimental effects on the water.

Water quality performance is determined either by comparing the pollutant masses of the contaminants in the influent to the effluent (which is affected by volume reductions and by pollutant reductions), or by comparing the pollutant concentrations (which are not directly affected by the reduced runoff volumes due to infiltration).

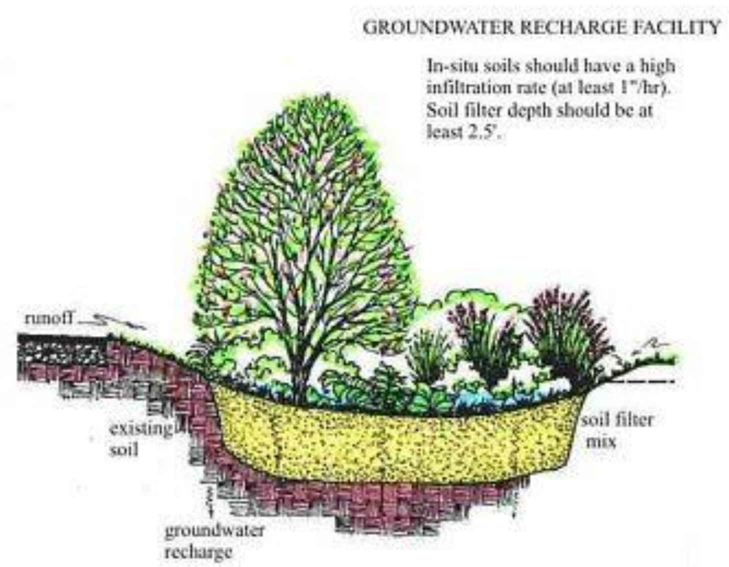


Figure 2.2. Schematic of a bioretention area (Source: www.epa.gov)

Bioretention facilities have the potential to decrease runoff volume, reduce runoff peak flows, and delay the peak runoff. Their effectivenesses vary greatly due to design, selection of materials, and most importantly, by the amount of runoff to be treated (Hunt et al., 2008; Hatt et al., 2009; Li et al., 2009; Yang et al., 2010). Hunt et al. (2008) examined a bioretention cell receiving runoff from an asphalt parking lot area for 23 events. Their analyses showed 96% peak flow reductions for precipitation events of less than 40 mm. In another study, Li et al. (2009) studied six bioretention cells; two systems in Maryland (one monitored for 22 storm events and the other one for 60 storm events) and four systems in North Carolina (two monitored for 46 storm events, and two monitored for 31-33 storms events) over a 10-15 month period. Their results indicated that all measurable storm events had peak flow reductions (peak flow rate ratio of effluent to influent (R_{peak}) <1). The predicted exceedance probability to achieve the target R_{peak} value (<0.33) ranged from 70% to >99% for different cells. The R_{delay} value (the peak discharge time span ratio of effluent to influent) ranged from 3 to 200, with predicted exceedance probability of 25%-80% to meet the R_{delay} target (>6). Except for one of the bioretention cells, others were found to meet the f_v (the effluent/influent volume ratio) target (<0.33) with probabilities ranging from 40% to 70%. They concluded that the media depth is the most significant factor affecting the hydrologic performance of a bioretention system. Increasing depth increases the holding capacity of the system due to increased void space, increases the contact time which could increase the water pollutant control, and increases the water pollutant capacity before failure (assuming the surface area remains constant). They also found that performance decreases with larger rainfall depths and longer rainfall durations. Table 2.3 summarizes the hydrology performance of bioretention facilities from different studies.

Table 2.3. Summary of hydrologic performance of bioretention facilities from different studies

Study	Flow Volume Reductions	Peak Flow Rate Reductions
Hunt and Jarrett, 2004	46 (winter) to 93 (summer)	
Dietz and Clausen, 2005	98.8	
Sharkey and Hunt, 2005		10.2 to 19.3 (Lined cell) 11.2 to 23.6 (Unlined cell)
Hunt et al., 2006	50	
Davis, 2008	55 to 70	49 to 58
Hunt et al., 2008		96.5
Lewis et al., 2008	42 (range: 15 to 83)	80 (range: 45 to 96)
Hatt et al., 2009	33	80
Brown and Hunt, 2010	62 to 89	
Yang et al., 2010		56 (monophasic) 80 (biphasic)
DeBusk and Wynn, 2011	97	99
Minimum	33	10
Maximum	98.8	99
Average	67	55

Bioretention facilities are capable of removing nitrogen-containing compounds through various mechanisms such as plant uptake and denitrification, adsorption, long-term storage in soil organic matter, and immobilization (Dietz and Clausen, 2005; Hunt et al., 2006 and 2008; Blecken et al., 2007; Bratieres et al., 2008; Lucas and Greenway, 2008; Read et al., 2008; Hatt et al., 2009; Collins et al., 2010). Many studies have reported moderate to good removal for total Kjeldahl nitrogen (TKN) and ammonium (Davis et al., 2001, Henderson et al., 2007; Hunt et al., 2008; Smith, 2008). However, in almost all studies (both laboratory and field), poor to moderate rates of nitrate removal have been observed, as nitrate is a very mobile anion in soils and does not absorb onto soil media (Davis et al., 2001, 2009; Hsieh and Davis, 2005; Hatt et al., 2008, Yang et al., 2010).

Numerous studies have indicated the success of bioretention in reduction of total phosphorus (TP) (i.e. 80% removal of TP (Davis et al., 2001); 70-85% removal rate (Davis et al., 2006); 63-85% removal (Hsieh et al., 2007b); 85-94% removal (Henderson et al., 2007); 31% removal (Hunt et al, 2008); about 85% removal (Bratieres et al., 2008)). In contrast, some studies have noted the production of phosphorus in effluent, likely due to the presence of high phosphorus-index soils (soils containing excess amounts of phosphorus) or organic composts in bioretention facilities (Hunt et al., 2006; Treese et al., 2012). Therefore, filter media selection is critical in order to achieve effective phosphorus removal (Bratieres et al., 2008; Davis et al., 2009).

Removal rates of heavy metals (copper, lead, and zinc) at bioretention facilities are typically very high (greater than 90%) (Davis et al., 2001 and 2003; Dietz and Clausen, 2005; Hatt et al., 2009). Studies have also noted that the plant uptake of heavy metals, such as Cd, Pb, and Zn, is influenced by temperature, resulting in higher plant uptake at 25◦C than 15◦C (Hooda and Alloway, 1993; Antoniadis and Alloway, 2001). In contrast, Cu removal improves at lower temperatures likely due to more biological activity in filter media at higher temperature, which causes an increased release of Cu with dissolved organic matter from root turnover (Blecken et al., 2011).

Fecal coliform and *E. coli* effluent levels in bioretention facilities are variable depending on the filter media, vegetation, exposure to sunlight, climate conditions (dry/humid), and hydraulic retention time. Previous studies have shown fecal coliform and *E. coli* removal rates generally greater than 50% (Barret, 2003; Hunt et al., 2008; Rusciano and Obropta, 2007; Zhang et al., 2010; Kim et al., 2012). Two major removal mechanisms of bacteria from bioretention facilities include straining and sorption, however, sorption is the most likely removal process for *E. coli* due to its small size (Zhang et al., 2010; Kim et al., 2012).

Significant reductions in total suspended solids (TSS) concentrations have also been observed in bioretention facilities, with removal efficiencies ranging between 45% to more 99% (Davis et al, 2001; Barret, 2003; Hsieh and Davis, 2005; Hatt et al, 2007; Hunt et al, 2008; Li and Davis, 2008). Field experiments in the city of Charlotte, NC from 2004 to 2006, indicated approximately 60% reductions in TSS concentrations (Hunt et al., 2008). However, some of the effluent TSS was believed to be partial washout of the bioretention media (Hseih and Davis, 2005).

2.4.2 Permeable Pavement

Permeable pavement infiltrates stormwater from runon from adjacent areas and, more commonly, from the direct rainfall onto the porous pavement. Permeable pavements can be made from porous asphalt, pervious concrete, or permeable interlocking pavers. A typical pervious concrete pavement comprises (from top to bottom) of 1) a permeable layer of concrete ranging from 4 to 8 inches depending on the traffic loads, 2) a bedding layer with thickness of 1 to 2 inches, consisting of small-sized aggregate to support the pervious concrete, 3) a base aggregate storage layer which is typically 6 to 24 inches consisting of crushed stones with high infiltration rates, 4) a sub-base layer with larger stones that the base layer, 5) an optional underdrain system to facilitate water removal from base and sub-base (located near the top of the storage layer to encourage infiltration), and 6) the natural soil (USEPA, 2014). Figure 2.3 illustrates an example pervious concrete pavement section. Filter fabrics are currently not recommended as they have been found to prematurely clog from infiltrating silts.

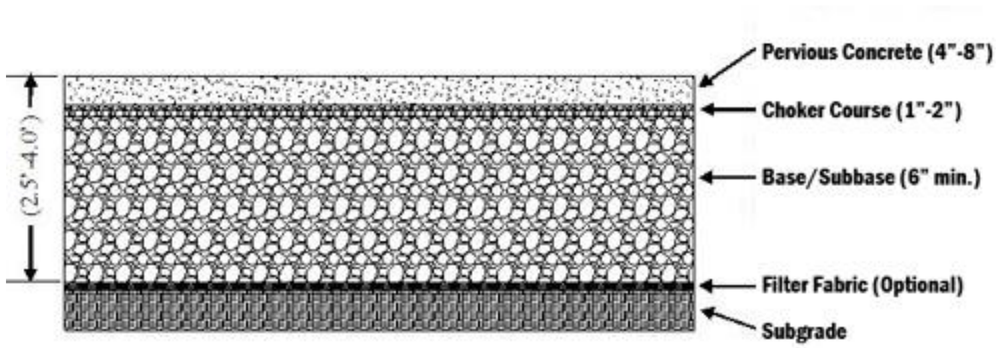


Figure 2.3. Typical pervious concrete pavement section (Source: www.epa.gov)

While permeable pavements significantly reduce the stormwater runoff volume from the treated area, the design characteristics, especially the filter media size and shape influence the hydraulic performance of these systems (Scholz and Grabowiecki, 2007). Since these systems partially filter the infiltrating stormwater, or allow fines to settle and be trapped in the base layer, permeable pavement systems can clog. Therefore, adequate knowledge of infiltration process, clogging, and maintenance cycles are key factors in the expected performance of permeable pavements (Sansalone et al., 2012)

Many studies have reported large improvements in stormwater quality for permeable pavement installations due to trapping of pollutants including; solids (TSS and SS), nutrients (i.e. nitrogen and phosphorus), heavy metals, herbicides and pesticides, oil and grease, and bacteria (Legret and Colandini, 1999; NCDENR, 2005; Gilbert and Clausen, 2006; Scholz, 2006; Scholz and Grabowiecki, 2007).

As a source control technique, permeable pavements may reduce solids and heavy metals concentrations in stormwater runoff by two thirds compared to traditional paved materials (Fassman, 2012). Permeable pavements are capable of effectively decreasing concentrations and loadings of metals such as Cu and Zn (Pagotto et al., 2000; Brattebo and Booth, 2003; Rushton, 2001). For example, Legret et al, (1996) studied a porous asphalt pavement system during 30 rainfall events and reported 64% and 79% reduction in suspended solids and lead concentrations, respectively.

Some studies have examined nutrient removals in permeable pavement systems and have reported generally low TN removal rates (Pagotto et al., 2000; Gilbert and Clausen, 2006; Bean et al, 2007; Collins et al, 2010). Similar studies have observed total phosphorus removal via adsorption of TP to the base and sub-base materials (Gilbert and Clausen, 2006; Bean et al, 2007). For instance, Bean et al., (2007) compared three types of permeable pavements to asphalt; permeable interlocking concrete pavers (PICP), porous concrete, and concrete grid pavers. They showed that concentration of total Kjeldahl nitrogen, ammonia, and total phosphorus in permeable pavement exfiltrates were significantly lower than asphalt surface runoff.

2.4.3 Dry Wells

A dry well, also known as a seepage pit, is a shallow subsurface disposal system that receives stormwater runoff from the surrounding areas for subsurface infiltration to shallow groundwaters. Dry wells normally receive water directly from roof drain leaders or by storm drain inlets located in driveways or small parking lots. Dry wells can significantly reduce the stormwater runoff volume for the treated areas. The main benefits of dry wells is reducing surface flows and simultaneously recharging groundwater aquifers (USEPA, 2012; Pennsylvania Stormwater BMP Manual, 2006). However, dry wells are not likely to provide significant water quality improvements during the disposal operations (Pitt and Talebi, 2012). Figure 2.4 is an illustration of a generic dry well with its main components labeled from the New Jersey Stormwater Manual.

Regulations and manuals for dry wells vary for different states. For instance, the New Jersey Stormwater Best Management Practices Manual (Standard for Dry Wells – Chapter 9.3) includes specific design criteria for dry wells used for the disposal of stormwater. It requires sufficient storage volumes in the dry well to contain the design storm runoff volume without overflow, while the subgrade soils' permeability rate must be sufficient to drain the stored runoff within 72 hr. For infiltration purposes, the manual requires Hydrologic Soil Group A and B soils with a minimum permeability rate of 0.5 in./hr (12.7 mm/hr) for dry wells designed for storms greater than the groundwater recharge storm. The New Jersey manual also only allows roof runoff to be discharged to dry wells for groundwater recharge.

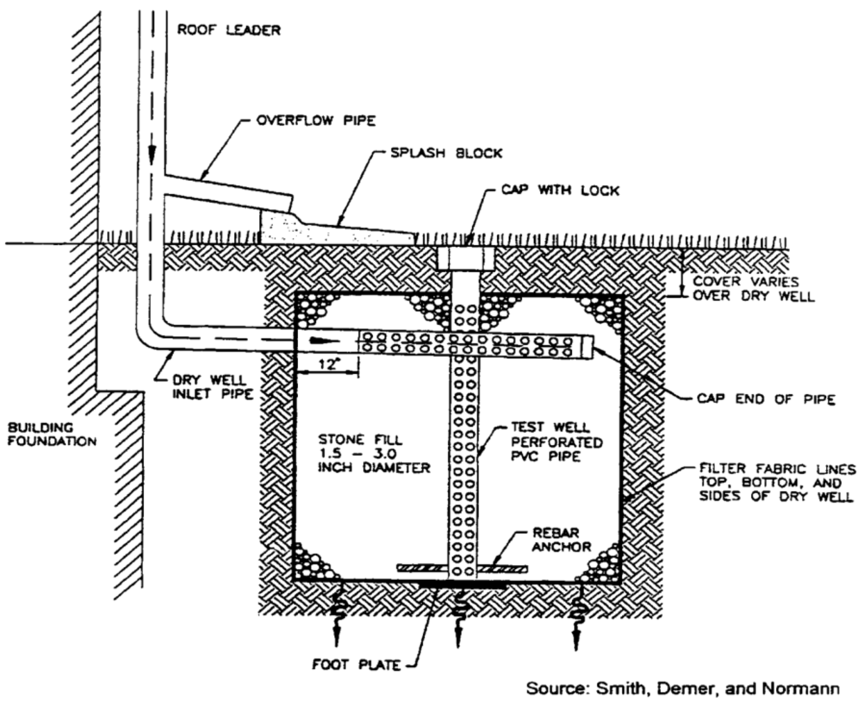


Figure 2.4. Example dry well included in the New Jersey Stormwater Manual. (Source: Adapted from Standards for Soil Erosion and Sediment Control in New Jersey)

Different studies have examined the impact of drywell discharges on groundwater quality. From 2008 to 2011, a USGS study examined the potential effects of roadside dry wells on groundwater quality on the Island of Hawaii. The study used a numerical method to simulate the groundwater flow, with an infiltration pulse of 5 ft^3/s for 1 hour containing a hypothetical nonreactive contaminant. The results indicate that depending on the rate of infiltration, dilution of contaminated surface water with non-contaminated water in a saturated aquifer quickly decreases the contamination concentration. At a horizontal distance of 0.5 mile downgadient from the dry well, the simulated concentrations were less than 0.1 percent of the concentrations in the infiltration model (Izuka and Johnson, 2009; Izuka, 2011) due to dilution with non-contaminated site water. Pitt, et al (2013) found that dry wells provided no measureable water quality improvements when comparing water exiting the bottom of dry wells with percolating waters sampled below 2 ft. of gravel plus at least 2 ft. of natural soils beneath the dry well perforated tanks. They concluded that dry wells are a safe stormwater disposal method as long as the influent water was of acceptable quality. However, they found that lead and bacteria concentrations in the infiltrating water exceeded the New Jersey groundwater disposal criteria, even when only disposing roof runoff.

2.4.4 Rain Water Harvesting/Cistern

Rainwater harvesting (RWH) is a technology used for collecting, storing, treating, and re-distributing rainwater that falls onto impervious surfaces, mostly rooftops. An appropriately designed rainwater harvesting system collects runoff from impervious surfaces, stores it in storage tanks, and re-uses the collected water as a resource for different purposes. These systems could be efficiently applicable in arid regions to reduce demands on increasingly limited water supplies. A typical RWH system generally comprises the catchment area, conveyance system, storage tank, treatment system, and re-distribution network (USEPA, 2014).

In a RWH system, stormwater runoff from the catchment area (i.e. rooftop, parking lot, landscaped area, and street) is directed to a collection point, where the conveyance system carries the stormwater to the storage tank. The sizing of the storage tank/cistern is a key factor to maximize stormwater capture and water use efficiency. The storage tank should have adequate capacity to retain the desired water volume for each storm event, resulting in runoff volume reductions at the site. On the other hand, storage tank costs are the largest component of the total RWH system cost (Chilton et al., 2000). There is substantial literature concerning evaluations of the performance and sizing of rainwater harvesting systems. The results indicate that storage tank size greatly depends on site-specific variables such as local precipitation patterns and climate, the catchment area, and end use water type and demand (Helmrich and Horn, 2009; Mwenge Kahinda et al., 2010; Aladenola and Adeboye, 2010; Campisano and Modica, 2012; Talebi and Pitt, 2012).

The collected stormwater from storage tanks may have several potable and non-potable beneficial uses including irrigation, garden watering and maintenance, toilet flushing, clothes washing, window washing, vehicle washing, fire stations, commercial/industrial cooling systems, construction activities, drinking and cooking, etc. Due to stormwater contamination, water treatment is often needed for the collected water in storage tanks/cisterns to meet the water quality criteria for different uses, and to minimize health risks associated with rainwater reuse. The type and degree of treatment, which is determined based on the type of end use, varies from simple filtration to ultra-violet (UV) lights. Filtration eliminates contaminants, along with supplying oxygen to water through the filtration process. Disinfection and filtration is used to remove some bacteria and viruses. Application of chlorine, ozone, and UV light are three common methods of disinfecting. Potable uses obviously require a higher degree of treatment compared to non-potable uses (Pitt et al., 2012).

Some rainwater harvesting manuals are starting to incorporate water reuse criteria including numeric bacteria standards for potable and non-potable uses. Most of the bacteria standards were originally written pertaining to the reuse of sanitary wastewaters and do not specifically address stormwater as a source water. Some regulations, however, were prepared to regulate the beneficial uses of stormwater (such as Texas and Virginia). These regulations focus on public health issues and contain restrictive levels for bacteria, with lower allowable limits where public access is not well controlled, and with higher allowable limits for water non-contact situations and where access can be well controlled. Table 2.4 summarizes water quality criteria from available regulations that specifically addressed stormwater beneficial uses (Pitt et al., 2012)

Table 2.4. Summary of water quality criteria in available regulations (Pitt et al., 2012)

State	Use	Bacteria Criteria
Berkeley, California (Berkeley, 2010)	Non-potable indoor uses: Toilet flushing & Laundry Non-potable outdoor uses: Sprinklers, HVAC, Car-washing	Total coliform: <500 cfu per 100 mL Fecal coliform: <100 cfu per 100 mL
	Outdoor uses: Sub-surface irrigation, Rain barrels under 100 gal	No treatment required
Texas (Texas, 2006)	Non-potable indoor uses:	Total coliform: <500 cfu per 100 mL Fecal coliform: <100 cfu per 100 mL Water testing recommended annually
	Potable uses: (Single Family)	Total Coliform - 0 Fecal Coliform - 0 Protozoan Cysts – 0; Viruses – 0 Turbidity < 1 NTU Water testing recommended every 3 months
	Potable uses: (Community or Public Water System)	Total Coliform - 0 Fecal Coliform - 0 Protozoan Cysts – 0; Viruses - 0 Turbidity < 0.3 NTU Water testing required monthly In addition, the water

		must meet all other public water supply regulations and water testing requirements per Texas Commission on Environmental Quality guidance document(s)
Virginia (Virginia 2009)	Potable indoor uses	Total coliforms - 0 Fecal coliforms - 0 Protozoan cysts – 0; Viruses - 0 Turbidity < 1 NTU
	Non-potable indoor Uses	Total coliforms < 500 cfu per 100 mL Fecal coliforms < 100 cfu per 100 mL

2.5 Current Practices of Integrated Green Infrastructure-based Controls in US Urban Areas

Several urban areas in the United States, including Portland, Seattle, Philadelphia, Kansas City, New York, Washington, Louisville, Connecticut and others, have sought to implement integrated green infrastructure-based controls for combined sewer overflows, and many more are or will be applying similar stormwater management frameworks soon (Wise et al., 2010). Despite many green infrastructure practices at small scales in urban areas, very few U.S. cities have invested in green infrastructure at large scales (Madden, 2010).

Philadelphia is one of the most recognizable cities for citywide integrated green infrastructure. In September, 2009, the Philadelphia Water Department finalized the new Combined Sewer Overflow Long Term Control Plan Update (LTCPU) and submitted it to the EPA and the Pennsylvania Department of Environmental Protection (PADEP) for approval. The plan proposed a citywide network of green infrastructure, requiring an investment of $1.6 billion over 20 years to mitigate runoff and CSOs, restore and preserve water bodies by implementing green roofs and green streets, restoring water bodies, greening surface parking lots, and expanding the rain barrel program. The plan is a transition from the gray to green approach (Madden, 2010).

New York City is another well-known city for its green infrastructure plan. In September 2010, the NYC Green Infrastructure Plan was issued to present an alternative approach to enhance water quality and achieve sustainability benefits that integrates “green infrastructure,” such as swales and green roofs into their historical CSO control plans. The NYC GI plan aimed to optimize the existing system and to build targeted, cost-effective “grey” or traditional infrastructure (City of New York, 2010). In March, 2012, the New York State Department of Environmental Conservation (DEC) updated the plan to incorporate an adaptive management approach, committing DEP to:

- manage 10% of the runoff from impervious surfaces by 2030 by constructing green infrastructure at the city scale,
- construct $2 million of green infrastructure in three neighborhood demonstration areas,
- construct $3.4 billion in grey infrastructure, of which $1.8 billion has already been incurred; and
- publish 11 Long Term Control Plans for the control of combined sewer overflows by 2017 (City of New York, 2012).

An often cited example of integrated infiltration stormwater controls at a moderate watershed scale is the Jordan Cove urban watershed project. This area is a small estuary located along the north or Connecticut side of the Long Island Sound. This urban watershed had water quality issues including high concentrations of bacteria, nutrients, sediment, arsenic and dissolved oxygen. Therefore, the main objective of runoff control implementation in this area was to improve water quality, as well as to reduce runoff volume. Three watersheds - control, traditional and green infrastructure (GI) - were monitored for stormwater runoff. Table 2.5 summarizes the characteristics of each study area. The GI features include grass swales, rain gardens, permeable driveways, bioretention areas, and permeable road surfaces. The monitoring results showed that there was a 74% reduction in stormwater volume after the GI construction period. Also, water pollutant exports after construction generally decreased, except for TSS and TP (source: http://www.jordancove.uconn.edu/jordan_cove/publications/final_report.pdf).

Table 2.5. Characteristics of control, traditional and GI watersheds at Jordan Cove area

	Control Watershed	Traditional Watershed	GI Watershed
Area (acres)	13.59	4.95	4.2
Number of lots	43	17	12
Average size of lots (acres)	.40	0.37	0.25
Total impervious (%)	29	32	22

* 1 acre = 4046.85 m^2

In St. Louis, Missouri, a neighborhood with the area of 3.78 acres with 24% impervious area was selected to be treated with GI stormwater controls. In this small demonstration area, rain gardens and planter boxes covered 2,774 ft^2 and 2,961 ft^2, respectively were used to reduce runoff volumes entering the sewer system. In addition, another neighborhood with the area of 4.82 acres was selected as a control area for comparison. The flow meters were installed in three manholes; upstream and downstream of the test area, and downstream of the control area. Comparing the flow from the test and control areas showed 60% reductions in stormwater volume for nine monitored events (Bloorchian et al., 2012).

2.6 Need of Research

As described in this chapter, many studies have evaluated the performance of individual green infrastructure components at relatively small scales, indicating that these features are expected to be effective in reducing runoff volumes (important for combined and separately sewered areas) as well as enhancing the stormwater runoff quality (important for separately sewered areas). While there are numerous applications of green infrastructure at small scales (i.e. single installations), there are only a few demonstrations of integrated green infrastructure at larger scales with explicit real time evaluations of its impacts on reducing flows in combined sewers. However, these past projects have only examined areas from about 5 to 15 acres, much smaller than typical urban watersheds.

Many stormwater management practices are needed to be integrated in a large-scale area (watershed) to achieve the necessary runoff controls and pollutant reductions associated with reduced CSOs. Although different models (such as WinSLAMM, SUSTAIN, and SWMM) predict hydrologic performance and model the water quality of green infrastructure in urban areas, it is important to study the real time pre- and post- construction flow and water quality data at multiple scales to quantify the actual benefits of the integrated green infrastructure components to better calibrate and verify the models.

2.7 Proposed Research

Based on the literature review and current stormwater runoff issues in urban areas, this proposed dissertation research will focus on:

1. Studying small-scale monitoring data of stormwater flow and water quality to measure the benefits of individual green infrastructure facilities.
2. Evaluating large-scale pre- and post- green infrastructure construction flows to confirm the benefits of integrated green infrastructure controls throughout the drainage areas when many of these controls are combined in a larger area.
3. Utilizing a calibrated version of WinSLAMM (a stormwater quality model that incorporates a wide range of sustainable infrastructure unit processes and associated

controls that are tailored for site-specific conditions) for different types of areas to quantify the benefits of design options.

CHAPTER 3.0

HYPOTHESIS AND METHODS

3.1 Hypothesis

The main objective of this research was to examine the effectiveness of retrofitted green infrastructure stormwater controls in small- and large-scale developed urban watersheds in areas served either by separate or combined sewer systems. The literature review and analyses have shown that the individual green infrastructure (GI) stormwater controls can be used to delay and reduce runoff, as well as improving the stormwater runoff quality. Therefore, green infrastructure stormwater controls can address flooding issues and reduce flows in combined and separate sewer systems. As described in Chapter 2, the impacts of individual GI stormwater controls on stormwater runoff quality and quantity at small scale (single installations), have been the subject of extensive prior research. However, few studies have been conducted to evaluate the impacts of integrated green infrastructure stormwater controls on reducing flows in combined sewers at large scales, using real time data. The following hypothesis statement for this dissertation research is based on the literature review and analyses.

Hypothesis:

Retrofitting integrated green infrastructure controls in large areas served by separate or combined sewers can result in significant runoff volume reductions.

Prediction:

Individual green infrastructure stormwater controls, such as rain gardens, bioretention facilities, permeable pavement/pavers, and rainwater harvesting systems, are becoming widely used in urban areas in order to mitigate peak flows, runoff volumes, and enhance water quality. In addition to stormwater management models that can predict hydrologic performance of green infrastructure, it is important to evaluate the real time flow data before and after construction of green infrastructure stormwater controls to verify their actual performance at different scales in the drainage areas. The performance of each stormwater control practice can be highly variable in improving water quality and quantity issues due to drainage area characteristics, different activities occurring in each land use, soil type, and storm event characteristics. The analyses conducted as part of this dissertation research will show that monitoring results for runoff volume reductions from isolated small-scale stormwater controls can be scaled-up for use in typical drainage area benefit predictions, but only if sufficient information is available (such as soil characteristics, land development, actual area treated, etc.).

Research Activities:

a. Examine the watershed areas and quantify the variability in land development characteristics based on available topographic information and high-resolution aerial photography, using ArcGIS 10, along with field verification and measurements for each watershed.
b. Describe the soil characteristics of the drainage areas based on soil survey websites for surface soils and shallow sub-surface soils, verified with site soil monitoring.
c. Determine long-term infiltration characteristics of individual GI stormwater controls after storm events.
d. Examine the effects of soil types, storm event characteristics, and land development characteristics on the infiltration behavior of individual green infrastructure stormwater controls based on field infiltration measurements during actual storm events.

e. Determine the base flow, and the dry and wet weather flow components of the flow time series in sanitary sewer lines.
f. Prepare individual storm event summaries that are coordinated with the rain data for each monitoring point, including rainfall and runoff characteristics such as start/end time of rain, rain duration, antecedent dry days, total rain, peak and average rain intensity, pipe-flow start/end time, total pipe-flow discharge volume, total runoff, peak and average flow discharge rates, R_v (the ratio of runoff to rainfall depth).
g. Compare runoff characteristics before and after stormwater control construction in order to measure the benefits of green infrastructure-based controls and to quantify the overall runoff volume reduction actually achieved at the demonstration locations.
h. Utilize a calibrated version of WinSLAMM (a stormwater quality model that incorporates a wide range of sustainable infrastructure unit processes and associated controls that are tailored for site specific conditions) to model GI stormwater controls at each study area to predict performance of control options for varying conditions.
i. Compare the observed event summary statistics with expected runoff responses from WinSLAMM model for each study area.

<u>Critical Tests1:</u>

a. Create box and whisker plots to graphically represent the infiltration data differences and to identify groupings of infiltration characteristics (Horton's coefficients) that explain the variabilities in individual green infrastructure control performance.
b. Perform non-linear regression analysis to fit the observed infiltration data to Horton's equation, in order to identify Horton coefficients for individual green infrastructure stormwater controls after different storm events (prior research has identified the Horton

equation to be the most suitable infiltration equation for these types of controls in disturbed urban soils, especially for ponded conditions as present in GI controls).

c. Perform One Way ANOVA or Kruskal-Wallis tests (depending upon data distribution types) for infiltration data to examine whether the data can be grouped based on different soil characteristics at the stormwater control locations.
d. Create daily time series plots for dry weekdays and dry weekends within each month to examine the overall base flow patterns and to identify specific errors or lag periods in the sanitary sewers at the monitoring locations to separate dry weather components from the wet weather flow observations.
e. Create run chart plots (Using Minitab) along with trends, and clustering tests that provide information on non-random variation due to trends, oscillation, mixtures, and clustering. These were done to examine weekday base flows and weekends base-flows for each month at each monitoring location in the sewer lines.
f. Compare the stage-discharge relationship plots for before and after stormwater controls construction for each site to verify the quality of data.
g. Perform analyses of best fitted Manning's equation for each flow monitoring location in sewer lines to verify the quality of data.
h. Conduct One Way Analysis of Variances or Kruskal-Wallis tests to indicate any significant differences between before and after stormwater controls construction periods.
i. Conduct Mann-Whitney Rank Sum Test to compare the observed runoff volumes with the modeled runoff volumes (using WinSLAMM).
j. Create box and whisker plots to graphically compare runoff volumes for different study periods (before and after construction).

k. Based on these analyses, evaluate different monitoring strategies to identify the most effective evaluations of large-scale GI performance.
l. Demonstrate the use of the calibrated WinSLAMM model to predict the best combinations of GI controls retrofitted into different types of areas.

3.2 Methodology

This dissertation research focuses on green infrastructure stormwater control performance at both small scales (individual practices), and large scales (integrated practices in large drainage areas). At small scales, infiltration measurements from individual stormwater controls including drywells and biofilters were applied to measure the benefits (such as runoff volume reductions). In addition, the effects of soil types, storm event characteristics, and land development characteristics on the infiltration behavior of individual green infrastructure stormwater controls were examined. At large scales, direct measurements of flow from in-system flow monitors placed in combined or separate sewers affected by individual green infrastructure devices were evaluated. Real-time rainfall and runoff data from combined and separate sewer systems affected by GI stormwater controls in upstream areas were analyzed both before and after construction of the stormwater controls. Then, the runoff characteristics of the pre- and post-construction conditions were compared to measure the benefits of integrated GI stormwater controls at large scales.

This dissertation research focus on three case studies associated with recent or on-going research at the University of Alabama, including: a) the Township of Millburn, New Jersey, b) Kansas City, Missouri, and c) Cincinnati, Ohio, as described in Table 3.1.

Table 3.1. Summary of case study characteristics

<table>
<tr><th>Case Study</th><th>Scale</th><th colspan="2">Type of Data</th></tr>
<tr><td rowspan="2">Millburn, NJ</td><td rowspan="2">Small scale</td><td rowspan="2">Infiltration data at dry wells</td><td>Control tests using township water from fire hydrants</td></tr>
<tr><td>Actual rain events</td></tr>
<tr><td rowspan="2">Kansas City, MO</td><td>Small scale</td><td colspan="2">Infiltration data of biofilters during actual rain events</td></tr>
<tr><td>Large scale</td><td colspan="2">Rainfall data and flow monitoring data in combined sewer systems affected by many GI controls.</td></tr>
<tr><td>Cincinnati, OH</td><td>Large scale</td><td colspan="2">Rainfall data and high resolution flow monitoring data from combined sewer systems and separate stormwater systems using several different monitoring strategies and several types of GI controls.</td></tr>
</table>

The Millburn, NJ project is a small-scale case study which uses dry wells as stormwater infiltration controls. The main objective of the Millburn's project was to investigate the effectiveness of the Township of Millburn's use of on-site dry wells to reduce stormwater flows into the local drainage system associated with land development modifications at small scales. The Kansas City, MO project is one of the largest projects in the United States using extensive GI controls in a completely monitored 100-acre neighborhood that encompasses implementation of over 100 green infrastructure-based stormwater controls along with sewer rehabilitation. Therefore, the Kansas City, MO case study provides an opportunity to evaluate the benefits of GI stormwater controls at small scales (using infiltration data from individual GI stormwater control monitoring), and large scales (overall impacts of all GI controls on 100-acre neighborhood and combined sewer systems compared to adjacent control watershed). The Cincinnati, OH project represents several studies at large scales that include implementation of integrated watershed based GI stormwater controls to reduce CSO volumes. In the Cincinnati case studies, the flow monitoring data obtained in the sewer lines after construction were compared to before construction conditions, while in the Kansas City case study, an adjacent 86-acre sub-watershed with no stormwater controls, along with "before" and "after" flow conditions in the test watershed were used for comparisons. Figure 3.1 is a linear Venn diagram showing how the case studies were investigated during this dissertation.

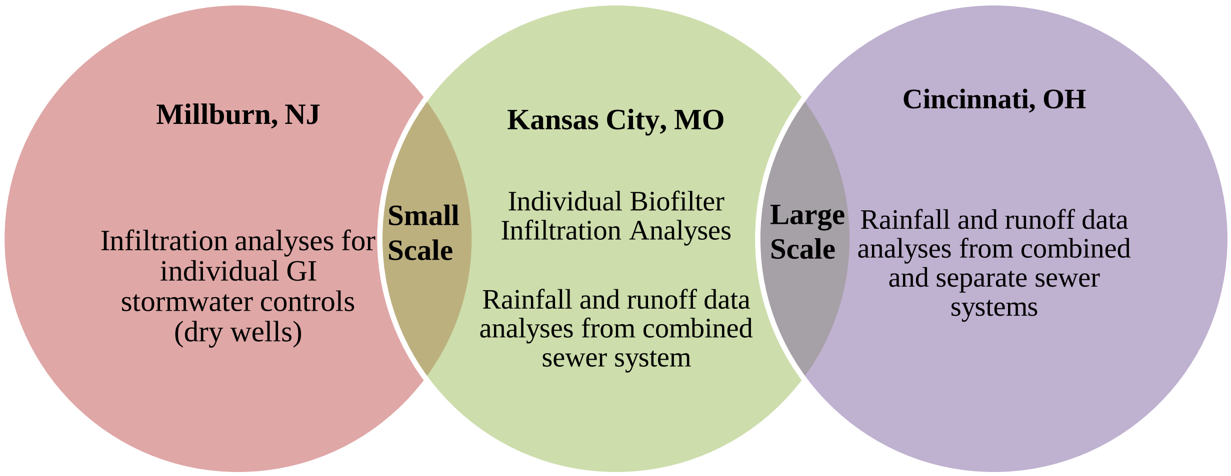


Figure 3.1 Linear Venn Diagram of case studies

This chapter is structured as follows:

- First, brief descriptions of the geographical locations of each case study, as well as a brief overview of the background and objectives for each case study are provided.
- Second, detailed descriptions of the green infrastructure features used in the case studies are provided. This includes structural descriptions and typical sizes for thr different types of the GI stormwater controls, along with maps showing the locations of the GI stormwater controls for each study area.
- Third, watershed analyses and land cover descriptions are provided to quantify the drainage area characteristics. High resolution aerial photos available in ArcMap 10 (base map) dataset has been used to identify drainage watershed characteristics of the study areas, as well as different land cover categories such as roofs, streets, parking lots, driveways, landscaped areas, etc.

- Fourth, soil characteristics for each study area are presented (using web soil survey), to evaluate the impact of general soil types on stormwater control performance.
- Fifth, an overview of the WinSLAMM model is provided. In this dissertation research, this tool was used to predict GI stormwater control benefits. The predicted results from WinSLAMM were compared to the measured values and used to illustrate monitoring strategies and predicted GI performance for other conditions.
- Sixth, statistical data analyses used are described. This section explains some selected statistical tests and their applications that were used for data evaluations during this research.

Table 3.2 lists the sources that were used to obtain the information described in this dissertation.

Table 3.2 Source of information described in this dissertation

Document/Material	**Source/Authors**
Millburn, NJ	
Infiltration data	LeveLogger observations conducted by PARS Environmental, Inc., Robbinsville, NJ 08691 (Ramjee Raghavan, Project Manager)
Soil data	http://websoilsurvey.nrcs.usda.gov/
Groundwater data	Michael D. Moore, PG, LSRP, Senior Project Manager, PARS Environmental, Inc., Robbinsville, NJ
Water Quality	Township of Millburn, NJ (Mel Singer, Project Director), and PARS Environmental, Inc., Robbinsville, NJ 08691 (Ramjee Raghavan, Project Manager)
Bing aerial maps	Basemap available in ArcMap 10
GIS layers	http://www.state.nj.us/dep/gis/
Evaluation and Demonstration of Stormwater Dry Wells and Cisterns in Millburn Township, New Jersey	Robert Pitt and Leila Talebi. Urban Watershed Management Branch, U.S. Environmental Protection Agency, Edison, NJ 08837. 302 pages. July, 2012
Kansas City, MO	
100% design plans and street side topographic info.	https://sites.tetratech.com/projects/100-KCADC/default.aspx
Subwatershed shapefile	John Riverson, Tetra Tech (from Sustain KC maps)
Sewer network shapefile	John Riverson, Tetra Tech (from Sustain KC maps)
Stormwater controls shapefile	John Riverson (TT) and https://sites.tetratech.com/projects/100-KCADC/default.aspx

Document/Material	**Source/Authors**
Bing aerial maps	Basemap available in ArcMap 10
Listing of locations and sampling equipment	Table supplied by Dr. Deb O'Bannon, UMKC
USGS topo maps (10 ft contours)	Basemap available in ArcMap 10
Topographic maps (1 ft) jpgs	Project map supplied by Dr. Deb O'Bannon, UMKC
"Monitoring water balance of a rain garden by installation of flow monitoring devices on a residential property." Thesis by Jason Nall, UMKC.	https://sites.tetratech.com/projects/100-KCADC/default.aspx
Site photos	Robert Pitt – Site visit on October 25 and 26, 2012
Modeling of Green Infrastructure Components and Large-Scale Test and Control Watersheds at Kansas City, MO	Robert Pitt, Leila Talebi, Deb O'Bannon, Dustin Bambic, and Jason Wright. Prepared for USEPA and Tetra Tech, 357 pages. December, 2013
Cincinnati, OH	
Arial photos	ArcGIS 10.0, Basemap
Topo maps (1ft), Shapefile	Laith Alfaqih, Project Manager, CH2M Hill, Cincinnati
Flow and rain data	ADS Environmental Services
Enabled Impact Program, Interim Summary Report	Prepared by Project Groundwork, December 2011.
Evaluation of Retrofitted Green Infrastructure Stormwater Controls at Cincinnati State College, the Cincinnati Zoo, and the Clark Montessori High School	Leila Talebi and Robert Pitt. Prepared for Metropolitan Sewer District of Greater Cincinnati and USEPA, 95 pages. October, 2013
Strategies and Experimental Design for Monitoring the Performance of Various Green Infrastructure Controls at Cincinnati Demonstration Project Sites - A Preliminary Strategy and Plan	Robert Pitt and Leila Talebi. Prepared for Metropolitan Sewer District of Greater Cincinnati, Cincinnati, OH. 163 pages. September, 2011

3.2.1 Geographical Locations and Description of Case Studies

3.2.1.1 The Township of Millburn

The Township of Millburn, NJ, is located in Essex County (Figure 3.2), near New York City, and less than 10 miles from Newark International Airport. Millburn has a population of about 20,150 people according to the 2010 US Census. Millburn, NJ, is a mature community of 6,450 acres (about 10 square miles), with less than 15 percent of its land vacant. There are approximately 7,195 total housing units (2010 US census) in the community. The community has a mix of commercial and retail establishments, parks and schools and an upscale shopping mall. There are about 5,900 detached homes in the township and about 1,500 have dry wells. About 60% of the community water supply is from public drinking water wells. The groundwater table is as shallow as 2.4 to 3 m (8 to 10 ft) along the river in town. The soils vary greatly in the community, with large areas having clayey surface soils.

In 1999, the Township of Millburn passed an ordinance that required increased runoff from new impervious areas to be directed into dry wells. The objective of this approach was to reduce local drainage and erosion problems associated with new development and increased impervious areas at currently developed locations. The Township of Millburn has a stable population where there is little vacant land and all new construction within the community occurs on previously developed plots. Table 3.3 lists locations of the study sites in the Township of Millburn where dry well water level measurements were obtained for different rain events during this research. Most of the study sites are residential buildings with one or two families.

Table 3.3. Infiltration Monitoring Dry Well Locations, Township of Millburn, NJ

Infiltration Monitoring Dry Well Location
1 Sinclair Terrace
15 Marion Avenue
258 Main Street
36 Farley Place, Short Hills
7, 9, and 11 Fox Hill Lane
11 Woodfield Drive
142 Fairfield Drive
2 Undercliff Road
260 Hartshorn Drive
383 Wyoming Avenue
8 South Beechcroft Road
87/89 Tennyson Drive

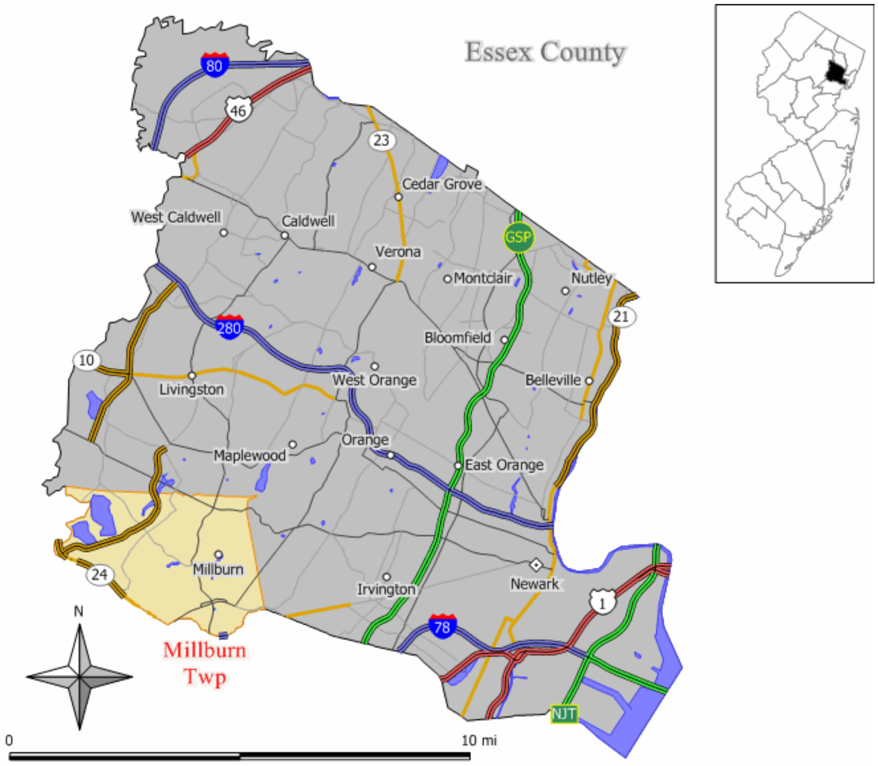


Figure 3.2. Location of the Township of Millburn, NJ

(Source: http://upload.wikimedia.org/wikipedia/commons/5/58/Millburn_twp_nj_013.png)

3.2.1.2 Kansas City, Missouri

Kansas City is the largest city in Missouri and encompasses parts of Cass, Jackson, Clay, and Platte counties (Figure 3.3). In 2012, the Kansas City Water Services Department (KCWSD) completed the construction of a 100-acre pilot project that included more than 100 green infrastructure-based stormwater controls to reduce CSOs. This EPA demonstration project is one of the largest in the United States having several types and scales of performance monitoring. This project was developed by the USEPA's Office of Research and Development (ORD) to measure the benefits of GI solutions on large-scale urban areas (overall pilot project area) and small-scale urban watersheds (individual GI solutions).

The pilot area is a 100-acre subcatchment in Middle Blue River watershed in Kansas City, located between East 74th Street and East 77th Street, and bounded by Paseo Boulevard to the east and Holmes Road to the west (Figure 3.4). Most of the pilot area consists of medium-density residential areas constructed before 1960, with a small portion of strip commercial area along Troost Avenue, and a small part of a school along 75th Street. An adjacent 86-acre subcatchment was also monitored as a control watershed with no stormwater controls for comparison.

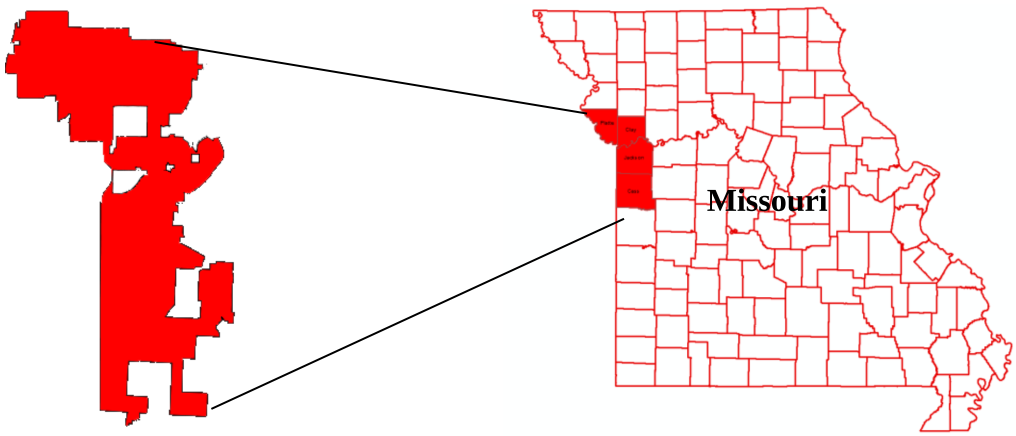


Figure 3.3. Location of Kansas City, MO

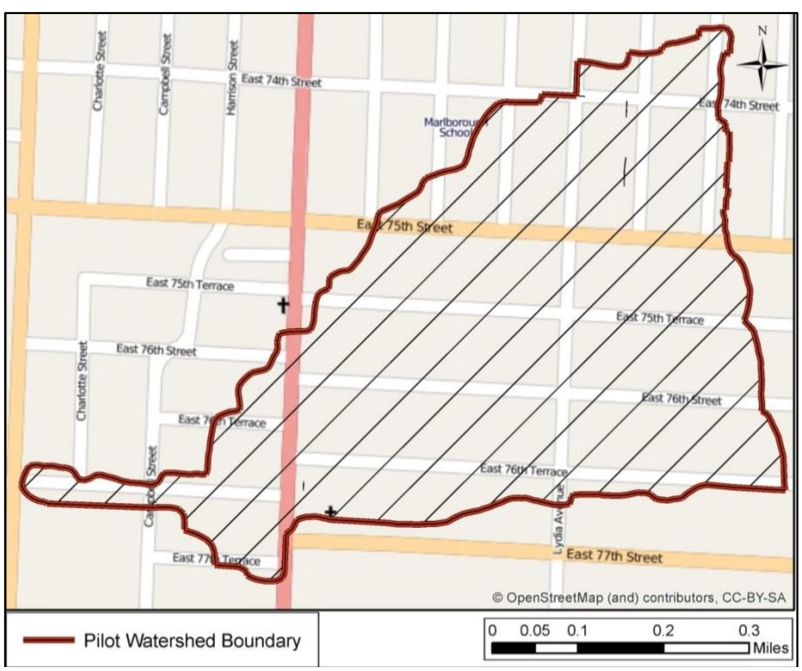


Figure 3.4. Location of pilot watershed area in Kansas City, MO

3.2.1.3 Cincinnati, Ohio

Three study areas in Cincinnati having two years of high-resolution (5-minute) flow measurements from in-system flow monitors located in combined and separate sewers on or adjacent to several green infrastructure installations, were evaluated. The flow data are available for before, during, and after the construction of the stormwater controls at most locations, but comparison areas not having stormwater controls are not available for these locations. Multiple flow monitors were in place at three locations at Cincinnati State College, the Cincinnati Zoo, and the Clark Montessori High School sites. Figure 3.5 is a map of these locations in Cincinnati, OH.

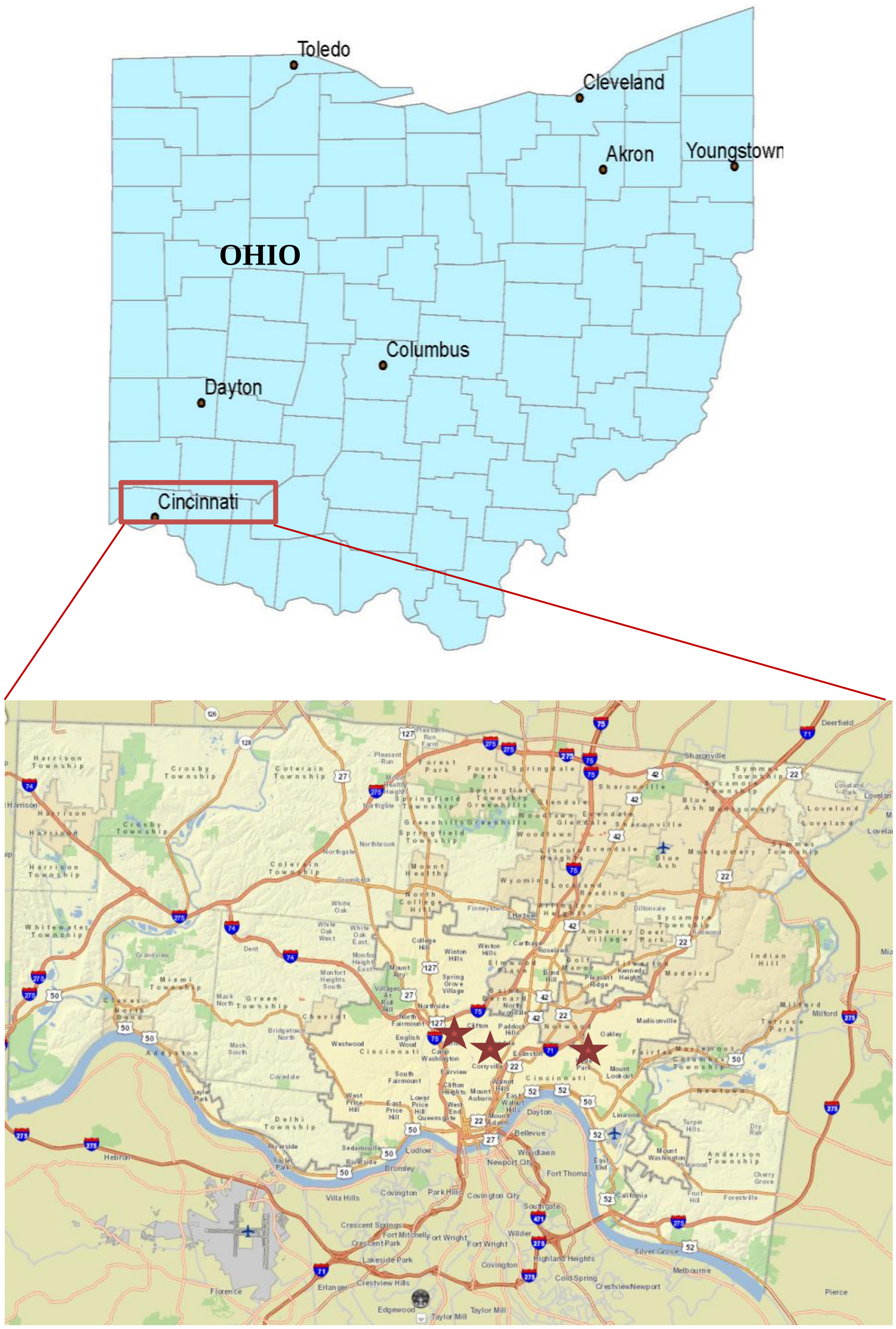


Figure 3.5. Location of Cincinnati, OH (Red stars on the bottom map show the locations of study areas in Cincinnati)

1) Cincinnati State Technical and Community College: The Cincinnati State College occupies approximately a 40-acre institutional area located east of I-75, bounded by Central Parkway to the North and West, and Ludlow to the east. Three monitoring locations describe the flows from this location (Figure 3.6). On the northeast side of the campus hill, a large 72 in combined sewer has a flow monitoring location above and below the confluence of several separate stormwater lines coming from Cincinnati State College areas. On the southwest side of the campus hill, a single monitoring location measures the separate stormwater from a 24 in line from the campus. Therefore, this site provides two typical scenarios for measuring the effects of watershed controls: above and below the discharge location, and monitoring the runoff directly.

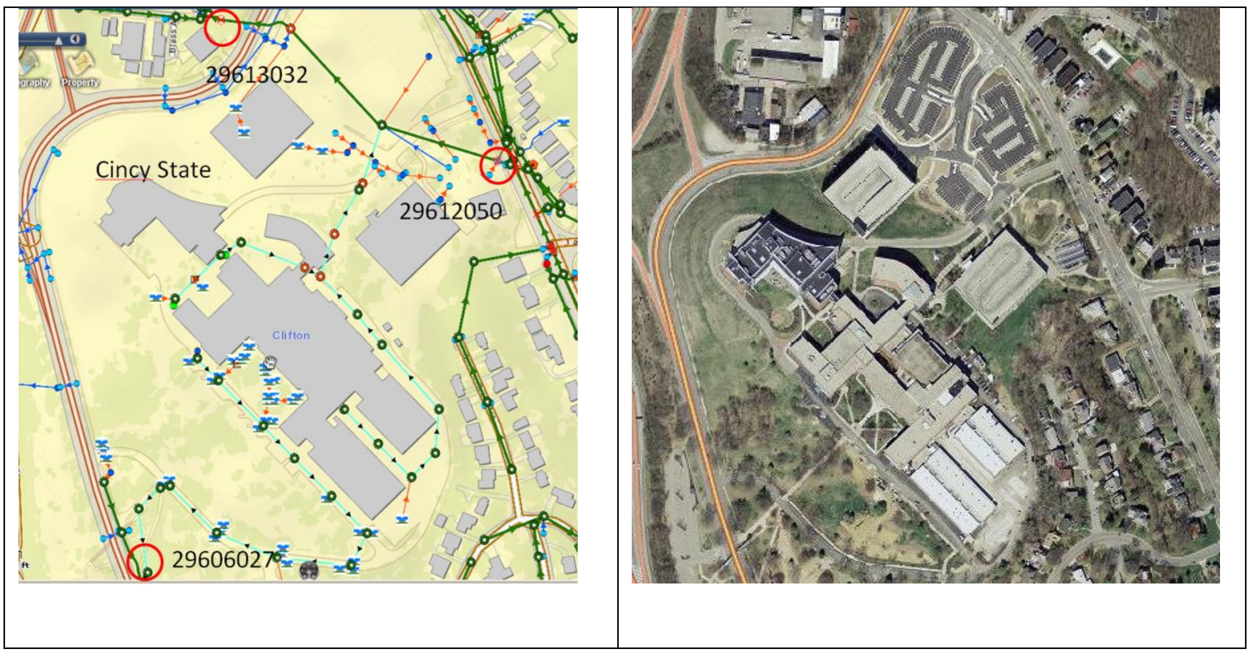


Figure 3.6. Flow monitoring locations (red circles) at Cincinnati State Technical and Community College

2) Cincinnati Zoo: The Cincinnati Zoo is located at the northeast corner of Vine Street and Erkenbrecher Avenue. Two monitoring locations are located at the African Savannah exhibit area (still under construction) and the main entry. The predevelopment conditions at the African Savannah area were a large parking lot, and open space. A flow monitoring station measures the flows in a 36 in combined sewer pipe coming from areas currently undergoing construction of large stormwater storage tanks and numerous smaller controls. The main entry monitoring location examines separate stormwater flows in a 24 in pipe draining areas where prior controls have been installed, including very large areas of porous pavers near the zoo entrance, and other smaller controls. (Figure 3.7)

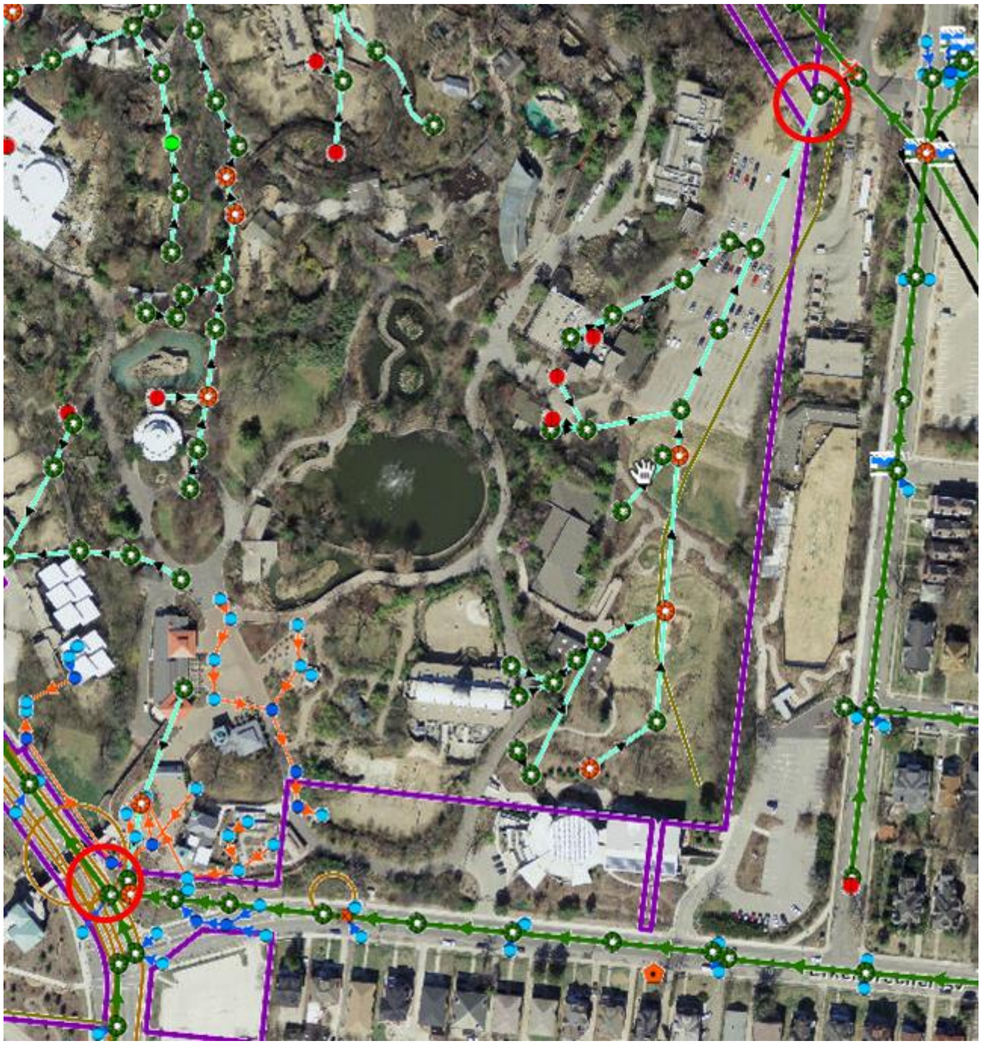


Figure 3.7. Flow monitoring locations (red circles) at Cincinnati Zoo

3) Clark Montessori High School: This high school project area is surrounded by an urban residential area, on Erie Avenue, east of downtown Hyde Park in Cincinnati, Ohio. One monitoring location measures the separate stormwater flows in a 20 in pipe from this newly constructed area before its discharge into the combined sewer system. (Figure 3.8)

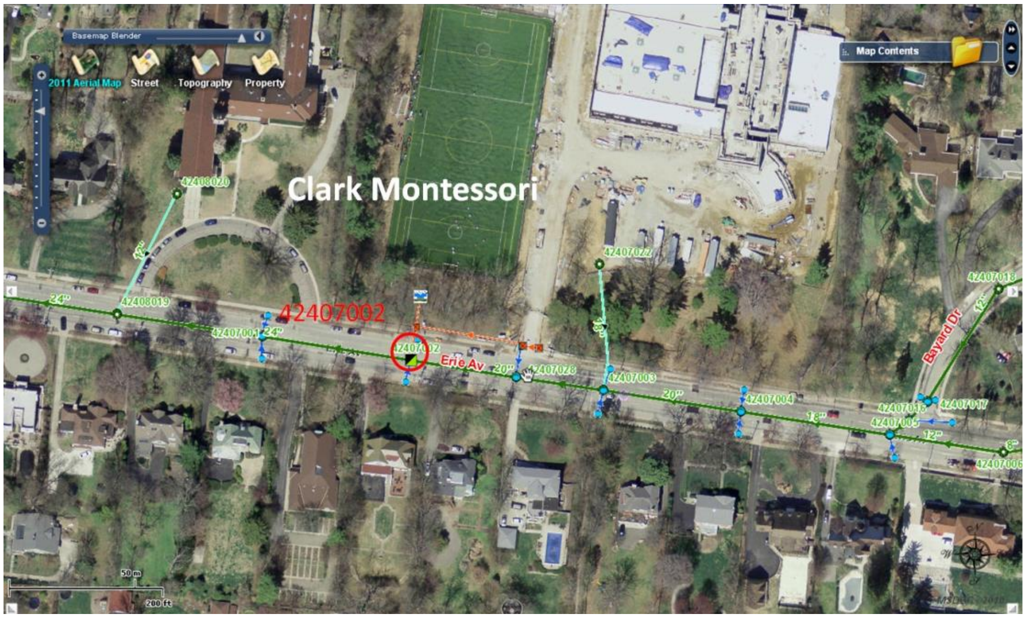


Figure 3.8. Flow monitoring location (red circle) at Clark Montessori High School

3.2.2 Green Infrastructure Features

3.2.2.1 Millburn, NJ

The Millburn Township Development Regulations list dry wells as one option for minimizing increased flows associated with new (and increased) development. A dry well is a subsurface infiltration stormwater disposal practice that receives stormwater runoff from surrounding areas for subsurface disposal to shallow groundwater. Most of the dry wells in the Township of Millburn are precast concrete structures (Figure 3.9), with open bottoms resting on 0.6 m (2 ft) crushed stone layers and with 0.6 m (2 ft) of crushed stone surrounding the dry wells.

Most of the dry wells receive water directly from roof drain leaders or by storm drain inlets located in driveways or small parking lots. Some also have grated covers and receive surface runoff from the surrounding lawn or paved areas.

Figure 3.9. Peerless Concrete Products, Butler, NJ, supplies the dry wells to many of the sites in Millburn (photo from http://www.peerlessconcrete.com/)

Eleven dry wells were monitored for water levels during periods ranging from two months to one year, or by controlled tests using township water from fire hydrants. Four rain gauges were also installed near the dry wells. Figure 3.10 shows typical dry well installations. Figure 3.11 is a large-scale map showing the locations of the study areas in the Township of Millburn.

 Backyard dry well showing lawn area also as a source.	 Backyard dry well showing driveway runoff also as a source.

Figure 3.10. Typical Millburn dry well locations.

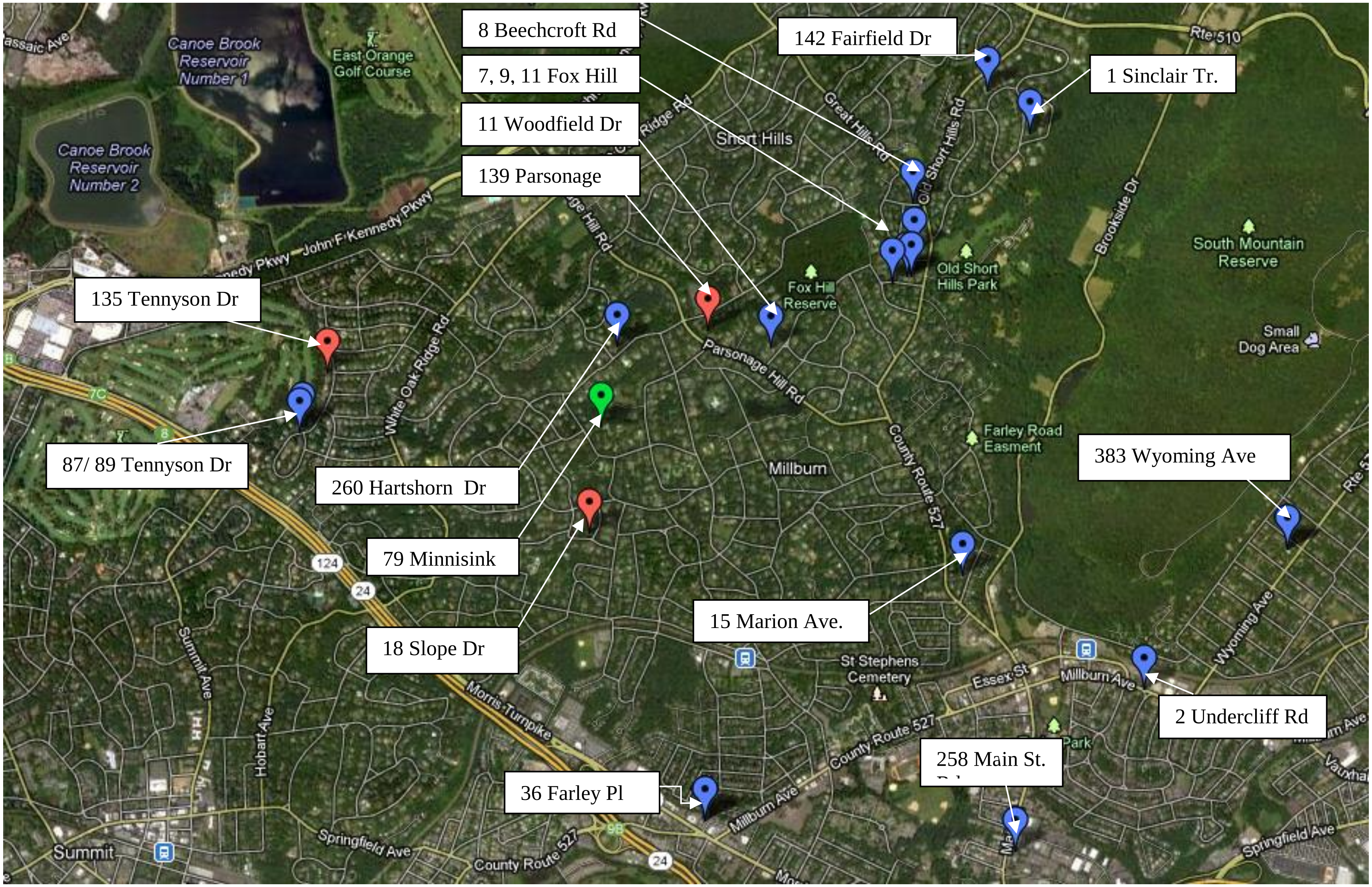


Figure 3.11. Locations of infiltration dry wells (shown with blue icons) and cistern (79 Minnisink, green icon) and water quality monitoring dry wells (shown with red icons) (Source: www.maps.google.com)

3.2.2.2 Kansas City, Missouri

Figure 3.12 shows the layout for the 100-acre pilot study area with the locations of the green infrastructure-based stormwater controls in the study area. There are 158 individual surface features, plus 21 supplemental underground storage pipe systems in this area. Table 3.4 is a list of the different surface and subsurface structural components. The schematic drawings of stormwater controls are also cross-referenced in Table 3.4 for each of the unique design plan component categories. Table 3.5 summarizes typical sizes for each type of stormwater control, based on reviewing several examples from the 100% design drawings.

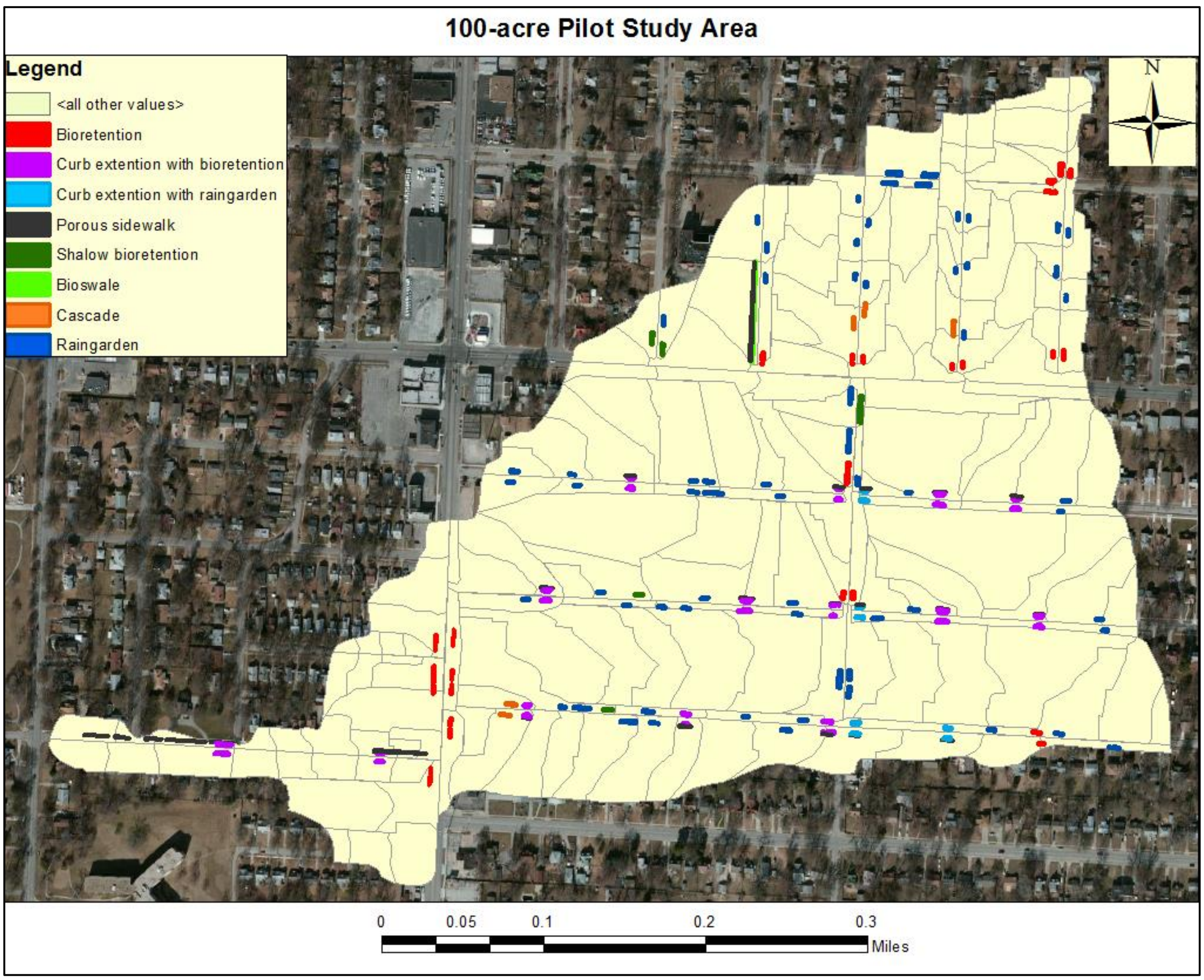


Figure 3.12. Stormwater controls in the 100-acre test (pilot) study area

Table 3.4. Summary of stormwater control design plan components

Design plan component	Structural description	Number of this type of stormwater control	Figure reference*
Bioretention	Bioretention without curb extension	24	Figure A-1
	Curb extensions with bioretention	28	
	Shallow bioretention	5	
Bioswale	Vegetated swale infiltrates to background soil	1	Figure A-2
Cascade	Terraced bioretention cells in series	5	Figure A-3
Porous sidewalk or pavement	With underdrain	18	Figure A-4
	With underground storage cubes	5	
Rain garden	Rain garden without curb extension	64	Figure A-5
	Curb extensions with rain gardens	8	
Below grade storage	Retains stormwater control overflow and underdrain outflow from selected bioretention cells or porous pavement	21	Figure A-6

Source: SUSTAIN report, 2011
* Source: 100% design plans and near-street topographic info.

Table 3.5. Typical sizes of different types of stormwater controls used in the test (pilot) area

Stormwater control type	Examples	Top area (ft^2)	Bottom area (ft^2)	Ponding depth	Total depth to bottom of device	Material
Cascade	1	423.41	105.58	8”–12”	> 16”–20”	Topsoil planting mix on side slopes, engineered soil mix 8-in. min depth on bottom.
	2	316.96	106.73			
	3	290.73	48.16			
	4	283.1	74.12			
Bioswale	1	1,948.86		12”	> 20”	Native soil amended with 3-in. compost, rototilled 8-in. min
Porous Sidewalk	1	1,640.42		Figure A-4	Figure A-4	Figure A-4
	2	650.1				
	3	277.62				
	4	362.86				
	5	544.15				
	6	391.02				
Bioretention	1	194.21	34.12	12”	> 20”	3-in. hardwood mulch on top, topsoil planting mix on side slopes, engineered soil mix 8-in. min depth on bottom.
	2	240.6	28.77			
	3	301.37	31.85			
	4	337.5	55.28			
	5	335.89	53.5			
Curb extension with bioretention	1	383.03	98	12”	24”	Engineering soil mix
	2	169.35	56.32			
	3	238.68	85.24			
Curb extension with rain garden	1	237.01	123.96	12”	24”	Engineering soil mix
	2	265.43	115.98			
	3	279.54	112.9			
	4	275.87	97.63			

Stormwater control type	Examples	Top area (ft^2)	Bottom area (ft^2)	Ponding depth	Total depth to bottom of device	Material
Rain garden	1	468.93	247.07	6”	> 17”	3-in. hardwood mulch on top, native soil amended with 3-in. compose, rototilled 8-in. min depth
	2	743.55	463			
	3	514.74	219.77			
	4	282.43	71.3			
	5	422.9	240			

1) Small-scale performance monitoring at Kansas City, MO

Table 3.6 is a list of the ten monitoring station locations in the test (pilot) watershed prepared by UMKC researchers. Figure 3.13 shows these locations on the map of the test area. The monitored curb extensions, and rain garden extensions are mostly along East 76th Street and East 76th Terrace. Example designs for each type of stormwater control being monitored are included in Appendix A.

Table 3.6. Locations of Monitoring Stations

No.	Stormwater control type	Address	Design station
1	Curb Extension	1324 E 76th St.	19+79.61
2	Curb Extension	1325 E 76th St.	19+79.61
3	Curb Extension	1419 E 76th Terr.	26+51.65
4	Rain Garden Extension	1612 E 76th St.	31+31.12
5	Rain Garden Extension	1336 E 76th St.	21+29.95
6	Site abandoned due to theft of monitoring equipment		
7	Rain Garden w/ Smart Drain	1140 E 76th Terr.	15+37.75
8	Rain Garden w/ Smart Drain	1222 E 76th St.	16+28.15
9	Cascade	1112 E 76th Terr.	12+18.80
10	Private rain garden	1312 E. 79th St.	Mrs. Thomas
11	Private rain garden	1505 E. 76th St.	Mrs. Moss

Source: UMKC

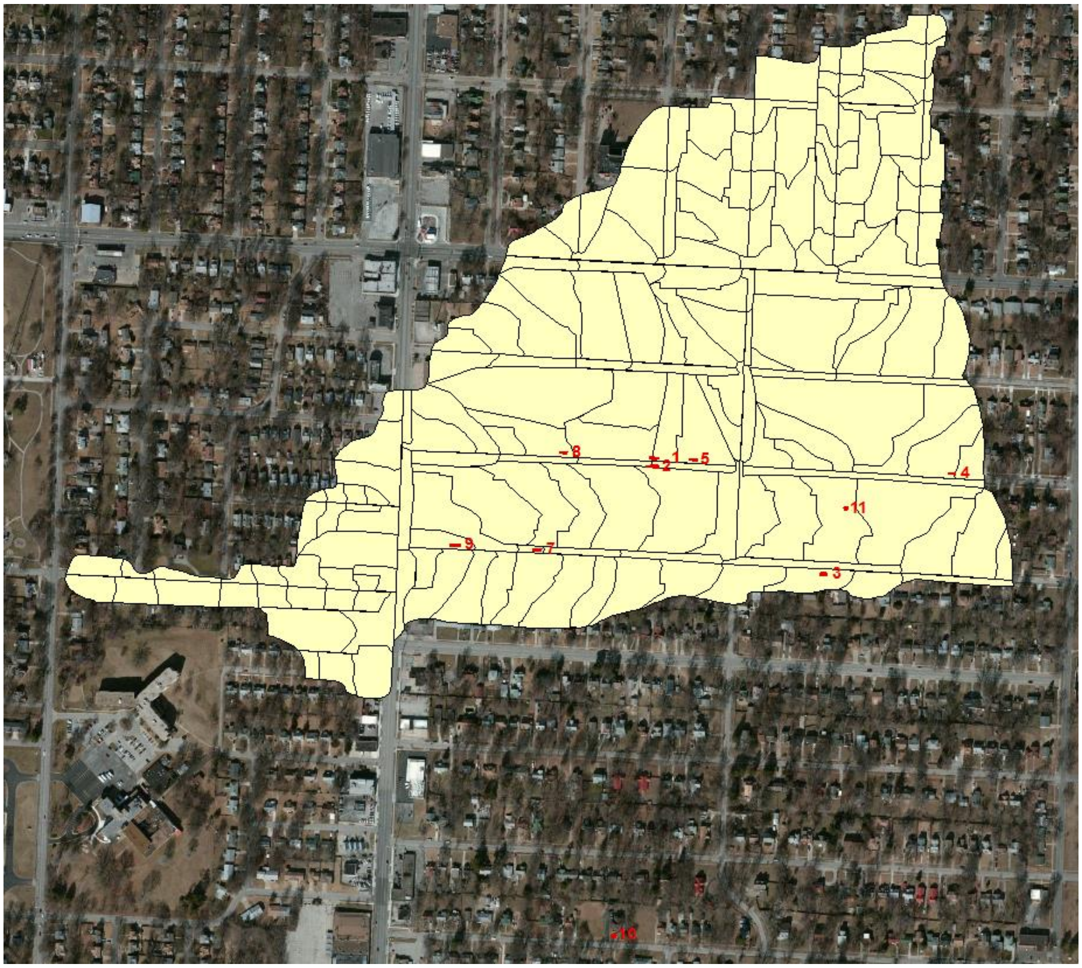


Figure 3.13. Location of stormwater controls monitored in test (pilot) watershed. (Note: One rain garden (shown as number 10 on the map) is located outside the pilot area)

2) Large-scale performance monitoring at Kansas City, MO

Runoff monitoring was conducted in the combined sewer system at several locations in the test and control watersheds. Figures 3.14 and 3.15 show the test and control watershed boundaries and the locations of the flow monitoring stations. Monitoring station S128-427 measures the flows portions of the control watershed; station S128-498 measures the flows from the test (pilot) watershed alone.

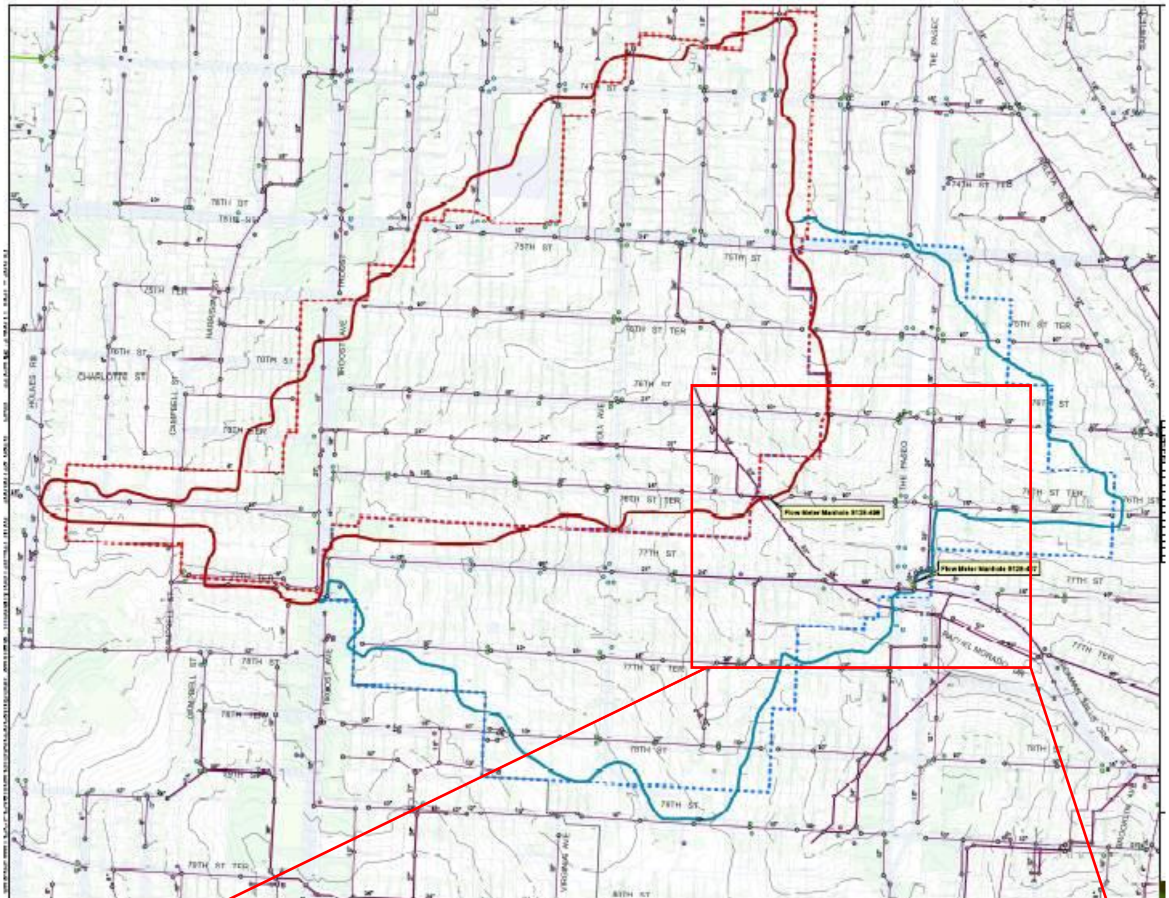


Figure 3.14. Test (100 acres) and control (86 acres) watersheds in Marlborough area of Kansas City, Missouri.

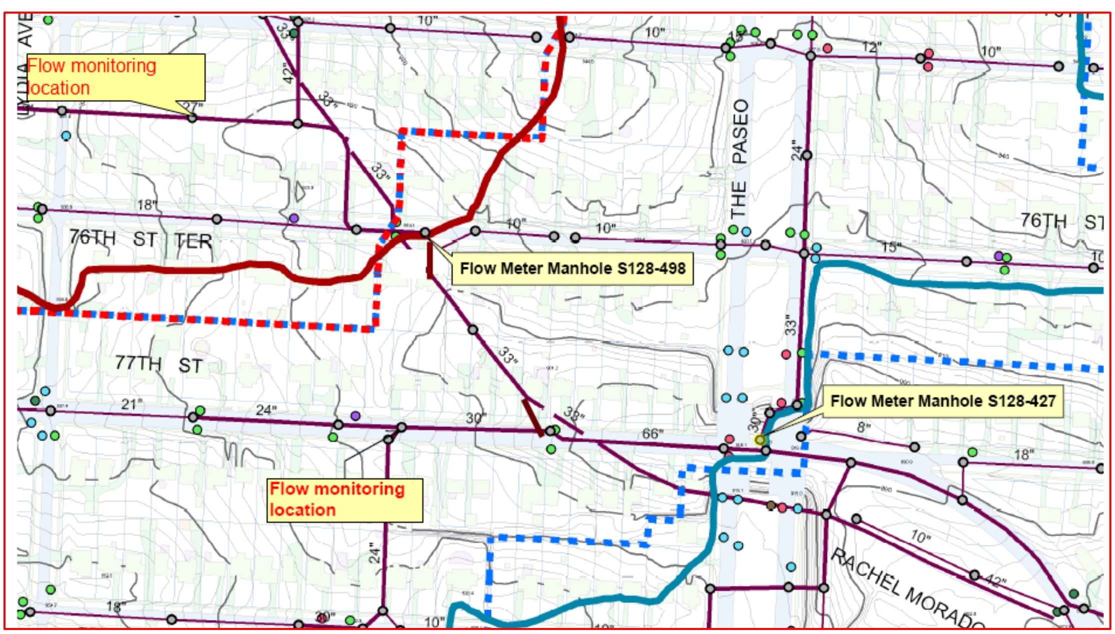


Figure 3.15. Flow monitoring locations at test and control area boundaries.

Each monitoring station included an ISCO 2150 area-velocity sensor. According to ISCO: "The 2150 Flow Module uses continuous wave Doppler technology to measure mean velocity. The sensor transmits a continuous ultrasonic wave, then measures the frequency shift of returned echoes reflected by air bubbles or particles in the flow. The 2150's "smart" area velocity probe is built on digital electronics, so the analog level is digitized in the sensor itself to overcome electromagnetic interference. The probe is also factory-calibrated for 10-foot (3 meter) span at different temperatures. This built-in calibration eliminates drift in the level signal, providing long-term level stability that reduces recalibration frequency and completely eliminates span recalibration." ISCO further states that this sensor can measure shallow flow in small pipes as the low-profile velocity sensor minimizes flow stream obstructions and senses velocity in flows down to 1 inch in depth. Table 3.7 lists some of the level and velocity measurement specifications for the ISCO 2150 sensor. The stated range includes minimum depths of about 0.4 inches with a 0.12 in accuracy, and long term stability of about 0.3 in per year. The velocity range is from -5 to 20 ft/sec (includes adverse flows) with a stated accuracy of about 0.1 ft/sec for low velocities.

Table 3.7. Level and Velocity Measurement Specifications for ISCO 2150 Sensor

Level Measurement	
Method:	Submerged pressure transducer mounted in the flow stream
Transducer Type:	Differential linear integrated circuit pressure transducer
Range:	(standard) 0.033 to 10 ft (0.010 to 3.05 m); (optional) up to 30 ft (9.15 m).
Maximum Allowable Level:	34 ft (10.5 m)
Accuracy:	±0.01 ft from 0.033 to 10 ft, (±0.003 m from 0.01 to 3.05 m)
Long-Term Stability:	±0.023 ft/yr (±0.007 m/yr)

Compensated Range:	32° to 122°F (0° to 50°C)
Velocity Measurement	
Method:	Doppler ultrasonic, frequency 500 kHz
Typical Minimum Depth:	0.08 ft (25 mm)
Range:	-5 to +20 ft/s (-1.5 to +6.1 m/s)
Accuracy:	(in water with uniform velocity profile, speed of sound = 4850 ft/s, for indicated velocity range); ±0.1 ft/s from -5 to 5 ft/s (±0.03 m/s from -1.5 to +1.5 m/s); ±2% of reading from 5 to 20 ft/s (1.5 to 6.1 m/s)

3.2.2.3 Cincinnati, Ohio

1) Cincinnati State Technical and Community College: The Cincinnati State College (Cincy State) campus is located on the top of a hill. Therefore, runoff from the southern portion of campus flows south into the Bates Run Regulator combined sewer system, while runoff from the northern part of campus flows north into the Streng Street Diversion Dam combined sewer system. The Cincinnati State College campus has a combination of several green infrastructure stormwater controls including; pervious pavers, rain gardens, cisterns, infiltration trenches, bioretention trenches (with level spreaders), and a green retaining wall. Table 3.8 summarizes the green infrastructure features for Cincy State. The schematic drawings of stormwater controls are also cross-referenced in Table 3.6, which can be found in Appendix B. Figure 3.16 shows a map of the location of the GI stormwater controls, along with the flow monitoring locations and the watershed boundaries.

Table 3.8. Summary of green infrastructure features at Cincinnati State College

GI Feature	Size	Comments	Figure Reference
Pervious Asphalt Pavement	2,002 ft^2	All have underdrains and located in various locations, mostly at parking lot "C" located in northeastern part of the campus	Figure B-1
Pervious Concrete Pavement	1,645 ft^2		
Pervious Concrete Pavers	40,038 ft^2		
Rain Gardens	56,222 ft^2	Ten rain gardens installed in various locations, mostly in southwestern part	Figure B-2
Cistern for Rainwater Harvesting	24,000 gallon	Two 10,000 gallon in-ground storage tanks connected to irrigation systems, and one 4,000 gallon above ground cistern for greenhouse	N/A
Infiltration trench	1,540 ft^2	Located in southwestern part of the campus	Figure B-3
Biodetentions (level spreader)	420 ft^2	Located in southwestern part of the campus	Figure B-4
Pond	6,900 ft^2	Located in northeastern part of the campus, close to the greenhouse	N/A
Retaining wall	140 ft	Planted with sedum	Figure B-5

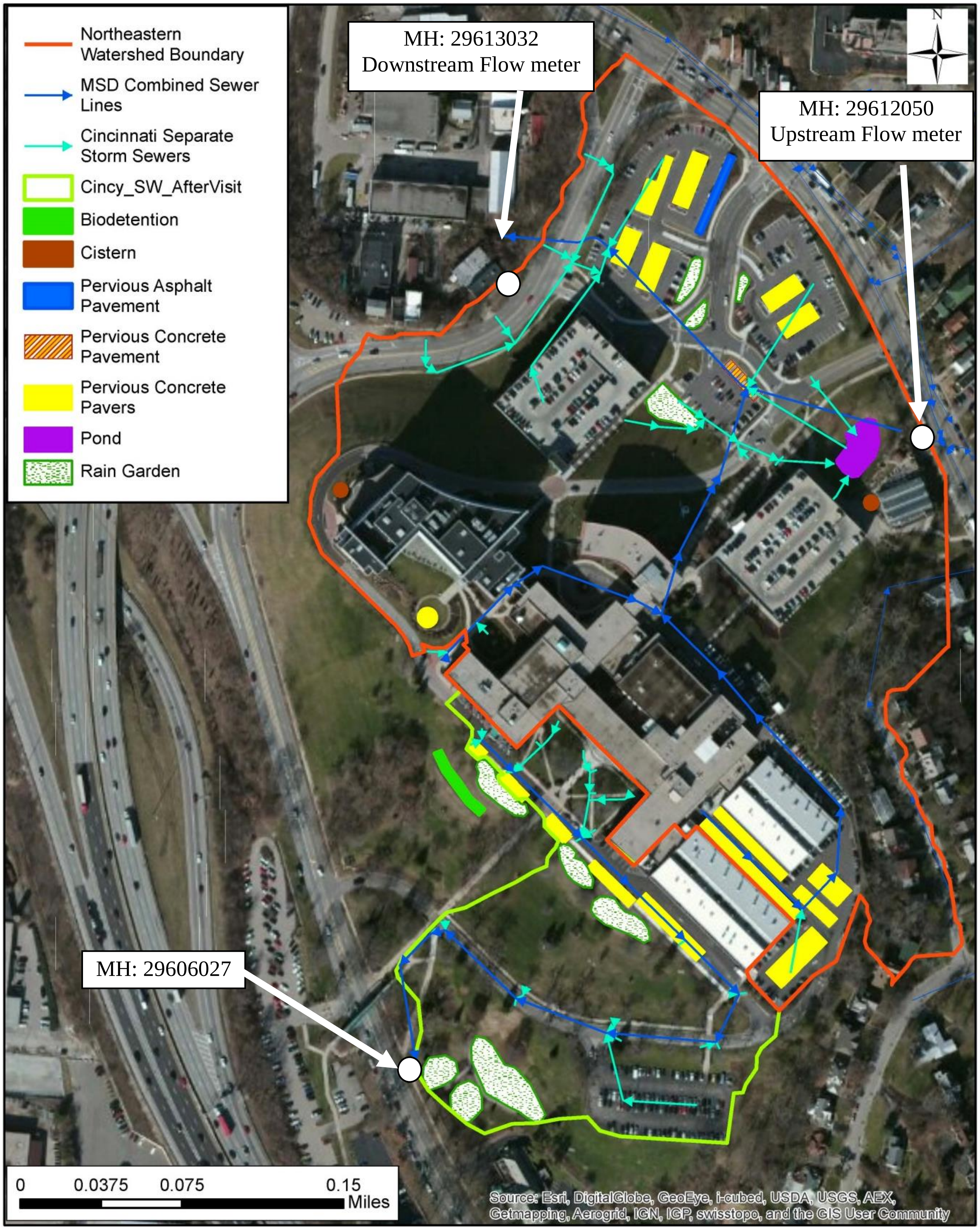


Figure 3.16. Location of GI stormwater controls at Cincinnati State College

2) Cincinnati Zoo: The Cincinnati Zoo's stormwater management objective is to have no site runoff during a 50-year storm event at the African Savannah and main entry areas. To meet this objective, the African Savannah area has different types of green infrastructure controls, including enhanced turf/vegetation, permeable pavers, and an underground rainwater harvesting storage system. One of the objectives of the stormwater control project in the African Savannah area is to disconnect the existing storm sewer and roof leader system, which currently discharges into the combined sewer. Stormwater runoff and roof drainage were collected and redirected to the rainwater harvesting system (RHS). Approximately 180,000 square feet of enhanced turf grass and permeable walkways will replace the existing impervious parking lot. The RWH system has a capacity of about 16,000 cubic feet and the collected water will be reused for on-site irrigation for outdoor zoo water features. The main entry area has 30,760 square feet of pervious pavers, and a 10,000 gallon storage tank to collect runoff from 11,700 square feet of rooftop for reuse for irrigation of nearby landscaped areas. Figure 3.17 illustrates the location of GI stormwater controls at the Cincinnati Zoo.

3) Clark Montessori High School: This site has various green stormwater controls including green roofs, permeable pavement, and bioretention facilities (bioswales, stormwater planters, and a rain garden). Green roofs comprise 9,200 square feet of intensive roof, which has a permanent sub-surface irrigation system, and 5,500 square feet of extensive roof. In addition, the site has 13,000 square feet of pervious concrete and 2,000 square feet of permeable pavers with no underdrains. Bioretention facilities include three stormwater planters, two bioswales, and one rain garden. Figure 3.18 is a map of the location of GI stormwater controls at Clark Montessori High School.

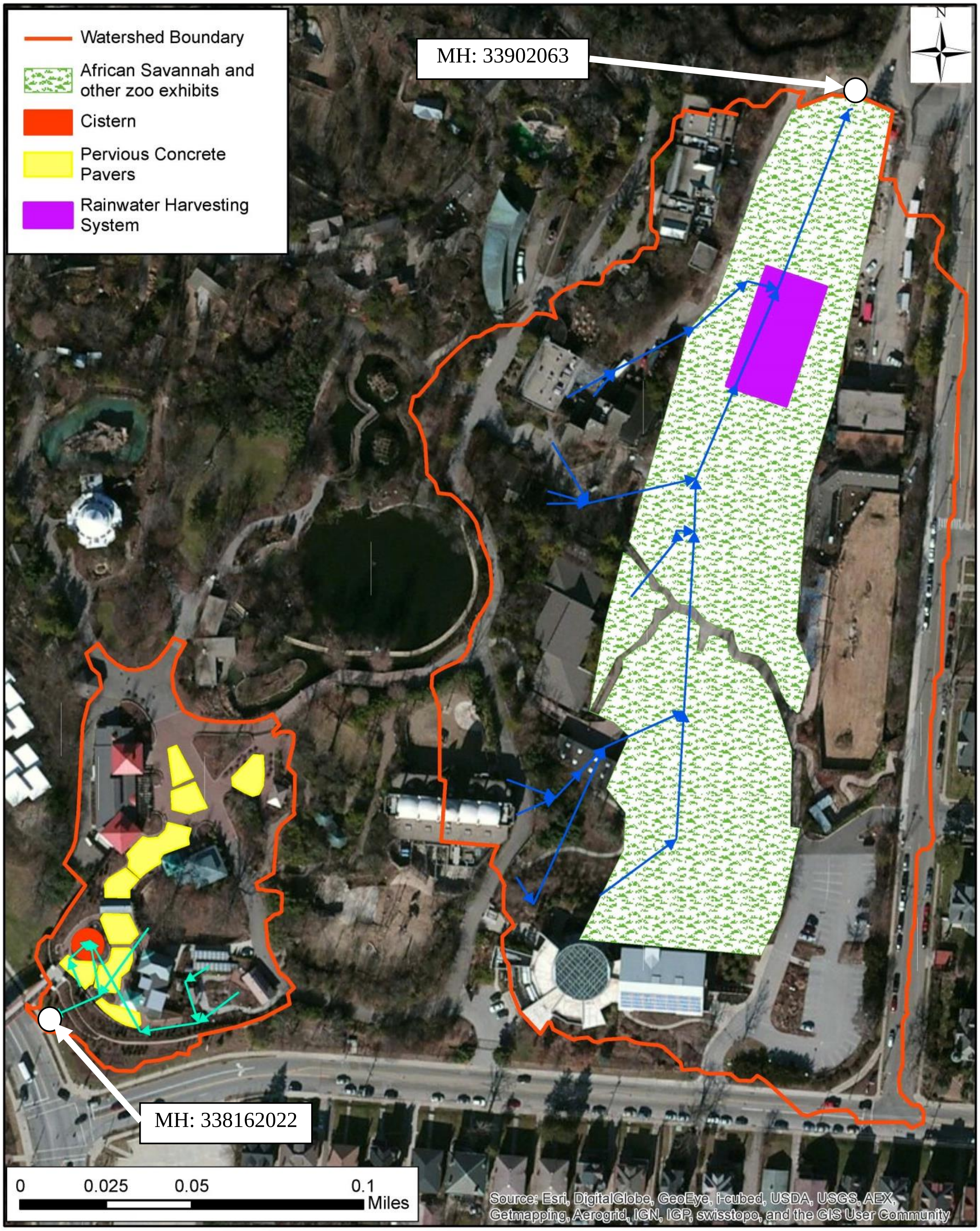


Figure 3.17. Location of GI stormwater controls at Cincinnati Zoo (Note: Enhanced vegetation area is still under construction)

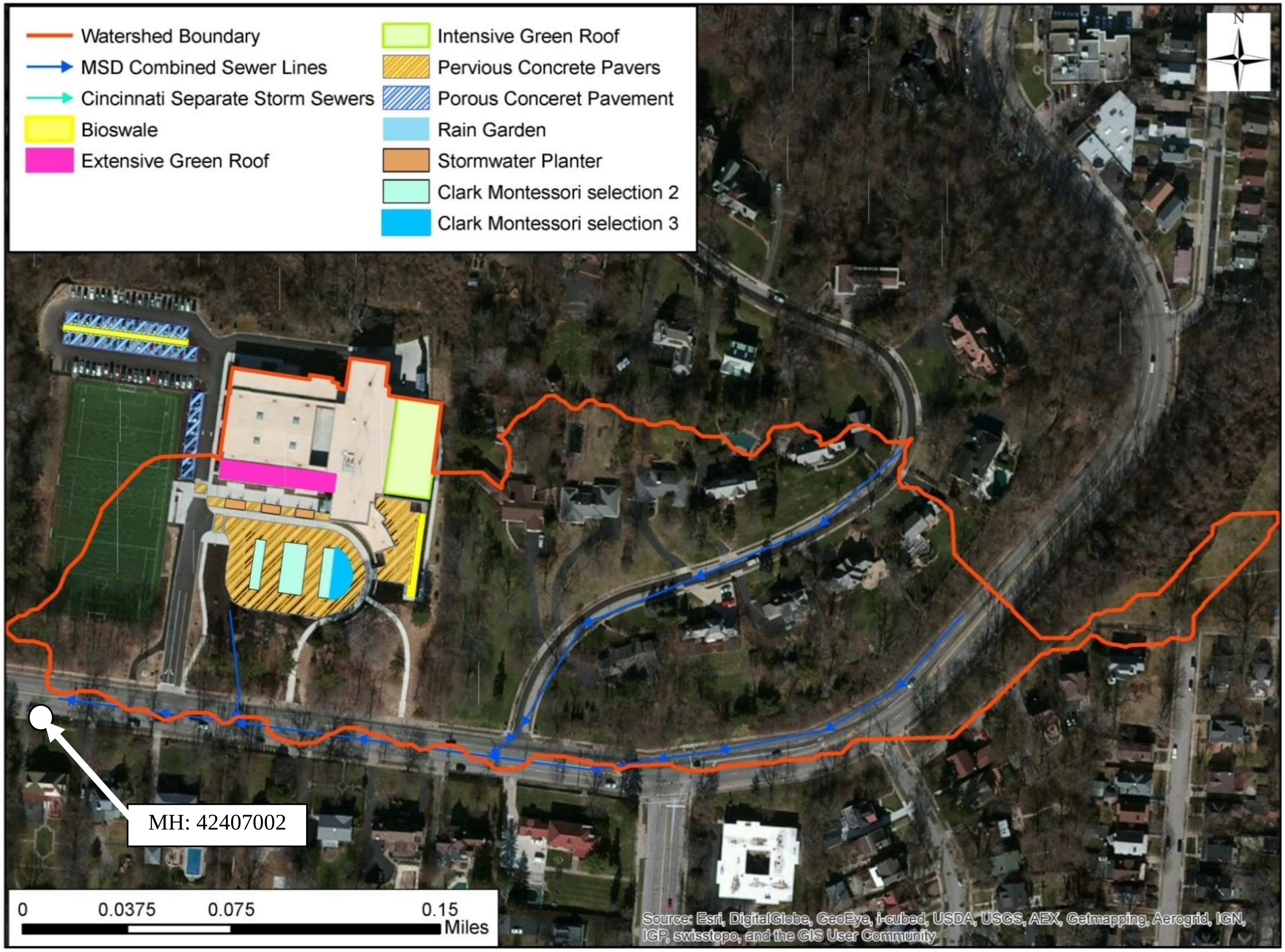


Figure 3.18. Location of GI stormwater controls at Clark Montessori High School

3.2.3 Watershed Analysis and Land Cover Description

One of the important steps in urban stormwater quantity and quality modeling is to quantify the drainage area characteristics. High resolution aerial photos available in ArcMap 10 base map dataset were used to determine the drainage watersheds of the study areas, as well as different land cover categories (such as roofs, streets, parking lots, driveways, landscaped areas, etc.).

3.2.3.1 Millburn, NJ

The land covers of the project sites, including roofs, driveways, sidewalks, streets, landscaped areas, patios, etc., are shown in Table 3.9. The percentages of each of these land covers are shown in Table 3.9. These data were calculated from the plan maps for each home obtained by PARS Environmental, Inc. from the Township.

Table 3.9. Land Covers for Millburn, NJ, Residential Study Sites (Area, ft^2)

Monitoring Location	**Roofs**	**Driveways**	**Parking**	**Side walks**	**Street**	**Landscape**	**Paved Patio**	**Rear Walkway and Steps**	**Shed**	**Deck**	**Total**	**Housing Density (units/acre)**
8 South Beechcroft	2,800	2,030	0	384	3,200	21,243	381	40	0	162	30,240	1.4
11 Fox Hill	2,183	1,125	0	50	1,650	11,003	277	0	0	0	16,288	2.7
43 Browning Road S.H	2,376	980	0	110	2,200	10,557	486	0	0	0	16,710	2.6
1 Sinclair terrace	3,216	1,438	0	237	1,900	22,277	0	433	88	0	29,589	1.5
7 Fox Hill	2,435	1,070	0	380	1,800	10,952	369	0	0	0	17,006	2.6
9 Lancer	3,360	2,214	0	448	2,100	14,189	0	537	0	288	23,136	1.9
135 Tennyson Dr	1,096	990	792	274	3,240	12,680	0	0	0	0	19,076	2.3
79 Minnisink Rd	9,150	5,200	3,200	2,600	3,000	24,450	0	0	0	0	47,600	0.9

Monitoring Location	Roofs	Driveways	Parking	Side walks	Street	Landscape	Paved Patio	Rear Walkway and Steps	Shed	Deck	Total	Housing Density (units/acre)
18 Slope Dr	3,713	2,812	1,406	0	6,000	10,125	0	0	0	0	24,056	1.8
139 Parsonage Hill Rd	4,560	2,246	2,722	272	5,775	18,692	0	0	0	0	34,267	1.3
Minimum	1,096	980	0	0	1,650	10,125	0	0	0	0	16,288	0.9
Maximum	9,150	5,200	3,200	2,600	6,000	24,450	486	537	88	288	47,600	2.7
Average	3,489	2,011	812	476	3,087	15,617	151	101	9	45	25,797	1.9
Standard Deviation	2,201	1,292	1,232	761	1,586	5,507	201	204	28	99	9,926	0.6
Coefficient of Variation (COV)	0.6	0.6	1.5	1.6	0.5	0.4	1.3	2.0	3.2	2.2	0.4	0.3

(1 ft^2 = 0.093 m^2)

As shown in Table 3.10, most of land cover is landscaped (62%), while roofs make up about 13% of the areas and streets make up about 12.5% of the areas. The variations of these major areas are relatively small, with the COVs (standard deviation/average) of these three areas all less than 0.5. The housing densities for these ten homes ranged from about 1 to 3 homes per acre, with an average of about 2 homes per acre.

Table 3.10. Land Covers for Millburn, NJ, Residential Study Sites (Area, as a percentage)

Monitoring Location	Roofs	Driveways	Parking	Side walks	Street	Landscape	Paved Patio	Rear Walkway and Steps	Shed	Deck	Total
8 South Beechcroft	9.3	6.7	0.0	1.3	10.6	70.2	1.3	0.1	0.0	0.5	100
11 Fox Hill	13.4	6.9	0.0	0.3	10.1	67.6	1.7	0.0	0.0	0.0	100
43 Browning Road S.H	14.2	5.9	0.0	0.7	13.2	63.2	2.9	0.0	0.0	0.0	100

Monitoring Location	Roofs	Driveways	Parking	Side walks	Street	Landscape	Paved Patio	Rear Walkway and Steps	Shed	Deck	Total
1 Sinclair terrace	10.9	4.9	0.0	0.8	6.4	75.3	0.0	1.5	0.3	0.0	100
7 Fox Hill	14.3	6.3	0.0	2.2	10.6	64.4	2.2	0.0	0.0	0.0	100
9 Lancer	14.5	9.6	0.0	1.9	9.1	61.3	0.0	2.3	0.0	1.2	100
135 Tennyson Dr	5.7	5.2	4.2	1.4	17.0	66.5	0.0	0.0	0.0	0.0	100
79 Minnisink Rd	19.2	10.9	6.7	5.5	6.3	51.4	0.0	0.0	0.0	0.0	100
18 Slope Dr	15.4	11.7	5.8	0.0	24.9	42.1	0.0	0.0	0.0	0.0	100
139 Parsonage Hill Rd	13.3	6.6	7.9	0.8	16.9	54.5	0.0	0.0	0.0	0.0	100
Minimum	5.7	4.9	0.0	0.0	6.3	42.1	0.0	0.0	0.0	0.0	
Maximum	19.2	11.7	7.9	5.5	24.9	75.3	2.9	2.3	0.3	1.2	
Average	13.0	7.5	2.5	1.5	12.5	61.6	0.8	0.4	0.0	0.2	
Standard Deviation	3.7	2.4	3.3	1.6	5.7	9.8	1.1	0.8	0.1	0.4	
Coefficient of Variation (COV)	0.3	0.3	1.3	1.0	0.5	0.2	1.4	2.1	3.2	2.3	

(1 ft^2 = 0.093 m^2)

3.2.3.2 Kansas City, Missouri

A large portion of the test (pilot) area at Kansas City, MO, receives direct treatment from many separate stormwater control devices. Figure 3.19 is a map showing the test (pilot) watershed with all major source area components including roofs, driveways, landscaped areas, sidewalks, driveways, and parking lots. Figure 3.20 is a similar map, but only provides details for the areas having stormwater controls. The blanked-out areas drain directly into the combined sewer without any control. Some of the treated area's runoff flows some distance along the curbs and gutters before it enters the stormwater control practices. In addition, other areas are treated by multiple control units, with overflows from upstream devices flowing into downstream controls. Figure 3.21 is a map showing the surface characteristics of the areas not being treated by any of the stormwater control devices before their runoff enters the combined sewer.

Figure 3.19. Map of test (pilot) area showing main surface characteristics.

Table 3.11 summarizes the source areas for each of the controlled and uncontrolled subareas in the test (pilot) watershed. About 45% of the complete watershed does not receive any control and drains directly into the combined sewer, and about 55% of the area is treated. The following table and associated maps indicate that the areas being treated are generally closer to the streets (including sidewalks, most of the driveways, and many of the roofs). The untreated areas have a greater portion of landscaped areas that drain through yard drains directly into the combined sewer system.

Figure 3.20. Map of test (pilot) area showing surface characteristics of areas receiving stormwater treatment.

Figure 3.21. Map of test (pilot) area showing surface characteristics of areas not receiving stormwater treatment.

Table 3.11. Site characteristics for areas receiving stormwater treatment and other areas

Land component	Areas in subwatersheds with no stormwater controls		Areas in subwatersheds with stormwater controls		Total area (ac)
	Area (acres)	Percentage	Area (acres)	Percentage	
roofs - directly connected	1.11	2.40%	1.05	1.9%	2.16
roofs - drain to landscaped	6.29	13.7%	5.95	10.9%	12.24
driveway - directly connected	2.00	4.40%	2.30	4.2%	4.30
driveways - drain to perv	2.00	4.40%	2.30	4.2%	4.30
sidewalk - directly connected	0.38	0.80%	0.97	1.8%	1.35
sidewalks - to perv	0.45	1.00%	1.13	2.1%	1.58
Parking lot/ Paved area - directly connected	1.40	3.1%	3.40	6.3%	4.80
Streets - directly connected	3.50	7.6%	7.30	13.4%	10.80
Landscaped area - pervious area	28.70	62.6%	30.00	55.1%	58.70
Total area	45.83	100.0%	54.40	100.0%	100.23

Table 3.12 summarizes the impervious areas that are directly connected or that flow to pervious areas, or are the pervious landscaped areas. The breakdown of the directly and indirectly connected impervious areas was estimated based on the full area land use monitoring. The total impervious area for the area being treated is about 45%, while the total impervious area for the untreated area is about 37%.

Table 3.12. Impervious and pervious areas in subareas receiving stormwater treatment and other areas

Land component	Areas in subwatersheds with no stormwater control		Areas in subwatersheds with stormwater controls	
	Area (acres)	Percent of subarea	Area (acres)	Percent of subarea
Impervious, directly connected	8.09	17.7%	15.02	27.6%
Impervious, draining to pervious areas	9.04	19.7%	9.38	17.2%
Pervious areas	28.70	62.6%	30.00	55.2%
Total area:	45.83	100.0%	54.40	100.0%

3.2.3.3 Cincinnati, Ohio

A GIS dataset of 1 ft topographic contours (shapefile) provided by MSD was used to create a digital elevation model (DEM) for each study area in Cincinnati. The hydrology tool of ArcMap 10 consists of fill, flow direction, flow accumulation, snap pour point, and watershed, processed the DEM to delineate watershed in order to calculate drainage areas and land cover characteristics.

1) Cincinnati State Technical and Community College

The Cincinnati State college study area includes three drainage areas. As shown in Figure 3.22, the largest sub-watershed (in purple) is 335.5 acres which drains towards the *Upstream Flow Meter* with manhole number 29612050. The drainage area for *Downstream Flow Meter* with manhole number 29613032 (shown in pink, on Figure 3.22) is 28 acres, which collects runoff from the northern part of the Cincinnati State College campus. Therefore, the drainage area between the *Downstream Flow Meter* and the *Upstream Flow Meter* is about 8% of the drainage area into the *Upstream Flow Meter*. The southern portion of the campus has a drainage area of about 8.71 acres and flows towards the south into the manhole number 29606027 (watershed boundary is shown in blue on Figure 3.22).

Aerial photography, available in ArcMap 10.0, was used to estimate the land coverage for each watershed. Table 3.13 summarizes different source areas for the Cincinnati State college study area. As shown in Table 3.13, a large portion of the study area is comprised of landscaped areas. Figure 3.23 illustrates the land cover characteristics of the Cincinnati State college study area, along with MSD combined sewer lines, and watershed boundaries.

Table 3.13. Summary of land cover characteristics for the Cincinnati State college study area

Land Cover type	Northern part of campus Areas drain into *Downstream Flow Meter* with manhole number 29613032		Southern part of campus Areas drain into manhole number 29606027	
	Area (ft^2)	Area (%)	Area (ft^2)	Area (%)
Landscaped area	486,835	39.7	227,411	59.9
Parking lot	270,558	22.1	48,556	12.8
Paved area	2,687	0.2	0	0
Roof	241,644	19.7	35,539	9.3
Street	156,707	12.8	43,050	11.3
Walkway	68,532	5.6	25,101	6.7
Total	1,226,962	100.0	379,657	100

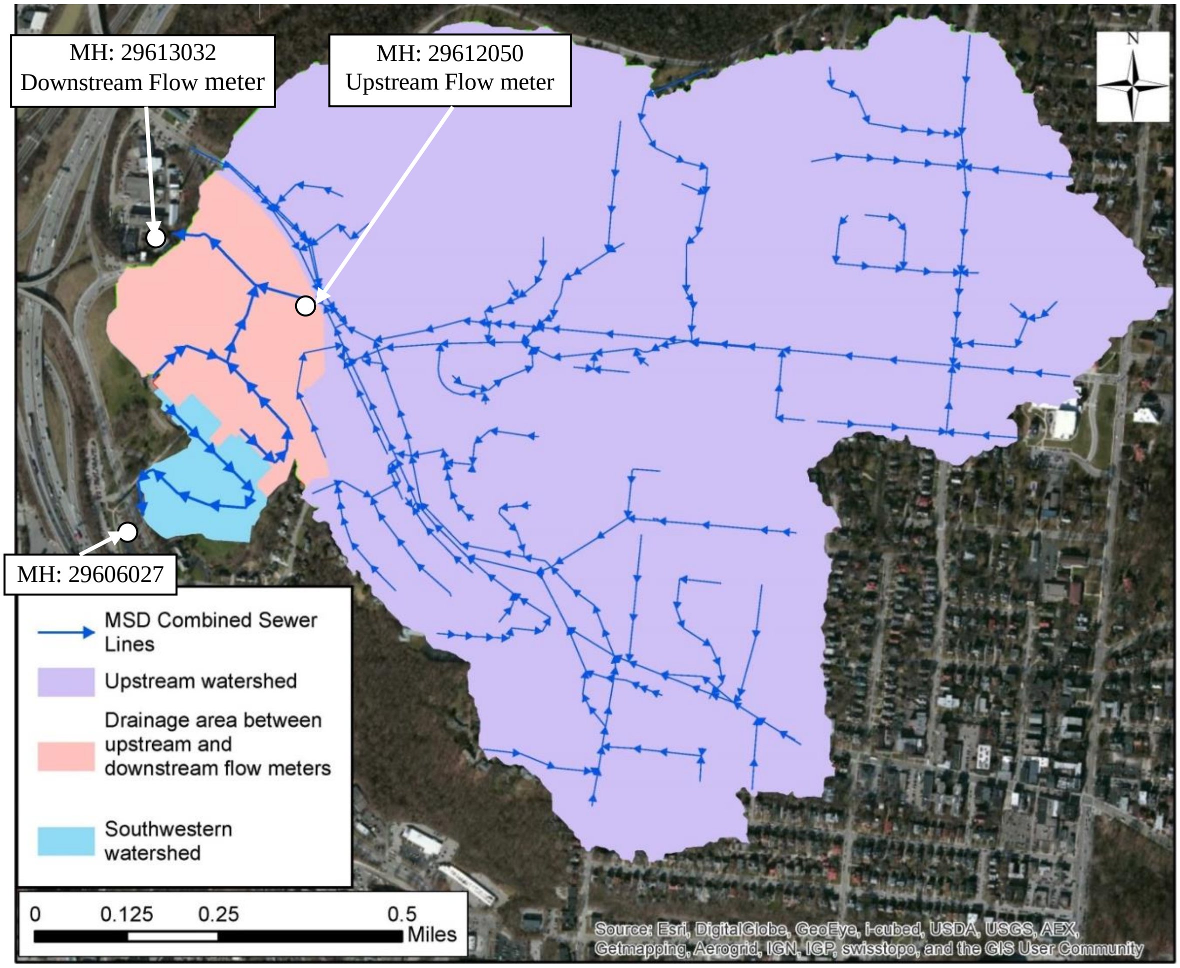


Figure 3.22. Watershed areas of Cincinnati State College

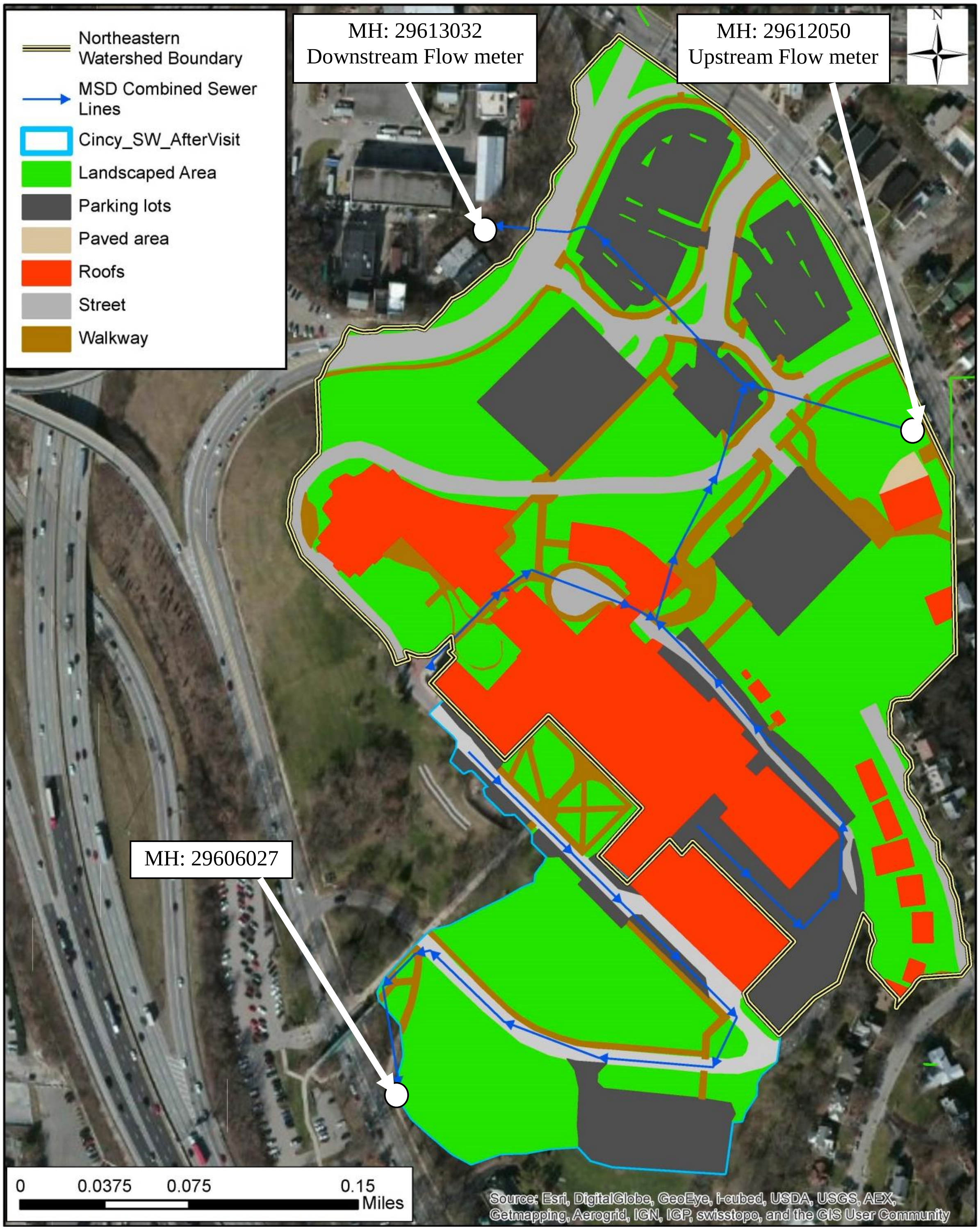


Figure 3.23. Map of Cincinnati State College area showing main surface characteristics.

2) Cincinnati Zoo

The African Savannah area, located in the northeastern part of the Zoo, has a drainage area of about 13.4 acres flows towards northeast to the flow monitor with manhole number of 33902063 (Figure 3.24). The main entrance area, located in southwestern part of the Zoo, has a drainage area of about 2.5 acres, comprised of landscaped areas, paved areas, and roofs (Figure 3.24). Figure 3.24 is a map of Cincinnati Zoo area showing main land cover characteristics.

Tables 3.14 and 3.15 summarize the breakdown of land cover characteristics for the African Savannah, and main entrance areas, respectively. About 40% of both watersheds are covered by landscaping. Twenty six percent of the African Savannah area is under construction and will be covered by enhanced vegetation in the near future.

Table 3.14. Summary of land cover characteristics for African Savannah area at Cincinnati Zoo

Land Cover type	**Area (ft^2)**	**Area (%)**
Landscaped area	228,614	39.2
Active Construction	152,923	26.2
Parking lot	30,521	5.2
Paved area	10,058	1.7
Roof	76,676	13.1
Street	24,907	4.3
Walkway	59,466	10.2
Total	583,166	100

Table 3.15. Summary of land cover characteristics for Main Entrance of Cincinnati Zoo area

Land Cover type	**Area (ft^2)**	**Area (%)**
Landscaped area	43,060	40.2
Paved area	47,996	44.8
Roof	16,150	15.1
Total	107,206	100

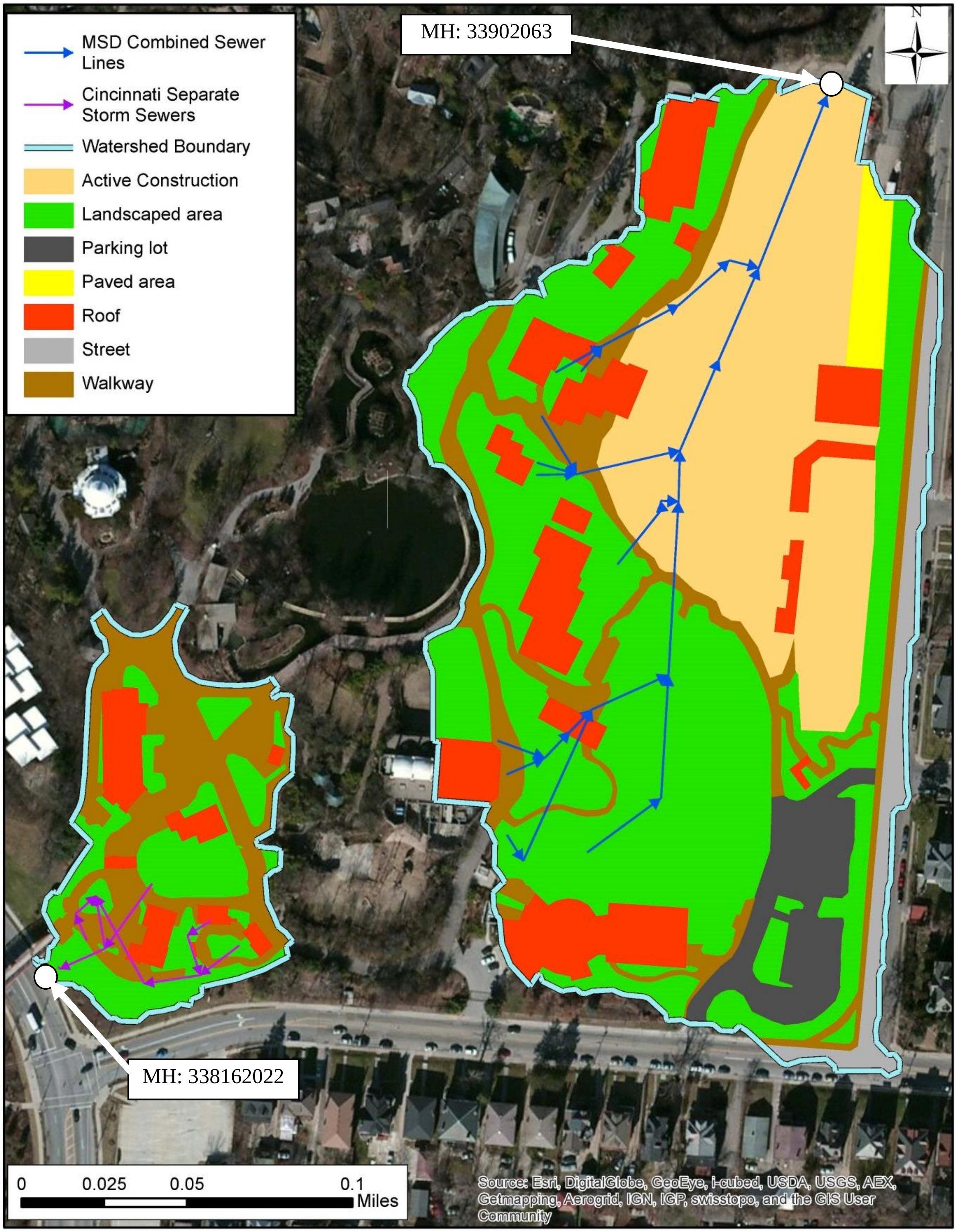


Figure 3.24. Map of Cincinnati Zoo area showing main surface characteristics.

3) Clark Montessori High School

The drainage area for the Clark Montessori High School above the monitoring location is approximately 14.8 acres, mostly consists of the high school's landscaped areas (58%), roofs (13.5%), and streets (13.4%) (Table 3.16, and Figure 3.25), and the upstream residential area.

Table 3.16. Summary of land cover characteristics for Clark Montessori High School

Land Cover type	**Area (ft^2)**	**Area (%)**
Driveway	22,842	3.6
Landscaped area	369,455	57.5
Parking lot	22,082	3.4
Paved area	15,026	2.3
Roof	86,624	13.5
Soccer Field	25,867	4.0
Street	86,134	13.4
Walkway	14,956	2.3
Total	642,986	100.0

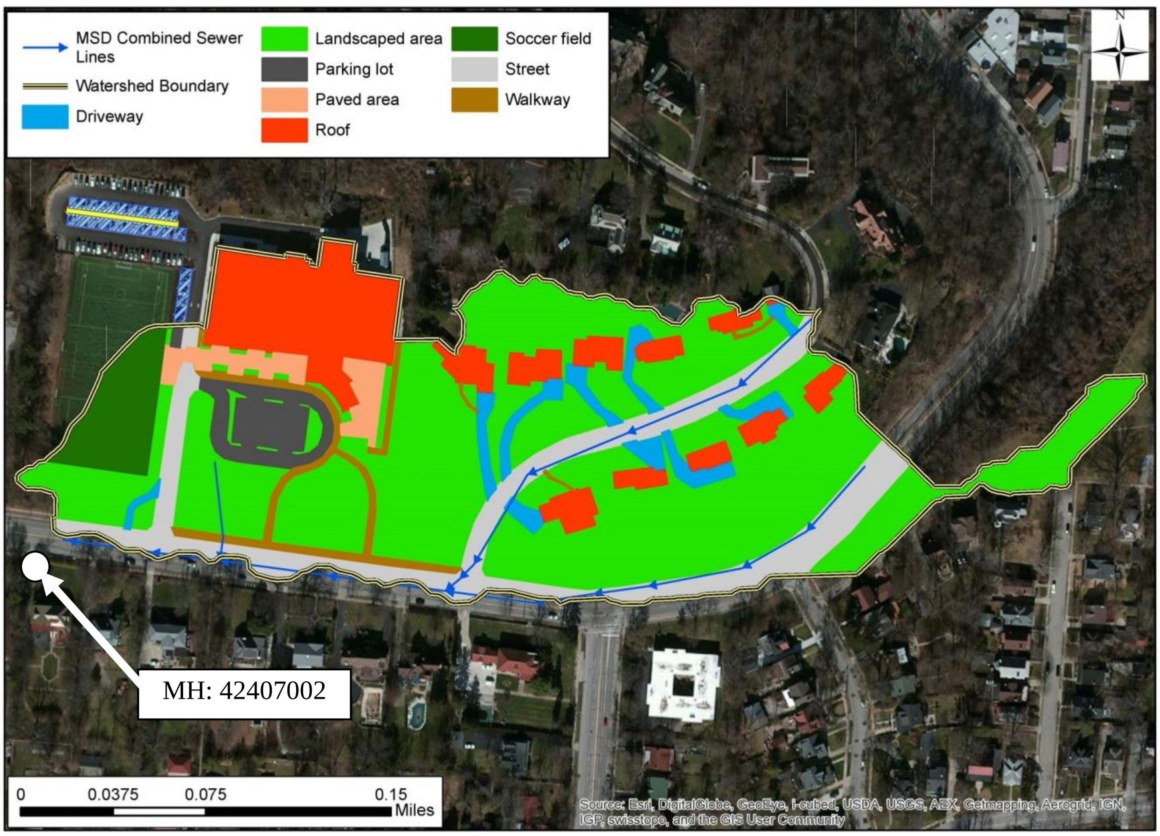


Figure 3.25. Map of Clark Montessori High School area showing main surface characteristics.

3.2.4 Soil Characteristics

3.2.4.1 Millburn, NJ

Soil characteristics are needed when evaluating stormwater infiltration and recharge potentials for an area and for designing these control practices. Table 3.17 lists locations of sites where infiltration measurements were made, along with the ID of each as shown on the map (Figure 3.26). Figure 3.26 is a map of the surface soil types for the Township of Millburn. The soil spatial and tabular map data were obtained from the Natural Resources Conservation Service (NRCS) Soil Survey for Essex County and imported into ArcMap 10. Most of the sites have "BowtB" soil type (Boonton - Urban land surface soils, Boonton substratum complex, terminal moraine). However, this is an old urban area and the standard soil profiles typically do not reflect compaction and other factors of disturbed urban soils.

Table 3.17. Locations of Infiltration Monitoring Sites and Soil Conditions in Millburn and Short Hills, NJ

Street Address	City	Latitude	Longitude	ID on Map (Fig. 3.5)	Surface Soil Name[1]	Surface Soil HSG[2]
1 Sinclair Terrace	Millburn	40.749	-74.307	1	BowtB	D
15 Marion Avenue	Millburn	40.729	-74.311	2	BowtB	D
258 Main Street	Millburn	40.717	-74.308	3	DuuB	A and D
11 Fox Hill Lane	Millburn	40.743	-74.314	4	BowtB	D
11 Woodfield Drive	Millburn	40.740	-74.322	5	BowtB	D
142 Fairfield Drive	Millburn	40.751	-74.310	6	BowtB	D
2 Undercliff Road	Millburn	40.724	-74.300	7	BowrB	C
260 Hartshorn Drive	Millburn	40.739	-74.331	8	BowtB	D
383 Wyoming Avenue	Millburn	40.730	-74.291	9	BowrB	C
7 Fox Hill Lane	Millburn	40.742	-74.314	10	BowtB	D
79 Minnisink Road	Millburn	40.736	-74.332	11	BowtC	D
8 South Beechcroft Road	Millburn	40.743	-74.314	12	BowtB	D
87/89 Tennyson Drive	Millburn	40.735	-74.350	13 and 14	BowtB	D
9 Fox Hill Lane	Millburn	40.742	-74.315	15	BowtB	D
36 Farley Pl	Short Hills	40.718	-74.326	16	UrbanB	D

[1] Natural Resources Conservation Service (NRCS)
[2] Source: *Soil Survey of Essex County*, New Jersey Report, USDA, NRCS.

Table 3.18 summarizes the surface and subsurface soil characteristics for the Millburn sites using the NRCS on-line soil survey. All the sites have surface soils with hydrologic soil group (HSG) “C” or “D”, except for the Main St. area that has “A” soils. Group “A” soils have a high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well drained to excessively drained sands or gravelly sands. These soils have a high rate of water transmission. Group “C” Soils have slow infiltration rates when thoroughly wet. These consist mainly of soils having a layer that impedes the downward movement of water or soils of moderately fine to fine texture. Group “D” soils have a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist mainly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. Group D soils have a very slow rate of water transmission. All of the sites’ subsurface soils shown on Table 3.18 are well drained. The dry wells are usually 2.4 m or 8 ft deep (2 ft of surface cover with a 6 ft tall concrete perforated tank), with another 2.4 m (2 ft) of gravel, so the main infiltration layer is from 0.6 m (2 ft) to about 3.1m (10 ft) below the ground surface. The soil profiles indicate increased infiltration potentials at these deeper soil depths, with all subsurface soils being group A or B from about 2.4 m (2 ft) and deeper, as shown on Figure 3.27, which likely better indicates the potential function of the dry wells compared to the surface soil conditions.

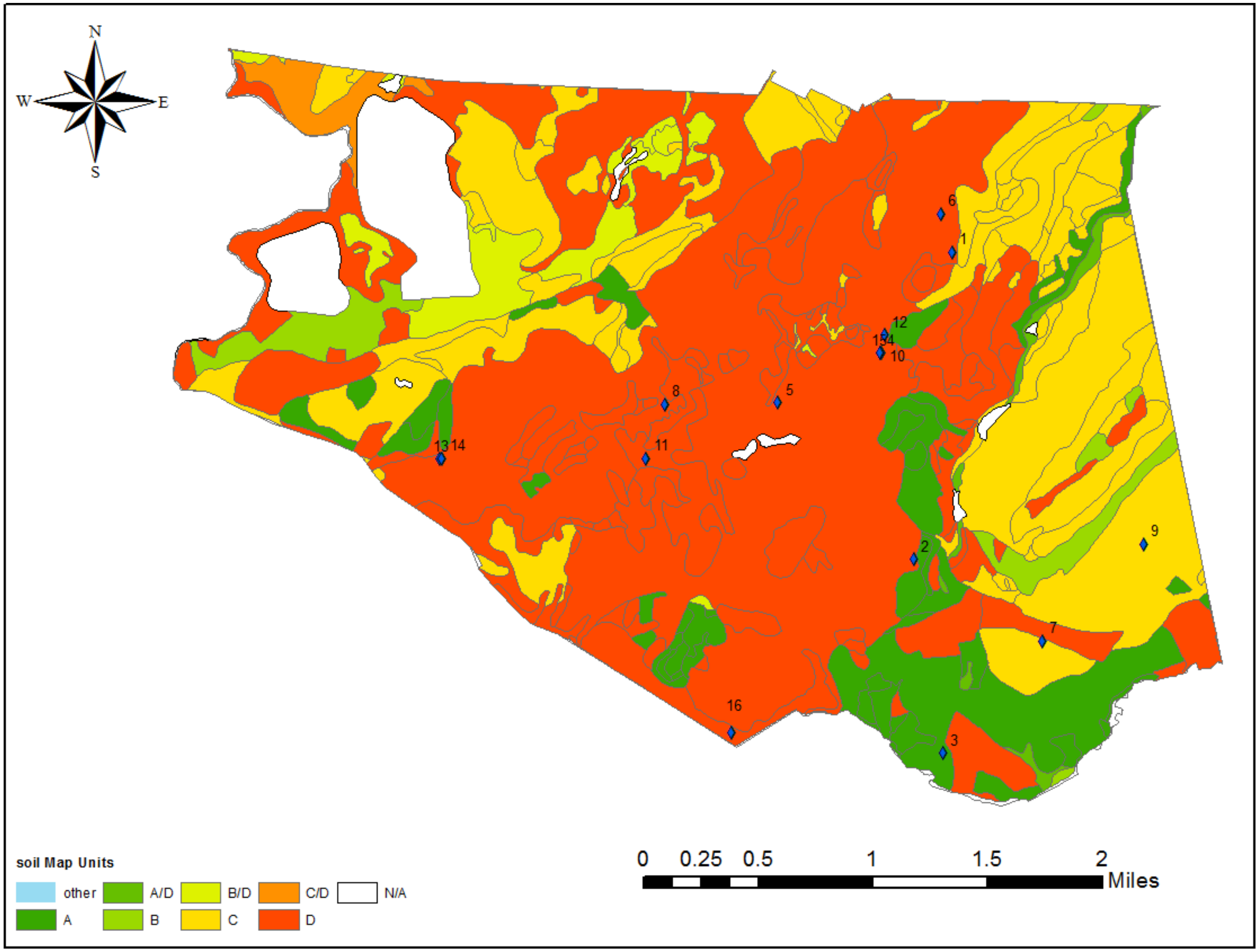


Figure 3.26. Hydrologic Soil Group Index of the Township of Millburn for Surface Soils (NRCS; http://soils.usda.gov/)

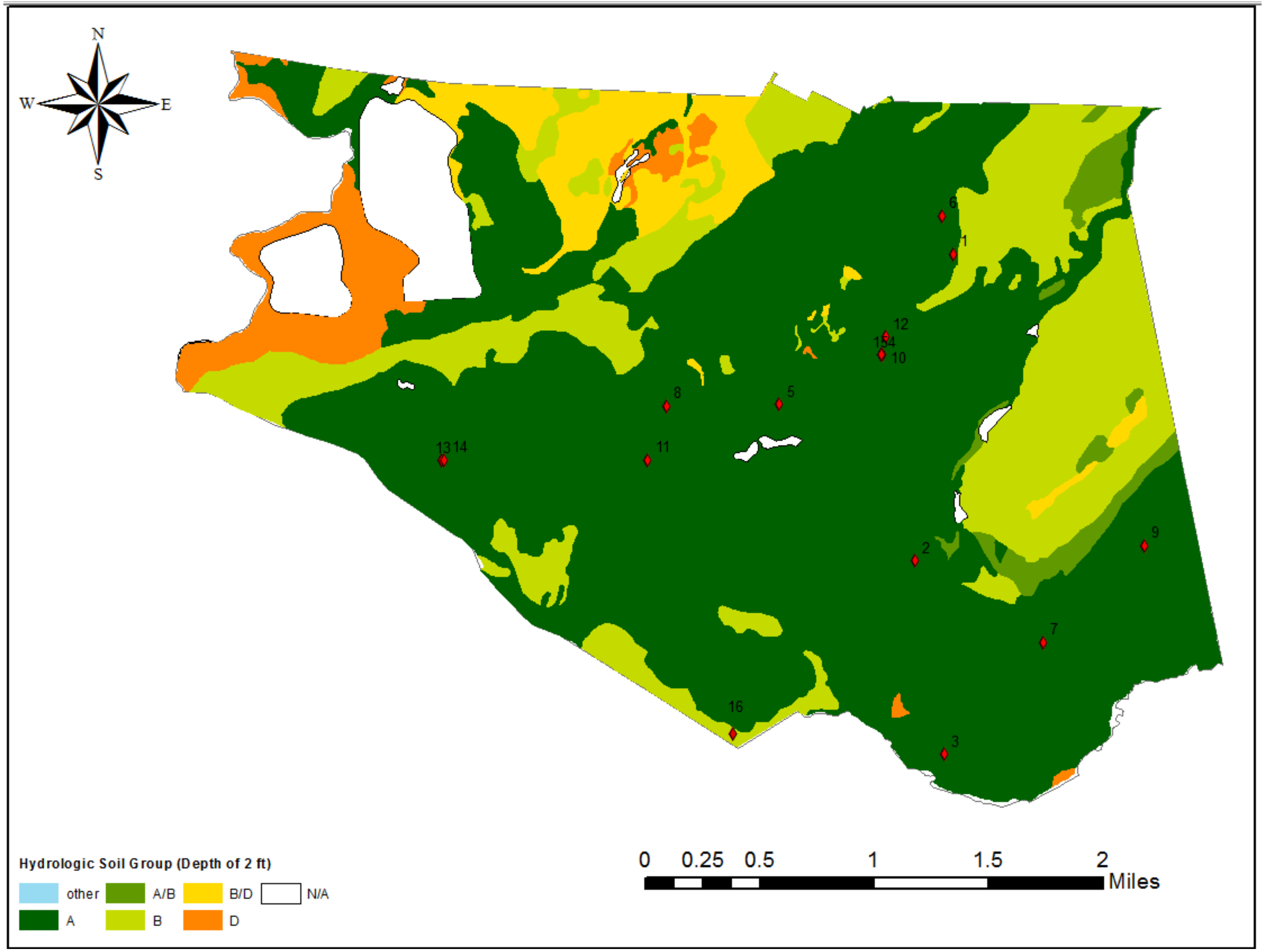


Figure 3.27. Hydrologic Soil Group Index of the Township of Millburn for Shallow Subsurface Soils 2 ft Deep (NRCS; http://soils.usda.gov/)

Table 3.18. Summary of soil characteristics for Millburn, NJ. case study
(Source: http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm)

Address	Soil Name	Slope (%)	K_{sat}[1]	Drainage class	Typical profile and associated Hydrologic Soil Groups for subsurface soils
383 Wyoming Ave. 90 Chestnut St.	Boonton-Urban land, Boonton substratum complex, red sandstone lowland	3-8	Moderately low to moderately high (0.06 to 0.20 in./hr)	Well drained	0 to1 in.: Slightly decomposed plant (C) 1-3 in.: Silt loam (C) 3-10 in.: Loam (C) 10-27 in.: Gravelly loam (B) 27-67 in.: Gravelly fine sandy loam (A) 67-83 in.: Gravelly sandy loam (A)
258 Main St.	Dunellen sandy loam	3-8	High (1.98 to 5.95 in./hr)	Well drained	0-42 in.: Sandy loam (A) 42-70 in.: Stratified gravelly sand to sand to loamy sand (A)
260 Hartshorn 142 Fairfield 87/89 Tennyson 7, 9, and 11 Fox Hill 8 South Beechcroft 2 Undercliff 15 Marion 11 Woodfield Dr	Boonton - Urban land, Boonton substratum complex, terminal moraine	3-8	Moderately low to moderately high (0.06 to 0.20 in./hr)	Well drained	0 to 1 in.: Highly decomposed plant (D) 1-24 in.: Sandy loam (B) 24-42 in.: Gravelly sandy loam (A) 42-60 in.: Fine sandy loam (B)
9 Lancer	Boonton - Urban land, Boonton substratum complex	8-15	Moderately low to moderately high (0.06 to 0.20 in./hr)	Well drained	0-5 in.: Loam (B/C) 5-30 in.: Silt loam (C) 30-40 in.: Gravelly fine sandy loam (A) 40-47 in.: Fine sandy loam (A) 47-72 in.: Loamy sand (A)
1 Sinclair Terrace	Boonton - Urban land, Boonton substratum complex	0-8	Moderately low to moderately high (0.06 to 0.20 in./hr)	Well drained	0-5 in.: Loam (B/D) 5-30 in.: Silt loam (C) 30-40 in.: Gravelly fine sandy loam (A) 40-47 in.: Fine sandy loam (A) 47-72 in.: Loamy sand (A)
36 Farley Place	Urban land, Boonton substratum	0-8	Moderate to moderately rapid	Well drained	0-12 in.: impervious material (D) 12-47 in.: silt loam (C) 47-72 in.: loamy sand (A)

[1]Capacity of the most limiting layer to transmit water
1 inch = 2.54 cm
Source: http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm

3.2.4.2 Kansas City, MO

Approximately 71% of the Kansas City 100-acre pilot area is mapped as having well-drained Sibley-Urban land complex soils with 5 to 9 percent slope. Less than 30% of the pilot study area includes Sibley-Urban land complex soils with 2 to 5 percent slope. The surface soils in the Kansas City 100-acre pilot area are silt loam. Table 3.19 summarizes the soil characteristics of the pilot area at Kansas City. Figure 3.28 represents a map of soils for the 100-acre study area.

Table 3.19. Summary of soil characteristics for Kansas City study area

Acreage	Soil Name	Slope (%)	K_{sat}[1]	Drainage class	Typical profile and associated Hydrologic Soil Groups for subsurface soils
71	Sibley-Urban land complex	5-9	Moderately high (0.20 to 0.57 in/hr)	Well drained	*0 to 26 inches:* Silt loam (C) *26 to 65 inches:* Silty clay loam (C/D) *65 to 80 inches:* Silt loam (C)
29	Sibley-Urban land complex	2-5			*0 to 17 inches:* Silt loam (C) *17 to 65 inches:* Silty clay loam (C/D) *65 to 80 inches:* Silt loam (C)

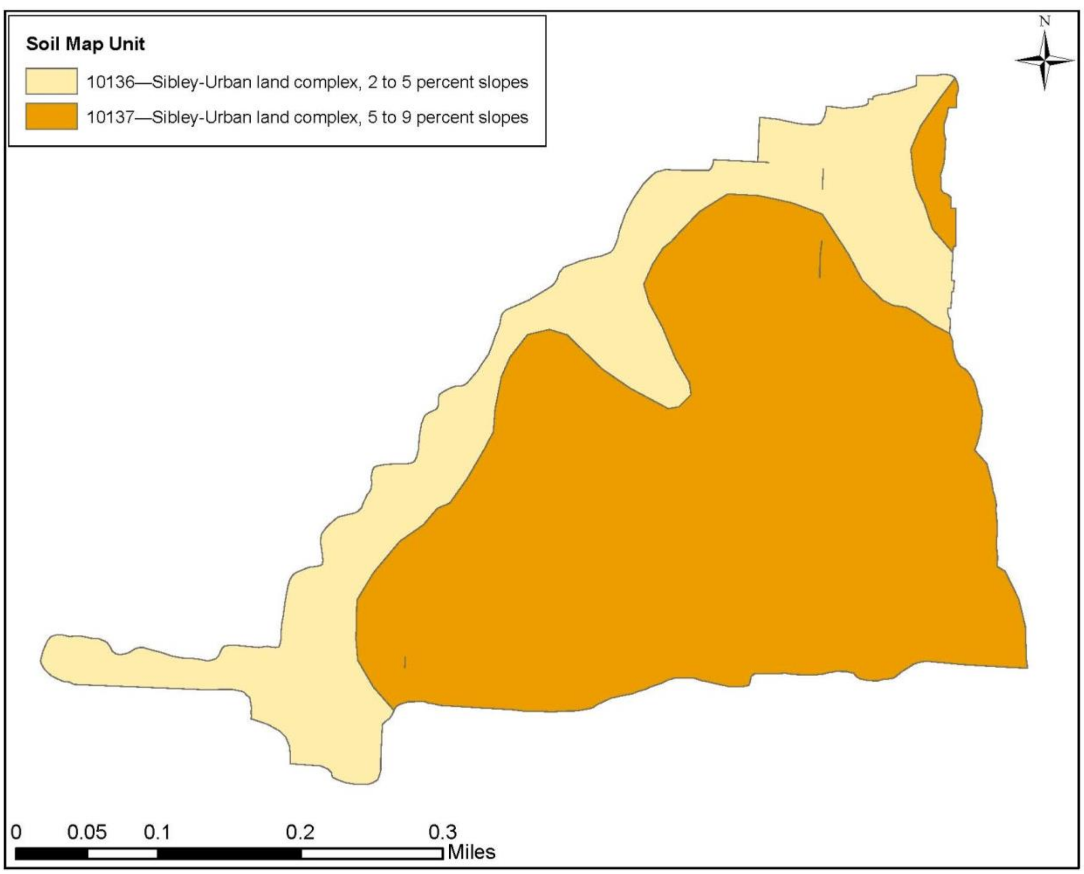


Figure 3.28. Soil Group Index of the 100-acre study area (NRCS; http://soils.usda.gov/)

3.2.4.3 Cincinnati, OH

All study areas in the Cincinnati, OH locations including Cincinnati State Technical and Community, Cincinnati Zoo, and Clark Montessori High school are mapped as having UrUXC—Urban land-Udorthents complex, with 0 to 12 percent slopes (Figures 3.29 to 3.31). Soils in this group have high to very high runoff potential when thoroughly wet. Drainage class and other properties of this soil type have not been rated.

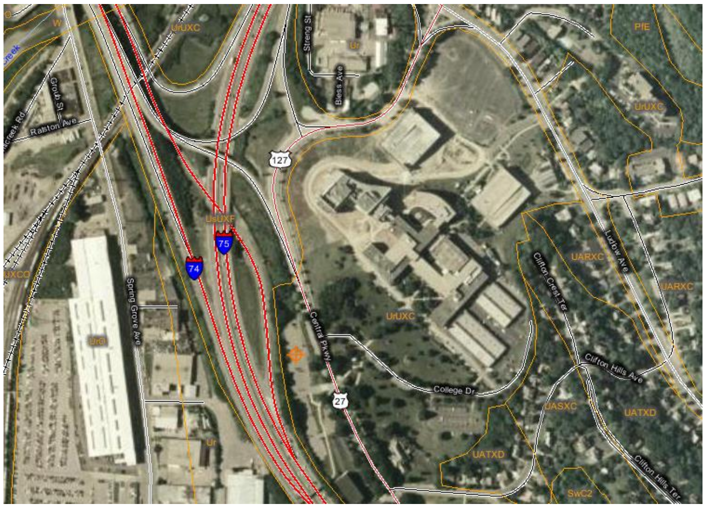


Figure 3.29. Soil Group Index for the Cincinnati State College area (http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx)

Figure 3.30. Soil Group Index for the Cincinnati Zoo area (http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx)

Figure 3.31. Soil Group Index for the Clark Montessori High School area (http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx)

3.2.5 WinSLAMM Model

WinSLAMM (Source Loading and Management Model for Windows) was developed to identify sources of problem pollutants and flows in urban areas and to identify and evaluate cost-effective management strategies. It accomplishes this by calculating stormwater runoff volumes and pollutant loadings for different land uses using continuous small storm hydrology calculations, in contrast to single event hydrology methods that have been traditionally used for much larger single storms used for drainage design (Pitt and Voorhees, 1995). Using the local rain records, WinSLAMM evaluates the runoff volume as well as pollutant loadings from each individual source area (such as roofs, streets, small and large landscaped areas, sidewalks, and parking lots) within each land use category (including residential, institutional, industrial, and commercial areas) for each rain. Detailed calculations considering source area, drainage system, and outfall stormwater controls are then used to help stormwater managers evaluate alternative management programs. The model does a complete mass balance and routing of water volume and particulate mass, considering the combined effects of all controls. Hydraulic and particle size routing occurs for each device individually, and serial effects of multiple devices are now accurately available in version 10.

In this dissertation research, WinSLAMM were used to calculate the effectiveness of GI stormwater controls, based upon long series of rainfalls, the source area characteristics, and the characteristics of stormwater control (such as size and location). WinSLAMM also calculates the stormwater contributions to the combined sewer system during wet weather before and after construction, by providing a time series of flows for various types of upland controls.

3.3 Statistical Analysis of the Data

This section provides description of some selected statistical tests and their data requirements that were used for data evaluations during this research.

3.3.1 Basic Data Plots

Several basic data plots including scatterplots, time series, and box-and-whisker plots were used during this dissertation research. These plots were used for demonstrating overall data trends, along with QA/QC analyses (such as finding data gaps and meter errors). In this dissertation research, time series plots were used to show water levels in individual green infrastructure facilities during short- and long-term infiltration tests. These time series plots are very informative concerning the trends and overall behavior of the infiltration characteristics at different sites. In addition, time series plots were used to show flows in combined and separate sewer lines over time, for monthly and daily periods. These time series help define trends, patterns, and possible clustering of data.

Box and whisker plots were used to graphically depict the distribution of a dataset, and to indicate possible groupings of the data. This type of plot provides many important characteristics of the datasets including median, first and third quartiles, skewness, and outliers. Box and whisker plots also help to examine the differences between the significant groupings of the data by comparing the range and major percentile locations of the data. If the lower and upper quartile lines of two boxes do not overlap, the medians of the two groups are likely significantly different at the 95% confidence level, when moderate numbers of data observations are available. In this dissertation, box plots were applied to graphically represent the infiltration data and to identify groupings of infiltration characteristics, which explain the variabilities in individual green infrastructure control practices. Moreover, box plots were used to compare runoff volumes for different study periods (before and after construction).

3.3.2 Regression Analyses

Regression analyses were used to determine the relationships between a response independent variable and one or more dependent predictors. There are two general types of regressions: linear and non-linear regressions. This dissertation research used non-linear regressions for many of the tests to fit with classical solutions to complex equations. To examine the goodness of the fitted equations, the normal probability plot of the residuals and related statistical tests (such as the Anderson-Darling test) were provided, along with ANOVA analyses. The scatterplot of the residuals versus the predicted values was verified for constant variance. The ($y = a + be^{-kx}$) non-linear regression was used to fit the observed infiltration observations from individual green infrastructure stormwater controls to Horton's equation. In addition, the ($y = ax^b$) non-linear regression was applied to fit the observed stage-discharge data to Manning's equation. Different Manning's roughness numbers were fitted to calculate the flow based on water stage in sewer pipes to check the calibration of the flow sensors. To find the best fit, the sum of the squares of differences between the observed and the corresponding estimated flows were calculated. The fitted regression with minimum sum of the squares of errors represents the best fit. The following equation is used to determine the sum of square errors (Dashtaki et. al, 2009):

$$SSE = \sum_{i=1}^{n} (Q(m)_i - Q(p)_i)^2$$

where SSE is the sum of square error, $Q(m)_i$ is the measured flow in the sewer line, and $Q(p)_i$ is the predicted flow using Manning's formula.

3.3.3 Analysis of Variance (ANOVA)

An Analysis of Variance (ANOVA) test is used to analyze the differences between two or more groups of data (within vs. between data groups). The null hypothesis in the ANOVA test is that the means of several sets of data are equal. ANOVA is a parametric test, which requires data to be independent, and normally distributed. In addition, the variance of data in groups should be equal. To interpret the ANOVA result, if the p-value is less than or equal to the selected α-level (confidence level), the null hypothesis will be rejected in favor of the alternative hypothesis, which indicates that at least one subset is statistically different from at least one other subset. However, ANOVA is not able to identify which group is different from the others. In this dissertation research, a traditional α value of 0.05 was used to test the hypothesis.

If the data did not meet the assumptions of normality and equal variance, the Kruskal-Wallis test was used to determine if there was a statistically significant difference between two or more sets of data. The Kruskal-Wallis test is a non-parametric test that requires data to be independent from continuous distributions, with the distributions having the same shape. Similar to the ANOVA test, Kruskal-Wallis does not identify which set of data is different from other sets, or how many different sets exist among all sets.

In this dissertation research, one-way ANOVA (when data are normally distributed) or Kruskal-Wallis (when data are not normally distributed) were conducted to indicate any significant differences between before, during, and after stormwater controls construction periods. In addition, one-way ANOVA or Kruskal-Wallis tests were used to examine infiltration data to determine whether the data can be grouped based on mapped soil characteristics.

3.3.4 Post-hoc Tests

While the ANOVA or Kruskal-Wallis tests do not determine which groups of the data are different from other groups, post-hoc tests can be applied to identify whether any two sets of data are similar or different. Post-hoc tests were used when a significant F-value was obtained from an ANOVA or Kruskal-Wallis test. The post hoc tests provide pairwise comparisons that help to determine if particular pairs of data are significantly different from each other. There are several post-hoc tests with different assumptions about group sizes and equality of variance including; Bonferroni t-test, Tukey’s test, and Mann-Whitney test. Grouped box and whisker plots and grouped probability plots were also used to identify likely groupings of the individual data sets.

3.3.5 Flow Pattern (Trend Analyses)

In this dissertation research, trend analyses were conducted on the flow monitoring data to identify flow patterns. Flow patterns for dry days (individually for each day of the week) were analyzed for evidence of reoccurring diurnal patterns within each month. The dry-weather flow patterns from the combined sewer flow monitors usually indicate differences between weekdays, weekends, and holidays/special events. Therefore, within each month, dry weekdays, as well as dry weekends were examined using flow pattern analyses with "run chart" tests (using Minitab), along with trends, and clustering tests.

The run chart test is a simple representation of process data over time which plots individual flow observations chronically, and draws a horizontal reference line at the mean of the data. Run charts provides information on non-random variations due to trends, oscillation, mixtures, and clustering. This information includes numbers of runs about the median, numbers of runs up or down, expected numbers of runs, p-values for clustering, trends, mixtures, and oscillations. The null hypothesis of run charts is that the data have a random sequence. "Run Chart converts the observed number of runs into a test statistic that is approximately standard normal, then uses the normal distribution to obtain p-values" (Minitab 16). Therefore, if the calculated p-value is less than the chosen α-level, the hypothesis of randomness was rejected. These tests were conducted to examine weekday base flow and weekend base flow for each month at each monitoring location.

3.3.6 Statistical Significance Measures

Type I errors (also known as false positives) involves the rejection of a null hypothesis when the null hypothesis is actually true. The significance level (alpha) is a pre-chosen probability of making Type I errors, while the p-value is the calculated probability of rejecting the null hypothesis. The calculated p-value is compared to the pre-chosen alpha level to examine if the null hypothesis is true or not. In this dissertation research, the traditional α-level of 0.05 was chosen, which indicates a 5% risk of having Type I errors. Therefore, if the p-value was less than or equal to the alpha level ($p \leq 0.05$), the null hypothesis was rejected in favor of the alternative hypothesis and the results were statistically significant. However, if the p-value was more than the alpha level ($p > 0.05$), we fail to reject the null hypothesis, meaning that there is no sufficient evidence to detect statistically significance difference for the examined conditions (highly dependent on the number of data observations).

A type II error is the failure to reject a false null hypothesis, which is a false negative. Beta (β) represents the probability of making a Type II error, and "power" is the certainty of not having a false negative, which is calculated as $(1 - \beta)$ (Burton and Pitt, 2002). A common level of beta is usually chosen as 0.20, which indicates a power of 80%.

Type I and type II errors are part of statistical hypothesis tests and cannot be completely eliminated. Typically by reducing the probability of one type of error, the probability for the other type increases. In a statistical test, α and β values need to be chosen in a way to have the smallest β at the largest α values (Devore 2008). Adequate power (along with suitable levels of confidence) is typically ensured by having sufficient numbers of data observations, as quantified during the experimental design project phase.

3.4 Summary

The main objective of this dissertation research is to examine the effectiveness of retrofitted green infrastructure stormwater controls in small- and large-scale developed urban watersheds. For this, data from three different case studies were used. The case studies include small scale demonstrations at Millburn, NJ, and Kansas City, MO, and large scale demonstrations at Kansas City, MO, and Cincinnati, OH.

In Millburn, NJ, eleven dry wells were monitored for water levels during short and long-term periods (ranging from 2 months to one year), or by controlled tests using township water from fire hydrants. This case study was selected to evaluate GI benefits at a small scale. Therefore, the effectiveness of Millburn's stormwater management practices that rely on the use of dry wells was investigated. There were varying levels of dry well performance in the area, but most were able to completely drain within a few days.

The Kansas City, MO project is one of the largest projects being monitored in the United States using extensive GI controls. The pilot 100-acre neighborhood has about 135 green infrastructure-based stormwater controls. It also underwent sewer rehabilitation to decrease sewage losses from the conveyance system. Therefore, the Kansa City, MO case study has been selected to examine the benefits of GI stormwater controls at small scales (using infiltration data from individual GI stormwater control monitoring), and large scales (using flow data from combined sewer systems in the pilot and adjacent control watersheds). Three curb extension biofilters, two curb-cut biofilters, two biofilters with smart drains, and a cascade biofilter were monitored for infiltration for several months. Also, flow data in the combined sewer system were available for before, during, and after the green infrastructure component construction periods, for both the pilot and control watersheds.

In Cincinnati, OH, three study areas including Cincinnati State College, the Cincinnati Zoo, and the Clark Montessori High School sites were evaluated for GI performance at large scales. These sites have about three years of high-resolution (5-minute) flow measurements from in-system flow monitors located in combined and separate sewers on or adjacent to several green infrastructure installations. The flow data is available before, during, and after stormwater controls construction for three of the study subareas, while after construction monitoring data are available for two of the study subareas.

Analyses were conducted for all combined and separate flow monitors in these areas to calculate the benefits of green infrastructure-based stormwater controls. The analyses indicated that some monitoring approaches are better than others, as some of the flow monitoring results appear to be faulty (downstream flows much less than upstream flows for example). Since the monitoring period has concluded and the equipment removed, it is not possible to verify the flow calibrations. Therefore, an important part of this dissertation research was to recommend an effective monitoring strategy and QA/QC process. Table 3.20 summarizes the availability of flow monitoring data for the different construction phases at each of the Cincinnati study areas.

Table 3.20. Availability of flow data for different construction phases at each study area of Cincinnati, OH

Location	Jan-10	Feb-10	Mar-10	Apr-10	May-10	Jun-10	Jul-10	Aug-10	Sep-10	Oct-10	Nov-10	Dec-10	Jan-11	Feb-11	Mar-11	Apr-11	May-11	Jun-11	Jul-11	Aug-11	Sep-11	Oct-11	Nov-11	Dec-11	Jan-12	Feb-12	Mar-12	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12
Cincinnati State College Combined Sewer (above & below site monitoring)																																				
Cincinnati State College Separate Sewer (single monitoring location)																																				
Cincinnati Zoo - Main Entrance (separate sewer)																																				
Cincinnati Zoo - African Savannah (combined sewer)																																				
Clark Montessori High School (combined sewer)																																				

Note: Before Construction (pink), During Construction (yellow), and After Construction (green)

This dissertation research also includes utilizing WinSLAMM for each study area, calibrated using the pre-construction flow data. This provides the opportunity to compare the observed runoff volumes with the modeled runoff volumes. In addition, for those sites that do not have pre-construction flow data available (i.e. main entry of the Cincinnati Zoo), WinSLAMM predict pre-development conditions for comparison to monitored results using regional calibration information for traditionally paved areas. The model were also verified for the monitoring conditions (with controls) to increase the confidence for the necessary comparisons. Individual stormwater control monitoring data, in conjunction with the large-scale flow monitoring data, increase the weight of evidence supporting the performance expectations of the sustainable infrastructure components in large-scale watershed areas. As noted above, the flow monitoring data were collected using different schemes, and the data evaluation phase illustrate the most appropriate methods to evaluate each, along with their varying levels of uncertainty.

CHAPTER 4.0

ASSESSING THE PERFORMANCE OF GREEN INFRASTRUCTURE STORMWATER CONTROLS AT DIFFERENT WATERSHED SCALES

4.1 Introduction

This chapter is structured as follows:

- First, this chapter provides results for individual GI stormwater controls at small scales. This section includes infiltration analyses for Millburn dry wells, as well as results of the monitored biofilters at Kansas City.
- Second, the results for integrated GI stormwater controls at large scales are examined. This section provides rainfall and flow analysis in combined and separate sewer lines, from different flow meters at both the Kansas City and Cincinnati study areas.
- Third, this chapter provides recommendations for flow monitoring and analyses for green infrastructure performance evaluations, considering special problems associated with small-scale and large-scale GI control monitoring.

4.2 Evaluation of Performance of Individual GI Stormwater Controls at Small Scales

4.2.1 Infiltration Analyses for Millburn Dry Wells

Infiltration tests at the Millburn dry wells were conducted during two project phases: the first phase filled the dry wells with domestic water from township fire hydrants and the decreasing water levels were recorded; the second phase used continuous water level monitoring in a fewer number of dry wells during many rains. Much information was collected as part of this research project in Millburn to measure actual performance of the dry wells. Both short and long-term infiltration measurements were therefore conducted at many locations. These data are analyzed and summarized in this section, with more detailed data included in Appendix C.

The infiltration measurements were conducted using continuously recording (10 minute observations) LeveLoggers by Solintest that were installed in the dry wells. Short-term tests were conducted in seven dry wells throughout the township to measure the influence of the conditions present in the community. These tests were conducted using water from nearby fire hydrants which was used to completely fill the dry wells. The LeveLoggers were then used to measure the decreasing water level over time (ranging from several hours to several days). The long-term tests were conducted in eleven dry wells (based on the number of LeveLoggers available). These were installed for several months to over a year and continuously recorded the water levels in the dry wells every 10 min. Close-by rain gauges were also used to record local rains associated with these events. These rain and water level data were downloaded by PARS Environmental personnel and uploaded to their FTP site where University of Alabama researchers downloaded the data for analysis.

The first step in the data analyses was to plot the data as time series. Figure 4.1 is an example time series plot of the water levels recorded over a two month period at 11 Woodfield Dr. showing 6 separate events (the first peak only shows the dropping water levels from the Oct 13, 2009 event). The infiltration characteristics of the dry well installations were calculated from the recession curves of the individual rain events. The infiltration rates for each 10 minute step were calculated based on the drop in water level per time increment, resulting in plots of infiltration rates vs. time since the peak water level. These are classical infiltration rate plots and statistical analyses were used to calculate infiltration rate equation parameters for two common infiltration equations (Horton and Green-Ampt). The following discussion presents and compares these results with varying site conditions.

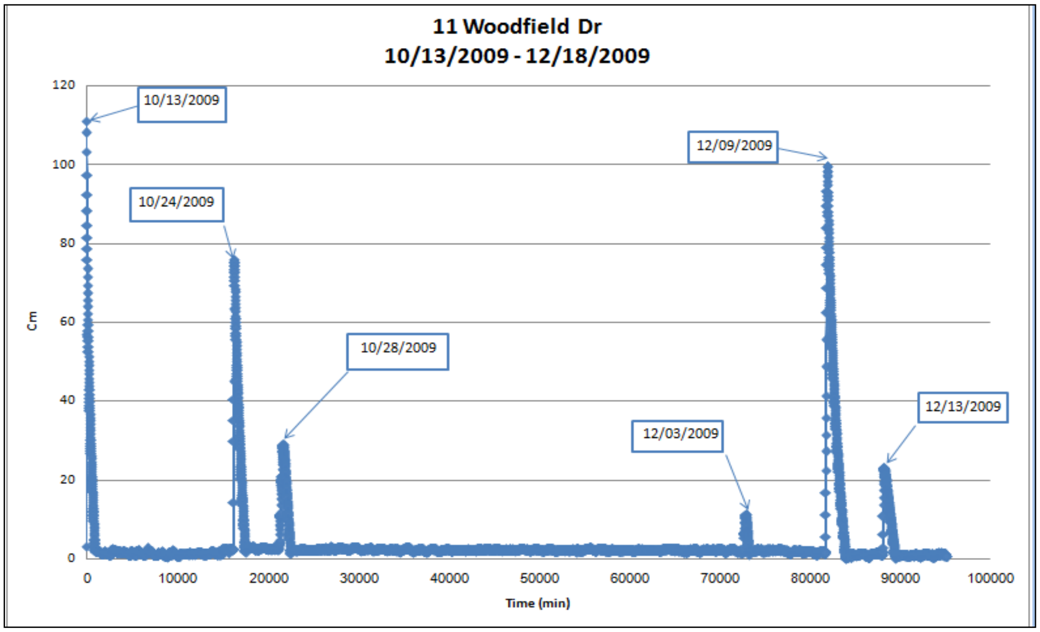


Figure 4.1. Time series example of dry well water levels at 11 Woodfield Dr.

4.2.1.1 Rainfall Measurements

Four rain gauges were installed in the study area for this project (HOBO® data logging rain gauge data logger). The rain gauges are battery-powered rainfall data collection and recording systems which included a HOBO® Pendant Event data logger integrated into a standard 8 inch tipping-bucket rain gauge. Table 4.1 represents a list of the locations of the four rain gauges that were installed in the study area. Figure 4.2 shows photos of the rain gauges (with some undergoing calibration).

Table 4.1. List of the locations of the four rain gauges that were installed in the study area

R1	Private house on top of chimney slab at 1 Delwick Lane - Calibrated and launched at 14:00 on 5/22/09
R2	Roof of Township’s maintenance garage on Essex Rd - Calibrated and launched at 12:00 on 5/13/09.
R3	Municipal Par 3 Golf Course on White Oak Ridge Rd - Calibrated and launched at 16:00 on 5/13/09.
R4	Old tennis court at Greenwood Gardens on Old Short Hills Rd – Calibrated and launched at 16:00 on 5/6/09.

Figure 4.4 shows the locations of the rain gauges and the monitoring locations, while Table 4.2 lists the monitoring sites and corresponding closest rain gauge location. The rain gauges provided information about the start time, end time, duration, depth, peak and average intensity of each rain event. Each separate rain event had at least 6 hr of no rain before and after the recorded rainfall. The rain information corresponding to the infiltration data is summarized for each infiltration event monitored, as shown in Table 4.3 and Figure 4.3. The rainfall graphs and information are presented in Appendix D, along with the detailed infiltration information.

R2: Roof of Township’s maintenance garage (gauge being calibrated)

R2: Roof of Township’s maintenance garage (gauge being calibrated)

R3: Municipal Par 3 Golf Course (gauge being calibrated)

R4: Old tennis court at Greenwood Gardens (with top funnel removed)

R2: Millburn Township Garage rooftop rain gauge location.

R1: Residential rooftop rain gauge location (located near chimney).

Figure 4.2. Photos of rain gauges (R1, R2, and R3 are shown during site calibration).

Table 4.2. List of Rain Gauges Closest to Monitoring Site Locations

Rain Gauge	Locations of Studied Dry Wells	ID on Map (Figure 4.4)
R1: 1 Delwick Ln	11 Woodfield Dr	1
R2: 345 Essex St	15 Marion Ave	2
	258 Main St	3
	2 Undercliff Rd	4
	383 Wyoming Ave	5
R3: 335 White Oak Ridge Rd	260 Hartshorn Dr	6
	79 Minnisink Rd	7
	87/89 Tennyson Dr	8 and 9
	36 Farley Pl	16
R4: 274 Old Short Hills Rd	1 Sinclair Terrace	10
	142 Fairfield Dr	11

	8 Beechcroft Rd	12
	7 Fox Hill Ln	13
	9 Fox Hill Ln	14
	11 Fox Hill Ln	15

Table 4.3. Example Summary of Rainfall Information (2/25/2011 – R3) (1 in = 25.4 mm)

Start time		End time		Duration (hr)	Depth (in)	Average intensity (in/hr)
2/25/2011	0:25	2/25/2011	18:44	18:19	1.36	0.06

Figure 4.3. Example of a rain event graph. (1 in = 25.4 mm)

Figure 4.4. Location of dry wells (blue icons), rain gauges (yellow icons), and water quality samplers (red icons for dry wells and green icon for cistern)(source: maps.google.com).

4.2.1.2 Infiltration Measurements

The water levels in the dry wells were recorded using Solinst Levelogger Gold and Barologger monitors. The Levelogger Gold is an absolute data logger which measures water levels and temperature. The Levelogger Gold devices use a sensitive piezoresistive silicon pressure transducer packaged in a stainless steel housing. The Levelogger converts the total pressure reading to its corresponding water level equivalent, after correction for changing atmospheric pressure from the Barologger. The typical accuracy of this type of Levelogger is about 0.05% to 0.1% of full scale (FS). The water levels were recorded every 10 min.

Initial infiltration studies were conducted by quickly filling selected dry wells with water from township fire hydrants and recording the subsequent fall of the water levels. These infiltration studies were performed after at least a 72 hr dry period. The photographs in Figure 4.5 show the process of filling the dry well with the township fire hydrant water at one of the test sites. Table 4.4 describes the township water infiltration tests for the seven selected sites.

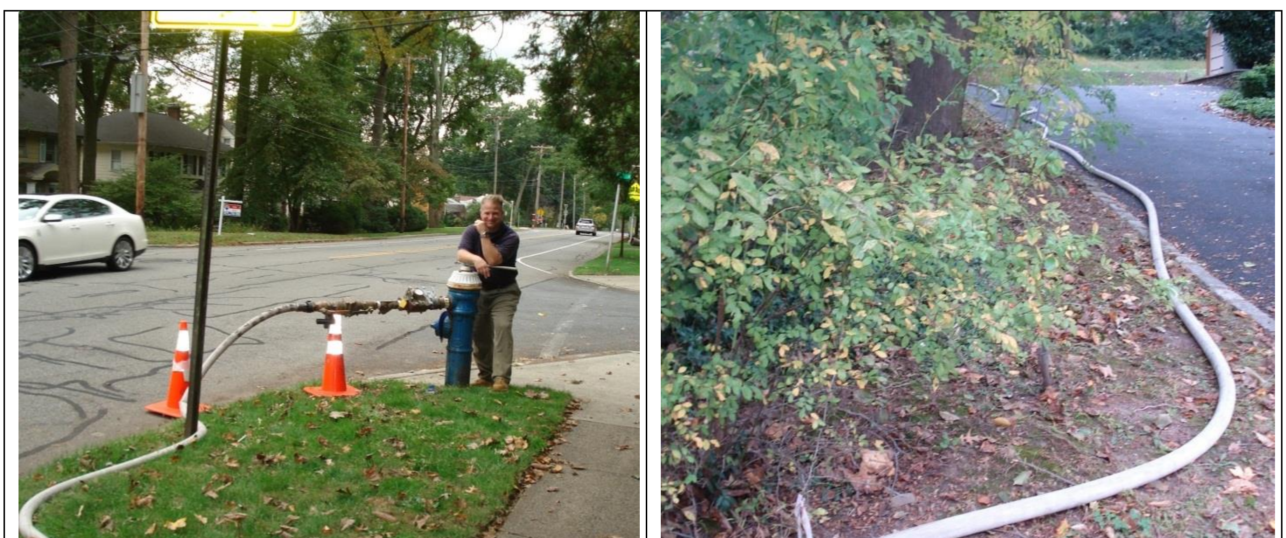


Figure 4.5. Infiltration studies for a dry well located at 383 Wyoming: filling the dry well with water from the fire hydrant and recording the fall of water level.

Table 4.4. Test Characteristics for Township Fire Hydrant Infiltration Tests at Seven Dry Wells

Location	**Fill Date**	**Start Fill Time**	**Stop Fill Time**	**Total Fill Time (min)**	**Total Fill Volume from Hydrant (gal)**	**Fill Rate (gal/min)**
1 Sinclair Terrace	7/15/2009	10:40	11:30	50	3,300	66
2 Undercliff Road	10/2/2009	09:07	09:26	19	2,500	132
383 Wyoming	10/2/2009	10:14	10:43	29	2,900	100
8 South Beechcroft	10/2/2009	12:07	12:15	8	900	113
9 Fox Hill Lane	10/2/2009	12:44	13:15	31	2,600	84
11Fox Hill Lane	10/2/2009	13:16	14:00	44	3,400	77
11 Woodfield Road	10/13/2009	10:07	10:30	23	3,600	157

4.2.1.3 Infiltration Equations

Site soil evaluations included infiltration measurements, along with soil density, texture, and moisture determinations. The water infiltration data can be fitted to soil water infiltration models, such as the Green–Ampt (1911), the Kostiakov (1932), the Horton (1940) and the Philip's (1957) equations. Although various infiltration equations have different mathematical structures and calibration parameters, their estimates are all premised on observed water infiltration data (in/hr as a function of time). The most common Green-Ampt and Horton equations were examined during this project and are briefly described in the following discussion.

4.2.1.4 Horton Infiltration Equation

One of the most commonly used infiltration equations was developed by Horton (1940). The equation is as follows:

$$f = f_c + (f_o - f_c)e^{-kt} \qquad (1)$$

where:

f is the infiltration rate at time t (in/hr),

f_o is the initial infiltration rate (in/hr),

f_c is the final (constant) infiltration rate (in/hr), and

k is first-order rate constant (hr^{-1} or min^{-1}).

This equation assumes that the rainfall intensity is greater than the infiltration capacity at all times and that the infiltration rate decreases with time (Bedient and Huber, 1992). This is a reasonable assumption for ponded conditions, such as in the dry wells. The capacity of the soil to hold additional water decreases as the time of the storm increases because the pores in the soil become saturated with water. The Horton equation's major drawback is that it does not consider the soil water storage availability after varying amounts of infiltration have occurred, but only considers infiltration as a function of time (Akan, 1993). It is recommended that f_c, f_o, and k all be obtained through field data, but they are rarely measured. Table 4.5 shows commonly used Horton infiltration parameter values, as summarized by Denver's Urban Drainage and Flood Control District (2001). This summary is for the four NRCS hydrologic soil groups (HSG) corresponding to HSG sandy (A) to clayey (D) conditions. The coefficient values for C and D soils are the same, with B soils having only slightly increased final infiltration rates.

Table 4.5. Horton Infiltration Coefficient Values Typically used in Urban Drainage Projects (Urban Drainage and Flood Control District, UDFCD 2001)

HSG	Initial infiltration rate, f_o (in/hr)	Final infiltration rate, f_c (in/hr)	First-order rate constant (1/hr)	First-order rate constant (1/min)
A	5.0	1.0	2.52	0.04
B	4.5	0.6	6.48	0.11
C	3.0	0.5	6.48	0.11
D	3.0	0.5	6.48	0.11

1 in/hr = 25.4 mm/hr

Akan (1993) presented a somewhat more detailed table for the initial infiltration rates (the other coefficients did not change greatly for the different soil conditions). Akan shows the effects of antecedent moisture and vegetation on these initial infiltration rates.

Table 4.6. Horton parameters (Akan, 1993)

Soil Type	f_o (in/hr)
Sandy soils with little to no vegetation	5
Dry loam soils with little to no vegetation	3
Dry clay soils with little to no vegetation	1
Dry sandy soils with dense vegetation	10
Dry loam soils with dense vegetation	6
Dry clay soils with dense vegetation	2
Moist sandy soils with little to no vegetation	1.7
Moist loam soils with little to no vegetation	1
Moist clay soils with little to no vegetation	0.3
Moist sandy soils with dense vegetation	3.3
Moist loam soils with dense vegetation	2
Moist clay soils with dense vegetation	0.7

1 in/hr = 25.4 mm/hr

4.2.1.5 Green-Ampt Infiltration Equation

Another common equation for infiltration calculations is by Green-Ampt. The Green-Ampt equation calculates cumulative infiltration as the water flows into a vertical soil profile (Green and Ampt, 1911).

$$f_t = K(\frac{\psi\Delta\theta}{F_t} + 1) \qquad (2)$$

Where: f_t is infiltration rate, mm/hr; ψ is suction at wetting front (negative pressure head) (mm); $\Delta\theta$ is the difference of soil water content after infiltration with initial water content (mm^3/ mm^3); K is hydraulic conductivity (mm/hr); and F_t is the cumulative infiltration at time t (mm). This equation requires a linear relationship between ft and ($1/F_t$). Table 4.7 shows some typical Green-Ampt equation parameter values suggested by Rawls et al. (1983).

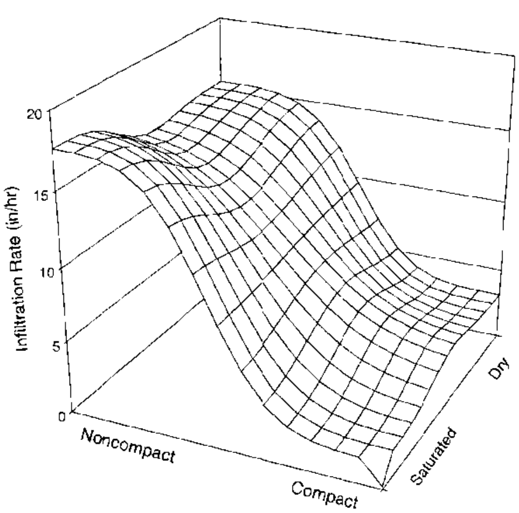
Table 4.7. Green-Ampt parameters (Rawls *et al.* 1983)

Soil type	Porosity	Effective porosity	Suction head (mm)	Hydraulic conductivity (mm/h)
sand	0.437	0.417	49.5	117.8
loamy sand	0.437	0.401	61.3	29.9
sandy loam	0.453	0.412	110.1	10.9
loam	0.463	0.434	88.9	3.4
silt loam	0.501	0.486	166.8	6.5
sandy clay loam	0.398	0.330	218.5	1.5
clay loam	0.464	0.309	208.8	1.0
silty clay loam	0.471	0.432	273.0	1.0
sandy clay	0.430	0.321	239.0	0.6
silty clay	0.479	0.423	292.2	0.5
clay	0.475	0.385	316.3	0.3

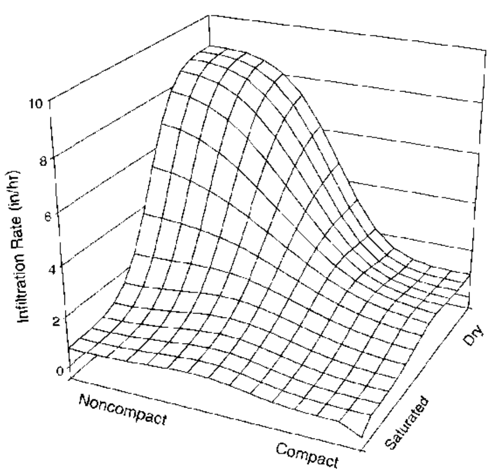
4.2.1.6 Infiltration as a Function of Soil Texture and Compaction

Hydrologic models must contain a process to address the infiltration of rain water into the soil. The infiltration process in most models is usually dependent on the porosity (assumed to be a function of soil texture) and moisture content of the soil: in an unsaturated soil, infiltration usually is initially rapid but then declines to a constant value as the soil becomes saturated. Water infiltration through the soil is of interest in urban watershed management due to concerns of groundwater contamination potential and because infiltration conditions dramatically decrease with land development which is an important cause of increased surface runoff (in addition to increased amounts of impervious surfaces) (Pitt et al. 1994 and 1995). It has been well documented that during urbanization, soils are greatly modified, especially related to soil density. Increased soil compaction results in soils that do not behave in a manner predicted by traditional infiltration models. It is crucial, therefore, that stormwater engineers better understand infiltration in disturbed urban soils. Laboratory and field tests can be used to determine expected infiltration behavior of disturbed urban soils for a specific area.

Since the early 1990s, Pitt et al. (1999) has conducted a series of laboratory and field tests on soils covering a wide range of soil textures, densities, and stiffness. As shown in Figure 4.6, these field tests highlighted the importance of compaction on the infiltration rate of soils. For sandy soils, minimal effects are seen associated with antecedent moisture conditions compared to soil compaction. For the clayey soils, both the compaction level and antecedent moisture conditions are likely important in determining the infiltration rate. Table 4.8 summarizes the Horton equation coefficients for these urban soils, showing the dramatic effect soil density has on the infiltration characteristics.



Three dimensional plots of infiltration rates for sandy soil conditions.



Three dimensional plots of infiltration rates for clayey soil conditions.

Figure 4.6. Effects of soil moisture and soil compaction on infiltration rates (Pitt *et al.* 1999).

Table 4.8. Horton Coefficients (Pitt *et al.* 1999)

Infiltration Parameter	Soil Group	90%	75%	50%	25%	10%
f_o (in/hr)	Clay – Dry Noncompacted	42	24	11	7	5
	Clay-Other	7	3.75	2	1	0
	Sand-Compact	42	12	5	1.5	0
	Sand-Noncompacted	52	46	34	24	0.25
f_c (in/hr)	Clay – Dry Noncompacted	20	12	3	0.75	0.25
	Clay-Other	0.75	0.5	0.25	0	0
	Sand-Compact	5	1.25	0.5	0.25	0
	Sand-Noncompacted	24	19	15	9	0
k (1/min)	Clay – Dry Noncompacted	0.3	0.22	0.16	0.07	0.05
	Clay-Other	0.18	0.1	0.06	0.03	0
	Sand-Compact	0.28	0.2	0.1	0.05	0.016
	Sand-Noncompacted	0.32	0.2	0.08	0.03	0

1 in/hr = 25.4 mm/hr

4.2.1.7 Fitted Horton Equation Parameters for Millburn Dry Well Infiltration Measurements

The initial infiltration data analysis was to prepare plots of the observed infiltration data in order to evaluate major trends and groupings of the data. Observed data included water stage changes in the dry wells every 10 min which were used to calculate the infiltration rates for these time increments during the runoff events. Data from each site for each event/infiltration test were fitted to the Horton infiltration equation by calculating f_o (the initial infiltration capacity), f_c (the constant infiltration capacity as t(time) approaches infinity), and k (a soil parameter that controls the rate of decrease of infiltration rate) equation parameters. For some of the sites, the Horton equation was not able to be fitted to the observed data, as little change in water levels occurred with time. This typically occurred for slowly decreasing water levels with time or when standing water occurred due to shallow water tables. For these conditions, the observed rates most likely corresponded to the fc values, the saturated infiltration rate (f_o and k were not calculated).

Figure 4.7 shows the observed infiltration rates and the fitted Horton equation parameter values for the dry well located at 7 Fox Hill Ln, Millburn, NJ, as an example. Graphs are for one single actual rain event representing observed data, fitted Horton equations, rain depths, and the water stages in the dry well. The remaining observed data along with fitted Horton graphs for each dry well and each event are presented in Appendix C. Some initial rates were very large, but decreased quickly with time. As shown on Figure 4.7 the variability of the infiltration rates is heterogeneous and is higher in the beginning of the infiltration process. After equilibrium had been reached there is less variation in infiltration rates. Basic statistical analyses, including average, minimum, maximum, standard deviation, and COV are included for all the data, as well as ANOVA test and residual plots for some of the fitted Horton equations in comparison to the Green-Ampt equation.

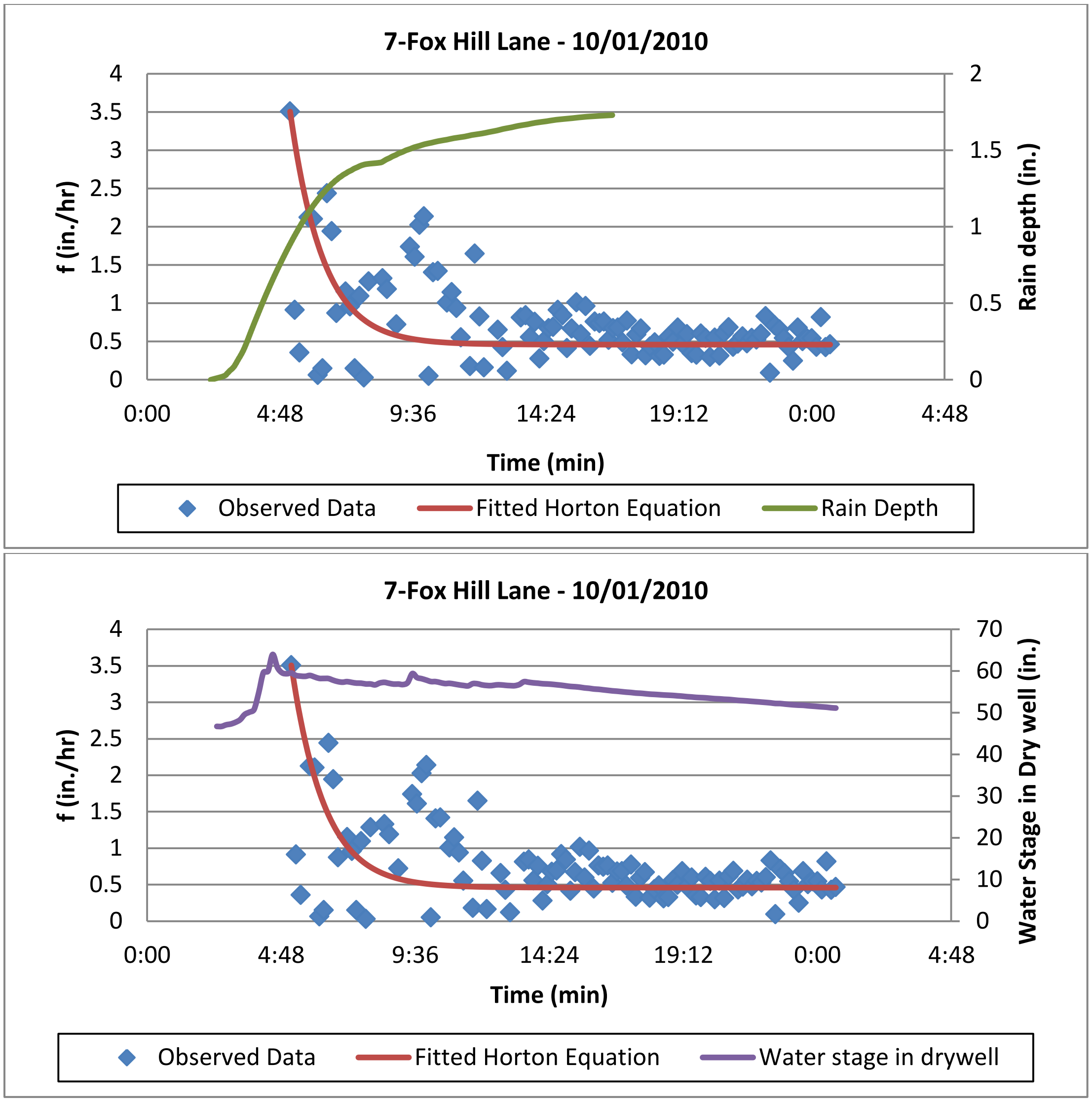


Figure 4.7 Example of observed data, fitted Horton equation, rain depth, and water stage in a dry well for a single rain event in a selected dry well. (1 in/hr = 25.4 mm/hr)

Tables 6a through 6n in Appendix C are a summary of the best-fit Horton equation parameter values based on infiltration tests for some sites at Millburn, NJ, for different rains. Three types of tables are included for the tests:

- Infiltration study test: A table summarizing Horton parameters, infiltration study test characteristics and water depth in the dry wells.

- Infiltration for rain events: Fitted observed data to Horton's equation resulting for fo, fc, and k values.
- Infiltration for rain events when fitting the observed data to Horton's equation results in fo = fc (and k is therefore not applicable): A table summarizing statistical analysis for fo = fc, rain characteristics of corresponding rain event, and water depth in the dry wells.

Multiple iterations of grouped box and whisker plots and ANOVA tests were used to identify data groupings for Horton parameters including f_o, f_c and k. The data were not normally distributed so ANOVA based on ranks and Mann-Whitney Rank Sum nonparametric tests were used to calculate the significance that the data did not originate from the same populations. There were two distinct sets for the f_c data: the 258 Main St location (the only location that had soils in the A group from the surface to about 1.1 m (3.5 ft) deep) vs. all of the other sites combined. Figure 4.8 shows these two data sets.

There were two different sets for the f_o data: the 258 Main St location combined with 8 South Beechcroft vs. all of the other sites combined. Figure 4.8 shows these two data sets. Figure 4.8 is the final box and whisker plot for f_o values, showing the two data groups: 258 Main St, plus 8 So. Beechcroft vs. all the data combined.

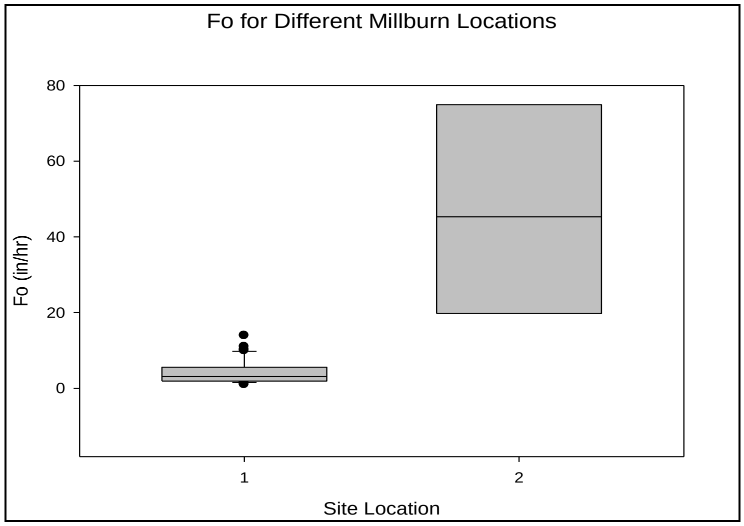


Figure 4.8. Box and whisker plot of f_o data showing two sets of data, 1: All sites combined, 2: 258 Main St. and 8 South Beechcroft combined. (1 in/hr = 25.4 mm/hr)

The results of the final Mann-Whitney Rank Sum test for fo are shown below:

Normality Test (Shapiro-Wilk)	Failed	($P < 0.050$)			
Group	N	Missing	Median	25%	75%
All the rest combined	43	0	3.12	1.94	5.63
258 Main & 8 So. Beechcroft	7	0	45.3	19.8	74.9

Mann-Whitney U Statistic= 0.000
T = 329; n (small) = 7; n (big) = 43; P = <0.001

The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference: P = <0.001. Tables 4.9 and 4.10 summarize the values and test conditions for these two sets of data.

Table 4.9. f_o Summary Values and Conditions for 258 Main St. and 8 So Beechdroft Rd.

	f_o (in/hr)	Rain Depth (in)	Max. depth of water in dry well (in)	Min. depth of water in dry well (in)
number	7	6	7	7
Minimum	16.12	0.52	16.76	0.10
Maximum	75.14	1.71	54.77	1.94
Average	44.55	1.14	38.29	0.54
Median	45.29	1.28	41.29	0.32
Std Dev	23.74	0.45	14.98	0.65
COV	0.53	0.39	0.39	1.21

1 in = 25.4 mm

Table 4.10. f_o Summary Values and Conditions for All of the Other Sites

	f_o (in/hr)	Rain Depth (in)	Max. depth of water in dry well (in)	Min. depth of water in dry well (in)
number	43	60	77	77
Minimum	1.01	0.22	6.51	0.00
Maximum	13.95	2.90	93.85	82.98
Average	4.34	1.20	51.28	21.93
Median	3.12	1.07	54.45	12.06
Std Dev	3.20	0.77	23.07	24.32
COV	0.74	0.64	0.45	1.11

1 in = 25.4 mm

There were two distinct sets for the f_c data: the 258 Main St location (the only location that had soils in the A group from the surface to about 1.1 m (3.5 ft) deep) vs. all of the other sites combined. Figure 4.9 shows these two data sets.

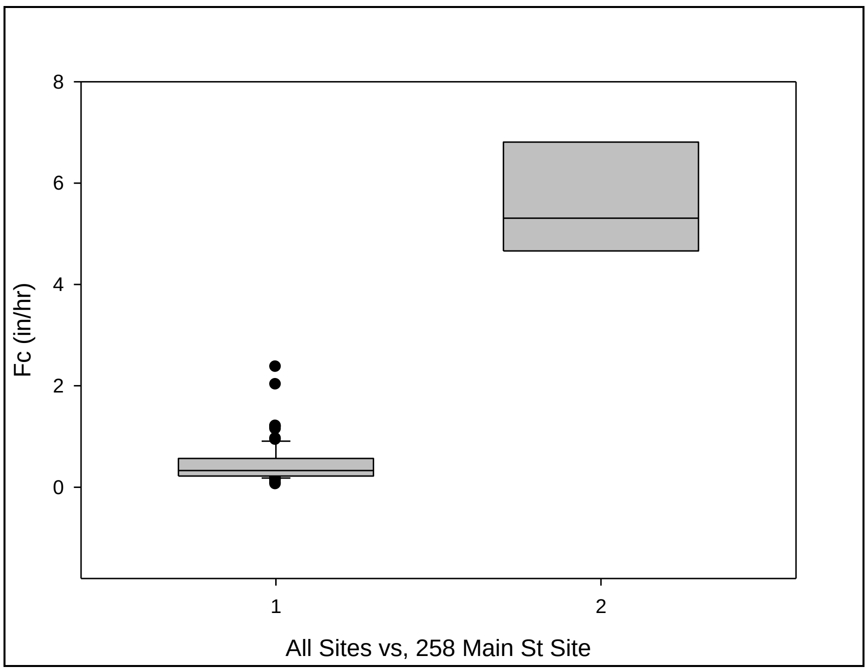


Figure 4.9. Box and whisker plot of f_c data showing two sets of data. 1: All sites combined, 2: 258 Main St. site (1 in/hr = 25.4 mm/hr)

The results of the final Mann-Whitney Rank Sum test for fc are shown below:

Normality Test (Shapiro-Wilk) Failed ($P < 0.050$)

Group	N	Missing	Median	25%	75%
Combined	81	0	0.33	0.22	0.57
258 Main	3	0	5.31	4.66	6.81

Mann-Whitney U Statistic= 0.000

T = 249; n (small) = 3; n (big) = 81; P = 0.004

The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference, with P = 0.004. Tables 4.11 and 4.12 summarize the f_c values and test conditions for these two sets of data.

Table 4.11. f_c Summary Values and Conditions for 258 Main St.

	f_c (in/hr)	Rain Depth (in)	Max. depth of water in dry well (in)	Min. depth of water in dry well (in)
number	3	3	3	3
Minimum	4.66	0.69	22.32	0.11
Maximum	6.81	1.34	54.77	0.67
Average	5.59	1.08	43.57	0.44
Median	5.31	1.22	53.62	0.53
Std Dev	1.10	0.35	18.41	0.29
COV	0.20	0.32	0.42	0.67

1 in = 25.4 mm

Table 4.12. f_c Summary Values and Conditions for All of the Other Sites

	f_c (in/hr)	Rain Depth (in)	Max. depth of water in dry well (in)	Min. depth of water in dry well (in)
number	81	63	81	81
Minimum	0.05	0.22	6.51	0.00
Maximum	2.37	2.90	93.85	82.98
Average	0.45	1.20	50.45	20.88
Median	0.33	1.15	53.76	10.07
Std Dev	0.38	0.76	22.93	24.15
COV	0.85	0.63	0.45	1.16

1 in = 25.4 mm

Similar tests were conducted to identify significant groups for the k data. Figure 4.10 is the final box and whisker plot, showing the two data groups: 258 Main St vs. all the other data combined.

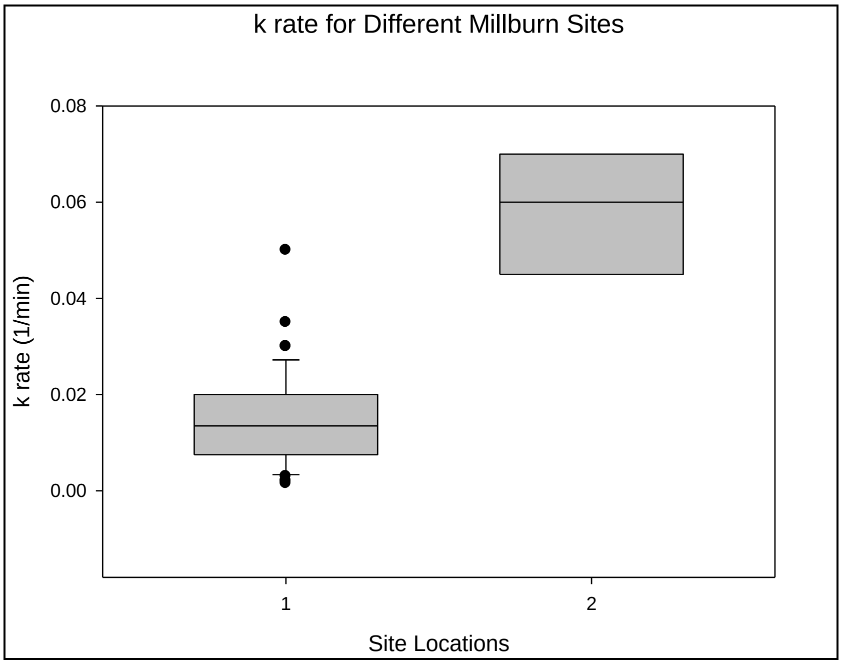


Figure 4.10. Box and whisker plot of k data showing two sets of data. 1: All sites combined, 2: 258 Main St. site

The results of the final Mann-Whitney Rank Sum test for k are shown below:

Normality Test (Shapiro-Wilk) Failed ($P < 0.050$)

Group	N	Missing	Median	25%	75%
All others combined	46	0	0.014	0.0075	0.02
258 Main	3	0	0.06	0.045	0.07

Mann-Whitney U Statistic= 1.000, T = 143; n (small) = 3; n (big) = 46; P = 0.005

The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference, with P = 0.005. Tables 4.13 and 4.14 summarize the values and test conditions for these two sets of data.

Table 4.13. k Summary Values and Conditions for 258 Main St.

	k (1/min)	Rain Depth (in)	Max. depth of water in dry well (in)	Min. depth of water in dry well (in)
number	3	3	3	3
Minimum	0.05	0.69	22.32	0.11
Maximum	0.07	1.34	54.77	0.67
Average	0.06	1.08	43.57	0.44
Median	0.06	1.22	53.62	0.53
Std Dev	0.01	0.35	18.41	0.29
COV	0.22	0.32	0.42	0.67

1 in = 25.4 mm

Table 4.14. k Summary Values and Conditions for All of the Other Sites

	k (1/min)	Rain Depth (in)	Max. depth of water in dry well (in)	Min. depth of water in dry well (in)
number	46	63	81	81
Minimum	0.002	0.22	6.51	0.00
Maximum	0.050	2.90	93.85	82.98
Average	0.014	1.20	50.45	20.88
Median	0.014	1.15	53.76	10.07
Std Dev	0.009	0.76	22.93	24.15
COV	0.666	0.63	0.45	1.16

1 in = 25.4 mm

4.2.1.8 Fitting Observed Data to Green-Ampt Equation

The Green-Ampt equation calculates cumulative infiltration assuming water flowing into a vertical soil profile. Figure 4.11 is an example comparison between fitted Horton and Green-Ampt equations for one of the events at a selected dry well, as well as associated statistical analyses and residual plots. The remaining graphs are in Appendix C.

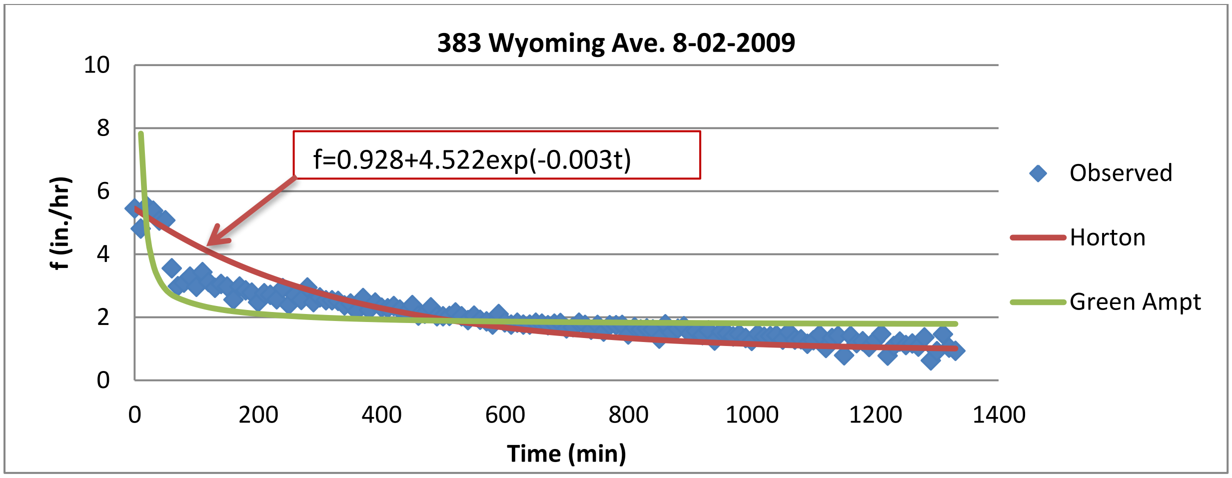


Figure 4.11. An example of fitted observed data to Horton equation and Green-Ampt equation (1 in = 25.4 mm)

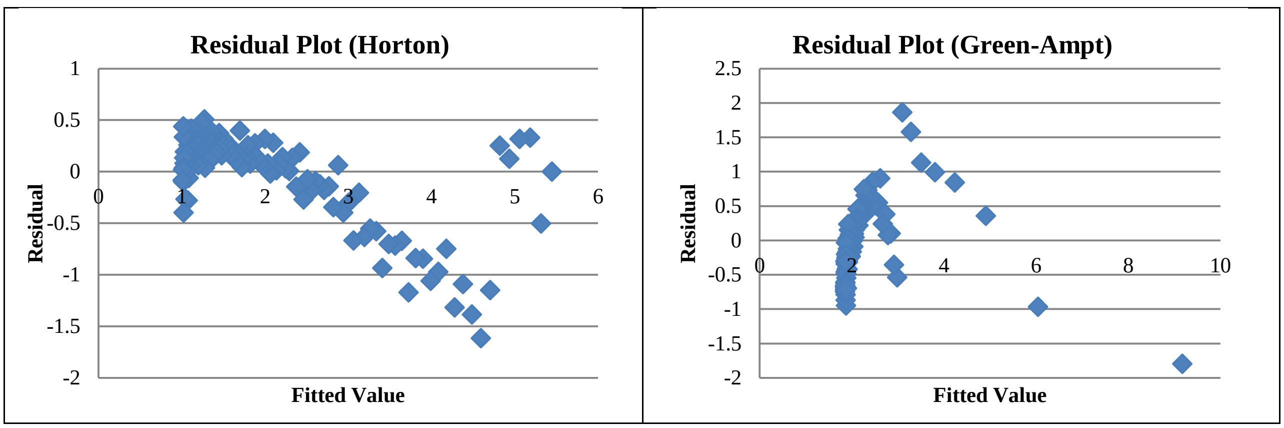


Figure 4.12. Residual Plots for Horton and Green-Ampt fitted values

ANOVA

	df	SS	MS	F	Significance F
Regression	1	51.25879	51.25879	129.5995	2.67E-21
Residual	131	51.81269	0.395517		
Total	132	103.0715			

	Coefficients	Standard Error	t Stat	p-value	Lower 95%	Upper 95%
Intercept	1.676322	0.062127	26.98234	2.4E-55	1.553421	1.799223
X Variable 1	5.26193	0.462214	11.38418	2.67E-21	4.34756	6.1763

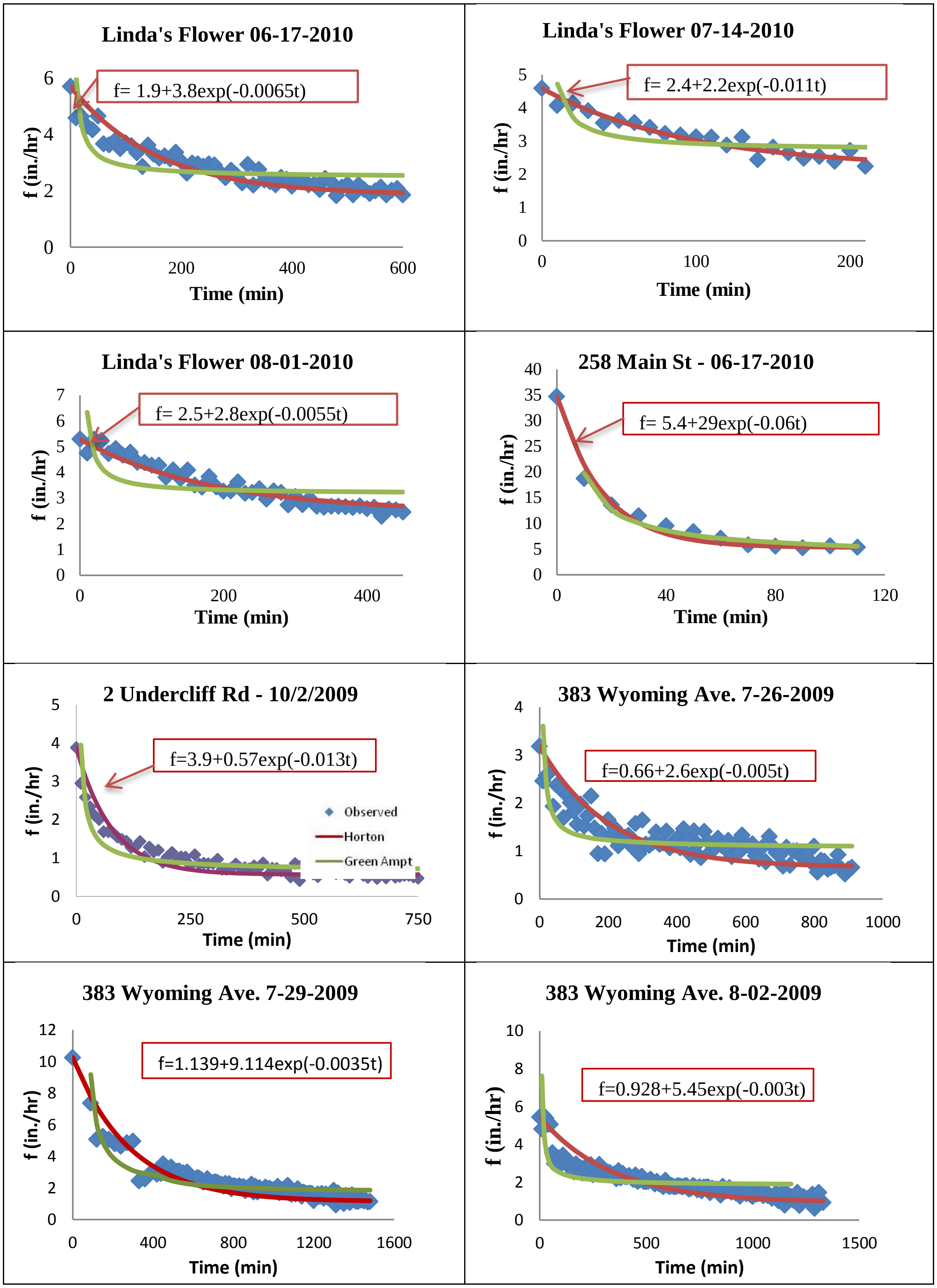


Figure 4.13. Horton and Green-Ampt fitted curves for observed data. (dots: observed data, red line: Horton and green line:Green-Ampt. The Horton equation is written on each graph) (1 in = 25.4 mm)

As it is shown in Figure 4.13, the Horton equation usually had a better fit to the data compared to the Green-Ampt equation for the Millburn data. However, for some sites, the Green-Ampt equation was a better fit. As noted previously, a linear relationship between ft and $(1/F_t)$ is needed to determine the Green-Ampt equation parameters. Figure 4.14 presents the linear regressions of ft vs $(1/F_t)$ for the monitored sites. The only visually acceptable linear regression is associated with the observations from the 258 Main St. site (the only location that had soils in the A group from the surface to about 1.1 m (3.5 ft) deep). This site also had the best Green-Ampt fitted equation shown in Figure 4.13 as well. In almost all cases, the linear relationship between ft vs $(1/F_t)$ is unacceptable (except for this one location), making the Horton equation a more suitable tool for calculating expected infiltration for the dry wells.

Table 4.15. Green-Ampt parameters

Site Address	Date	Hydraulic conductivity K (in/hr)		Soil Group
		Millburn data	Rawls et al. (1983)	
Linda's Flower	06-17-2010	2.435	0.429	Not Available
	07-14-2010	2.685		
	08-01-2010	3.131		
258 Main St.	06-17-2010	1.018	1.17	0-42 in.: Sandy loam (A) 42-70 in.: Stratified gravelly sand to sand to loamy sand (A)
2 Undercliff	10-02-2009	0.557	0.429	0 to 1 in.: Highly decomposed plant (D) 1-24 in.: Sandy loam (B) 24-42 in.: Gravelly sandy loam (A) 42-60 in.: Fine sandy loam (B)
383 Wyoming Ave.	7-26-2009	1.039	0.13-0.43	0 to1 in.: Slightly decomposed plant (C) 1-3 in.: Silt loam (C) 3-10 in.: Loam (C) 10-27 in.: Gravelly loam (B) 27-67 in.: Gravelly fine sandy loam (A) 67-83 in.: Gravelly sandy loam (A)

1 in = 25.4 mm

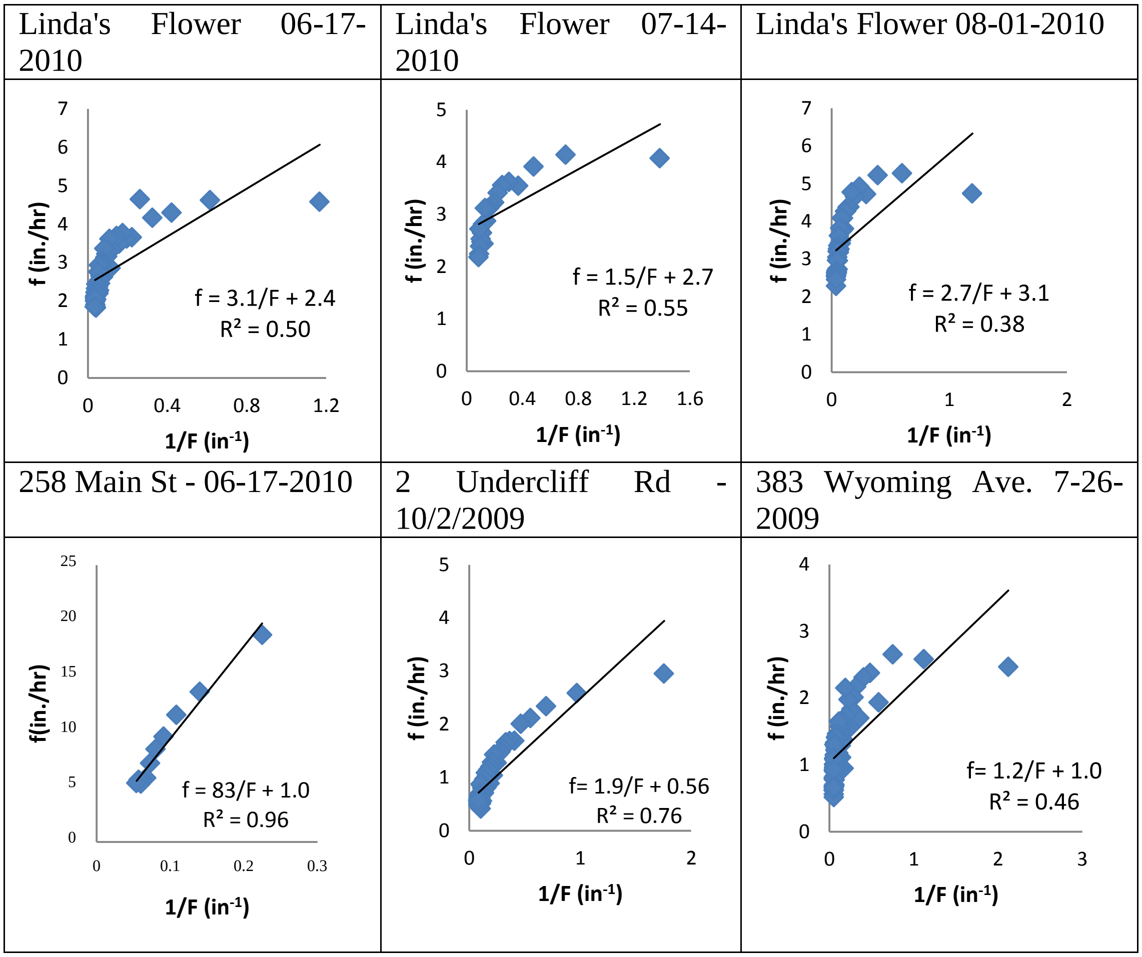


Figure 4.14. Linear regression of ft vs ($1/F_t$) for some sites in Millburn, NJ. (1 in = 25.4 mm)

Small-scale evaluations of green infrastructure stormwater controls, such as assessment of infiltration characteristics which are site specific, provide information on individual status of the stormwater controls. Having sufficient data and site characteristics, small scale monitoring and performance evaluations can contribute to the large-scale system-wide performance evaluations, and/or provide in-depth information at specific sites. However, some factors such as site specific data and incorrect assumptions (due to lack of information such as actual soil characteristics) can affect large-scale modeling. The following section provides analysis of factors affecting small-scale performance of green infrastructure stormwater controls.

4.2.1.10 Factors Affecting Infiltration Rates

The data analyses of the infiltration data indicated several interesting conclusions. One of the first issues noted by the field personnel when installing the level recorders and observing the dry wells over time was that some of the locations experienced periodic (or continuous) standing water in the dry wells, indicating seasonal or permanent high water table conditions, or partially clogged dry wells.

Figures 4.15 and 4.16 show examples of time series plots of the water levels (more time series are presented in Appendix E) for the long-term infiltration tests at the dry wells and are very informative concerning the trends and overall behavior of the infiltration characteristics at the different sites. The hydrant water tests are shown separately (with expanded time scales), and are also shown on the longer period plots. The plots show the water elevations in the dry wells along with the corresponding rain depths as recorded at the nearest rain gauge. In some cases, dry well activity is indicated with no corresponding rainfall. This is likely due to variable (small) rains in the areas that were not recorded at all of the gauges. The rain data indicate the total rain depth and the start and end times; the graphs cover too long of a period to show variable rain intensities during the rains. The times and depths are the most important rain information for these measurements, as they relate most closely to the runoff quantity and the dry well water elevations.

In almost all cases, the general shapes of the recession limbs (water elevation drops with infiltration) are similar for the same site, including the hydrant tests. However, some changed with time, including several that indicated slower infiltration with more standing water conditions in the winter and spring. This may be due to SAR issues (sodium adsorption ratio) that results in dispersed clays from high sodium content in snowmelt. Normally, snowmelt would not affect these units if only roof runoff is directed to the dry wells. However, if walkway or driveway runoff drains to dry wells, de-icing chemicals (heavy salt loads) may be in the runoff.

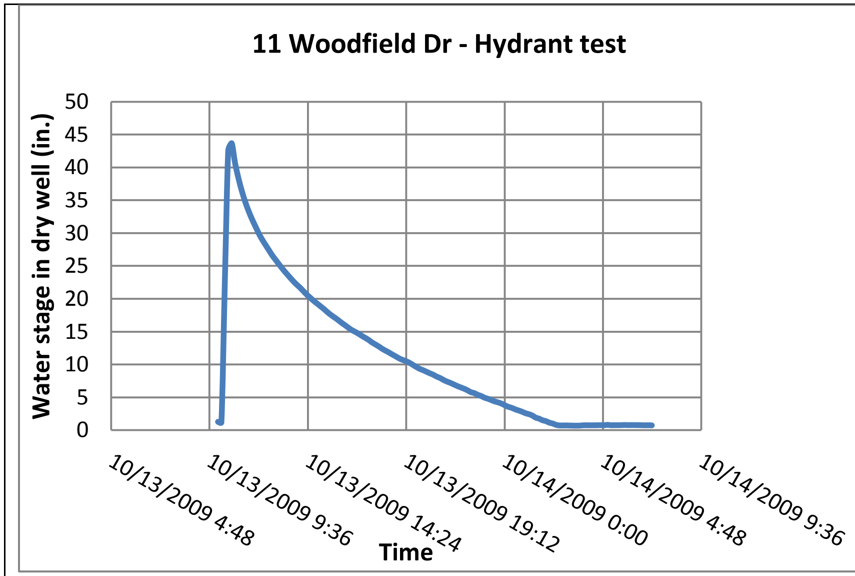
Standing water was observed in the dry well at 87/89 Tennyson when sufficient time occurred to allow the water to reach a consistent minimum water level (about 0.9 m or 3 ft deep). It is expected that this site very likely has a high water table condition. The drainage rates were very slow, so the interevent periods were not sufficiently long to enable drainage to the stable water level until after about a two week dry period. The slow drainage rate may have been caused by saturated conditions.

Several sites (260 Hartshorn, 7 Fox Hill, and 142 Fairfield) experienced periodic slowly draining conditions, mainly in the spring that could have been associated with SAR problems. The slow infiltration rates could be due to poor soils (with the clays resulting in SAR problems), or saturated soil conditions. The other sites all had rapid drainage rates that were consistent with time.

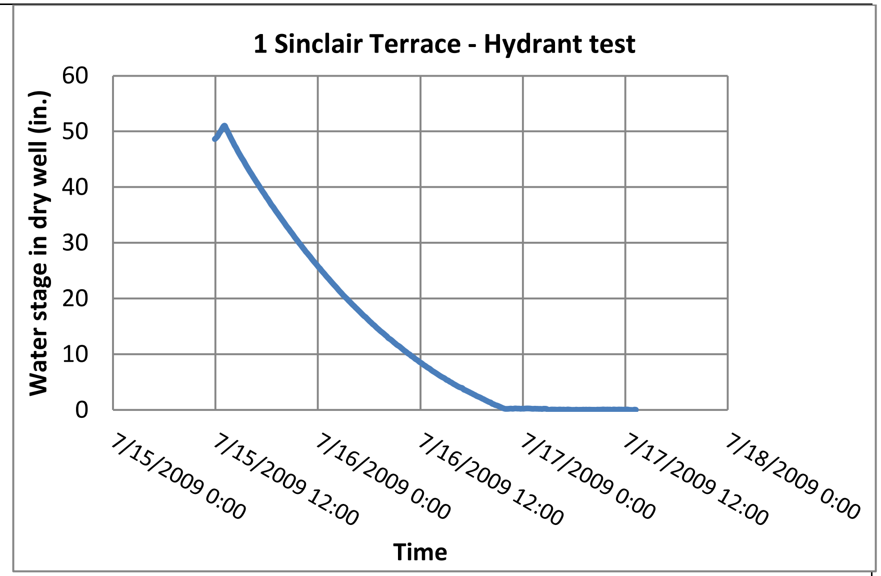
Table 4.16. Summary of Infiltration Conditions with Time

	Start date of series	**End date of series**	**# of dry well events**	**% of time dry well was dry**	**Consistent shape with time?**	**Standing water after events?**	**Other comments**
11 Woodfield Dr.	Oct 11, 2009	Dec 20, 2009	1 hydrant 5 rains (1 small rain missing)	89%	Consistent shape with time	Quickly drained (within a day); No standing water at any time	15 hr total drainage time during hydrant test
15 Marion Dr.	June 17, 2010	August 6, 2010	1 hydrant 5 rains (2 small rains missing)	71%	Consistent shape with time	Several days to drain; No standing water at any time	4.5 days total drainage time during hydrant test
383 Wyoming Ave.	July 16, 2009	October 14, 2009	1 hydrant 6 rains (2 small rains missing)	81%	Consistent shape with time	Several days to drain if full; No standing water at any time	1 day total drainage time during hydrant test
258 Main St.	June 16, 2010	August 5, 2010	5 rains (2 smaller rains missing)	98%	Consistent shape with time	Very rapid drainage time; No standing water at any time	
260 Hartshorn	August 9, 2010	August 1, 2011	Many	10%	Consistent shape with time	Slow drainage time (about a week if full), but dry if given enough time between rains	Clogging or poor soils, not high water table. Possible SAR issues in the Winter and Spring, recovered by mid-summer.
2 Undercliff Rd	July 18, 2009	October 6, 2009	1 hydrant 3 rains	79%	Consistent shape with time	Several days to drain if full; No standing water at any time	10 days total drainage time during hydrant test

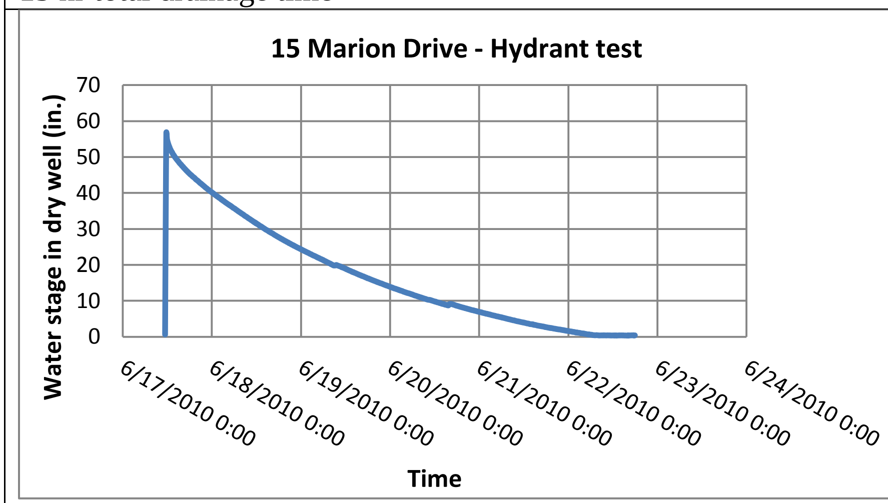
	Start date of series	End date of series	# of dry well events	% of time dry well was dry	Consistent shape with time?	Standing water after events?	Other comments
87/89 Tennyson	August 10, 2010	August 5, 2011	Many	0%	Consistent shape with time	Very slow drainage time (a couple of weeks); standing water and never dry during this year period	Slow drainage may be due to saturated conditions, never reached stable low water level. If due to SAR, did not recover.
7 Fox Hill	August 7, 2010	March 23, 2011	Many	2%	Consistent shape with time	Slow drainage time (about a week or two if full), but dry if given enough time between rains	Clogging or poor soils especially in Spring, possibly SAR issues, not high water table
8 So. Beechcroft	July 19, 2009	September 27, 2009	1 hydrant 6 rains	71%	Consistent shape with time for rains, but hydrant test (at end of periods at end of Sept) was very rapid	Quickly drained (within a day or two if full); No standing water at any time	3 hr total drainage time (half full) during hydrant test
142 Fairfield	August 10, 2010	March 4, 2011	many	66%	Somewhat inconsistent shape with time	Quickly drained (within a day or two if full) to poorly drained (a week for moderate rains); Standing water during periods of large and frequent rains	Slowly drained conditions in Spring likely due to saturated conditions, or SAR. Not likely due to high water table
36 Farley Place	June 16, 2010	August 5, 2010	3 rains	97%	Consistent shape with time	Very rapid drainage time; No standing water at any time	



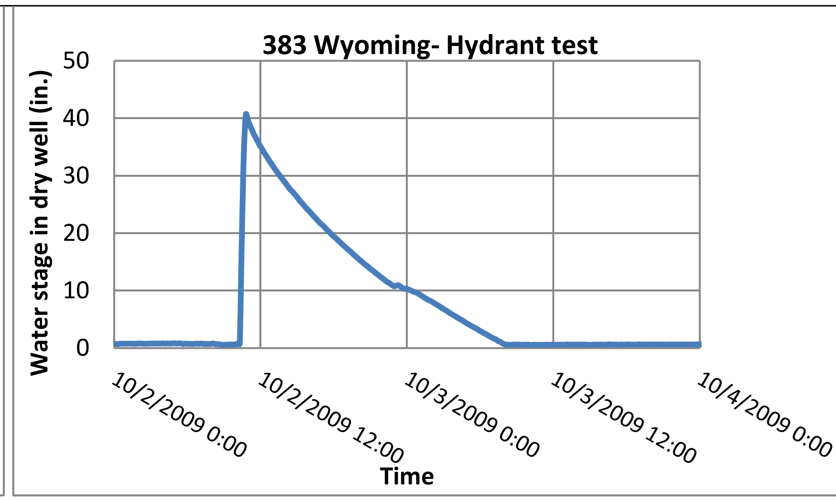
15 hr total drainage time



28 hr total drainage time

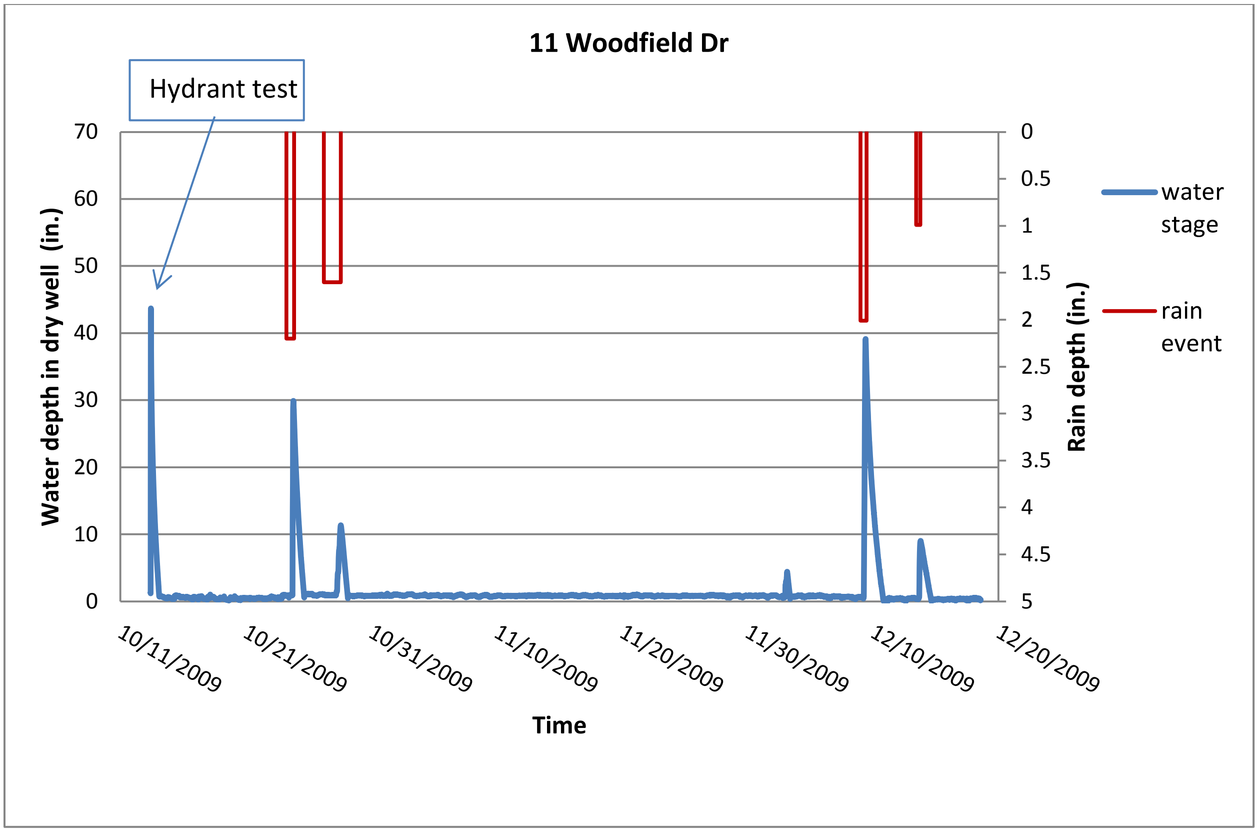


4.5 days total drainage time



1 day total drainage time

Figure 4.15. Hydrant water test infiltration plots. (1 in = 25.4 mm)



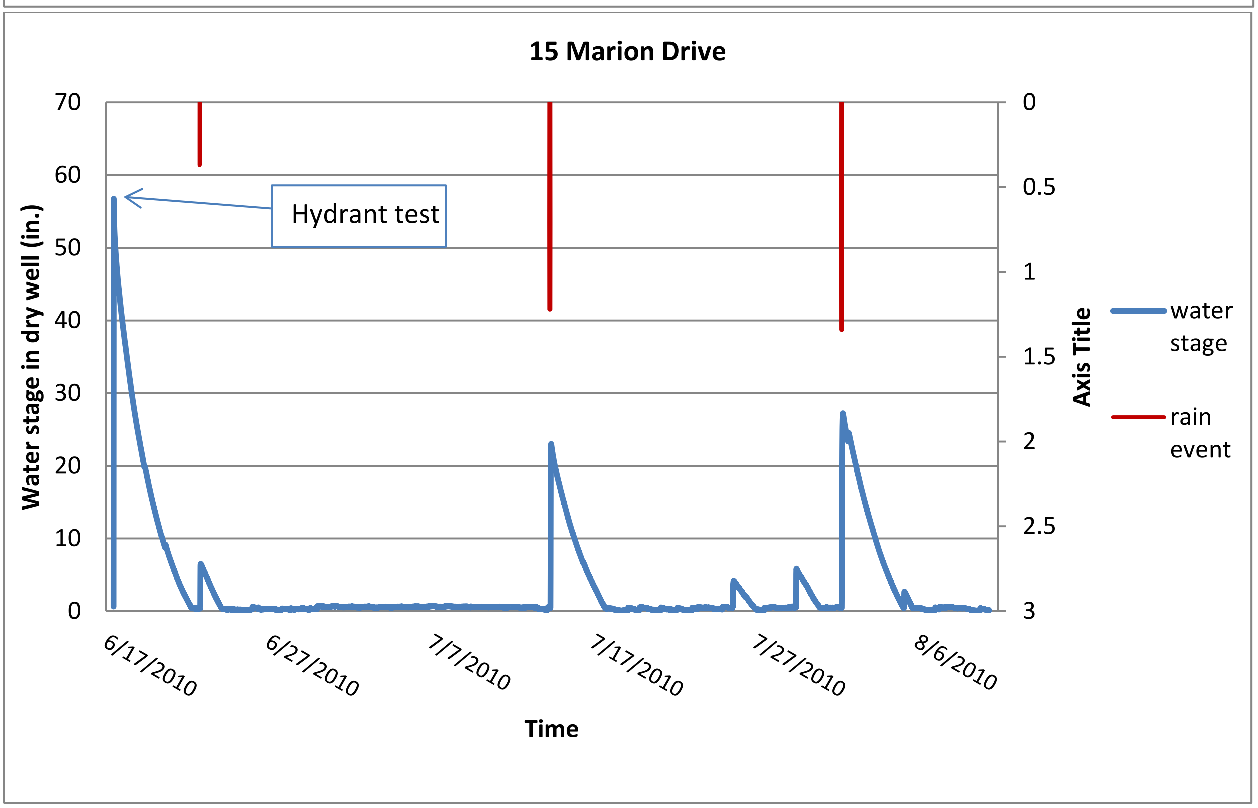


Figure 4.16. Time series plots of the water levels for the long-term infiltration tests at the dry wells (1 in = 25.4 mm)

The New Jersey dry well disposal regulations for stormwater require that the seasonal water table be no closer than two ft below the bottom of the dry well (and underlying rock storage area) due to expected deceased performance (and increased groundwater contamination potential). Water table information was not readily available and some of the dry wells were apparently constructed in areas having water tables that were too shallow. The following list shows the water table conditions at the dry well monitoring locations:

• Sites having no standing water after the events (completely drained with no apparent high water table conditions):

11 Woodfield Dr

15 Marion

258 Main St

1 Sinclair Terrace (only one observation)

8 South Beechcroft Rd

11 Fox Hill Lane (only one observation)

36 Farley Place

• Sites having a few standing water conditions after the events (standing water of several inches, or more, indicating possible seasonal high water table conditions):

2 Undercliff Rd (one high water condition out of 3 observations; July 29 2009 event)

383 Wyoming Ave (one high water condition out of 5 observations; July 29 2009 event)

142 Fairfield Dr (two high water conditions out of 7 observations; Feb 26, 2011 and March 7, 2011 events)

• Sites with all or most events having high water conditions:

260 Hartshorn Dr (16 of 19 observations had high water conditions; 8/25/10, 5/30/11, and 7/8/11 drained almost completely)

87/89 Tennyson Dr (20 out of 20 observations had high water conditions)

7 Fox Hill Lane (9 of 11 observations had high water conditions; 8/22/10 and 12/13/10 drained almost completely)

9 Fox Hill Lane (only 1 observation)

Figure 4.17 is a map showing these conditions for the Township. Most of the monitored dry wells were along a ridge between the two main drainages of the township, with no obvious pattern of high water conditions, except that the high standing water dry wells were located along a line to the southwest along the ridge and are located fairly close to headwaters of streams (high water tables were noted in areas with nearby streams, but that was assumed to be in the larger stream valleys and not at the headwaters). The sites that had high standing water long after the events ended had substantially reduced infiltration rates. In the analyses, these rates were considered to be the constant (final) rates observed, with no initial rate data or first-order decay Horton coefficients used (relatively constant, but very low infiltration rates).

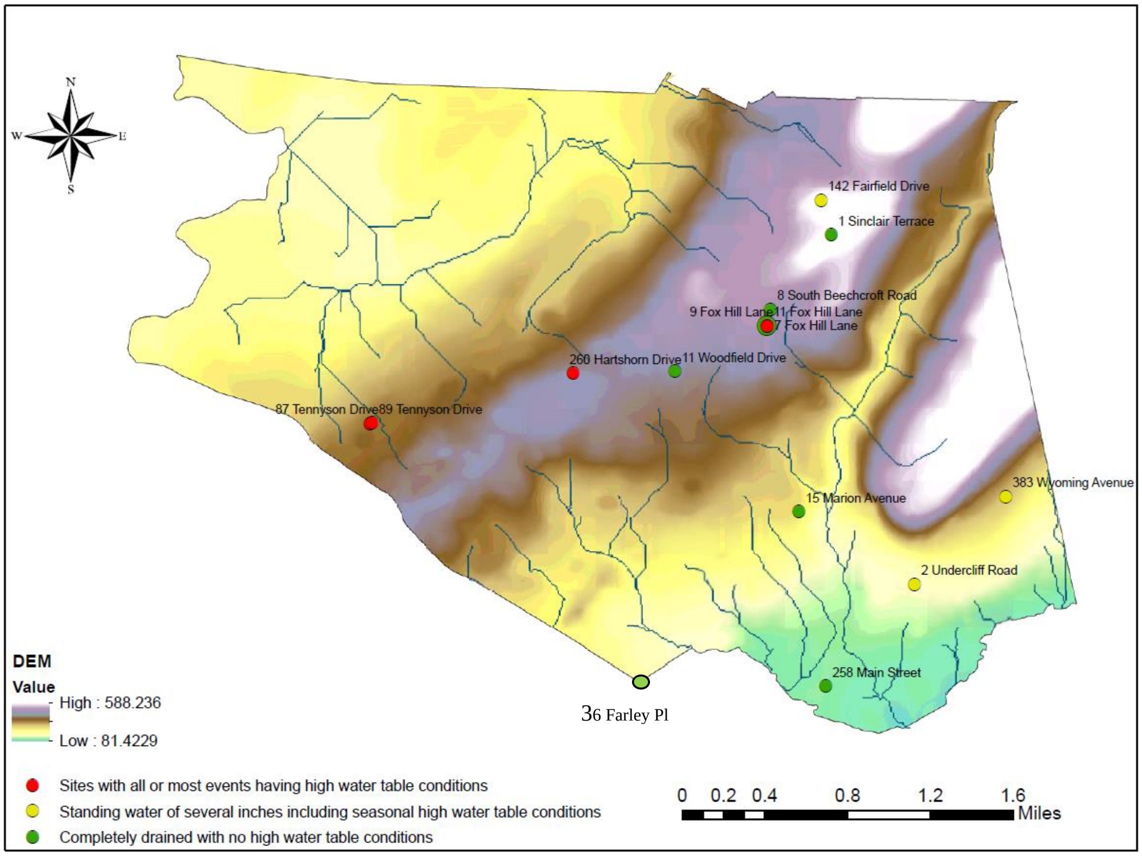


Figure 4.17. Township map showing locations having varying standing water conditions in monitored dry wells.

Another obvious factor affecting the observed infiltration rates was that one or two of the locations had significantly higher infiltration rates than the other sites (all having no standing water issues). These sites were the ones indicated as having the highest surface infiltration rate potentials (even though the infiltration rates of the dry wells were mostly affected by the subsurface soil conditions, which were mapped as being similar A and B conditions for all locations). It is therefore expected that these locations had better subsurface soil conditions compared to the other sites, even though mapped as being similar.

Therefore, the Township of Millburn infiltration rate characteristics were separated into three conditions:

• A and B surface soils and having well drained HSG A subsurface soils

• C and D surface soils and having well drained A and B subsurface soils

• C and D surface soils and having poorly drained A and B subsurface soils with long-term standing water

The infiltration rate conditions for these Township of Millburn situations are presented in Figures 4.18 through 4.20 and Tables 4.17 through 4.19.

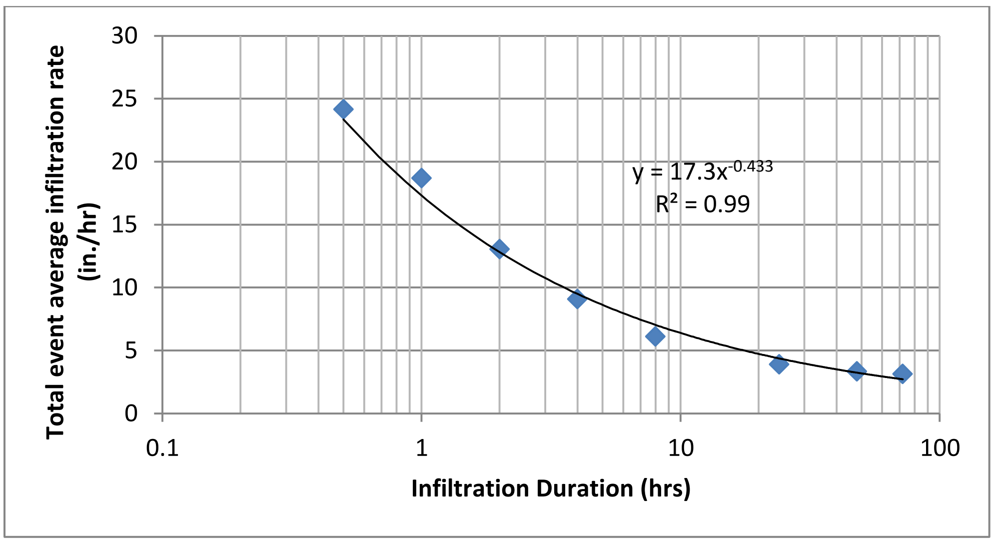


Figure 4.18. Infiltration rates averaged over event durations for A and B surface soils and well-drained A subsurface soils. (1 in/hr = 25.4 mm/hr)

Table 4.17. Infiltration Rates Averaged Over Event Durations for A and B Surface Soils and Well-Drained A Subsurface Soils

duration (hrs)	infiltration rate averaged over duration of event (in/hr)	COV
0.5	24.1	0.3
1	18.7	0.3
2	13.0	0.3
4	9.1	0.3
8	6.1	0.4
24	3.9	0.6
48	3.3	0.8
72	3.1	0.8

(1 in/hr = 25.4 mm/hr)

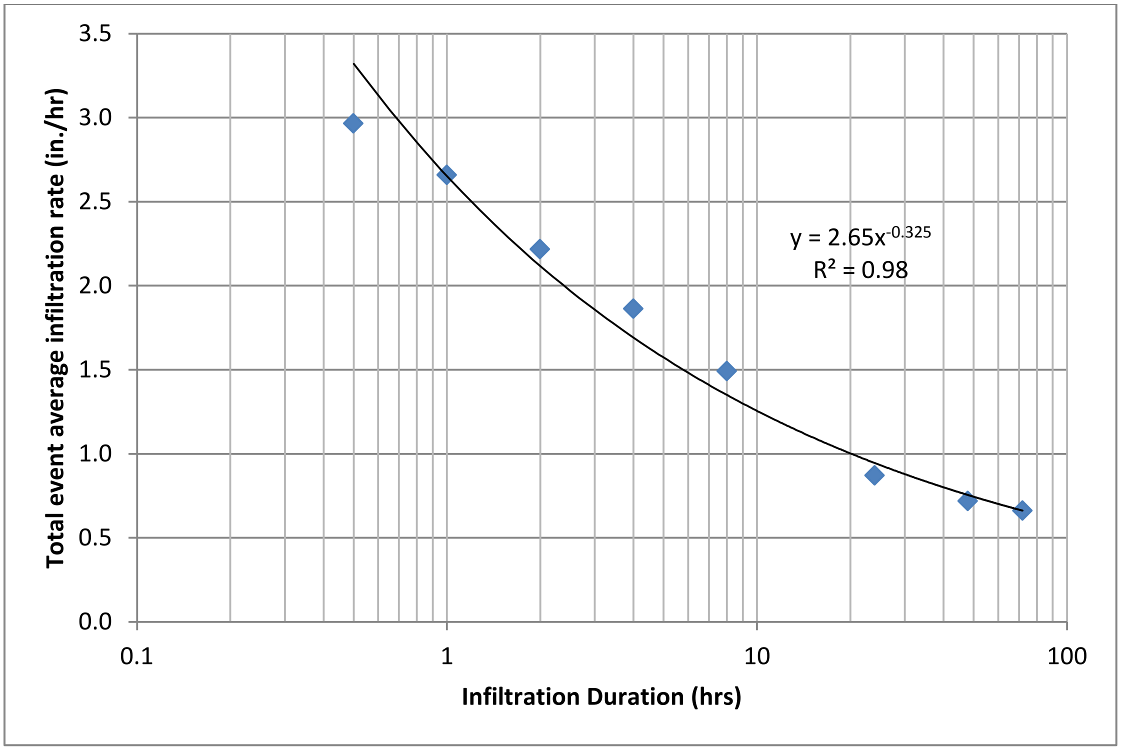


Figure 4.19. Infiltration rates averaged over event durations for C and D surface soils and well-drained A and B subsurface soils. (1 in/hr = 25.4 mm/hr)

Table 4.18. Infiltration Rates Averaged Over Event Durations for C and D Surface Soils and Well-Drained A and B Subsurface Soils

duration (hrs)	infiltration rate averaged over duration of event (in/hr)	COV
0.5	3.0	1.0
1	2.7	1.0
2	2.2	0.9
4	1.9	0.9
8	1.5	0.8
24	0.9	0.6
48	0.7	0.6
72	0.7	0.6

(1 in/hr = 25.4 mm/hr)

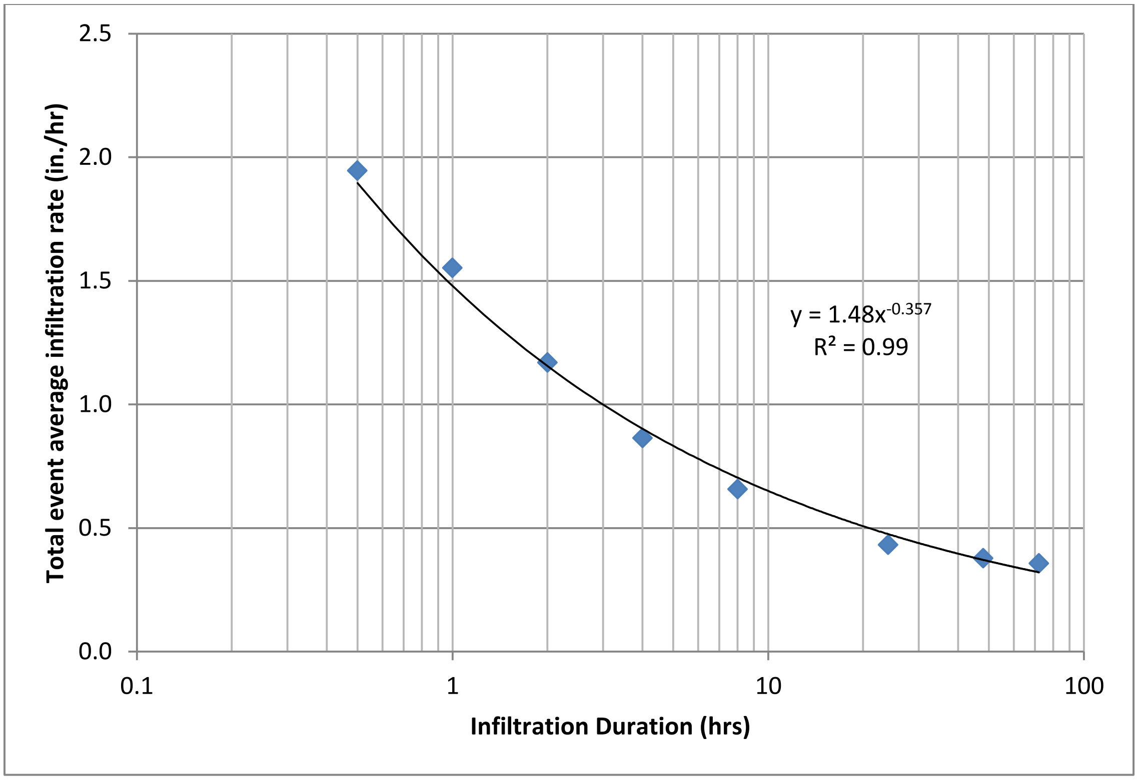


Figure 4.20. Infiltration rates averaged over event durations for C and D surface soils and poorly-drained A and B subsurface soils having extended standing water. (1 in/hr = 25.4 mm/hr)

Table 4.19. Infiltration Rates Averaged Over Event Durations for C and D Surface Soils and Poorly-Drained A and B Subsurface Soils Having Extended Standing Water

duration (hrs)	infiltration rate averaged over duration of event (in/hr)	COV
0.5	1.9	1.2
1	1.6	1.1
2	1.2	1.0
4	0.9	0.9
8	0.7	0.8
24	0.4	0.6
48	0.4	0.6
72	0.4	0.6

(1 in/hr = 25.4 mm/hr)

These figures and tables show that the over-all event infiltration rates decrease as the duration increases. For example, for a typical 5 hour rain period (having about a 6 hour runoff period), the event-averaged infiltration rate would be about 190 mm (7.6 in) per hour for the best conditions having A or B surface soils and well-drained subsurface A and B soils. This reduces to about 43 mm (1.7 in) per hour for the C or D surface soils having well-drained subsurface A and B soils. For the condition having standing water and poorly drained subsurface soils, the infiltration rates would be about 20 mm (0.8 in) per hour. Complete drainage times for the best soil conditions for this event would be several hours, extending to about a day for the intermediate condition, and several days for the condition with standing water. Of course, for the situation having standing water, the "dry" well may never drain completely if the standing water was associated with a high water table. If the standing water observations were due to clogging from debris, the dry wells may eventually drain completely, if enough time occurs between rains.

The New Jersey stormwater regulations require the infiltration of excess water above natural conditions associated with development or land modifications (either maintaining the pre-development groundwater recharge or preventing excess surface runoff), for the 24-hr, 2-year storm, which is about 86 mm (3.4 in) for Essex County. The dry well regulations describe the construction of the dry wells, the acceptable soil conditions (HSG A and B), groundwater conditions (at least 2 ft or 60 cm above seasonal water table), and source waters (roof runoff only). The minimum design infiltration rate for groundwater recharge is 5 mm/hr (0.2 in/hr) while it is 12 mm/hr (0.5 in/hr) for stormwater quality use. These design standards for total event infiltration rates would not be met only for conditions having standing water for very long event durations. The largest rain that had infiltration measurements during this study was about 74 mm (2.9 in), close to the design storm value.

4.2.1.11 Observed Infiltration Coefficient Values Compared to Literature Values

Table 4.20 compares the observed Horton equation coefficients with values that have been reported in the literature. The standing water data are not shown on this table as most of the observations could not be successfully fitted to the Horton equation. The almost steady infiltration rates (but with substantial variation) were all very low for those conditions and likely represent the fc conditions only and were therefore included in that parameter category.

The very large observed f_o value (45 in/hr) for the A and B surface soil sites that are well drained is greater than any of the reported literature values, and only approaches the observations for the non-compacted sandy soil conditions (34 in/hr) observed by Pitt et al. (1999). The subsurface soil conditions affecting the dry well infiltration rates are likely natural with little compaction. Also, the subsurface soils at that location are noted as being sandy loam (A) and stratified gravelly sand to sand to loamy sand (A). The other sites having smaller fo rates (4.3 in/hr) are described as gravelly sandy loam (A) and fine sandy loam (B) and are similar to many of the reported literature values for sandy soils, with some compaction.

Table 4.20. Observed and Reported Horton Equation Coefficients

	f_o (in/hr)	f_c (in/hr)	K (1/min)
Surface A and B soils well drained A subsurface soils (average and COV)	44.6 (0.53)	5.6 (0.2)	0.06 (0.22)
Surface C and D soils well drained A and B subsurface soils (average and COV)	4.3 (0.64)	0.45 (0.85)	0.01 (0.63)
UDFCD (2001) A soils (average)	5.0	1.0	0.04
UDFCD (2001) B soils (average)	4.5	0.6	0.11
UDFCD (2001) C and D soils (average)	3.0	0.5	0.11
Pitt *et al.* (1999) Clayey, dry and non-compacted (median)	11	3	0.16
Pitt *et al.* (1999) Clayey, other (median)	2	0.25	0.06
Pitt *et al*. (1999) Sandy, compacted (median)	5	0.5	0.1
Pitt *et al.* (1999) Sandy, non-compacted (median)	34	15	0.08
Akan (1993) Sandy soils with little to no vegetation	5		
Akan (1993) Dry loam soils with little to no vegetation	3		
Akan (1993) Dry clay soils with little to no vegetation	1		
Akan (1993) Moist sandy soils with little to no vegetation	1.7		
Akan (1993) Moist loam soils with little to no vegetation	1		
Akan (1993) Moist clay soils with little to no vegetation	0.3		

(1 in/hr = 25.4 mm/hr)

The largest f_c value (5.6 in/hr) observed for the well-drained A and B surface soil location is bracketed by the non-compacted clayey and sandy soil conditions (3 and 15 in/hr) reported by Pitt et al. (1999), but is substantially larger than the other reported values. The fc value observed for the well-drained C and D surface soil site (0.45 in/hr) is similar to the other reported values (0.5 to 1.0 in/hr). The k first-order rate values (0.01 and 0.06 1/min) are similar, but on the low side, of the reported values (0.04 to 0.11 1/min).

In order to most accurately design dry well installations in an area, actual site observations of the expected infiltration rates should be used instead of general literature values. This is especially true for surface infiltration devices (such as rain gardens), where compaction will have a much greater effect than on the deeper subsurface soils. Also, all of the sites in this study had improved infiltration characteristics with depth compared to expected surface conditions; in other cases, this may not be true. Criteria based only on surface soil conditions are likely not good predictors of deeper dry well performance. Luckily, county soil surveys do have some subsurface soil information that was found to be generally accurate during this study. Unfortunately, shallow water table conditions are not well known for the area and that characteristic can have a significant detrimental effect on the observed dry well performance.

4.2.2 Infiltration Analysis for Kansas City Monitored Biofilters

For each of the monitoring locations in Kansas City, areas for different urban surfaces contributing flows (including rooftops, streets, landscaped areas, sidewalks, driveways, and parking lots) were measured using aerial photos and site visits, plus GIS shapefile layers. Each home in the study area was individually visited to determine their roof drain connections, for example. This information, along with the attributes of the designs of each control, was used to evaluate the performance of the different controls at the source areas and at the large-scale drainage system using statistical and modeling tools. Table 4.21 lists the information sources that were used to obtain the information described in this chapter and in Appendix F.

Table 4.21. Sources of small-scale drainage area information

Document/Material	Source
100% design plans and street side topographic info.	https://sites.tetratech.com/projects/100-KCADC/default.aspx
Subwatershed shapefile	Mr. John Riverson, Tetra Tech (from Sustain KC maps)
Sewer network shapefile	Mr. John Riverson, Tetra Tech (from Sustain KC maps)
Stormwater controls shapefile	Mr. John Riverson (TT) and https://sites.tetratech.com/projects/100-KCADC/default.aspx
Bing aerial maps	Basemap available in ArcMap 10
Listing of locations and sampling equipment	Table supplied by Dr. Deb O'Bannon, UMKC
USGS topo maps (10 ft contours)	Basemap available in ArcMap 10
Topographic maps (1 ft) jpgs	Project map supplied by Dr. Deb O'Bannon, UMKC
"Monitoring water balance of a rain garden by installation of flow monitoring devices on a residential property." Thesis by Jason Nall, UMKC.	https://sites.tetratech.com/projects/100-KCADC/default.aspx
Site photos	Robert Pitt – Site visit on October 25 and 26, 2012
Roof drainage connections	Site surveys conducted at each home by Dr. Deb O'Bannon's graduate students (UMKC)
Site infiltration rate conditions in pervious areas	Double-ring infiltration tests conducted throughout pilot watershed by Dr. Deb O'Bannon's graduate students (UMKC)

Table 4.22 is a list of the ten monitoring station locations in the test (pilot) watershed installed and maintained by UMKC and TetraTech researchers. Figure 4.21 shows these locations on the map of the test area. They were mostly along East 76th Street and East 76th Terrace. Detailed site information is contained in Appendix F, including subarea drainages for each area draining to each stormwater control being monitored (including the land surface breakdowns). Example designs for each type of stormwater control being monitored are included in Appendix G. Appendix H contains detailed information concerning the observed infiltration rates in each of the stormwater controls. The information presented in these three appendices was

then used to verify the performance of the stormwater controls at the source areas and at the watershed scale and to calibrate WinSLAMM for the site-specific conditions.

Table 4.22. Locations of Monitoring Stations

No.	Stormwater control type	Address	Design station
1	Curb Extension Biofilter	1324 E 76th St.	19+79.61
2	Curb Extension Biofilter	1325 E 76th St.	19+79.61
3	Curb Extension Biofilter	1419 E 76th Terr.	26+51.65
4	Curb-Cut Biofilter	1612 E 76th St.	31+31.12
5	Curb-Cut Biofilter	1336 E 76th St.	21+29.95
6	Site abandoned due to theft of monitoring equipment		
7	Shallow Curb-Cut Biofilter w/ Smart Drain	1140 E 76th Terr.	15+37.75
8	Shallow Curb-Cut Biofilter w/ Smart Drain	1222 E 76th St.	16+28.15
9	Cascading swale biofilter	1112 E 76th Terr.	12+18.80
10	Private rain garden	1312 E. 79th St.	Mrs. Thomas
11	Private rain garden	1505 E. 76th St.	Mrs. Moss

Source: UMKC

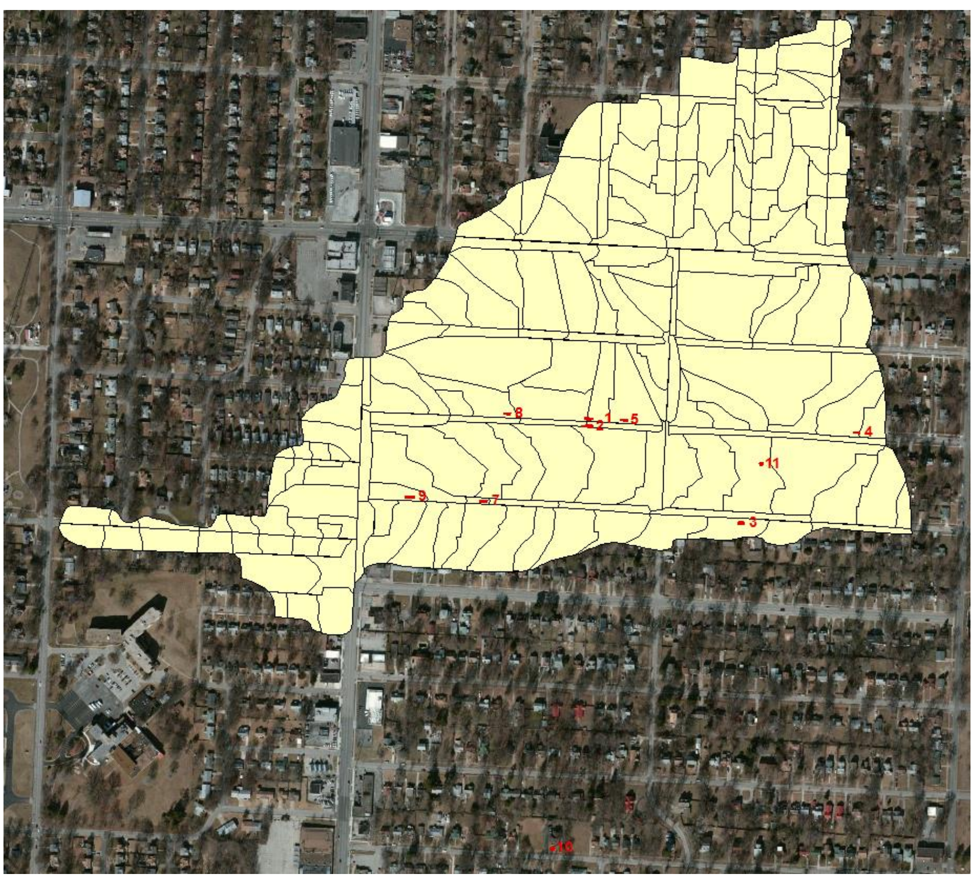
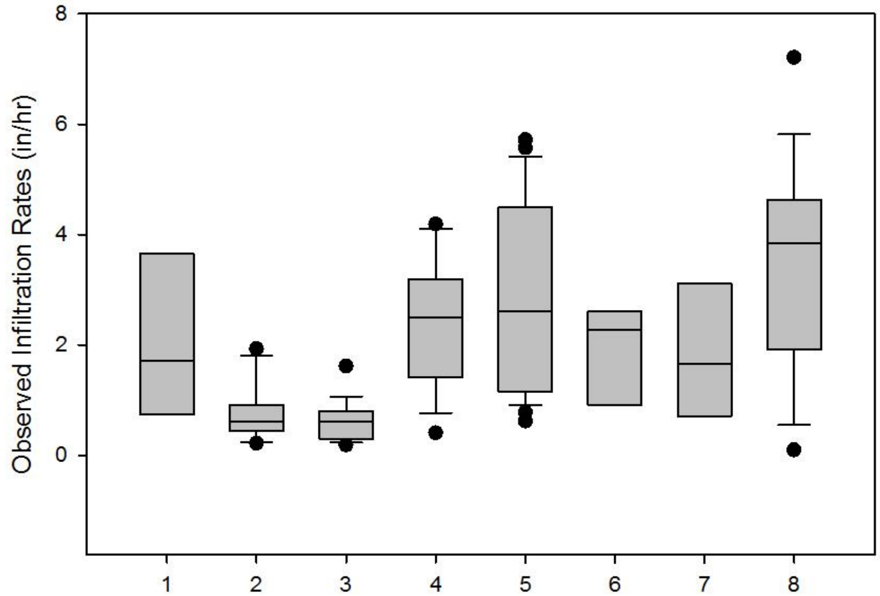


Figure 4.21. Location of stormwater controls monitored in test (pilot) watershed.

4.2.2.1 Infiltration Rates in Monitored Biofilters

Tables in Appendix H list the infiltration rates calculated using the monitored data obtained during each rain. As shown in Appendix H, plots of the water depths in the biofilters were used to identify recession limbs of the infiltration periods as recorded from the water level recorders in the biofilters. In some cases, runoff was still entering the devices during the decreasing water elevation periods. The basic infiltration rates were very consistent for each event, with multiple recession limbs showing no decreasing rates with time. This indicates that the systems were already saturated, and the rates represented the lowest values occurring (fc Horton parameter). If an infiltration rate was measured during a time having inflowing water, the rates were listed as greater than the calculated rates.

Figure 4.22 is a SigmaPlot (ver. 11) box and whisker plot comparing the infiltration rates observed at the eight different biofilter installations. There were 5 to 26 observations at each site, for about 110 total separate infiltration rate observations. Kruskal-Wallis statistical analyses indicated that at least one of the sites was significantly different ($p = <0.05$) from the others.



site 1: 1324 E. 76th St. curb-extension biofilter; site 2: 1325 E. 76th St. curb-extension biofilter;
site 3: 1419 E. 76th Terrace curb-extension biofilter; site 4: 1612 E. 76th St. curb-cut biofilter;
site 5: 1336 E. 76th St. curb-cut biofilter; site 6: 1140 E. 76th Terrace shallow curb-cut biofilter with SmartDrain;
site 7: 1222 E. 76th St. shallow curb-cut biofilter with SmartDrain; site 8: 1112 E. 76th Terrace cascading swale biofilter

Figure 4.22. Plot of Observed Infiltration Rates at Monitored Biofilters during Rain Events

The following box and whisker plot and Mann-Whitney Rank Sum test results compares the infiltration rates at the two locations having significantly slower infiltration rates (1325 E. 76th St. and 1419 E. 76th Terrace, both curb-extension biofilters) to the other locations. The biofilter media at these two locations were likely compacted during construction, and/or the media contained more fines than the other locations.

Table 4.23. Summary of Infiltration Rate Observations at Each Monitoring Location during Rain Events (in/hr)

Monitoring Location	Number of Infiltration Rate Observations	Average Infiltration Rate	Std. Dev.
1324 E 76th St	8	2.3	2.0
1325 E 76th St	17	0.78	0.48
1419 E 76th Terrace	19	0.64	0.35
1612 E 76th St	14	2.4	1.2
1336 E 76th St	26	2.9	1.7
1140 E 76th Terrace SD	5	1.9	0.89
1222 E 76th St SD	6	1.8	1.2
1112 E 76th Terrace	17	3.5	1.9

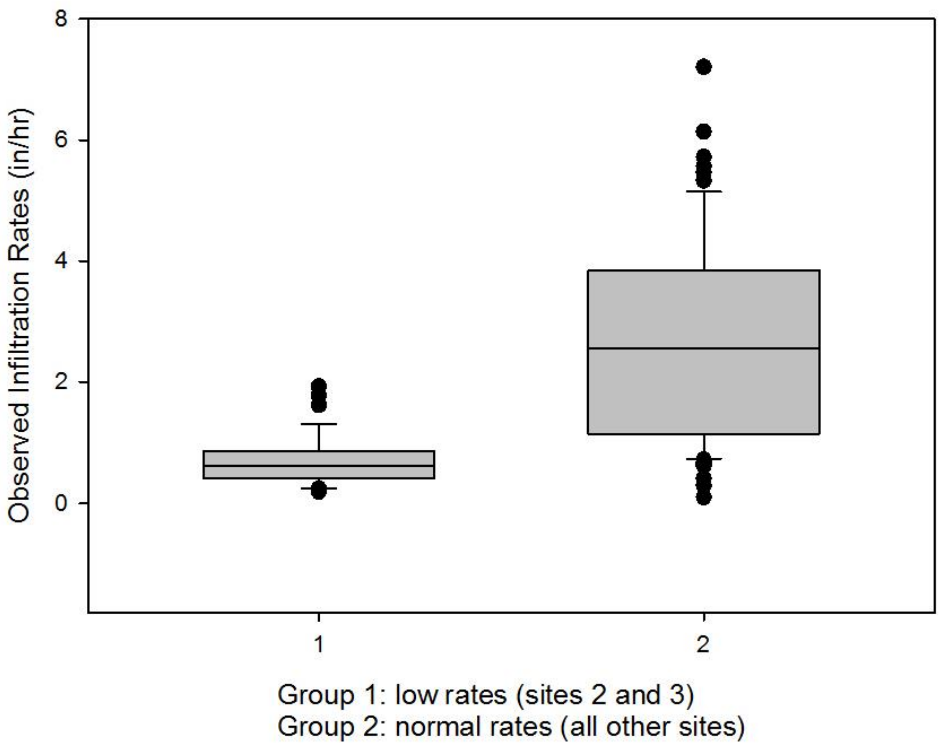


Figure 4.23. Site Groupings of Infiltration Rates Observed during Rain Events

Table 4.24. Mann-Whitney Rank Sum Test to Compare Two Groups of Infiltration Rate Site Conditions (in/hr)

Group	N	Missing	Median	25%	75%
Slow (1325 and 1419)	34	0	0.62	0.41	0.86
Fast (all others)	76	0	2.56	1.14	3.85

Mann-Whitney U Statistic= 263.000

T = 858.000; n (small) = 34; n (big) = 76; P = <0.001

The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

4.2.2.2 Runoff Duration before Ponding in Biofilters

A similar analysis was conducted to investigate the time since the beginning of flow entering the biofilters to the beginning of ponding. The total amount of rain or runoff before ponding might be a more useful measure, but those data were not available. The time before ponding was obtained from the inflow hydrograph and ponding depth measurements presented in Appendix H. Figure 4.24 is a box and whisker plot showing the ranges and percentiles of these durations before ponding for each of the eight monitored biofilters.

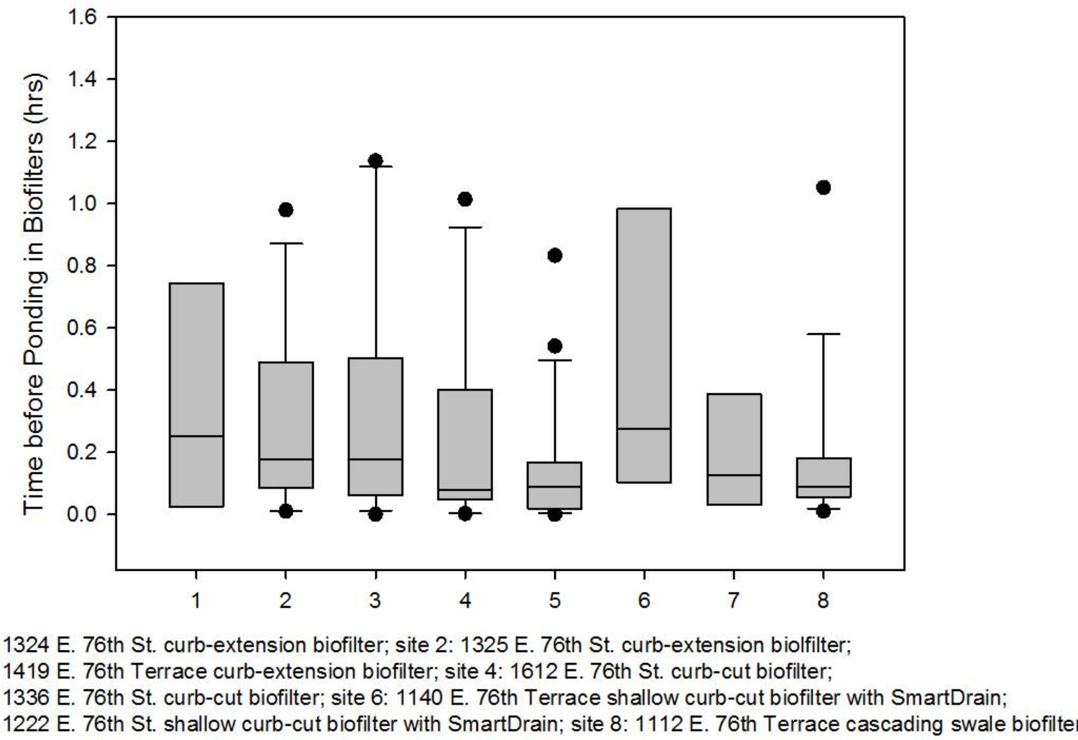


Figure 4.24. Plots of Time to Ponding after Start of Rain for Each Monitored Biofilter Site

Table 4.25. Summary of Time to Ponding after Start of Rain at Monitored Biofilters (hrs)

Monitoring Location	Number of Infiltration Rate Observations	Average Time to Ponding	Std. Dev.
1324 E 76th St	8	0.38	0.40
1325 E 76th St	17	0.30	0.30
1419 E 76th Terrace	19	0.30	0.36
1612 E 76th St	14	0.25	0.32
1336 E 76th St	26	0.15	0.21
1140 E 76th Terrace SD	5	0.49	0.55
1222 E 76th St SD	6	0.20	0.20
1112 E 76th Terrace	17	0.18	0.25

The following box and whisker plot and Mann-Whitney statistical test results summarize the time to ponding for these two significantly different groups of data. The biofilters at 1336 E 76th St and 1112 E 76th Terrace had the shortest ponding periods (about 5 minutes), and were also the two sites with the highest average infiltration rates (possibly the opposite of what would be expected, but may be due to other site characteristics). The other sites had average ponding times of about 10 minutes since the start of the observed runoff.

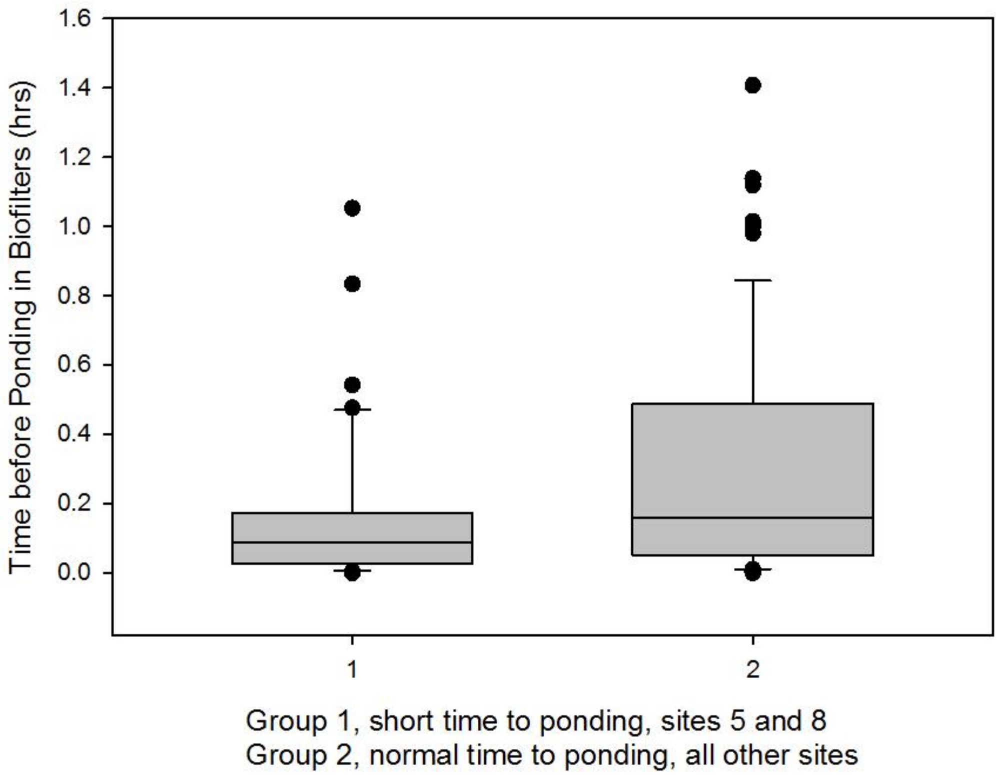


Figure 4.25. Short and Long Time to Ponding Groups at Monitored Biofilters

Table 4.26. Mann-Whitney Rank Sum Test to Compare Two Groups of Time to Ponding at Monitored Sites (hrs)

Group	N	Missing	Median	25%	75%
Short (5 and 8)	43	0	0.088	0.026	0.17
Long (1, 2, 3, 4, 6, 7)	69	0	00.16	0.051	0.49

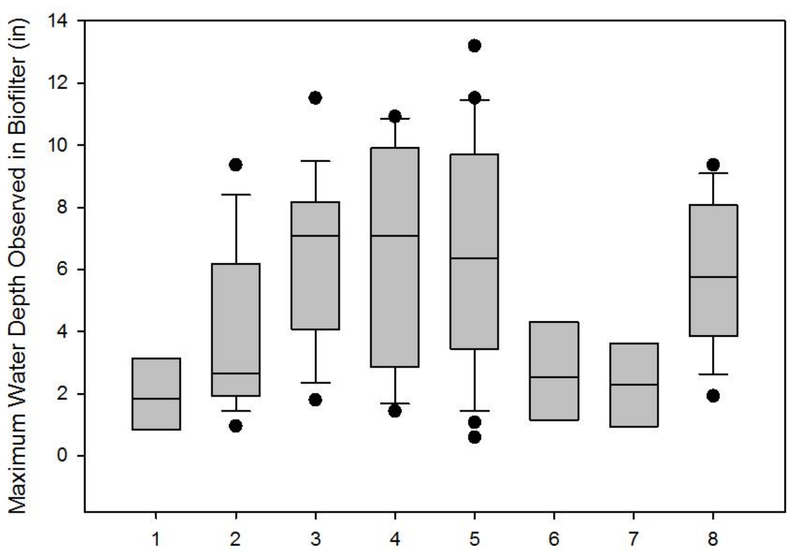
Mann-Whitney U Statistic= 1139.500

T = 2085.500; n (small) = 43; n (big) = 69; P = 0.040

The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P = 0.040).

4.2.2.3 Maximum Water Depth Observed in Biofilters

The maximum depth observed in the biofilters was also obtained for each monitored event in each of the biofilters and examined using similar procedures as described above. Figure 4.26 is a box and whisker plot showing the median and ranges for each of the eight sites.



site 1: 1324 E. 76th St. curb-extension biofilter; site 2: 1325 E. 76th St. curb-extension biofilter
site 3: 1419 E. 76th Terrace curb-extension biofilter; site 4: 1612 E. 76th St. curb-cut biofilter
site 5: 1336 E. 76th St. curb-cut biofilter; site 6: 1140 E. 76th Terrace curb-cut biofilter with SmartDrain
site 7: 1222 E. 76th St. curb-cut biofilter with SmartDrain; site 8: 1112 E. 76th Terrace cascading swale biofliter

Figure 4.26. Plots of Maximum Water Depth Observed in Monitored Biofilters during Rains

Table 4.27. Summary of Maximum Water Depth Observed at Monitored Biofilters (in)

Monitoring Location	Number of Infiltration Rate Observations	Maximum Ponded Water Depth (in)	Std. Dev.
1324 E 76th St	8	3.0	3.6
1325 E 76th St	17	4.1	2.7
1419 E 76th Terrace	19	6.4	2.6
1612 E 76th St	14	6.5	3.4
1336 E 76th St	26	6.6	3.7
1140 E 76th Terrace SD	5	2.7	1.8
1222 E 76th St SD	6	2.4	1.4
1112 E 76th Terrace	17	5.8	2.3

The following box and whisker plot and Mann-Whitney Rank Sum statistical test result summarizes the maximum depths observed for two groups of sites that were found to be significantly different. The median depth for the sites having the deepest standing water depths was about 6.5 inches, while it was only about 2.5 inches for the other sites. With a typical infiltration rate of 2.5 inches per hour, this standing water would be expected to be completely infiltrated within a few hours after the rain ended, much less than typical 24 to 72 hr maximum requirements to prevent nuisance conditions.

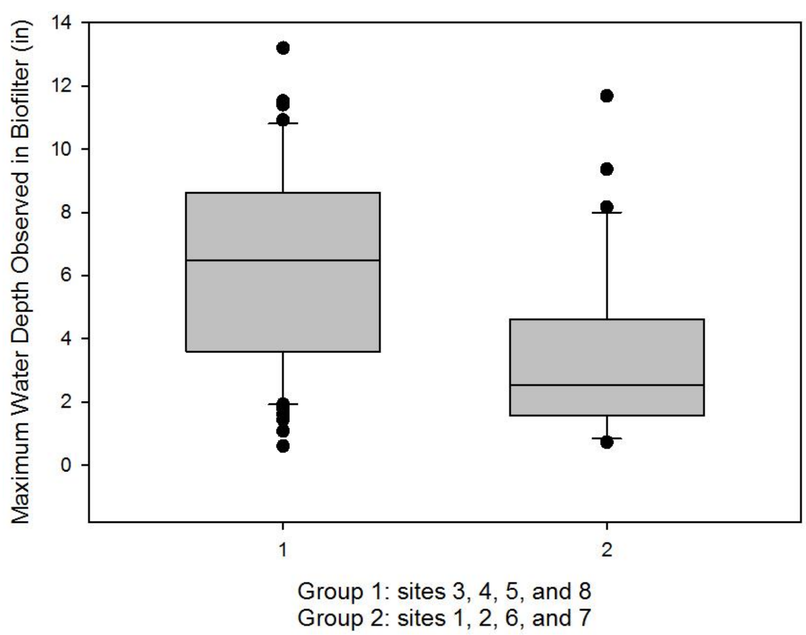


Figure 4.27. Deep and Shallow Maximum Water Depth Groups for Monitored Biofilters

Table 4.28. Mann-Whitney Rank Sum Test to Compare Two Groups of Maximum Ponding Depths at Monitored Sites (in)

Group	N	Missing	Median	25%	75%
Deep (3, 4, 5, 8)	76	0	6.5	3.6	8.6
Low and Medium (1, 2, 6, 7)	36	0	2.5	1.6	4.6

Mann-Whitney U Statistic= 606.500

T = 1272.500; n (small) = 36; n (big) = 76; P = <0.001

The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

4.3 Evaluation of Performance of Integrated Green Infrastructure (GI) Stormwater Controls at Large Scales

At large scales, direct measurements of flows by in-system flow monitors in the combined or separate sewers in large drainage areas having green infrastructure facilities are used to directly measure system performance. The small-scale facility infiltration results described previously were used to calibrate the WinSLAMM model and the system measurements were used to verify the larger-scale predictions based on the small scale measurements.

Real time rainfall and runoff data from combined and separate sewer systems that are affected by GI stormwater controls in upstream areas were analyzed before, during and after the construction of the stormwater controls. The runoff characteristics of pre- and post-construction conditions were then compared to quantify the benefits of the integrated GI stormwater controls at large scales. The hypothesis is that the flows being discharged from the study areas are significantly less than would occur if the GI stormwater controls were not present. The linearity between the small-scale measurements and the scaled-up large scale measured flows will verify the system benefits by using distributed small GI controls, a rare confirmation in the literature.

The first step in analyzing flow characteristics in combined stormwater/sanitary sewer systems is to determine the base flow and the dry and wet weather flow components from the flow time series in sewer lines. The following procedure were used for the combined sewer flow data at the Kansas City and the Cincinnati locations.

Figure 4.28 shows an example of the diurnal flow time series for dry Tuesdays in August 2012, for the Cincinnati State College combined sewer system at manhole number 29613032 (also known as the downstream flow meter in this dissertation research). Since time series analyses for all dry weekdays within this month were found to have similar trends, flow data for all dry weekdays were combined for each month separately and statistically analyzed to identify whether the data have a random sequence. Figures 4.29 is an example of a run chart test for all dry weekdays in August 2012, for the Cincinnati State College combined sewer system at manhole number 29613032 (Minitab, 16). In this figure, fewer runs about the median are observed than expected, which indicates clustering of data. In addition, fewer numbers of runs up or down were observed than expected, which indicates trending of data. Therefore, the run chart results were used to support the combining of dry weekday flow data. In this project, the statistical tests indicated that for most of the months there were two base flow patterns within each month; one for all dry weekdays of the month, and another for all dry weekends of that month.

The dry weather flow patterns (showing the diurnal flow fluctuations that vary by day of the week and time of day) were subtracted from the combined sewer flows to result in the separate rainfall-runoff contributions (direct runoff from rain events). Figures 4.30 and 4.31 are examples of subtracting base flows from combined flows after a storm event in August 2012 for the Cincinnati State College combined sewer system at manhole number 29613032.

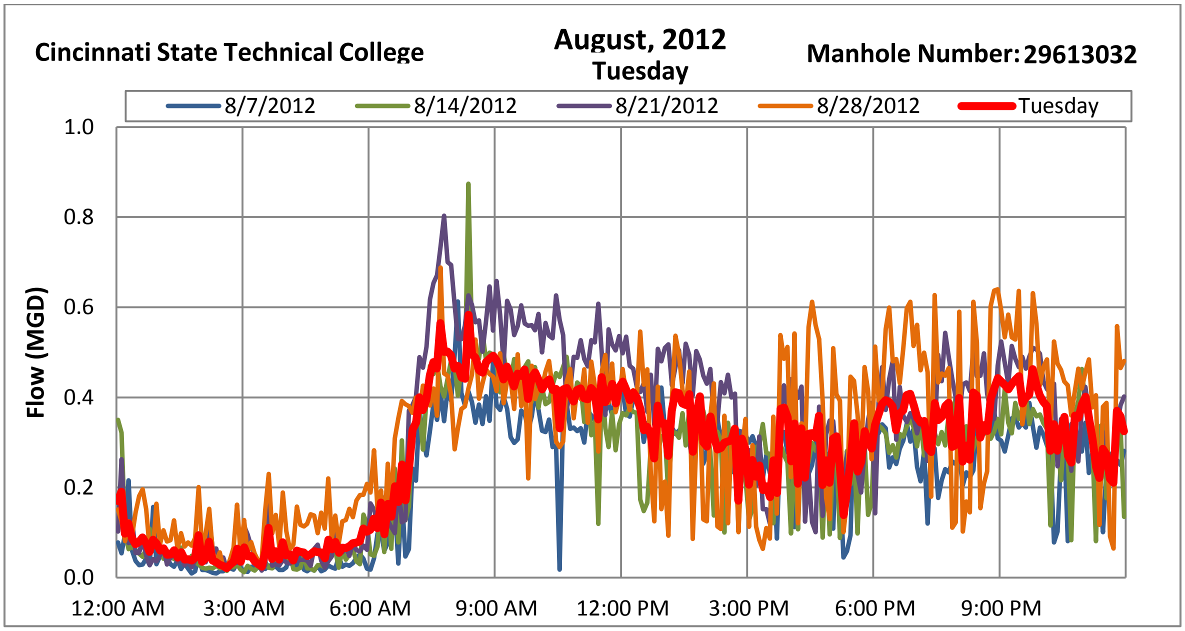


Figure 4.28. Example of diurnal flow time series for dry Tuesdays in August 2012, for Cincinnati State College combined sewer system at manhole number 29613032

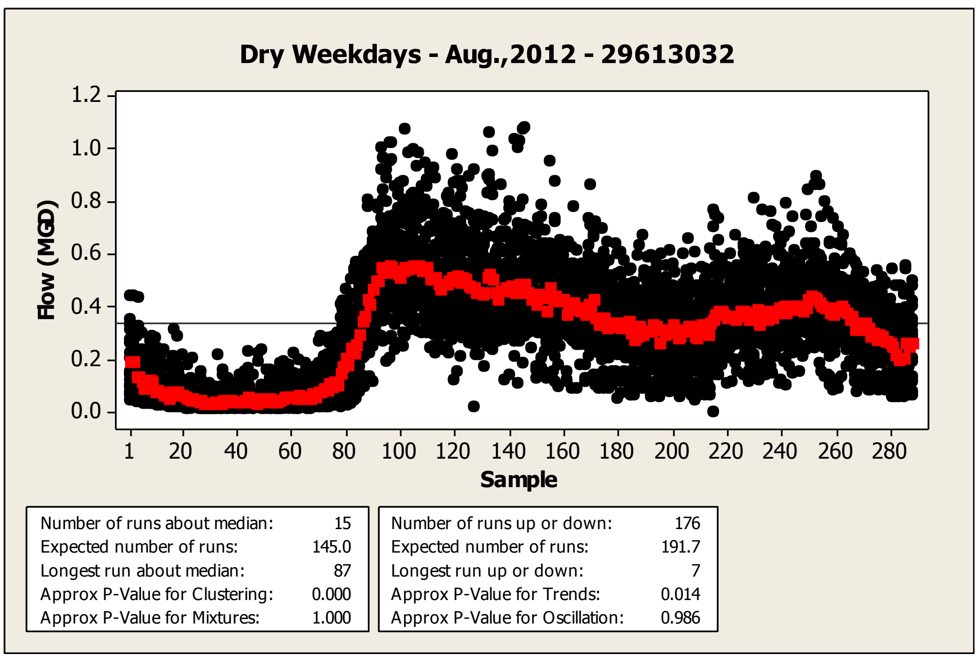


Figure 4.29. Example of diurnal flow time series for dry weekdays in August 2012, for Cincinnati State College combined sewer system at manhole number 29613032

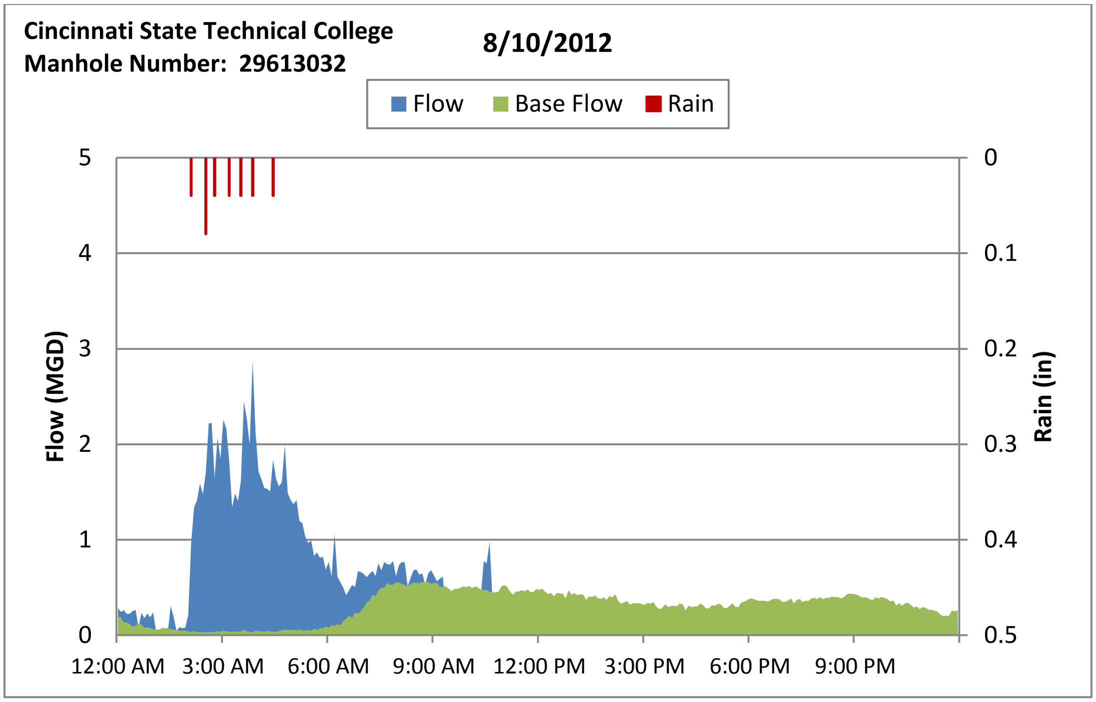


Figure 4.30. Example of monitored flows after a storm event in August 2012, for Cincinnati State College combined sewer system at manhole number 29613032

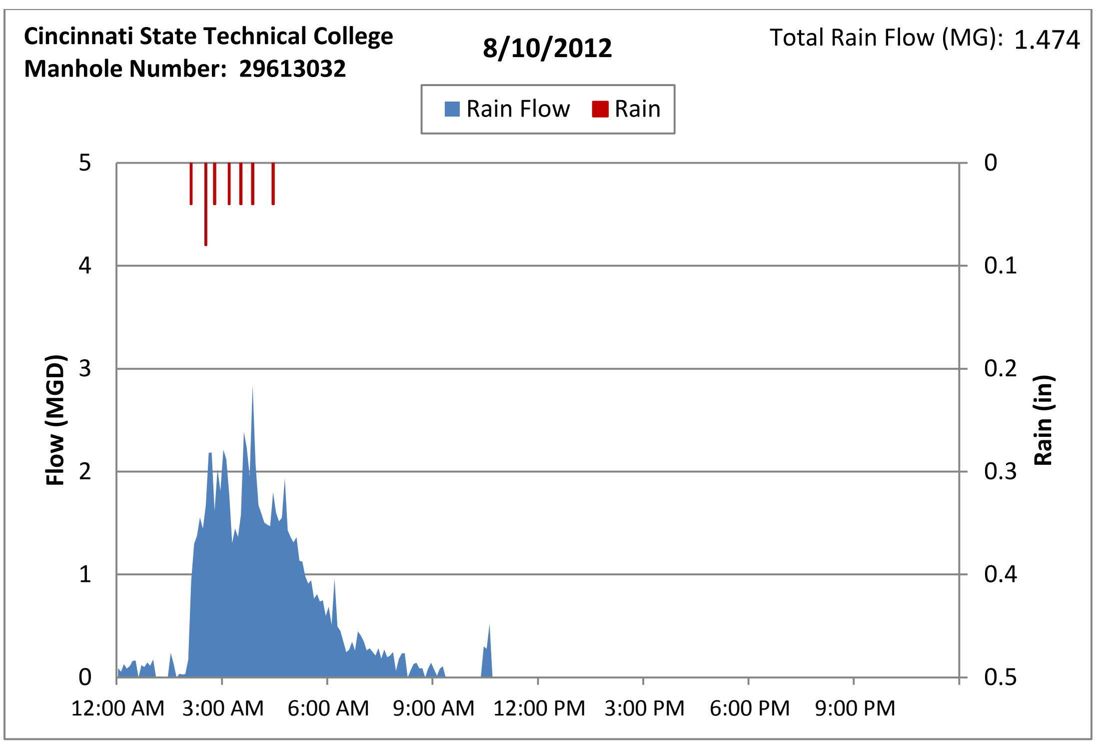


Figure 4.31. Example of wet weather flows after a storm event in August 2012, for Cincinnati State College combined sewer system at manhole number 29613032

The next step in the flow analyses at the large scales was to summarize the event flow and rainfall characteristics for all events at each monitoring location (after subtracting the base flows), and compare the results using land use characteristics and watershed analyses. Also, upstream flows were also subtracted from downstream flows to isolate direct runoff from the sites, as appropriate.

4.3.1 Large-Scale Performance Evaluation of Integrated GI Stormwater Controls at Kansas City

4.3.1.1 Monitoring Locations in Test and Control Watersheds

Runoff monitoring was conducted in the combined sewer system at several locations in the test and control watersheds in Kansas City. This sampling arrangement enabled flows to be separated for the test (pilot) and the control watersheds. Nine complete events were monitored in the area in 2009, and six events were monitored in 2010 before the construction of the GI controls were constructed. These initial flow data were used for the verification of the WinSLAMM runoff calculations. Additional events were monitored after the sewer in the pilot watershed was rehabilitated, and these data were compared to the flows observed before re-lining. Construction of the stormwater controls started after the re-lining, with the final seven events from April 1 to the first part of June 2012 representing built conditions with the stormwater controls for the first study period. The project continued to collect data through 2013 and further data analyses were conducted with the complete data set. A total of 76 events were available for the pre-construction baseline conditions and 37 events were available for the post-construction conditions.

As noted previously, the detailed land development and land use information for the test and control watersheds enabled the verification of the water quantity portion of WinSLAMM using the site rainfall and runoff data in order to illustrate how the small-scale data can be used when predicting large-scale benefits. Figures 4.32 and 4.33 show the test and control watershed boundaries and the locations of the flow monitoring stations. Monitoring stations UMKC02a, 02b, and 3 measured flows from the control watershed, while station UMKC01 measured the flows from the test (pilot) watershed alone.

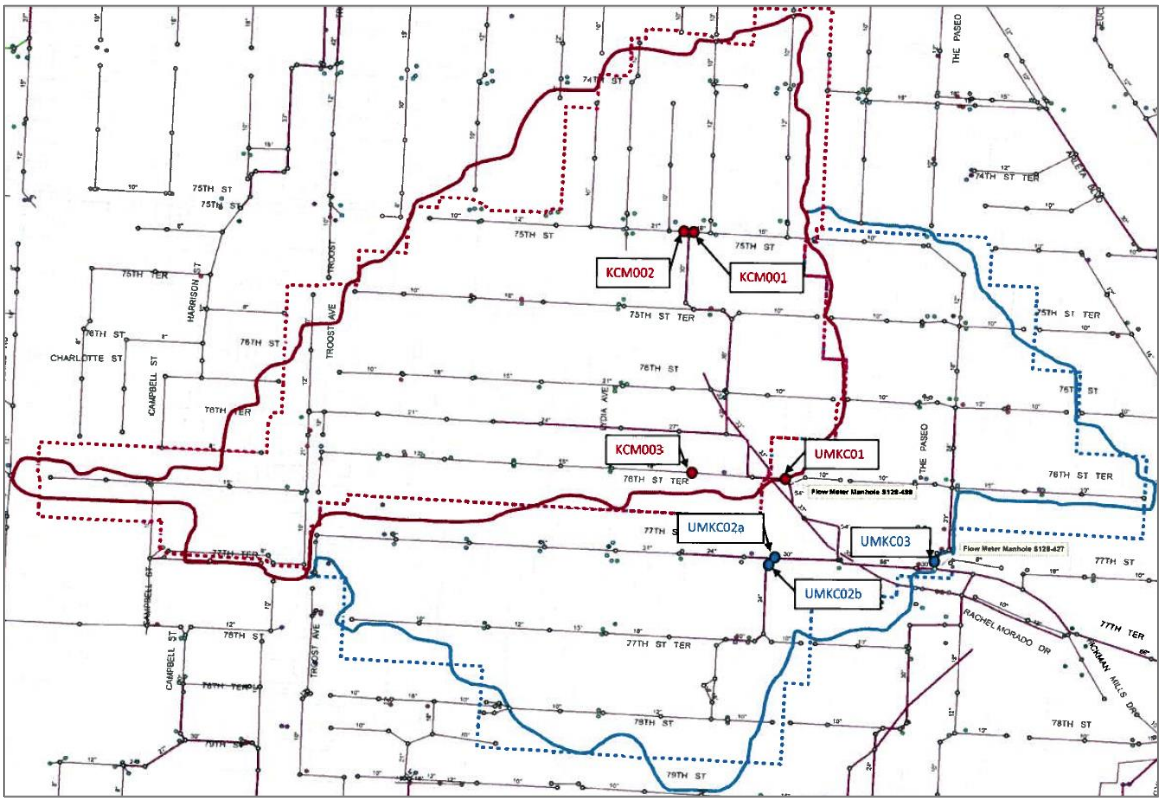


Figure 4.32. Test (100 acres) and control (86 acres) watersheds in Marlborough area of Kansas City, Missouri.

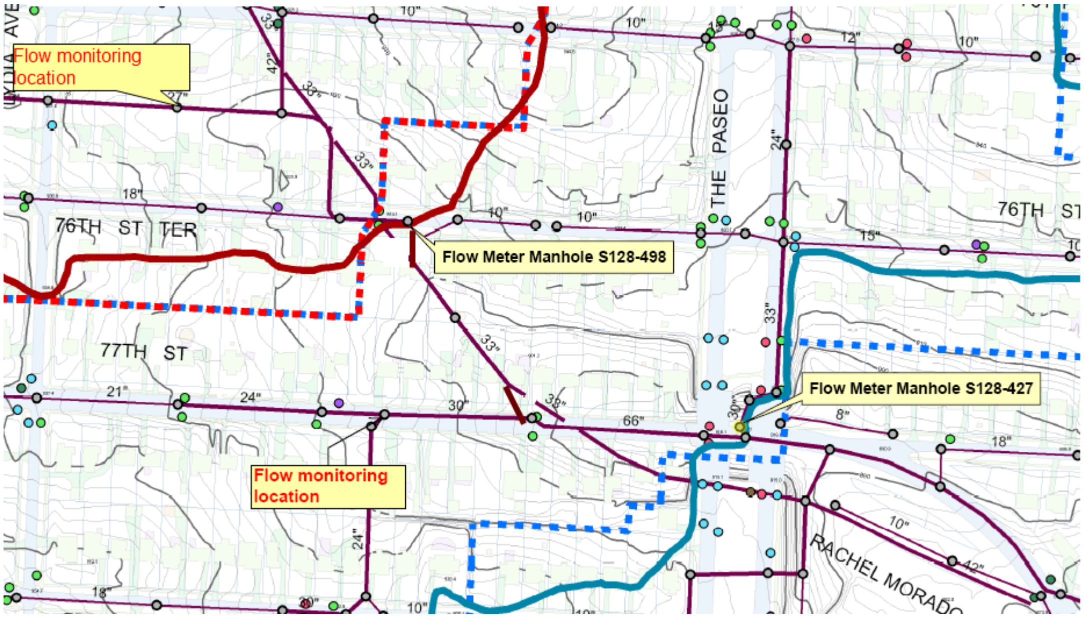


Figure 4.33. Flow monitoring locations at test and control area boundaries.

Table 4.29 summarizes the four flow monitoring locations established for this project as shown in the above figures. The combined sewers ranged from 24 to 42 inches in diameter. The areas were re-evaluated during the project using as-built sewer maps and some site surveys using GIS tools. The UMKC1 meter location measured flows from the test (or pilot) watershed where the GI controls were constructed, while UMKC2a, 2b, and 3 monitored portions of the control watershed.

Table 4.29. Flow Monitoring Locations in Combined Sewers for Test and Control Watersheds

GI Project Location	Area Type	Location	Design Station	Date Installed	Drainage Area (acres)	Pipe Diameter at Monitoring Location
UMKC1 flow meter	Test/Pilot	Near 1461 E 76th Terrace	S128-498	11/7/08	99.7	42”
UMKC2a flow meter	Control	Near 1451 E. 77th St.	S128-422	11/7/08	41.4	30”
UMKC2b flow meter	Control	Near 1451 E. 77th St.	S128-420	11/7/08	27.6	24”
UMKC3 flow meter	Control	77th St & Paseo Overpass	S128-426	11/7/08	17.6	30”

4.3.1.2 Rain Gauges near the Monitoring Locations

Data from seven rain gauges reported by Johnson County Kansas Regional Weather (www.stormwatch.com) near the study area during the monitoring period were examined as part of the project QA/QC activities. Figure 4.34 shows the locations of these stations which were: sensor ID 1800 (Allied Signal @ Indian Creek), sensor ID 2400 (Allied Signal @ Blue River), sensor ID 2420 (85th @ Blue River), sensor ID 2790 (92nd and Ward Parkway Trib to Indian Creek), sensor ID 5050 (Lee Blvd @ Dykes Branch), sensor ID 5100 (Brooklyn PS), and sensor ID 5110 (75th Terrace and Troost). Rain gauges 1800 and 2400 have a lot of missing data over the study period, and only three (2420, 5100, and 5050) had rain depth data available for the whole study period from 2009. The sensor ID 2420 rain gauge was used for these analyses as it was closest to the flow monitors and had continuous information.

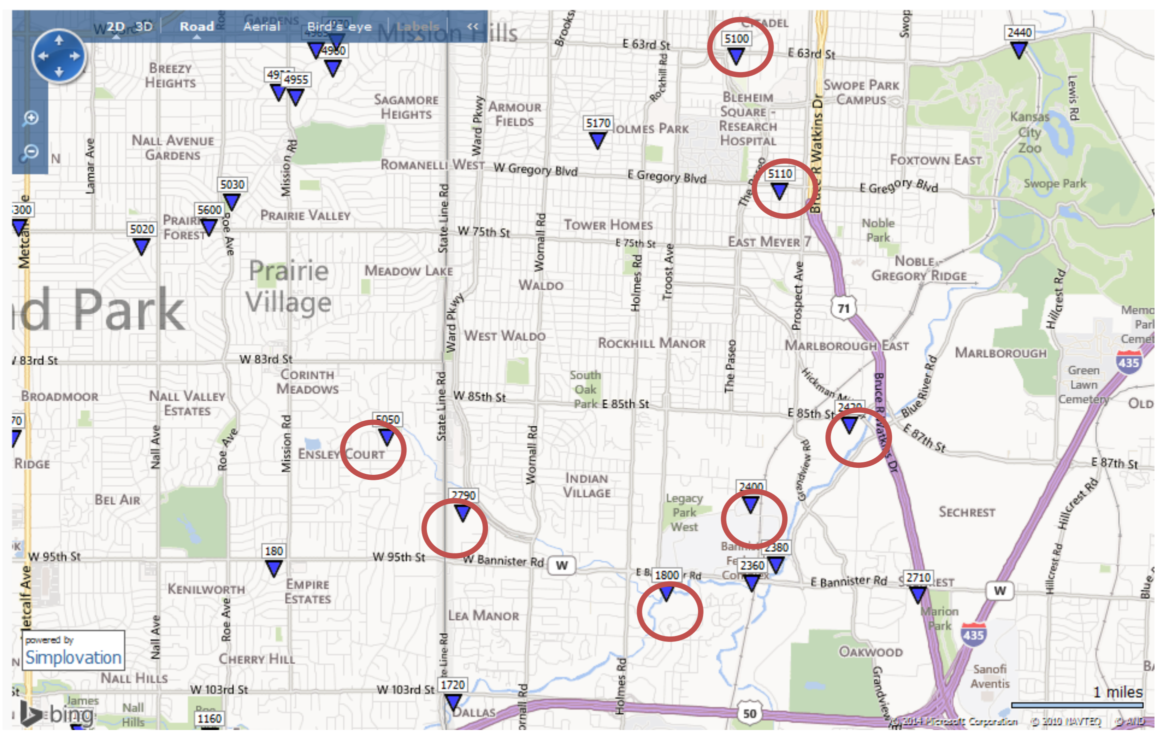


Figure 4.34. Locations of rain gauges near the study area (source: www.stormwatch.com).

4.3.1.3 Runoff and Rainfall Observations in Test and Control Watersheds

Large amounts of data were collected as part of the Kansas City Green Infrastructure demonstration project. The project was designed to include multiple scales of monitoring which would be complementary and to some extend redundant. This discussion describes the large-scale monitoring in adjacent pilot (test) and control areas served by combined sewers. Monitoring at these four monitoring locations (described previously) started before the construction of the GI facilities in order to obtain baseline information. The pilot watershed combined sewer drainage system was also relined to reduce infiltration and exfiltration near the end of this baseline period. Monitoring was also conducted during and after the construction of the GI facilities. Much information was obtained during the "initial" baseline period (before the relining) at all of the monitoring locations. However, few events were monitored after the relining and during the construction period. The real time rainfall and runoff data from combined sewer systems that are affected by green infrastructure (GI) stormwater controls in upstream areas were analyzed for different phases, including an initial baseline before relining, after relining, and after the construction of the stormwater controls. The R_v values (the ratio of runoff to rainfall depths) of pre- and post-construction conditions were compared to measure the benefits of the integrated GI stormwater controls at the large watershed scales.

Table 4.31 shows the dates associated with each project monitoring period. The initial baseline period extended for about 15 months and 69 events were monitored before the sewer relining which lasted for about seven months. The period after the re-lining included about seven events before the construction of the GI facilities began. The monitoring after the GI facility construction began in April of 2013 and lasted for about six months, with 37 events being monitored.

Table 4.31. Monitoring Periods in Test/Pilot and Control Area Watersheds

Monitoring period	Dates corresponding to monitoring period	Number of monitored storms in each monitoring period*
Initial baseline	03/23/09 – 06/19/10	69 events
After re-lining	01/22/11 – 03/19/11	7 events
After construction (after April 1, 2012)	04/07/13 – 10/30/13	37 events

* there are gaps in the flow record (such as during the sewer re-lining in the test watershed, and flow monitoring equipment failures) so not all rains had flow data available for these analyses

4.3.1.4 Quality Assurance and Quality Control Examinations of Monitored Runoff and Rainfall Data

The monitored stage-discharge relationship in the combined sewer was plotted and compared to basic plots based on Manning’s equation as part of the QA/QC process. These data were obtained from an area-velocity sensor that reports the discharge (flow) directly, using a calculated flow cross-sectional area based on the stage value multiplied by the measured velocity value. Figure 4.35 shows the stage-discharge at UMKC01 (downstream of the 100 ac pilot study area). This figure was plotted using the separately recorded stage and flow data. As shown on this figure, changing Manning's roughness coefficient “n” values were used to account for the varying n values with depth and the observed stage-discharge relationship (basic Camp’s curve relationships) (0.0082 to 0.012). This plot shows three regions of data observations. The “main sequence” includes almost all of the data and was fitted using reasonable n roughness values that slightly varied with depth. Most of the data inside area 1 were observed during 6/2009 and 6/2010 (occurring during the "before construction" period). The reduced discharge values for these stage observations were therefore deemed incorrect for unknown reasons. The stage values inside area 2 represent surcharged conditions, being greater than the 42" pipe diameter. These six surcharged pressure recorded stage values were therefore re-adjusted to 42”. The stage observations in area 2 were therefore changed to 42” and full-flowing discharge values were assigned for these data. The stage values for the observations in area 1 were also applied to the Manning’s equation with the calibrated n roughness values. In all, only about 3% of the measured flows were modified at UMKC01. Figure 4.36 shows the final set of stage-discharge values for all observations at this monitoring location.

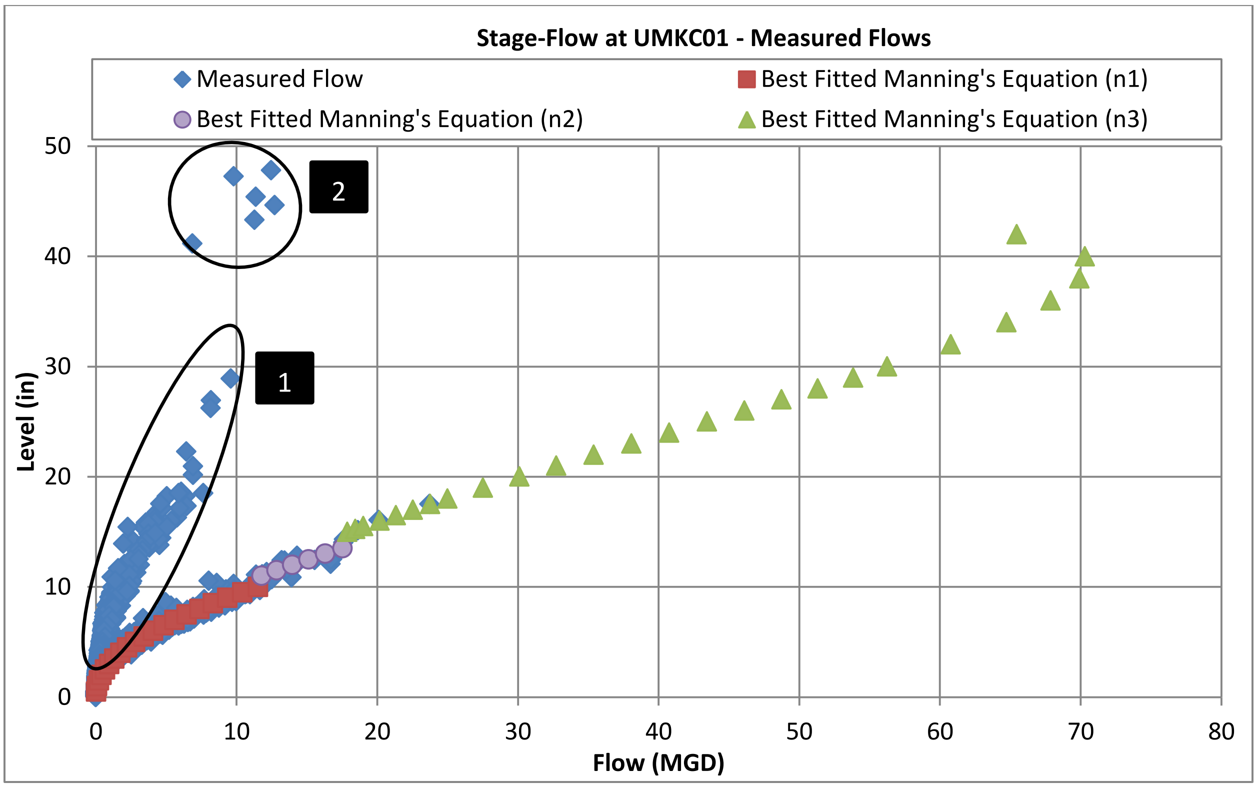


Figure 4.35. Stage-discharge relationship at UMKC01 for measured flows

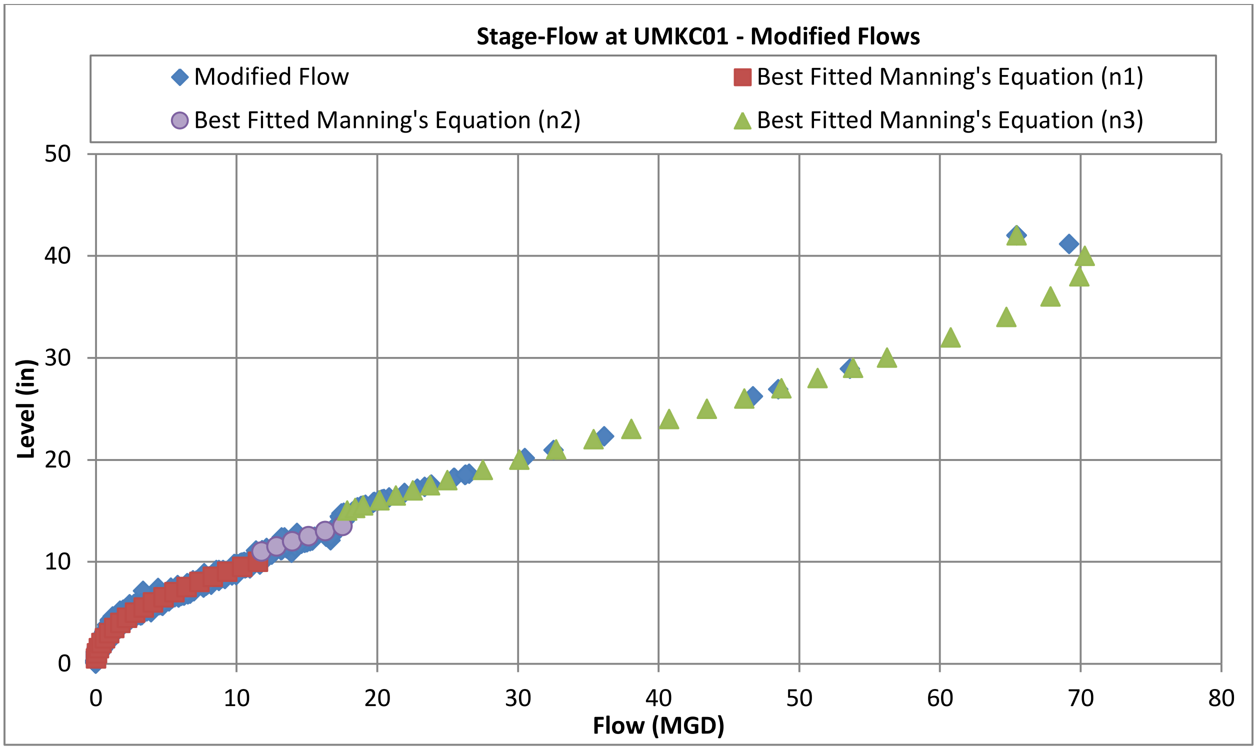


Figure 4.36. Modified Stage-discharge relationship at UMKC01

Similarly, the stage-discharge relationships were plotted and studied for the observed data from the UMKC02a monitoring location (part of the control watershed area). Different Manning's n values were also fitted to the observed flows that varies with the stage values (ranging from n = 0.012 to 0.019). As shown in Figure 4.37, the measured flow data are more scattered at UMKC02a than at UMKC01, requiring about 80% of the data being modified using the calibrated Manning’s equation. Figure 4.38 shows the final set of observations. Figure 4.37 represents stage-discharge conditions at UMKC02a for the measured flows.

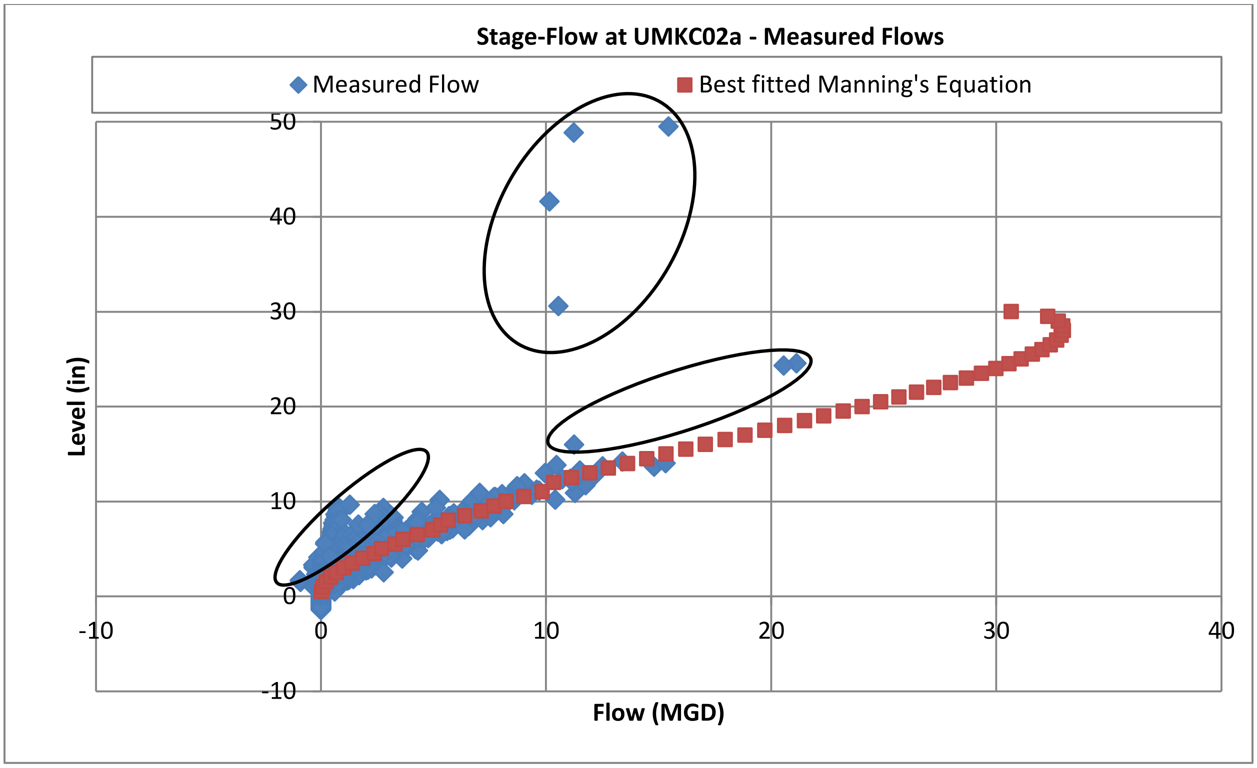


Figure 4.37. Stage-discharge relationship at UMKC02a for measured flows

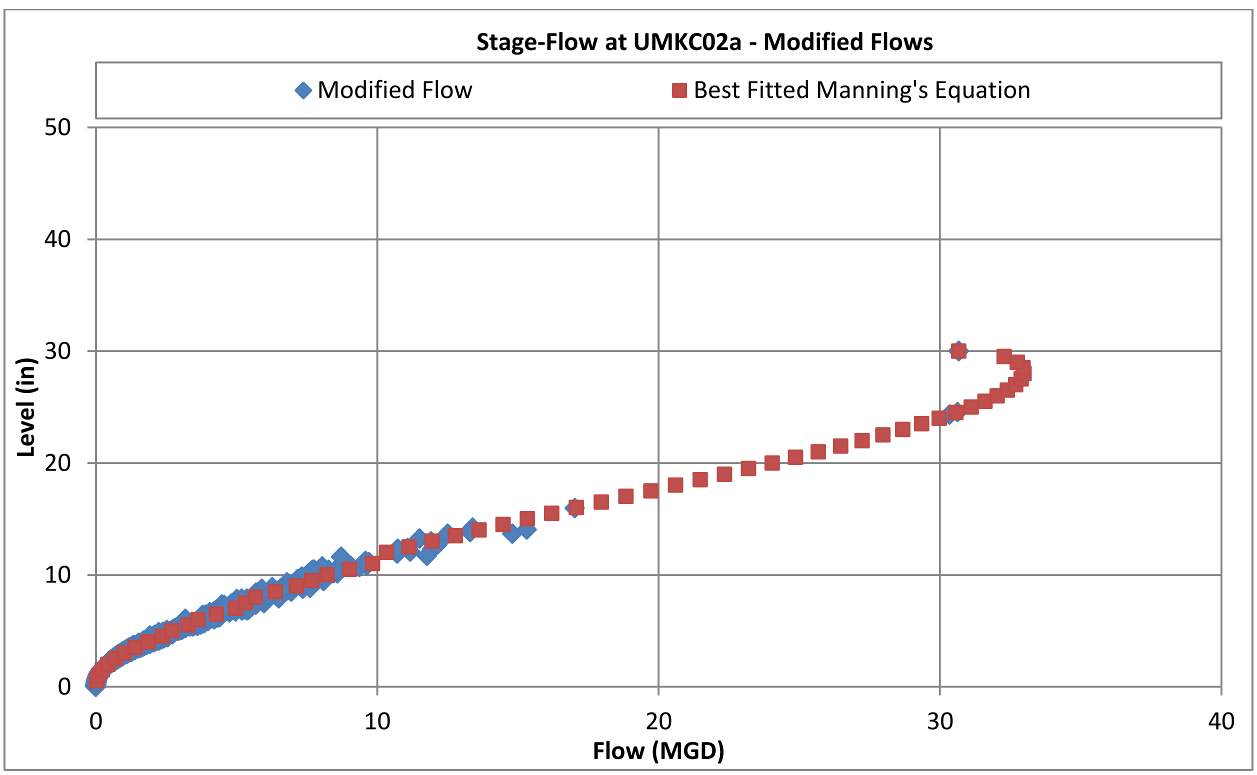


Figure 4.38. Modified Stage-discharge relationship at UMKC02a

Figures 4.39 and 4.40 are similar stage-discharge plots for the two other control area monitoring locations: UMKC02b and UMKC03. As seen on both of these plots, there is a great deal of uncertainty in the plots and all stage values observed were quite small (most less than about 4 inches at UMKC2b in a 24 inch pipe and a maximum stage of about 2.5 inches at UMKC03 in a 30 inch pipe). It was not possible to perform a suitable Manning's n calibration with these data. It is very challenging to measure flows accurately at low stages, especially when the pipes are relatively large.

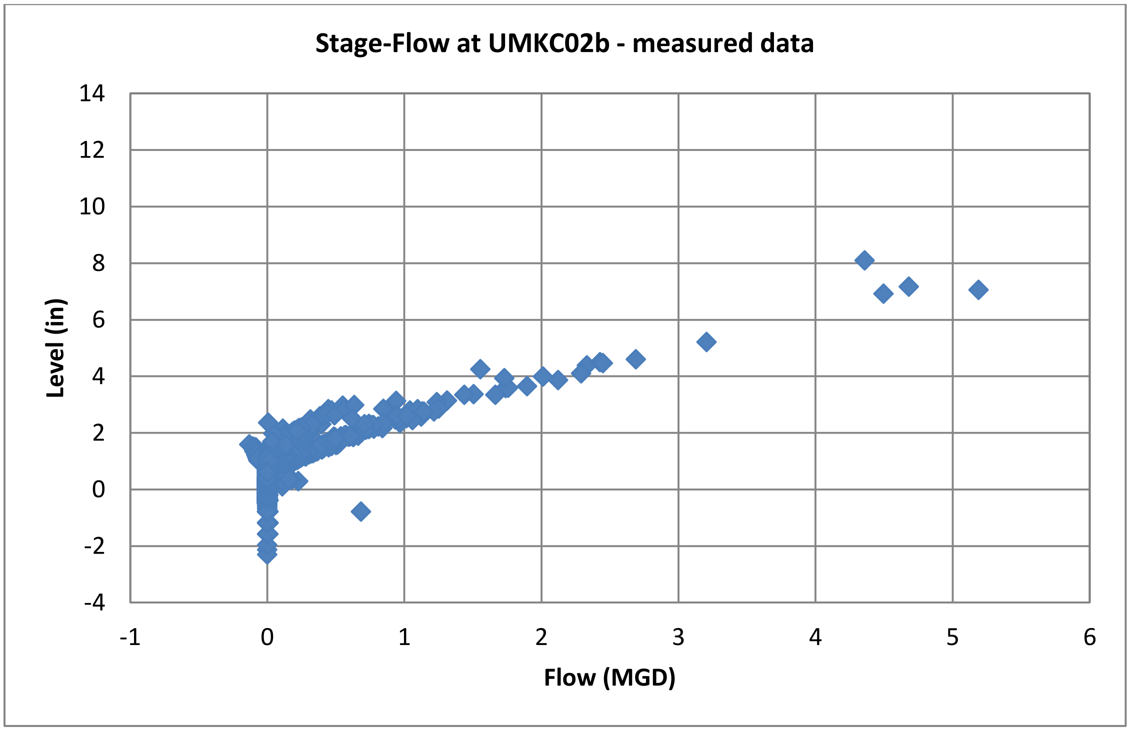


Figure 4.39. Stage-discharge relationship at UMKC02b for measured flows.

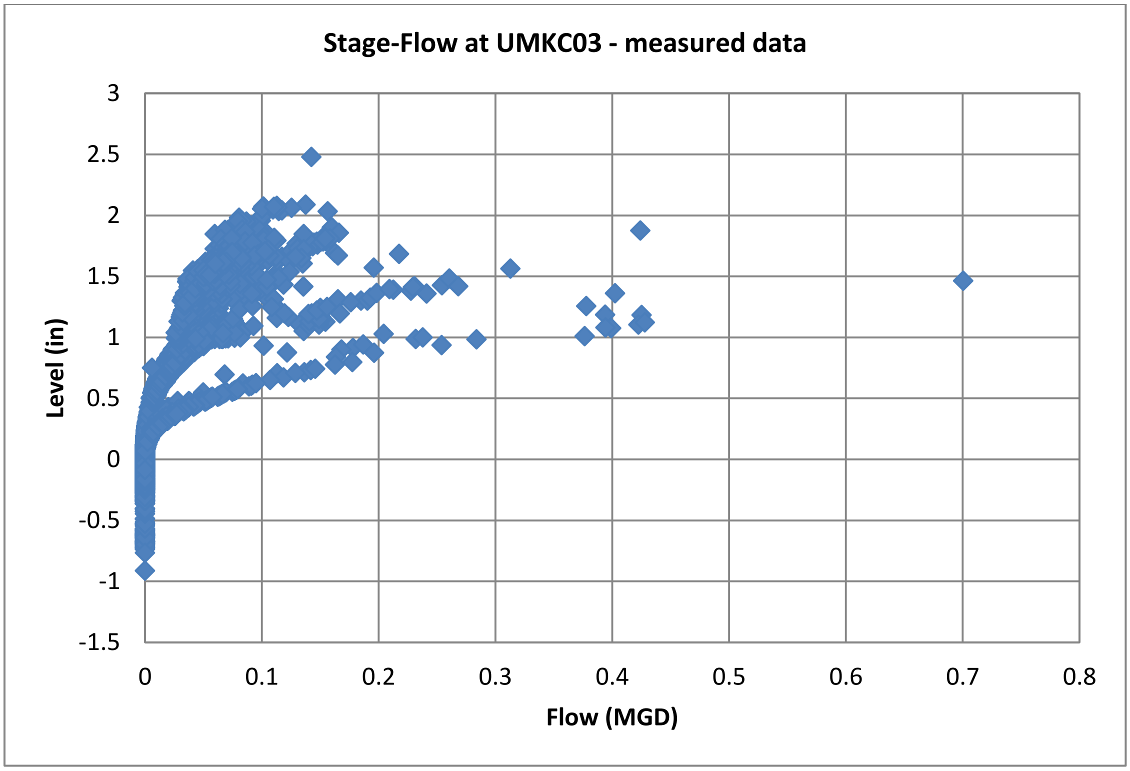


Figure 4.40. Stage-discharge relationship at UMKC03 for measured flows.

Besides examining these monitored stage and discharge values, runoff volumes for each event for these four locations were also examined as part of the QA/QC process. As noted previously, the land use and soil characteristics, along with detailed land development characteristics, in the test (pilot) and control areas were very similar, but with varying drainage areas. Therefore, the unit area runoff characteristics (usually expressed as the volumetric runoff coefficient, or R_v, the ratio of the runoff depth to the rainfall depth) should be similar for the test and control areas before any GI construction (or relining) and the control areas should have similar R_v values during all test phases as no watershed changes occurred in those areas during the study. The following lists the flow-weighted R_v values for the different areas:

- UMKC01 (test/pilot watershed), before relining and pre-construction: 0.26
- UMKC02a, all monitoring periods combined: 0.50

- UMKC02b, all monitoring periods combined: 0.08
- UMKC03, all monitoring periods combined: 0.18

The R_v values varied greatly during conditions when they should have been similar. This was especially evident for UMKC02a being very high and UMKC02b being very low. The expected R_v value for all of these areas for the land use, development, and soil conditions should have been in the range of about 0.25 to 0.40. The R_v values are calculated based on the total runoff volume, the total rain depth, and the watershed area. The watershed areas obviously did not change during the monitoring period, and the runoff and rains were monitored for each event. The rain data was verified by examining the data from the surrounding rain gauges for all monitored events. There were no significant or obvious differences between the gauges having available rainfall information for the monitored events. The drainage area maps showing the "as-built" combined sewers had several areas of confusion that were not able to be clarified by field surveys. However, any errors in the effective drainage areas would not cause any trends in the R_v values with time for the area not affected by site construction. Therefore, R_v trends were examined for all of these areas. The observed R_v values for UMKC02b and UMKC03 were highly variable, while UMKC02a were less so, and UMKC01 more consistent (for each monitoring phase). The flow data from UMKC02b and UMKC03 were therefore judged not reliable for these analyses. The flow data from UMKC01 and UMKC2a were further evaluated (with the resulting event data for these two locations presented in Appendix I).

After the basic discharge values were examined and modified as necessary, the next processing step involved studying and understanding the dry weather sewage flows in the combined sewers. The time series analyses for all dry weekdays within each month had similar trends, from a Run Chart analysis in Minitab. Therefore, for each month, all flow data patterns for the dry weekdays were combined and their average was used as the base flow of weekdays. Similarly, the average flow patterns for all dry weekends were used as the base flow for weekends for each month. This resulted in two base flow patterns for each month for each watershed. These dry weather flow patterns were subtracted from the combined flows during wet weather to result in the direct runoff associated with each rain event. The direct runoff information was then used, along with the rain data for each event, to calculate the total runoff volumes and other characteristics at each monitoring location, as presented in Appendix I.

4.3.1.5 Rainfall and Runoff Evaluations at Test and Control Watersheds

Appendix I contains the flow data observed during the different monitoring periods at the monitoring locations. These tables contain the observed values and the calculated rain and flow parameters based on the observed data. The raw flow data represent both the dry and wet weather flows together in the monitored combined sewers. However, because we are interested in the wet weather flows, the flow values in the wet weather flow tables have had the dry weather sanitary sewage flows subtracted. The dry weather flow pattern (showing the diurnal flow fluctuations that vary by day of the week and time of day) were subtracted from the combined flows to result in the separate rainfall-runoff contributions. These data were also used in the model calibration efforts.

Table 4.32 summarizes the observed rain and runoff characteristics at the UMKC01 monitoring location for the test/pilot watershed, before the green infrastructure facility construction, while Table 4.33 summarizes similar information for the monitoring period after the construction of the stormwater controls. Figure 4.41 illustrates how the measured R_v (the volumetric runoff coefficient, the runoff to rainfall depth ratio) varied with time during the monitoring activities and Figure 4.42 is a plot of the rainfall vs. runoff depths. The variability of the R_v values are quite large, but do illustrate how the values dropped during the “after construction” period. R_v values vary by rain depth, with smaller values associated with smaller rains (a smaller fraction of the rain occurs as runoff for small rains with larger portions of initial abstractions and infiltration losses). Figure 4.43 is a box and whisker plot showing the range of R_v values for each monitoring period. Even with the variability, it is obvious that the after GI facility construction runoff responses are smaller than the before runoff responses for the same rain conditions. Tables 4.34, 4.35, and 4.36 are Kruskal-Wallis one way analysis of variance on means tests comparing the different R_v values for the different conditions. These tests confirm that there were no statistically significant differences between the R_v values for the initial baseline vs. the after relining periods for the number of observations available (results affected by the few data available after the relining and before the construction began). As expected, the combined baseline conditions (initial baseline plus after relining periods) are significantly larger than the after GI facility construction ($P < 0.001$).

Table 4.32. Rain and Flow Characteristics at UMKC01 Test/Pilot Area before GI Construction

	Antecedent dry days	Rain dur. (hrs)	Total rain (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)	Flow dur. (hrs)	Total pipeflow discharge volume (ft^3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
count	74	76	76	75	76	75	75	75	75	75	75	75	75
sum		949.6	58.53			3772.0	5,584,861	15.39					
minimum	0.6	1.0	0.12	0.47	0.01	2.4	3,430	0.01	0.2	0.1	0.3	0.05	0.4
maximum	36.6	64.5	3.50	1.90	0.67	2232.8	780,680	2.15	106.7	5.3	41.5	0.94	179.8
average	6.3	12.5	0.77	0.89	0.10	50.3	74,465	0.21	9.2	0.8	10.1	0.24	5.1
median	4.0	9.6	0.49	0.95	0.07	17.9	40,157	0.11	3.9	0.5	8.1	0.20	2.0
standard deviation	7.2	11.4	0.74	0.42	0.11	255.7	114,061	0.31	15.0	0.9	7.5	0.16	20.5
COV	1.1	0.9	1.0	0.5	1.1	5.1	1.5	1.5	1.6	1.2	0.7	0.67	4.0

Table 4.33. Rain and Flow Characteristics at UMKC01 Test/Pilot Area after GI Construction

	Antecedent dry days	Rain dur. (hrs)	Total rain (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)	Flow dur. (hrs)	Total pipeflow discharge volume (ft^3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
count	36	37	37	37	37	37	37	37	37	37	37	37	37
sum		393.1	30.29			706.1	1,960,646	5.40					
minimum	0.6	0.3	0.12	0.47	0.01	0.8	1,155	0.00	0.1	0.0	2.2	0.03	0.2
maximum	21.8	49.0	3.43	2.85	0.56	58.8	219,477	0.60	36.4	3.8	48.7	0.41	8.0
average	5.3	10.6	0.82	0.97	0.14	19.1	52,990	0.15	6.7	0.7	10.6	0.14	2.7
median	3.8	5.2	0.79	0.95	0.09	15.8	23,841	0.07	3.1	0.4	9.6	0.12	2.2
standard deviation	5.1	11.1	0.70	0.57	0.15	12.9	62,642	0.17	8.1	0.8	8.6	0.09	1.6
COV	1.0	1.0	0.9	0.6	1.0	0.7	1.2	1.2	1.2	1.2	0.8	0.62	0.6

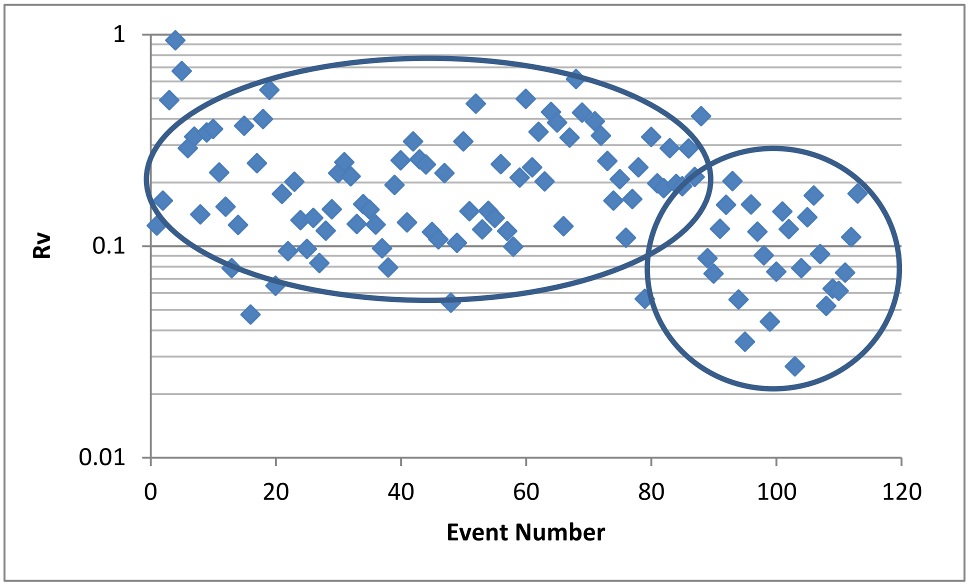


Figure 4.41. Volumetric runoff coefficients at UNKC01 before and after GI construction.

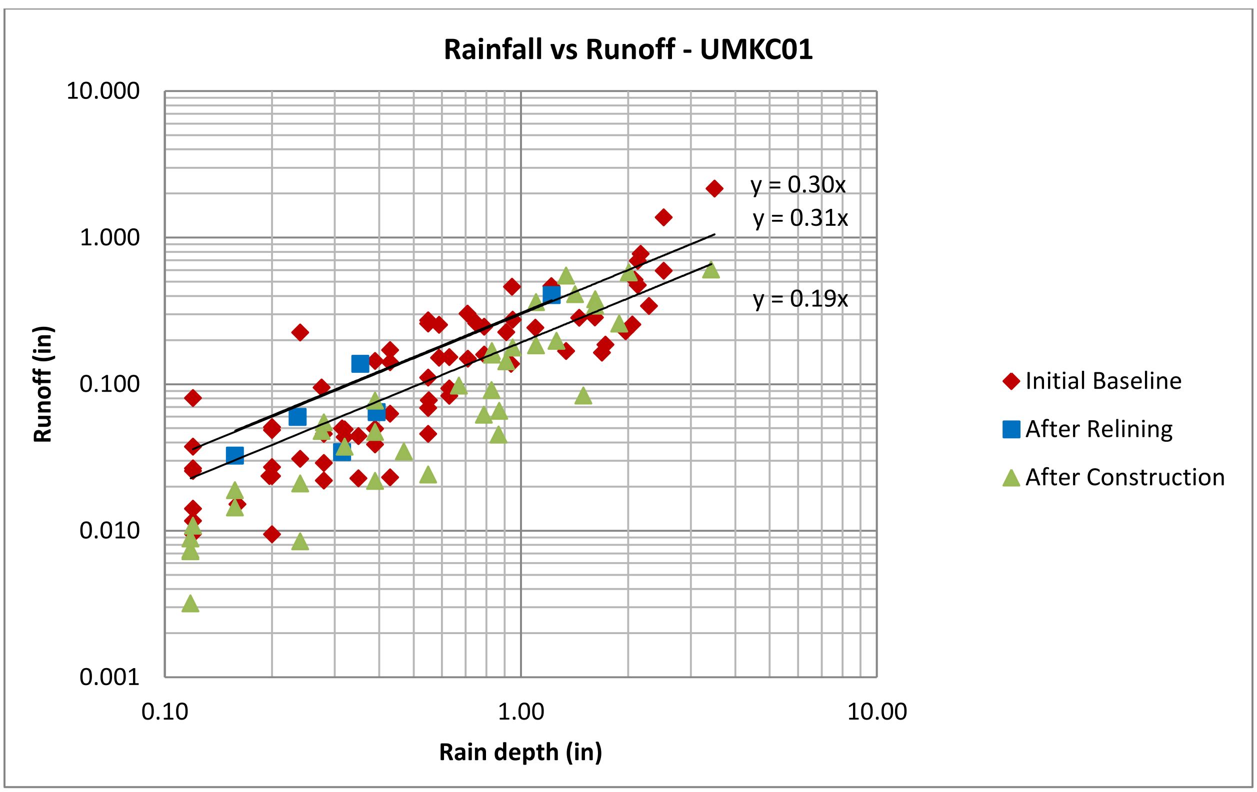


Figure 4.42. Rain vs. runoff plots for UMKC01 during different monitoring periods.

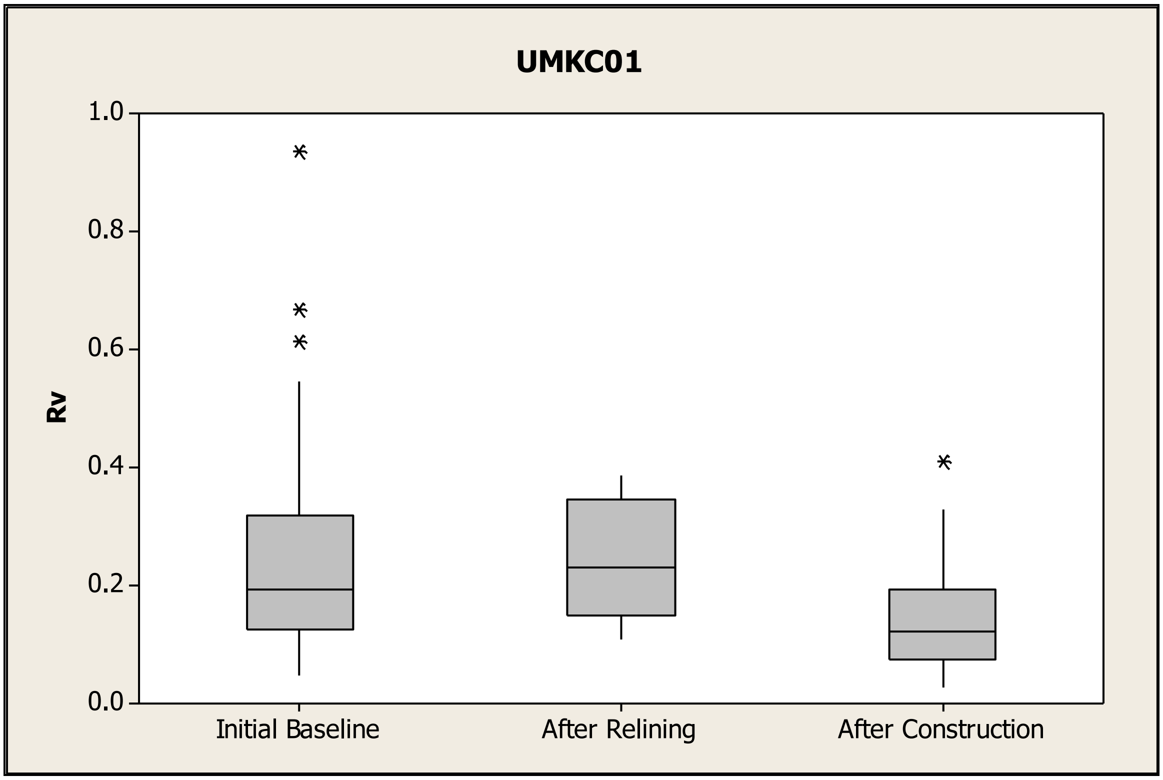


Figure 4.43. R_v values at UMKC01 during different monitoring periods.

Table 4.34. Kruskal-Wallis Statistical Tests Comparing R_v Values for Different Monitoring Periods at UMKC01

Group	N	Missing	Median	25%	75%
Initial Baseline	69	0	0.19	0.12	0.315
After Relining	6	0	0.23	0.148	0.345
After Construction	37	0	0.12	0.0723	0.195
H = 12.288 with 2 degrees of freedom. (P = 0.002)					

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.002).

Table 4.35. Kruskal-Wallis Statistical Tests Comparing R_v Values for Initial Baseline vs. After Relining Monitoring Periods at UMKC01

Group	N	Missing	Median	25%	75%
Initial Baseline	69	0	0.19	0.12	0.315
After Relining	6	0	0.23	0.148	0.345
Mann-Whitney U Statistic= 173.500					
T = 261.500 n(small)= 6 n(big)= 69 (P = 0.519)					

The difference in the median values between the two groups is not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.519).

Table 4.36. Kruskal-Wallis Statistical Tests Comparing R_v Values for Baseline vs. After GI Facility Construction Monitoring Periods at UMKC01

Group	N	Missing	Median	25%	75%
InitialBaseline & AfterRelining	75	0	0.20	0.12	0.32
After Construction	37	0	0.12	0.072	0.195
Mann-Whitney U Statistic= 832.000					
T = 1535.000 n(small)= 37 n(big)= 75 (P = <0.001)					

The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Figure 4.44 is a plot of the R_v values at UMKC01 comparing the before and after R_v values for different rain depths, while Tables 4.37, 4.38, and 4.39 summarize the Mann-Whitney rank sum test results for these comparisons. The R_v differences for the two smallest rain categories are shown to be significantly different (which were at 40 and 33% respectively), but the largest rain category did not show significant differences (at 13% reductions) for the number of observations available. Table 4.40 summarizes the overall R_v comparison tests showing that the 32% decrease in R_v value observed after the GI facility construction was highly significant.

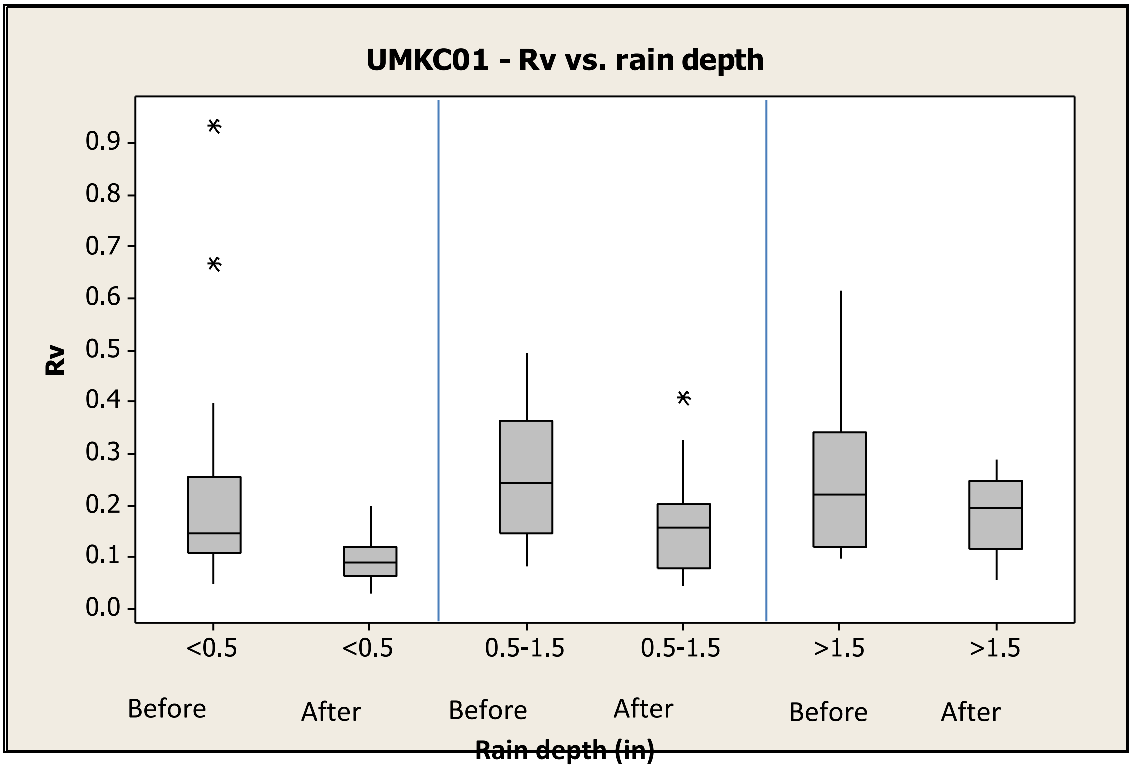


Figure 4.44. Comparisons of R_v Values at UMKC01 for Before and After GI Facility Construction Monitoring Periods.

Table 4.37. Mann-Whitney Comparison Tests of Before and After Construction R_v Values at UMKC01 for Rains <0.5 inches

Group	N	Missing	Median	25%	75%
Initial baseline and after relining	37	0	0.15	0.105	0.25
After construction	16	0	0.09	0.06	0.12
Mann-Whitney U Statistic= 133.500					
T = 269.500 n(small)= 16 n(big)= 37 (P = 0.002)					

The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P = 0.002).

Table 4.38. Mann-Whitney Comparison Tests of Before and After Construction R_v Values at UMKC01 for Rains between 0.5 and 1.5 inches

Group	N	Missing	Median	25%	75%
Initial baseline and after relining	25	0	0.24	0.15	0.365
After construction	15	0	0.16	0.08	0.2
Mann-Whitney U Statistic= 106.000					
T = 226.000 n(small)= 15 n(big)= 25 (P = 0.023)					

The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P = 0.023).

Table 4.39. Mann-Whitney Comparison Tests of Before and After Construction R_v Values at UMKC01 for Rains Larger than 1.5 inches

Group	N	Missing	Median	25%	75%
Initial Baseline and after relining	13	0	0.22	0.12	0.34
After construction	6	0	0.195	0.12	0.245
Mann-Whitney U Statistic= 32.000					
T = 53.000 n(small)= 6 n(big)= 13 (P = 0.568)					

The difference in the median values between the two groups is not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.568).

Table 4.40. Summary of Statistical Comparisons for Before and After GI Facility Construction at UMKC01

Monitoring period	Dates corresponding to monitoring period	Number of monitored storms in each monitoring period	Flow-Weighted R_v values	% change compared to "initial baseline and after relining (combined)" (p from Mann-Whitney Rank-Sum test)
Initial baseline and after Relining	(03/23/09 – 06/16/10) and (02/24/11 – 03/19/11)	75	0.26	n/a
After construction	04/07/13 – 10/31/2013	37	0.18	32.3% decrease ($p < 0.001$)

Tables 4.41 and 4.42 summarize the observed rain and flow conditions for the UMKC02a control area location for all monitoring phases combined. Since there were no changes in the control area during the monitoring period, the runoff characteristics were hypothesized to be similar during the complete monitoring period. Figure 4.45 is a scatterplot of the monitored rain vs. runoff depth values at this control location, while Figure 4.46 is a box and whisker plot of the R_v values for the different monitoring periods. It appears that the runoff responses do not differ greatly for the different monitoring periods as the data regions generally overlap. Table 4.43 shows the results of the Kruskal-Wallis one way analysis of variance on ranks test for the R_v values for these monitoring phases and indicates that no significant differences were found for the number of data observations available. Statistical tests were also conducted comparing the different phases by rain depth; none of those non-parametric Mann Whitney tests indicated any significant differences for the number of observations available at this control area monitoring location. Table 4.44 is a summary of some of these test results.

Table 4.41. Rain and Flow Characteristics at UMKC02a Control Area during All Monitoring Phases Combined

	Antecedent dry days	Rain dur. (hrs)	Total rain (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)	Flow dur. (hrs)	Total pipeflow discharge volume (ft^3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
count	112	115	115	114	115	114	114	114	114	114	114	114	114
sum	703.2	1380.4	91.6			2290.6	3,193,275	48.87					
minimum	0.6	0.3	0.1	0.47	0.01	0.3	397	0.01	0.1	0.0	0.3	0.04	0.1
maximum	36.6	64.5	3.5	2.85	0.67	74.3	292,467	4.48	47.3	3.6	55.0	3.12	21.7
average	6.3	12.0	0.8	0.95	0.11	20.1	28,011	0.43	3.8	0.4	12.6	0.45	2.7
median	4.1	8.2	0.6	0.95	0.07	16.0	12,289	0.19	1.5	0.2	10.4	0.33	1.9
standard deviation	6.8	11.2	0.7	0.52	0.12	13.1	48,752	0.75	5.8	0.7	9.9	0.46	2.7
COV	1.1	0.9	0.9	0.5	1.1	0.7	1.7	1.7	1.5	1.7	0.8	1.0	1.0

Table 4.42. Rain, Runoff and R_v Monitored Values at UMKC02a Control Location during Different Monitoring Periods

	Initial Baseline			After Relining			After Construction		
	Rain Depth (in)	Runoff Depth (in)	Flow-Weighted R_v	Rain Depth (in)	Runoff Depth (in)	Flow-Weighted R_v	Rain Depth (in)	Runoff Depth (in)	Flow-Weighted R_v
Count	71	71	71	6	6	6	37	37	37
Sum, or flow-weighted	58.50	32.99	0.56	2.68	1.15	0.43	30.29	14.73	0.49
Average	0.82	0.46	0.49	0.45	0.19	0.37	0.82	0.40	0.38
Median	0.55	0.22	0.35	0.33	0.09	0.38	0.79	0.13	0.21

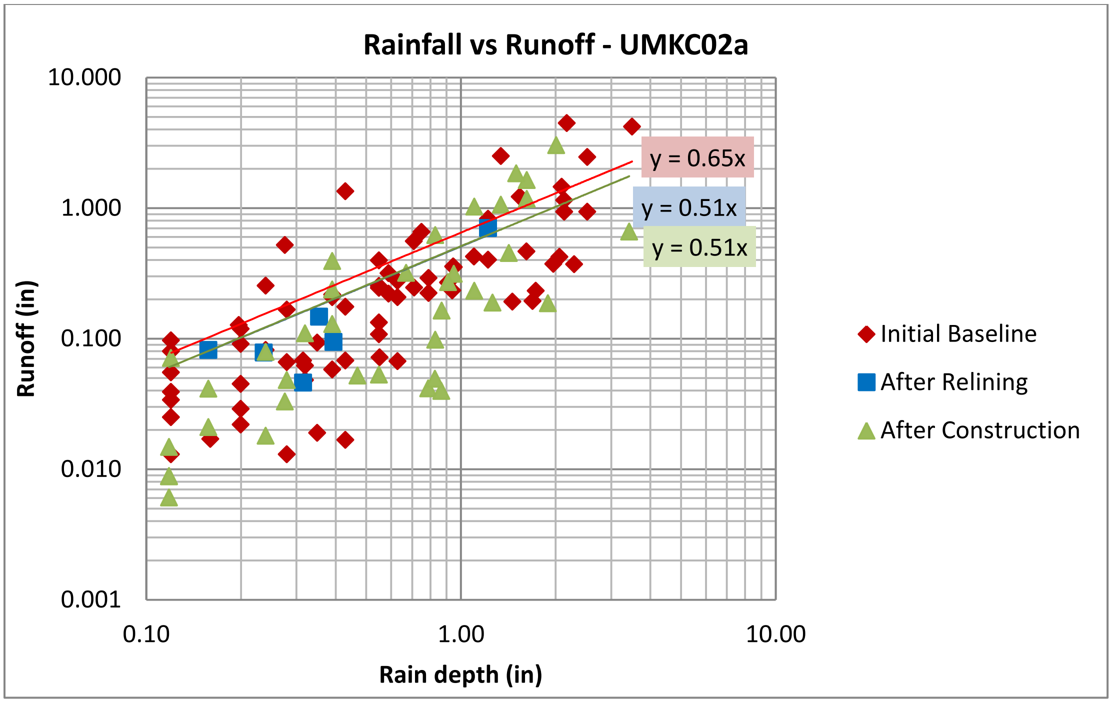


Figure 4.45. Scatterplot of monitored rain vs. runoff conditions at UMKC02a control location for different monitoring periods.

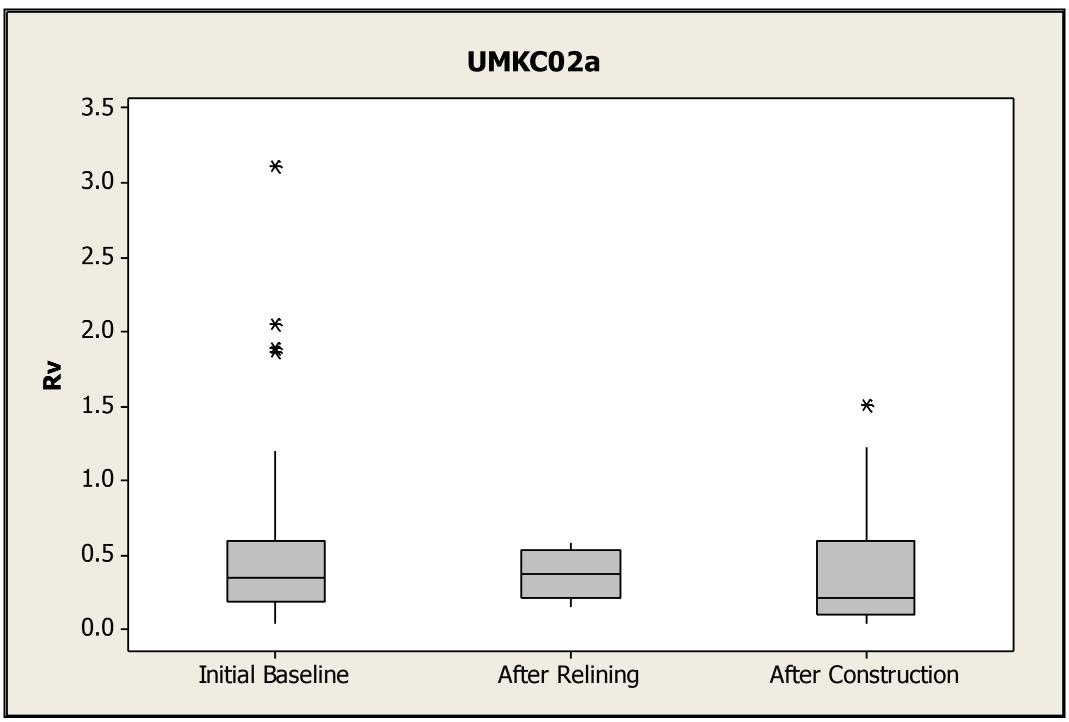


Figure 4.46. Box and whisker plot of monitored R_v values at UMKC02a control area for different monitoring phases (this area was not re-lined, but this plot compares the rain and runoff conditions during these time periods that had separate activities in the parallel UMKC01 test area).

Table 4.43. Kruskal-Wallis One Way Analysis of Variance on Ranks Test for R_v Values from Different Monitoring Phases at UMKC02a Control Location

Group	N	Missing	Median	25%	75%
Initial Baseline	71	0	0.35	0.19	0.6
After Relining	6	0	0.375	0.218	0.535
After Construction	37	0	0.21	0.105	0.6
H = 3.547 with 2 degrees of freedom. (P = 0.170)					

The differences in the median values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.170).

Table 4.44. Summary Statistics Comparing R_v Values for Different Monitoring Periods at UMKC02a Control Location

Monitoring period corresponding to changes in UMKC01; no modifications were made to UMKC2a during the study period	Dates corresponding to monitoring period	Number of monitored storms in each monitoring period	Flow-Weighted R_v values	% change compared to "initial baseline and after relining (combined)" (p from Mann-Whitney Rank-Sum test)
Initial baseline and After Relining period for UMKC01	(03/23/09 – 06/16/10) and (02/24/11 – 03/19/11)	75	0.56	n/a
After construction period for UMKC01	04/07/13 – 10/31/13	37	0.49	no significant difference (*p =0.28*)

Initially, the monitoring plan was to simultaneously track the R_v values in the test/pilot watershed represented by monitoring at UMKC01 with the R_v values in the control watershed represented by runoff volumes at UMKC02a plus UMKC02b plus UMKC03. The ratio of the R_v values for each rain for the test/pilot watershed to the control watershed was expected to change as the GI facilities were constructed. However, as noted above, there were problems with the control area flow sensors due to a high degree of equipment failure and large uncertainties in the observations (most likely due to the generally low flow depths in large pipes at the monitoring locations). In addition, the volumetric runoff values (Rv) were suspect (also likely due to watershed area questions). The control area sensor at UMKC02a appeared to provide better results that at UMKC02b and UMKC03 and was therefore further examined. Figure 4.47 is a time series plot of the ratio of the test/pilot area R_v values to the control area R_v values (UMKC01/UMKC02a), with the pre-construction and post-construction events indicated. These is no apparent decrease in this ratio after the construction for the general range of the observations, but more of the post-construction R_v values appear to be somewhat less that the pre-construction values. The box and whisker plot in Figure 4.48 indicates a couple of very large pre-construction R_v values, but otherwise, the post-construction R_v ratios have a larger 25 to 75 percentile range (represented by the height of the box). Statistical tests were also used to compare these data sets, as shown in the Table 4.45 results for the Mann-Whitney rank sum test. The average of the R_v ratios was somewhat less for post-construction data, but the differences were not significant (P = 0.66) for the amount of data available. Additional Mann-Whitney rank sum nonparametric statistical tests were conducted examining all combinations of the R_v ratios for all rain categories with no statistically significant differences identified for the number of observations available. The variabilities in the ratios for each group were very large likely due to the high variable runoff measurements obtained at the UMKC02a control location. Table 4.46 summarizes the test results.

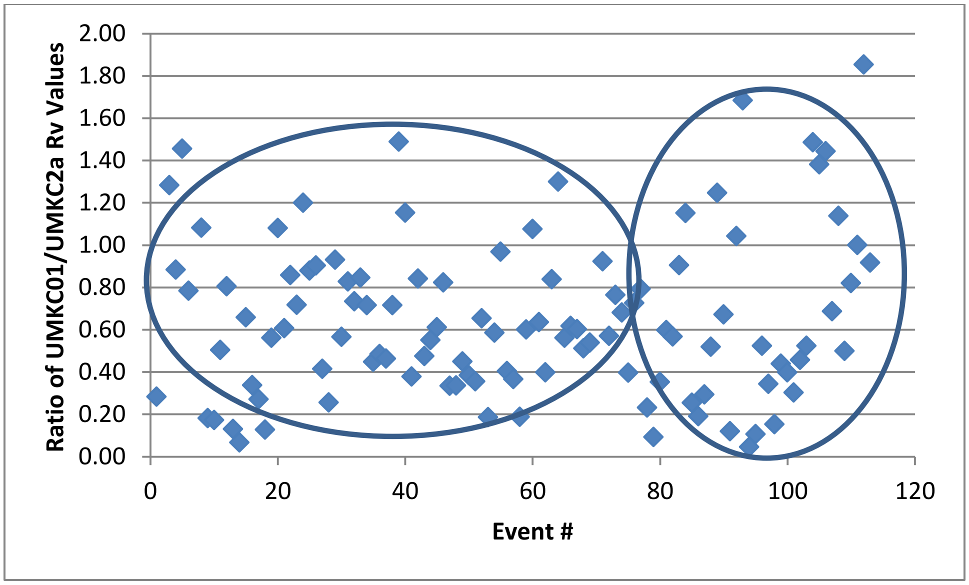


Figure 4.47. Time series plot of UMKC01/UMKC02a (test/control) R_v ratios for different monitoring periods (two large values removed).

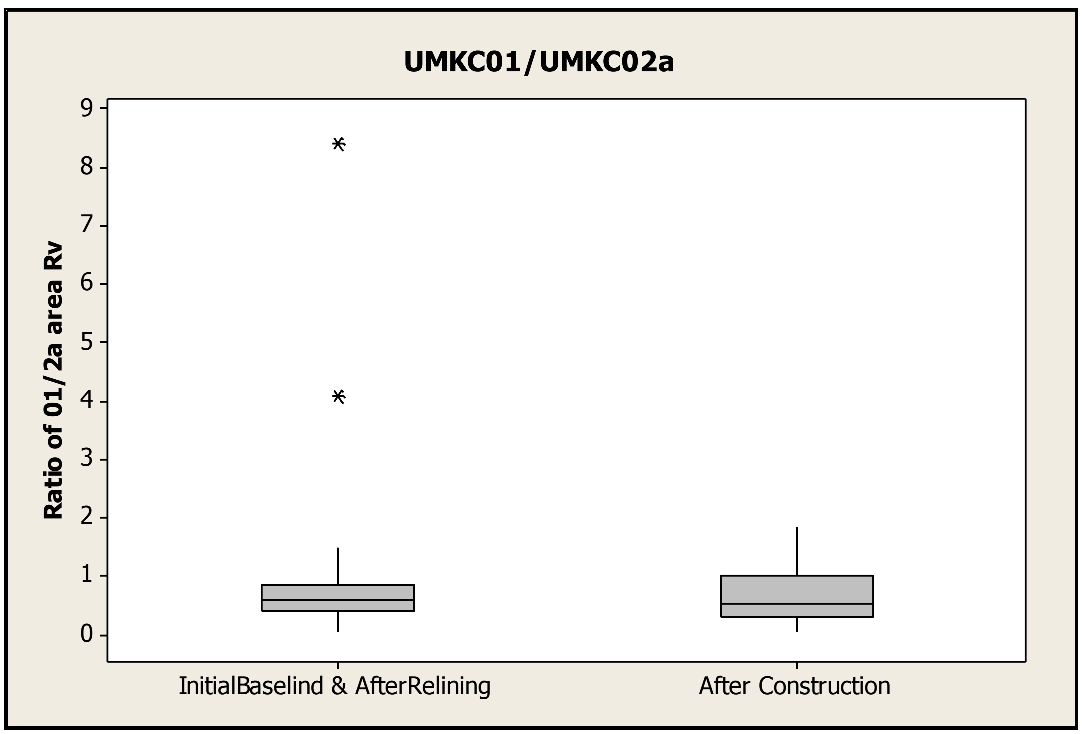


Figure 4.48. Ratio of UMKC01 to UMKC02a R_v values during monitoring phases.

Table 4.45. Mann-Whitney Rank Sum Test Comparing Ratios of UMKC01/UMKC02a R_v Values

Group	N	Missing	Median	25%	75%
InitialBaseline & After Relinig	75	0	0.606	0.397	0.845
After Construction	37	0	0.524	0.298	1.021
Mann-Whitney U Statistic= 1316.000					
T = 2019.000 n(small)= 37 n(big)= 75 (P = 0.661)					

The difference in the median values between the two groups is not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.661).

Table 4.46. Summary of Test Statistics Comparing Ratios of UMKC01/UMKC02a R_v Values for Different Site Conditions

Monitoring period corresponding to changes in UMKC01; no modifications were made to UMKC2a during the study period	Dates corresponding to monitoring period	Number of monitored storms in each monitoring period	Ratio of Flow-Weighted R_v values (01/2a)	% change compared to "initial baseline and after relining (combined)" (p from Mann-Whitney Rank-Sum test)
Initial baseline and After Relining period for UMKC01	(03/23/09 – 06/16/10) and (02/24/11 – 03/19/11)	75	0.46	n/a
After construction period for UMKC01	04/07/13 – 10/31/13	37	0.37	no significant difference (*p =0.661*)

4.3.1.6 Green Infrastructure Effects on Peak Discharge Rates

Green infrastructure facilities are also expected to reduce the peak discharge rates. Figure 4.49 is a box and whisker plot comparing the pre-construction to the post-construction peak runoff rates at the test/pilot monitoring location at UMKC01 for different peak rain intensities. All of the rain gauge data indicated peak rain intensities in one of these four categories due to the number of rain gauge tips that occurred in a 5 minute period. The 0.47 in/hr rate corresponds to 1 tip of 0.04 inches in 5 minutes for example, 0.95 in/hr corresponds to 2 tips per 5 minutes, 1.42 in/hr corresponds to 3 tips per 5 minutes, and 1.9 in/hr corresponds to 4 tips per 5 minutes (the maximum observed). This plot indicates that the pre-construction range of peak flow rates for each of these peak rain intensity categories was larger than for the post-construction range, but statistical tests did not indicate any significant differences in the groups for the number of observations available.

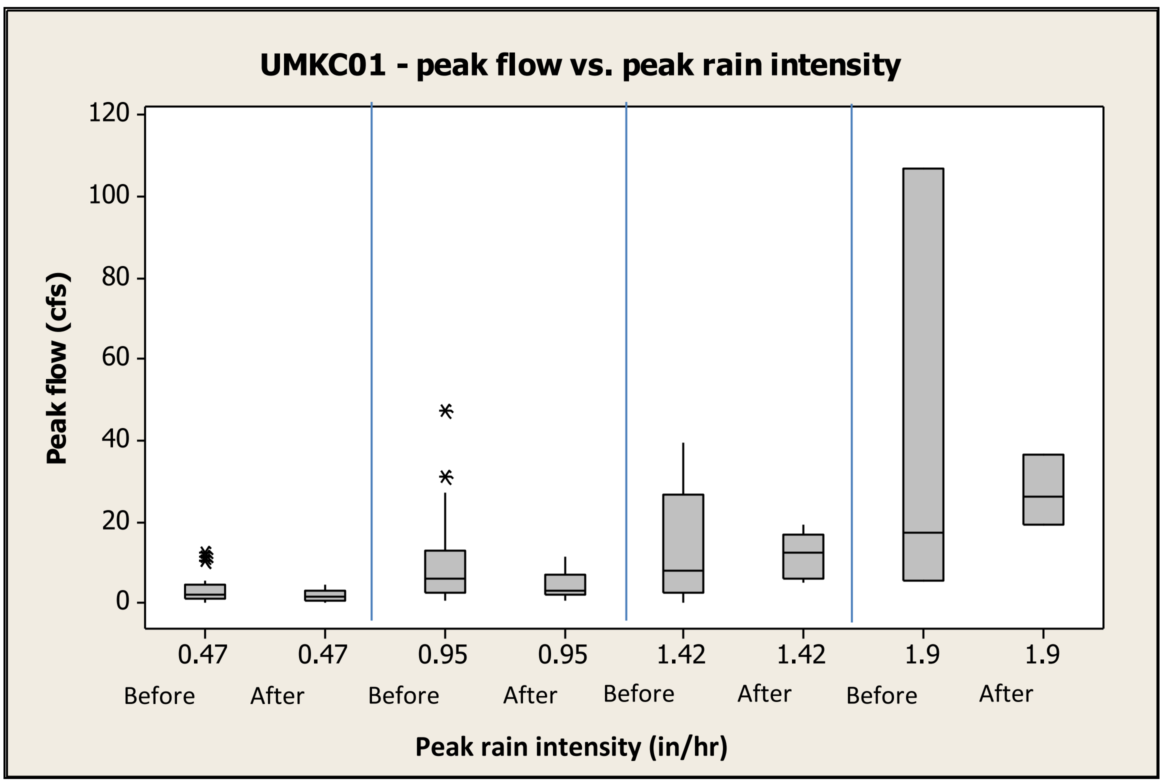


Figure 4.49. Box and whisker plots of peak flow rates before and after GI facility construction at UMKC01 test/pilot area for different rain intensity categories.

4.3.1.7 Model Calibration using Site Monitoring Data

Table 4.47 lists the seven events that were observed in the test (pilot) watershed, after the re-lining was completed and before the construction of the stormwater controls that were used for calibrating WinSLAMM runoff volumes. Also shown are the modeled runoff volume values and the ratio comparing the observed to the modeled flow values.

Table 4.47. Rain data with observed and modeled flow characteristics after re-lining of the combined sewer and before the construction of the stormwater controls (final baseline conditions)

Event #	Rain start date	Rain start time	Rain end date	Rain end time	Total rain (in)	Total pipe flow discharge volume (ft^3)	modeled runoff (ft^3)	ratio of flows (obs/modeled)
119	1/22/2011	12:20	1/23/2011	3:40	0.12	2,246	6,021	0.37
120	2/24/2011	9:00	2/25/2011	3:00	0.35	33,011	21,124	1.56
121	2/26/2011	13:50	2/28/2011	8:20	1.22	129,497	103,676	1.25
122	3/4/2011	11:10	3/5/2011	1:40	0.24	23,412	12,694	1.84
123	3/8/2011	8:10	3/9/2011	1:10	0.39	13,056	24,597	0.53
124	3/13/2011	23:00	3/15/2011	0:25	0.20	10,708	10,035	1.07
125	3/19/2011	14:30	3/20/2011	4:15	0.32	5,900	18,662	0.32
Sum:					2.84	217,830	196,809	Ratio of sums: 1.11

For these seven monitored events, the sum of the observed flows was about 11% greater than the sum of the modeled flows. Figure 4.50 is a scatterplot showing the observed versus the modeled total flows for each of these seven events. As shown, these are all close to the line of equivalent values.

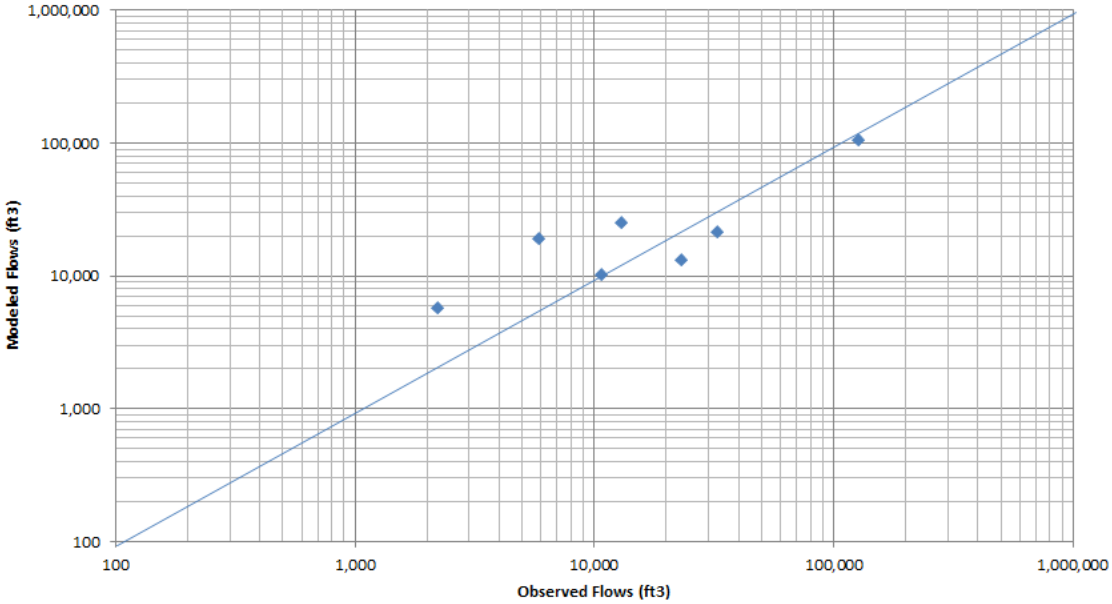


Figure 4.50. Observed versus modeled flows during final baseline conditions (after re-lining)

Figure 4.51 is a box plot that compares the single event observed flows to the modeled flows. The boxes substantially overlap, but the observed flows are much more variable than the modeled flows.

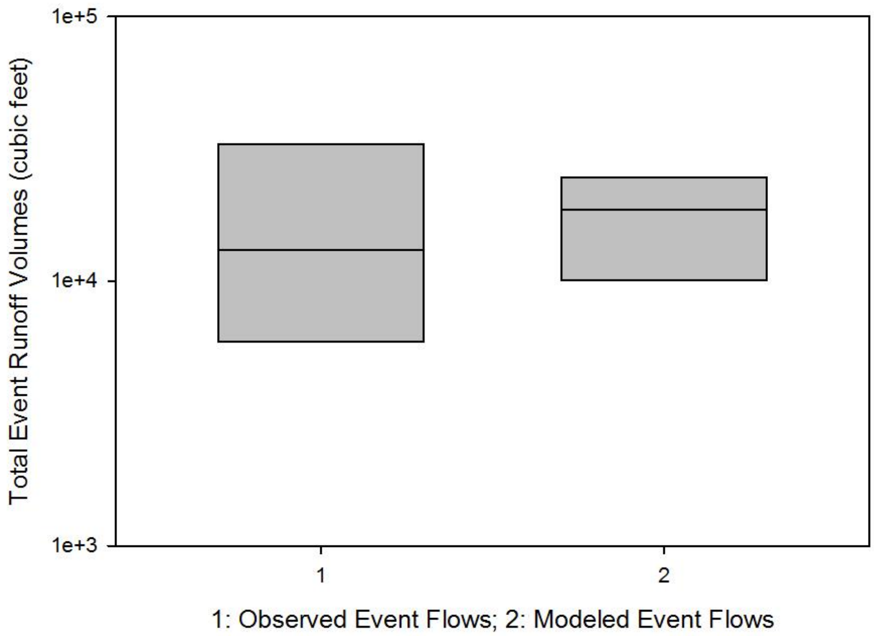


Figure 4.51. Variabilities of runoff volumes observed and modeled.

The Mann-Whitney Rank Sum Test (using SigmaPlot ver 11) was used to compare the observed with the modeled runoff volumes. The seven pairs of data were not sufficient to detect a significant difference in the two sets of runoff volumes:

Group	N	Missing	Median	25%	75%
Observed flows	7	0	13,056	5,900	33,011
Modeled flows	7	0	18,662	10,035	24,597

Mann-Whitney U Statistic= 23.000

T = 51.000; n (small) = 7; n (big) = 7; P (est.) = 0.898; P (exact) = 0.90

The difference in the median values between the two groups is not great enough to exclude the possibility that the difference is because of random sampling variability; there is not a statistically significant difference (p = 0.90).

4.3.1.8 Variability and Uncertainty with WinSLAMM Modeling

WinSLAMM contains various Monte Carlo components that enable uncertainly to be evaluated during the model runs. These are available for the infiltration rates for the various infiltration and biofiltration devices and for the pollutant concentrations. During field investigations, these model parameters have been recognized as having the greatest variabilities that are not explained by the model. The Monte Carlo elements are described by probability distributions, with average and coefficient of variation values (COV) provided, and assumes log-normal distributions of the actual values. If these uncertainty options are selected, the model randomly selects a value of the parameter from this distribution for each rain event. The long-term simulations therefore result in calculated concentrations and loadings of the constituents and the runoff volumes that vary in a similar manner as observed during monitoring. For the calculations in this dissertation research, when different options are being directly compared, the

Monte Carlo option was not used because that could affect the average ordering of the different options. However, several different scenarios were repeatedly analyzed and the different concentrations and loads were examined to estimate the likely variability in the relative model outcomes. The absolute errors are described above with the calibration and verification discussions. As noted, the flow calculations might have a low to moderate bias by underreporting the expected runoff quantities.

Table 4.48 summarizes these Monte Carlo results by showing the groups of constituents associated with different ranges of variability and uncertainty. As an example, when calibrated, WinSLAMM is able to predict the runoff volumes and particulate solids loads more accurately than the other constituents. With COV values (the relative standard deviations compared to the average values) of about 5% of the average values, the 95% confidence range of these constituents would be within about 10% of the average (for normal distributions, about 95% of the data are obtained within ±2 times the standard deviation values). However, for zinc concentrations, the 95% confidence interval is about ±20 to 30% of the average values. The bacteria data has an even wider range for the confidence interval, as expected (±60 to 70% for Escherichia coli and even wider for fecal coliforms). The relative runoff volume (the primary stormwater characteristic of interest in the Kansas City project) and TSS mass load reduction predictions for the alternative stormwater control programs are expected to be more precise.

Table 4.48. Expected modeling variability

COV (standard deviation as a percentage of average concentration)	
< 10%	runoff volume Rv total and filterable total Kjeldahl nitrogen (TKN) TSS total and filterable copper total and filterable lead nitrates
10 to 15%	total and filterable zinc total and filterable chemical oxygen demand (COD) TDS
30 to 35%	*E. coli* bacteria total and filterable phosphorus
65%	fecal coliform bacteria

4.3.2 Large-Scale Performance Evaluation of Integrated GI Stormwater Controls at Cincinnati, Ohio.

Direct measurements of flows by the in-system flow monitors in the combined or separate sewers on or adjacent to several of green infrastructure facilities at Cincinnati test areas were used to directly measure system performance.

Real time rainfall and runoff data from combined and separate sewer systems that are affected by GI stormwater controls in upstream areas were analyzed before, during, and after the construction of the stormwater controls. Then, runoff characteristics of pre- and post-construction conditions were compared to measure the benefits of integrated GI stormwater controls at large scales. The hypothesis is that the flows being discharged from the study areas are much less than would occur if the GI stormwater controls were not present.

4.3.2.1 Cincinnati State College Combined Sewer Flow Analyses (above and below site monitoring)

Due to questionable flows (upstream flows generally larger than downstream flows for example) during the early monitoring period for Cincinnati State College combined sewer lines (manhole 29612050 at upstream, and manhole 29612032 at downstream), the flow and hydrological analyses have only been conducted for the period from the beginning of August, 2012, through December, 2012 (the after construction period). During this period of time, about 21 rain events have increasing flows downstream and are therefore suitable for the statistical and hydrological analyses. Tables 4.49 and 4.50 summarize flow and runoff characteristics for Cincinnati State College combined sewer lines at downstream and upstream locations. The detailed tables are attached in Appendix J, including rainfall and runoff characteristics for about 21events. Figures 4.52 and 4.53 summarize the total discharge depth versus the rain depth for 21 "after construction" events for upstream and downstream locations at Cincinnati State College.

Table 4.49. Rainfall characteristics for downstream and upstream flow monitoring locations at Cincinnati State College combined sewer system (Manholes 29612032, and 29612050)

	Antecedent dry days	**Rain duration (hrs)**	**Total rain (in)**	**5-minute peak rain intensity (in/hr)**	**Avg. rain int. (in/hr)**
number	21	21	21	21	21
average	5.02	7.81	0.43	0.63	0.12
median	4.41	4.75	0.32	0.48	0.07
st dev	3.51	9.27	0.38	0.65	0.13
COV	0.70	1.19	0.88	1.02	1.13
min	0.54	0.08	0.01	0.05	0.01
max	14.38	40.92	1.38	2.64	0.48

Note: Data for September, 2012 are not included

Table 4.50. Runoff characteristics for downstream and upstream flow monitoring locations at Cincinnati State College combined sewer system

	Pipe flow duration (hrs)	**Total pipe flow discharge volume (ft^3)**	**Total discharge (in)**	**Peak pipe flow discharge rate (cfs)**	**Avg. pipe flow discharge rate (cfs)**	**Peak/avg. pipe flow rate ratio**	**R_v**	**Pipe flow/rain duration ratio**
Manhole 29612032 at downstream location								
number	21	21	21	21	21	21	21	21
average	19.9	126,660	0.10	9.16	1.51	5.23	0.19	5.32
median	11.8	56,994	0.04	4.97	1.47	3.30	0.16	2.81
st dev	19.6	164,353	0.13	15.01	0.48	5.92	0.11	7.78
COV	0.98	1.30	1.30	1.64	0.32	1.13	0.58	1.46
min	1.4	0.00	0.00	2.64	0.79	2.25	0.05	0.72
max	64.2	587,551	0.45	71.21	2.54	29.30	0.45	34.00
Manhole 29612050 at upstream location								
number	21	21	21	21	21	21	21	21
average	14.9	36,948	0.03	3.70	0.69	5.01	0.06	4.50
median	8.4	19,238	0.02	2.80	0.66	4.06	0.06	1.94
st dev	14.7	41,628	0.03	3.92	0.38	2.93	0.03	7.93
COV	0.99	1.13	1.13	1.06	0.55	0.58	0.56	1.76
min	1.0	0.00	0.00	0.43	0.17	2.08	0.01	0.38
max	47.8	143,887	0.12	18.70	1.49	13.75	0.14	34.00

Note: Data for September, 2012 are not included

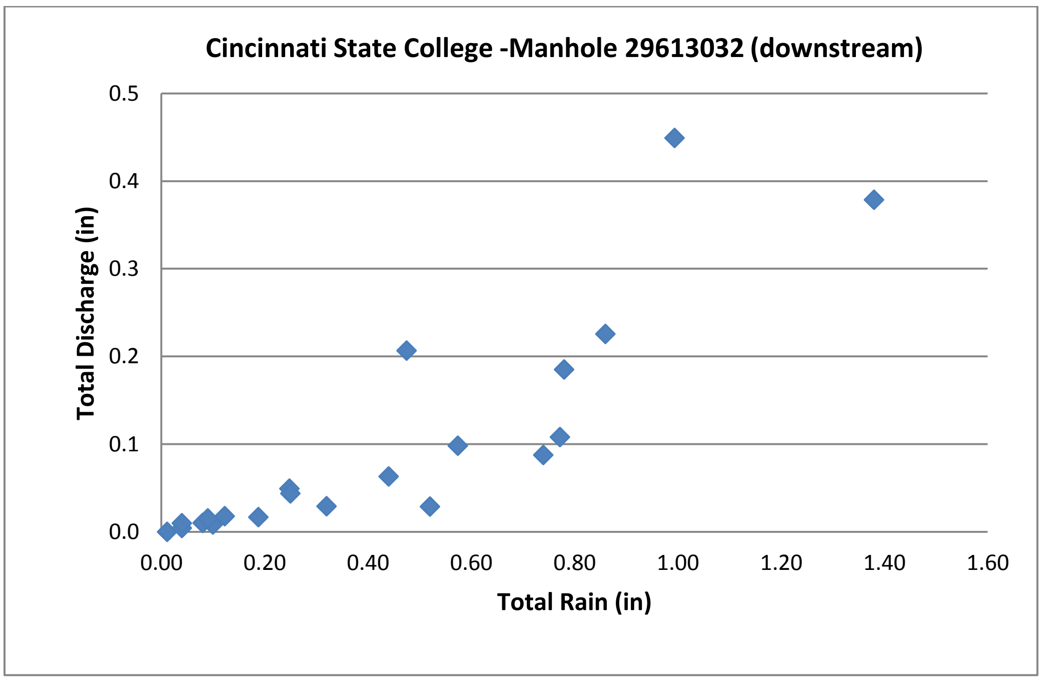


Figure 4.52. Runoff depth vs. rain depth at Cincinnati State College – Manhole 29613021 (downstream) (Note: Data for September, 2012 are not included)

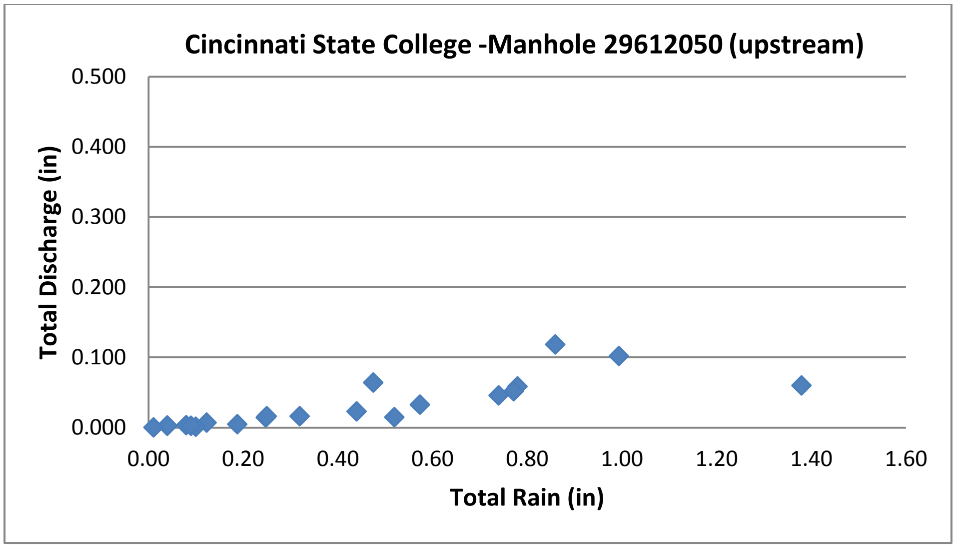


Figure 4.53. Runoff depth vs. rain depth at Cincinnati State College – Manhole 29612050 (upstream) (Note: Data for September, 2012 are not included)

Figure 4.54 is a box and whisker plot that shows the R_v values (ratio of runoff depth to rain depth) for upstream and downstream flows, showing that the downstream unit area runoff depths were much larger than the upstream runoff depths. Considering that the drainage area above the upstream location is more than 90% of the drainage area above the downstream location, and the area between upstream and downstream is served by several green infrastructures, the recorded flows are questionable. In addition, Mann-Whitney test result indicates that the upstream runoff depths are significantly different from the downstream runoff depths (p-value < 0.05).

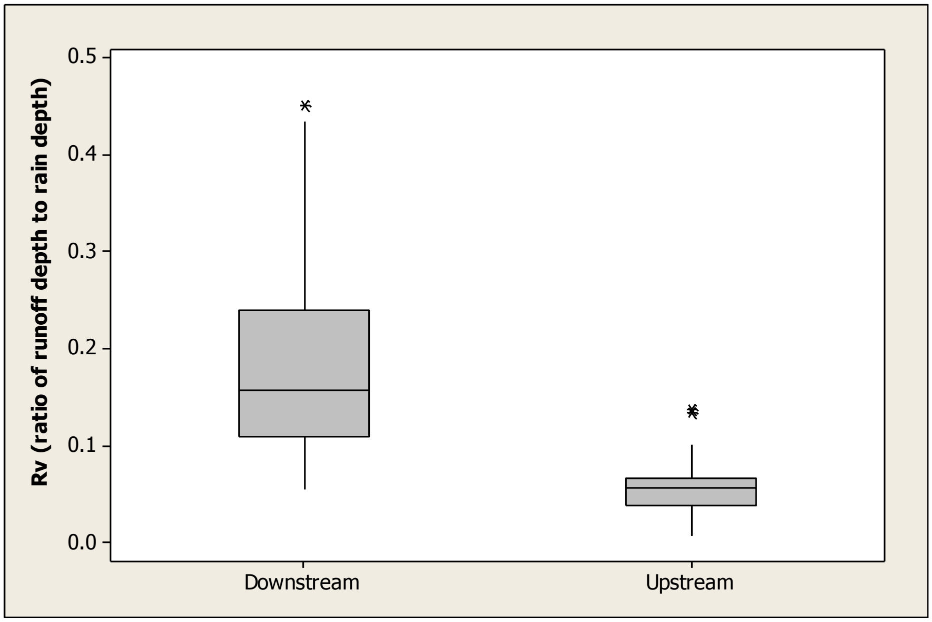


Figure 4.54. Box and whisker plot of R_v for upstream and downstream locations at Cincinnati State College. (Note: Data for September, 2012 are not included)

Mann-Whitney Test and CI: Downstream, Upstream

	N	Median
Downstream	20	0.15678
Upstream	20	0.05644

Point estimate for ETA1-ETA2 is 0.10307

95.0 Percent CI for ETA1-ETA2 is (0.06569, 0.14577)

W = 584.0

Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.0000

Therefore, further analyses at this drainage area was not deemed worthwhile as the flow data cannot resolve the effects of the relatively small portion of the watershed affected by the control practices compared to the very large up-gradient watershed area that is also being monitored at the flow monitoring locations. Basically, subtracting two very large numbers having substantial variability (and uncertainty) does not result in confident results of the difference. These data were evaluated many ways to reduce the variability in the larger flows, but the results were still not clear. The desired outcome would be to show that there were significant differences between the upstream and downstream flow results. Unfortunately, in most cases, the downstream flow values were much smaller than the upstream flow values, an impossible outcome for the drainage system (as illustrated in Figure 4.54). It is thought that the flow monitoring at one or both of the locations was hindered by poor flow conditions, or faulty sensors (especially considering that the flow depths were very low, a challenging situation).

4.3.2.2 Cincinnati State College Separate Storm Sewer Analyses (single monitoring location)

This portion of the Cincy State study area includes a single separate stormwater drainage system that serves a portion of the hilltop campus, having a small impervious area (access roads and roofs) along with a large turf grass hillside). A number of controls are located in the flow path above the single flow monitoring location that is located before this separate stormwater drainage enters the larger combined sewer.

Tables 4.51 and 4.52 summarize the rainfall and runoff characteristics for this Cincinnati State College separate storm sewer line (manhole number 29606027). The detailed tables are attached in Appendix J, including rainfall and runoff characteristics for about 169 events. Tables 4.51, and 4.52 contain the observed values and the calculated rain and flow parameters based on the observed data. The raw flow data represent both the dry and wet weather flows together in the monitored combined sewers. These data are also being used in the model calibration efforts.

Tables 4.51 and 4.52 are divided into three sections: before construction, during construction, and after construction. Table 4.51 describes the rain conditions, while Table 4.52 describes the observed runoff conditions for each of the three mentioned periods.

Figure 4.55 is a box and whisker plot that shows the observed R_v values (ratio of runoff depth to rain depth) for before, during, and after construction periods for the Cincinnati State

College separate sewer system (manhole number 29606027). The Kruskal-Wallis One Way Analysis of Variance on Ranks test was used to indicate if any significant differences between these categories occurred. This test indicated that at least one category was significantly different from the others ($p < 0.001$).

Table 4.51. Rainfall characteristics during different flow monitoring periods for Cincinnati State College separate sewer system (manhole number 29606027)

	Antecedent dry days	**Rain duration (hrs)**	**Total rain (in)**	**5-minute peak rain intensity (in/hr)**	**Avg. rain int. (in/hr)**
Before Construction					
number	41	41	41	41	41
average	6.43	3.96	0.62	1.48	0.33
median	3.61	2.50	0.40	0.96	0.16
st dev	7.28	4.35	0.64	1.12	0.47
COV	1.13	1.10	1.03	0.76	1.41
min	0.27	0.08	0.04	0.48	0.02
max	27.52	18.42	2.84	5.78	2.88
During Construction					
number	52	52	52	52	52
average	4.83	6.15	0.92	1.91	0.24
median	2.92	4.75	0.68	1.45	0.17
st dev	6.38	5.96	0.87	2.70	0.24
COV	1.32	0.97	0.95	1.42	1.03
min	0.24	0.50	0.12	0.48	0.02
max	31.89	27.50	5.16	19.76	1.33
After Construction					
number	76	76	76	76	76
average	5.40	6.90	0.70	1.16	0.22
median	4.27	5.25	0.56	0.96	0.10
st dev	4.58	6.97	0.63	1.03	0.33
COV	0.85	1.01	0.89	0.89	1.55
min	0.28	0.25	0.09	0.05	0.01
max	19.91	40.92	3.36	6.27	2.08

Note: Data for August, 2012 and September, 2012 are not included

Table 4.52. Flow characteristics during different flow monitoring periods for Cincinnati State College separate sewer system (manhole number 29606027)

	Pipe flow duration (hrs)	**Total pipe flow discharge volume (ft^3)**	**Total discharge (in)**	**Peak pipe flow discharge rate (cfs)**	**Avg. pipe flow discharge rate (cfs)**	**Peak/avg. pipe flow rate ratio**	**R_v**	**Pipe flow/rain duration ratio**
Before Construction								
number	41	41	41	41	41	41	41	41
average	7.42	7,497	0.15	1.88	0.28	10.19	0.23	6.21
median	5.92	3,973	0.08	1.70	0.20	7.36	0.23	2.22
st dev	5.47	9,274	0.18	1.19	0.26	6.70	0.10	9.93
COV	0.74	1.24	1.24	0.63	0.95	0.66	0.43	1.60
min	0.75	824	0.02	0.54	0.03	1.72	0.04	0.15
max	24.75	42,160	0.82	6.12	1.20	26.33	0.47	41.00
During Construction								
number	52	52	52	52	52	52	52	52
average	12.88	10,270	0.20	1.68	0.21	10.21	0.22	3.18
median	10.17	6,913	0.13	1.43	0.18	8.40	0.21	2.24
st dev	8.97	11,059	0.21	1.03	0.12	7.38	0.13	2.77
COV	0.70	1.08	1.08	0.61	0.58	0.72	0.60	0.87
min	1.50	211	0.00	0.13	0.02	2.29	0.01	0.58
max	34.08	47,914	0.93	4.93	0.49	39.50	0.73	13.33
After Construction								
number	76	76	76	76	76	76	76	76
average	12.01	1,914	0.04	0.63	0.06	11.78	0.04	2.60
median	7.33	785	0.02	0.48	0.03	9.14	0.03	1.24
st dev	13.14	2,905	0.06	0.71	0.08	10.64	0.04	5.85
COV	1.09	1.52	1.52	1.12	1.33	0.90	0.98	2.25
min	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
max	67.50	14,794	0.29	2.80	0.52	43.00	0.24	44.67

Note: Data for August, 2012 and September, 2012 are not included

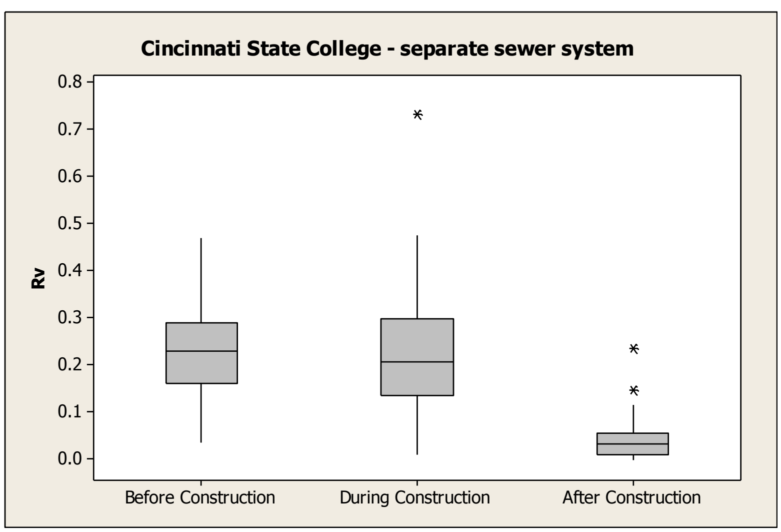


Figure 4.55. R_v values for different study periods for Cincinnati State College separate sewer system (manhole number 29606027) (Note: Data for August, 2012 and September, 2012 are not included)

The Kruskal-Wallis One Way Analysis of Variance on Ranks test was conducted to identify any significant differences between these categories. This test indicated that at least one category was significantly different from the others ($p < 0.001$).

Group	N	Missing	Median	25%	75%
Before Construction	41	0	0.230	0.160	0.290
During Construction	52	0	0.205	0.135	0.297
After Construction	76	0	0.0300	0.0100	0.060

H = 99.041 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001). In this case, it is obvious that the "after" construction period is significantly different from the other two periods. A statistical post-hoc comparison test (Dunn's test) was conducted to verify these groupings.

Comparison	Diff of Ranks	Q	P<0.05
Before vs After Construction	78.663	8.297	Yes
Before vs During Construction	6.431	0.629	No
During vs After Construction	72.232	8.203	Yes

Figure 4.56 is a box and whisker plot that shows the R_v values for before and during construction periods (combined), and the after construction period for the Cincinnati State College separate sewer system (manhole number 29606027). The Mann-Whitney Rank Sum Test was used to statistically identify the differences between these two categories. This test indicated that the R_v values for the after construction period were significantly different from the before plus during construction periods.

Mann-Whitney Rank Sum Test

Group	N	Missing	Median	25%	75%
Before and During Construction	93	0	0.220	0.155	0.295
After Construction	76	0	0.0300	0.01000	0.0600

Mann-Whitney U Statistic= 394.500

T = 3320.500 n(small)= 76 n(big)= 93 (P = <0.001)

The difference in the median values between the two groups was greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

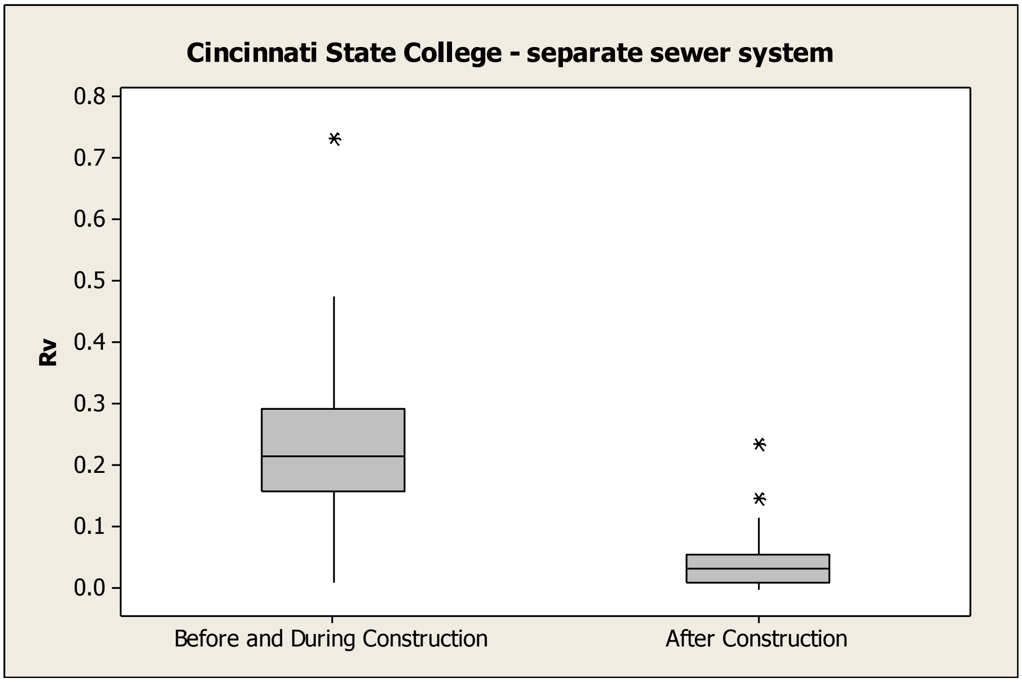


Figure 4.56. R_v values for before and during construction periods (combined) compared to before construction period at Cincinnati State College separate sewer system

At this study area, the statistical tests indicate that the “after” construction flows were much less than the “before” and “during” construction flows. This supports the hypothesis that the flows being discharged from areas with GI stormwater controls are much less than would occur if the GI stormwater controls were not present. Since a monitored area with “no stormwater controls” is not available for this study area, the “before” construction runoff and rainfall data are being used to calibrate WinSLAMM. The calibrated WinSLAMM will be used to model GI stormwater controls in order to predict performance of control options for varying conditions. Then the observed event summary statistics will be compared with the predicted runoff responses from WinSLAMM model to account for varying rain conditions during the different monitoring periods.

4.3.2.3 Cincinnati Zoo Main Entrance Area

The main entrance of the Cincinnati Zoo is about 2.5 ac served by a separate sewer system. More than 60% of the paved area has been replaced by porous paver blocks. There is also a cistern with a capacity of 10,000 gallon to collect runoff from rooftops and reuse it for irrigation of landscaped areas. For the main entrance of the Cincinnati Zoo area, all the available recorded flows belong to the "after construction" period. Tables 4.53 and 4.54 summarize the rainfall and runoff characteristics of about 176 events for the main entrance of the Cincinnati Zoo (The detailed tables are provided in Appendix J). Figure 4.57 shows total discharge depth versus the rain depth for 176 after construction events at the main entrance of the Cincinnati Zoo. The average R_v values for after GI construction was about 0.1 (compared to about 0.8 for conventional pavement in the area)

Table 4.53. Rainfall characteristics for main entrance of the Cincinnati zoo separate sewer line

	Antecedent dry days	**Rain duration (hrs)**	**Total rain (in)**	**5-minute peak rain intensity (in/hr)**	**Avg. rain int. (in/hr)**
number	176	176	176	176	176
average	5.39	7.31	0.67	1.01	0.20
median	3.82	5.04	0.48	0.72	0.10
st dev	5.10	8.62	0.63	0.90	0.29
COV	0.95	1.18	0.95	0.89	1.48
min	0.12	0.08	0.07	0.05	0.01
max	31.45	61.25	3.38	5.90	2.33

Note: Data for August, 2012 and September, 2012 are not included

Table 4.54. Runoff characteristics for main entrance of the Cincinnati zoo separate sewer line

	Pipe flow duration (hrs)	**Total pipe flow discharge volume (ft^3)**	**Total discharge (in)**	**Peak pipe flow discharge rate (cfs)**	**Avg. pipe flow discharge rate (cfs)**	**Peak/avg. pipe flow rate ratio**	**R_v**	**Pipe flow/rain duration ratio**
number	176	176	176	176	176	176	176	176
average	9.09	733	0.08	0.17	0.03	7.18	0.08	1.34
median	5.92	151	0.02	0.04	0.01	5.56	0.04	0.84
st dev	11.02	3,391	0.38	0.77	0.10	6.06	0.20	2.51
COV	1.21	4.63	4.63	4.53	3.92	0.84	2.60	1.86
min	0.00	0.00	0.00	0.00	0.00	0.90	0.00	0.00
max	56.75	43,925	4.92	9.88	1.07	49.55	1.92	25.00

Note: Data for August, 2012 and September, 2012 are not included

At the main entrance area of the Cincinnati zoo, all available monitored flows are for the "after" construction condition. Therefore, WinSLAMM was applied to predict the "before" construction condition. The predicted "no control" flows from WinSLAMM were then statistically compared to the measured flows to compare the "before" and "after" construction conditions to determine the benefits of the porous paved areas and rainwater harvesting system at this study area.

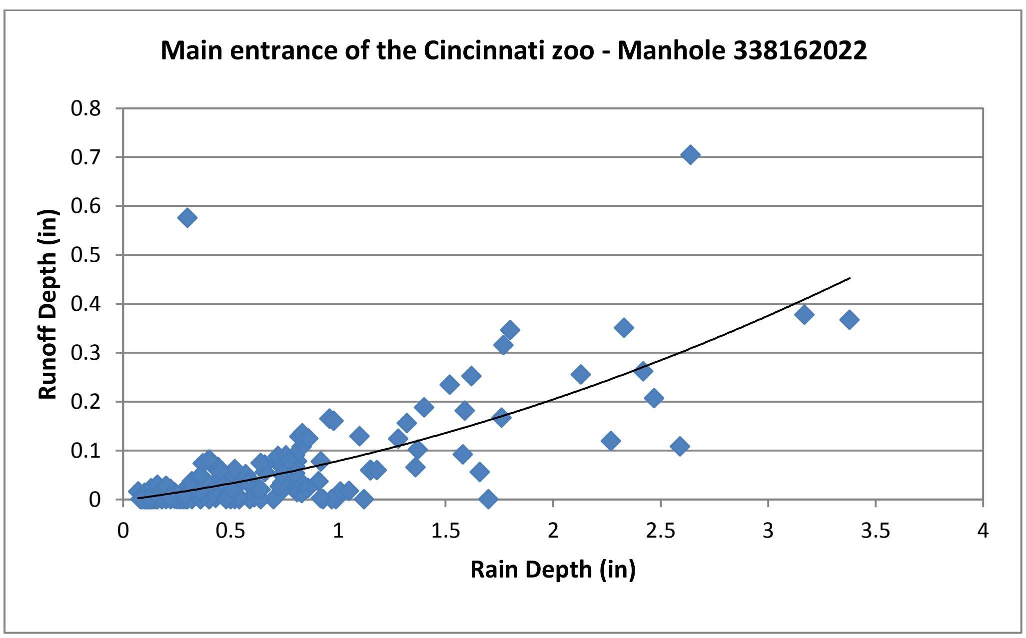


Figure 4.57. Runoff depth versus the rain depth for 176 after construction events at the main entrance of the Cincinnati zoo. (Note: Data for August, 2012 and September, 2012 are not included)

4.3.2.4 Cincinnati Zoo African Savannah Combined Stormwater Monitoring Location

The African Savannah is served by a combined sewer system. This study area has different types of green infrastructure controls, including permeable pavers, and an underground rainwater harvesting storage system. In addition, the African Savannah area will have enhanced turf/vegetation, which is currently under construction. Construction of the African Savannah project started in October, 2011, and the underground storage component was completed in January, 2012. Therefore, the available flow monitoring data are mostly for “before” and “during” construction conditions.

Since the African Savannah area is served by a combined sewer system, the first step in analyzing flow characteristics was to determine the base flow and to separate the dry weather flows from the wet weather flow components. The flow data analyses and statistical tests for this study site were similar to the steps that were described for the Cincinnati State College combined sewer system (above and below site monitoring) under section 4.3.2.1.

Tables 4.55 and 4.56 are summaries of the rainfall and runoff characteristics for the 167 events monitored at the African Savannah portion of the zoo (The detailed tables are provided in Appendix J). 107, 15, and 41 events have been recorded for before construction, during construction, and after construction periods, respectively. Figure 4.58 shows total discharge depths versus the rain depths for different construction periods at the African Savannah area. As shown in Figure 4.58, the slope of the rainfall vs. runoff decreases for after construction period compared to the before construction period.

Figure 4.59 is a box and whisker plot that shows the R_v values for before, during, and after construction periods for the African Savannah combined sewer system. The Kruskal-Wallis One Way Analysis of Variance on Ranks test was used to indicate if any significant differences between these categories occurred. This test indicated that at least one category was significantly different from the others ($p < 0.001$). A statistical post-hoc comparison test (Dunn's test) was conducted to verify these groupings. The results show that the "after construction" period was statistically different from the "before construction" and "during construction" periods.

Table 4.55. Rainfall characteristics for African Savannah combined sewer line

	Antecedent dry days	Rain duration (hrs)	Total rain (in)	5-minute peak rain intensity (in/hr)	Avg. rain int. (in/hr)
Before Construction					
number	107	107	107	107	107
average	5.79	7.67	0.71	1.05	0.19
median	3.58	5.42	0.53	0.72	0.11
st dev	6.48	8.20	0.68	0.90	0.29
COV	1.12	1.07	0.95	0.86	1.50
min	0.21	0.17	0.08	0.12	0.01
max	31.45	44.42	3.38	5.90	2.33
During Construction					
number	15	15	15	15	15
average	4.92	13.69	0.99	0.75	0.08
median	4.44	9.08	0.66	0.48	0.07
st dev	4.17	12.86	0.88	0.71	0.04
COV	0.85	0.94	0.89	0.95	0.53
min	0.24	2.92	0.16	0.24	0.02
max	14.60	50.92	3.17	2.41	0.16
After Construction					
number	41	41	41	41	41
average	5.99	5.30	0.53	1.20	0.25
median	4.43	5.00	0.40	0.96	0.09
st dev	4.72	4.37	0.37	1.00	0.36
COV	0.79	0.82	0.70	0.83	1.47
min	0.27	0.08	0.10	0.05	0.02
max	19.78	17.67	1.52	5.30	1.92

Note: Data for August, 2012 and September, 2012 are not included

Table 4.56. Runoff characteristics for African Savannah combined sewer line

	Pipe flow duration (hrs)	Total pipe flow discharge volume (ft^3)	Total discharge (in)	Peak pipe flow discharge rate (cfs)	Avg. pipe flow discharge rate (cfs)	Peak/avg. pipe flow rate ratio	R_v	Pipe flow/rain duration ratio
Before Construction								
number	107	107	107	107	107	107	107	107
average	12.15	24469.89	0.39	2.85	0.59	7.19	0.45	2.79
median	9.08	12146.20	0.19	2.58	0.42	5.90	0.41	1.53
st dev	12.03	31945.07	0.51	2.10	0.63	5.17	0.27	3.88
COV	0.99	1.31	1.31	0.74	1.06	0.72	0.60	1.39
min	0.58	22.28	0.00	0.03	0.00	0.71	0.00	0.41
max	90.33	157096.58	2.52	12.13	3.59	27.40	1.28	30.33
During Construction								
number	15	15	15	15	15	15	15	15
average	13.61	46776.33	0.75	2.46	0.89	4.30	0.56	0.98
median	10.33	17639.00	0.28	2.54	0.70	3.55	0.52	0.99
st dev	12.84	64334.36	1.03	1.41	0.82	2.38	0.39	0.18
COV	0.94	1.38	1.38	0.57	0.93	0.55	0.70	0.18
min	3.00	2314.09	0.04	0.85	0.11	0.98	0.10	0.71
max	52.17	222056.45	3.56	5.51	2.93	8.49	1.26	1.32
After Construction								
number	41	41	41	41	41	41	41	41
average	7.36	6281.80	0.10	1.41	0.28	6.96	0.16	3.87
median	5.96	3474.53	0.06	1.01	0.14	5.15	0.13	1.38
st dev	5.12	8511.85	0.14	1.26	0.34	5.88	0.14	8.87
COV	0.70	1.36	1.36	0.90	1.22	0.84	0.86	2.29
min	2.17	0.00	0.00	0.06	0.01	1.73	0.00	0.44
max	24.25	36631.59	0.59	4.47	1.51	28.65	0.61	52.00

Note: Data for August, 2012 and September, 2012 are not included

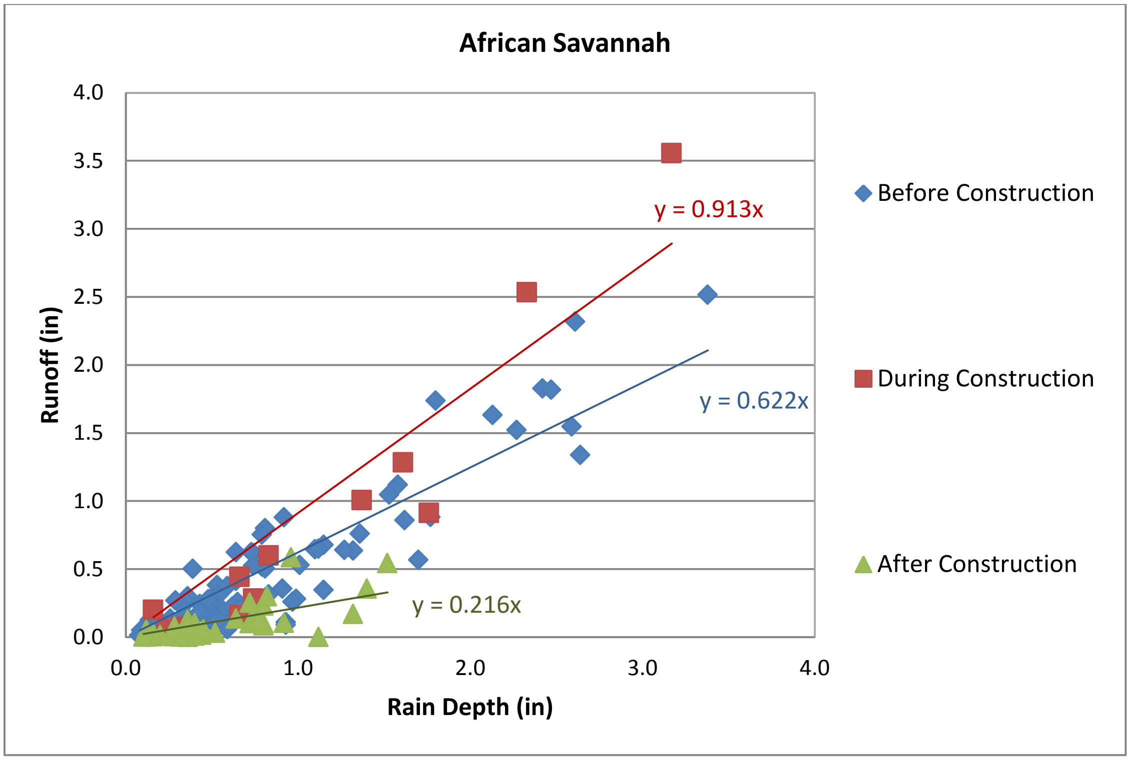


Figure 4.58. Runoff depth versus the rain depth for different study periods at African Savannah.

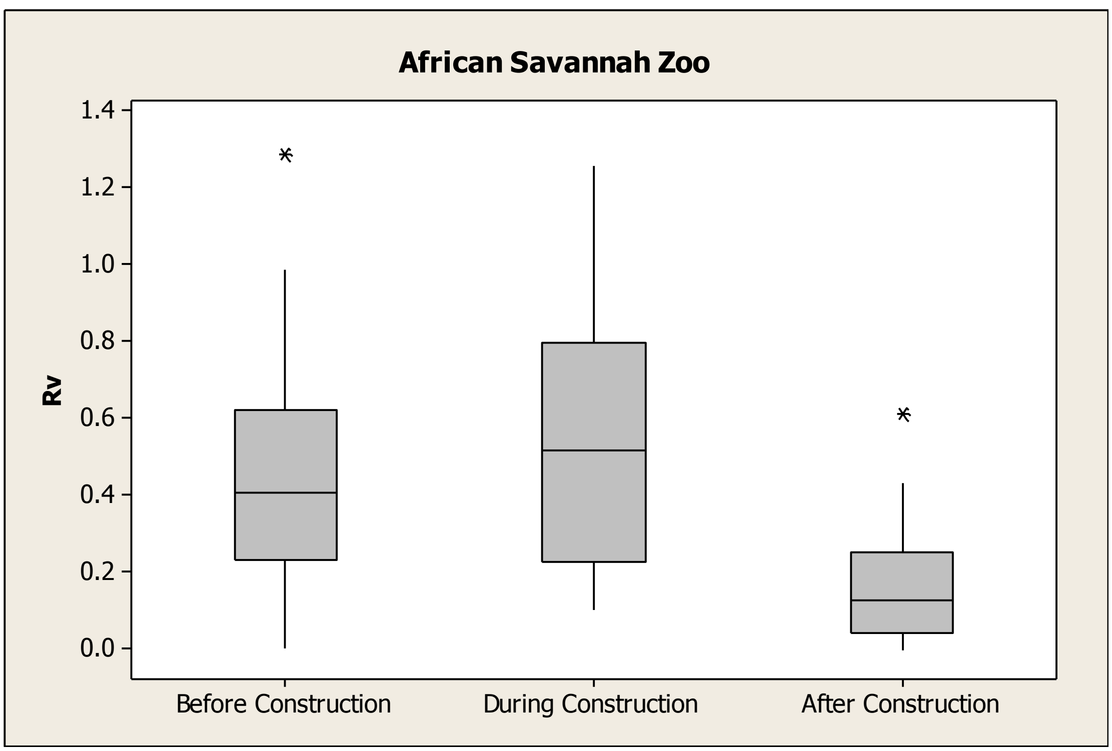


Figure 4.59. R_v values for different study periods at African Savannah.

Group	N	Missing	Median	25%	75%
Before Construction	107	0	0.410	0.232	0.621
During Construction	15	0	0.518	0.228	0.797
After Construction	41	0	0.126	0.0409	0.254

H = 42.053 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

All Pairwise Multiple Comparison Procedures (Dunn's Method):

Comparison	Diff of Ranks	Q	P<0.05
During Construction vs After Construction	61.971	4.351	Yes
During Construction vs Before Construction	7.940	0.610	No
Before Construction vs After Construction	54.031	6.233	Yes

Figure 4.60 is a box and whisker plot that shows the R_v values for before and during construction (combined), and after construction periods. The R_v values for the after construction period were significantly less than the before and during construction periods (combined).

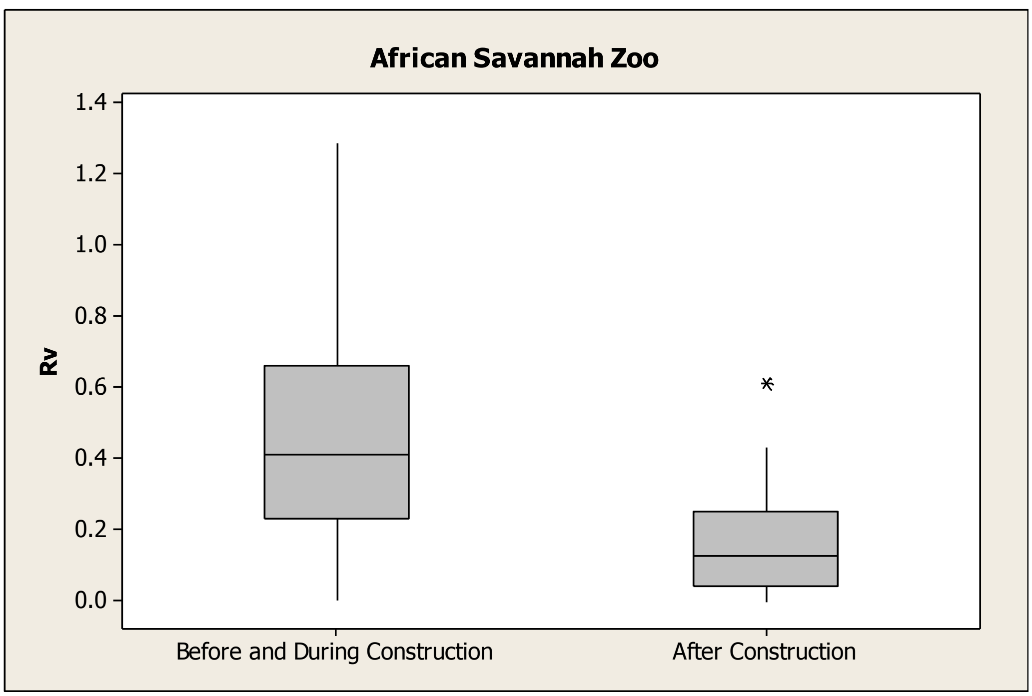


Figure 4.60. R_v values for before and during construction periods (combined) compared to before construction period at African Savannah.

Mann-Whitney Rank Sum Test

Group	N	Missing	Median	25%	75%
Before and During Construction	122	0	0.412	0.230	0.660
After Construction	41	0	0.126	0.0409	0.254

Mann-Whitney U Statistic= 813.000

T = 1674.000 n (small)= 41 n (big) = 122 (P = <0.001)

The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

At the African Savannah study area, the statistical tests indicate that the “after” construction flows were significantly less than the “before” and “during” construction flows. This supports the hypothesis that the flows being discharged from areas with GI stormwater controls are much less than would occur if the GI stormwater controls were not present. The “before” construction runoff and rainfall data were used to calibrate the WinSLAMM model.

4.3.2.5 Clark Montessori High School Combined Stormwater Monitoring Location

The Clark Montessori High School study area has various green stormwater controls including green roofs, permeable pavements, and bioretention facilities. The construction of GI stormwater controls at this site started in April/May of 2011 and ended in April/May 2012. Therefore for this site, flow monitoring data are available for three construction phases including; before, during, and after construction. This presents an opportunity to compare runoff characteristics for all phases.

Since the data were collected from a combined sewer system, the base dry weather flows were subtracted from the recorded wet weather flows to separate the wet weather components to obtain direct runoff data. Summaries of flow and runoff characteristics are shown in Tables 4.57 and 4.58 for the three construction phases, including the recorded values and the calculated rain and flow parameters based on the observed data. These data are also being used in the model calibration efforts. Box and whisker plots of R_v values (ratio of runoff depth to rain depth) for before, during, and after construction periods are shown on Figure 4.61. The Kruskal-Wallis One Way Analysis of Variance on Ranks test were used to determine if there were any statistically significant differences between different construction phases. A post-hoc test was also used to identify which data group(s) were different from the others. Figure 4.62 is a box and whisker plot that shows the R_v values for before and during construction (combined), and after construction periods. The statistical tests showed that the R_v values for the after construction period were significantly different from the before and during construction periods (combined).

The "before" construction rainfall and runoff characteristics were also used to calibrate WinSLAMM. The calibrated model was used to examine GI stormwater controls and to predict performance of control options for varying conditions, especially to account for varying rains during the different monitoring periods. The recorded event characteristics were statistically compared with the expected runoff responses from the WinSLAMM model.

Table 4.57. Rainfall characteristics for Clark Montessori High School combined sewer line

	Antecedent dry days	**Rain duration (hrs)**	**Total rain (in)**	**5-minute peak rain intensity (in/hr)**	**Avg. rain int. (in/hr)**
Before Construction					
number	47	47	47	47	47
average	6.46	7.09	0.59	1.31	0.29
median	3.34	4.17	0.36	0.96	0.08
st dev	9.47	7.19	0.57	1.14	0.68
COV	1.47	1.01	0.97	0.87	2.32
min	0.23	0.08	0.08	0.48	0.01
max	57.04	32.33	2.56	5.78	3.84
During Construction					
number	80	80	80	80	80
average	4.60	7.66	0.79	1.38	0.20
median	3.40	5.17	0.54	0.96	0.12
st dev	4.81	8.63	0.69	1.16	0.25
COV	1.05	1.13	0.87	0.84	1.22

min	0.25	0.08	0.12	0.16	0.01
max	21.34	48.33	3.16	7.23	1.44
After Construction					
number	39	39	39	39	39
average	5.69	5.82	0.52	1.25	0.17
median	3.97	5.17	0.40	0.69	0.08
st dev	5.04	3.99	0.41	1.66	0.32
COV	0.88	0.68	0.78	1.33	1.82
min	0.39	0.33	0.08	0.05	0.01
max	17.94	15.67	1.96	8.19	1.80

Note: Data for August, 2012 and September, 2012 are not included

Table 4.58. Runoff characteristics for Clark Montessori High School combined sewer line

	Pipe flow duration (hrs)	**Total pipe flow discharge volume (ft^3)**	**Total discharge (in)**	**Peak pipe flow discharge rate (cfs)**	**Avg. pipe flow discharge rate (cfs)**	**Peak/avg. pipe flow rate ratio**	**R_v**	**Pipe flow/rain duration ratio**
Before Construction								
number	47	47	47	47	47	47	47	47
average	13.40	10,698	0.20	1.97	0.20	11.86	0.27	5.30
median	10.75	4,058	0.08	1.52	0.15	9.63	0.27	1.99
st dev	9.09	13,827	0.26	1.86	0.20	7.99	0.17	9.68
COV	0.68	1.29	1.29	0.94	0.97	0.67	0.63	1.83
min	1.83	68	0.00	0.03	0.00	2.42	0.01	1.04
max	36.75	48,686	0.91	8.09	0.76	41.21	0.76	55.00
During Construction								
number	80	80	80	80	80	80	80	80
average	13.80	14,512	0.27	2.59	0.31	10.43	0.30	3.63
median	11.79	8,435	0.16	1.84	0.22	7.97	0.29	2.10
st dev	10.48	16,450	0.31	2.25	0.31	7.68	0.13	7.35
COV	0.76	1.13	1.13	0.87	1.01	0.74	0.42	2.03
min	1.67	252	0.00	0.08	0.01	0.38	0.03	1.06
max	56.33	97,119	1.81	9.06	2.50	39.80	0.70	65.00
After Construction								
number	39	39	39	39	39	39	39	39
average	10.08	7,065	0.13	1.49	0.18	8.79	0.23	3.11
median	8.08	4,583	0.09	1.06	0.15	8.77	0.23	1.62
st dev	6.83	7,343	0.14	1.58	0.17	4.35	0.16	4.90
COV	0.68	1.04	1.04	1.06	0.95	0.49	0.71	1.58
min	0.92	32	0.00	0.01	0.00	2.62	0.00	0.22
max	31.83	25,177	0.47	6.68	0.86	20.00	0.62	28.50

Note: Data for August, 2012 and September, 2012 are not included

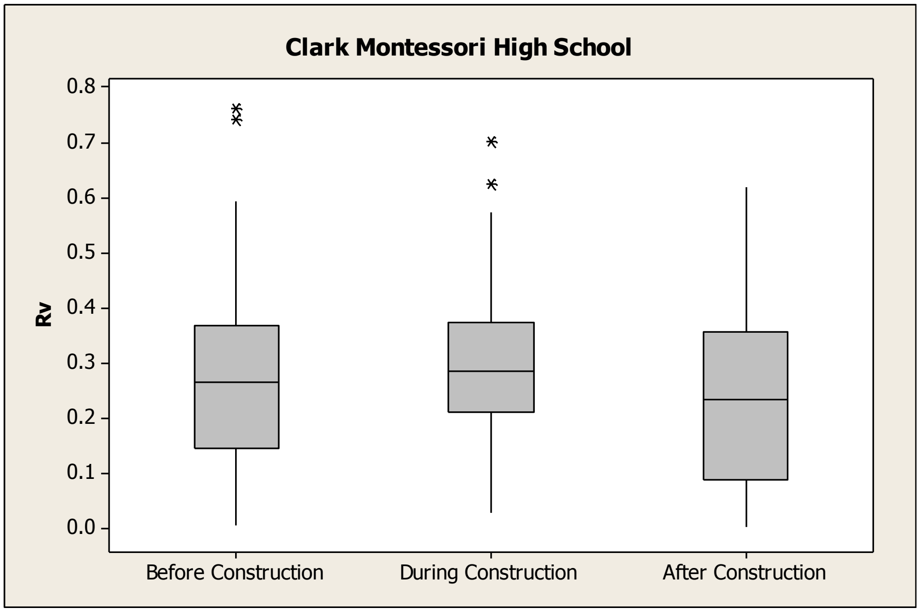


Figure 4.61. R_v values for different study periods at Clark Montessori High School.

Kruskal-Wallis One Way Analysis of Variance on Ranks

Group	N	Missing	Median	25%	75%
Before	47	0	0.270	0.150	0.370
During	80	0	0.285	0.210	0.370
After	39	0	0.230	0.0900	0.360

H = 6.705 with 2 degrees of freedom. (P = 0.035)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.035)

All Pairwise Multiple Comparison Procedures (Dunn's Method):

Comparison	Diff of Ranks	Q	P<0.05
During vs After	23.873	2.543	Yes
During vs Before	11.801	1.336	No
Before vs After	12.072	1.160	No

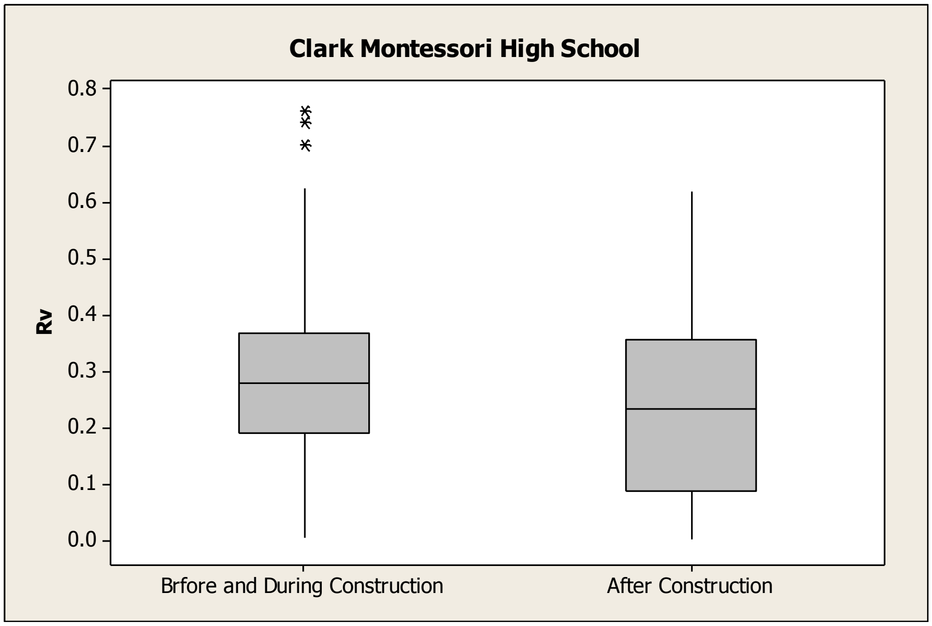


Figure 4.62. R_v values for before and during construction periods (combined) compared to before construction period at Clark Montessori High School.

Kruskal-Wallis One Way Analysis of Variance on Ranks

Group	N	Missing	Median	25%	75%
Before and During	127	0	0.280	0.190	0.370
After	39	0	0.230	0.090	0.360

H = 4.918 with 1 degrees of freedom. (P = 0.027)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.027)

All Pairwise Multiple Comparison Procedures (Dunn's Method) :

Comparison	Diff of Ranks	Q	P<0.05
Before and During vs. After	19.506	2.217	Yes

4.3.2.6 Model Calibration using Site Monitoring Data

Figures 4.63, 4.64, and 6.65 are scatterplots showing the observed versus the modeled total flows for each of the studied areas in Cincinnati. As shown, these are all close to the line of equivalent values.

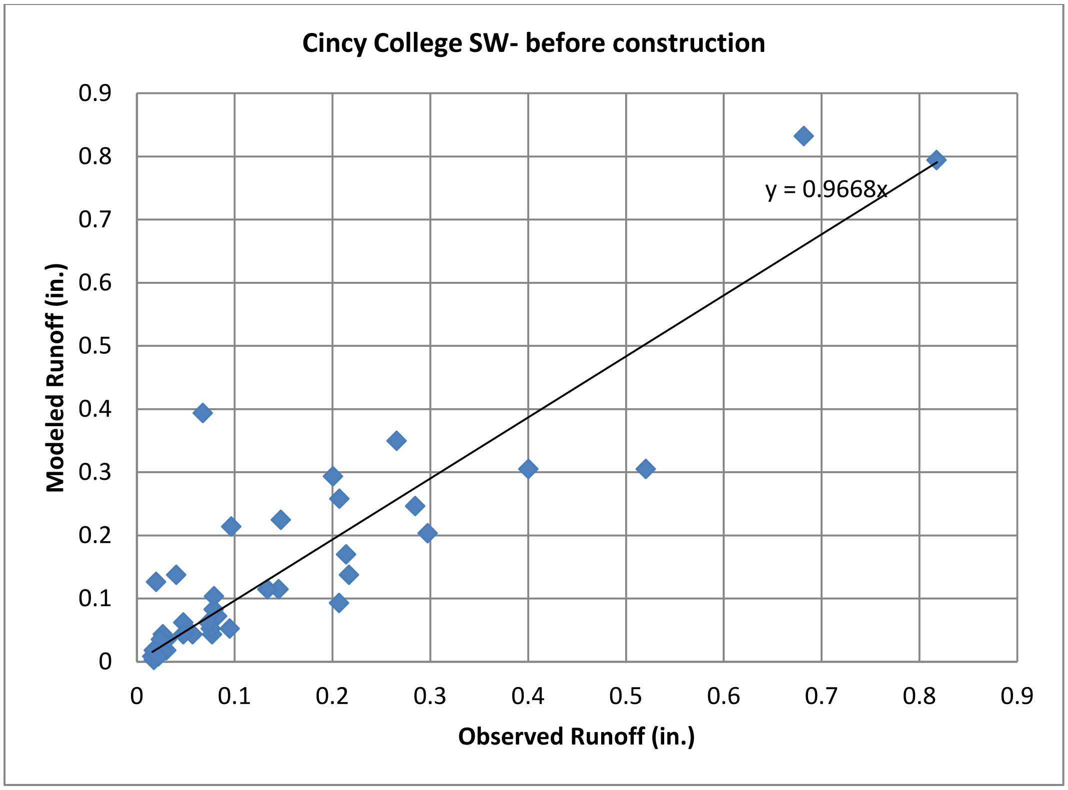


Figure 4.63. Observed versus modeled flows for Cincinnati State College Separate Sewer System

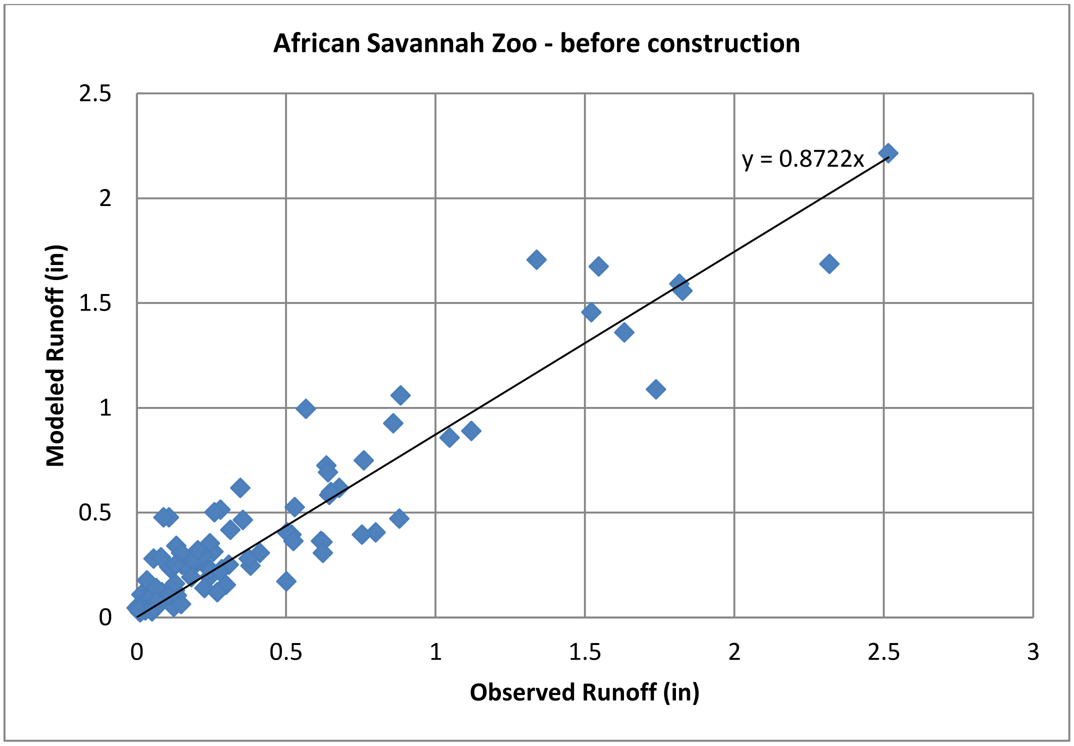


Figure 4.64. Observed versus modeled flows for African Savannah Zoo

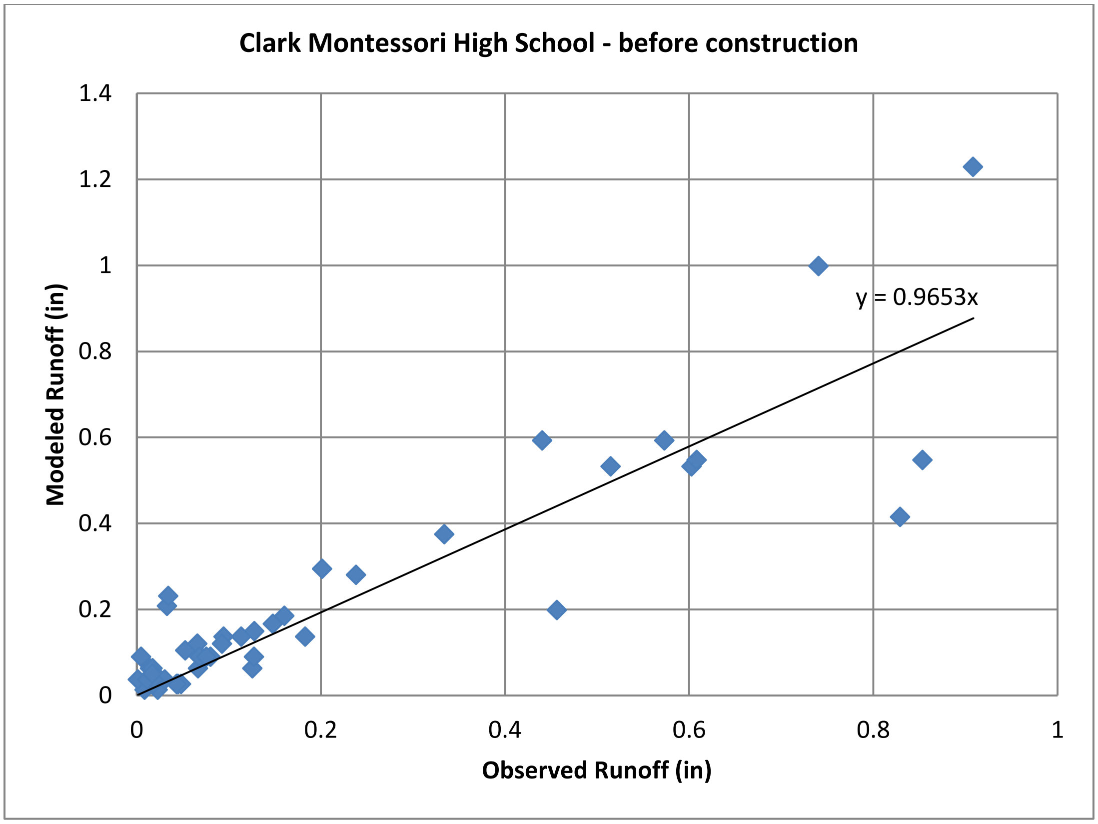


Figure 4.65. Observed versus modeled flows for Clark Montessori High School

Figures 4.66, 4.67, and 4.68 are box plots (using Minitab 16) that compare the single event observed flows to the modeled flows for Cincinnati State College separate sewer system, African Savannah Zoo, and Clark Montessori High School. For all three sites the modeled and observed boxes significantly overlap.

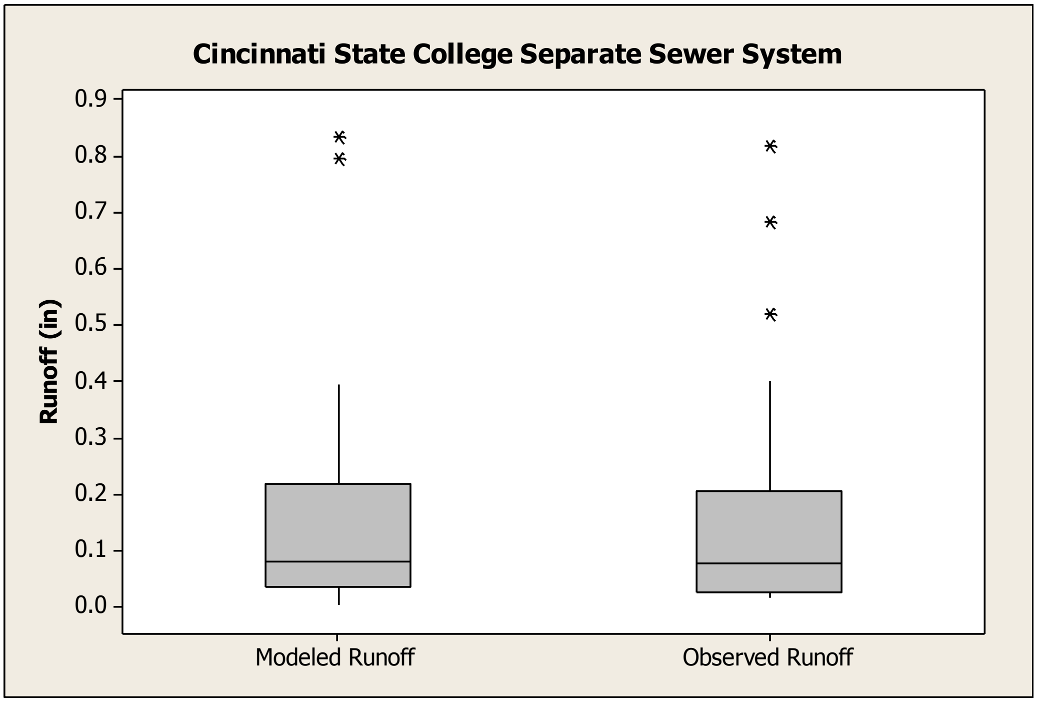


Figure 4.66. Variabilities of runoff volumes observed and modeled at Cincinnati State College Separate Sewer System.

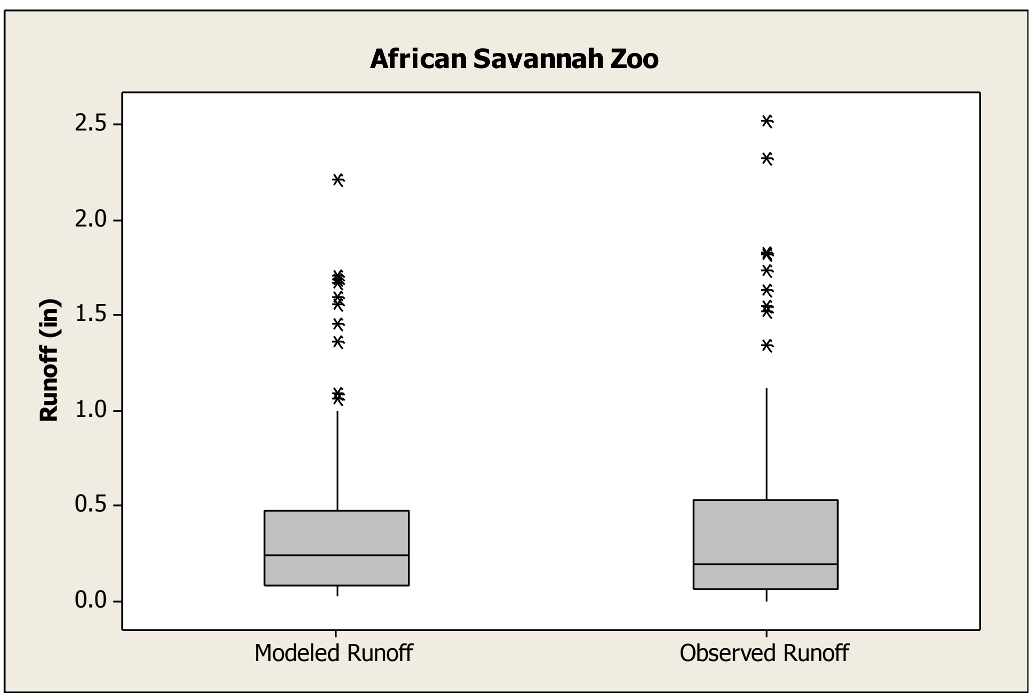


Figure 4.67. Variabilities of runoff volumes observed and modeled at African Savannah Zoo.

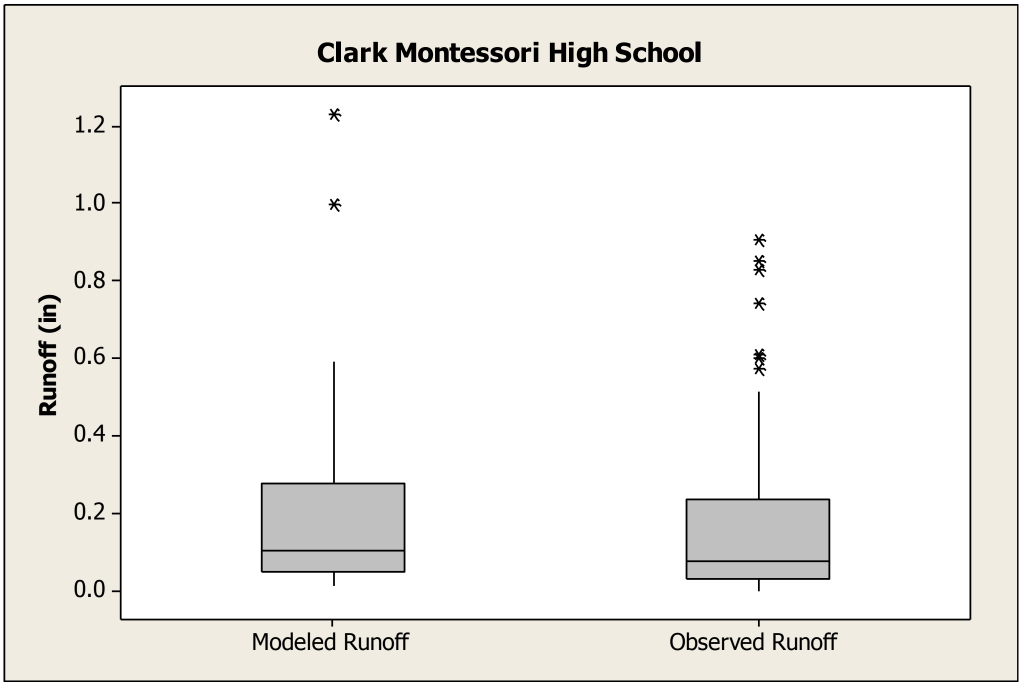


Figure 4.68. Variabilities of runoff volumes observed and modeled at Clark Montessori High School.

The Mann-Whitney Rank Sum Test (using Minitab 16) was used to compare the observed with the modeled runoff volumes for all three study areas.

- Cincinnati State College Separate Sewer System

Group	N	Missing	Median	25%	75%
Modeled flows	41	0	0.0824	0.0346	0.219
Observed flows	41	0	0.0771	0.0266	0.207

Mann-Whitney U Statistic= 839.000

T = 1700.000 n(small)= 41 n(big)= 41 (P = 0.993)

The difference in the median values between the observed and modeled runoff groups at Cincinnati State College (separate sewer system) is not great enough to exclude the possibility that the difference is because of random sampling variability; there is not a statistically significant difference (p = 0.993).

- African Savannah Zoo

Group	N	Missing	Median	25%	75%
Modeled flows	107	0	0.246	0.0858	0.470
Observed flows	107	0	0.195	0.0640	0.529

Mann-Whitney U Statistic= 5301.000

T = 11926.000 n(small)= 107 n(big)= 107 (P = 0.350)

The difference in the median values between the observed and modeled runoff groups at African Savannah Zoo is not great enough to exclude the possibility that the difference is because of random sampling variability; there is not a statistically significant difference (p = 0.350).

- Clark Montessori High School:

Group	N	Missing	Median	25%	75%
Modeled flows	47	0	0.104	0.0500	0.280
Observed flows	47	0	0.0757	0.0305	0.238

Mann-Whitney U Statistic= 965.000

T = 2372.000 n(small)= 47 n(big)= 47 (P = 0.293)

The difference in the median values between the observed and modeled runoff groups at Clark Montessori High School is not great enough to exclude the possibility that the difference is because of random sampling variability; there is not a statistically significant difference (p = 0.293).

4.4. WinSLAMM modeling results

4.4.1 Modeling of Test (Pilot) Watershed Area with Stormwater Controls Compared to Observed Flows at Kansas City

Table 4.59 lists the initial monitored events in 2012 that occurred after the majority of the site construction was completed in the Kansas City project area and includes the observed and calculated runoff for the complete area. The best for the model was related to a native soil infiltration rate of about 1 in/hr below the biofilters, which corresponded to the initial soil infiltration conditions at the site. Lower infiltration rates, such as used by the design consultants, significantly decreased the calculated discharges, resulting in poor agreement between the monitored and calculated values.

Table 4.59. Events after construction of stormwater controls in pilot watershed

Rain start date	Rain start time	Rain end date	Rain end time	Total rain (in)	Observed total pipe flow discharge volume (ft^3)	Modeled with controls (1 in/hr)
4/4/2012	8:45:00 PM	4/5/2012	9:10:00 AM	0.18	1,818	3,204
4/12/2012	3:20:00 PM	4/13/2012	4:15:00 AM	0.12	2,546	2,034
4/27/2012	8:40:00 PM	4/28/2012	8:40:00 AM	0.12	1,249	2,034
4/28/2012	10:45:00 PM	4/30/2012	7:50:00 AM	0.75	20,505	21,820
5/1/2012	1:40:00 AM	5/1/2012	10:30:00 PM	0.43	6,626	10,260
5/6/2012	10:05:00 AM	5/7/2012	8:55:00 PM	1.85	34,962	95,046
5/24/2012	8:35:00 PM	5/25/2012	8:10:00 PM	0.40	43,119	9,283
6/11/2012	2:50:00 AM	6/11/2012	7:35:00 PM	1.22	15,514	44,473
6/21/2012	1:20:00 AM	6/21/2012	9:00:00 PM	0.91	30,410	27,777

Figure 4.69 compares the predicted with the observed total runoff volumes for the complete test (pilot) watershed for the first nine events after biofilter construction. Figure 4.70 shows a box plot of observed vs. modeled flows for the pilot watershed for the after construction

duration. The additional monitoring at the large scale enabled more precise fits of the data and confirms the expected performance of the stormwater controls.

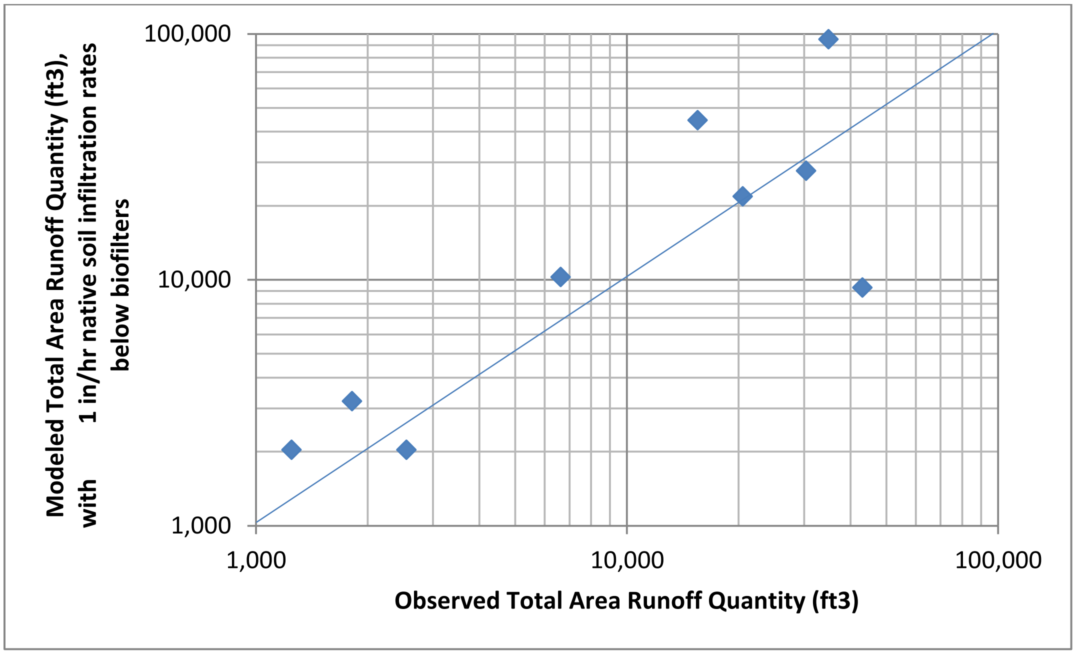


Figure 4.69. Observed and calculated flows for Kansas City, after biofilter construction.

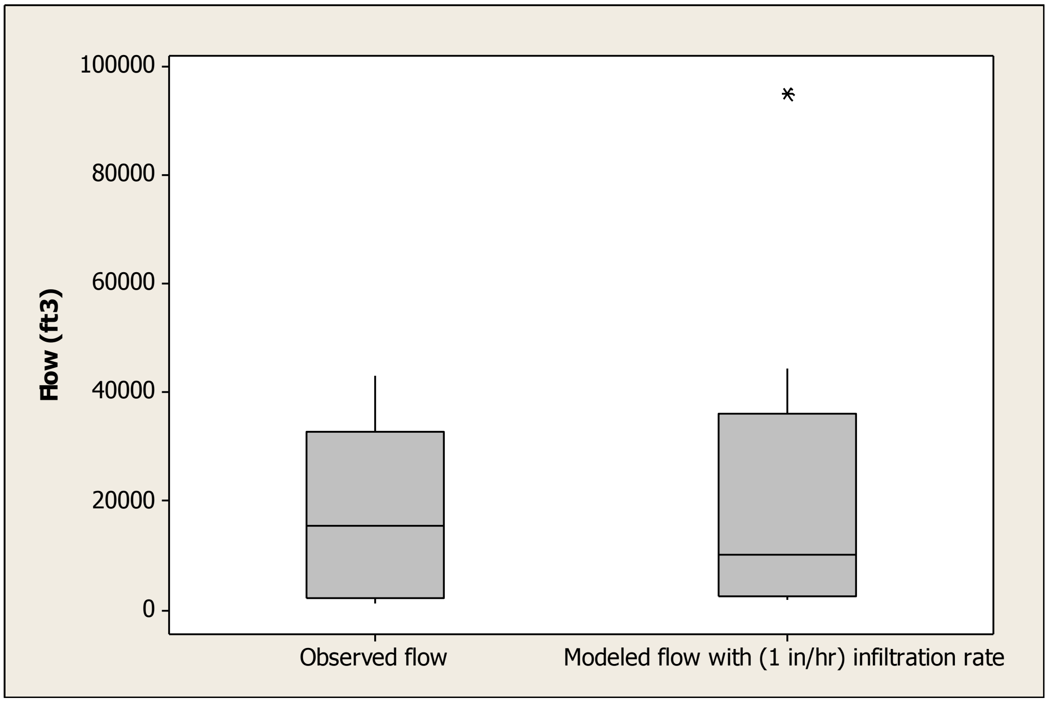
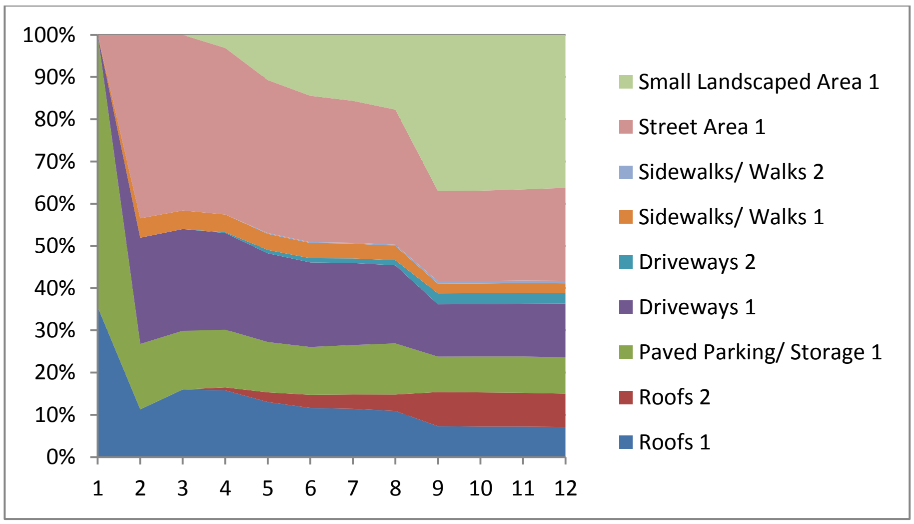


Figure 4.70. Box plot of observed and calculated flows for Kansas City, after biofilter construction.

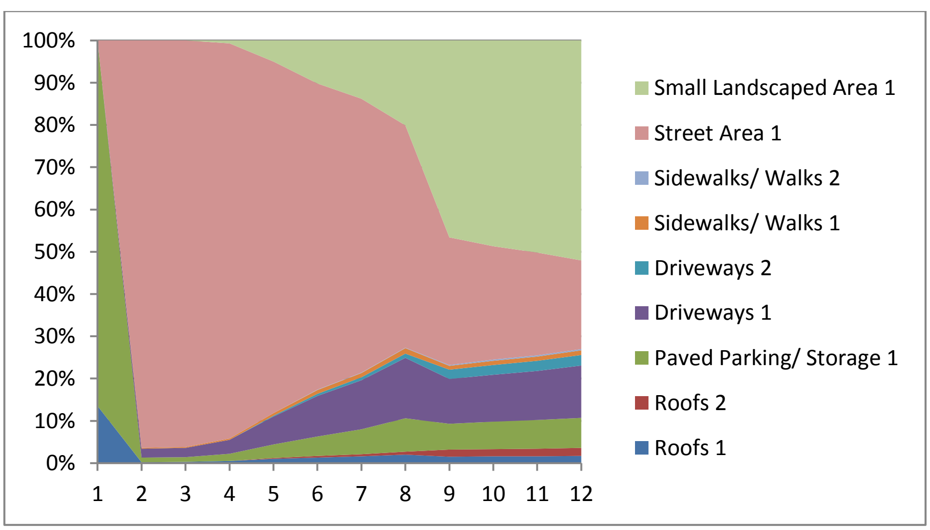
4.4.1.1 Sources of Flows and Particulates in Untreated Watershed

Before a stormwater management plan is selected for an area, knowing the sources of the flows and pollutants of concern is very helpful. One of the main features of WinSLAMM is its ability to calculate these source contributions for varying rain conditions. The plots shown in Figures 4.71.a and 4.71.b illustrate these source contributions for the test (pilot) area without (before) stormwater controls, for rains ranging from 0.01 to 4 in.



Event number on graphs	Rain depth (in)
1	0.01
2	0.05
3	0.10
4	0.25
5	0.50
6	0.75
7	1.00
8	1.50
9	2.00
10	2.50
11	3.00

Figure 4.71.a Sources of runoff volume during different rain events (no control practices).



Event number on graphs	Rain depth (in)
1	0.01
2	0.05
3	0.10
4	0.25
5	0.50
6	0.75
7	1.00
8	1.50
9	2.00
10	2.50
11	3.00
12	4.00

Figure 4.71.b Sources of particulate solids during different rain events (no control practices).

Table 4.60 summarizes the major flow and particulate flows for 0.5, 1.0, and 3.0 in rains. As expected, the directly connected impervious areas are responsible for most of these contributions, but landscaped areas become important flow and particulate solids contributions for the largest rains expected in Kansas City.

Table 4.60. Major source areas contributing runoff and particulate solids

Rain depth (in)	**Runoff volume**	**Particulate solids**
0.5	Street areas (36%) Driveways, directly connected (21%) Paved parking areas, directly connected (12%) Small landscaped areas (11%)	Street areas (83%)
1.0	Street areas (32%) Driveways, directly connected (19%) Small landscaped areas (18%) Paved parking areas, directly connected (12%)	Street areas (53%) Small landscaped areas (20%) Driveways, directly connected (14%)
3.0	Small landscaped areas (37%) Street areas (22%) Driveways, directly connected (13%)	Small landscaped areas (50%) Street areas (24%) Driveways, directly connected (12%)

4.4.2 Modeling of Stormwater Controls at Cincinnati

Figure 4.72 compares the modeled with the measured runoff volumes for the Cincinnati State College site (separate sewer system) for 75 events after GI construction. Figure 4.73 shows the box plot of measured vs. modeled flows for the after construction period. Figure 4.74 shows residual plots for the Cincinnati State College observed vs. calculated flows, while Figures 4.75 to 4.83 show similar graphs for the other study areas examined in Cincinnati, OH.

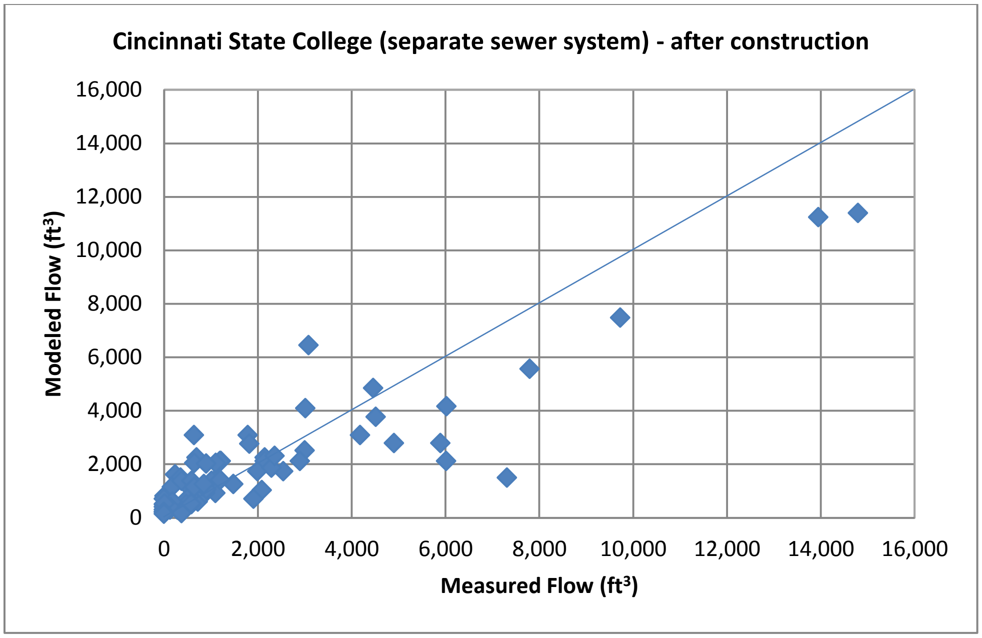


Figure 4.72. Observed and modeled flows for Cincinnati State College, after GI construction.

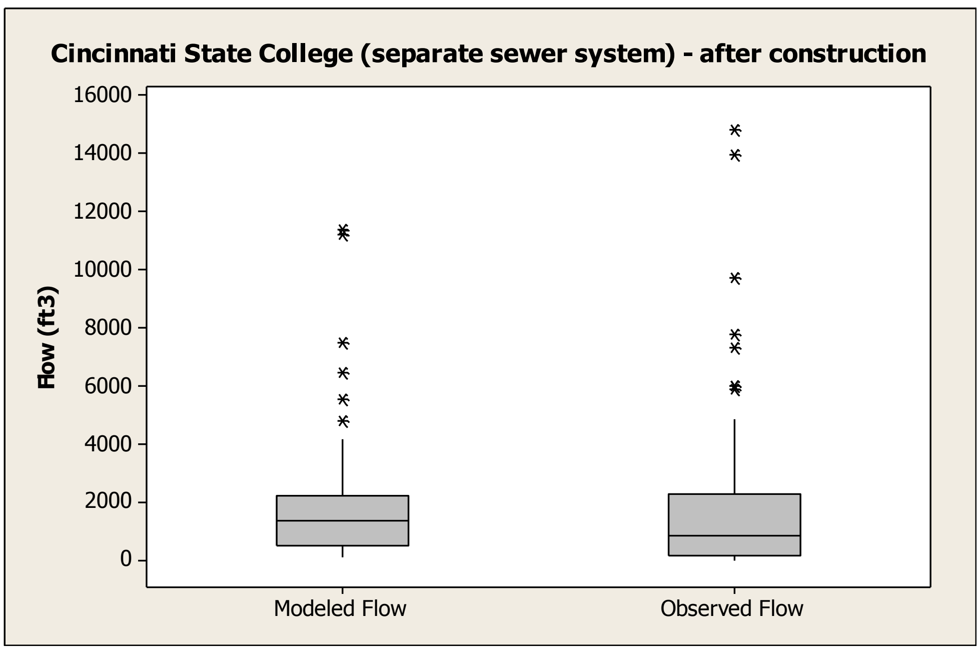


Figure 4.73. Box plot of modeled and observed flows for Cincinnati State College, after GI construction.

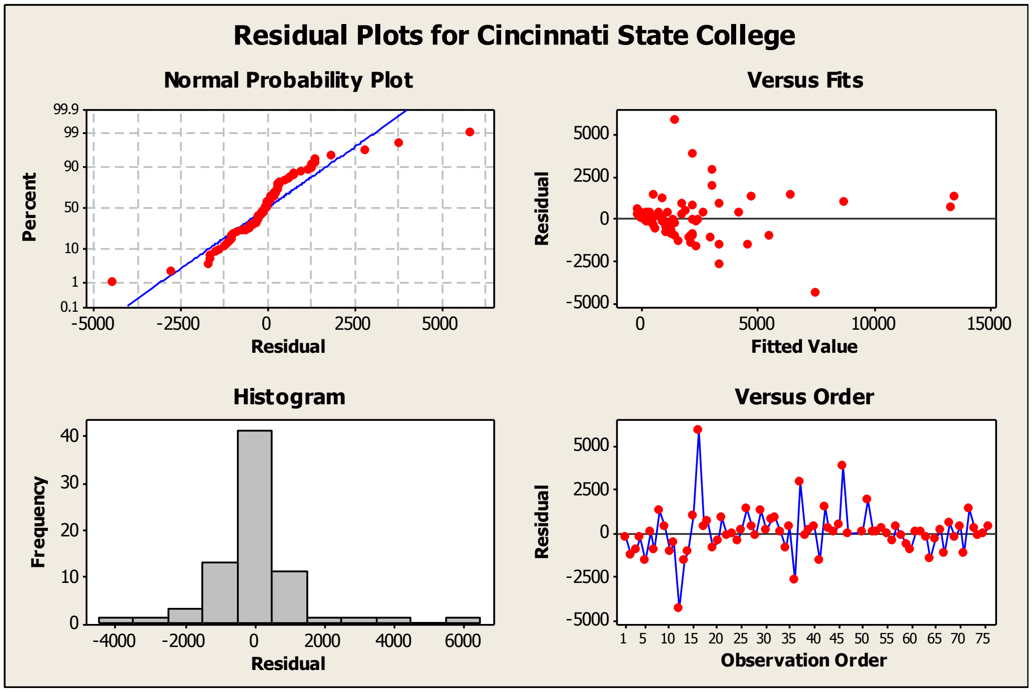


Figure 4.74. Residual plots for Cincinnati State College for observed vs. calculated flows, after GI construction.

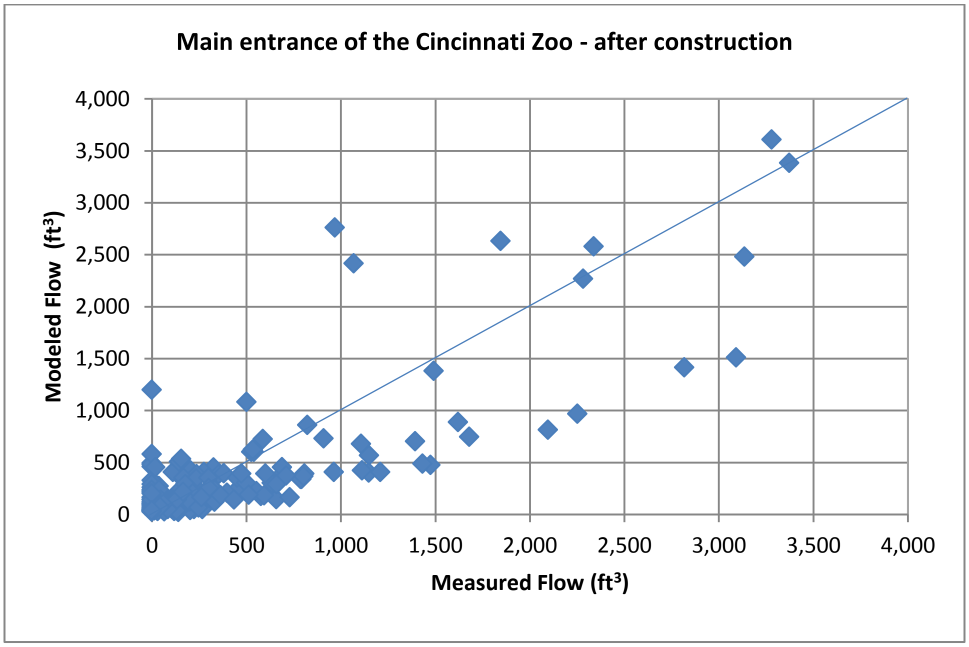


Figure 4.75. Observed and modeled flows for main entrance of the Cincinnati Zoo, after GI construction.

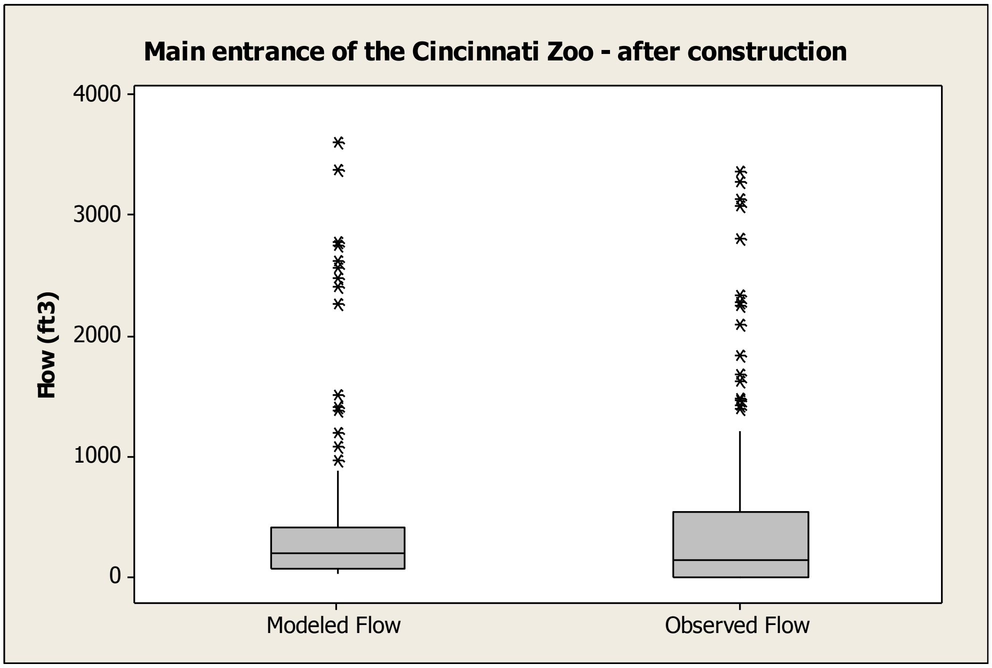


Figure 4.76. Box plot of modeled and observed flows for main entrance of the Cincinnati Zoo, after GI construction.

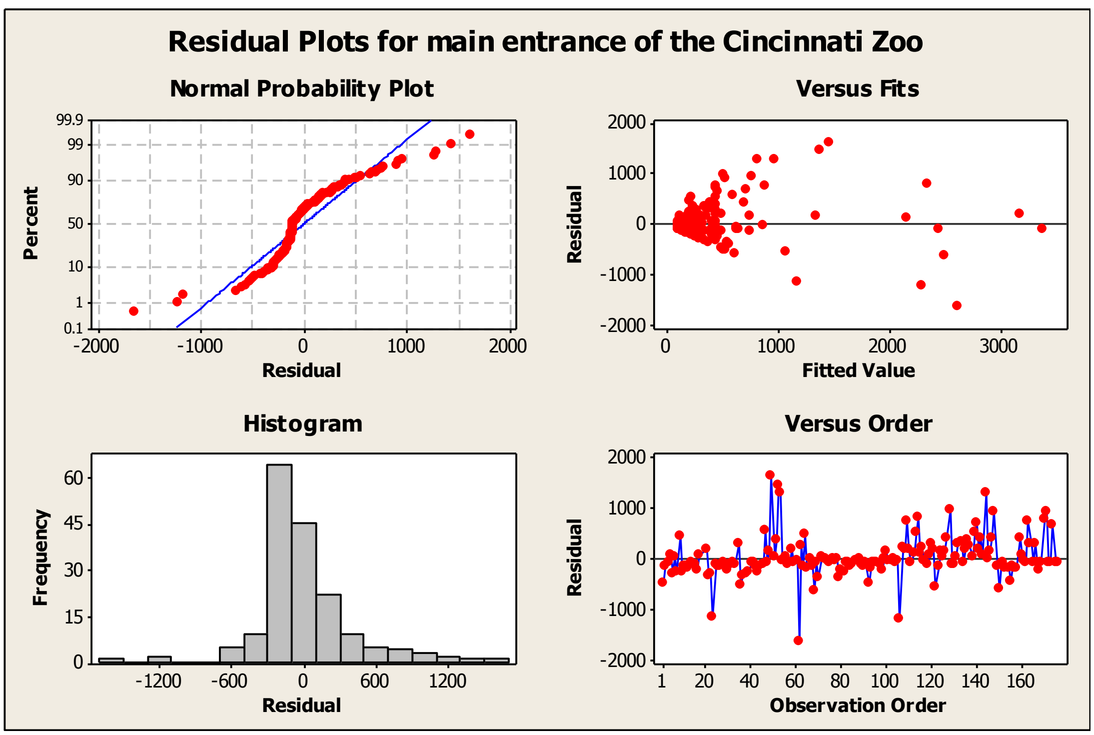


Figure 4.77. Residual plots for main entrance of the Cincinnati Zoo, after GI construction.

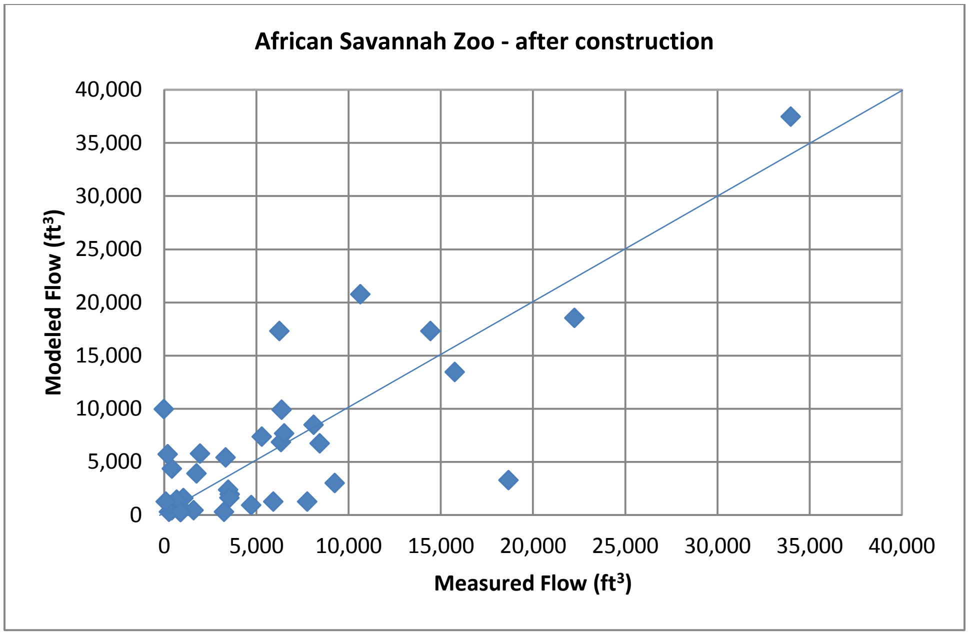


Figure 4.78. Observed and modeled flows for African Savannah Zoo, after GI construction.

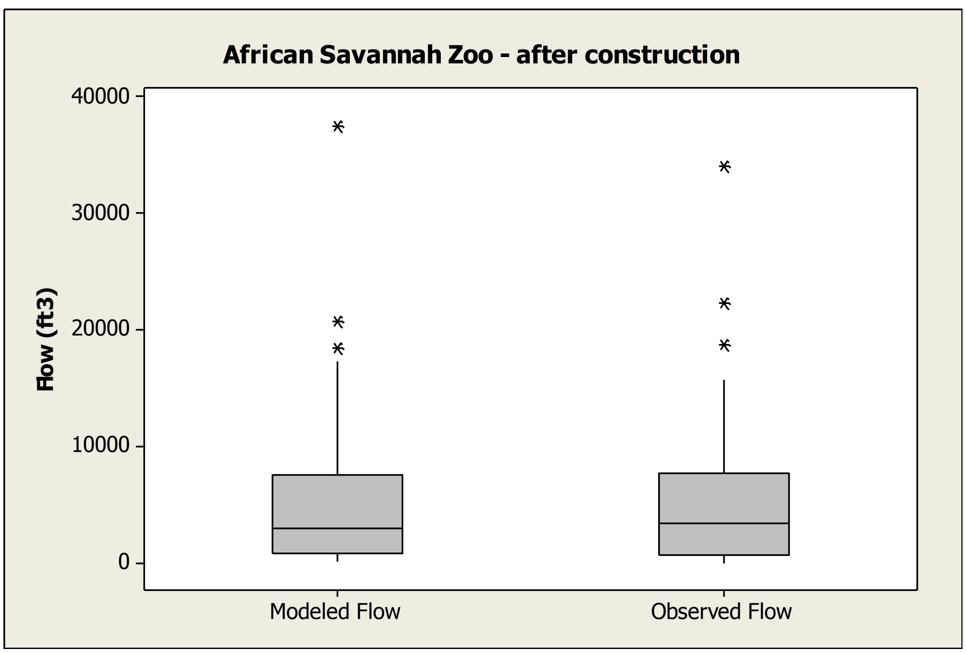


Figure 4.79. Box plot of modeled and observed flows for African Savannah Zoo, after GI construction.

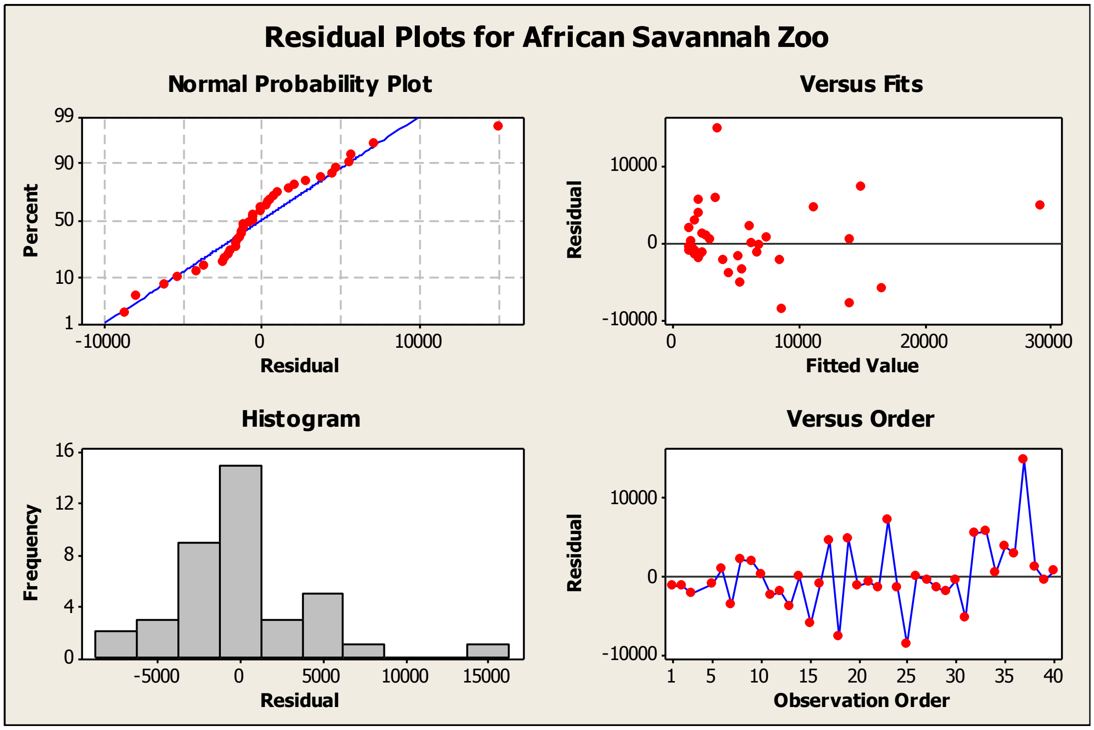


Figure 4.80. Residual plots for African Savannah Zoo, after GI construction.

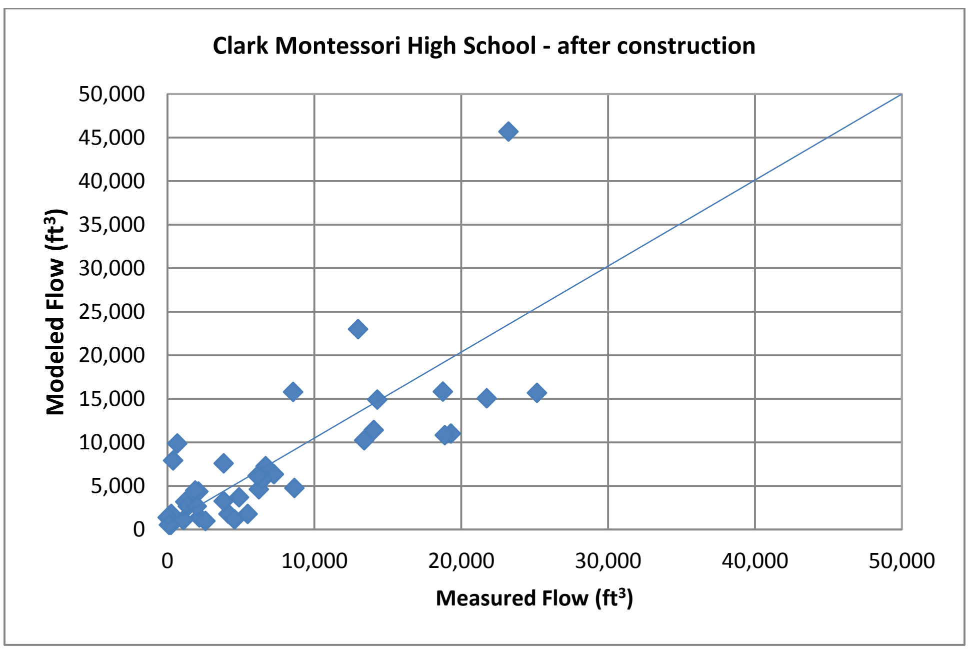


Figure 4.81. Observed and modeled flows for Clark Montessori High School, after GI construction.

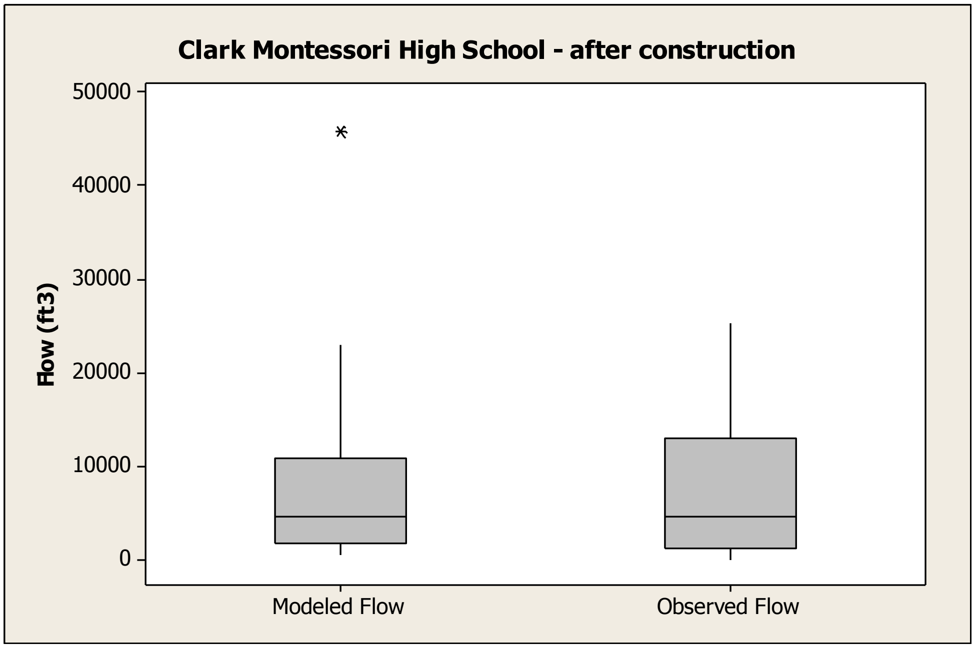


Figure 4.82. Box plot of modeled and observed flows for Clark Montessori High School, after GI construction.

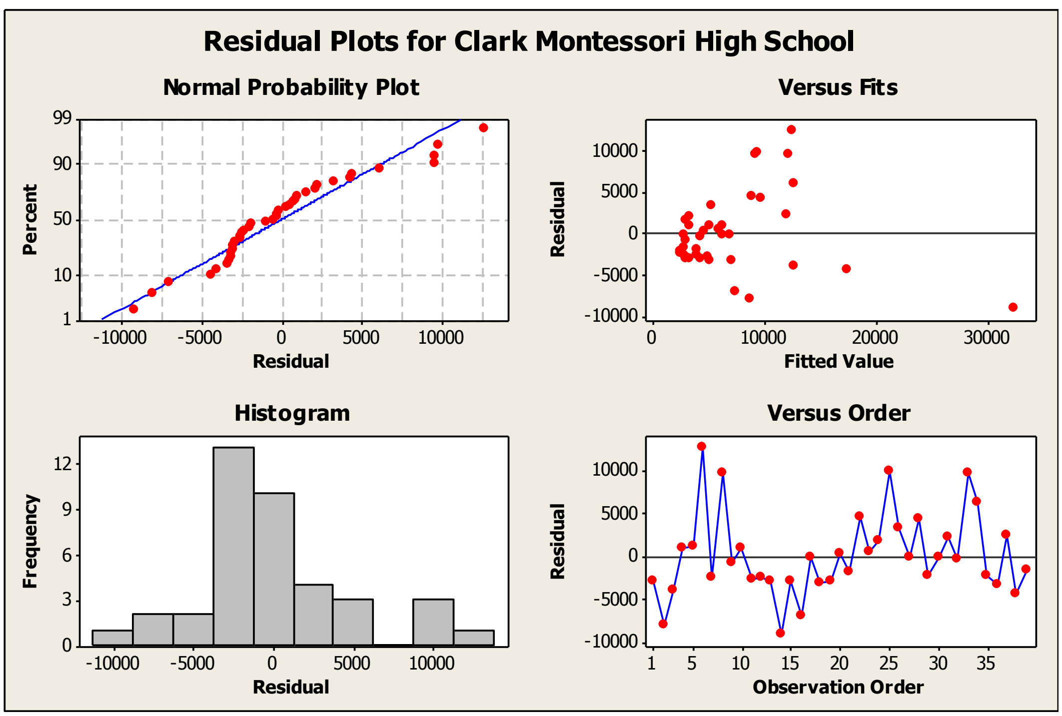


Figure 4.83. Residual plots for Clark Montessori High School for observed vs. modeled flows, after GI construction.

Table 4.61 summarizes the Rank Sum Test analysis results for all the study areas (using Minitab 16). As shown, the p-values for most of the areas are greater than 0.05, indicating that observed flows and modeled flows are not significantly different. For the main entrance of the Cincinnati Zoo the p-value is 0.031, which indicates that the difference in the median values between the two groups (observed flows vs. modeled flows) is greater than would be expected by chance, therefore there is a statistically significant difference between the two groups. One possible reason for differences in modeled and observed flows is that the before construction data were not available at the main entrance of the Cincinnati Zoo to calibrate the model. With a power analysis (alpha = 0.05, and beta = 0.2), the number of samples available and the monitored flow variations would allow differences of about 15% to 30%, or larger, to be detected.

Table 4.61 Summary of Rank Sum Test results for study areas in Cincinnati

Study area	Group	N	Median	25%	75%	Mann-Whitney U Statistic	T value	P-value	Significant difference between modeled and measures flow?
Cincinnati State College	Modeled flow (ft^3)	76	1378	523	2247	2251	6000	0.062	No
	Observed flow (ft^3)	76	865	176	2307				
Main entrance of the Cincinnati Zoo	Modeled flow (ft^3)	176	196	74	401	12802	31660	0.031	Yes
	Observed flow (ft^3)	176	146	0	550				
African Savannah Zoo	Modeled flow (ft^3)	40	2992	900	7649	740	1561	0.84	No
	Observed flow (ft^3)	40	3475	777	7765				
Clark Montessori High School	Modeled flow (ft^3)	39	4616	1775	10816	716	1585	0.66	No
	Observed flow (ft^3)	39	4583	1225	12990				

4.5 Summary

4.5.1 Summary of Recharge Observations with Dry Wells at Millburn, NJ

Groundwater recharge is a suitable beneficial use of stormwater in many areas and can be used to augment local groundwater resources and provide more stable base flows in receiving waters. This study showed how the dry wells could be very effective in delivering the stormwater to the shallow groundwaters. Even though the surface soils were almost all marginal for infiltration options, the relatively shallow dry wells were constructed into subsurface soil layers that had much greater infiltration potentials. However, some of the monitored dry well locations experienced seasonal high groundwater elevations, restricting complete draining of the dry wells after rains. While surface and subsurface soil information is readily available for the Township (and in most other areas of the country), the presence of the shallow water table (or bedrock) is not well known. This makes identifying the most suitable locations for dry wells difficult, as the seasonal groundwater should be at least 3.6 m (12 ft) below the ground surface (or 60 cm, 2 ft, below the lowest gravel fill layer beneath the dry well).

Calculating the benefits of the dry wells (including developing sizing requirements) requires the use of an appropriate infiltration equation, preferably as part of a continuous model examining many years of actual rain fall data for a specific area. Two commonly used infiltration models, the Horton and Green-Ampt equations, were evaluated for their potential use to calculate groundwater recharge at the case study locations in the Township of Millburn, NJ. The fitted graphs and resulting derived equation parameters indicate that although the Horton curve is usually a better fit to the observed data, the calculated parameters of both infiltration models are not close to values reported in the literature for urban areas. This is likely because the infiltration characteristics in the dry wells were mostly affected by subsurface conditions compared to the literature values that were compared to the surface soil characteristics. When the subsurface conditions are used in the comparisons, the observed and literature values are in better (but still not close) agreement. Therefore, locally measured infiltration test data at a scale approaching the size and depth of the final devices should be used for more reliable design guidance, instead of relying on literature values.

4.5.2 Summary of Biofilter Measurements during Rain Events at Kansas City, MO

A tremendous amount of information was collected for evaluation of biofilters at Kansas City, ranging from drainage area characteristics to runoff and flow monitoring data at different scales, locations, and project phases. The infiltration rates in the biofilters were monitored during actual rains by measuring the rate of drop of the ponded water during large rains. Statistical analyses identified two distinct groups of these data, as shown in the following list and group box and whisker plot (Figure 4.84).

- Low rates: average 0.70 in/hr; range 0.19 to 1.9
- Normal rates: average 2.7 in/hr; range 0.10 to 7.2

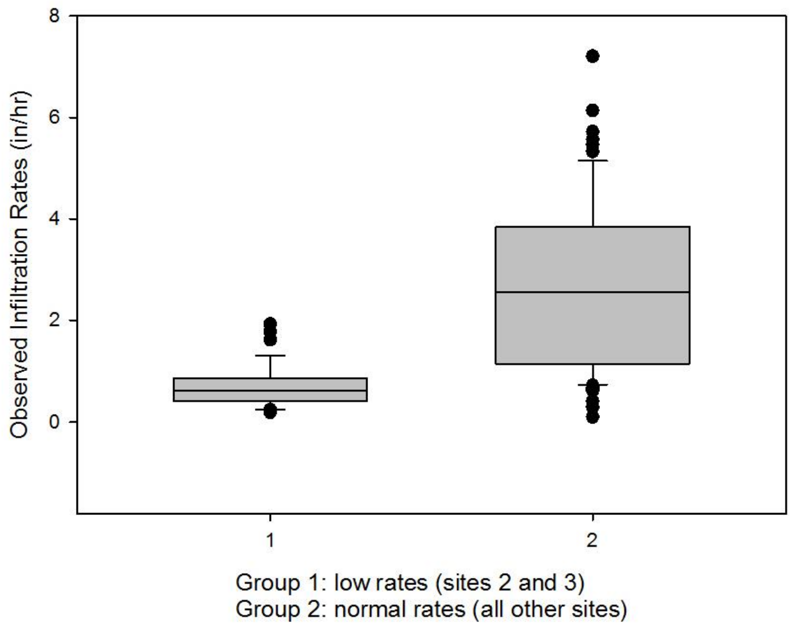


Figure 4.84. Measured infiltration rates in biofilters during actual rains.

The average time to ponding for each of the eight curb-side biofilters after the rain started ranged from 0.15 to 0.5 hr, with the fast group starting ponding in about 0.16 hrs and the slow group starting in about 0.3 hrs. The maximum depth of ponding was also separated into two categories, as shown below:

- Shallow: average of 3.4 in., range of 0.72 to 12 in.
- Deep: average of 6.3, range of 0.60 to 13 in

Figure 4.85 is a group box and whisker plot showing these two combined sets of data for maximum depth of ponding.

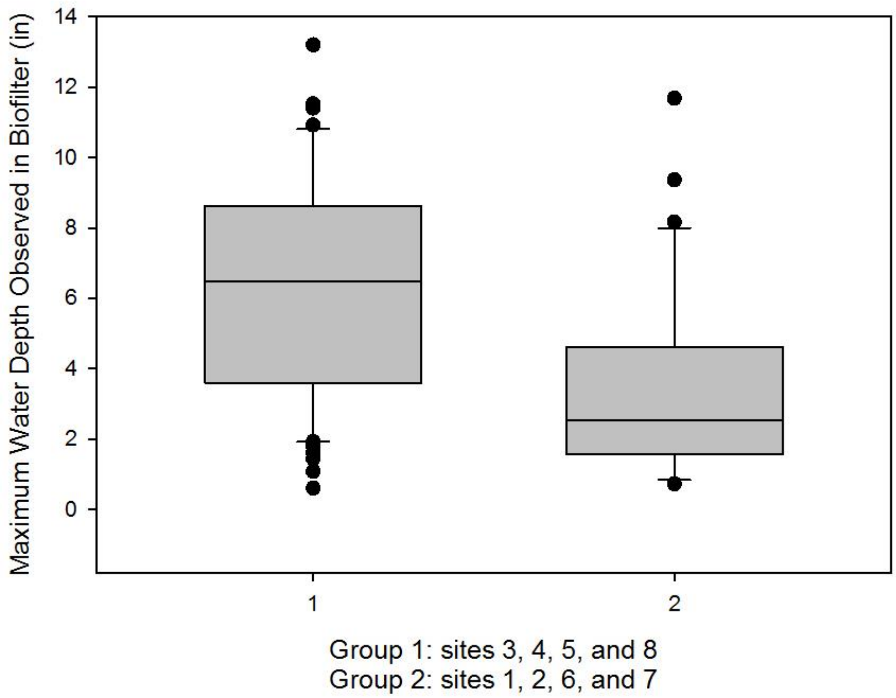


Figure 4.85. Maximum ponding depth observed in biofilters during actual rains.

4.5.3 Summary of System-wide Monitoring Observations and Model Calibration at Kansas City, Missouri

Runoff monitoring was conducted in the combined sewer system at several locations in the test and control watersheds at Kansas City. Events were monitored after the sewer was rehabilitated, and these data were used as a new baseline condition. WinSLAMM evaluated the test (pilot) and control watershed conditions during the two monitoring periods (post re-lining, as the new baseline versus after construction of controls) to verify the rainfall-runoff calibration based on site development characteristics and the actual rains monitored.

Figure 4.86 compares the pre and post-construction R_v values for the test/pilot watershed as monitored at UMKC01. The post-construction R_v values are apparently smaller than the pre-construction R_v values, as expected. Comparisons of pre and post-construction R_v values were also made for different rain categories which had similar apparent trends, especially for the small rains. The R_v differences for the two smallest rain categories were significantly different (which were at 40 and 33% for <0.5 inches and 0.5 to 1.5 inches respectively), but the largest rain category (>1.5 inches) did not have significant differences (at 13%) for the number of observations available. Biofilters remove larger fractions of flows from smaller events based on their storage capacity and other design features. Table 4.62 summarizes the overall reduction in flows observed in the test/pilot watershed which were calculated to be about 32% on a flow-weighted basis and were highly significant (p <0.001).

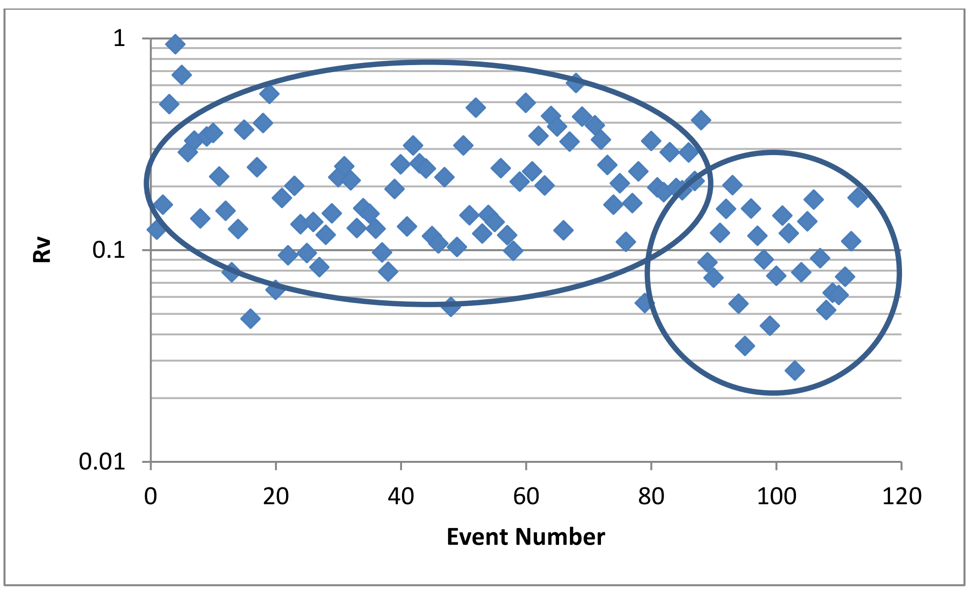


Figure 4.86. Volumetric runoff coefficients at UNKC01 before and after GI construction.

Table 4.62. Summary of Statistical Comparisons for Before and After GI Facility Construction at UMKC01 in Kansas City, MO

Monitoring period	Dates corresponding to monitoring period	Number of monitored storms in each monitoring period	Flow-Weighted R_v values	% change compared to "initial baseline and after relining (combined)" (p from Mann-Whitney Rank-Sum test)
Initial baseline and after Relining	(03/23/09 – 06/16/10) and (02/24/11 – 03/19/11)	75	0.26	n/a
After construction	04/07/13 – 10/31/2013	37	0.18	32.3% decrease ($p < 0.001$)

Figure 4.87 is a scatterplot showing the observed versus the modeled test (pilot) watershed area total flows for each of the events during the after re-lining baseline period. As shown, these are all close to the line of equivalent values.

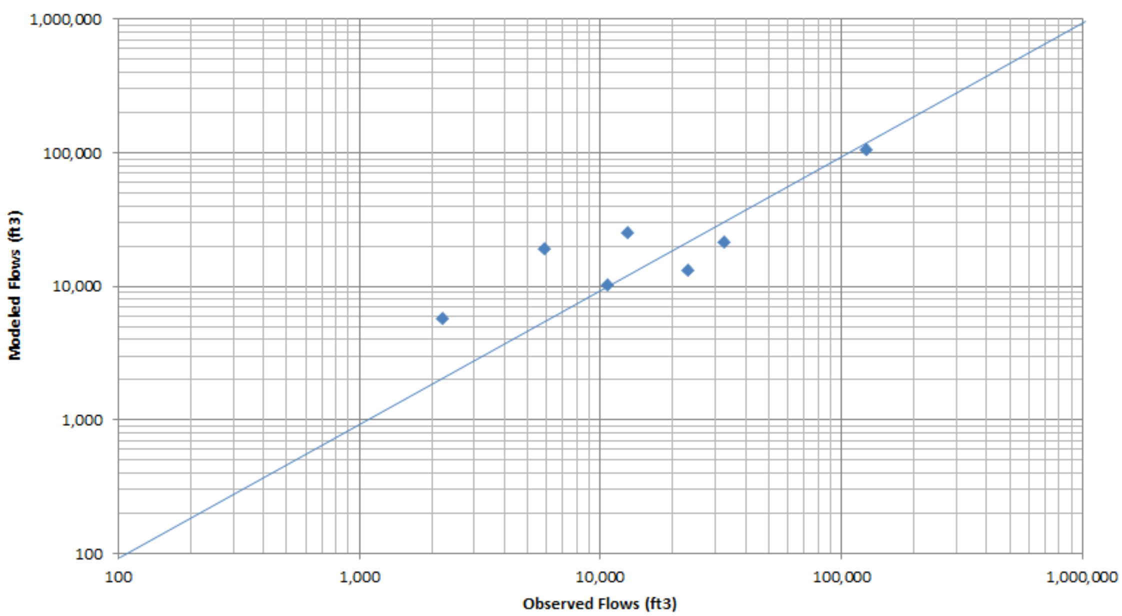


Figure 4.87. Observed versus modeled flows during final baseline conditions (after re-lining).

4.5.4 Summary of Large-scale Performance Evaluation of GI Controls in Cincinnati, OH

The effectiveness of green infrastructure stormwater controls in combined and separate sewer systems was determined at three Cincinnati locations, including Cincinnati State College, the Cincinnati Zoo, and the Clark Montessori High School sites. High-resolution flow measurements from in-system flow sensors were evaluated to measure the runoff volume reductions after GI facility construction at each study site. The flow data are available from before, during, and after stormwater controls construction for most of the study areas, and after construction for all.

Analyses indicate that the post-construction pipe flow data were significantly less than the pre-construction pipe flow data for all of the sites studied. Table 4.63 summarizes the runoff volume reductions (percentages) compared to pre-construction period for each of the monitoring locations.

Table 4.63. Summary of runoff volume reduction at Cincinnati study areas

Location	**Runoff Volume Reduction (%) Compared to Pre-Construction Data**
Cincinnati State College – Southern Area (bioinfiltration and rain gardens)	85 ($p<0.001$)
Cincinnati Zoo – Main Entrance (extensive paver blocks)	>80 (Average R_v values after construction are about 0.1 ,compared to about 0.8 for conventional pavement)
Cincinnati Zoo – African Savannah (rainwater harvesting system and pavement removal)	70 ($p<0.001$)
Clark Montessori High School (green roofs and parking lot biofilters on small portion of watershed)	20 ($p = 0.027$)

CHAPTER 5.0

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

Green infrastructure (GI) 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. The literature review identified several benefits for GI stormwater control practices such as reducing runoff volume, reducing stormwater pollutants, promoting groundwater discharge, and reducing combined sewer overflow volumes and frequency. Awareness of the performance of GI practices at small and large scales in urban areas is a key factor affecting decision making on urban stormwater management, and may increase the predictability of GI stormwater control benefits and thus improve their design. Many prior research studies have reported on the benefits of individual GI stormwater controls on stormwater runoff quality and quantity at small scales, while only a few studies have been conducted to assess how integrated GI stormwater controls affect flows in combined sewers at large scales using real time data.

This research was conducted to examine GI stormwater practices at small and large scales. Three main case studies at Millburn, NJ, Kansas City, MO, and Cincinnati, OH were studied in this dissertation research. At small scales, infiltration measurements from individual stormwater controls including drywells and biofilters were applied to measure the benefits (such as runoff volume reductions). At large scales, direct measurements of flow from in-system flow monitors placed in combined or separate sewers affected by individual green infrastructure devices were evaluated. The runoff characteristics of the pre- and post-construction conditions were compared to measure the benefits of integrated GI stormwater controls at large scales and their impacts on reducing CSOs. The second stage of this research utilized calibrated versions of WinSLAMM for each study area to compare the observed runoff volumes with the modeled runoff volumes. This, in conjunction with the large-scale flow monitoring data, increases the weight of evidence supporting the performance expectations of the sustainable infrastructure components in large-scale watershed areas for a wide variety of conditions.

5.2 Dissertation Research Hypothesis and Findings

As described in Chapter 3, the hypothesis of this research is: "*Retrofitting integrated green infrastructure controls in large areas served by separate or combined sewers can result in significant runoff volume reductions.*" In addition to proving the research hypothesis, another important part of this dissertation research was to develop and demonstrate an effective monitoring and evaluation strategy and QA/QC process to measure green infrastructure based stormwater control effectiveness in reducing CSOs. Below is a summary of research findings that support the hypothesis.

- At small scales, short and long-term infiltration monitoring was conducted in a selection of GI stormwater control devices. In selected dry wells at Millburn, NJ, there were varying levels of dry well performance in the area, but most were able to completely drain within a few days. However, several had extended periods of standing water that may have been associated with high water tables, poorly draining soils (or partially clogged soils), or detrimental effects from snowmelt on the clays in the soils. The infiltration rate characteristics were separated into three conditions: 1) hydrologic group soil (HSG) A and B surface soils and having well drained HSG A subsurface soils, 2) C and D surface soils and having well drained A and B subsurface soils, and 3) C and D surface soils and having poorly drained subsurface soils with long-term standing water. Even sites having surface C and D soils (not acceptable infiltration sites according to the New Jersey dry well standards) all had much better subsurface conditions where the dry wells were located. The infiltration rates for these conditions were less than for the excellent soil areas having HSG A and B surface soils, but all met the infiltration rate criterion in the state guidelines.

- At large scales, runoff monitoring was conducted in the combined and separate sewer system at several locations in the watersheds that are served by GI stormwater controls in both Kansas City and Cincinnati. The results showed that the runoff volume reductions at large scales depends on the location and coverage of the GI stormwater control practices. In order to have large runoff volume reductions in watersheds, the areas should have most of their flows treated by the control practices. Also, the results indicated that GI stormwater control practices result in major runoff volume reductions for rainfall depths less than about 1.5 inches, with fewer benefits for larger rains (based on the available data for studied areas in this dissertation research).
    - In the Kansas City study area, the test area is a 100-acre watershed of an aging neighborhood that had sewer rehabilitation (extensive re-lining) followed with implementation of over 100 green infrastructure (GI) controls. About half of the study area receives direct treatment from many separate stormwater control devices, and the area was monitored for pre- and post- GI construction to demonstrate the actual flow reductions. WinSLAMM evaluated the test (pilot) and control watershed conditions during the two monitoring periods to verify the rainfall-runoff relationships based on

site development and soil characteristics for the actual rains monitored. A total of 75 events were examined for the pre-construction baseline conditions and 37 events were examined for the post-construction conditions. The overall reductions in flows observed in the test/pilot watershed were calculated to be about 32% on a flow-weighted basis and were highly significant ($p < 0.001$). The annual runoff volume directed to the green infrastructure stormwater controls was calculated to be about half of the total test/pilot area annual runoff. The maximum level of flow reductions that could have been associated with the stormwater controls was therefore about 50%.

- In Cincinnati, three study areas were studied that included Cincinnati State College, the Cincinnati Zoo (2 locations), and Clark Montessori High School. These sites were also evaluated to examine the effectiveness of retrofitted green infrastructure stormwater controls.
    - Cincinnati State College southwest drainage area (separate sewer system) is approximately 8.7 acres and was monitored for about 170 events (including 76 post-construction events). This area contains four rain gardens and several pervious parking areas. The statistical analyses indicated about 85% reductions in runoff volume for this study area ($p < 0.001$). This supports the hypothesis that the flows being discharged from areas with GI stormwater controls are much less than would occur if the GI stormwater controls were not present. Since a monitored area with “no stormwater controls” was not available for this study area, the “before” construction runoff and rainfall data were used to calibrate WinSLAMM.

- The main entrance of the Cincinnati Zoo has a 2.5 acre drainage area and is served by a separate sewer system. More than 60% of the area has been replaced by porous paver blocks. This area has been monitored for 176 events (all being in the post-construction period). The average R_v values after GI controls is about 0.1 (compared to about 0.8 for conventional pavement in the area, using calibrated WinSLAMM to predict pre-construction conditions).
- The African Savannah area of the Cincinnati Zoo is served by a combined sewer system. This study area has different types of green infrastructure controls, including permeable pavers, and an underground rainwater harvesting storage system. In addition, the African Savannah area will have enhanced turf/vegetation, which is currently under construction. 107, 15, and 40 events were recorded during the before construction, during construction, and after construction periods, respectively. At the African Savannah study area, the statistical tests indicate that the "after" construction flows were significantly less than the "before" and "during" construction flows (about 70% reductions in runoff volume). This also supports the dissertation hypothesis.
- The Clark Montessori High School study area has various green stormwater controls including green roofs, permeable pavements, and bioretention facilities, but only a small portion of the whole drainage area is served by GI stormwater control practices. This area has been monitored during about 166 events, with 39 events during the post-construction period. The statistical analysis indicated 20% reductions in runoff volume and showed that the R_v values for the after construction period were significantly different from the before and during

construction periods ($p < 0.05$). For this area, the runoff volume directed to the green infrastructure stormwater controls was estimated using WinSLAMM to be about 20% to 25% of the total watershed area runoff. Therefore, the maximum level of flow reductions that could have been associated with the stormwater controls was estimated to be 20% to 25%, close to the reductions observed.

- During these projects, WinSLAMM was calibrated using before construction period data, if available. The as-built stormwater control designs were then included in the model and the calculated flows were then compared to the monitored flows after construction. In all cases, the agreement between the modeled and observed flows were very good, indicating the ability to expand results from small-scale monitoring to larger systems, as long as critical site characteristics are known.

5.3 Recommendations for Flow Monitoring of Green Infrastructure Controls for Performance Evaluations

a) Groundwater table information is needed in the study area, especially if promoting recharge of groundwater and development of local water supplies as beneficial uses. This is also needed to evaluate the potential of groundwater interfering with the subsurface structures and infiltration processes, and also affects potential groundwater intrusion into the drainage systems.

b) Soil surveys at pilot-scales are needed to identify site selection of GI stormwater controls in order to maximize their benefits.

c) It is essential to have adequate rain gauges (at least several) near the flow sensors in the study area.

d) Monitor adjacent test and control areas before and after construction of GI stormwater controls for the greatest reliability (to account for typical year-to-year rainfall variations and to detect sensor problems early). A calibrated stormwater model can be used to calculate performance over very long periods, but the data collection must consider the wide range of likely rainfall and site conditions.

e) Monitor as many rain events as practical, due to high variability in data. This also helps analyze GI benefits for different ranges of rain events. The experimental design of the monitoring plan must quantify the likely expected detectable level of performance through a power analysis.

f) Test areas should have most of their flows treated by the control practices to maximize measurable reductions and provide significant benefits. Any untreated up-gradient areas should be very small in comparison to the test areas. It is difficult to subtract two large numbers (each having measurement errors and other sources of variability), such as above- and down-gradient monitoring stations, and have sufficient confidence on the resulting flows.

g) Most monitored flows from common rains may only result in shallow depths in the sewerage, a flow condition that is difficult to accurately monitor.

h) Flow sensors should not be located near pipe joints in order to minimize or eliminate possible backflows.

i) Flow sensors may fail more often than expected and costs of flow monitoring are small compared to the green infrastructure investment. Therefore:

1. Use redundant sensors, such as an area-velocity sensor (or bubbler) in addition to an acoustic depth sensor mounted on the crown.

2. Calibrate the flow sensors at the beginning and periodically throughout the project period.

3. Review flow data frequently and completely to identify sensor failures or other issues.

4. Use hydraulic control sections to obtain the most accurate flow data. Normally, these are not used in combined sewers due to issues associated with head loss or clogging. However, if placed on the down-gradient side of large manholes, pooled wastewater can flow through a v-notch weir after some partial settling and the large area reduces head loss issues. Again, use redundant depth sensors to optimize both shallow and deep flow depths.

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APPENDIX A

EXAMPLE DESIGNS FOR MONITORED STORMWATER CONTROLS AT KANSAS CITY

Figures A-1 through A-6 in Appendix A, are example construction drawings from the 100% design plans representing the various stormwater control designs constructed in the test (pilot) area, referenced in Table 3-4. (Source: Middle Blue River – Green Solutions Pilot Project, Water Services Department – Engineering Division. 100% plans prepared by URS Corporation, December 21, 2010)

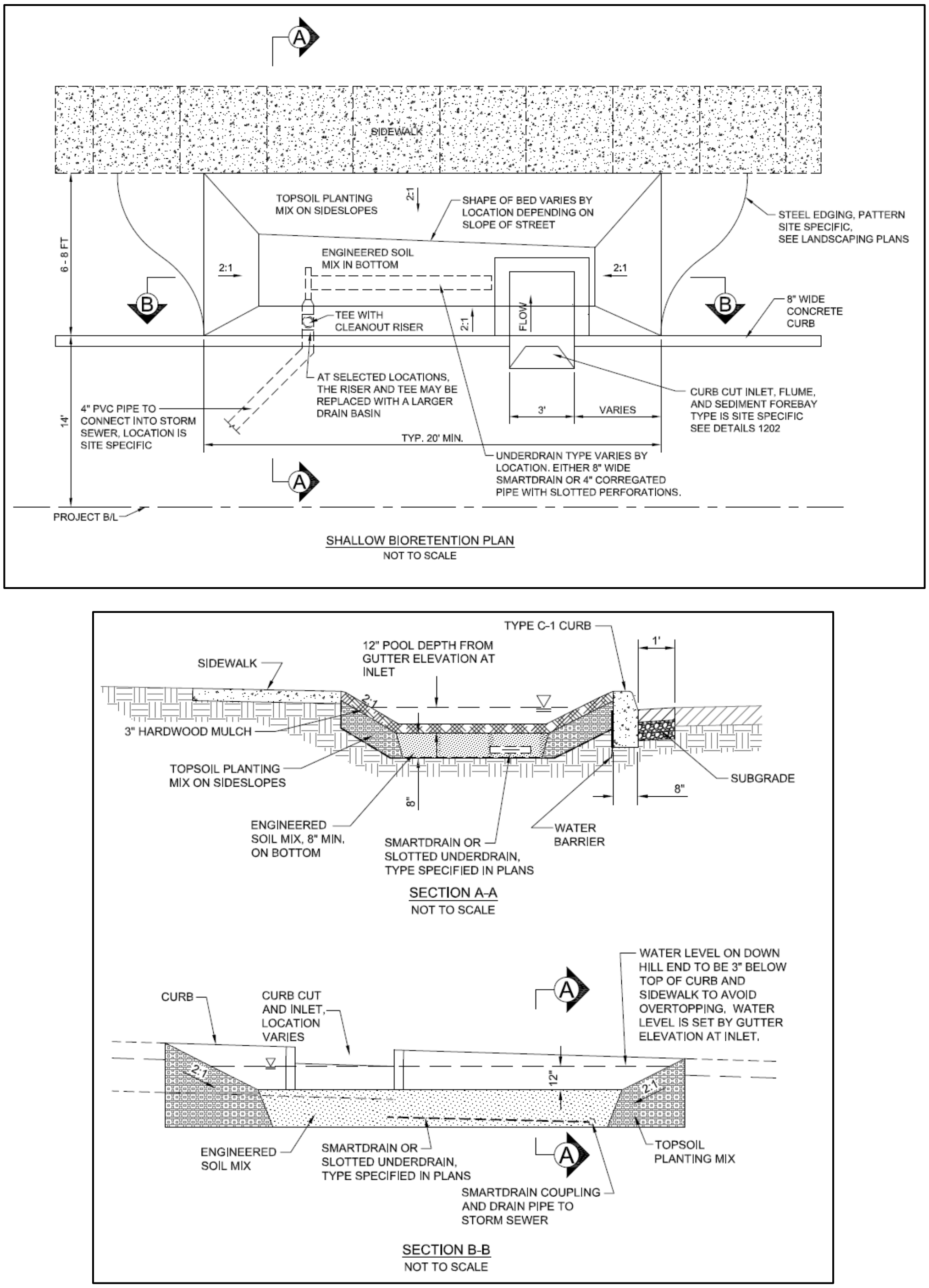


Figure A-1. Shallow bioretention device typical details for residential streets.

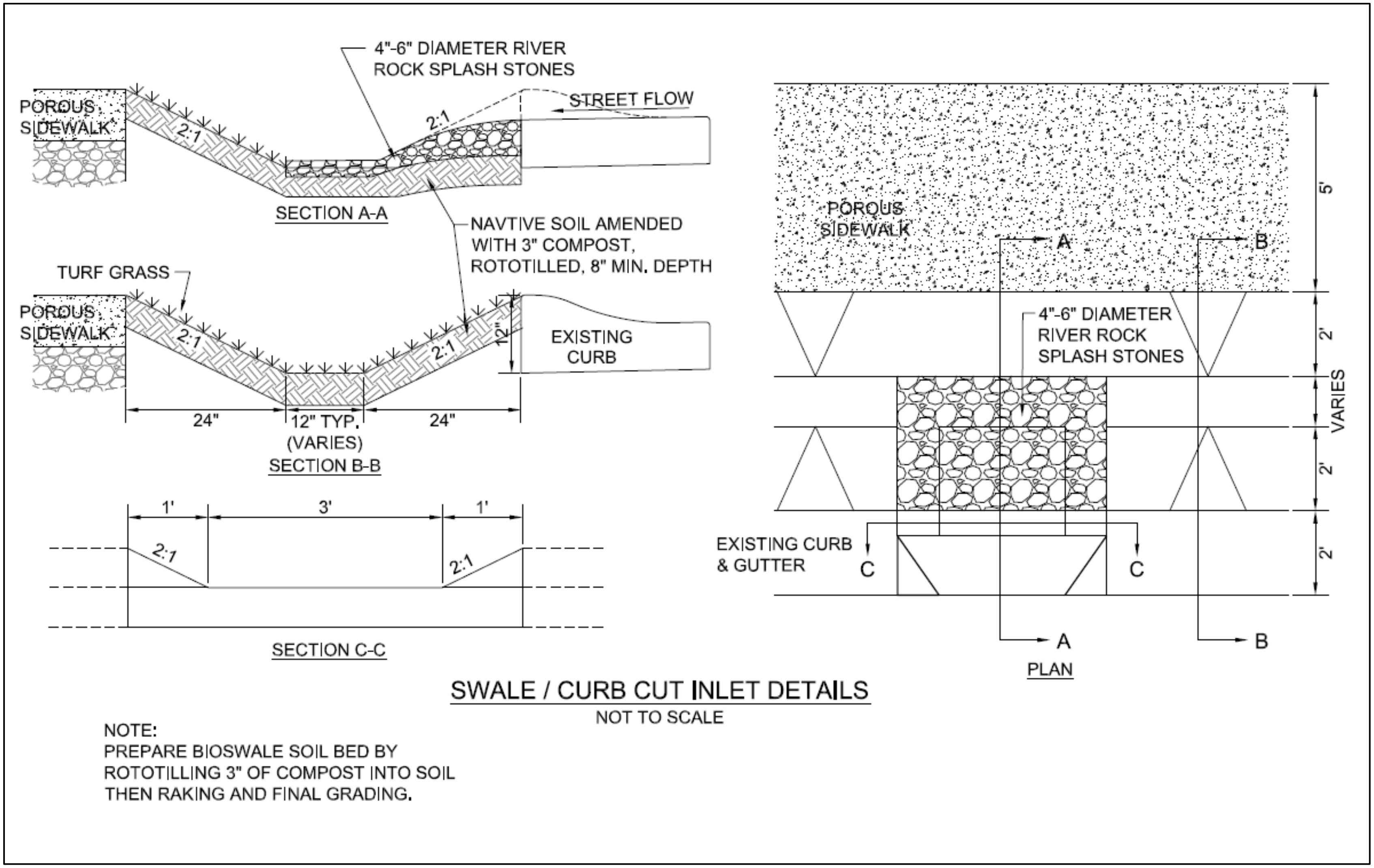


Figure A-2. Bioswale typical details for residential streets.

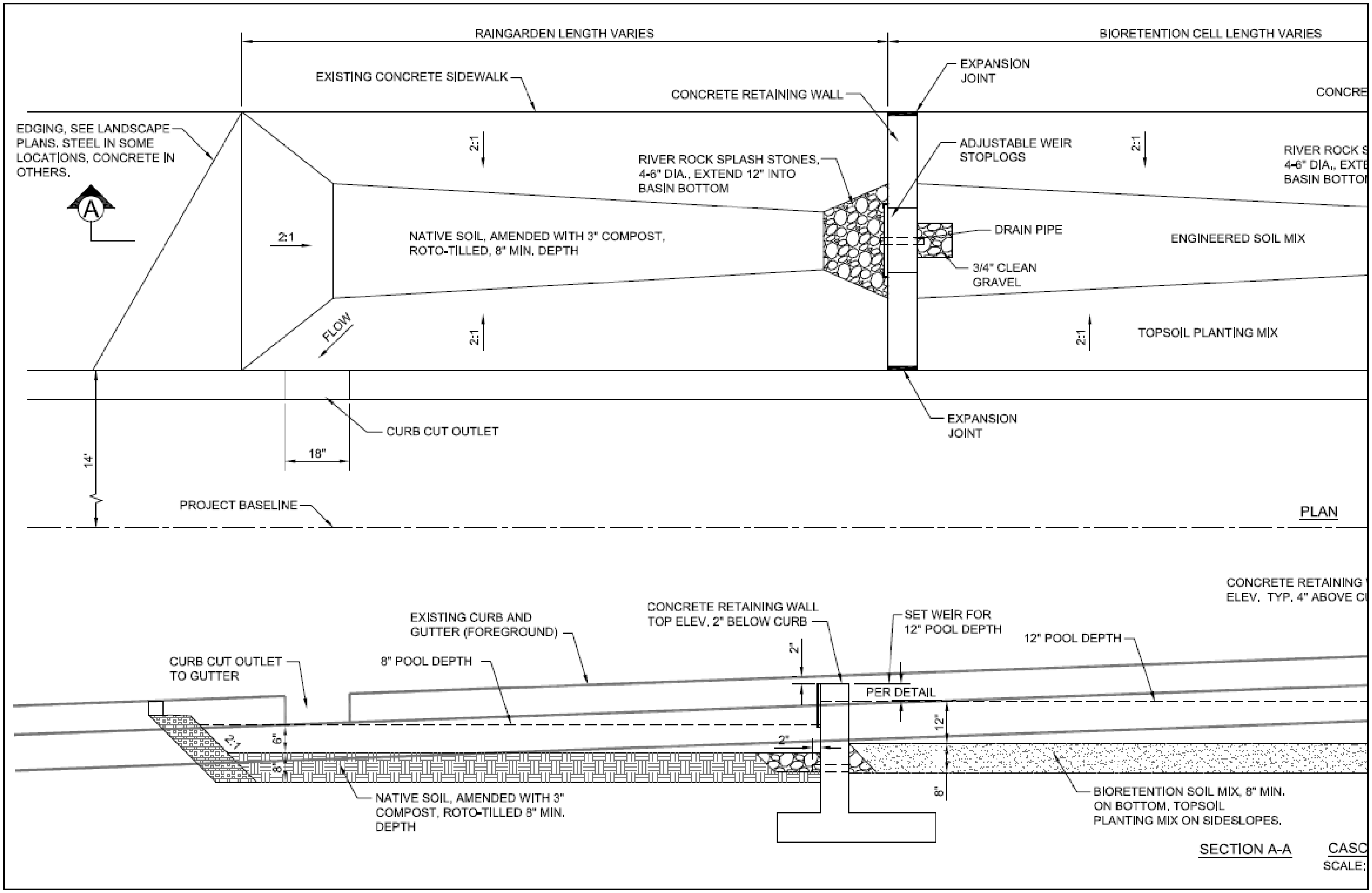


Figure A-3. Cascade rain garden typical details for residential streets.

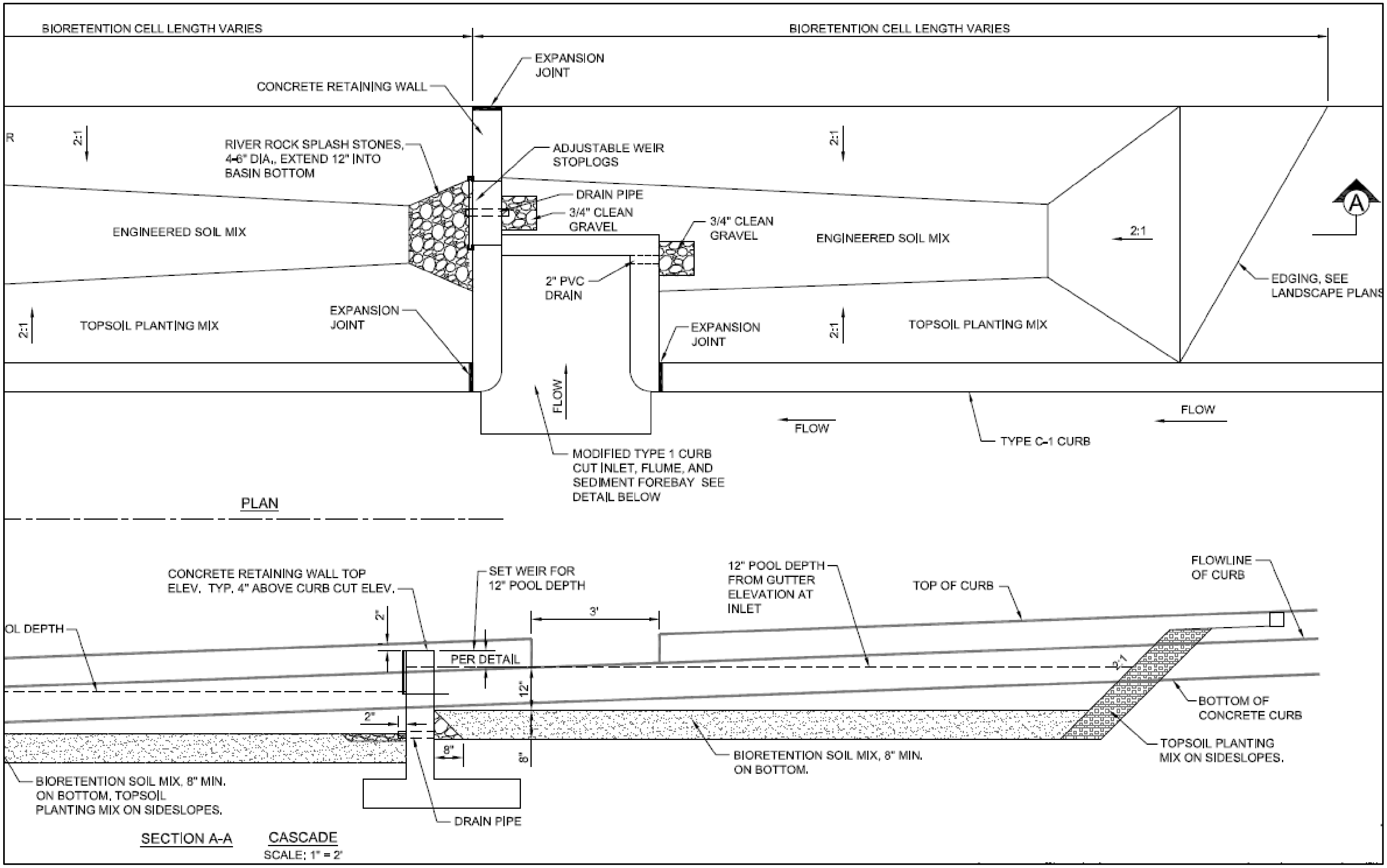


Figure A-3. Cascade rain garden typical details for residential streets (continued).

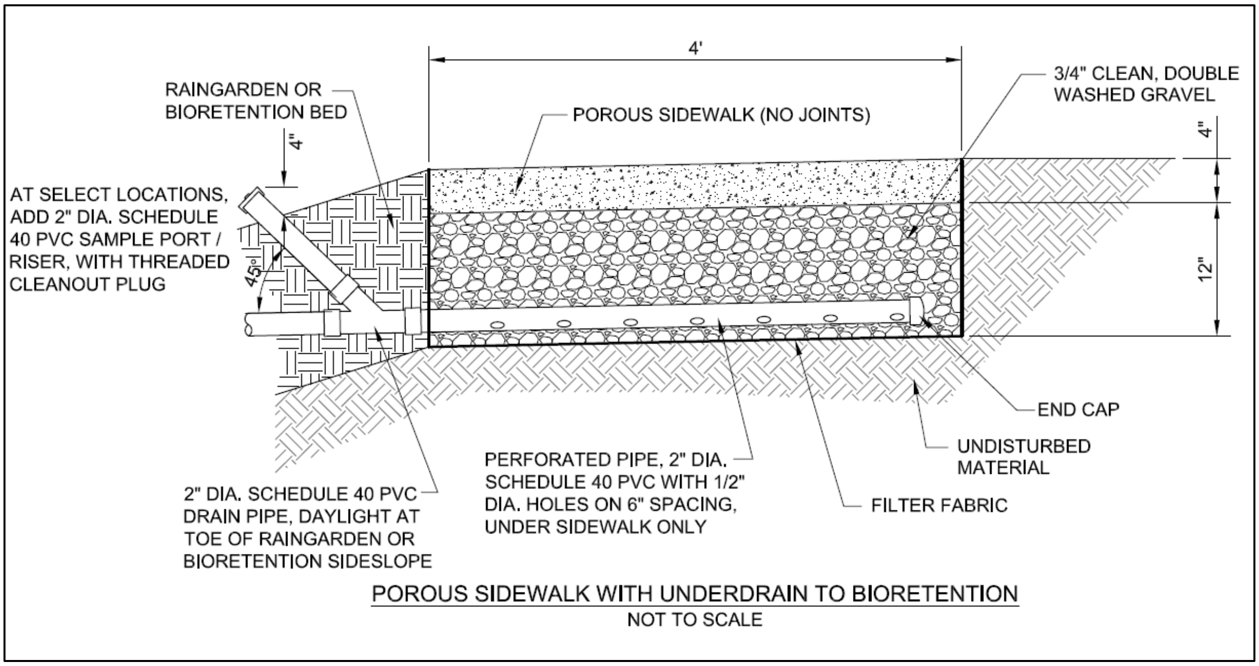
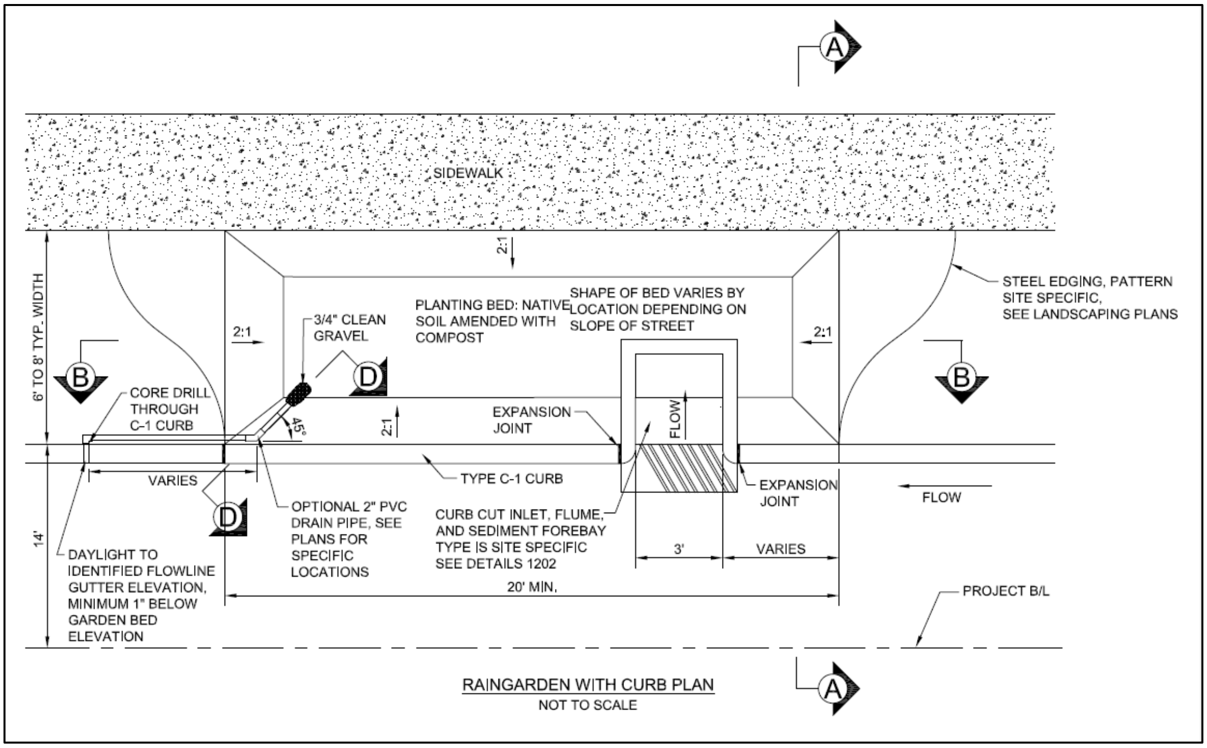


Figure A-4. Porous sidewalk typical details for residential streets.



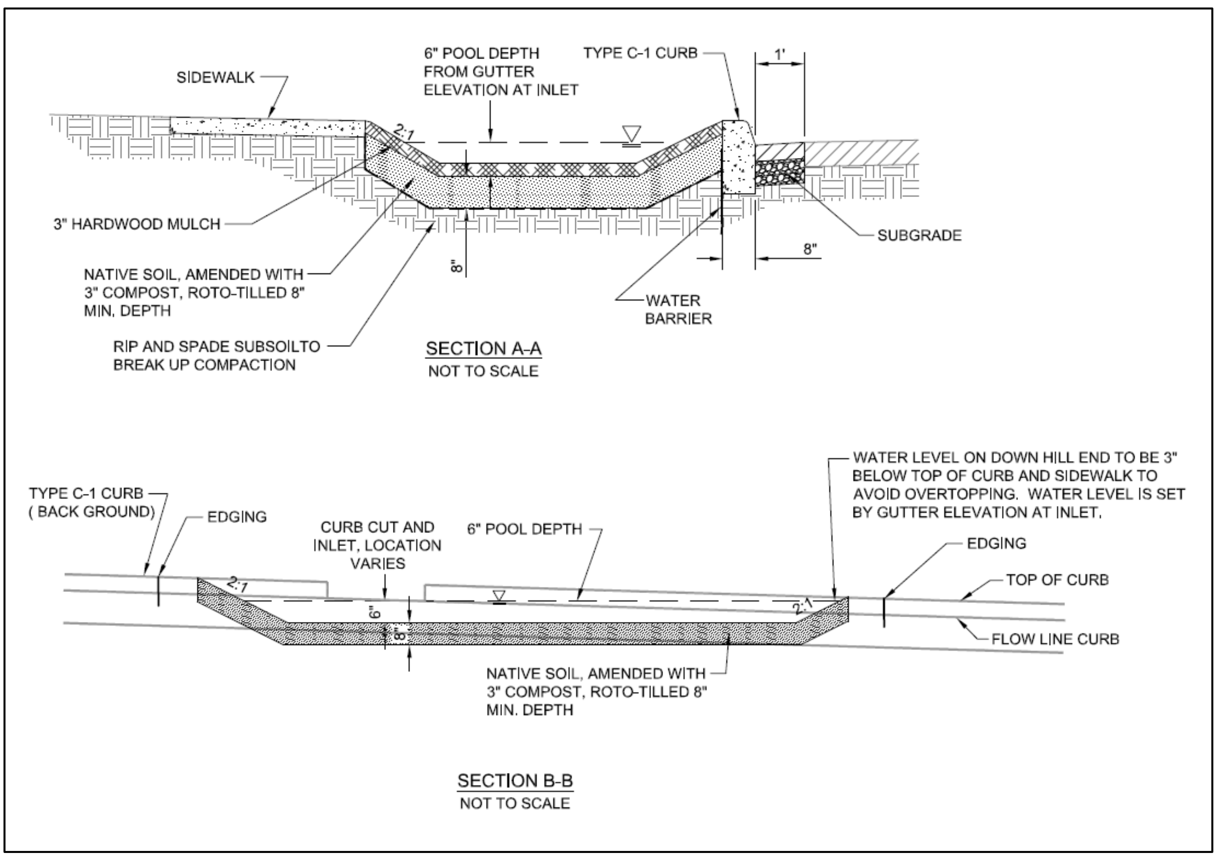


Figure A-5. Rain garden typical details for residential streets.

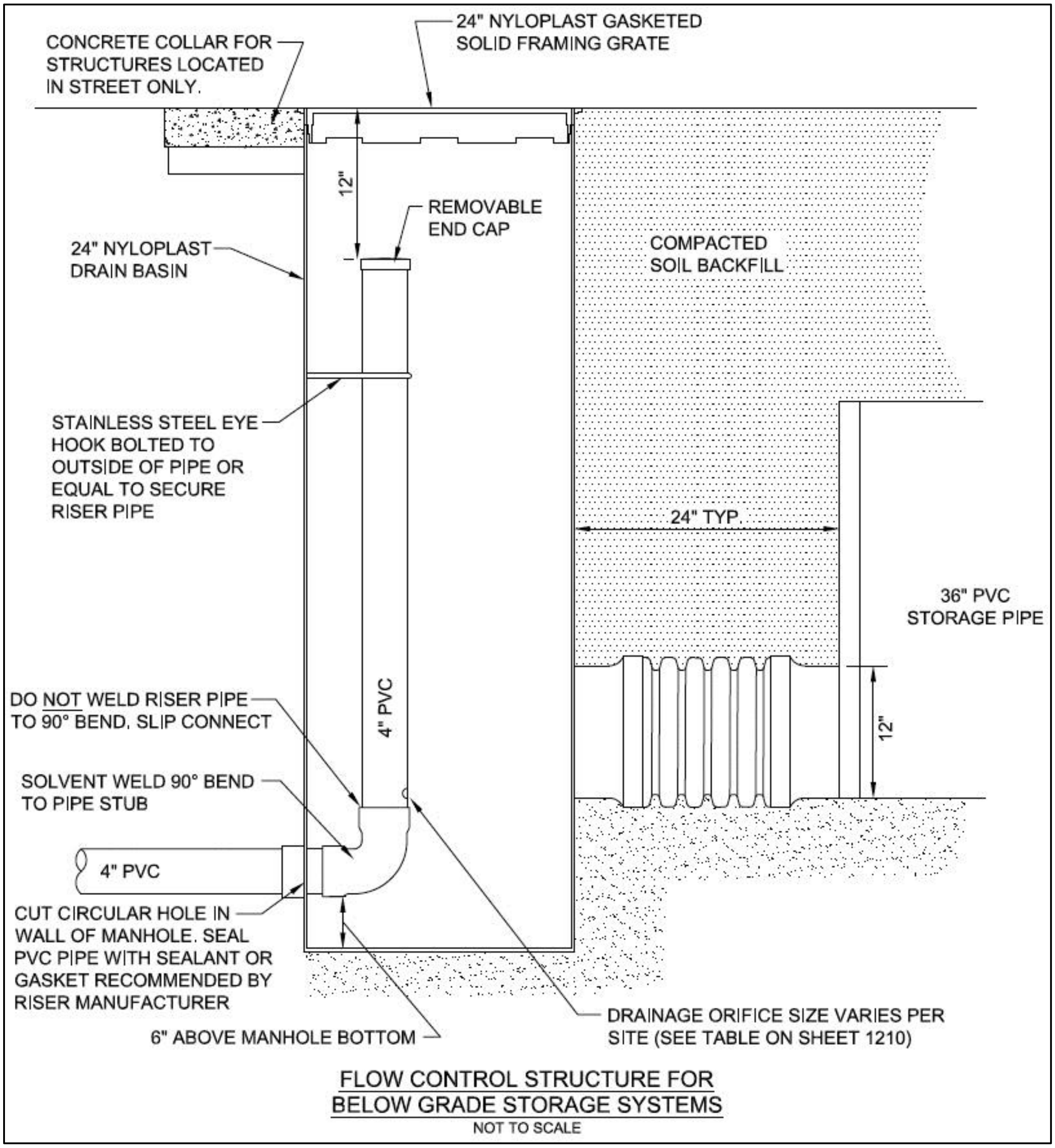


Figure A-6. Below grade storage system typical details for residential streets.

APPENDIX B

SCHEMATIC DRAWING OF STORMWATER CONTROLS AT CINCINNATI STUDY AREAS

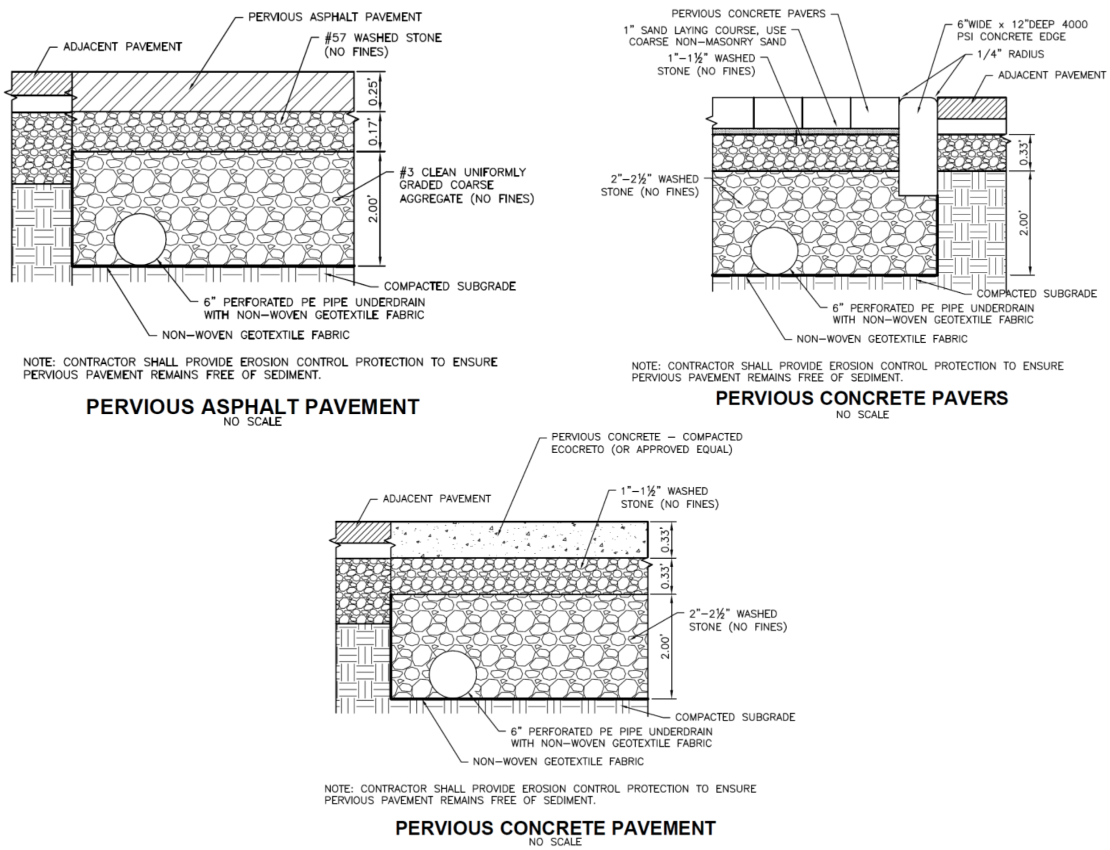


Figure B-1 Permeable pavement/pavers typical details

(Source: MSDGC Green Demonstration Project, Part 1, Appendix A, Sheet NO. C500, April 19, 2010.)

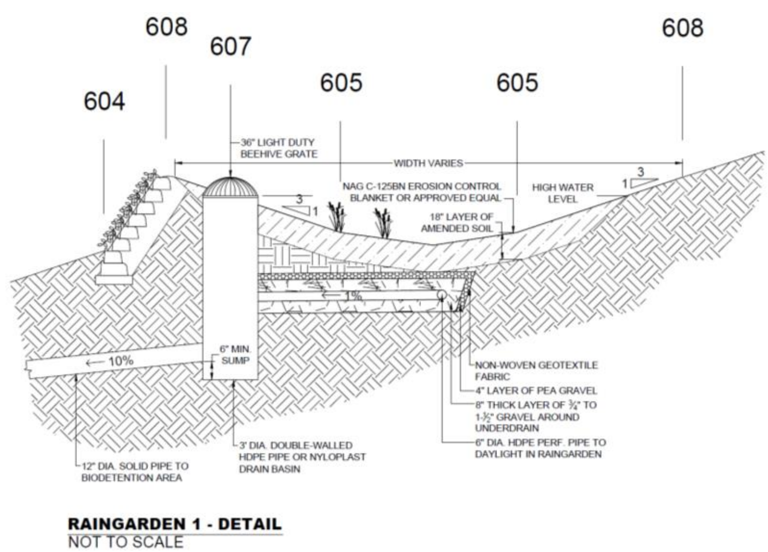


Figure B-2 Rain garden typical details

(Source: MSDGC Green Demonstration Project, Part 1, Appendix A, Sheet NO. C500, April 19, 2010.)

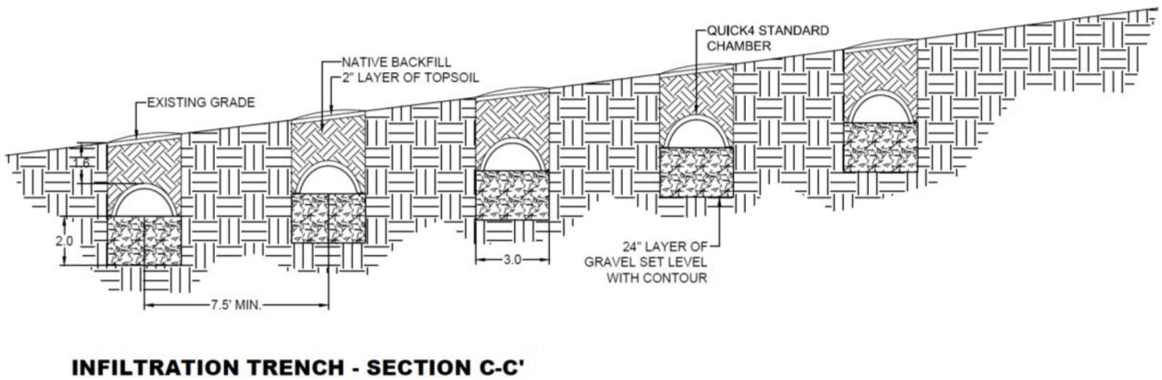


Figure B-3 Infiltration trench typical details

(Source: MSDGC Green Demonstration Project, Part 1, Appendix A, Sheet NO. C500, April 19, 2010.)

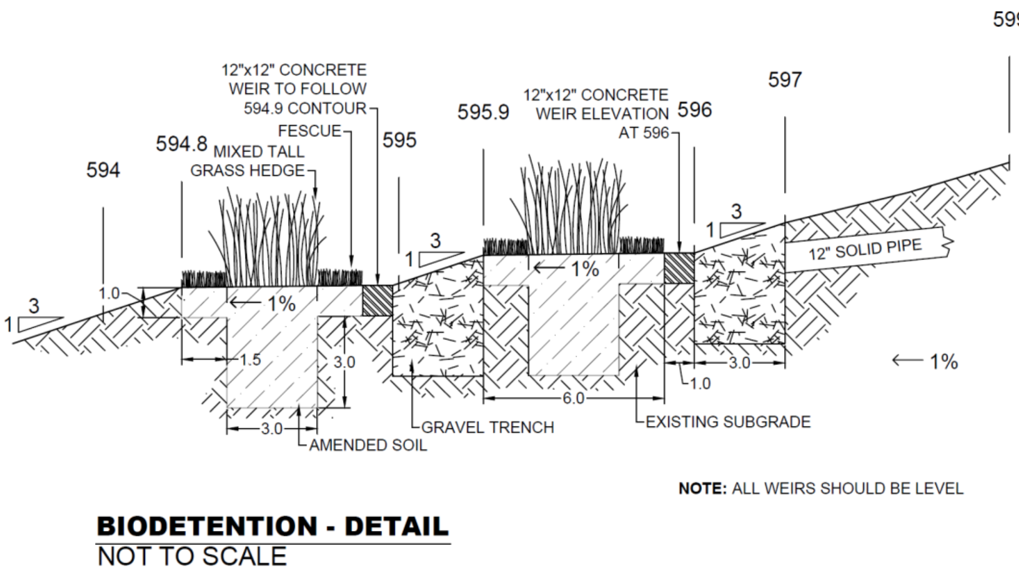
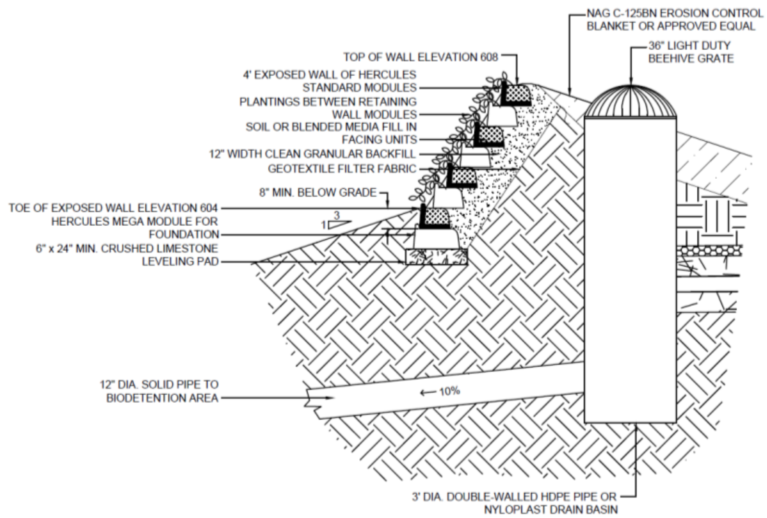


Figure B-4 Biodetention typical details

(Source: MSDGC Green Demonstration Project, Part 1, Appendix A, Sheet NO. C500, April 19, 2010.)



GREEN RETAINING WALL - DETAIL SIDE VIEW
NOT TO SCALE

Figure B-5 Retaining wall details

(Source: MSDGC Green Demonstration Project, Part 1, Appendix A, Sheet NO. C500, April 19, 2010.)

APPENDIX C

SOILS AND INFILTRATION MEASUREMENTS AT MILLBURN DRY WELL STUDY LOCATIONS

Tables 9 to 30 present summary of Horton parameters and rain characteristics as well as statistical analysis for each drywell for infiltration study test and different rain events. Table 6 is a site summary by event showing the test conditions, the Horton parameter values, rain depth, and maximum and minimum dry well water levels during the event. Also noted is the likely presence of high water table conditions at the end of the monitoring event.

11 Woodfield Dr

Table B-1. Summary of infiltration hydrant water test (11 Woodfield Dr)

Date	Horton's parameters			Study Test				Water Depth in Drywell (in)	
	f_0 (in/hr)	f_c (in/hr)	k (1/min)	Start Time	End Time	Duration (hr:min)	Fill Rate (gal/min)	Max.	Min.
10-13-2009	13.945	1.2	0.012	10/13/2009 10:07	10/13/2009 10:30	0:23	156.52	43.68	0.72

Table B-2. Summary of Horton parameters (f0, fc, and k) for rain events (11 Woodfield Dr)

Date	Horton's Parameters			Rain Characteristics					Water Depth in Drywell (in)	
	f_0 (in/hr)	f_c (in/hr)	k (1/min)	Start Time	End Time	Duration (hr:min)	Depth (in)	Average intensity (in/hr)	Max.	Min.
10-24-2009	2.987	0.95	0.005	10/23/2009 5:40	10/24/2009 20:30	25:33	2.20	0.09	28.11	0.57
12-09-2009	4.117	0.72	0.006	12/9/2009 0:03	12/9/2009 11:38	11:35	2.01	0.17	39.12	0.03

Table B-3. Summary of Horton parameters (fc; f0 and k are n/a) for different rains having "constant" infiltration rates (11 Woodfield Dr)

Date	f_c infiltration rate (in/hr)			Rain Characteristics					Water Depth in Drywell (in)	
	Average	Std Deviation	COV	Start Time	End Time	Duration (hr:min)	Depth (in)	Average intensity (in/hr)	Max.	Min.
10/28/2009	0.83	0.13	0.16	10/27/2009 5:40	10/28/2009 14:04	32:24	1.6	0.05	11.1	0.45
12/13/2009	0.44	0.25	0.56	12/13/2009 10:39	12/13/2009 18:38	7:59	0.99	0.12	9.02	0.2

Table B-4. Statistical Analysis for Horton parameters (fo, fc, and k) (11 Woodfield Dr)

Statistical Analysis	Horton's Parameters			Water Depth in Drywell (in)	
	f_0 (in/hr)	f_c (in/hr)	k (1/min)	Max.	Min.
Number of Events	3	5	3	5	5
Minimum	2.99	0.44	0.01	9.02	0.03
Maximum	13.95	1.20	0.01	43.68	0.72
Average	7.02	0.83	0.01	26.21	0.39
Std Dev	6.03	0.28	0.00	15.81	0.28
COV	0.86	0.34	0.49	0.60	0.71

15 Marion Ave

Table B-5. Summary of infiltration rain events (15 Marion Ave)

Date	Horton's Parameters			Rain Characteristics					Water Depth in Drywell (in)	
	f_0 (in/hr)	f_c (in/hr)	k (1/min)	Start Time	End Time	Duration (hr:min)	Depth (in)	Average intensity (in/hr)	Max.	Min.
6-16-2010	9.95	0.5	0.02	6/16/2010 23:45	6/17/2010 0:41	0:56	0.69	0.74	56.74	0.36

Table B-6. Summary of Horton parameters (fc; f0 and k are n/a) for different rains having "constant" infiltration rates (15 Marion Ave)

Date	f_c infiltration rate (in/hr)			Rain Characteristics					Water Depth in Drywell (in)	
	Average	Std Deviation	Cov.	Start Time	End Time	Duration (hr:min)	Depth (in)	Average intensity (in/hr)	Max.	Min.
6-22-2010	0.20	0.16	0.8	6/22/2010 18:33	6/22/2010 18:54	0:21	0.37	1.06	6.51	0.25
7-14-2010	0.30	0.18	0.6	7/14/2010 8:21	7/14/2010 10:04	1:02	1.22	1.18	23.02	0.35
8-1-2010	0.34	0.26	0.76	8/1/2010 8:21	8/1/2010 9:54	1:33	1.34	0.86	26.85	0.25

Table B-7. Statistical Analysis for Horton parameters (fo, fc, and k) (15 Marion Ave)

Statistical Analysis	Horton's Parameters			Water Depth in Drywell (in)	
	f_0 (in/hr)	f_c (in/hr)	k (1/min)	Max.	Min.
Number of Events	1	4	1	4	4
Minimum	9.95	0.20	0.02	6.51	0.25
Maximum	9.95	0.50	0.02	56.74	0.36
Average	9.95	0.34	0.02	28.28	0.30
Std Dev	n/a	0.12	n/a	20.93	0.06
COV	n/a	0.37	n/a	0.74	0.20

258 Main St

Table B-8. Summary of Horton parameters (f0, fc, and k) for different events (258 Main St)

Date	Horton's Parameters			Rain Characteristics					Water Depth in Drywell (in)	
	f_0 (in/hr)	f_c (in/hr)	k (1/min)	Start Time	End Time	Duration (hr:min)	Depth (in)	Average intensity (in/hr)	Max.	Min.
06-17-2010	34.653	5.308	0.06	6/16/2010 23:45	6/17/2010 0:41	0:56	0.69	0.74	22.32	0.11
07-14-2010	75.142	6.808	0.07	7/14/2010 8:21	7/14/2010 10:04	1:02	1.22	1.18	53.62	0.67
08-01-2010	74.916	4.662	0.045	8/1/2010 8:21	8/1/2010 9:54	1:33	1.34	0.86	54.77	0.53

Table B-9. Statistical Analysis for Horton parameters (fo, fc, and k) (258 Main St)

Statistical Analysis	Horton's Parameters			Water Depth in Drywell (in)	
	f_0 (in/hr)	f_c (in/hr)	k (1/min)	Max.	Min.
Number of Events	3	3	3	3	3
Minimum	34.65	4.66	0.05	22.32	0.11
Maximum	75.14	6.81	0.07	54.77	0.67
Average	61.57	5.59	0.06	43.57	0.44
Std	23.31	1.10	0.01	18.41	0.29
COV	0.38	0.20	0.22	0.42	0.67

2 Undercliff Rd

Table B-10. Summary of infiltration hydrant water test (2 Undercliff Rd)

Date	Horton's parameters			Study Test				Water Depth in Drywell (in)	
	f_0 (in/hr)	f_c (in/hr)	k (1/min)	Start Time	End Time	Duration (hr:min)	Fill Rate (gal/min)	Max.	Min.
10-2-2009	3.881	0.566	0.013	10/2/2009 9:07	10/2/2009 9:26	0:19	131.58	54.21	0.23

Table B-11. Summary of Horton parameters (fc; f0 and k are n/a) for different rains having "constant" infiltration rates (2 Undercliff Rd)

Date	f_c infiltration rate (in/hr)			Rain Characteristics					Water Depth in Drywell (in)	
	Average	Std Deviation	Cov.	Start Time	End Time	Duration (hr:min)	Depth (in)	Average intensity (in/hr)	Max.	Min.
7-29-2009	2.368	0.007	0.003	7/29/2009 10:00	7/29/2009 19:13	9:13	1.33	0.14	9.16	5.01 (high watertable)
8-2-2009	0.17	0.093	0.55	8/2/2009 6:29	8/2/2009 12:55	6:26	1.31	0.2	16.54	0.39

Table B-12 Statistical Analysis for Horton parameters (fo, fc, and k) (2 Undercliff Rd)

Statistical Analysis	Horton's Parameters			Water Depth in Drywell (in)	
	f_0 (in/hr)	f_c (in/hr)	k (1/min)	Max.	Min.
Number of Events	1	3	1	3	3
Minimum	3.88	0.17	0.01	9.16	0.23
Maximum	3.88	2.37	0.01	54.21	5.01
Average	3.88	1.03	0.01	26.64	1.88
Std	n/a	1.17	n/a	24.16	2.71
COV	n/a	1.13	n/a	0.91	1.45

383 Wyoming Ave

Table B-13 Summary of infiltration hydrant water test (383 Wyoming Ave)

Date	Horton's parameters			Study Test				Water Depth in Drywell (in)	
	f_0 (in/hr)	f_c (in/hr)	k (1/min)	Start Time	End Time	Duration (hr:min)	Fill Rate (gal/min)	Max.	Min.
10-2-2009	5.631	1.171	0.0045	10/2/2009 10:14	10/2/2009 10:43	0:29	100.00	40.65	0.53

Table B-14 Summary of Horton parameters (f0, fc, and k) for rain events (383 Wyoming Ave)

Date	Horton's Parameters			Rain Characteristics					Water Depth in Drywell (in)	
	f_0 (in/hr)	f_c (in/hr)	k (1/min)	Start Time	End Time	Duration (hr:min)	Depth (in)	Average intensity (in/hr)	Max.	Min.
7-26-2009	3.188	0.659	0.005	7/26/2009 16:46	7/26/2009 23:22	6:36	1.37	0.21	22.73	0.22
7-29-2009	10.253	1.139	0.0035	7/29/2009 10:00	7/29/2009 19:13	9:13	1.33	0.14	75.85	7.34 (high watertable)
8-02-2009	5.45	0.928	0.003	8/2/2009 6:29	8/2/2009 12:55	6:26	1.31	0.2	77.87	0.43
8-22-2009	3.623	1.186	0.03	8/21/2009 23:54	8/22/2009 10:43	10:49	1.9	0.18	35.82	0.37

Table B-15 Statistical Analysis for Horton parameters (fo, fc, and k) (383 Wyoming Ave)

Statistical Analysis	Horton's Parameters			Water Depth in Drywell (in)	
	f_0 (in/hr)	f_c (in/hr)	k (1/min)	Max.	Min.
Number of Events	5	5	5	5	5
Minimum	3.19	0.66	0.00	22.73	0.22
Maximum	10.25	1.19	0.03	77.87	7.34
Average	5.63	1.02	0.01	50.58	1.78
Std	2.80	0.23	0.01	24.88	3.11
COV	0.50	0.22	1.27	0.49	1.75

260 Hartshorn Dr

Table B-17 Summary of Horton parameters (f0, fc, and k) for different events (260 Hartshorn Dr)

Date	Horton's Parameters			Rain Characteristics					Water Depth in Drywell (in)	
	f_0 (in/hr)	f_c (in/hr)	k (1/min)	Start Time	End Time	Duration (hr:min)	Depth (in)	Average intensity (in/hr)	Max.	Min.
08-10-2010	8.774	0.4	0.009						53.76	15.35 (high watertable)
08-22-2010	8.4097	0.6	0.011	8/22/2010 12:41	8/22/2010 20:42	8:01	1.51	0.19	55.71	28.81 (high watertable)
08-25-2010	1.0131	0.23	0.02	8/25/2010 2:00	8/25/2010 10:21	8:21	0.43	0.05	46.52	0.77
09-16-2010	2.411	0.3	0.005	9/16/2010 15:55	9/16/2010 22:14	6:19	0.61	0.10	40.20	8.49 (high watertable)
09-30-2010	8.158	0.65	0.03	9/30/2010 4:14	9/30/2010 10:01	5:47	1.83	0.32	56.81	38.64 (high watertable)
10-01-2010	5.862	0.7	0.02	10/1/2010 1:41	10/1/2010 13:05	11:24	2.53	0.22	63.97	7.41 (high watertable)
02-25-2011	1.897	0.4	0.02	2/25/2011 0:25	2/25/2011 18:44	18:19	1.36	0.06	54.45	36.27 (high watertable)
03-07-2011	1.586	0.4	0.002	3/6/2011 7:55	3/7/2011 3:29	19:34	2.78	0.14	54.47	31.64 (high watertable)
06-17-2011	9.6229	0.6	0.05	6/17/2011 13:45	6/17/2011 18:22	4:37	2.78	0.62	56.00	18.24 (high watertable)
07-08-2011	9.284	0.45	0.035	7/8/2011 16:02	7/8/2011 20:46	4:44	0.73	0.15	55.19	1.14
08-01-2011	1.434	0.25	0.015	8/1/2011 0:25	8/1/2011 0:42	0:17	0.46	1.62	31.74	24.38 (high watertable)
08-04-2011	3.045	0.6	0.008	8/3/2011 16:28	8/4/2011 4:02	11:34	0.65	0.06	49.56	5.40 (high watertable)

Table B-18 Summary of Horton parameters (fc; f0 and k are n/a) for different rains having "constant" infiltration rates (260 Hartshorn Dr)

Date	f_c infiltration rate (in/hr)			Rain Characteristics					Water Depth in Drywell (in)	
	Average	Std Deviation	Cov.	Start Time	End Time	Duration (hr:min)	Depth (in)	Average intensity (in/hr)	Max.	Min.
08-16-2010	0.21	0.13	0.6	8/16/2010 16:24	8/16/2010 20:53	4:29	0.26	0.06	29.91	7.87 (high watertable)
09-13-2010	0.23	018	081	9/13/2010 17:00	9/13/2010 17:58	0:58	0.51	0.53	28.47	14.62 (high watertable)
09-27-2010	0.21	0.25	1.19	9/27/2010 7:40	9/28/2010 12:36	28:56	0.69	0.02	29.58	20.48 (high watertable)
05-23-2011	0.23	0.21	0.93	5/23/2011 22:19	5/23/2011 23:17	0:58	0.68	0.70	41.68	15.31 (high watertable)
05-30-2011	0.19	0.11	0.6	5/30/2011 6:07	5/30/2011 6:41	0:34	0.27	0.48	24.07	0.94
06-11-2011	0.22	0.15	0.68	6/11/2011 1:26	6/11/2011 5:29	4:03	0.56	0.14	19.16	11.72 (high watertable)
07-03-2011	0.18	0.11	0.62	7/3/2011 4:46	7/3/2011 21:23	16:37	0.33	0.02	19.74	14.67 (high watertable)

Table B-19 Statistical Analysis for Horton parameters (fo, fc, and k) (260 Hartshorn Dr)

Statistical Analysis	Horton's Parameters			Water Depth in Drywell (in)	
	f_0 (in/hr)	f_c (in/hr)	k (1/min)	Max.	Min.
Number of Events	12	19	12	19	19
Minimum	1.01	0.18	0.00	19.16	0.77
Maximum	9.62	0.70	0.05	63.97	38.64
Average	5.12	0.37	0.02	42.68	15.90
Std	3.52	0.18	0.01	14.35	11.64
COV	0.69	0.48	0.74	0.34	0.73

87/89 Tennyson Dr

Table B-20 Summary of Horton parameters (f0, fc, and k) for rain events (87/89 Tennyson Dr)

Date	Horton's Parameters			Rain Characteristics					Water Depth in Drywell (in)	
	f_0 (in/hr)	f_c (in/hr)	k (1/min)	Start Time	End Time	Duration (hr:min)	Depth (in)	Average intensity (in/hr)	Max.	Min.
09-30-2010	1.717	0.196	0.006	9/30/2010 4:14	9/30/2010 10:01	5:47	1.83	0.32	89.08	82.98 (high watertable)
10-01-2010	1.721	0.251	0.008	10/1/2010 1:41	10/1/2010 13:05	11:24	2.53	0.22	93.08	35.37 (high watertable)
03-06-2011	3.281	0.45	0.015	3/6/2011 7:55	3/7/2011 3:29	19:34	2.78	0.14	93.85	82.135 (high watertable)
03-11-2011	2.899	0.28	0.015	3/10/2011 2:47	3/11/2011 8:05	29:18	2.90	0.10	93.37	46.85 (high watertable)
06-17-2011	10.99	0.28	0.12	6/17/2011 13:45	6/17/2011 18:22	4:37	2.78	0.62	91.17	64.71 (high watertable)

Table B-21 Summary of Horton parameters (fc; f0 and k are n/a) for different rains having "constant" infiltration rates (87/89 Tennyson Dr)

Date	f_c infiltration rate (in/hr)			Rain Characteristics					Water Depth in Drywell (in)	
	Average	Std Deviation	Cov.	Start Time	End Time	Duration (hr:min)	Depth (in)	Average intensity (in/hr)	Max.	Min.
08-10-2010	0.18	0.12	0.64						67.23	45.66 (high watertable)
08-23-2010	0.199	0.14	0.72	8/22/2010 12:41	8/22/2010 20:42	8:01	1.51	0.19	80.90	74.83 (high watertable)
08-25-2010	0.18	0.12	0.67	8/25/2010 2:00	8/25/2010 10:21	8:21	0.43	0.05	83.47	34.33 (high watertable)
09-14-2010	0.16	0.10	0.64	9/13/2010 17:00	9/13/2010 17:58	0:58	0.51	0.53	50.06	45.91 (high watertable)
09-28-2010	0.35	0.33	0.94	9/27/2010 7:40	9/28/2010 12:36	28:56	0.69	0.02	51.81	48.77 (high watertable)
11-05-2010	0.26	0.19	0.73	11/4/2010 3:26	11/5/2010 7:35	28:09	1.16	0.04	58.29	26.45 (high watertable)
12-01-2010	0.23	0.18	0.79	12/1/2010 1:05	12/1/2010 15:07	14:02	1.88	0.13	71.94	44.4 (high watertable)
12-13-2010	0.26	0.21	0.81	12/12/2010 0:57	12/13/2010 6:51	29:54	1.87	0.06	83.88	26.63 (high watertable)
02-28-2011	0.27	0.21	0.78						89.79	74.40 (high)
05-23-2011	0.22	0.17	0.75	5/23/2011 22:19	5/23/2011 23:17	0:58	0.68	0.70	83.67	69.66 (high watertable)
05-30-2011	0.15	0.10	0.68	5/30/2011 6:07	5/30/2011 6:41	0:34	0.27	0.48	74.62	58.65 (high watertable)
06-11-2011	0.18	0.13	0.73	6/11/2011 1:26	6/11/2011 5:29	4:03	0.56	0.14	69.38	63.55 (high watertable)
07-08-2011	0.22	0.14	0.65	7/8/2011 16:02	7/8/2011 20:46	4:44	0.73	0.15	81.71	46.41 (high watertable)
08-01-2011	0.18	0.13	0.7	8/1/2011 0:25	8/1/2011 0:42	0:17	0.46	1.62	61.96	56.53 (high watertable)
08-04-2011	0.18	0.08	0.48	8/3/2011 16:28	8/4/2011 4:02	11:34	0.65	0.06	73.23	72.4 (high watertable)

Table B-22 Statistical Analysis for Horton parameters (fo, fc, and k) (87/89 Tennyson Dr)

Statistical Analysis	Horton's Parameters			Water Depth in Drywell (in)	
	f_0 (in/hr)	f_c (in/hr)	k (1/min)	Max.	Min.
Number of Events	5	20	5	20	20
Minimum	1.72	0.20	0.01	50.06	26.45
Maximum	10.99	0.45	0.12	93.85	82.98
Average	4.12	0.29	0.03	77.12	5.03
Std	3.90	0.10	0.05	13.82	17.60
COV	0.95	0.33	1.49	0.18	0.32

1 Sinclair Terrace

Table B-23 Summary of infiltration hydrant water test (1 Sinclair Terrace)

Date	Horton's parameters			Study Test				Water Depth in Drywell (in)	
	f_0 (in/hr)	f_c (in/hr)	k (1/min)	Start Time	End Time	Duration (hr:min)	Fill Rate (gal/min)	Max.	Min.
07-15-2009	3.306	0.700	0.0015	7/15/2009 10:40	7/15/2009 11:30	0:50	66.00	51.02	0

142 Fairfield Dr

Table B-24 Summary of Horton parameters (f0, fc, and k) for rain events (142 Fairfield Dr)

Date	Horton's Parameters			Rain Characteristics					Water Depth in Drywell (in)	
	f_0 (in/hr)	f_c (in/hr)	k (1/min)	Start Time	End Time	Duration (hr:min)	Depth (in)	Average intensity (in/hr)	Max.	Min.
08-10-2010	3.061	0.051	0.01						35.55	0.64
10-01-2010	3.010	0.61	0.002	10/1/2010 2:17	10/1/2010 16:48	14:31	1.73	0.12	73.75	0.28
10-07-2010	1.543	0.548	0.01						25.95	0.49

Table B-25 Summary of Horton parameters (fc; f0 and k are n/a) for different rains having "constant" infiltration rates (142 Fairfield Dr)

Date	f_c infiltration rate (in/hr)			Rain Characteristics					Water Depth in Drywell (in)	
	Average	Std Deviation	Cov.	Start Time	End Time	Duration (hr:min)	Depth (in)	Average intensity (in/hr)	Max.	Min.
08-22-2010	0.33	0.63	1.87	8/22/2010 11:20	8/22/2010 19:19	7:59	1.43	0.18	28.82	0.47
12-01-2010	0.33	0.18	0.56	12/1/2010 2:15	12/2/2010 1:05	22:50	0.67	0.02	24.59	0.56
02-26-2011	0.32	0.51	1.59	2/24/2011 21:58	2/25/2011 13:46	15:48	0.59	0.04	33.8	12.06 (high watertable)
03-07-2011	0.72	0.37	0.52	3/6/2011 9:00	3/7/2011 3:22	18:22	1.15	0.06	73.69	23.29 (high watertable)

Table B-26 Statistical Analysis for Horton parameters (fo, fc, and k) (142 Fairfield Dr)

Statistical Analysis	Horton's Parameters			Water Depth in Drywell (in)	
	f_0 (in/hr)	f_c (in/hr)	k (1/min)	Max.	Min.
Number of Events	3	7	3	7	7
Minimum	1.54	0.05	0.00	24.59	0.28
Maximum	3.06	0.72	0.01	73.75	23.29
Average	2.54	0.42	0.01	42.31	5.40
Std	0.86	0.23	0.00	21.81	8.99
COV	0.34	0.54	0.63	0.52	1.67

8 South Beechcroft Rd

Table B-27 Summary of infiltration hydrant water test (8 Beechcroft Rd)

Date	Horton's parameters			Study Test				Water Depth in Drywell (in)	
	f_0 (in/hr)	f_c (in/hr)	k (1/min)	Start Time	End Time	Duration (hr:min)	Fill Rate (gal/min)	Max.	Min.
10-02-2009	16.12	0.08	0.017	10/2/2009 12:07	10/2/2009 12:15	0:08	112.50	16.76	0.32

Table B-28 Summary of Horton parameters (f0, fc, and k) for rain events (8 Beechcroft Rd)

Date	Horton's Parameters			Rain Characteristics					Water Depth in Drywell (in)	
	f_0 (in/hr)	f_c (in/hr)	k (1/min)	Start Time	End Time	Duration (hr:min)	Depth (in)	Average intensity (in/hr)	Max.	Min.
7/26/2009	45.29	2.02	0.026	7/26/2009 16:46	7/27/2009 0:17	7:31	1.38	0.18	41.29	1.94
8/22/2009	45.95	0.3	0.011	8/21/2009 23:57	8/22/2009 18:28	18:28	1.71	0.09	47.04	0.10
8/29/2009	19.78	0.24	0.009	8/29/2009 5:45	8/29/2009 12:27	6:42	0.52	0.08	32.25	0.13

Table B-29 Statistical Analysis for Horton parameters (fo, fc, and k) (8 Beechcroft Rd)

Statistical Analysis	Horton's Parameters			Water Depth in Drywell (in)	
	f_0 (in/hr)	f_c (in/hr)	k (1/min)	Max.	Min.
Number of Events	4	4	4	4	4
Minimum	16.12	0.08	0.01	16.76	0.10
Maximum	45.95	2.02	0.03	47.04	1.94
Average	31.79	0.66	0.02	34.34	0.62
Std	16.05	0.91	0.01	13.20	0.88
COV	0.50	1.38	0.48	0.38	1.42

7 Fox Hill Ln

Table B-30 Summary of Horton parameters (f0, fc, and k) for rain events (7 Fox Hill Ln)

Date	Horton's Parameters			Rain Characteristics					Water Depth in Drywell (in)	
	f_0 (in/hr)	f_c (in/hr)	k (1/min)	Start Time	End Time	Duration (hr:min)	Depth (in)	Average intensity (in/hr)	Max.	Min.
08-10-2010	3.667	0.19	0.013						50.13	18.32 (high watertable)
08-22-2010	2.800	0.57	0.014	8/22/2010 11:20	8/22/2010 19:19	7:59	1.43	0.18	58.29	1.34
09-30-2010	2.200	0.39	0.014	9/30/2010 4:20	9/30/2010 9:42	5:22	0.92	0.17	58.85	46.7 (high watertable)
10-01-2010	3.506	0.46	0.014	10/1/2010 2:17	10/1/2010 16:48	14:31	1.73	0.12	63.98	10.07 (high watertable)
11-05-2010	1.701	0.34	0.015						42.51	5.62 (high watertable)
12-01-2010	3.891	0.49	0.020	12/1/2010 2:15	12/2/2010 1:05	22:50	0.67	0.02	59.5	5.65 (high watertable)
12-13-2010	2.189	0.368	0.017	12/12/2010 17:25	12/13/2010 3:18	9:53	0.23	0.02	56.53	0.19
02-25-2011	3.116	0.45	0.020	2/24/2011 21:58	2/25/2011 13:46	15:48	0.59	0.04	57.44	41.48 (high watertable)
02-28-2011	1.941	0.423	0.019	2/28/2011 4:12	2/28/2011 11:32	7:20	0.22	0.03	56.39	23.97 (high watertable)
03-06-2011	2.748	0.40	0.021	3/6/2011 9:00	3/7/2011 3:22	18:22	1.15	0.06	56.73	42.19 (high watertable)
03-11-2011	1.924	0.276	0.018	3/10/2011 5:30	3/11/2011 4:33	23:03	0.98	0.04	58.05	25.86 (high watertable)

Table B-31 Statistical Analysis for Horton parameters (fo, fc, and k) (7 Fox Hill Ln)

Statistical Analysis	Horton's Parameters			Water Depth in Drywell (in)	
	f_0 (in/hr)	f_c (in/hr)	k (1/min)	Max.	Min.
Number of Events	11	11	11	11	11
Minimum	1.70	0.19	0.01	42.51	0.19
Maximum	3.89	0.57	0.02	63.98	46.70
Average	2.70	0.40	0.02	56.22	20.13
Std	0.77	0.10	0.00	5.59	17.24
COV	0.28	0.26	0.17	0.10	0.86

9 Fox Hill Ln

Table B-32 Summary of infiltration hydrant water test, "constant" rate (fc; f0 and k are n/a) (9 Fox Hill Ln)

Date	fc infiltration rate (in/hr)			Study Test				Water Depth in Drywell (in)	
	Average	Std Deviation	Cov.	Start Time	End Time	Duration (hr:min)	Fill Rate (gal/min)	Max.	Min.
10-02-2009	0.12	0.16	1.32	10/2/2009 12:44	10/2/2009 13:15	0:31	83.87	21.06	9.023* (high watertable)

* on 10/12/2009

11 Fox Hill Ln

Table B-33 Summary of infiltration hydrant water test (11 Fox Hill Ln)

Date	Horton's parameters			Study Test				Horton's parameters	
	f_0 (in/hr)	f_c (in/hr)	k (1/min)	Start Time	End Time	Duration (hr:min)	Fill Rate (gal/min)	Max.	Min.
10-02-2009	1.09	0.25	0.012	10/2/2009 13:16	10/2/2009 14:00	0:44	77.27	31.73	0.12*

* on 10/12/2009

Table 6a. 11 Woodfield Dr. (D surface HSG soil conditions, and A and B subsurface soil conditions)

test conditions	date	fo (in/hr)	fc (in/hr)	k (1/min)	Rain Depth (in)	Max. depth (in)	Min. depth (in)	water table conditions
hydrant	10/13/2009	13.945	1.2	0.012	n/a	43.68	0.72	OK
Horton	10/24/2009	2.987	0.95	0.005	2.2	28.11	0.57	OK
constant	10/28/2009	n/a	0.83	n/a	1.6	11.1	0.45	OK
Horton	12/9/2009	4.117	0.72	0.006	2.01	39.12	0.03	OK
constant	12/13/2009	n/a	0.44	n/a	0.99	9.02	0.2	OK
	number	3	5	3	4	5	5	
	Minimum	2.99	0.44	0.01	0.99	9.02	0.03	
	Maximum	13.95	1.20	0.01	2.20	43.68	0.72	
	Average	7.02	0.83	0.01	1.70	26.21	0.39	
	Std Dev	6.03	0.28	0.00	0.54	15.81	0.28	
	COV	0.86	0.34	0.49	0.31	0.60	0.71	

Table 6b. 15 Marion (D surface HSG soil conditions, and A and B subsurface soil conditions)

test conditions	date	fo (in/hr)	fc (in/hr)	k (1/min)	Rain Depth (in)	Max. depth (in)	Min. depth (in)	water table conditions
Horton	6/16/2010	9.95	0.5	0.02	0.69	56.74	0.36	OK
constant	6/22/2010	n/a	0.2	n/a	0.37	6.51	0.25	OK
constant	7/14/2010	n/a	0.3	n/a	1.22	23.02	0.35	OK
constant	8/1/2010	n/a	0.34	n/a	1.34	26.85	0.25	OK
	number	1	4	1	4	4	4	
	Minimum	9.95	0.20	0.02	0.37	6.51	0.25	
	Maximum	9.95	0.50	0.02	1.34	56.74	0.36	
	Average	9.95	0.34	0.02	0.91	28.28	0.30	
	Std Dev	n/a	0.12	n/a	0.45	20.93	0.06	
	COV	n/a	0.37	n/a	0.50	0.74	0.20	

Table 6c. 258 Main St. (A and D surface HSG soil conditions, and A subsurface soil conditions)

test conditions	**date**	**fo (in/hr)**	**fc (in/hr)**	**k (1/min)**	**Rain Depth (in)**	**Max. depth (in)**	**Min. depth (in)**	**water table conditions**
Horton	6/17/2010	34.653	5.308	0.06	0.69	22.32	0.11	OK
Horton	7/14/2010	75.142	6.808	0.07	1.22	53.62	0.67	OK
Horton	8/1/2010	74.916	4.662	0.045	1.34	54.77	0.53	OK
	number	3	3	3	3	3	3	
	Minimum	34.65	4.66	0.05	0.69	22.32	0.11	
	Maximum	75.14	6.81	0.07	1.34	54.77	0.67	
	Average	61.57	5.59	0.06	1.08	43.57	0.44	
	Std Dev	23.31	1.10	0.01	0.35	18.41	0.29	
	COV	0.38	0.20	0.22	0.32	0.42	0.67	

Table 6d. 2 Undercliff Rd (C surface HSG soil conditions, and A and B subsurface soil conditions)

test conditions	**date**	**fo (in/hr)**	**fc (in/hr)**	**k (1/min)**	**Rain Depth (in)**	**Max. depth (in)**	**Min. depth (in)**	**water table conditions**
constant	7/29/2009	n/a	2.368	n/a	1.33	9.16	5.01	high
constant	8/2/2009	n/a	0.17	n/a	1.31	16.54	0.39	OK
hydrant	10/2/2009	3.881	0.566	0.013	n/a	54.21	0.23	OK
	number	1	3	1	2	3	3	
	Minimum	3.88	0.17	0.01	1.31	9.16	0.23	
	Maximum	3.88	2.37	0.01	1.33	54.21	5.01	
	Average	3.88	1.03	0.01	1.32	26.64	1.88	
	Std Dev	n/a	1.17	n/a	0.01	24.16	2.71	
	COV	n/a	1.13	n/a	0.01	0.91	1.45	

Table 6e. 383 Wyoming Ave (C surface HSG soil conditions, and A subsurface soil conditions)

test conditions	**date**	**fo (in/hr)**	**fc (in/hr)**	**k (1/min)**	**Rain Depth (in)**	**Max. depth (in)**	**Min. depth (in)**	**water table conditions**
Horton	7/26/2009	3.188	0.659	0.005	1.37	22.73	0.22	OK
Horton	7/29/2009	10.253	1.139	0.0035	1.33	75.85	7.34	high
Horton	8/2/2009	5.45	0.928	0.003	1.31	77.87	0.43	OK
Horton	8/22/2009	3.623	1.186	0.03	1.9	35.82	0.37	OK
hydrant	10/2/2009	5.631	1.171	0.0045	n/a	40.65	0.53	OK
	number	5	5	5	4	5	5	
	Minimum	3.19	0.66	0.00	1.31	22.73	0.22	
	Maximum	10.25	1.19	0.03	1.90	77.87	7.34	
	Average	5.63	1.02	0.01	1.48	50.58	1.78	
	Std Dev	2.80	0.23	0.01	0.28	24.88	3.11	
	COV	0.50	0.22	1.27	0.19	0.49	1.75	

Table 6f. 260 Hartshorn Dr (D surface HSG soil conditions, and A and B subsurface soil conditions)

test conditions	**date**	**fo (in/hr)**	**fc (in/hr)**	**k (1/min)**	**Rain Depth (in)**	**Max. depth (in)**	**Min. depth (in)**	**water table conditions**
Horton	8/10/2010	8.774	0.4	0.009	n/a	53.76	15.35	high
constant	8/16/2010	n/a	0.21	n/a	0.26	29.91	7.87	high
Horton	8/22/2010	8.4097	0.6	0.011	1.51	55.71	28.81	high
Horton	8/25/2010	1.0131	0.23	0.02	0.43	46.52	0.77	OK
constant	9/13/2010	n/a	0.23	n/a	0.51	28.47	14.62	high
Horton	9/16/2010	2.411	0.3	0.005	0.61	40.2	8.49	high
constant	9/27/2010	n/a	0.21	n/a	0.69	29.58	20.48	high
Horton	9/30/2010	8.158	0.65	0.03	1.83	56.81	38.64	high
Horton	10/1/2010	5.862	0.7	0.02	2.53	63.97	7.41	high
Horton	2/25/2011	1.897	0.4	0.02	1.36	54.45	36.27	high
Horton	3/7/2011	1.586	0.4	0.002	2.78	54.47	31.64	high
constant	5/23/2011	n/a	0.23	n/a	0.68	41.68	15.31	high
constant	5/30/2011	n/a	0.19	n/a	0.27	24.07	0.94	OK
constant	6/11/2011	n/a	0.22	n/a	0.56	19.16	11.72	high
Horton	6/17/2011	9.6229	0.6	0.05	2.78	56	18.24	high
constant	7/3/2011	n/a	0.18	n/a	0.33	19.74	14.67	high
Horton	7/8/2011	9.284	0.45	0.035	0.73	55.19	1.14	OK
Horton	8/1/2011	1.434	0.25	0.015	0.46	31.74	24.38	high
Horton	8/4/2011	3.045	0.6	0.008	0.65	49.56	5.4	high
	number	12	19	12	18	19	19	

test conditions	date	fo (in/hr)	fc (in/hr)	k (1/min)	Rain Depth (in)	Max. depth (in)	Min. depth (in)	water table conditions
	Minimum	1.01	0.18	0.00	0.26	19.16	0.77	
	Maximum	9.62	0.70	0.05	2.78	63.97	38.64	
	Average	5.12	0.37	0.02	1.05	42.68	15.90	
	Std Dev	3.52	0.18	0.01	0.87	14.35	11.64	
	COV	0.69	0.48	0.74	0.82	0.34	0.73	

Table 6g. 87/89 Tennyson Dr (D surface HSG soil conditions, and A and B subsurface soil conditions)

test conditions	date	fo (in/hr)	fc (in/hr)	k (1/min)	Rain Depth (in)	Max. depth (in)	Min. depth (in)	water table conditions
constant	8/10/2010	n/a	0.18	n/a	n/a	67.23	45.66	high
constant	8/23/2010	n/a	0.199	n/a	1.51	80.9	74.83	high
constant	8/25/2010	n/a	0.18	n/a	0.43	83.47	34.33	high
constant	9/14/2010	n/a	0.16	n/a	0.51	50.06	45.91	high
constant	9/28/2010	n/a	0.35	n/a	0.69	51.81	48.77	high
Horton	9/30/2010	1.717	0.196	0.006	1.83	89.08	82.98	high
Horton	10/1/2010	1.721	0.251	0.008	2.53	93.08	35.37	high
constant	11/5/2010	n/a	0.26	n/a	1.16	58.29	26.45	high
constant	12/1/2010	n/a	0.23	n/a	1.88	71.94	44.4	high
constant	12/13/2010	n/a	0.26	n/a	1.87	83.88	26.63	high
constant	2/28/2011	n/a	0.27	n/a	n/a	89.79	74.4	high
Horton	3/6/2011	3.281	0.45	0.015	2.78	93.85	82.135	high
Horton	3/11/2011	2.899	0.28	0.015	2.9	93.37	46.85	high
constant	5/23/2011	n/a	0.22	n/a	0.68	83.67	69.66	high
constant	5/30/2011	n/a	0.15	n/a	0.27	74.62	58.65	high
constant	6/11/2011	n/a	0.18	n/a	0.56	69.38	63.55	high
Horton	6/17/2011	10.99	0.28	0.12	2.78	91.17	64.71	high
constant	7/8/2011	n/a	0.22	n/a	0.73	81.71	46.41	high
constant	8/1/2011	n/a	0.18	n/a	0.46	61.96	56.53	high
constant	8/4/2011	n/a	0.18	n/a	0.65	73.23	72.4	high
	number	5	20	5	18	20	20	
	Minimum	1.72	0.20	0.01	0.27	50.06	26.45	
	Maximum	10.99	0.45	0.12	2.90	93.85	82.98	
	Average	4.12	0.29	0.03	1.35	77.12	55.03	
	Std Dev	3.90	0.10	0.05	0.93	13.82	17.60	
	COV	0.95	0.33	1.49	0.69	0.18	0.32	

Table 6h. 1 Sinclair Terrace (D surface HSG soil conditions, and A subsurface soil conditions)

test conditions	date	fo (in/hr)	fc (in/hr)	k (1/min)	Rain Depth (in)	Max. depth (in)	Min. depth (in)	water table conditions
hydrant	7/15/2009	3.306	0.7	0.0015		51.02	0	OK

Table 6i. 142 Fairfield Dr (D surface HSG soil conditions, and A and B subsurface soil conditions)

test conditions	date	fo (in/hr)	fc (in/hr)	k (1/min)	Rain Depth (in)	Max. depth (in)	Min. depth (in)	water table conditions
Horton	8/10/2010	3.061	0.051	0.01	n/a	35.55	0.64	OK
constant	8/22/2010	n/a	0.33	n/a	n/a	28.82	0.47	OK
Horton	10/1/2010	3.01	0.61	0.002	1.73	73.75	0.28	OK
Horton	10/7/2010	1.543	0.548	0.01	n/a	25.95	0.49	OK
constant	12/1/2010	n/a	0.33	n/a	n/a	24.59	0.56	OK
constant	2/26/2011	n/a	0.32	n/a	n/a	33.8	12.06	high
constant	3/7/2011	n/a	0.72	n/a	n/a	73.69	23.29	high
	number	3	7	3	1	7	7	
	Minimum	1.54	0.05	0.00	1.73	24.59	0.28	
	Maximum	3.06	0.72	0.01	1.73	73.75	23.29	
	Average	2.54	0.42	0.01	1.73	42.31	5.40	
	Std Dev	0.86	0.23	0.00	n/a	21.81	8.99	
	COV	0.34	0.54	0.63	n/a	0.52	1.67	

Table 6j. 8 So. Beechcroft Rd (2 years old, D surface HSG soil conditions, and A and B subsurface soil conditions)

test conditions	date	fo (in/hr)	fc (in/hr)	k (1/min)	Rain Depth (in)	Max. depth (in)	Min. depth (in)	water table conditions
Horton	7/26/2009	45.29	2.02	0.026	1.38	41.29	1.94	OK
Horton	8/22/2009	45.95	0.3	0.011	1.71	47.04	0.1	OK
Horton	8/29/2009	19.78	0.24	0.009	0.52	32.25	0.13	OK
hydrant	10/2/2009	16.12	0.08	0.017	n/a	16.76	0.32	OK
	number	4	4	4	3	4	4	
	Minimum	16.12	0.08	0.01	0.52	16.76	0.10	
	Maximum	45.95	2.02	0.03	1.71	47.04	1.94	
	Average	31.79	0.66	0.02	1.20	34.34	0.62	
	Std Dev	16.05	0.91	0.01	0.61	13.20	0.88	
	COV	0.50	1.38	0.48	0.51	0.38	1.42	

Table 6k. 7 Fox Hill Lane (2.3 years old, D surface HSG soil conditions, and A and B subsurface soil conditions)

test conditions	**date**	**fo (in/hr)**	**fc (in/hr)**	**k (1/min)**	**Rain Depth (in)**	**Max. depth (in)**	**Min. depth (in)**	**water table conditions**
Horton	8/10/2010	3.667	0.19	0.013	n/a	50.13	18.32	high
Horton	8/22/2010	2.8	0.57	0.014	1.43	58.29	1.34	OK
Horton	9/30/2010	2.2	0.39	0.014	0.92	58.85	46.7	high
Horton	10/1/2010	3.506	0.46	0.014	1.73	63.98	10.07	high
Horton	11/5/2010	1.701	0.34	0.015	n/a	42.51	5.62	high
Horton	12/1/2010	3.891	0.49	0.02	0.67	59.5	5.65	high
Horton	12/13/2010	2.189	0.368	0.017	0.23	56.53	0.19	OK
Horton	2/25/2011	3.116	0.45	0.02	0.59	57.44	41.48	high
Horton	2/28/2011	1.941	0.423	0.019	0.22	56.39	23.97	high
Horton	3/6/2011	2.748	0.4	0.021	1.15	56.73	42.19	high
Horton	3/11/2011	1.924	0.276	0.018	0.98	58.05	25.86	high
	number	11	11	11	9	11	11	
	Minimum	1.70	0.19	0.01	0.22	42.51	0.19	
	Maximum	3.89	0.57	0.02	1.73	63.98	46.70	
	Average	2.70	0.40	0.02	0.88	56.22	20.13	
	Std Dev	0.77	0.10	0.00	0.51	5.59	17.24	
	COV	0.28	0.26	0.17	0.58	0.10	0.86	

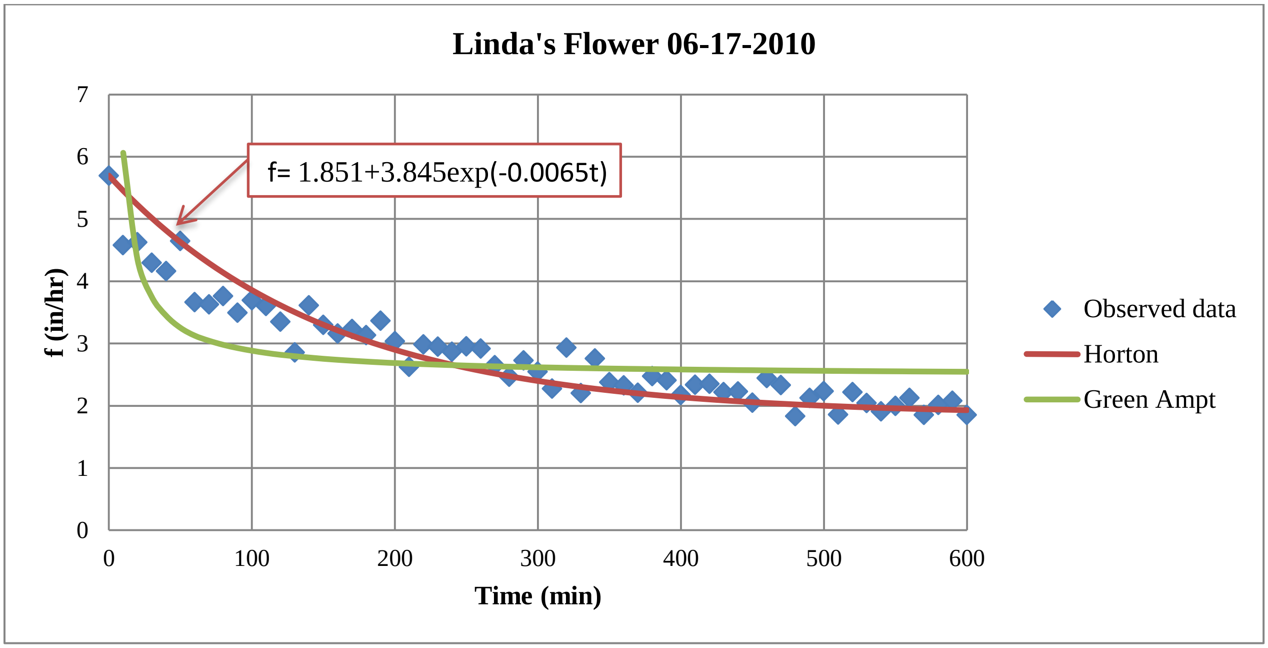
Table 6l. 9 Fox Hill Lane (D surface HSG soil conditions, and A and B subsurface soil conditions)

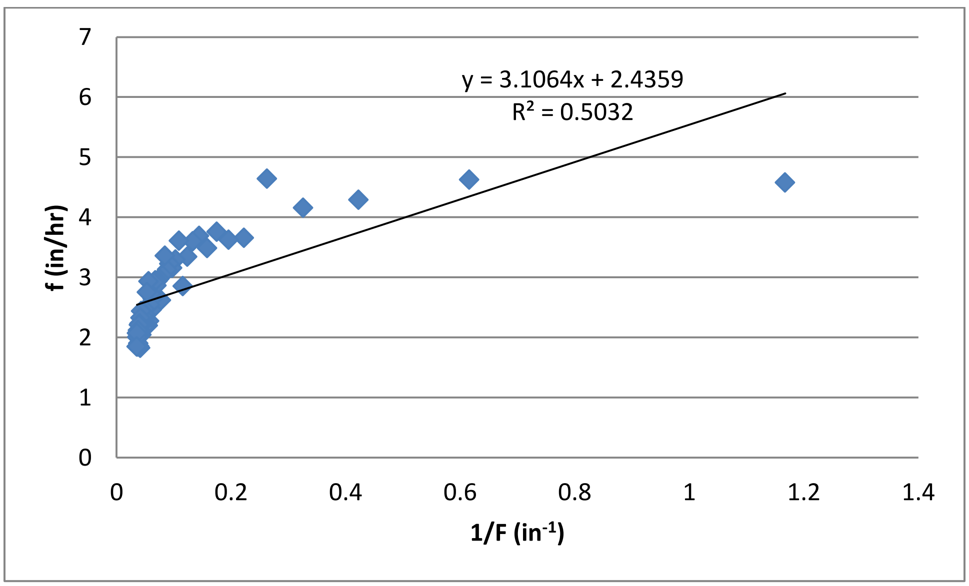
test conditions	**date**	**fo (in/hr)**	**fc (in/hr)**	**k (1/min)**	**Rain Depth (in)**	**Max. depth (in)**	**Min. depth (in)**	**water table conditions**
hydrant	10/2/2009	n/a	0.12	n/a	n/a	21.06	9.023	high

Table 6m. 11 Fox Hill Lane (D surface HSG soil conditions, and A and B subsurface soil conditions)

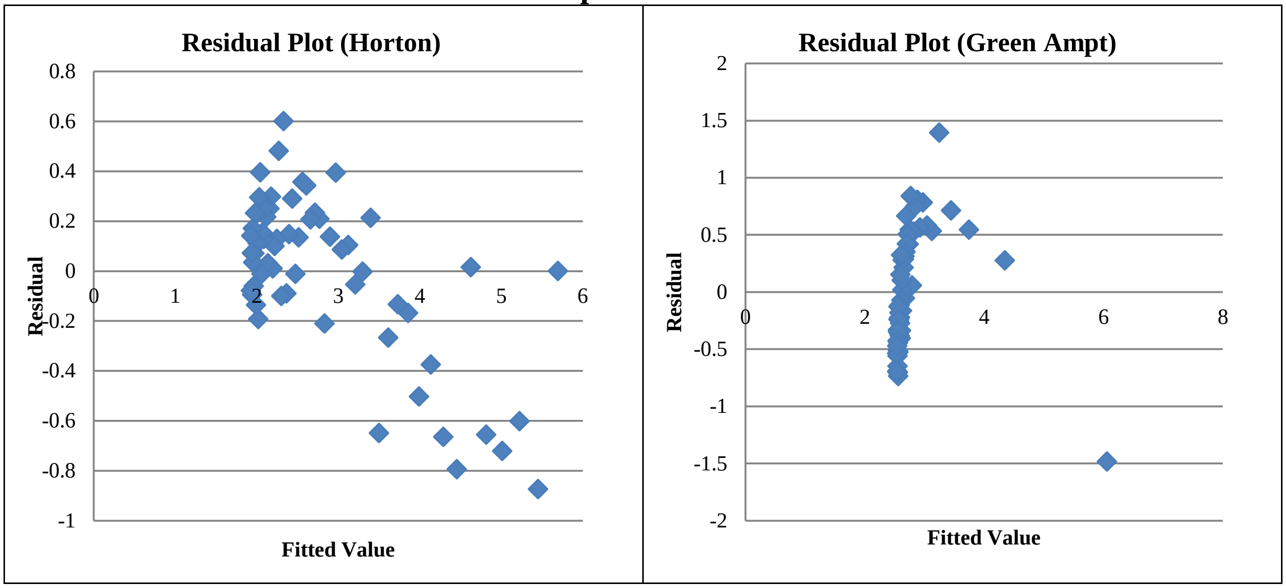
test conditions	date	fo (in/hr)	fc (in/hr)	k (1/min)	Rain Depth (in)	Max. depth (in)	Min. depth (in)	water table conditions
hydrant	10/2/2009	1.09	0.25	0.012	n/a	31.73	0.12	OK

Linda's Flower 06-17-2010





Residual Plots for Horton and Green Ampt fitted values

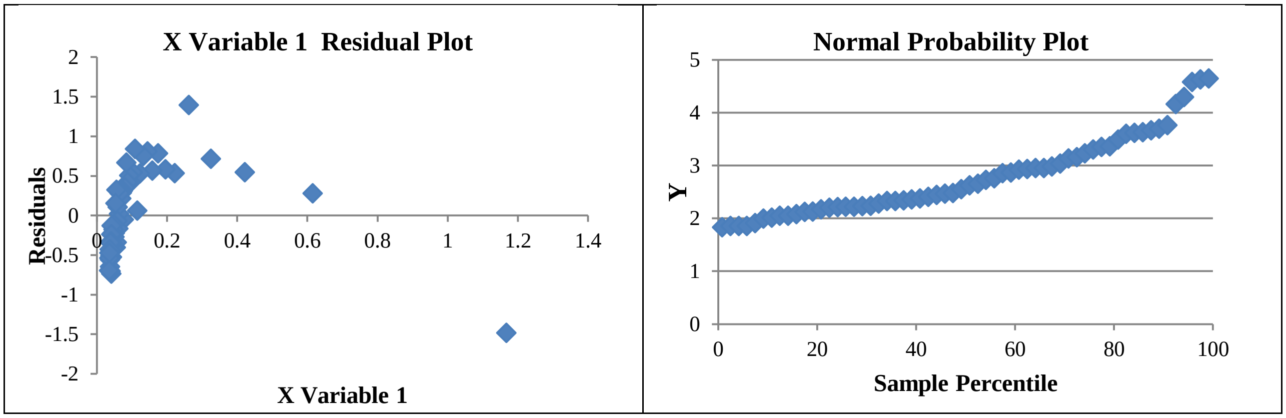


Regression Analysis for f vs. 1/F (Green Ampt)

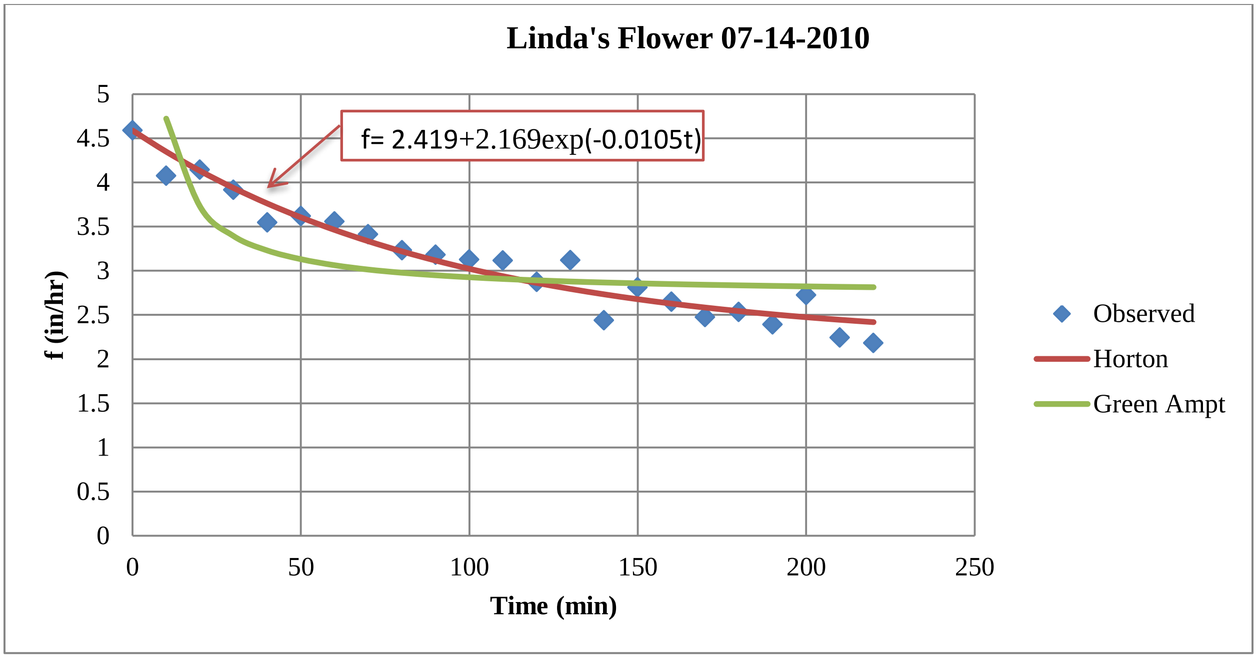
ANOVA

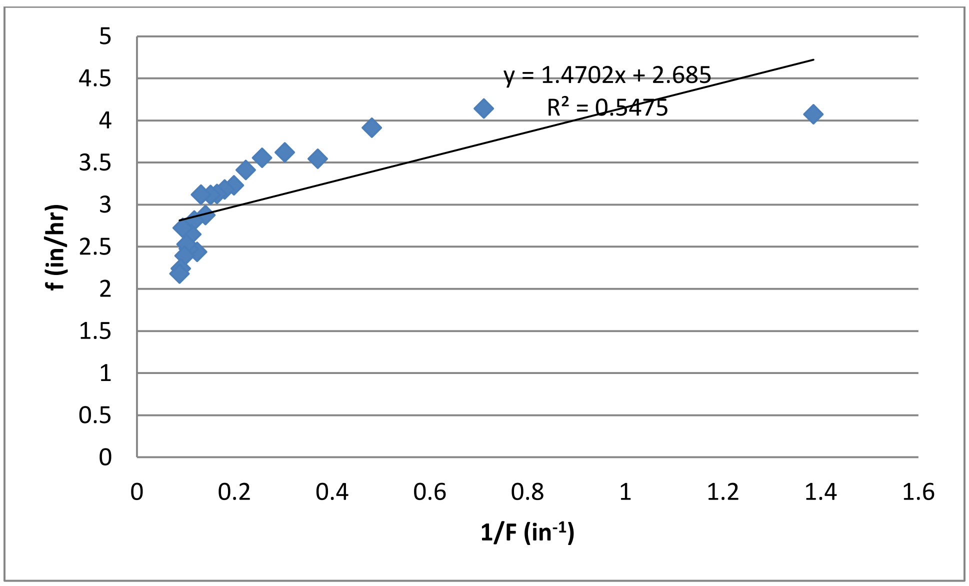
	df	SS	MS	F	Significance F
Regression	1	16.62278	16.62278	58.74998	2.24E-10
Residual	58	16.41058	0.282941		
Total	59	33.03335			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	2.435893	0.082297	29.5987	1.07E-36	2.271157	2.600629
X Variable 1	3.106365	0.405274	7.664854	2.24E-10	2.295121	3.917609

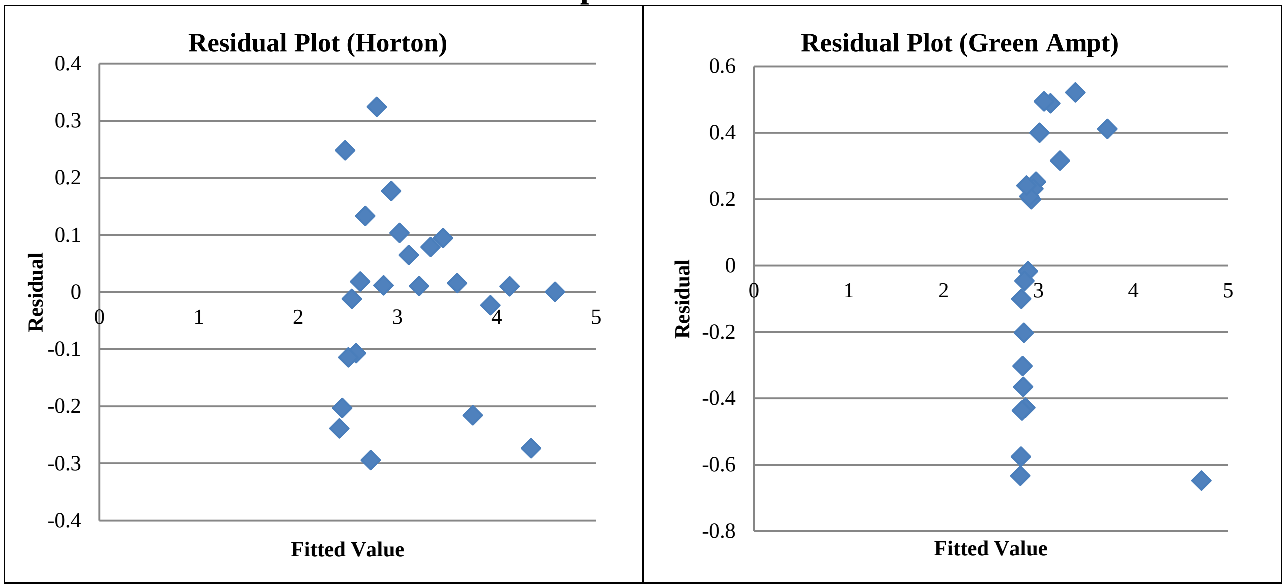


Linda's Flower 07-14-2010


Linda's Flower 07-14-2010
f= 2.419+2.169exp(-0.0105t)
f (in/hr)
Time (min)
Observed
Horton
Green Ampt
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
50
100
150
200
250


y = 1.4702x + 2.685
R² = 0.5475
f (in/hr)
1/F (in-1)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6

Residual Plots for Horton and Green Ampt fitted values

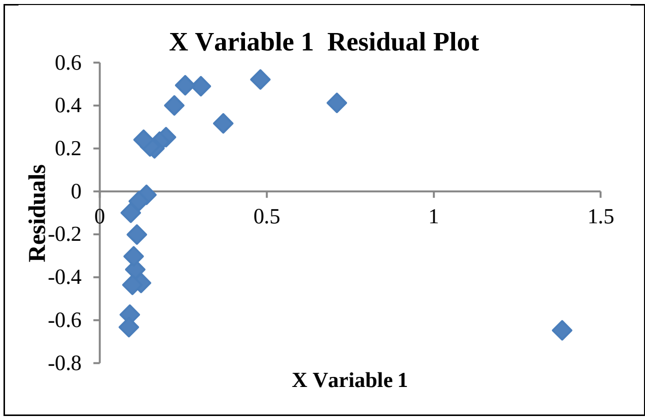


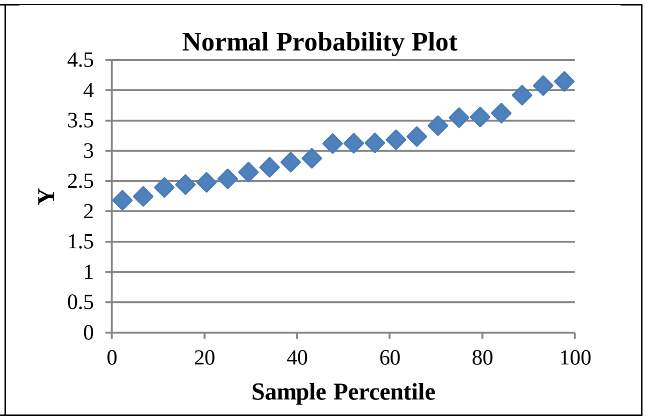
Regression Analysis for f vs. 1/F (Green Ampt)

ANOVA

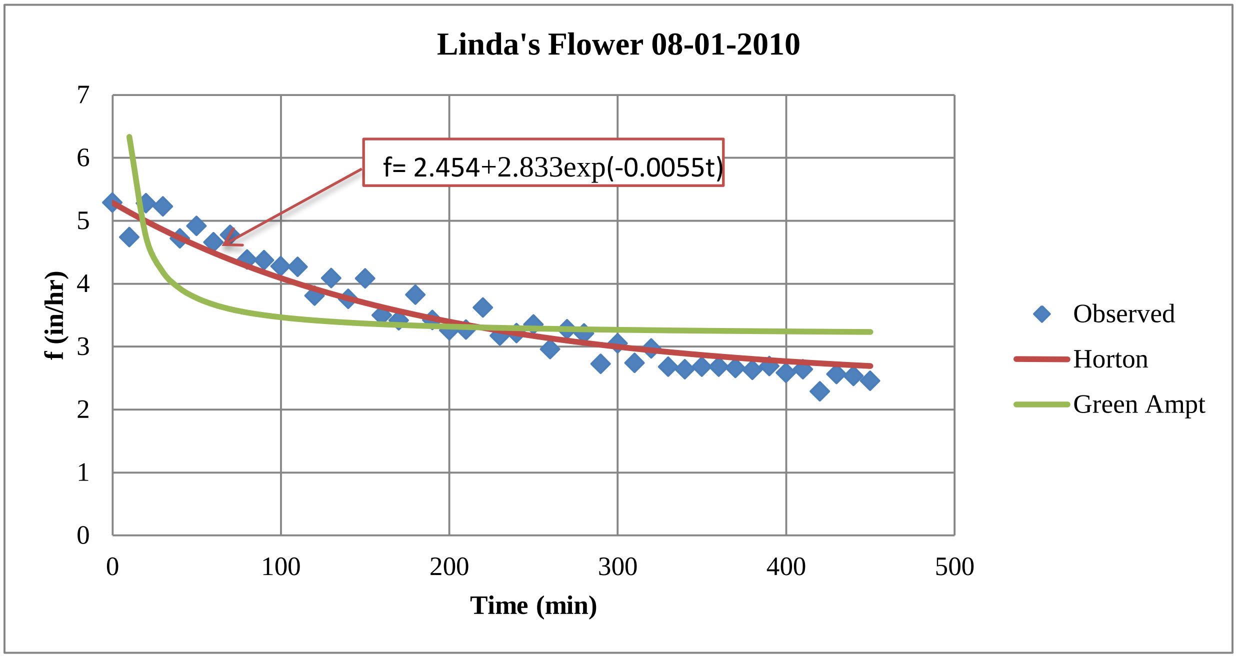
	df	SS	MS	F	Significance F
Regression	1	3.929311	3.929311	24.20193	8.27E-05
Residual	20	3.247105	0.162355		
Total	21	7.176416			

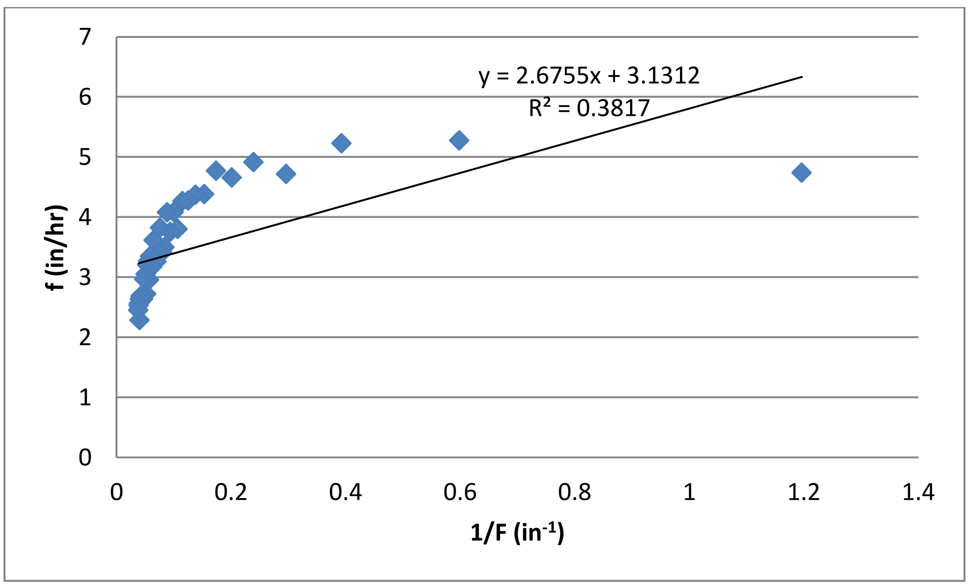
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	2.684982	0.115014	23.34489	5.53E-16	2.445068	2.924897
X Variable 1	1.47021	0.298851	4.919545	8.27E-05	0.846818	2.093602



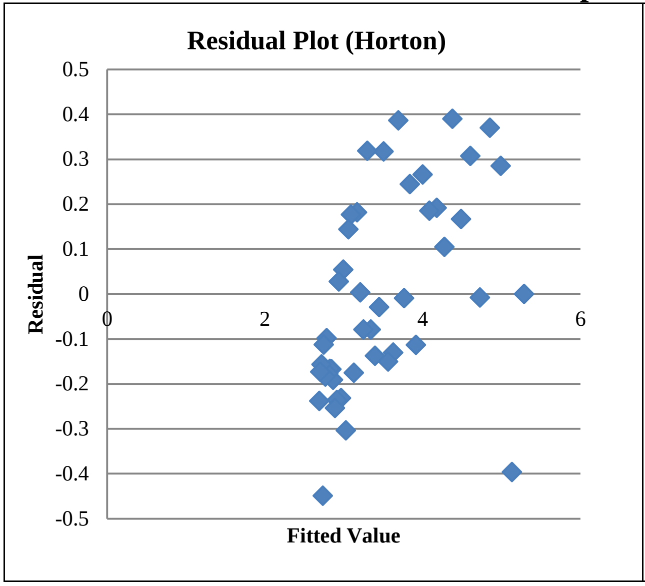


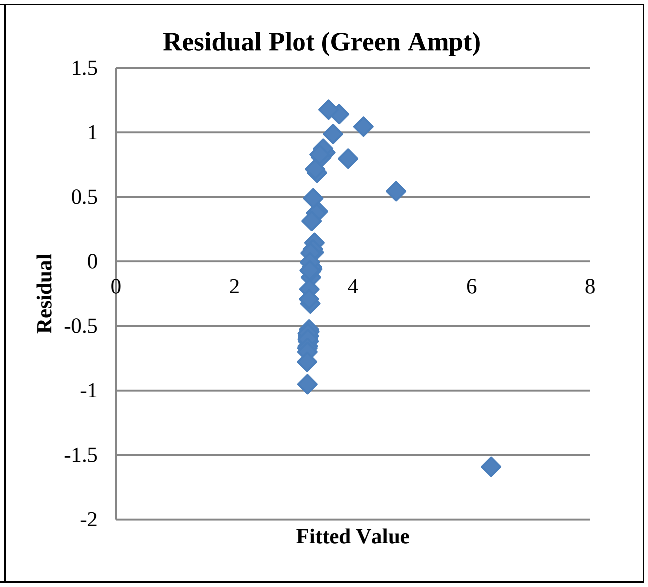
Linda's Flower 08-01-2010





Residual Plots for Horton and Green Ampt fitted values



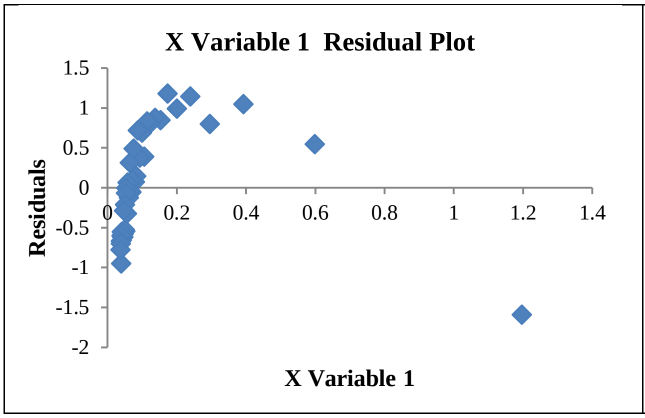


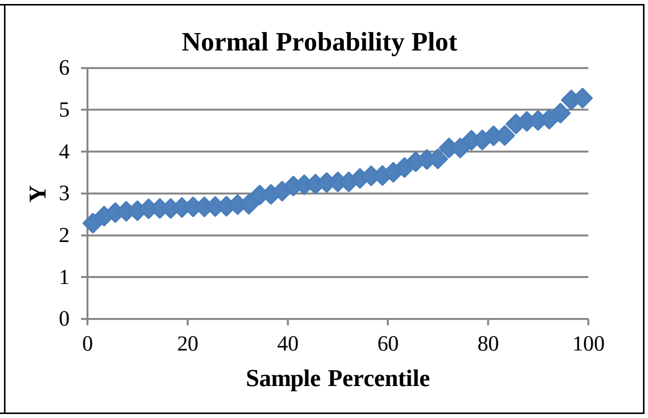
Regression Analysis for f vs. 1/F (Green Ampt)

ANOVA

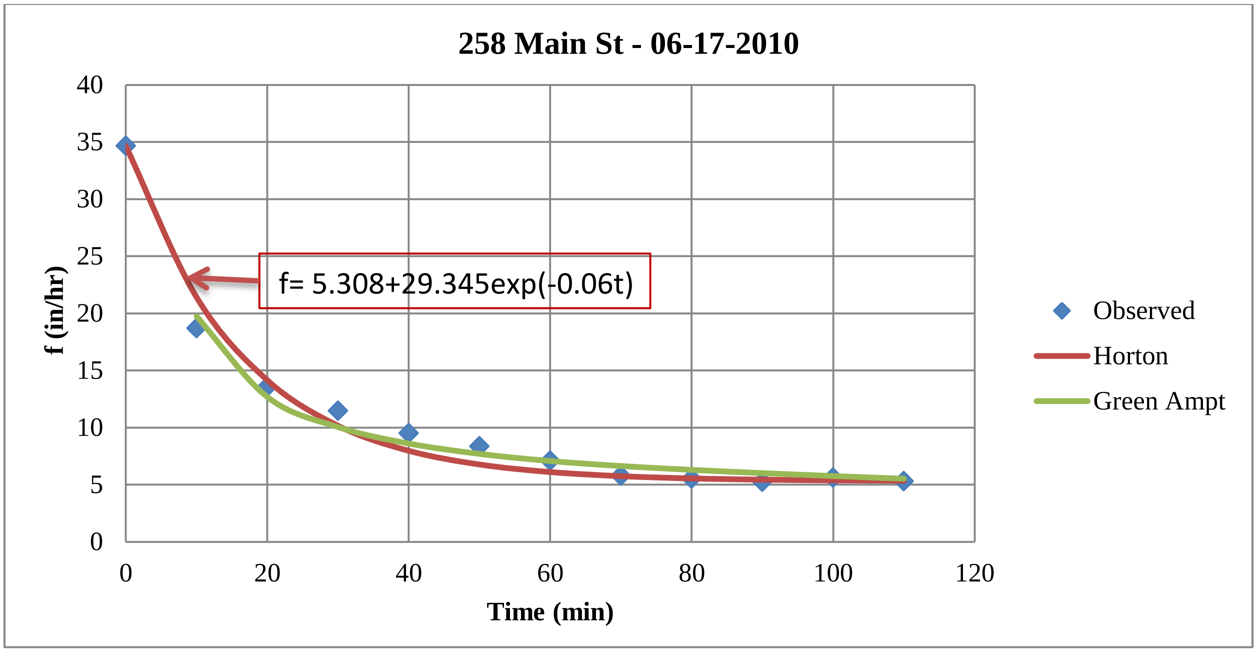
	df	SS	MS	F	Significance F
Regression	1	11.85864	11.85864	26.54858	6.13E-06
Residual	43	19.20711	0.446677		
Total	44	31.06574			

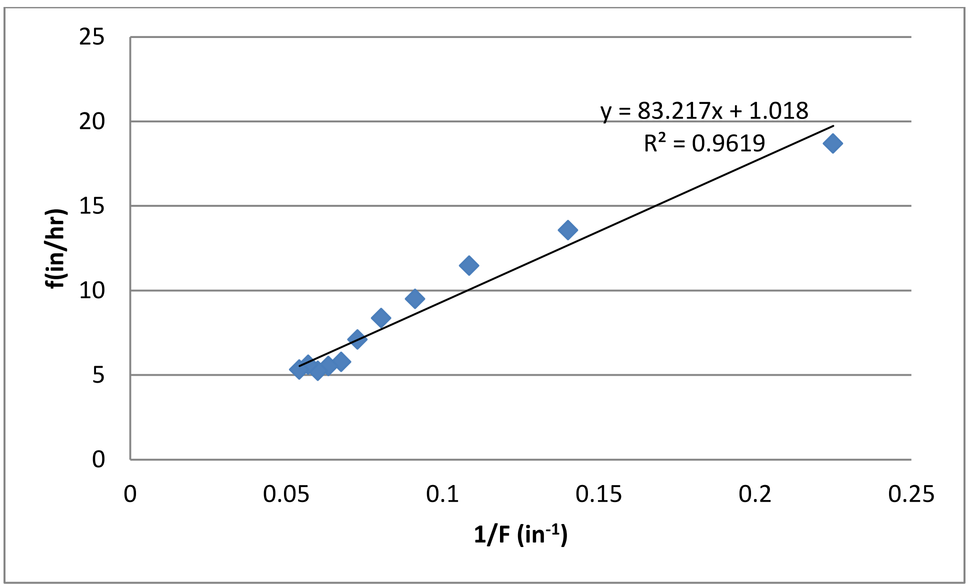
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	3.13121	0.118969	26.31959	3.81E-28	2.891286	3.371133
X Variable 1	2.675481	0.519256	5.152531	6.13E-06	1.628302	3.72266



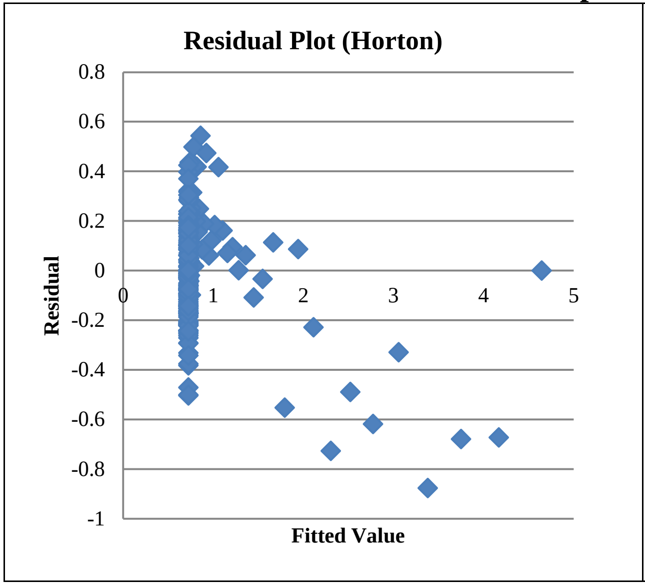


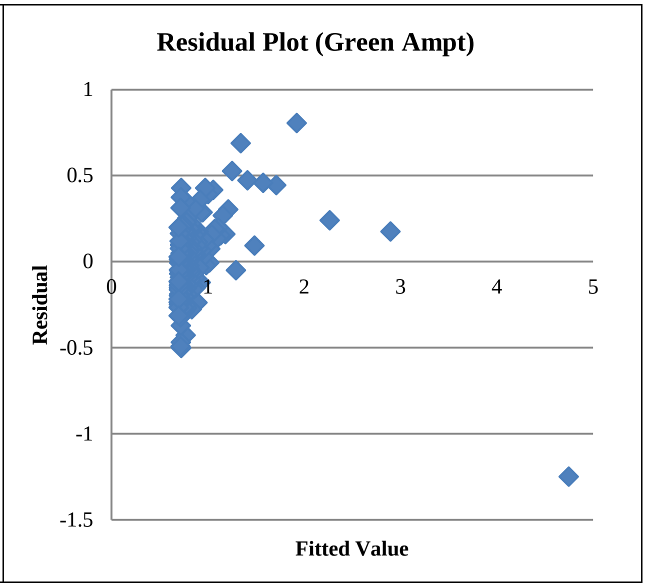
258 Main St - 06-17-2010


258 Main St - 06-17-2010
f= 5.308+29.345exp(-0.06t)
f (in/hr)
Time (min)
0
5
10
15
20
25
30
35
40
0
20
40
60
80
100
120
Observed
Horton
Green Ampt


y = 83.217x + 1.018
R² = 0.9619
f(in/hr)
1/F (in⁻¹)
0
5
10
15
20
25
0
0.05
0.1
0.15
0.2
0.25

Residual Plots for Horton and Green Ampt fitted values



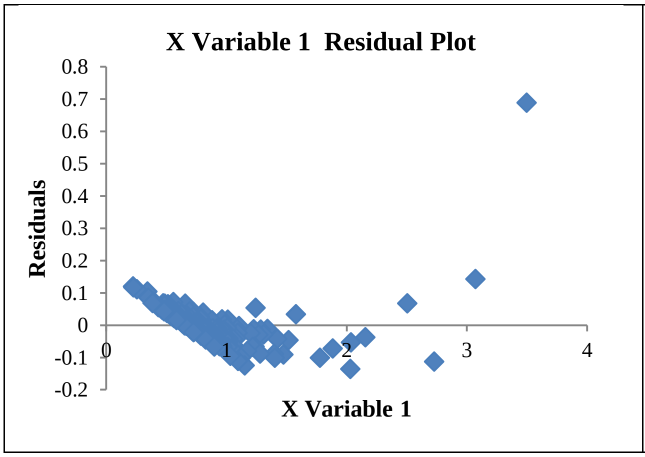


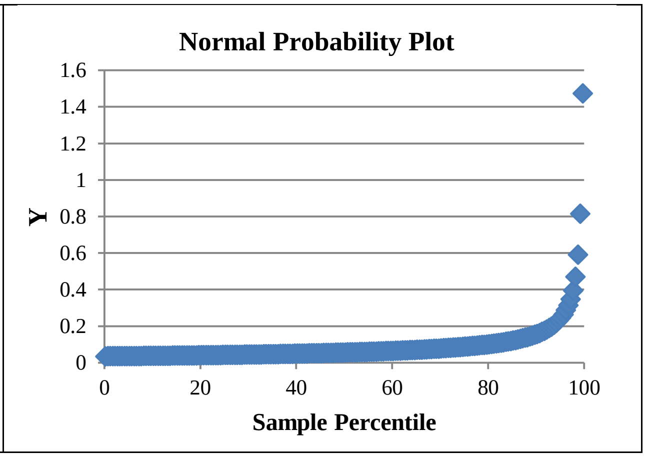
Regression Analysis for f vs. 1/F (Green Ampt)

ANOVA

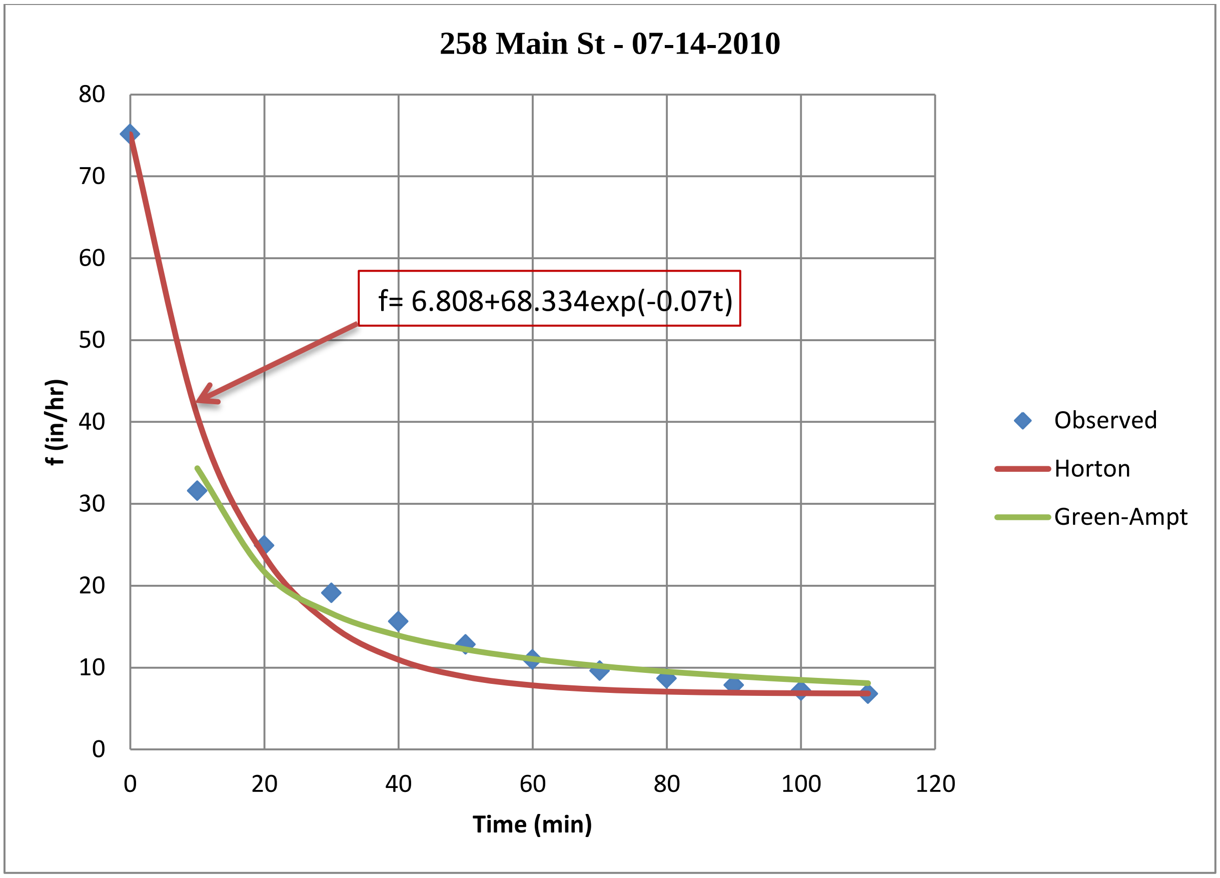
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2.60167	2.60167	561.9697	9.75E-60
Residual	198	0.916652	0.00463		
Total	199	3.518323			

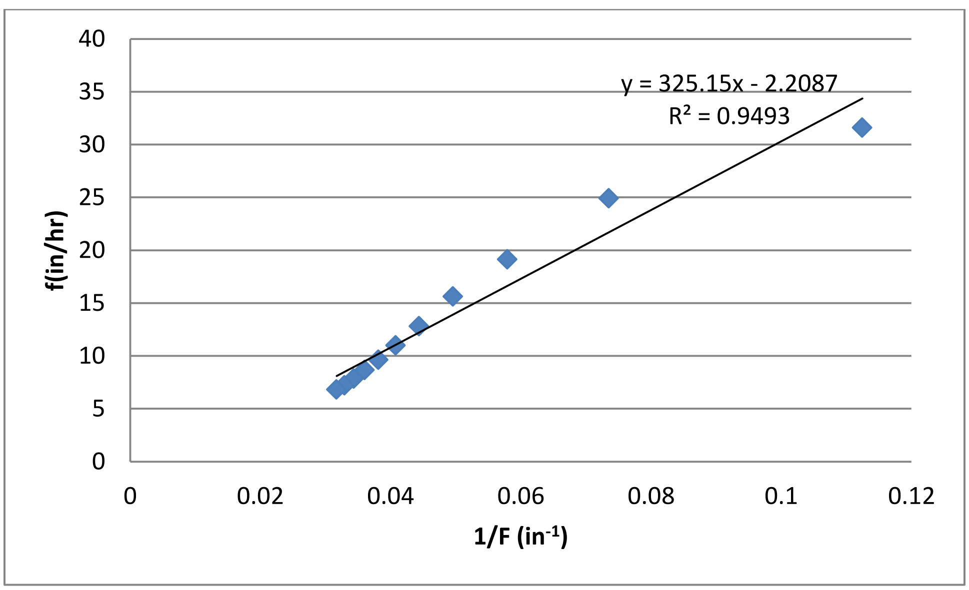
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-0.13475	0.01066	-12.6412	3.05E-27	-0.15578	-0.11373
X Variable 1	0.262705	0.011082	23.7059	9.75E-60	0.240851	0.284558



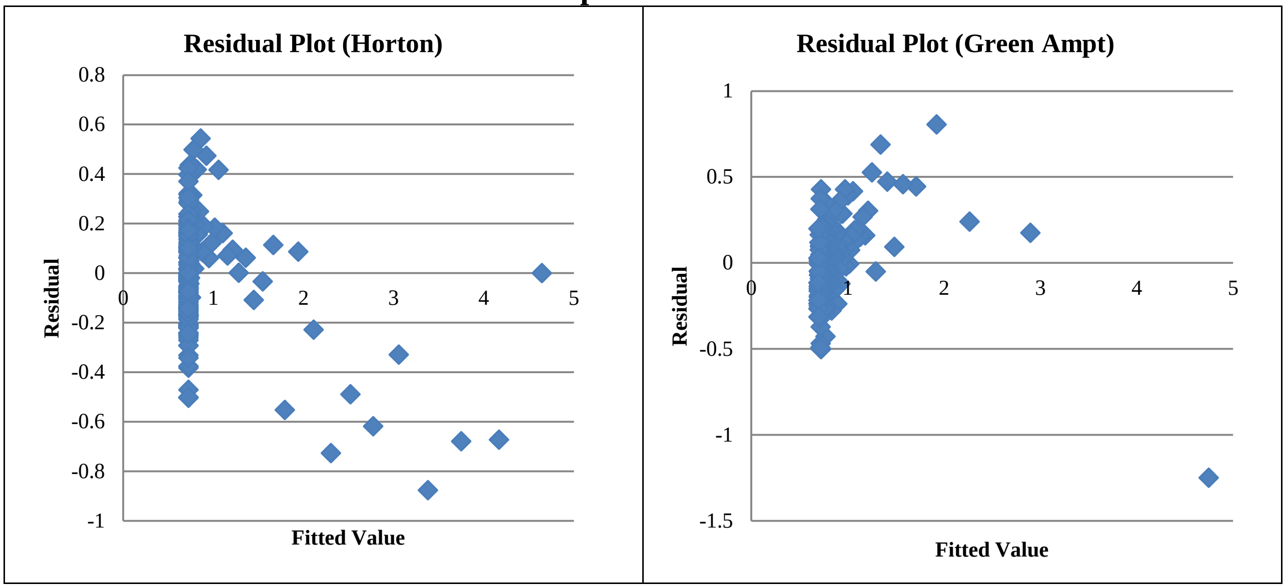


258 Main St - 07-14-2010


258 Main St - 07-14-2010
f= 6.808+68.334exp(-0.07t)
f (in/hr)
Time (min)
Observed
Horton
Green-Ampt
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120


y = 325.15x - 2.2087
R² = 0.9493
f(in/hr)
1/F (in⁻¹)
40
35
30
25
20
15
10
5
0
0
0.02
0.04
0.06
0.08
0.1
0.12

Residual Plots for Horton and Green Ampt fitted values

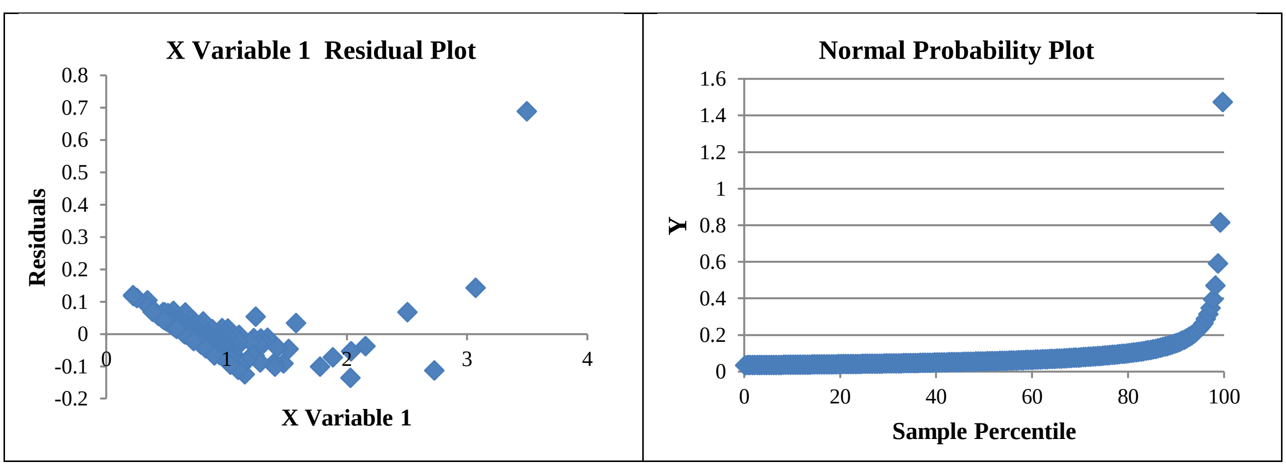


Regression Analysis for f vs. 1/F (Green Ampt)

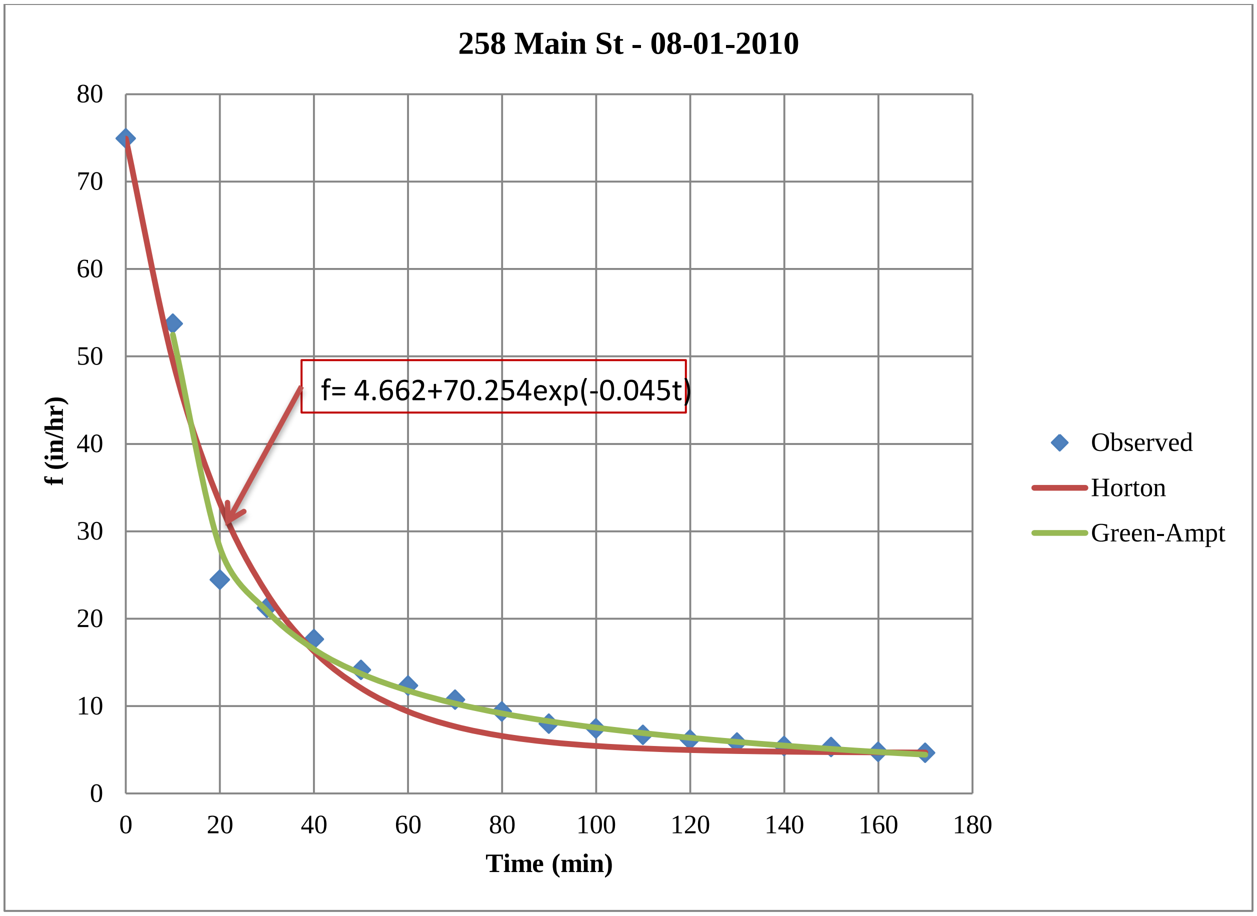
ANOVA

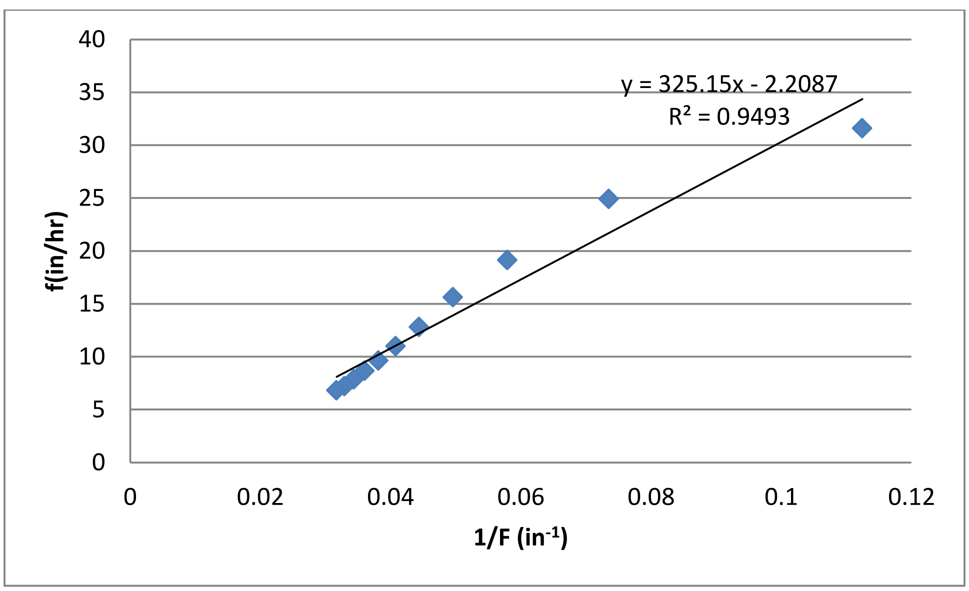
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2.60167	2.60167	561.9697	9.75E-60
Residual	198	0.916652	0.00463		
Total	199	3.518323			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-0.13475	0.01066	-12.6412	3.05E-27	-0.15578	-0.11373
X Variable 1	0.262705	0.011082	23.7059	9.75E-60	0.240851	0.284558

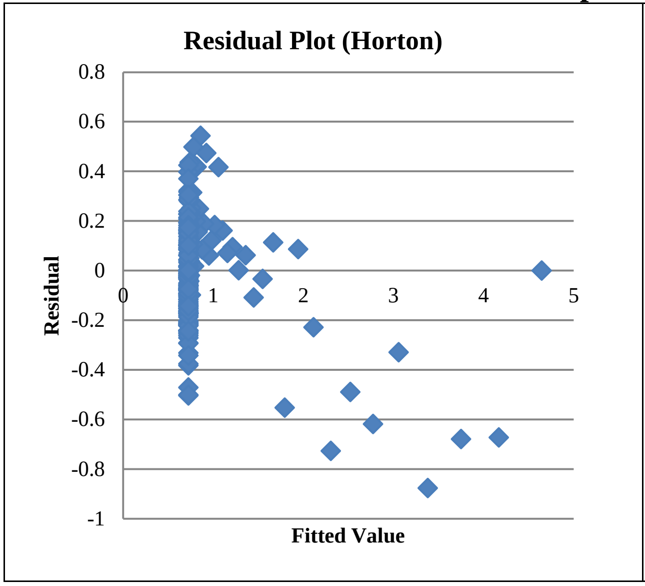


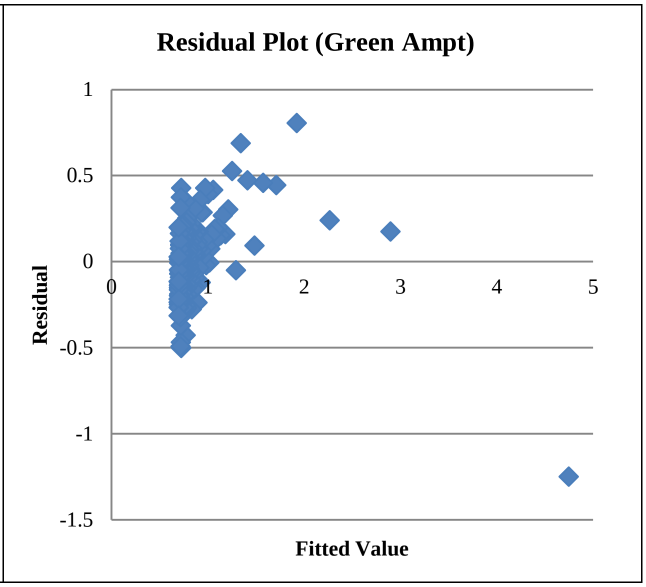
258 Main St - 08-01-2010


258 Main St - 08-01-2010
f= 4.662+70.254exp(-0.045t)
f (in/hr)
Time (min)
Observed
Horton
Green-Ampt
0
10
20
30
40
50
60
70
80
0
20
40
60
80
100
120
140
160
180


y = 325.15x - 2.2087
R² = 0.9493
f(in/hr)
1/F (in-1)
0
5
10
15
20
25
30
35
40
0
0.02
0.04
0.06
0.08
0.1
0.12

Residual Plots for Horton and Green Ampt fitted values



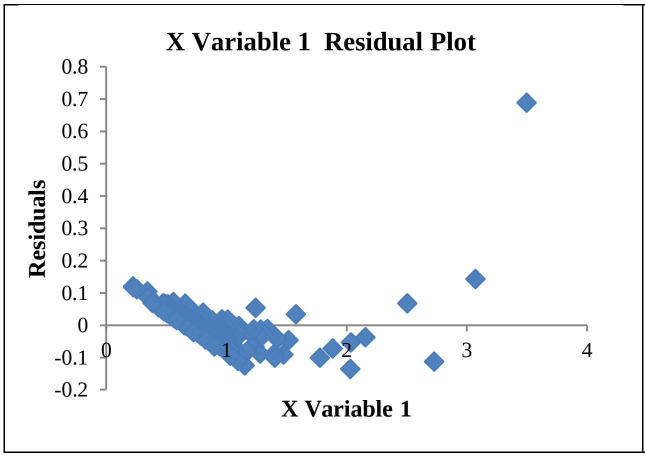


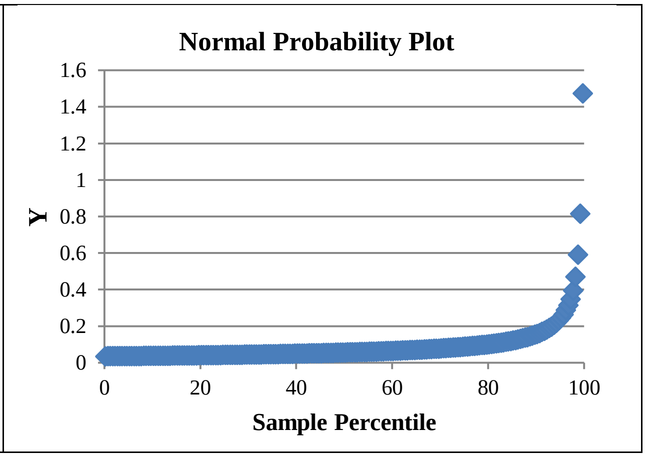
Regression Analysis for f vs. 1/F (Green Ampt)

ANOVA

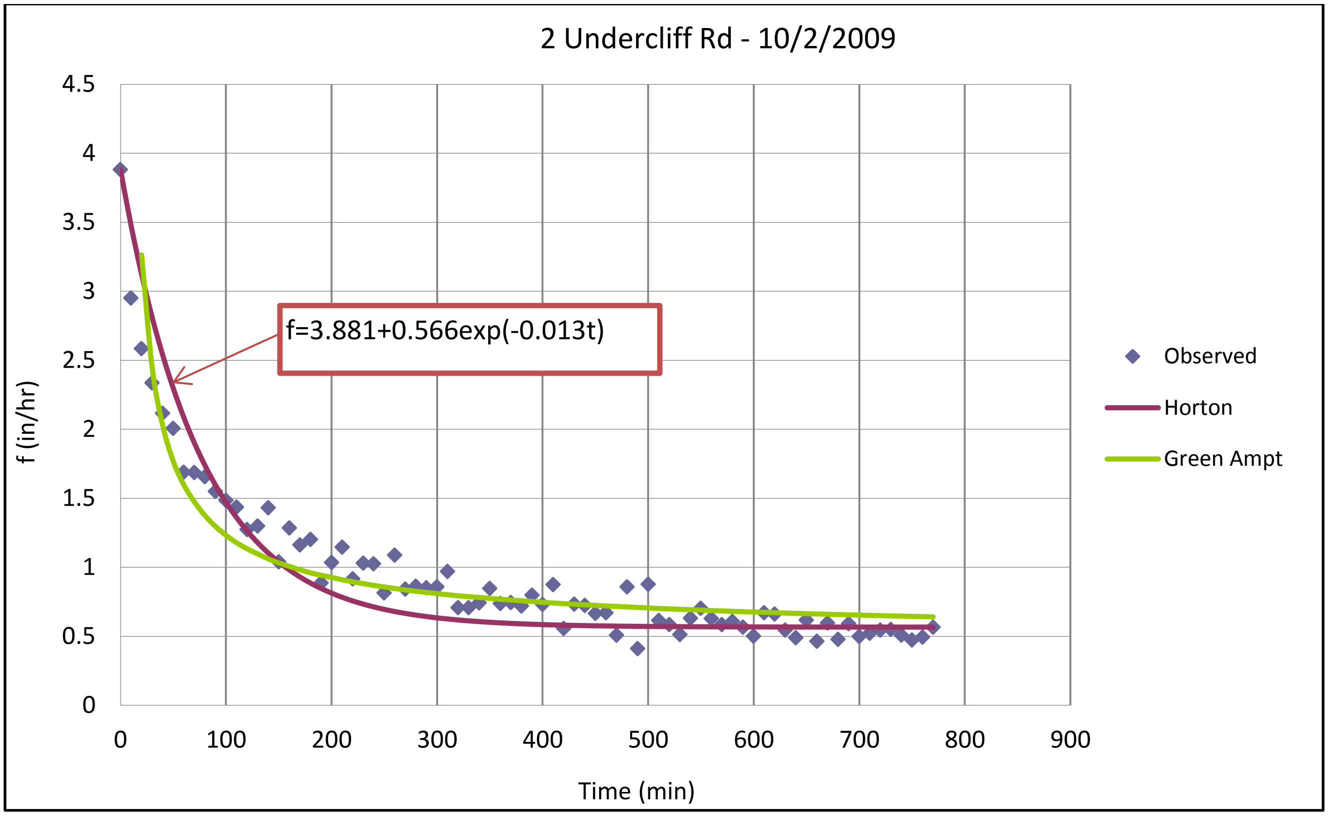
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2.60167	2.60167	561.9697	9.75E-60
Residual	198	0.916652	0.00463		
Total	199	3.518323			

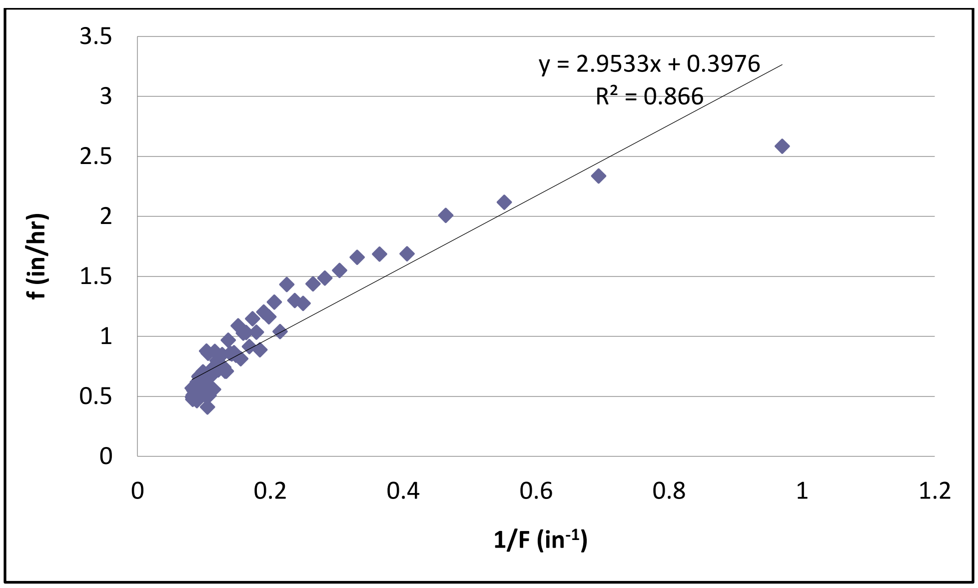
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-0.13475	0.01066	-12.6412	3.05E-27	-0.15578	-0.11373
X Variable 1	0.262705	0.011082	23.7059	9.75E-60	0.240851	0.284558



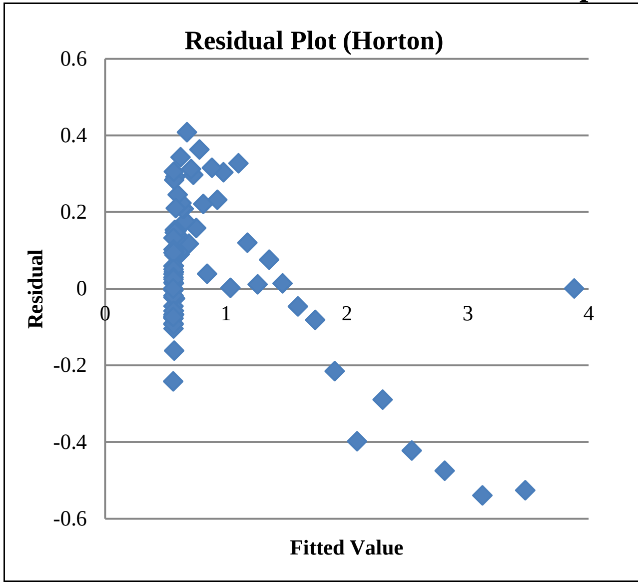


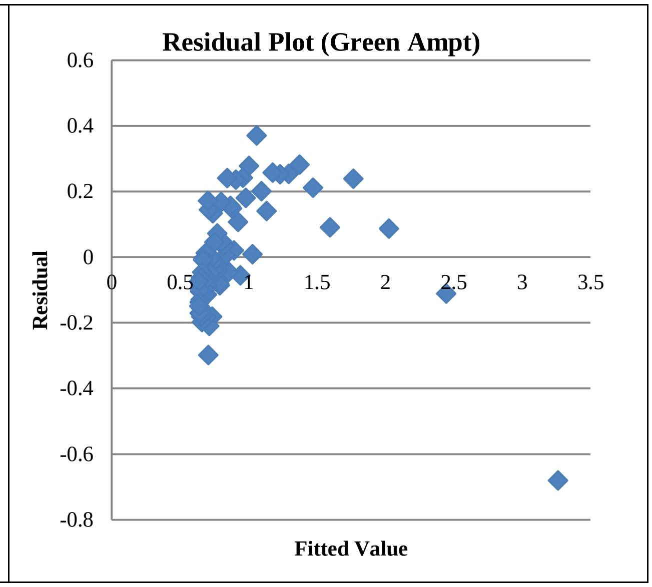
2 Undercliff Rd 10-2-2009


2 Undercliff Rd - 10/2/2009
f=3.881+0.566exp(-0.013t)
f (in/hr)
Time (min)
Observed
Horton
Green Ampt
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
100
200
300
400
500
600
700
800
900


y = 2.9533x + 0.3976
R² = 0.866
f (in/hr)
1/F (in⁻¹)
3.5
3
2.5
2
1.5
1
0.5
0
0.2
0.4
0.6
0.8
1.2

Residual Plots for Horton and Green Ampt fitted values



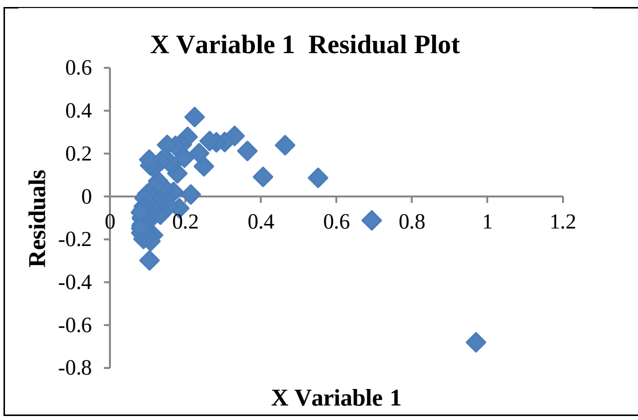


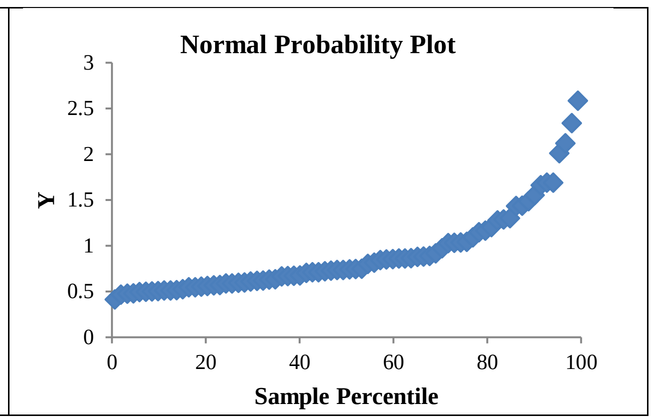
Regression Analysis for f vs. 1/F (Green Ampt)

ANOVA

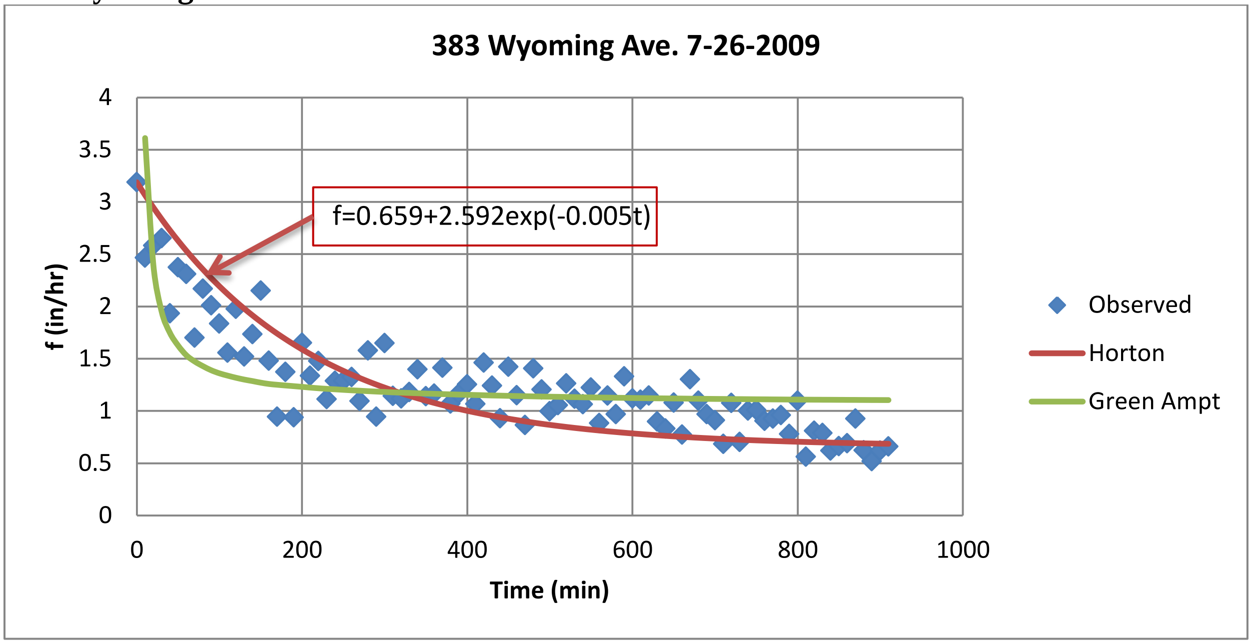
	df	SS	MS	F	Significance F
Regression	1	13.53029	13.53029	478.1812	5.02E-34
Residual	74	2.093854	0.028295		
Total	75	15.62415			

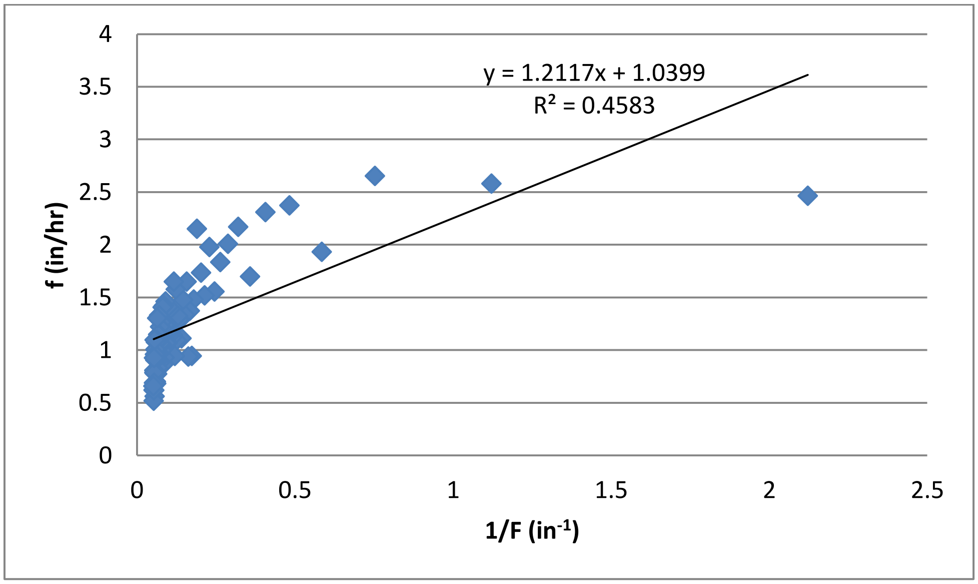
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0.397557	0.029966	13.2671	3E-21	0.337849	0.457265
X Variable 1	2.953296	0.135055	21.86735	5.02E-34	2.684193	3.222399



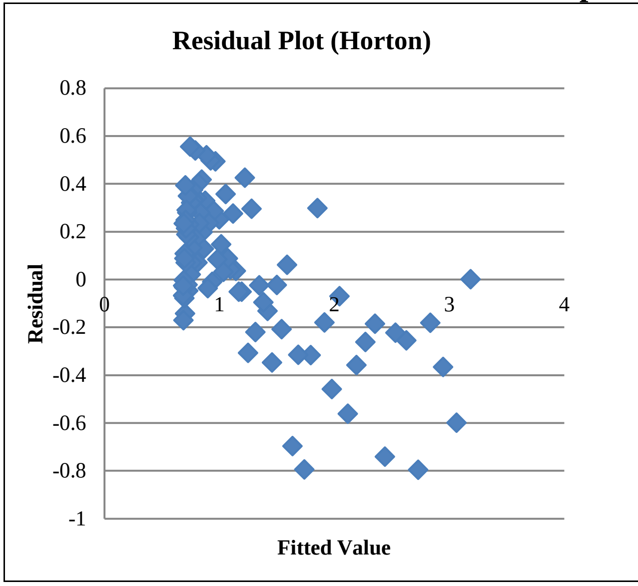


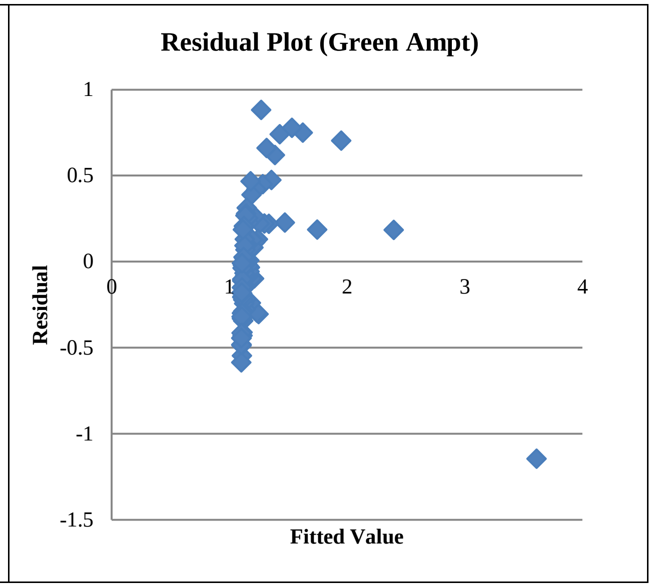
383 Wyoming Ave. 7-26-2009





Residual Plots for Horton and Green Ampt fitted values



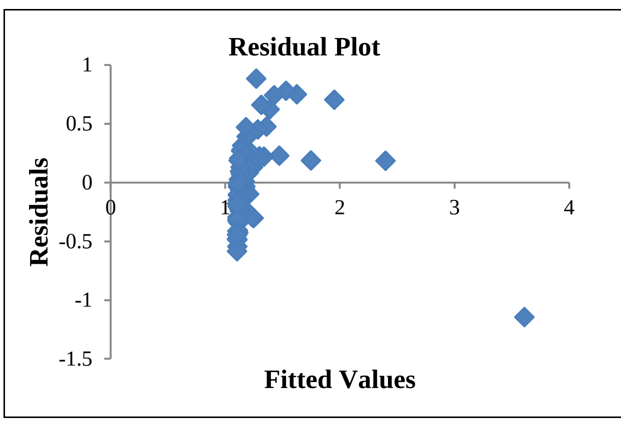


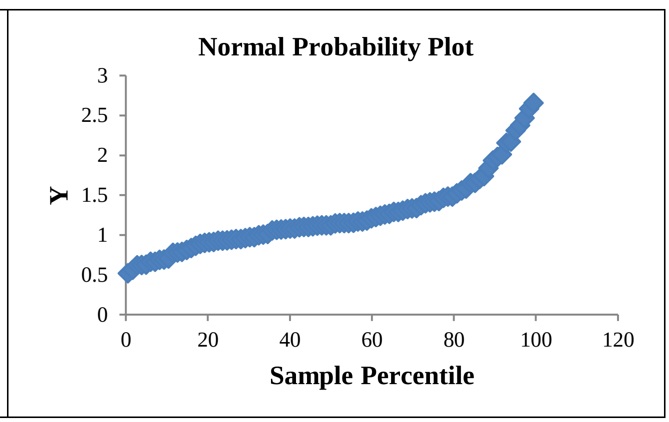
Regression Analysis for f vs. 1/F (Green Ampt)

ANOVA

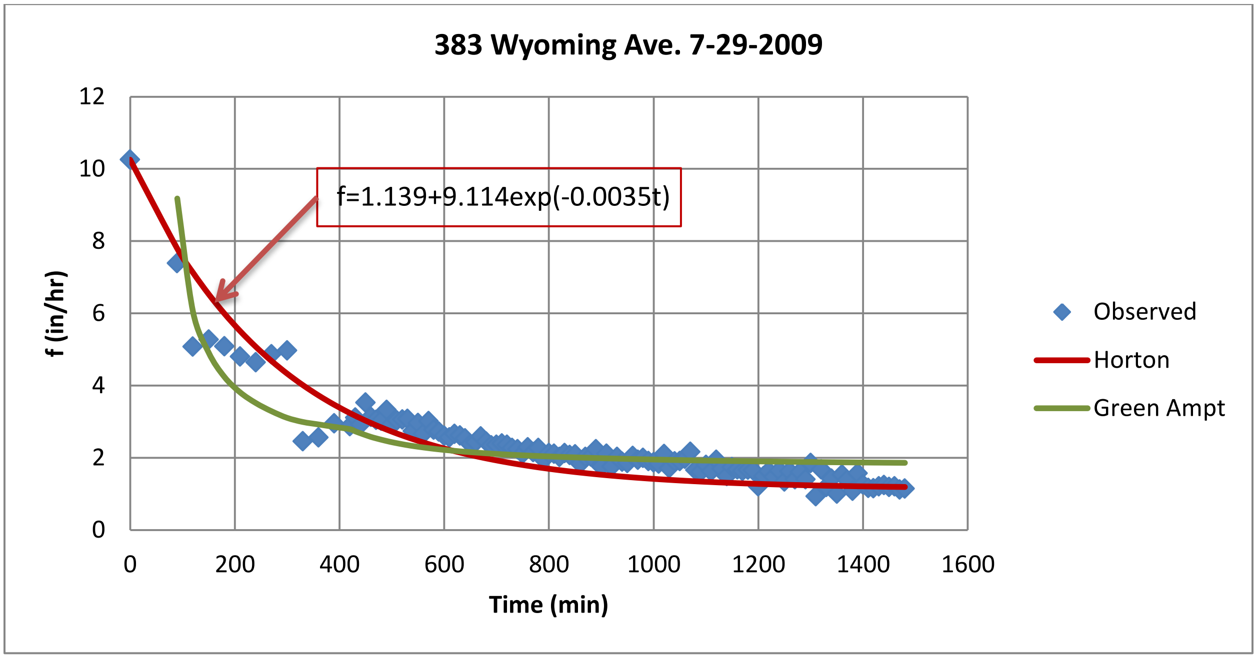
	df	SS	MS	F	Significance F
Regression	1	8.909624	8.909624	75.30019	1.75E-13
Residual	89	10.5306	0.118321		
Total	90	19.44023			

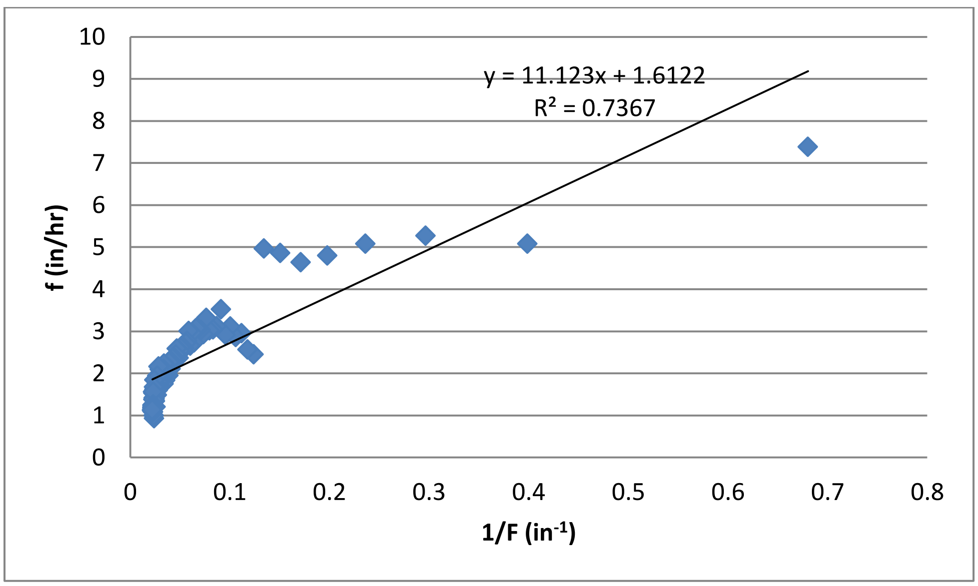
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	1.039948	0.042319	24.57386	1.97E-41	0.95586	1.124035
X Variable 1	1.211721	0.139638	8.677568	1.75E-13	0.934263	1.48918



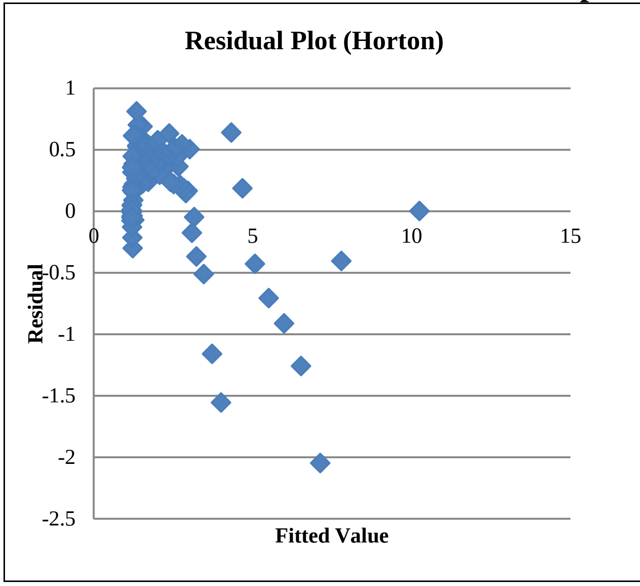


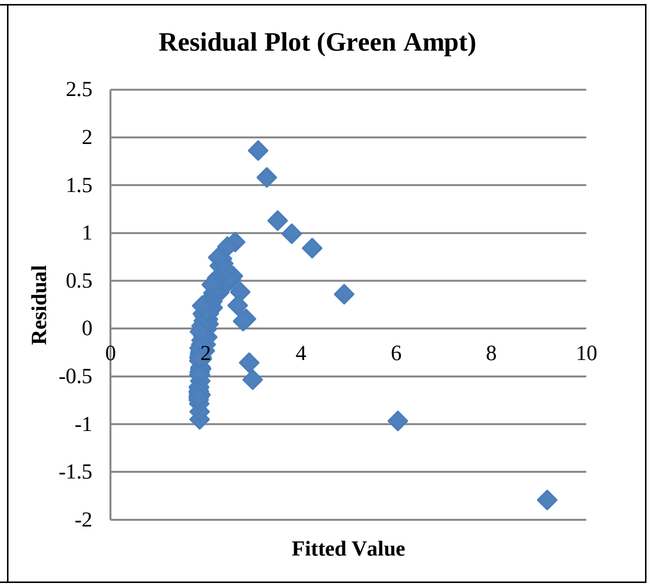
383 Wyoming Ave. 7-29-2009





Residual Plots for Horton and Green Ampt fitted values



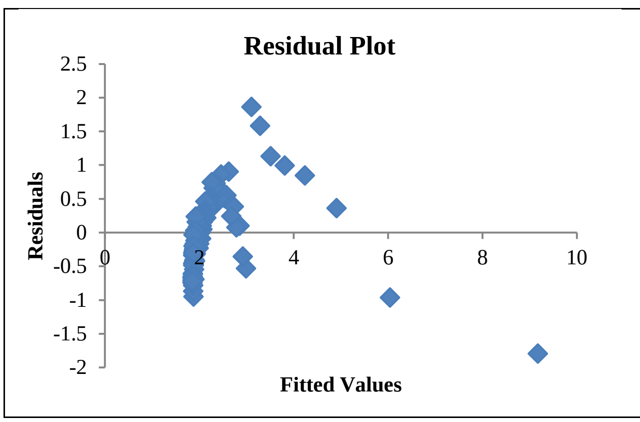


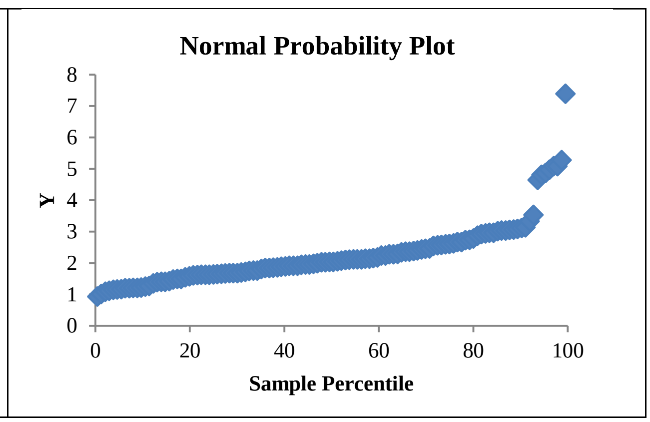
Regression Analysis for f vs. 1/F (Green Ampt)

ANOVA

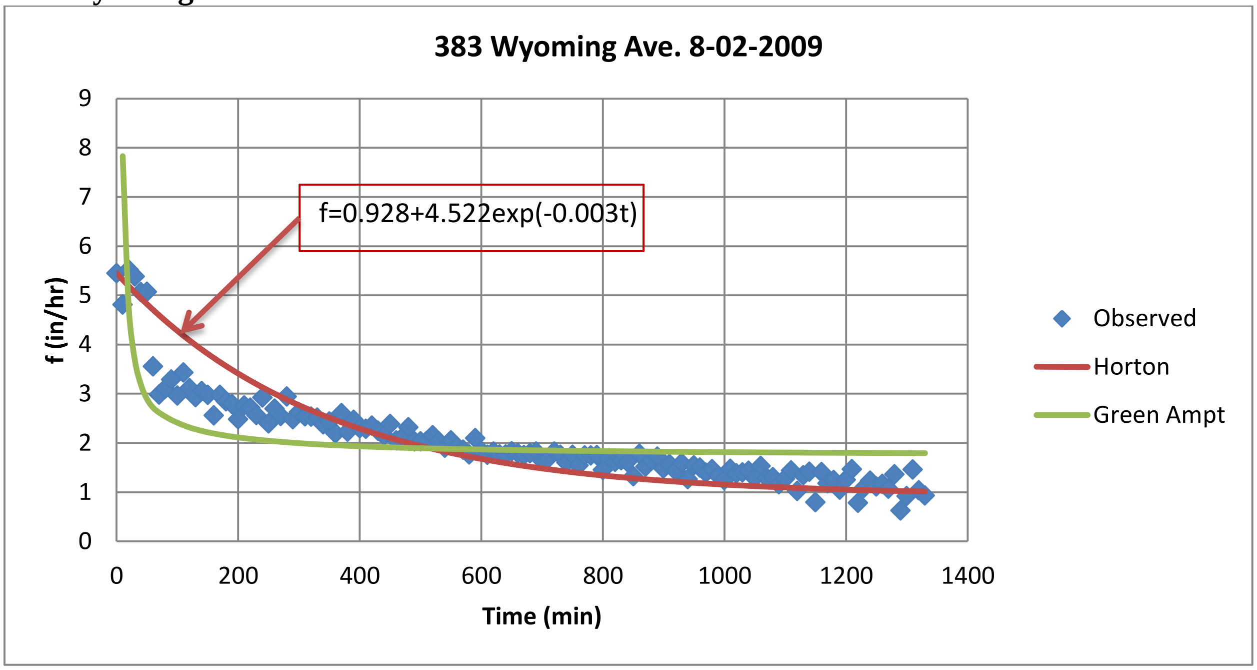
	df	SS	MS	F	Significance F
Regression	1	89.86926	89.86926	324.6359	2.07E-35
Residual	116	32.11239	0.276831		
Total	117	121.9817			

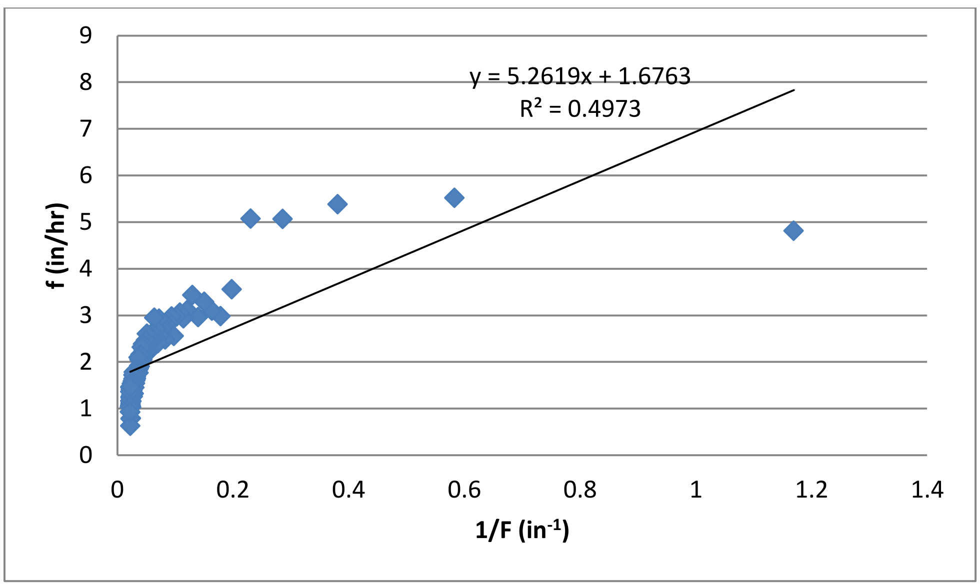
	Coefficients	Standard Error	t Stat	P-value	Lower 95%
Intercept	1.612247	0.060141	26.80775	1.56E-51	1.49313
X Variable 1	11.12316	0.617348	18.01765	2.07E-35	9.900421



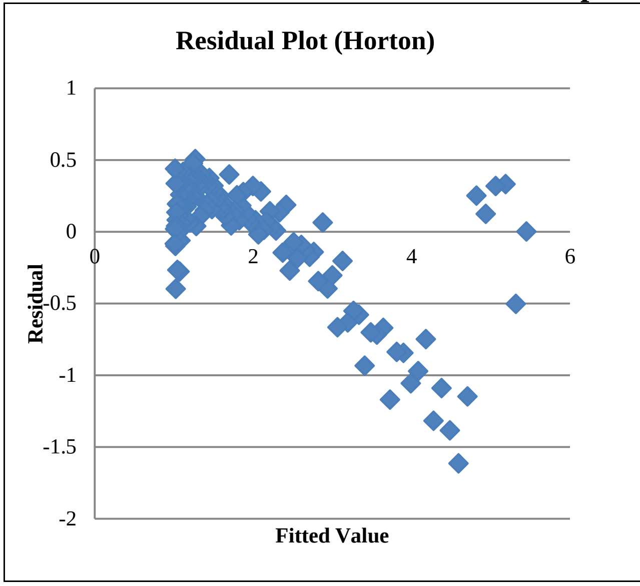


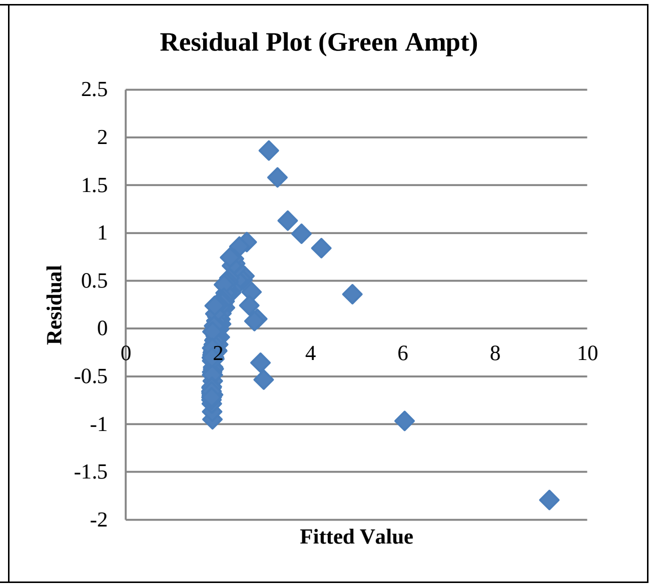
383 Wyoming Ave. 8-02-2009





Residual Plots for Horton and Green Ampt fitted values



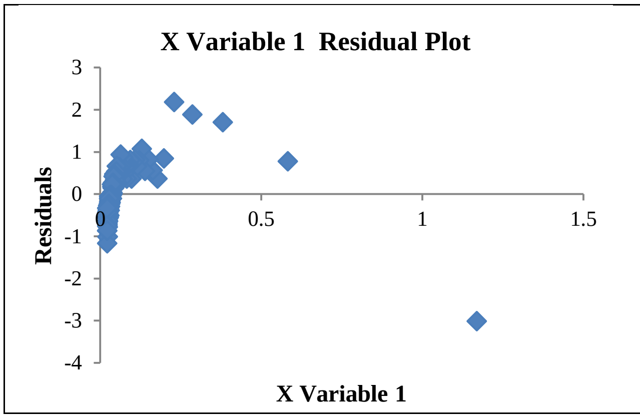


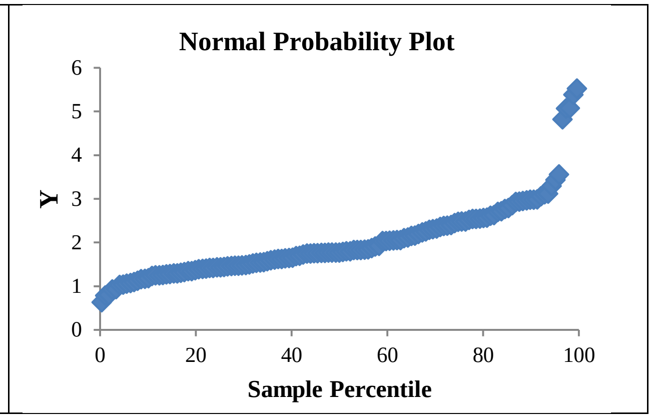
Regression Analysis for f vs. 1/F (Green Ampt)

ANOVA

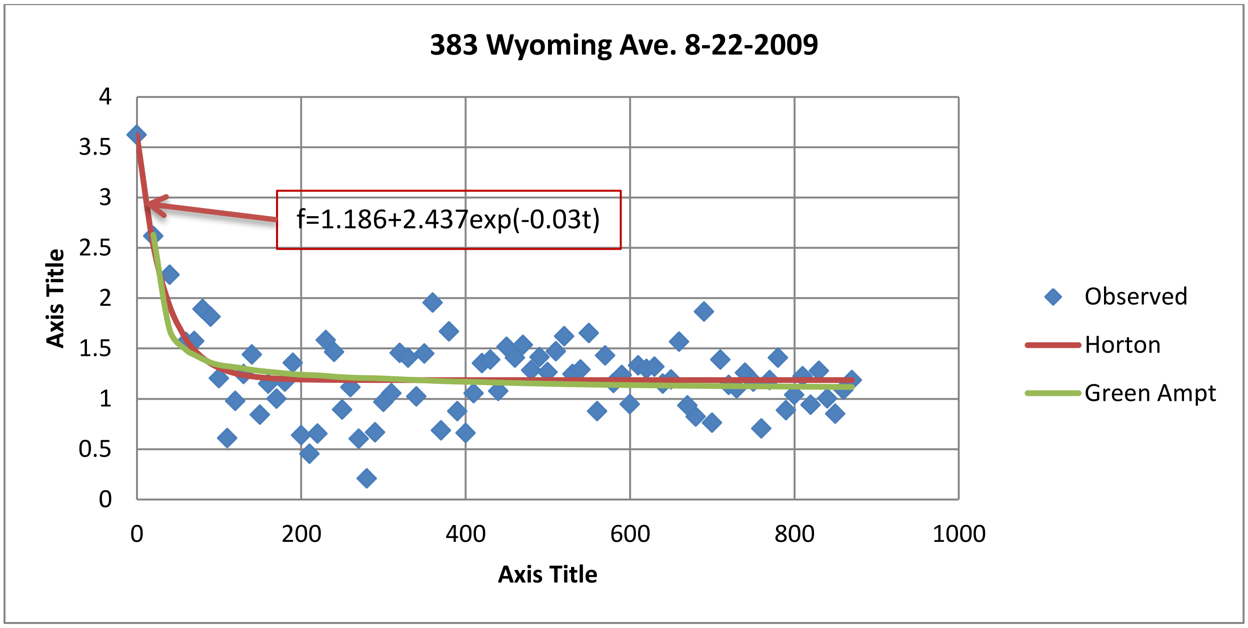
	df	SS	MS	F	Significance F
Regression	1	51.25879	51.25879	129.5995	2.67E-21
Residual	131	51.81269	0.395517		
Total	132	103.0715			

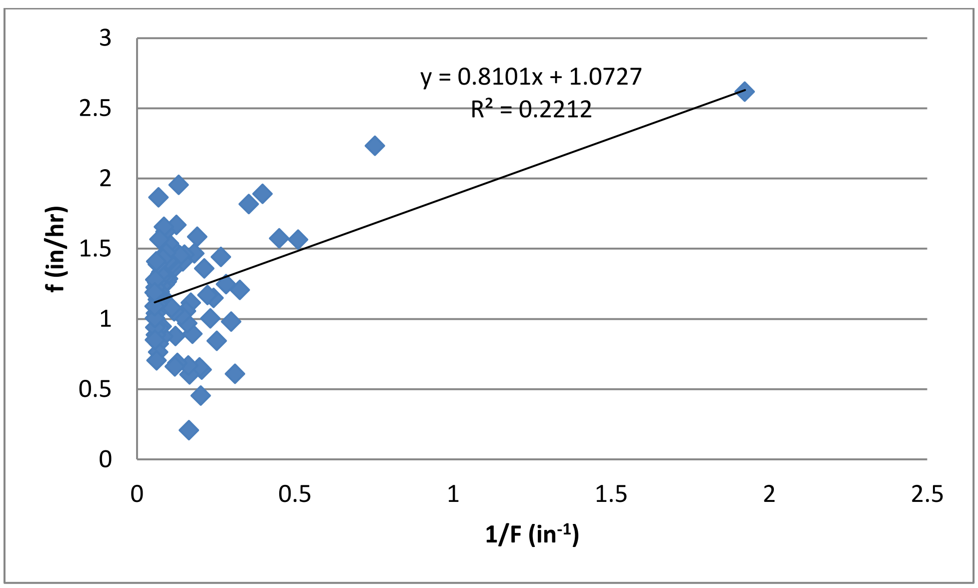
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	1.676322	0.062127	26.98234	2.4E-55	1.553421	1.799223
X Variable 1	5.26193	0.462214	11.38418	2.67E-21	4.34756	6.1763



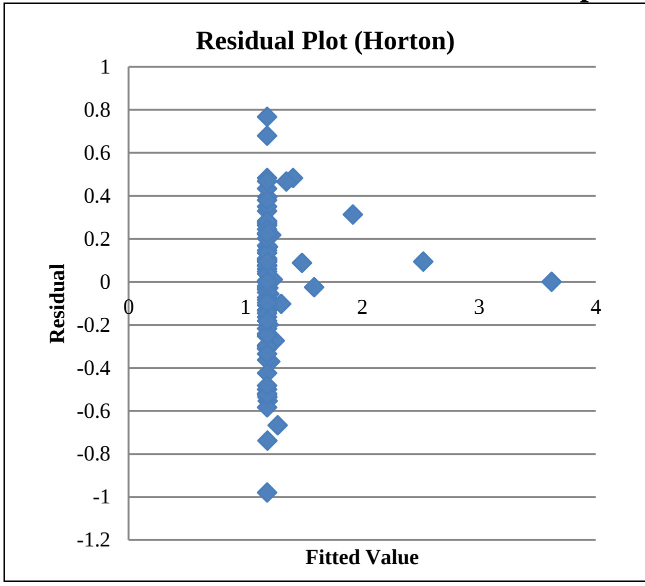


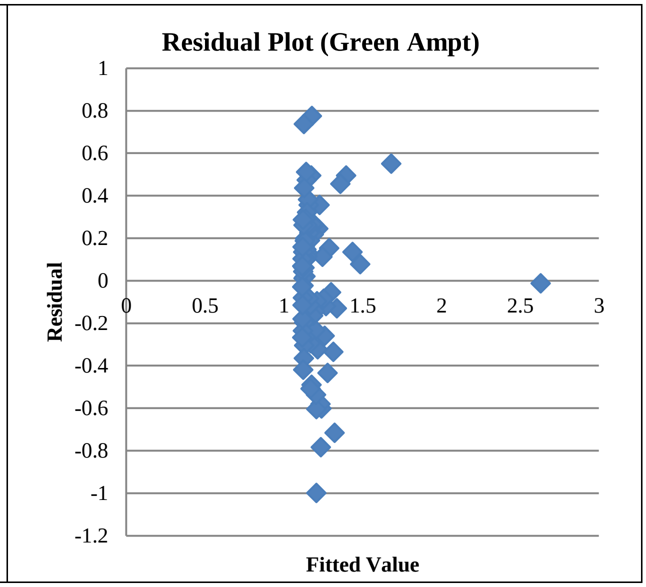
383 Wyoming Ave. 8-22-2009





Residual Plots for Horton and Green Ampt fitted values



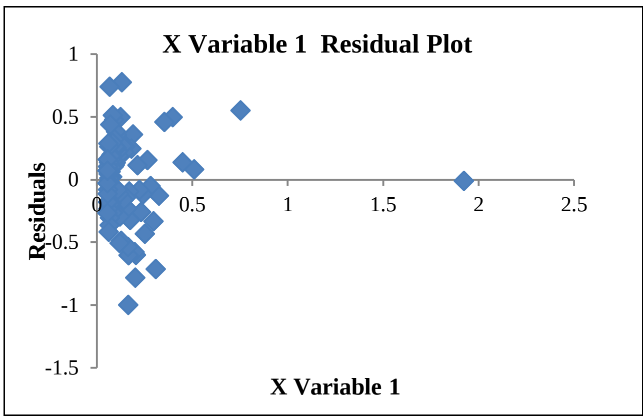


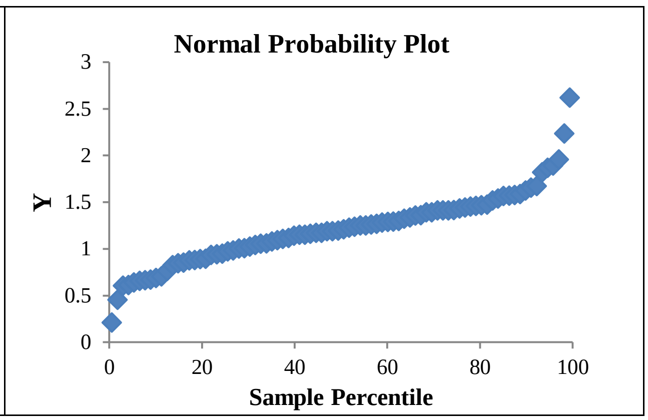
Regression Analysis for f vs. 1/F (Green Ampt)

ANOVA

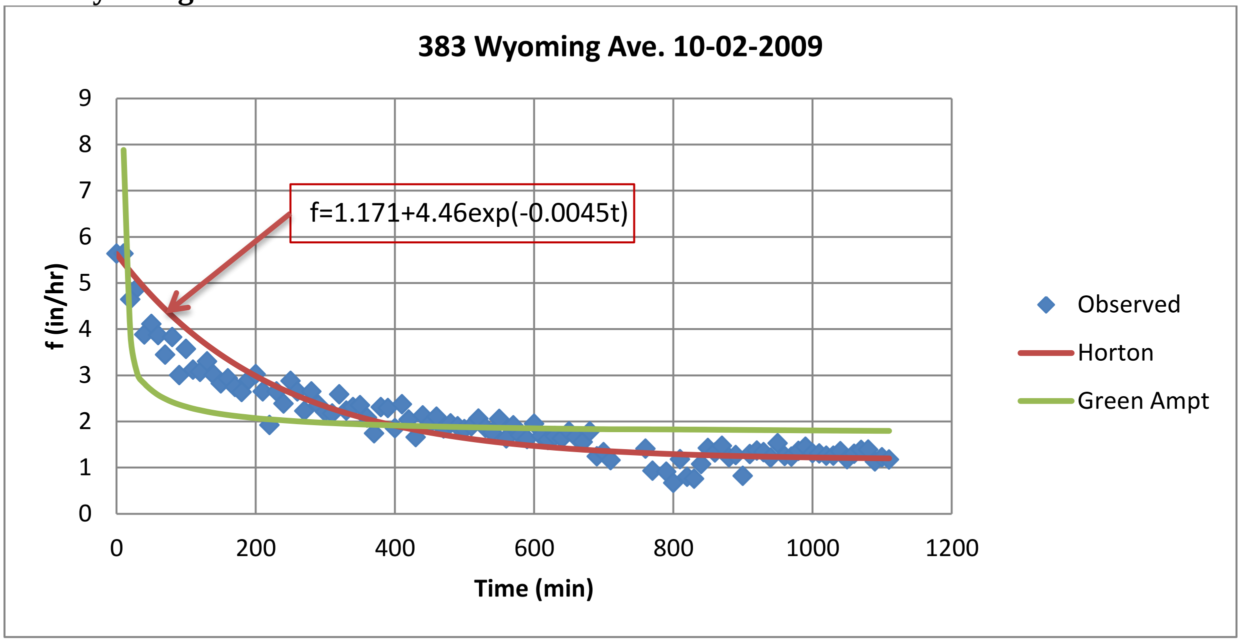
	df	SS	MS	F	Significance F
Regression	1	2.771267	2.771267	23.2845	6.37E-06
Residual	82	9.759448	0.119018		
Total	83	12.53072			

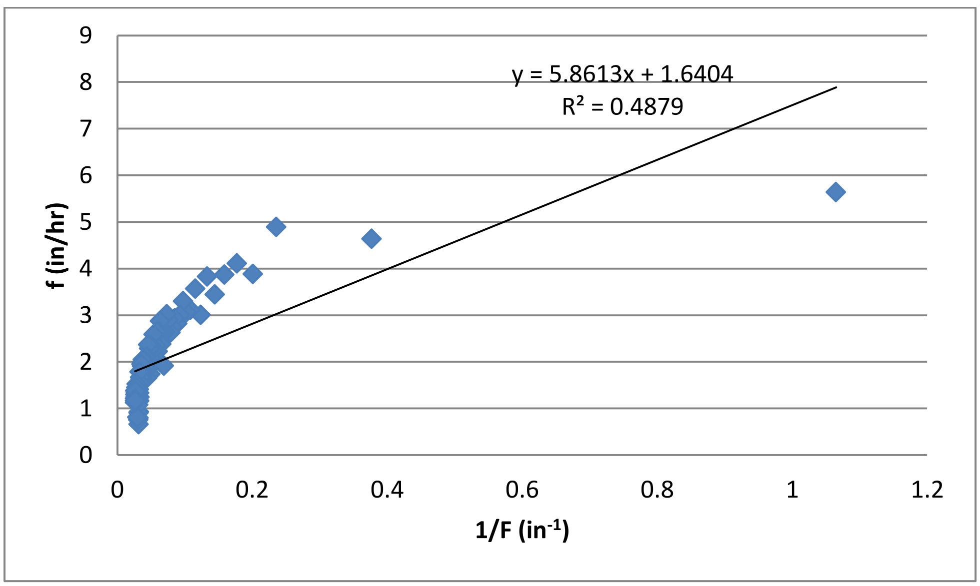
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	1.072661	0.046968	22.83825	2.7E-37	0.979227	1.166095
X Variable 1	0.810101	0.167883	4.825402	6.37E-06	0.476129	1.144073



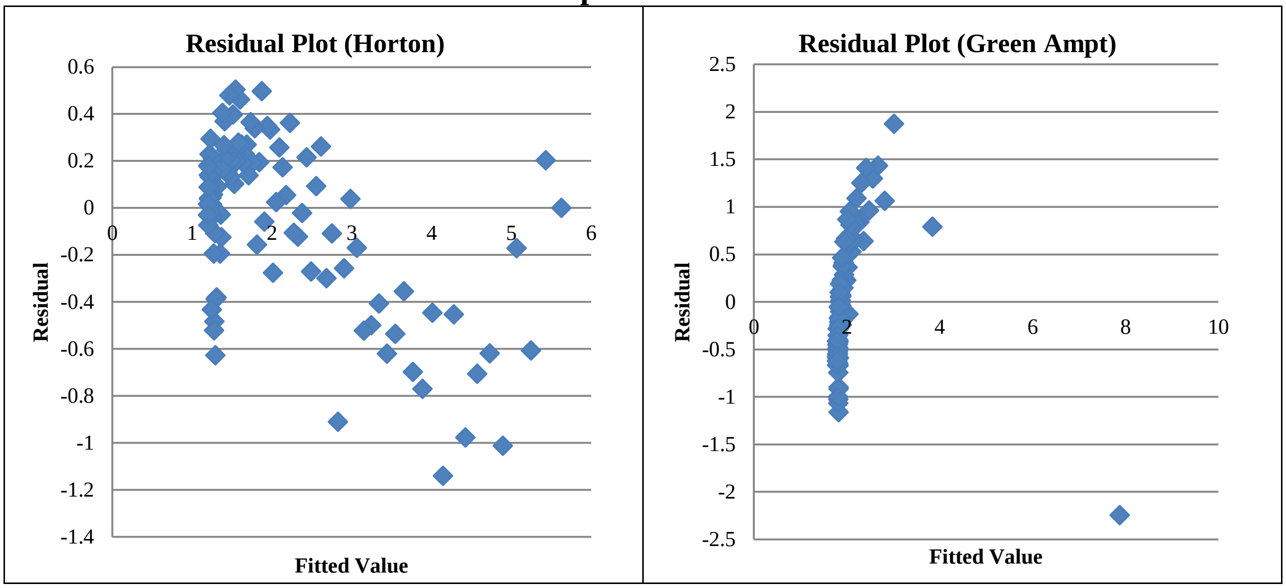


383 Wyoming Ave. 10-02-2009





Residual Plots for Horton and Green Ampt fitted values

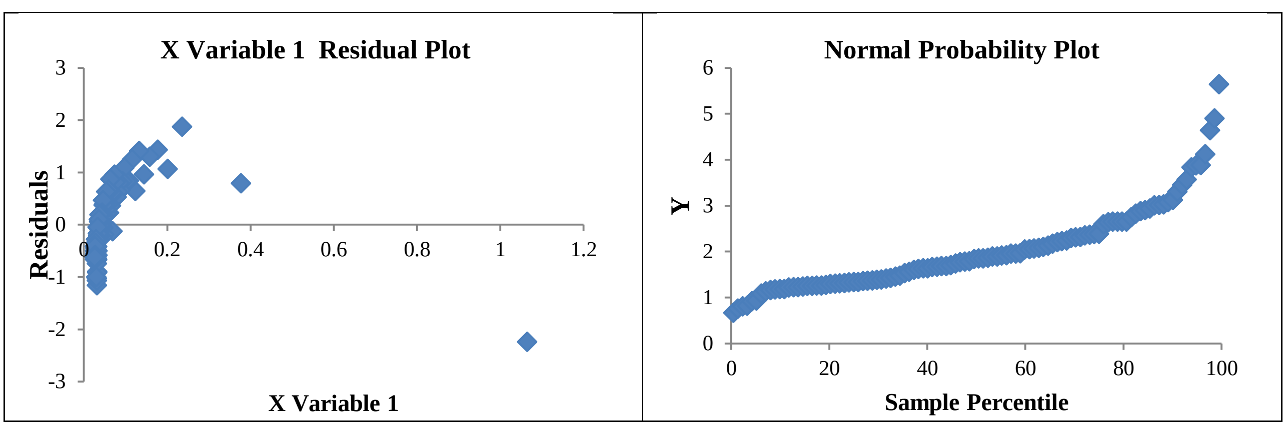


Regression Analysis for f vs. 1/F (Green Ampt)

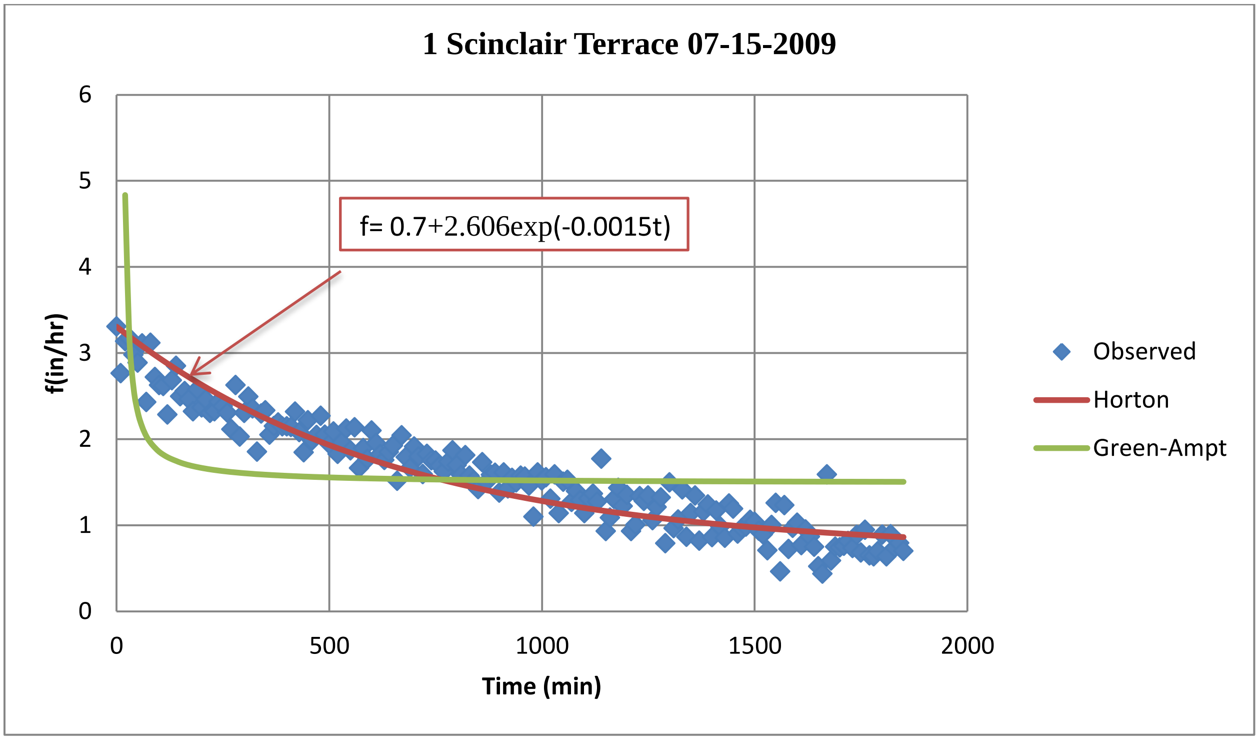
ANOVA

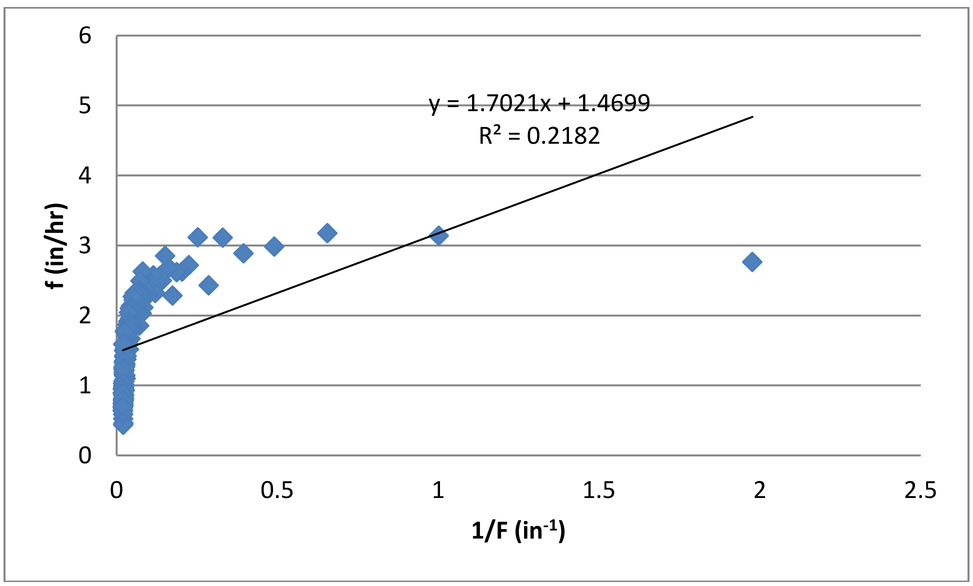
	df	SS	MS	F	Significance F
Regression	1	43.29224	43.29224	99.08553	8.52E-17
Residual	104	45.43946	0.436918		
Total	105	88.7317			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	1.640422	0.074959	21.88437	1.02E-40	1.491776	1.789067
X Variable 1	5.861307	0.588829	9.954172	8.52E-17	4.693636	7.028977

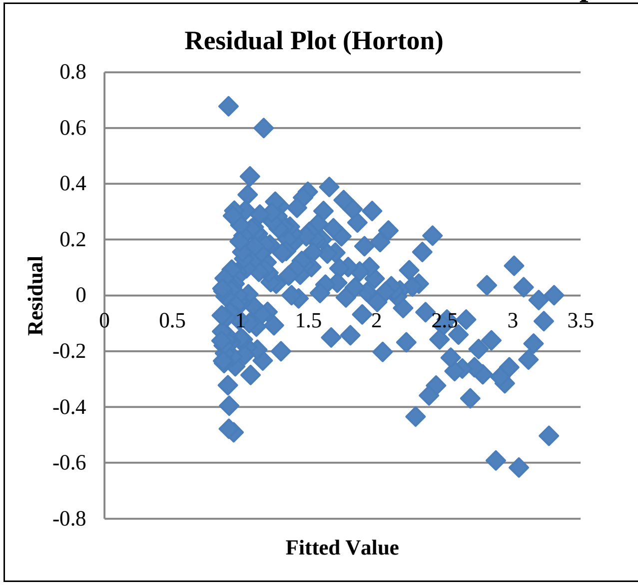


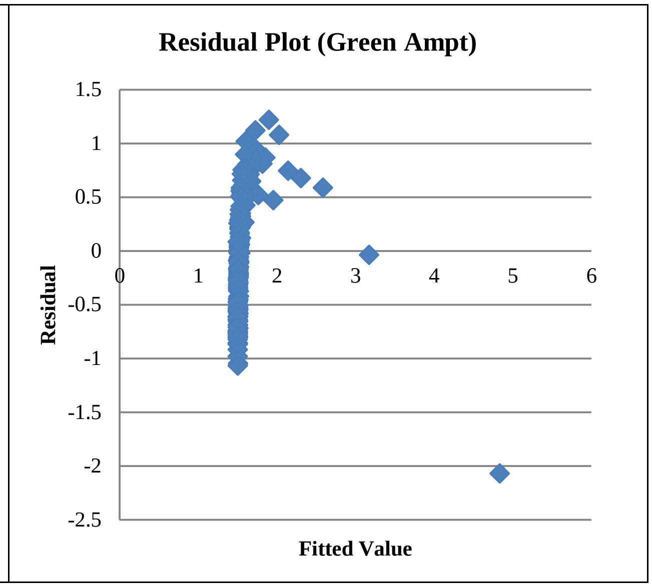
1 Sinclair Terrace 07-15-2009





Residual Plots for Horton and Green Ampt fitted values



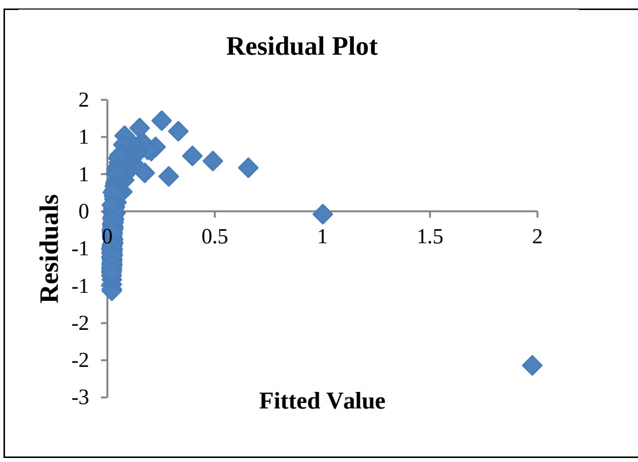


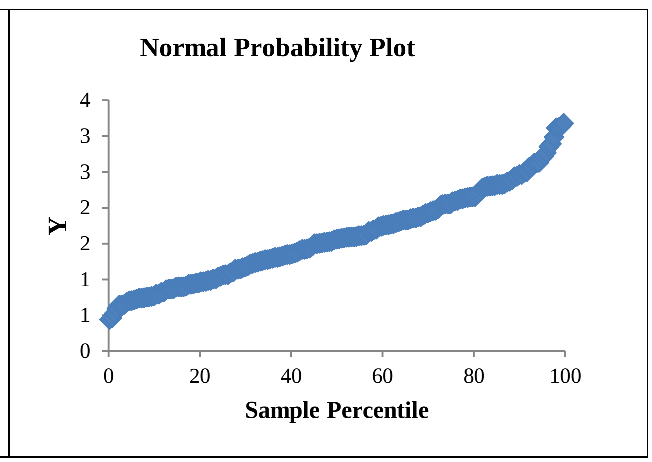
Regression Analysis for f vs. 1/F (Green Ampt)

ANOVA

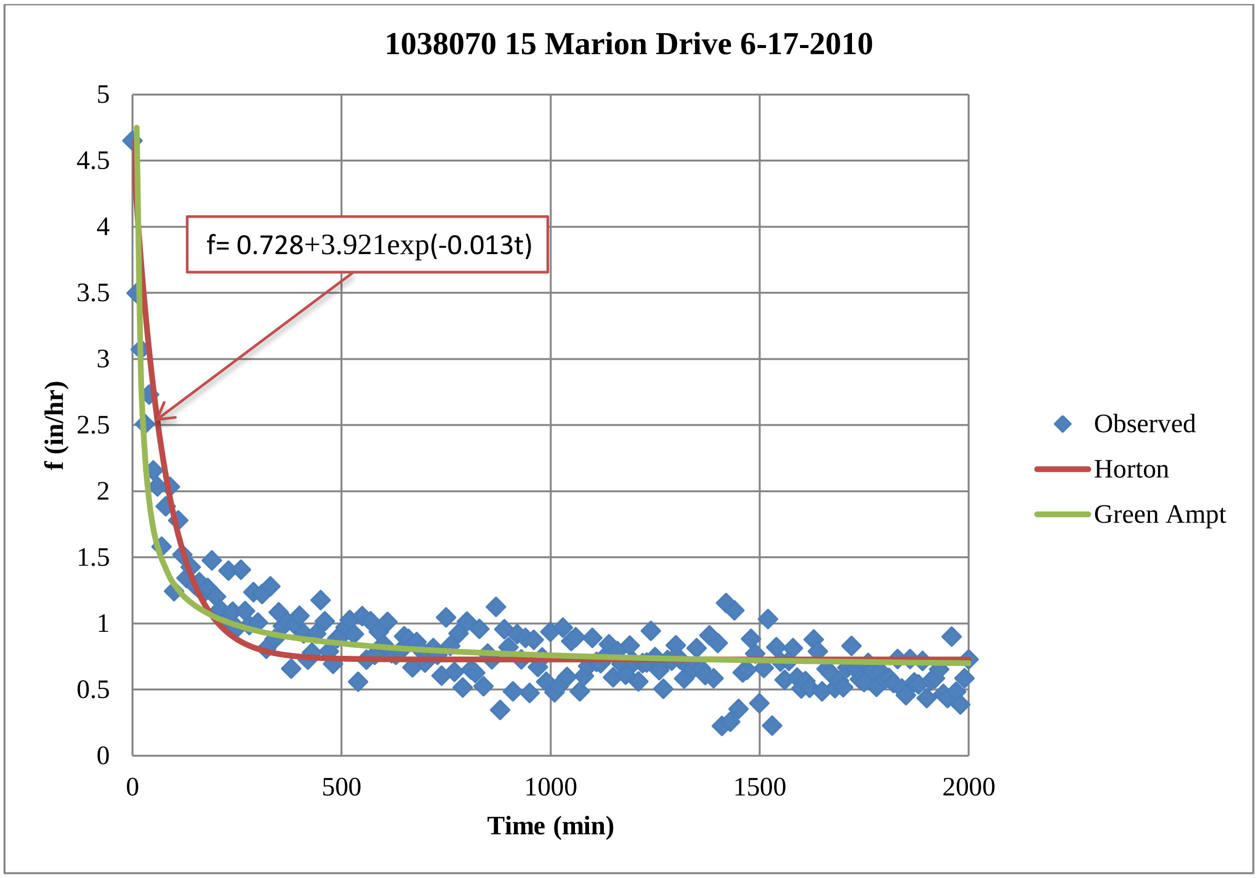
	df	SS	MS	F	Significance F
Regression	1	16.316	16.316	51.085	2.04E-11
Residual	183	58.449	0.319		
Total	184	74.765			

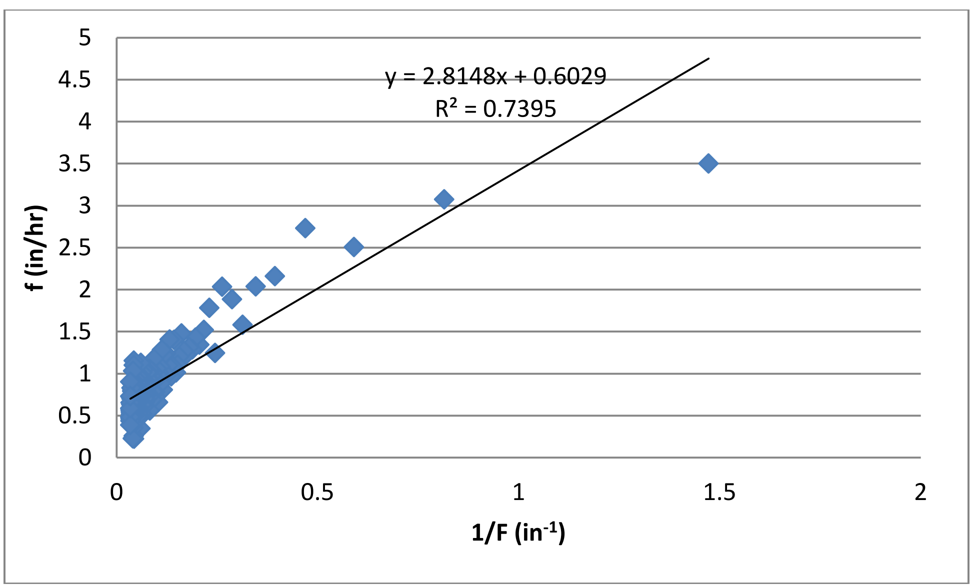
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	1.470	0.045	32.746	1.91E-78	1.381	1.558
X Variable 1	1.702	0.238	7.147	2.04E-11	1.232	2.172



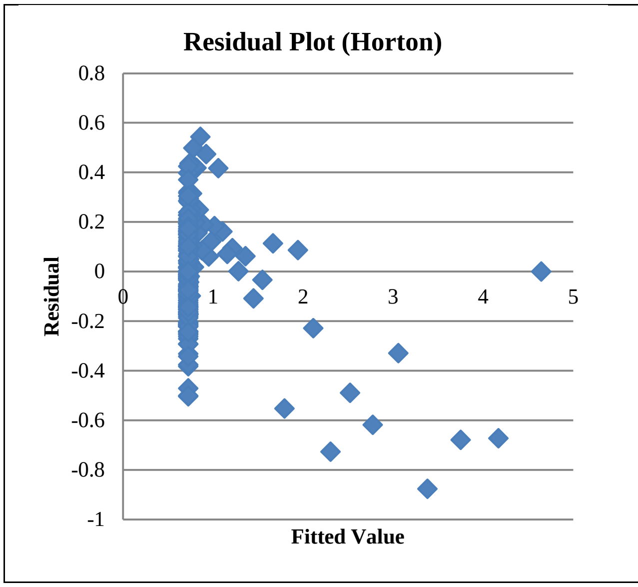


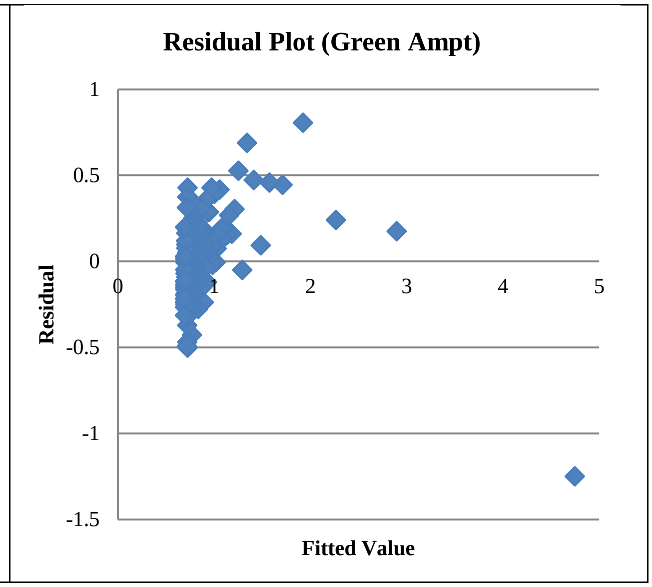
15 Marion Drive 6-17-2010





Residual Plots for Horton and Green Ampt fitted values



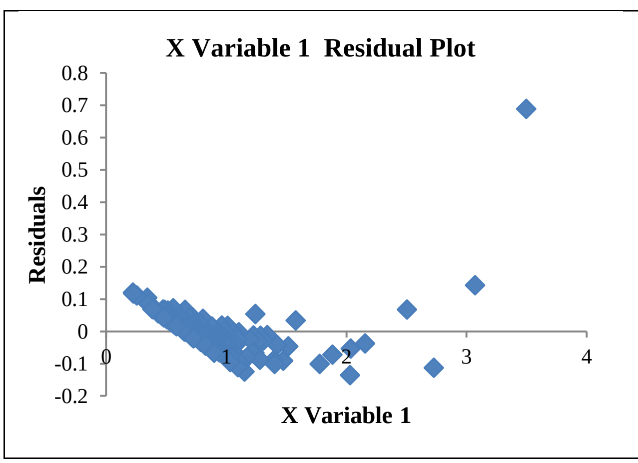


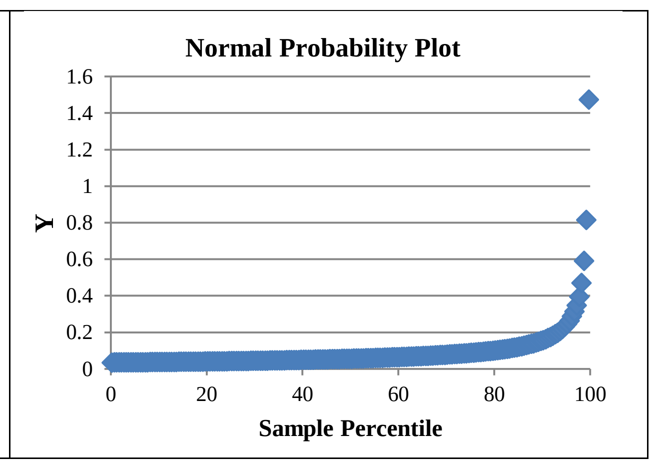
Regression Analysis for f vs. 1/F (Green Ampt)

ANOVA

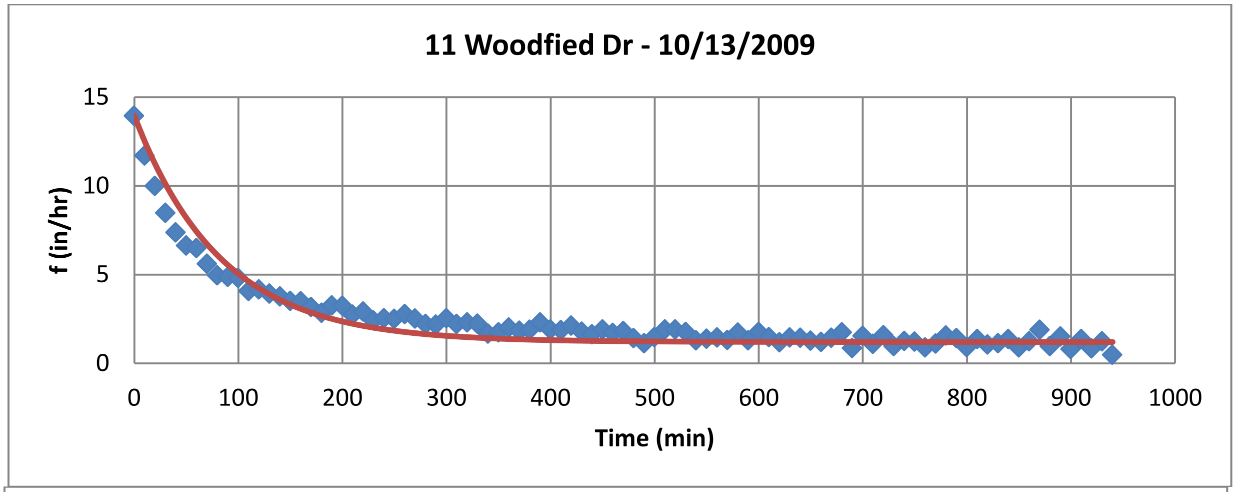
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2.60167	2.60167	561.9697	9.75E-60
Residual	198	0.916652	0.00463		
Total	199	3.518323			

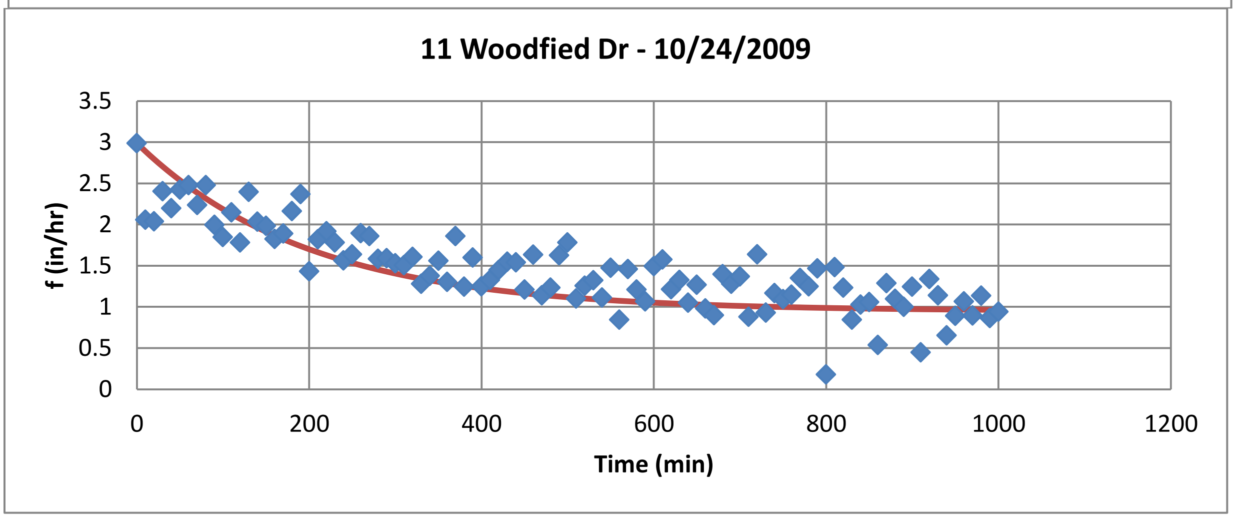
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-0.13475	0.01066	-12.6412	3.05E-27	-0.15578	-0.11373
X Variable 1	0.262705	0.011082	23.7059	9.75E-60	0.240851	0.284558

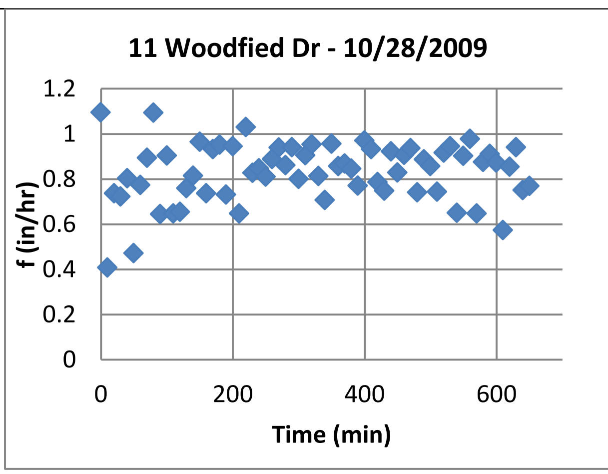


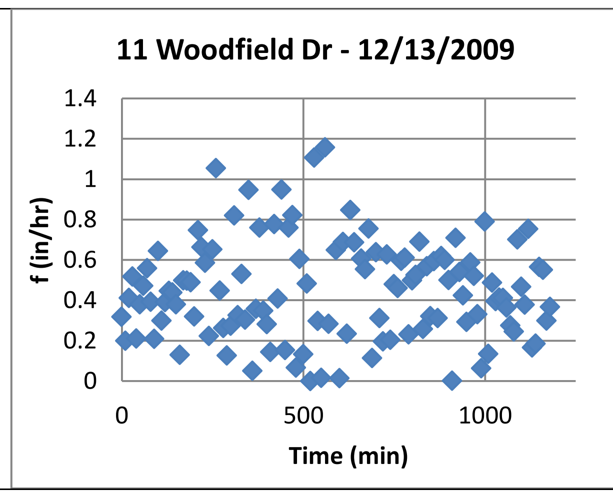


11 Woodfield Drive

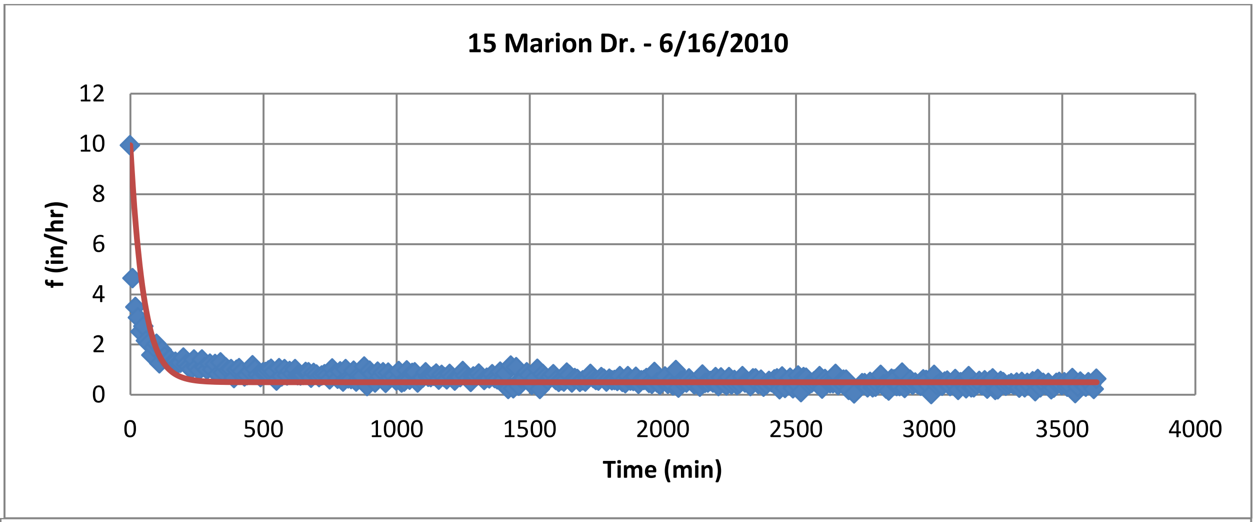


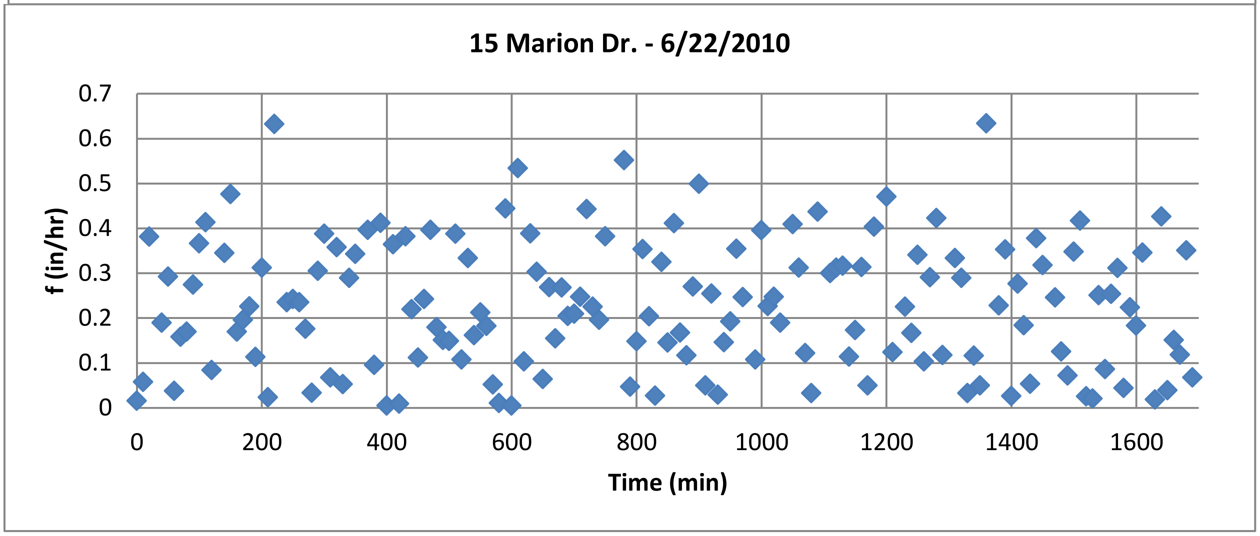


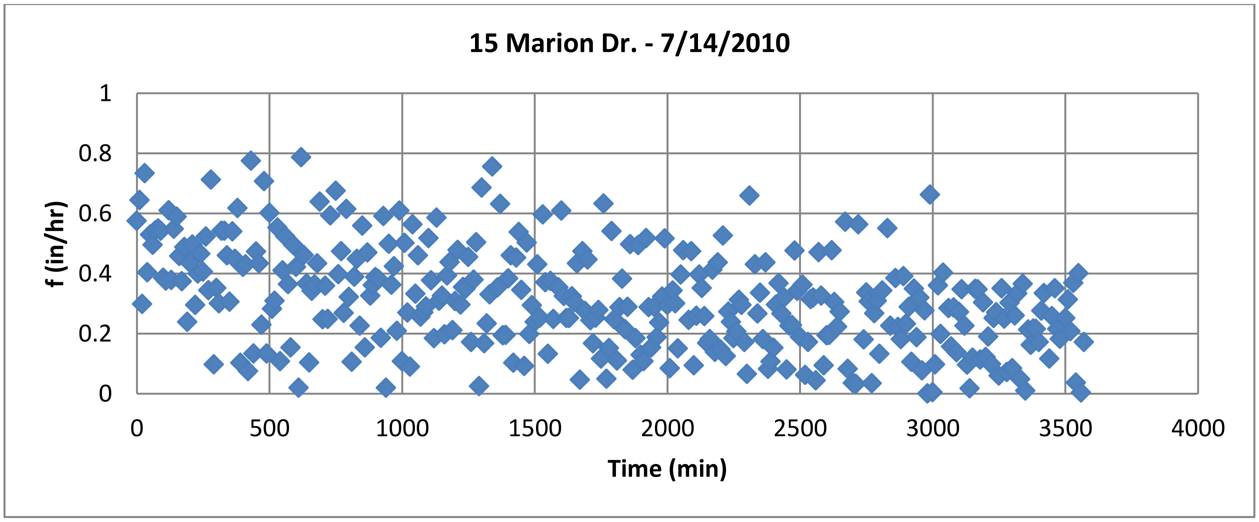


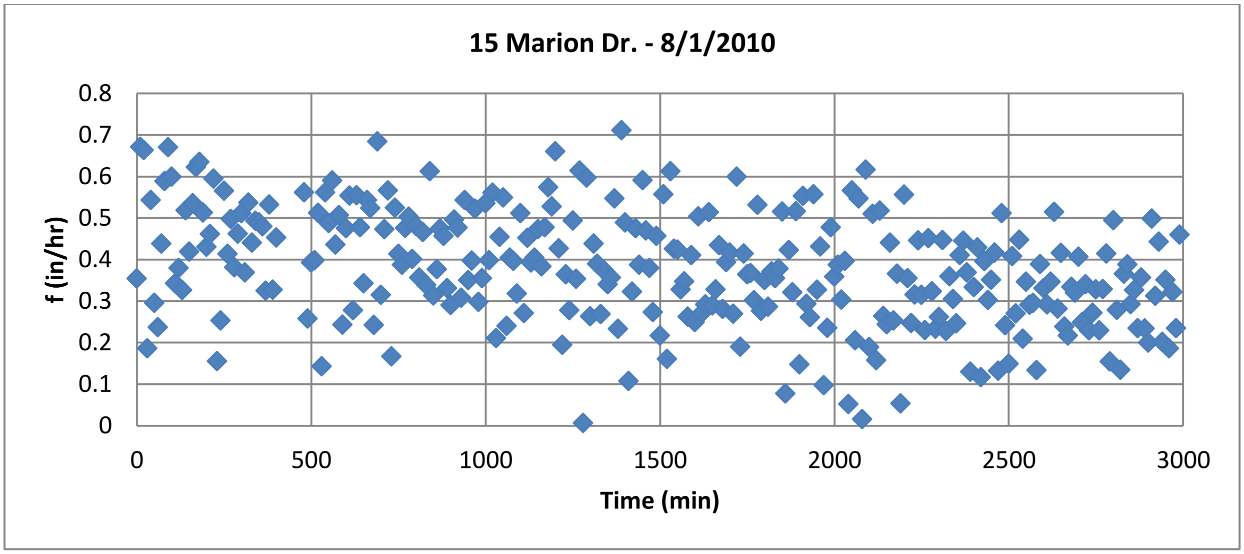


15 Marion Drive

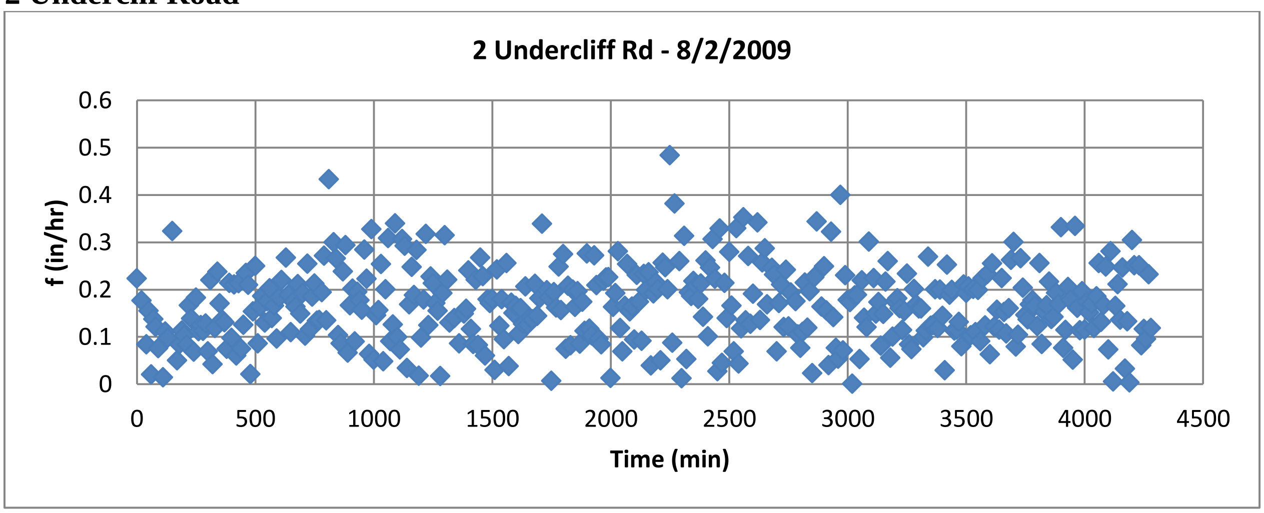




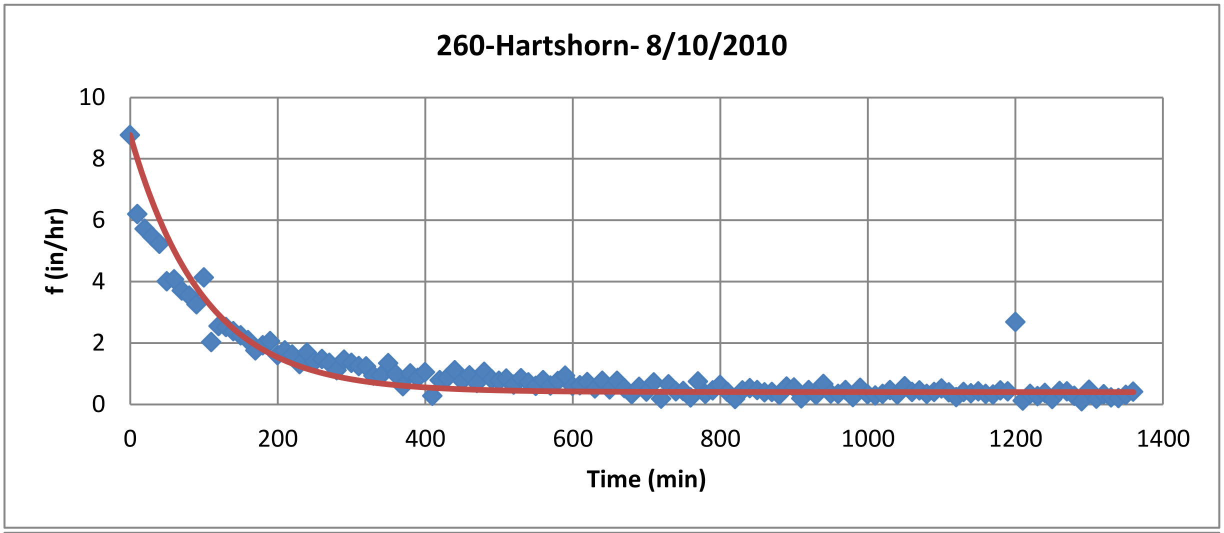


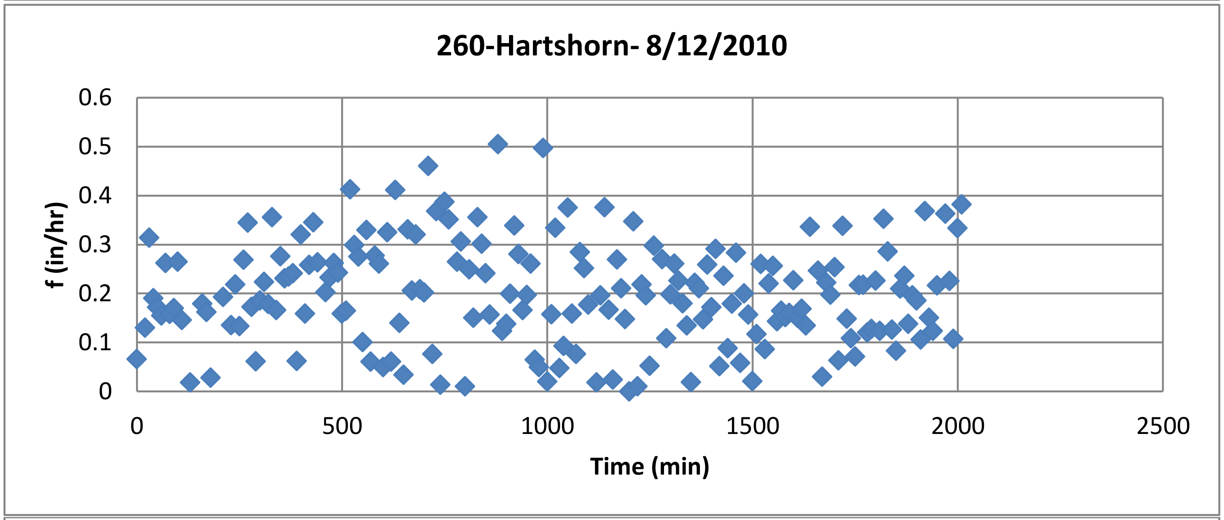


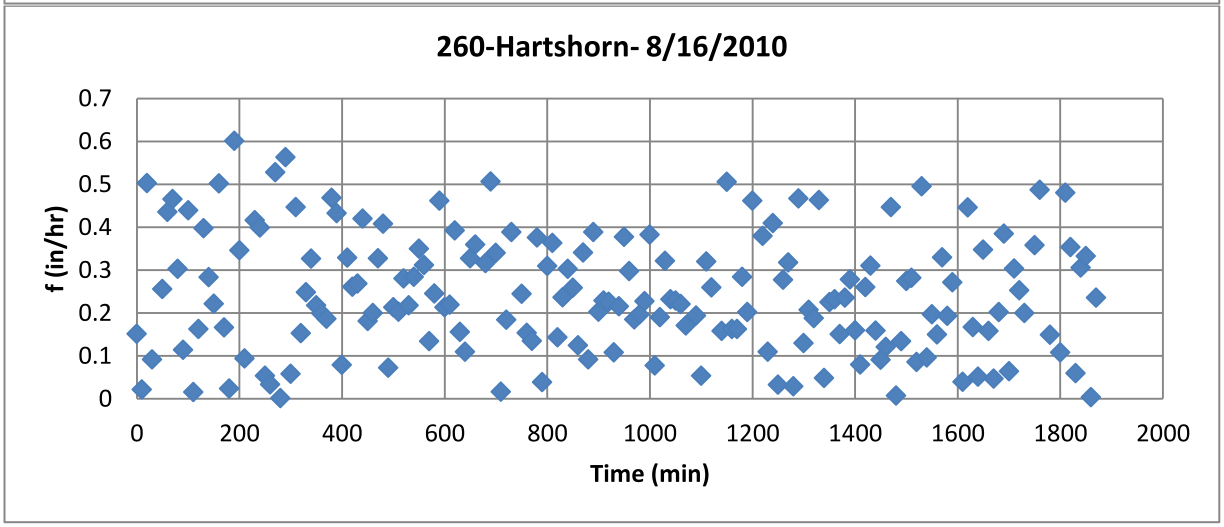
2 Underclif Road

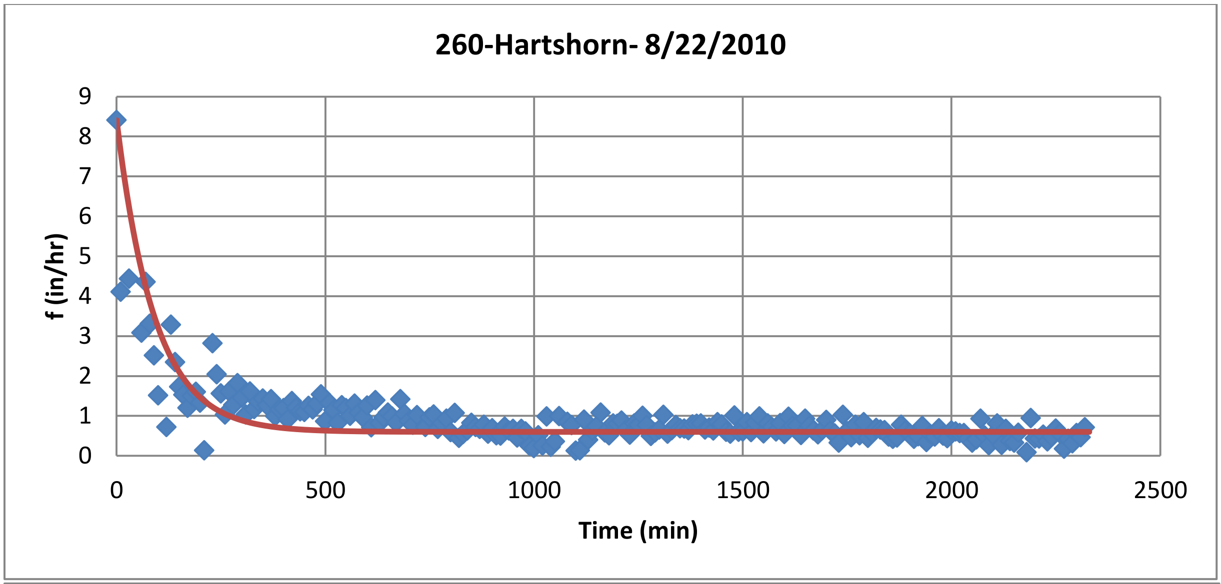


260 Hartshorn








260-Hartshorn- 8/22/2010
f (in/hr)
Time (min)
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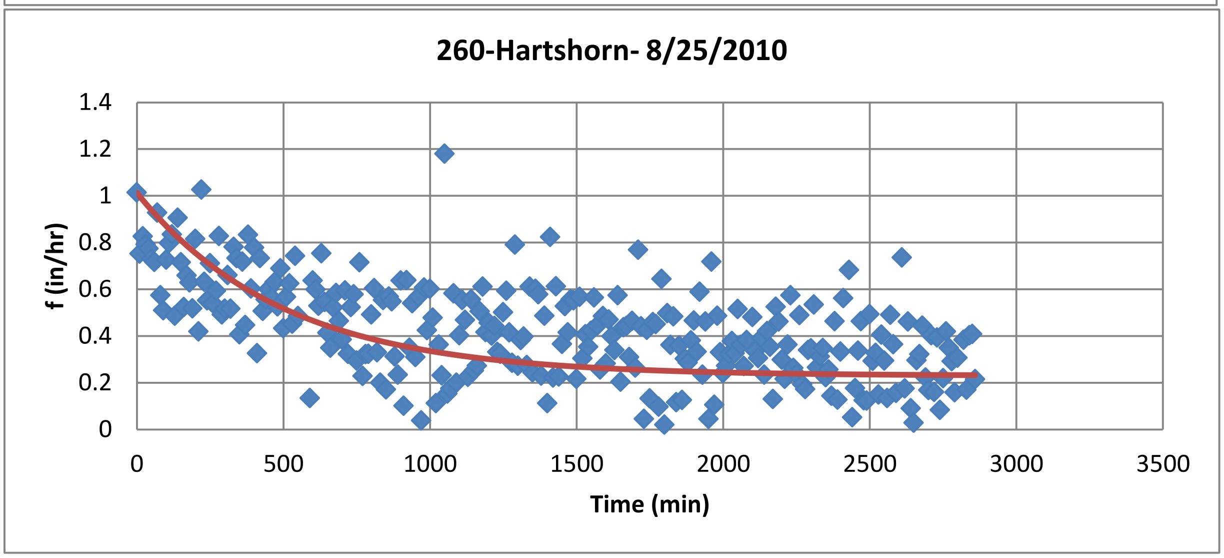
2000
2500


260-Hartshorn- 8/25/2010
f (in/hr)
Time (min)
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1.2
1.4
0
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2500
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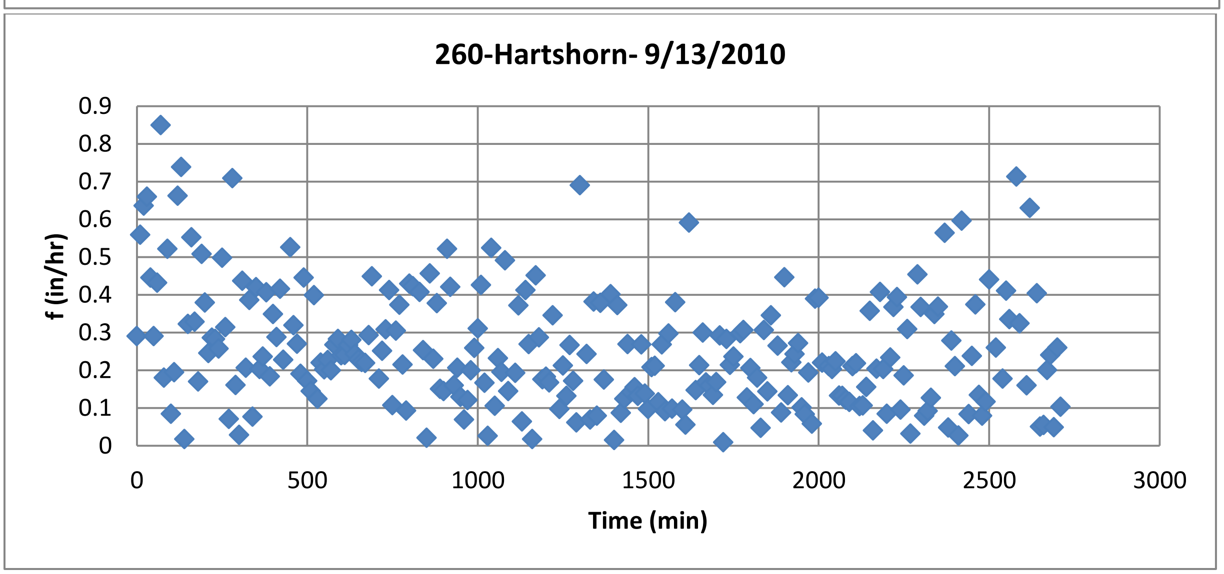
3500


260-Hartshorn- 9/13/2010
f (in/hr)
Time (min)
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0.7
0.8
0.9
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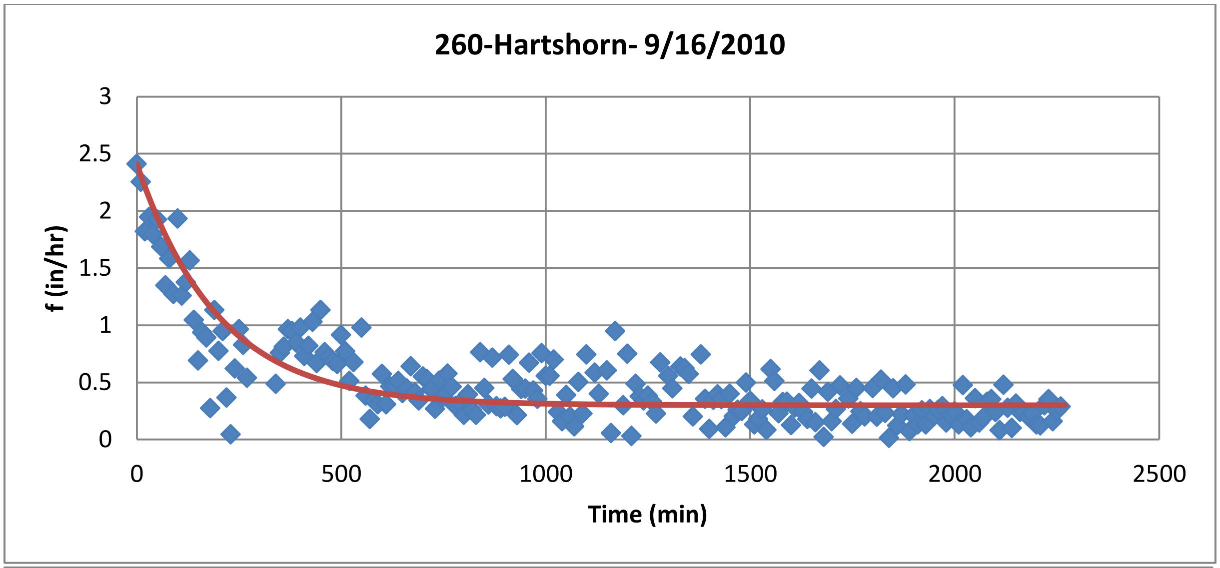
260-Hartshorn- 9/16/2010
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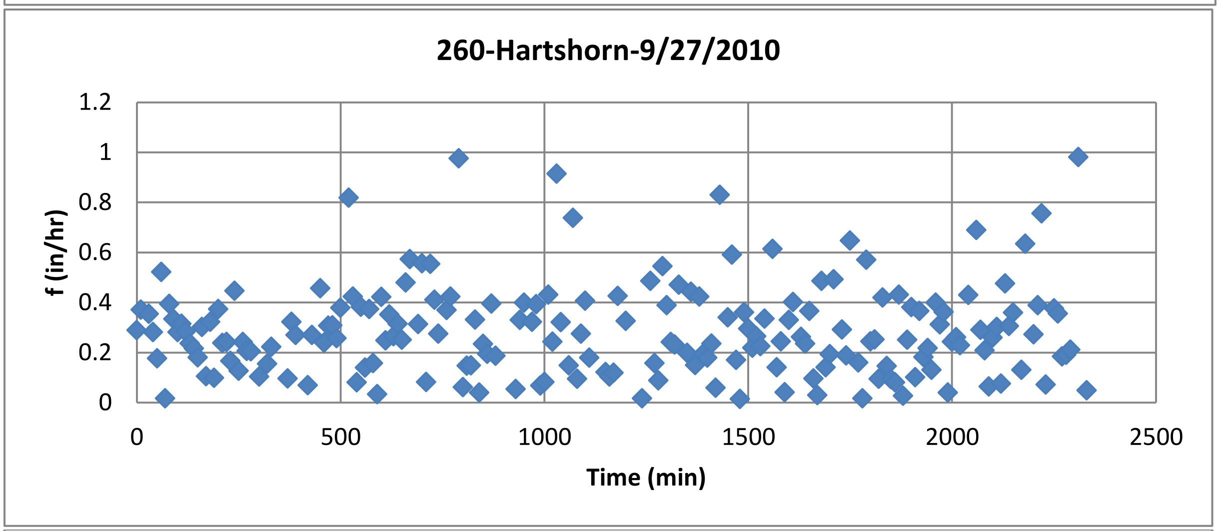
260-Hartshorn-9/27/2010
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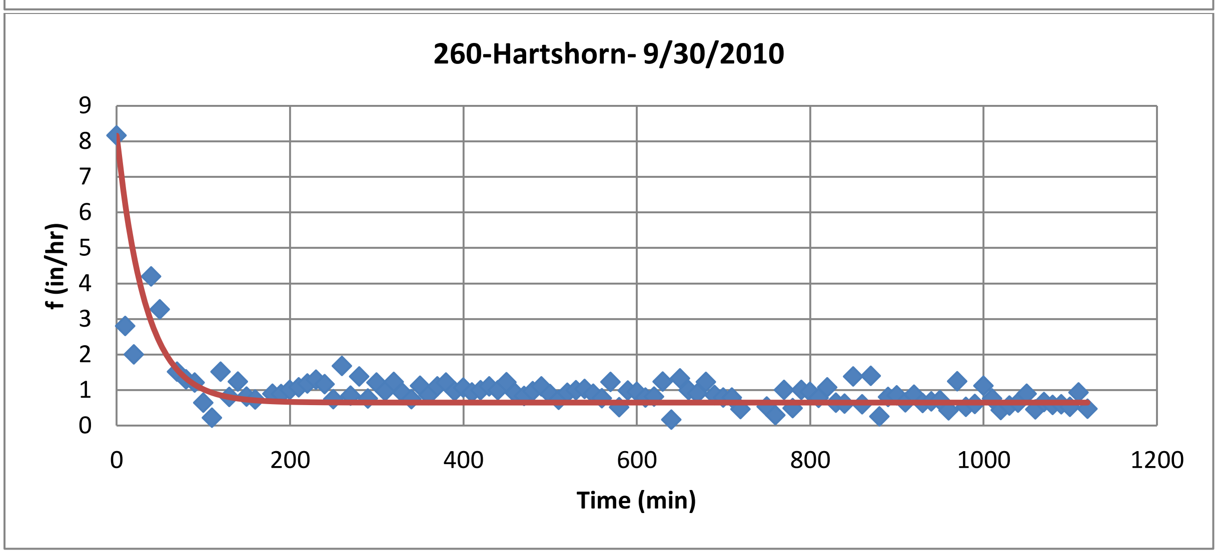
260-Hartshorn- 9/30/2010
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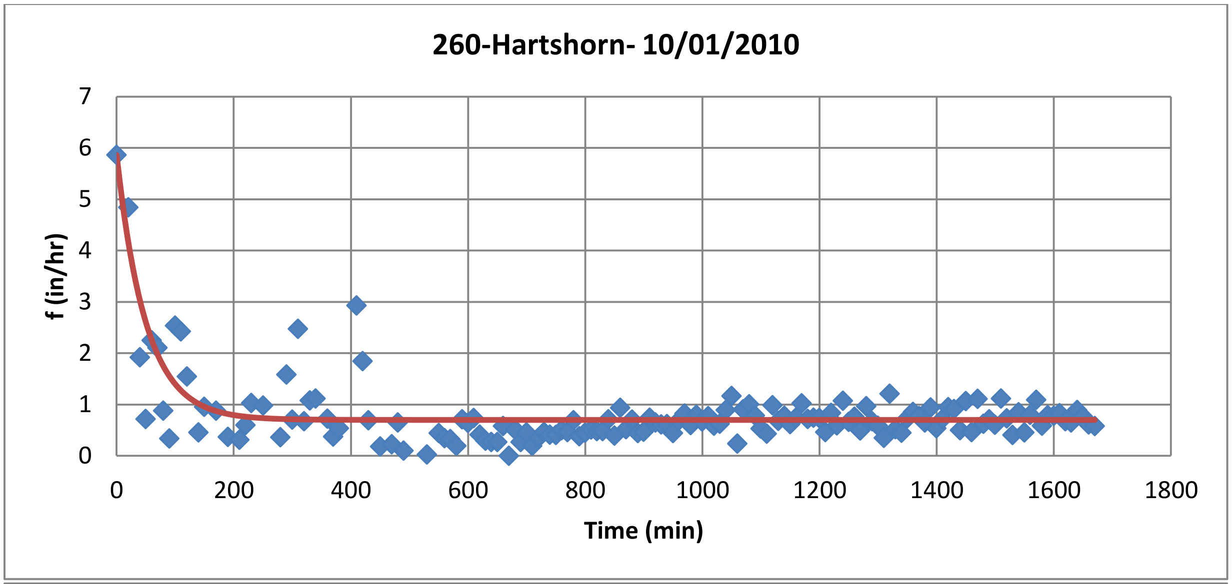
260-Hartshorn- 10/01/2010
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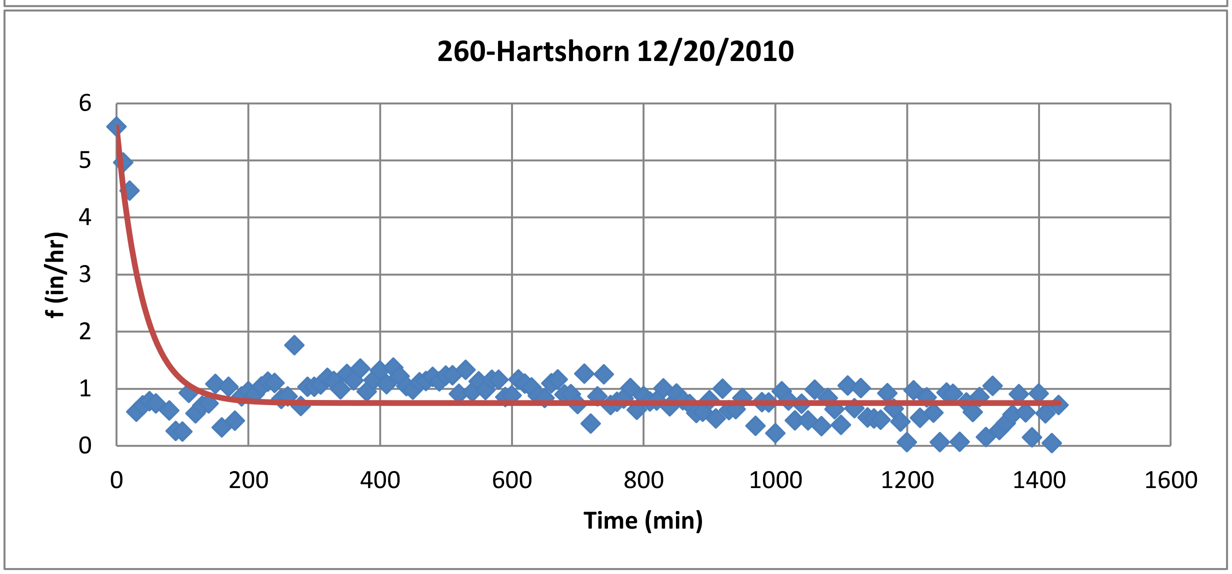
260-Hartshorn 12/20/2010
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Time (min)
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1400
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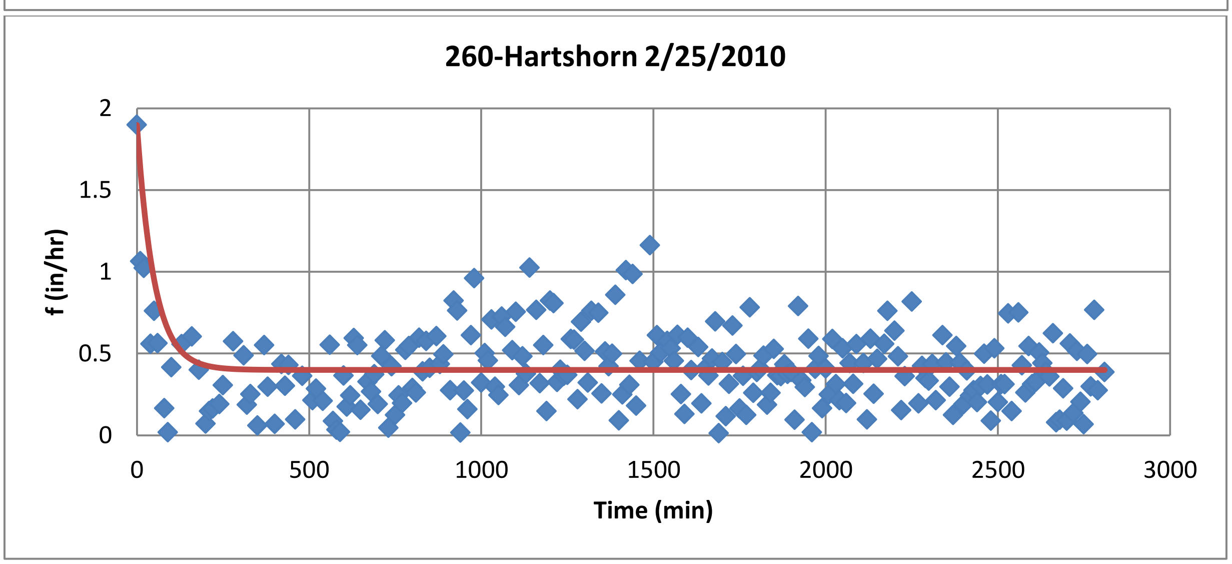
260-Hartshorn 2/25/2010
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Time (min)
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1.5
2
0
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1500
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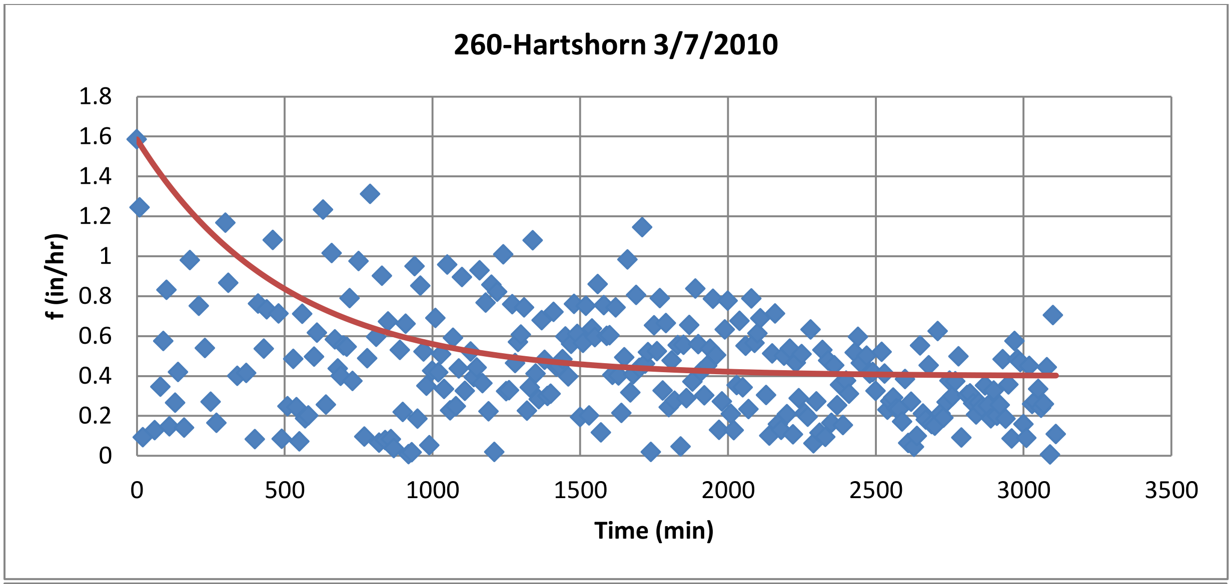
2500
3000


260-Hartshorn 3/7/2010
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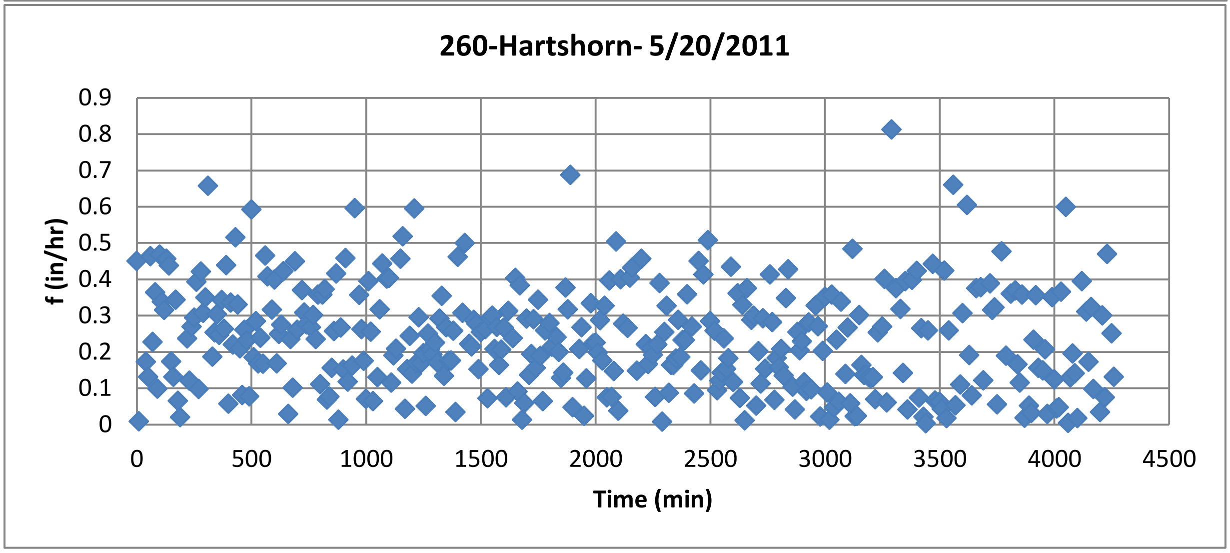
260-Hartshorn- 5/20/2011
f (in/hr)
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0.3
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0.8
0.9
0
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1000
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2500
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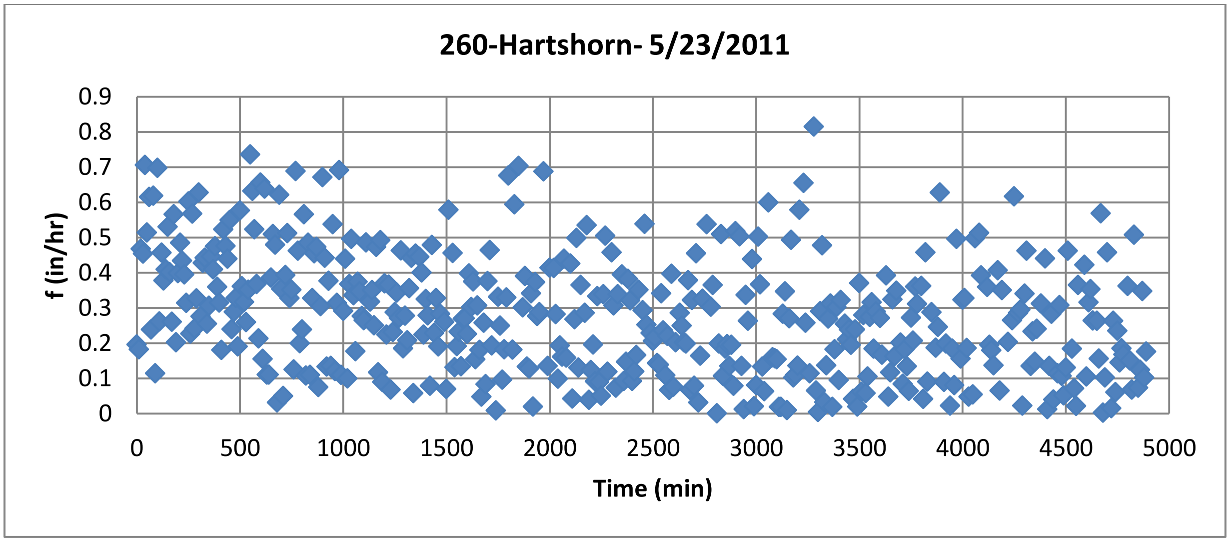
3500
4000
4500


260-Hartshorn- 5/23/2011
f (in/hr)
Time (min)
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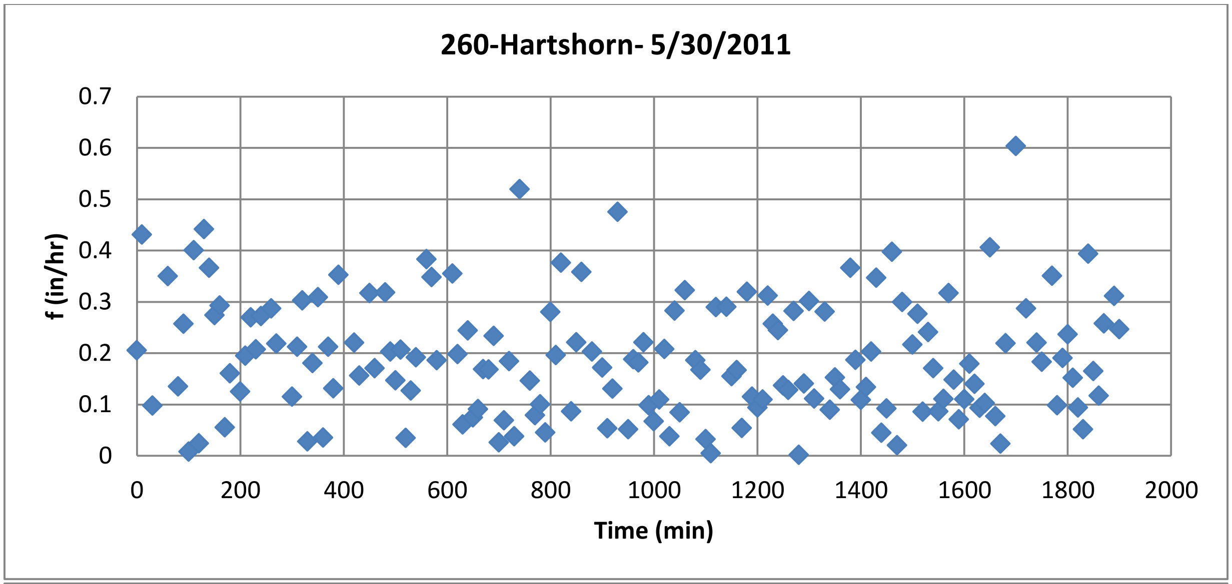
5000


260-Hartshorn- 5/30/2011
f (in/hr)
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0.5
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0
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200
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1200
1400
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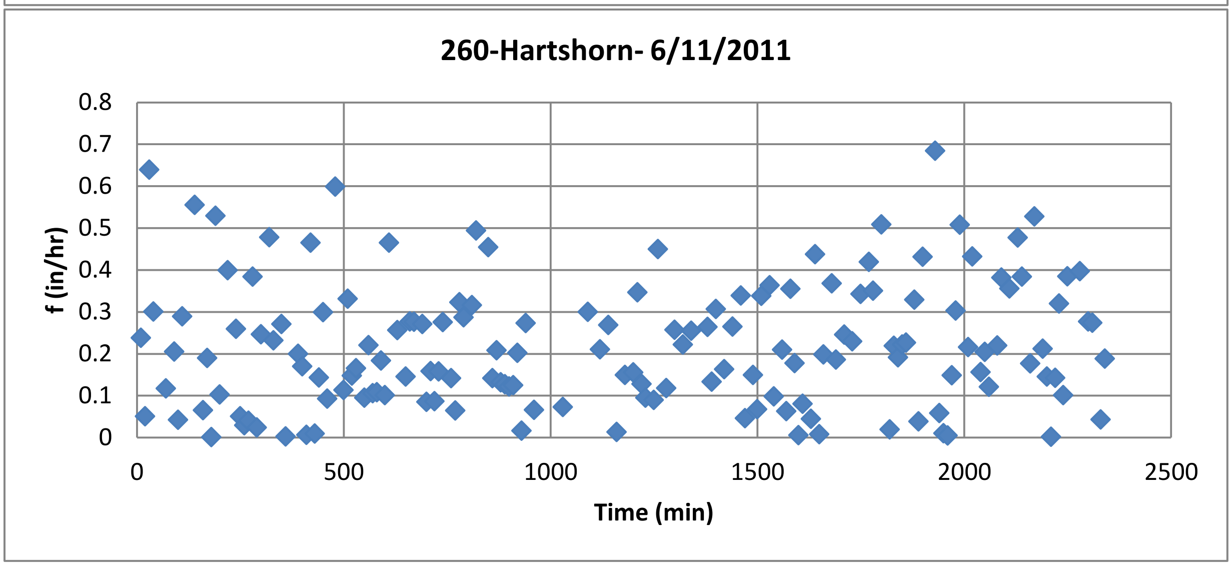
1800
2000
Time (min)


260-Hartshorn- 6/11/2011
f (in/hr)
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0.1
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0
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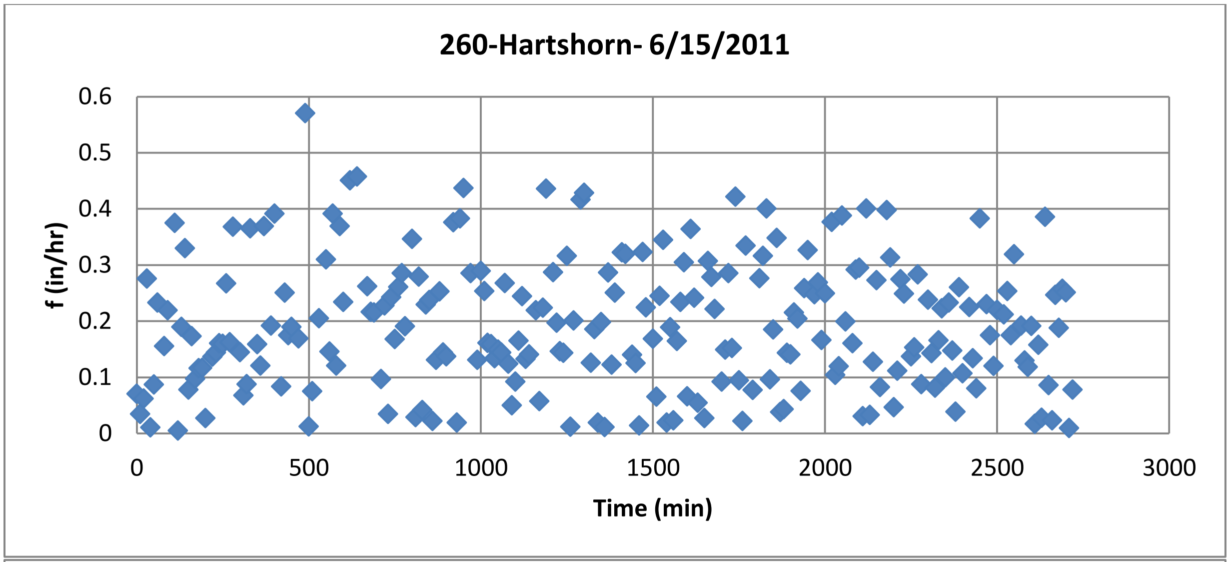
2000
2500
Time (min)


260-Hartshorn- 6/15/2011
f (in/hr)
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0.1
0
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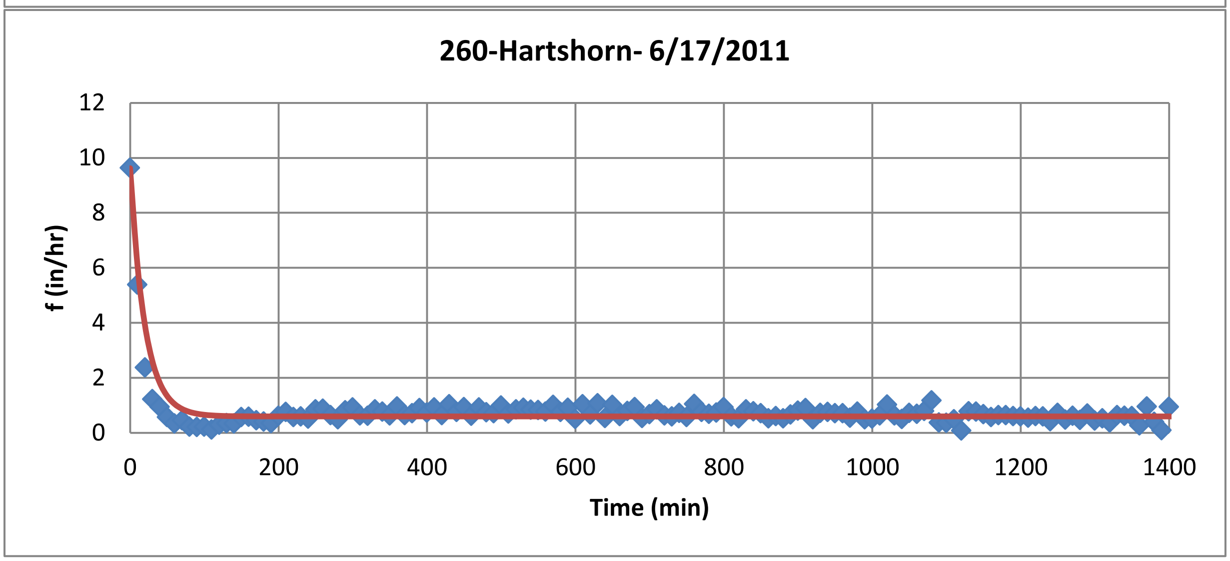
1500
2000
2500
3000
Time (min)


260-Hartshorn- 6/17/2011
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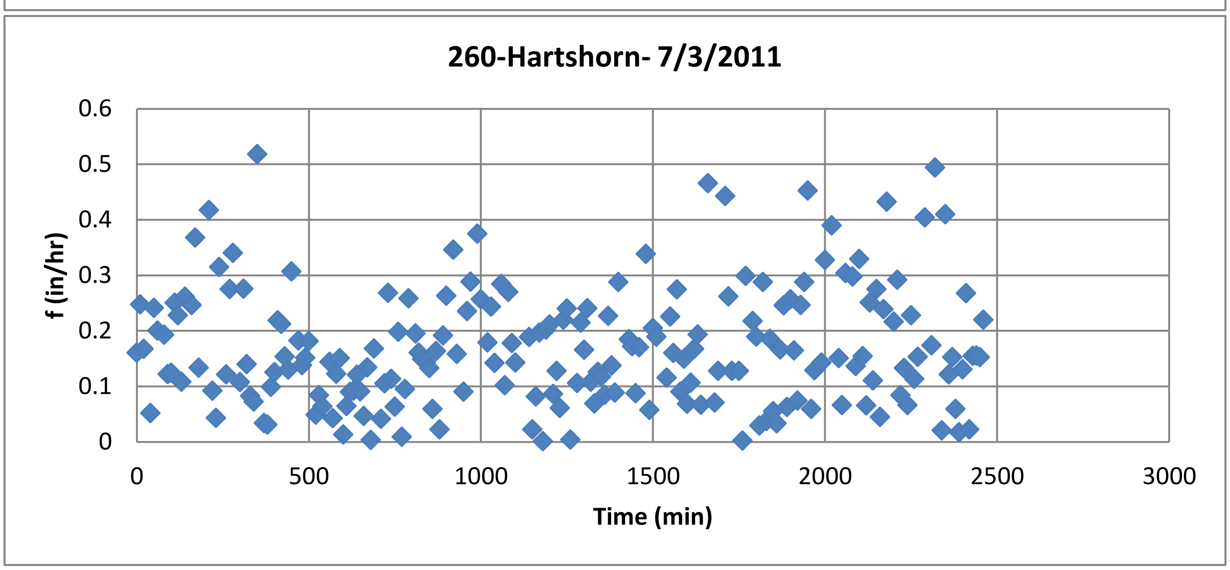
1200
1400
Time (min)


260-Hartshorn- 7/3/2011
f (in/hr)
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0.1
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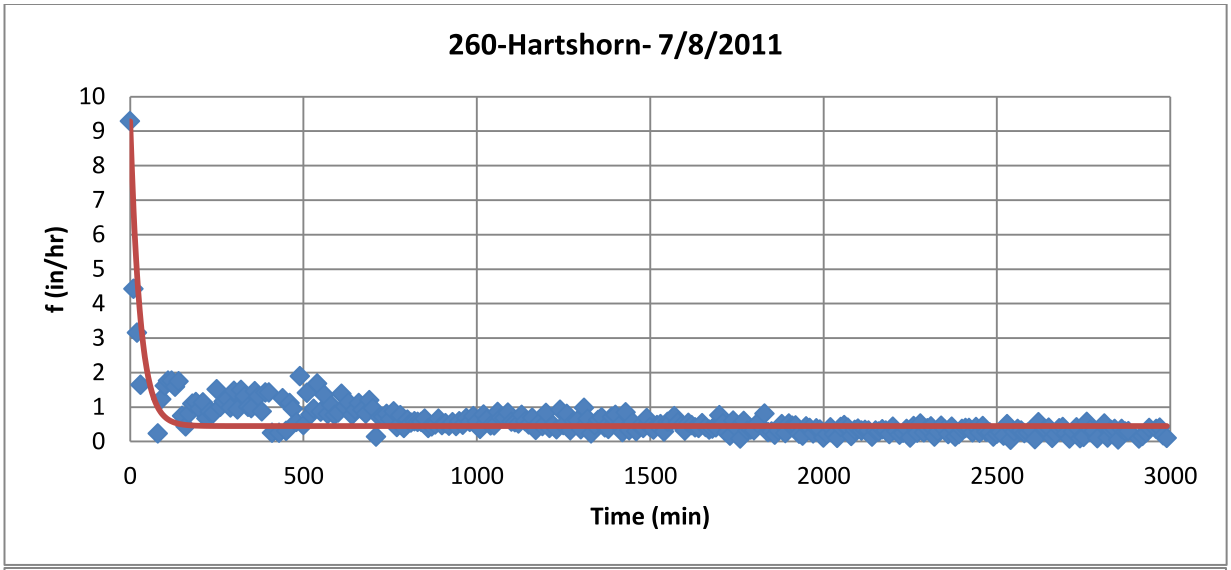
2000
2500
3000
Time (min)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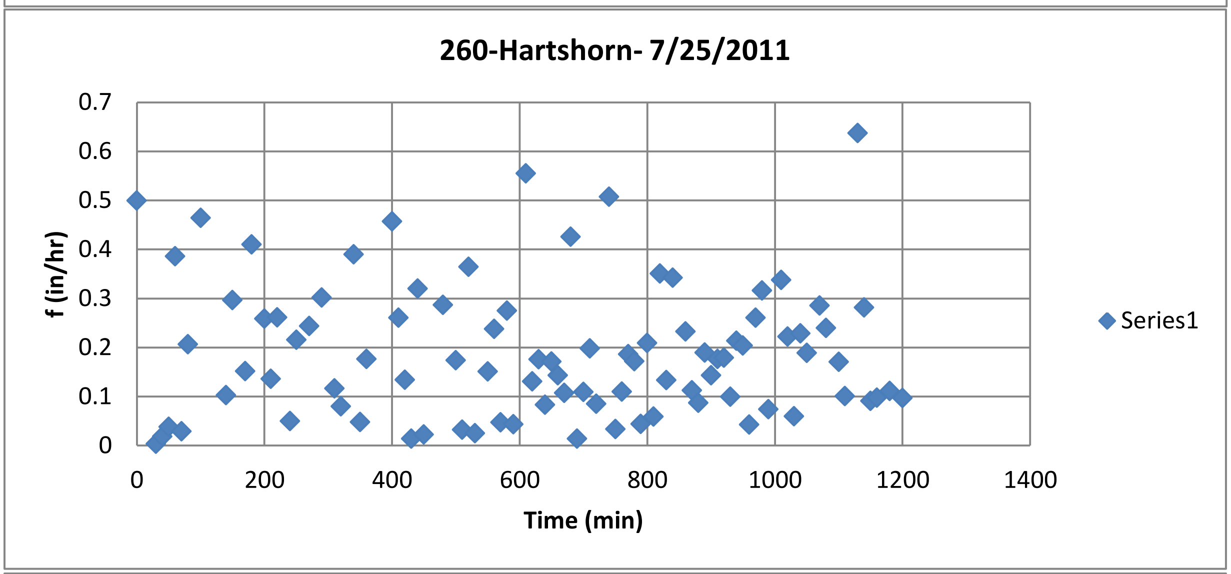
260-Hartshorn- 7/25/2011
f (in/hr)
Time (min)
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1200
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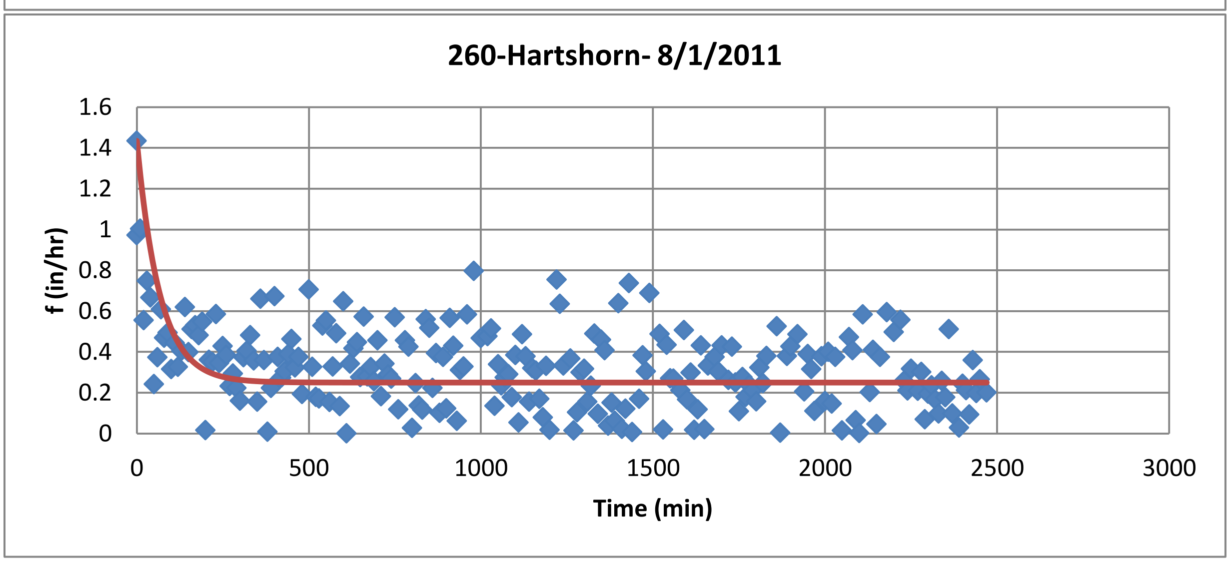
260-Hartshorn- 8/1/2011
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1.6
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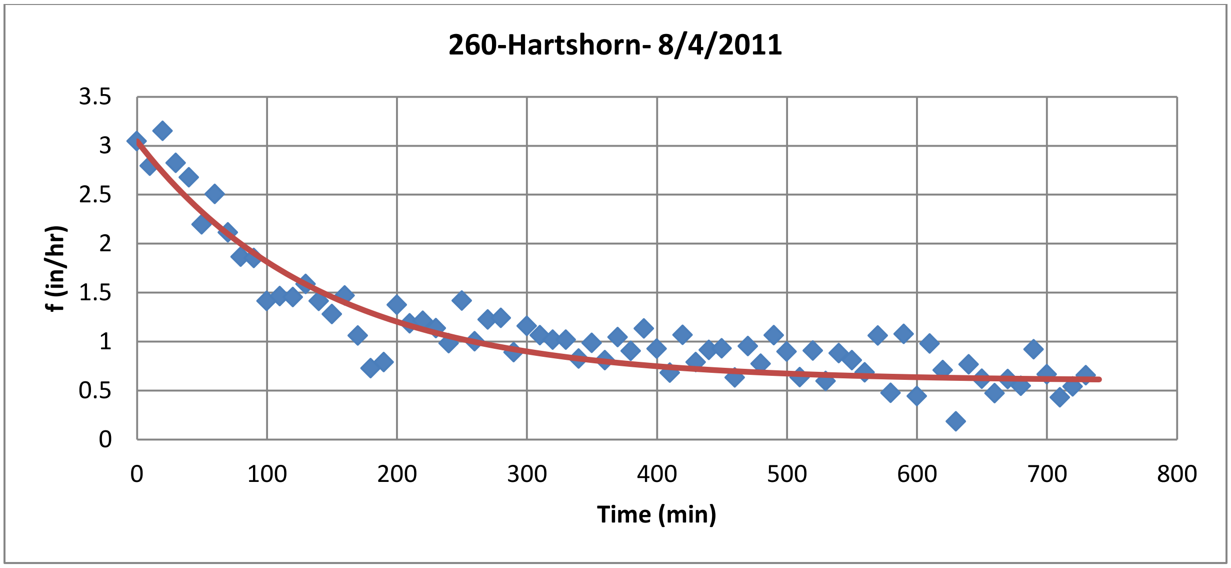
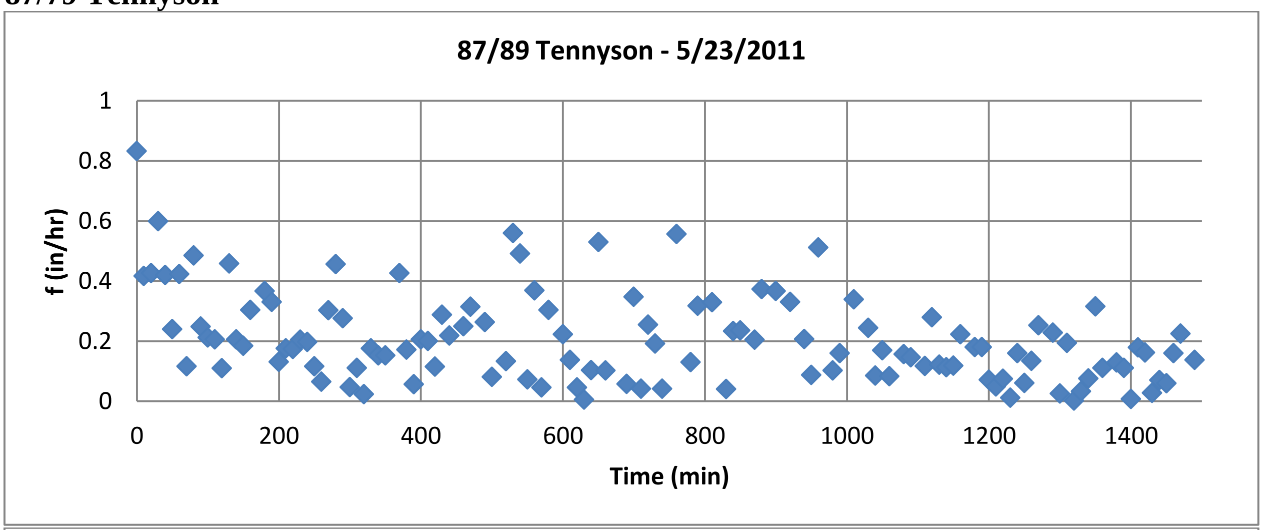
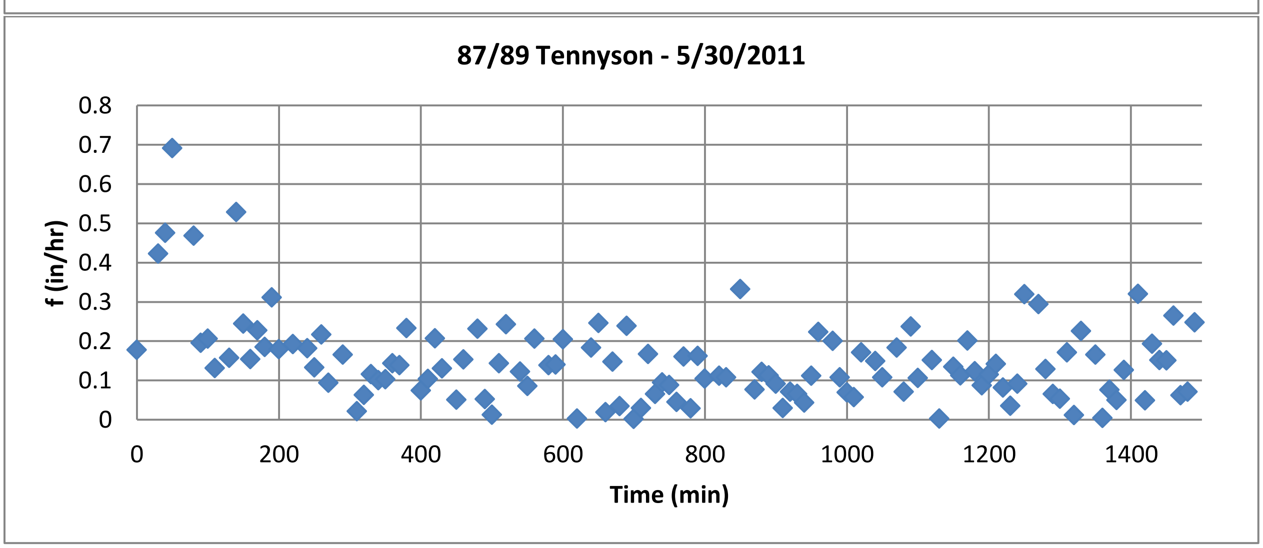
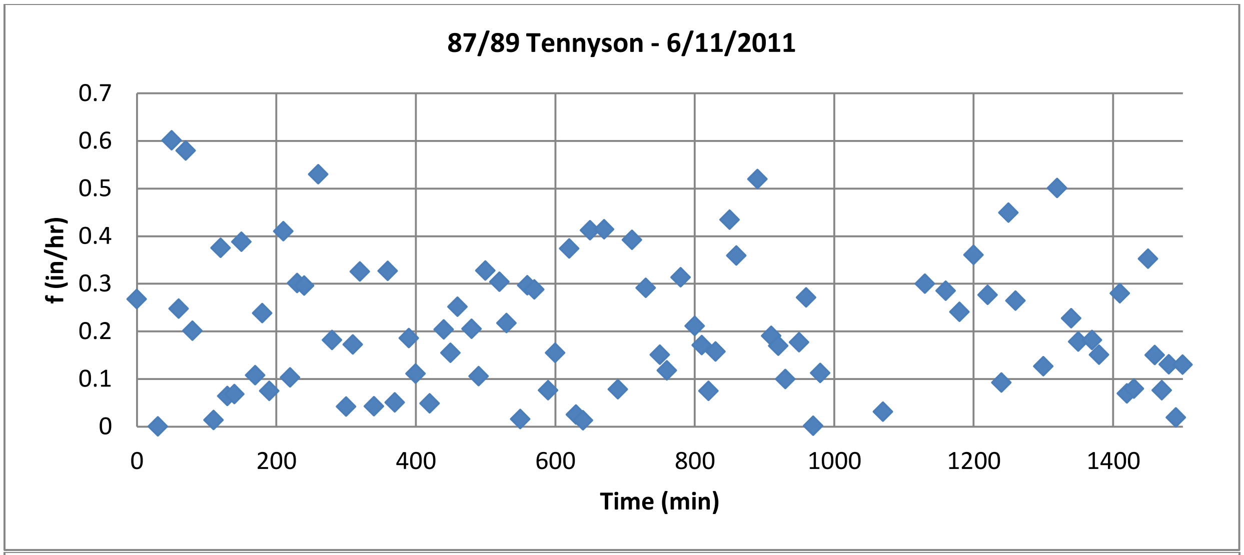
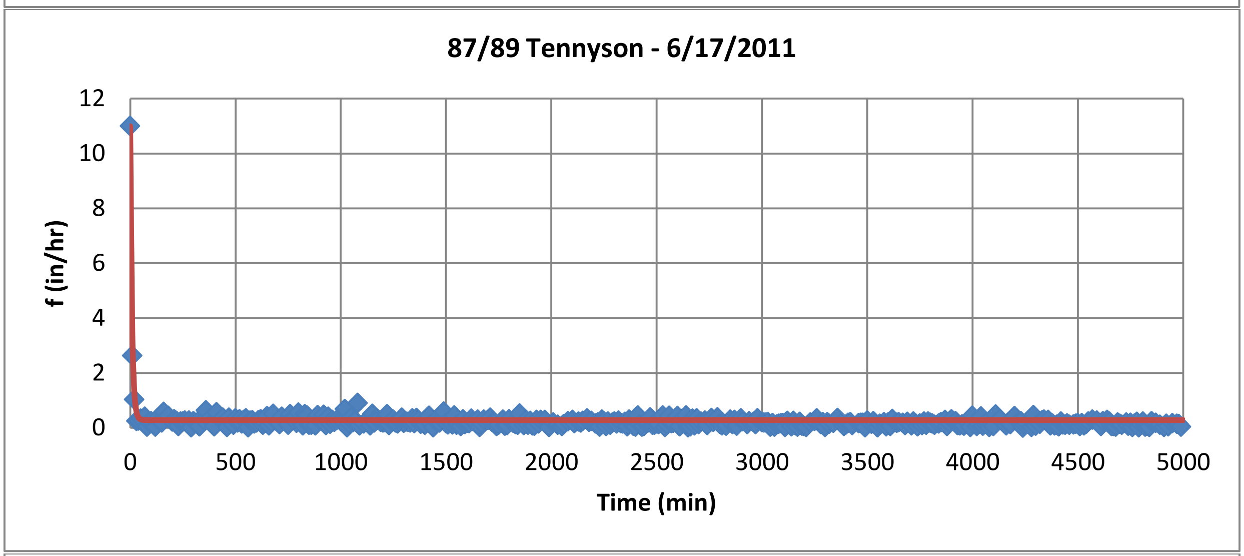


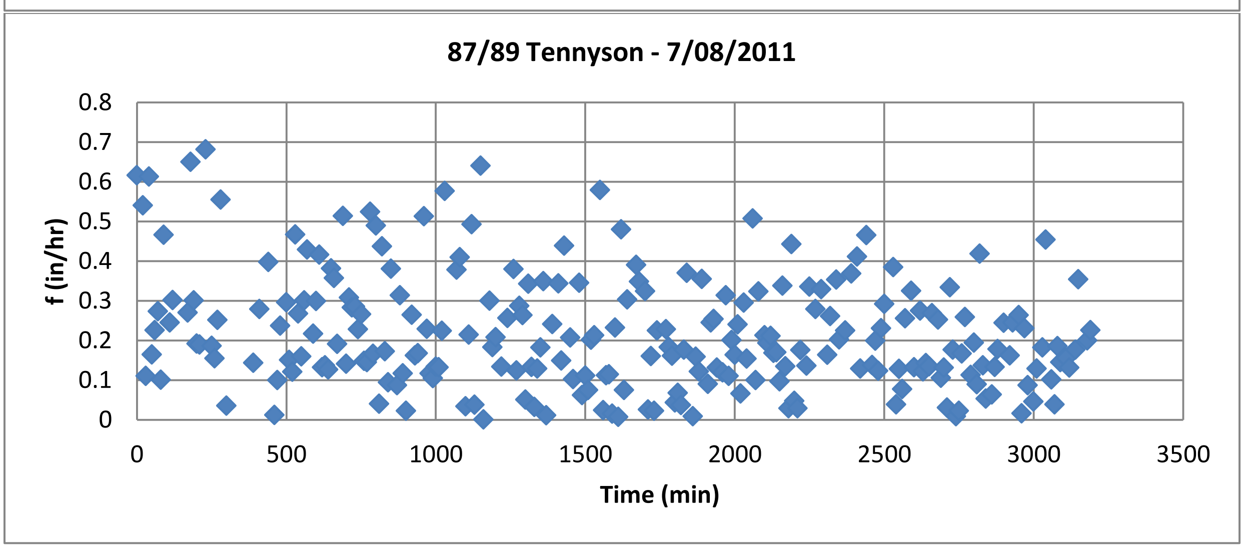
87/79 Tennyson






87/89 Tennyson - 6/11/2011
f (in/hr)
Time (min)


87/89 Tennyson - 6/17/2011
f (in/hr)
Time (min)


87/89 Tennyson - 7/08/2011
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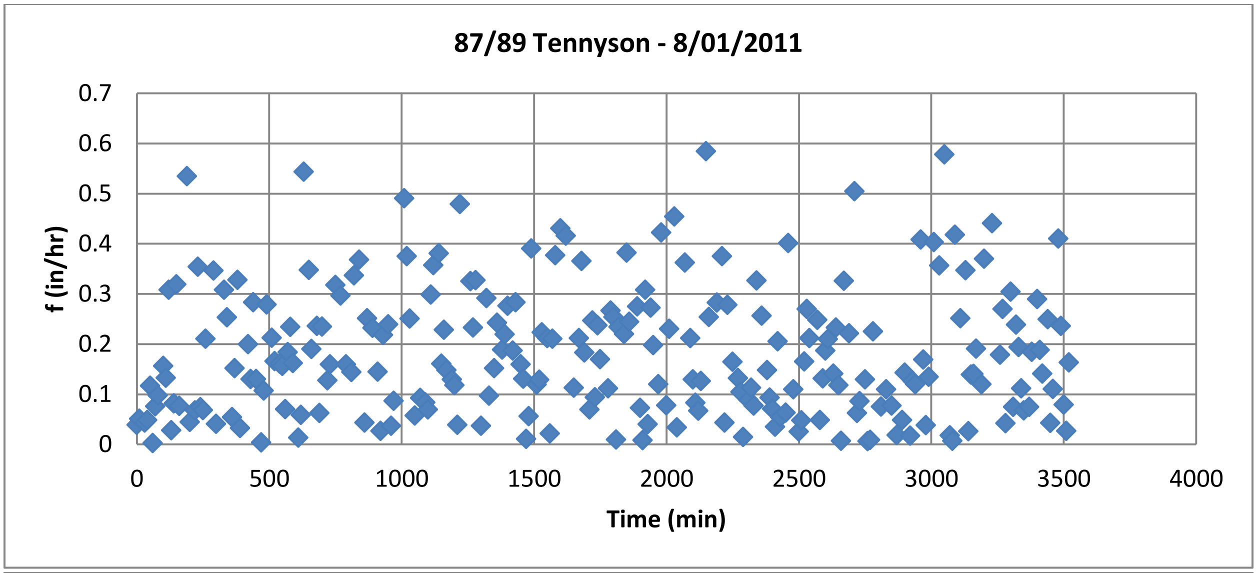
Time (min)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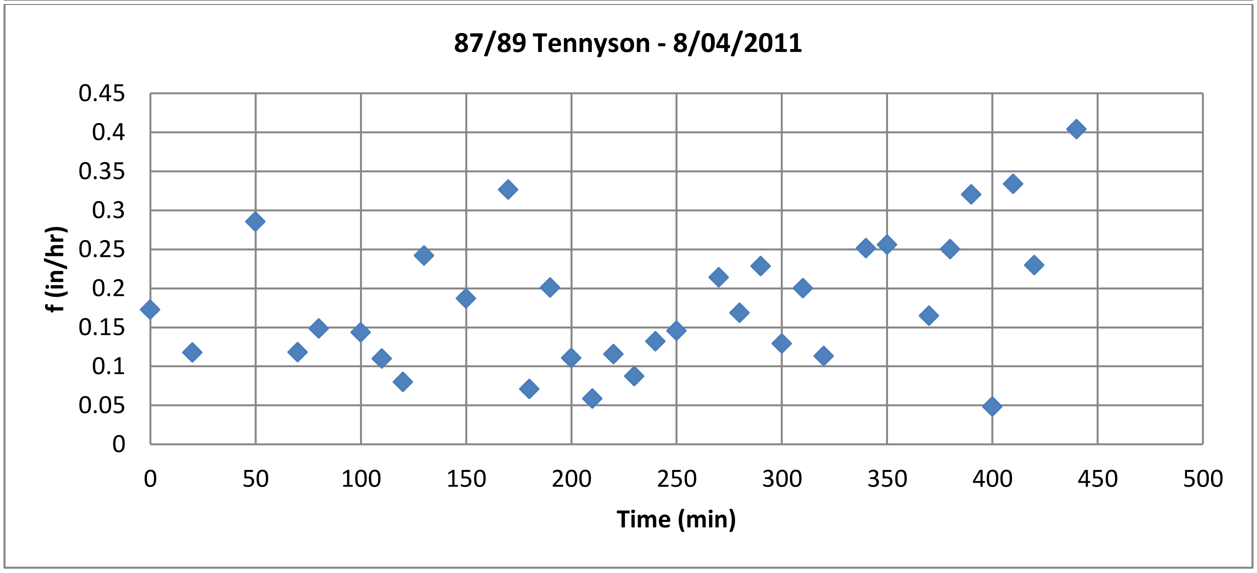
Time (min)


87/89 Tennyson - 8/04/2011
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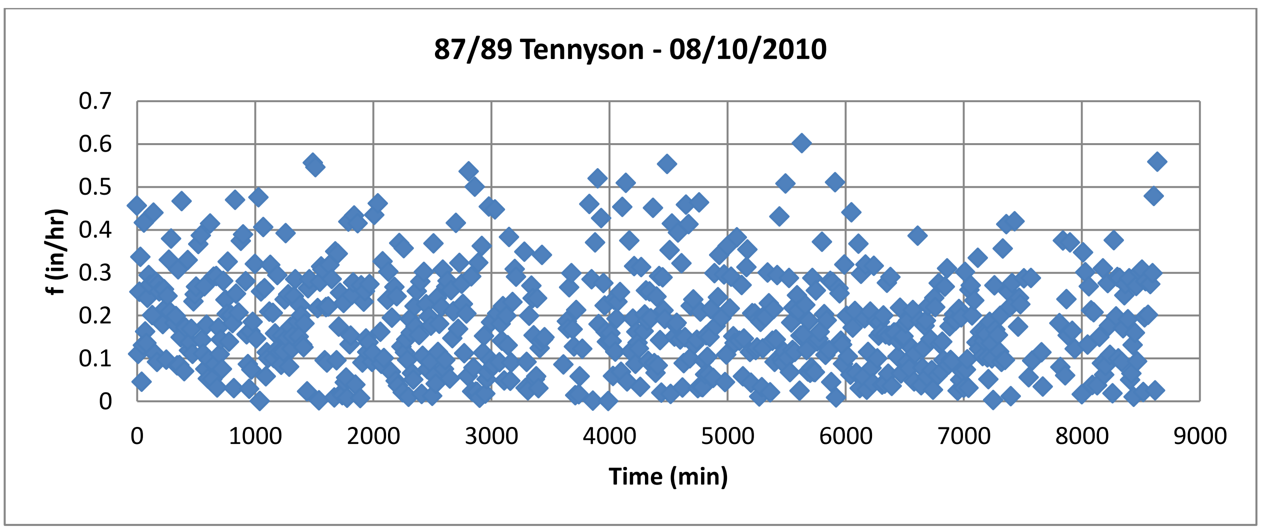
500
Time (min)


87/89 Tennyson - 08/10/2010
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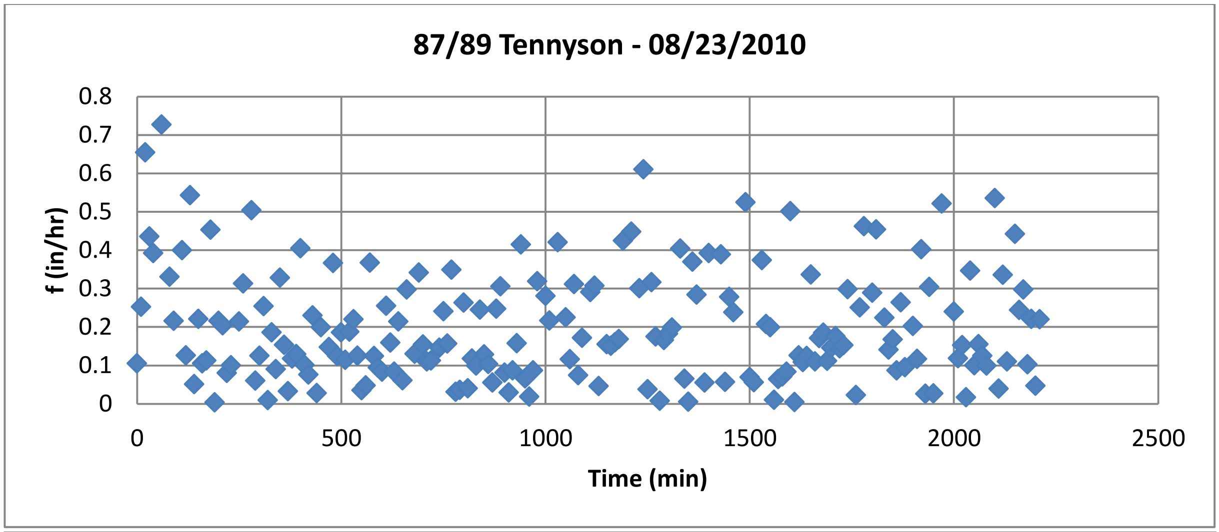
Time (min)


87/89 Tennyson - 08/23/2010
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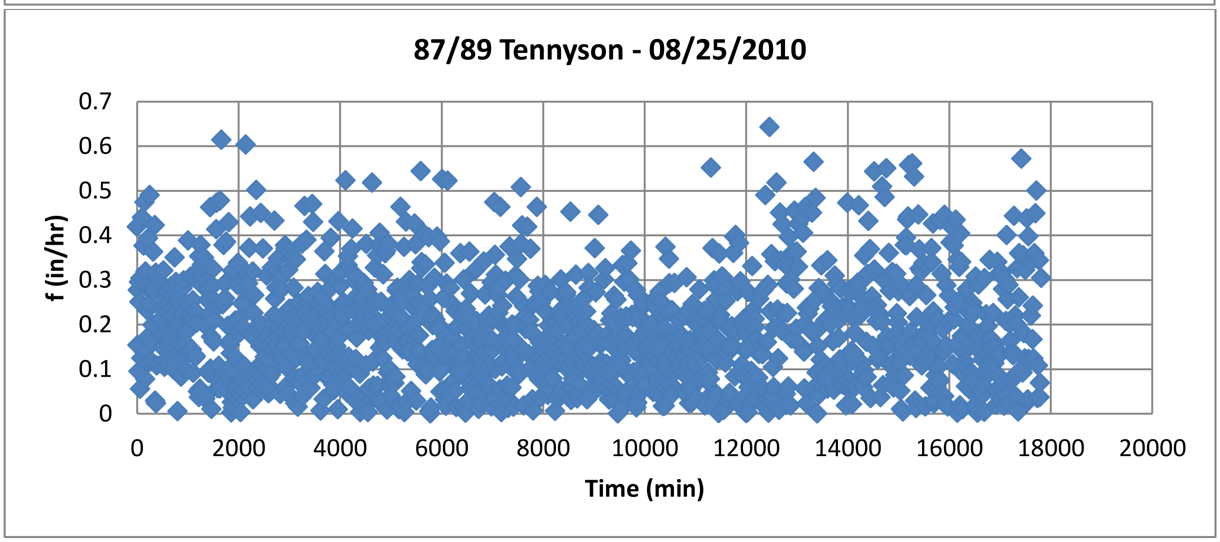
Time (min)


87/89 Tennyson - 08/25/2010
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14000
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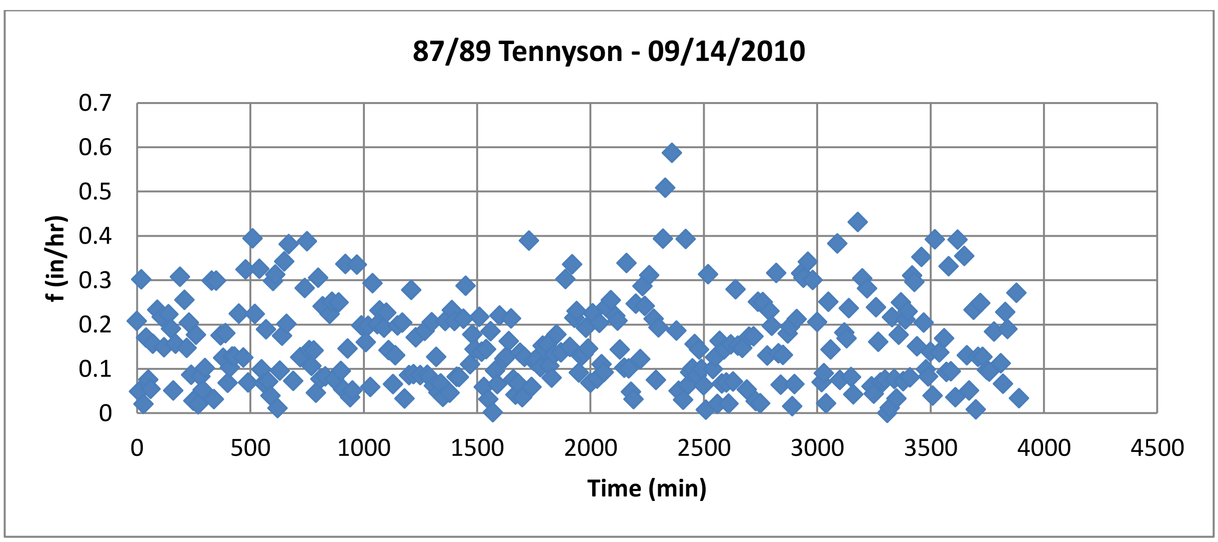
Time (min)


87/89 Tennyson - 09/14/2010
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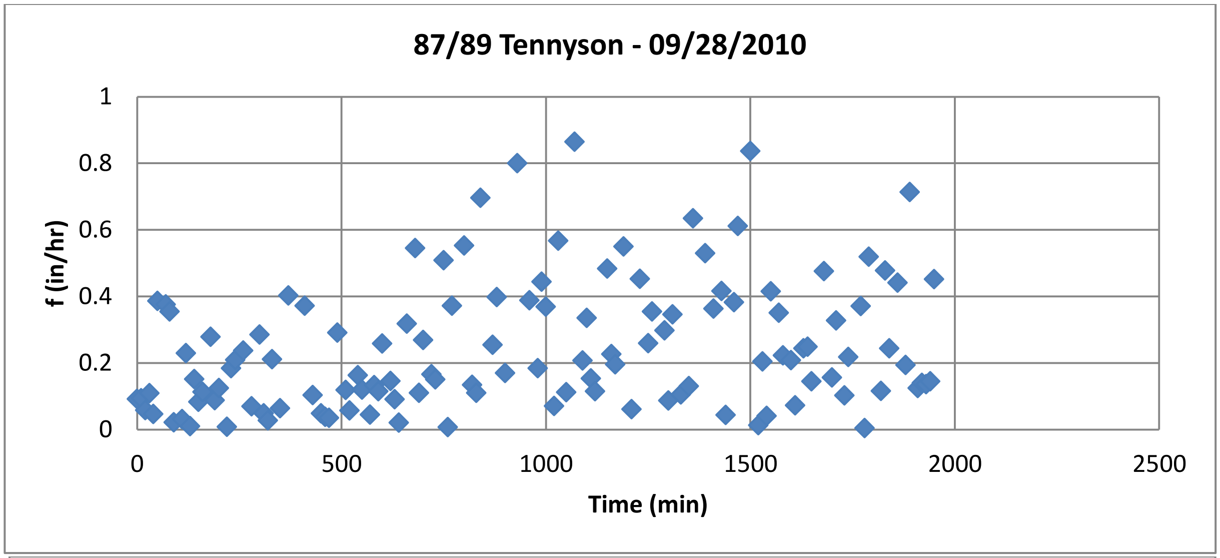
Time (min)


87/89 Tennyson - 09/28/2010
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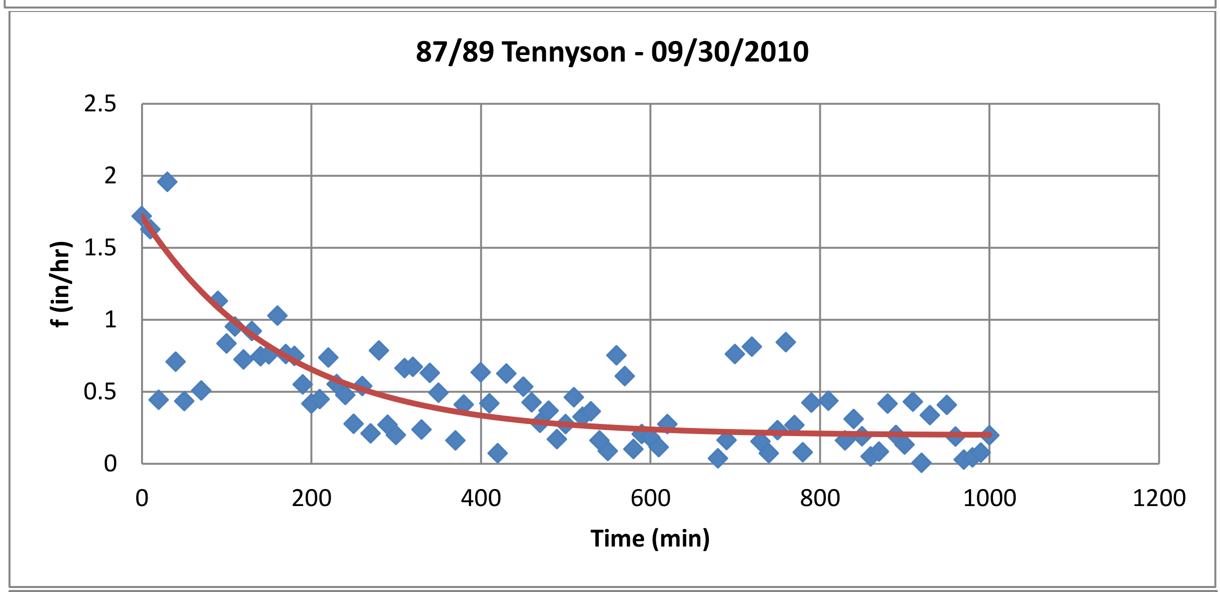
87/89 Tennyson - 09/30/2010
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1.5
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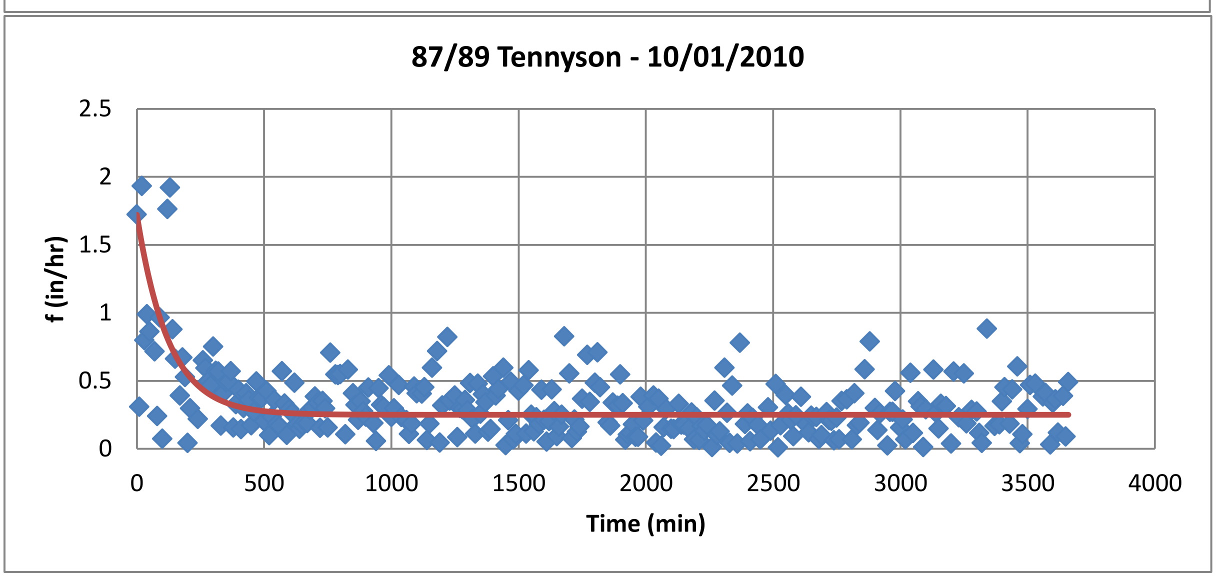
87/89 Tennyson - 10/01/2010
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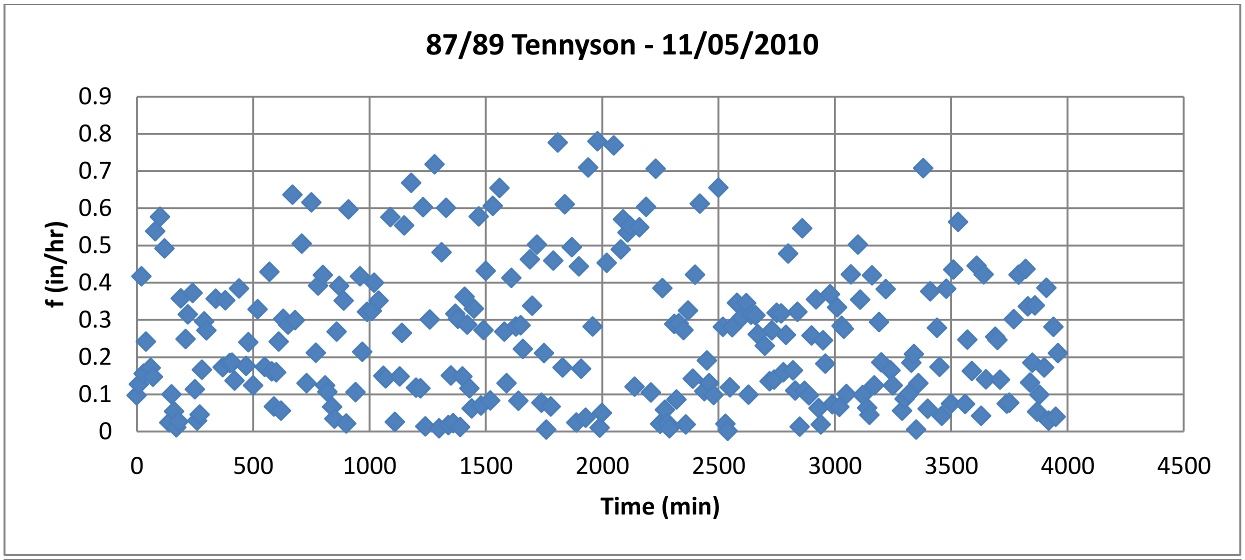
87/89 Tennyson - 11/05/2010
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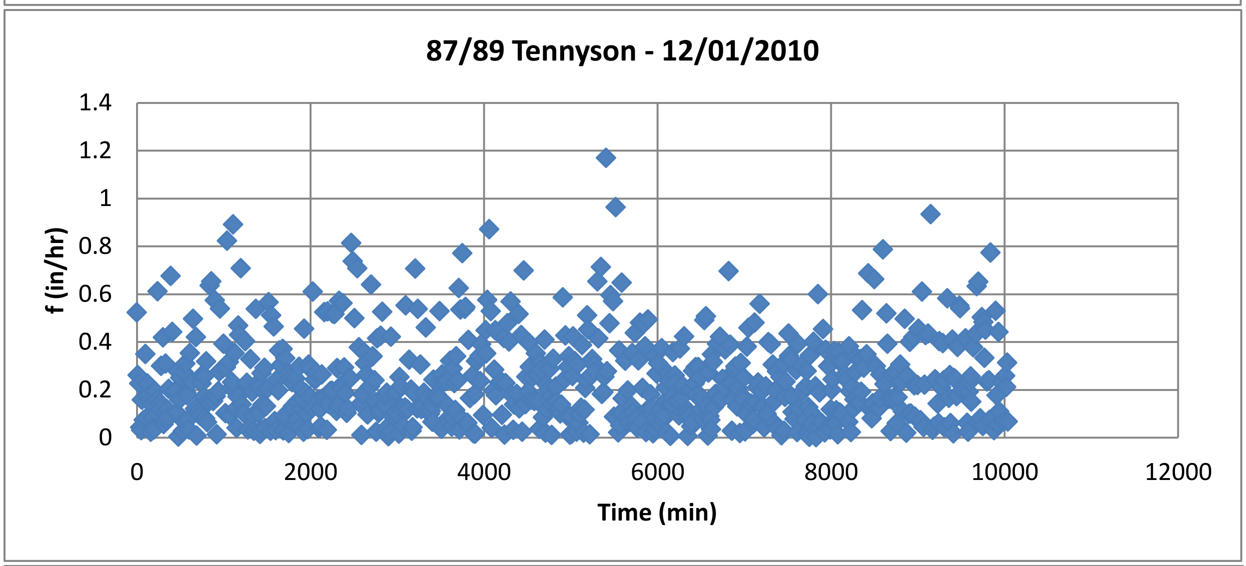
Time (min)


87/89 Tennyson - 12/01/2010
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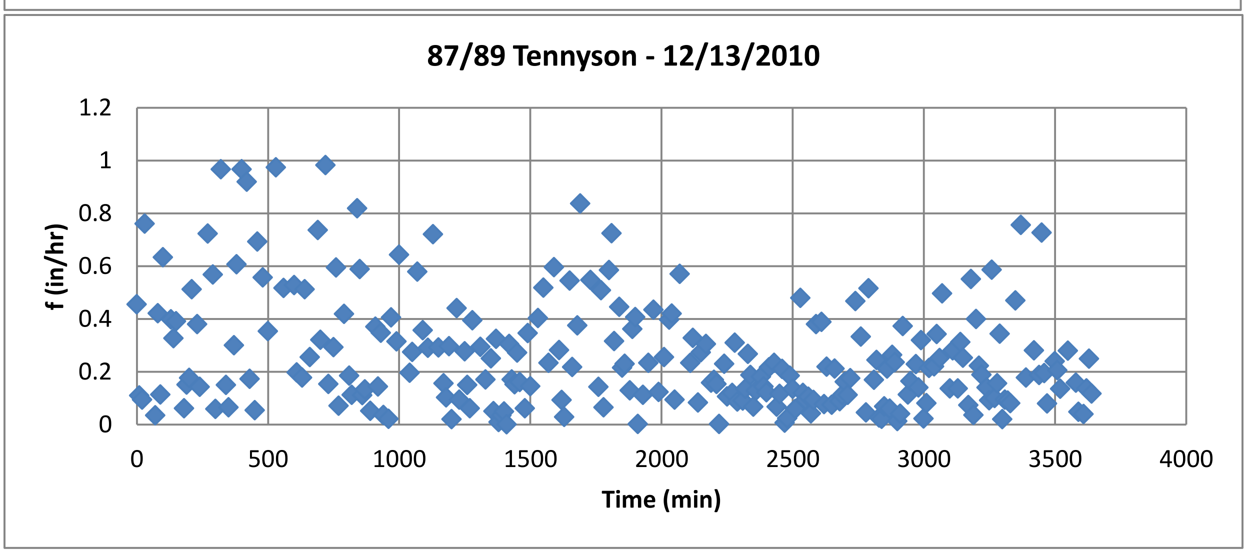
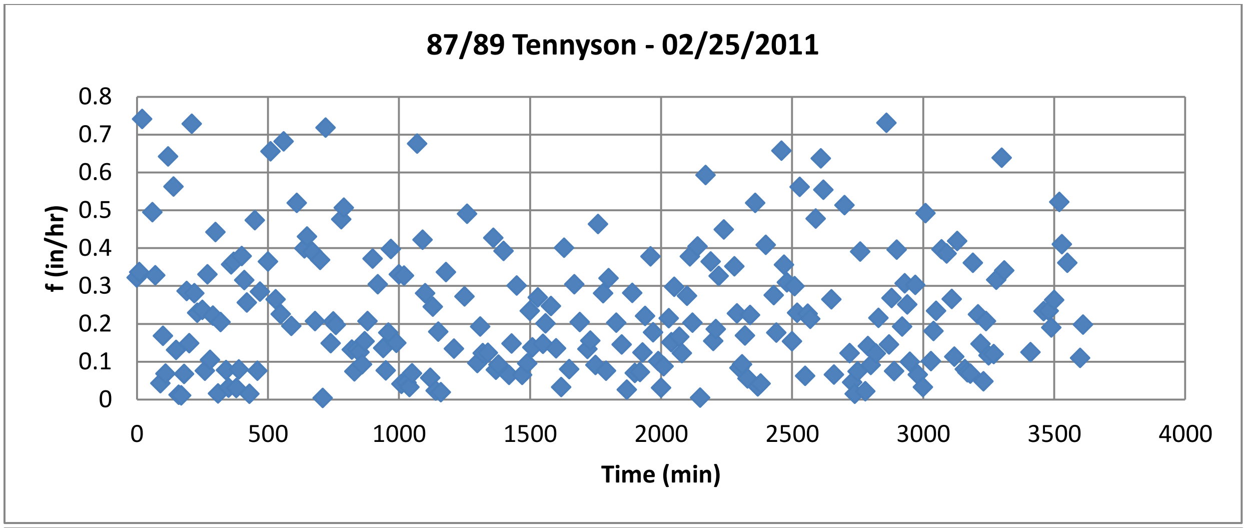
Time (min)


87/89 Tennyson - 12/13/2010
f (in/hr)
Time (min)


87/89 Tennyson - 02/25/2011
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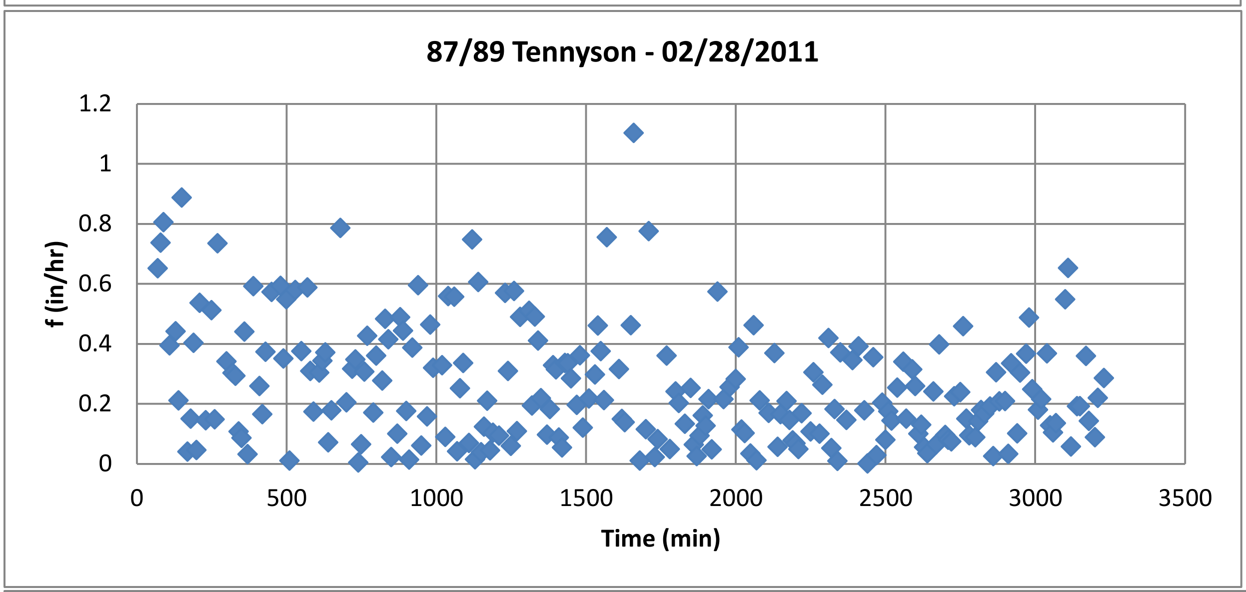
87/89 Tennyson - 02/28/2011
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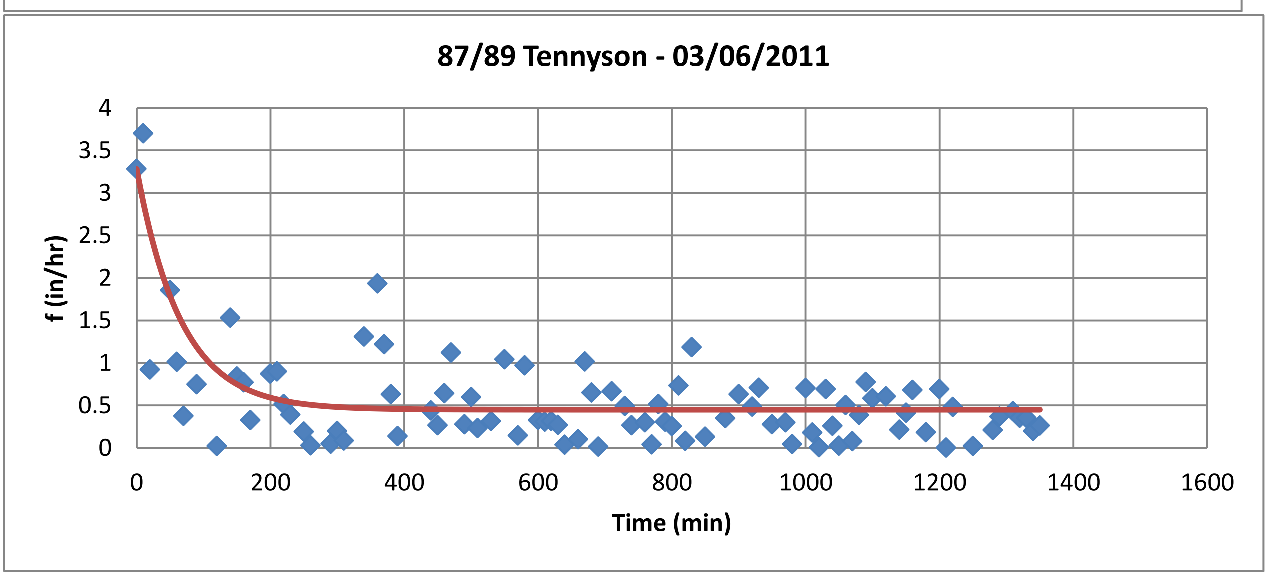
87/89 Tennyson - 03/06/2011
f (in/hr)
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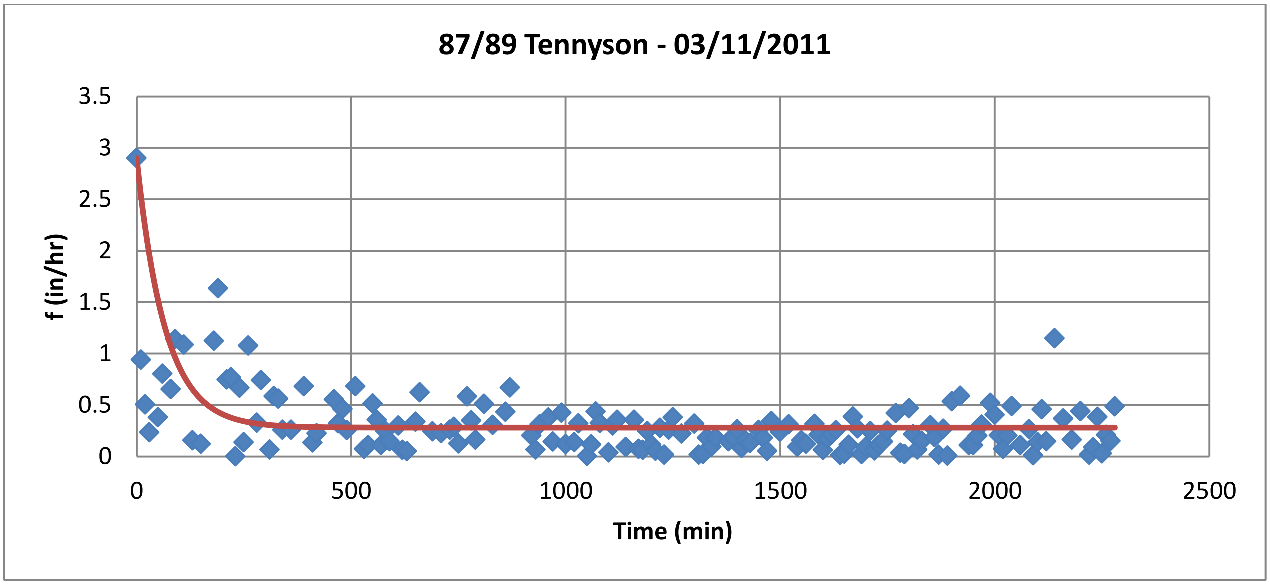
1400
1600


87/89 Tennyson - 03/11/2011
f (in/hr)
Time (min)
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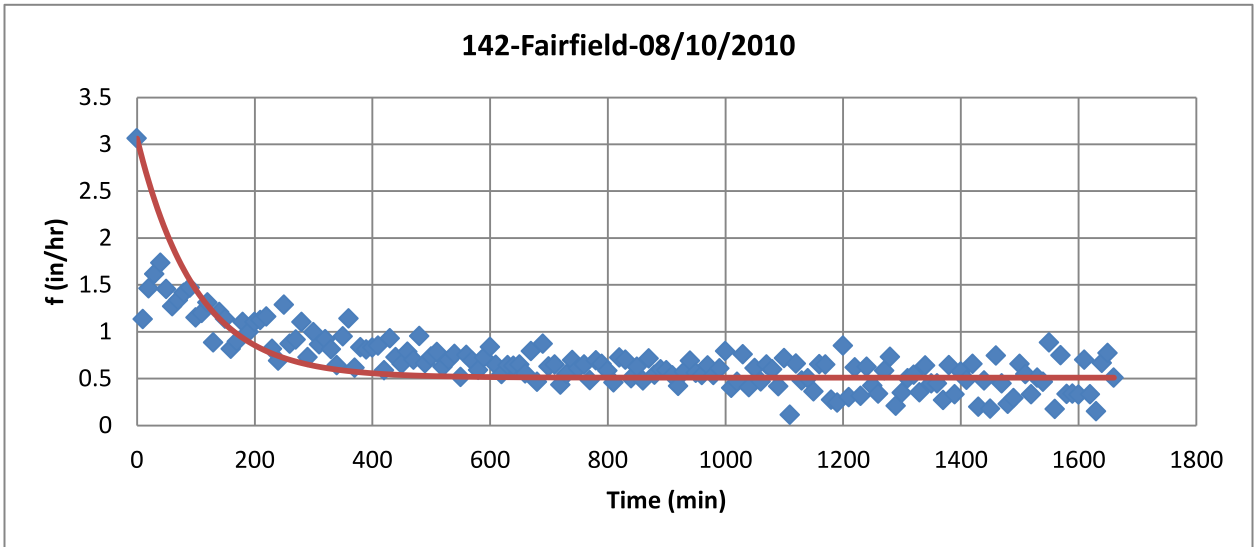
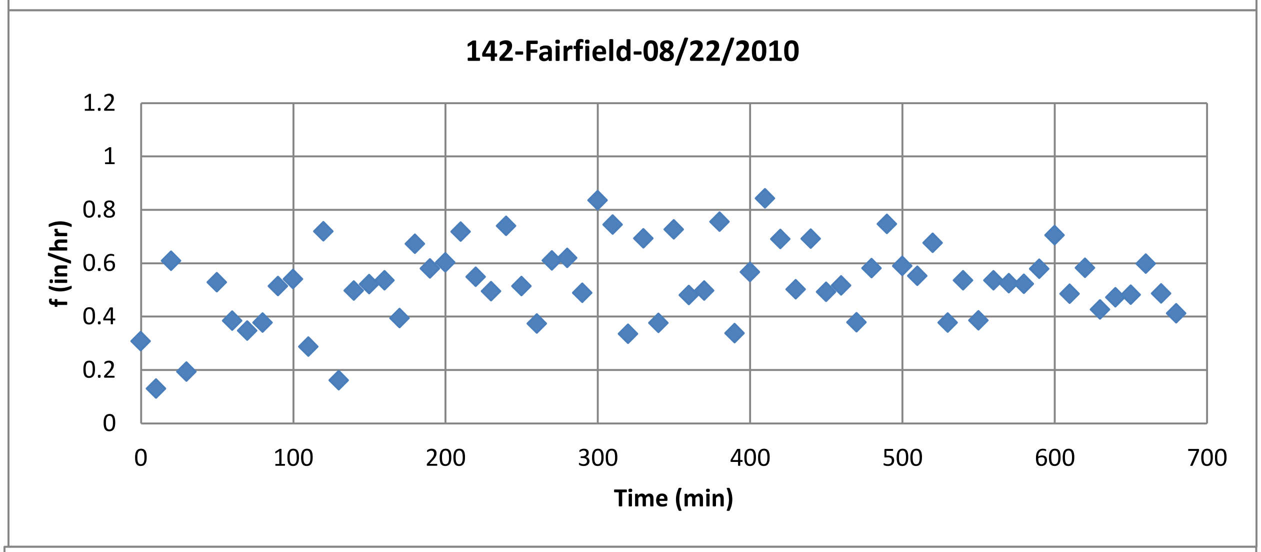
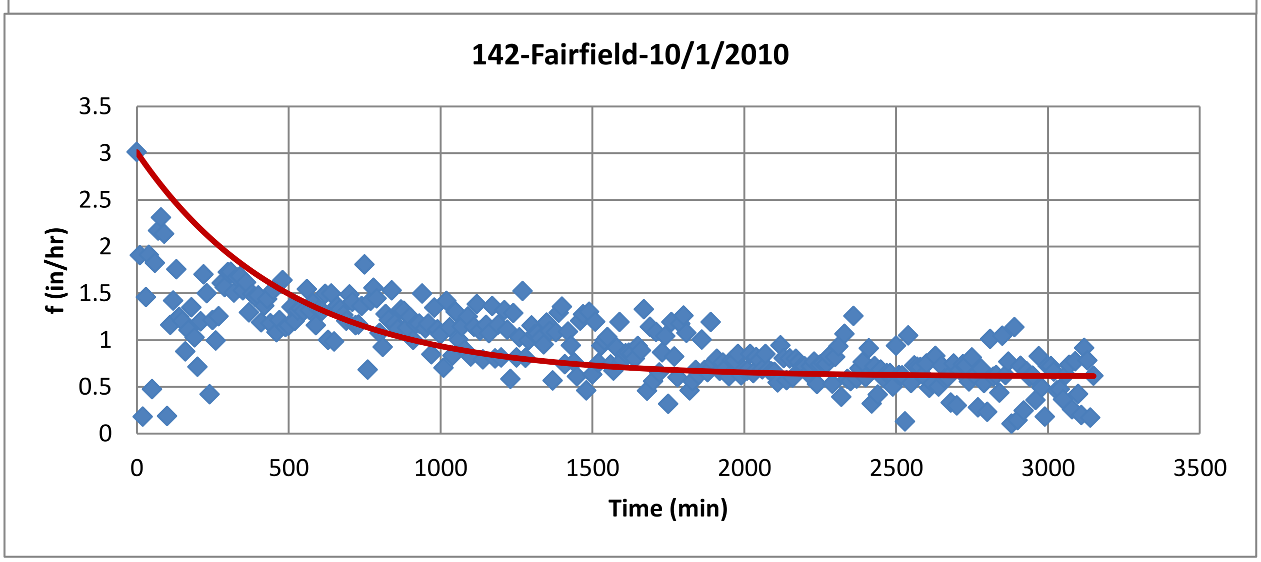
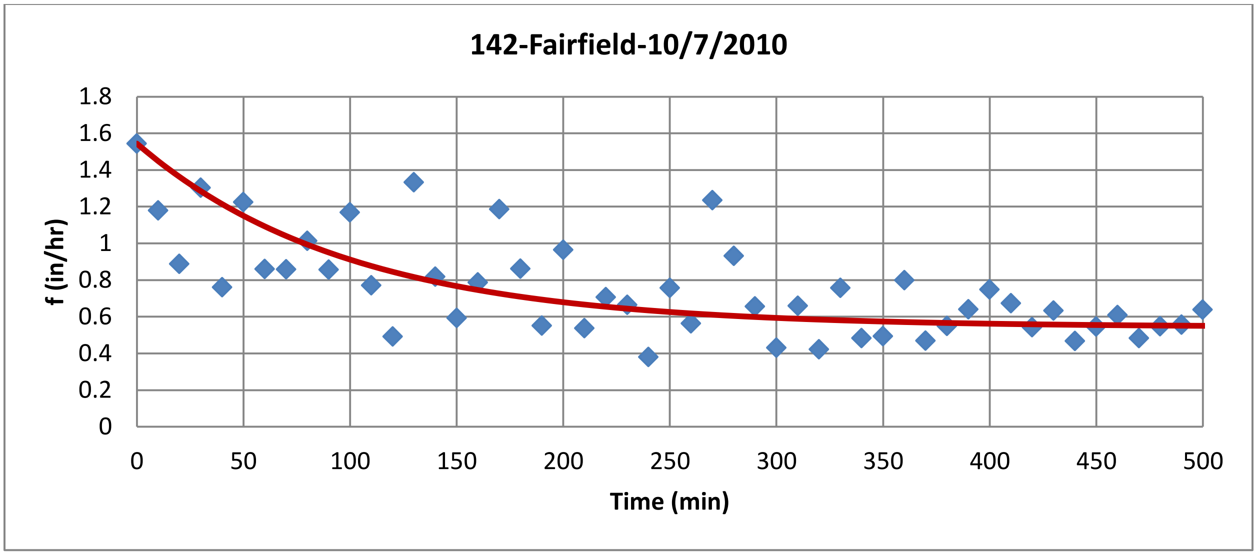
1000
1500
2000
2500

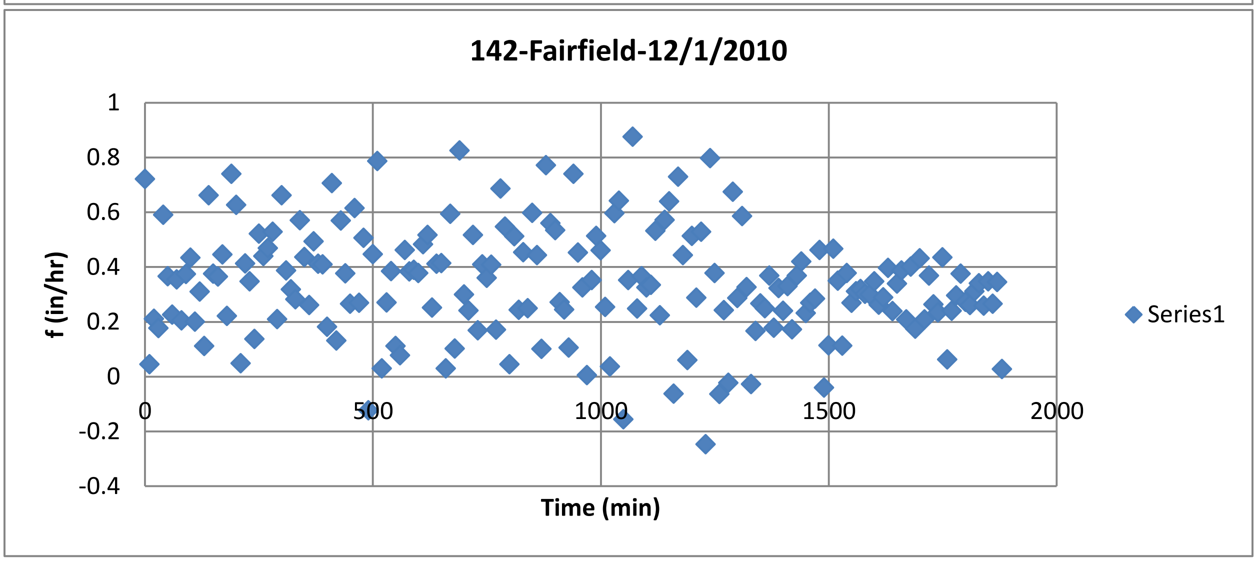
142 Fairfield

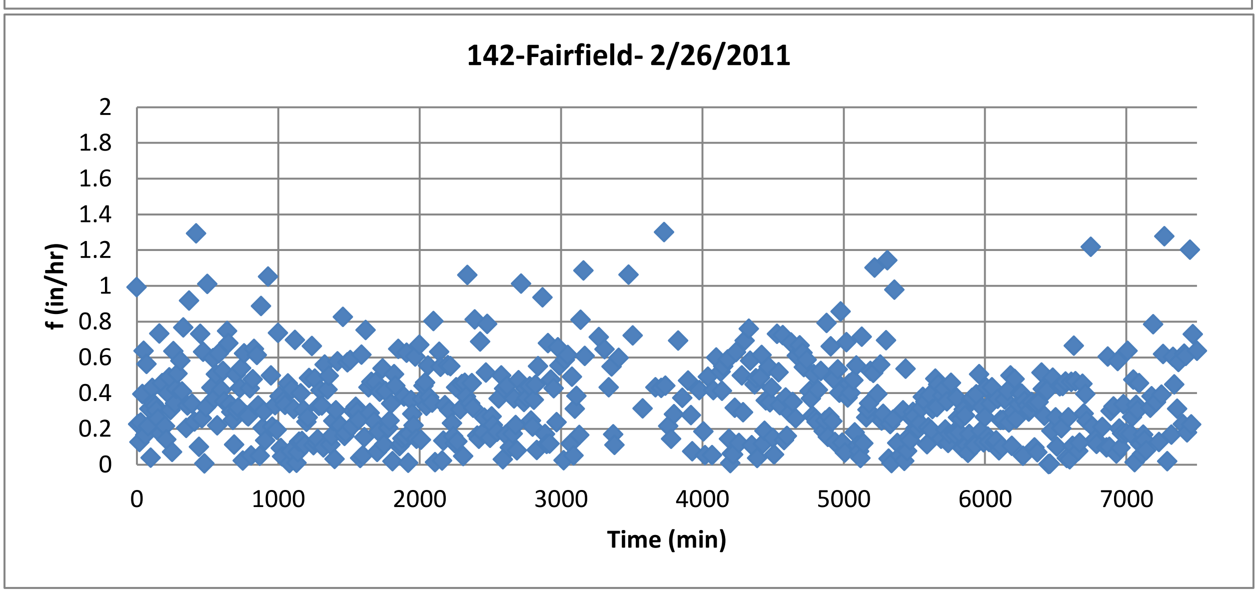


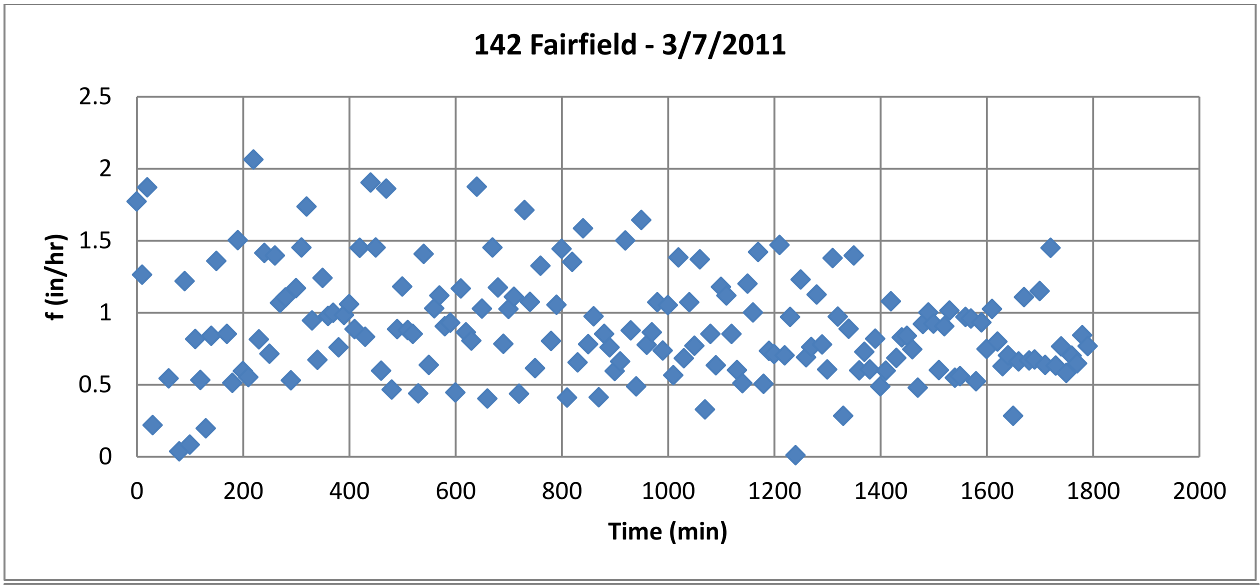


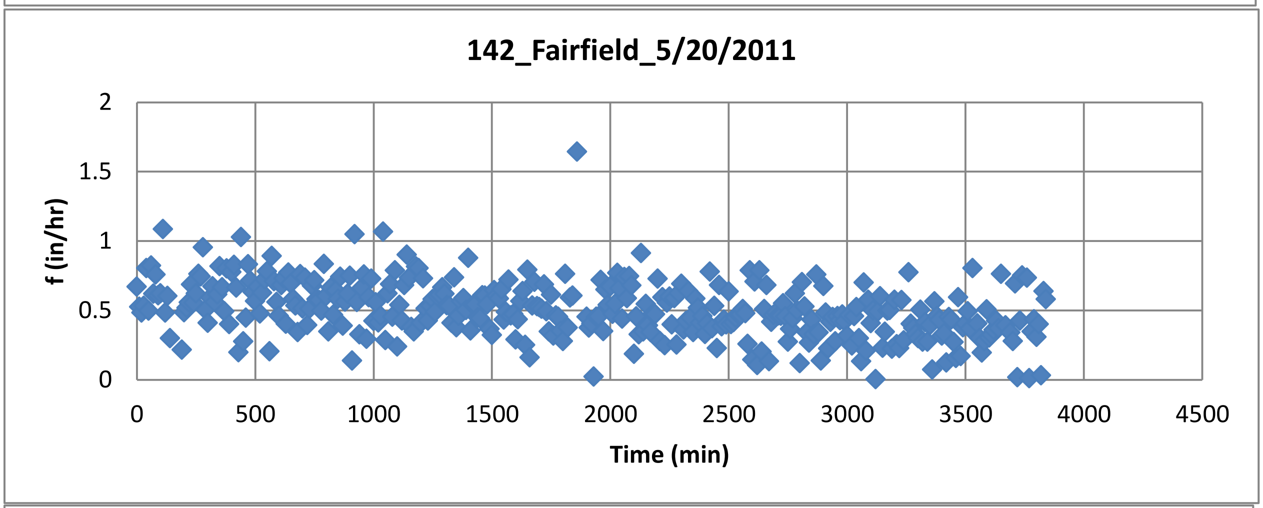


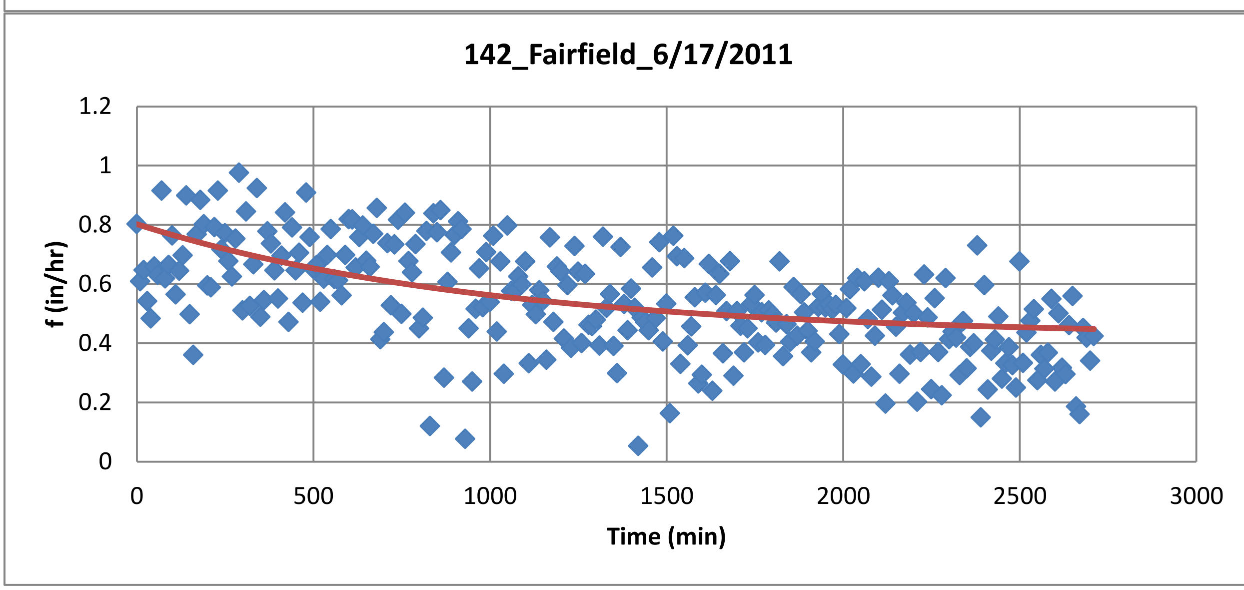

142-Fairfield-10/7/2010
f (in/hr)
Time (min)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
50
100
150
200
250
300
350
400
450
500


142-Fairfield-12/1/2010
f (in/hr)
Time (min)
Series1
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0
500
1000
1500
2000

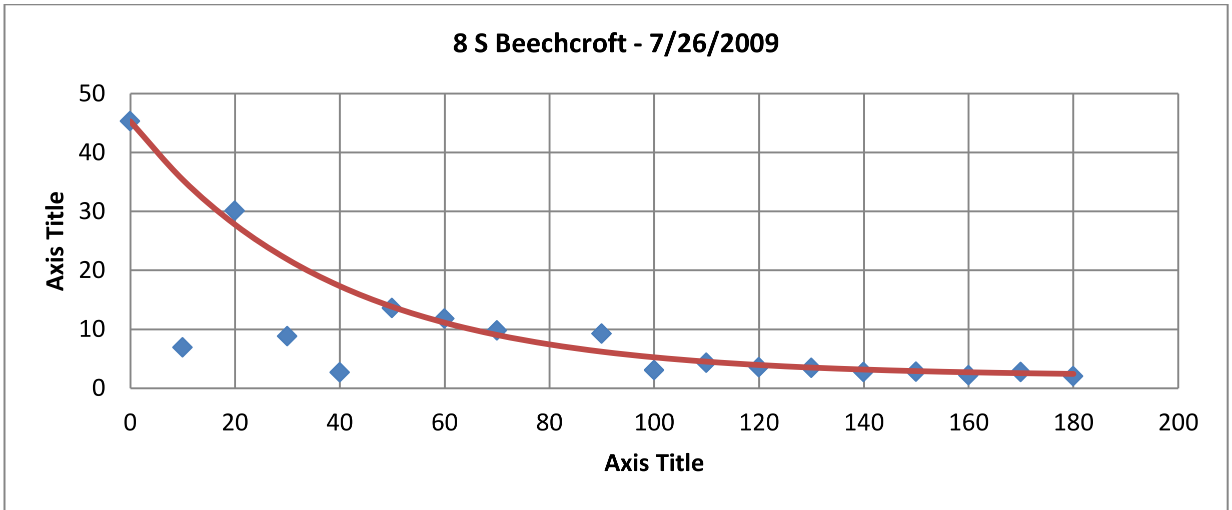

142-Fairfield- 2/26/2011
f (in/hr)
Time (min)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
1000
2000
3000
4000
5000
6000
7000

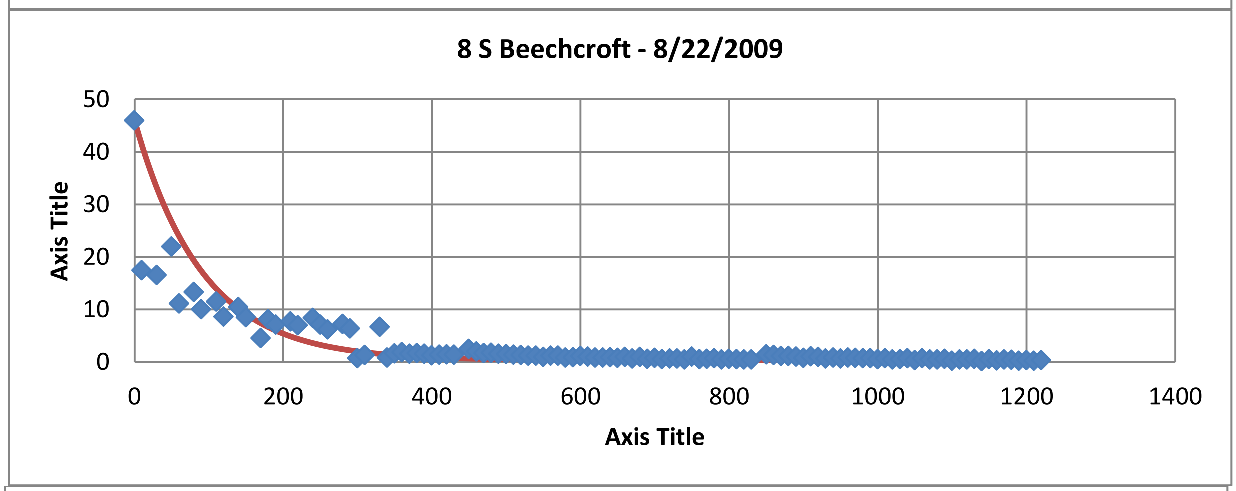

142 Fairfield - 3/7/2011
f (in/hr)
Time (min)
0
0.5
1
1.5
2
2.5
0
200
400
600
800
1000
1200
1400
1600
1800
2000

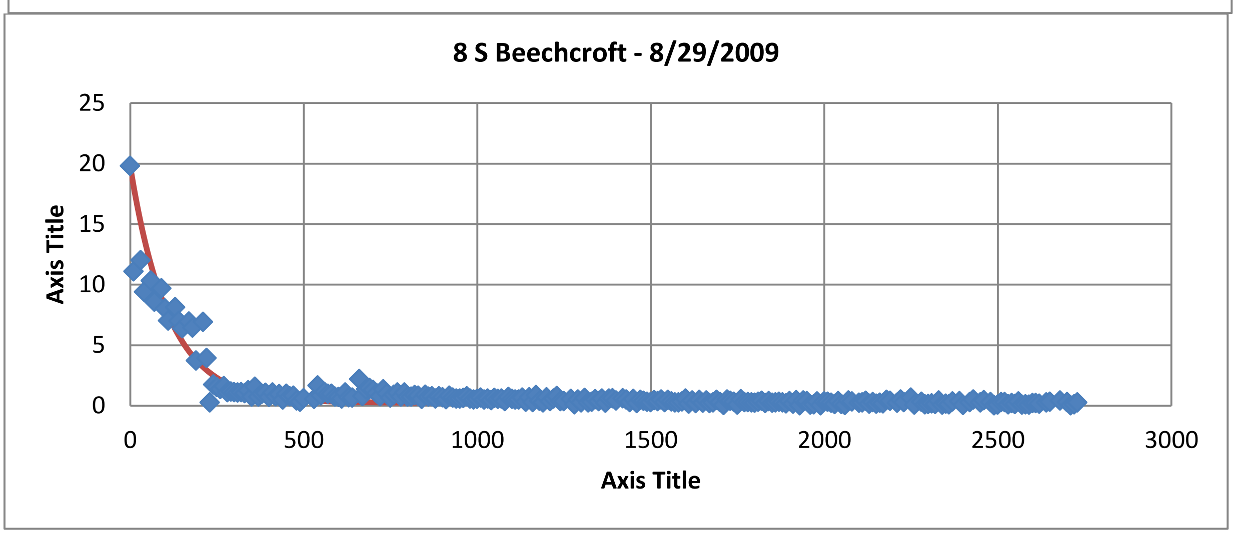

142_Fairfield_5/20/2011
f (in/hr)
Time (min)
0
0.5
1
1.5
2
0
500
1000
1500
2000
2500
3000
3500
4000
4500

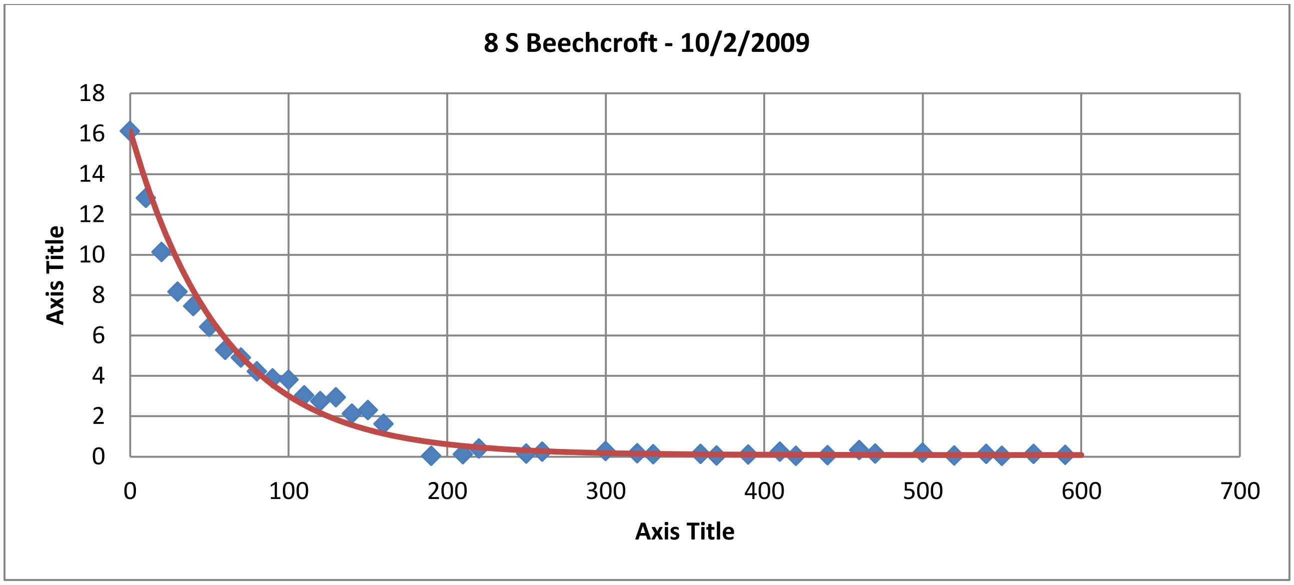

142_Fairfield_6/17/2011
f (in/hr)
Time (min)
0
0.2
0.4
0.6
0.8
1
1.2
0
500
1000
1500
2000
2500
3000

8 South Beechcroft

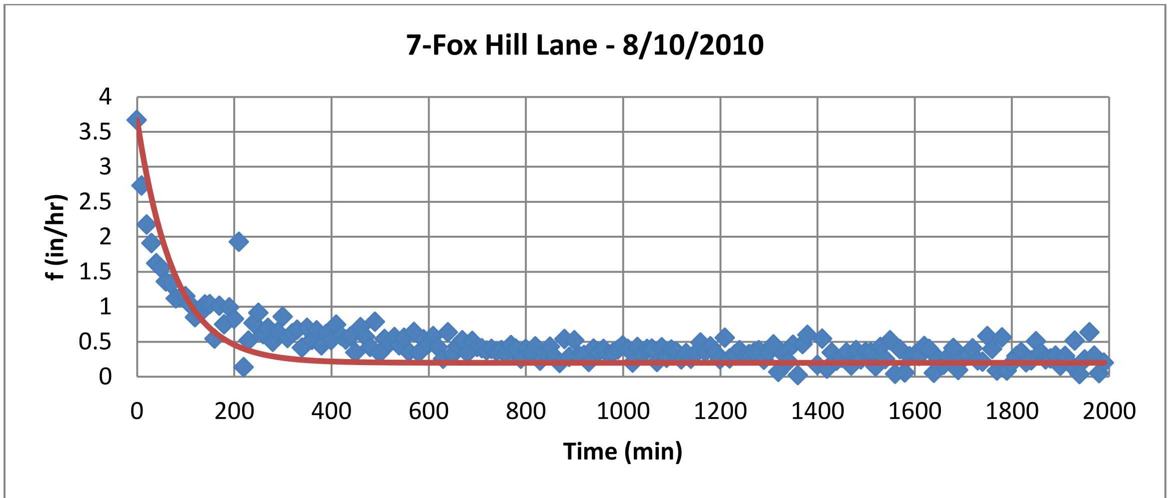


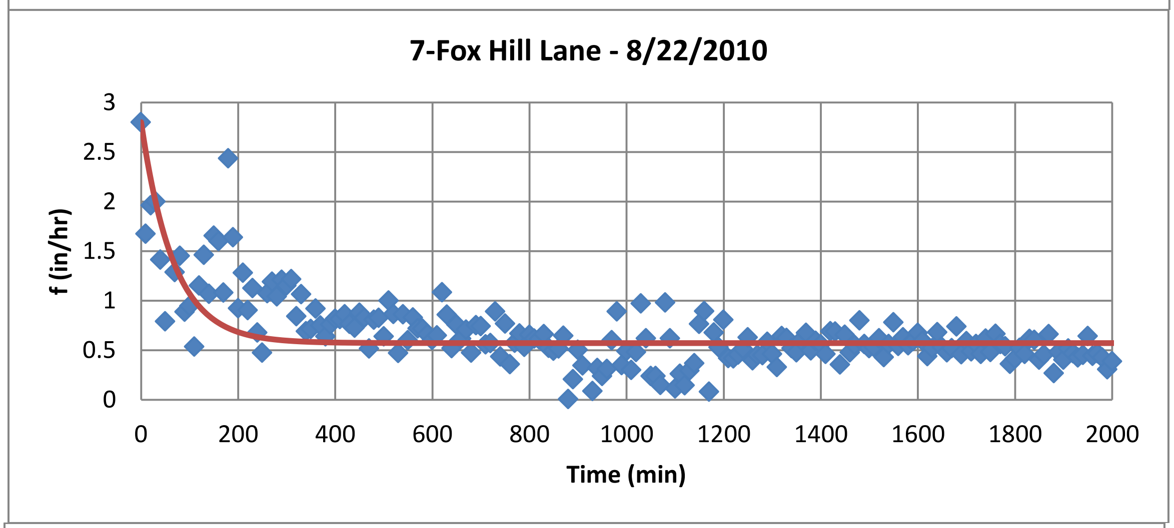


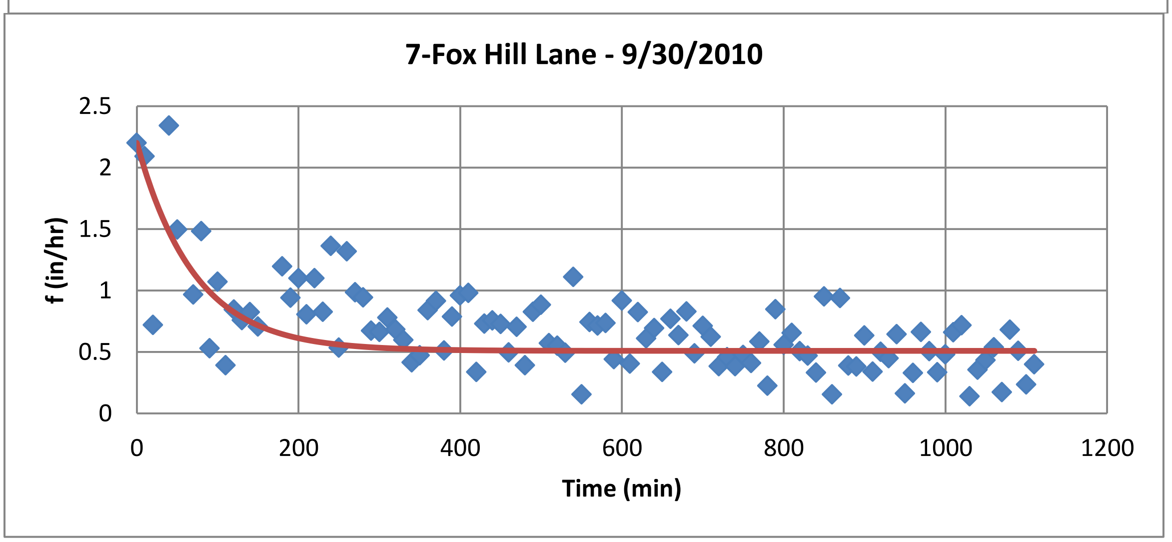


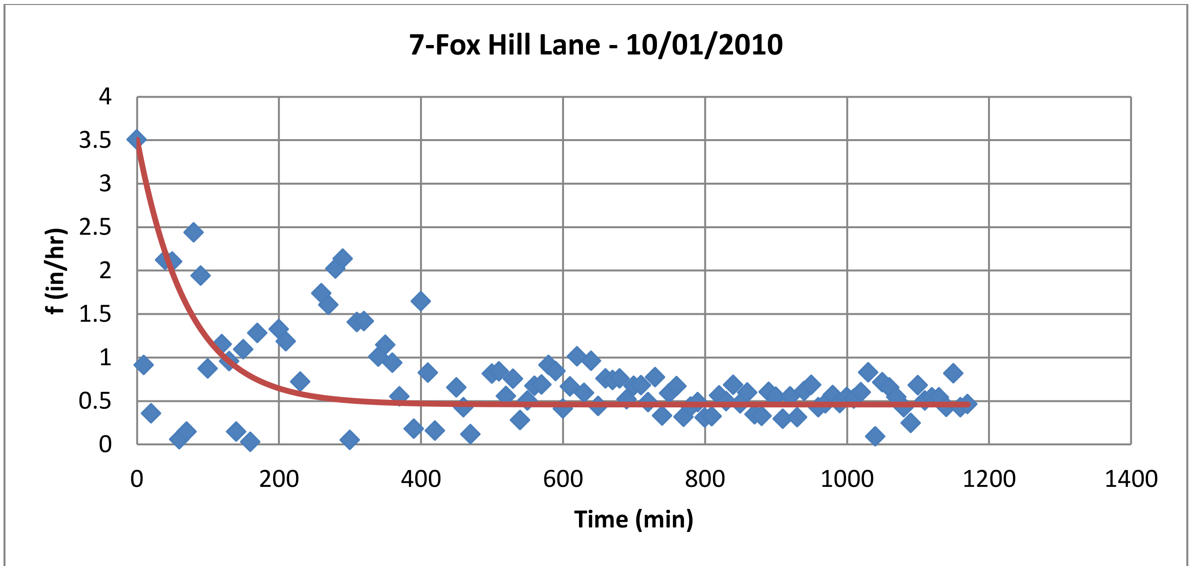

8 S Beechcroft - 10/2/2009
Axis Title
18
16
14
12
10
8
6
4
2
0
0
100
200
300
400
500
600
700
Axis Title

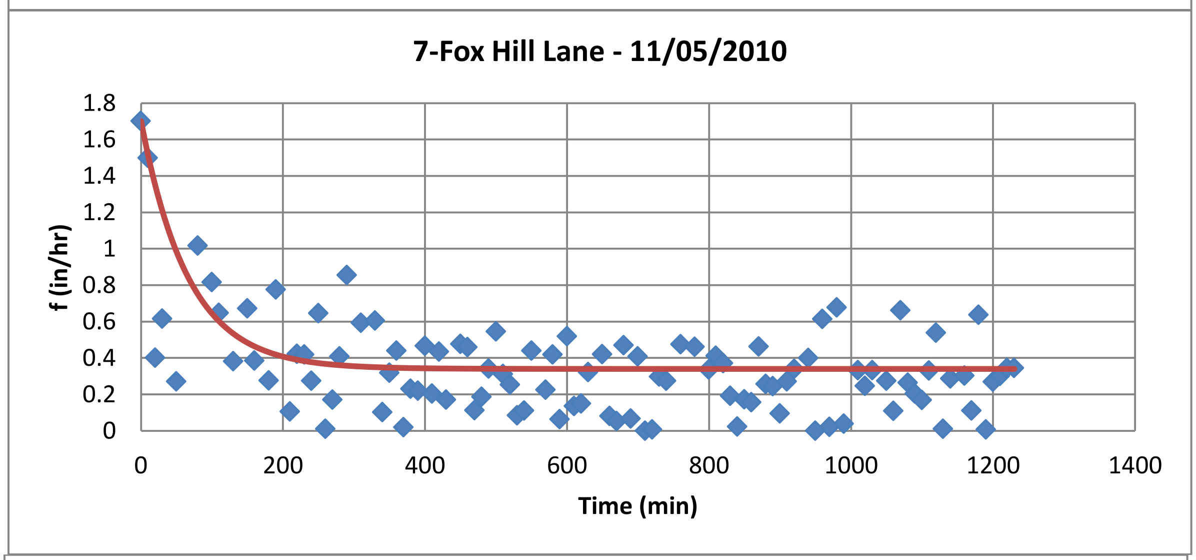
7 Fox Hill Lane 8-10-2010

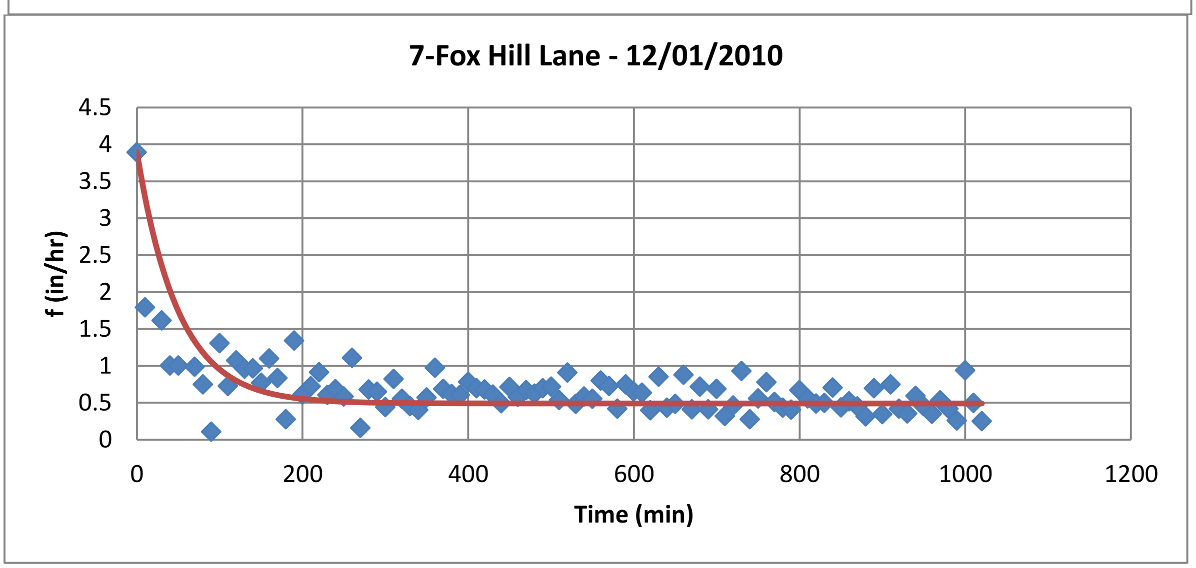


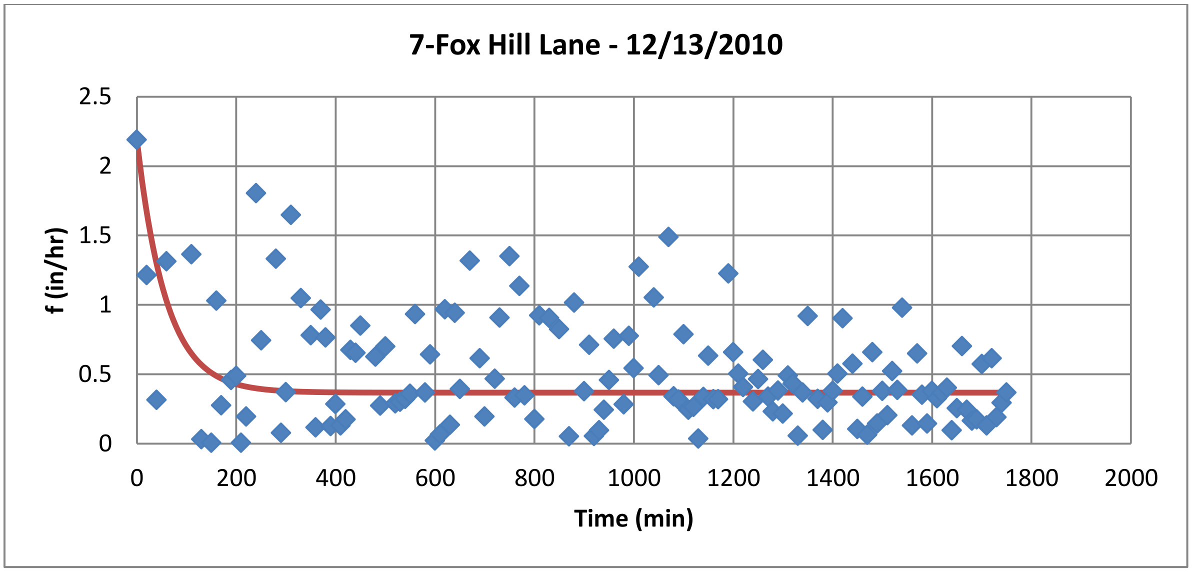


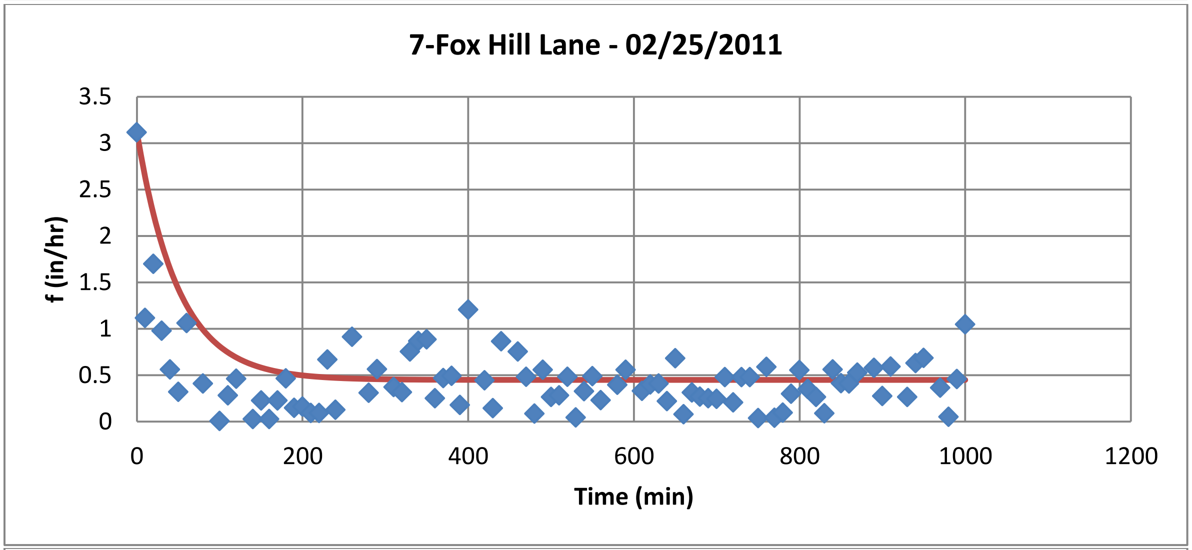


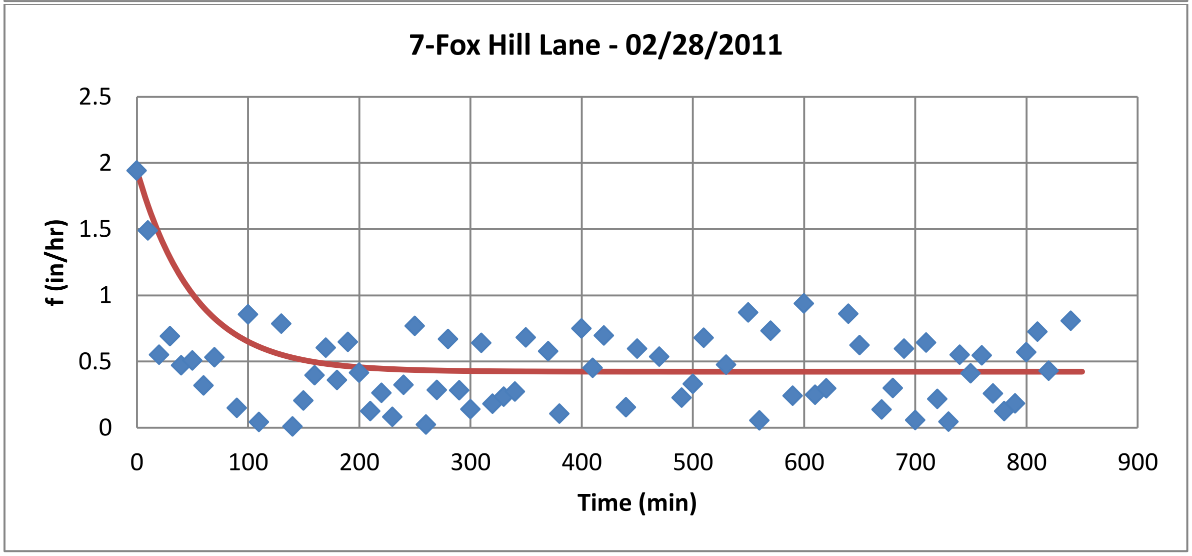

7-Fox Hill Lane - 10/01/2010
f (in/hr)
Time (min)

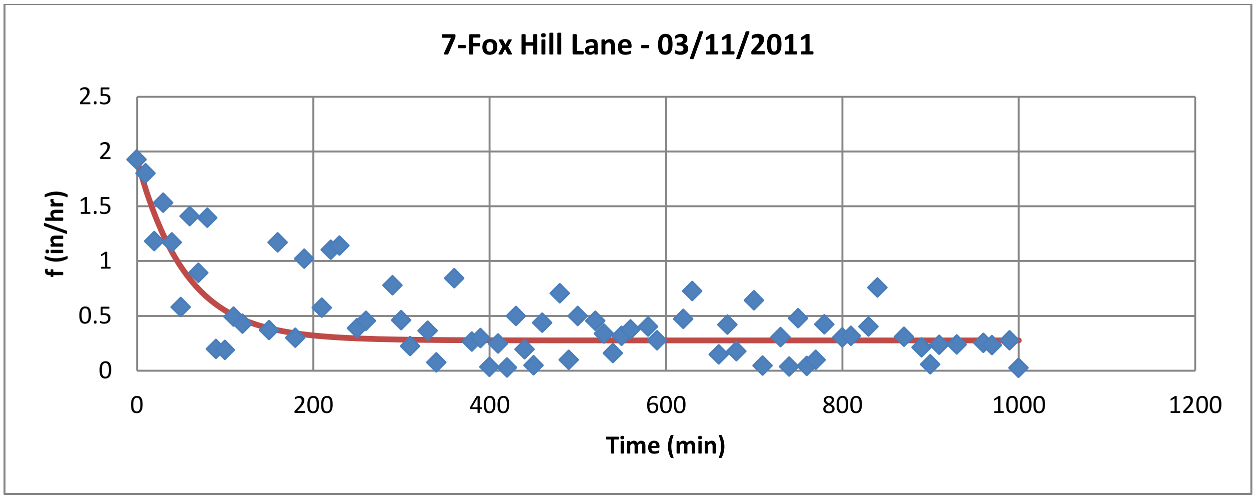

7-Fox Hill Lane - 11/05/2010
f (in/hr)
Time (min)


7-Fox Hill Lane - 12/01/2010
f (in/hr)
Time (min)

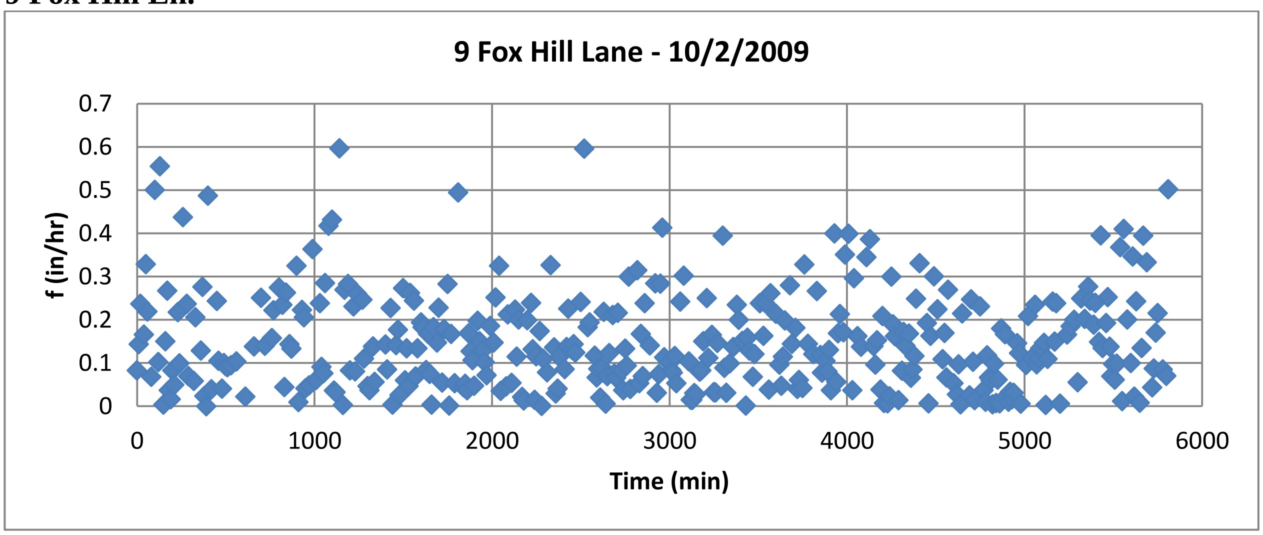

7-Fox Hill Lane - 12/13/2010
f (in/hr)
Time (min)
0
0.5
1
1.5
2
2.5
200
400
600
800
1000
1200
1400
1600
1800
2000


7-Fox Hill Lane - 02/25/2011
f (in/hr)
Time (min)
0
0.5
1
1.5
2
2.5
3
3.5
200
400
600
800
1000
1200

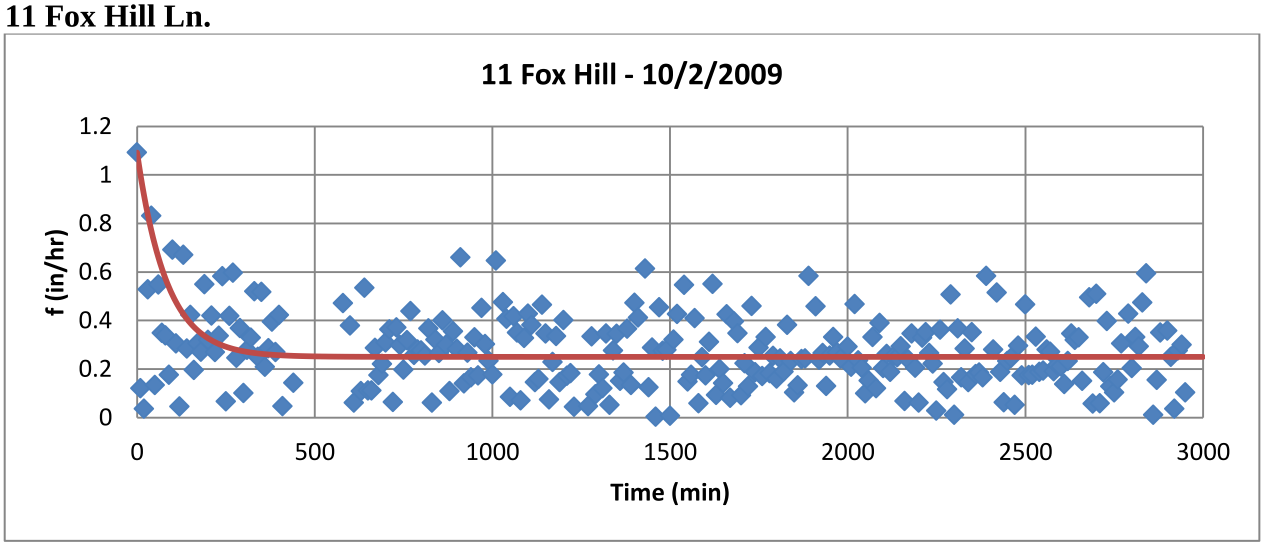

7-Fox Hill Lane - 02/28/2011
f (in/hr)
Time (min)
0
0.5
1
1.5
2
2.5
100
200
300
400
500
600
700
800
900



9 Fox Hill Ln.



11 Fox Hill Ln.

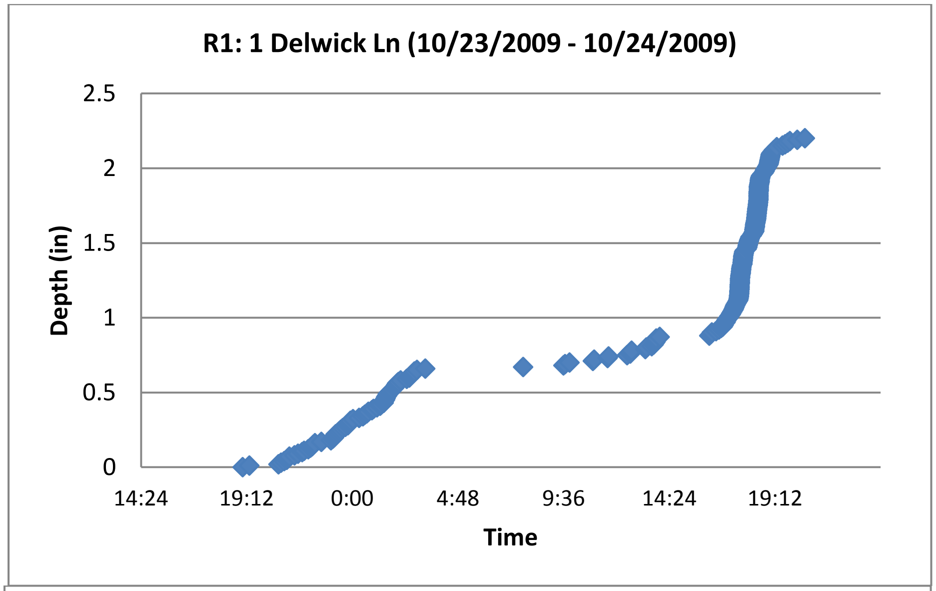


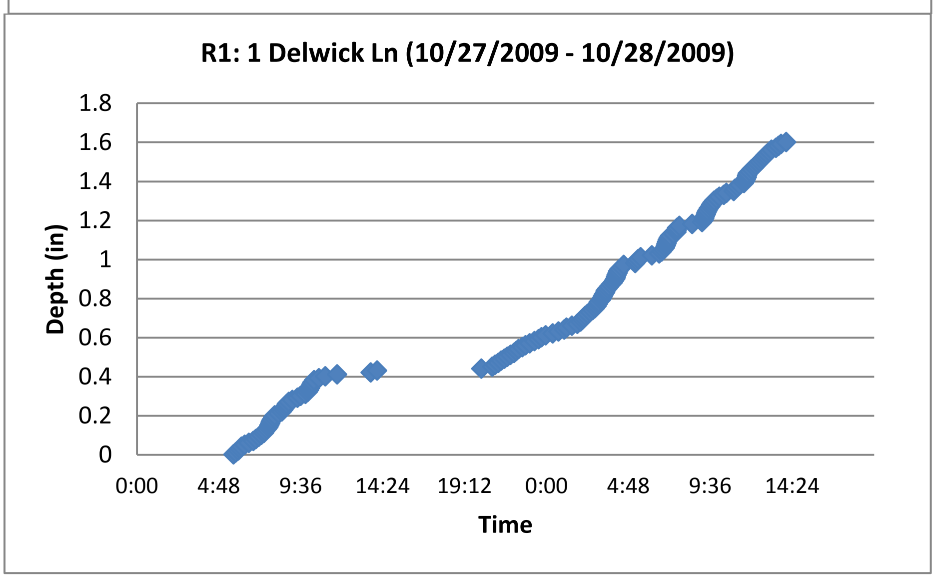
APPENDIX D

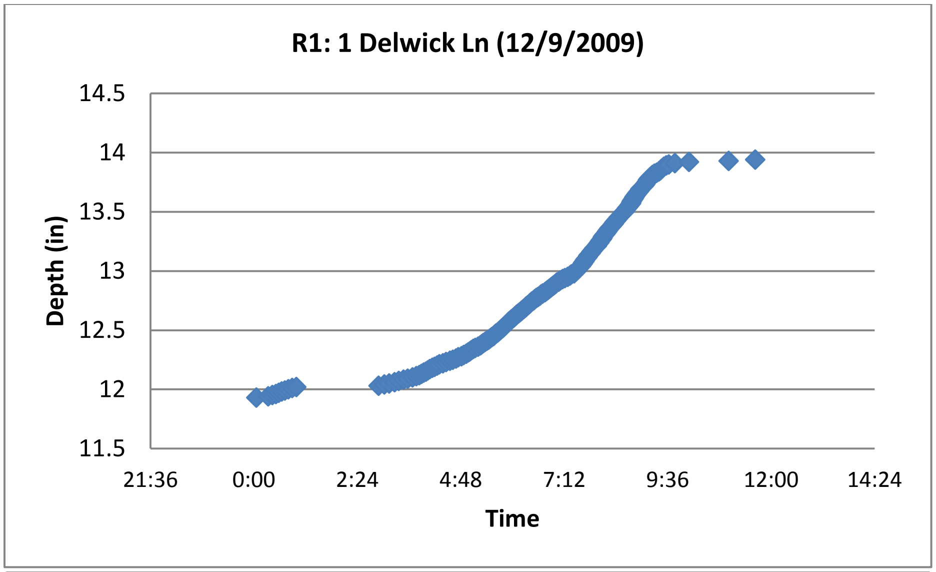
RAIN GAGE DATA AND ANALYSIS FOR MILLBURN, NJ

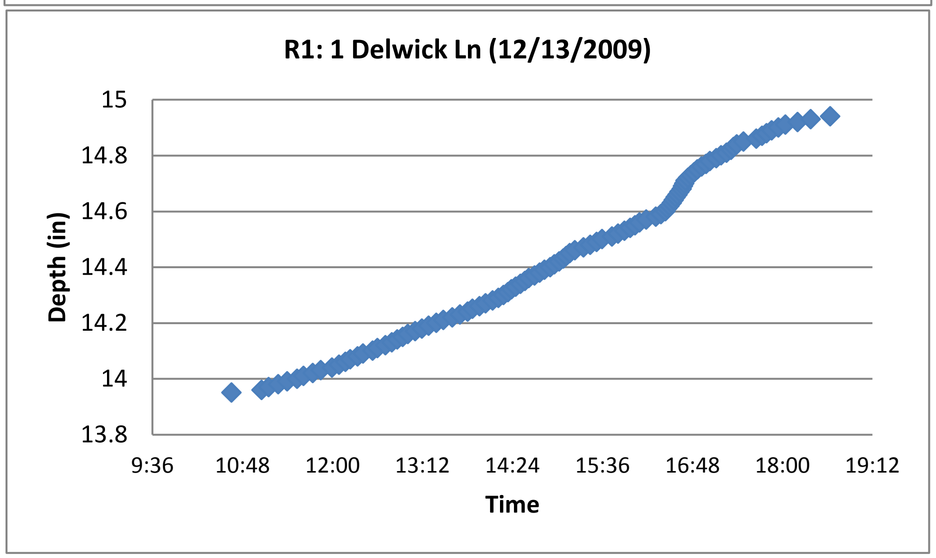
R1: Mel Singer's house on top of chimney slab at 1 Delwick Ln - Calibrated and launched at 14:00 on 5/22/09 by HDB

Start time		End time		Duration (hr)	Depth (in)	Average intensity (in/hr)
10/23/2009	19:01	10/24/2009	20:34	25:33	2.20	0.09
10/27/2009	5:40	10/28/2009	14:04	32:24	1.60	0.05
12/9/2009	0:03	12/9/2009	11:38	11:35	2.01	0.17
12/13/2009	10:39	12/13/2009	18:38	7:59	0.99	0.12



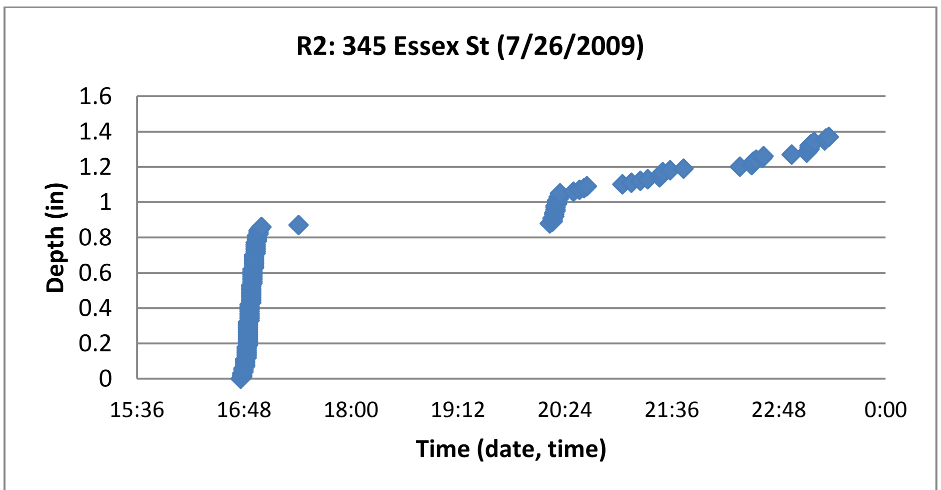


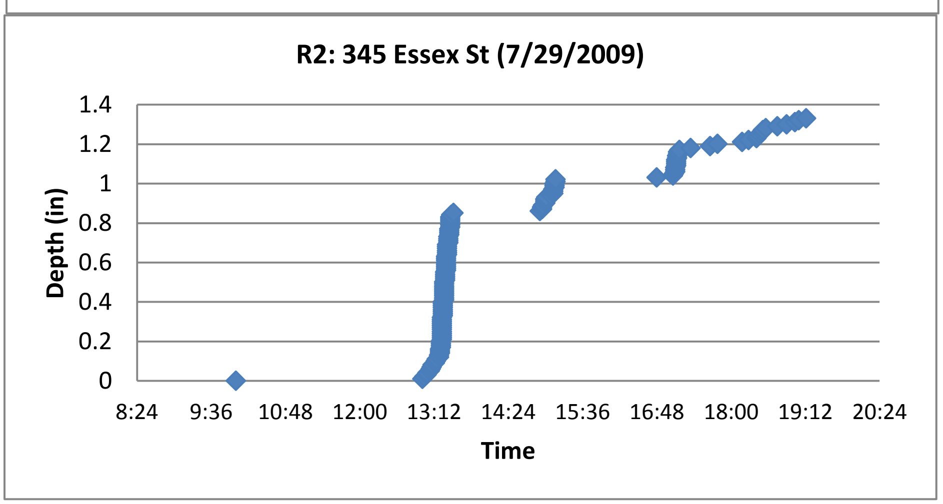

R1: 1 Delwick Ln (12/9/2009)
Depth (in)
14.5
14
13.5
13
12.5
12
11.5
21:36
0:00
2:24
4:48
7:12
9:36
12:00
14:24
Time

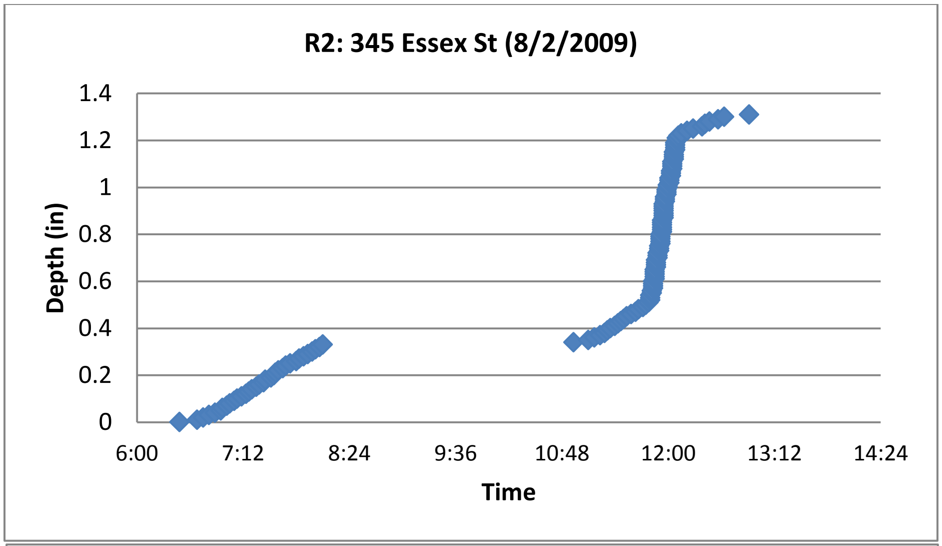

R1: 1 Delwick Ln (12/13/2009)
Depth (in)
15
14.8
14.6
14.4
14.2
14
13.8
9:36
10:48
12:00
13:12
14:24
15:36
16:48
18:00
19:12
Time

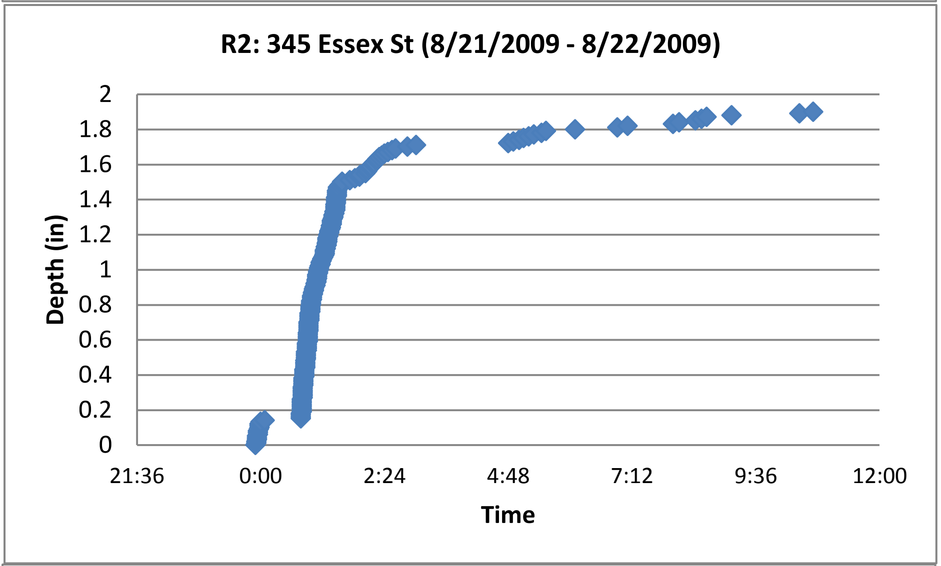
R2: Roof of Township's maintenance garage on Essex Rd - Calibrated and launched at 12:00 on 5/13/09 by HDB

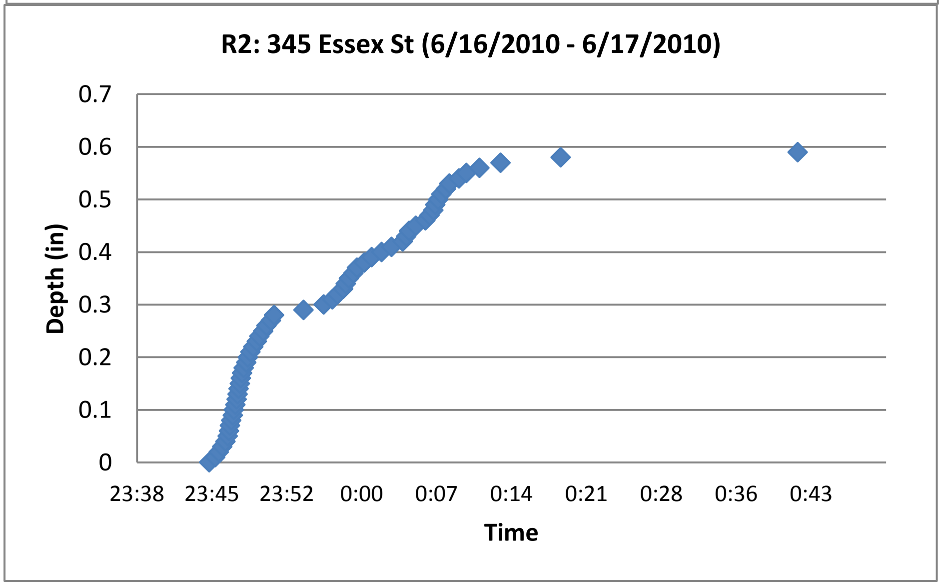
Start time		End time		Duration (hr)	Depth (in)	Average intensity (in/hr)
7/26/2009	16:46	7/26/2009	23:22	6:36	1.37	0.21
7/29/2009	10:00	7/29/2009	19:13	9:13	1.33	0.14
8/2/2009	6:29	8/2/2009	12:55	6:26	1.31	0.20
8/21/2009	23:54	8/22/2009	10:43	10:49	1.90	0.18
6/16/2010	23:45	6/17/2010	0:41	0:56	0.69	0.74
6/22/2010	18:33	6/22/2010	18:54	0:21	0.37	1.06
7/14/2010	9:02	7/14/2010	10:04	1:02	1.22	1.18
8/1/2010	8:21	8/1/2010	9:54	1:33	1.34	0.86
7/8/2011	16:02	7/8/2011	20:46	4:44	0.73	0.15
8/1/2011	0:25	8/1/2011	0:42	0:17	0.46	1.62
8/3/2011	16:28	8/4/2011	4:02	11:34	0.65	0.06

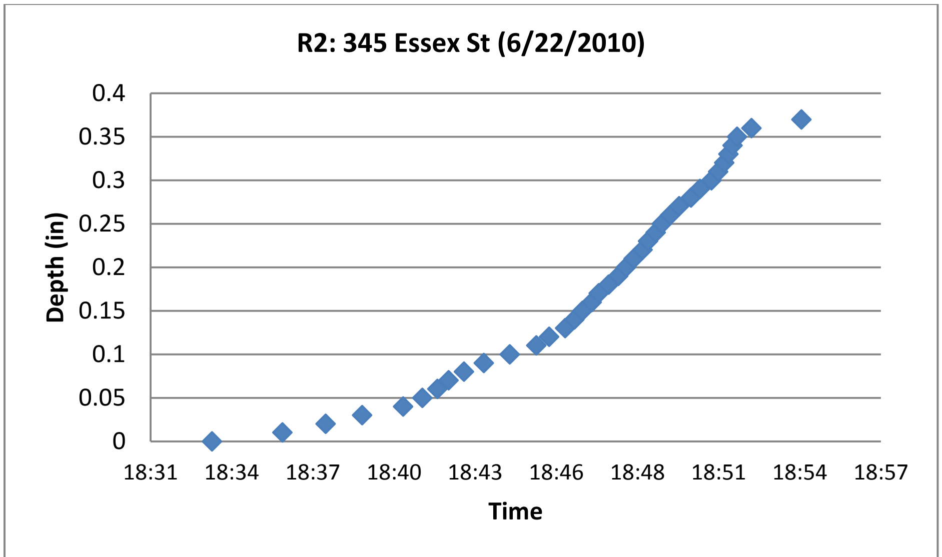


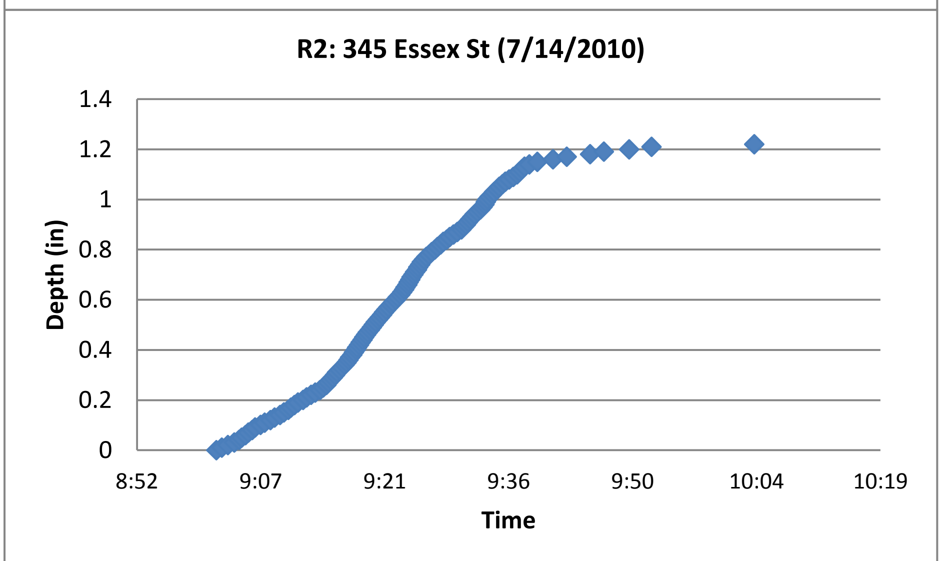


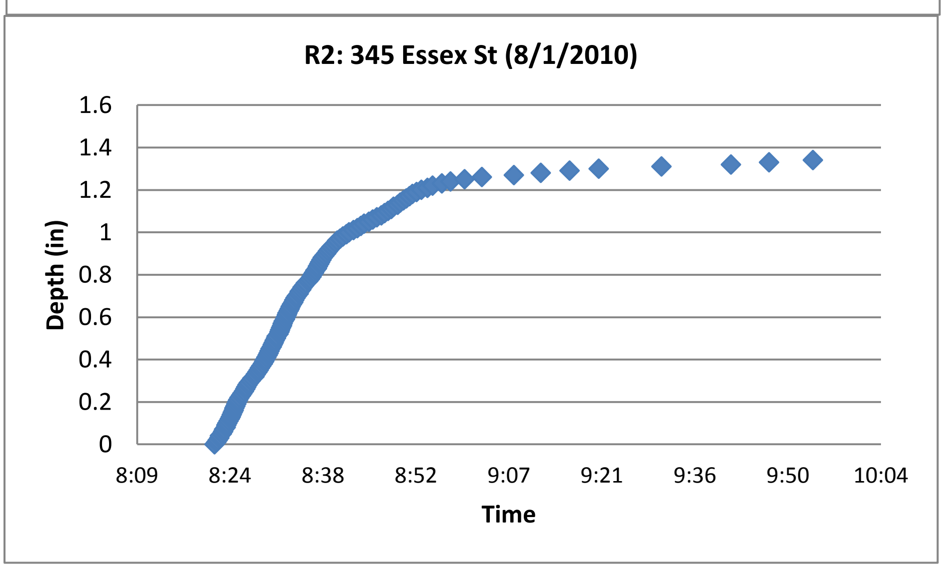

R2: 345 Essex St (8/2/2009)
Depth (in)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
6:00
7:12
8:24
9:36
10:48
12:00
13:12
14:24
Time

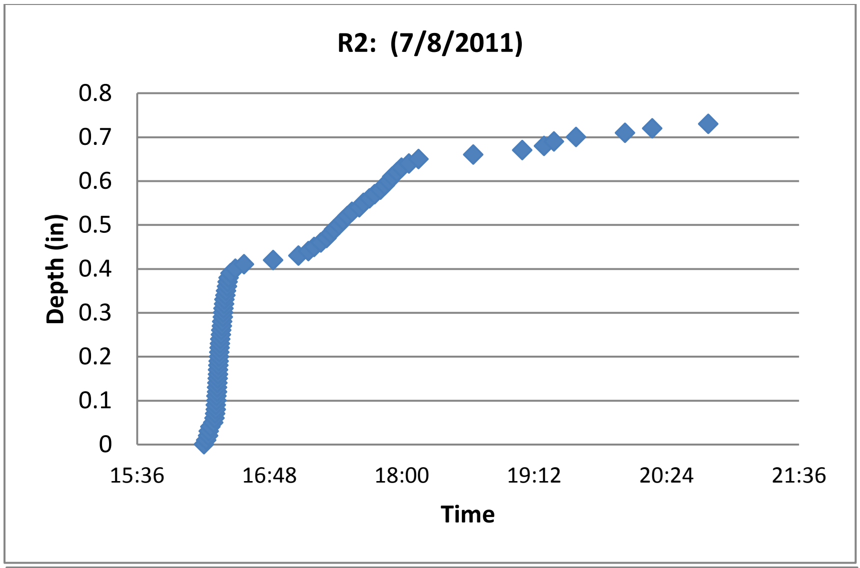

R2: 345 Essex St (8/21/2009 - 8/22/2009)
Depth (in)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
21:36
0:00
2:24
4:48
7:12
9:36
12:00
Time

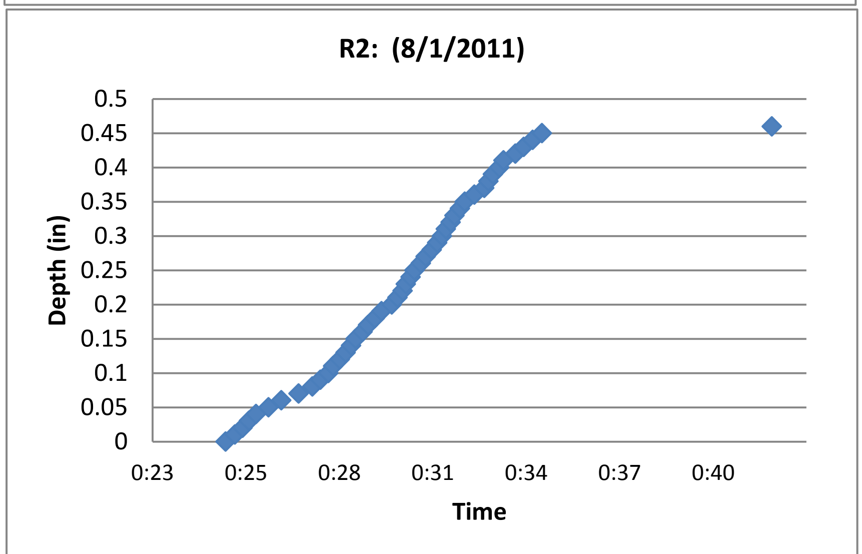

R2: 345 Essex St (6/16/2010 - 6/17/2010)
Depth (in)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
23:38
23:45
23:52
0:00
0:07
0:14
0:21
0:28
0:36
0:43
Time

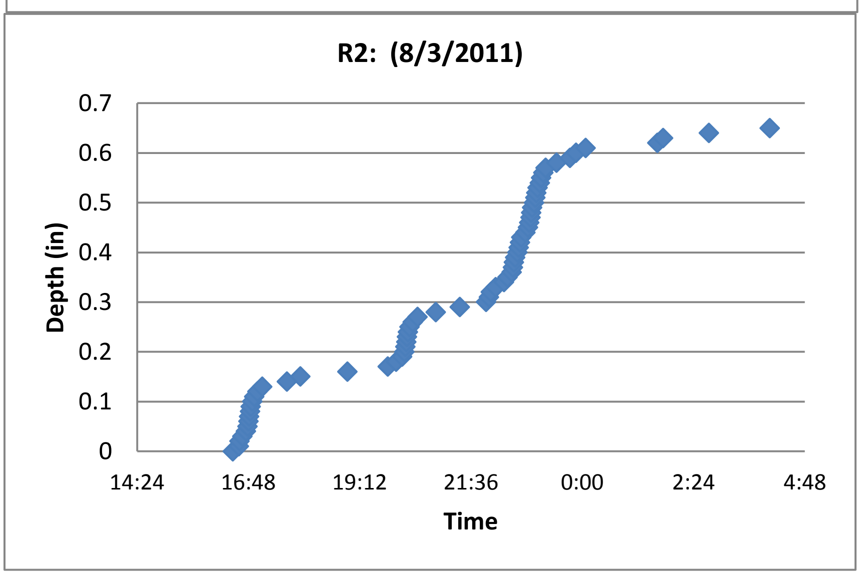

R2: 345 Essex St (6/22/2010)
Depth (in)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
18:31
18:34
18:37
18:40
18:43
18:46
18:48
18:51
18:54
18:57
Time


R2: 345 Essex St (7/14/2010)
Depth (in)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
8:52
9:07
9:21
9:36
9:50
10:04
10:19
Time


R2: 345 Essex St (8/1/2010)
Depth (in)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
8:09
8:24
8:38
8:52
9:07
9:21
9:36
9:50
10:04
Time

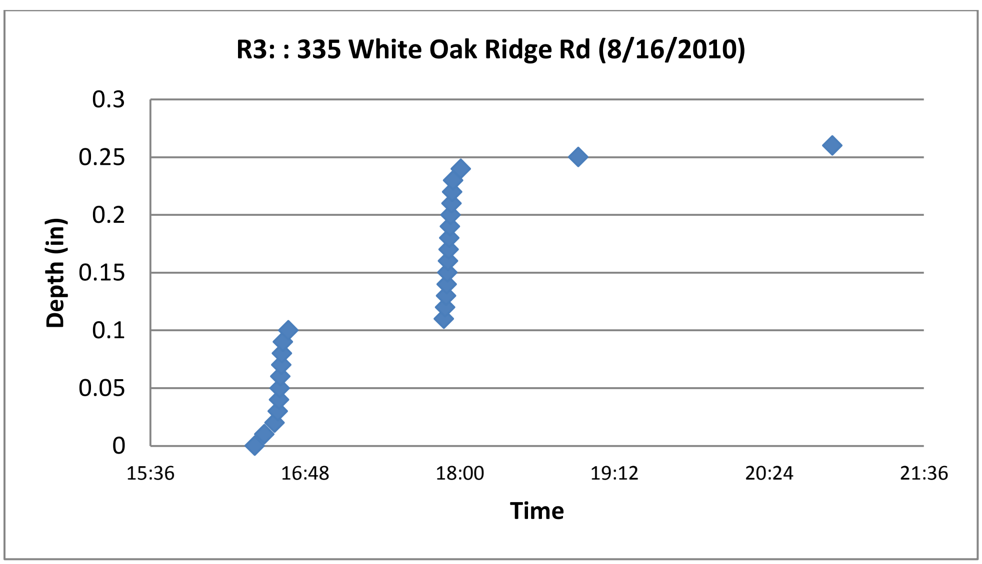

R2: (7/8/2011)
Depth (in)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
15:36
16:48
18:00
19:12
20:24
21:36
Time

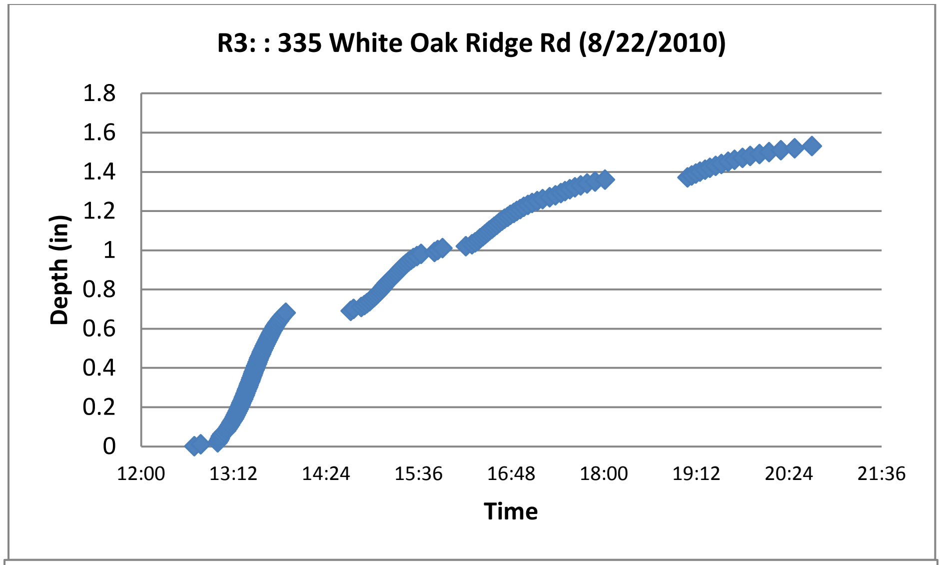

R2: (8/1/2011)
Depth (in)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0:23
0:25
0:28
0:31
0:34
0:37
0:40
Time

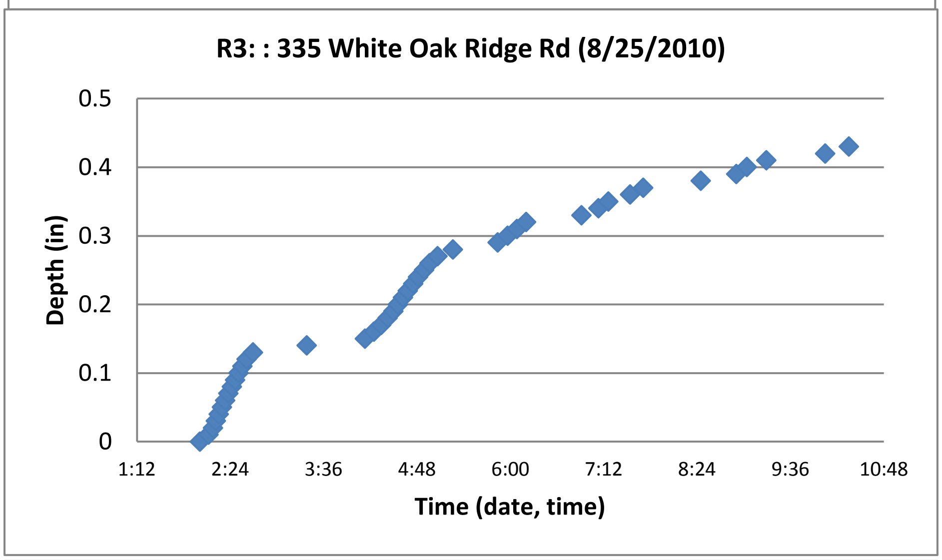

R2: (8/3/2011)
Depth (in)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
14:24
16:48
19:12
21:36
0:00
2:24
4:48
Time

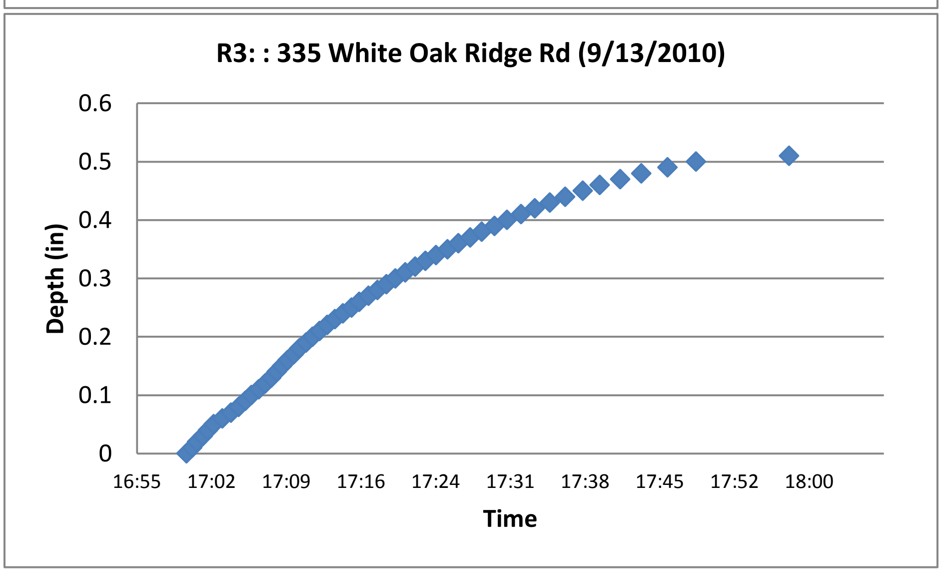
R3: Municipal Par 3 Golf Course on White Oak Ridge Rd - Calibrated and launched at 16:00 on 5/13/09 by HDB

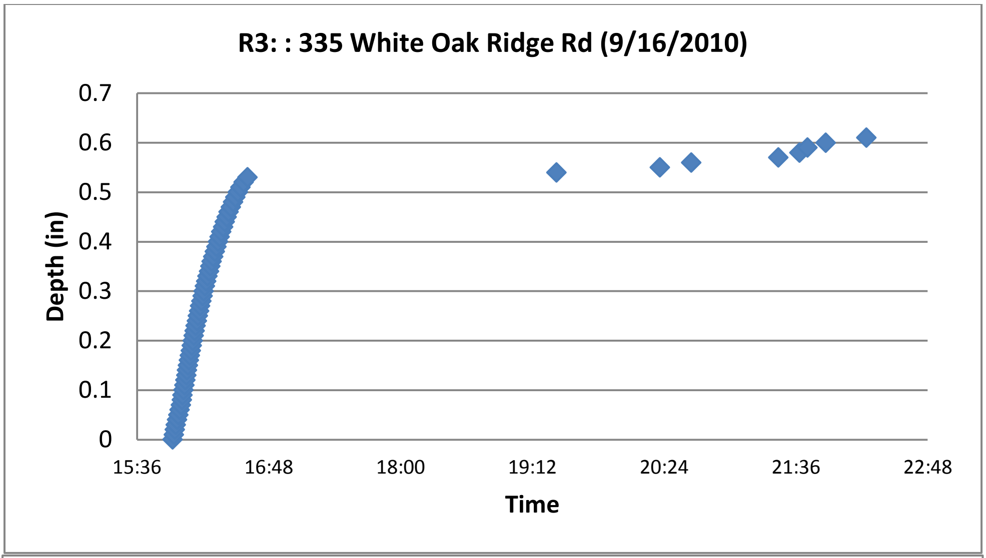
Start time		End time		Duration (hr)	Depth (in)	Average intensity (in/hr)
8/16/2010	16:24	8/16/2010	20:53	4:29	0.26	0.06
8/22/2010	12:41	8/22/2010	20:42	8:01	1.53	0.19
8/25/2010	2:00	8/25/2010	10:21	8:21	0.43	0.05
9/13/2010	17:00	9/13/2010	17:58	0:58	0.51	0.53
9/16/2010	15:55	9/16/2010	22:14	6:19	0.61	0.10
9/27/2010	7:40	9/28/2010	12:36	28:56	0.69	0.02
9/30/2010	4:14	9/30/2010	10:01	5:47	1.83	0.32
10/1/2010	1:41	10/1/2010	13:05	11:24	2.53	0.22
10/11/2010	18:29	10/11/2010	23:57	5:28	0.71	0.13
11/4/2010	3:26	11/5/2010	7:35	28:09	1.16	0.04
12/1/2010	1:05	12/1/2010	15:07	14:02	1.88	0.13
12/12/2010	0:57	12/13/2010	6:51	29:54	1.87	0.06
2/25/2011	0:25	2/25/2011	18:44	18:19	1.36	0.06
2/28/2011	3:50	2/28/2011	11:30	7:40	0.49	0.06
3/6/2011	7:55	3/7/2011	3:29	19:34	2.78	0.14
3/10/2011	2:47	3/11/2011	8:05	29:18	2.90	0.10
5/23/2011	22:19	5/23/2011	23:17	0:58	0.68	0.70
5/30/2011	6:07	5/30/2011	6:41	0:34	0.27	0.48
6/11/2011	1:26	6/11/2011	5:29	4:03	0.56	0.14
6/17/2011	13:45	6/17/2011	18:22	4:37	2.78	0.62
7/3/2011	4:46	7/3/2011	21:23	16:37	0.33	0.02



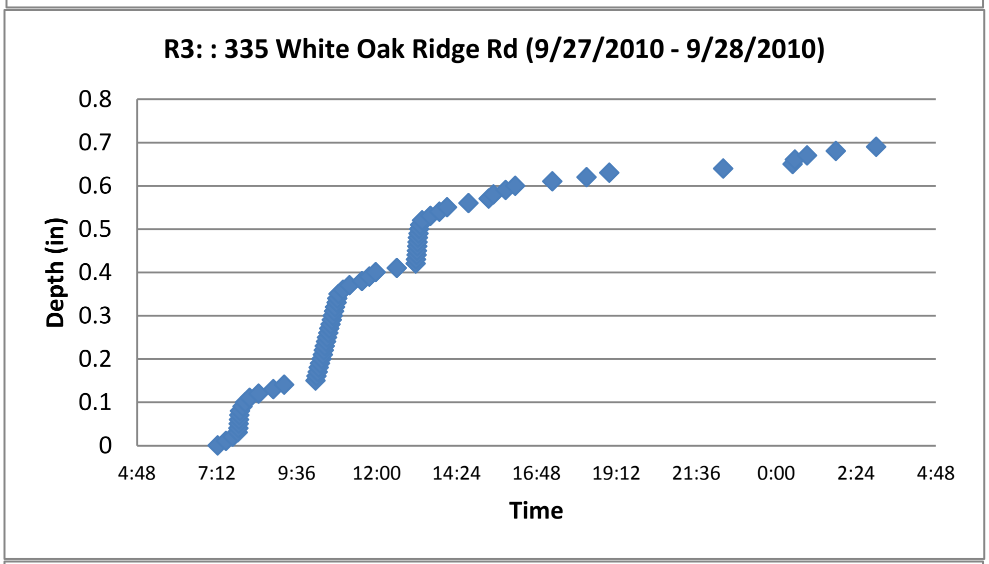

R3: : 335 White Oak Ridge Rd (8/22/2010)
Depth (in)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
12:00
13:12
14:24
15:36
16:48
18:00
19:12
20:24
21:36
Time


R3: : 335 White Oak Ridge Rd (8/25/2010)
Depth (in)
0.5
0.4
0.3
0.2
0.1
0
1:12
2:24
3:36
4:48
6:00
7:12
8:24
9:36
10:48
Time (date, time)

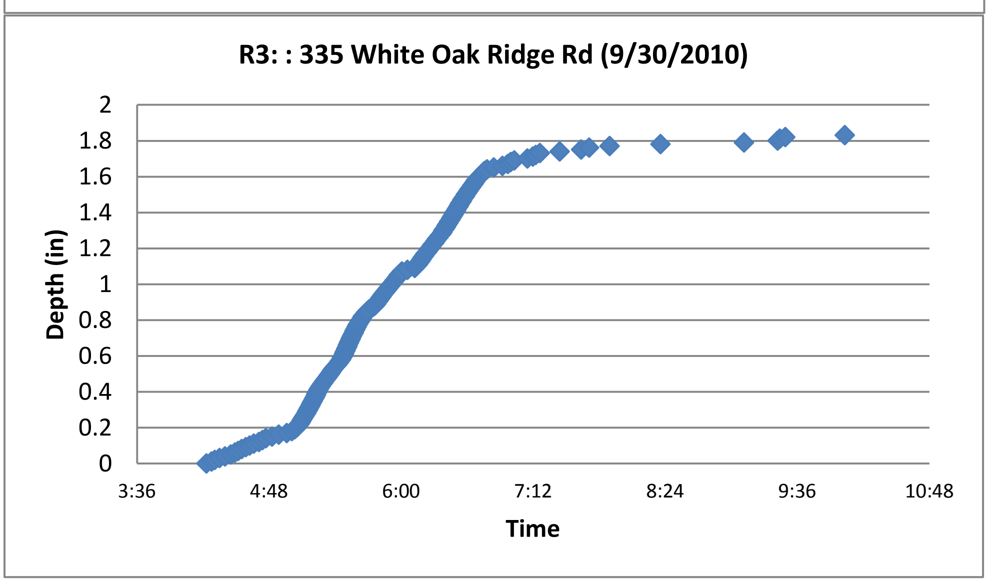

R3: : 335 White Oak Ridge Rd (9/13/2010)
Depth (in)
0.6
0.5
0.4
0.3
0.2
0.1
0
16:55
17:02
17:09
17:16
17:24
17:31
17:38
17:45
17:52
18:00
Time



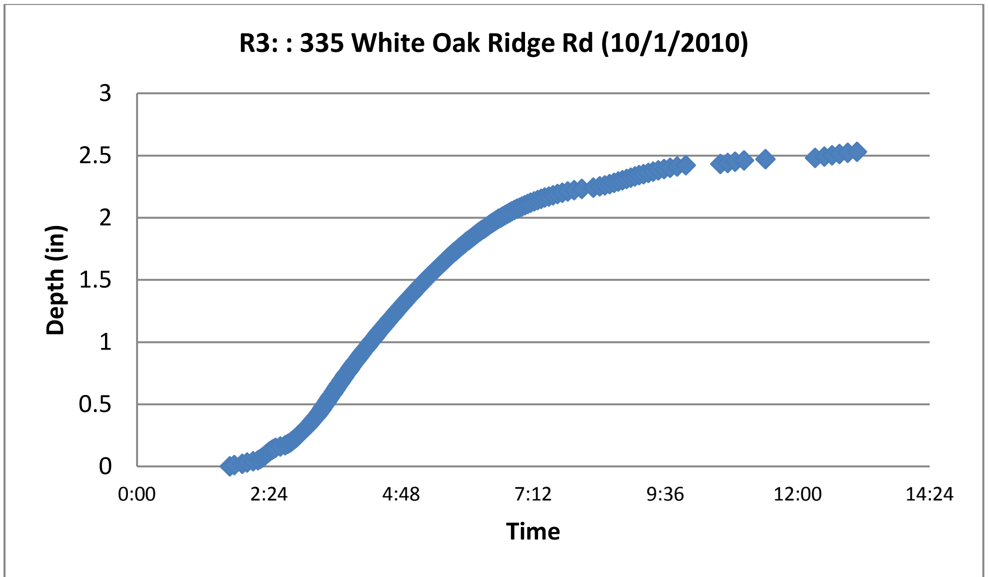
R3: : 335 White Oak Ridge Rd (9/16/2010)
Depth (in)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
15:36
16:48
18:00
19:12
20:24
21:36
22:48
Time

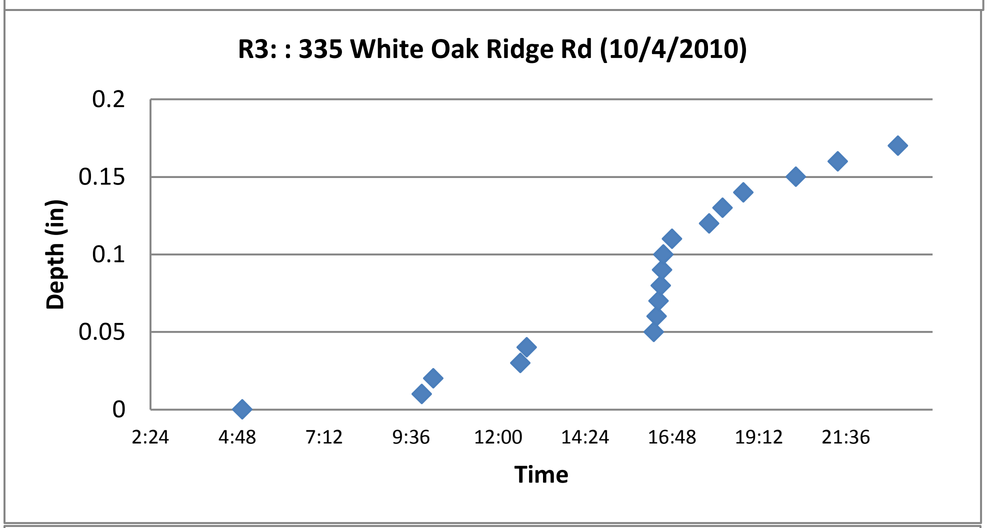


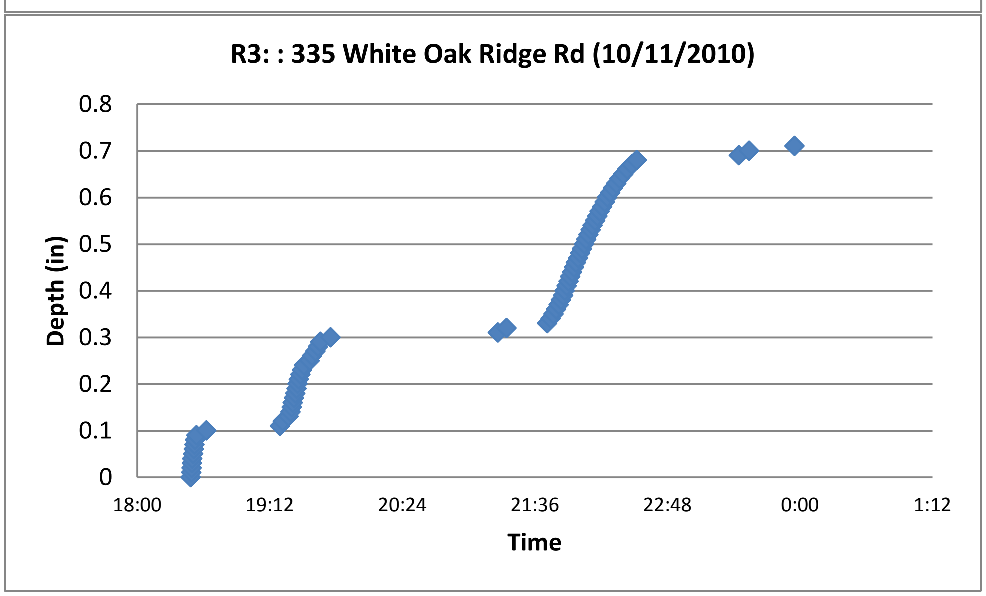
R3: : 335 White Oak Ridge Rd (9/27/2010 - 9/28/2010)
Depth (in)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
0:00
2:24
4:48
Time

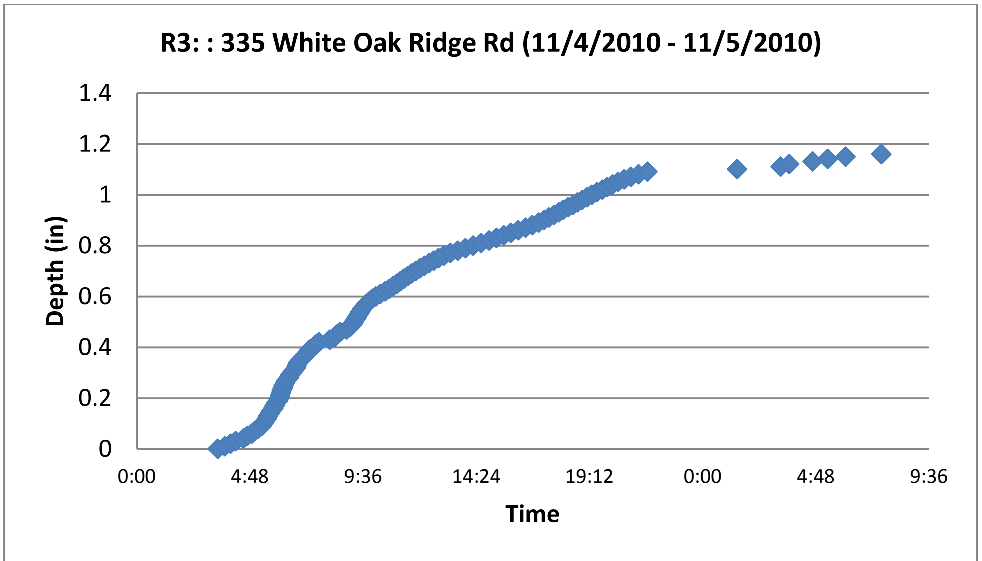


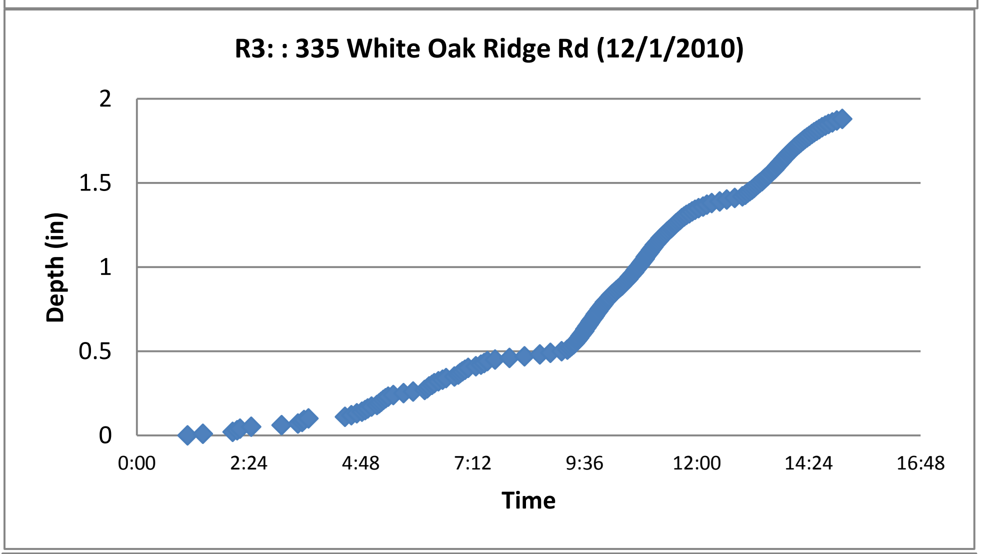
R3: : 335 White Oak Ridge Rd (9/30/2010)
Depth (in)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
3:36
4:48
6:00
7:12
8:24
9:36
10:48
Time

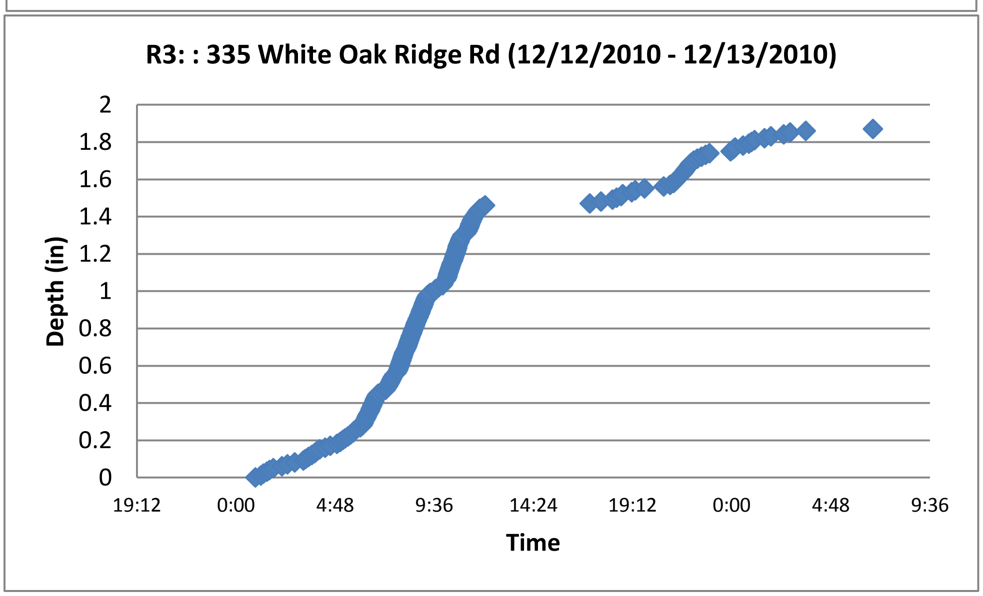

R3: : 335 White Oak Ridge Rd (10/1/2010)
Depth (in)
3
2.5
2
1.5
1
0.5
0
0:00
2:24
4:48
7:12
9:36
12:00
14:24
Time

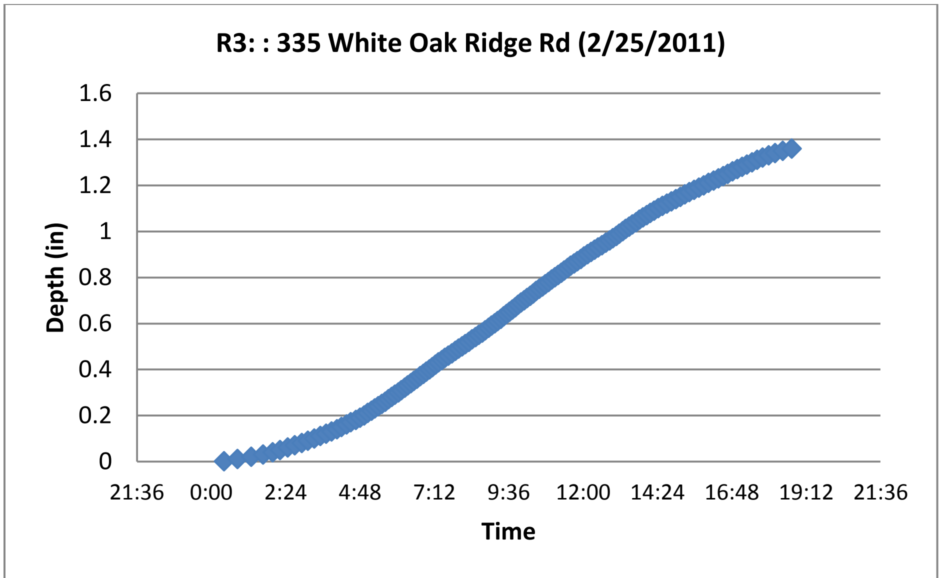

R3: : 335 White Oak Ridge Rd (10/4/2010)
Depth (in)
0.2
0.15
0.1
0.05
0
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time

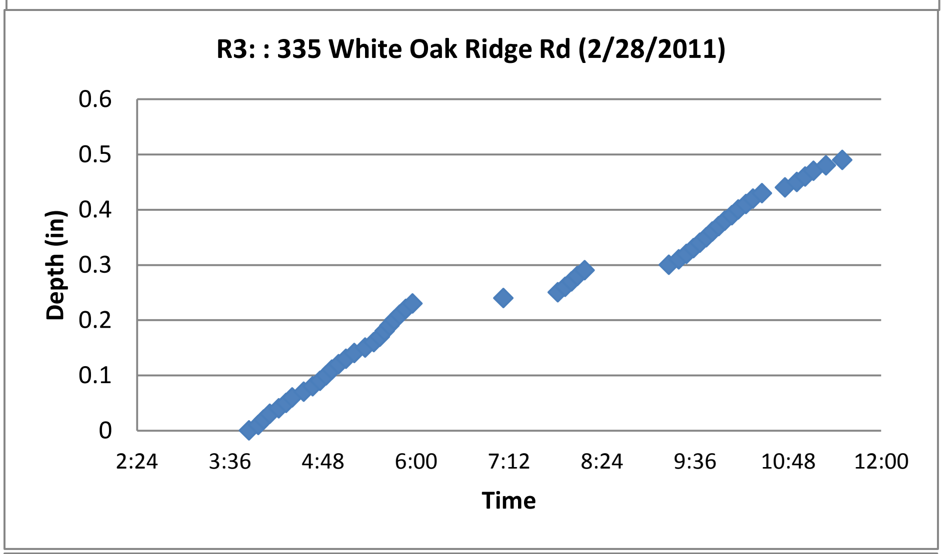

R3: : 335 White Oak Ridge Rd (10/11/2010)
Depth (in)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
18:00
19:12
20:24
21:36
22:48
0:00
1:12
Time

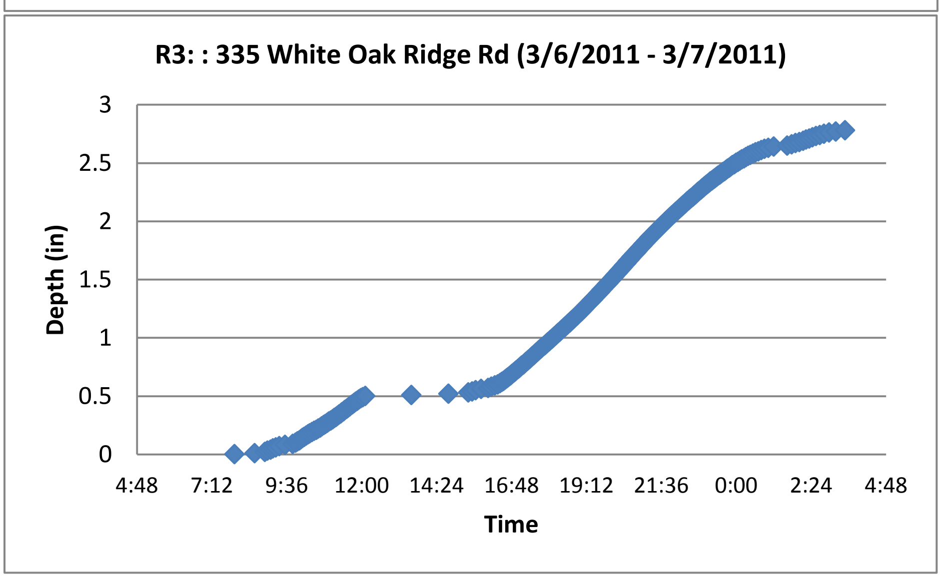

R3: : 335 White Oak Ridge Rd (11/4/2010 - 11/5/2010)
Depth (in)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0:00
4:48
9:36
14:24
19:12
0:00
4:48
9:36
Time

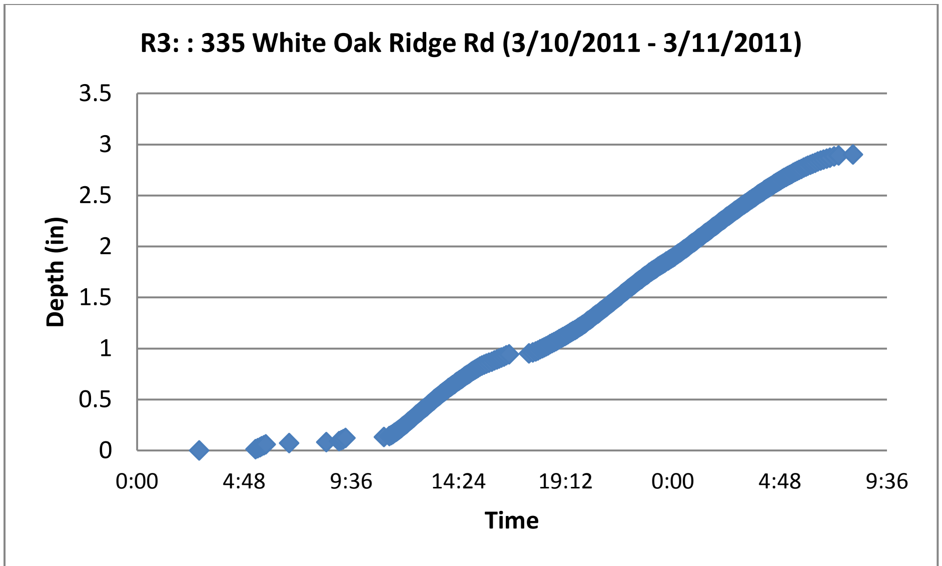

R3: : 335 White Oak Ridge Rd (12/1/2010)
Depth (in)
2
1.5
1
0.5
0
0:00
2:24
4:48
7:12
9:36
12:00
14:24
16:48
Time

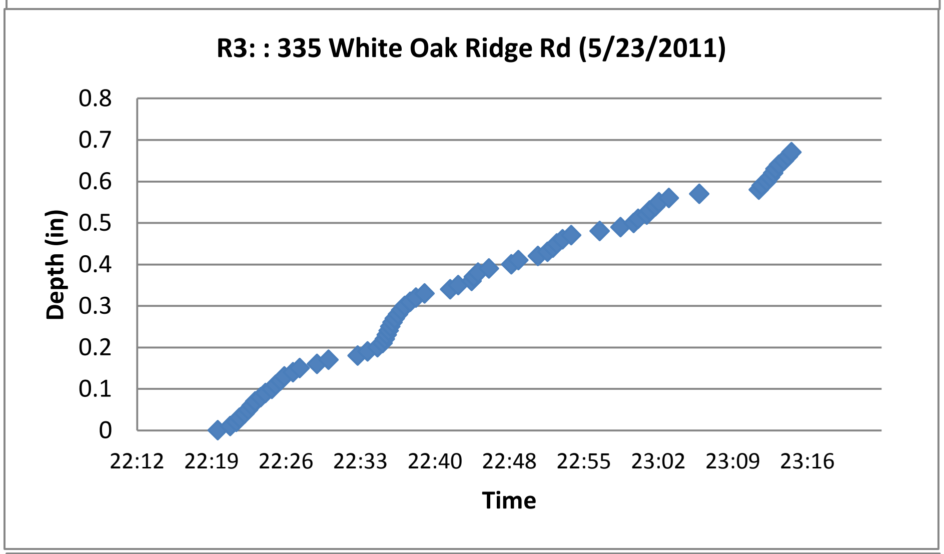

R3: : 335 White Oak Ridge Rd (12/12/2010 - 12/13/2010)
Depth (in)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
19:12
0:00
4:48
9:36
14:24
19:12
0:00
4:48
9:36
Time

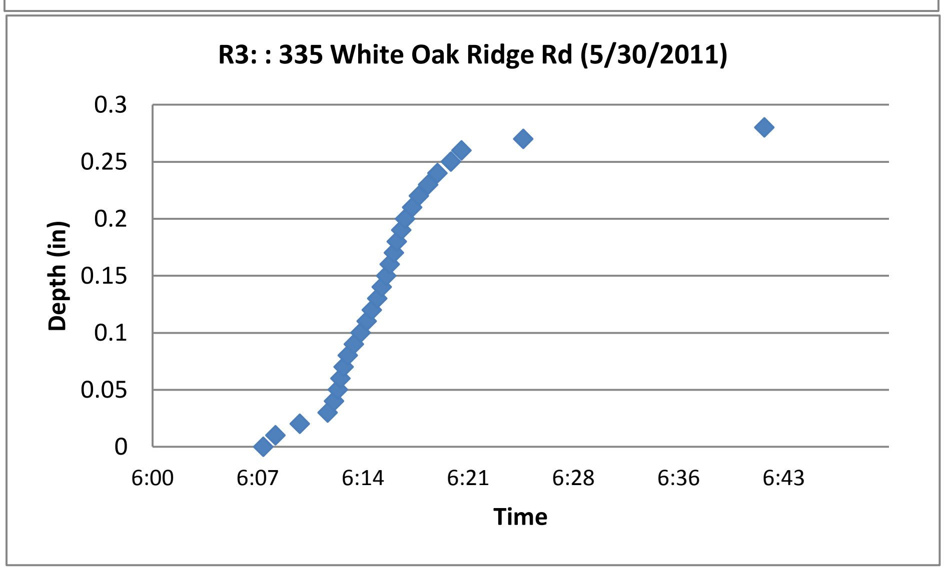

R3: : 335 White Oak Ridge Rd (2/25/2011)
Depth (in)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
21:36
0:00
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time

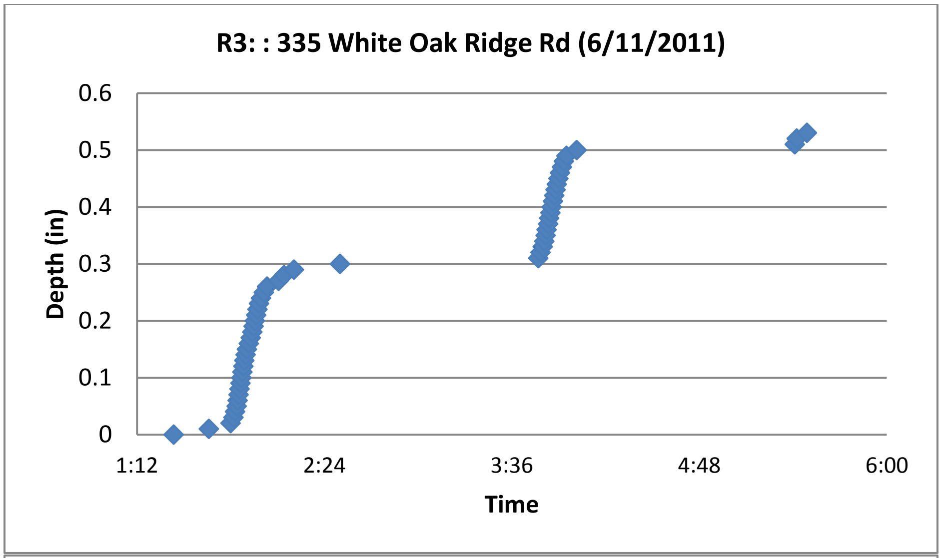

R3: : 335 White Oak Ridge Rd (2/28/2011)
Depth (in)
0.6
0.5
0.4
0.3
0.2
0.1
0
2:24
3:36
4:48
6:00
7:12
8:24
9:36
10:48
12:00
Time

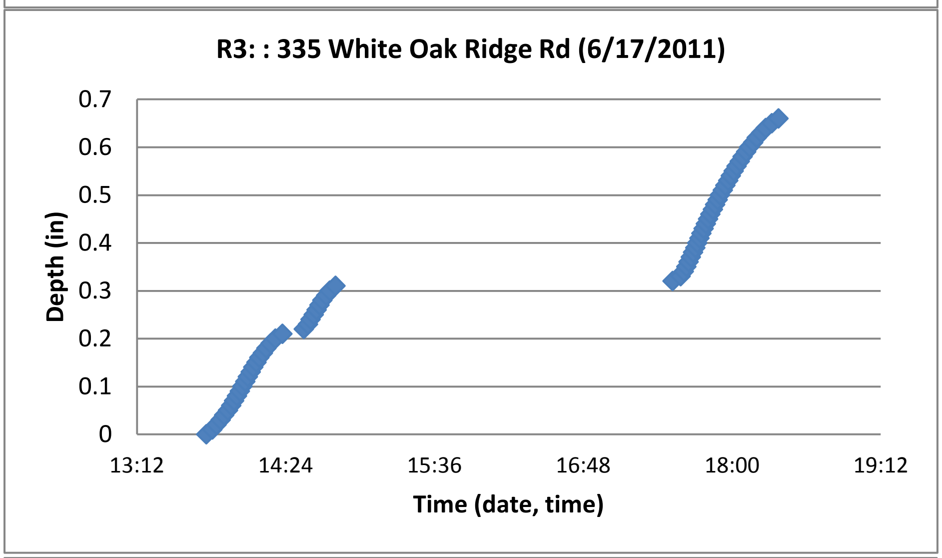

R3: : 335 White Oak Ridge Rd (3/6/2011 - 3/7/2011)
Depth (in)
3
2.5
2
1.5
1
0.5
0
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
0:00
2:24
4:48
Time

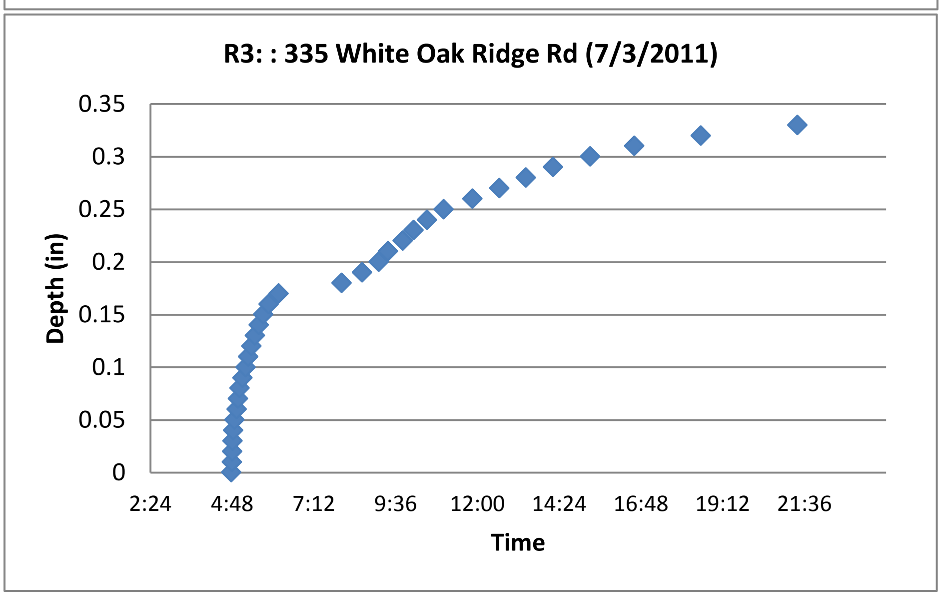

R3: : 335 White Oak Ridge Rd (3/10/2011 - 3/11/2011)
Depth (in)
3.5
3
2.5
2
1.5
1
0.5
0
0:00
4:48
9:36
14:24
19:12
0:00
4:48
9:36
Time


R3: : 335 White Oak Ridge Rd (5/23/2011)
Depth (in)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
22:12
22:19
22:26
22:33
22:40
22:48
22:55
23:02
23:09
23:16
Time


R3: : 335 White Oak Ridge Rd (5/30/2011)
Depth (in)
0.3
0.25
0.2
0.15
0.1
0.05
0
6:00
6:07
6:14
6:21
6:28
6:36
6:43
Time

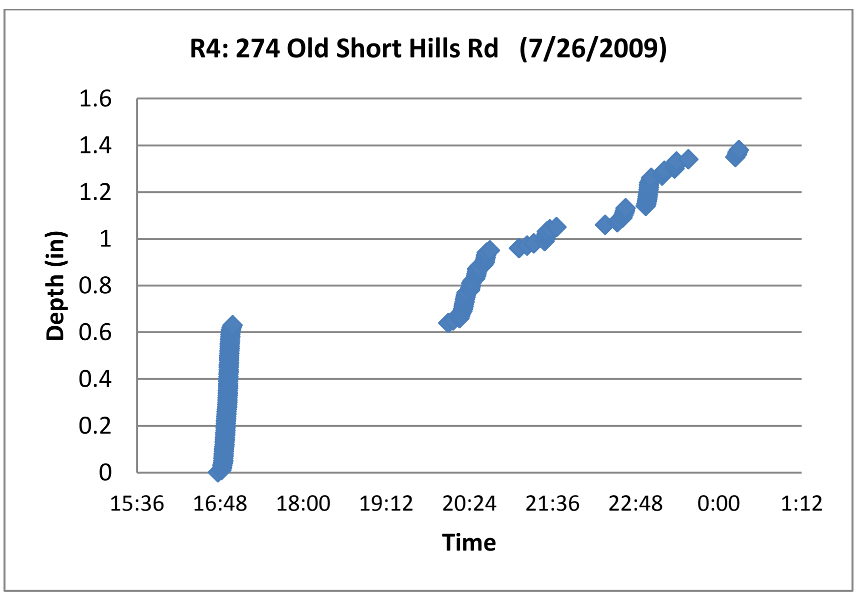

R3: : 335 White Oak Ridge Rd (6/11/2011)
Depth (in)
0.6
0.5
0.4
0.3
0.2
0.1
0
1:12
2:24
3:36
4:48
6:00
Time

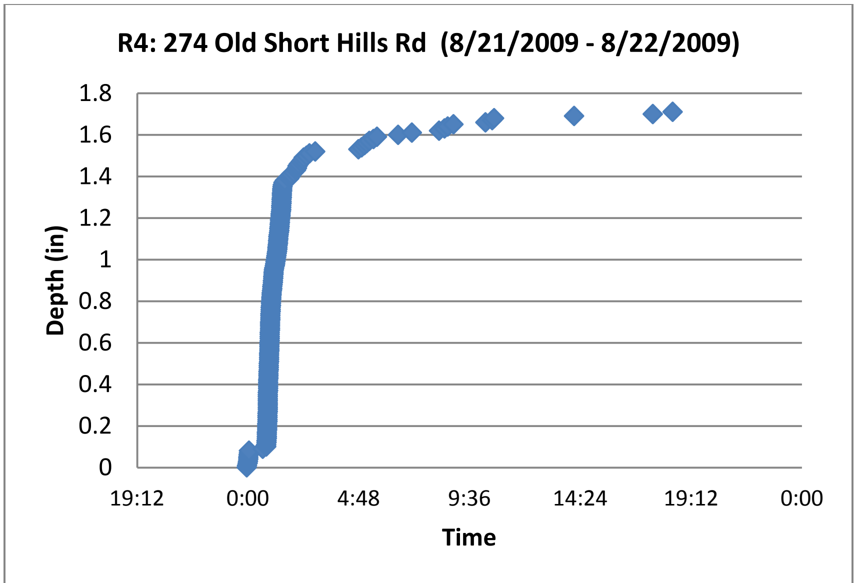

R3: : 335 White Oak Ridge Rd (6/17/2011)
Depth (in)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
13:12
14:24
15:36
16:48
18:00
19:12
Time (date, time)

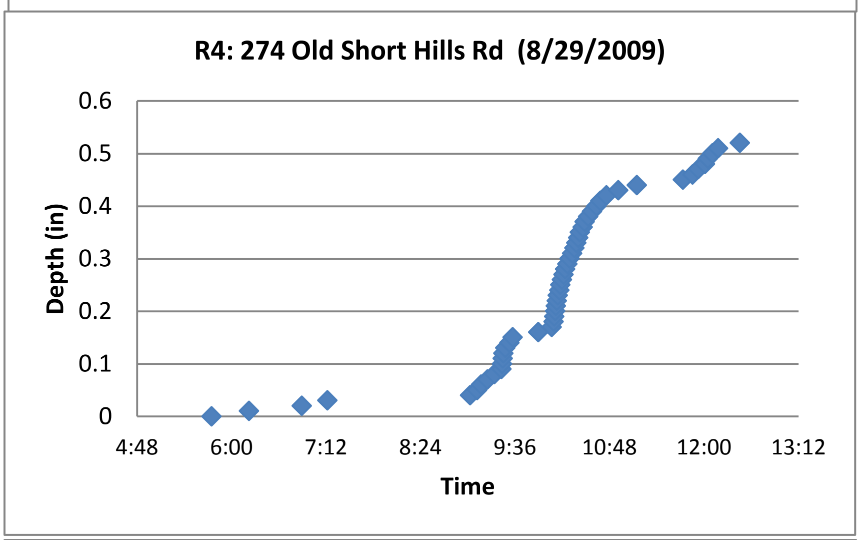

R3: : 335 White Oak Ridge Rd (7/3/2011)
Depth (in)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
Time

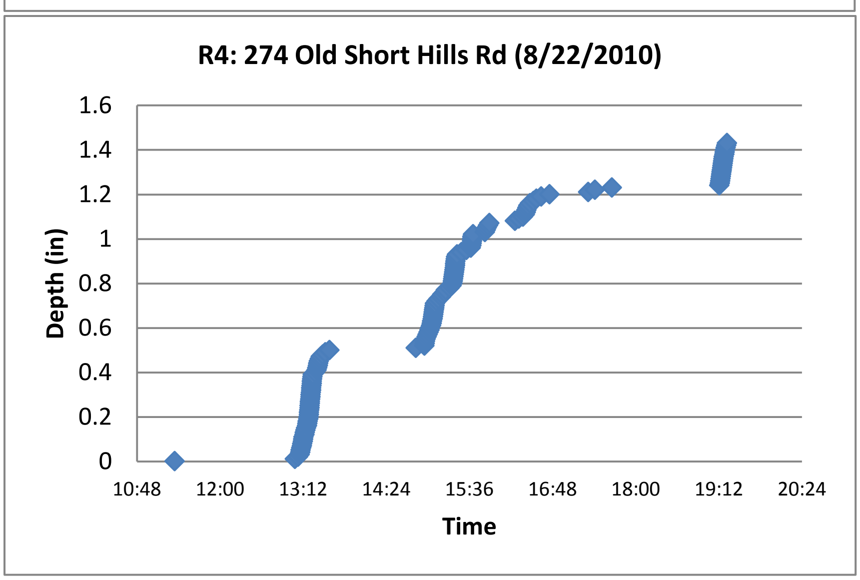
R4: Old tennis court at Greenwood Gardens on Old Short Hills Rd – Calibrated and launched at 16:00 on 5/6/09 by HDB

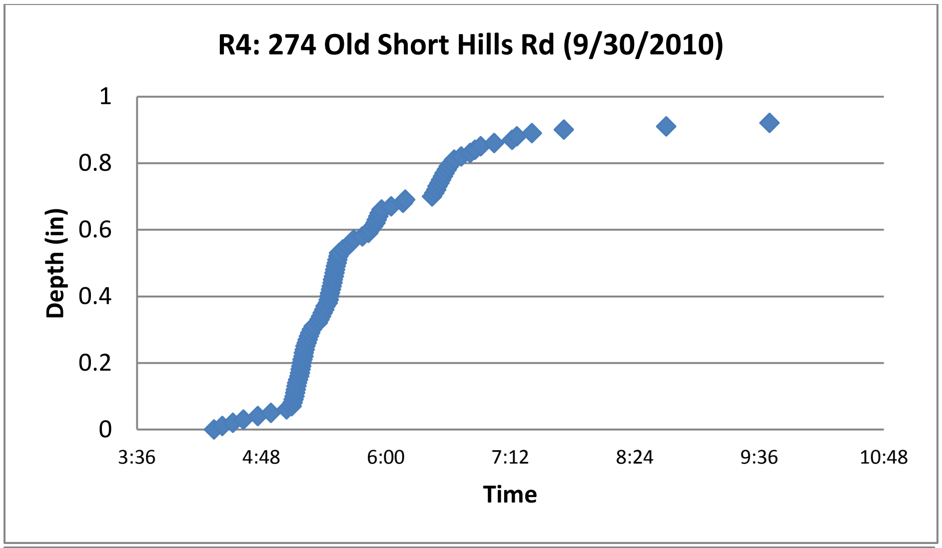
Start time		End time		Duration (hr)	Depth (in)	Average intensity (in/hr)
7/26/2009	16:46	7/27/2009	0:17	7:31	1.38	0.18
8/21/2009	23:57	8/22/2009	18:25	18:28	1.71	0.09
8/29/2009	5:45	8/29/2009	12:27	6:42	0.52	0.08
8/22/2010	11:20	8/22/2010	19:19	7:59	1.43	0.18
9/30/2010	4:20	9/30/2010	9:42	5:22	0.92	0.17
10/1/2010	2:17	10/1/2010	16:48	14:31	1.73	0.12
10/11/2010	18:33	10/12/2010	5:52	11:19	0.17	0.02
11/27/2010	7:40	11/27/2010	12:36	4:56	0.34	0.07
12/1/2010	2:15	12/2/2010	1:05	22:50	0.67	0.02
12/12/2010	2:13	12/12/2010	11:38	9:25	0.33	0.04
12/12/2010	17:25	12/13/2010	3:18	9:53	0.23	0.02
2/24/2011	21:58	2/25/2011	13:46	15:48	0.59	0.04
2/28/2011	4:12	2/28/2011	11:32	7:20	0.22	0.03
3/6/2011	9:00	3/7/2011	3:22	18:22	1.15	0.06
3/10/2011	5:30	3/11/2011	4:33	23:03	0.98	0.04
3/16/2011	4:29	3/16/2011	8:48	4:19	0.23	0.05

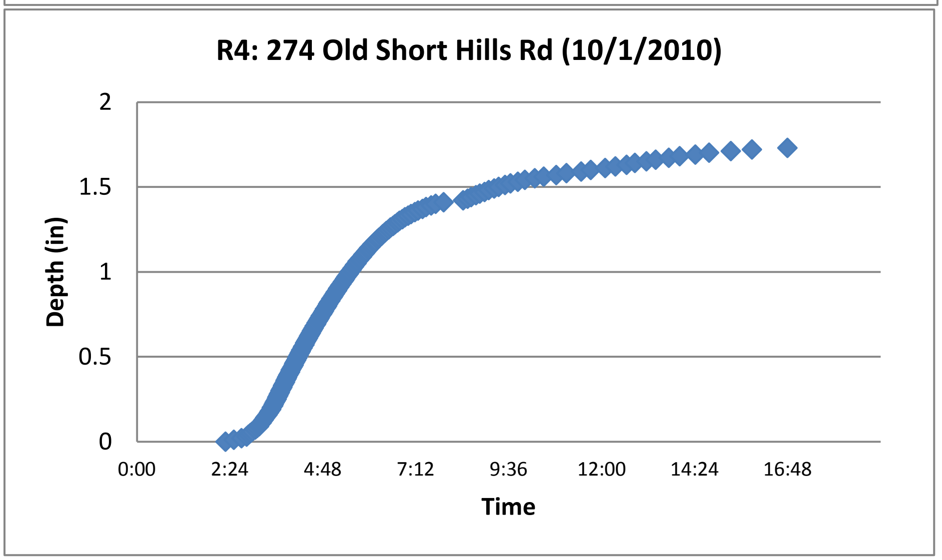


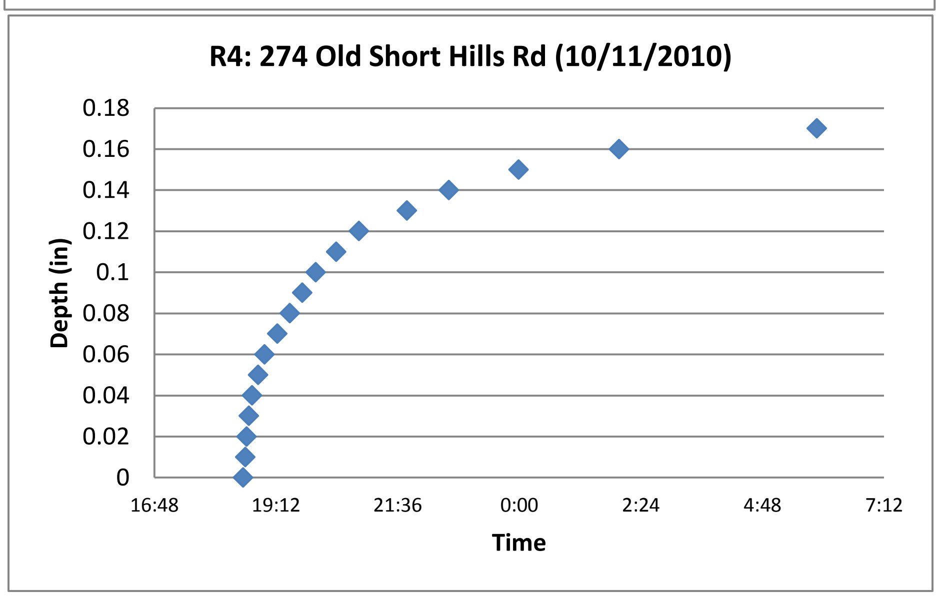

R4: 274 Old Short Hills Rd (8/21/2009 - 8/22/2009)
Depth (in)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
19:12
0:00
4:48
9:36
14:24
19:12
0:00
Time

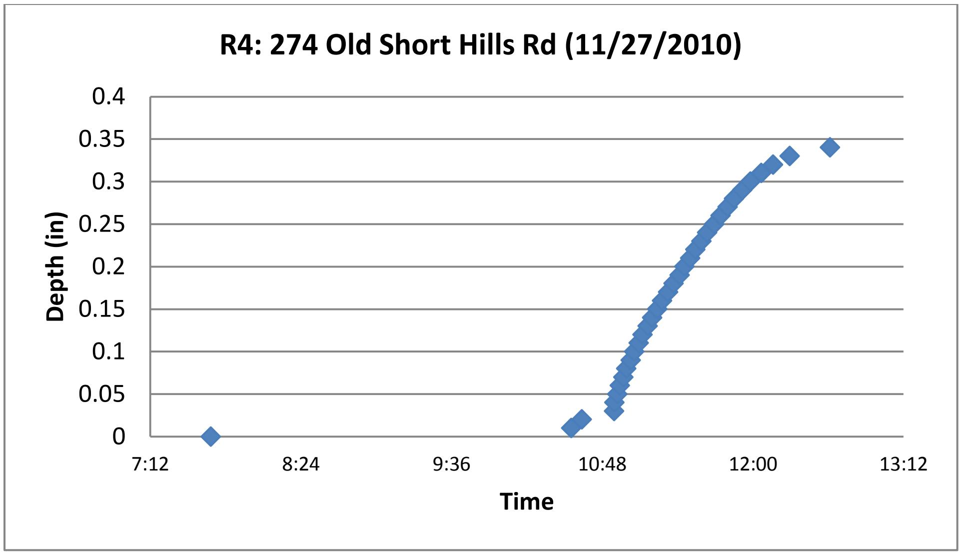

R4: 274 Old Short Hills Rd (8/29/2009)
Depth (in)
0.6
0.5
0.4
0.3
0.2
0.1
0
4:48
6:00
7:12
8:24
9:36
10:48
12:00
13:12
Time

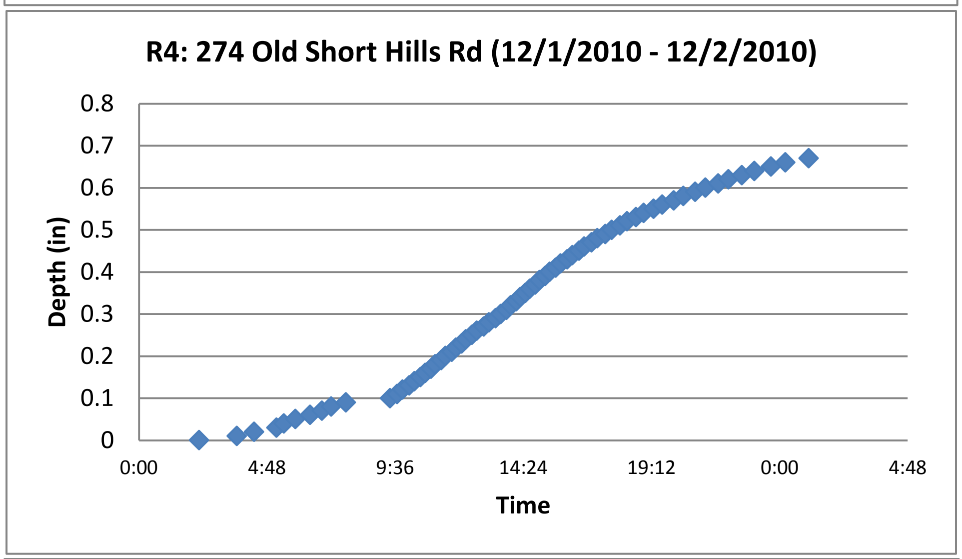

R4: 274 Old Short Hills Rd (8/22/2010)
Depth (in)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
10:48
12:00
13:12
14:24
15:36
16:48
18:00
19:12
20:24
Time

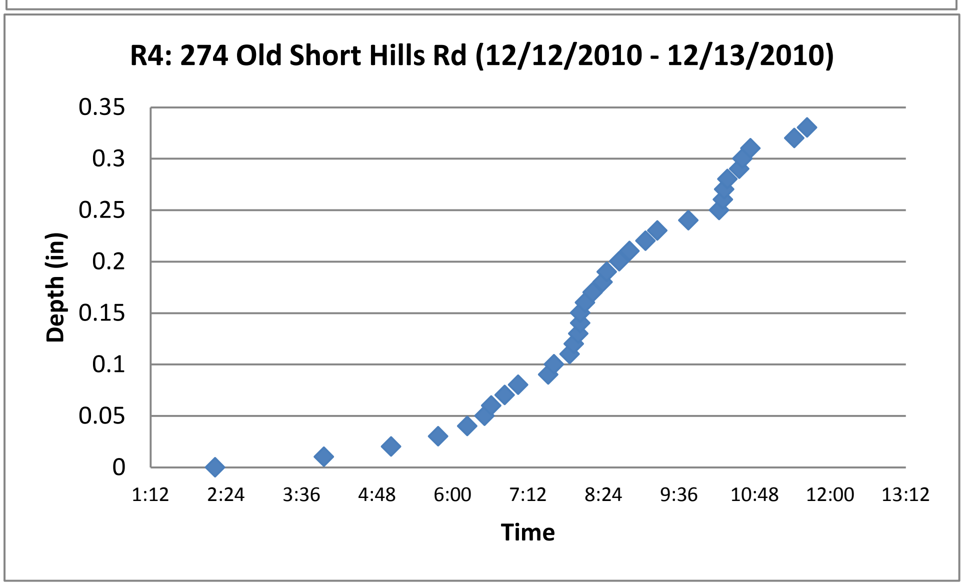

R4: 274 Old Short Hills Rd (9/30/2010)
Depth (in)
1
0.8
0.6
0.4
0.2
0
3:36
4:48
6:00
7:12
8:24
9:36
10:48
Time

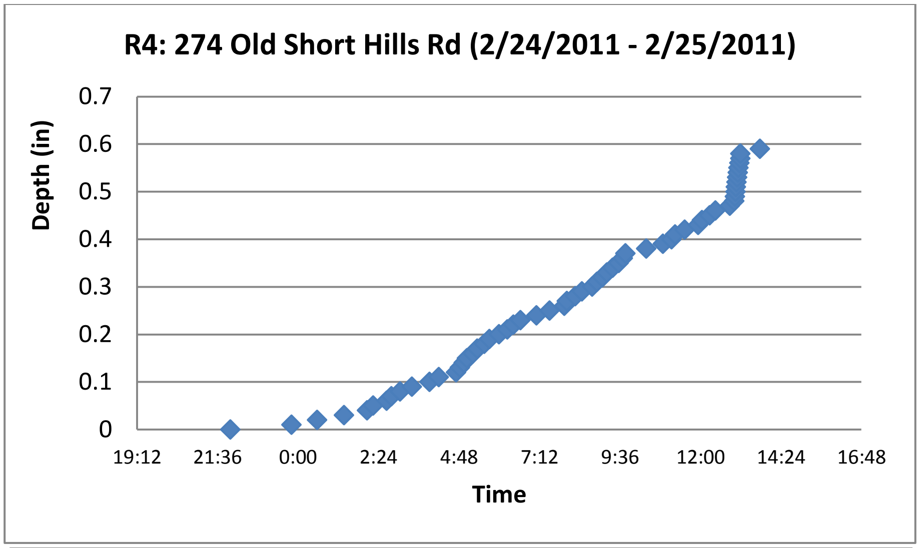

R4: 274 Old Short Hills Rd (10/1/2010)
Depth (in)
2
1.5
1
0.5
0
0:00
2:24
4:48
7:12
9:36
12:00
14:24
16:48
Time

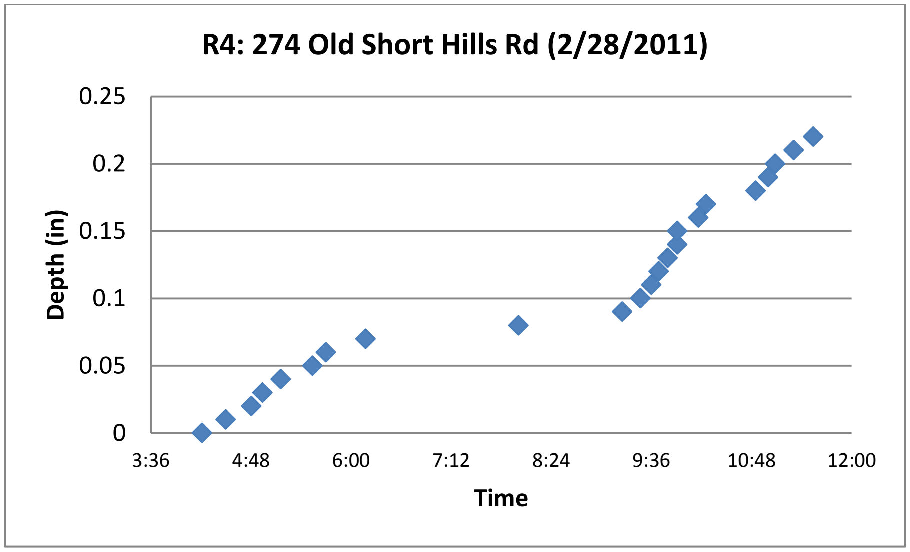

R4: 274 Old Short Hills Rd (10/11/2010)
Depth (in)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
16:48
19:12
21:36
0:00
2:24
4:48
7:12
Time

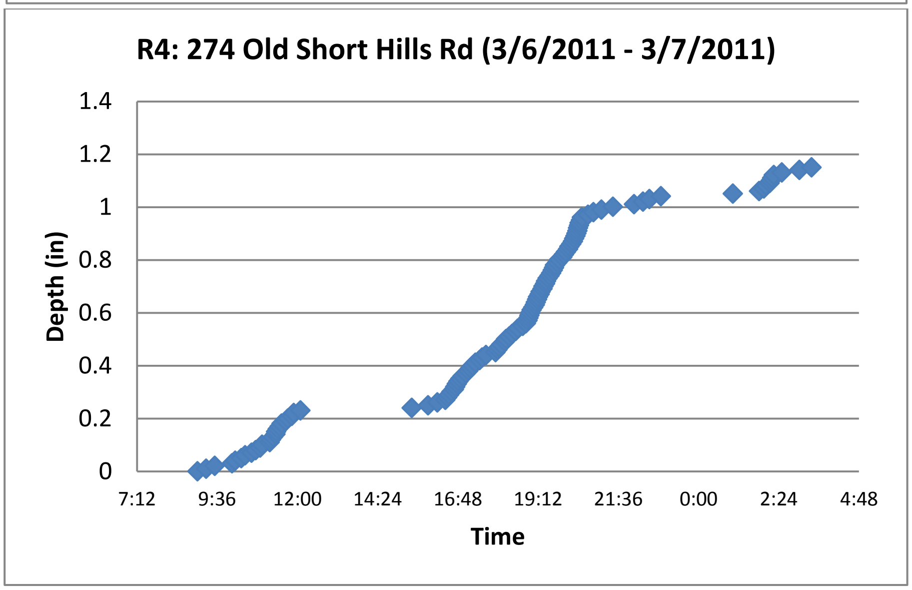

R4: 274 Old Short Hills Rd (11/27/2010)
Depth (in)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
7:12
8:24
9:36
10:48
12:00
13:12
Time

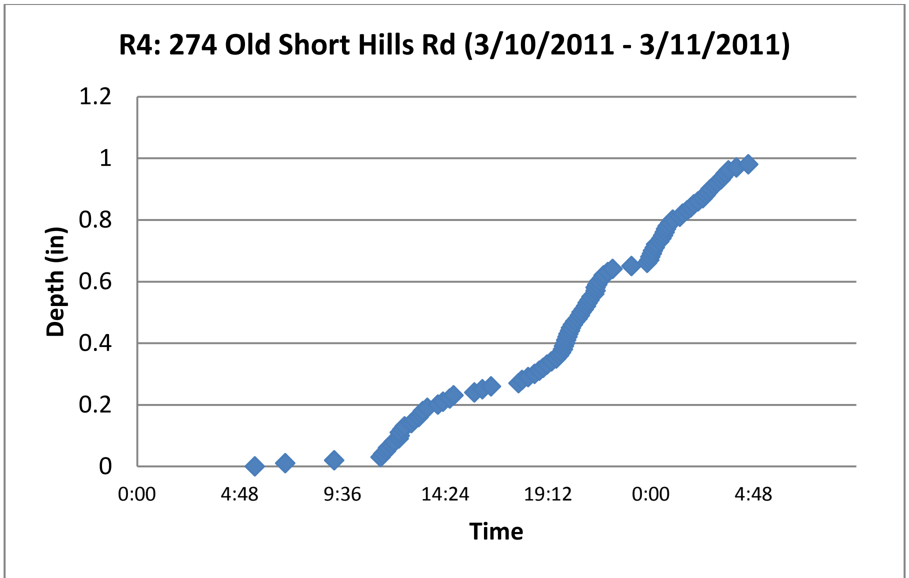

R4: 274 Old Short Hills Rd (12/1/2010 - 12/2/2010)
Depth (in)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0:00
4:48
9:36
14:24
19:12
0:00
4:48
Time

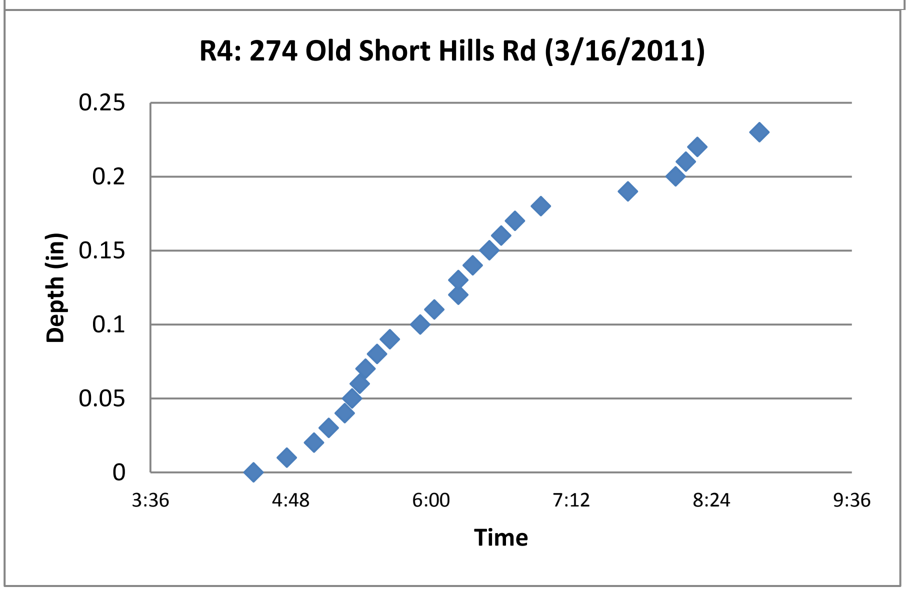

R4: 274 Old Short Hills Rd (12/12/2010 - 12/13/2010)
Depth (in)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1:12
2:24
3:36
4:48
6:00
7:12
8:24
9:36
10:48
12:00
13:12
Time


R4: 274 Old Short Hills Rd (2/24/2011 - 2/25/2011)
Depth (in)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
19:12
21:36
0:00
2:24
4:48
7:12
9:36
12:00
14:24
16:48
Time


R4: 274 Old Short Hills Rd (2/28/2011)
Depth (in)
0.25
0.2
0.15
0.1
0.05
0
3:36
4:48
6:00
7:12
8:24
9:36
10:48
12:00
Time

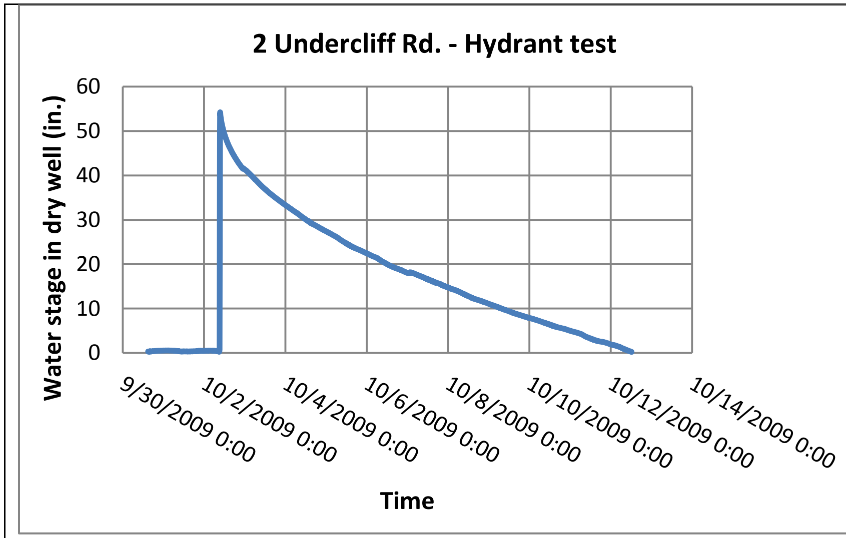

R4: 274 Old Short Hills Rd (3/6/2011 - 3/7/2011)
Depth (in)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
7:12
9:36
12:00
14:24
16:48
19:12
21:36
0:00
2:24
4:48
Time


R4: 274 Old Short Hills Rd (3/10/2011 - 3/11/2011)
Depth (in)
1.2
1
0.8
0.6
0.4
0.2
0
0:00
4:48
9:36
14:24
19:12
0:00
4:48
Time

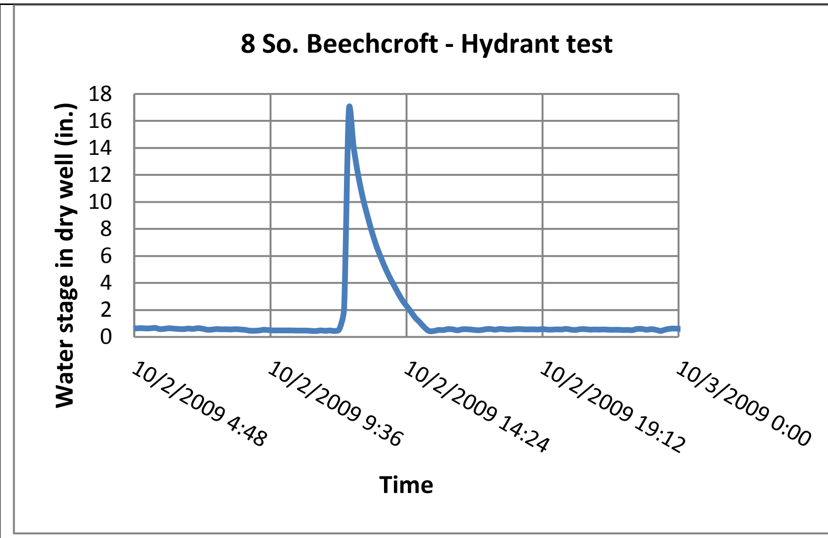

R4: 274 Old Short Hills Rd (3/16/2011)
Depth (in)
0.25
0.2
0.15
0.1
0.05
0
3:36
4:48
6:00
7:12
8:24
9:36
Time

APPENDIX E

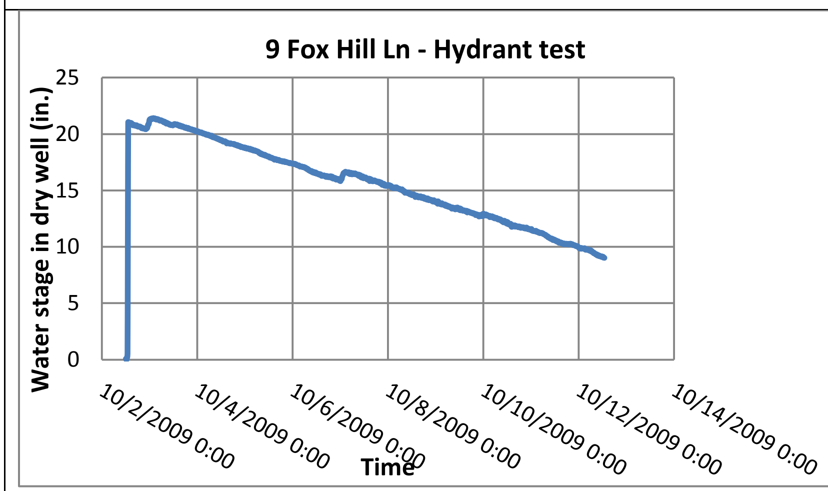
TIME SERIES PLOTS OF THE WATER LEVELS FOR THE LONG-TERM INFILTRATION TESTS AT THE DRY WELLS, MILLBURN, NJ



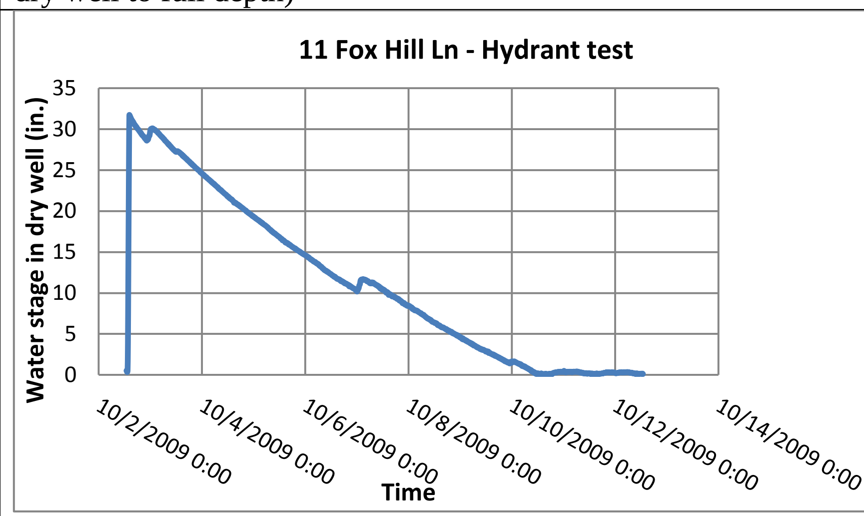
10 days total drainage time



3 hr total drainage time (only half full as too rapid infiltration to fill dry well to full depth)

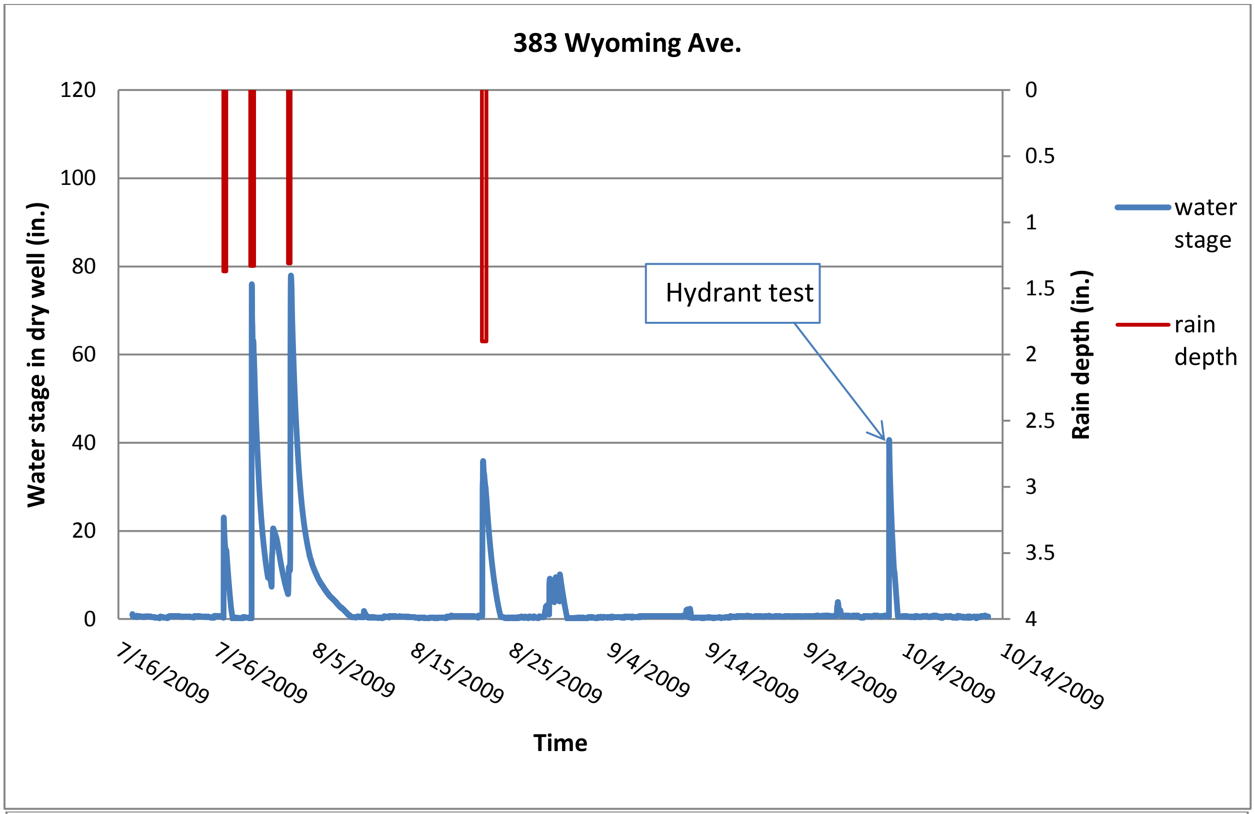


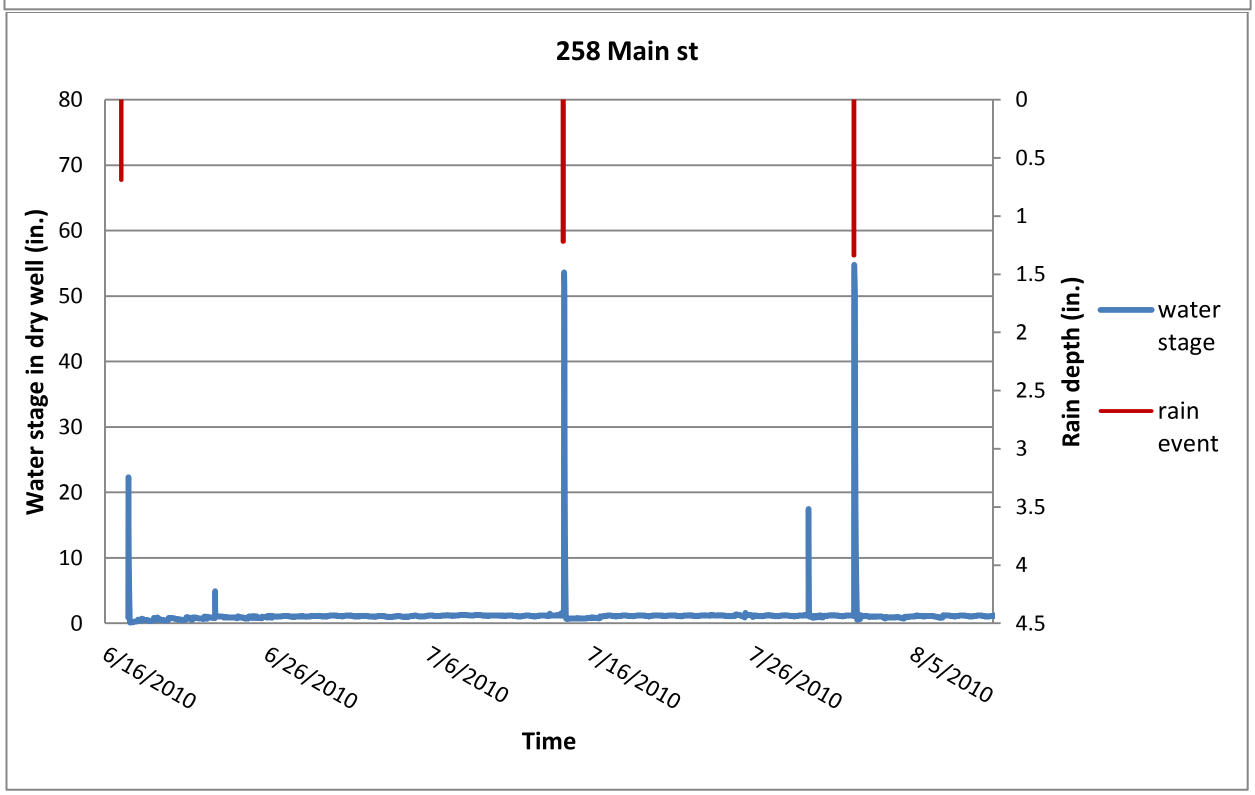
About 20 days total drainage time (extrapolated as rains interrupted test)



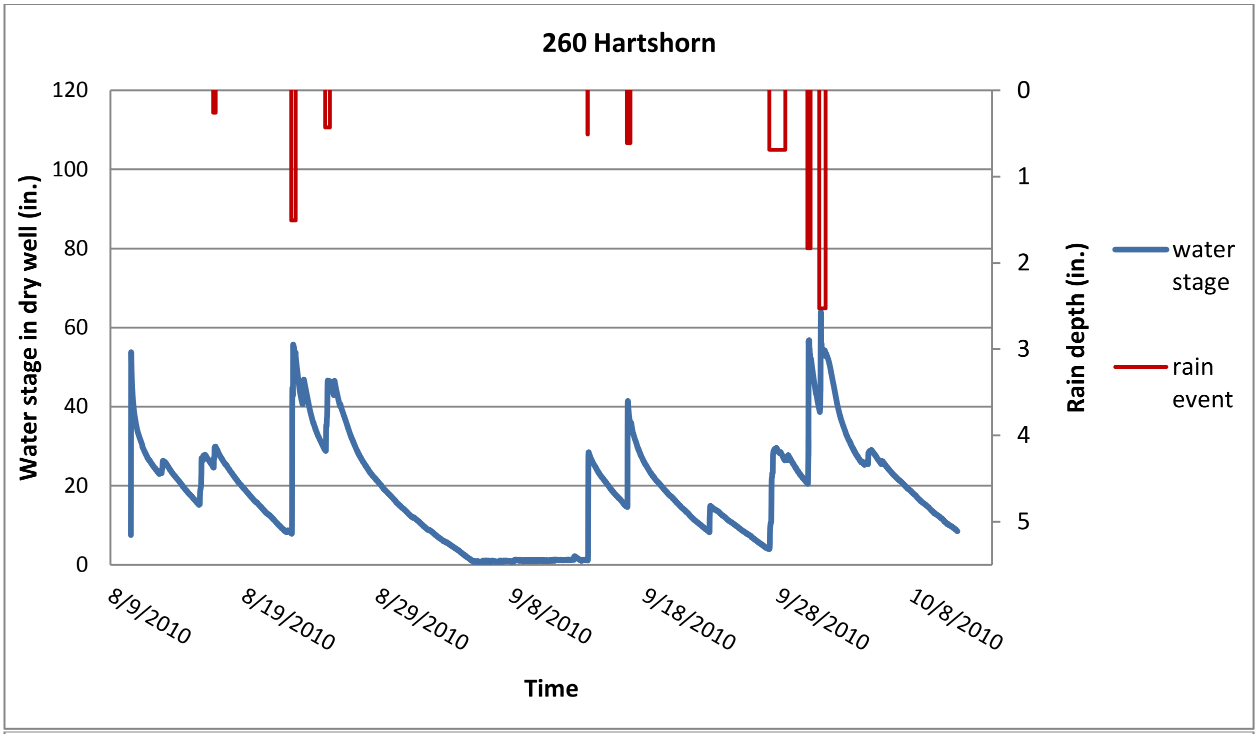
8 days total drainage time

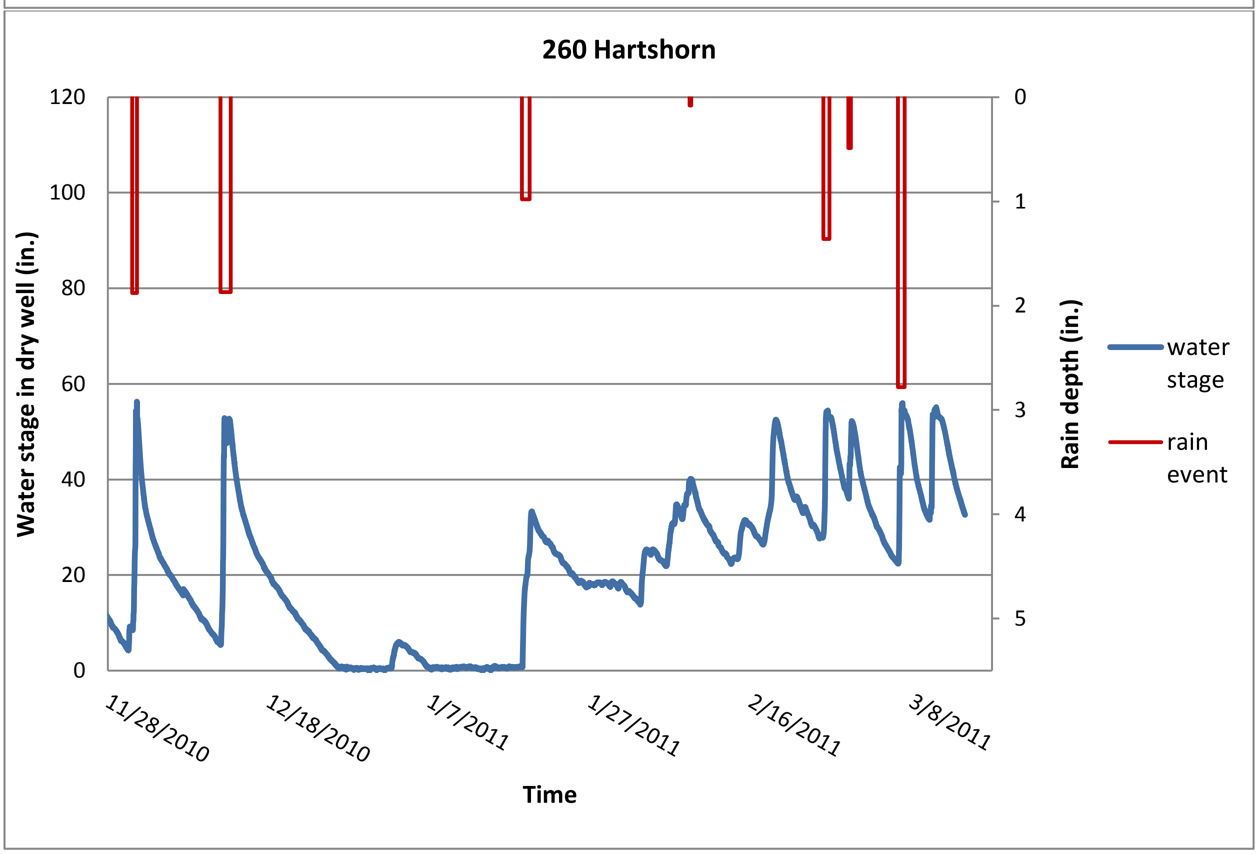
Hydrant water test infiltration plots (cont.).(1 in = 25.4 mm)



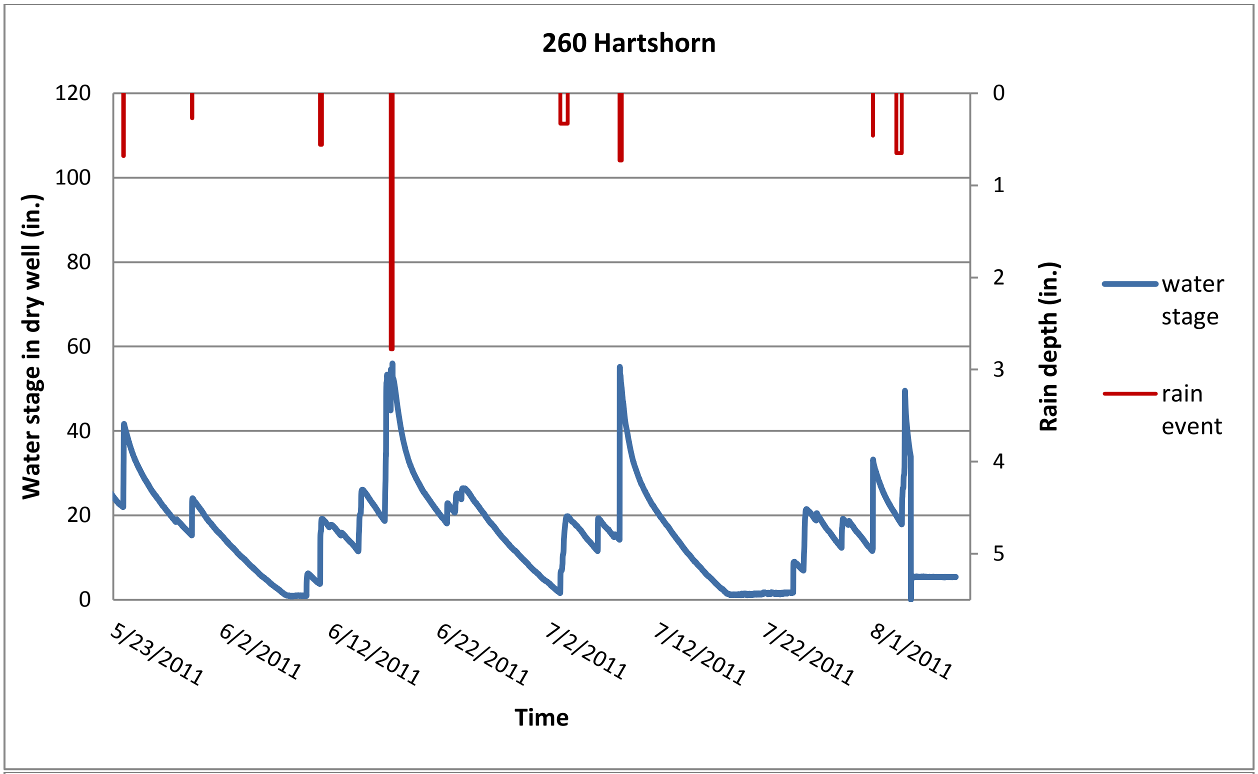


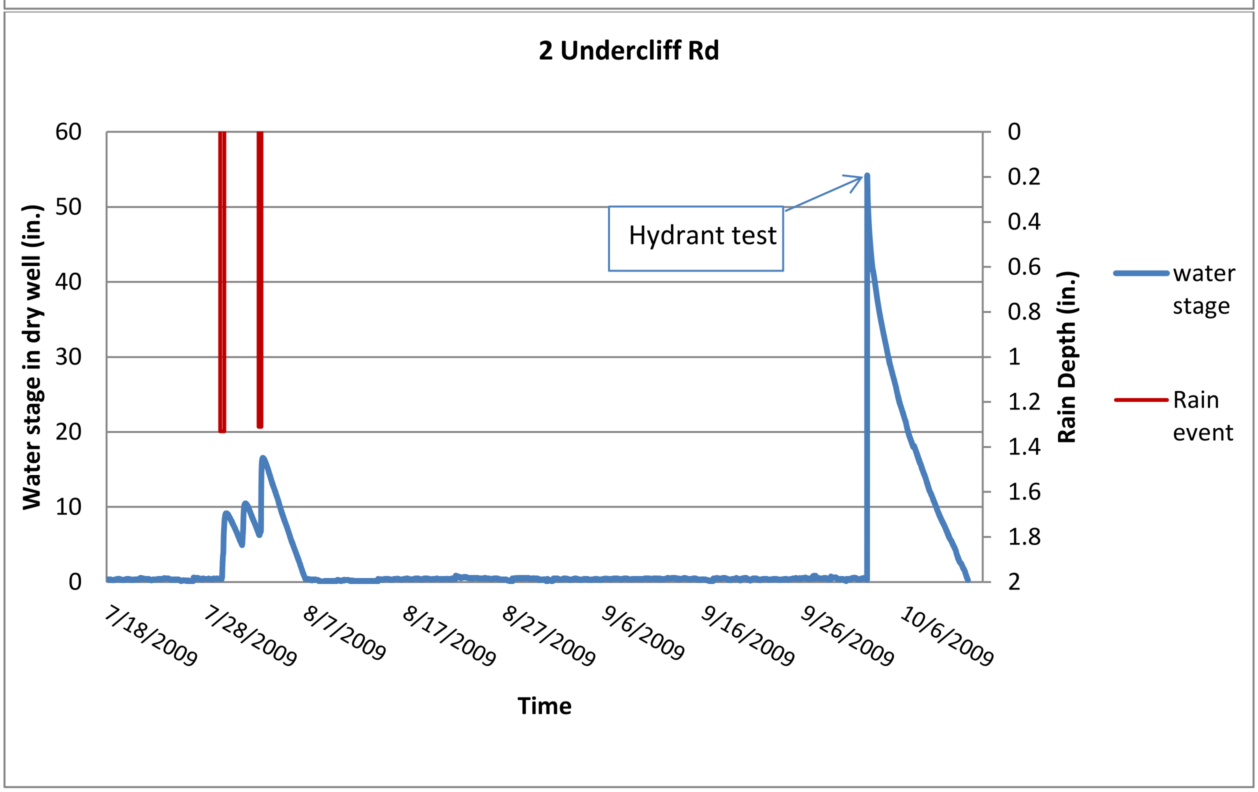
Time series plots of the water levels for the long-term infiltration tests at the dry wells (cont.) (1 in = 25.4 mm)



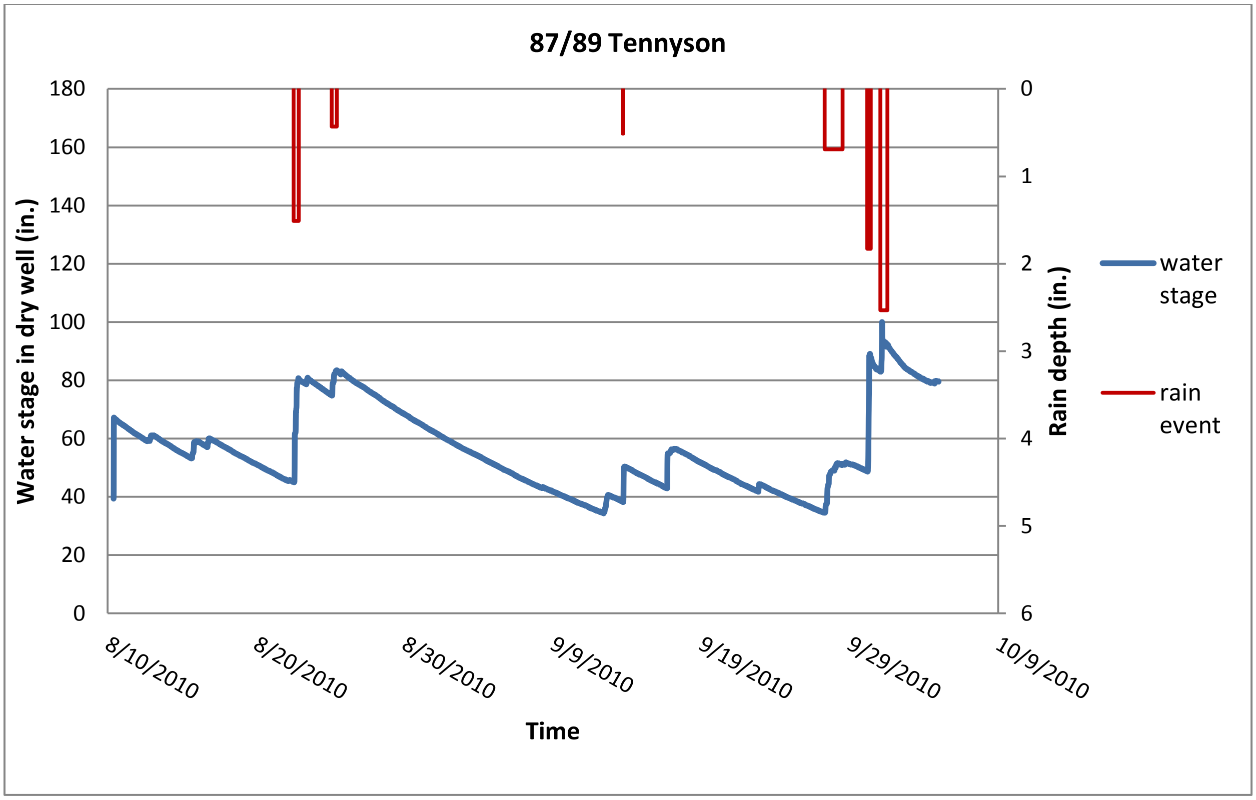


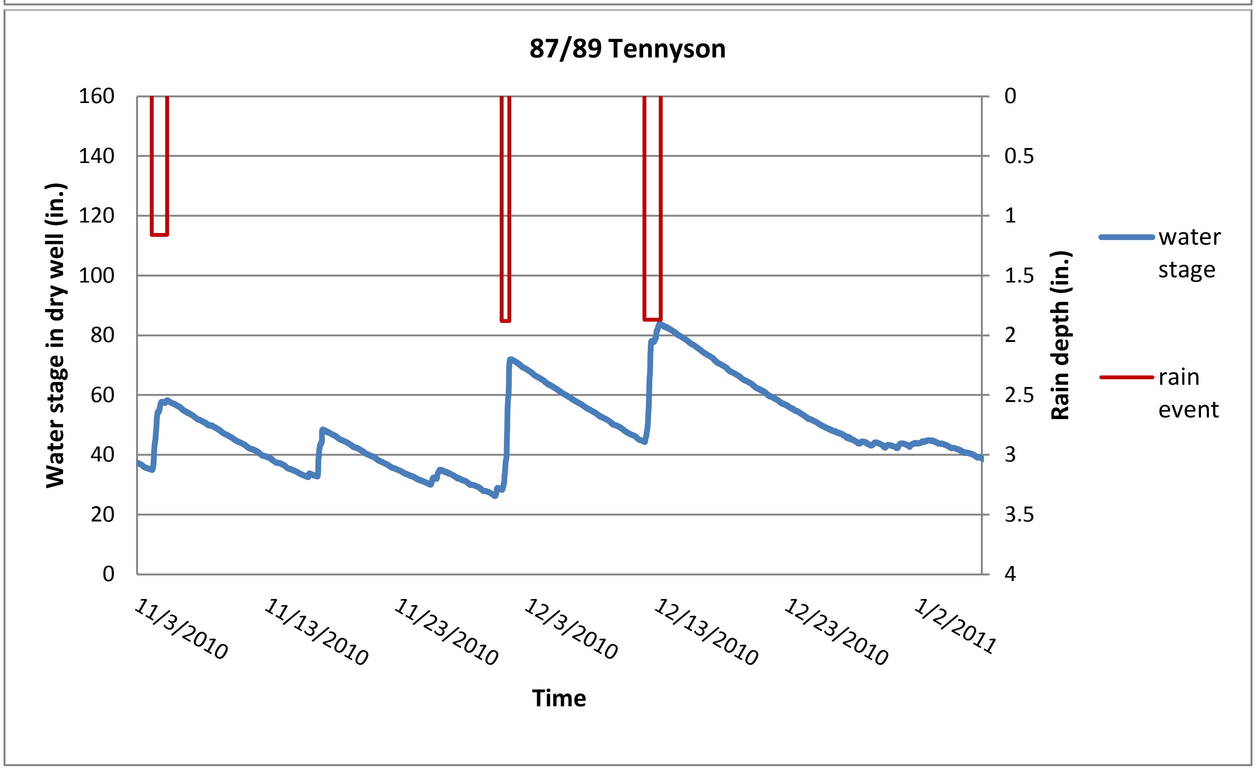
Time series plots of the water levels for the long-term infiltration tests at the dry wells (cont.) (1 in = 25.4 mm)



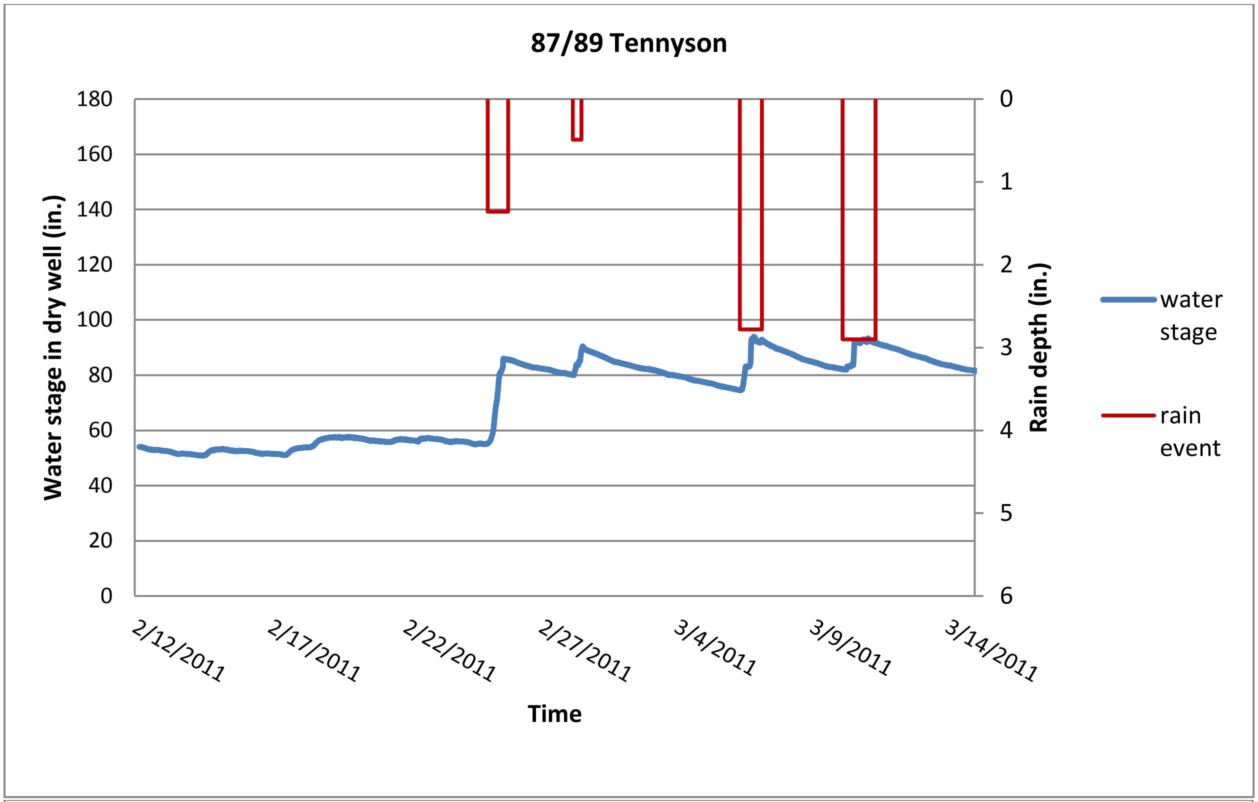


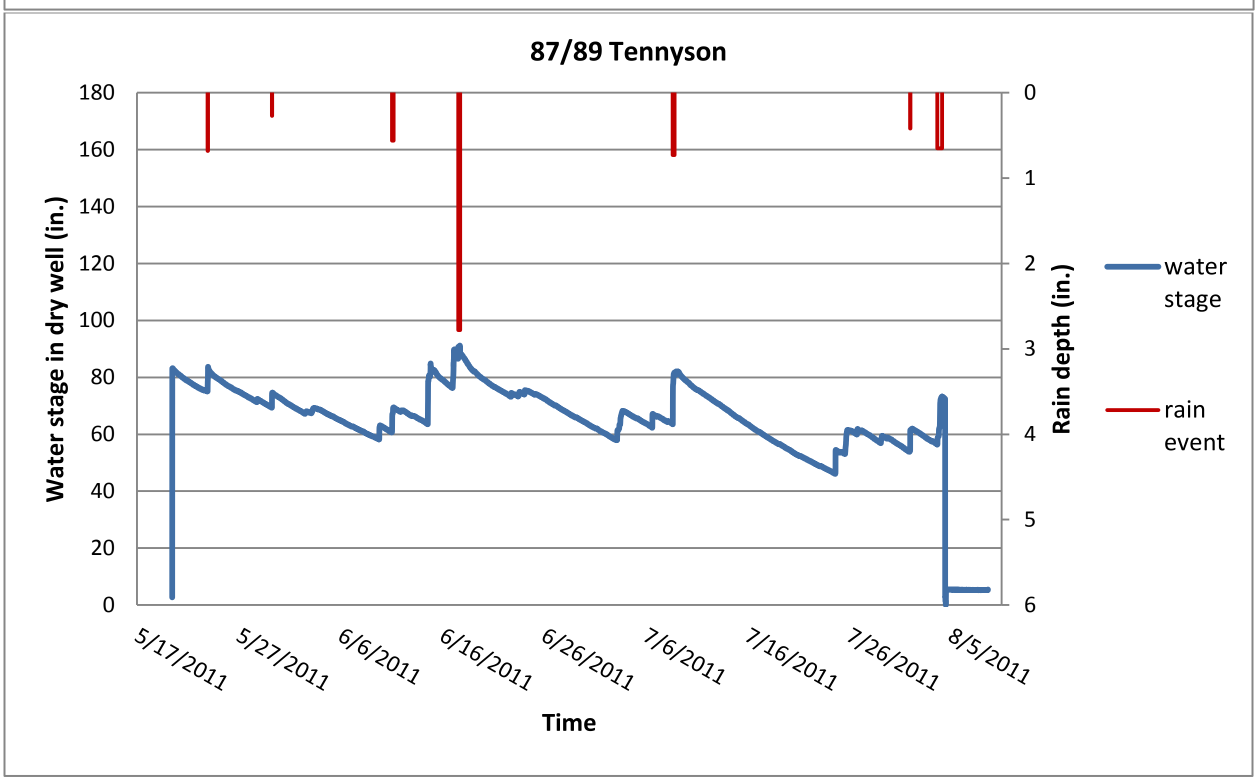
Time series plots of the water levels for the long-term infiltration tests at the dry wells (cont.) (1 in = 25.4 mm)



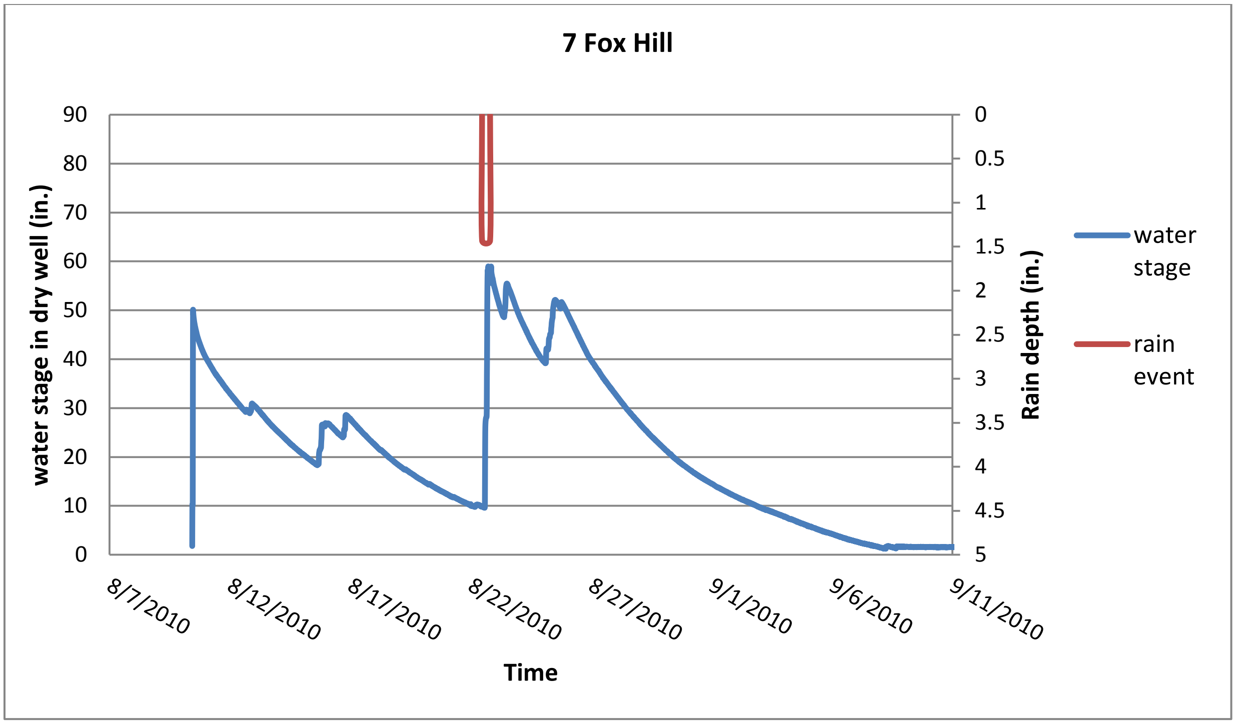


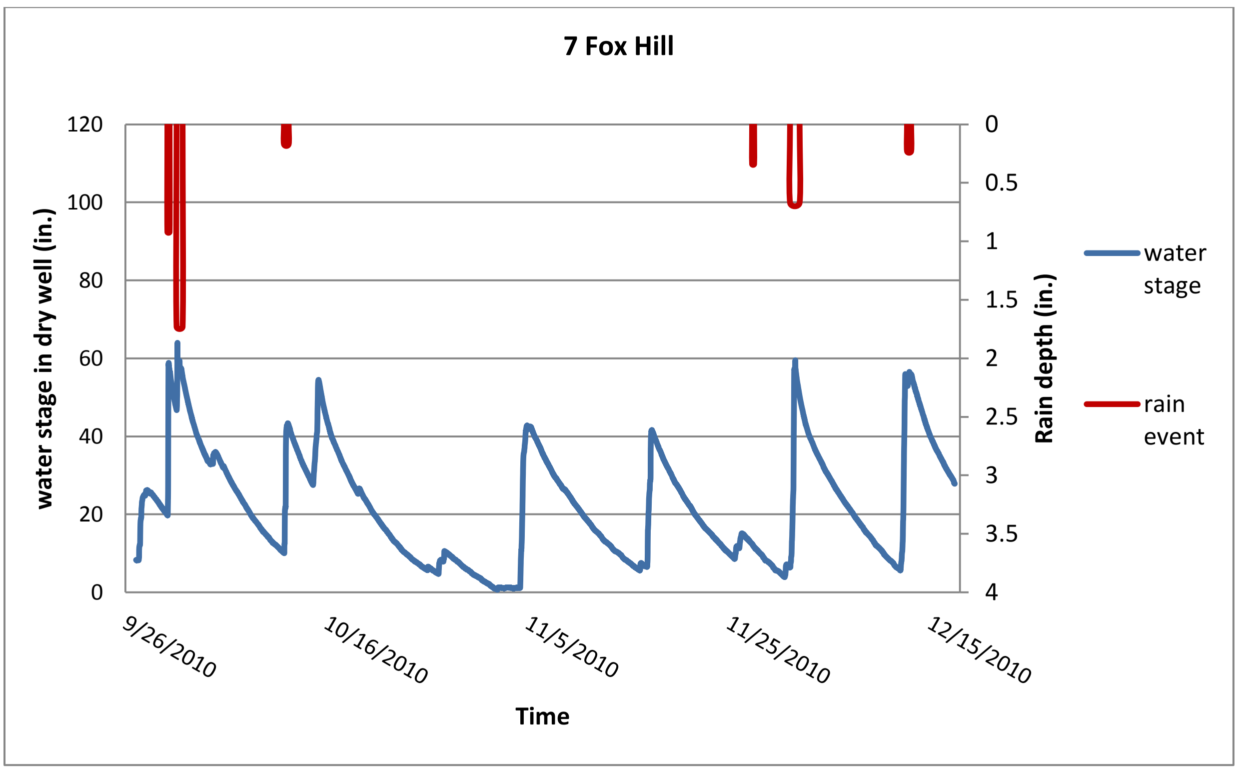
Time series plots of the water levels for the long-term infiltration tests at the dry wells (cont.) (1 in = 25.4 mm)



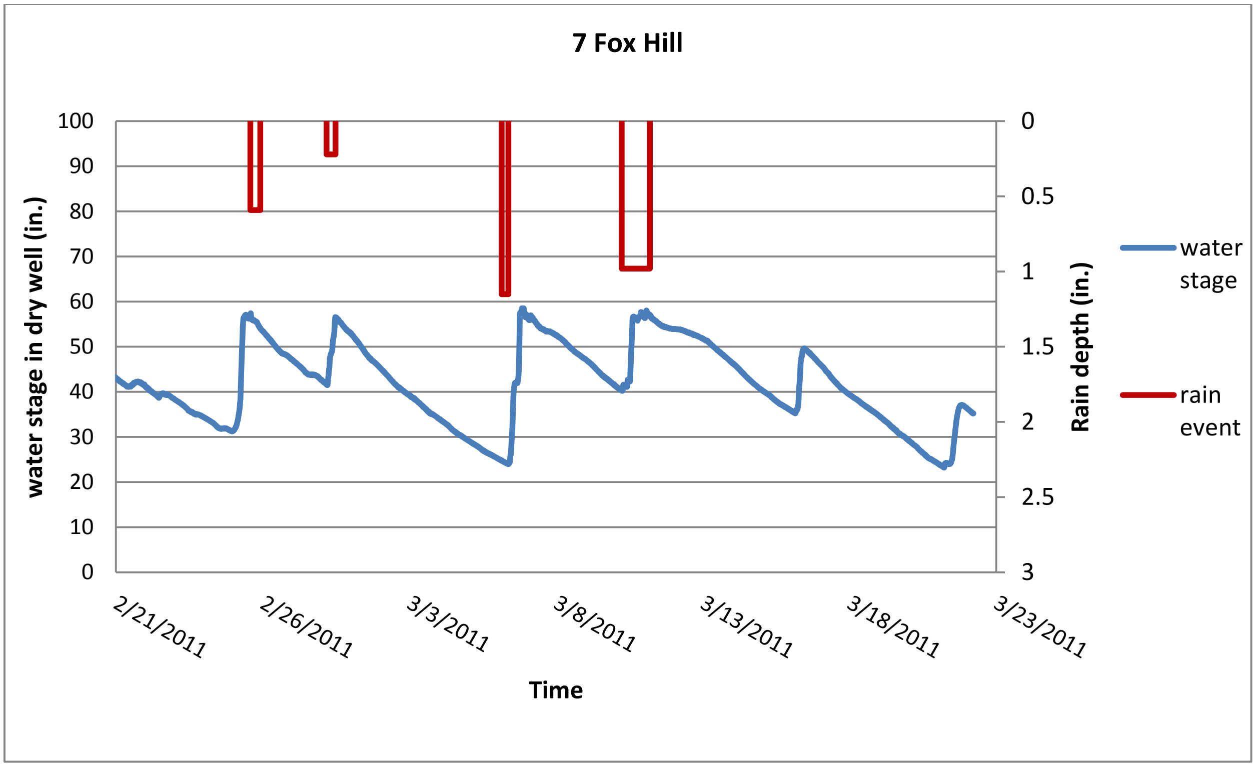


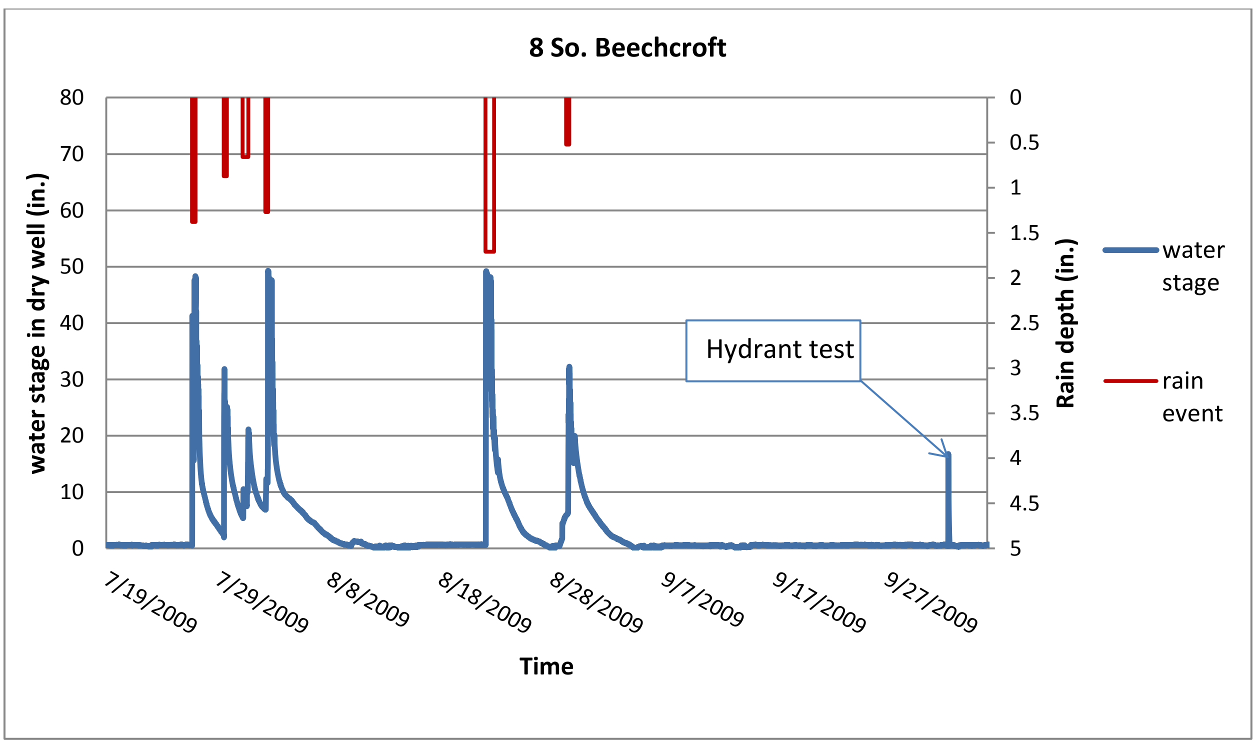
Time series plots of the water levels for the long-term infiltration tests at the dry wells (cont.) (1 in = 25.4 mm)



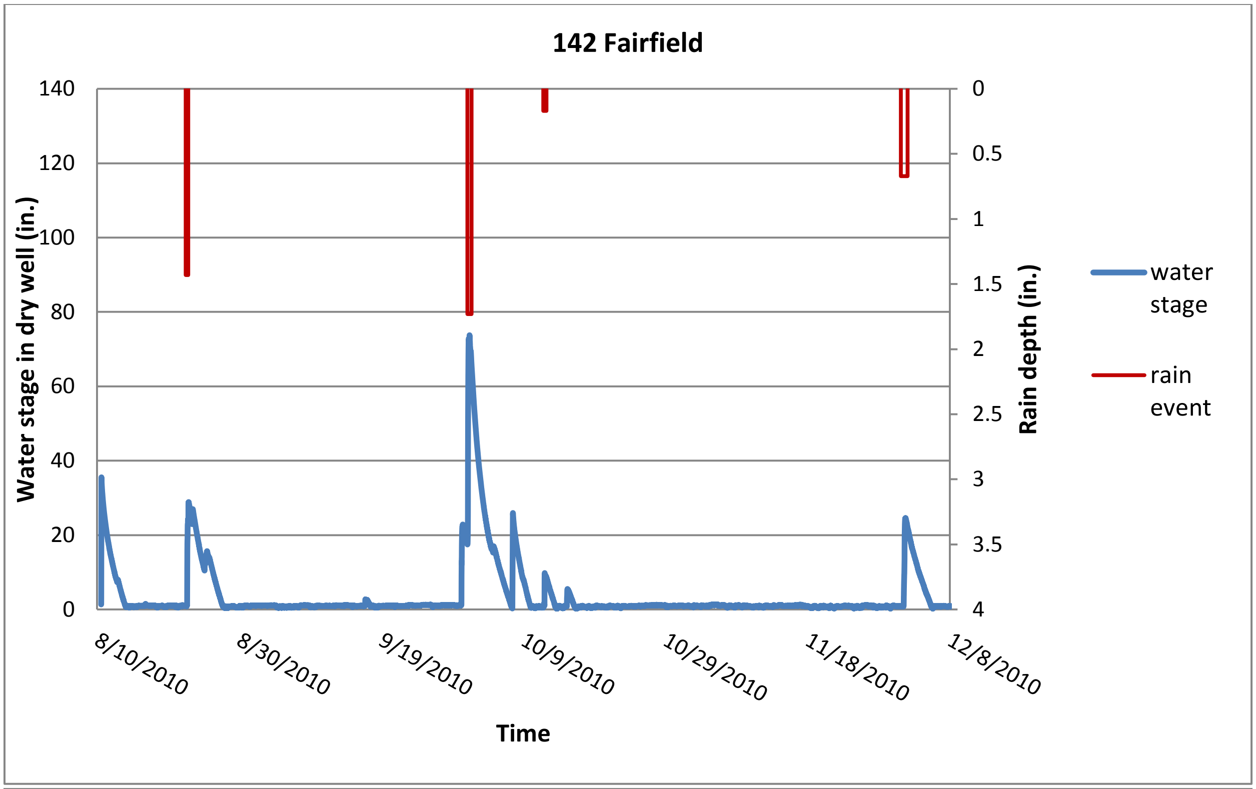


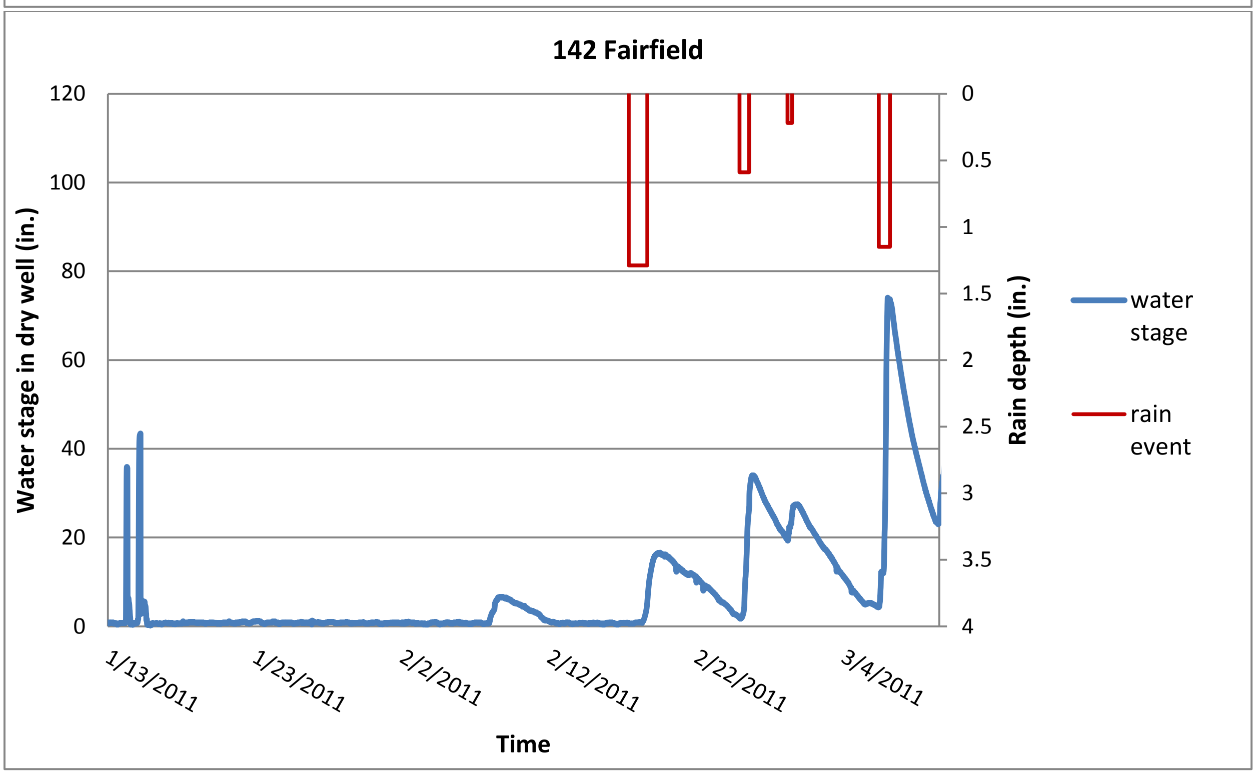
Time series plots of the water levels for the long-term infiltration tests at the dry wells (cont.) (1 in = 25.4 mm)



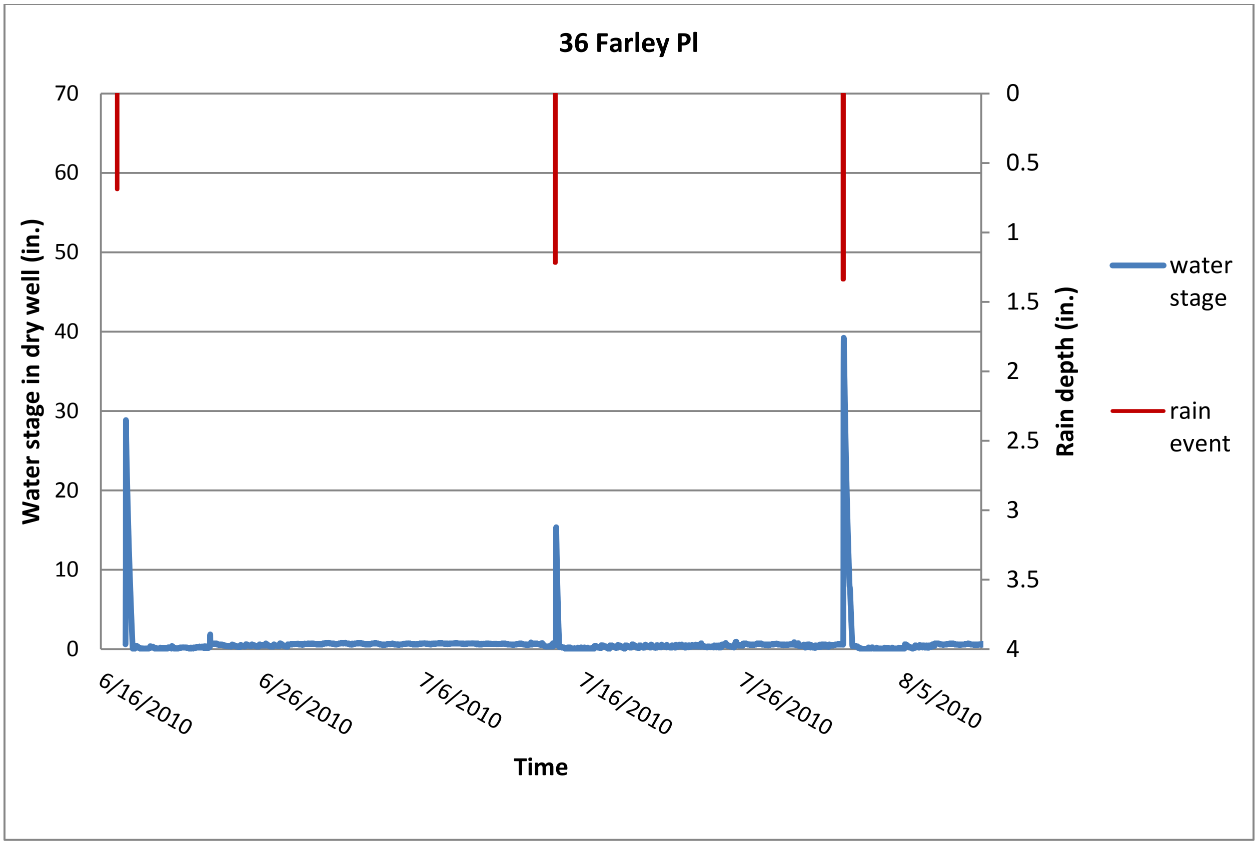


Time series plots of the water levels for the long-term infiltration tests at the dry wells (cont.) (1 in = 25.4 mm)





Time series plots of the water levels for the long-term infiltration tests at the dry wells (cont.) (1 in = 25.4 mm)



Time series plots of the water levels for the long-term infiltration tests at the dry wells (cont.) (1 in = 25.4 mm)

APPENDIX F

MONITORED BIOFILTER SITE DESCRIPTIONS IN KANSAS CITY

1. Curb Extension with BR - 1324 E 76th St.

Figure 1 – Aerial photos, topo map, and urban classifications for device #1

Location	Urban	Area (ac)	Note

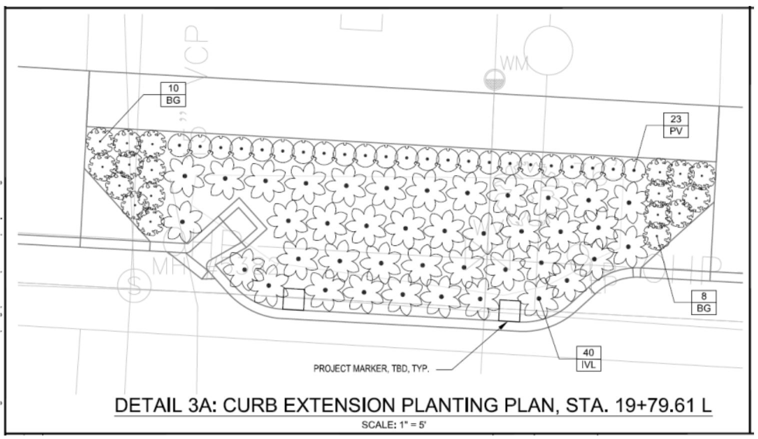
	Classification		
Figure 1-b	Driveway	0.04524	There is no overflow from upstream as shown in Figure 1-b.
	Landscaped area	0.246	
	Roof	0.07541	
	Sidewalk	0.01603	
	Street	0.03869	
Total area (ac)		0.42137	
Figure 1-c	Driveway	0.12188	Overflow from device#1-u1 as shown in figure 1-c.
	Landscaped area	0.29362	
	Roof	0.14325	
	Sidewalk	0.03706	
	Street	0.06726	
Total area (ac)		0.66307	

1324 E 76th St #1 (sheet 305 for as-built details); no underdrains

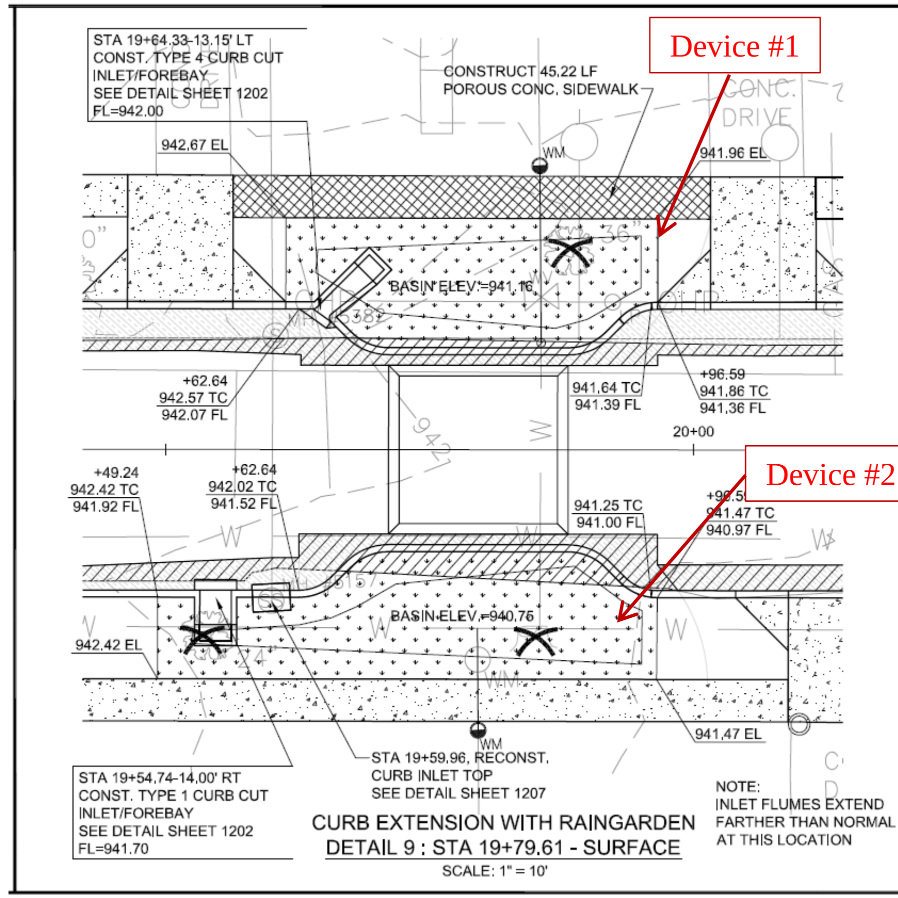
 Only received flows from W along E 76th St (from driveway up)	
 2 samplers and 2 level recorders (inlet and bottom of garden)	 Two inlet samples from small event in morning of Oct 25, 2012

 Leaves washed into inlet		
	 Porous concrete alongside of rain garden collects yard runoff to garden	

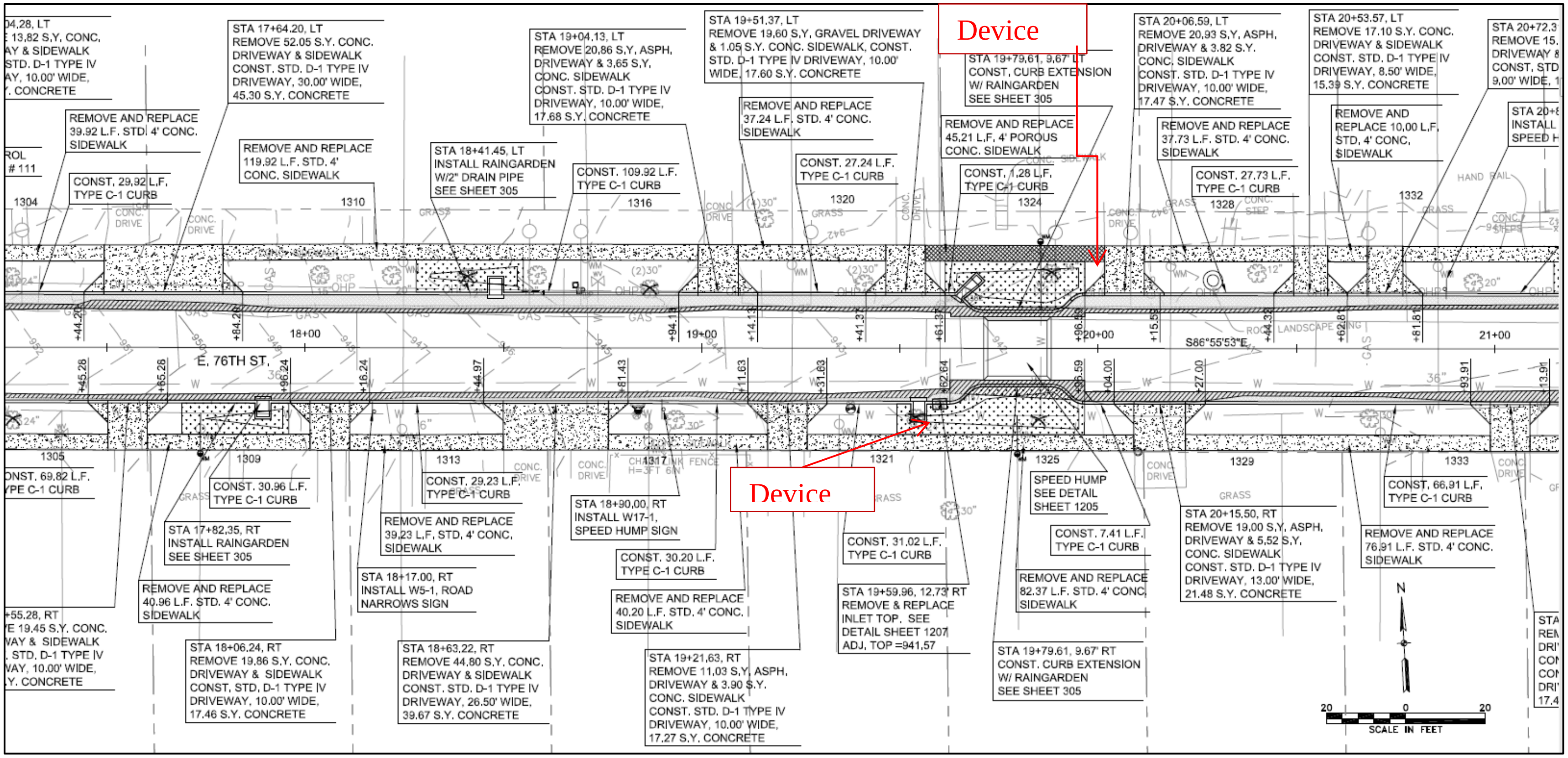
Date of Construction	Dwelling Type	Building Maintenance	Building Height	Pervious %	Impervious %	Underground %	Roof Type	Sediment Source	Treated Wood	Landscaping Quantity	Landscaping Type	Landscaping Mainten.	% Connected Sidewalk	% Connected Driveway	Driveway Type	Driveway Condition	Driveway Texture	Stormwater Control Potential
<1960	Single	Adequate	2	50	50	0	Composite Shingle	Yes	1 pole	Much	Lawn	Poor	0	100	Unpaved	Poor	Rough	Poor



DETAIL 3A: CURB EXTENSION PLANTING PLAN, STA. 19+79.61 L
SCALE: 1" = 5'



CURB EXTENSION WITH RAINGARDEN
DETAIL 9 : STA 19+79.61 - SURFACE
SCALE: 1" = 10'


Device
Device

2. Curb Extension with Bioretention - 1325 E 76th St.

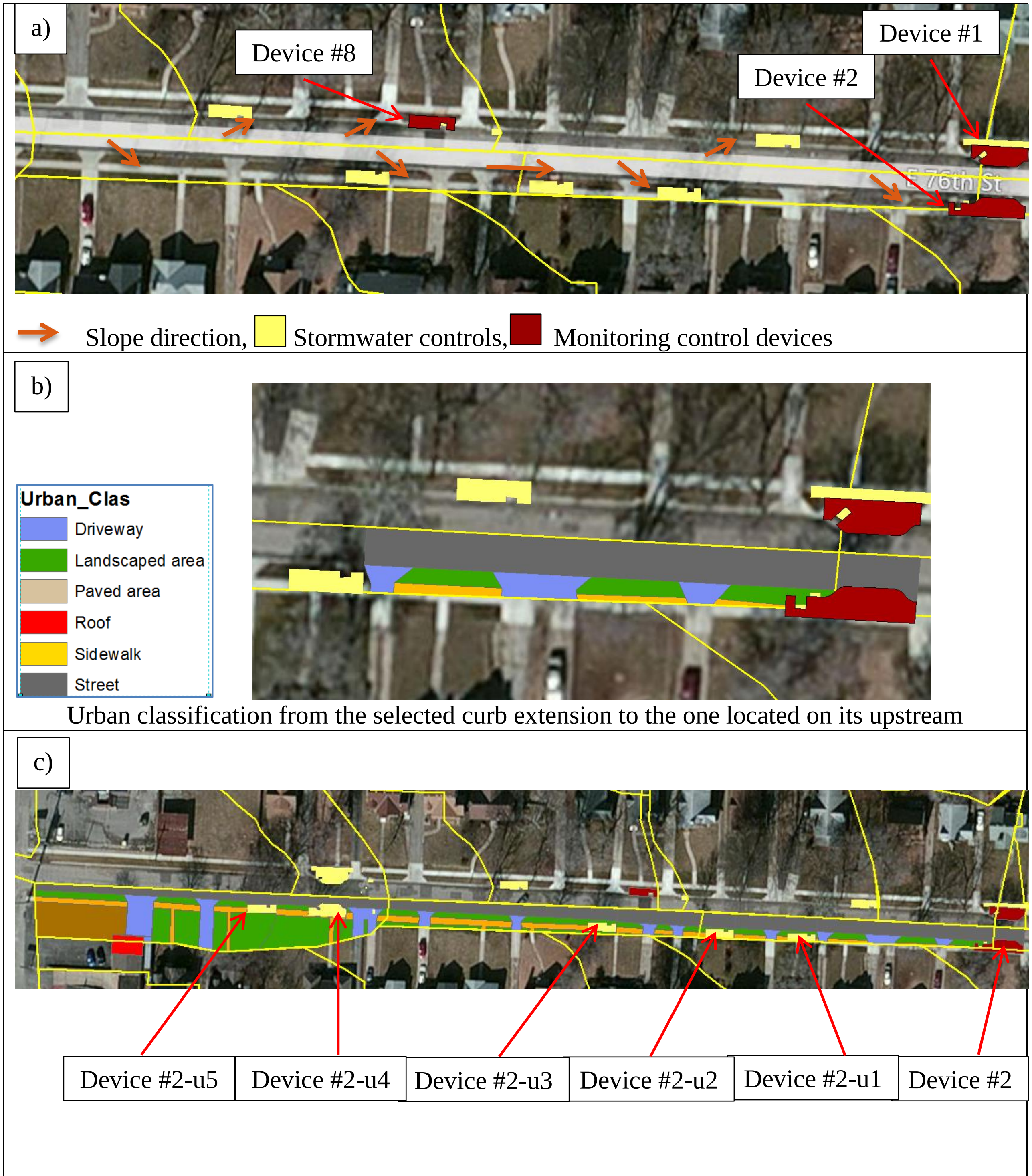


Figure 2 – Aerial photos, topo map, and urban classifications for device #2

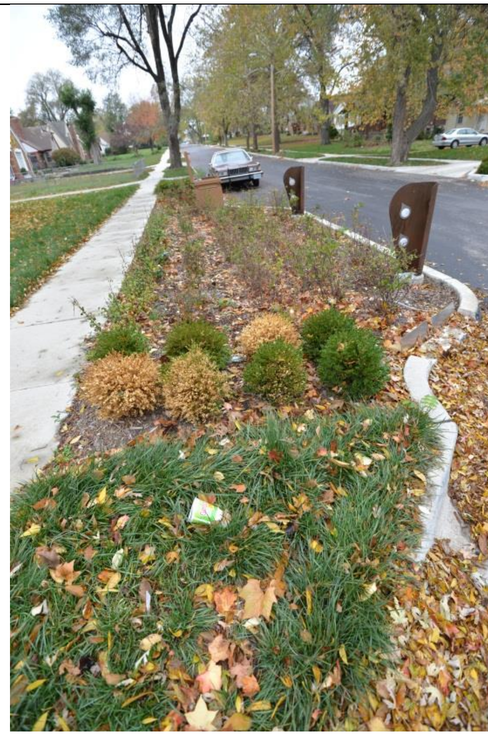
Location	Urban Classification	Area (ac)	Note/Assumption
From downstream of device#2-u1 to device#2	Driveway	0.01137	There is no overflow from upstream.
	Sidewalk	0.00636	
	Landscaped area	0.01570	
	Street	0.06257	
Total Area (ac)		0.09600	
From downstream of device#2-u2 to device#2	Driveway	0.01420	Overflow from device#2-u1
	Sidewalk	0.01108	
	Landscaped area	0.02292	
	Street	0.08827	
Total Area (ac)		0.13647	
From downstream of device#2-u3 to device#2	Driveway	0.02054	Overflow from device#2-u1 and device#2-u2
	Sidewalk	0.01933	
	Landscaped area	0.03378	
	Street	0.12520	
Total Area (ac)		0.19885	
From upstream of device#2-u3 to device#2	Driveway	0.04243	Overflow from device#2-u1, device#2-u2, and device#2-u3
	Sidewalk	0.08235	
	Landscaped area	0.04561	
	Street	0.1925	
Total Area (ac)		0.36289	
From upstream of device#2-u4 to device#2	Driveway	0.04243	Overflow from device#2-u1, device#2-u2, device#2-u3, and device#2-u4
	Landscaped area	0.12921	
	Sidewalk	0.05392	
	Street	0.2079	
Total Area (ac)		0.43346	
From upstream of device#2-u5 to device#2	Driveway	0.08275	Overflow from device#2-u1, device#2-u2, device#2-u3, device#2-u4, and device#2-u5
	Landscaped area	0.22758	
	Parking lot	0.066	
	Roof	0.01274	
	Sidewalk	0.08054	
	Street	0.25172	
Total Area (ac)		0.72133	

1325 E 76th St #2 (sheet 305 for as-built details); no underdrains

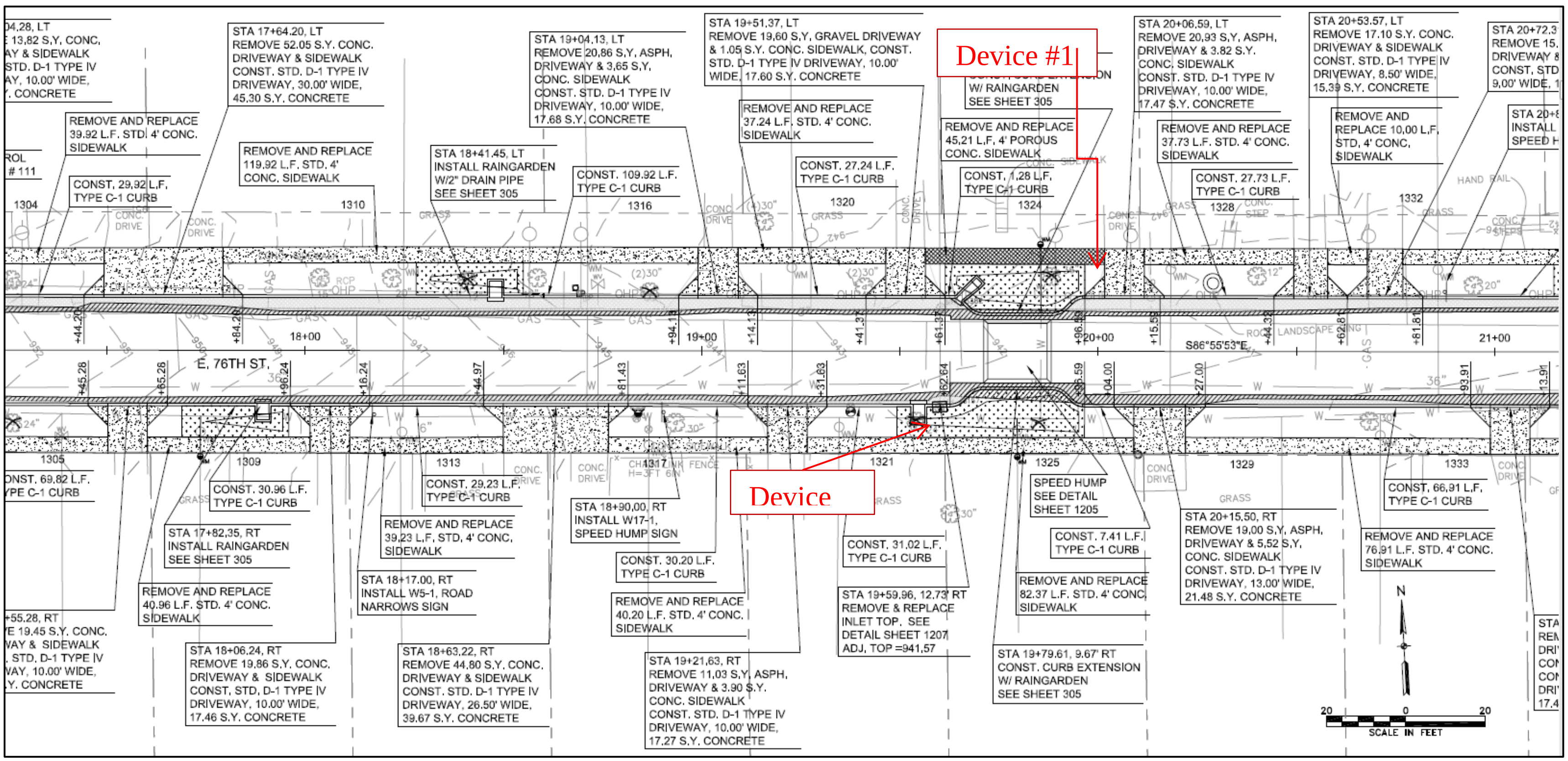
Drains from street centerline to far side of sidewalk to centerline of Troost

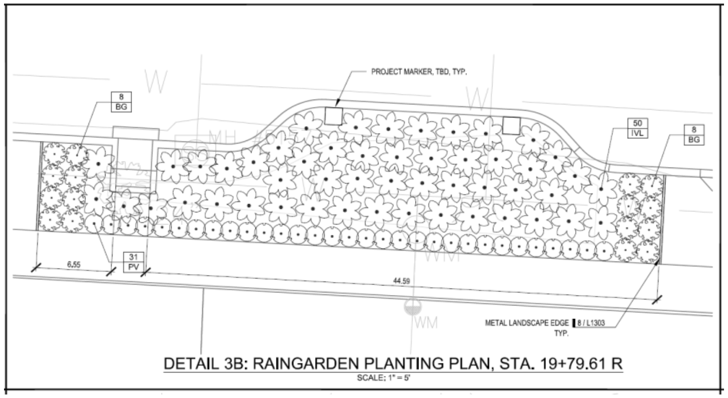
Looking upgradient towards Troost (most of lawns and homes slope south away from this location)

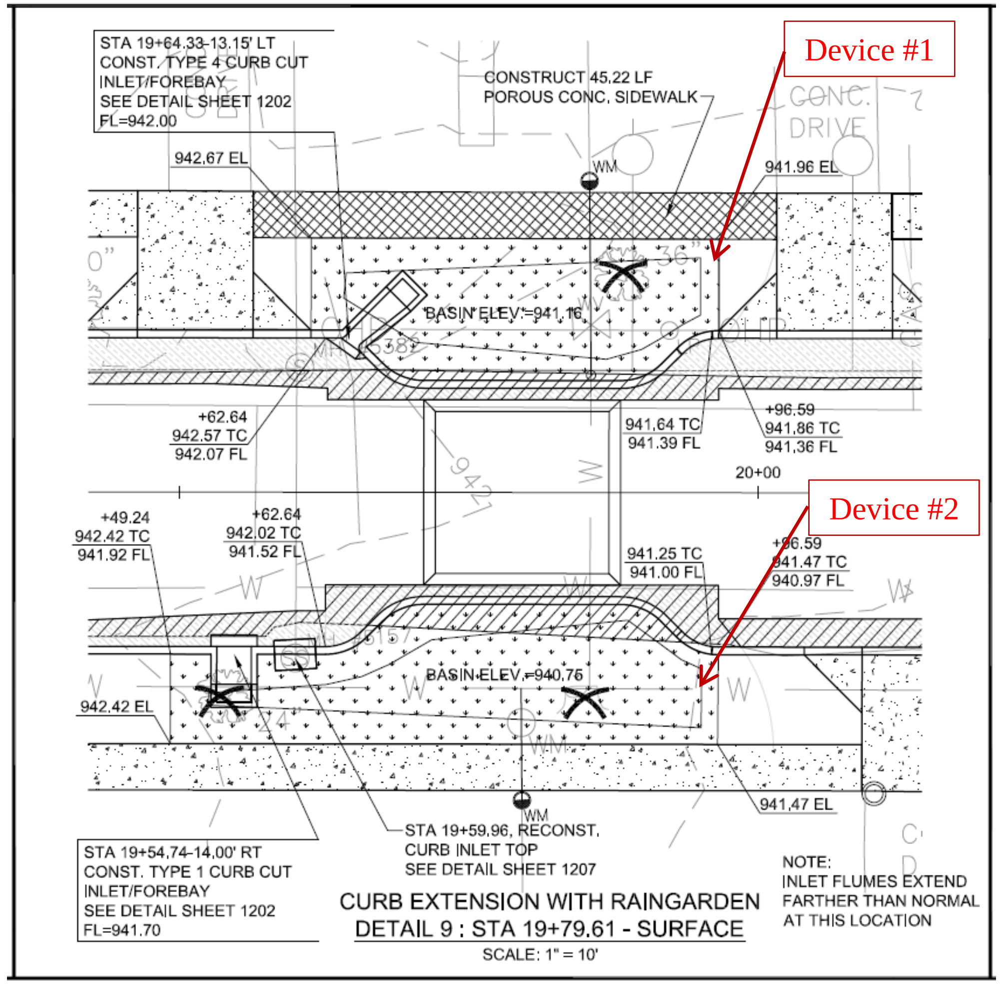
2 inlet samples from small rain in morning of Oct 25, 2012

Date of Construction	Dwelling Type	Building Maintenance	Building Height	Pervious %	Impervious %	Underground %	Roof Type	Sediment Source	Treated Wood	Landscaping Quantity	Landscaping Type	Landscaping Mainten.	% Connected Sidewalk	% Connected Driveway	Driveway Type	Driveway Condition	Driveway Texture	Stormwater Control Potential
<1960	Single	Poor	1	100	0	0	Composite Shingle	Yes	No	Much	Lawn/Dec.	Poor	0	0	Unpaved	Poor	Rough	Poor




PROJECT MARKER, TBD, TYP.
METAL LANDSCAPE EDGE
DETAIL 3B: RAINGARDEN PLANTING PLAN, STA. 19+79.61 R


Device #1
Device #2
STA 19+64.33-13.15' LT
CONST. TYPE 4 CURB CUT
INLET/FOREBAY
SEE DETAIL SHEET 1202
FL=942.00
CONSTRUCT 45.22 LF
POROUS CONC. SIDEWALK
CONC. DRIVE
942.67 EL
941.96 EL
BASIN ELEV.=941.16
+62.64
942.57 TC
942.07 FL
941.64 TC
941.39 FL
+96.59
941.86 TC
941.36 FL
20+00
+49.24
942.42 TC
941.92 FL
+62.64
942.02 TC
941.52 FL
941.25 TC
941.00 FL
+96.59
941.47 TC
940.97 FL
BASIN ELEV.=940.76
942.42 EL
941.47 EL
STA 19+54.74-14.00' RT
CONST. TYPE 1 CURB CUT
INLET/FOREBAY
SEE DETAIL SHEET 1202
FL=941.70
STA 19+59.96, RECONST.
CURB INLET TOP
SEE DETAIL SHEET 1207
NOTE:
INLET FLUMES EXTEND
FARTHER THAN NORMAL
AT THIS LOCATION
CURB EXTENSION WITH RAINGARDEN
DETAIL 9 : STA 19+79.61 - SURFACE
SCALE: 1" = 10'

3. Curb Extension with BR - 1419 E 76th Terr.

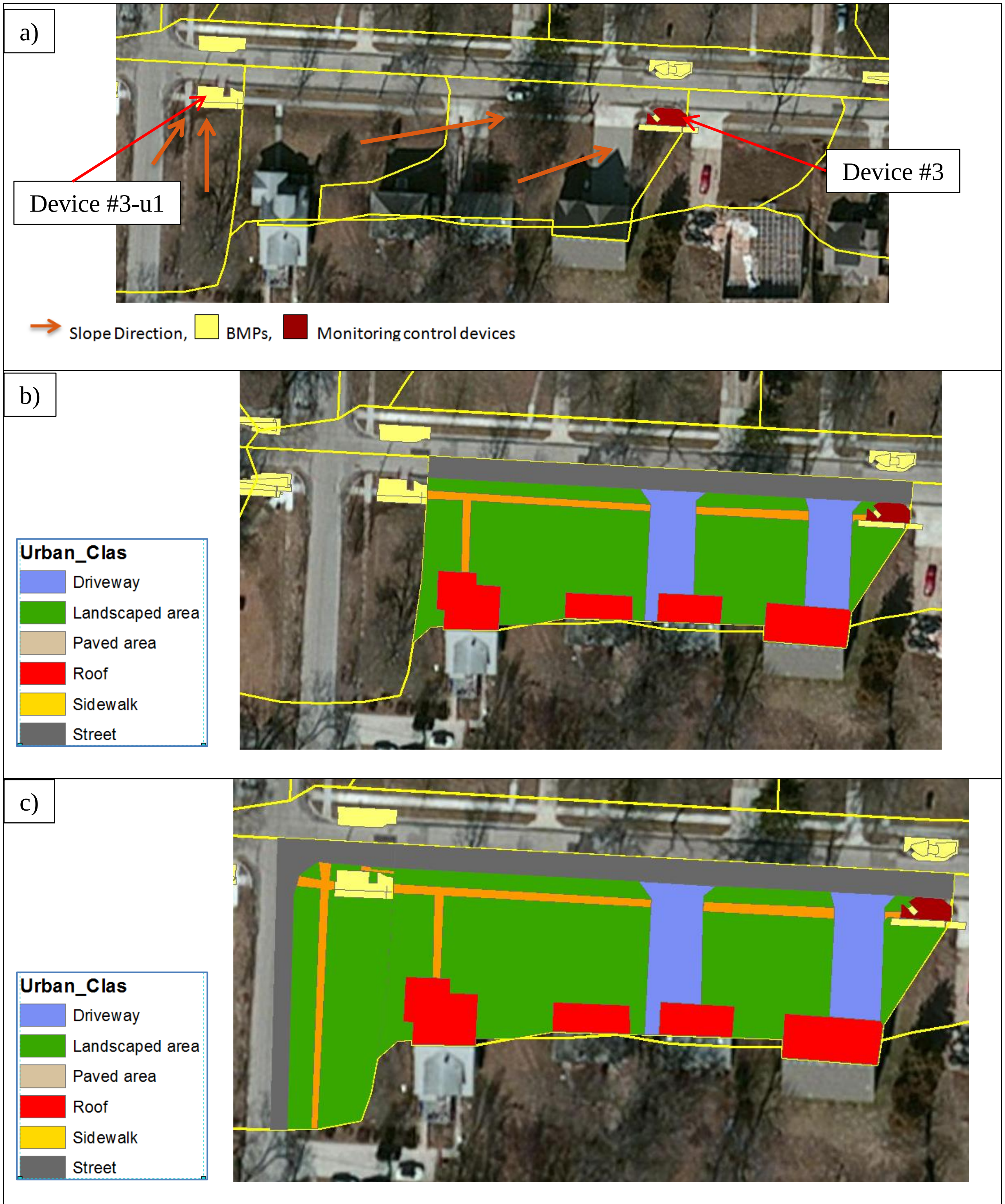
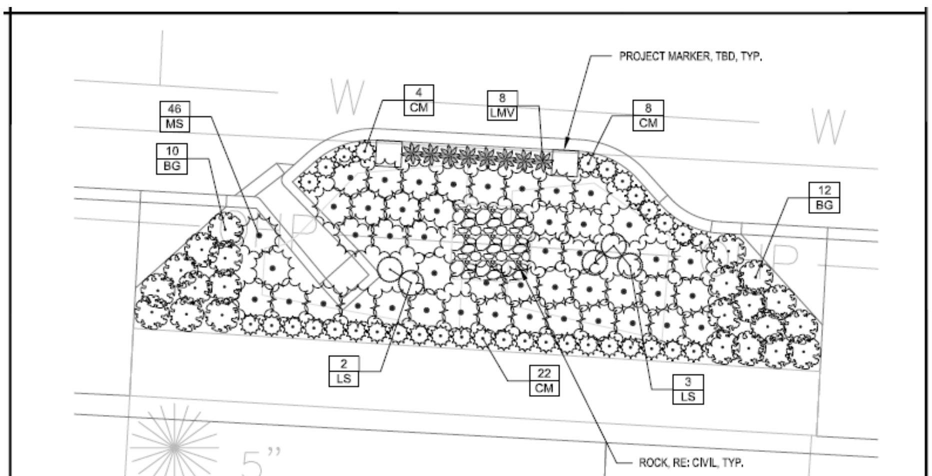


Figure 3 – Aerial photos, topo map, and urban classifications for device #3

Location	Urban Classification	Area (ac)	Note
Figure 3-b	Driveway	0.0875	There is no overflow from upstream as shown in Figure 3-b.
	Landscaped area	0.3388	
	Roof	0.0856	
	Sidewalk	0.0295	
	Street	0.0885	
Total area (ac)		0.6299	
Figure 3-c	Driveway	0.0875	Overflow from device#3-u1 as shown in figure 3-c.
	Landscaped area	0.4678	
	Roof	0.0856	
	Sidewalk	0.0462	
	Street	0.1376	
		0.8247	



DETAIL 3B: CURB EXTENSION PLANTING PLAN, STA. 26+51.65 R

SCALE: 1" = 5'

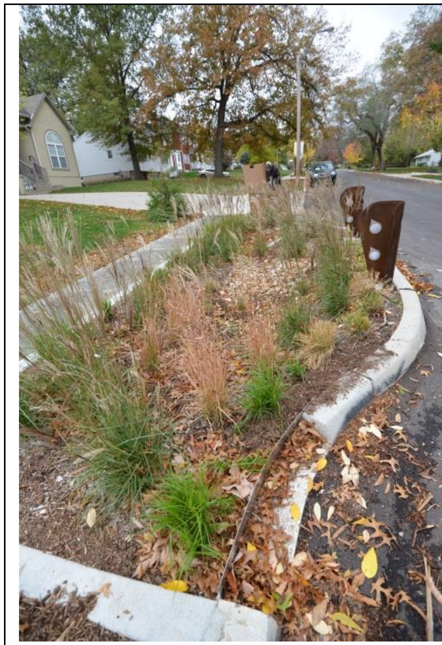
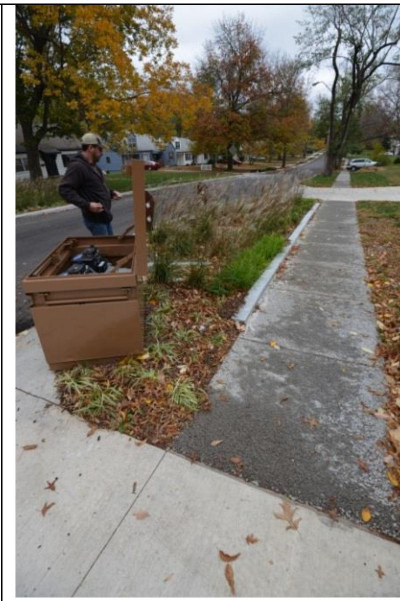
1419 E 76th Terrace #3 (sheet 207 for as-built details); no underdrains; reported to not drain well

Downgradient (towards east)

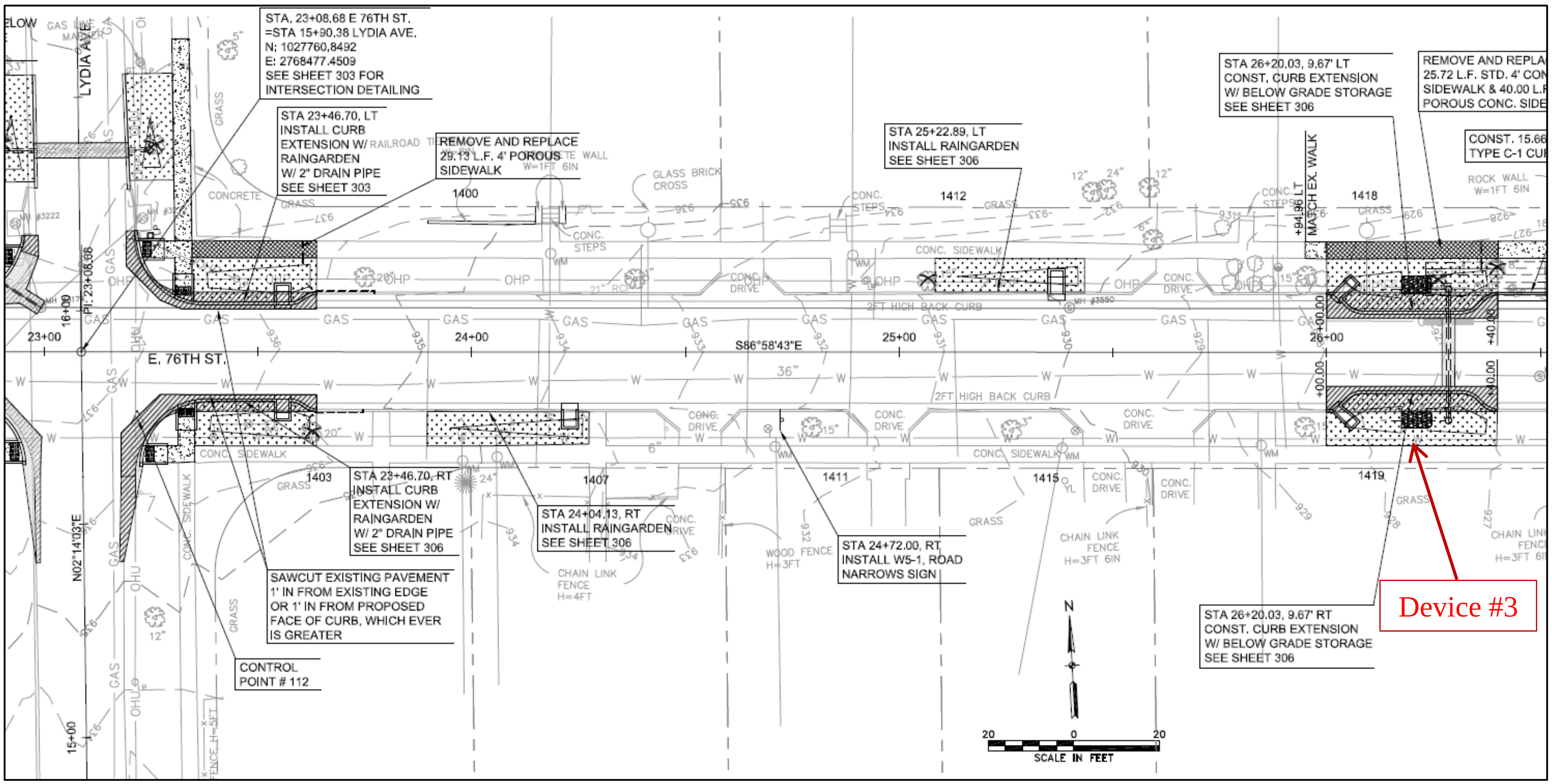
Upgradient (towards west to Lydia); drains from center of lots to Lydia

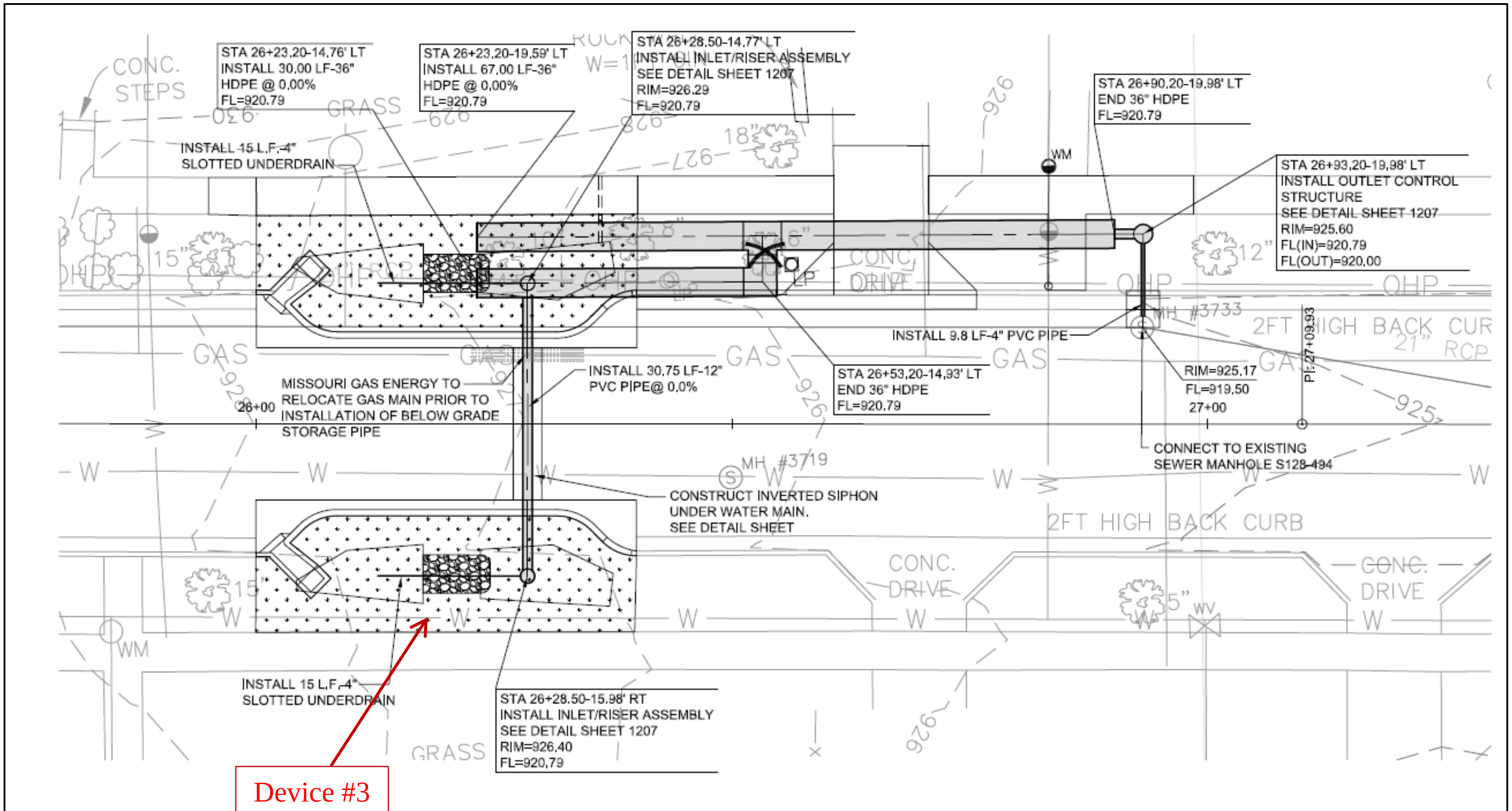
4 inlet samples from small rain of morning of Oct 25, 2012

Showing bottom edge of drainage area	(initial sample contains more sediment)

		 Porous concrete sidewalks all along street from Lydia to monitored rain garden
	 Corner of Lydia to E 76th Terrace (upper end of drainage)	

Date of Construction	Dwelling Type	Building Maintenance	Building Height	Pervious %	Impervious %	Underground %	Roof Type	Sediment Source	Treated Wood	Landscaping Quantity	Landscaping Type	Landscaping Mainten.	% Connected Sidewalk	% Connected Driveway	Driveway Type	Driveway Condition	Driveway Texture	Stormwater Control Potential
>2000	Single	Excellent	2	100	0	0	Composite Shingle	No	1 pole	Much	Lawn	Adequate	75	100	Paved	Good	Smooth	Good

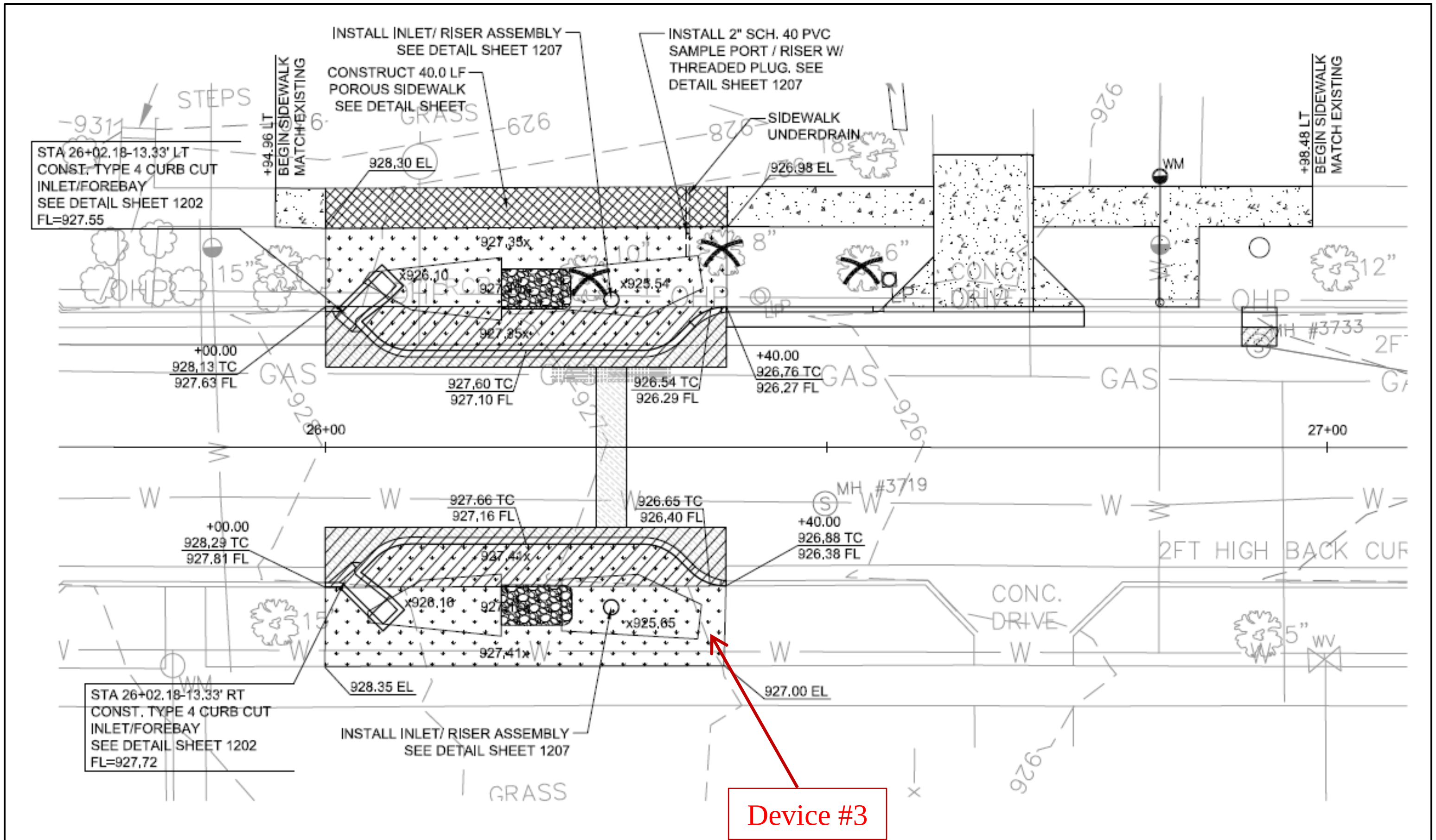




CURB EXTENSION WITH BELOW GRADE STORAGE

DETAIL 15A : STA 26+20.03 – SUBSURFACE

SCALE: 1" = 10'



CURB EXTENSION WITH BELOW GRADE STORAGE
DETAIL 15 : STA 26+20.03 - SURFACE
SCALE: 1" = 10'

4. Rain Garden Extension - 1612 E 76th St.

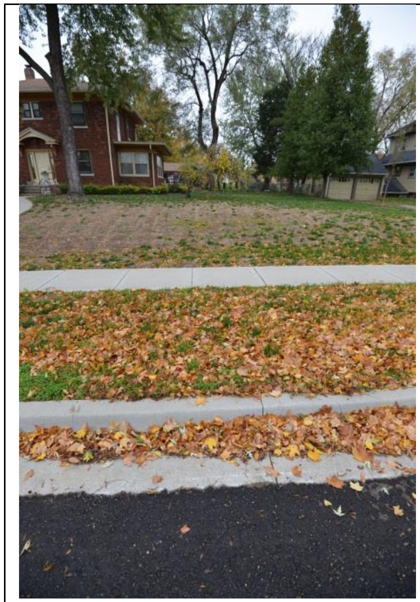
Figure 4 – Aerial photos, topo map, and urban classifications for device #4

Location	Urban Classification	Area (ac)	Note/Assumption
Figure 4-b	Driveway	0.03175	Figure 4-b.
	Landscaped area	0.33922	
	Paved area	0.05197	
	Roof	0.09569	
	Sidewalk	0.02906	
	Street	0.04938	
Total Area (ac)		0.59707	

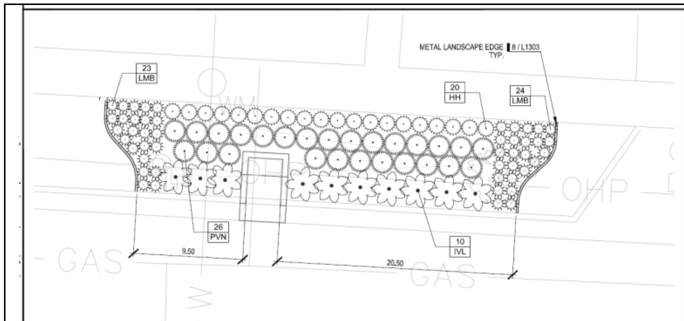
1612 E 76th St. #4 (sheet 307 for as-built details); no underdrains

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

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

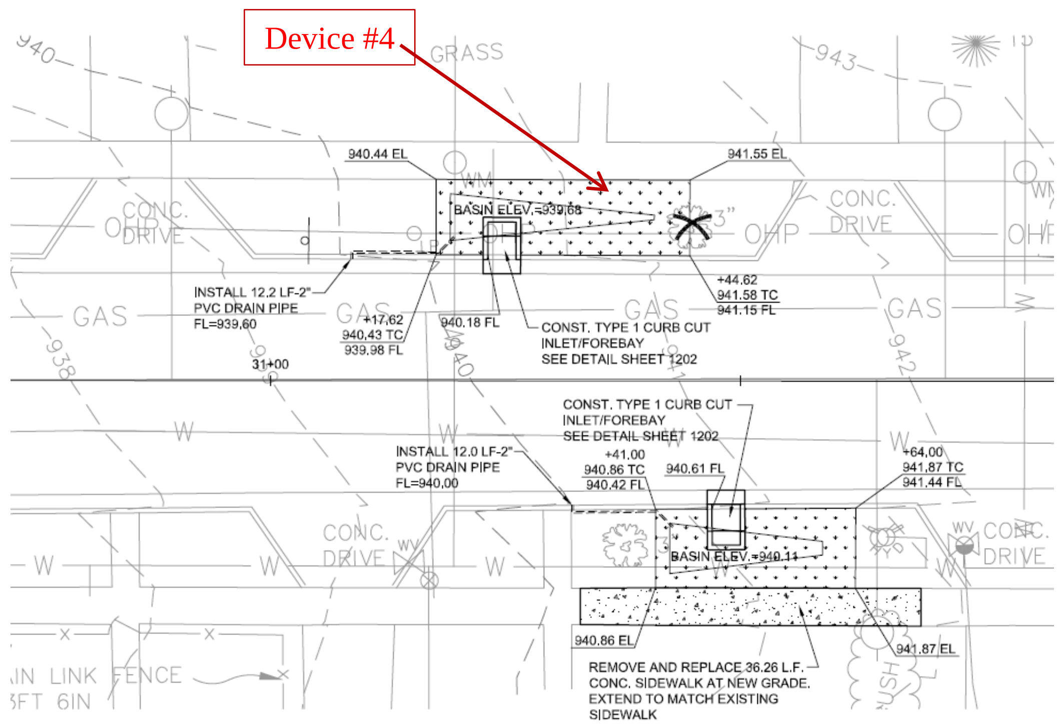
 Drainage break to east (flows to left to device from edge of house)		
 Level sensor recorder in bottom of rain garden		

Date of Construction	Dwelling Type	Building Maintenance	Building Height	Pervious %	Impervious %	Underground %	Roof Type	Sediment Source	Treated Wood	Landscaping Quantity	Landscaping Type	Landscaping Mainten.	% Connected Sidewalk	% Connected Driveway	Driveway Type	Driveway Condition	Driveway Texture	Stormwater Control Potential
<1960	Single	Poor	2	100	0	0	Composite Shingle	No	1 pole	Much	Lawn/Dec.	Good	100	100	Paved	Good	Smooth	Good



DETAIL 2: RAINGARDEN PLANTING PLAN, STA. 31+31.12

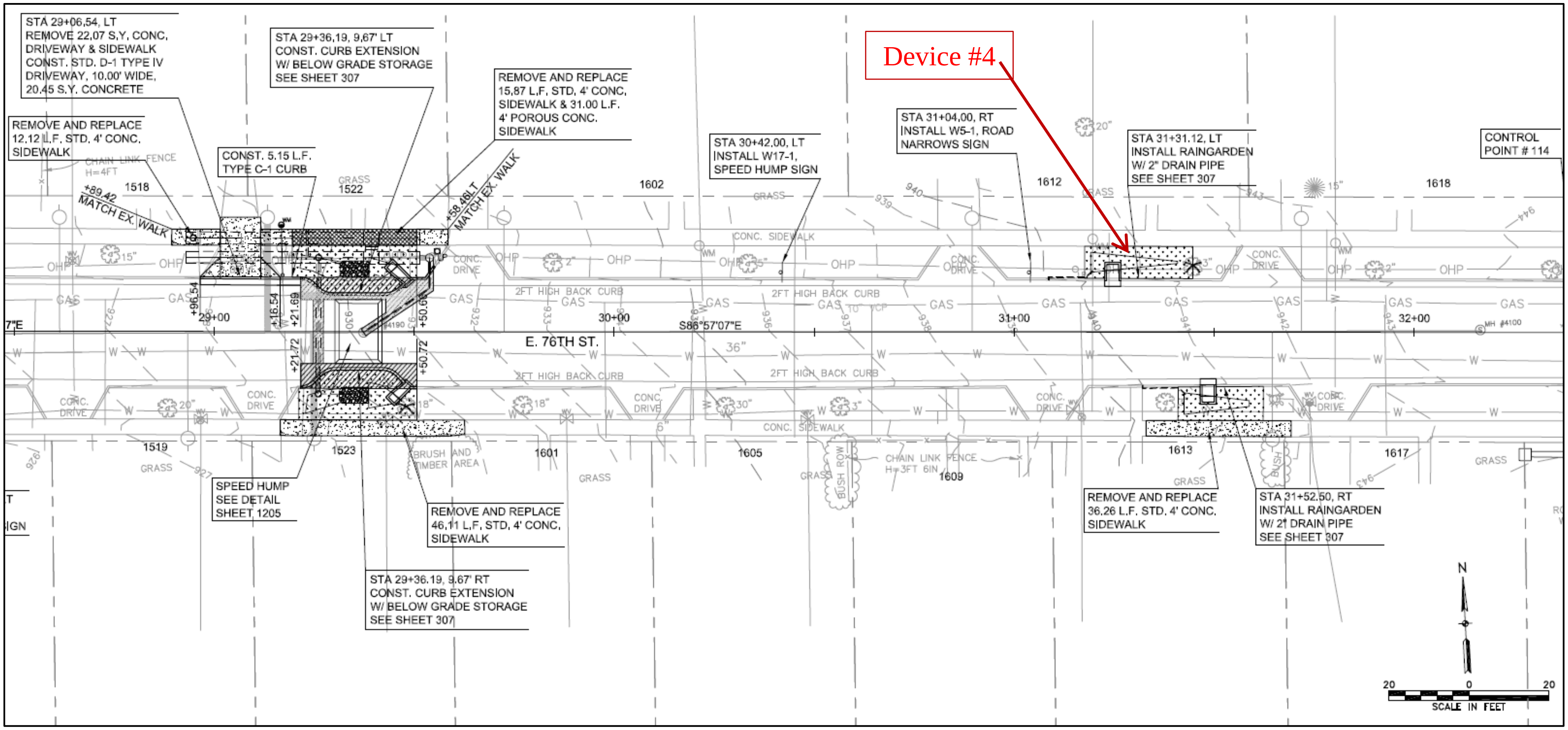
SCALE: 1" = 5'



RAINGARDEN W/ 2" DRAIN PIPE

DETAIL 17 : STA 31+31.12 & 31+52.50 - SURFACE

SCALE: 1" = 10'



Device #4
STA 29+06.54, LT
REMOVE 22.07 S.Y. CONC. DRIVEWAY & SIDEWALK
CONST. STD. D-1 TYPE IV DRIVEWAY, 10.00' WIDE, 20.45 S.Y. CONCRETE
STA 29+36.19, 9.67' LT
CONST. CURB EXTENSION W/ BELOW GRADE STORAGE
SEE SHEET 307
REMOVE AND REPLACE 15.87 L.F. STD. 4' CONC. SIDEWALK & 31.00 L.F. 4' POROUS CONC. SIDEWALK
REMOVE AND REPLACE 12.12 L.F. STD. 4' CONC. SIDEWALK
CONST. 5.15 L.F. TYPE C-1 CURB
STA 30+42.00, LT
INSTALL W17-1, SPEED HUMP SIGN
STA 31+04.00, RT
INSTALL W5-1, ROAD NARROWS SIGN
STA 31+31.12, LT
INSTALL RAINGARDEN W/ 2" DRAIN PIPE
SEE SHEET 307
CONTROL POINT # 114
E. 76TH ST.
29+00
30+00
31+00
32+00
S86°57'07"E
SPEED HUMP SEE DETAIL SHEET 1205
REMOVE AND REPLACE 46.11 L.F. STD. 4' CONC. SIDEWALK
STA 29+36.19, 9.67' RT
CONST. CURB EXTENSION W/ BELOW GRADE STORAGE
SEE SHEET 307
REMOVE AND REPLACE 36.26 L.F. STD. 4' CONC. SIDEWALK
STA 31+52.50, RT
INSTALL RAINGARDEN W/ 2" DRAIN PIPE
SEE SHEET 307
N
20
0
20
SCALE IN FEET

5. Rain Garden Extension - 1336 E 76th St.

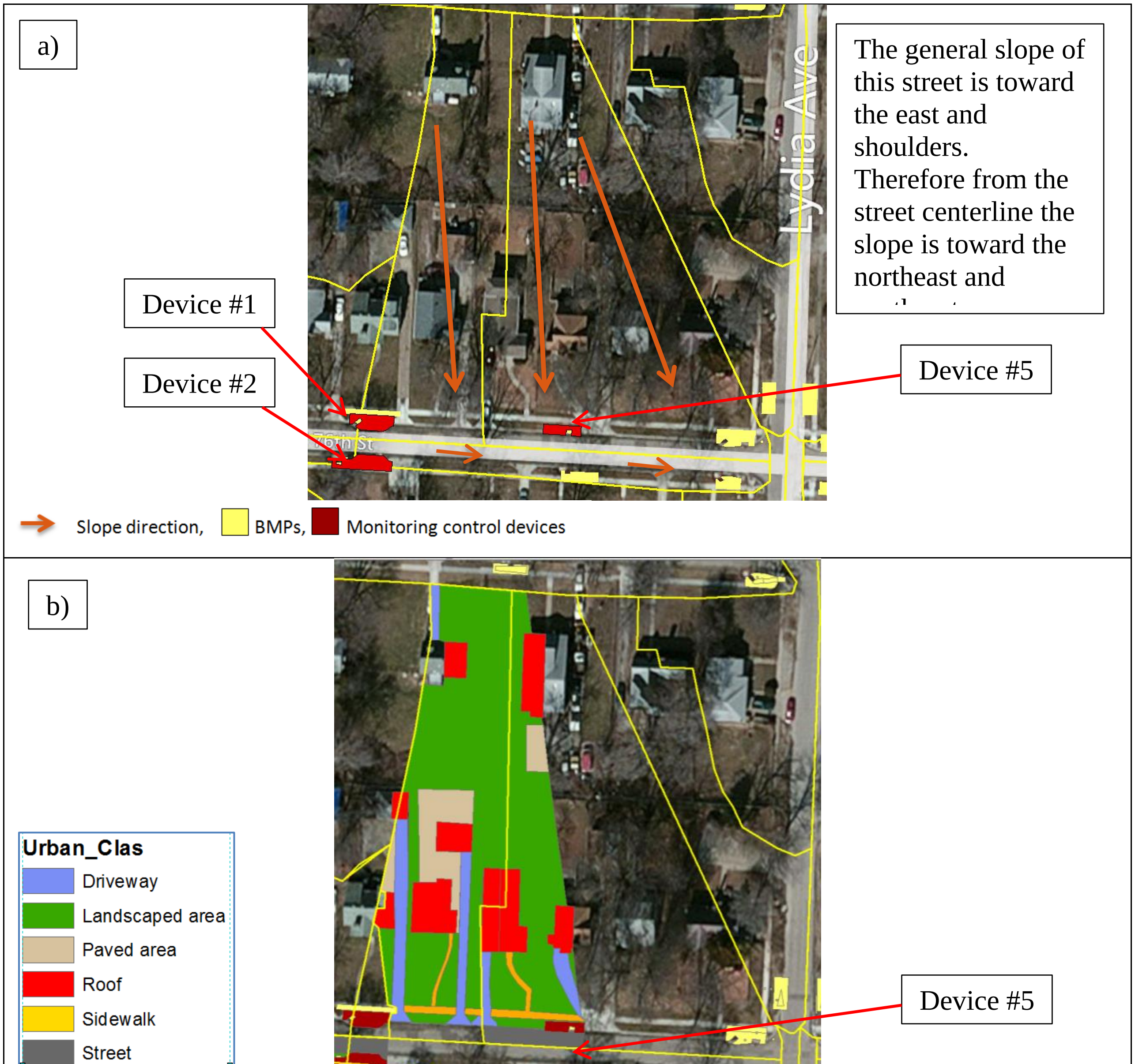


Figure 5 – Aerial photos, topo map, and urban classifications for device #5

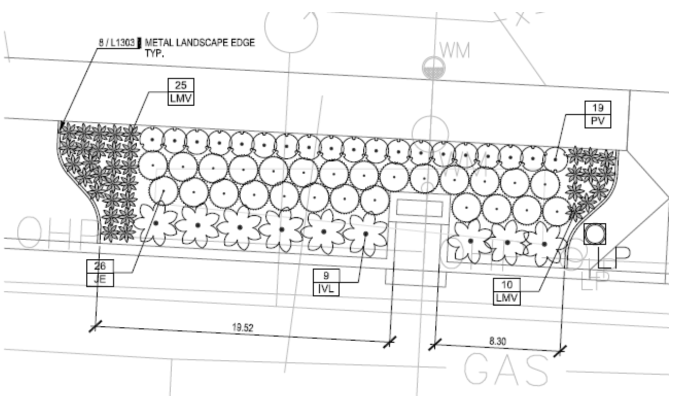
Location	Urban Classification	Area (ac)	Note/Assumption
Figure 5-b	Driveway	0.08434	
	Landscaped area	0.55210	
	Paved area	0.07051	
	Roof	0.14523	
	Sidewalk	0.02434	
	Street	0.02202	
Total Area (ac)		0.89854	

1336 E 76th St #5 (sheet 305 for as-built details); no underdrains

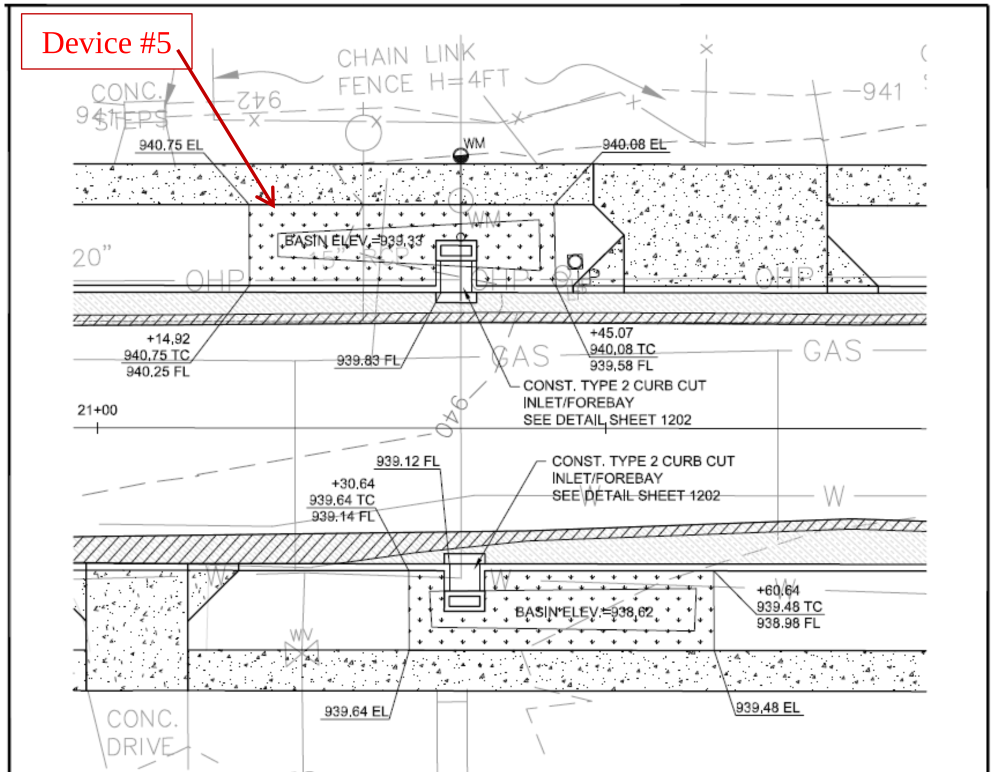
No samplers, 2 level recorders (inlet and bottom of rain garden)

Upgradient from rain garden

Date of Construction	Dwelling Type	Building Maintenance	Building Height	Pervious %	Impervious %	Underground %	Roof Type	Sediment Source	Treated Wood	Landscaping Quantity	Landscaping Type	Landscaping Mainten.	% Connected Sidewalk	% Connected Driveway	Driveway Type	Driveway Condition	Driveway Texture	Stormwater Control Potential
<1960	Single	Good	2	50	50	0	Composite Shingle	Yes	1 pole	Much	Lawn/Dec.	Adequate	0	100	Paved	Fair	Smooth	Poor



DETAIL 4: RAINGARDEN PLANTING PLAN, STA. 21+29.95
SCALE: 1" = 5'



RAINGARDEN
DETAIL 10 : STA 21+29.95 & 21+45.88 - SURFACE
SCALE: 1" = 10'

6. Site #6 was abandoned and is not being monitored

7. Shallow Bioretention Device w/ Smart Drain - 1140 E 76th Terr.

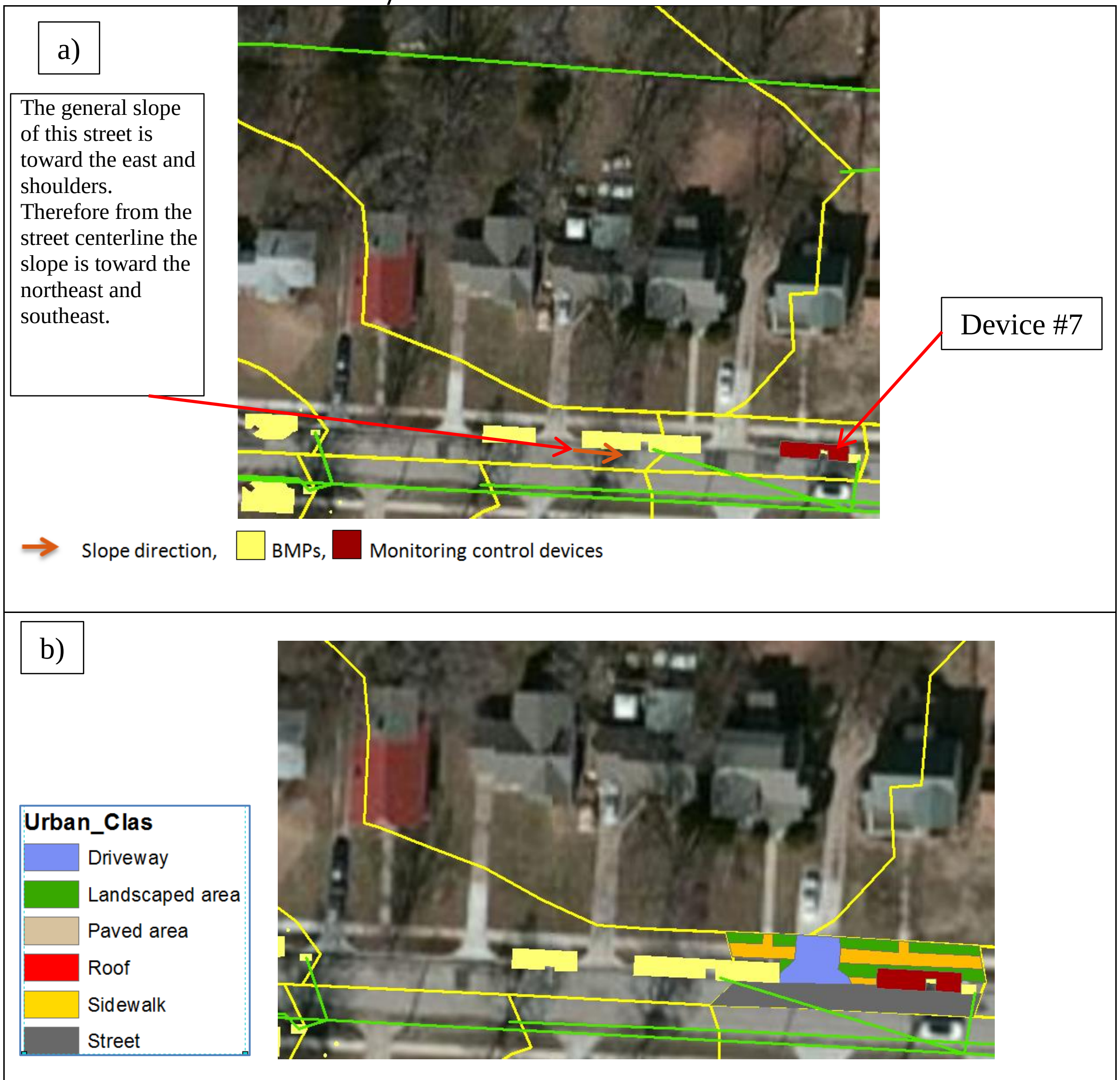


Figure 7 – Aerial photos, topo map, and urban classifications for device #7

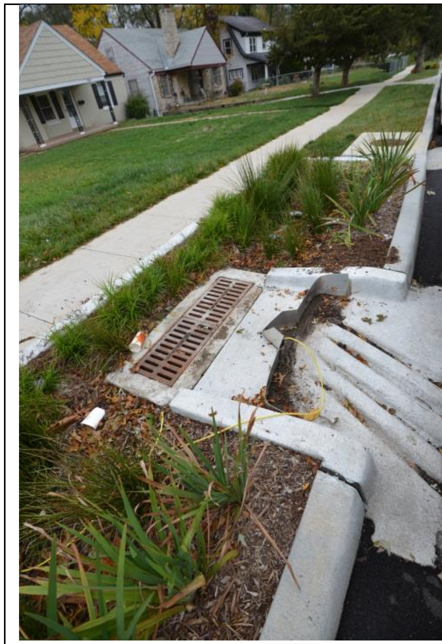
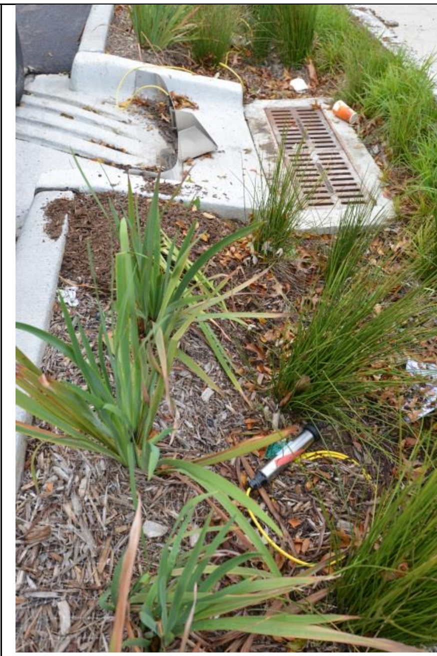
Location	Urban Classification	Area (ac)	Note/Assumption
Figure 7-b	Driveway	0.00482	
	Landscaped area	0.00318	
	Sidewalk	0.00067	
	Street	0.01596	
Total area (ac)		0.02462	

1140 E 76th Terrace #7 (sheet 205 for as-built details); Smart Drains

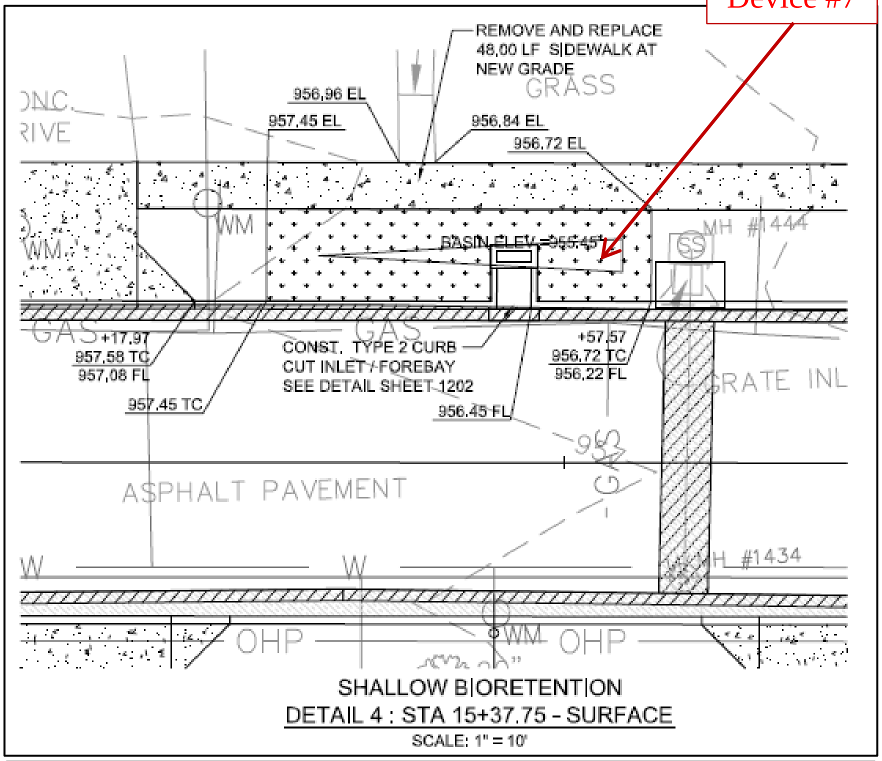
Towards E showing sloping driveway from rain garden; only half of street and a bit of yard to system (near top of street slope)

Very small drainage area; large inlet right below rain garden

Yard slopes away from rain garden; sidewalk edge to street center	Driveway slopes away from rain garden towards yard inlets

 No samplers, but 2 level recorders at inlet and bottom of rain garden		

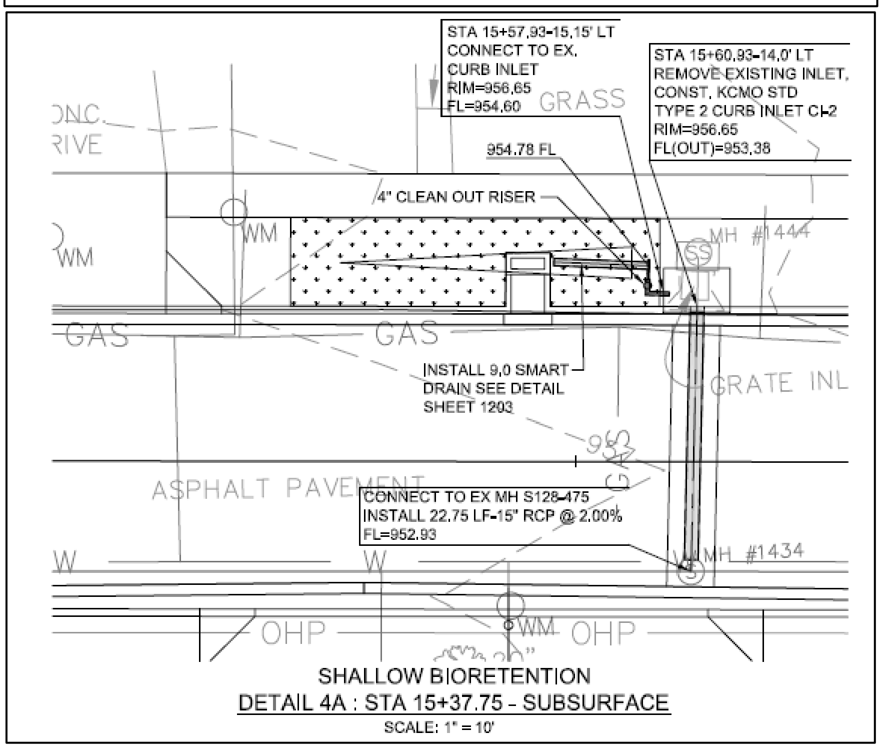
Device #7



SHALLOW BIORETENTION

DETAIL 4 : STA 15+37.75 - SURFACE

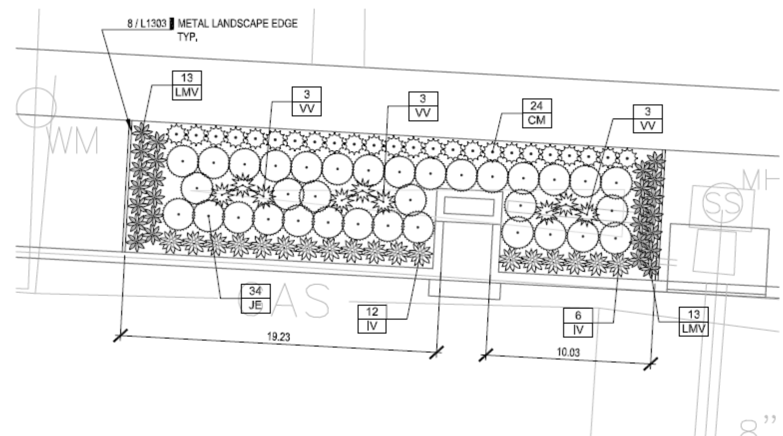
SCALE: 1" = 10'



SHALLOW BIORETENTION

DETAIL 4A : STA 15+37.75 - SUBSURFACE

SCALE: 1" = 10'



DETAIL 6: SHALLOW BIO-RETENTION PLANTING PLAN, STA. 15+37.75

SCALE: 1" = 5'

8. Rain Garden w/ Smart Drain - 1222 E 76th St.

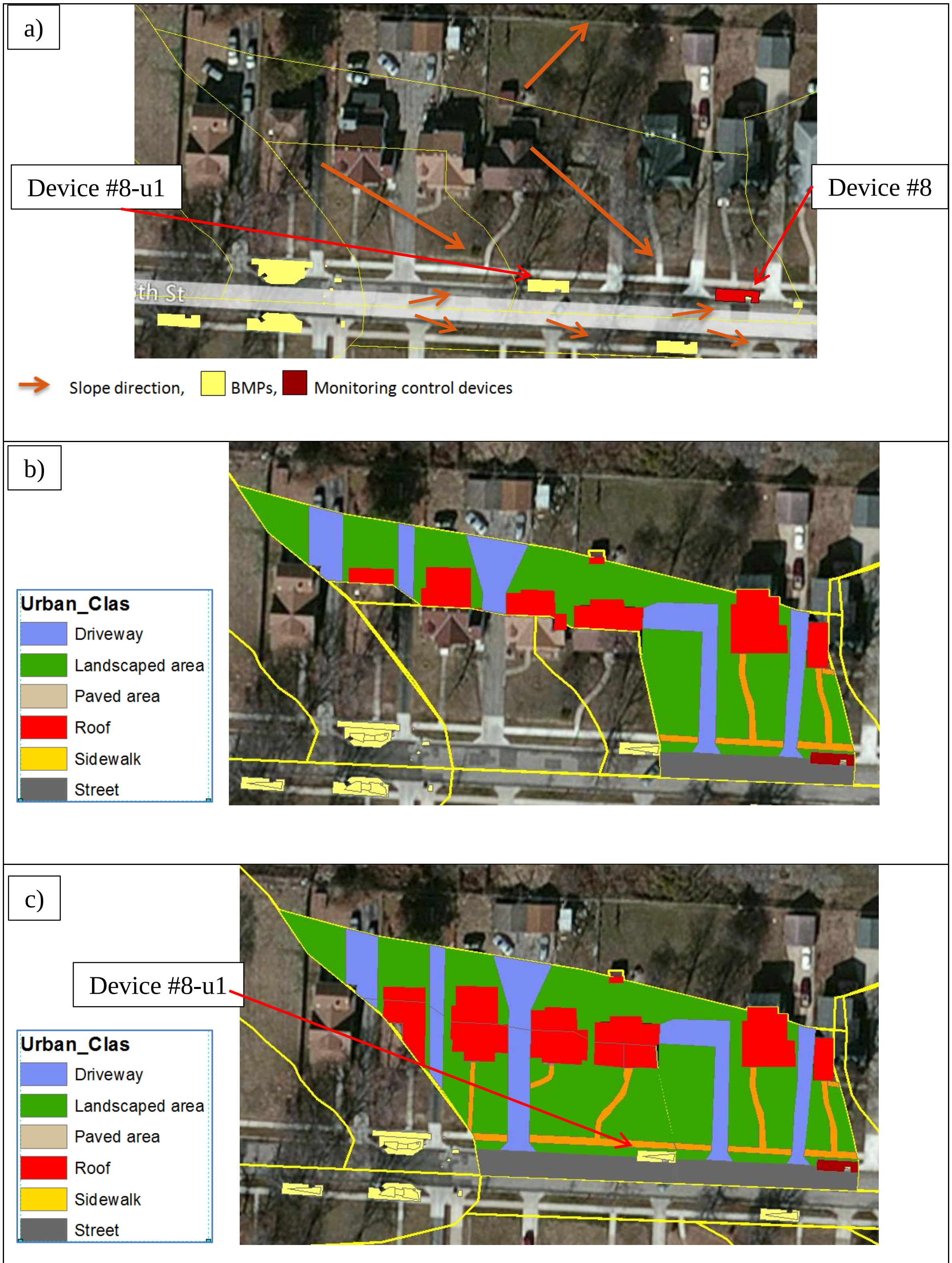


Figure 8 – Aerial photos, topo map, and urban classifications for device #8

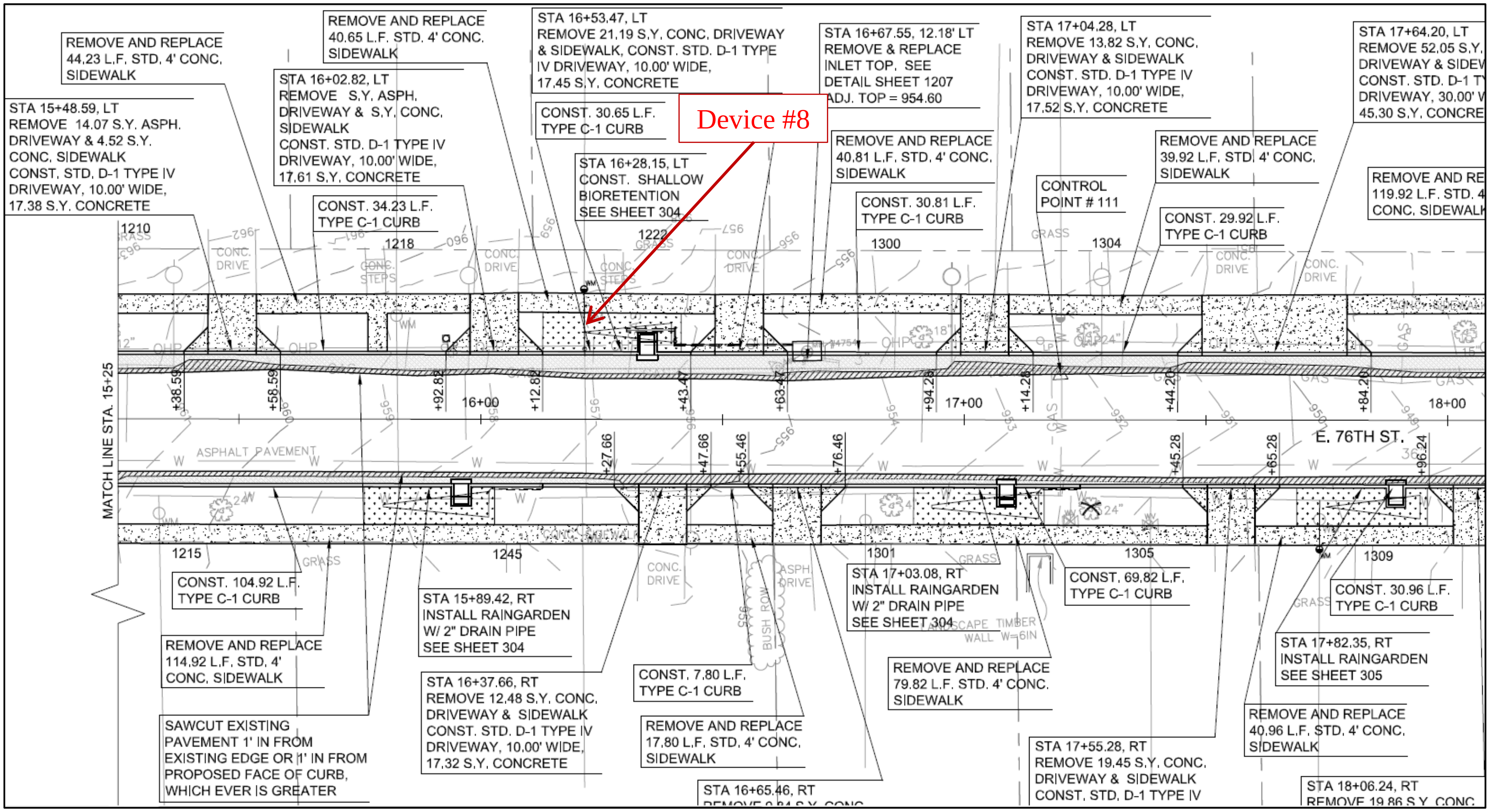
Location	Urban Classification	Area (ac)	Note/Assumption
Figure 8-b	Driveway	0.12166	There is no overflow from upstream, as shown in Figure 8-b.
	Landscaped area	0.30035	
	Roof	0.09538	
	Sidewalk	0.02348	
	Street	0.0442	
Total area (ac)		0.5851	
Figure 8-c	Driveway	0.17259	As shown in Figure 8-c, there is an overflow from device# 8-u1.
	Landscaped area	0.48239	
	Roof	0.17459	
	Sidewalk	0.05274	
	Street	0.10525	
Total area (ac)		0.98756	

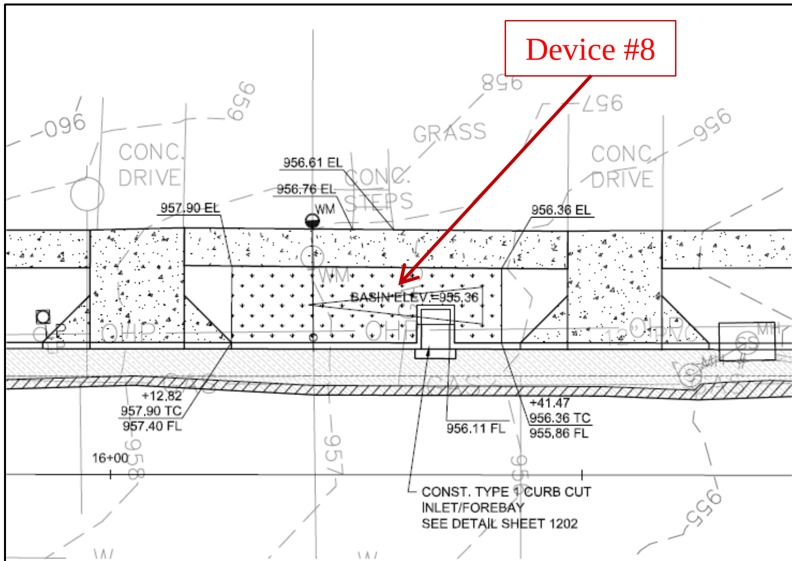
1222 E 76th St #8 (sheet 304 for as-built details); Smart Drains

 2 samplers and 2 level recorders (inlet and smartdrain underdrain)	
	 E edge of drainage area slopes away from rain garden (no house or driveway)

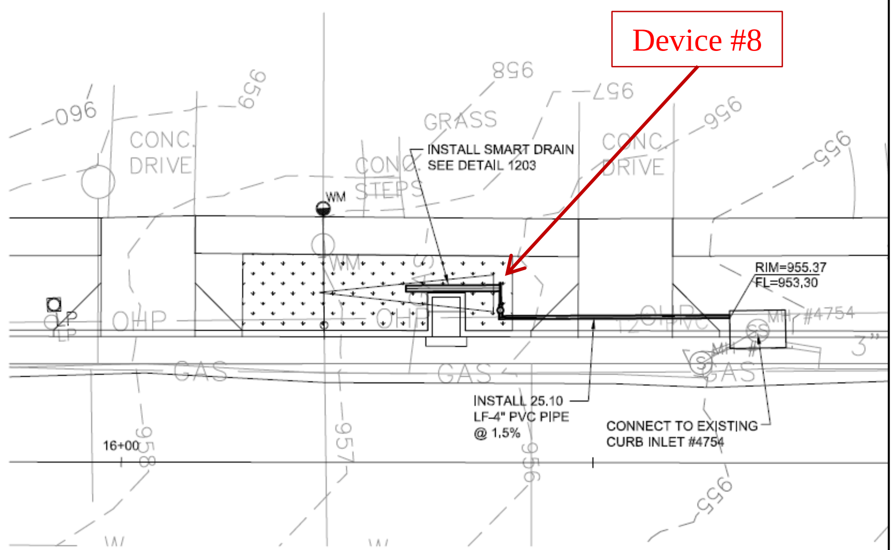
Upgradient rain garden and signage

Date of Construction	Dwelling Type	Building Maintenance	Building Height	Pervious %	Impervious %	Underground %	Roof Type	Sediment Source	Treated Wood	Landscaping Quantity	Landscaping Type	Landscaping Mainten.	% Connected Sidewalk	% Connected Driveway	Driveway Type	Driveway Condition	Driveway Texture	Stormwater Control Potential
<1960	Single	Good	2	50	50	0	Composite Shingle	No	No	Much	Lawn/Dec.	Adequate	100	100	Paved	Good	Smooth	Possible

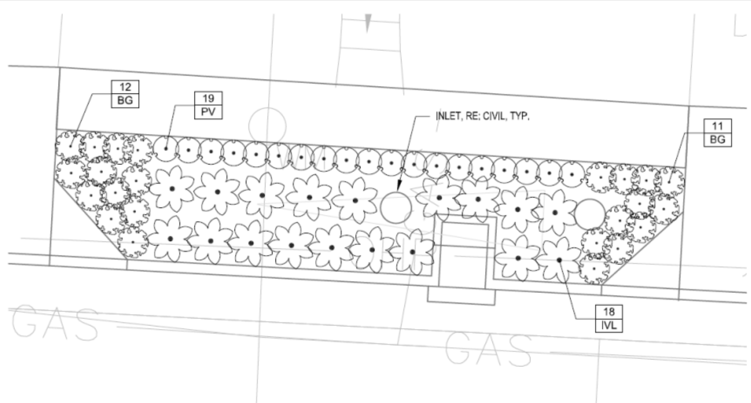




SHALLOW BIORETENTION
DETAIL 5 : STA 16+28.15 - SURFACE
SCALE: 1" = 10'



SHALLOW BIORETENTION
DETAIL 5A : STA 16+28.15 - SUBSURFACE
SCALE: 1" = 10'



DETAIL 5: BIO-RETENTION PLANTING PLAN, STA. 16+28.15
SCALE: 1" = 5'

9. Cascade - 1112 E 76th Terr.

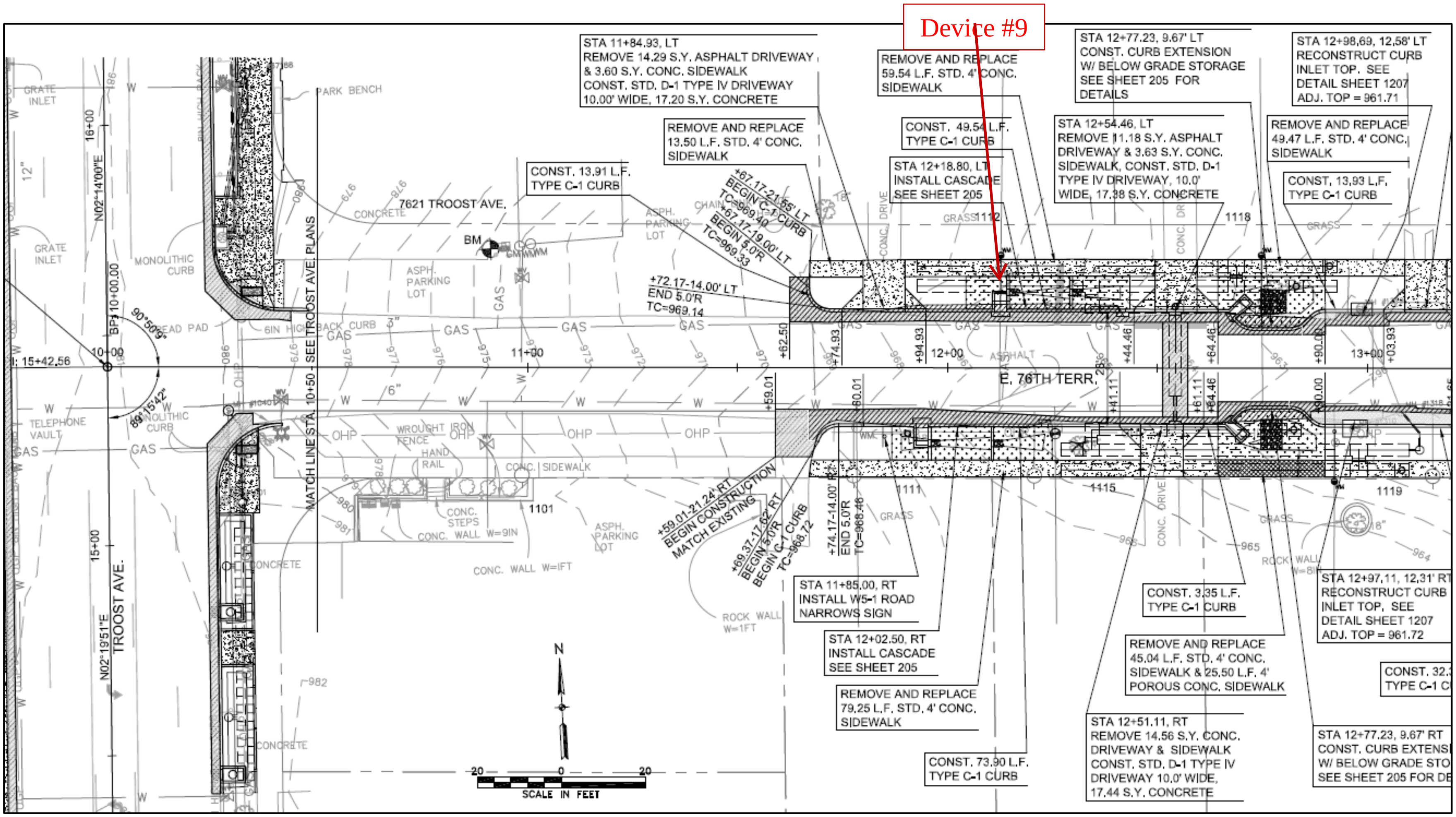
Figure 9 – Aerial photos, topo map, and urban classifications for device #9

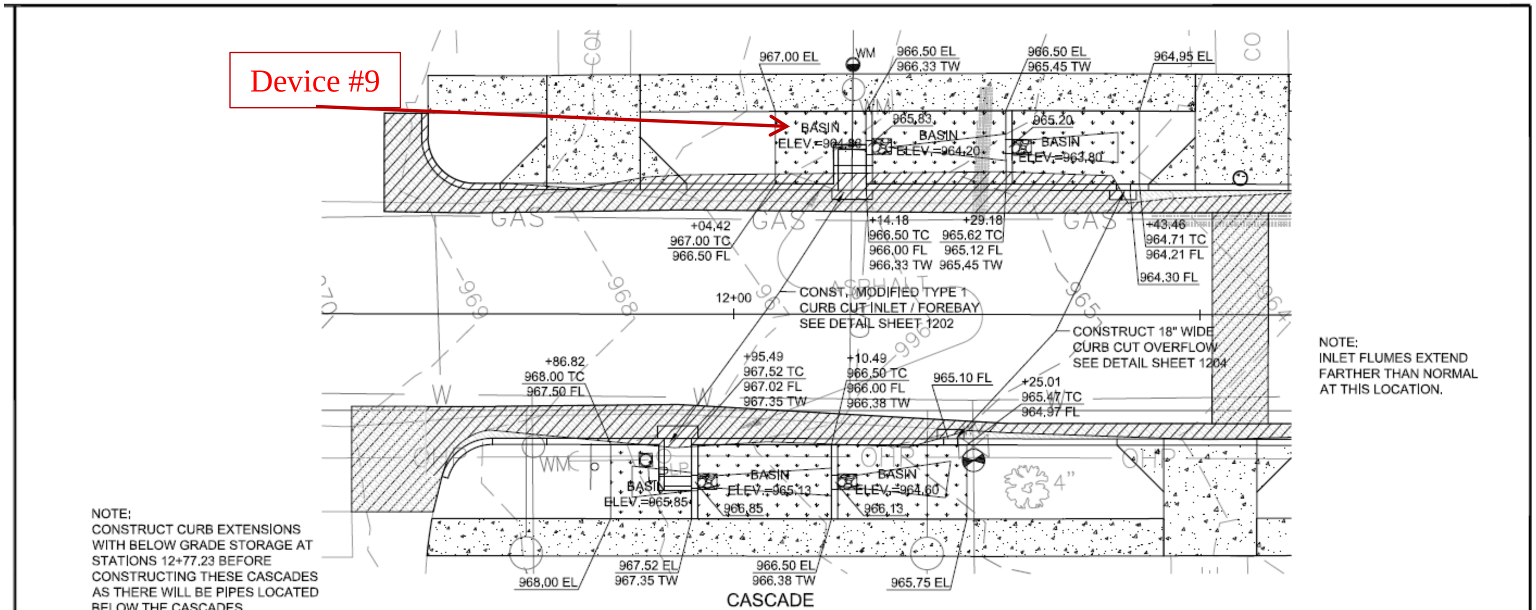
Location	Urban Classification	Area (ac)	Note/Assumption
Figure 9-b	Driveway	0.0392	There is no overflow from upstream, as shown in Figure 9-b.
	Landscaped area	0.0337	
	Parking lot	0.0639	
	Roof	0.0958	
	Sidewalk	0.0101	
	Street	0.0505	
Total area (ac)		0.2931	

1112 E 76th Terrace #9 (sheet 205 for as-built details); cascading swale (but upper weir set high so runoff bypasses other cells), no underdrains

W towards Troost and two businesses that drain to this device

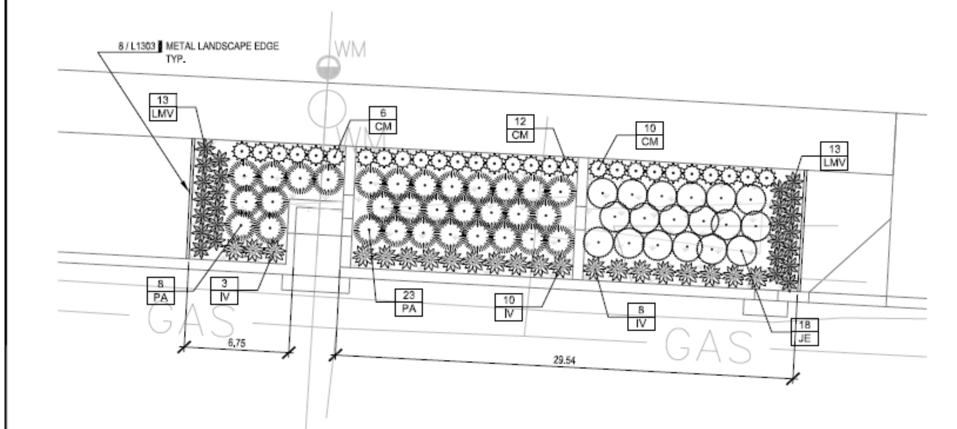
	 Towards cascade from next downgradient rain garden and drain inlet	
		


Device #9
STA 11+84.93, LT
REMOVE 14.29 S.Y. ASPHALT DRIVEWAY & 3.60 S.Y. CONC. SIDEWALK
CONST. STD. D-1 TYPE IV DRIVEWAY 10.00' WIDE, 17.20 S.Y. CONCRETE
REMOVE AND REPLACE 59.54 L.F. STD. 4' CONC. SIDEWALK
STA 12+77.23, 9.67' LT
CONST. CURB EXTENSION W/ BELOW GRADE STORAGE SEE SHEET 205 FOR DETAILS
STA 12+98.69, 12.58' LT
RECONSTRUCT CURB INLET TOP. SEE DETAIL SHEET 1207
ADJ. TOP = 961.71
REMOVE AND REPLACE 13.50 L.F. STD. 4' CONC. SIDEWALK
CONST. 49.54 L.F. TYPE C-1 CURB
STA 12+54.46, LT
REMOVE 11.18 S.Y. ASPHALT DRIVEWAY & 3.63 S.Y. CONC. SIDEWALK, CONST. STD. D-1 TYPE IV DRIVEWAY, 10.0' WIDE, 17.38 S.Y. CONCRETE
REMOVE AND REPLACE 49.47 L.F. STD. 4' CONC. SIDEWALK
CONST. 13.91 L.F. TYPE C-1 CURB
STA 12+18.80, LT
INSTALL CASCADE SEE SHEET 205
CONST. 13.93 L.F. TYPE C-1 CURB
7621 TROOST AVE.
E. 76TH TERR.
TROOST AVE.
MATCH LINE STA 10+50 - SEE TROOST AVE. PLANS
+72.17-14.00' LT
END 5.0'R
TC=969.14
+59.01-21.24' RT
BEGIN CONSTRUCTION
MATCH EXISTING
STA 11+85.00, RT
INSTALL W5-1 ROAD NARROWS SIGN
STA 12+02.50, RT
INSTALL CASCADE SEE SHEET 205
REMOVE AND REPLACE 79.25 L.F. STD. 4' CONC. SIDEWALK
CONST. 73.90 L.F. TYPE C-1 CURB
CONST. 3.35 L.F. TYPE C-1 CURB
REMOVE AND REPLACE 45.04 L.F. STD. 4' CONC. SIDEWALK & 25.50 L.F. 4' POROUS CONC. SIDEWALK
STA 12+51.11, RT
REMOVE 14.56 S.Y. CONC. DRIVEWAY & SIDEWALK
CONST. STD. D-1 TYPE IV DRIVEWAY 10.0' WIDE, 17.44 S.Y. CONCRETE
STA 12+97.11, 12.31' RT
RECONSTRUCT CURB INLET TOP. SEE DETAIL SHEET 1207
ADJ. TOP = 961.72
STA 12+77.23, 9.67' RT
SCALE IN FEET



DETAIL 1 : STA 12+02.50 & 12+18.80 - SURFACE

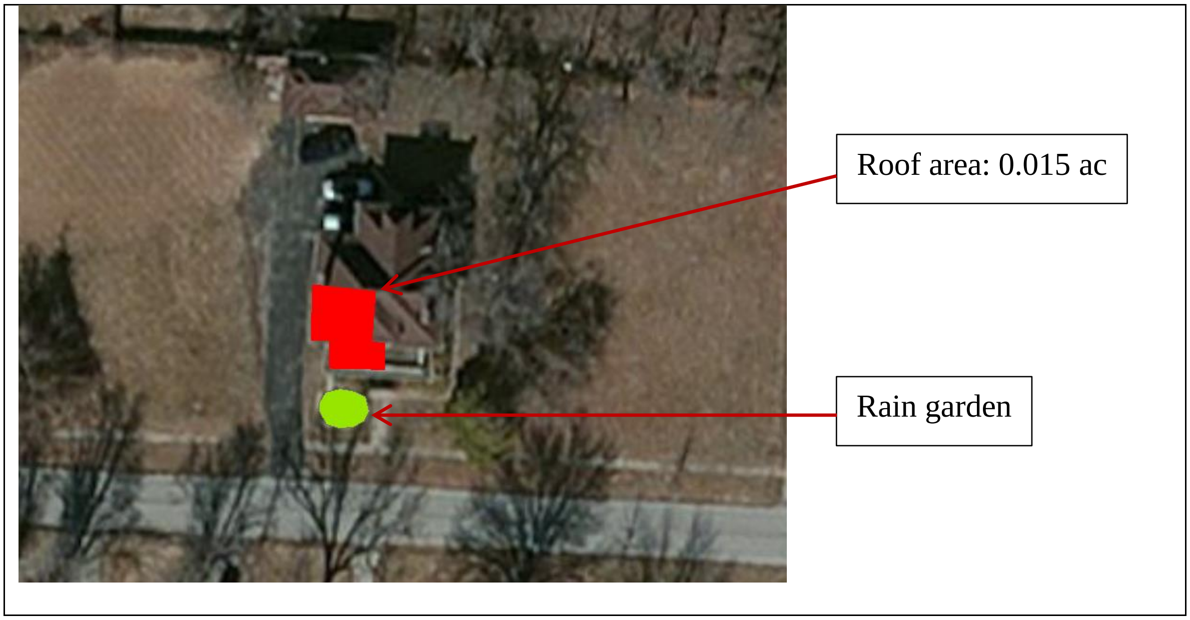
SCALE: 1" = 10'



DETAIL 2: CASCADE PLANTING PLAN, STA. 12+18.80

SCALE: 1" = 5'

10. Private rain garden - 1312 E. 79th St. - Mrs. Thomas



1312 E 79th St #10; Mrs. Thomas Rain Garden (no details; two level recorders, inlet and bottom of rain garden)

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

	 Typical street without rain gardens

11. 1505 E 76th St, #11; Mrs. Moss rain garden (no details); level recorders for inlet and bottom of garden)

	
 Side of house; rain garden in rear	

APPENDIX G

DETAILS OF TYPICAL STORMWATER CONTROLS IN TEST AREA AT KANSAS CITY

Device at Site No.	Top area (sq ft)	Bottom area (sq ft)	Pool depth	Material
1	422.9	240		
2	513.5	228.5		
3	341.5	160.5		
4	200.86	59.72	6’’	3’’ hardwood mulch on top, Native soil amended with 3’’ compost, roto-tilled 8’’ min depth
5	222.35	93.5	6’’	
7	247.06	37.9	12’’	3’’ hardwood mulch on top, Topsoil planting mix on side slopes, Engineering soil mix 8’’ min depth on bottom.
8	284	36.28	6’’	3’’ hardwood mulch on top, Native soil amended with 3’’ compost, roto-tilled 8’’ min depth
9	290.73	48.16	12’’	Topsoil planting mix on side slopes, Engineering soil mix 8’’ min depth on bottom.

Subsurface layer properties for applicable stormwater control layers (Source Table 2-10 of the “Report on Enhanced Framework (SUSTAIN) and Field Applications for Placement of BMPs in Urban Watersheds”)

Soil layer	Property	Value	Units
Engineered soil media	Porosity	0.4	--
	Field capacity	0.3	--
	Wilting point	0.1	--
	Holtan vegetation parameter	0.6	--
	Saturated infiltration rate	2	in./hr
Underdrain layer	Void fraction	0.4	--
Native background soil	Saturated infiltration rate	0.1	in./hr

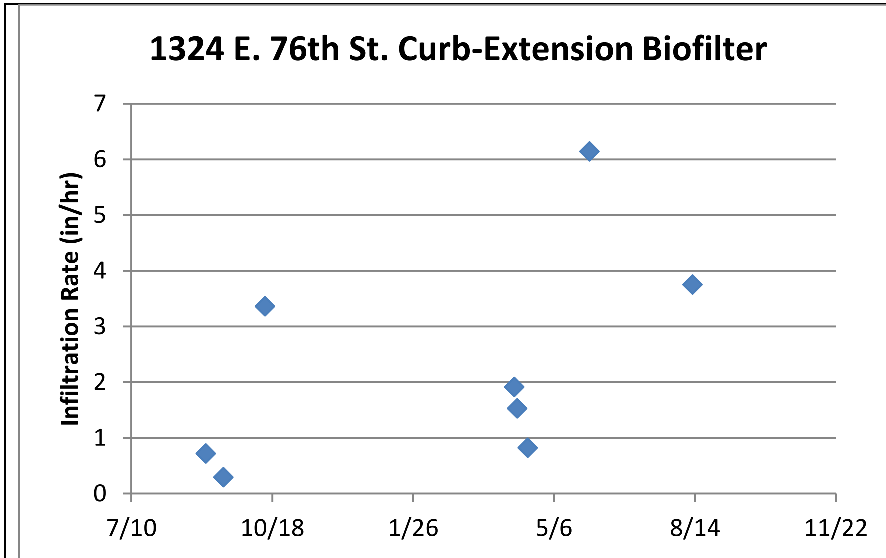
Private rain garden design dimensions and specifications. (Source Table 2-11 of the “Report on Enhanced Framework (SUSTAIN) and Field Applications for Placement of BMPs in Urban Watersheds”)

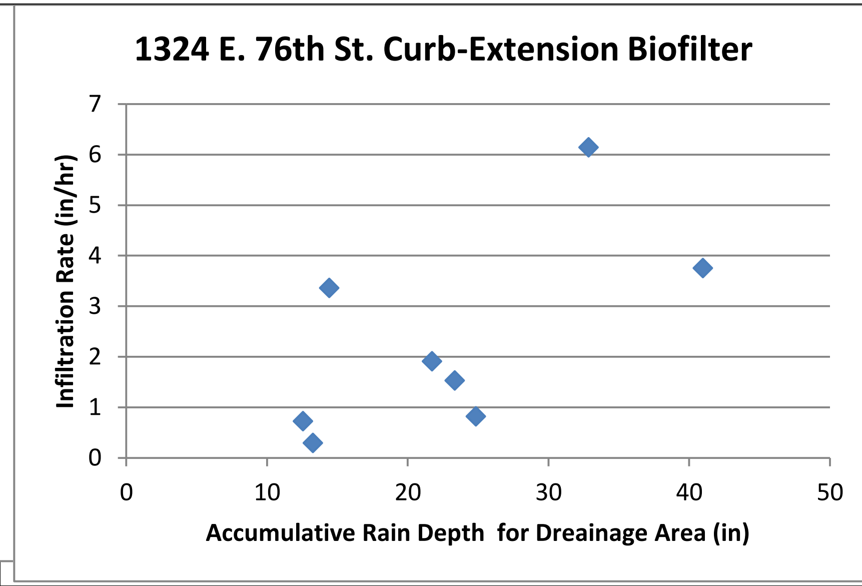
BMP categories	BMP dimensions				Outlet type
	Surface area	Ponding (ft)	Soil media (ft)	Underdrain	
Rain garden	200 sq ft per house (1,000 sq ft roof)	1	2	No underdrain	Weir
Influent flow monitoring device	35-gallon tank with orifice on standpipe				Weir and orifice

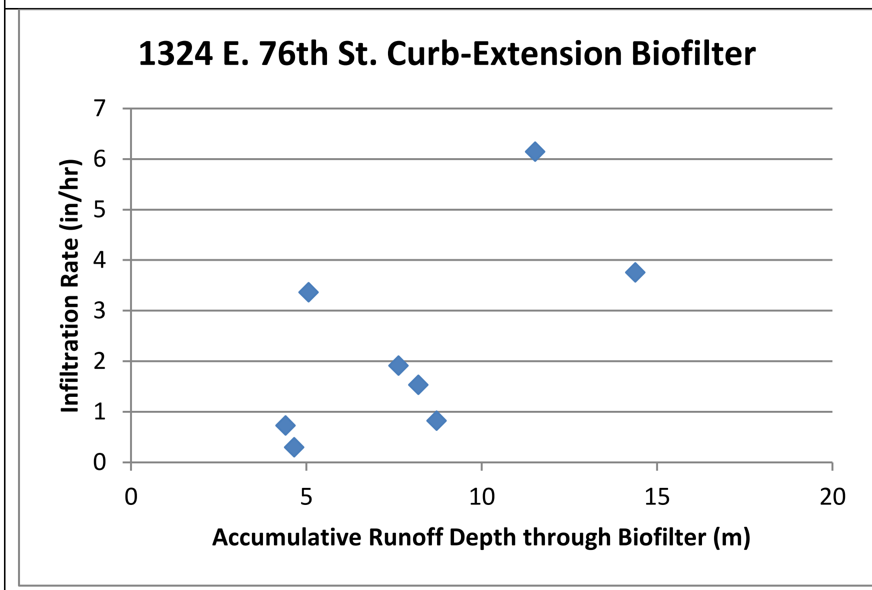
APPENDIX H

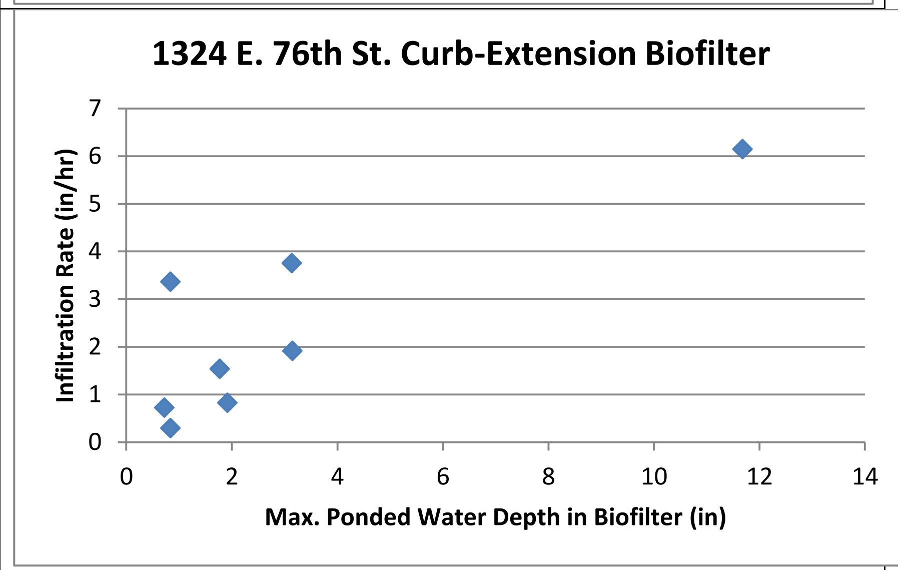
MEASURED INFILTRATION RATES IN BIOFILTERS AT KANSAS CITY

1324 E. 76th St. curb-extension biofilter													
biofilter top area: 264 ft2 (24.2 m2)													
drainage area: 0.42 ac (0.17 ha); biofilter is 1.4% of drainage area													
Rv: 0.2; avg SSC: 205 mg/L													
years of monitoring: 1.35; 4.6 years to reach 10 kg/m2; 11.4 years to reach 25 kg/m2													
Start Time	End Time	Event Duration (hr:min)	Rainfall Depth (in.)	Total volume of inflow (gal)	Total runoff depth (in)	Rv: Runoff/ rainfall	f (in/hr)	Max Water Depth in Biofilter (in)	Time Duration before Ponding Occurred (hr:min)	Accum. rain depth since April 1, 2012 (in)	Accum. runoff to biofilter (m3)	Accum. runoff (m thru biofilter)	Accum. sediment to biofilter (kg/m2)
6/20/12 7:05 PM	6/21/12 11:55 AM	16:50	1.03	916	0.08	0.08				8.87	75.4	3.1	0.6
7/25/12 11:15 AM	7/26/12 12:25 PM	1:10	0.49	338	0.03	0.06				9.36	79.5	3.3	0.7
8/31/12 10:20 PM	8/31/12 8:15 PM	21:55	2.61	4000	0.35	0.13	0.7	0.72	18:00	12.56	106.7	4.4	0.9
9/13/12 12:00 PM	9/14/12 10:45 AM	22:45	0.43	2101	0.18	0.43	0.3	0.84	17:30	13.27	112.8	4.7	1.0
10/12/12 9:00 PM	10/14/12 9:40 AM	12:40	0.86	2778	0.24	0.28	3.4	0.84	0:00	14.42	122.5	5.1	1.0
4/7/13 7:52 PM	4/8/13 2:25 AM	6:33	1.1	3556	0.31	0.28	1.9	3.15	1:13	21.73	184.6	7.6	1.6
4/9/13 9:56 PM	4/10/13 6:30 PM	20:34	1.62	3151	0.28	0.17	1.5	1.77	1:01	23.35	198.4	8.2	1.7
4/17/13 11:00 AM	4/18/13 8:41 PM	9:41	1.1	3339	0.29	0.27	0.8	1.92	10:51	24.84	211.1	8.7	1.8
5/31/13 5:26 AM	5/31/13 9:21 AM	3:55	1.34	5710	0.50	0.37	6.1	11.68	0:28	32.85	279.1	11.5	2.4
8/12/13 7:07 AM	8/12/13 10:18 AM	3:11	0.67	N/A	N/A	N/A	3.8	3.14	0:00	40.98	348.2	14.4	2.9
average						0.23	2.3	3.01					
minimum						0.06	0.3	0.72					
maximum						0.43	6.1	11.68					
st dev						0.13	2.0	3.64					
COV						0.56	0.9	1.21					

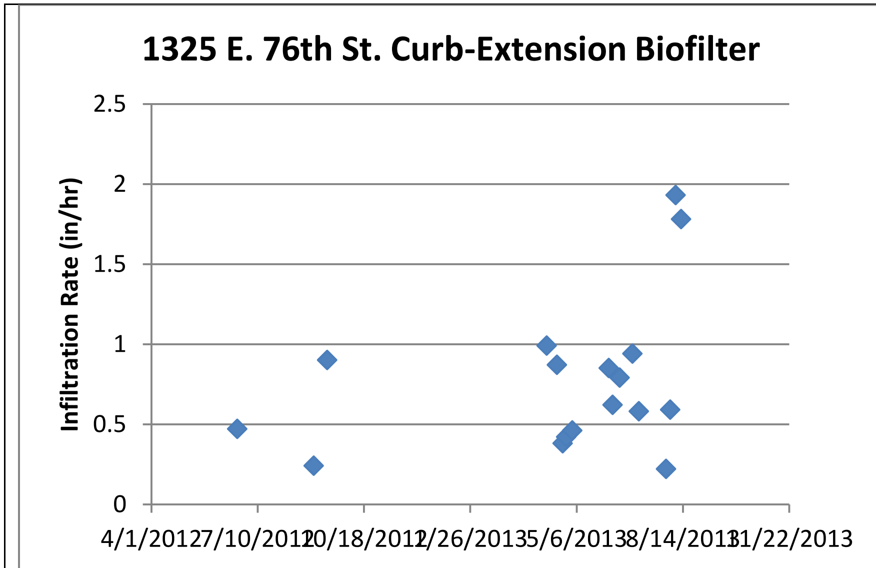

1324 E. 76th St. Curb-Extension Biofilter
Infiltration Rate (in/hr)
0
1
2
3
4
5
6
7
7/10
10/18
1/26
5/6
8/14
11/22


1324 E. 76th St. Curb-Extension Biofilter
Infiltration Rate (in/hr)
0
1
2
3
4
5
6
7
0
10
20
30
40
50
Accumulative Rain Depth for Dreainage Area (in)

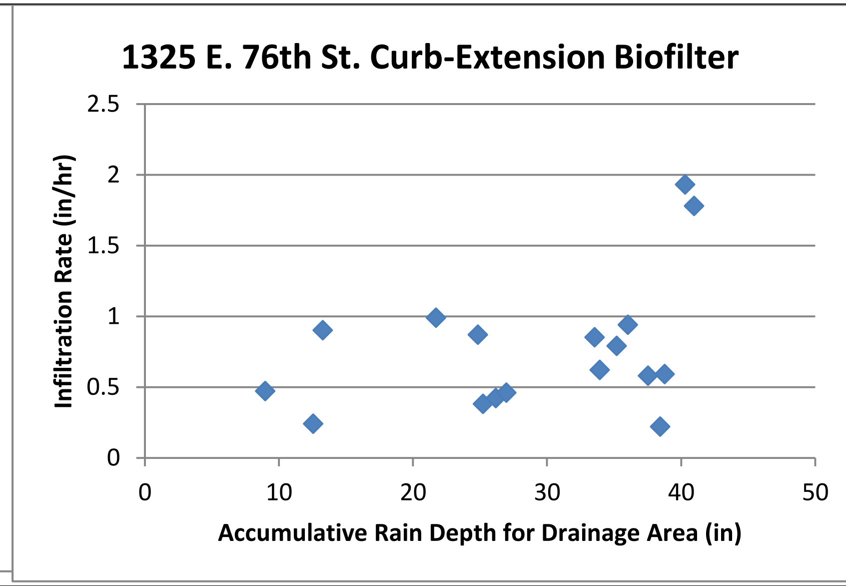

1324 E. 76th St. Curb-Extension Biofilter
Infiltration Rate (in/hr)
0
1
2
3
4
5
6
7
0
5
10
15
20
Accumulative Runoff Depth through Biofilter (m)


1324 E. 76th St. Curb-Extension Biofilter
Infiltration Rate (in/hr)
0
1
2
3
4
5
6
7
0
2
4
6
8
10
12
14
Max. Ponded Water Depth in Biofilter (in)

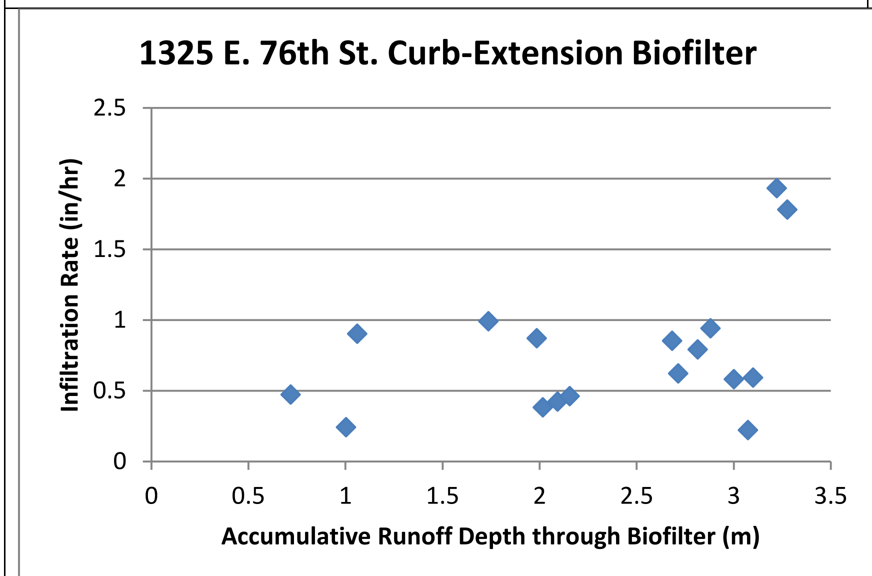
1325 E 76th St. curb-extension biofilter														
biofilter top area: 264 ft2 (24.2 m2)														
drainage area: 0.096 ac (0.039 ha); biofilter is 6.3% of drainage area														
Rv: 0.2; avg SSC: 200 mg/L														
years of monitoring: 1.35; 21 years to reach 10 kg/m2; 52 years to reach 25 kg/m2														
Start Time	End Time	Event Duration (hr:min)	Rainfall Depth (in.)	Total volume of inflow (gal)	Total runoff depth (in)	Rv: Runoff/rainfall	f (in/hr)	Max Water Depth in Biofilter (in)	Time Duration before Ponding Occurred (hr:min)	Accum. rain depth since April 1, 2012 (in)	Accum. runoff to biofilter (m3)	Accum. runoff (m thru biofilter)	Accum. sediment to biofilter (kg/m2)
6/10/12 10:05 PM	6/11/12 1:20 PM	15:15	0.8	346.5	0.13	0.17				7.96	15.4	0.6	0.1
6/20/12 7:10 PM	6/21/12 11:55 AM	16:45	1.03	1370	0.53	0.51	0.5	0.96	9:45	8.99	17.4	0.7	0.1
7/25/12 5:00 PM	7/26/12 12:30 PM	19:30	0.49	328	0.13	0.26				9.48	18.4	0.8	0.2
8/31/12 7:00 PM	8/31/12 6:15 PM	23:15	2.61	4870	1.87	0.72	0.2	1.80	20:15	12.56	24.3	1.0	0.2
9/13/12 11:10 AM	9/14/12 10:55 AM	23:45	0.43	5954	2.28	5.31	0.9	1.56	0:15	13.27	25.7	1.1	0.2
10/12/12 7:00 PM	10/14/12 2:20 AM	7:20	0.86	1553	0.60	0.69				14.42	27.9	1.2	0.2
4/7/13 7:52 PM	4/8/13 2:25 AM	6:33	1.1	2452	0.94	0.86	1.0	9.36	5:25	21.73	42.1	1.7	0.3
4/17/13 11:00 AM	4/18/13 8:41 PM	9:41	1.1	3947	1.51	1.38	0.9	2.16	12:03	24.84	48.1	2.0	0.4
4/23/13 1:34 AM	4/23/13 10:53 AM	9:19	0.39	5082	1.95	5.00	0.4	6.12	4:14	25.23	48.8	2.0	0.4
4/26/13 4:19 AM	4/27/13 11:02 AM	6:43	0.95	7504	2.88	3.03	0.4	4.44	23:31	26.18	50.7	2.1	0.4
5/2/13 3:08 AM	5/4/13 4:11 AM	1:03	1.42	2471	0.95	0.67	0.5	2.04	12:10	26.97	52.2	2.2	0.4
6/5/13 9:44 AM	6/5/13 12:47 PM	3:03	0.47	632	0.24	0.52	0.9	2.64	3:05	33.56	65.0	2.7	0.5
6/9/13 12:54 AM	6/9/13 3:53 AM	2:59	0.39	540	0.21	0.53	0.6	2.52	1:55	33.95	65.7	2.7	0.5
6/15/13 3:50 PM	6/15/13 10:05 PM	6:15	1.26	N/A	N/A	N/A	0.8	6.24	0:14	35.21	68.2	2.8	0.6
6/27/13 11:46 AM	6/28/13 12:49 AM	13:03	0.83	N/A	N/A	N/A	0.9	8.16	11:18	36.04	69.8	2.9	0.6
7/3/13 5:54 PM	7/3/13 9:36 PM	3:42	1.5	N/A	N/A	N/A	0.6	7.92	2:10	37.54	72.7	3.0	0.6
7/29/13 6:27 AM	7/30/13 9:41 AM	3:14	0.91	N/A	N/A	N/A	0.2	2.16	11:26	38.45	74.4	3.1	0.6
8/2/13 3:46 AM	8/2/13 8:10 AM	4:24	0.32	N/A	N/A	N/A	0.6	1.56	2:07	38.77	75.1	3.1	0.6
8/7/13 4:13 AM	8/7/13 8:45 AM	4:32	0.87	N/A	N/A	N/A	1.9	4.68	2:25	40.31	78.0	3.2	0.6
8/12/13 7:07 AM	8/12/13 10:18 AM	3:11	0.67	N/A	N/A	N/A	1.8	5.52	0:16	40.98	79.3	3.3	0.7
average						1.51	0.8	4.11					
minimum						0.17	0.2	0.96					
maximum						5.31	1.9	9.36					
st dev						1.77	0.5	2.67					
COV						1.17	0.6	0.65					



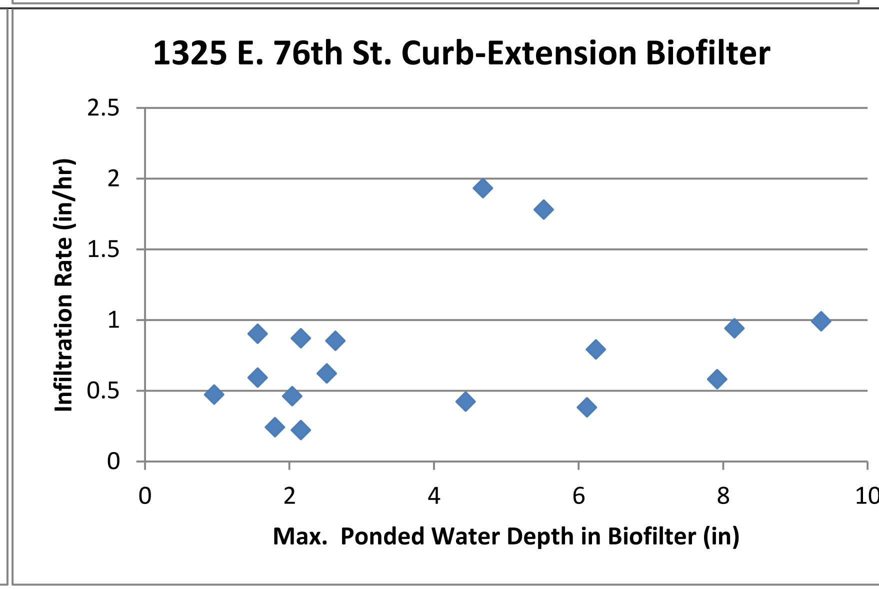
1325 E. 76th St. Curb-Extension Biofilter
Infiltration Rate (in/hr)
2.5
2
1.5
1
0.5
0
4/1/2012
7/10/2012
10/18/2012
1/26/2013
5/6/2013
8/14/2013
11/22/2013



1325 E. 76th St. Curb-Extension Biofilter
Infiltration Rate (in/hr)
2.5
2
1.5
1
0.5
0
0
10
20
30
40
50
Accumulative Rain Depth for Drainage Area (in)

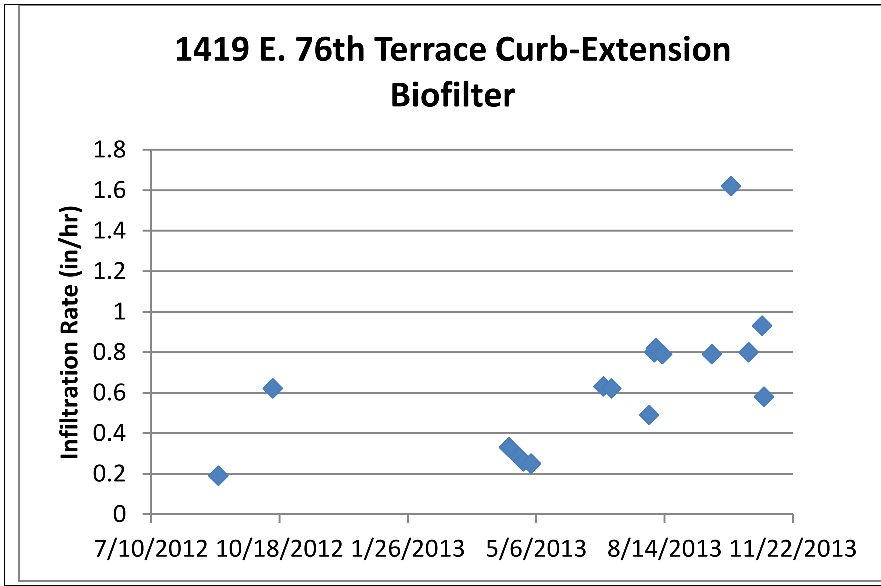


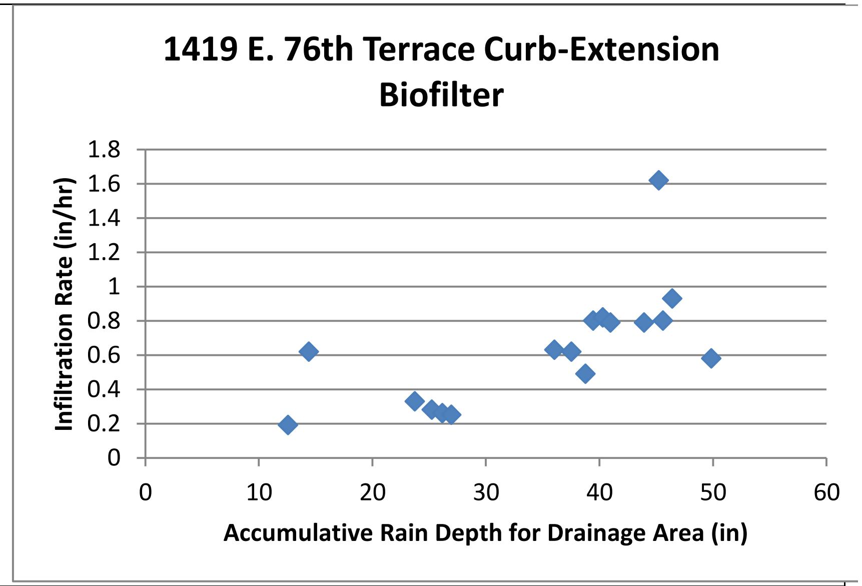
1325 E. 76th St. Curb-Extension Biofilter
Infiltration Rate (in/hr)
2.5
2
1.5
1
0.5
0
0
0.5
1
1.5
2
2.5
3
3.5
Accumulative Runoff Depth through Biofilter (m)

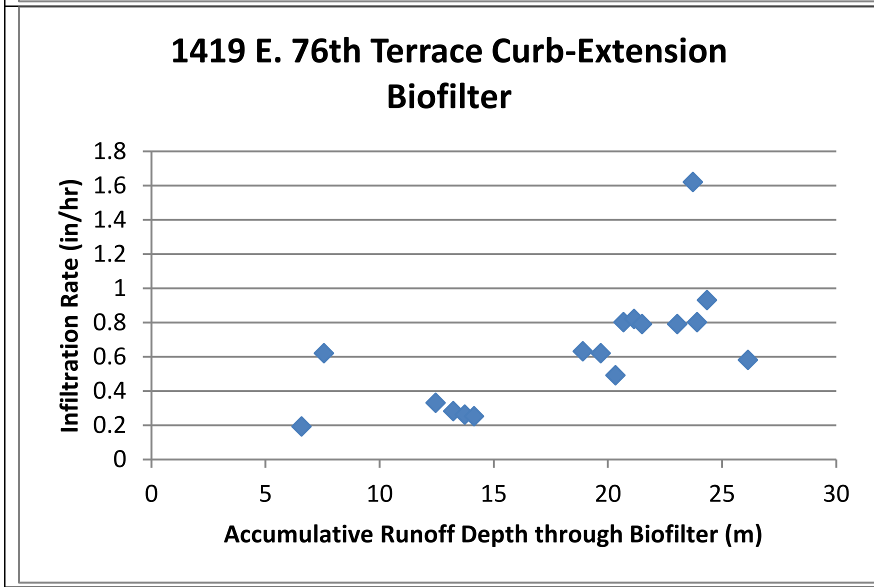


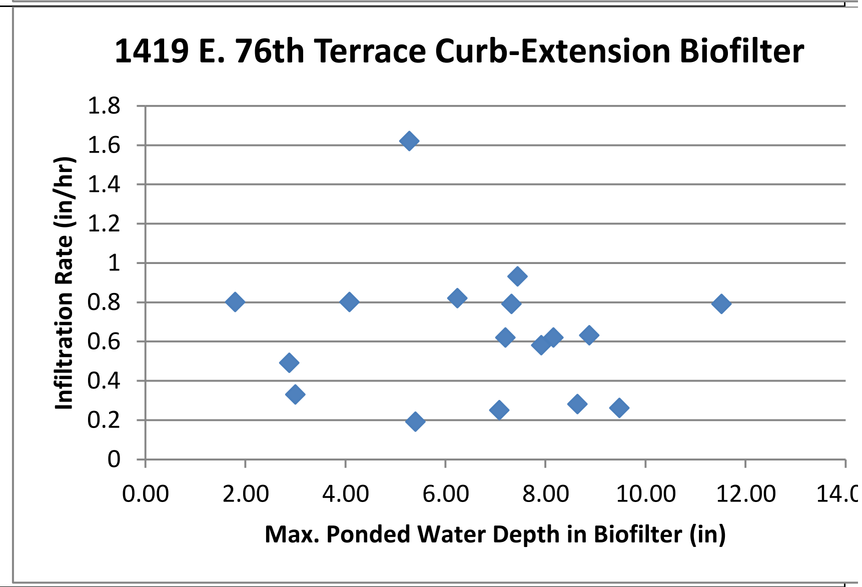
1325 E. 76th St. Curb-Extension Biofilter
Infiltration Rate (in/hr)
2.5
2
1.5
1
0.5
0
0
2
4
6
8
10
Max. Ponded Water Depth in Biofilter (in)

1419 E 76th Terr. curb-extension biofilter													
biofilter top area: 264 ft2 (24.2 m2)													
drainage area: 0.63 ac (0.25 ha); biofilter is 1.0% of drainage area													
Rv: 0.2; avg SSC: 133 mg/L													
years of monitoring: 1.6; 4.7 years to reach 10 kg/m2; 12 years to reach 25 kg/m2													
Start Time	End Time	Event Duration (hr:min)	Rainfall Depth (in.)	Total volume of inflow (gal)	Total runoff depth (in)	Rv: Runoff/ rainfall	f (in/hr)	Max Water Depth in Biofilter (in)	Time Duration before Ponding Occurred (hr:min)	Accum. rain depth since April 1, 2012 (in)	Accum. runoff to biofilter (m3)	Accum. runoff (m thru biofilter)	Accum. sediment to biofilter (kg/m2)
6/21/12 12:55 AM	6/21/12 11:25 AM	10:30	1.03	232	0.01	0.01				8.99	114.2	4.7	0.6
7/25/12 5:55 PM	7/26/12 8:30 AM	12:35	0.49	103	0.01	0.01		2.35	7:30	9.48	120.4	5.0	0.7
8/31/12 11:00 AM	8/31/12 5:00 PM	6:00	2.61	1940	0.11	0.04	0.2	5.40	4:15	12.56	159.5	6.6	0.9
9/13/12 2:10 PM	9/14/12 10:10 AM	20:00	0.43	3987	0.23	0.54		6.50	2:30	13.27	168.6	7.0	0.9
9/26/12 2:25 AM	9/26/12 04:30:00 AM	2:05	0.23	583	0.03	0.15				13.51	171.6	7.1	0.9
10/12/12 9:00 PM	10/13/12 10:15 PM	1:15	0.86	3487	0.20	0.24	0.6	7.20	4:55	14.42	183.2	7.6	1.0
4/14/13 7:02 PM	4/15/13 7:08 AM	12:06	0.39	N/A	N/A	N/A	0.3	3.00	13:51	23.74	301.6	12.5	1.7
4/23/13 1:34 AM	4/23/13 10:53 AM	9:19	0.39	1281	0.07	0.19	0.3	8.64	7:19	25.23	320.5	13.2	1.8
4/26/13 4:19 AM	4/27/13 11:02 AM	6:43	0.95	1550	0.09	0.10	0.3	9.48	3:19	26.18	332.5	13.7	1.8
5/2/13 3:08 AM	5/4/13 4:11 AM	1:03	1.42	1400	0.08	0.06	0.3	7.08	2:51	26.97	342.6	14.1	1.9
6/27/13 11:46 AM	6/28/13 12:49 AM	13:03	0.83	N/A	N/A	N/A	0.6	8.88	12:03	36.04	457.8	18.9	2.5
7/3/13 5:54 PM	7/3/13 9:36 PM	3:42	1.5	N/A	N/A	N/A	0.6	8.16	1:11	37.54	476.8	19.7	2.6
8/2/13 3:46 AM	8/2/13 8:10 AM	4:24	0.32	N/A	N/A	N/A	0.5	2.88	1:53	38.77	492.5	20.3	2.7
8/6/13 3:24 AM	8/6/13 4:59 AM	1:35	0.55	N/A	N/A	N/A	0.8	4.08	1:30	39.44	501.0	20.7	2.8
8/7/13 4:13 AM	8/7/13 8:45 AM	4:32	0.87	N/A	N/A	N/A	0.8	6.24	2:41	40.31	512.0	21.1	2.8
8/12/13 7:07 AM	8/12/13 10:18 AM	3:11	0.67	N/A	N/A	N/A	0.8	7.32	0:17	40.98	520.5	21.5	2.9
9/19/13 7:00 PM	9/19/13 10:23 PM	3:23	1.89	N/A	N/A	N/A	0.8	11.52	0:25	43.94	558.1	23.1	3.1
10/4/13 10:36 PM	10/5/13 3:48 AM	5:12	0.87	N/A	N/A	N/A	1.6	5.28	1:34	45.24	574.7	23.7	3.2
10/18/13 2:03 PM	10/18/13 5:05 PM	3:02	0.12	N/A	N/A	N/A	0.8	1.80	0:00	45.5898	579.1	23.9	3.2
10/29/13 2:52 AM	10/29/13 9:41 AM	6:49	0.83	N/A	N/A	N/A	0.9	7.44	4:19	46.4172	589.6	24.4	3.2
10/30/13 12:09 PM	10/31/13 11:46 AM	23:37	3.43	N/A	N/A	N/A	0.6	7.92	17:49	49.845	633.1	26.1	3.5
average						0.15	0.6	6.38					
minimum						0.01	0.2	1.80					
maximum						0.54	1.6	11.52					
st dev						0.17	0.3	2.63					
COV						1.12	0.5	0.41					



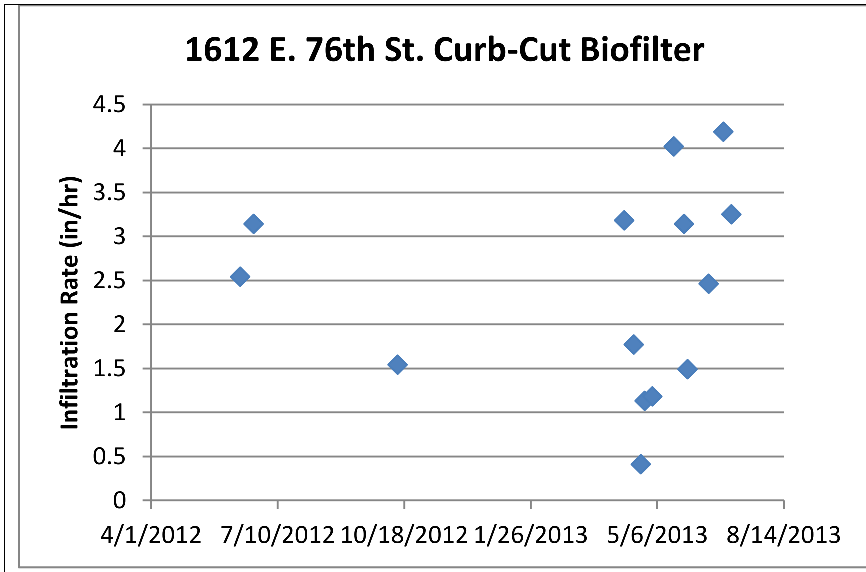


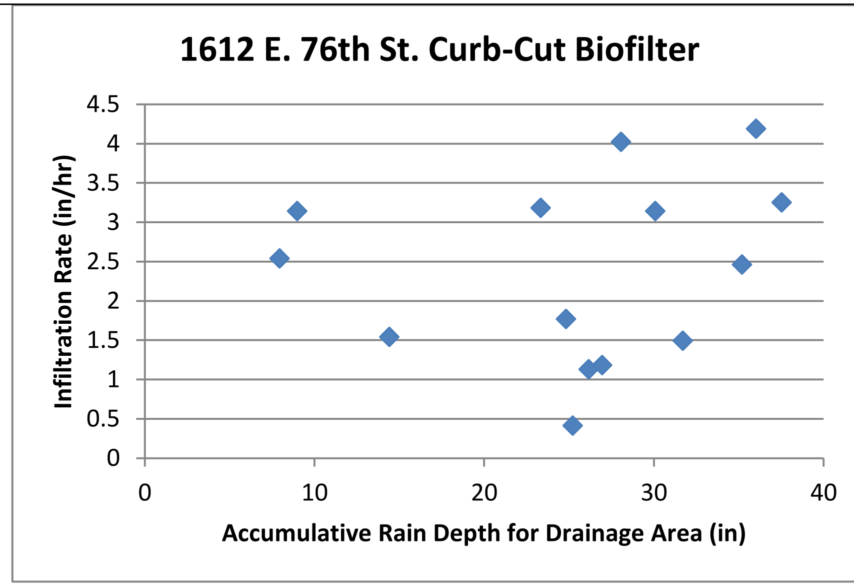


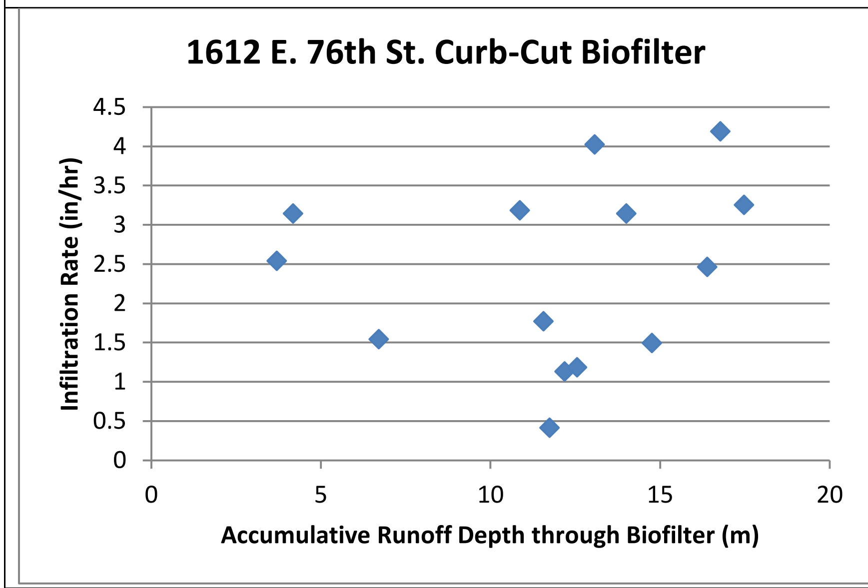


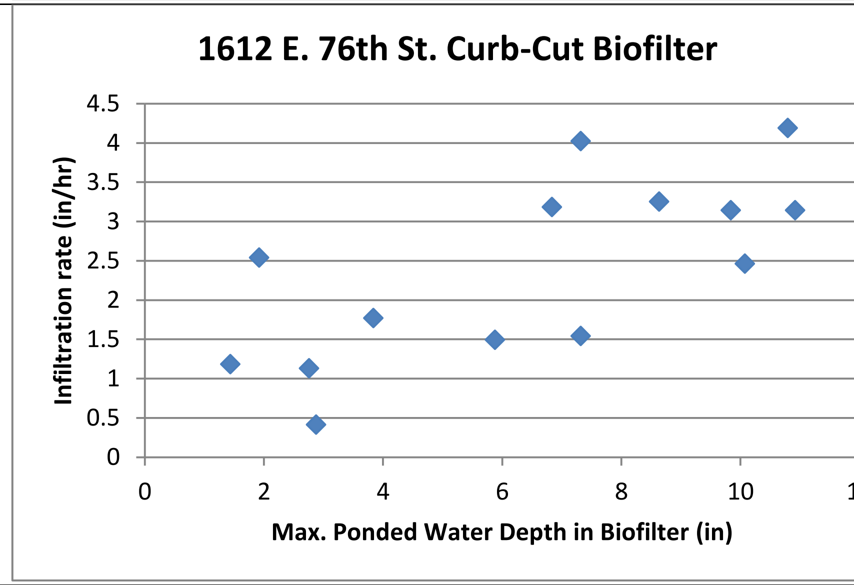
1612 E 76th St. curb-cut biofilter
biofilter top area: 282 ft2 (25.9 m2)
drainage area: 0.60 ac (0.24 ha); biofilter is 1.1% of drainage area

Rv: 0.2; avg SSC: 166 mg/L													
years of monitoring: 1.25; 4.3 years to reach 10 kg/m2; 11 years to reach 25 kg/m2													
Start Time	End Time	Event Duration (hr:min)	Rainfall Depth (in.)	Total volume of inflow (gal)	Total runoff depth (in)	Rv: Runoff/rainfall	f (in/hr)	Max Water Depth in Biofilter (in)	Time Duration before Ponding Occurred (hr:min)	Accum. rain depth since April 1, 2012 (in)	Accum. runoff to biofilter (m3)	Accum. runoff (m thru biofilter)	Accum. sediment to biofilter (kg/m2)
6/10/12 9:45 AM	6/11/12 10:00 AM	0:15	0.8	1.1	0.00	0.00	2.5	1.92	20:00	7.96	95.8	3.7	0.6
6/21/12 12:12 AM	6/21/12 12:02 PM	11:50	1.03	1061	0.07	0.06	3.1	9.84	1:45	8.99	108.2	4.2	0.7
8/31/12 11:00 AM	9/1/12 3:00 PM	4:00	5.6	1194	0.07	0.01				12.56	151.2	5.8	1.0
9/13/12 2:40 PM	9/13/12 8:25 PM	5:45	0.43	40	0.00	0.01				13.27	159.8	6.2	1.0
9/26/12 2:55 AM	9/26/12 5:30 AM	2:35	0.23	30	0.00	0.01				13.51	162.7	6.3	1.0
10/12/12 9:00 PM	10/13/12 9:05 PM	0:05	0.86	754	0.05	0.05	1.5	7.32	9:00	14.42	173.6	6.7	1.1
4/9/13 9:56 PM	4/10/13 6:30 PM	20:34	1.62	7539	0.47	0.29	3.2	6.84	1:13	23.35	281.1	10.9	1.8
4/17/13 11:00 AM	4/18/13 8:41 PM	9:41	1.1	N/A	N/A	N/A	1.8	3.84	0:58	24.84	299.1	11.6	1.9
4/23/13 1:34 AM	4/23/13 10:53 AM	9:19	0.39	1837	0.11	0.29	0.4	2.88	4:50	25.23	303.8	11.7	1.9
4/26/13 4:19 AM	4/27/13 11:02 AM	6:43	0.95	1220	0.08	0.08	1.1	2.76	0:20	26.18	315.2	12.2	2.0
5/2/13 3:08 AM	5/4/13 4:11 AM	1:03	1.42	N/A	N/A	N/A	1.2	1.44	2:01	26.97	324.7	12.6	2.1
5/19/13 2:21 AM	5/20/13 1:44 AM	23:23	0.83	N/A	N/A	N/A	4.0	7.32	1:18	28.08	338.1	13.1	2.2
5/27/13 8:31 AM	5/27/13 12:35 PM	4:04	2.01	12126	0.75	0.37	3.1	10.92	1:40	30.09	362.3	14.0	2.3
5/29/13 10:53 PM	5/30/13 3:17 PM	14:52	1.62	8855	0.55	0.34	1.5	5.88	3:48	31.71	381.8	14.8	2.5
6/15/13 3:50 PM	6/15/13 10:05 PM	6:15	1.26	N/A	N/A	N/A	2.5	10.08	0:06	35.21	423.9	16.4	2.7
6/27/13 11:46 AM	6/28/13 12:49 AM	13:03	0.83	N/A	N/A	N/A	4.2	10.80	11:26	36.04	433.9	16.8	2.8
7/3/13 5:54 PM	7/3/13 9:36 PM	3:42	1.5	N/A	N/A	N/A	3.3	8.64	0:03	37.54	452.0	17.5	2.9
average						0.14	2.39	6.46					
minimum						0.00	0.41	1.44					
maximum						0.37	4.19	10.92					
st dev						0.15	1.15	3.39					
COV						1.09	0.48	0.52					



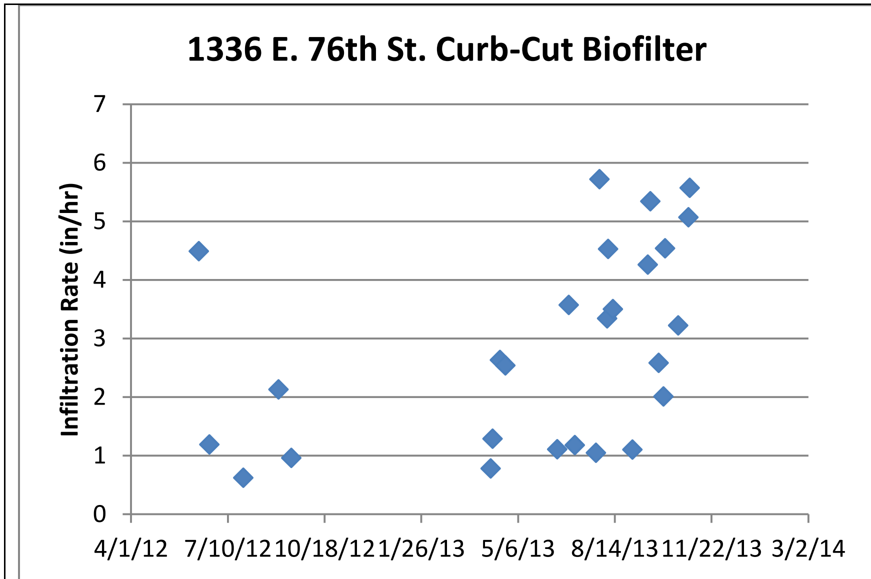


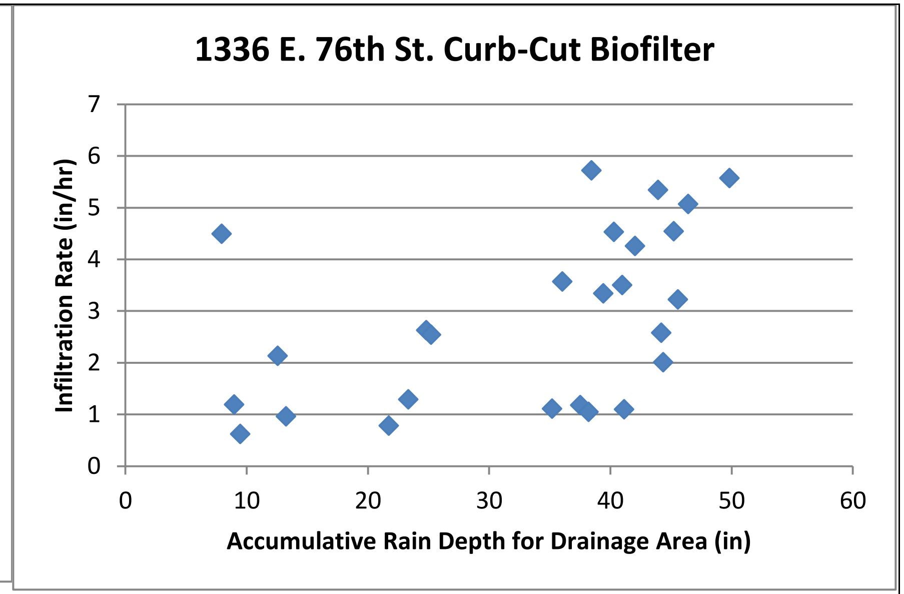


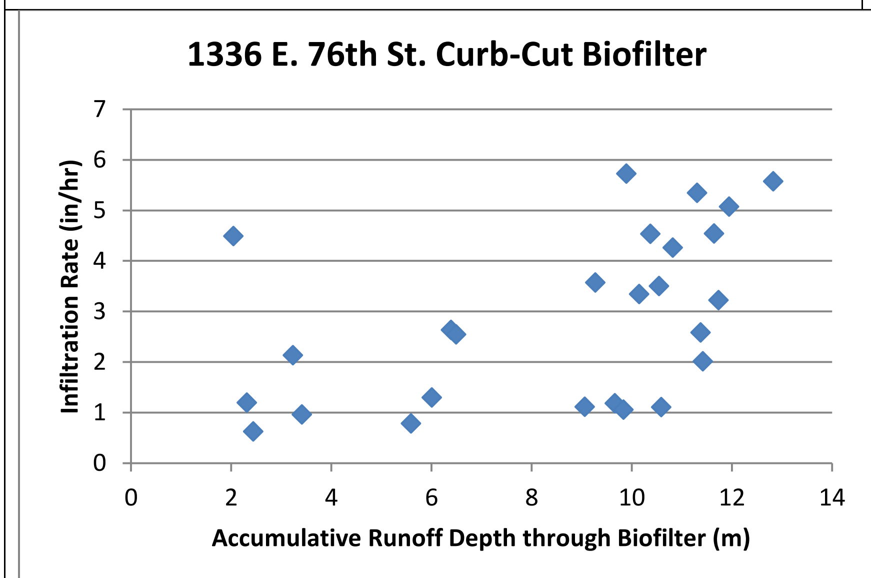


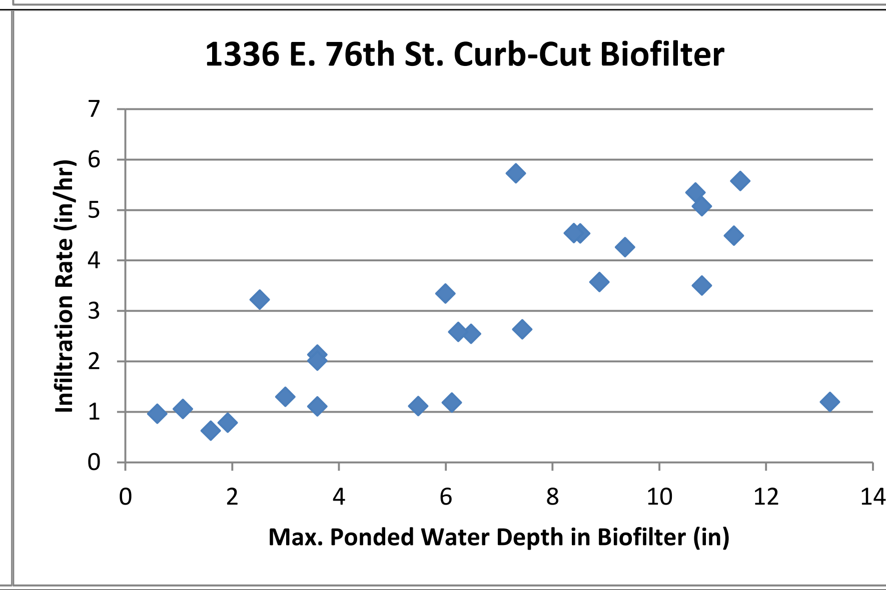
1336 E 76th St. curb-cut biofilter

biofilter top area: 282 ft2 (25.9 m2)													
drainage area: 0.33 ac (0.13 ha); biofilter is 2.0% of drainage area													
Rv: 0.2; avg SSC: 166 mg/L													
years of monitoring: 1.6; 7.5 years to reach 10 kg/m2; 19 years to reach 25 kg/m2													
Start Time	End Time	Event Duration (hr:min)	Rainfall Depth (in.)	Total volume of inflow (gal)	Total runoff depth (in)	Rv: Runoff/ rainfall	f (in/hr)	Max Water Depth in Biofilter (in)	Time Duration before Ponding Occurred (hr:min)	Accum. rain depth since April 1, 2012 (in)	Accum. runoff to biofilter (m3)	Accum. runoff (m thru biofilter)	Accum. sediment to biofilter (kg/m2)
5/29/12 5:17 AM	5/30/12 6:07 PM	12:47	0.29	289	0.03	0.11				6.74	44.9	1.7	0.3
6/10/12 7:02 AM	6/11/12 3:02 PM	8:00	0.8	14.7	0.00	0.00	4.5	11.40	20:00	7.96	53.0	2.0	0.3
6/21/12 12:17 AM	6/21/12 12:02 PM	11:45	1.03	3884	0.43	0.42	1.2	13.20	1:00	8.99	59.8	2.3	0.4
7/26/12 1:31 AM	7/26/12 12:16 PM	10:45	0.49	75	0.01	0.02	0.6	1.60	4:00	9.48	63.1	2.4	0.4
8/31/12 3:47 PM	9/2/12 11:02 AM	19:15	5.6	6877	0.77	0.14	2.1	3.60	9:30	12.56	83.6	3.2	0.5
9/13/12 2:37 PM	9/14/12 10:47 AM	20:45	0.43	1692	0.19	0.44	1.0	0.60	2:00	13.27	88.3	3.4	0.6
9/26/12 3:02 AM	9/26/12 7:22 AM	4:20	0.23	156	0.02	0.08				13.51	89.9	3.5	0.6
10/11/12 5:32 PM	10/14/12 10:47 AM	17:15	0.86	293	0.03	0.04				14.42	96.0	3.7	0.6
4/7/13 7:52 PM	4/8/13 2:25 AM	6:33	1.1	502	0.06	0.05	0.8	1.92	13:00	21.73	144.6	5.6	0.9
4/9/13 9:56 PM	4/10/13 6:30 PM	20:34	1.62	8419	0.94	0.58	1.3	3.00	0:57	23.35	155.4	6.0	1.0
4/17/13 11:00 AM	4/18/13 8:41 PM	9:41	1.1	N/A	N/A	N/A	2.6	7.44	0:00	24.84	165.4	6.4	1.1
4/23/13 1:34 AM	4/23/13 10:53 AM	9:19	0.39	N/A	N/A	N/A	2.5	6.48	4:04	25.23	167.9	6.5	1.1
6/15/13 3:50 PM	6/15/13 10:05 PM	6:15	1.26	6748	0.75	0.60	1.1	5.49	0:16	35.21	234.4	9.1	1.5
6/27/13 11:46 AM	6/28/13 12:49 AM	13:03	0.83	5041	0.56	0.68	3.6	8.88	11:25	36.04	239.9	9.3	1.5
7/3/13 5:54 PM	7/3/13 9:36 PM	3:42	1.5	N/A	N/A	N/A	1.2	6.12	2:17	37.54	249.9	9.7	1.6
7/25/13 5:00 PM	7/26/13 11:00 AM	18:00	0.24	N/A	N/A	N/A	1.1	1.08	2:15	38.21	254.4	9.8	1.6
7/29/13 6:27 AM	7/30/13 9:41 AM	3:14	0.91	N/A	N/A	N/A	5.7	7.32	8:03	38.45	255.9	9.9	1.6
8/6/13 3:24 AM	8/6/13 4:59 AM	1:35	0.55	N/A	N/A	N/A	3.3	6.00	0:37	39.44	262.5	10.2	1.7
8/7/13 4:13 AM	8/7/13 8:45 AM	4:32	0.87	N/A	N/A	N/A	4.5	8.52	2:48	40.31	268.3	10.4	1.7
8/12/13 7:07 AM	8/12/13 10:18 AM	3:11	0.67	N/A	N/A	N/A	3.5	10.80	0:24	40.98	272.8	10.5	1.8
9/1/13 7:42 AM	9/1/13 9:02 AM	1:20	0.16	N/A	N/A	N/A	1.1	3.60	0:05	41.1376	273.8	10.6	1.8
9/17/13 7:04 AM	9/17/13 3:14 PM	8:10	0.79	N/A	N/A	N/A	4.3	9.36	3:14	42.0438	279.9	10.8	1.8
9/19/13 7:00 PM	9/19/13 10:23 PM	3:23	1.89	N/A	N/A	N/A	5.3	10.68	2:49	43.935	292.5	11.3	1.9
9/28/13 8:29 AM	9/28/13 11:29 AM	3:00	0.28	N/A	N/A	N/A	2.6	6.24	0:51	44.2108	294.3	11.4	1.9
10/3/13 11:04 AM	10/3/13 11:24 AM	0:20	0.16	N/A	N/A	N/A	2.0	3.60	0:02	44.3684	295.3	11.4	1.9
10/4/13 10:36 PM	10/5/13 3:48 AM	5:12	0.87	N/A	N/A	N/A	4.5	8.40	0:30	45.2352	301.1	11.6	1.9
10/18/13 2:03 PM	10/18/13 5:05 PM	3:02	0.12	N/A	N/A	N/A	3.2	2.52	0:04	45.5898	303.5	11.7	1.9
10/29/13 2:52 AM	10/29/13 9:41 AM	6:49	0.83	N/A	N/A	N/A	5.1	10.80	3:45	46.4172	309.0	11.9	2.0
10/30/13 12:09 PM	10/31/13 11:46 AM	23:37	3.43	N/A	N/A	N/A	5.6	11.52	0:29	49.845	331.8	12.8	2.1
average						0.26	2.9	6.55					
minimum						0.00	0.6	0.60					
maximum						0.68	5.7	13.20					
st dev						0.26	1.7	3.66					
COV						0.99	0.6	0.56					

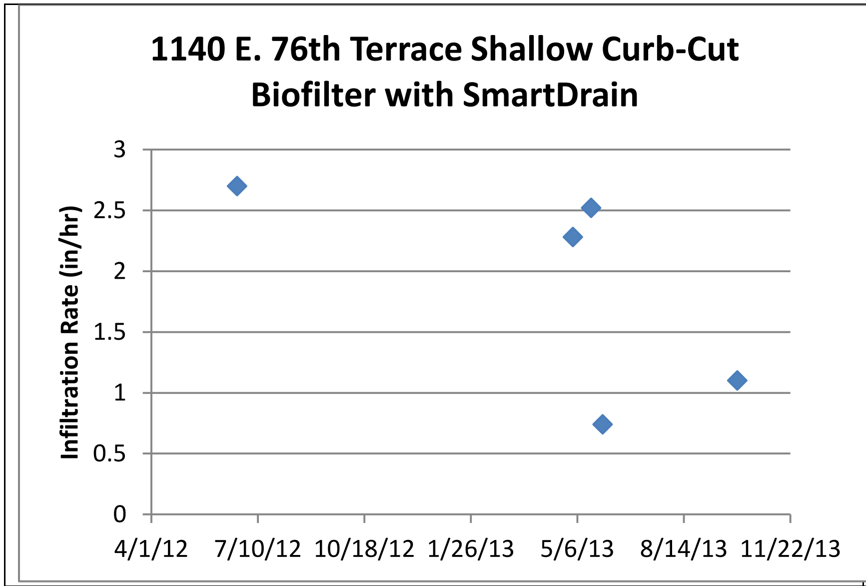

1336 E. 76th St. Curb-Cut Biofilter
Infiltration Rate (in/hr)
0
1
2
3
4
5
6
7
4/1/12
7/10/12
10/18/12
1/26/13
5/6/13
8/14/13
11/22/13
3/2/14

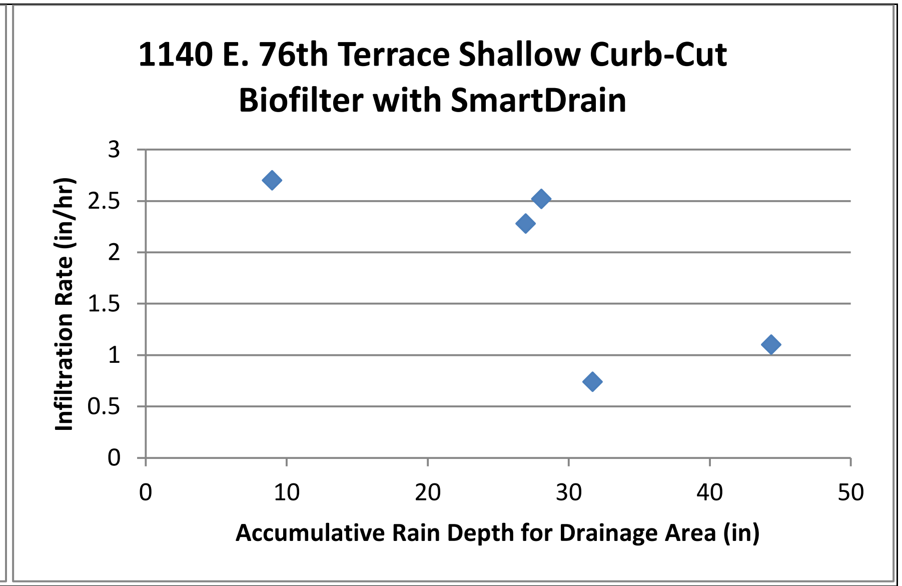

1336 E. 76th St. Curb-Cut Biofilter
Infiltration Rate (in/hr)
0
1
2
3
4
5
6
7
0
10
20
30
40
50
60
Accumulative Rain Depth for Drainage Area (in)

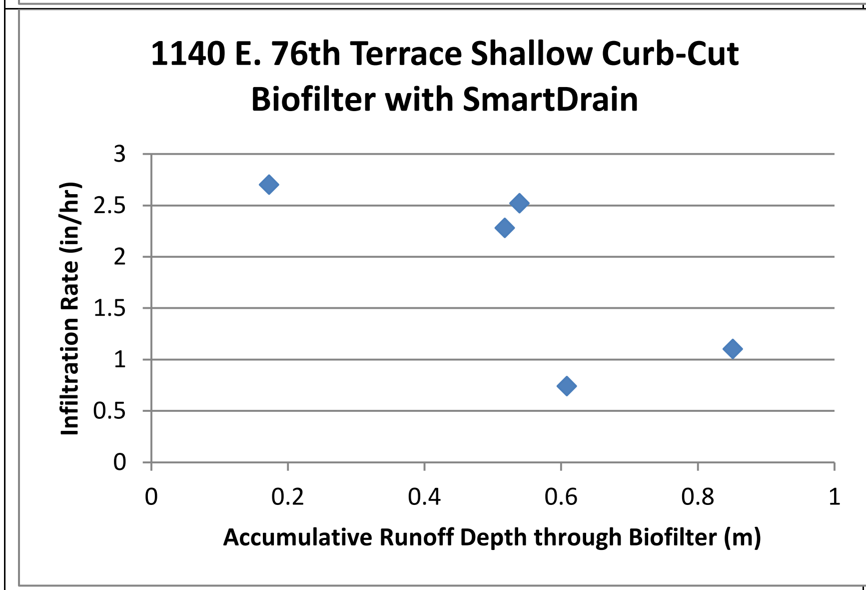

1336 E. 76th St. Curb-Cut Biofilter
Infiltration Rate (in/hr)
0
1
2
3
4
5
6
7
0
2
4
6
8
10
12
14
Accumulative Runoff Depth through Biofilter (m)

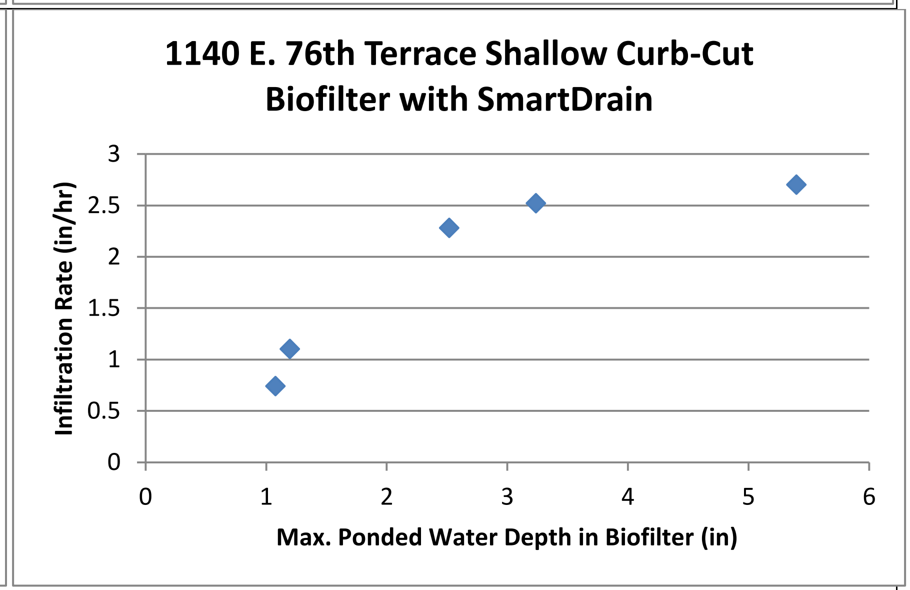

1336 E. 76th St. Curb-Cut Biofilter
Infiltration Rate (in/hr)
0
1
2
3
4
5
6
7
0
2
4
6
8
10
12
14
Max. Ponded Water Depth in Biofilter (in)

1140 E 76th Terr. Shallow curb-cut biofilter with SmartDrain													
biofilter top area: 282 ft2 (25.9 m2)													
drainage area: 0.025 ac (0.010 ha); biofilter is 26% of drainage area													
Rv: 0.2; avg SSC: 166 mg/L													
years of monitoring: 1.6; >100 years to reach 10 kg/m2; >100 years to reach 25 kg/m2													
Start Time	End Time	Event Duration (hr:min)	Rainfall Depth (in.)	Total volume of inflow (gal)	Total runoff depth (in)	Rv: Runoff/ rainfall	f (in/hr)	Max Water Depth in Biofilter (in)	Time Duration before Ponding Occurred (hr:min)	Accum. rain depth since April 1, 2012 (in)	Accum. runoff to biofilte r (m3)	Accum. runoff (m thru biofilter)	Accum. sediment to biofilter (kg/m2)
6/11/12 2:03 AM	6/11/12 12:03 PM	10:00	0.8	18.2	0.03	0.03				7.96	4.0	0.2	0.0
6/20/12 7:22 PM	6/21/12 11:32 AM	16:10	1.03	14203	21.25	20.63	2.7	5.40	6:35	8.99	4.5	0.2	0.0
8/31/12 11:02 AM	9/1/12 6:02 PM	7:00	5.6	46827	70.05	12.51				12.56	6.2	0.2	0.0
9/13/12 2:37 PM	9/14/12 10:34 AM	20:00	0.43	N/A	N/A	N/A				13.27	6.6	0.3	0.0
9/25/12 11:54 PM	9/26/12 8:34 AM	8:40	0.23	869	1.30	5.65				13.51	6.7	0.3	0.0
10/12/12 8:59 PM	10/12/12 10:39 PM	1:40	0.86	536	0.80	0.93				14.42	7.2	0.3	0.0
5/2/13 3:08 AM	5/4/13 4:11 AM	1:03	1.42	785	1.17	0.83	2.3	2.52	13:30	26.97	13.4	0.5	0.1
5/19/13 2:21 AM	5/20/13 1:44 AM	23:23	0.83	N/A	N/A	N/A	2.5	3.24	4:48	28.08	13.9	0.5	0.1
5/29/13 10:53 PM	5/30/13 3:17 PM	16:24	1.62	N/A	N/A	N/A	0.7	1.08	9:46	31.71	15.7	0.6	0.1
10/3/13 11:04 AM	10/3/13 11:24 AM	0:20	0.16	N/A	N/A	N/A	1.1	1.20	0:07	44.37	22.0	0.9	0.1
average						6.76	1.9	2.69					
minimum						0.03	0.7	1.08					
maximum						20.63	2.7	5.40					
st dev						8.26	0.9	1.77					
COV						1.22	0.5	0.66					

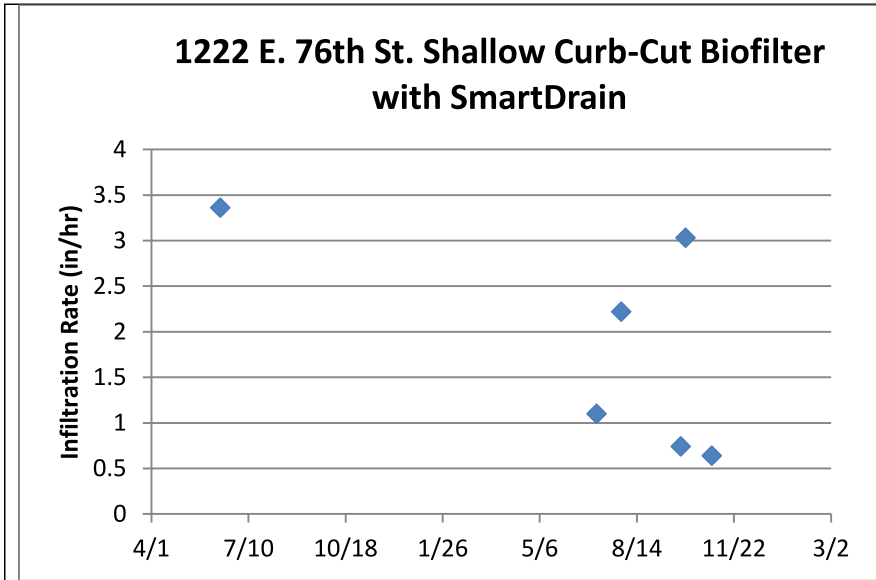

1140 E. 76th Terrace Shallow Curb-Cut Biofilter with SmartDrain
Infiltration Rate (in/hr)
0
0.5
1
1.5
2
2.5
3
4/1/12
7/10/12
10/18/12
1/26/13
5/6/13
8/14/13
11/22/13

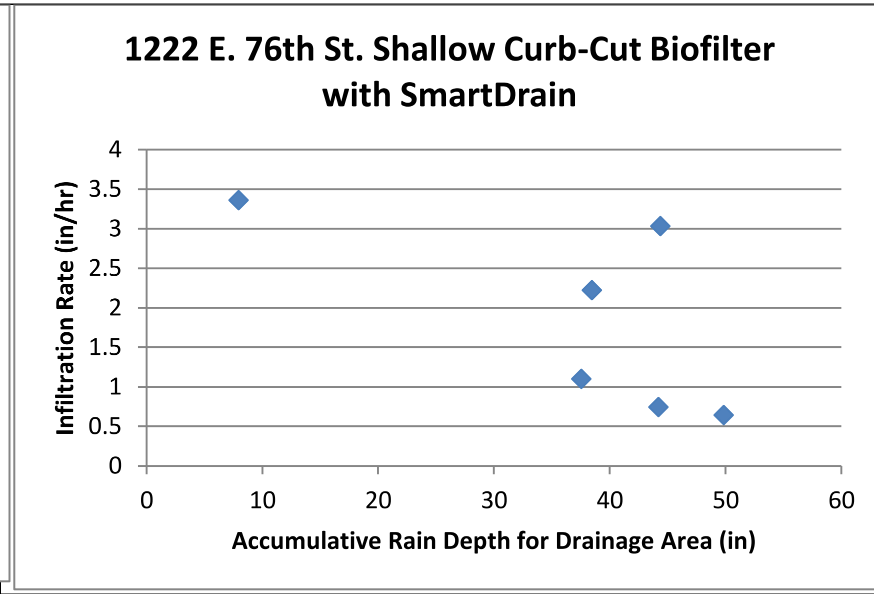

1140 E. 76th Terrace Shallow Curb-Cut Biofilter with SmartDrain
Infiltration Rate (in/hr)
0
0.5
1
1.5
2
2.5
3
0
10
20
30
40
50
Accumulative Rain Depth for Drainage Area (in)

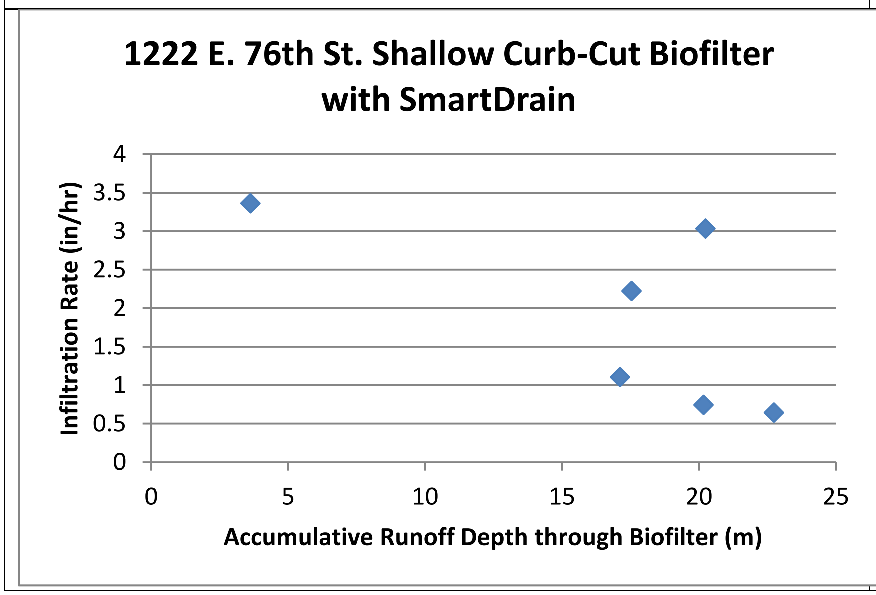

1140 E. 76th Terrace Shallow Curb-Cut Biofilter with SmartDrain
Infiltration Rate (in/hr)
0
0.5
1
1.5
2
2.5
3
0
0.2
0.4
0.6
0.8
1
Accumulative Runoff Depth through Biofilter (m)

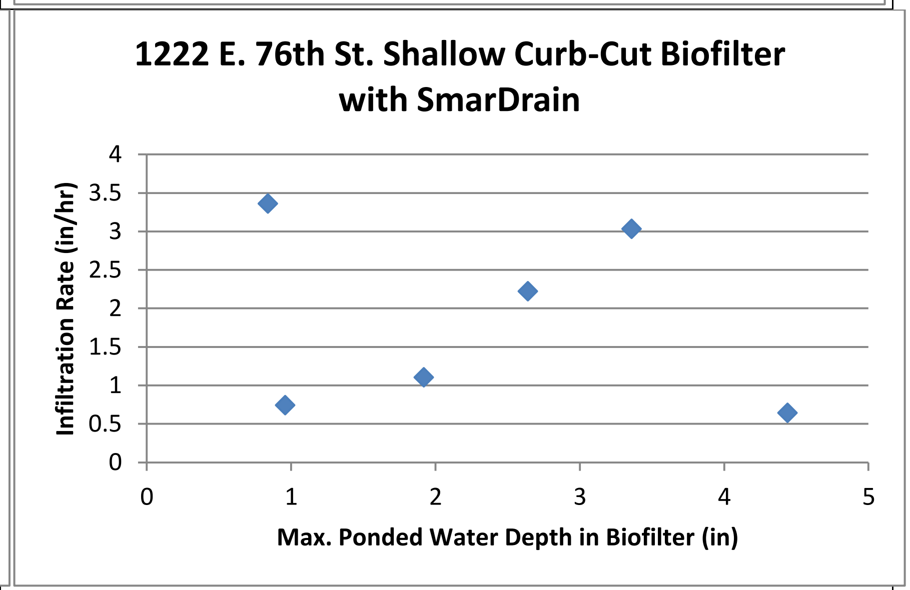

1140 E. 76th Terrace Shallow Curb-Cut Biofilter with SmartDrain
Infiltration Rate (in/hr)
0
0.5
1
1.5
2
2.5
3
0
1
2
3
4
5
6
Max. Ponded Water Depth in Biofilter (in)

1222 E 76th St. Shallow curb-cut biofilter with SmartDrain													
biofilter top area: 282 ft2 (25.9 m2)													
drainage area: 0.59 ac (0.24 ha); biofilter is 1.1% of drainage area													
Rv: 0.2; avg SSC: 163 mg/L													
years of monitoring: 1.6; 4.3 years to reach 10 kg/m2; 11 years to reach 25 kg/m2													
Start Time	End Time	Event Duration (hr:min)	Rainfall Depth (in.)	Total volume of inflow (gal)	Total runoff depth (in)	Rv: Runoff/ rainfall	f (in/hr)	Max Water Depth in Biofilter (in)	Time Duration before Ponding Occurred (hr:min)	Accum. rain depth since April 1, 2012 (in)	Accum. runoff to biofilter (m3)	Accum. runoff (m thru biofilter)	Accum. sediment to biofilter (kg/m2)
6/11/12 2:05 AM	6/11/12 6:50 AM	4:55	0.8	6.7	0.00	0.00	3.4	0.84	3:40	7.96	93.9	3.6	0.6
7/25/12 6:00 PM	7/26/12 5:00 AM	11:00	0.49	82	0.01	0.01				9.48	111.9	4.3	0.7
8/31/12 11:35 AM	8/31/12 11:00 PM	11:25	2.61	1492	0.09	0.04				12.56	148.2	5.7	0.9
9/13/12 2:30 PM	9/13/12 8:30 PM	6:00	0.43	762	0.05	0.11				13.27	156.6	6.1	1.0
9/26/12 2:00 AM	9/26/12 9:15 AM	7:15	0.23	527	0.03	0.14				13.51	159.4	6.2	1.0
10/13/12 12:30 AM	10/13/12 10:00 PM	21:30	0.86	547	0.03	0.04				14.42	170.1	6.6	1.1
7/3/13 5:54 PM	7/3/13 9:36 PM	3:42	1.5	N/A	N/A	N/A	1.1	1.92	2:23	37.54	442.9	17.1	2.8
7/29/13 6:27 AM	7/30/13 9:41 AM	3:14	0.91	N/A	N/A	N/A	2.2	2.64	8:08	38.45	453.7	17.5	2.9
9/28/13 8:29 AM	9/28/13 11:29 AM	3:00	0.28	N/A	N/A	N/A	0.7	0.96	0:51	44.2108	521.6	20.2	3.3
10/3/13 11:04 AM	10/3/13 11:24 AM	0:20	0.16	N/A	N/A	N/A	3.0	3.36	0:20	44.37	523.5	20.2	3.3
10/30/13 12:09 PM	10/31/13 11:46 AM	23:35	3.43	N/A	N/A	N/A	0.6	4.44	12:41	49.85	588.2	22.7	3.7
average						0.06	1.8	2.36					
minimum						0.00	0.6	0.84					
maximum						0.14	3.4	4.44					
st dev						0.06	1.2	1.40					
COV						1.01	0.6	0.60					

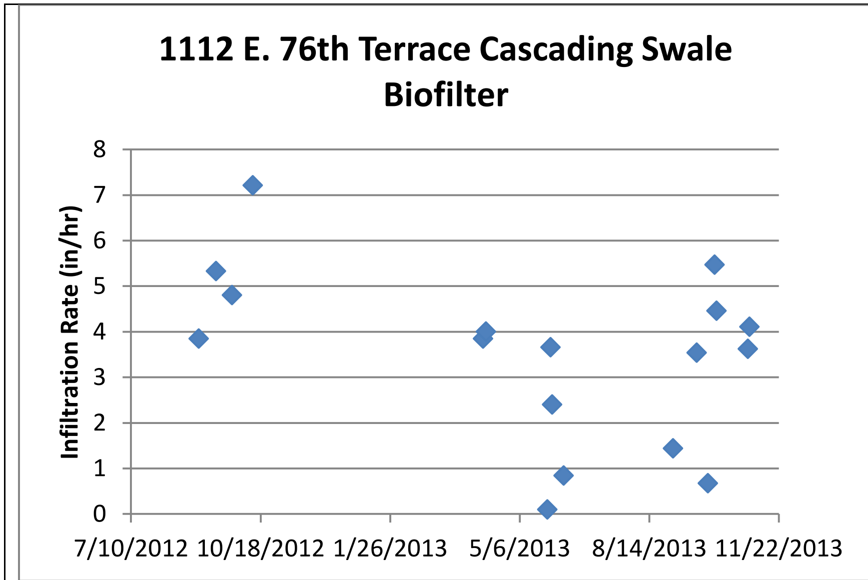

1222 E. 76th St. Shallow Curb-Cut Biofilter with SmartDrain
Infiltration Rate (in/hr)
0
0.5
1
1.5
2
2.5
3
3.5
4
4/1
7/10
10/18
1/26
5/6
8/14
11/22
3/2

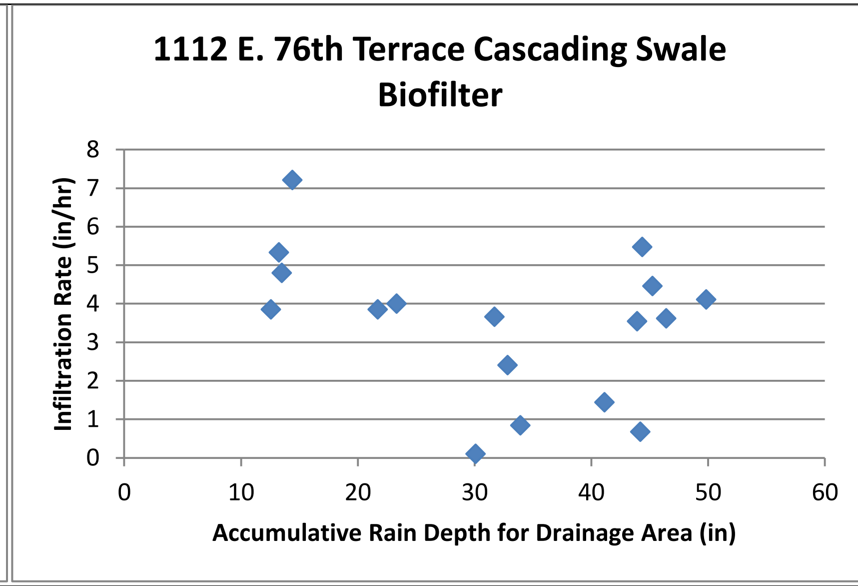

1222 E. 76th St. Shallow Curb-Cut Biofilter with SmartDrain
Infiltration Rate (in/hr)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
10
20
30
40
50
60
Accumulative Rain Depth for Drainage Area (in)

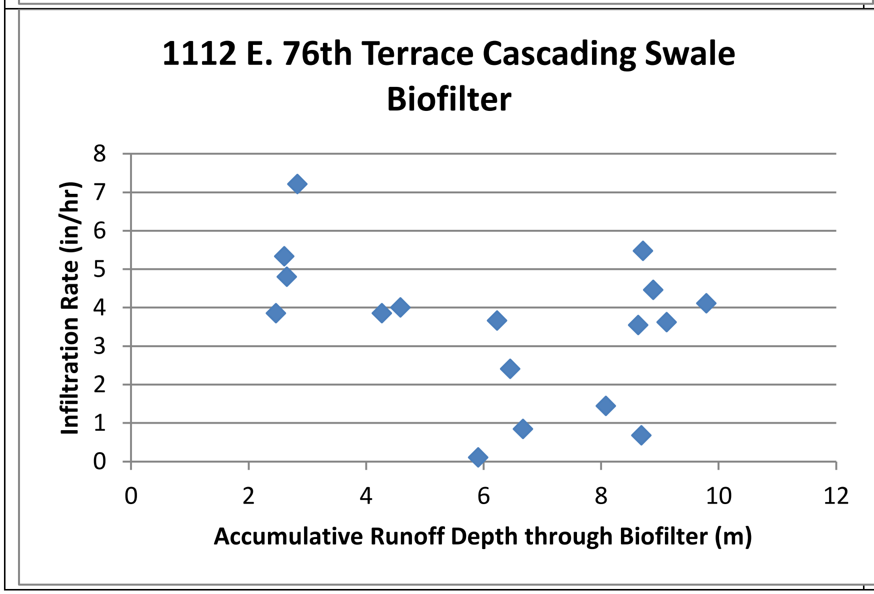

1222 E. 76th St. Shallow Curb-Cut Biofilter with SmartDrain
Infiltration Rate (in/hr)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
5
10
15
20
25
Accumulative Runoff Depth through Biofilter (m)

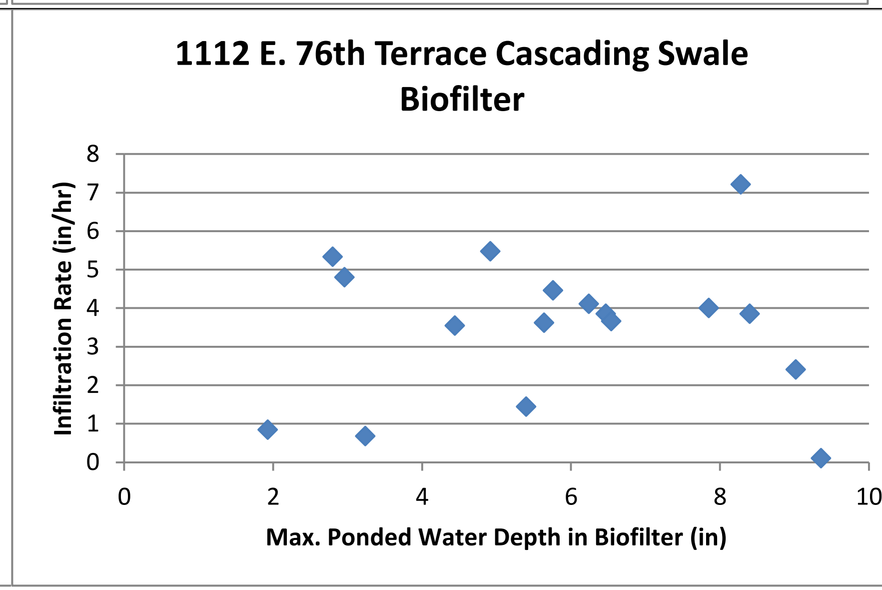

1222 E. 76th St. Shallow Curb-Cut Biofilter with SmarDrain
Infiltration Rate (in/hr)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
1
2
3
4
5
Max. Ponded Water Depth in Biofilter (in)

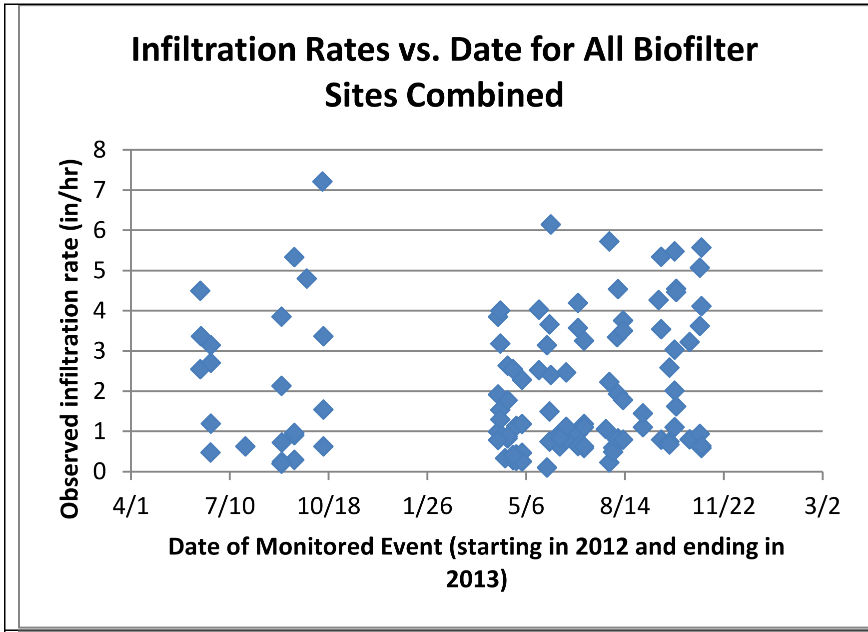
1112 E 76th Terr. Cascading swale biofilters													
biofilter top area: 328 ft2 (30.1 m2)													
drainage area: 0.29 ac (0.12 ha); biofilter is 2.6% of drainage area													
Rv: 0.2; avg SSC: 166 mg/L													
years of monitoring: 1.6; 10 years to reach 10 kg/m2; 25 years to reach 25 kg/m2													
Start Time	End Time	Event Duration (hr:min)	Rainfall Depth (in.)	Total volume of inflow (gal)	Total runoff depth (in)	Rv: Runoff/ rainfall	f (in/hr)	Max Water Depth in Biofilter (in)	Time Duration before Ponding Occurred (hr:min)	Accum. rain depth since April 1, 2012 (in)	Accum. runoff to biofilter (m3)	Accum. runoff (m thru biofilter)	Accum. sediment to biofilter (kg/m2)
8/31/12 11:08 AM	9/1/12 3:08 PM	4:00	5.6	8533	1.07	0.19	3.9	6.47	4:15	12.56	74.2	2.5	0.4
9/13/12 2:08 PM	9/14/12 10:23 AM	20:15	0.43	2098	0.26	0.61	5.3	2.80	1:45	13.27	78.4	2.6	0.4
9/26/12 2:08 AM	9/26/12 4:53 AM	2:45	0.23	261	0.03	0.14	4.8	2.96	2:15	13.51	79.9	2.7	0.4
10/12/12 12:03 AM	10/14/12 7:48 AM	7:45	0.86	1197	0.15	0.17	7.2	8.28	1:15	14.42	85.2	2.8	0.5
4/7/13 7:52 PM	4/8/13 2:25 AM	6:33	1.1	11502	1.45	1.31	3.9	8.40	2:01	21.73	128.4	4.3	0.7
4/9/13 9:56 PM	4/10/13 6:30 PM	20:34	1.62	10047	1.26	0.78	4.0	7.85	2:01	23.35	138.0	4.6	0.8
5/27/13 8:31 AM	5/27/13 12:35 PM	4:04	2.01	26303	3.31	1.64	0.1	9.36	2:05	30.09	177.8	5.9	1.0
5/29/13 10:53 PM	5/30/13 3:17 PM	16:24	1.62	15060	1.89	1.17	3.7	6.54	4:28	31.71	187.4	6.2	1.0
5/31/13 5:26 AM	5/31/13 9:21 AM	3:55	1.34	N/A	N/A	N/A	2.4	9.02	0:55	32.85	194.2	6.5	1.1
6/9/13 12:54 AM	6/9/13 3:53 AM	2:59	0.39	686	0.09	0.22	0.8	1.93	5:41	33.95	200.7	6.7	1.1
9/1/13 7:42 AM	9/1/13 9:02 AM	1:20	0.16	N/A	N/A	N/A	1.4	5.40	0:15	41.14	243.2	8.1	1.3
9/19/13 7:00 PM	9/19/13 10:23 PM	3:23	1.89	N/A	N/A	N/A	3.5	4.44	2:43	43.94	259.7	8.6	1.4
9/28/13 8:29 AM	9/28/13 11:29 AM	3:00	0.28	N/A	N/A	N/A	0.7	3.24	0:29	44.2108	261.3	8.7	1.4
10/3/13 11:04 AM	10/3/13 11:24 AM	0:20	0.16	N/A	N/A	N/A	5.5	4.92	0:39	44.37	262.2	8.7	1.4
10/4/13 10:36 PM	10/5/13 3:48 AM	5:12	0.87	N/A	N/A	N/A	4.5	5.76	2:07	45.24	267.4	8.9	1.5
10/29/13 2:52 AM	10/29/13 9:41 AM	6:49	0.83	N/A	N/A	N/A	3.6	5.64	4:07	46.4172	274.3	9.1	1.5
10/30/13 12:09 PM	10/31/13 11:46 AM	23:35	3.43	N/A	N/A	N/A	4.1	6.24	11:05	49.845	294.6	9.8	1.6
average						0.69	3.5	5.84					
minimum						0.14	0.1	1.93					
maximum						1.64	7.2	9.36					
st dev						0.57	1.9	2.27					
COV						0.82	0.5	0.39					

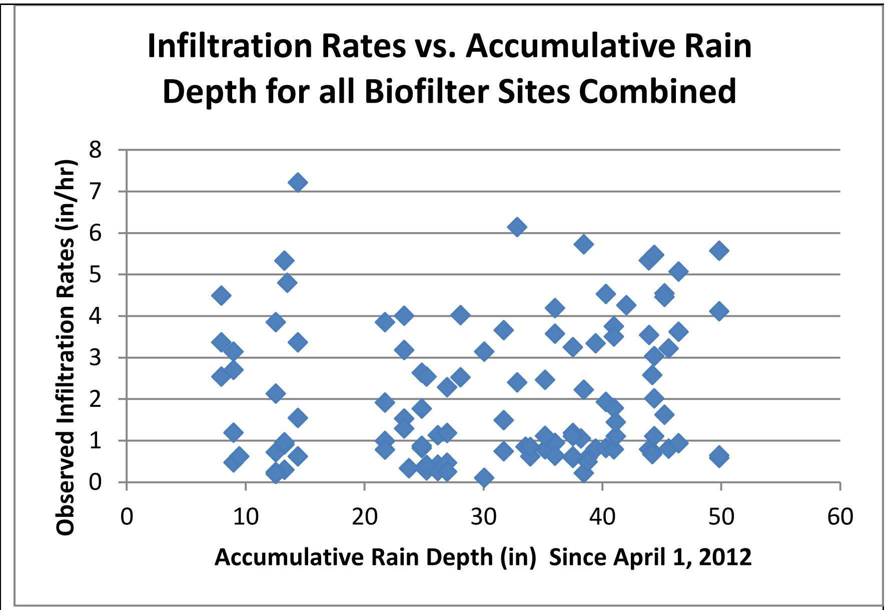

1112 E. 76th Terrace Cascading Swale Biofilter
Infiltration Rate (in/hr)
0
1
2
3
4
5
6
7
8
7/10/2012
10/18/2012
1/26/2013
5/6/2013
8/14/2013
11/22/2013

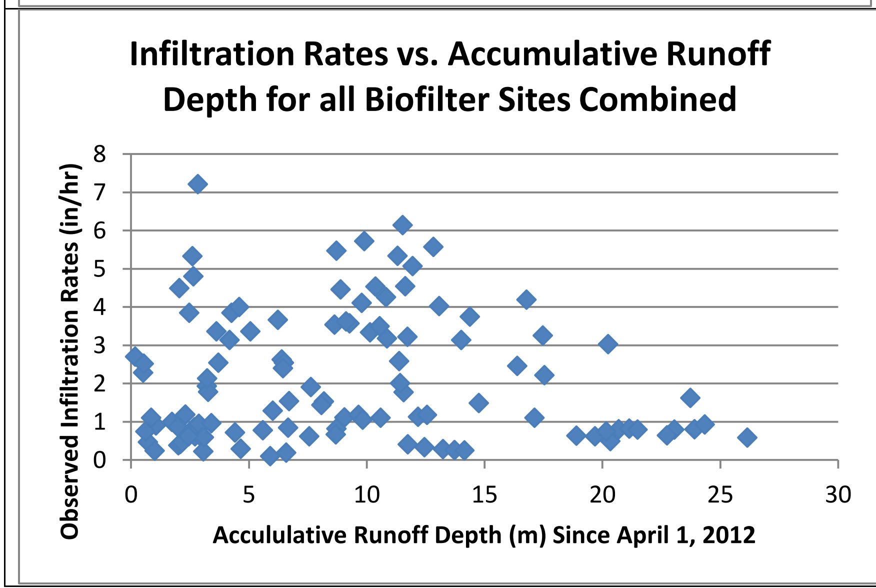

1112 E. 76th Terrace Cascading Swale Biofilter
Infiltration Rate (in/hr)
0
1
2
3
4
5
6
7
8
0
10
20
30
40
50
60
Accumulative Rain Depth for Drainage Area (in)

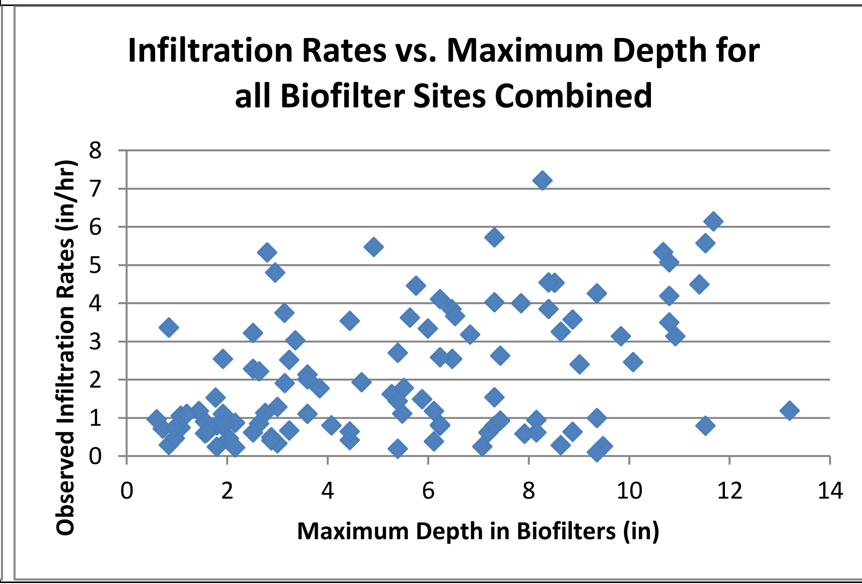

1112 E. 76th Terrace Cascading Swale Biofilter
Infiltration Rate (in/hr)
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
Accumulative Runoff Depth through Biofilter (m)

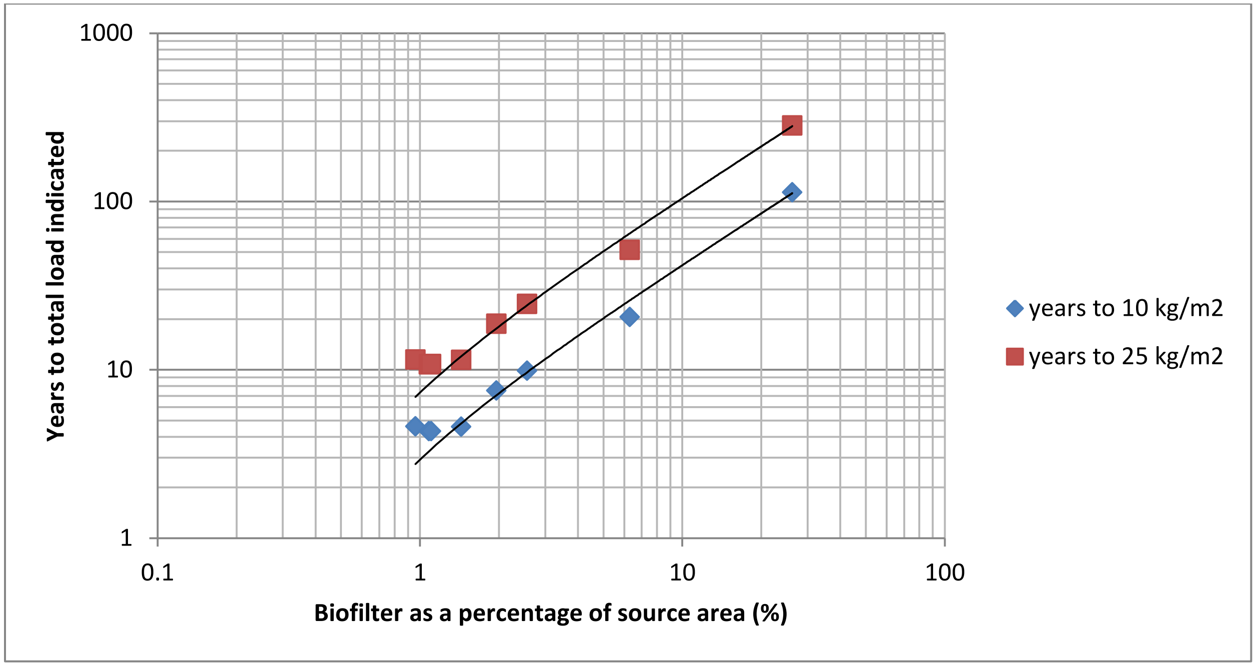

1112 E. 76th Terrace Cascading Swale Biofilter
Infiltration Rate (in/hr)
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
Max. Ponded Water Depth in Biofilter (in)


Infiltration Rates vs. Date for All Biofilter Sites Combined
Observed infiltration rate (in/hr)
0
1
2
3
4
5
6
7
8
4/1
7/10
10/18
1/26
5/6
8/14
11/22
3/2
Date of Monitored Event (starting in 2012 and ending in 2013)

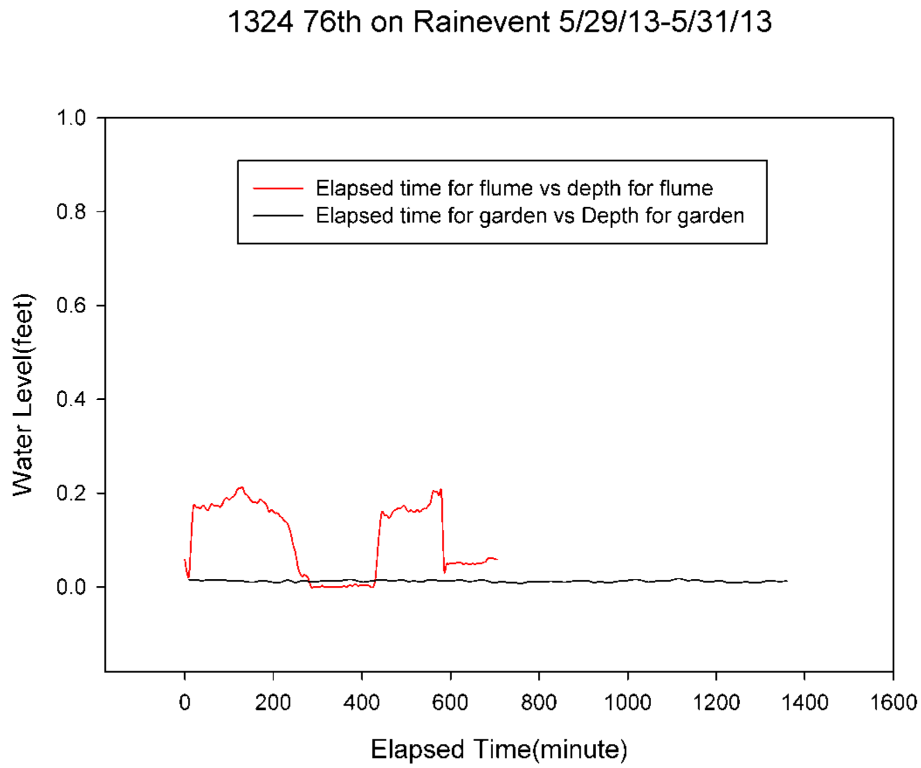

Infiltration Rates vs. Accumulative Rain Depth for all Biofilter Sites Combined
Observed Infiltration Rates (in/hr)
0
1
2
3
4
5
6
7
8
0
10
20
30
40
50
60
Accumulative Rain Depth (in) Since April 1, 2012

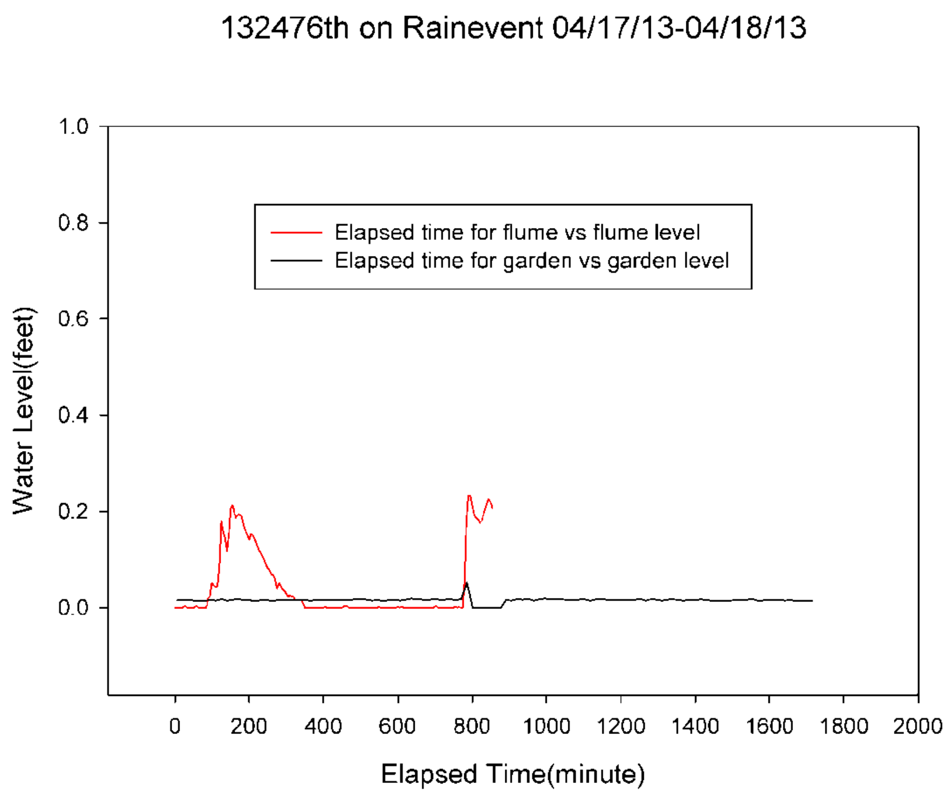

Infiltration Rates vs. Accumulative Runoff Depth for all Biofilter Sites Combined
Observed Infiltration Rates (in/hr)
0
1
2
3
4
5
6
7
8
0
5
10
15
20
25
30
Acculative Runoff Depth (m) Since April 1, 2012


Infiltration Rates vs. Maximum Depth for all Biofilter Sites Combined
Observed Infiltration Rates (in/hr)
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
Maximum Depth in Biofilters (in)

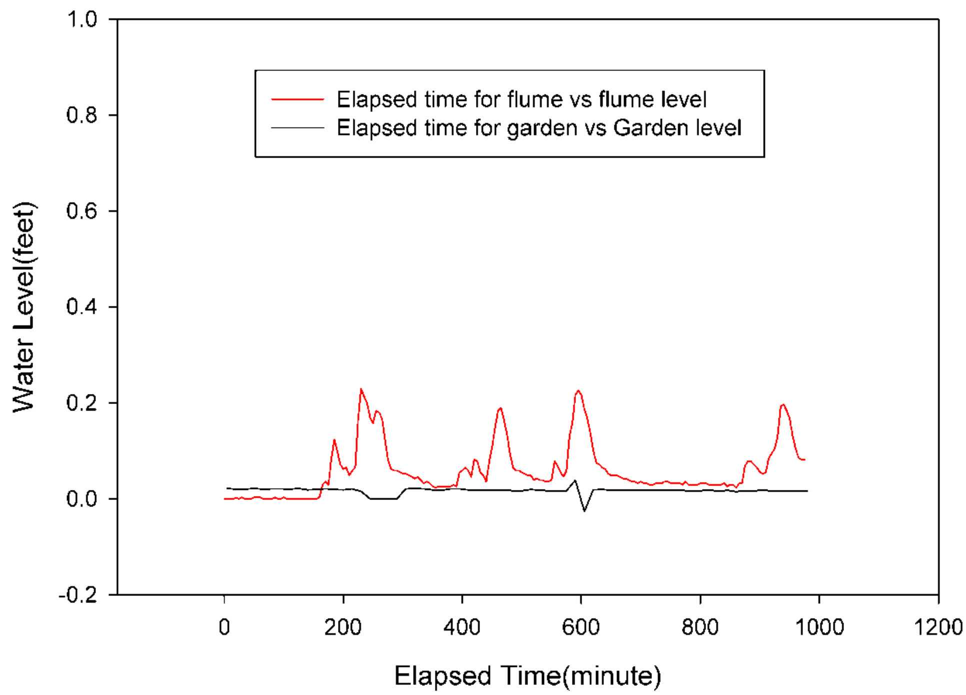

1000
100
10
1
0.1
1
10
100
Years to total load indicated
Biofilter as a percentage of source area (%)
years to 10 kg/m2
years to 25 kg/m2

1- Curb Extension Biofilter - 1324 E 76th St.

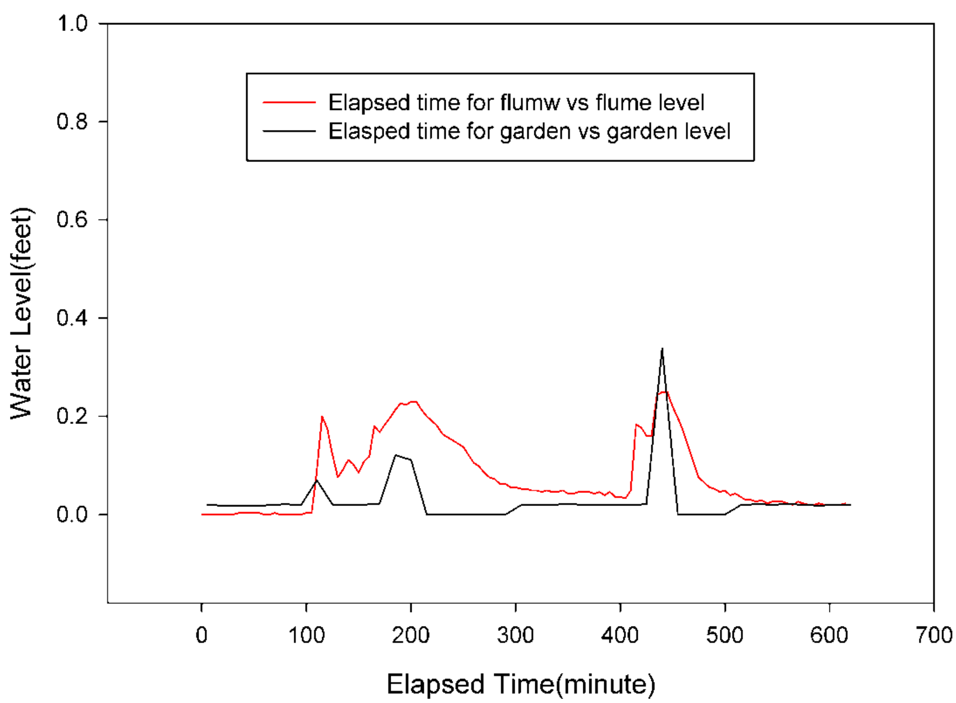




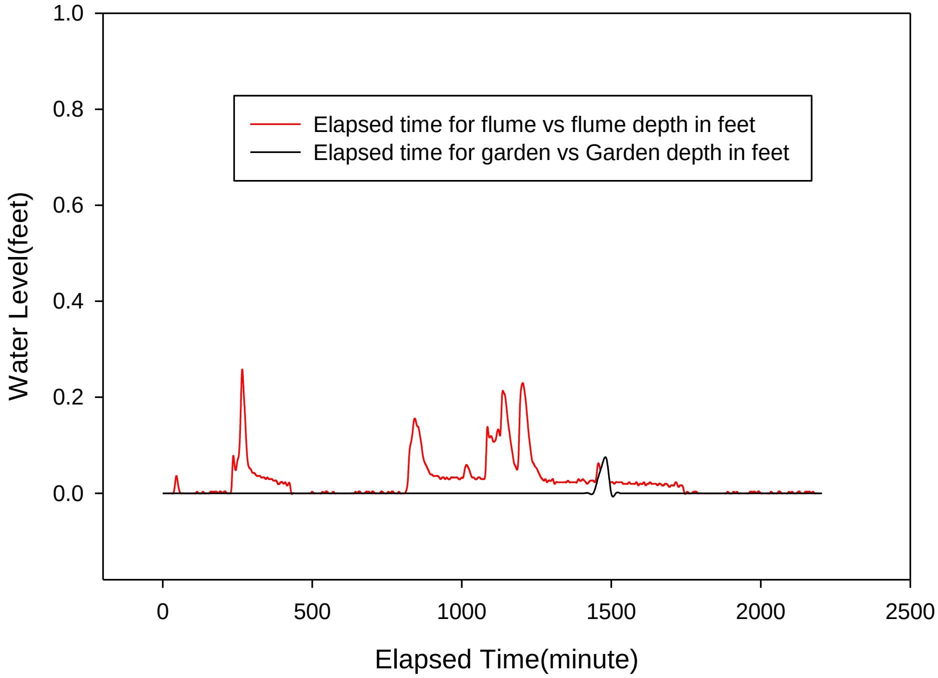
1324 76th on Rainevent 04/09/13--04/10/13



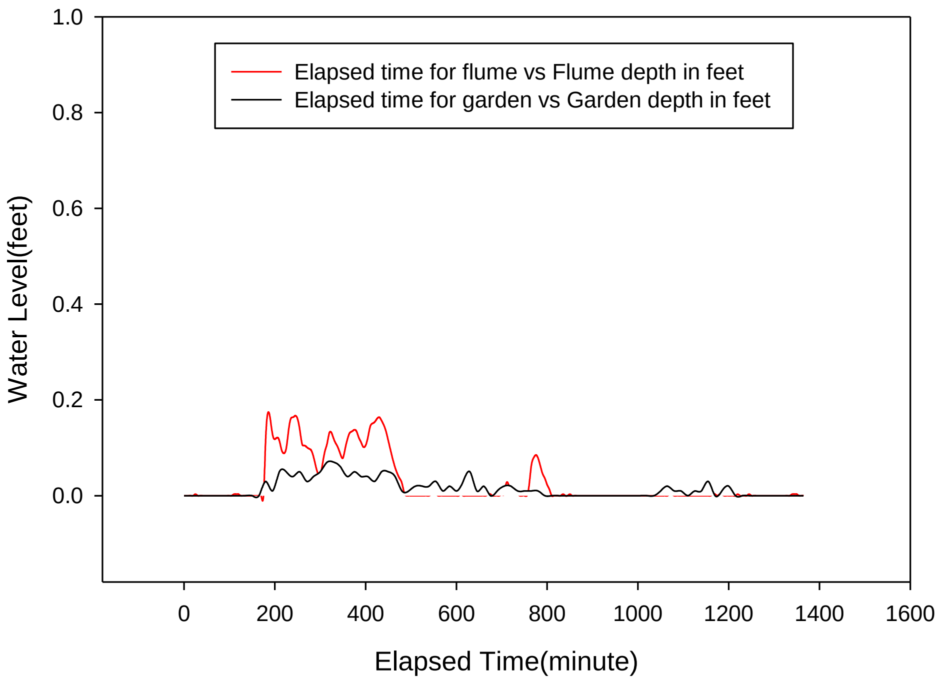
1324 76th on Rainevent 04/07/13



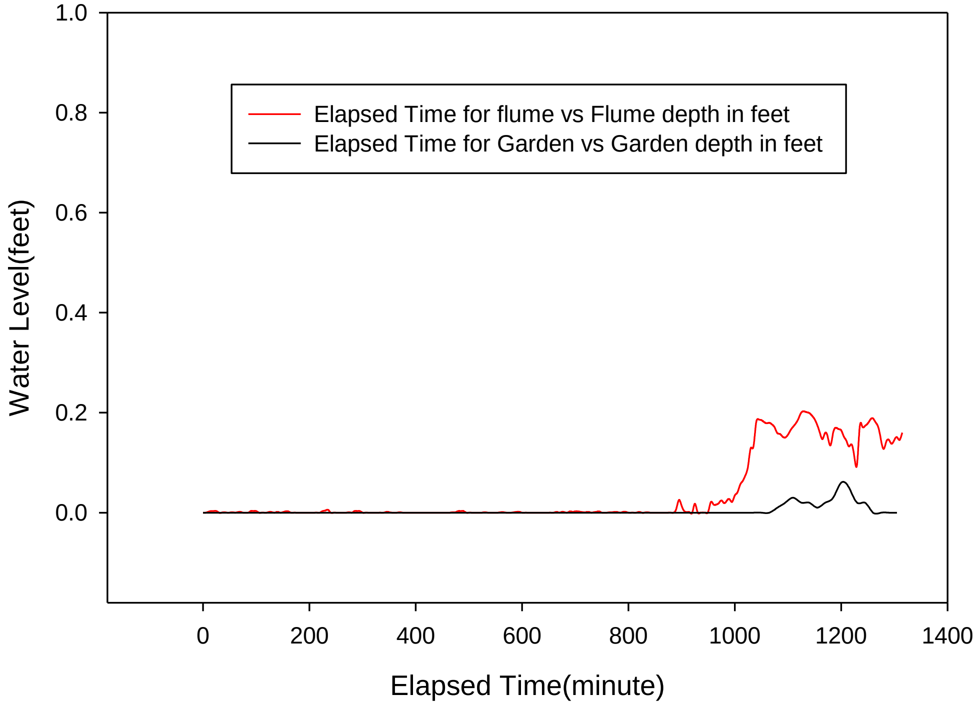
1324 76th Raingarden on Rainevent 10/13/2012



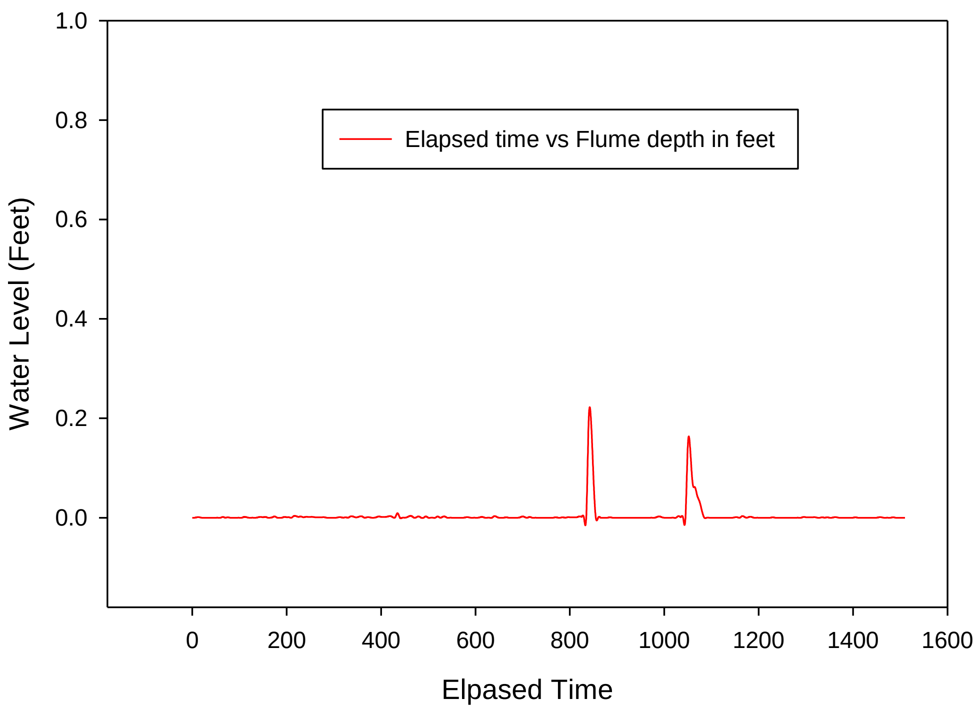
1324 76th Raingarden on Rainevent 9/13/2012



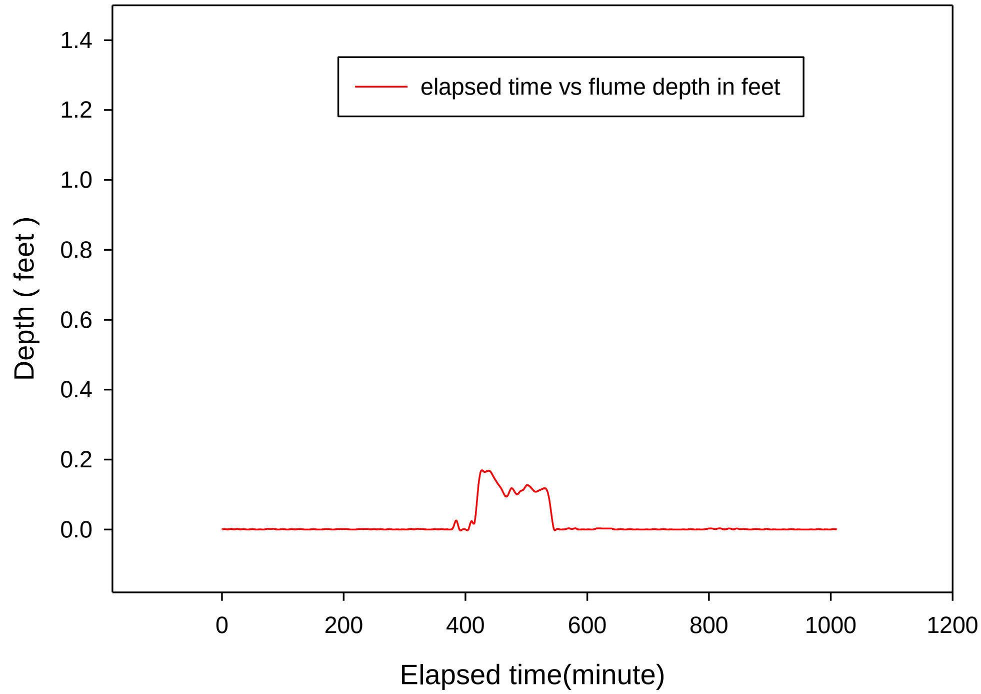
1324 76th Raingarden on Rainevent 8/31/2012



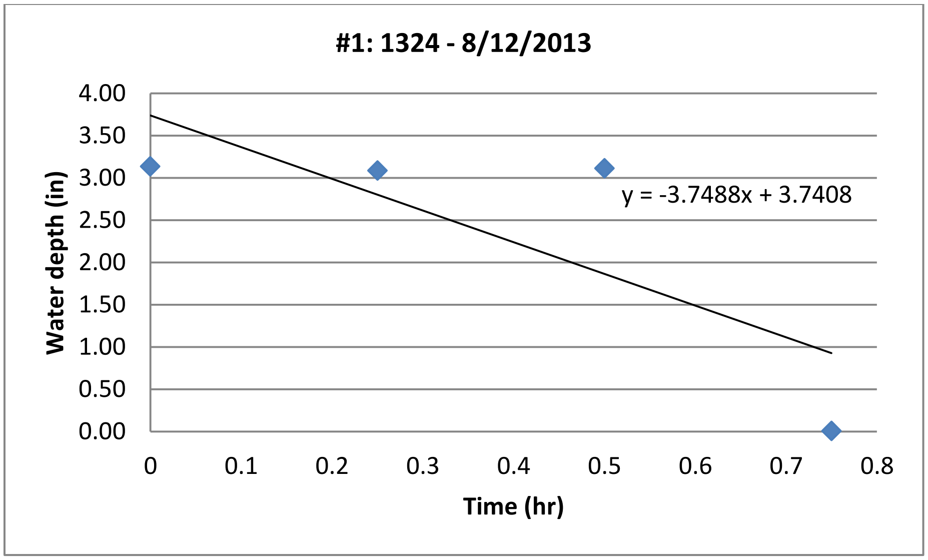
1324 76th Raingarden on Rainevent 7/26/2012

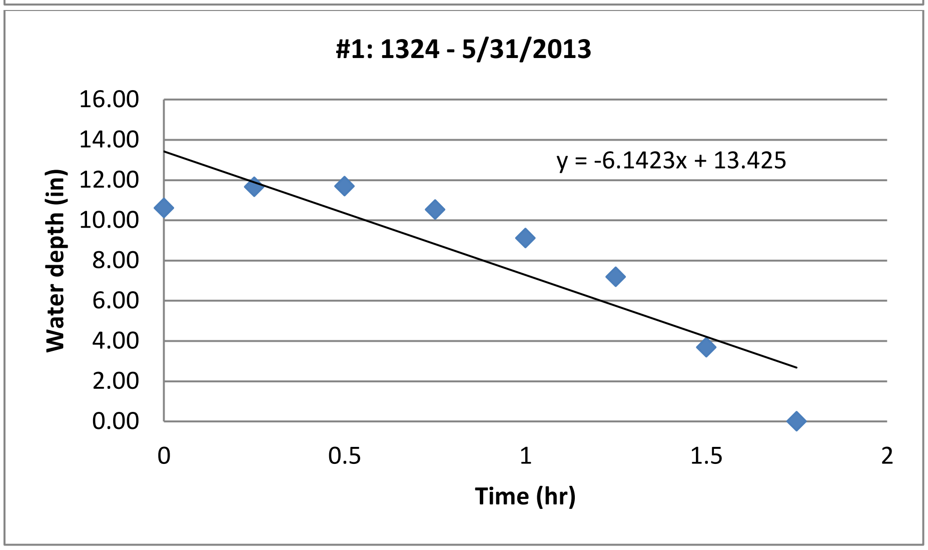


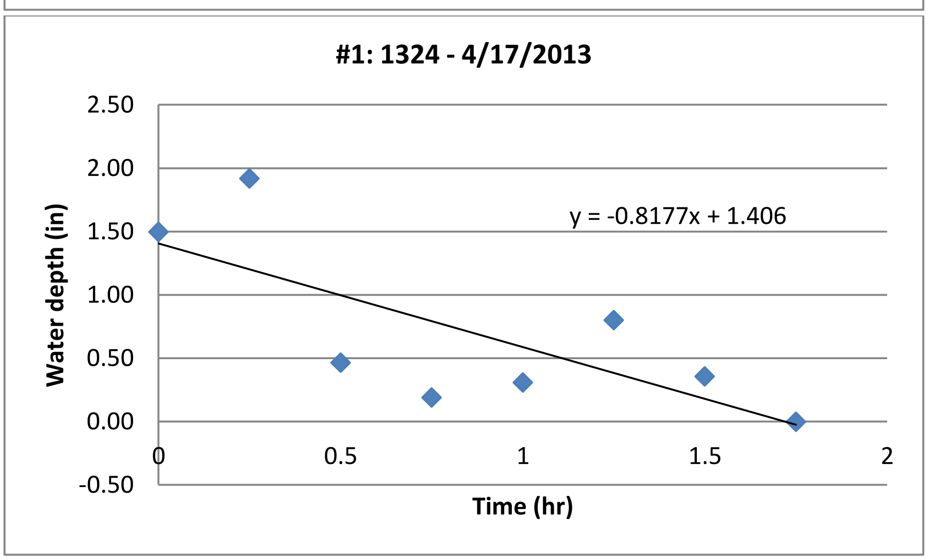
1324 76th Raingarden on Rainevent 6/21/2012

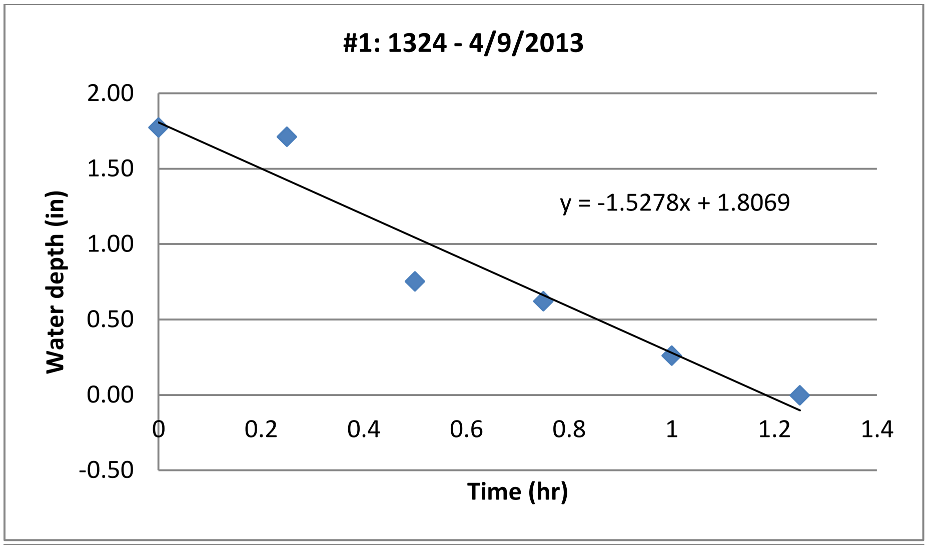


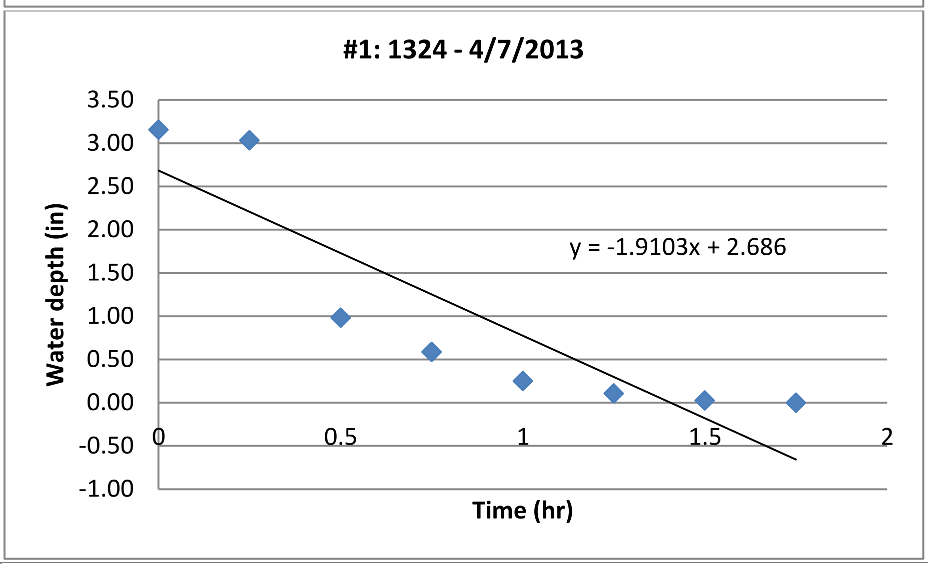
Rainfall Depth (in.)	Start Time	End Time	Event Duration (hr:min)	Max Water Depth in Garden (in)	Time Duration before Ponding Occurred (hr:min)	f (in/hr)
0.67	8/12/2013 7:07:00	8/12/2013 10:18:00	3:11	3.14	0	3.75
1.34	5/31/2013 5:26:00	5/31/2013 9:21:00	3:55	11.68	0:28	6.14
1.10	4/17/2013 11:00:00	4/18/2013 20:41:00	33:41	1.92	10:51	0.82
1.62	4/9/2013 21:56:00	4/10/2013 18:30:00	20:34	1.77	1:01	1.53
1.10	4/7/2013 19:52:00	4/8/2013 2:25:00	6:33	3.15	1:13	1.91
0.86	10/12/2012 21:00:00	10/14/2012 09:40:00	36:40	0.84	24:00	>3.36
0.43	9/13/2012 12:00:00	9/14/2012 10:45:00	22:45	0.84	17:30	0.288
					18:45	1.44
					20:00	0.96
2.61	8/31/2012 22:20:00	8/31/2012 20:15:00	21:55	0.72	18:00	>0.72
0.49	7/25/2012 11:15:00	7/26/2012 12:25:00	25:10	0		
1.03	6/20/2012 19:05:00	6/21/2012 11:55:00	16:50	0		

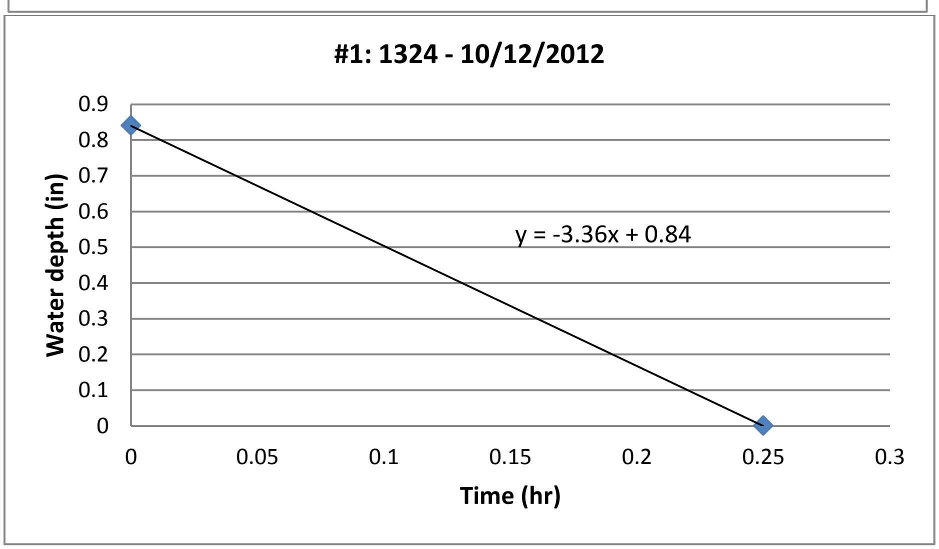

#1: 1324 - 8/12/2013
Water depth (in)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Time (hr)
y = -3.7488x + 3.7408

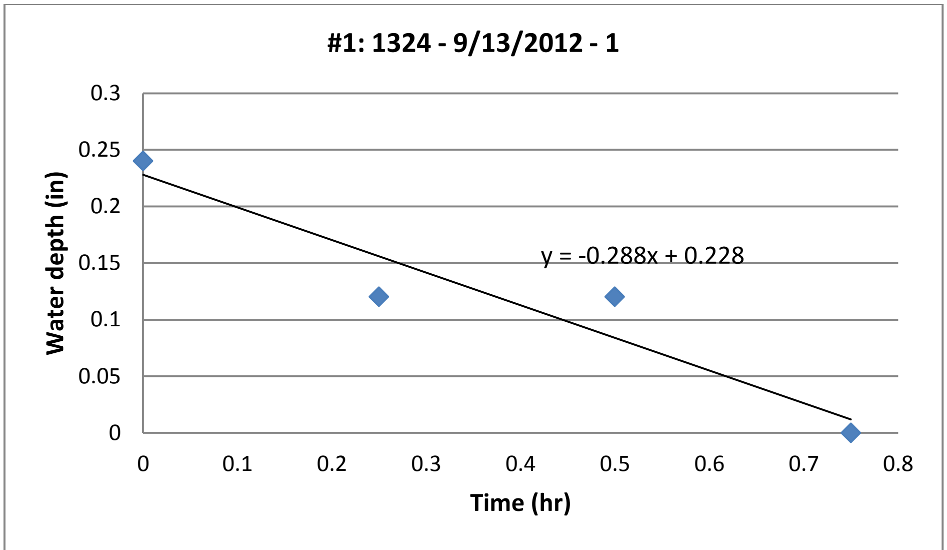

#1: 1324 - 5/31/2013
Water depth (in)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
0.5
1
1.5
2
Time (hr)
y = -6.1423x + 13.425

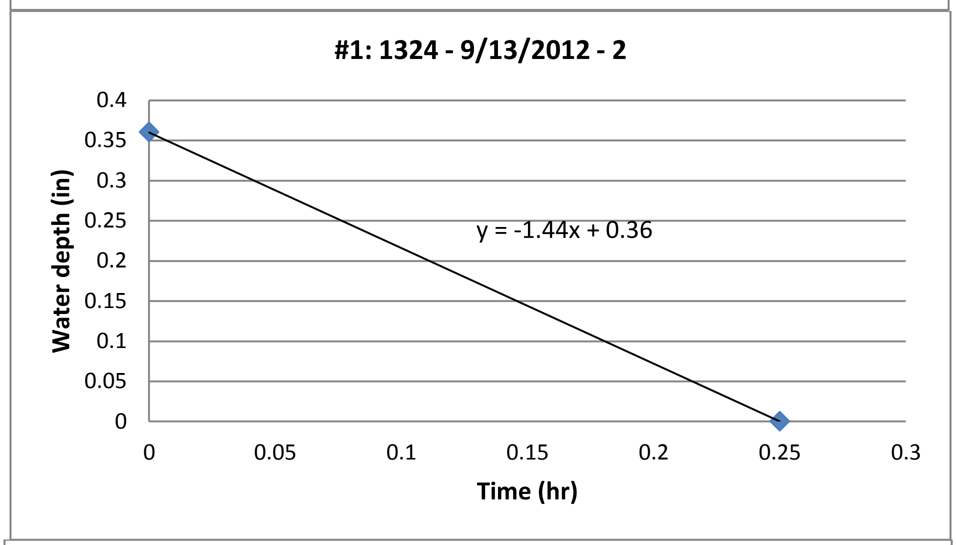

#1: 1324 - 4/17/2013
Water depth (in)
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
0
0.5
1
1.5
2
Time (hr)
y = -0.8177x + 1.406

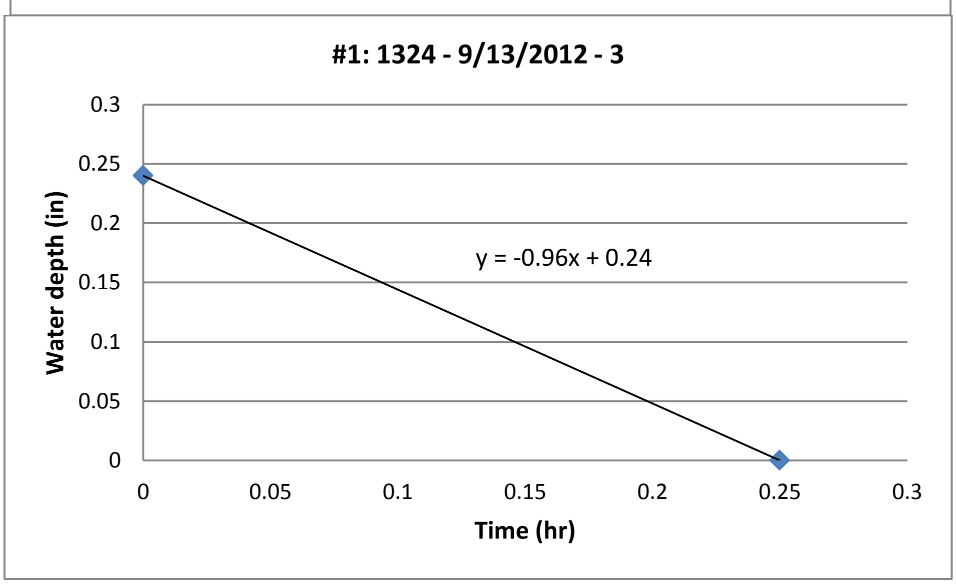

#1: 1324 - 4/9/2013
Water depth (in)
Time (hr)
y = -1.5278x + 1.8069
2.00
1.50
1.00
0.50
0.00
-0.50
0
0.2
0.4
0.6
0.8
1
1.2
1.4

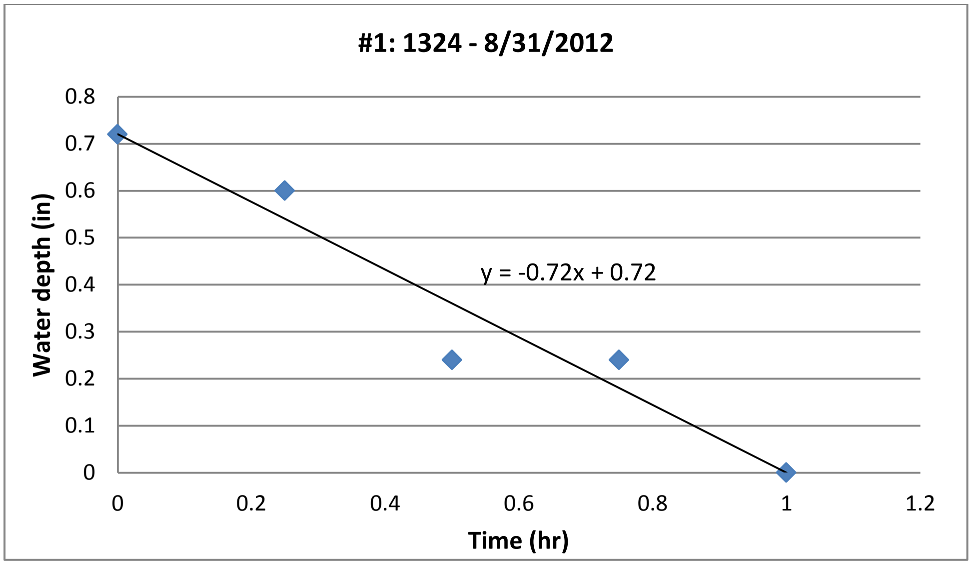

#1: 1324 - 4/7/2013
Water depth (in)
Time (hr)
y = -1.9103x + 2.686
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
0
0.5
1
1.5
2


#1: 1324 - 10/12/2012
Water depth (in)
Time (hr)
y = -3.36x + 0.84
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.05
0.1
0.15
0.2
0.25
0.3

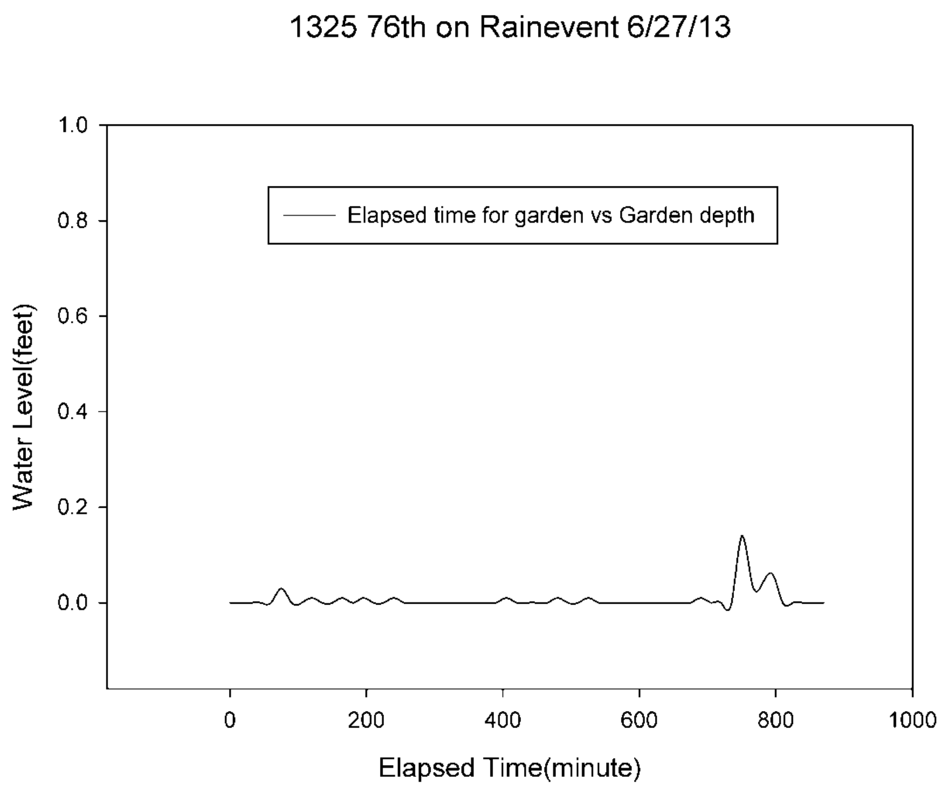

#1: 1324 - 9/13/2012 - 1
Water depth (in)
0.3
0.25
0.2
0.15
0.1
0.05
0
y = -0.288x + 0.228
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8
Time (hr)

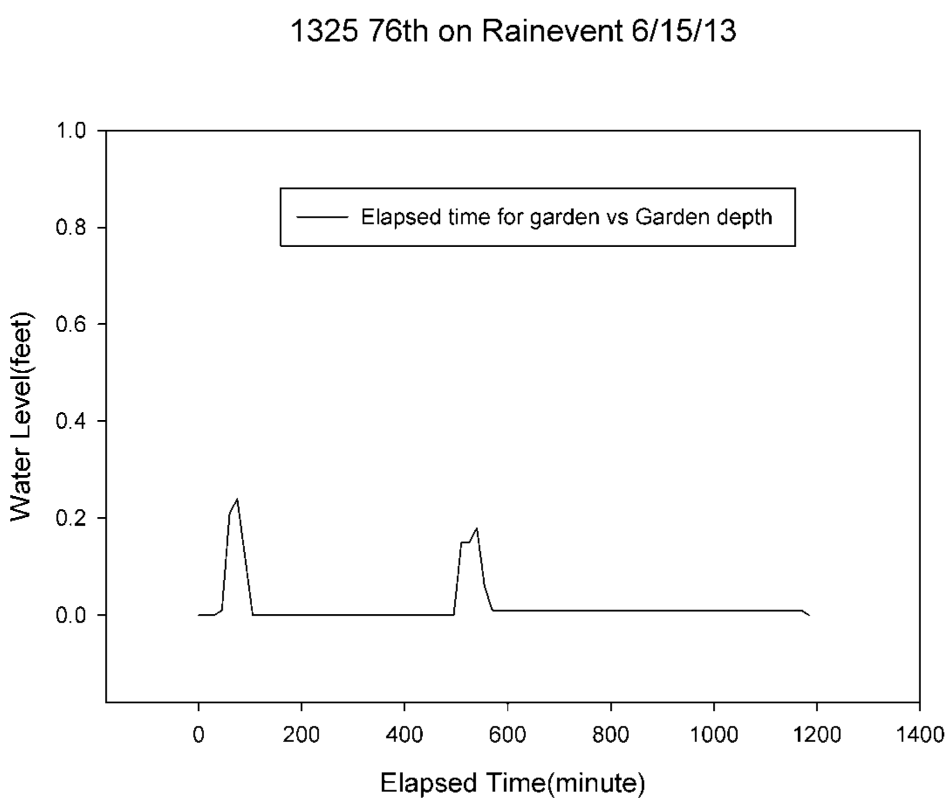

#1: 1324 - 9/13/2012 - 2
Water depth (in)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
y = -1.44x + 0.36
0 0.05 0.1 0.15 0.2 0.25 0.3
Time (hr)


#1: 1324 - 9/13/2012 - 3
Water depth (in)
0.3
0.25
0.2
0.15
0.1
0.05
0
y = -0.96x + 0.24
0 0.05 0.1 0.15 0.2 0.25 0.3
Time (hr)

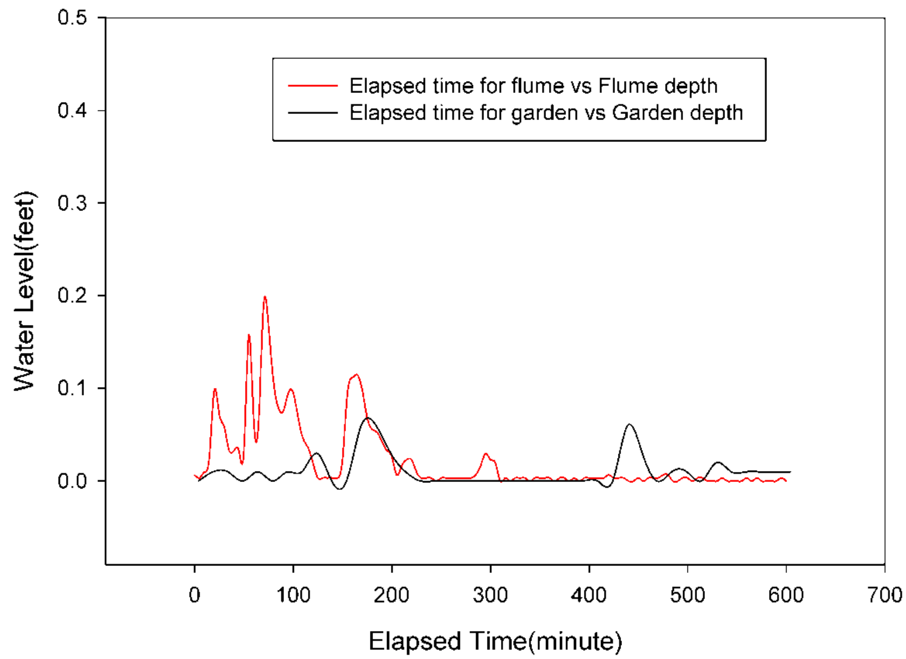

#1: 1324 - 8/31/2012
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Water depth (in)
y = -0.72x + 0.72
0
0.2
0.4
0.6
0.8
1
1.2
Time (hr)

2- Curb Extension Biofilter - 1325 E 76th St.

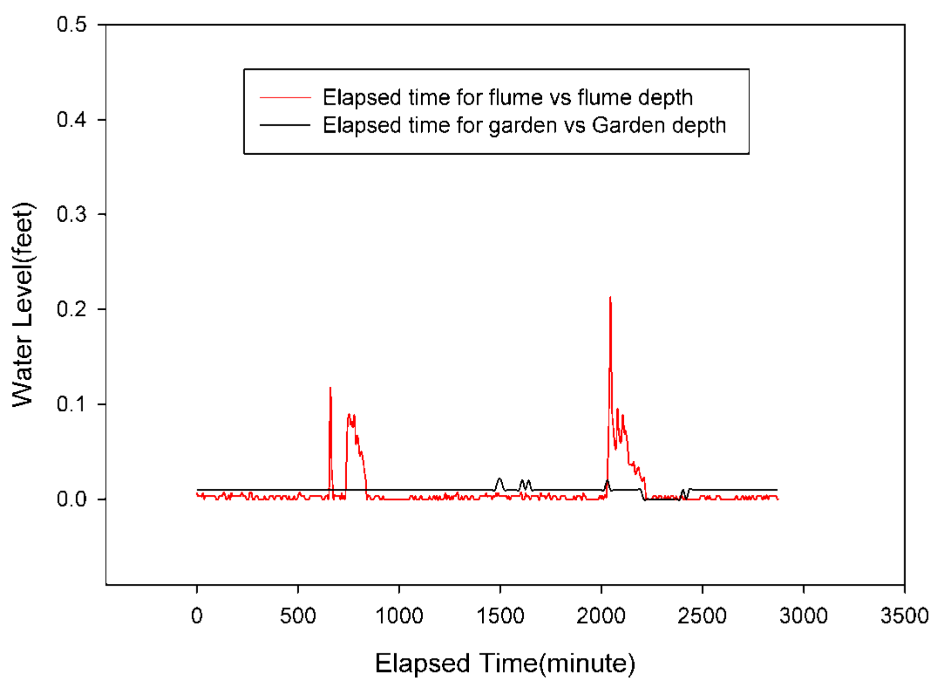




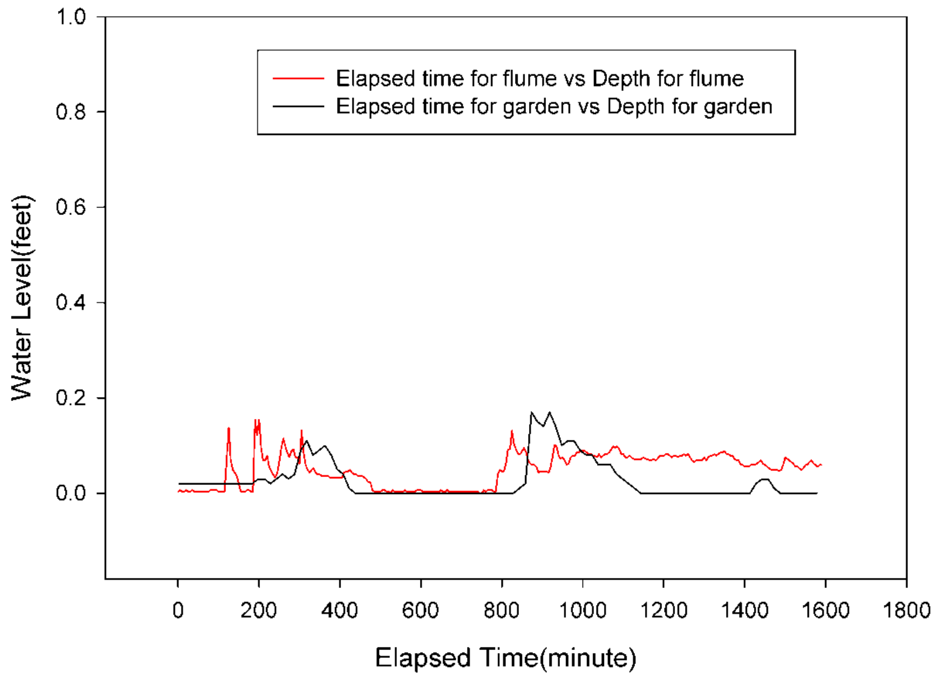
1325 76th on Rainevent 6/9/13



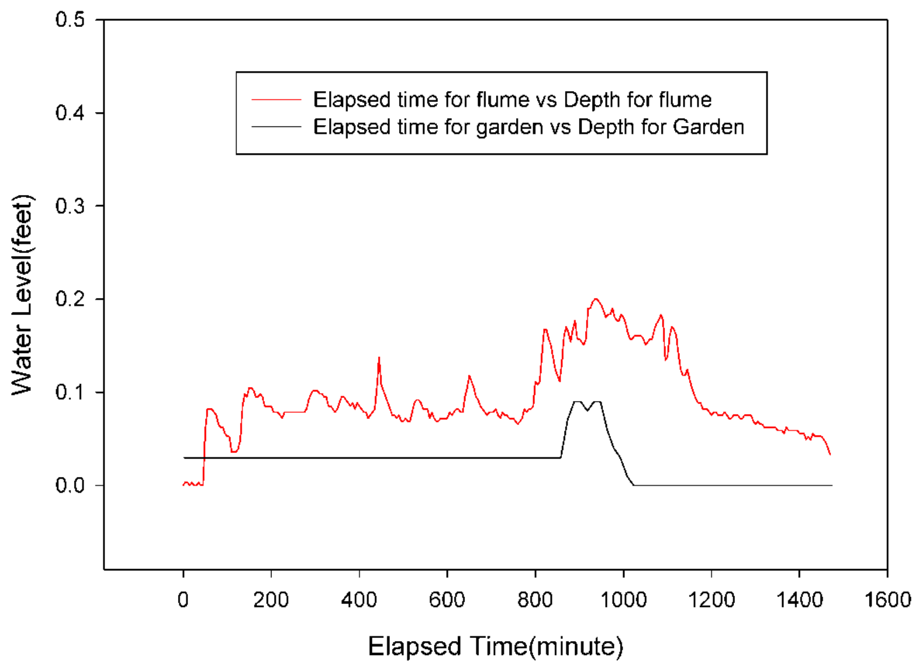
1325 76th on Rainevent 6/4/13-6/5/13



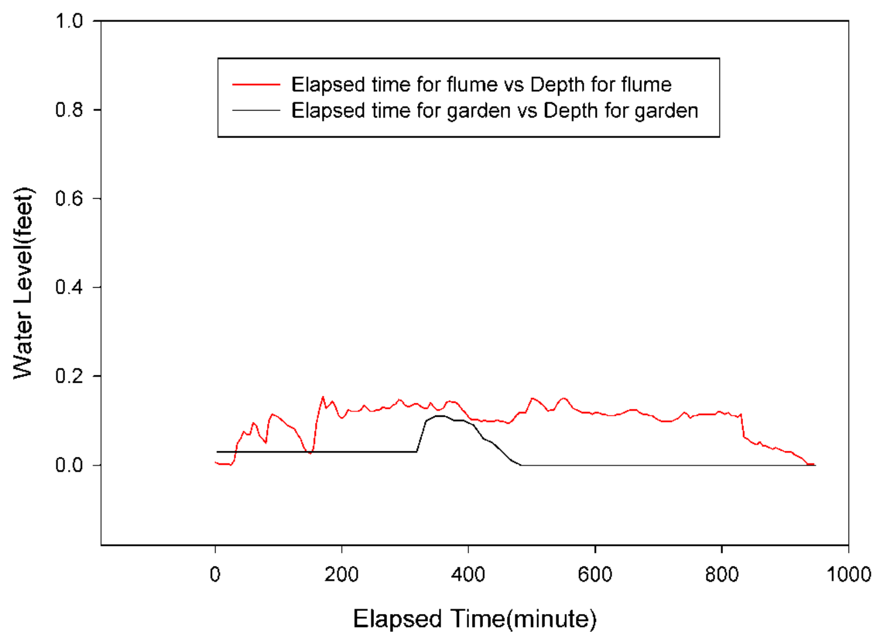
1325 76th on Rainevent 5/2/13-5/3/13



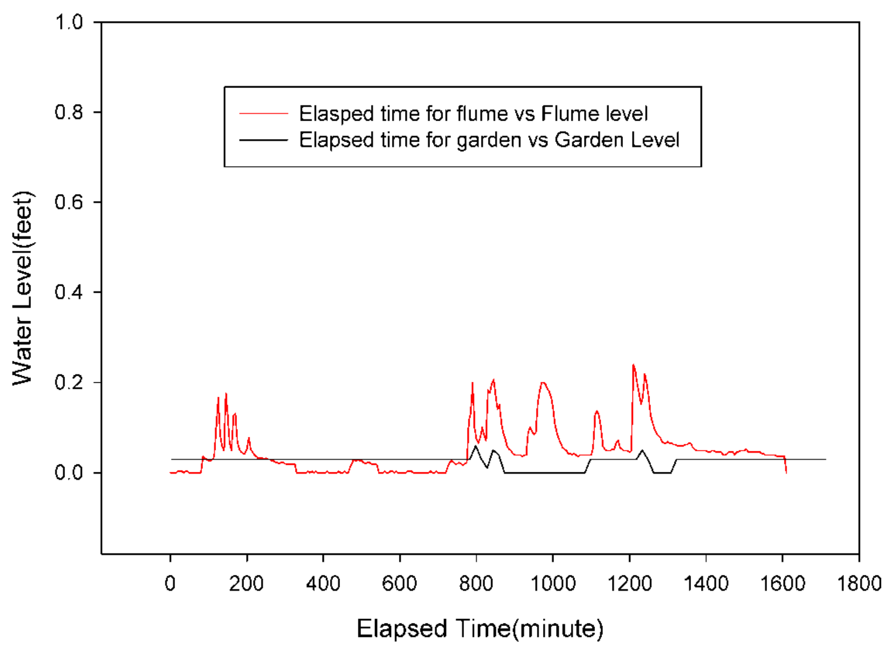
1325 76th on Rainevent 04/26/13-04/27/13

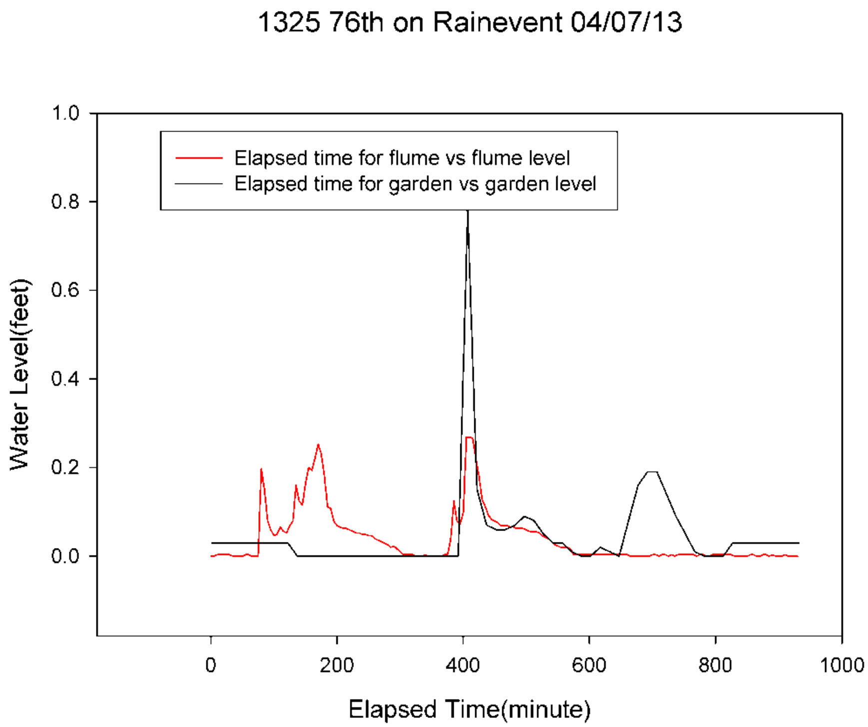


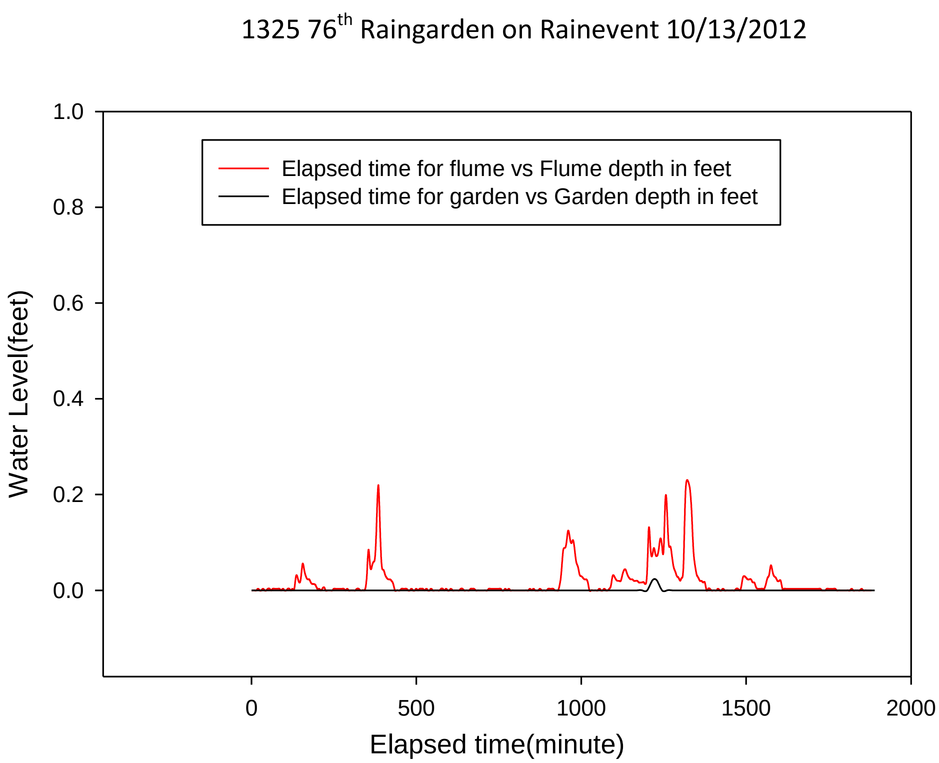
1325 76th on Rainevent 04/23/13



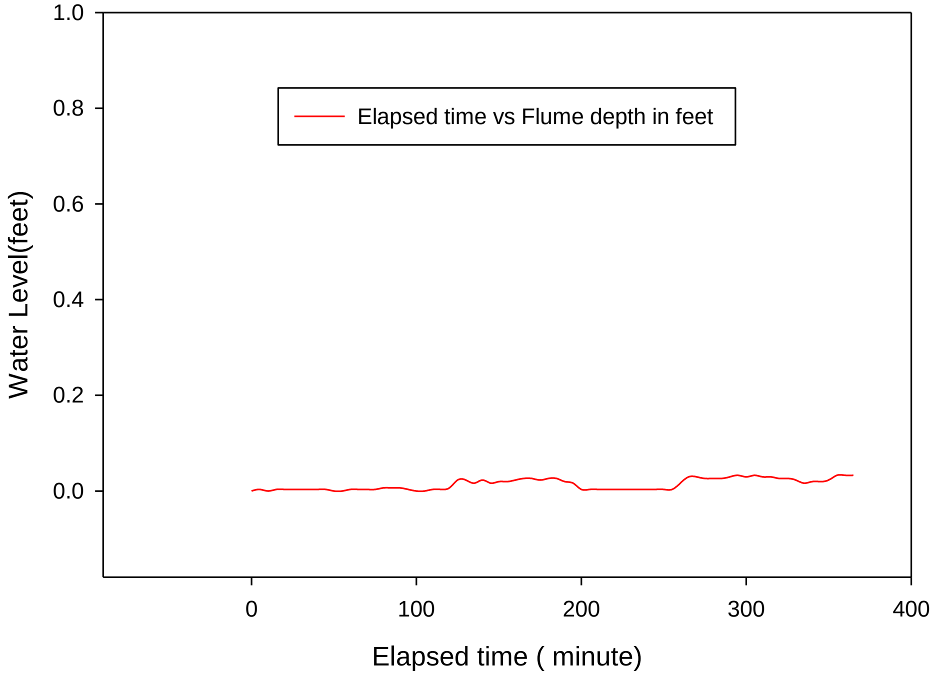
1325 76th on Rainevent 04/17/13-04/18/13



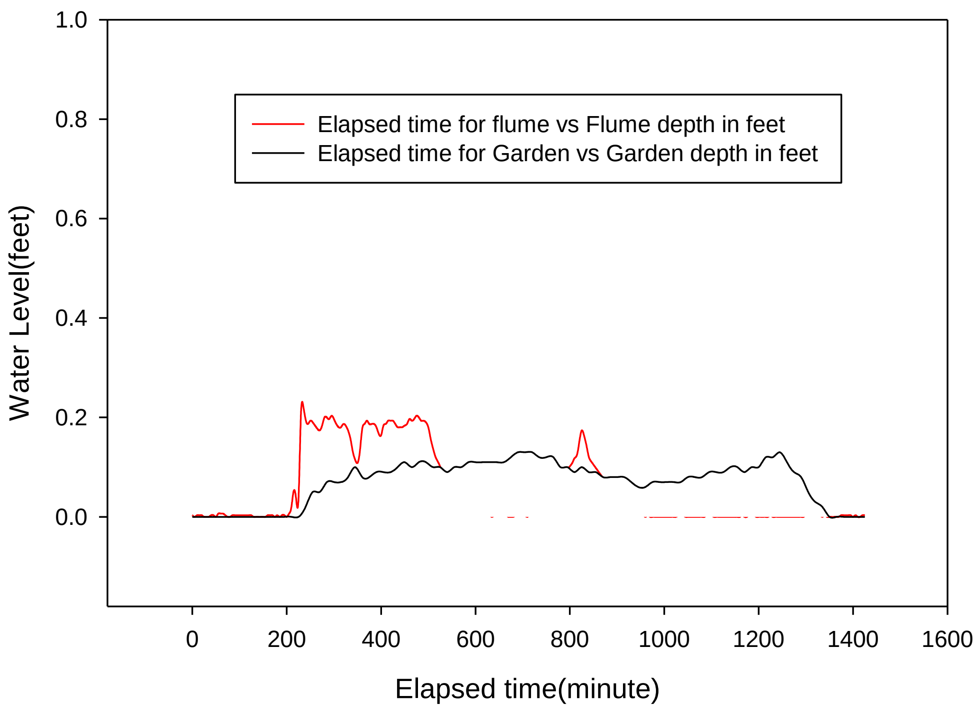

1325 76th on Rainevent 04/07/13
Elapsed time for flume vs flume level
Elapsed time for garden vs garden level
Water Level(feet)
1.0
0.8
0.6
0.4
0.2
0.0
0
200
400
600
800
1000
Elapsed Time(minute)


1325 76th Raingarden on Rainevent 10/13/2012
Elapsed time for flume vs Flume depth in feet
Elapsed time for garden vs Garden depth in feet
Water Level(feet)
1.0
0.8
0.6
0.4
0.2
0.0
0
500
1000
1500
2000
Elapsed time(minute)

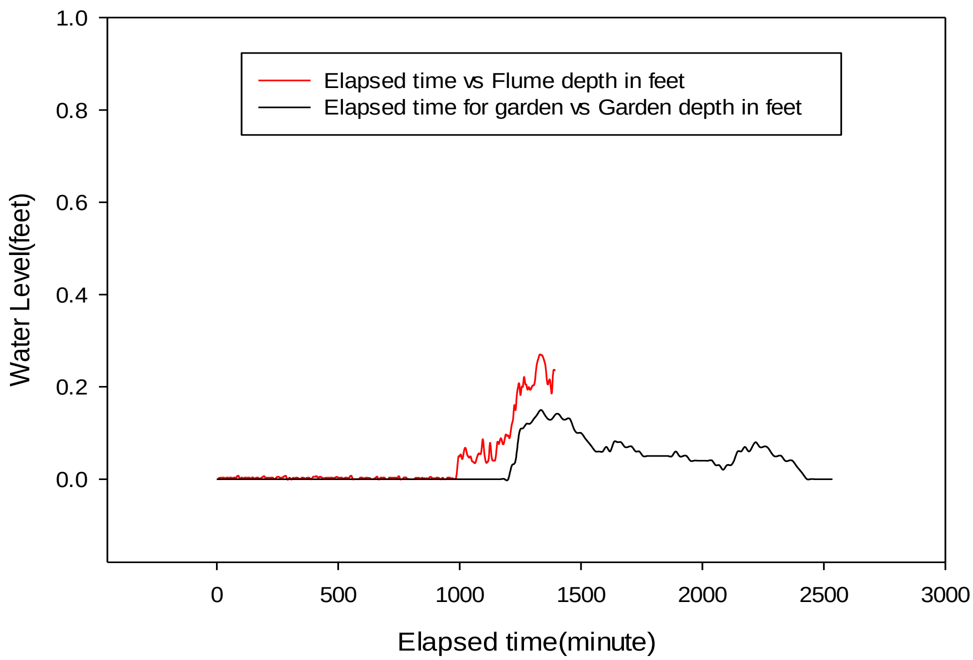
1325 76th Raingarden on Rainevent 9/26/2012



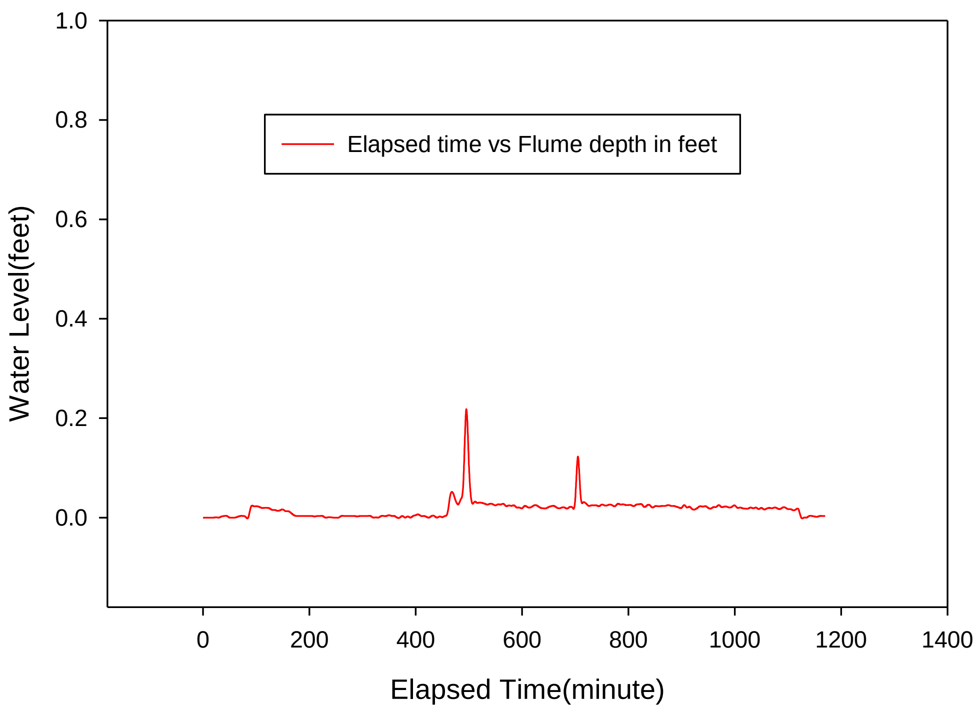
1325 76th Raingarden on Rainevent 9/13/2012



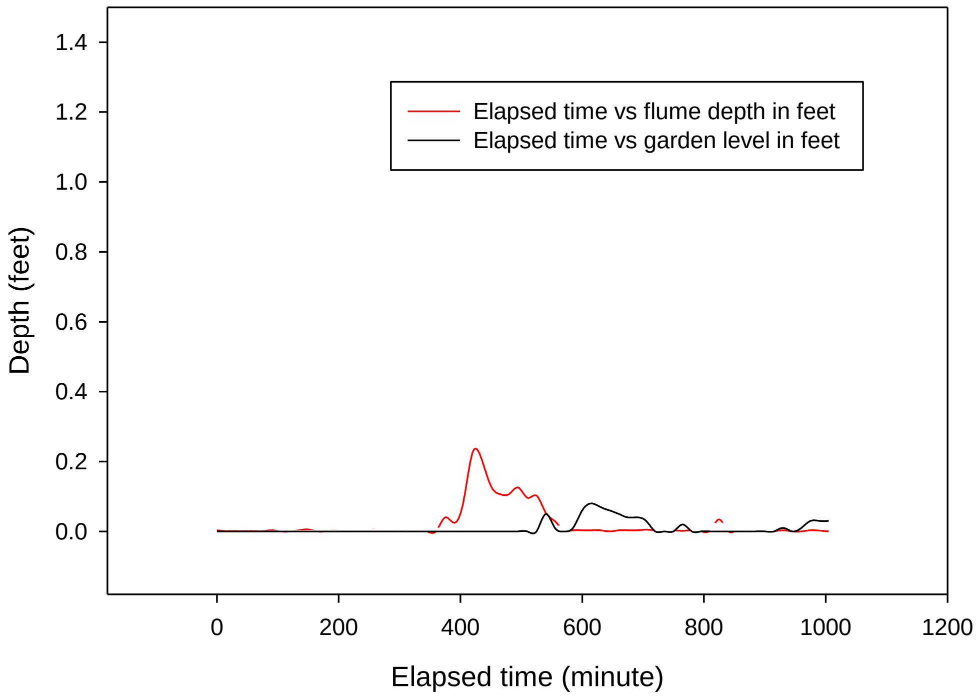
1325 76th Flume on Rainevent 08/31/2012



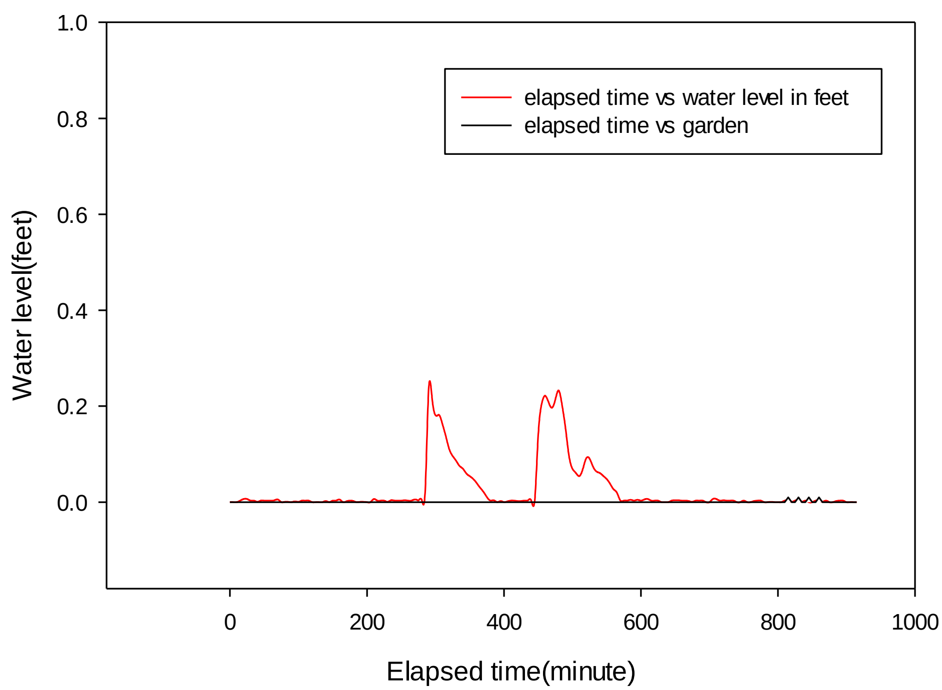
1325 76th Raingarden on Rainevent 7/26/2012



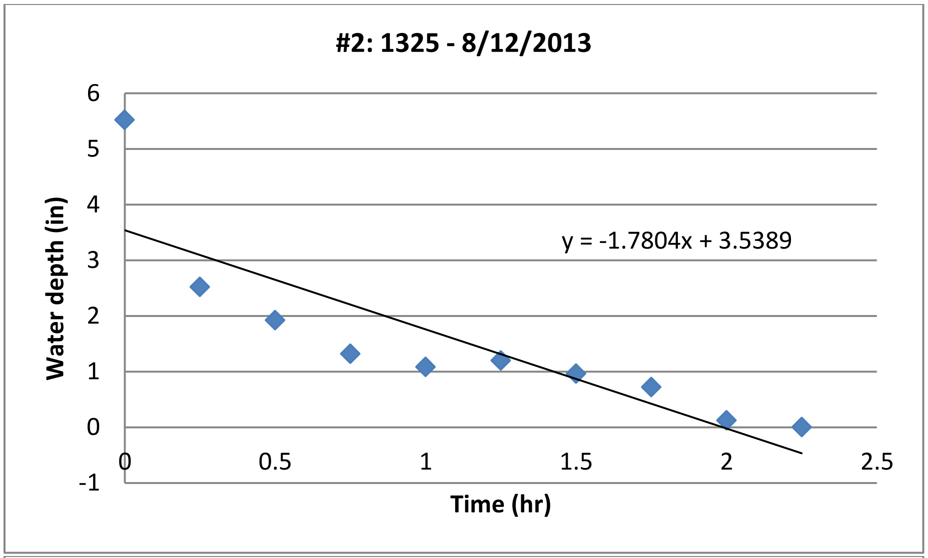
1325 76th Raingarden on Rainevent 6/21/2012

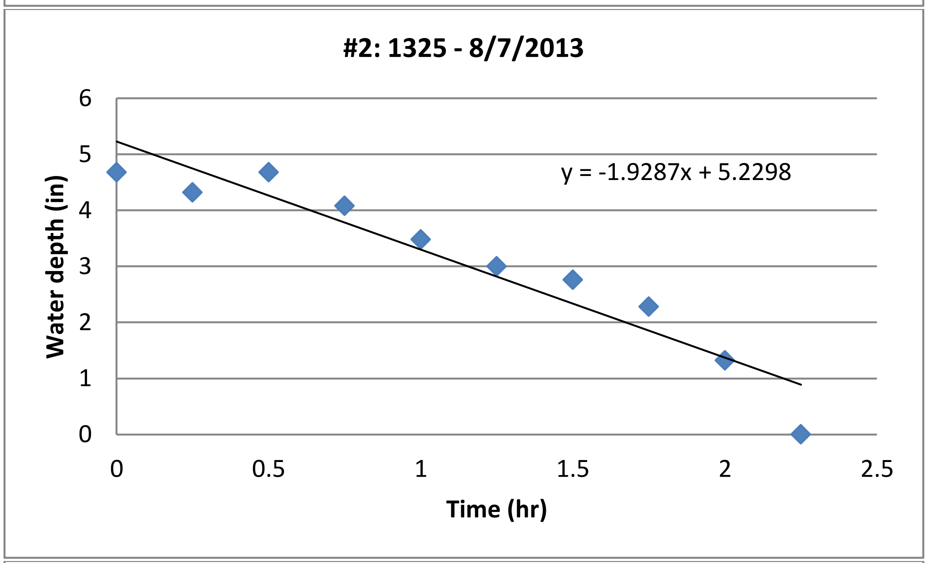


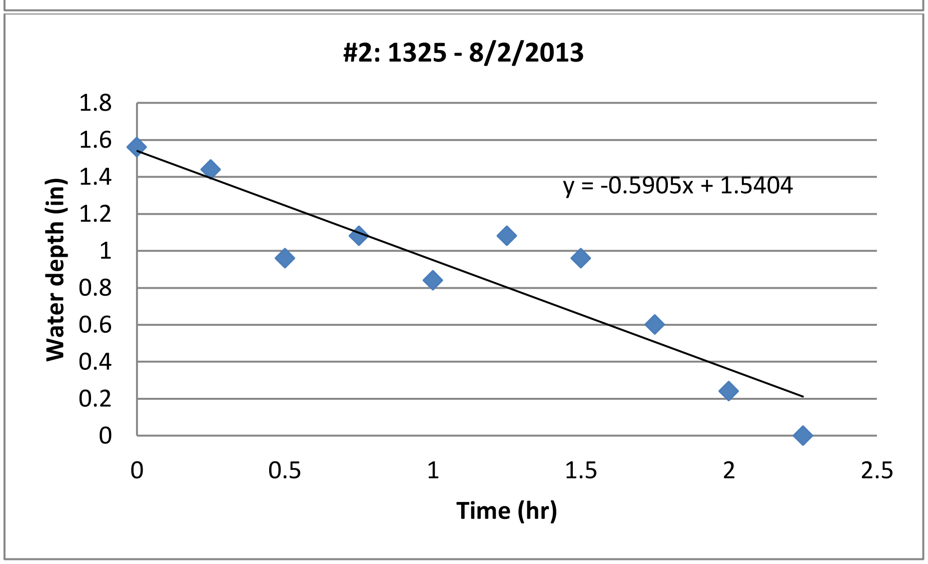
1325 76th Raingarden on Rainevent 06/11/2012

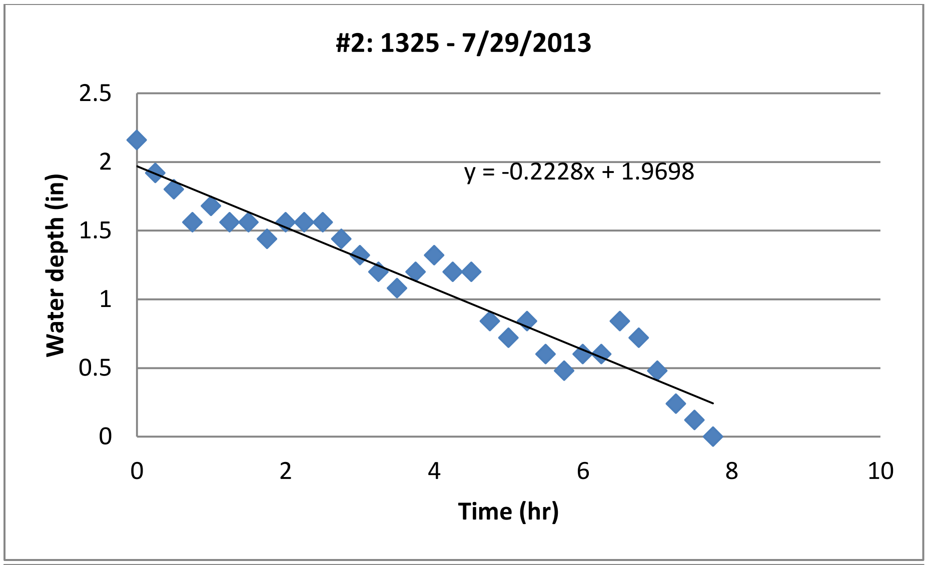


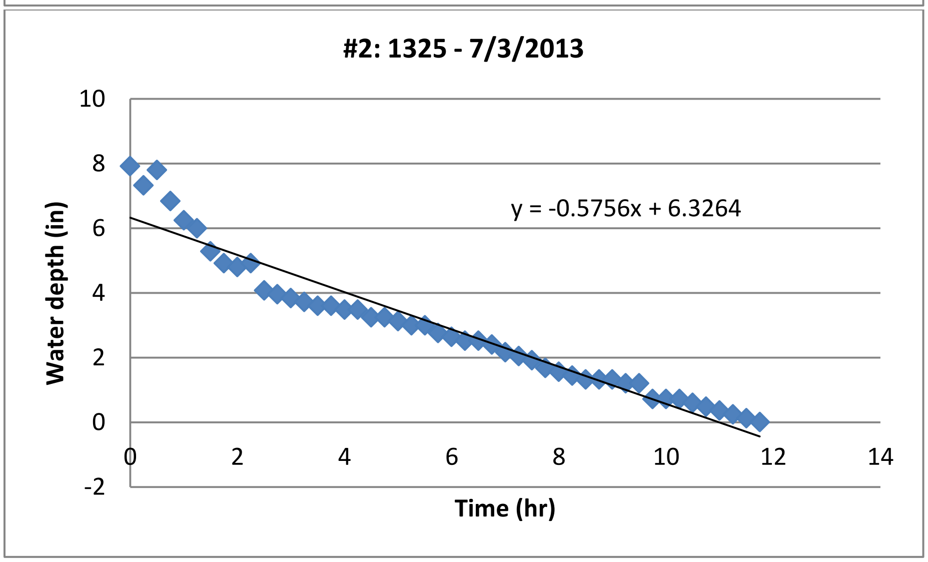
Rainfall Depth (in.)	Start Time	End Time	Event Duration (hr:min)	Max Water Depth in Garden (in)	Time Duration before Ponding Occurred (hr:min)	f (in/hr)
0.67	8/12/2013 7:07:00	8/12/2013 10:18:00	3:11	5.52	0:16	1.78
0.87	8/7/2013 4:13:00	8/7/2013 8:45:00	4:32	4.68	2:25	1.93
0.32	8/2/2013 3:46:00	8/2/2013 8:10:00	4:24	1.56	2:07	0.59
0.91	7/29/2013 6:27:00	7/30/2013 9:41:00	27:14	2.16	11:26	0.22
1.5	7/3/2013 17:54:00	7/3/2013 21:36:00	3:42	7.92	2:10	0.58
0.83	6/27/2013 11:46:00	6/28/2013 0:49:00	13:03	8.16	11:18	0.94
1.26	6/15/2013 15:50:00	6/15/2013 22:05:00	6:15	6.24	0:14	0.79
0.39	6/9/2013 00:54:00	6/9/2013 3:53:00	2:59	2.52	1:55	0.62
0.47	6/5/2013 9:44:00	6/5/2013 12:47:00	3:03	2.64	3:05	0.85
1.42	5/2/2013 3:08:00	5/4/2013 4:11:00	49:03	2.04	12:10	0.46
0.95	4/26/2013 4:19:00	4/27/2013 11:02:00	30:43	4.44	23:31	0.42
0.39	4/23/2013 1:34:00	4/23/2013 10:53:00	9:19	6.12	4:14	0.38
1.10	4/17/2013 11:00:00	4/18/2013 20:41:00	33:41	2.16	12:03	0.87
1.10	4/7/2013 19:52:00	4/8/2013 2:25:00	6:33	9.36	5:25	0.99
0.86	10/12/2012 21:00:00	10/13/2012 22:15:00	25:15	0.24		
0.23	9/26/2012 02:25:00	9/26/2012* 04:30:00	02:05	0		
0.43	9/13/2012 14:10:00	9/14/2012 10:10:00	20:00	1.56	0:15	0.9
2.61	8/31/2012 11:00:00	8/31/2012 17:00:00	06:00	1.8	20:15	0.24
0.49	7/25/2012 17:55:00	7/26/2012 08:30:00	12:35	0		
1.03	6/21/2012 00:55:00	6/21/2012 11:25:00	10:30	0.96	9:45	0.47
0.8	6/10/2012 22:05:00	6/11/2012 13:20:00	15:15	0.12		

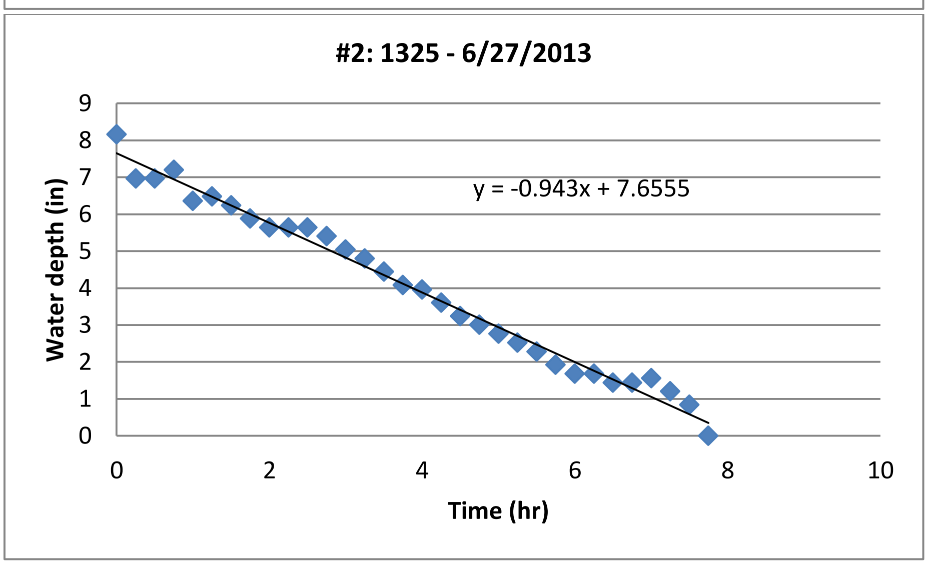

#2: 1325 - 8/12/2013
Water depth (in)
Time (hr)
y = -1.7804x + 3.5389
6
5
4
3
2
1
0
-1
0
0.5
1
1.5
2
2.5

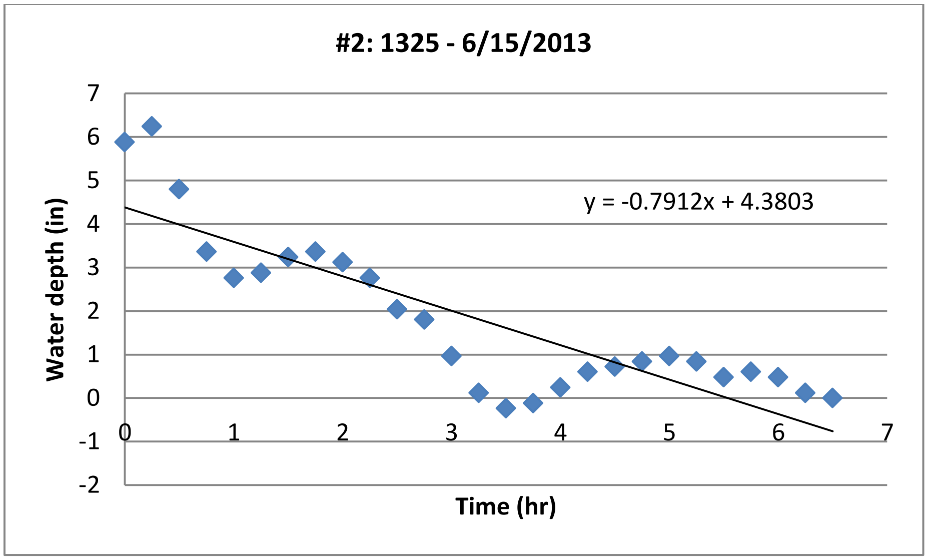

#2: 1325 - 8/7/2013
Water depth (in)
Time (hr)
y = -1.9287x + 5.2298
6
5
4
3
2
1
0
0
0.5
1
1.5
2
2.5

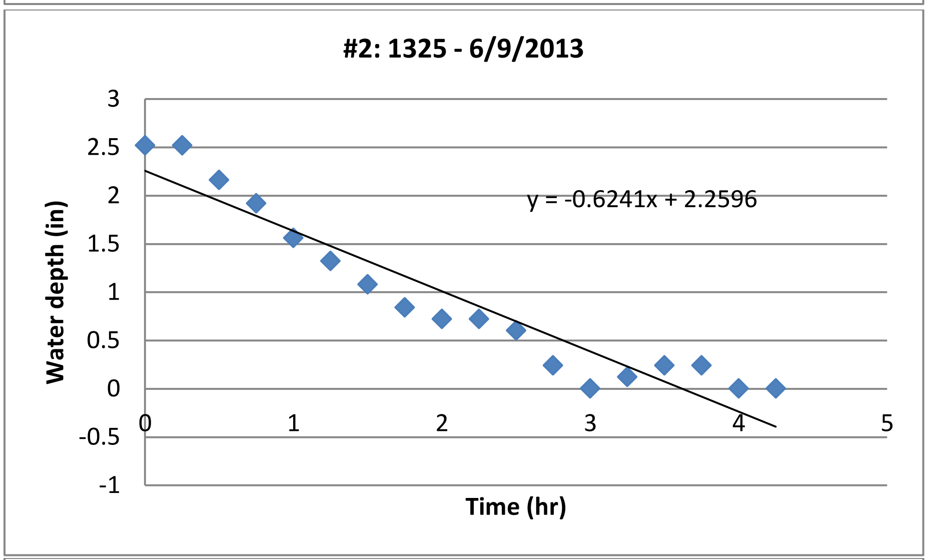

#2: 1325 - 8/2/2013
Water depth (in)
Time (hr)
y = -0.5905x + 1.5404
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5

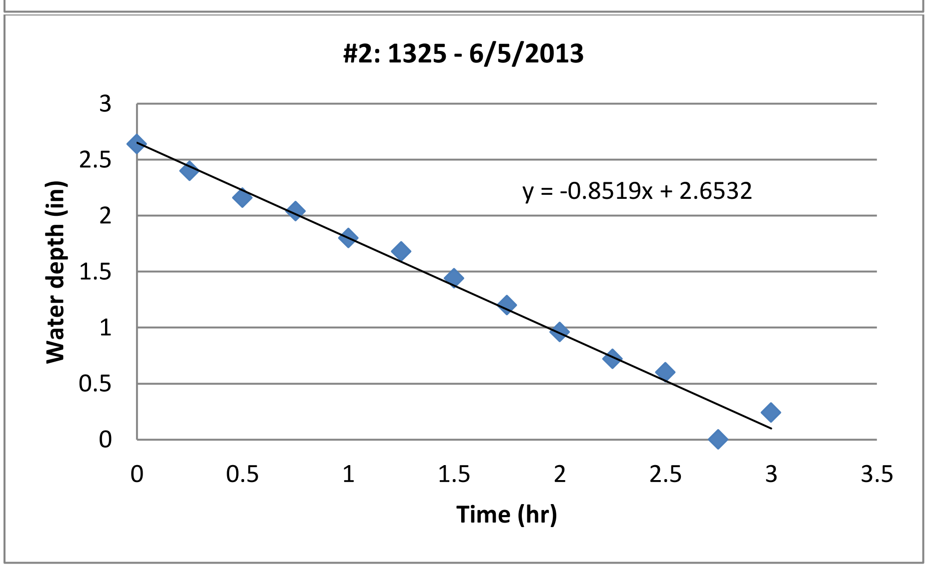

#2: 1325 - 7/29/2013
y = -0.2228x + 1.9698
Water depth (in)
Time (hr)
0
0.5
1
1.5
2
2.5
0
2
4
6
8
10

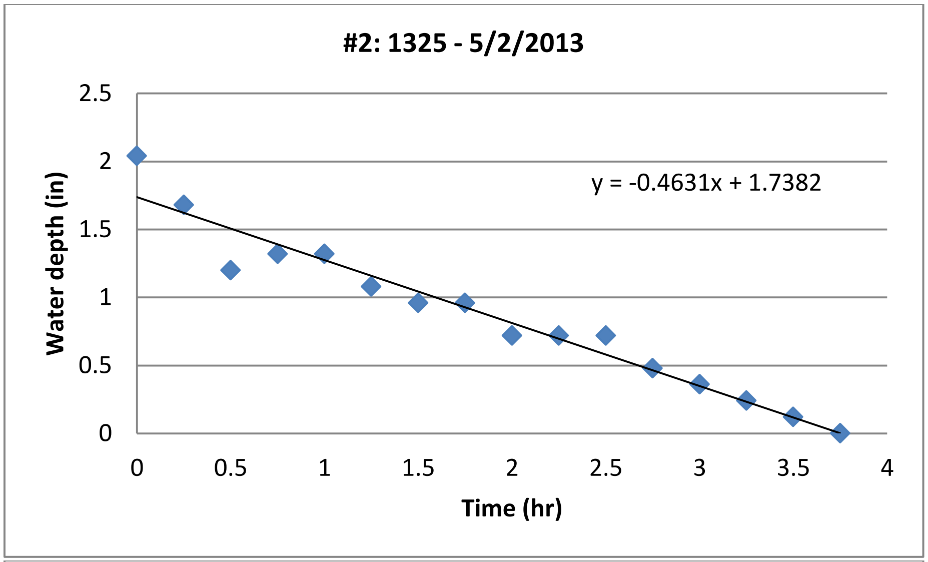

#2: 1325 - 7/3/2013
y = -0.5756x + 6.3264
Water depth (in)
Time (hr)
-2
0
2
4
6
8
10
0
2
4
6
8
10
12
14

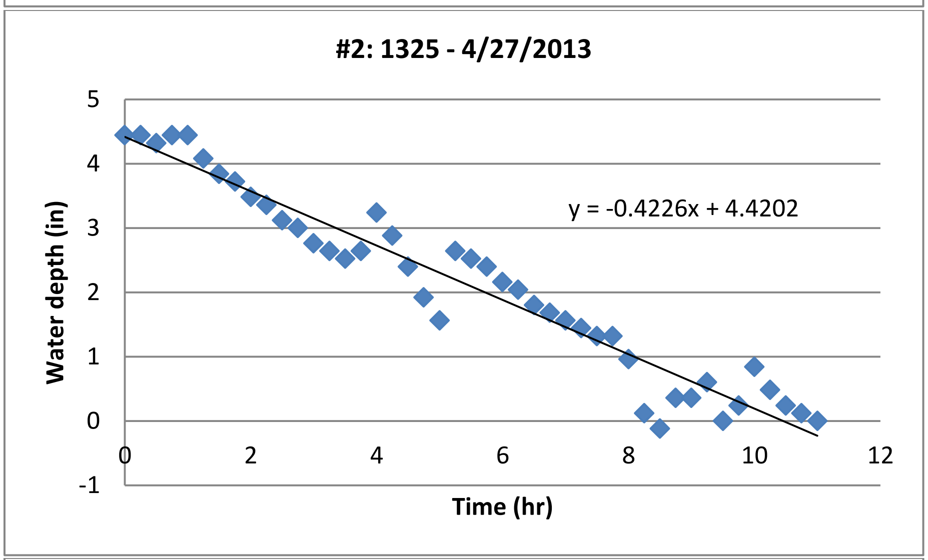

#2: 1325 - 6/27/2013
y = -0.943x + 7.6555
Water depth (in)
Time (hr)
0
1
2
3
4
5
6
7
8
9
0
2
4
6
8
10

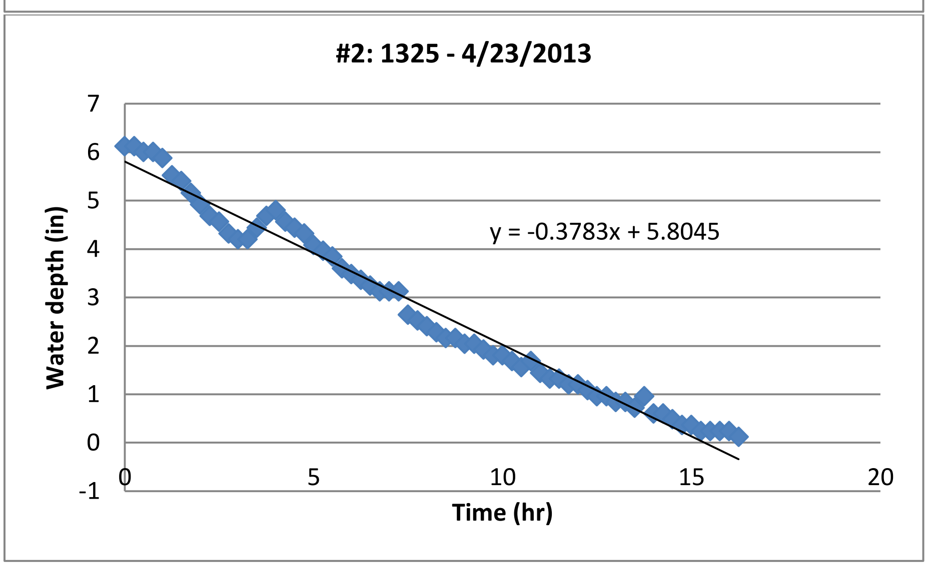

#2: 1325 - 6/15/2013
Water depth (in)
Time (hr)
y = -0.7912x + 4.3803

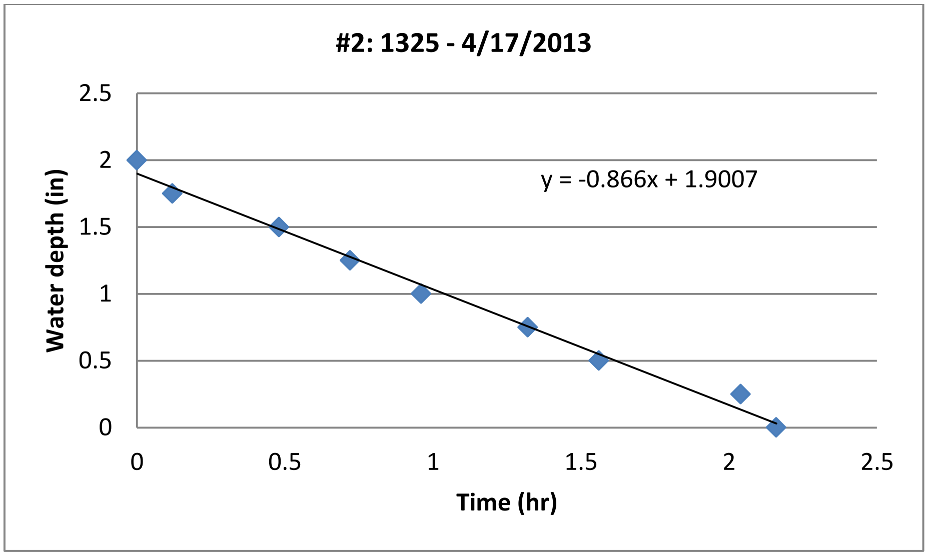

#2: 1325 - 6/9/2013
Water depth (in)
Time (hr)
y = -0.6241x + 2.2596

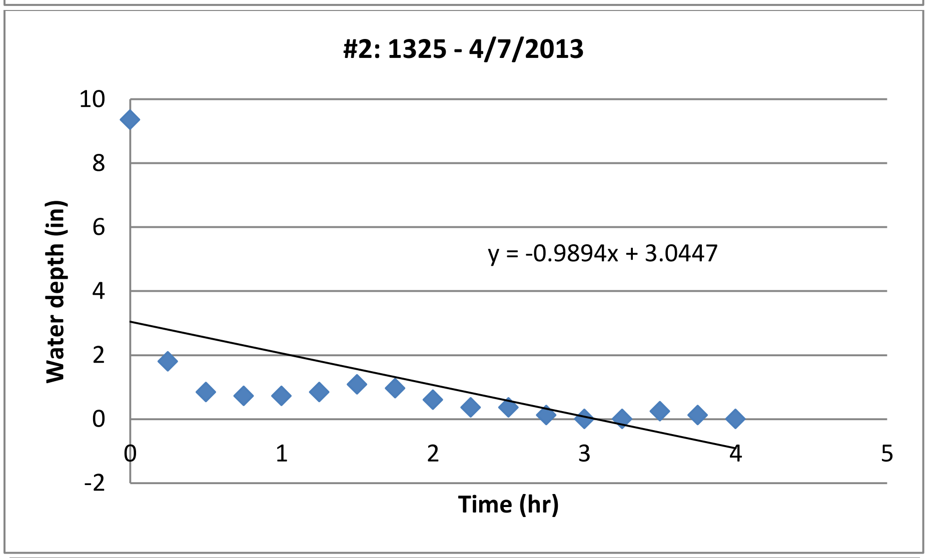

#2: 1325 - 6/5/2013
Water depth (in)
Time (hr)
y = -0.8519x + 2.6532

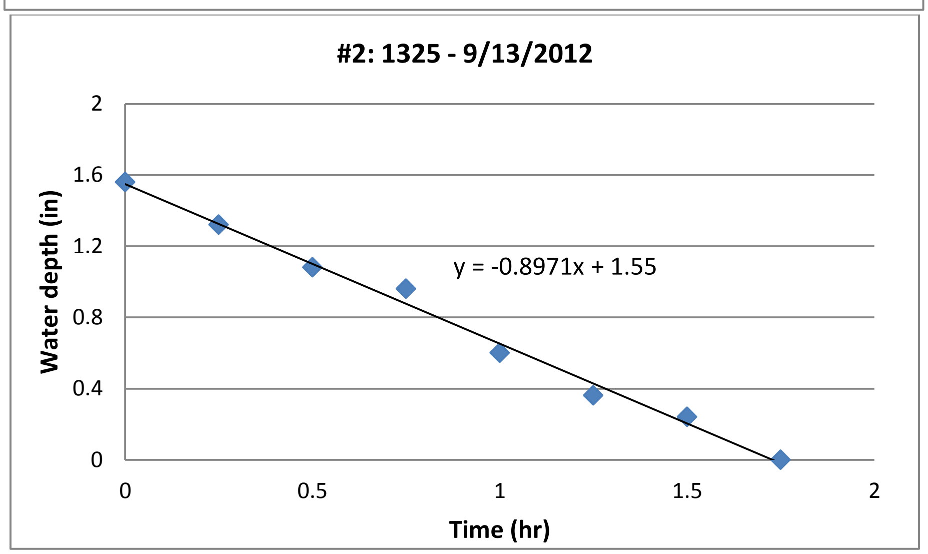

#2: 1325 - 5/2/2013
y = -0.4631x + 1.7382
Water depth (in)
Time (hr)
0
0.5
1
1.5
2
2.5
3
3.5
4

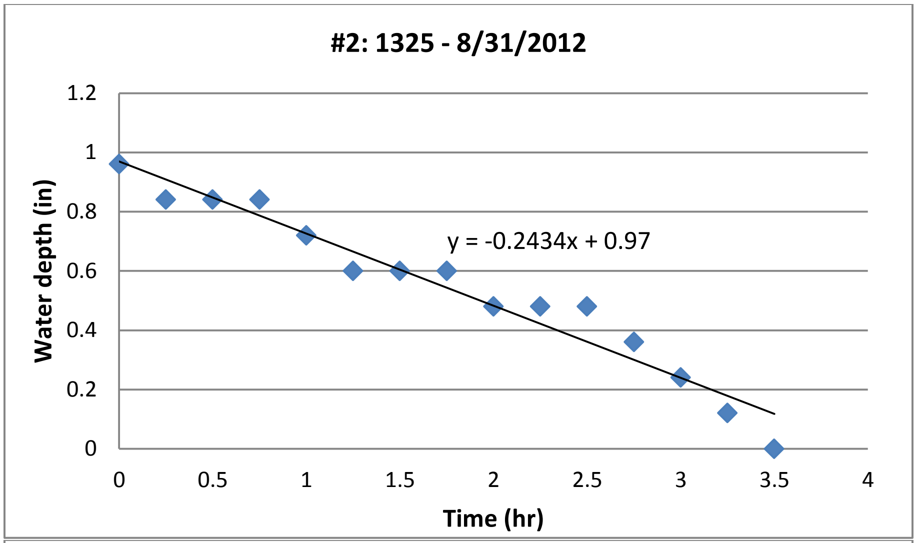

#2: 1325 - 4/27/2013
y = -0.4226x + 4.4202
Water depth (in)
Time (hr)
-1
0
1
2
3
4
5
6
8
10
12

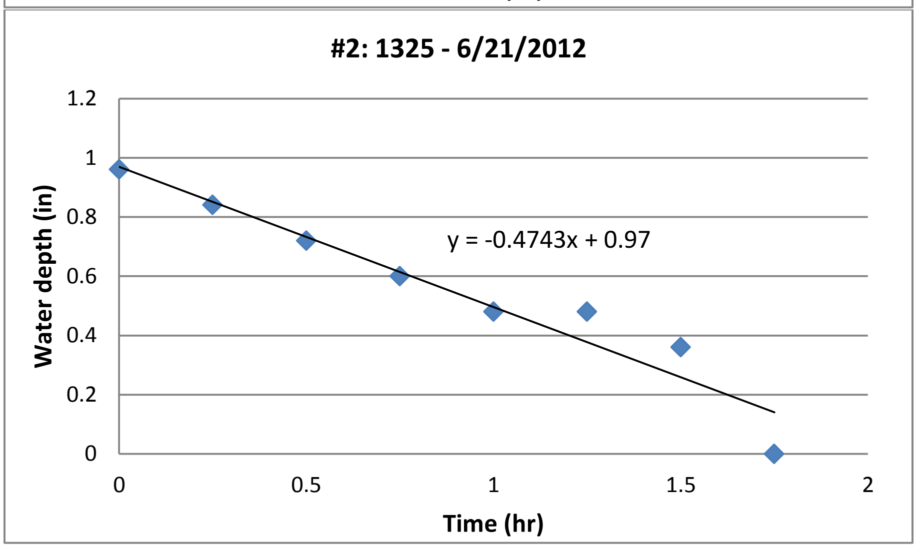

#2: 1325 - 4/23/2013
y = -0.3783x + 5.8045
Water depth (in)
Time (hr)
-1
0
1
2
3
4
5
6
7
10
15
20


#2: 1325 - 4/17/2013
y = -0.866x + 1.9007
Water depth (in)
Time (hr)
2.5
2
1.5
1
0.5
0
0
0.5
1
1.5
2
2.5

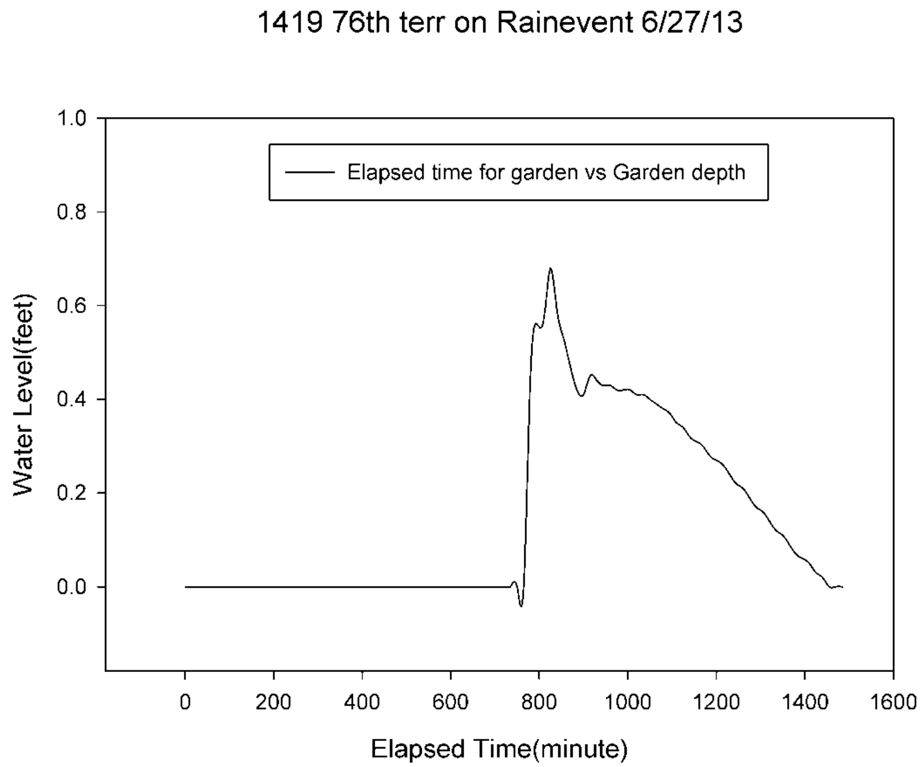

#2: 1325 - 4/7/2013
y = -0.9894x + 3.0447
Water depth (in)
Time (hr)
10
8
6
4
2
0
-2
0
1
2
3
4
5

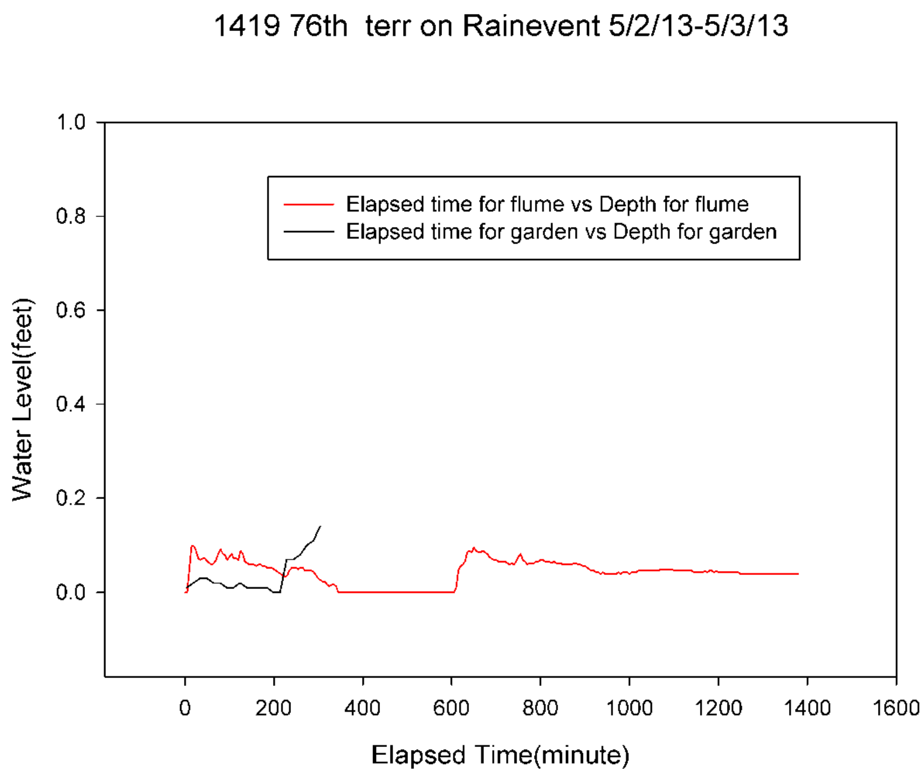

#2: 1325 - 9/13/2012
y = -0.8971x + 1.55
Water depth (in)
Time (hr)
2
1.6
1.2
0.8
0.4
0
0
0.5
1
1.5
2


#2: 1325 - 8/31/2012
Water depth (in)
1.2
1
0.8
0.6
0.4
0.2
0
y = -0.2434x + 0.97
0
0.5
1
1.5
2
2.5
3
3.5
4
Time (hr)

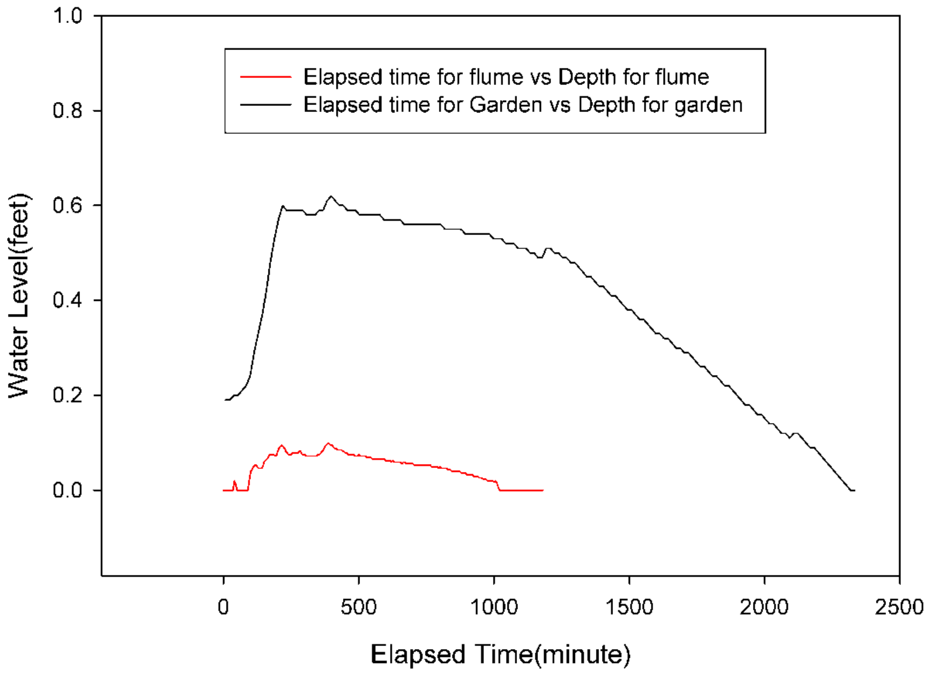

#2: 1325 - 6/21/2012
Water depth (in)
1.2
1
0.8
0.6
0.4
0.2
0
y = -0.4743x + 0.97
0
0.5
1
1.5
2
Time (hr)

3- Curb Extension Biofilter - 1419 E 76th Terr.

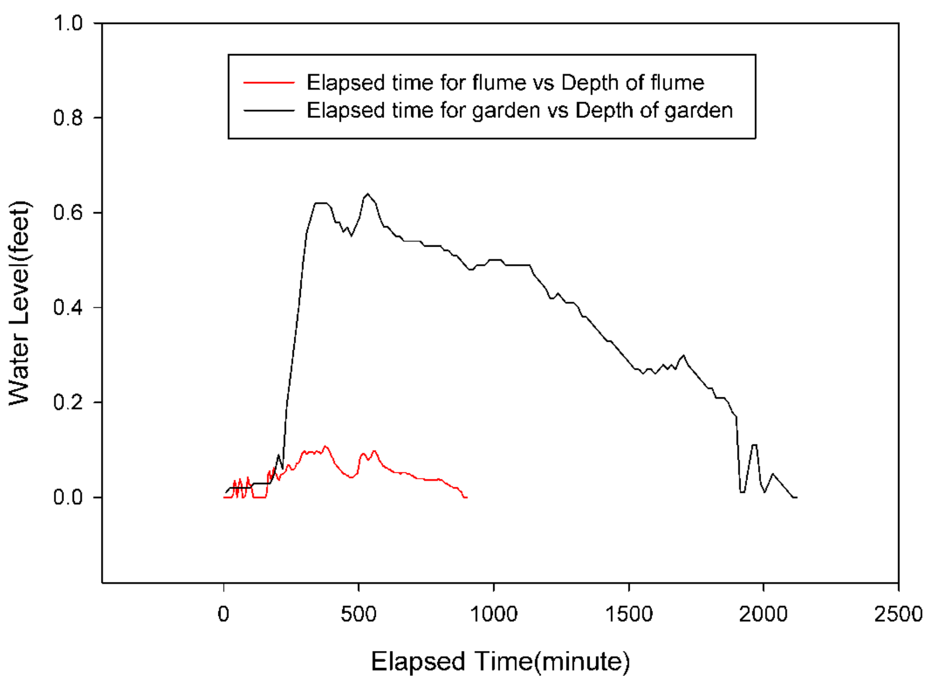




1419 76th terr on Rainevent 04/26/13-04/27/13

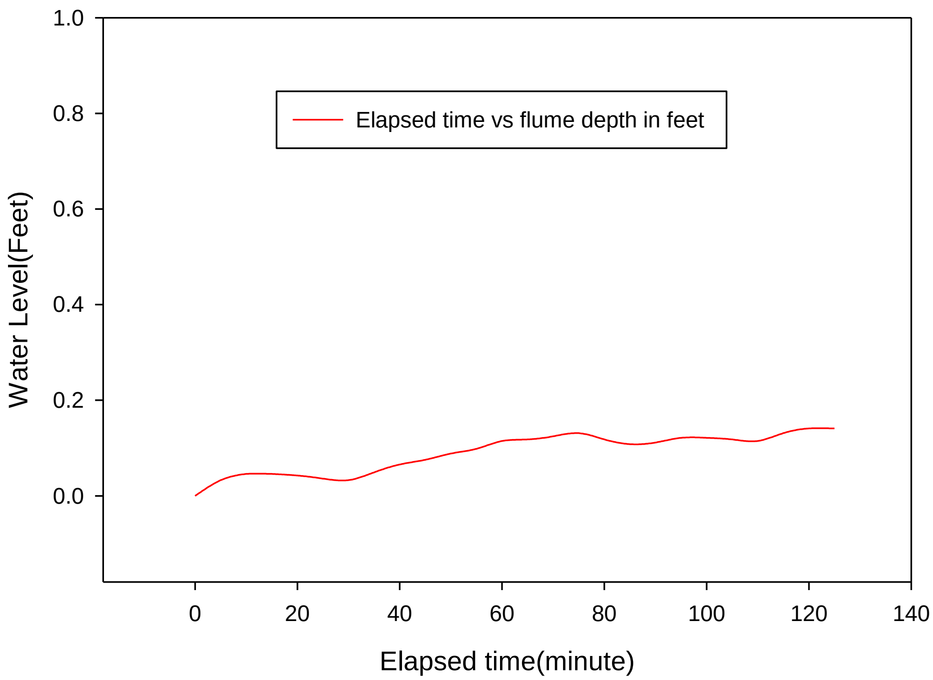


1425 76th terr on Rainevent 04/23/13

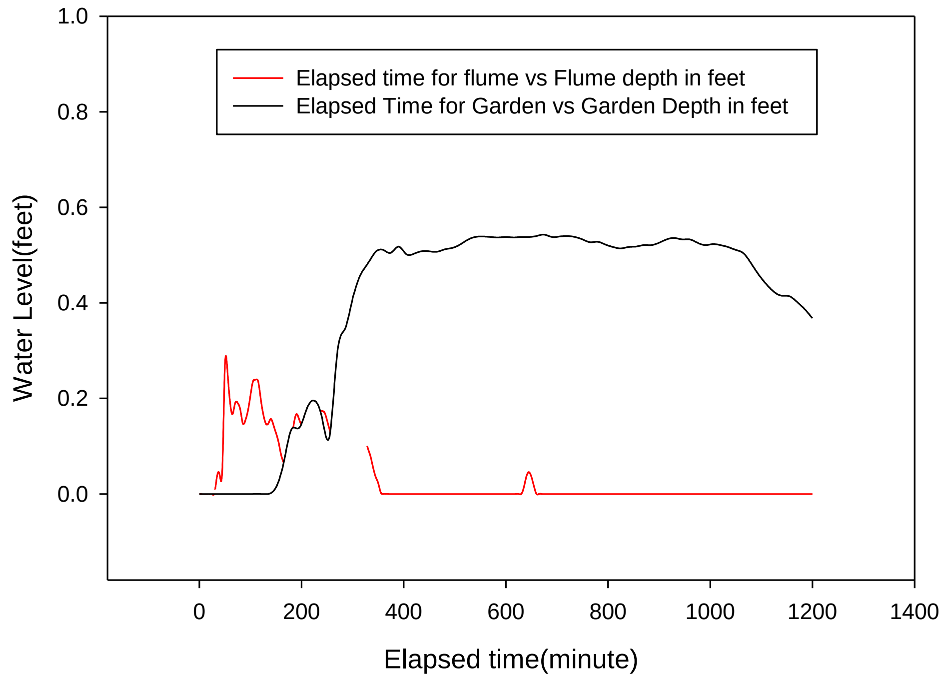


1419 76th terr Raingarden on Rainevent 10/13/2012

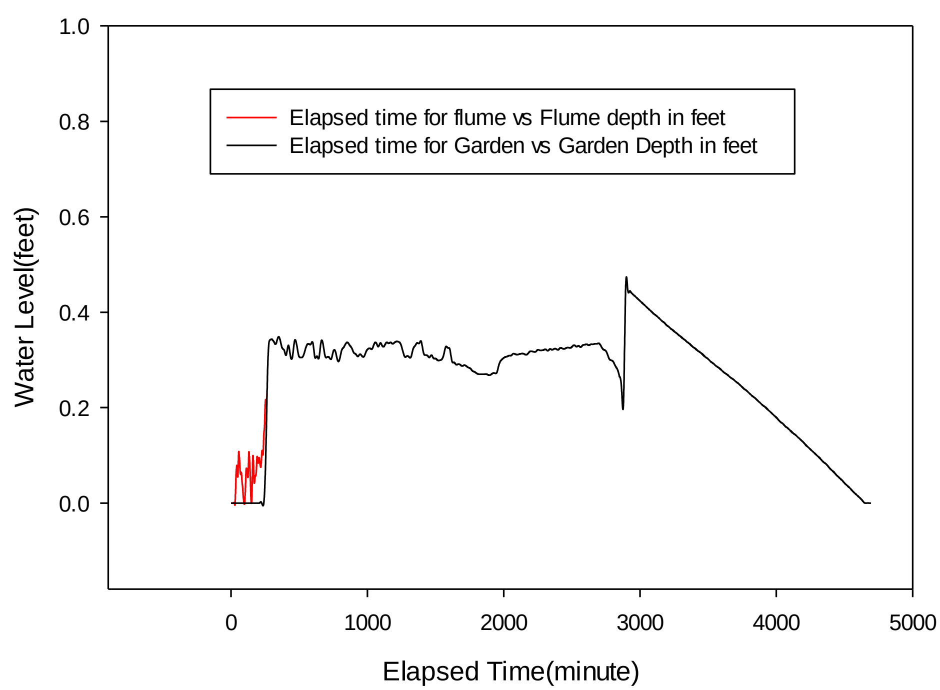
1419 76th terr Raingarden on Rainevent 9/26/2012



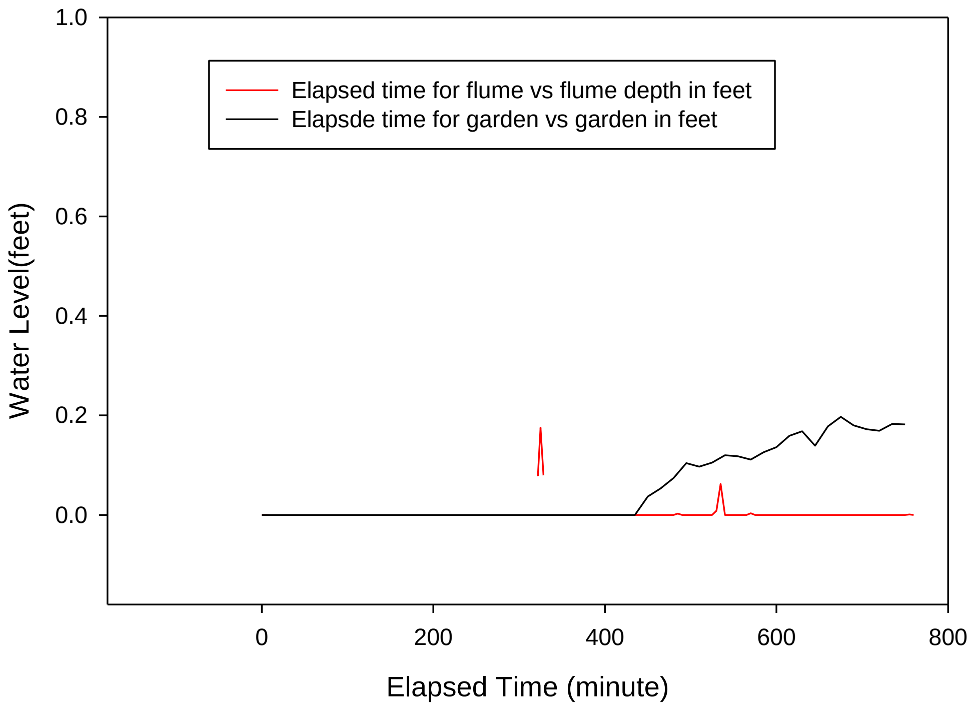
1419 76th terr Raingarden on Rainevent 9/13/2012



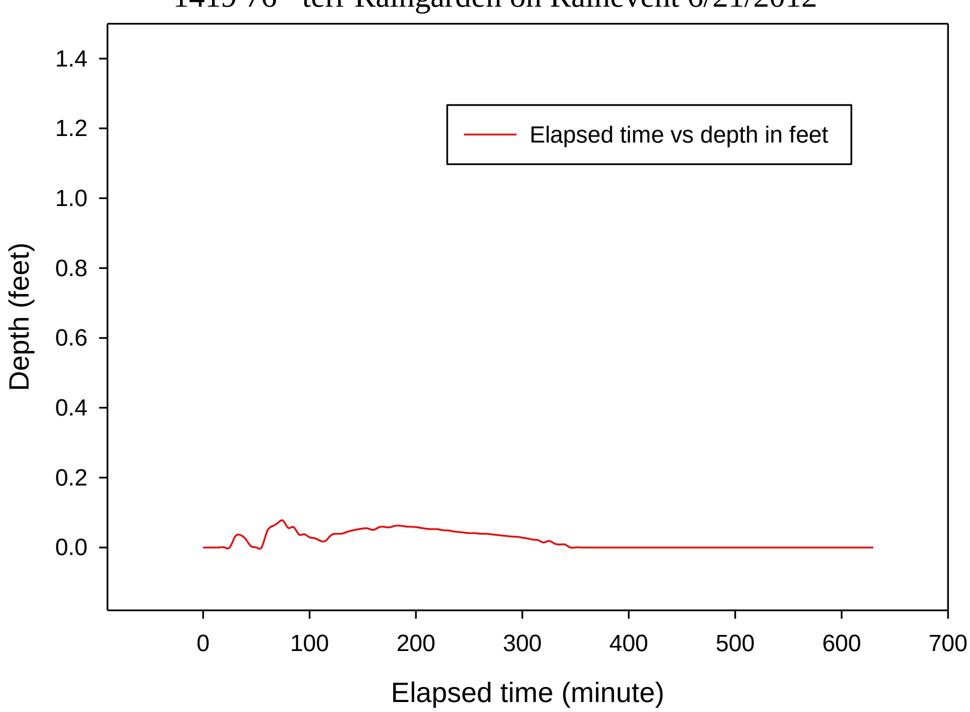
1419 76th Terr Flume on Rainevent 08/31/2012



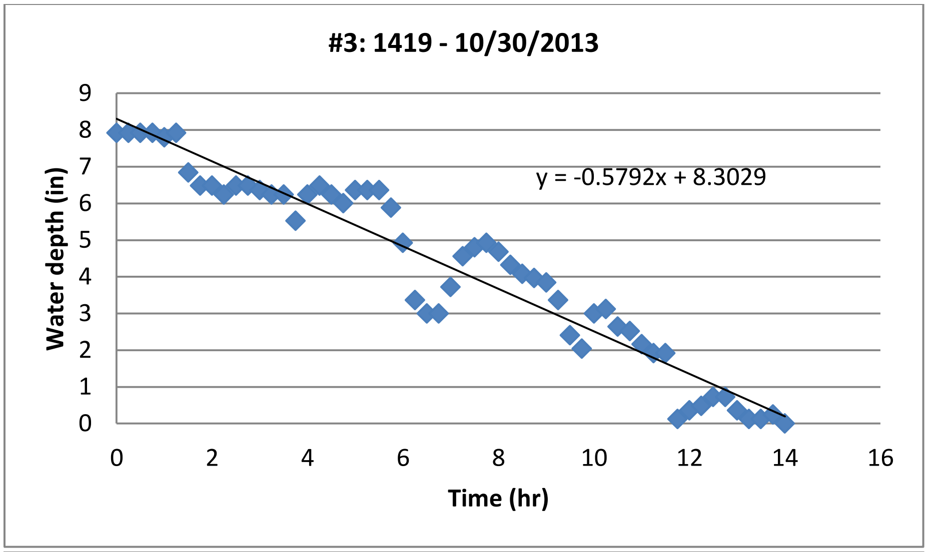
1419 76th terr Raingarden on Rainevent 7/26/2012

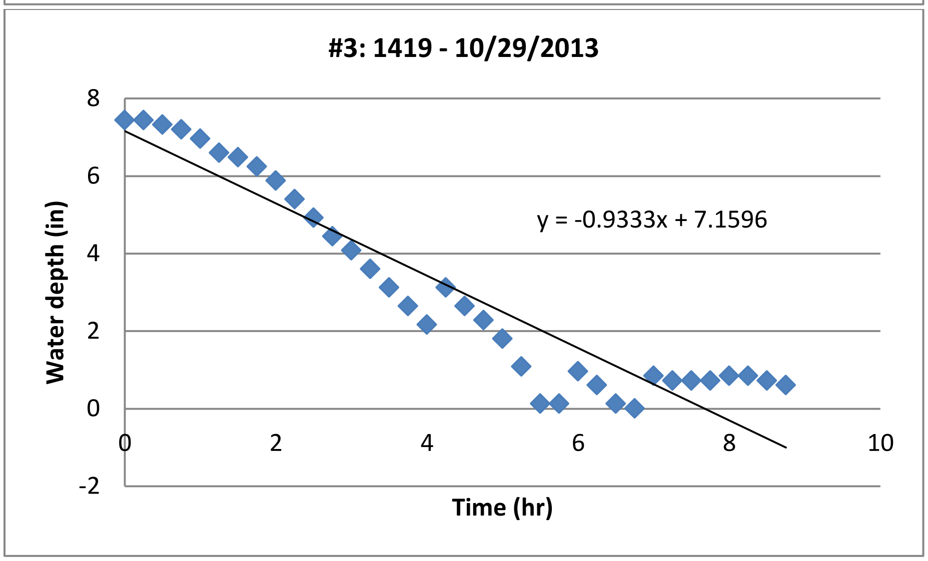


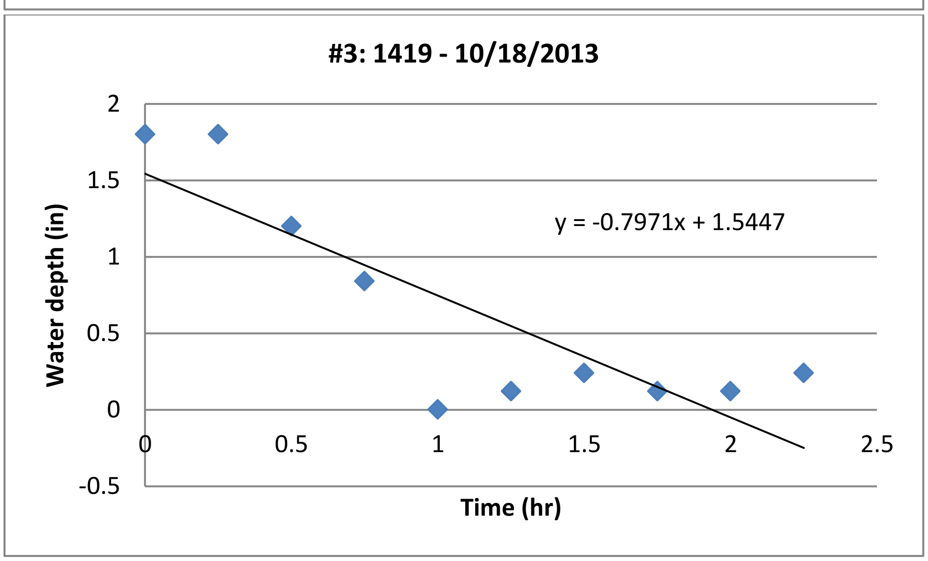
1419 76th terr Raingarden on Rainevent 6/21/2012

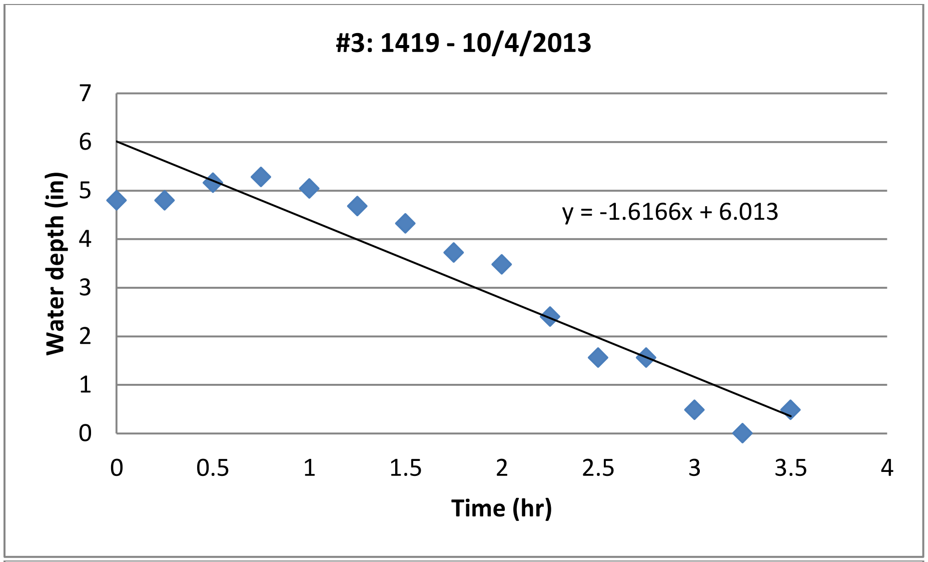


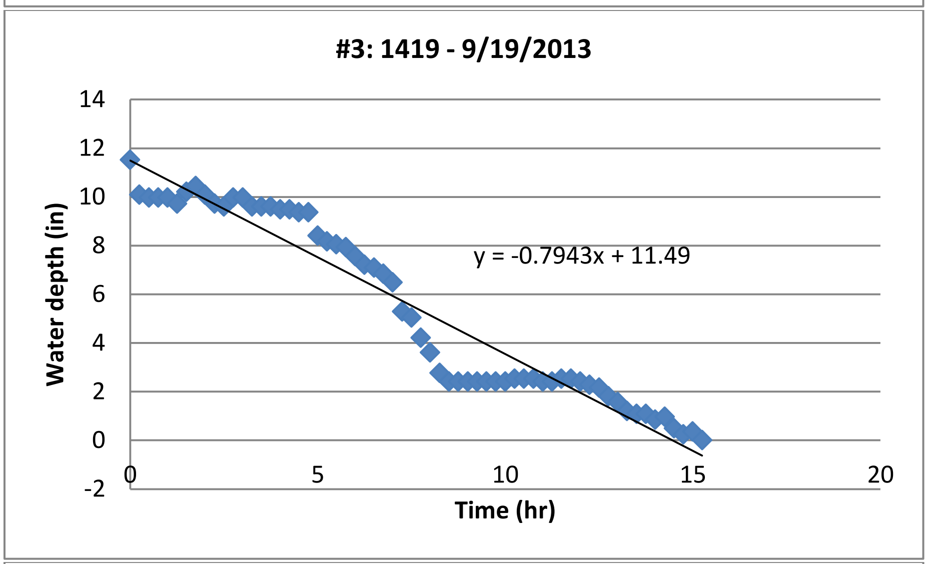
Rainfall Depth (in.)	Start Time	End Time	Event Duration (hr:min)	Total volume of inflow (gal)	Max Water Depth in Garden (in)	Time Duration before Ponding Occurred (hr:min)	f (in/hr)
3.43	10/30/2013 12:09:00	10/31/2013 11:46:00	23:37		7.92	17:49	0.58
0.83	10/29/2013 2:52:00	10/29/2013 9:41:00	6:49		7.44	4:19	0.93
0.12	10/18/2013 14:03:00	10/18/2013 17:05:00	3:02		1.8	0	0.80
0.87	10/4/2013 22:36:00	10/5/2013 3:48:00	5:12		5.28	1:34	1.62
1.89	9/19/2013 19:00:00	9/19/2013 22:23:00	3:23		11.52	0:25	0.79
0.67	8/12/2013 7:07:00	8/12/2013 10:18:00	3:11		7.32	0:17	0.79
0.87	8/7/2013 4:13:00	8/7/2013 8:45:00	4:32		6.24	2:41	0.82
0.55	8/6/2013 3:24:00	8/6/2013 4:59:00	1:35		4.08	1:30	0.80
0.32	8/2/2013 3:46:00	8/2/2013 8:10:00	4:24		2.88	1:53	0.49
1.5	7/3/2013 17:54:00	7/3/2013 21:36:00	3:42		8.16	1:11	0.62
0.83	6/27/2013 11:46:00	6/28/2013 0:49:00	13:03		8.88	12:03	0.63
1.42	5/2/2013 3:08:00	5/4/2013 4:11:00	49:03		7.08	26:51	0.25
0.95	4/26/2013 4:19:00	4/27/2013 11:02:00	30:43		9.48	27:19	0.26
0.39	4/23/2013 1:34:00	4/23/2013 10:53:00	9:19		8.64	7:19	0.28
0.39	4/14/2013 19:02:00	4/15/2013 7:08:00	12:06		2.16	28:51	0.72
0.39	4/14/2013 19:02:00	4/15/2013 7:08:00	12:06		3.0	13:51	0.33
0.86	10/12/2012 21:00:00	10/13/2012 22:15:00	25:15	3487	7.2	4:55	0.62
0.23	9/26/2012 02:25:00	9/26/2012* 04:30:00	02:05	583	0		
0.43	9/13/2012 14:10:00	9/14/2012 10:10:00	20:00	3987	6.5	2:30	More water depth is needed
2.61	8/31/2012 11:00:00	8/31/2012 17:00:00	06:00	1940	5.4	4:15	0.19
0.49	7/25/2012 17:55:00	7/26/2012 08:30:00	12:35	103	2.35	7:30	More water depth is needed
1.03	6/21/2012 00:55:00	6/21/2012 11:25:00	10:30	232	0		

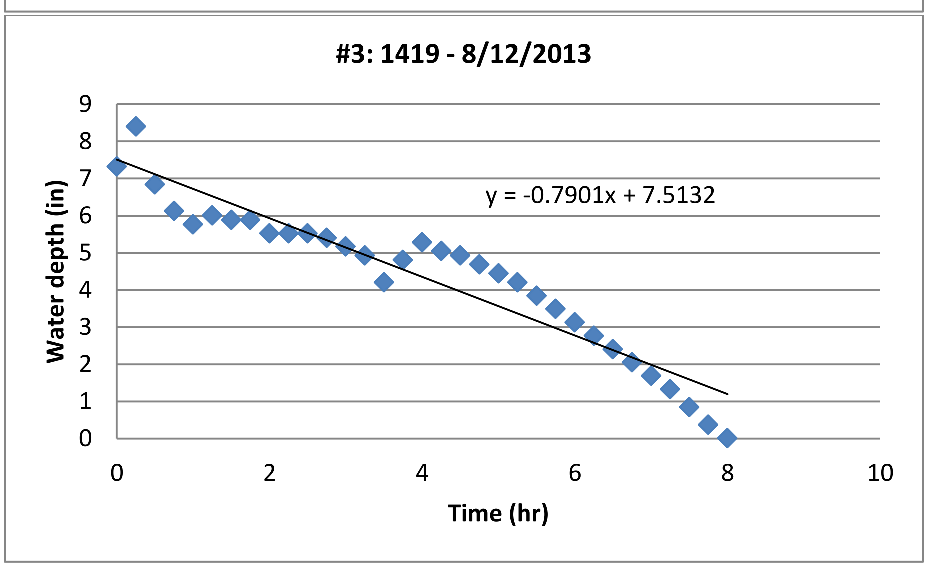

#3: 1419 - 10/30/2013
y = -0.5792x + 8.3029
Water depth (in)
Time (hr)
0
1
2
3
4
5
6
7
8
9
0
2
4
6
8
10
12
14
16

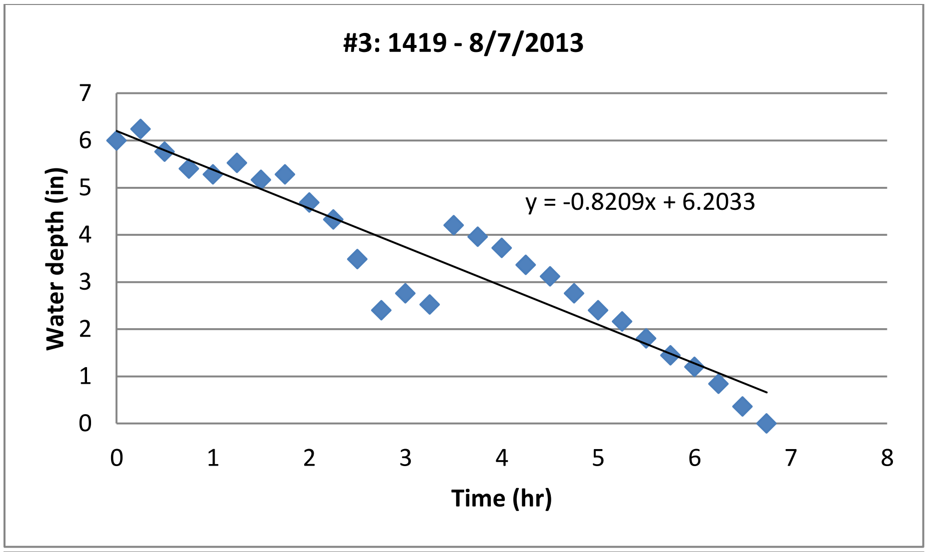

#3: 1419 - 10/29/2013
y = -0.9333x + 7.1596
Water depth (in)
Time (hr)
-2
0
2
4
6
8
0
2
4
6
8
10

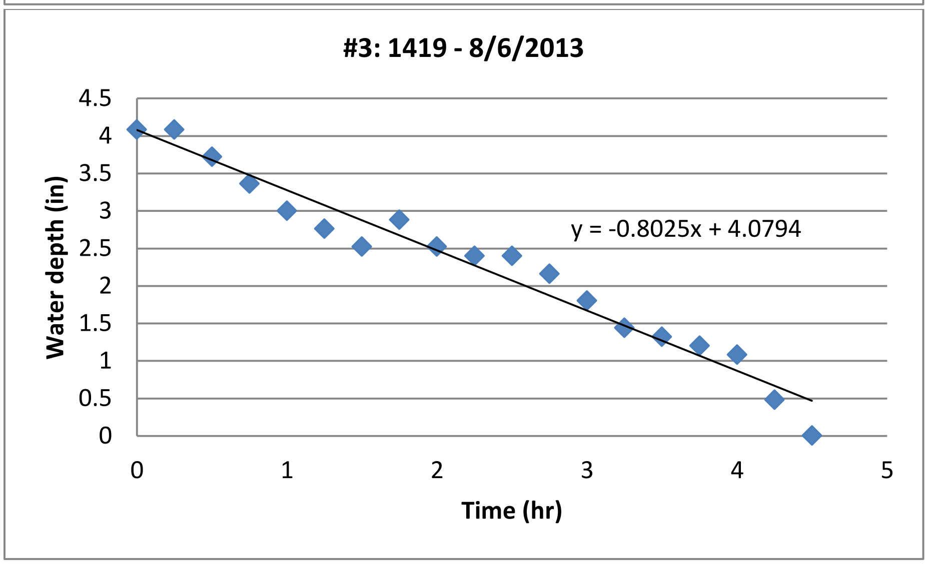

#3: 1419 - 10/18/2013
y = -0.7971x + 1.5447
Water depth (in)
Time (hr)
-0.5
0
0.5
1
1.5
2
0
0.5
1
1.5
2
2.5

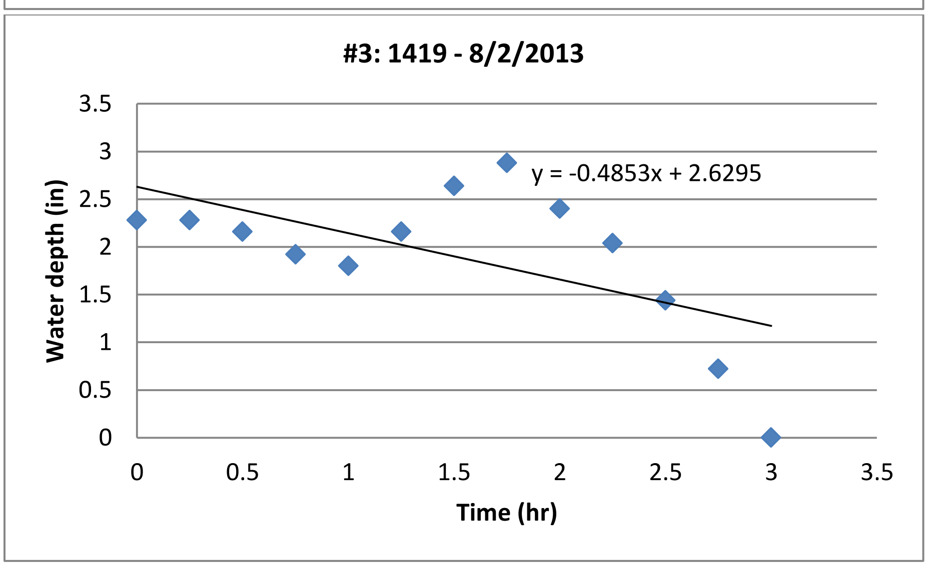

#3: 1419 - 10/4/2013
Water depth (in)
Time (hr)
y = -1.6166x + 6.013
0
1
2
3
4
5
6
7
0
0.5
1
1.5
2
2.5
3
3.5
4

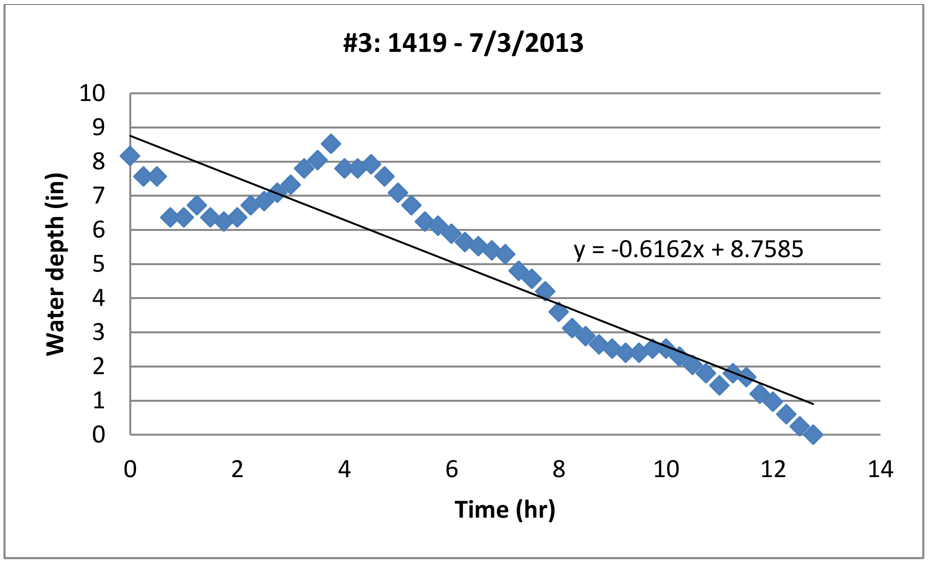

#3: 1419 - 9/19/2013
Water depth (in)
Time (hr)
y = -0.7943x + 11.49
-2
0
2
4
6
8
10
12
14
0
5
10
15
20

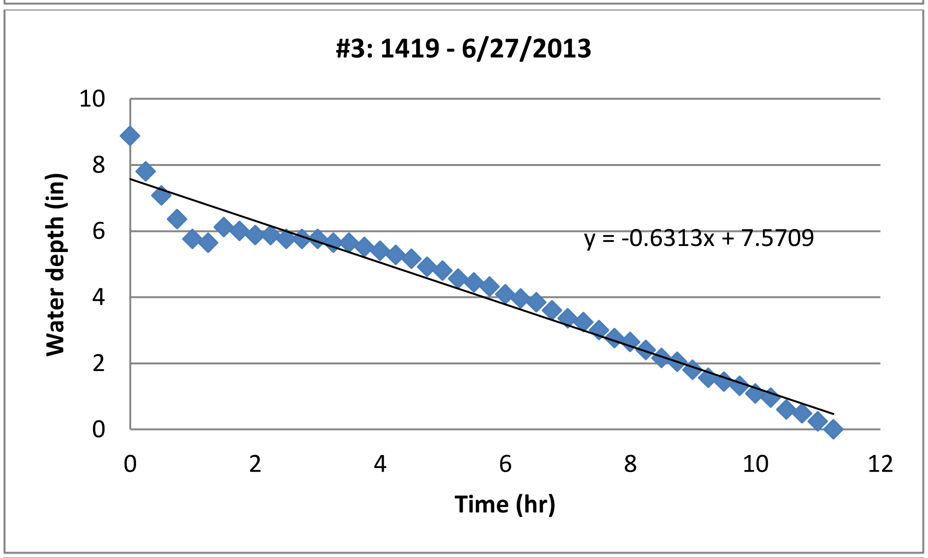

#3: 1419 - 8/12/2013
Water depth (in)
Time (hr)
y = -0.7901x + 7.5132
0
1
2
3
4
5
6
7
8
9
0
2
4
6
8
10

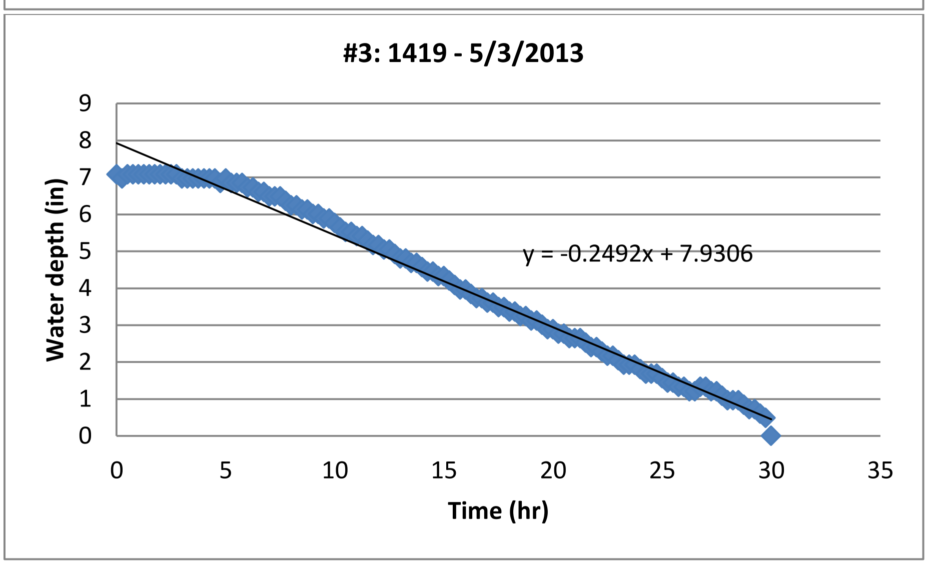

#3: 1419 - 8/7/2013
y = -0.8209x + 6.2033
Water depth (in)
Time (hr)
0
1
2
3
4
5
6
7
8

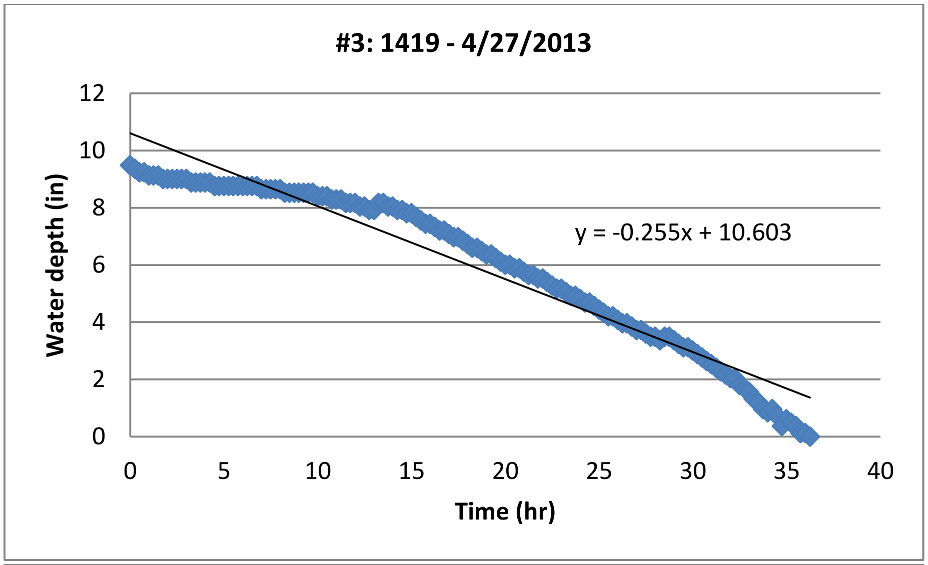

#3: 1419 - 8/6/2013
y = -0.8025x + 4.0794
Water depth (in)
Time (hr)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

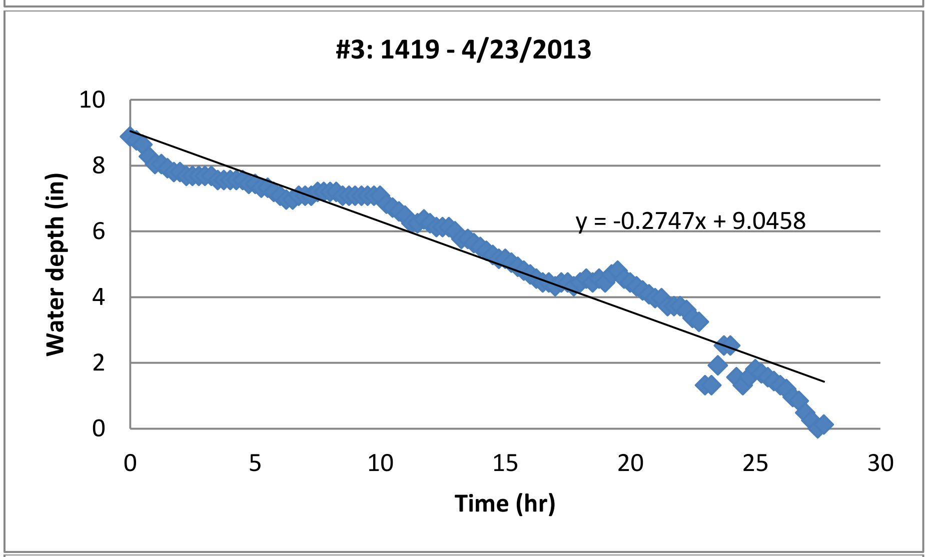

#3: 1419 - 8/2/2013
y = -0.4853x + 2.6295
Water depth (in)
Time (hr)
0
0.5
1
1.5
2
2.5
3
3.5

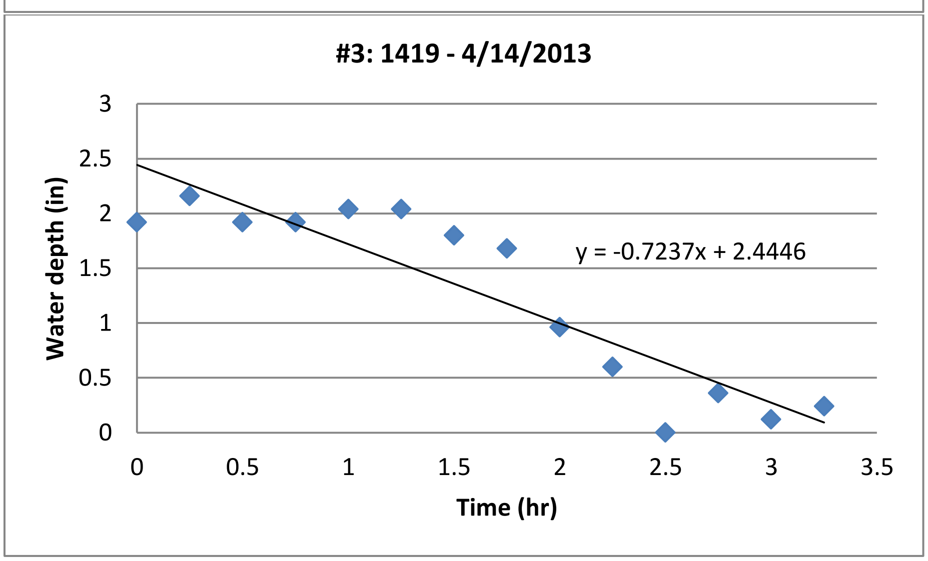

#3: 1419 - 7/3/2013
Water depth (in)
Time (hr)
y = -0.6162x + 8.7585
0
1
2
3
4
5
6
7
8
9
10
0
2
4
6
8
10
12
14

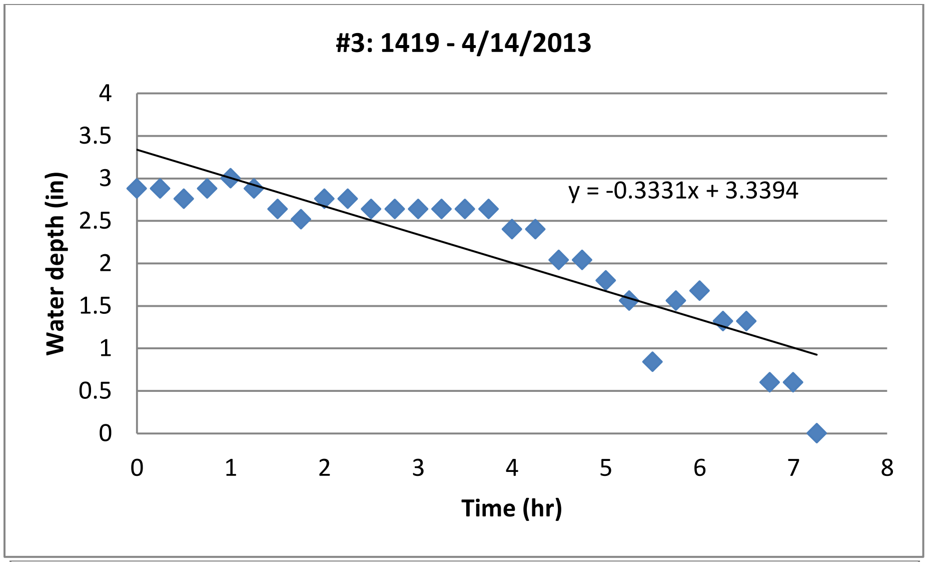

#3: 1419 - 6/27/2013
Water depth (in)
Time (hr)
y = -0.6313x + 7.5709
0
2
4
6
8
10
0
2
4
6
8
10
12

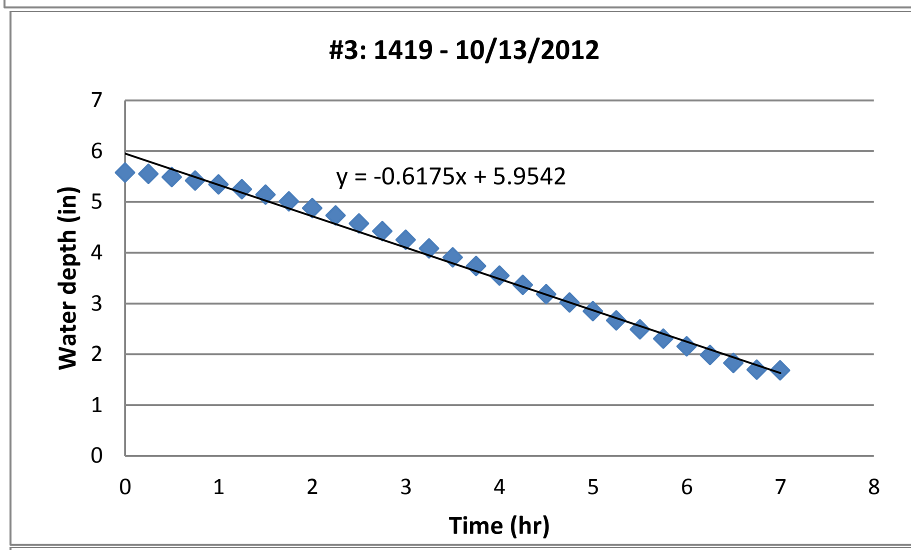

#3: 1419 - 5/3/2013
Water depth (in)
Time (hr)
y = -0.2492x + 7.9306
0
1
2
3
4
5
6
7
8
9
0
5
10
15
20
25
30
35

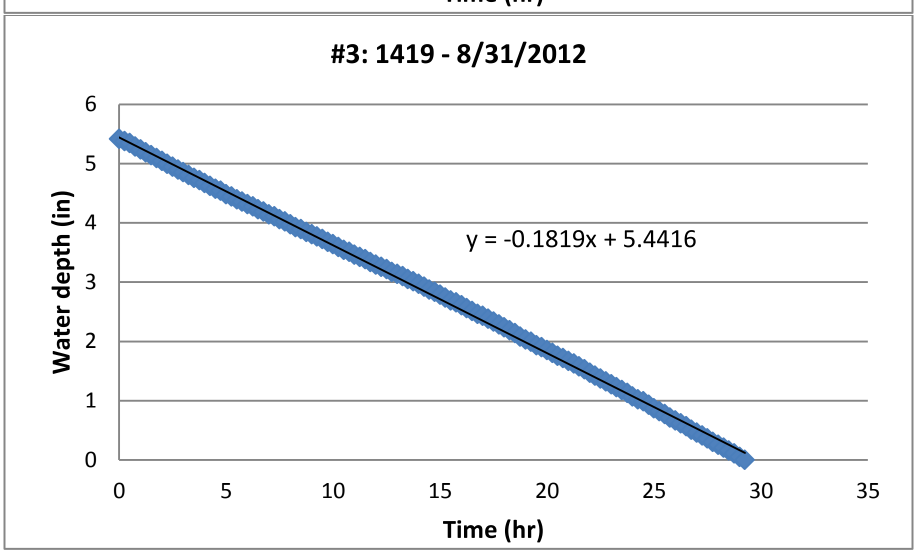

#3: 1419 - 4/27/2013
Water depth (in)
Time (hr)
y = -0.255x + 10.603
0
2
4
6
8
10
12
0
5
10
15
20
25
30
35
40


#3: 1419 - 4/23/2013
Water depth (in)
Time (hr)
y = -0.2747x + 9.0458
0
2
4
6
8
10
0
5
10
15
20
25
30

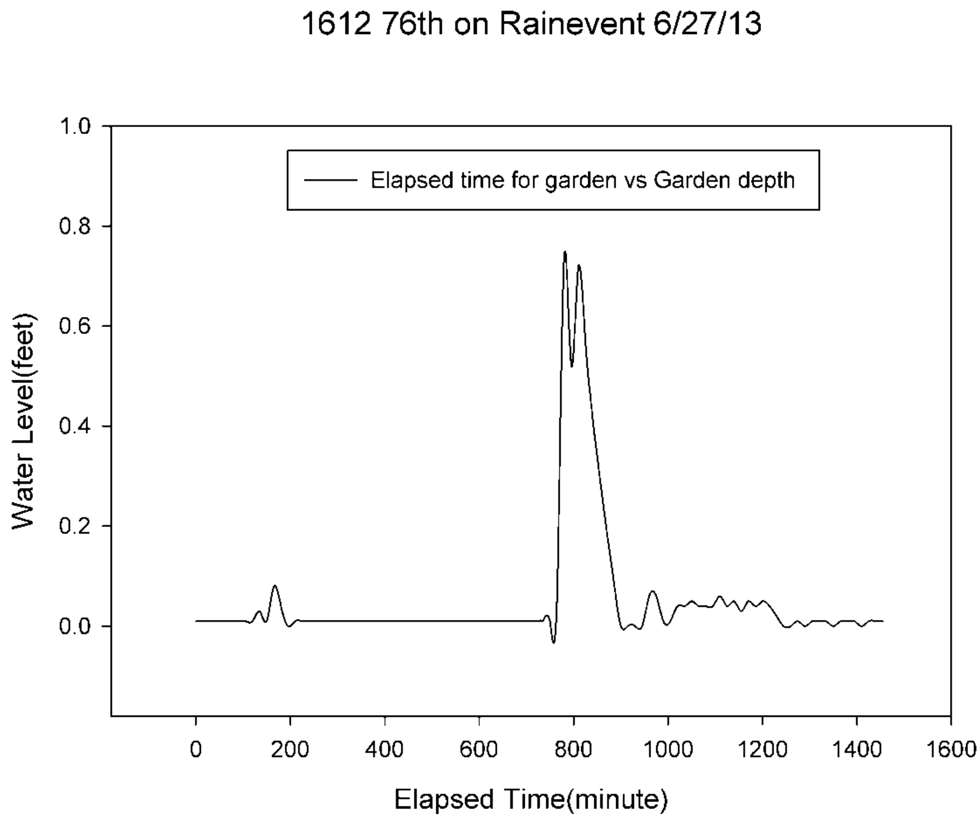

#3: 1419 - 4/14/2013
Water depth (in)
Time (hr)
y = -0.7237x + 2.4446
0
0.5
1
1.5
2
2.5
3
0
0.5
1
1.5
2
2.5
3
3.5


#3: 1419 - 4/14/2013
y = -0.3331x + 3.3394
Water depth (in)
Time (hr)
4
3.5
3
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
6
7
8

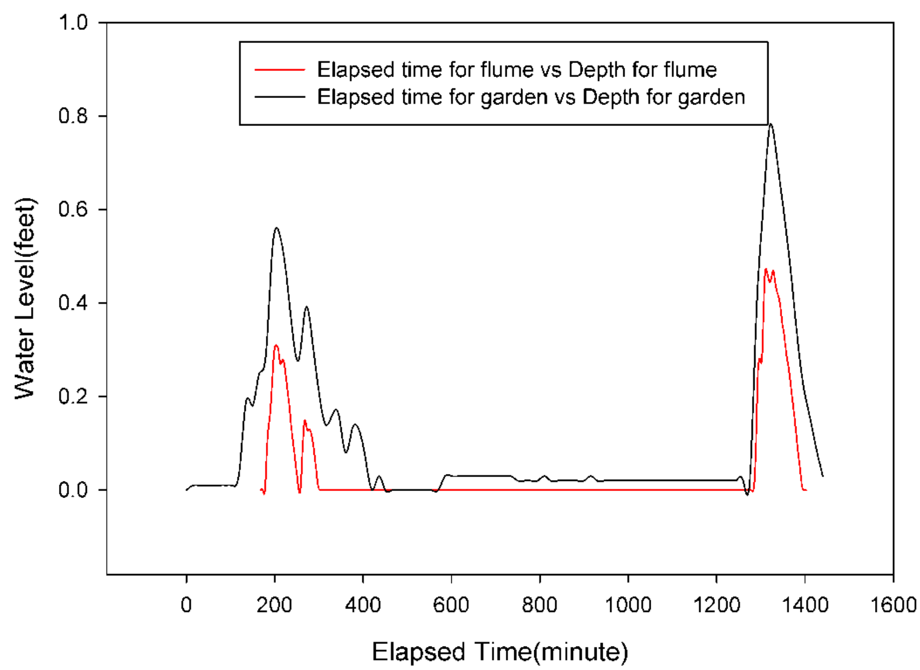

#3: 1419 - 10/13/2012
y = -0.6175x + 5.9542
Water depth (in)
Time (hr)
7
6
5
4
3
2
1
0
0
1
2
3
4
5
6
7
8


#3: 1419 - 8/31/2012
y = -0.1819x + 5.4416
Water depth (in)
Time (hr)
6
5
4
3
2
1
0
0
5
10
15
20
25
30
35

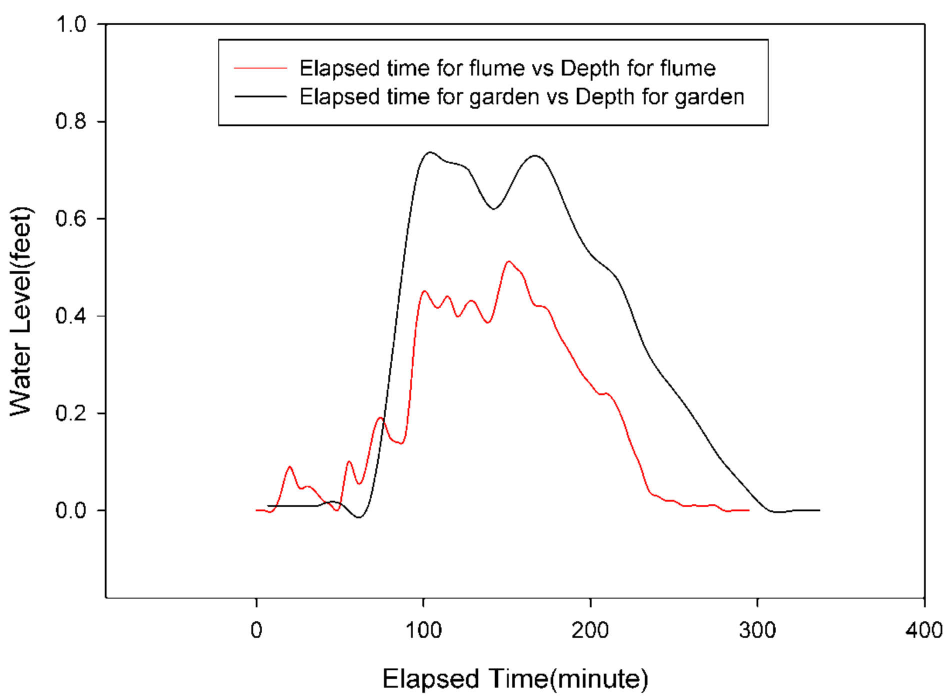
4- Curb-Cut Biofilter - 1612 E 76th St.



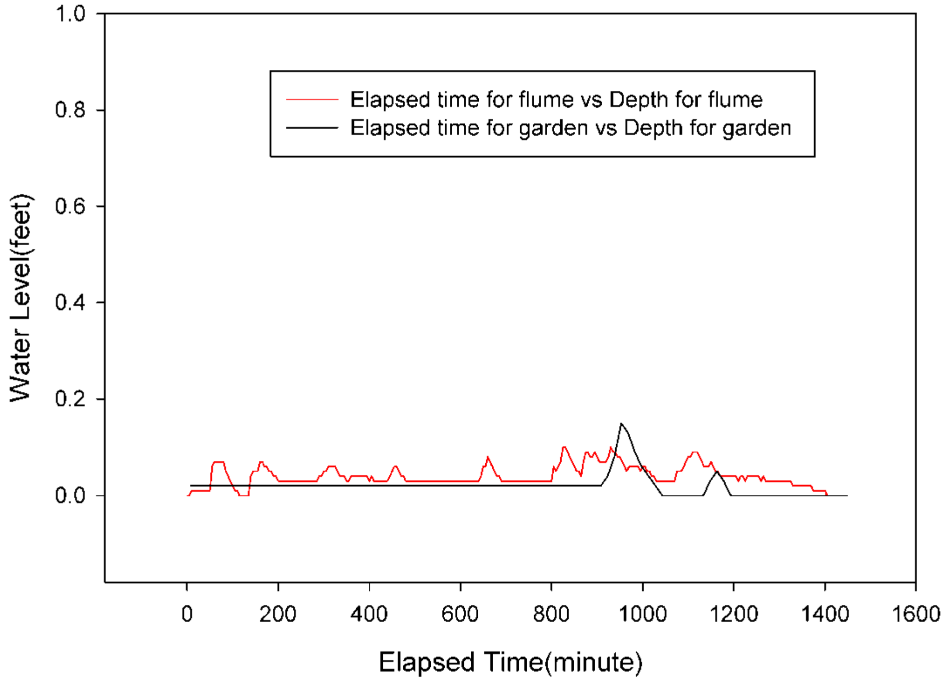
1612 76th on Rainevent 5/29/13-5/31/13



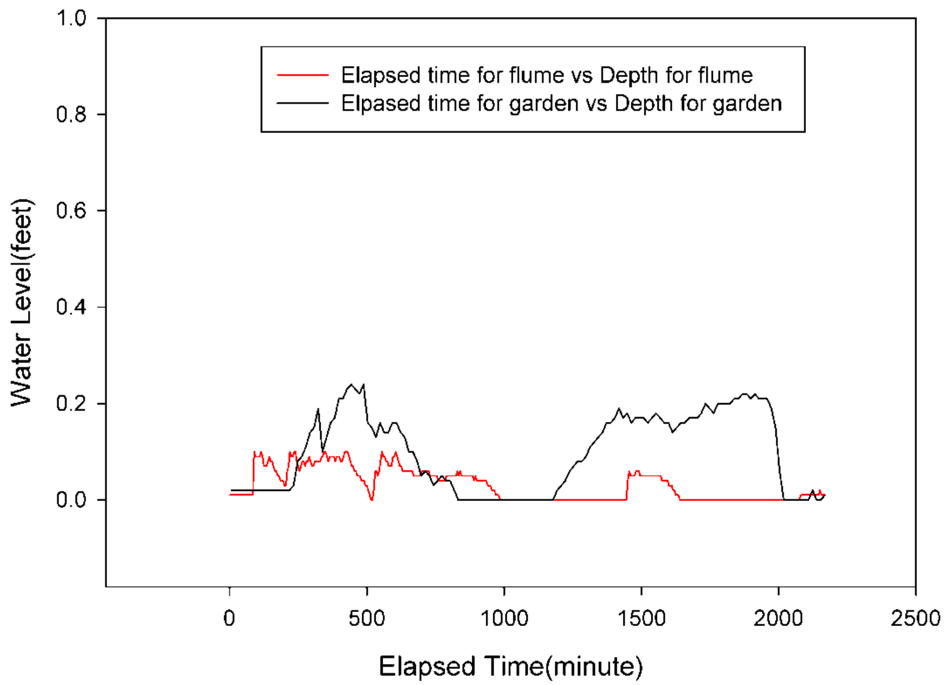
1612 76th on Rainevent 5/27/13-5/28/13



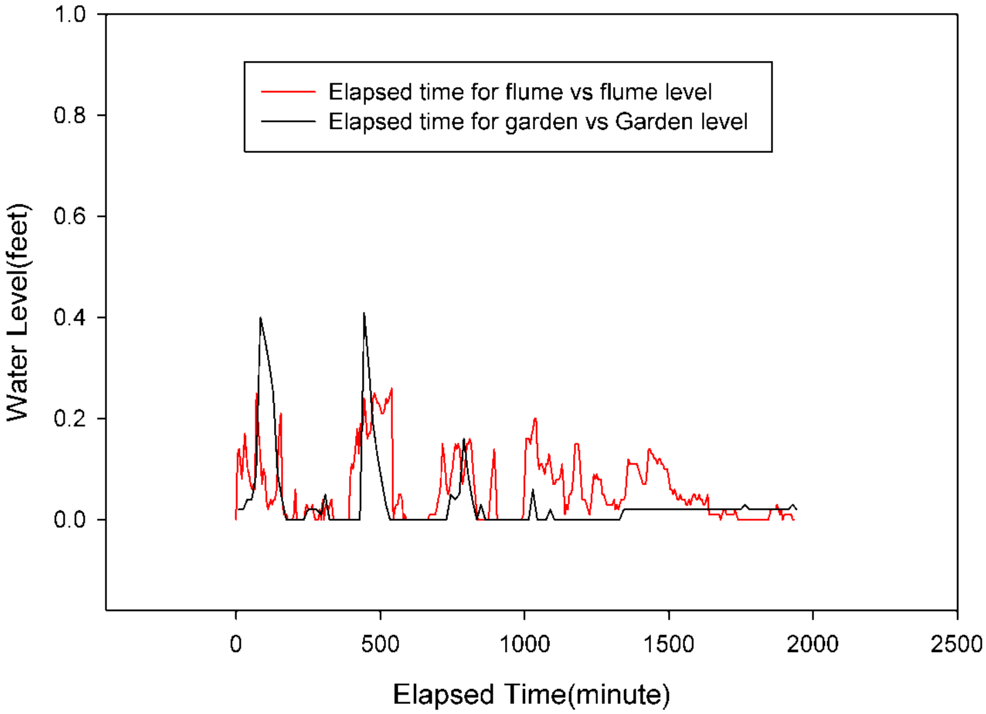
1612 76th on Rainevent 04/26/13-04/27/13



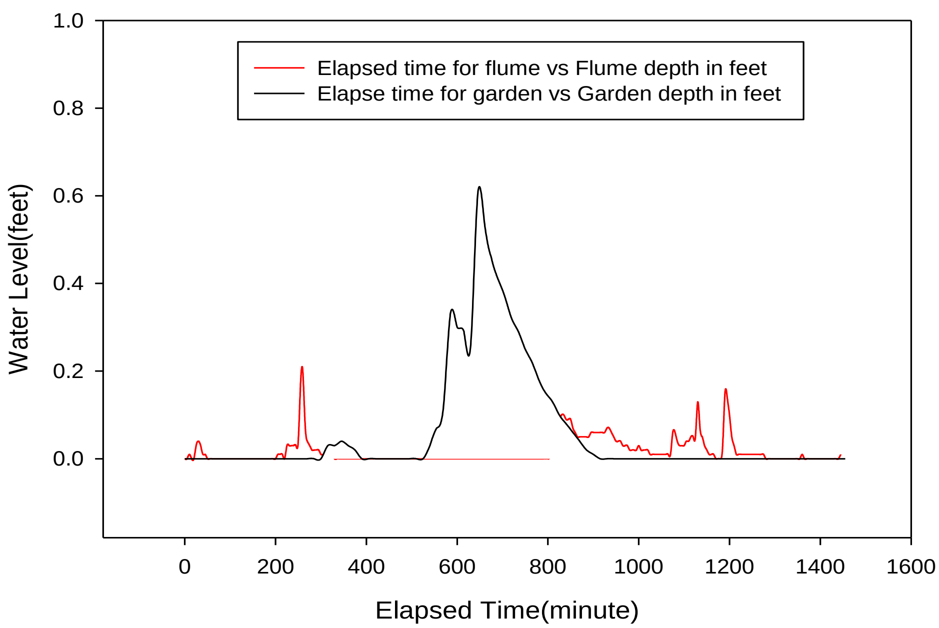
1612 76th on Rainevent 04/22/13-04/2313



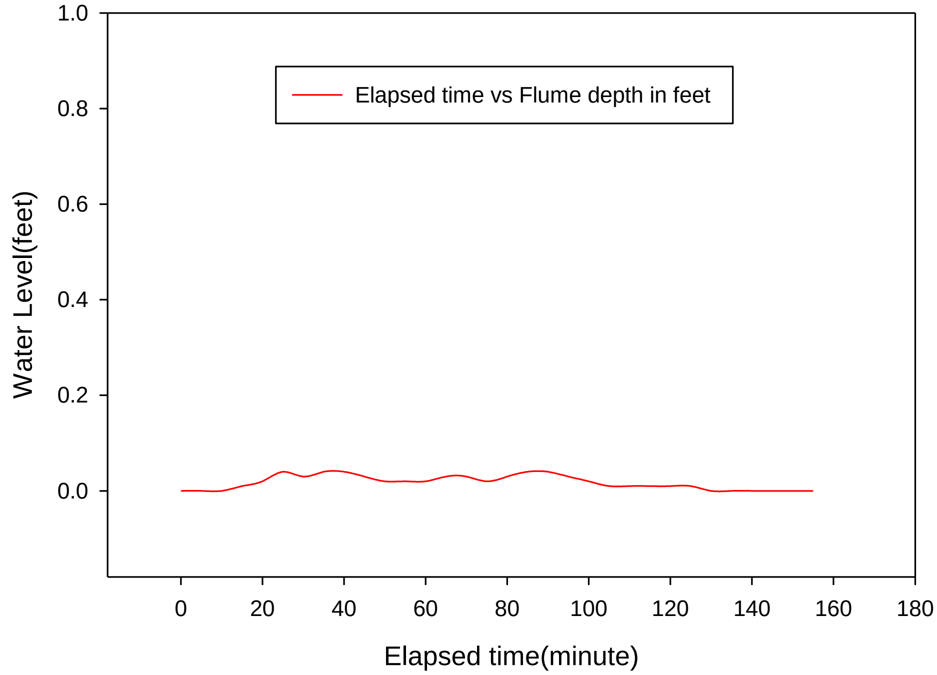
1612 76th on Rainevent 04/09/13--04/10/13



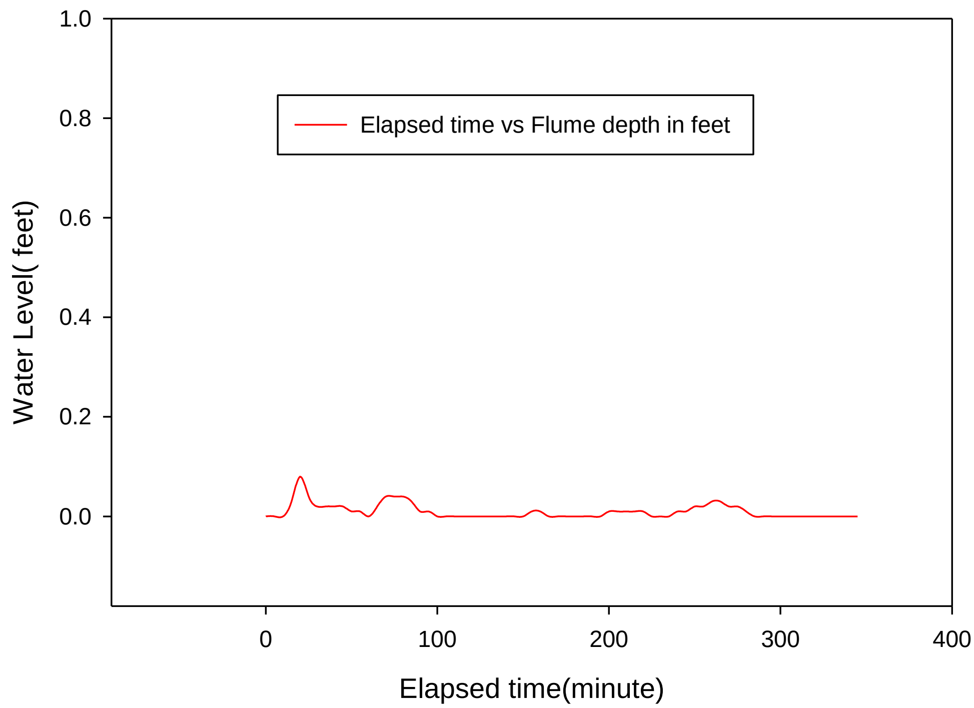
1612 76th Raingarden on Rainevent 10/12/2012



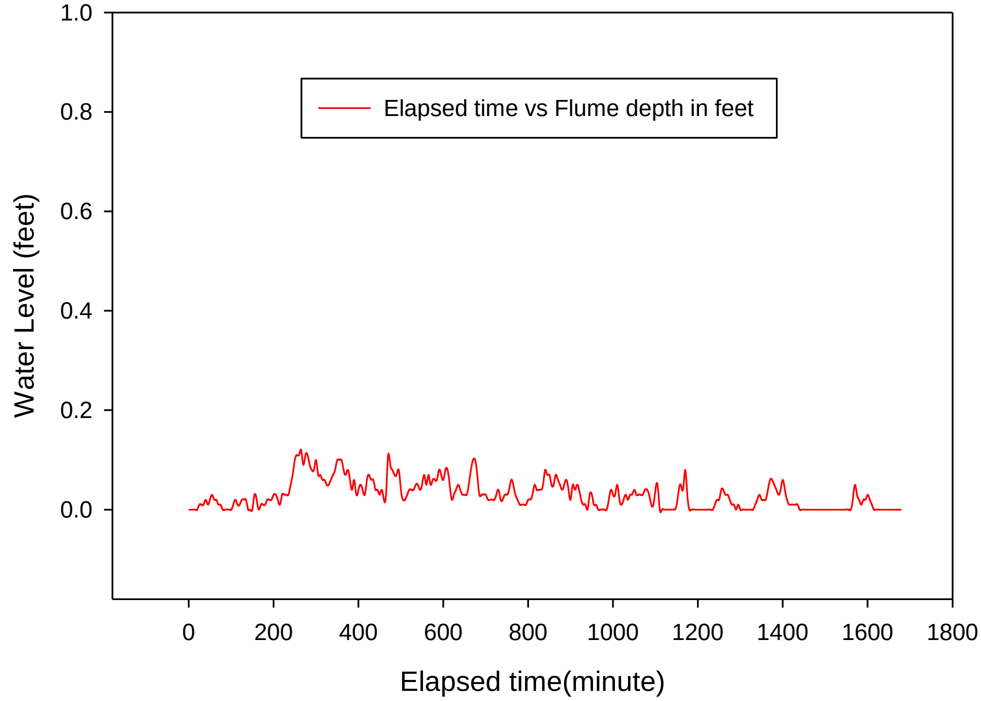
1612 76th Raingarden on Rainevent 9/26/2012



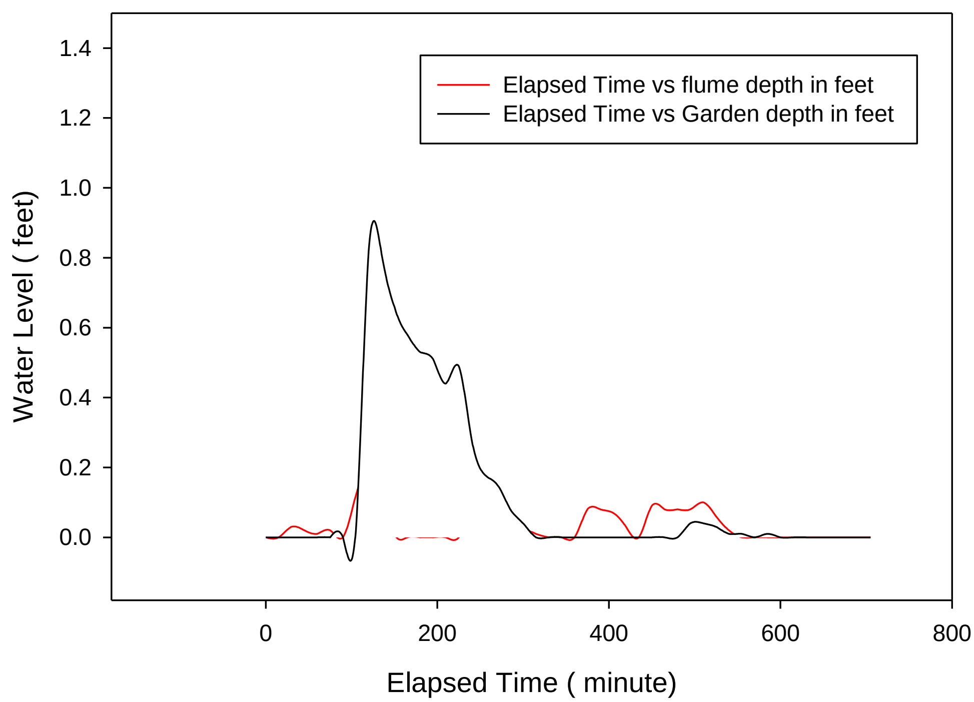
1612 76th Raingarden on Rainevent 9/13/2012

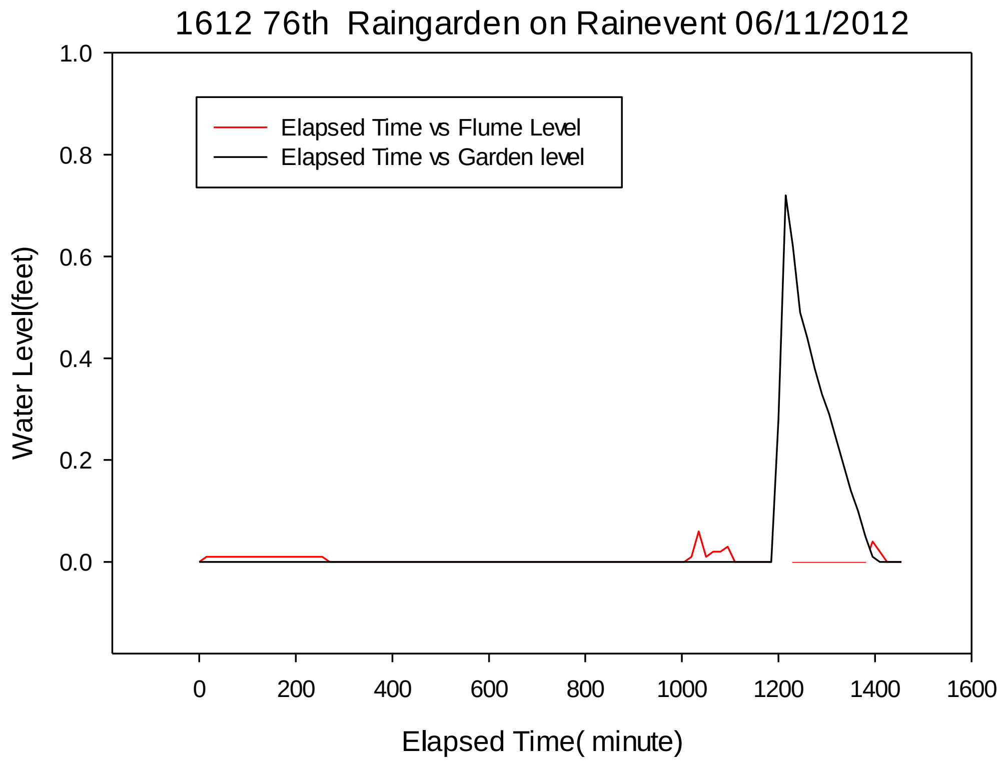


1612 76th Raingarden on Rainevent 9/1/2012



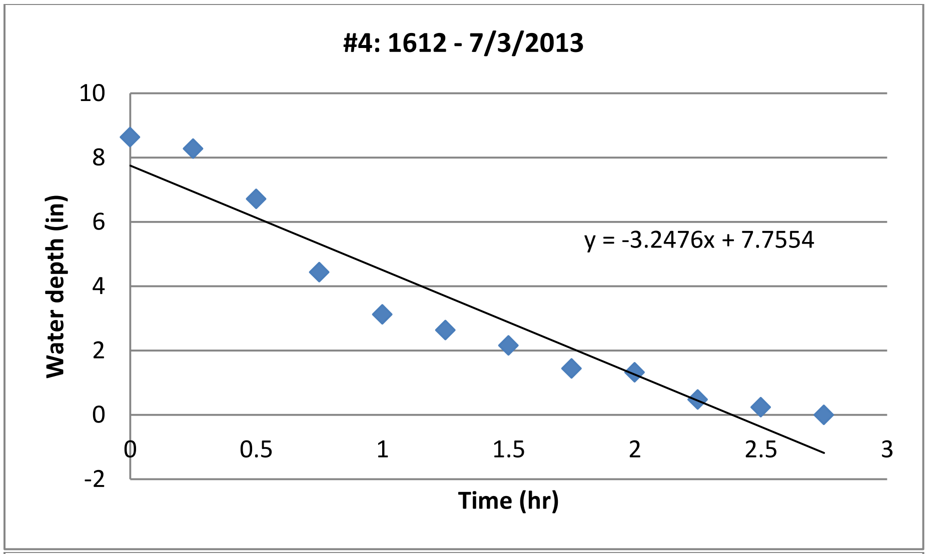
1612 76th Raingarden on Rainevent 6/21/2012

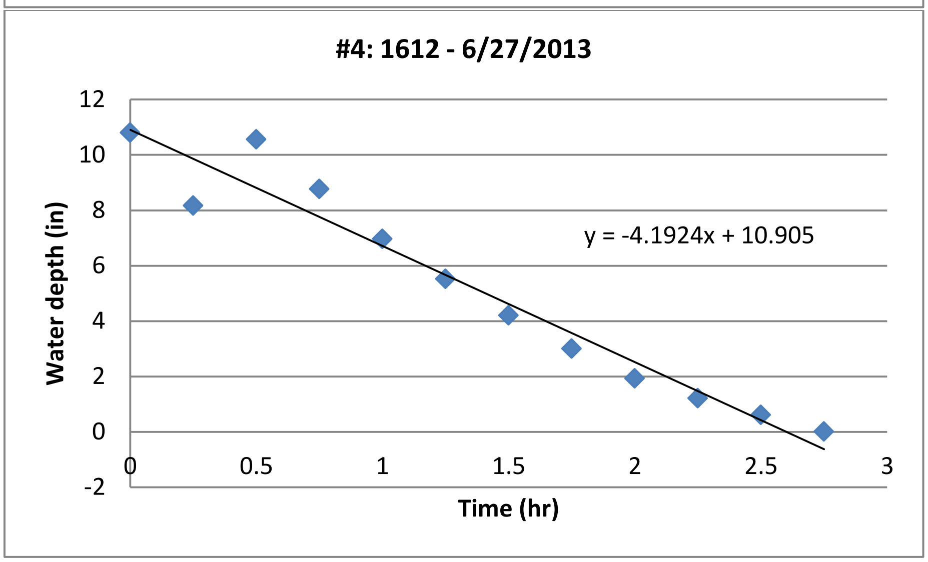


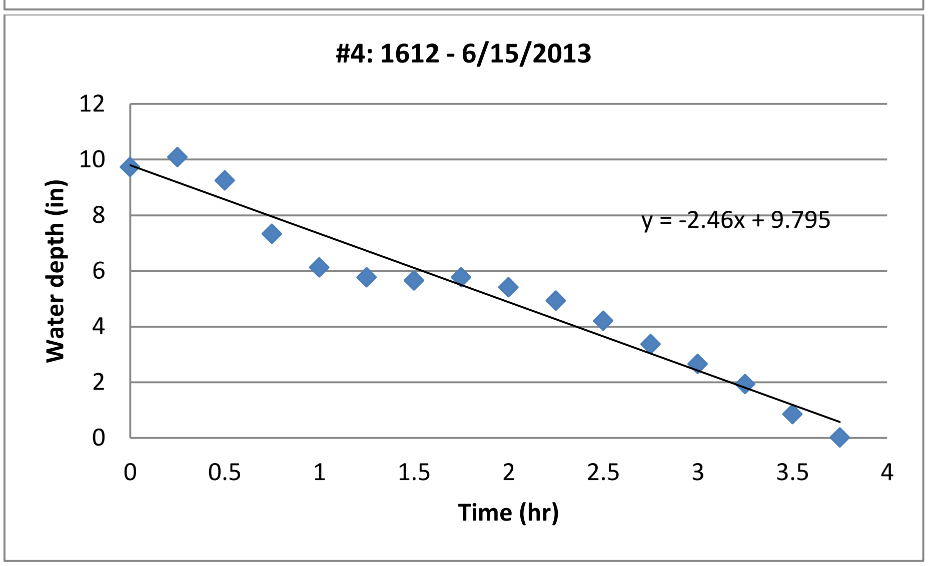


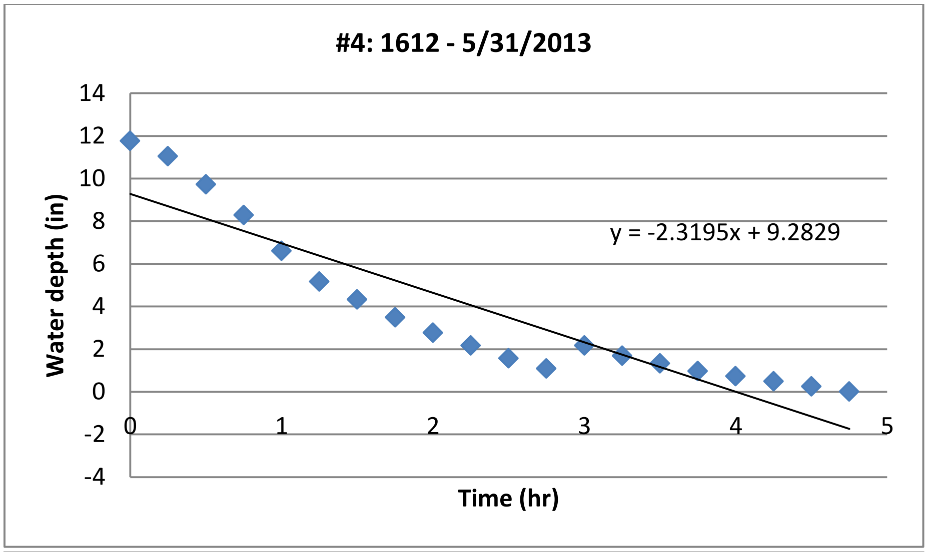
1612 76th Raingarden on Rainevent 06/11/2012
Elapsed Time vs Flume Level
Elapsed Time vs Garden level
Water Level(feet)
1.0
0.8
0.6
0.4
0.2
0.0
0
200
400
600
800
1000
1200
1400
1600
Elapsed Time(minute)

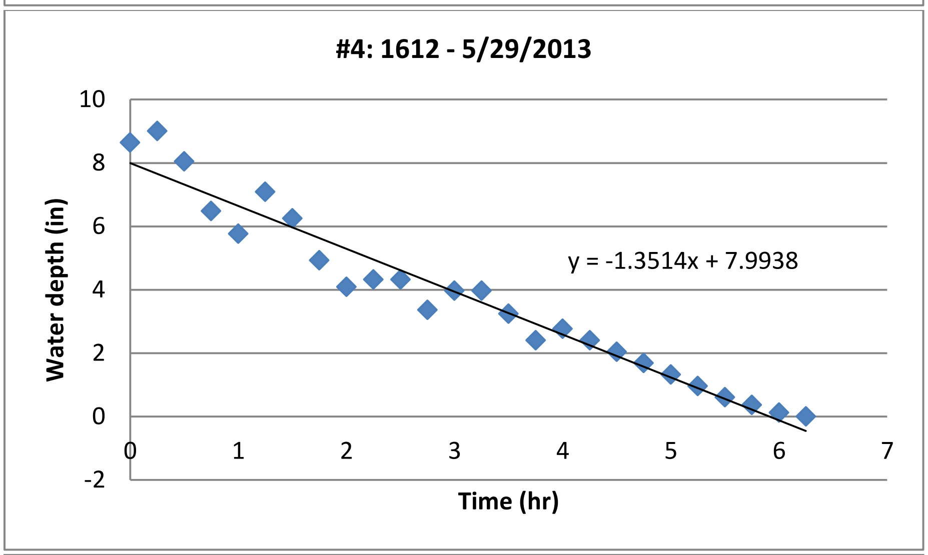
Rainfall Depth (in.)	Start Time	End Time	Event Duration (hr:min)	Max Water Depth in Garden (in)	Time Duration before Ponding Occurred (hr:min)	f (in/hr)
1.5	7/3/2013 17:54:00	7/3/2013 21:36:00	3:42	8.64	0:03	3.25
0.83	6/27/2013 11:46:00	6/28/2013 0:49:00	13:03	10.8	11:26	4.19
1.26	6/15/2013 15:50:00	6/15/2013 22:05:00	6:15	10.08	0:06	2.46
1.34	5/31/2013 5:26:00	5/31/2013 9:21:00	3:55	11.76	0:30	2.32
1.62	5/29/2013 22:53:00	5/30/2013 15:17:00	1.62	9	12:18	1.35
1.62	5/29/2013 22:53:00	5/30/2013 15:17:00	1.62	5.88	3:48	1.49
2.01	5/27/2013 8:31:00	5/27/2013 12:35:00	4:04	10.92	1:40	3.14
0.83	5/19/2013 2:21:00	5/20/2013 1:44:00	23:23	7.32	1:18	4.02
1.42	5/2/2013 3:08:00	5/4/2013 4:11:00	49:03	1.44	2:01	1.18
0.95	4/26/2013 4:19:00	4/27/2013 11:02:00	30:43	2.76	24:20	1.13
0.39	4/23/2013 1:34:00	4/23/2013 10:53:00	9:19	2.88	4:50	0.41
1.10	4/17/2013 11:00:00	4/18/2013 20:41:00	33:41	3.84	0:58	1.77
1.62	4/9/2013 21:56:00	4/10/2013 18:30:00	20:34	4.68	12:43	1.08
1.62	4/9/2013 21:56:00	4/10/2013 18:30:00	20:34	7.68	6:58	2.59
1.62	4/9/2013 21:56:00	4/10/2013 18:30:00	20:34	6.84	1:13	3.18
0.86	10/12/2012 21:00:54	10/13/2012 21:05:54	24:05	7.32	9:00	1.54
0.23	9/26/2012 02:55:54	9/26/2012 05:30:54	02:35	0		
0.43	9/13/2012 14:40:54	9/13/2012 20:25:54	05:45	0		
5.60	8/31/2012 11:00:54	9/1/2012 15:00:54	28:00	0		
1.03	6/21/2012 00:12:33	6/21/2012 12:02:33	11:50	9.84	1:45	>3.14
0.8	6/10/2012 09:45:52	6/11/2012 10:00:52	24:15	1.92	20:00	2.54

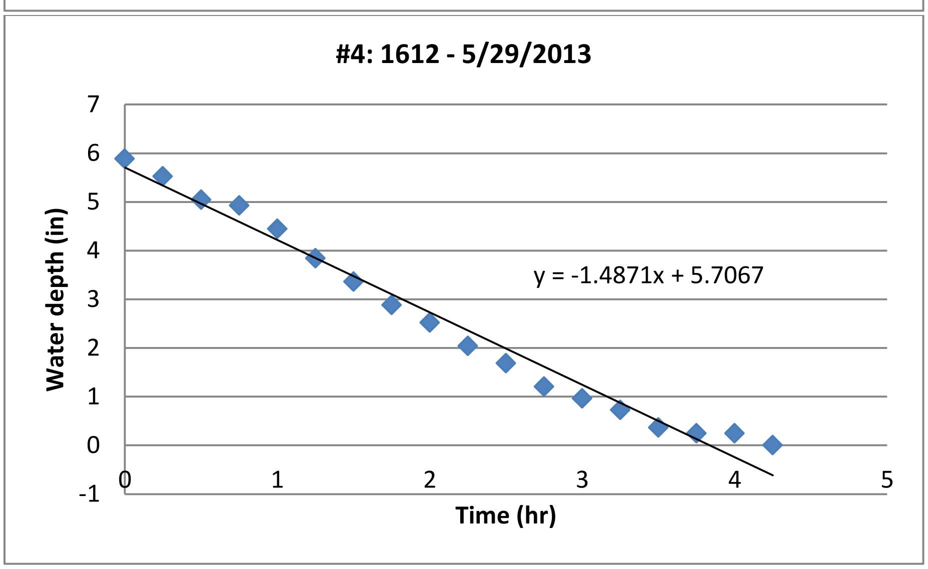

#4: 1612 - 7/3/2013
Water depth (in)
Time (hr)
y = -3.2476x + 7.7554
10
8
6
4
2
0
-2
0
0.5
1
1.5
2
2.5
3

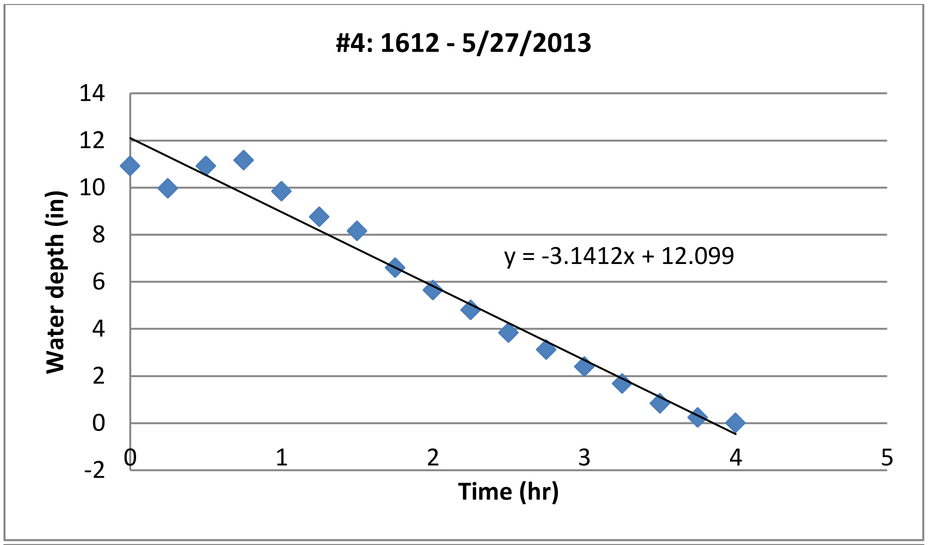

#4: 1612 - 6/27/2013
Water depth (in)
Time (hr)
y = -4.1924x + 10.905
12
10
8
6
4
2
0
-2
0
0.5
1
1.5
2
2.5
3

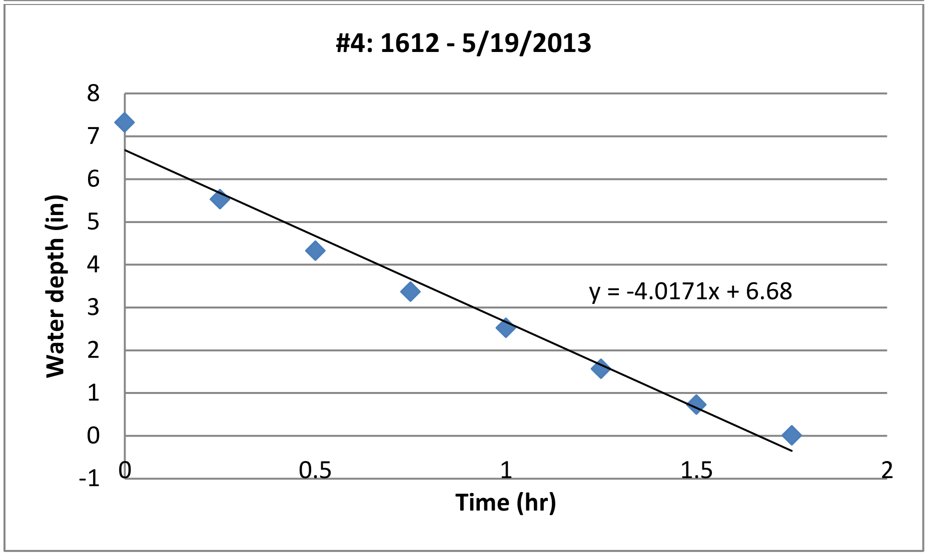

#4: 1612 - 6/15/2013
Water depth (in)
Time (hr)
y = -2.46x + 9.795
12
10
8
6
4
2
0
0
0.5
1
1.5
2
2.5
3
3.5
4

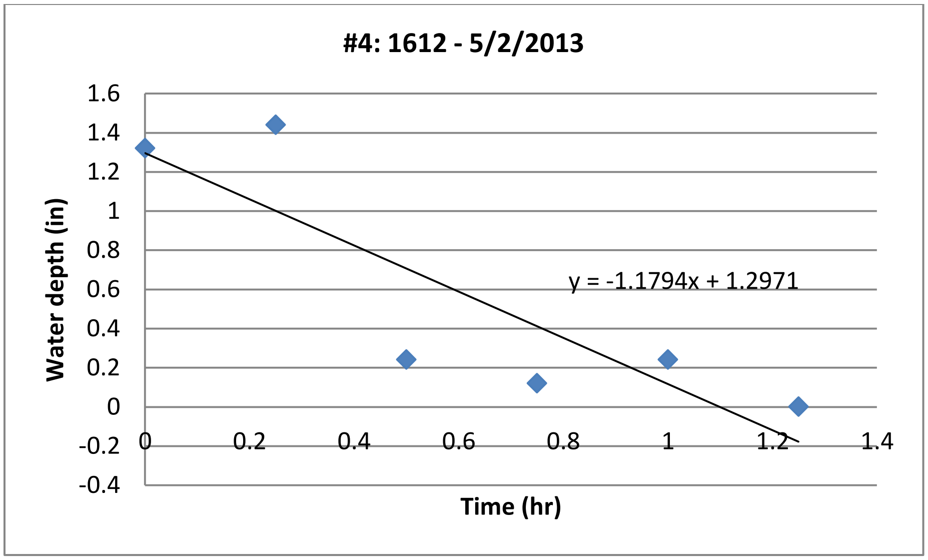

#4: 1612 - 5/31/2013
y = -2.3195x + 9.2829
Water depth (in)
Time (hr)

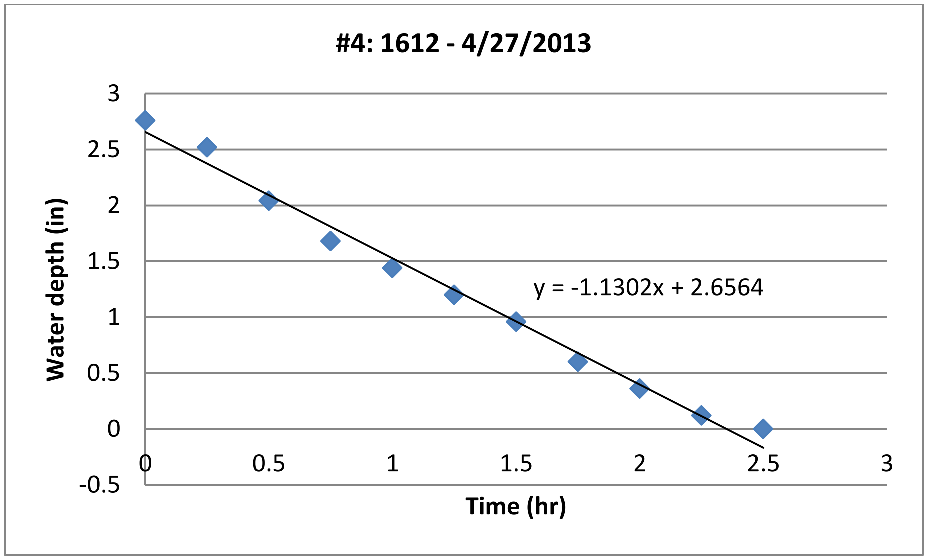

#4: 1612 - 5/29/2013
y = -1.3514x + 7.9938
Water depth (in)
Time (hr)

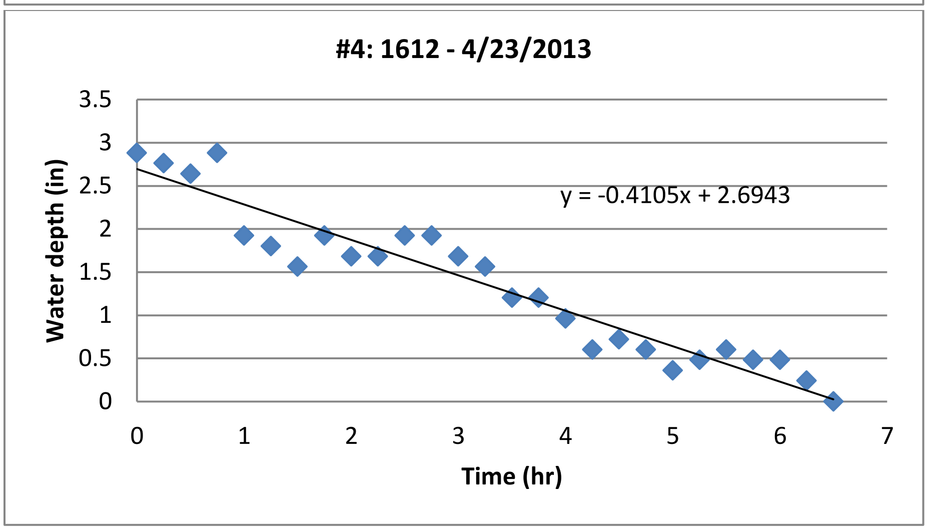

#4: 1612 - 5/29/2013
y = -1.4871x + 5.7067
Water depth (in)
Time (hr)

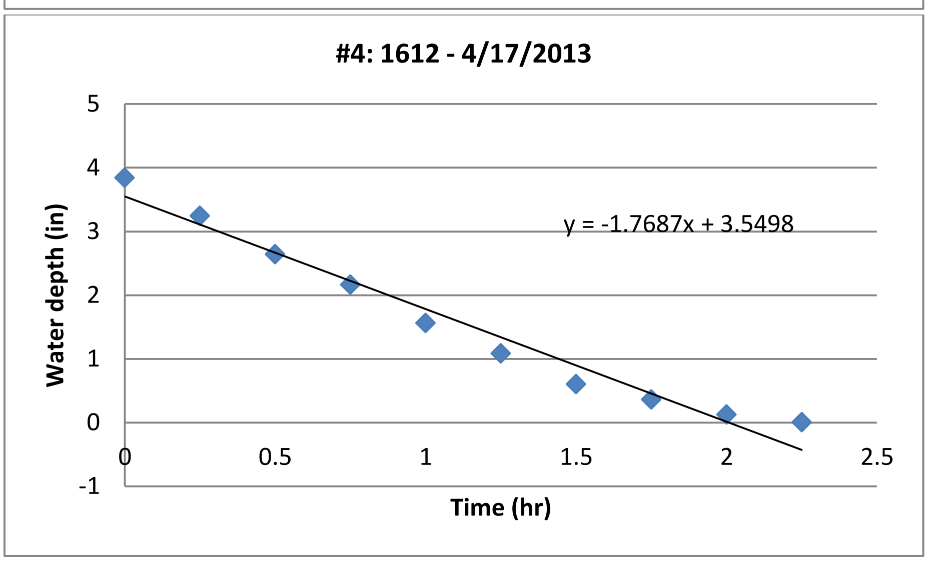

#4: 1612 - 5/27/2013
Water depth (in)
Time (hr)
y = -3.1412x + 12.099
14
12
10
8
6
4
2
0
-2
0
1
2
3
4
5

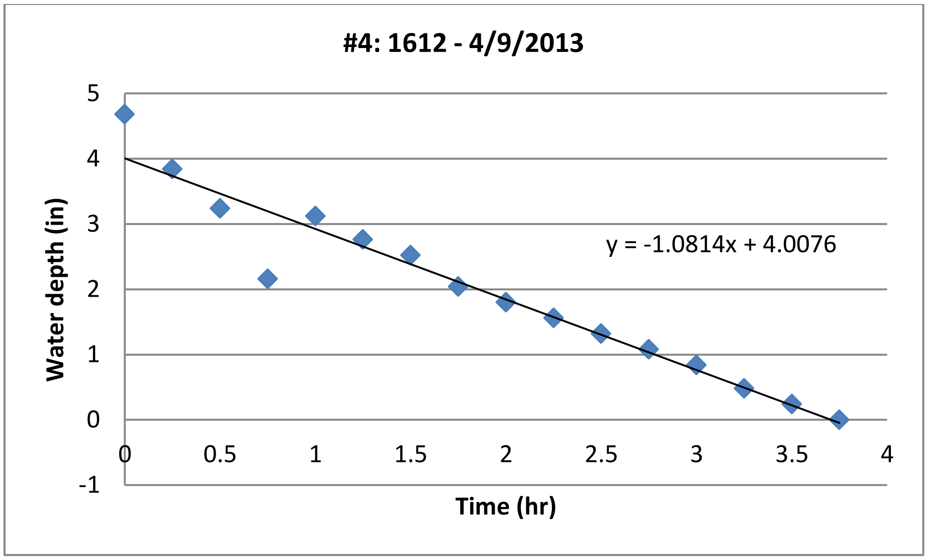

#4: 1612 - 5/19/2013
Water depth (in)
Time (hr)
y = -4.0171x + 6.68
8
7
6
5
4
3
2
1
0
-1
0
0.5
1
1.5
2

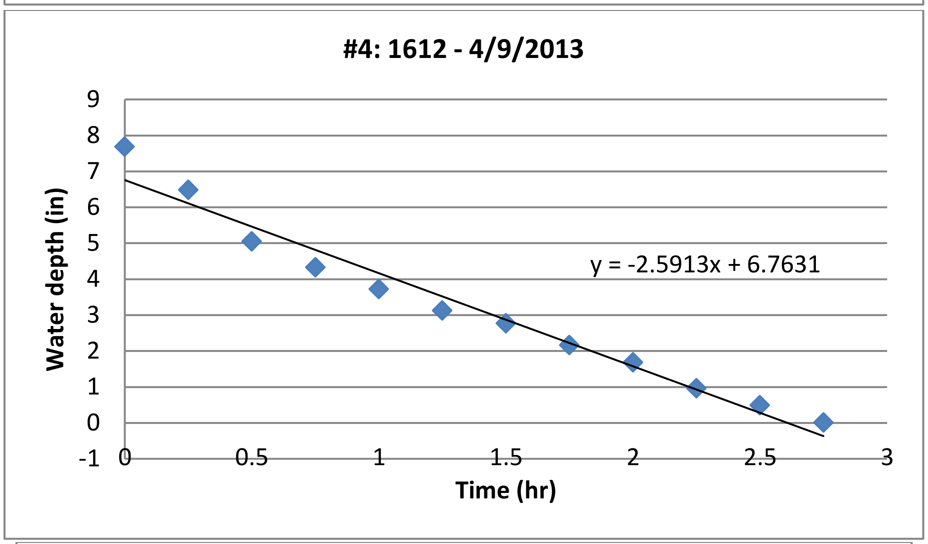

#4: 1612 - 5/2/2013
Water depth (in)
Time (hr)
y = -1.1794x + 1.2971
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0
0.2
0.4
0.6
0.8
1
1.2
1.4

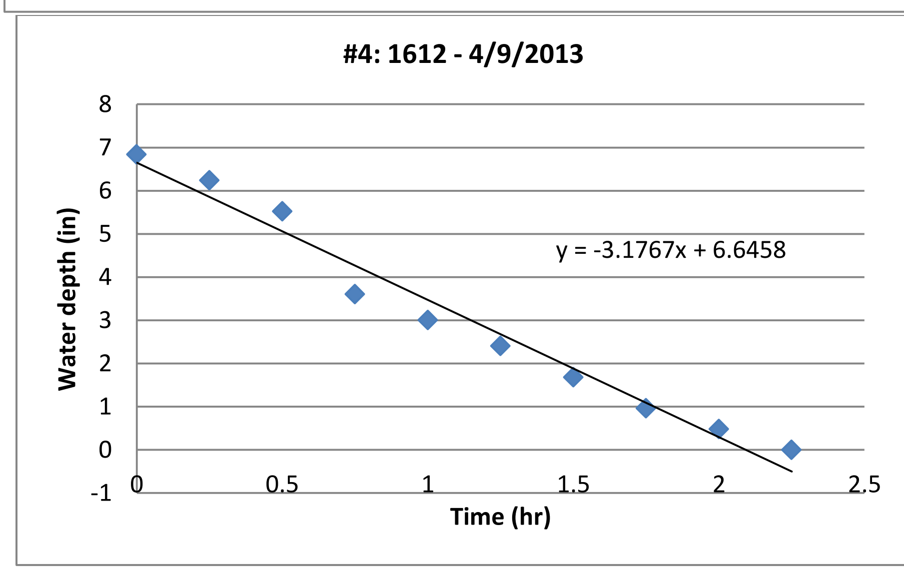

#4: 1612 - 4/27/2013
Water depth (in)
3
2.5
2
1.5
1
0.5
0
-0.5
0
0.5
1
1.5
2
2.5
3
y = -1.1302x + 2.6564
Time (hr)

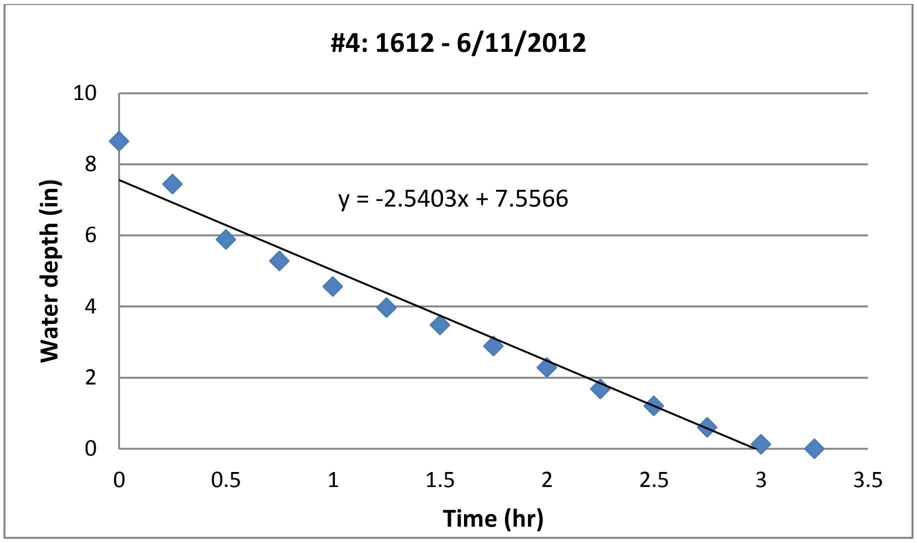

#4: 1612 - 4/23/2013
Water depth (in)
3.5
3
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
6
7
y = -0.4105x + 2.6943
Time (hr)


#4: 1612 - 4/17/2013
Water depth (in)
5
4
3
2
1
0
-1
0
0.5
1
1.5
2
2.5
y = -1.7687x + 3.5498
Time (hr)

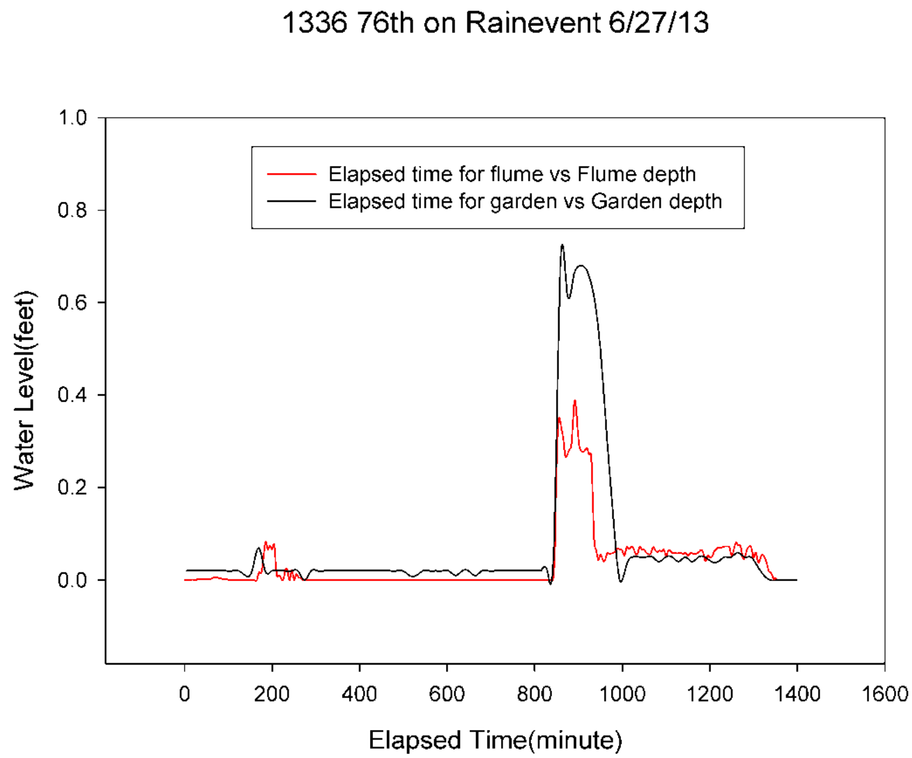

#4: 1612 - 4/9/2013
Water depth (in)
Time (hr)
y = -1.0814x + 4.0076
5
4
3
2
1
0
-1
0
0.5
1
1.5
2
2.5
3
3.5
4

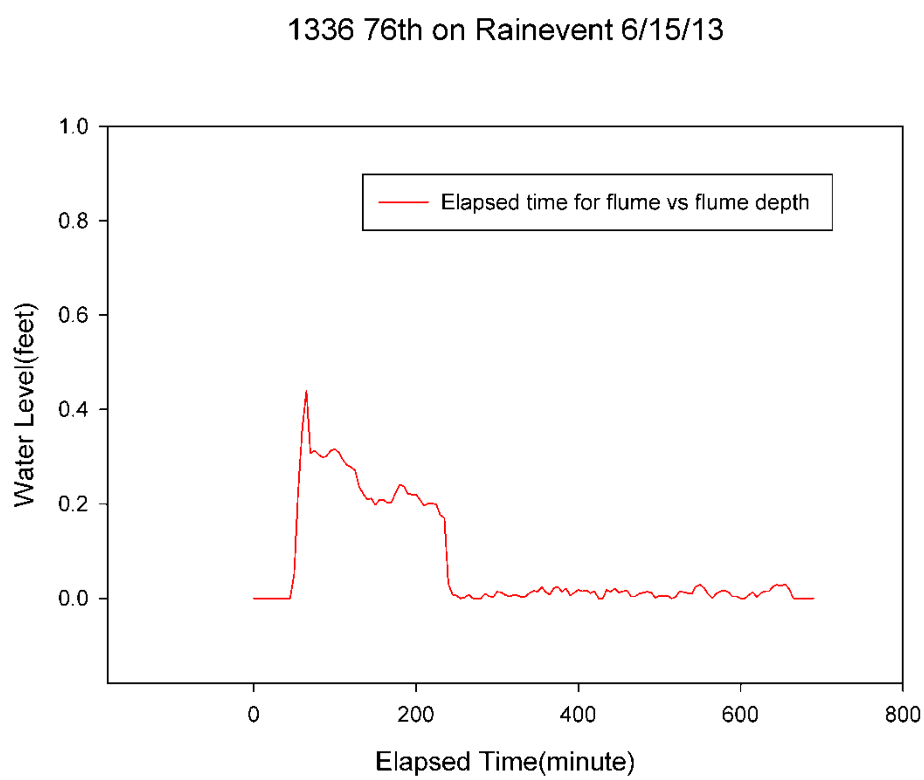

#4: 1612 - 4/9/2013
Water depth (in)
Time (hr)
y = -2.5913x + 6.7631
9
8
7
6
5
4
3
2
1
0
-1
0
0.5
1
1.5
2
2.5
3


#4: 1612 - 4/9/2013
Water depth (in)
Time (hr)
y = -3.1767x + 6.6458
8
7
6
5
4
3
2
1
0
-1
0
0.5
1
1.5
2
2.5

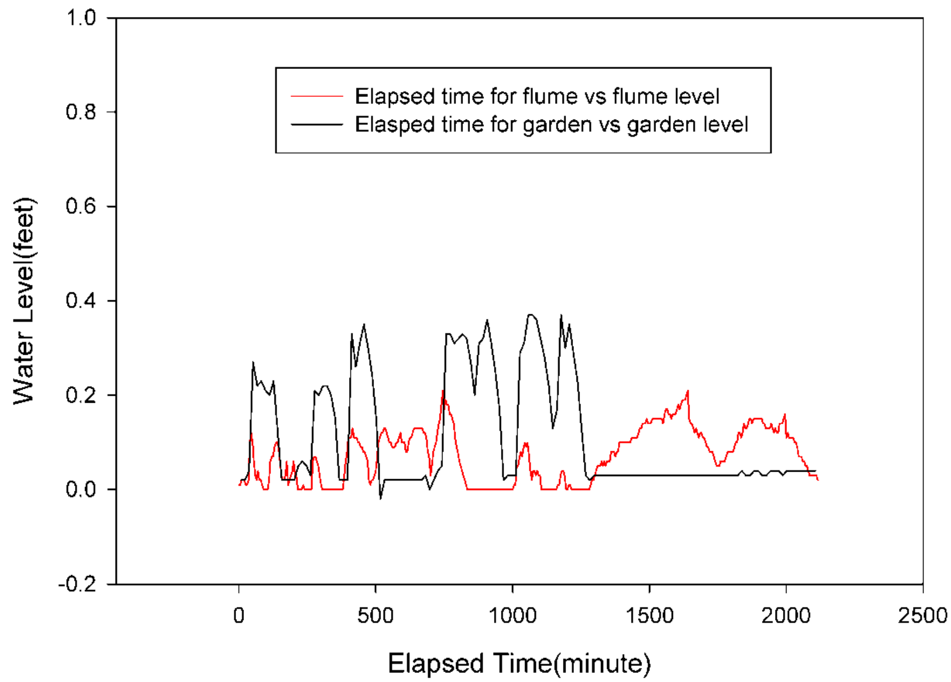

#4: 1612 - 6/11/2012
y = -2.5403x + 7.5566
Water depth (in)
Time (hr)
10
8
6
4
2
0
0
0.5
1
1.5
2
2.5
3
3.5

5- Curb-Cut Biofilter - 1336 E 76th St.

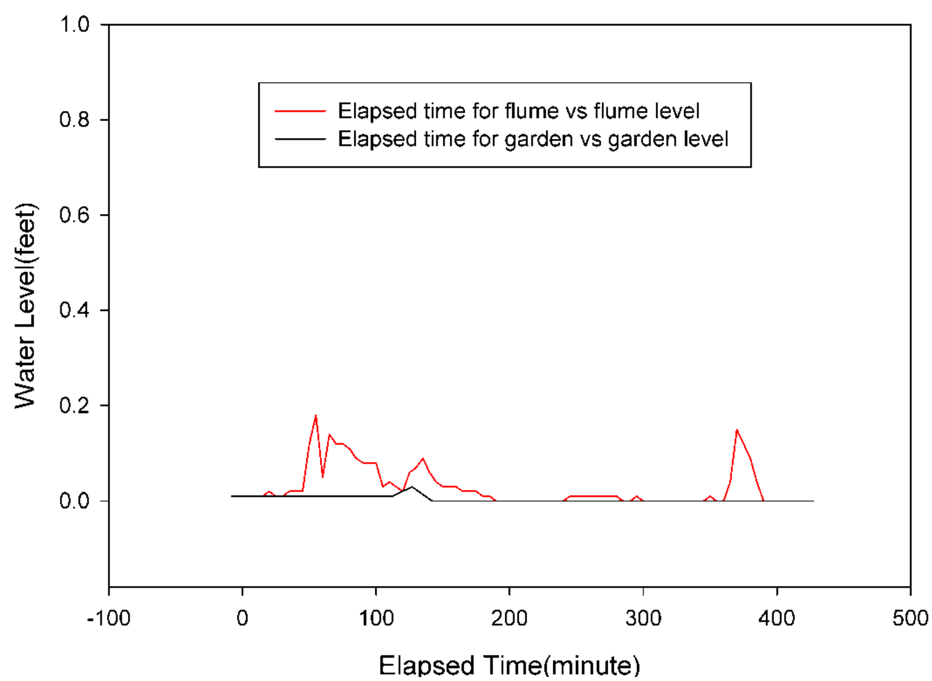




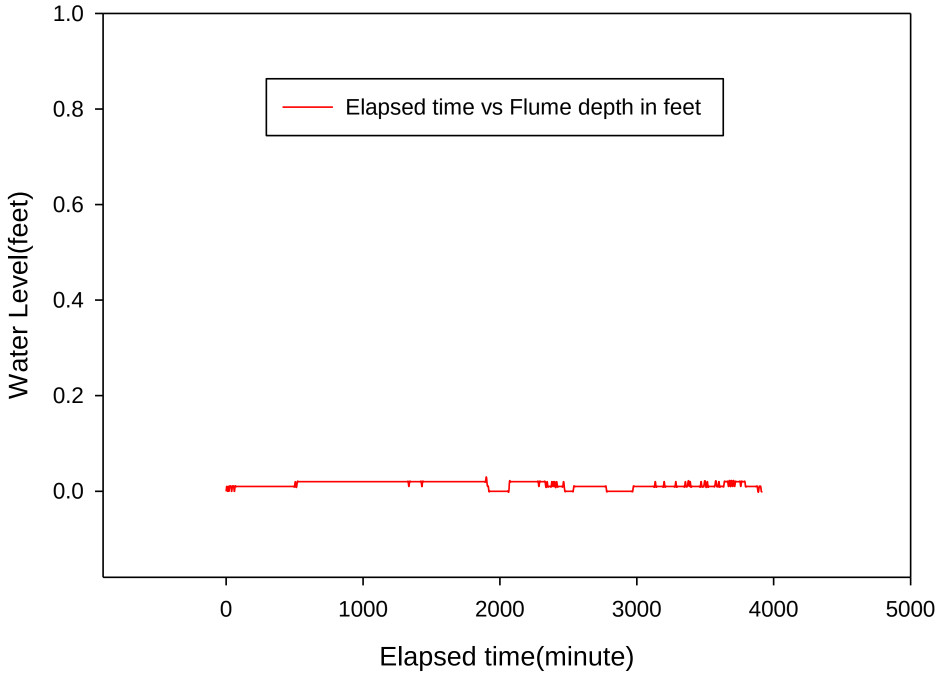
1336 76th on Rainevent 04/09/13--04/10/13



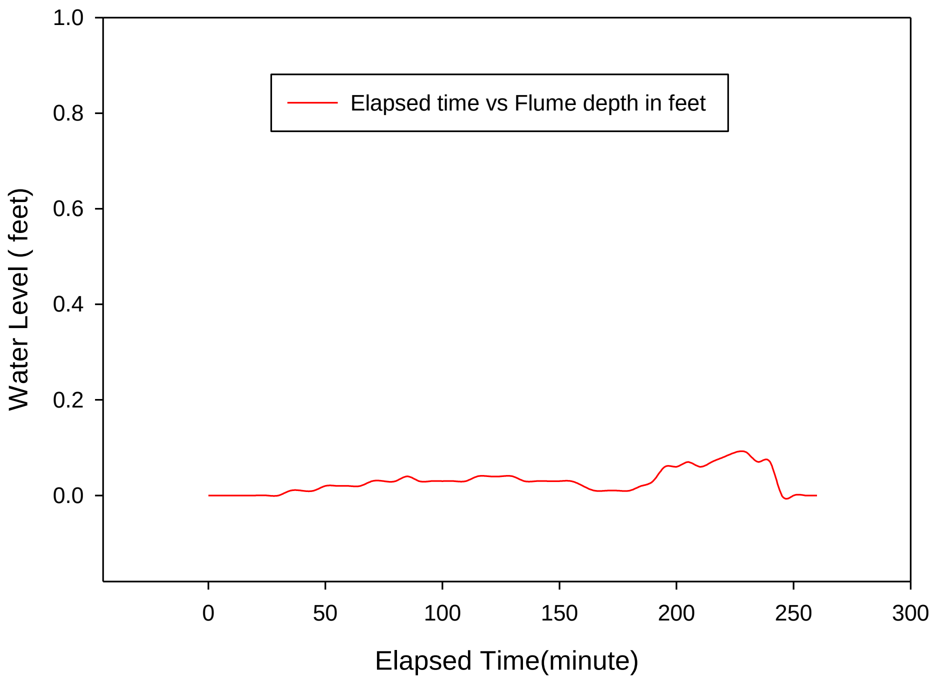
1336 76th on Rainevent 04/07/13



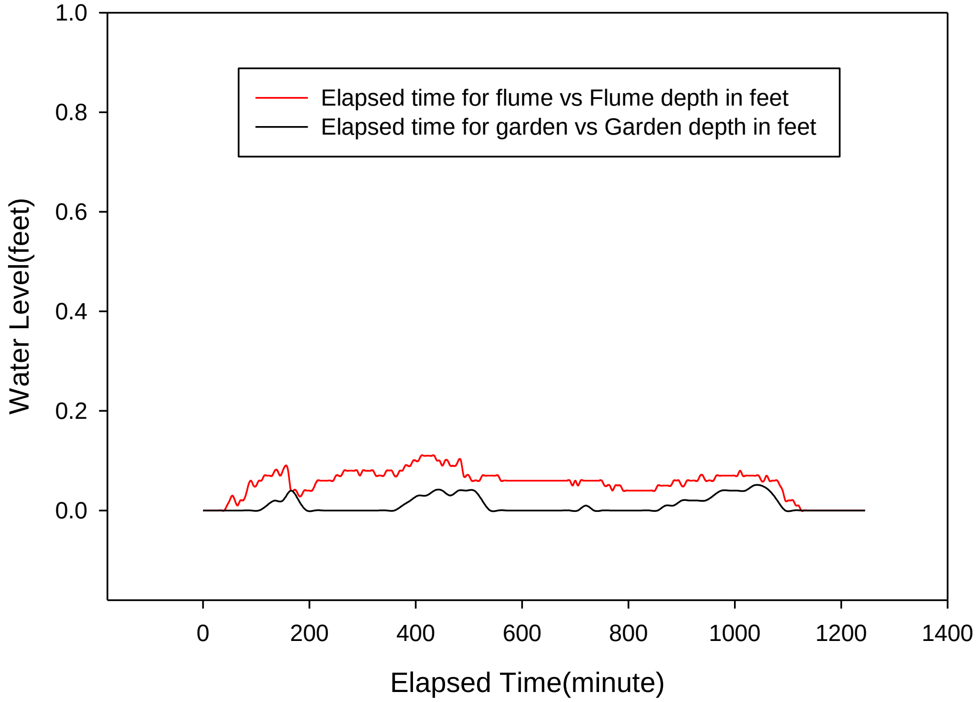
1336 76th Raingarden on Rainevent 10/13/2012



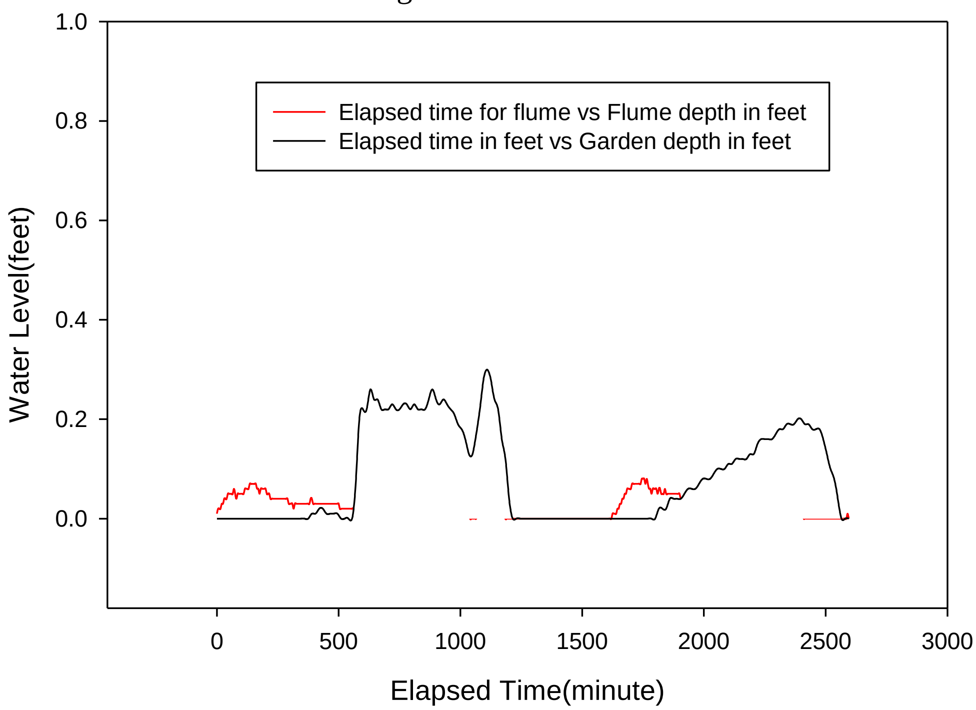
1336 76th Raingarden on Rainevent 9/26/2012



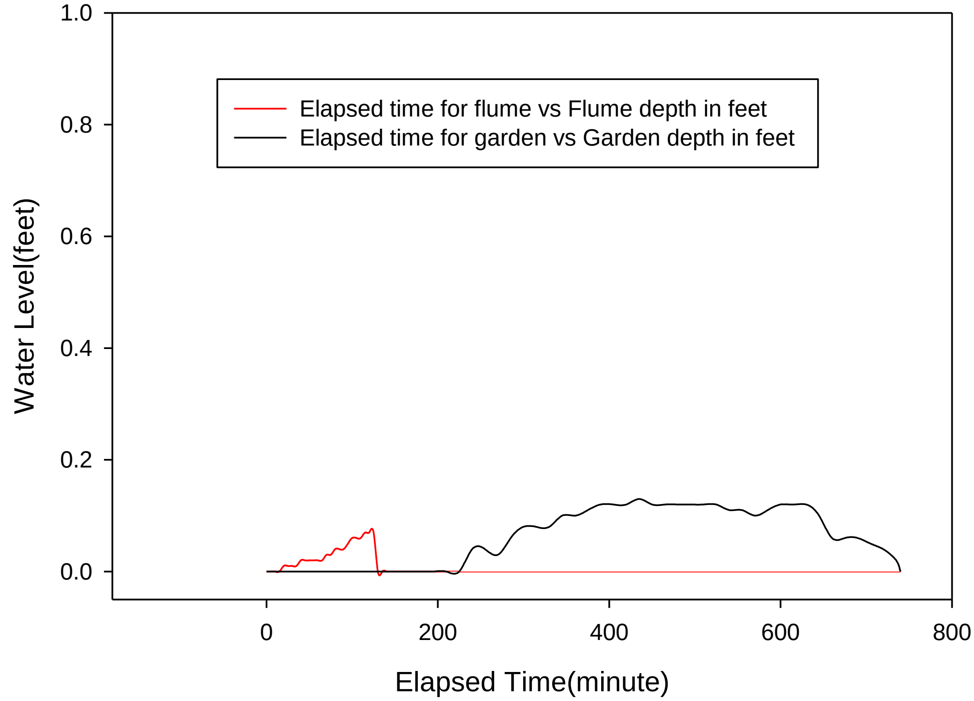
1336 76th Raingarden on Rainevent 9/13/2012



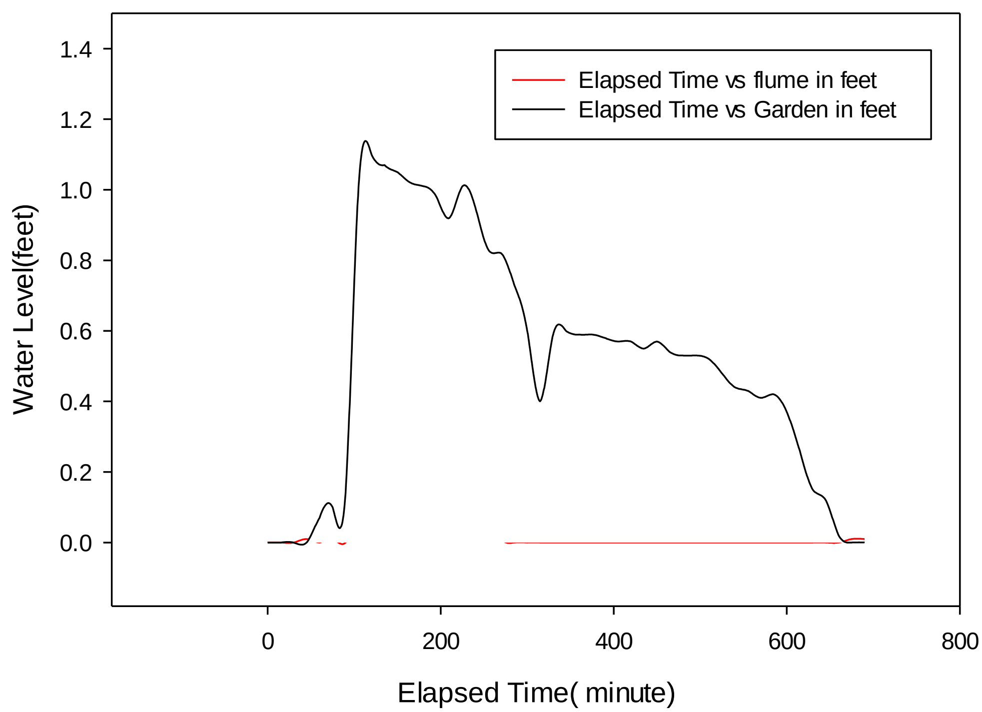
1336 76th Raingarden on Rainevent 9/1/2012



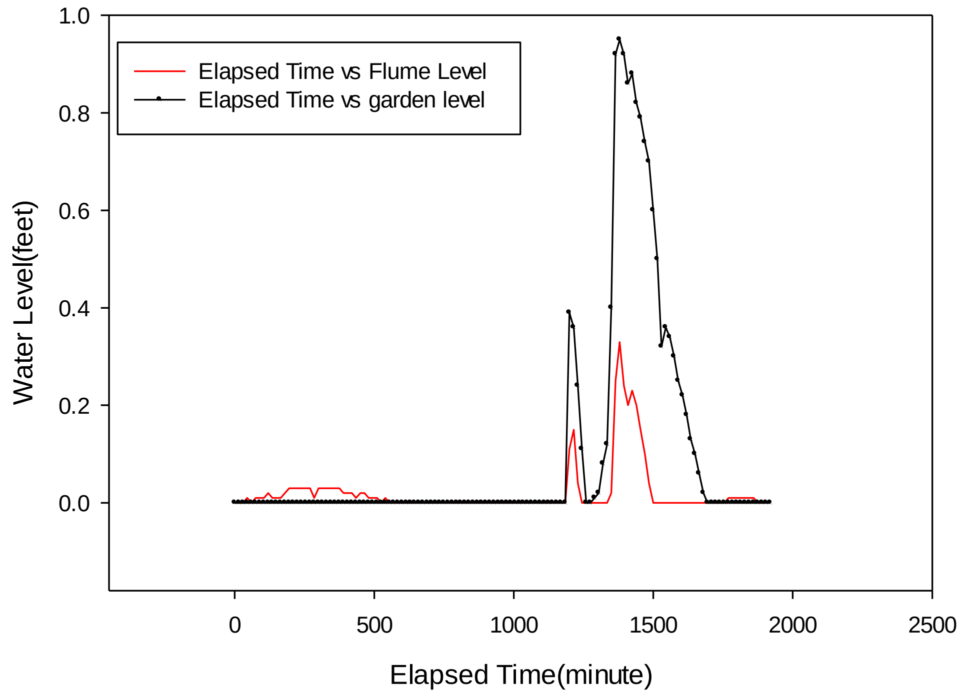
1336 76th Raingarden on Rainevent 7/26/2012



1336 76th Graphs on Rainevent 06/21/2012

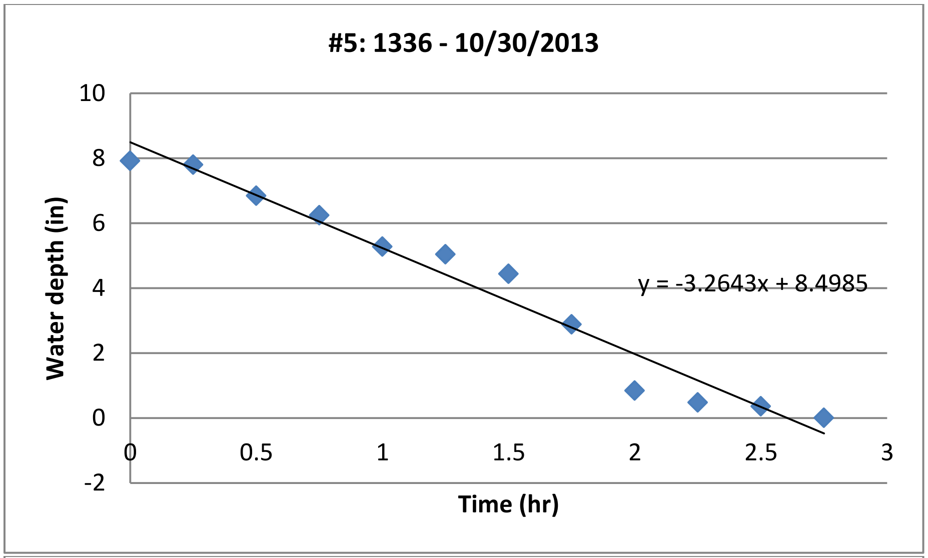


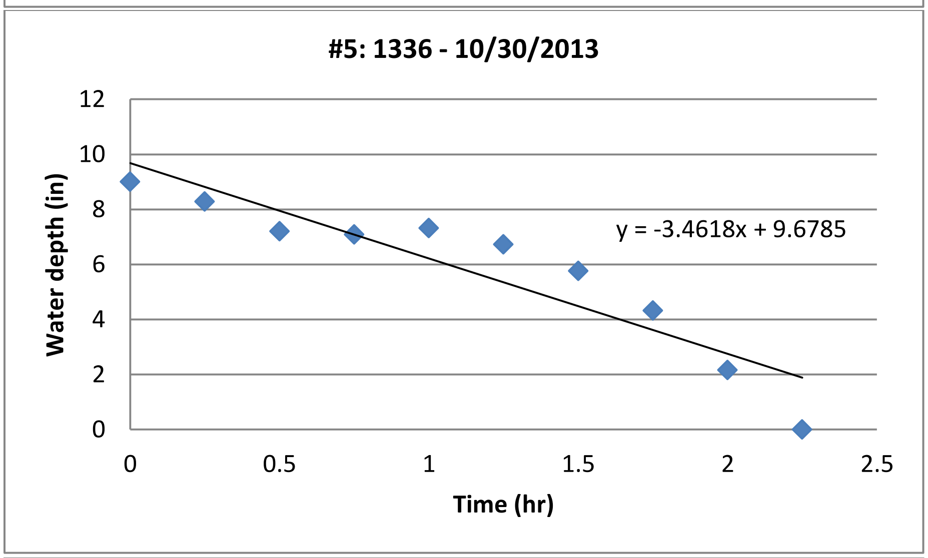
1336 76th Raingarden on Rainevent 06/11/2012

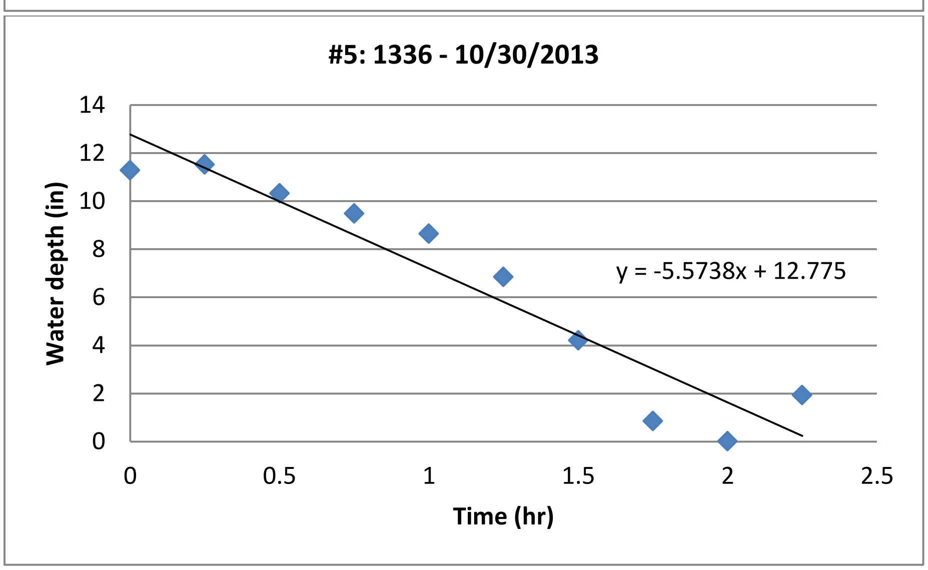


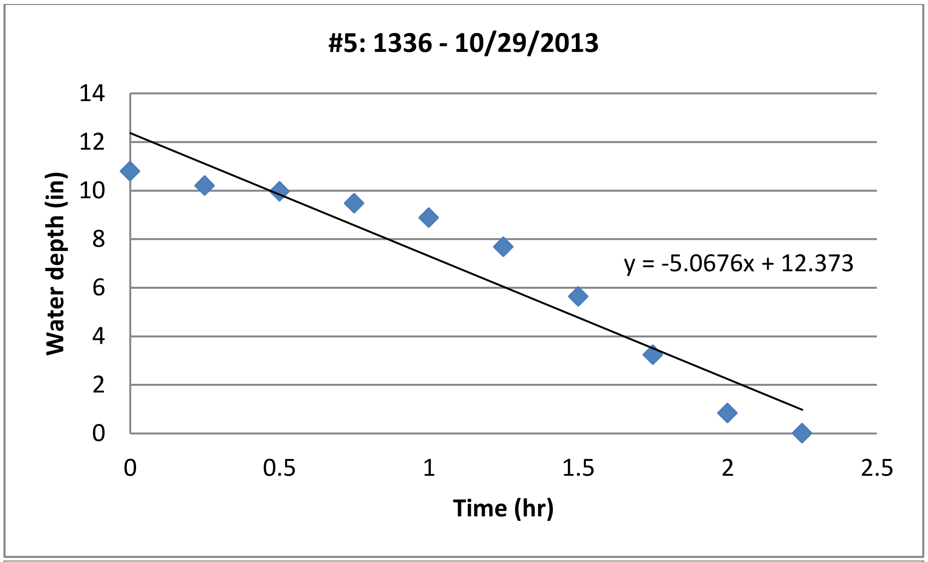
Rainfall Depth (in.)	Start Time	End Time	Event Duration (hr:min)	Max Water Depth in Garden (in)	Time Duration before Ponding Occurred (hr:min)	f (in/hr)
3.43	10/30/2013 12:09:00	10/31/2013 11:46:00	23:37	7.92	18:44	3.26
3.43	10/30/2013 12:09:00	10/31/2013 11:46:00	23:37	9	3:44	3.46
3.43	10/30/2013 12:09:00	10/31/2013 11:46:00	23:37	11.52	0:29	5.57
0.83	10/29/2013 2:52:00	10/29/2013 9:41:00	6:49	10.8	3:45	5.07
0.12	10/18/2013 14:03:00	10/18/2013 17:05:00	3:02	2.52	0:04	3.22
0.87	10/4/2013 22:36:00	10/5/2013 3:48:00	5:12	8.4	0:30	4.54
0.16	10/3/2013 11:04:00	10/3/2013 11:24:00	0:20	3.6	0:02	2.01
0.28	9/28/2013 8:29:00	9/28/2013 11:29	3:00	6.24	0:51	2.58
1.89	9/19/2013 19:00:00	9/19/2013 22:23:00	3:23	10.68	2:49	5.34
0.79	9/17/2013 7:04:00	9/17/2013 15:14:00	8:10	9.36	3:14	4.26
0.16	9/1/2013 07:42:00	9/1/2013 09:02:00	1:20	3.6	0:05	1.1

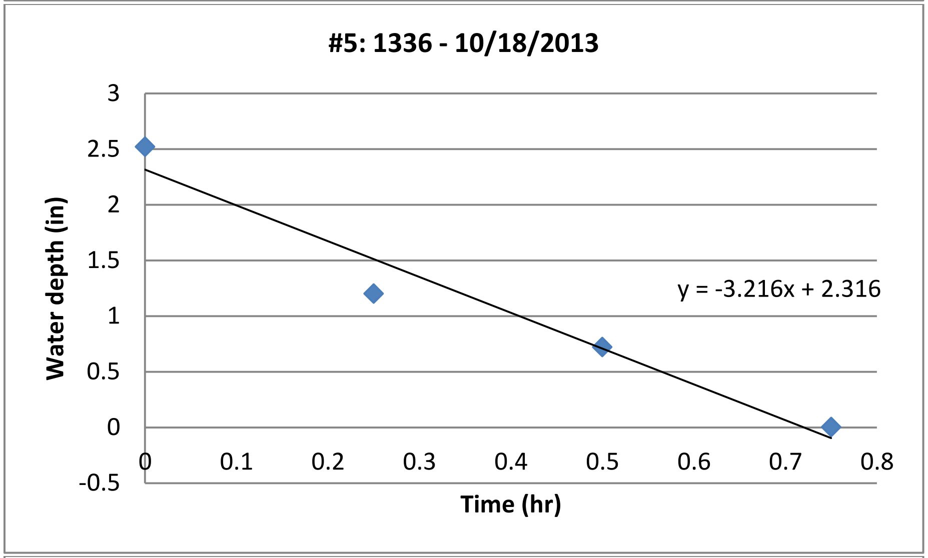
Rainfall Depth (in.)	Start Time	End Time	Event Duration (hr:min)	Max Water Depth in Garden (in)	Time Duration before Ponding Occurred (hr:min)	f (in/hr)
0.67	8/12/2013 7:07:00	8/12/2013 10:18:00	3:11	10.8	0:24	3.5
0.87	8/7/2013 4:13:00	8/7/2013 8:45:00	4:32	8.52	2:48	4.53
0.55	8/6/2013 3:24:00	8/6/2013 4:59:00	1:35	6.0	0:37	3.34
0.91	7/29/2013 6:27:00	7/30/2013 9:41:00	27:14	7.32	8:03	5.72
0.24	7/25/2013 17:00:00	7/26/2013 11:00:00	18:00	1.08	2:15	1.05
1.5	7/3/2013 17:54:00	7/3/2013 21:36:00	3:42	6.12	2:17	1.18
0.83	6/27/2013 11:46:00	6/28/2013 0:49:00	13:03	8.88	11:25	3.57
1.26	6/15/2013 15:50:00	6/15/2013 22:05:00	6:15	5.49	0:16	1.11
0.39	4/23/2013 1:34:00	4/23/2013 10:53:00	9:19	6.48	4:04	2.54
1.10	4/17/2013 11:00:00	4/18/2013 20:41:00	33:41	5.16	18:23	1.83
1.10	4/17/2013 11:00:00	4/18/2013 20:41:00	33:41	7.44	0	2.63
1.62	4/9/2013 21:56:00	4/10/2013 18:30:00	20:34	4.08	14:57	2.92
1.62	4/9/2013 21:56:00	4/10/2013 18:30:00	20:34	3	0:57	1.29
1.10	4/7/2013 19:52:00	4/8/2013 2:25:00	6:33	1.92	13:00	0.78
0.86	10/11/2012 17:32:07	10/14/2012 10:47:07	65:15	0		
0.23	9/26/2012 03:02:07	9/26/2012 07:22:07	04:20	0		
0.43	9/13/2012 14:37:17	9/14/2012 10:47:07	20:45	0.6	2:00	>0.96
					6:15	>0.96
					14:30	>0.82
5.60	8/31/2012 15:47:07	9/2/2012 11:02:07	43:15	3.6	9:30	>2.13
					30:15	0.82
0.49	7/26/2012 01:31:19	7/26/2012 12:16:19	10:45	1.6	4:00	0.62
1.03	6/21/2012 00:17:19	6/21/2012 12:02:19	11:45	13.2	1:00	1.19
0.8	6/10/2012 07:02:19	6/11/2012 15:02:19	32:00	11.4	20:00	>4.94
					21:30	>2.38

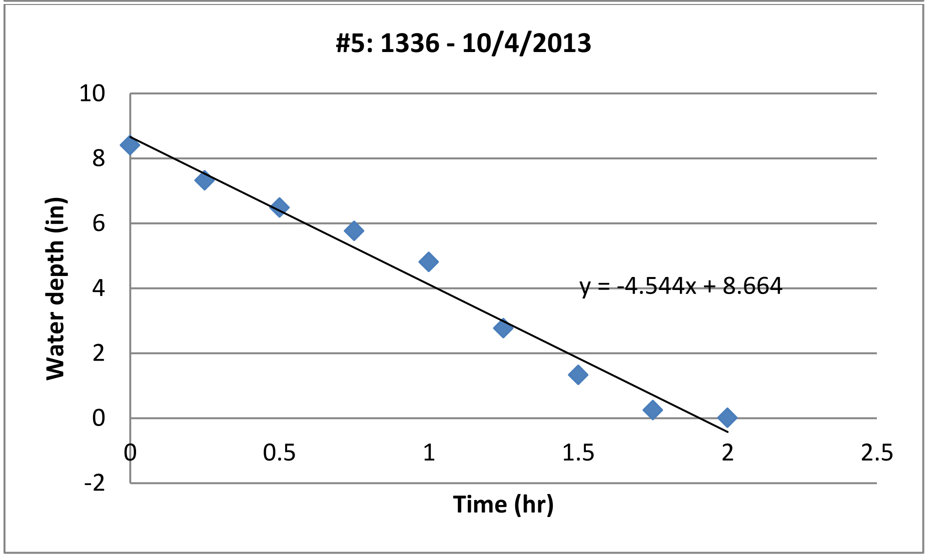

#5: 1336 - 10/30/2013
y = -3.2643x + 8.4985
Water depth (in)
Time (hr)
10
8
6
4
2
0
-2
0
0.5
1
1.5
2
2.5
3

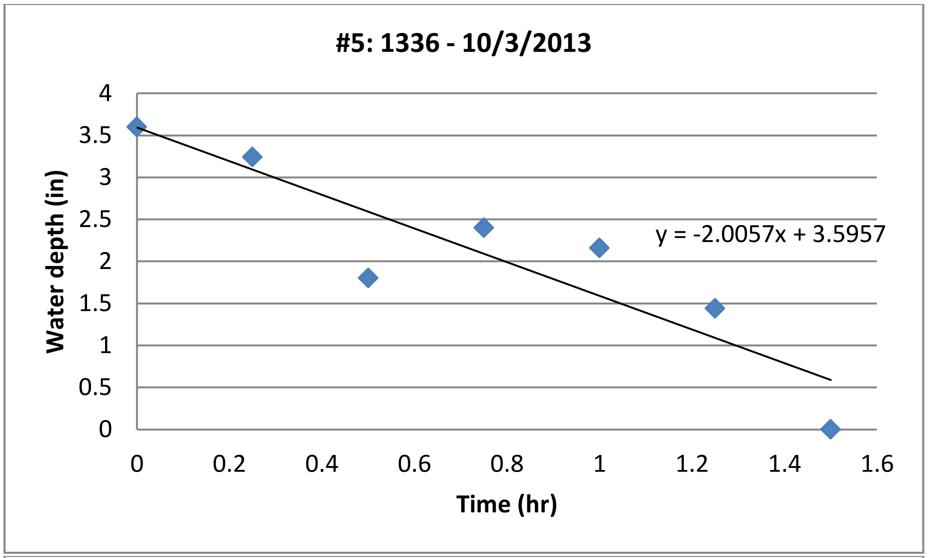

#5: 1336 - 10/30/2013
y = -3.4618x + 9.6785
Water depth (in)
Time (hr)
12
10
8
6
4
2
0
0
0.5
1
1.5
2
2.5

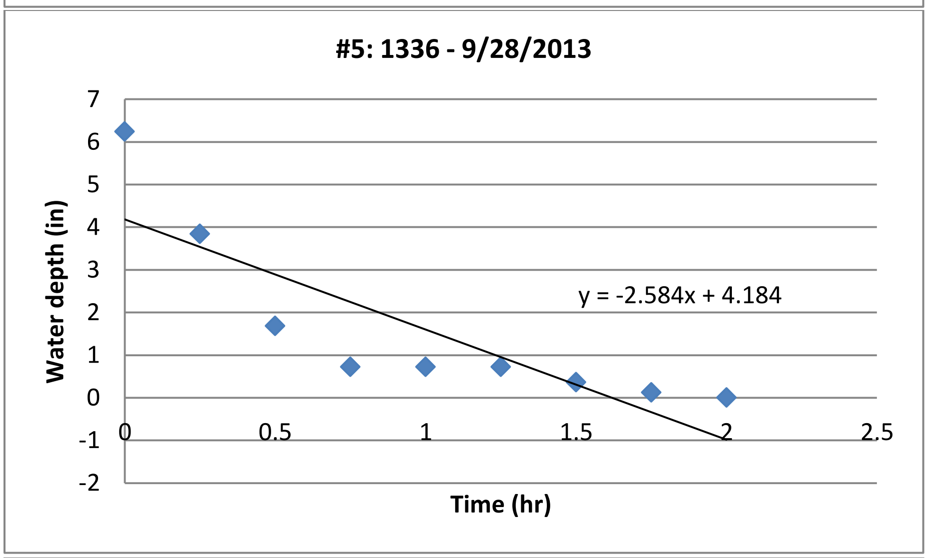

#5: 1336 - 10/30/2013
y = -5.5738x + 12.775
Water depth (in)
Time (hr)
14
12
10
8
6
4
2
0
0
0.5
1
1.5
2
2.5

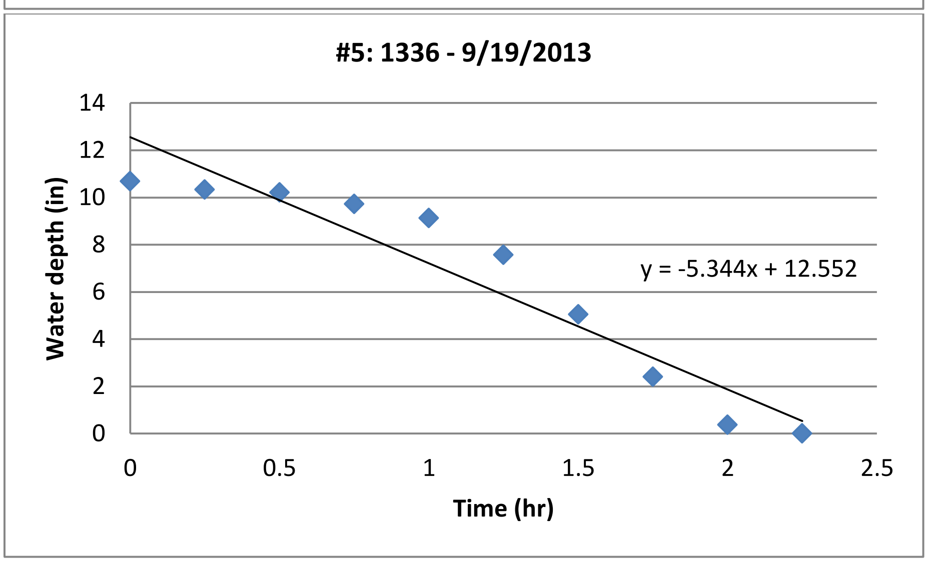

#5: 1336 - 10/29/2013
Water depth (in)
14
12
10
8
6
4
2
0
0
0.5
1
1.5
2
2.5
Time (hr)
y = -5.0676x + 12.373

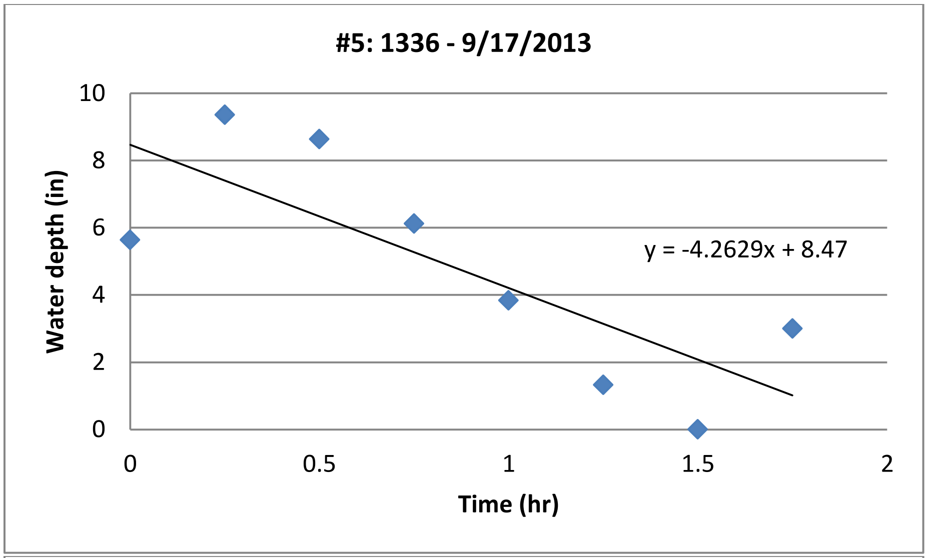

#5: 1336 - 10/18/2013
Water depth (in)
3
2.5
2
1.5
1
0.5
0
-0.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Time (hr)
y = -3.216x + 2.316

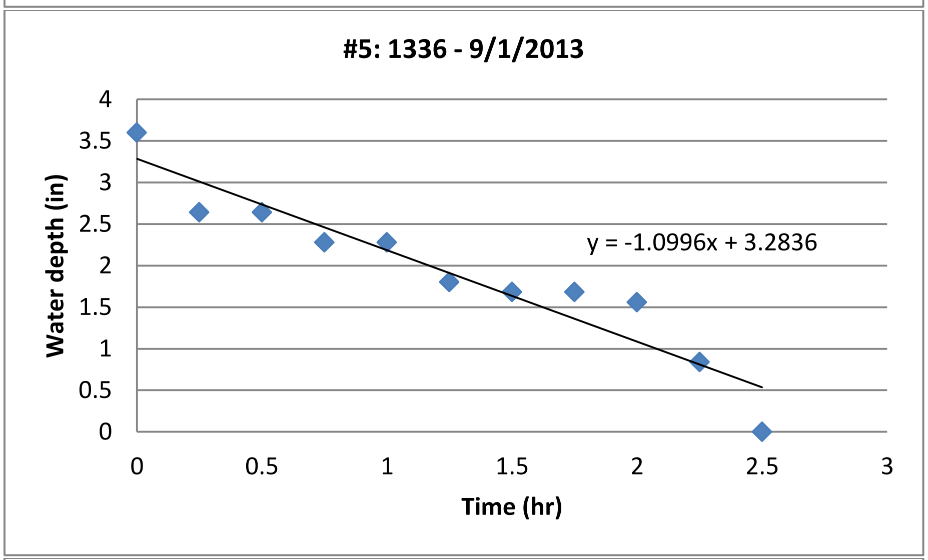

#5: 1336 - 10/4/2013
Water depth (in)
10
8
6
4
2
0
-2
0
0.5
1
1.5
2
2.5
Time (hr)
y = -4.544x + 8.664

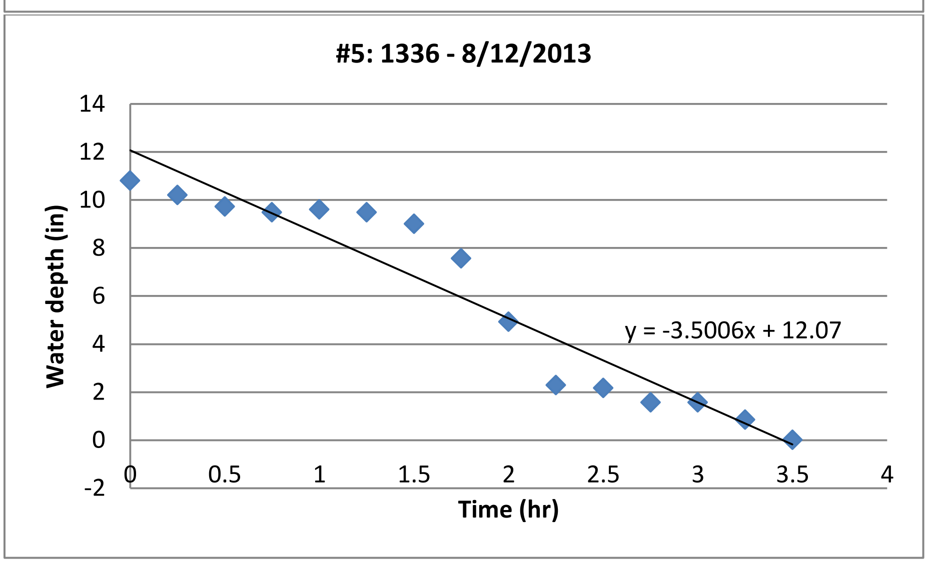

#5: 1336 - 10/3/2013
Water depth (in)
Time (hr)
y = -2.0057x + 3.5957
4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6

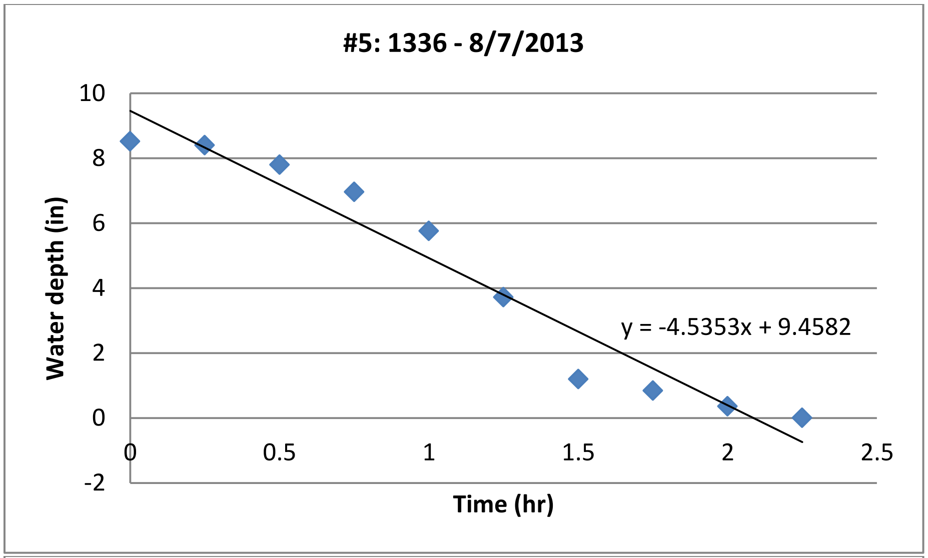

#5: 1336 - 9/28/2013
Water depth (in)
Time (hr)
y = -2.584x + 4.184
7
6
5
4
3
2
1
0
-1
-2
0
0.5
1
1.5
2
2.5

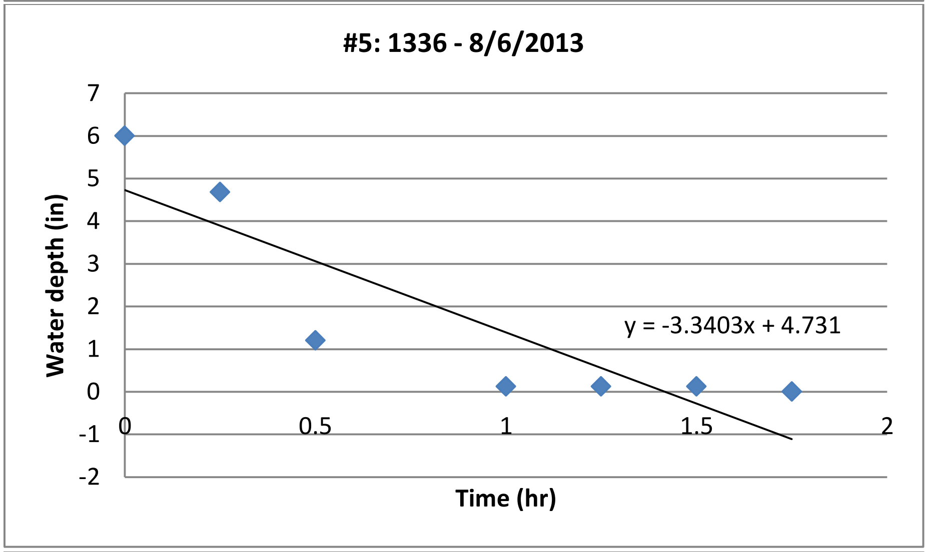

#5: 1336 - 9/19/2013
Water depth (in)
Time (hr)
y = -5.344x + 12.552
14
12
10
8
6
4
2
0
0
0.5
1
1.5
2
2.5

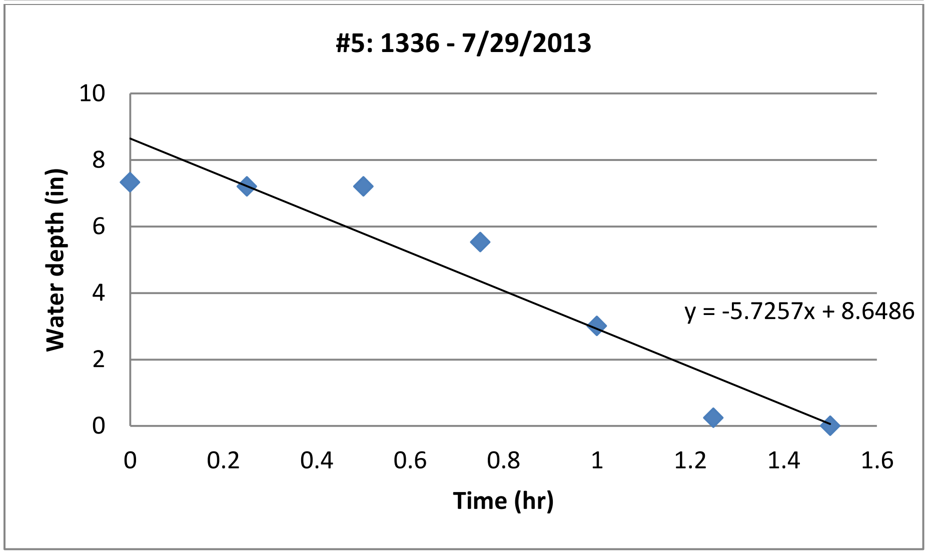

#5: 1336 - 9/17/2013
Water depth (in)
Time (hr)
y = -4.2629x + 8.47
10
8
6
4
2
0
0
0.5
1
1.5
2

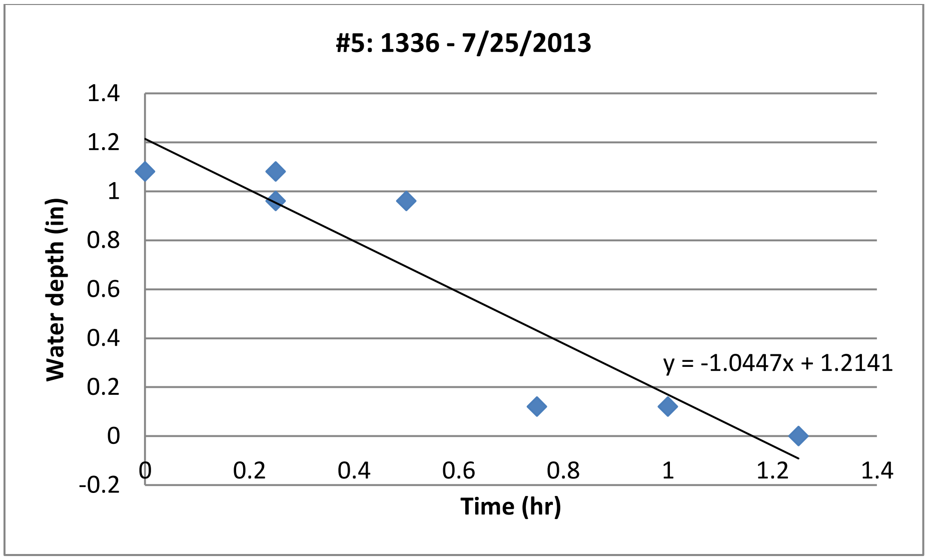

#5: 1336 - 9/1/2013
Water depth (in)
Time (hr)
y = -1.0996x + 3.2836
4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.5
1
1.5
2
2.5
3

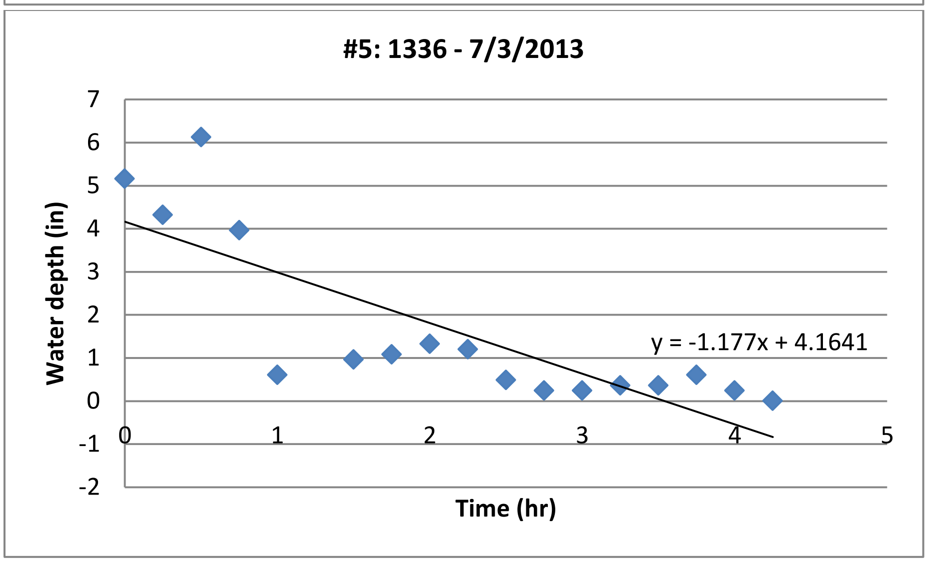

#5: 1336 - 8/12/2013
Water depth (in)
Time (hr)
y = -3.5006x + 12.07
14
12
10
8
6
4
2
0
-2
0
0.5
1
1.5
2
2.5
3
3.5
4

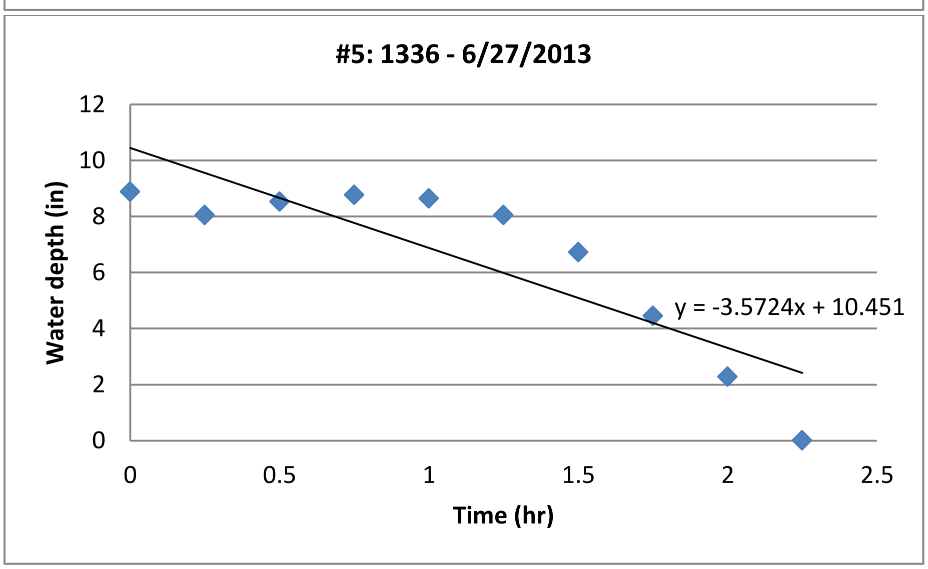

#5: 1336 - 8/7/2013
Water depth (in)
Time (hr)
y = -4.5353x + 9.4582
10
8
6
4
2
0
-2
0
0.5
1
1.5
2
2.5

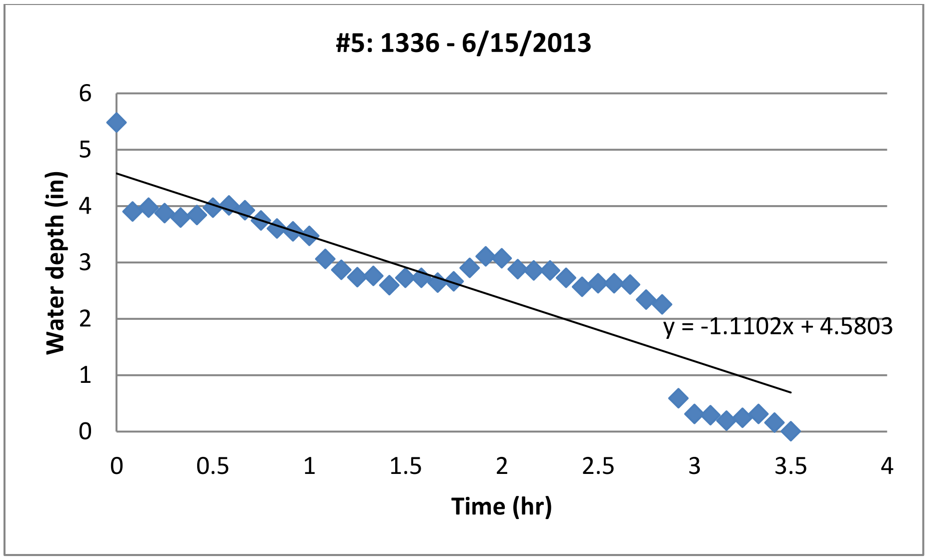

#5: 1336 - 8/6/2013
Water depth (in)
Time (hr)
y = -3.3403x + 4.731
7
6
5
4
3
2
1
0
-1
-2
0
0.5
1
1.5
2

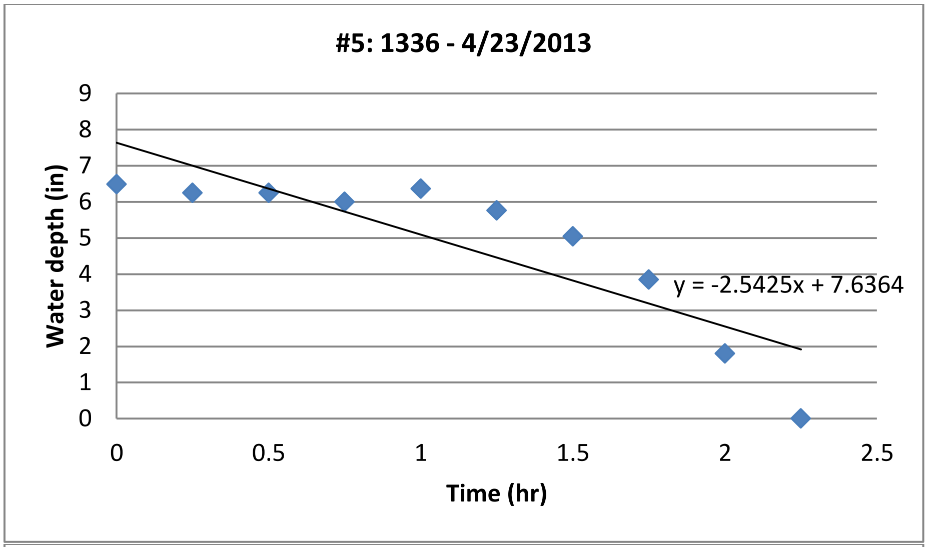

#5: 1336 - 7/29/2013
Water depth (in)
Time (hr)
y = -5.7257x + 8.6486
10
8
6
4
2
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6

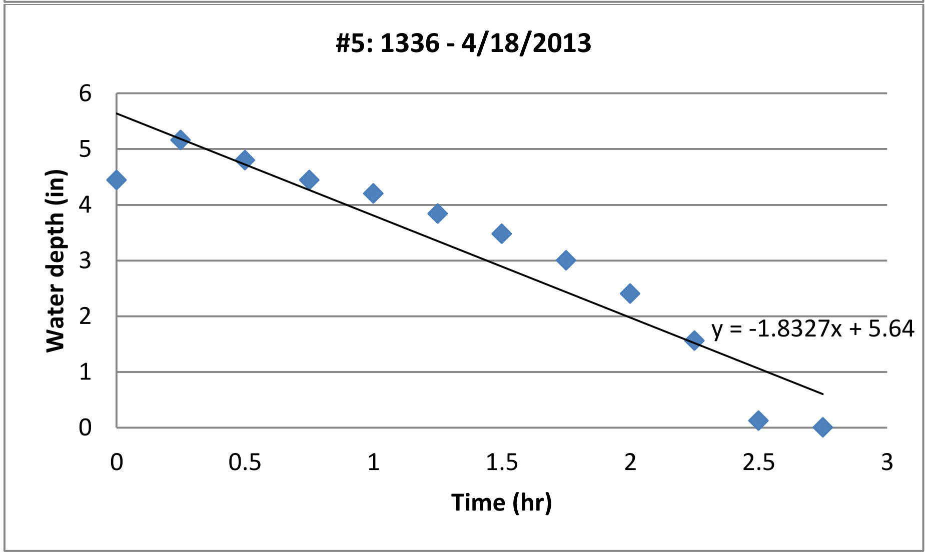

#5: 1336 - 7/25/2013
Water depth (in)
Time (hr)
y = -1.0447x + 1.2141
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4

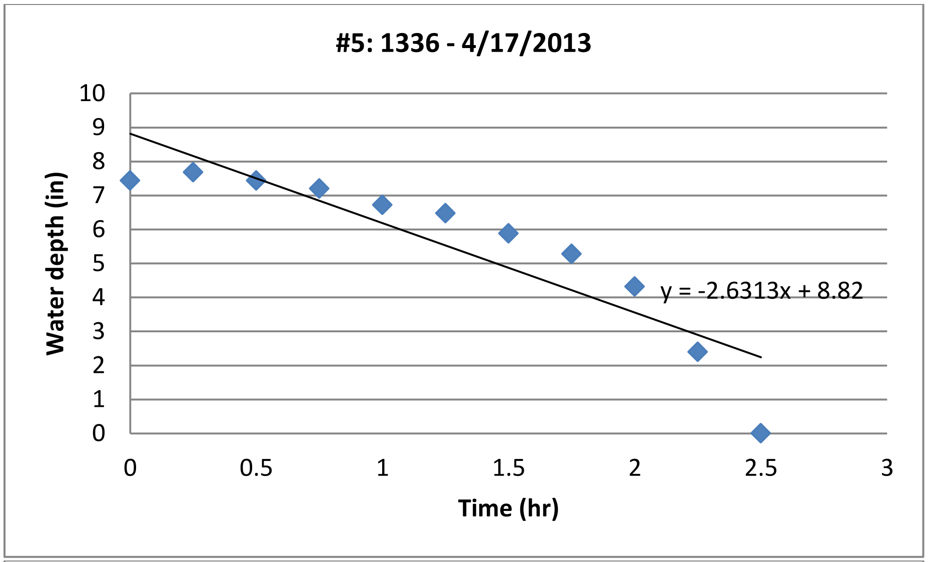

#5: 1336 - 7/3/2013
Water depth (in)
Time (hr)
y = -1.177x + 4.1641
7
6
5
4
3
2
1
0
-1
-2
0
1
2
3
4
5

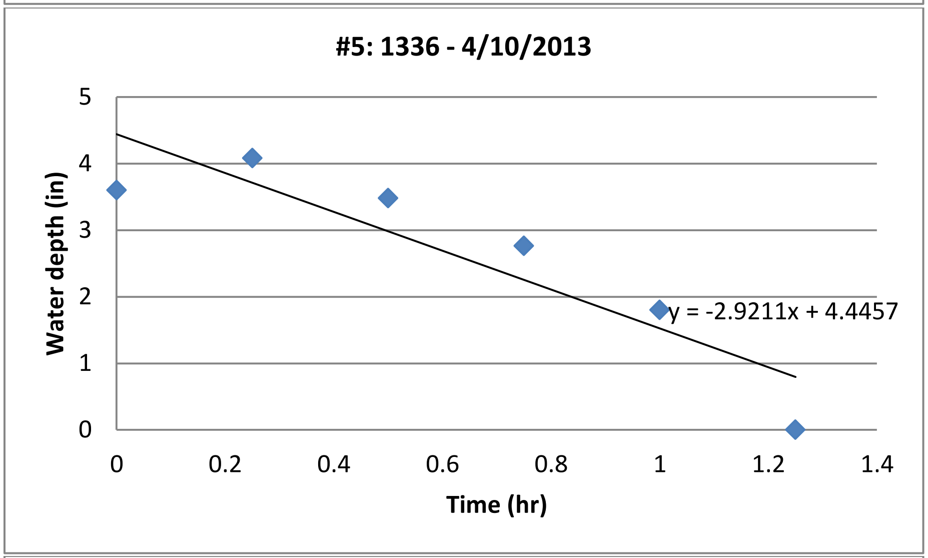

#5: 1336 - 6/27/2013
Water depth (in)
Time (hr)
y = -3.5724x + 10.451
12
10
8
6
4
2
0
0
0.5
1
1.5
2
2.5

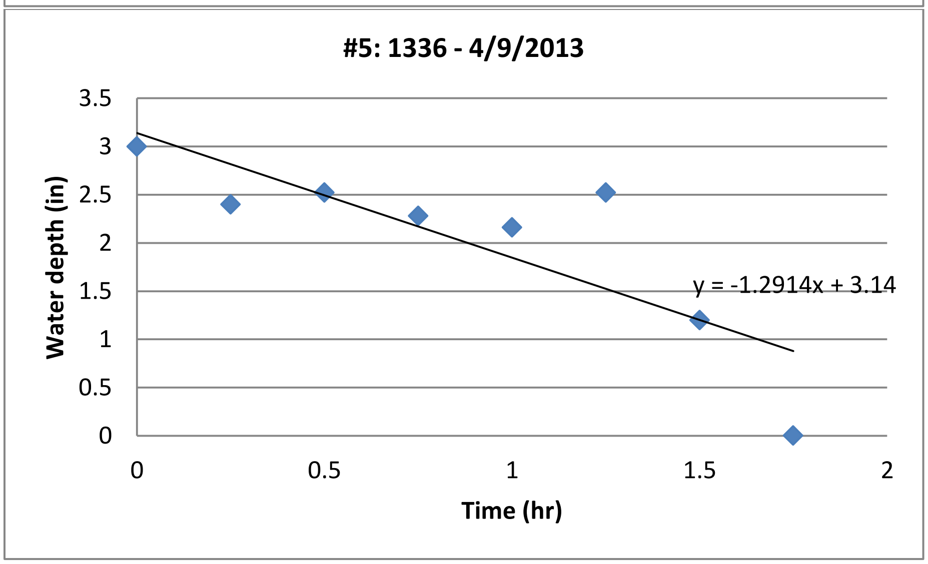

#5: 1336 - 6/15/2013
Water depth (in)
Time (hr)
y = -1.1102x + 4.5803
0
1
2
3
4
5
6
0
0.5
1
1.5
2
2.5
3
3.5
4

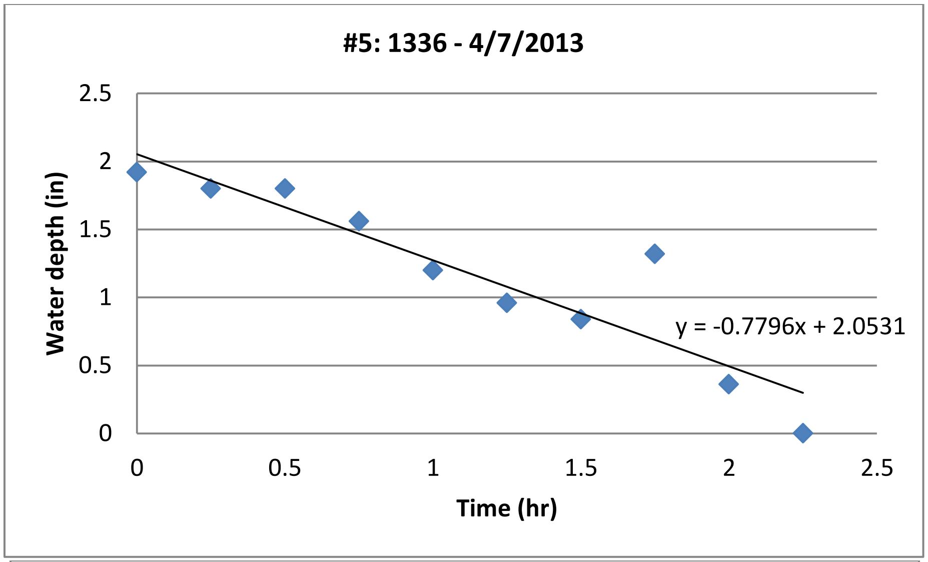

#5: 1336 - 4/23/2013
Water depth (in)
Time (hr)
y = -2.5425x + 7.6364
0
1
2
3
4
5
6
7
8
9
0
0.5
1
1.5
2
2.5

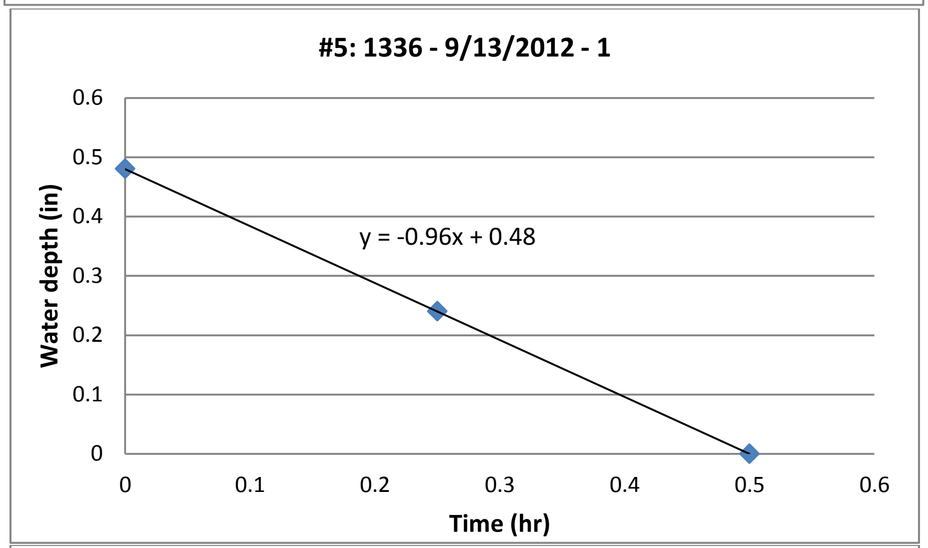

#5: 1336 - 4/18/2013
Water depth (in)
Time (hr)
y = -1.8327x + 5.64
0
1
2
3
4
5
6
0
0.5
1
1.5
2
2.5
3

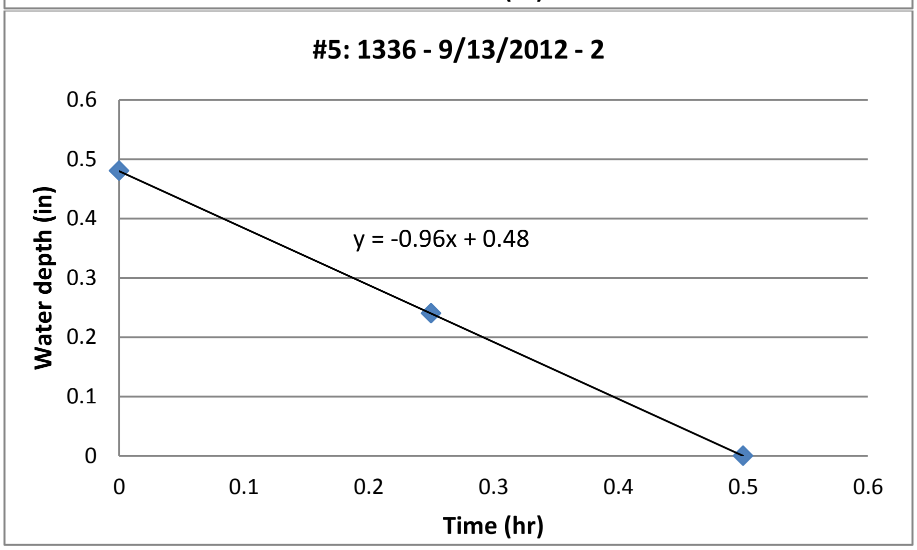

#5: 1336 - 4/17/2013
10
9
8
7
6
5
4
3
2
1
0
Water depth (in)
y = -2.6313x + 8.82
0
0.5
1
1.5
2
2.5
3
Time (hr)

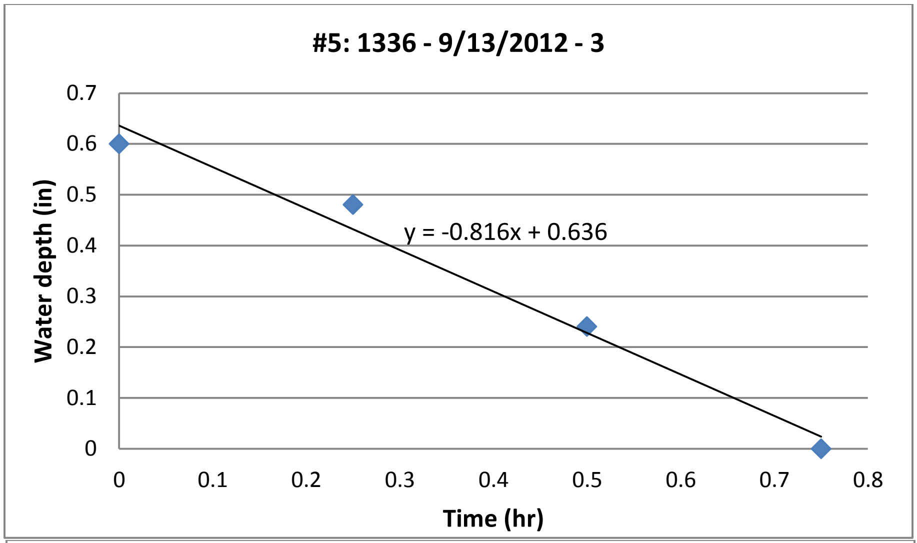

#5: 1336 - 4/10/2013
5
4
3
2
1
0
Water depth (in)
y = -2.9211x + 4.4457
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Time (hr)

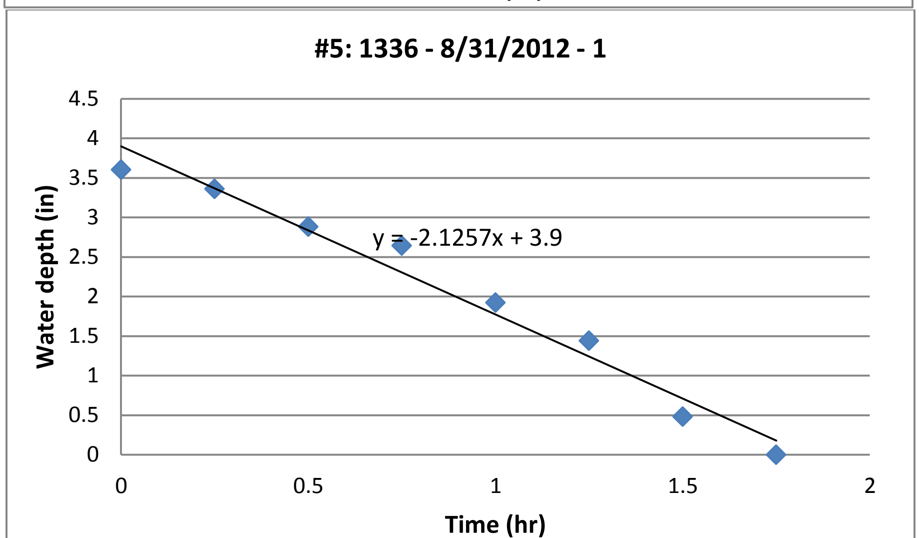

#5: 1336 - 4/9/2013
3.5
3
2.5
2
1.5
1
0.5
0
Water depth (in)
y = -1.2914x + 3.14
0
0.5
1
1.5
2
Time (hr)

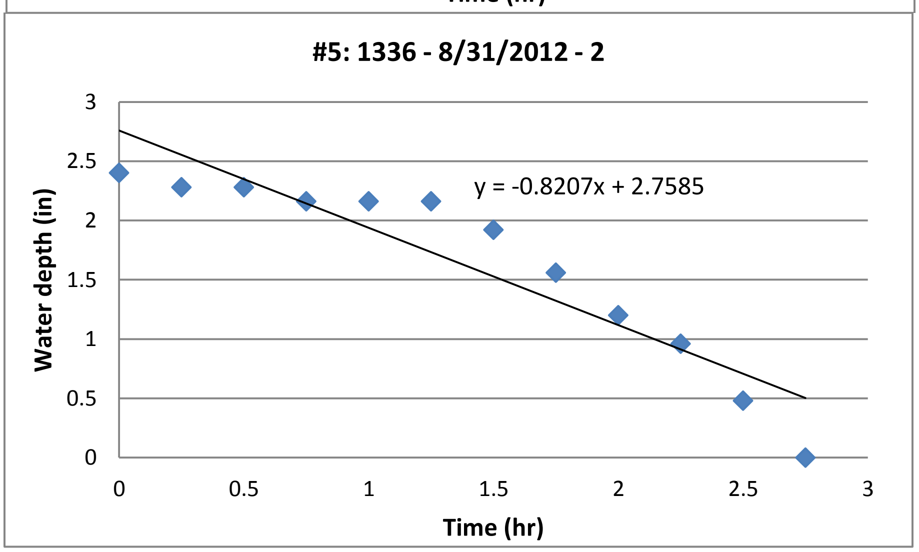

#5: 1336 - 4/7/2013
Water depth (in)
2.5
2
1.5
1
0.5
0
0
0.5
1
1.5
2
2.5
Time (hr)
y = -0.7796x + 2.0531

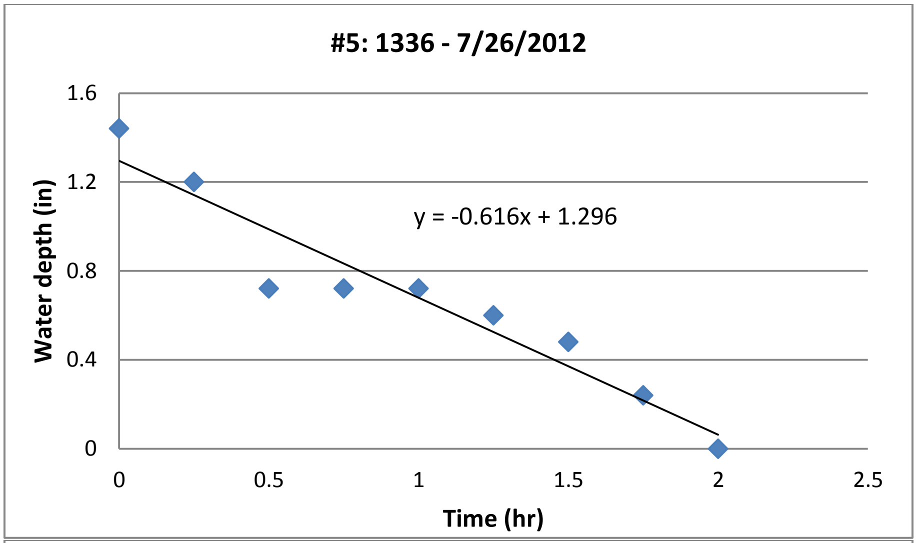

#5: 1336 - 9/13/2012 - 1
Water depth (in)
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
Time (hr)
y = -0.96x + 0.48

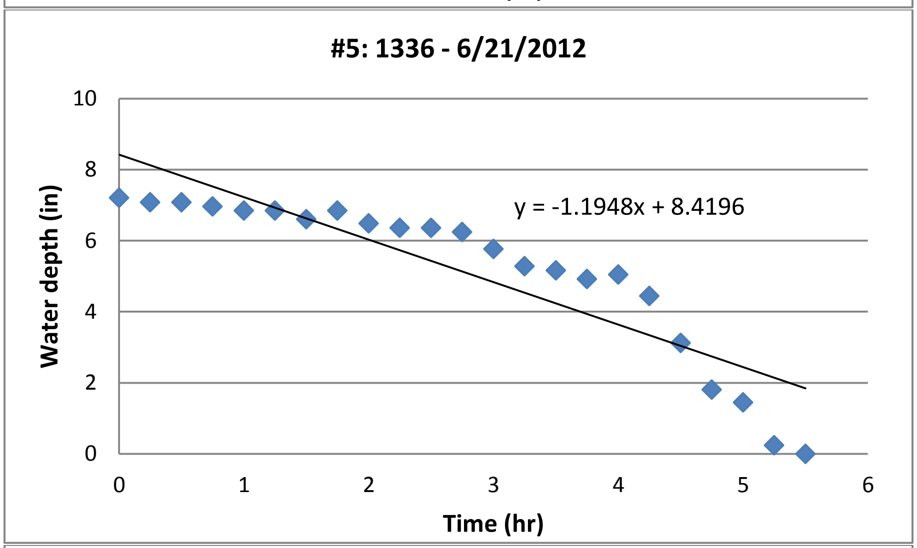

#5: 1336 - 9/13/2012 - 2
Water depth (in)
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
Time (hr)
y = -0.96x + 0.48

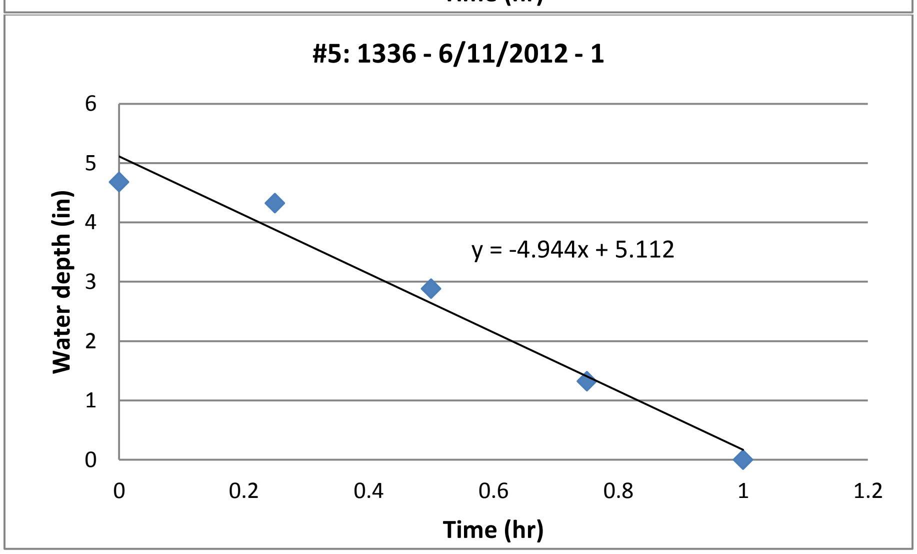

#5: 1336 - 9/13/2012 - 3
y = -0.816x + 0.636
Water depth (in)
Time (hr)

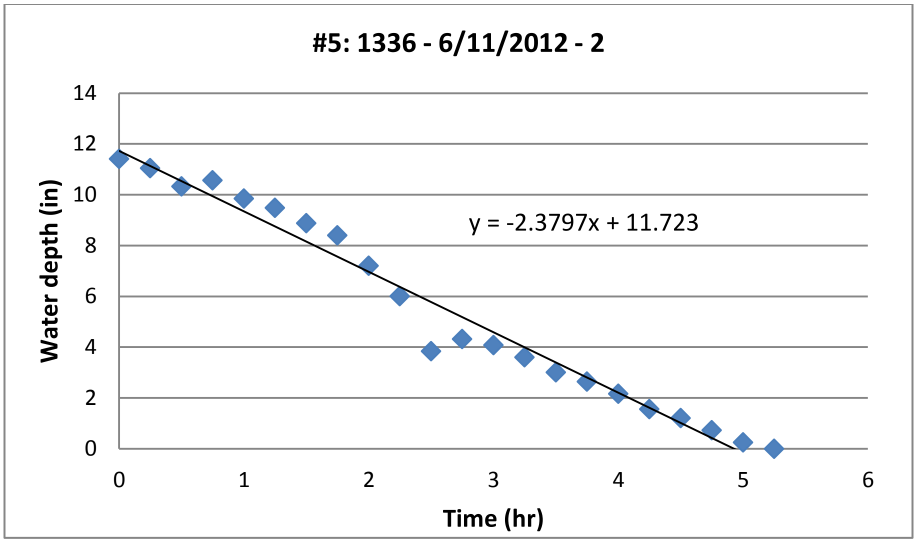

#5: 1336 - 8/31/2012 - 1
y = -2.1257x + 3.9
Water depth (in)
Time (hr)


#5: 1336 - 8/31/2012 - 2
y = -0.8207x + 2.7585
Water depth (in)
Time (hr)

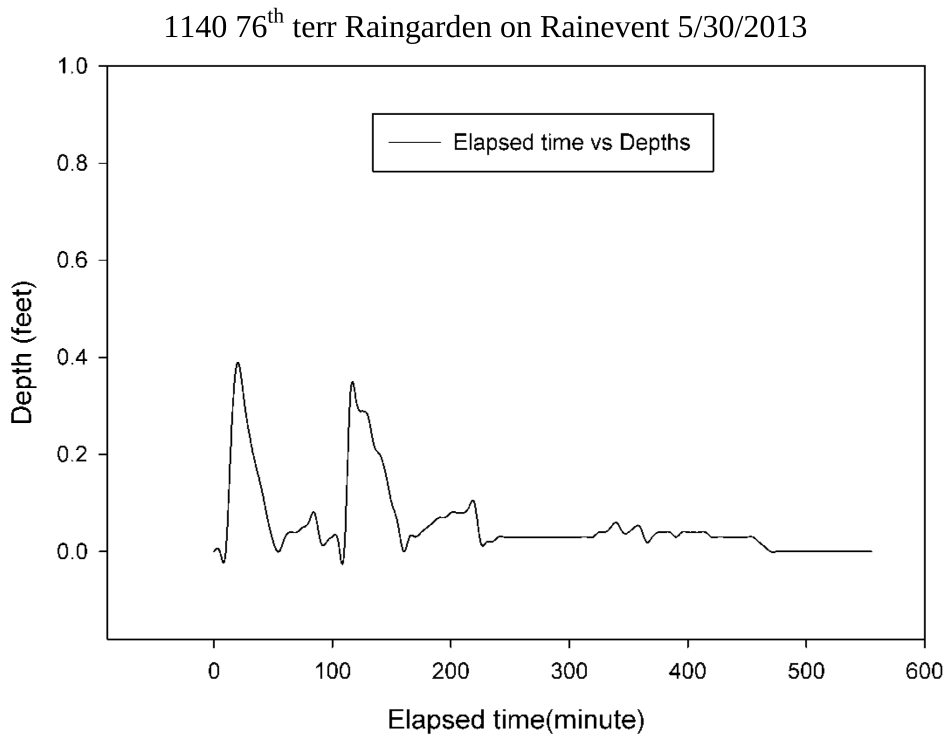

#5: 1336 - 7/26/2012
1.6
1.2
0.8
0.4
0
Water depth (in)
y = -0.616x + 1.296
0
0.5
1
1.5
2
2.5
Time (hr)

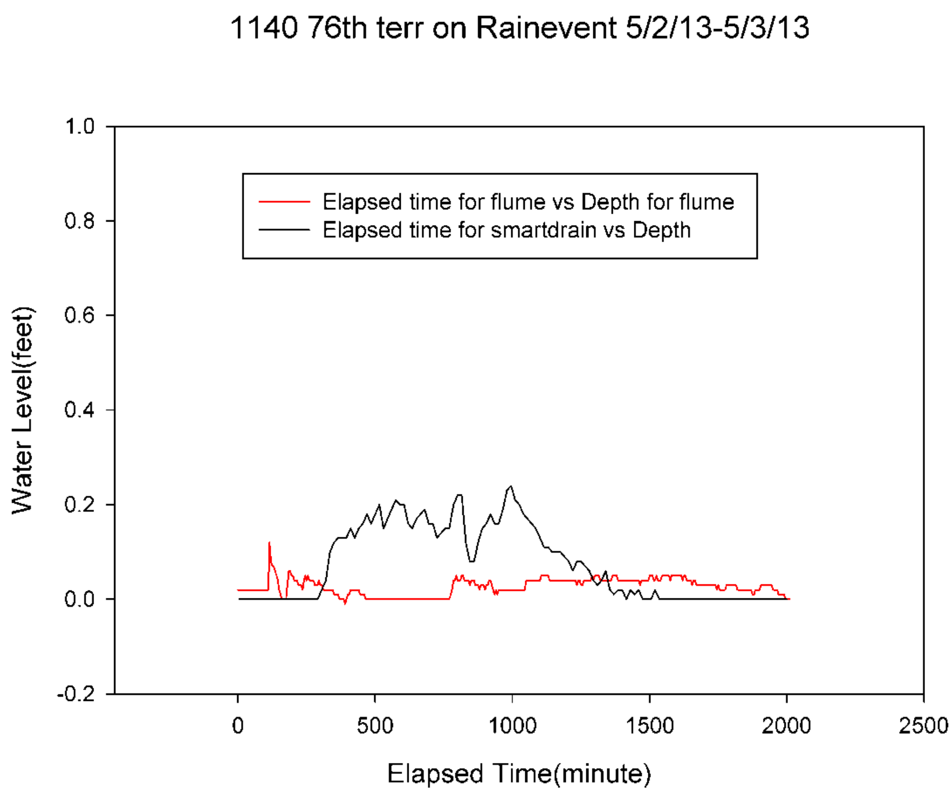

#5: 1336 - 6/21/2012
10
8
6
4
2
0
Water depth (in)
y = -1.1948x + 8.4196
0
1
2
3
4
5
6
Time (hr)


#5: 1336 - 6/11/2012 - 1
6
5
4
3
2
1
0
Water depth (in)
y = -4.944x + 5.112
0
0.2
0.4
0.6
0.8
1
1.2
Time (hr)

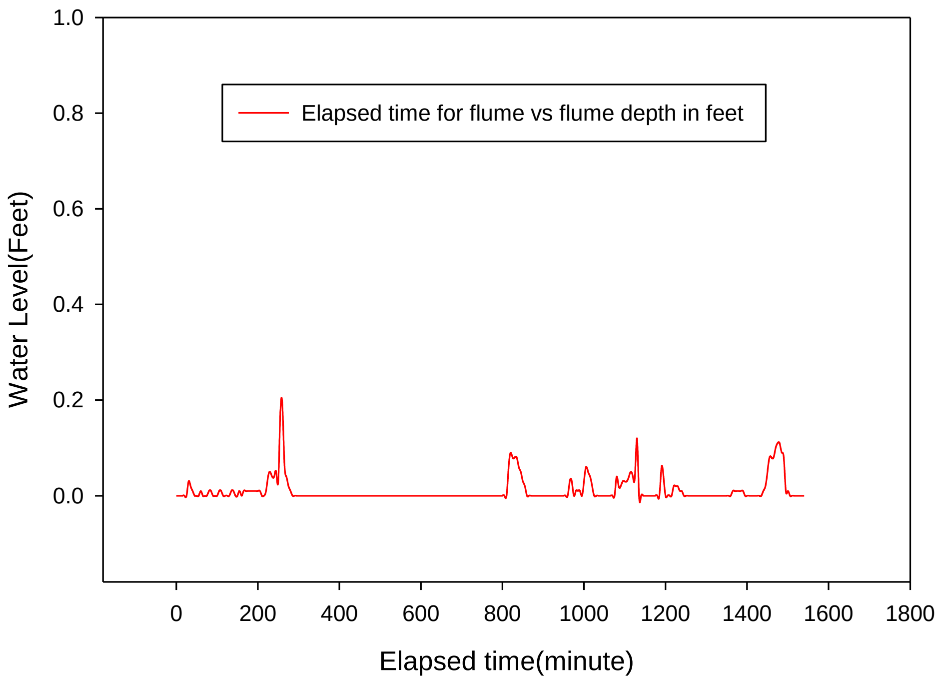

#5: 1336 - 6/11/2012 - 2
14
12
10
8
6
4
2
0
Water depth (in)
y = -2.3797x + 11.723
0
1
2
3
4
5
6
Time (hr)

7- Shallow Curb-Cut Biofilter with SmartDrain - 1140 E 76th Terr.

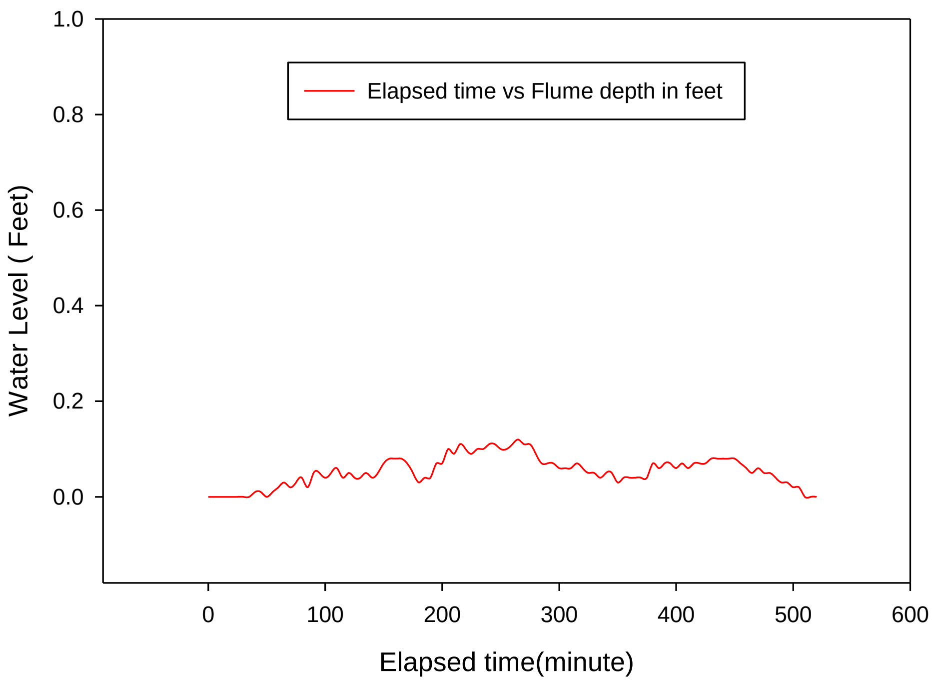




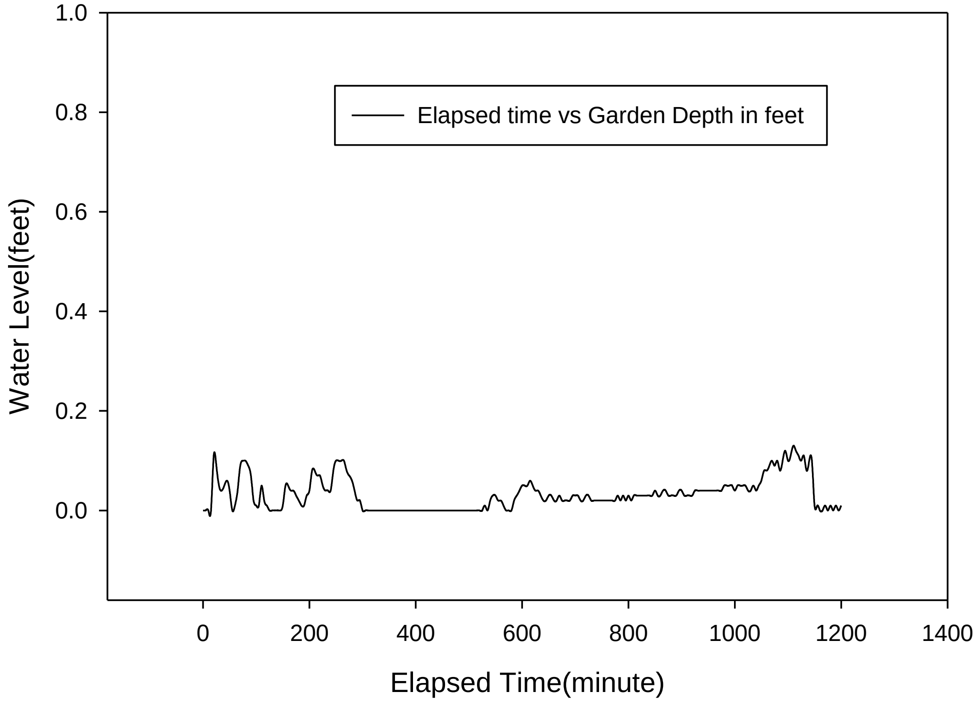
1140 76th terr Raingarden on Rainevent 10/13/2012



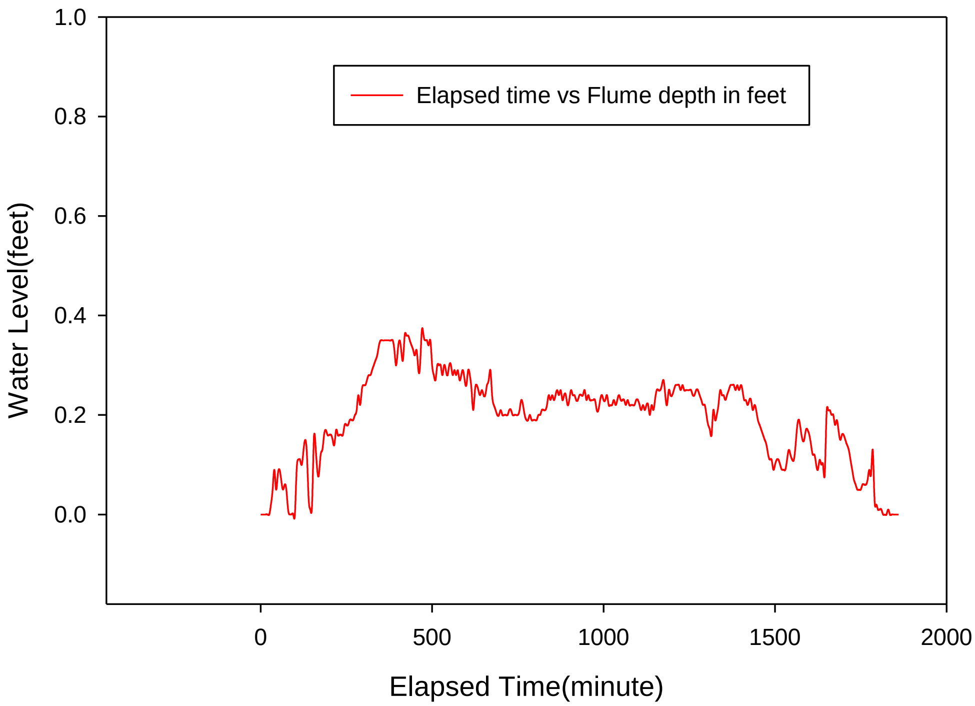
1140 76th terr Raingarden on Rainevent 9/26/2012



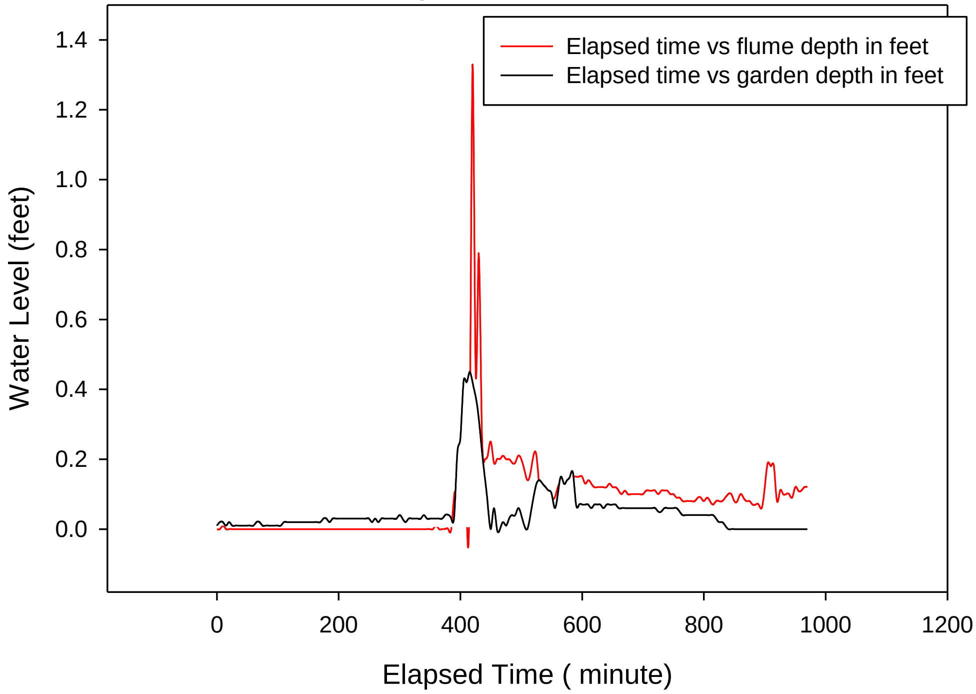
1140 76th terr Raingarden on Rainevent 9/13/2012



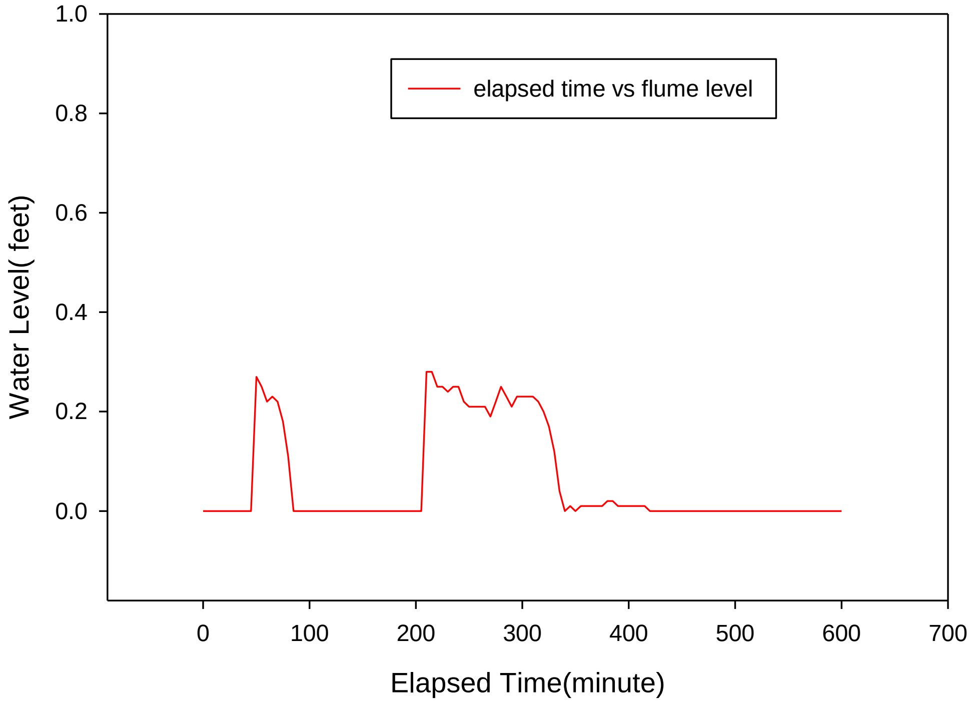
1140 76th terr Raingarden on Rainevent 9/1/2012



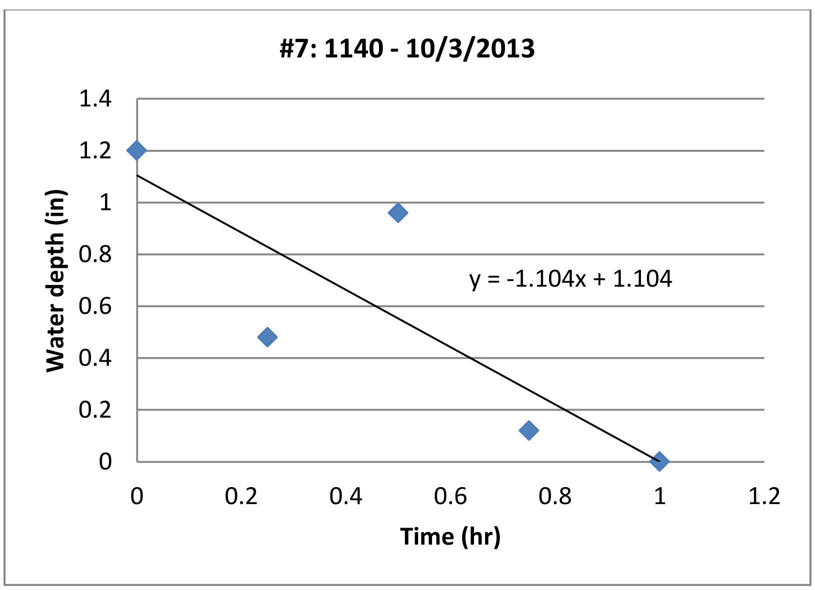
1140 76th terr Raingarden on Rainevent 6/21/2012

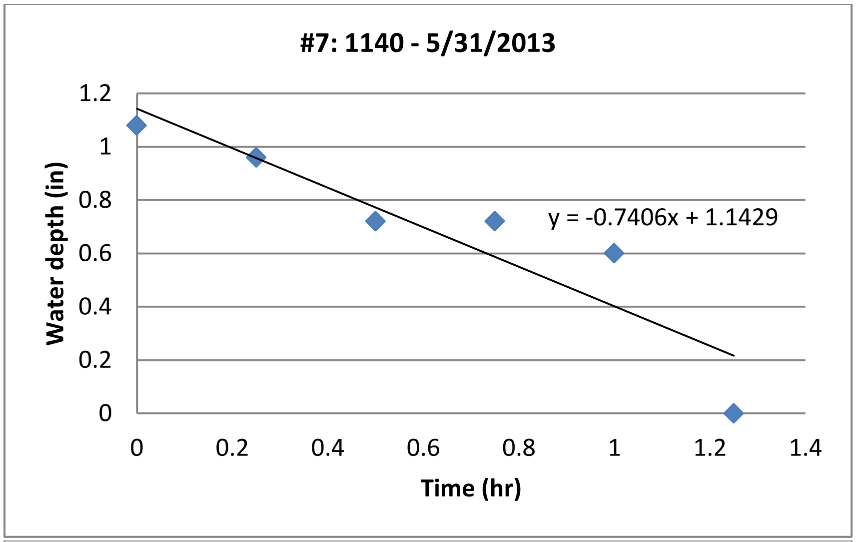


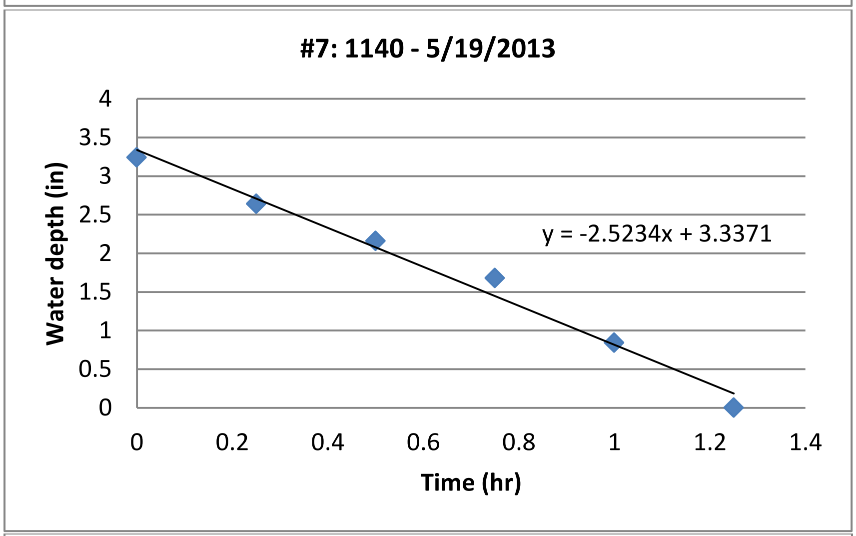
1140 76th terr Raingarden on Rainevent 6/11/2012

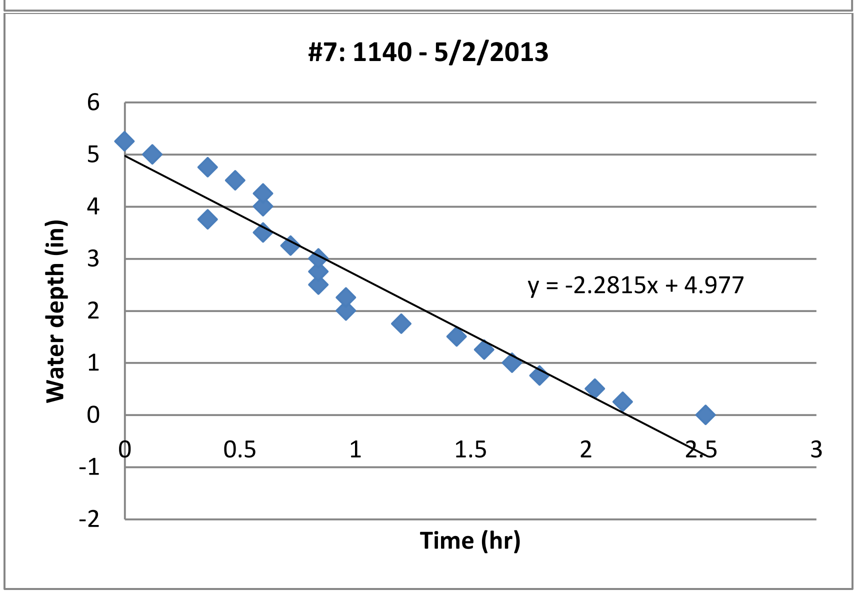


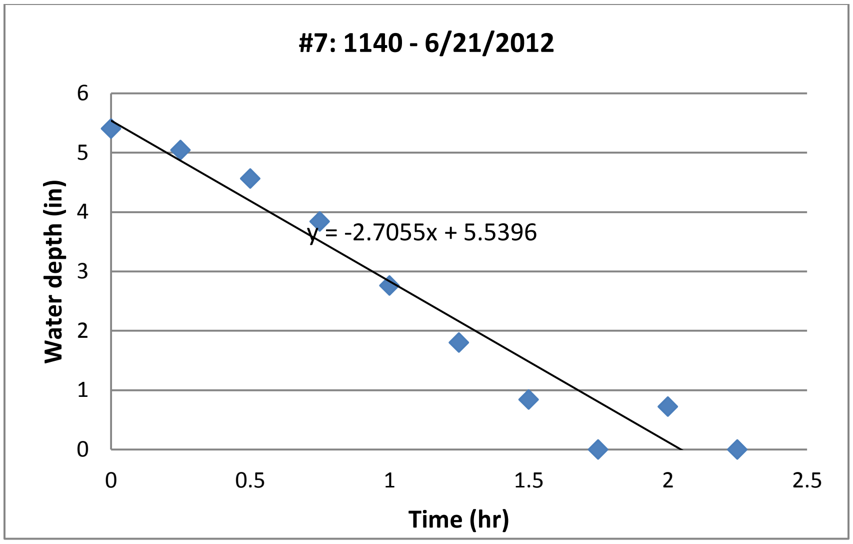
Rainfall Depth (in.)	Start Time	End Time	Event Duration (hr:min)	Max Water Depth in Garden (in)	Time Duration before Ponding Occurred (hr:min)	f (in/hr)
0.16	10/3/2013 11:04:00	10/3/2013 11:24:00	0:20	1.2	0:07	1.1
1.62	5/29/2013 22:53:00	5/30/2013 15:17:00	16:24	1.08	33:46	0.74
0.83	5/19/2013 2:21:00	5/20/2013 1:44:00	23:23	3.24	4:48	2.52
1.42	5/2/2013 03:08:00	5/4/2013 04:11:00	49:03	2.52	13:30	2.28
0.86	10/12/2012 20:59:34	10/12/2012 22:39:34	25:40	0		
0.23	9/25/2012 23:54:34	9/26/2012 08:34:34	08:40	0		
0.43	9/13/2012 14:37:17	9/14/2012 10:34:34	20:00	1.56	No Flume data	No Flume data
5.60	8/31/2012 11:02:17	9/1/2012 18:02:17	31:00	0		
1.03	6/20/2012 19:22:24	6/21/2012 11:32:24	16:10	5.4	6:35	>2.7
0.8	6/11/2012 02:03:12	6/11/2012 12:03:12	10:00	0		




#7: 1140 - 5/31/2013
Water depth (in)
1.2
1
0.8
0.6
0.4
0.2
0
y = -0.7406x + 1.1429
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Time (hr)


#7: 1140 - 5/19/2013
Water depth (in)
4
3.5
3
2.5
2
1.5
1
0.5
0
y = -2.5234x + 3.3371
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Time (hr)

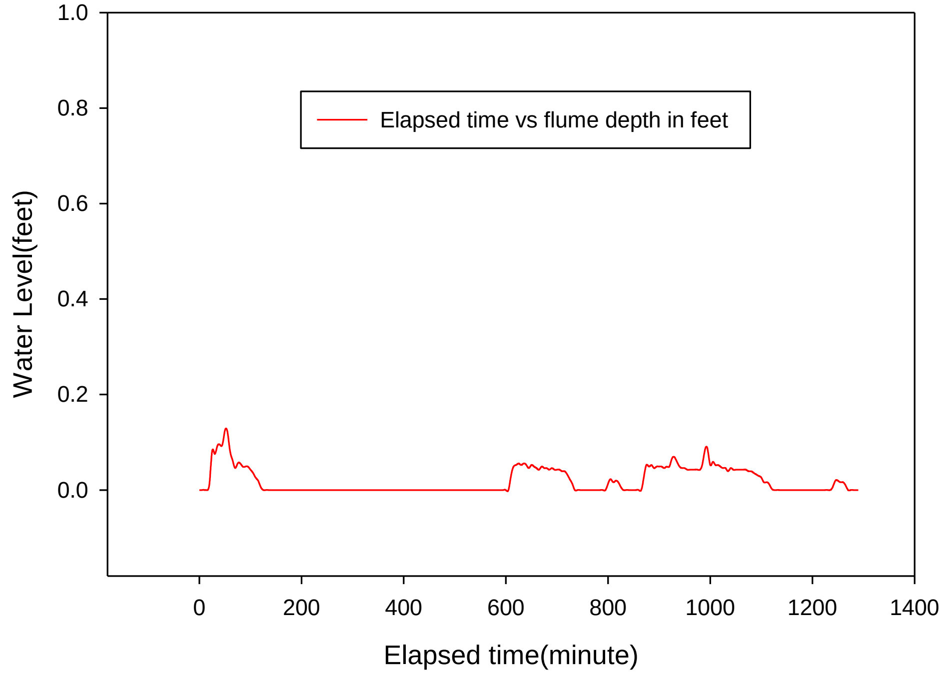

#7: 1140 - 5/2/2013
Water depth (in)
6
5
4
3
2
1
0
-1
-2
y = -2.2815x + 4.977
0
0.5
1
1.5
2
2.5
3
Time (hr)



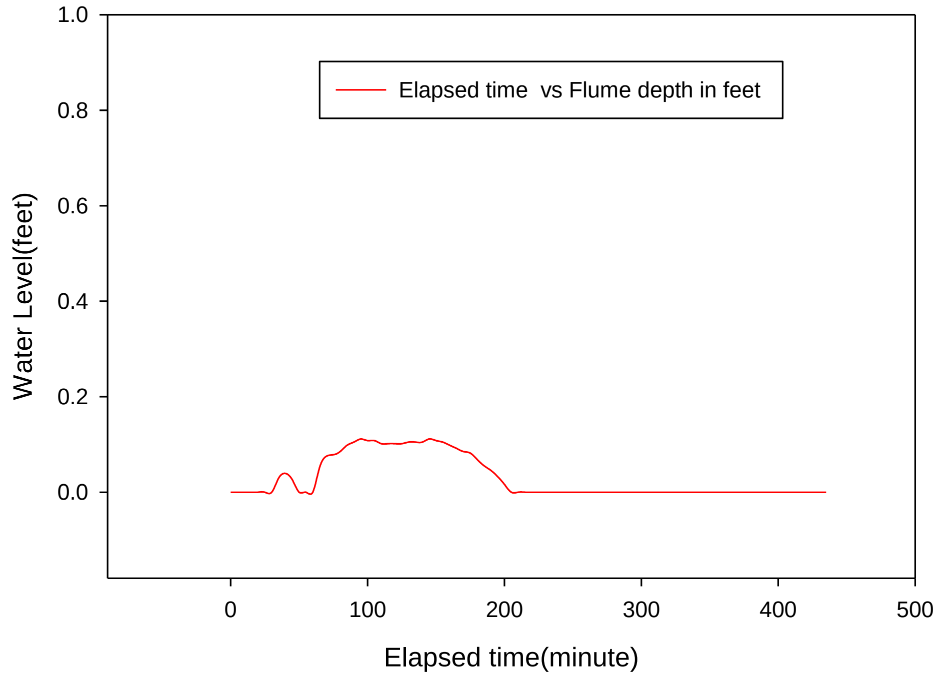
#7: 1140 - 6/21/2012
Water depth (in)
Time (hr)
y = -2.7055x + 5.5396
0
1
2
3
4
5
6
0
0.5
1
1.5
2
2.5

8- Shallow Curb-Cut Biofilter with SmartDrain - 1222 E 76th St.

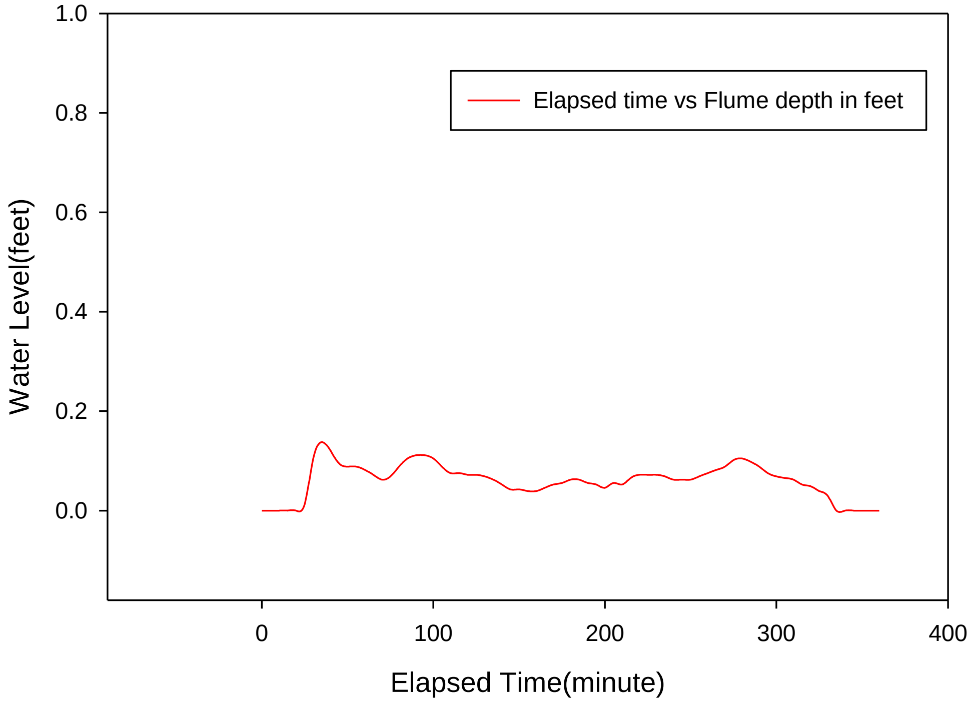
1222 76th Raingarden on Rainevent 10/13/2012



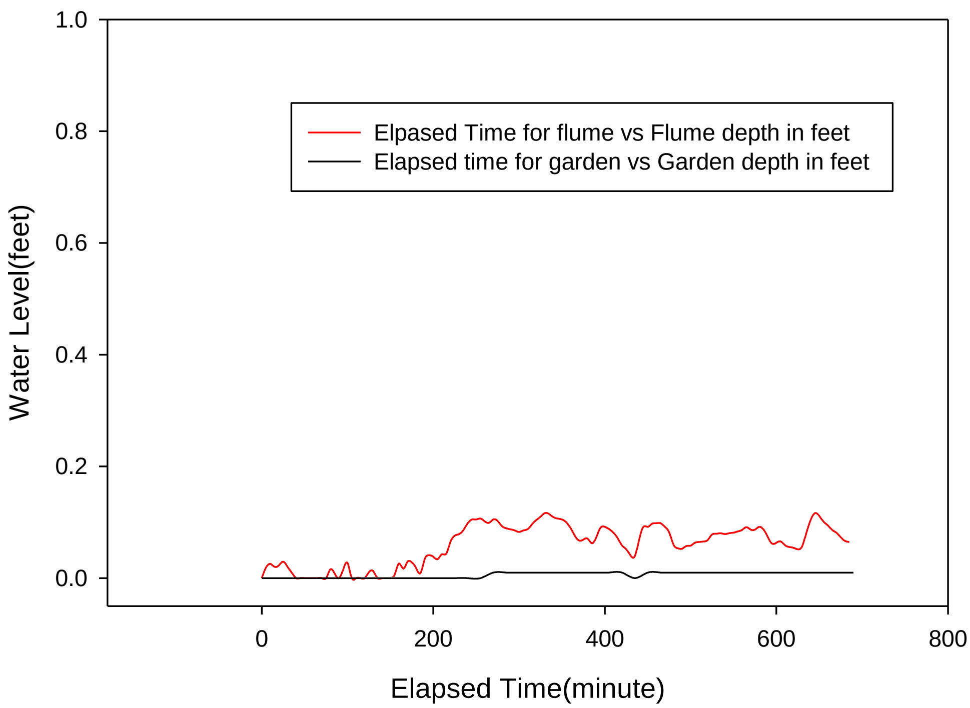
1222 76th Raingarden on Rainevent 9/26/2012



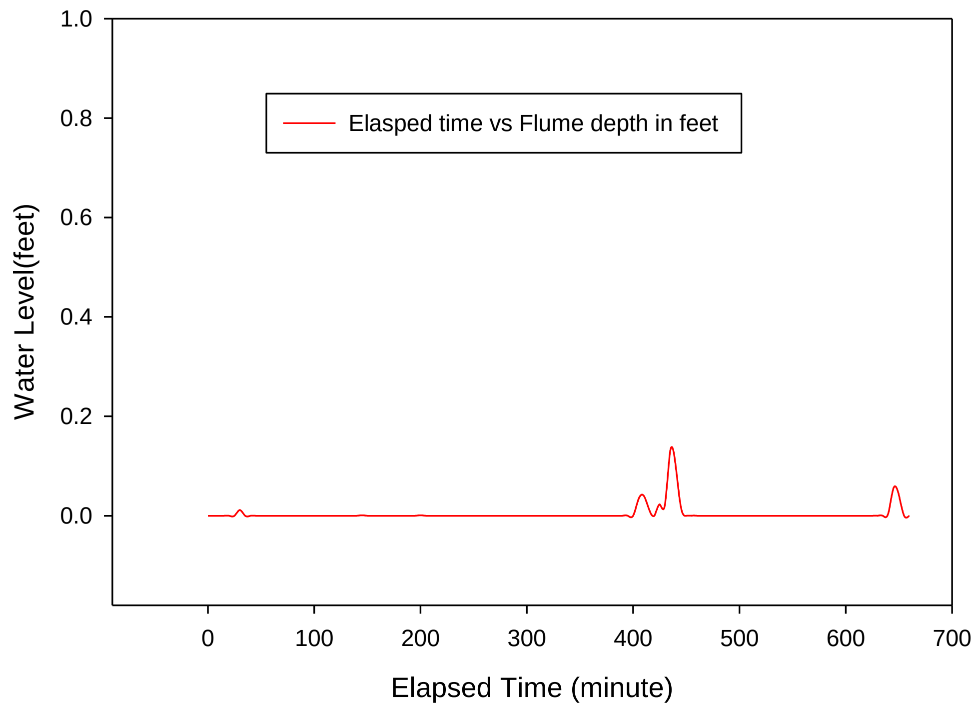
1222 76th Raingarden on Rainevent 9/13/2012



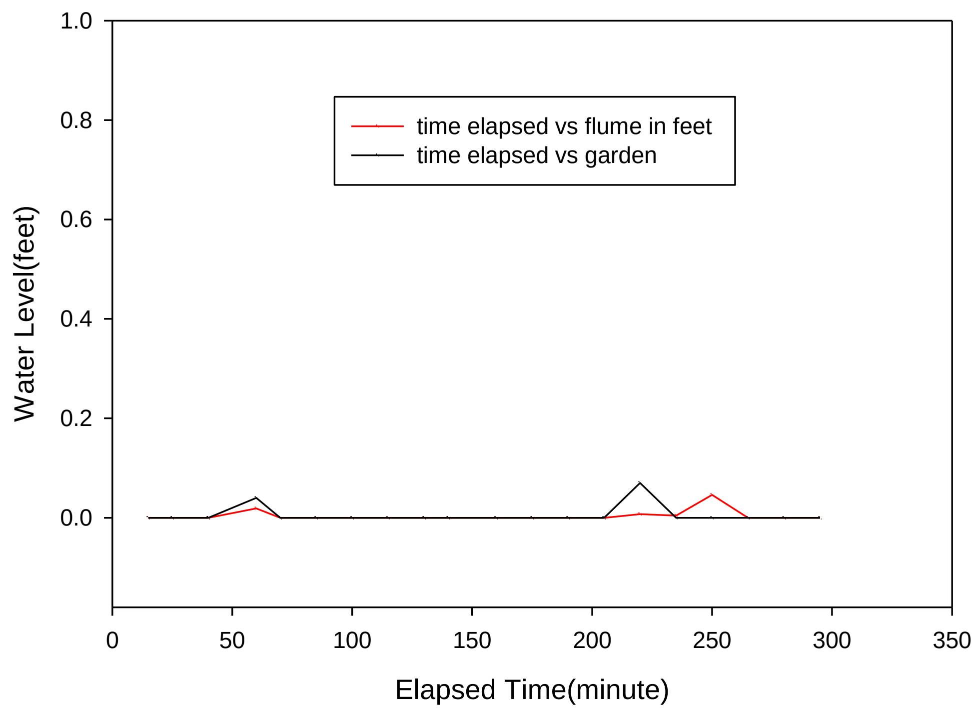
1222 76th Raingarden on Rainevent 8/31/2012



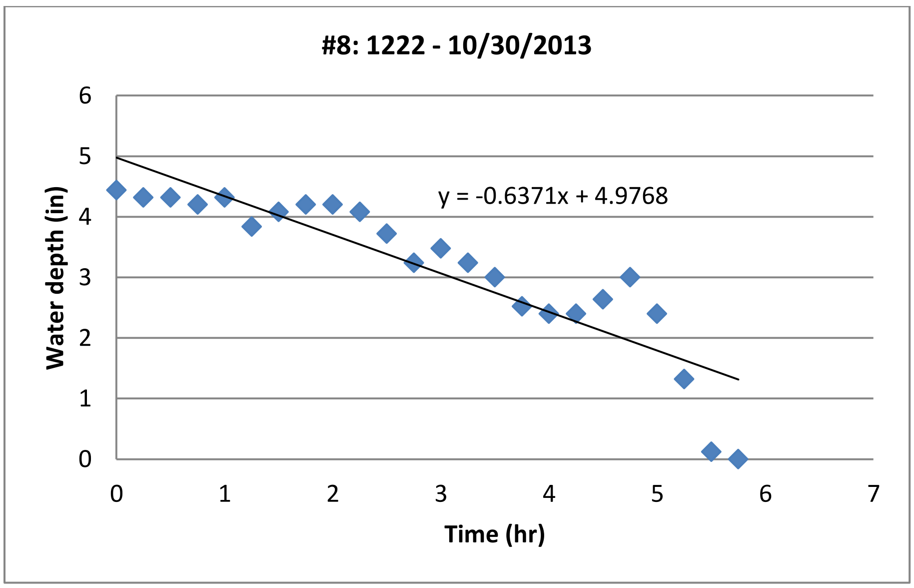
1222 76th Raingarden on Rainevent 7/26/2012

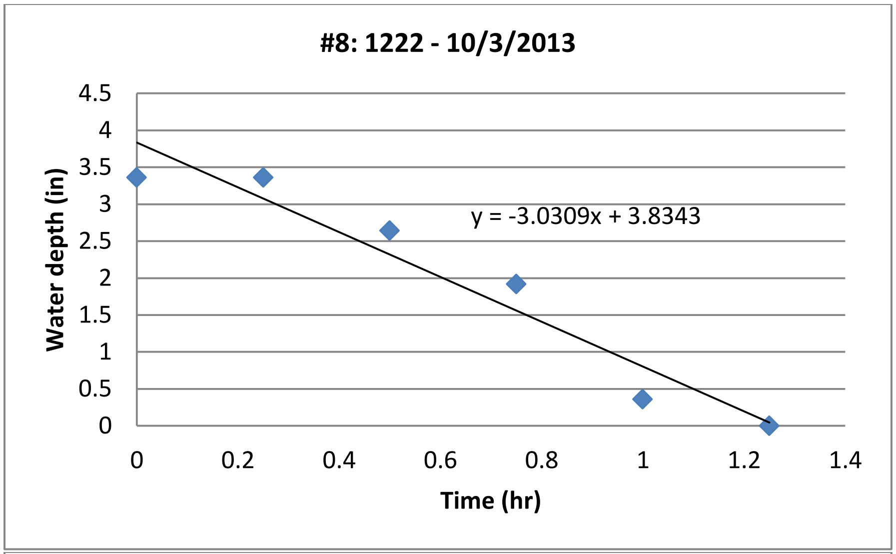


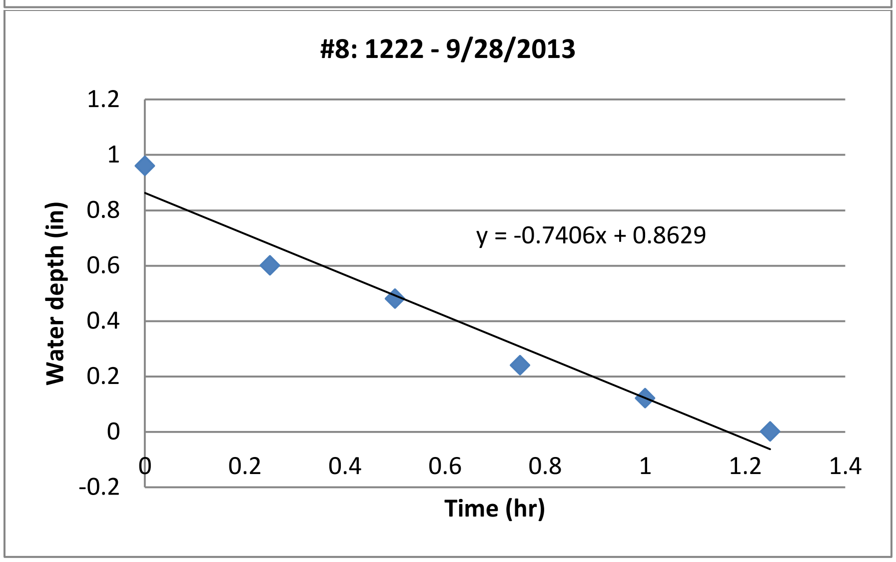
1222 76th Raingarden on Rainevent 6/11/2012

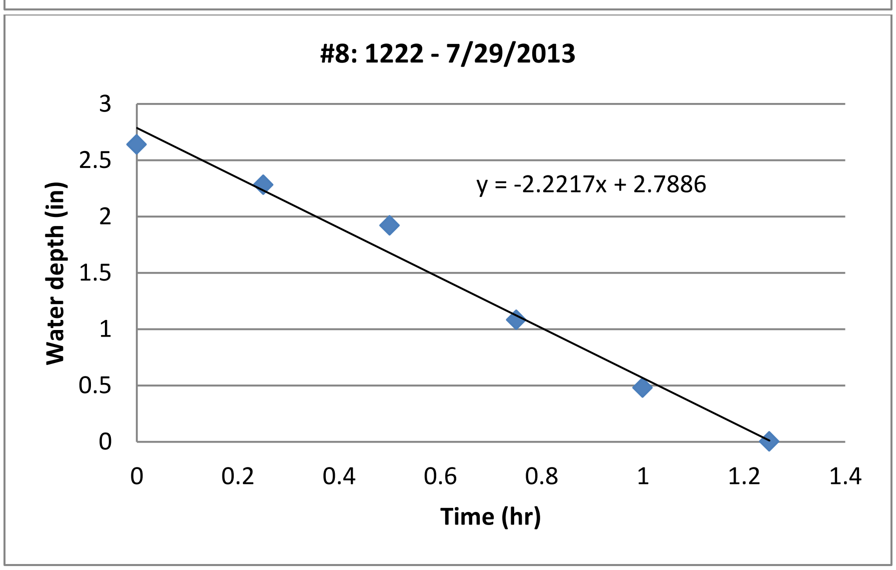


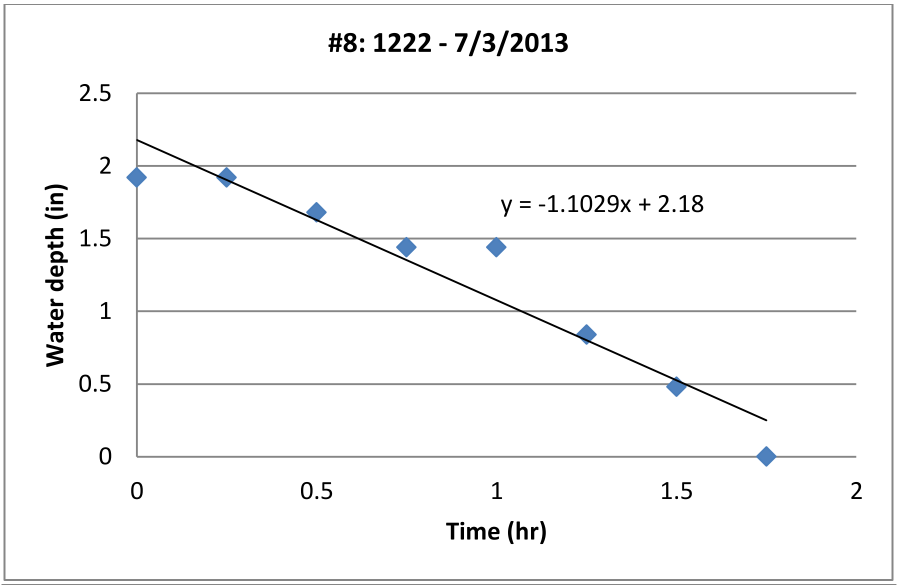
Rainfall Depth (in.)	Start Time	End Time	Event Duration (hr:min)	Max Water Depth in Garden (in)	Time Duration before Ponding Occurred (hr:min)	f (in/hr)
3.43	10/30/2013 12:09:00	10/31/2013 11:46:00	23:35	4.44	12:41	0.64
0.16	10/3/2013 11:04:00	10/3/2013 11:24:00	0:20	3.36	0:20	3.03
0.28	9/28/2013 8:29:00	9/28/2013 11:29	3:00	0.96	0:51	0.74
0.91	7/29/2013 6:27:00	7/30/2013 9:41:00	27:14	2.64	8:08	2.22
1.5	7/3/2013 17:54:00	7/3/2013 21:36:00	3:42	1.92	2:23	1.10
0.86	10/13/2012 00:30:00	10/13/2012 22:00:00	21:30	0		
0.23	9/26/2012 02:00:00	9/26/2012 09:15:00	07:15	0		
0.43	9/13/2012 14:30:00	9/13/2012 20:30:00	06:00	0		
2.61	8/31/2012 11:35:00	8/31/2012 23:00:00	11:25	0.12		
0.49	7/25/2012 18:00:00	7/26/2012 05:00:00	11:00	0		
0.8	6/11/2012 02:05:00	6/11/2012 06:50:00	04:55	0.84	3:40	3.36

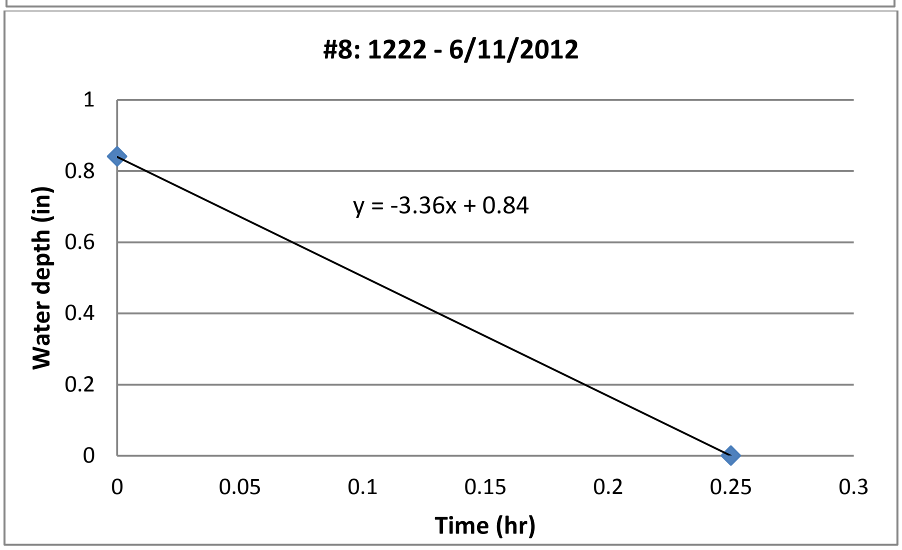



#8: 1222 - 10/3/2013
Water depth (in)
Time (hr)
y = -3.0309x + 3.8343
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4

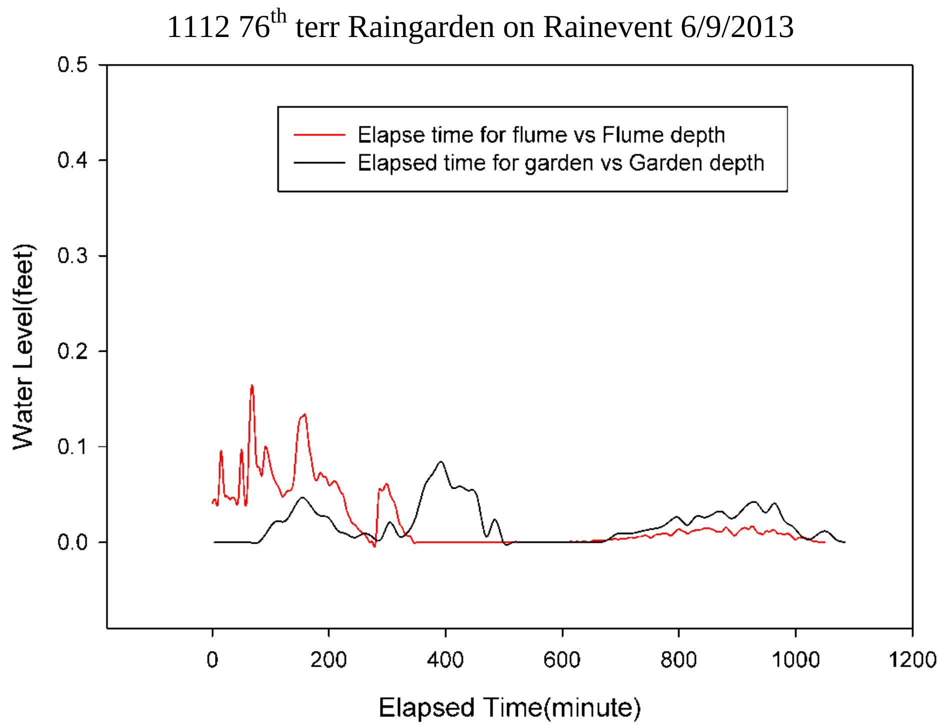

#8: 1222 - 9/28/2013
Water depth (in)
Time (hr)
y = -0.7406x + 0.8629
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4

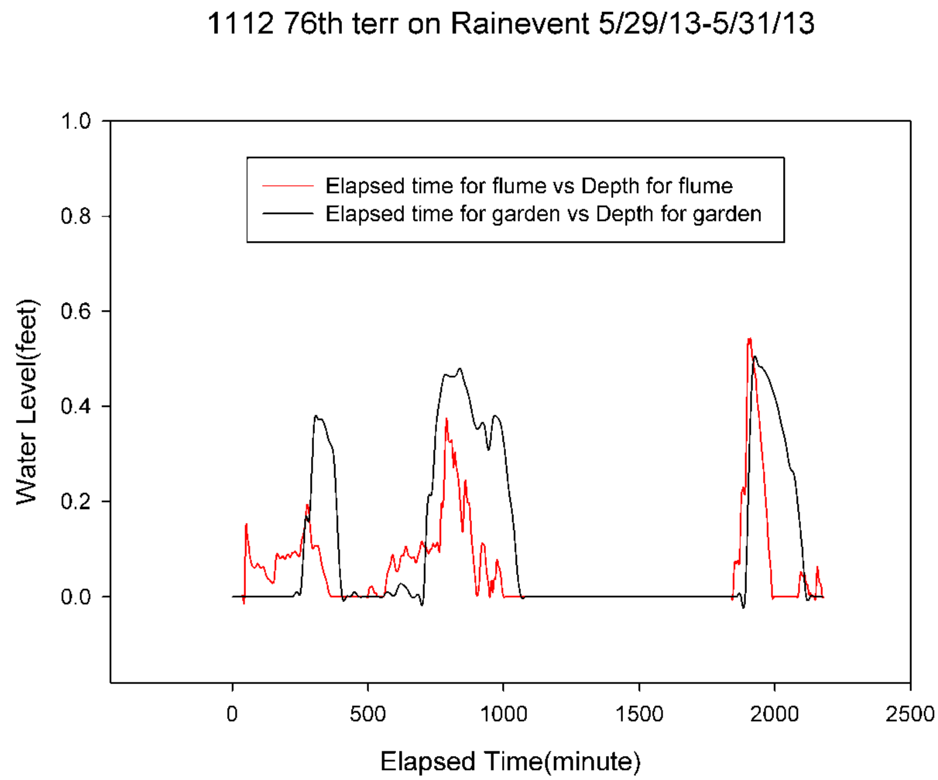

#8: 1222 - 7/29/2013
Water depth (in)
Time (hr)
y = -2.2217x + 2.7886
3
2.5
2
1.5
1
0.5
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4


#8: 1222 - 7/3/2013
Water depth (in)
2.5
2
1.5
1
0.5
0
0
0.5
1
1.5
2
y = -1.1029x + 2.18
Time (hr)

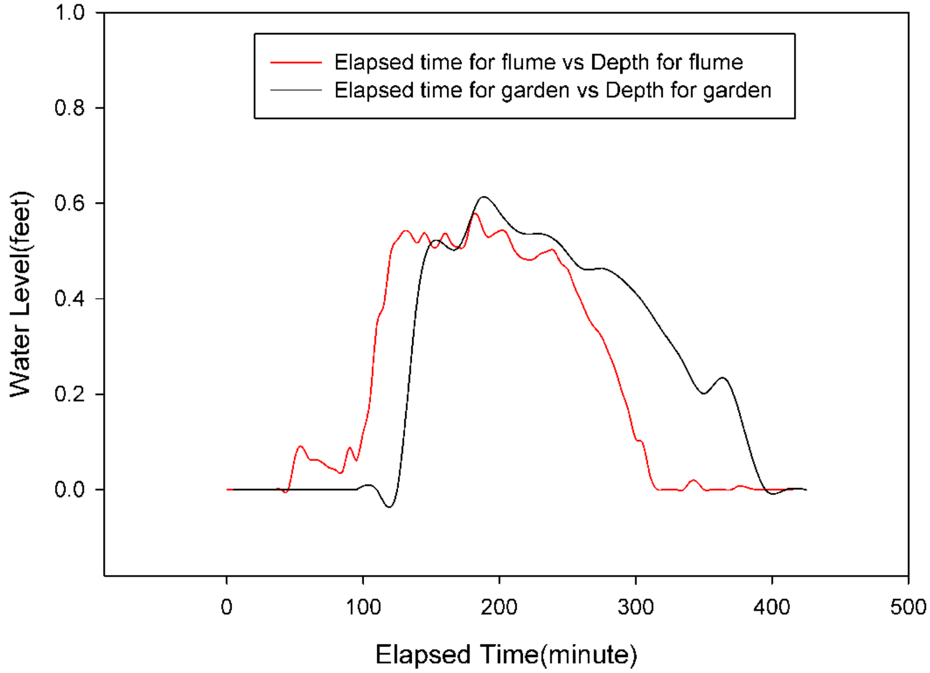

#8: 1222 - 6/11/2012
Water depth (in)
1
0.8
0.6
0.4
0.2
0
0
0.05
0.1
0.15
0.2
0.25
0.3
y = -3.36x + 0.84
Time (hr)

9- Cascading Swale Biofilter - 1112 E 76th Terr.

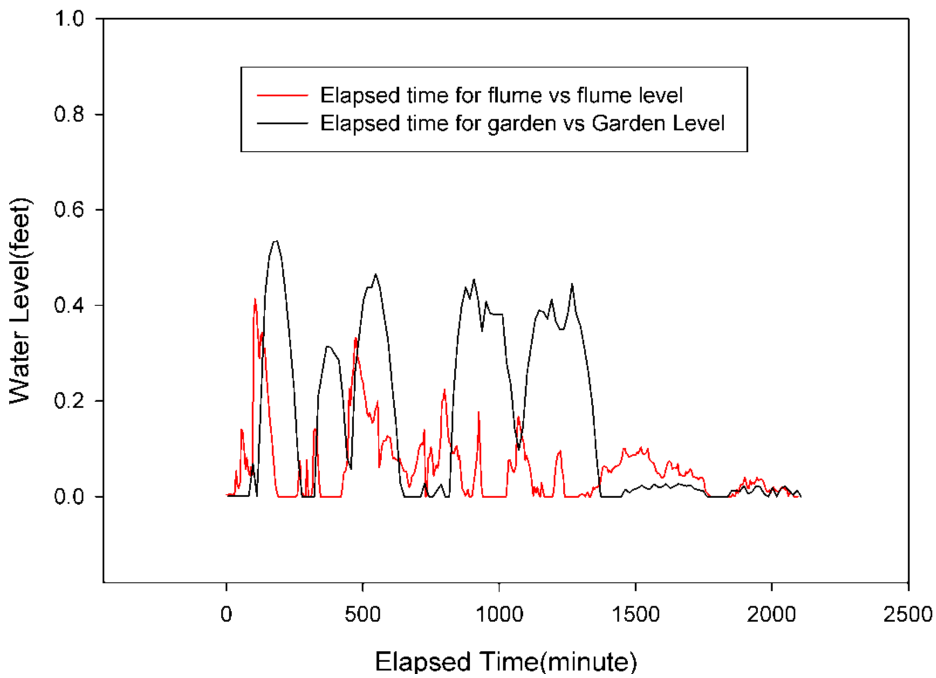




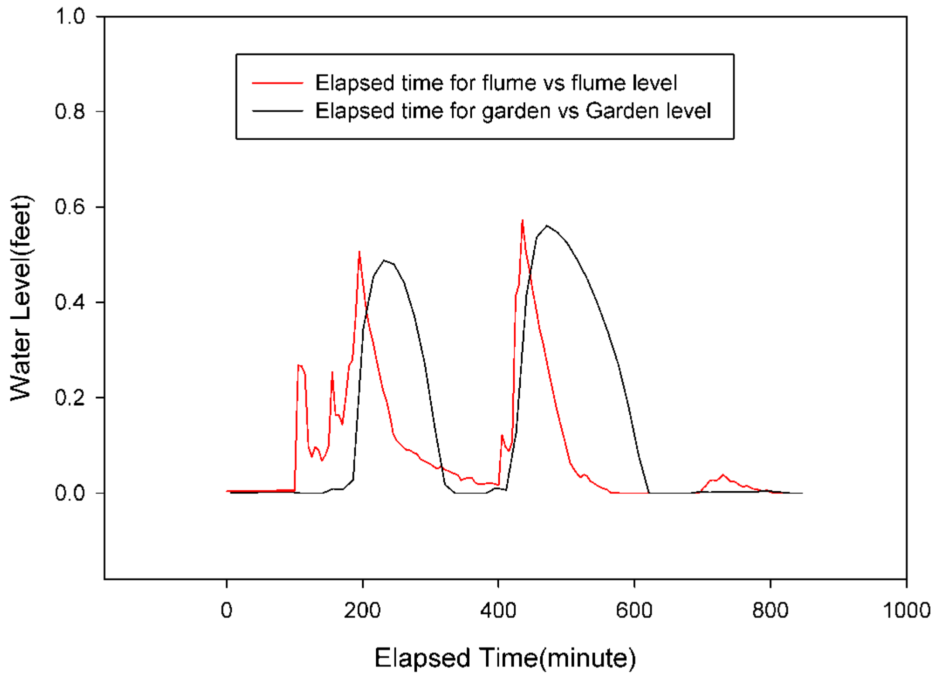
1112 76th terr on Rainevent 5/27/13-5/28/13



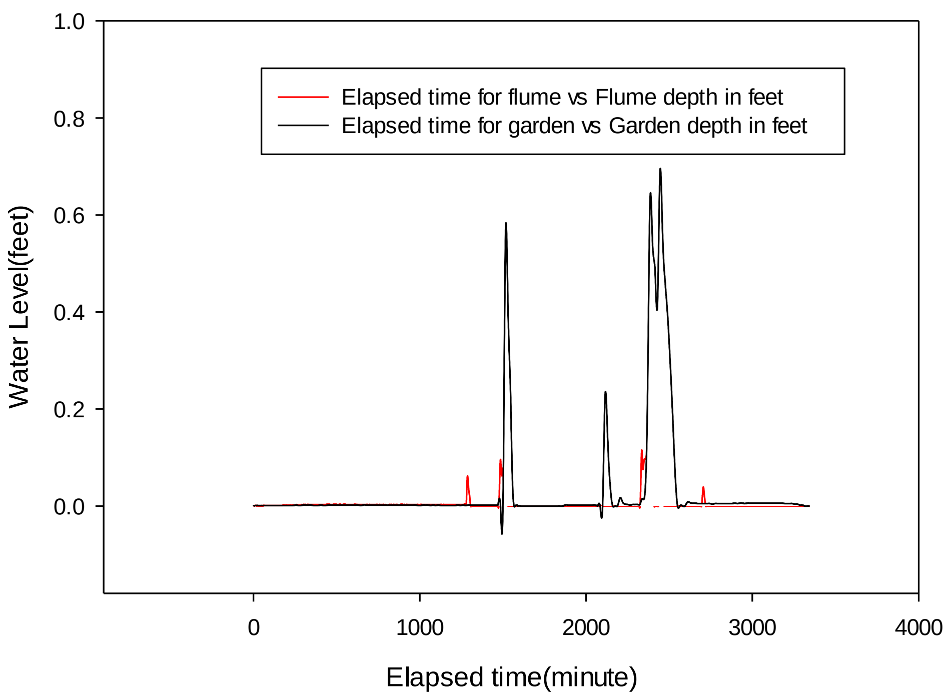
1112 76th terr on Rainevent 04/09/13--04/10/13



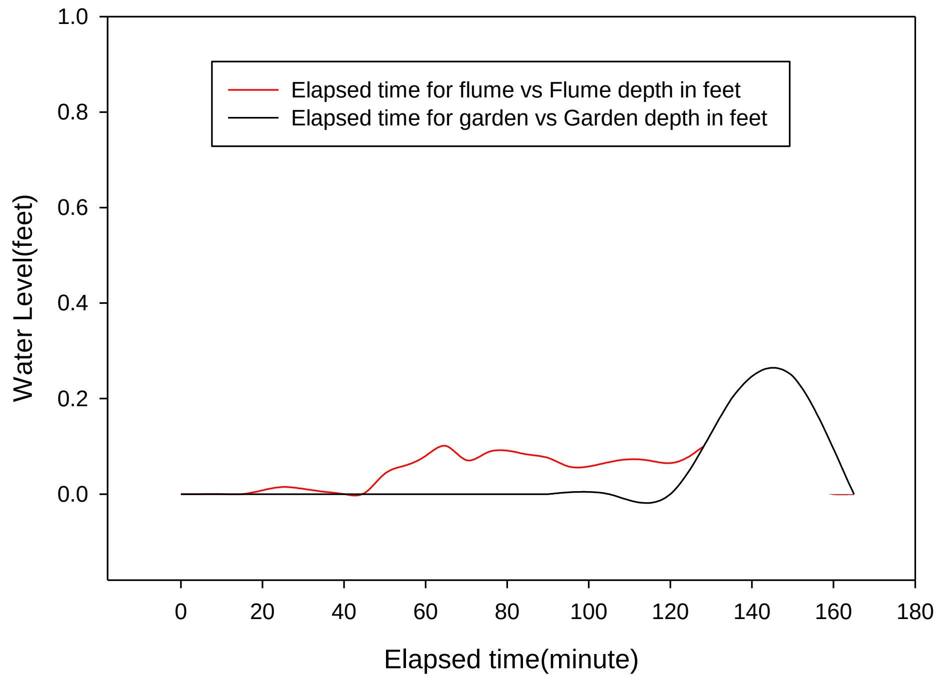
1112 76th terr on Rainevent 04/07/13



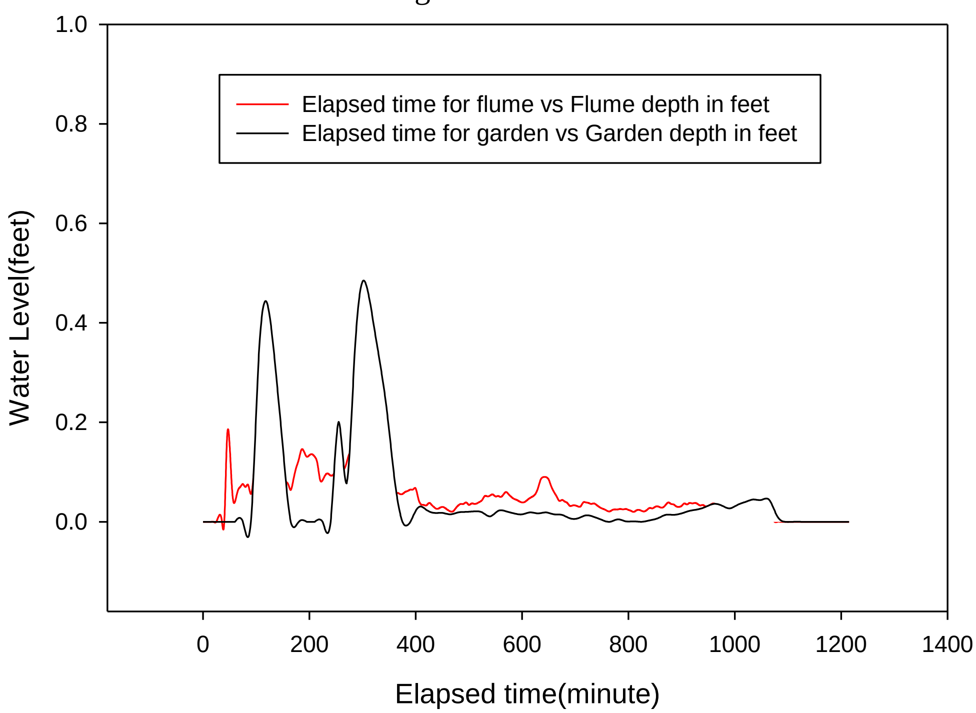
1112 76 terr Raingarden on Rainevent 10/13/2012



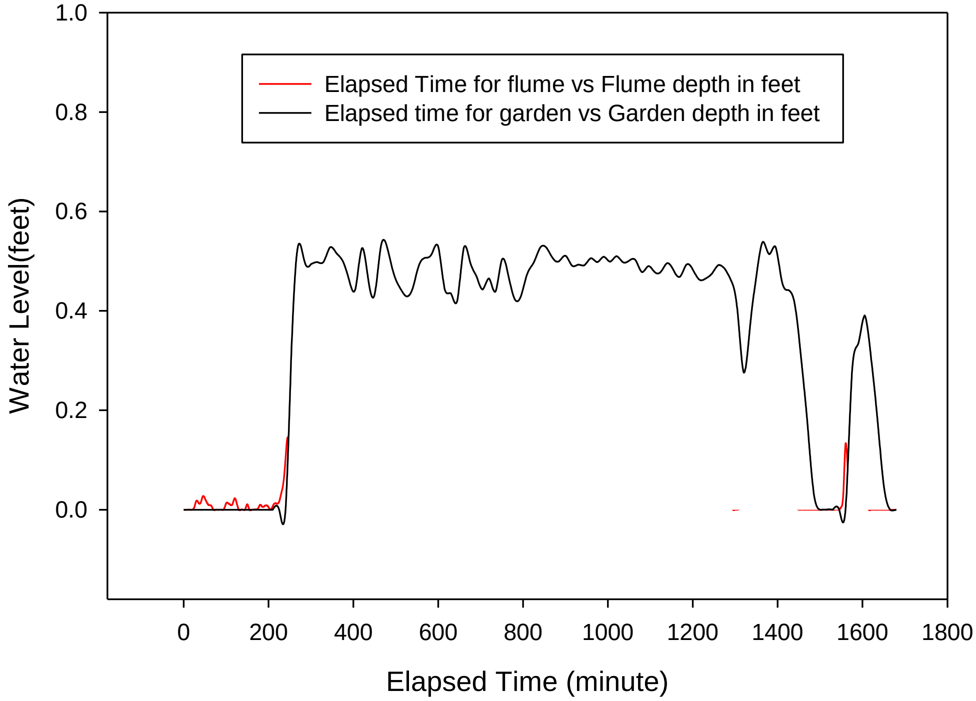
1112 76th terr Raingarden on Rainevent 9/26/2012



1112 76th terr Raingarden on Rainevent 9/13/2012

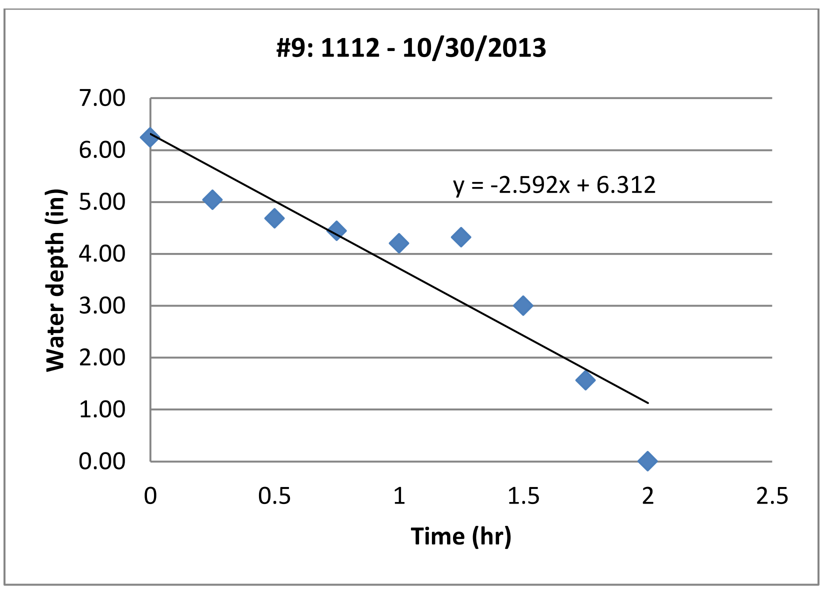


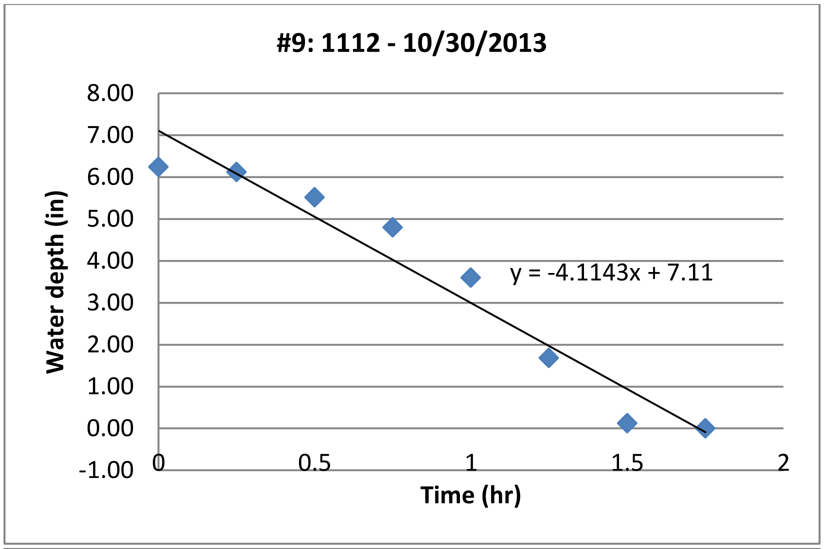
1112 76th terr Raingarden on Rainevent 9/1/2012



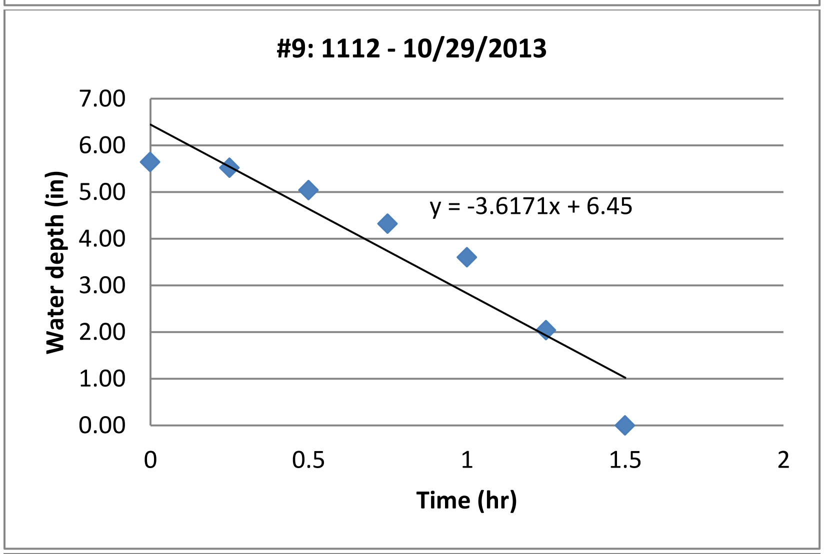
Rainfall Depth (in.)	Start Time	End Time	Event Duration (hr:min)	Max Water Depth in Garden (in)	Time Duration before Ponding Occurred (hr:min)	f (in/hr)
3.43	10/30/2013 12:09:00	10/31/2013 11:46:00	23:35	6.24	19:05	2.59
3.43	10/30/2013 12:09:00	10/31/2013 11:46:00	23:35	6.24	11:05	4.11
0.83	10/29/2013 2:52:00	10/29/2013 9:41:00	6:49	5.64	4:07	3.62
0.87	10/4/2013 22:36:00	10/5/2013 3:48:00	5:12	5.76	2:07	4.46
0.16	10/3/2013 11:04:00	10/3/2013 11:24:00	00:20	4.92	0:39	5.47
0.28	9/28/2013 8:29:00	9/28/2013 11:29:00	3:00	3.24	0:29	0.67
1.89	9/19/2013 19:00:00	9/19/2013 22:23:00	3:23	4.44	2:43	3.54
0.16	9/1/2013 07:42:00	9/1/2013 09:02:00	1:20	5.40	0:15	1.44
0.39	6/9/2013 00:54:00	6/9/2013 03:53:00	2:59	1.93	5:41	0.84
1.34	5/31/2013 5:26:00	5/31/2013 9:21:00	3:55	9.02	0:55	2.40
1.62	5/29/2013 22:53:00	5/30/2013 15:17:00	16:24	6.54	4:28	3.66
2.01	5/27/2013 8:31:00	5/27/2013 12:35:00	4:04	9.36	2:05	2:23

Rainfall Depth (in.)	Start Time	End Time	Event Duration (hr:min)	Max Water Depth in Garden (in)	Time Duration before Ponding Occurred (hr:min)	f (in/hr)
1.62	4/9/2013 21:56:00	4/10/2013 18:30:00	20:34	7.85	2:01	4.00
1.10	4/7/2013 19:52:00	4/8/2013 2:25:00	6:33	8.40	2:01	3.85
0.86	10/12/2012 00:03:23	10/14/2012 07:48:23	55:45	8.28	25:15	>7.21
					35:15	>3.76
					39:00	>4.69
0.23	9/26/2012 02:08:23	9/26/2012 04:53:23	02:45	2.96	2:15	>4.8
0.43	9/13/2012 14:08:23	9/14/2012 10:23:23	20:15	2.8	1:45	>5.33
					4:15	>4.9
5.60	8/31/2012 11:08:23	9/1/2012 15:08:23	28:00	6.47	4:15	3.85
					26:15	4.99

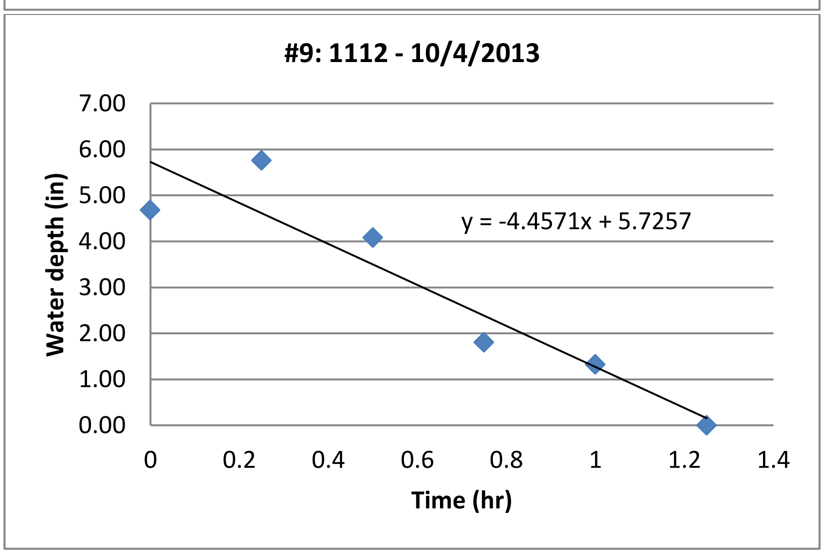




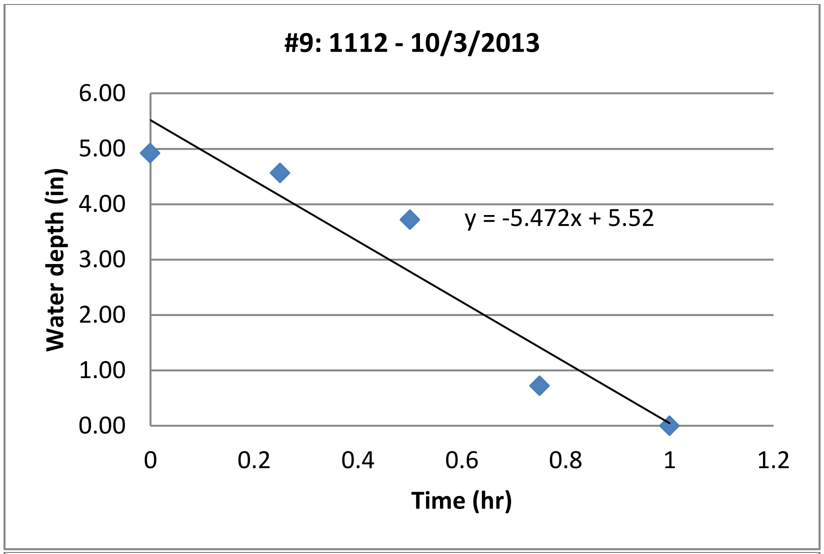
#9: 1112 - 10/30/2013
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
Water depth (in)
y = -4.1143x + 7.11
0
0.5
1
1.5
2
Time (hr)



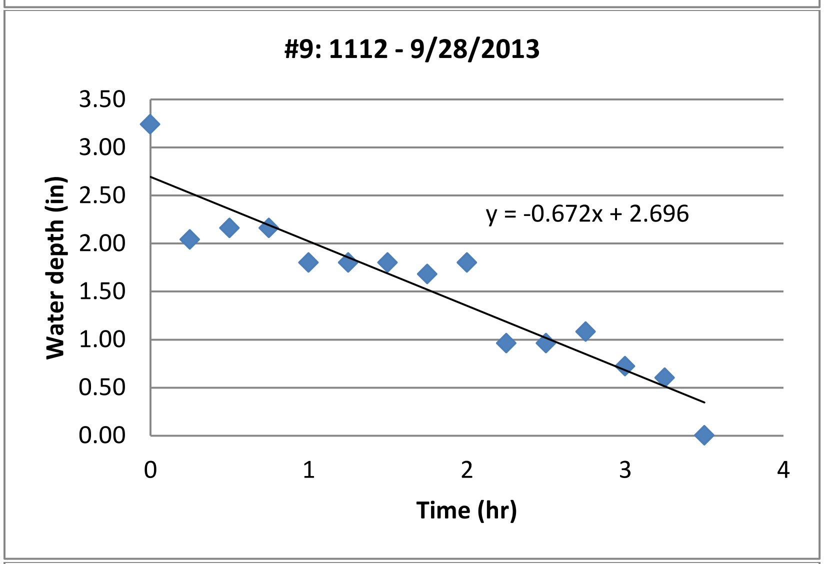
#9: 1112 - 10/29/2013
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Water depth (in)
y = -3.6171x + 6.45
0
0.5
1
1.5
2
Time (hr)



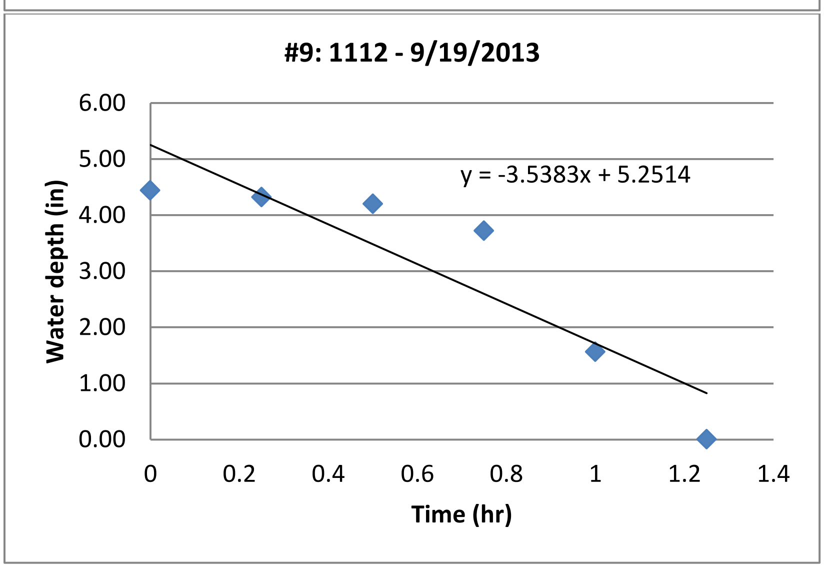
#9: 1112 - 10/4/2013
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Water depth (in)
y = -4.4571x + 5.7257
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Time (hr)



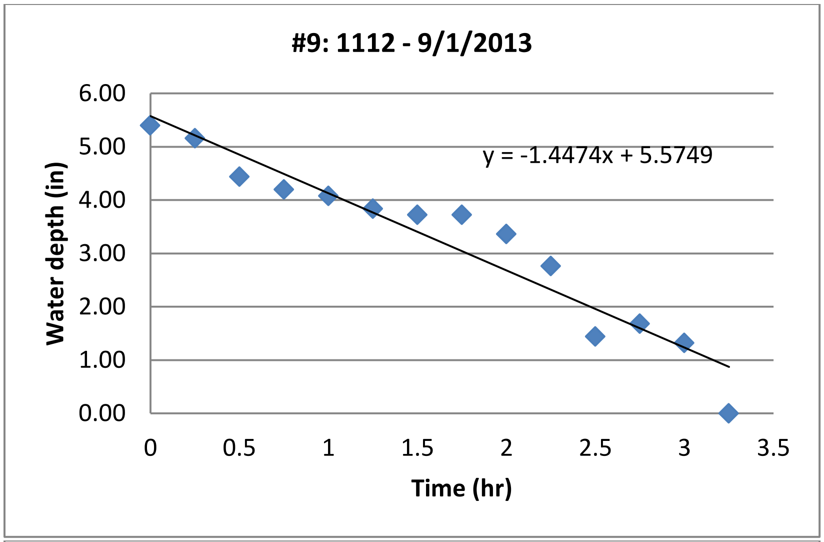
#9: 1112 - 10/3/2013
y = -5.472x + 5.52
Water depth (in)
Time (hr)

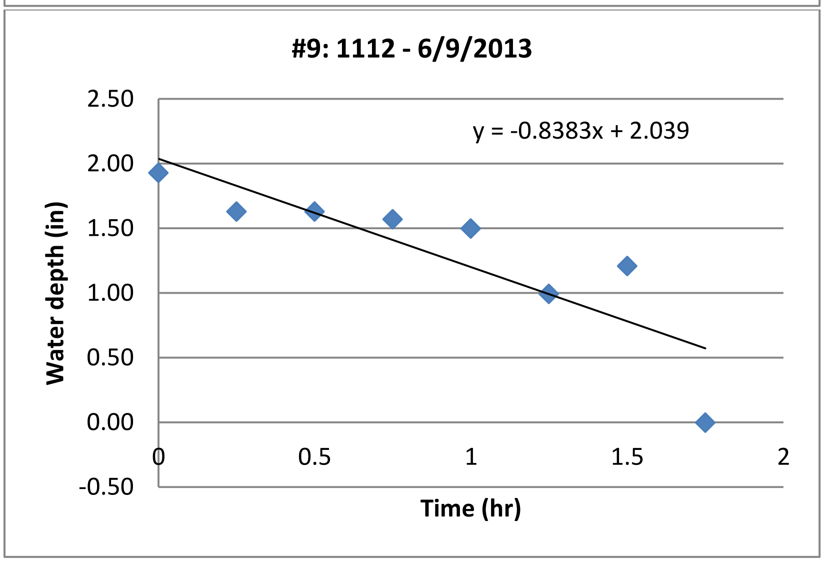


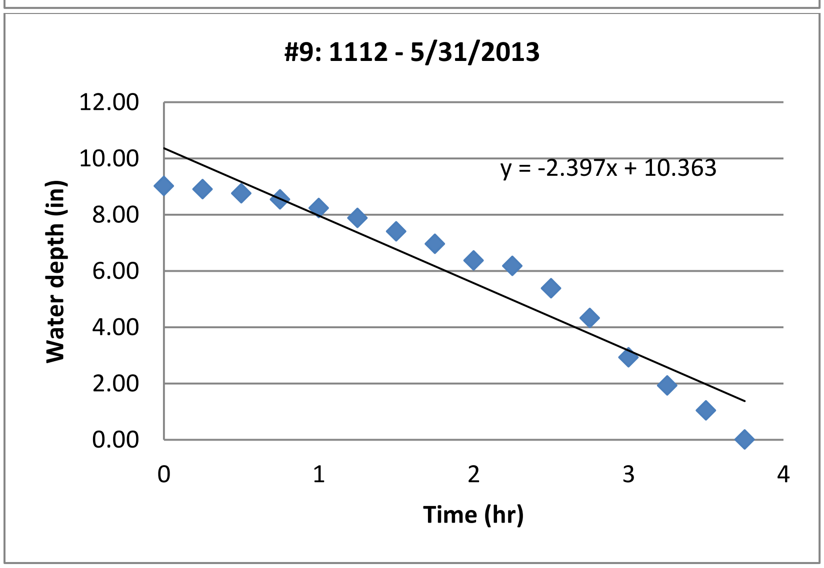
#9: 1112 - 9/28/2013
y = -0.672x + 2.696
Water depth (in)
Time (hr)

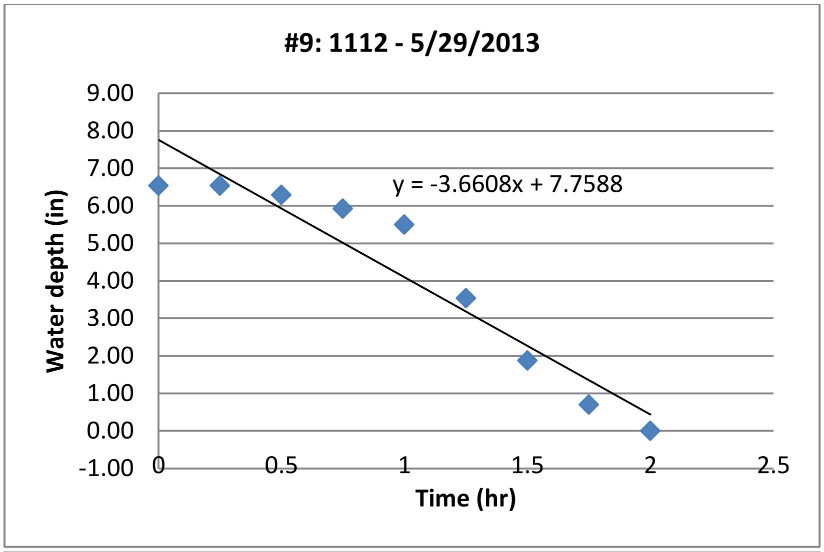


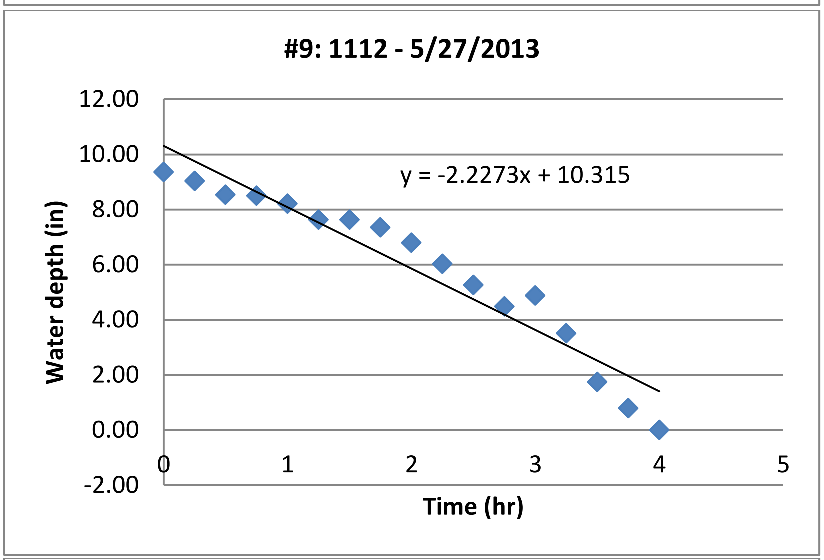
#9: 1112 - 9/19/2013
y = -3.5383x + 5.2514
Water depth (in)
Time (hr)

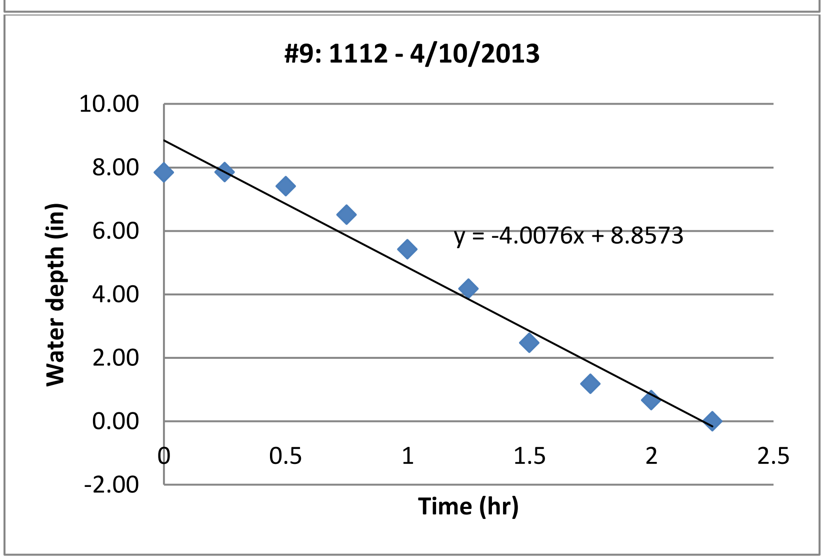

#9: 1112 - 9/1/2013
y = -1.4474x + 5.5749
Water depth (in)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
0.5
1
1.5
2
2.5
3
3.5
Time (hr)

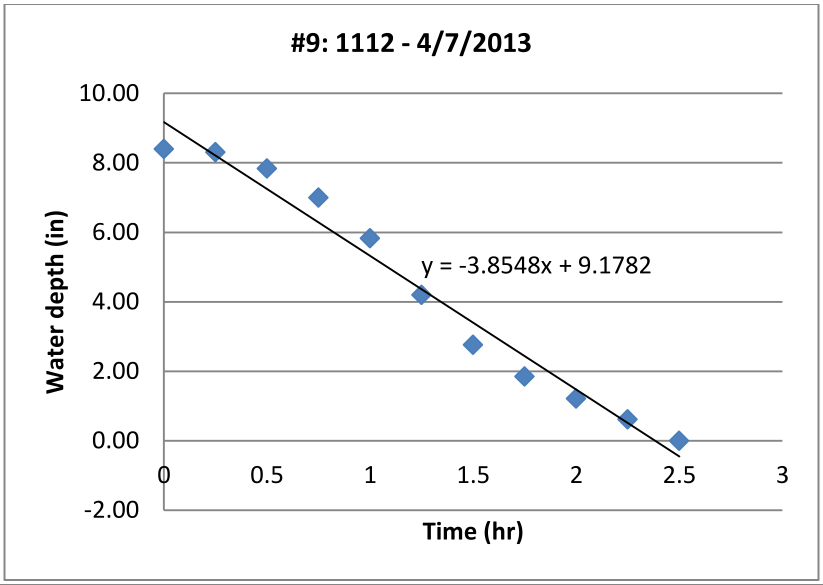

#9: 1112 - 6/9/2013
y = -0.8383x + 2.039
Water depth (in)
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
0
0.5
1
1.5
2
Time (hr)

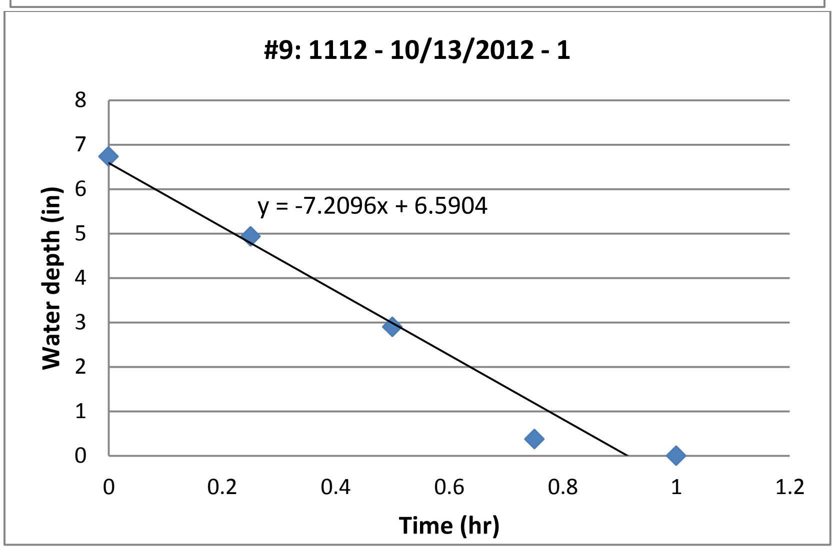

#9: 1112 - 5/31/2013
y = -2.397x + 10.363
Water depth (in)
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
1
2
3
4
Time (hr)

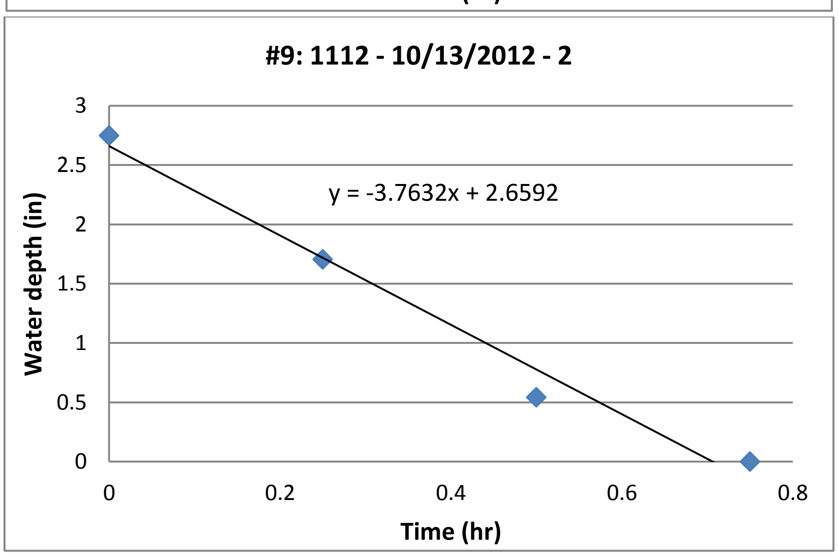

#9: 1112 - 5/29/2013
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
y = -3.6608x + 7.7588
Water depth (in)
0
0.5
1
1.5
2
2.5
Time (hr)

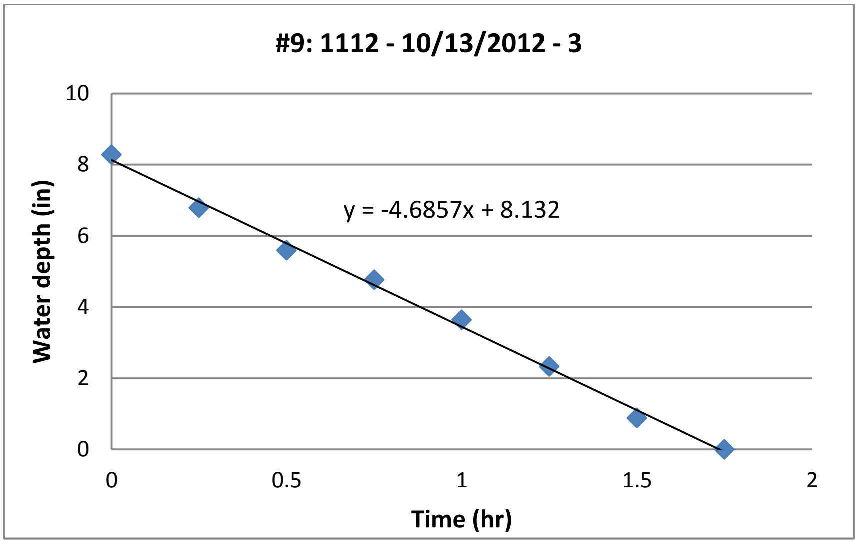

#9: 1112 - 5/27/2013
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
y = -2.2273x + 10.315
Water depth (in)
0
1
2
3
4
5
Time (hr)


#9: 1112 - 4/10/2013
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
y = -4.0076x + 8.8573
Water depth (in)
0
0.5
1
1.5
2
2.5
Time (hr)

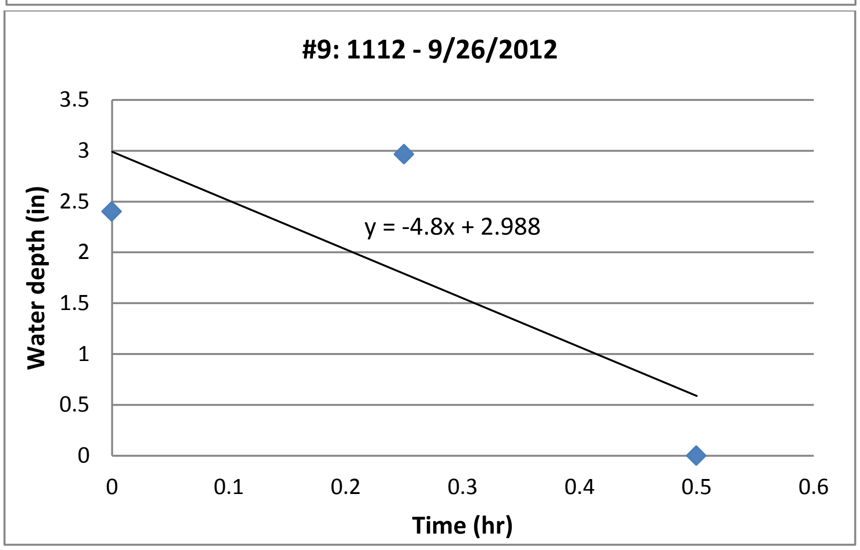

#9: 1112 - 4/7/2013
Water depth (in)
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
0
0.5
1
1.5
2
2.5
3
y = -3.8548x + 9.1782
Time (hr)


#9: 1112 - 10/13/2012 - 1
Water depth (in)
8
7
6
5
4
3
2
1
0
0
0.2
0.4
0.6
0.8
1
1.2
y = -7.2096x + 6.5904
Time (hr)

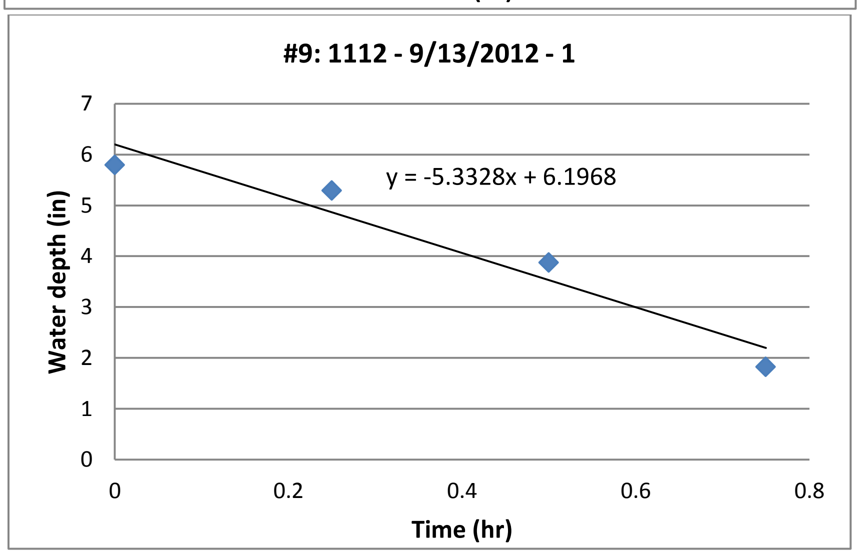

#9: 1112 - 10/13/2012 - 2
Water depth (in)
3
2.5
2
1.5
1
0.5
0
0
0.2
0.4
0.6
0.8
y = -3.7632x + 2.6592
Time (hr)



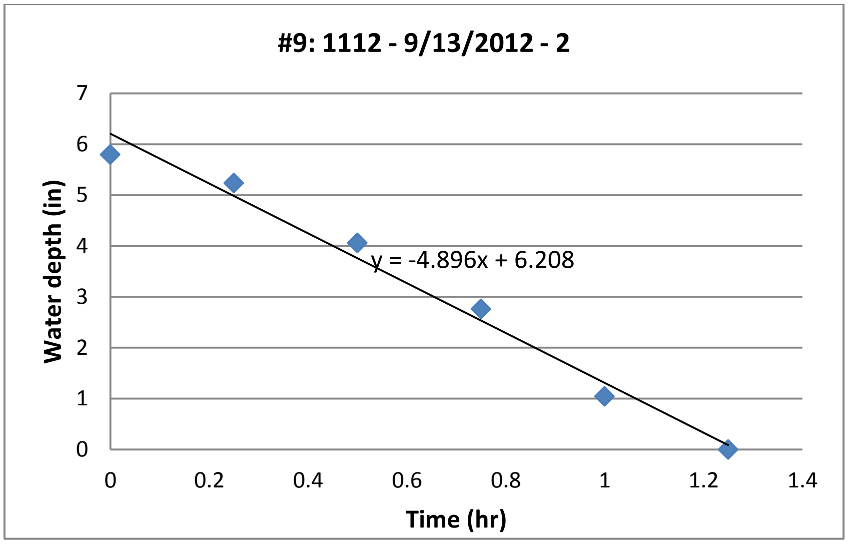
#9: 1112 - 10/13/2012 - 3
y = -4.6857x + 8.132
Water depth (in)
Time (hr)

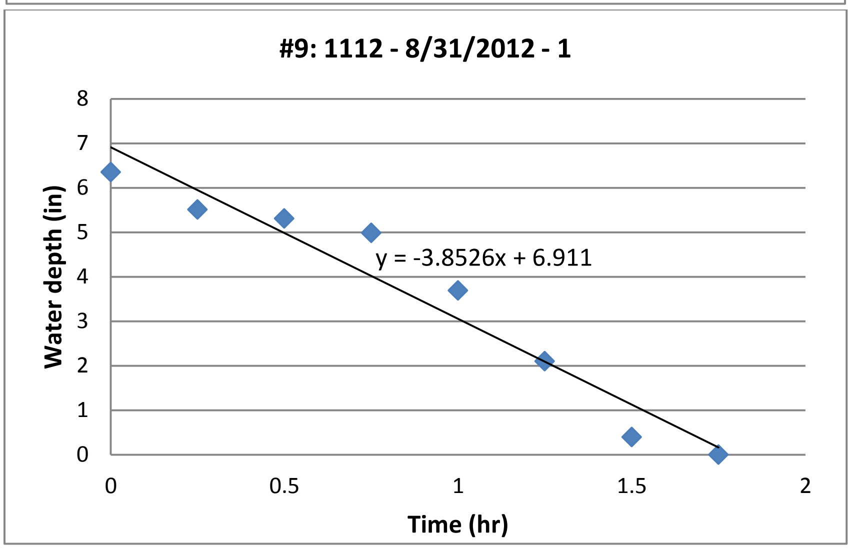


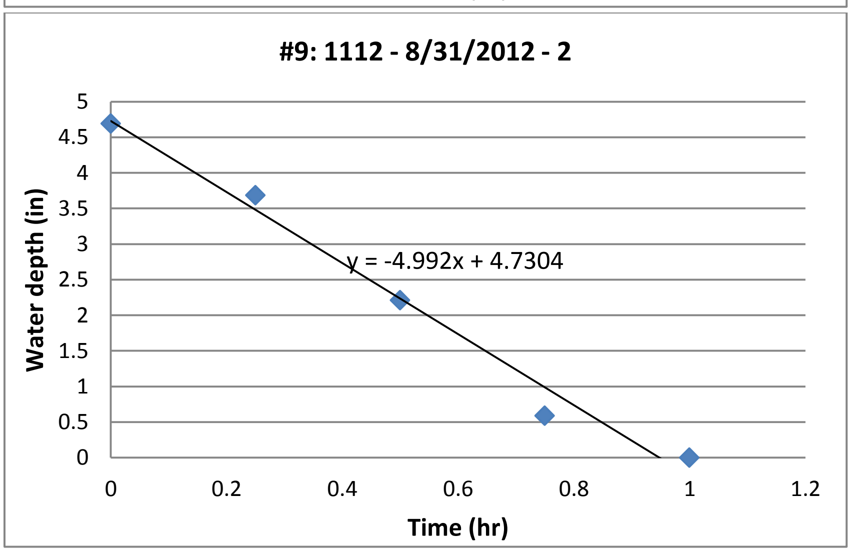
#9: 1112 - 9/26/2012
y = -4.8x + 2.988
Water depth (in)
Time (hr)



#9: 1112 - 9/13/2012 - 1
y = -5.3328x + 6.1968
Water depth (in)
Time (hr)


#9: 1112 - 9/13/2012 - 2
Water depth (in)
Time (hr)
y = -4.896x + 6.208
0
1
2
3
4
5
6
7
0
0.2
0.4
0.6
0.8
1
1.2
1.4


#9: 1112 - 8/31/2012 - 1
Water depth (in)
Time (hr)
y = -3.8526x + 6.911
0
1
2
3
4
5
6
7
8
0
0.5
1
1.5
2


#9: 1112 - 8/31/2012 - 2
Water depth (in)
Time (hr)
y = -4.992x + 4.7304
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
0.2
0.4
0.6
0.8
1
1.2

APPENDIX I

LARGE-SCALE COMBINED SEWER MONITORING DATA AT KANSAS CITY (RAW DATA FROM KCMO, UMKC, AND TETRA TECH, CALCULATIONS BY UA)

Large-Scale Rainfall and Runoff Monitoring from Combined Sewer System for Test (Pilot) Area UMKC01 Monitoring Location before Construction of Green Infrastructure Controls (raw data from KCMO, UMKC, and Tetra Tech, calculations by UA)

	Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
Initial Baseline	1	3/23/2009	21:14	3/24/2009	6:57		9.72	0.55	0.47	0.06
	2	3/26/2009	19:55	3/27/2009	2:20	2.54	6.42	0.28	0.95	0.04
	3	3/28/2009	9:19	3/29/2009	15:14	1.29	29.92	0.95	0.95	0.03
	4	3/30/2009	23:23	3/31/2009	1:25	1.34	2.03	0.24	0.95	0.12
	5	4/2/2009	5:53	4/2/2009	12:42	2.19	6.82	0.12	0.47	0.02
	6	4/9/2009	20:05	4/10/2009	14:16	7.31	18.18	0.95	1.42	0.05
	7	4/12/2009	14:07	4/13/2009	8:59	1.99	18.87	0.43	0.47	0.02
	8	4/18/2009	7:17	4/18/2009	12:44	4.93	5.45	0.55	0.47	0.10
	9	4/19/2009	3:15	4/19/2009	6:49	0.60	3.57	0.28	0.47	0.08
	10	4/26/2009	22:48	4/27/2009	13:06	7.67	14.30	2.17	1.42	0.15
	11	4/29/2009	14:51	4/30/2009	21:14	2.07	30.38	2.13	0.95	0.07
	12	5/8/2009	6:00	5/8/2009	9:16	7.37	3.27	0.32	0.47	0.10
	13	5/13/2009	18:07	5/13/2009	19:32	5.37	1.42	0.28	0.47	0.20
	14	5/15/2009	17:14	5/15/2009	22:00	1.90	4.77	1.34	1.90	0.28
	15	6/2/2009	13:12	6/2/2009	19:47	17.63	6.58	0.39	0.47	0.06
	16	6/8/2009	2:38	6/8/2009	3:59	5.29	1.35	0.20	0.95	0.15
	17	6/9/2009	10:37	6/9/2009	23:02	1.28	12.42	2.09	1.42	0.17
	18	6/11/2009	2:42	6/11/2009	5:13	1.15	2.52	0.43	1.42	0.17
	19	6/15/2009	2:38	6/16/2009	7:15	3.89	28.62	2.52	1.42	0.09
	20	6/23/2009	23:33	6/24/2009	1:23	7.68	1.83	0.35	0.95	0.19
	21	7/3/2009	8:24	7/4/2009	6:17	9.29	21.88	1.62	1.42	0.07
	22	7/10/2009	5:13	7/10/2009	6:20	5.96	1.12	0.16	0.47	0.14
	23	7/12/2009	7:58	7/12/2009	18:48	2.07	10.83	0.79	0.95	0.07
	24	7/20/2009	16:47	7/21/2009	3:39	7.92	10.87	0.63	0.95	0.06
	25	7/27/2009	21:38	7/28/2009	16:41	6.75	19.05	1.69	0.95	0.09
	26	8/1/2009	4:02	8/1/2009	6:48	3.47	2.77	0.32	0.95	0.12
	27	8/4/2009	5:59	8/4/2009	8:43	2.97	2.73	0.55	0.47	0.20
	28	8/10/2009	1:19	8/10/2009	3:55	5.69	2.60	0.20	0.47	0.08
	29	8/15/2009	19:42	8/16/2009	10:50	5.66	15.13	2.29	0.95	0.15
	30	8/17/2009	7:39	8/17/2009	12:57	0.87	5.30	1.10	1.42	0.21
	31	8/19/2009	7:00	8/20/2009	1:05	1.75	18.08	0.91	0.95	0.05
	32	8/27/2009	1:31	8/27/2009	6:49	7.02	5.30	0.12	0.47	0.02
	33	9/4/2009	12:04	9/5/2009	6:06	8.22	18.03	0.39	0.47	0.02
	34	9/8/2009	17:16	9/9/2009	18:08	3.47	24.87	0.32	0.47	0.01
	35	9/21/2009	10:37	9/21/2009	23:14	11.69	12.62	0.63	0.47	0.05

	Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
	36	9/26/2009	1:42	9/26/2009	11:08	4.10	9.43	0.35	0.47	0.04
	37	10/1/2009	4:27	10/1/2009	7:49	4.72	3.37	0.12	0.47	0.04
	38	10/6/2009	2:40	10/6/2009	4:18	4.79	1.63	0.12	0.47	0.07
	39	10/8/2009	0:38	10/8/2009	21:16	1.85	20.63	1.46	0.95	0.07
	40	10/13/2009	17:56	10/14/2009	0:19	4.86	6.38	0.20	0.47	0.03
	41	10/20/2009	5:27	10/20/2009	6:41	6.21	1.23	0.24	0.95	0.19
	42	10/21/2009	15:36	10/22/2009	14:06	1.37	22.50	0.79	0.47	0.04
	43	10/25/2009	14:11	10/26/2009	0:47	3.00	10.60	0.59	0.47	0.06
	44	10/29/2009	6:01	10/29/2009	18:30	3.22	12.48	0.63	0.95	0.05
	45	11/14/2009	23:22	11/17/2009	15:50	16.20	64.47	1.97	1.42	0.03
	46	12/22/2009	21:27	12/24/2009	12:59	35.23	39.53	1.73	1.42	0.04
	47	12/28/2009	4:32	12/28/2009	14:16	3.65	9.73	0.12	0.47	0.01
	48	12/30/2009	6:01	12/30/2009	19:35	1.66	13.57	0.43	1.42	0.03
	49	2/5/2010	9:55	2/6/2010	4:05	36.60	18.17	0.28	0.47	0.02
	50	2/7/2010	19:35	2/8/2010	13:33	1.65	17.97	0.12	0.47	0.01
	51	2/19/2010	6:56	2/19/2010	17:21	10.72	10.42	0.43	0.47	0.04
	52	2/21/2010	5:32	2/22/2010	13:46	1.51	32.23	0.55	1.42	0.02
	53	3/8/2010	20:41	3/9/2010	14:54	14.29	18.22	0.20	0.95	0.01
	54	3/10/2010	18:53	3/11/2010	3:20	1.17	8.45	0.94	1.42	0.11
	55	3/21/2010	12:21	3/21/2010	15:34	10.38	3.22	0.20	1.42	0.06
	56	3/24/2010	12:55	3/24/2010	21:15	2.89	8.33	0.20	0.47	0.02
	57	3/27/2010	8:04	3/27/2010	11:20	2.45	3.27	0.12	0.95	0.04
	58	4/2/2010	9:51	4/2/2010	13:47	5.94	3.93	0.39	1.90	0.10
	59	4/5/2010	7:28	4/5/2010	9:24	2.74	1.93	0.71	0.95	0.37
	60	4/6/2010	20:04	4/7/2010	0:49	1.44	4.75	0.55	0.95	0.12
	61	4/22/2010	10:20	4/23/2010	8:34	15.40	22.23	2.52	1.42	0.11
	62	4/24/2010	11:39	4/25/2010	11:36	1.13	23.95	0.75	0.47	0.03
	63	4/30/2010	7:03	4/30/2010	14:15	4.81	7.20	0.55	0.47	0.08
	64	5/15/2010	7:21	5/16/2010	11:01	14.71	27.67	0.59	0.95	0.02
	65	5/19/2010	12:20	5/20/2010	20:02	3.05	31.70	1.22	0.95	0.04
	66	6/8/2010	8:30	6/9/2010	12:30	18.52	28.00	2.06	0.95	0.07
	67	6/12/2010	10:05	6/12/2010	13:40	2.90	3.58	2.13	0.95	0.59
	68	6/13/2010	7:15	6/14/2010	12:45	0.73	29.50	3.50	1.90	0.12
	69	6/16/2010	18:23	6/16/2010	19:26	2.23	1.05	0.71	1.42	0.67
After Relining	70	1/22/2011	12:20	1/22/2011	15:40		3.33	0.12		0.04
	71	2/24/2011	9:00	2/24/2011	15:00	32.58	6.00	0.35	0.47	0.06
	72	2/26/2011	13:50	2/27/2011	20:20	2.15	16.67	1.22	1.42	0.07
	73	3/4/2011	11:10	3/4/2011	13:40	5.08	2.50	0.24	0.95	0.09

	Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
	74	**3/8/2011**	**8:10**	**3/8/2011**	**13:10**	**3.65**	**5.00**	**0.39**	**0.47**	**0.08**
	75	**3/13/2011**	**23:00**	**3/14/2011**	**12:25**	**5.07**	**13.42**	**0.16**	**0.47**	**0.01**
	76	**3/19/2011**	**14:30**	**3/19/2011**	**16:15**	**5.69**	**1.75**	**0.32**	**0.95**	**0.18**
	count					**74**	**76**	**76**	**75**	**76**
	sum						**950**	**58.53**		
	minimum					**0.60**	**1.05**	**0.12**	**0.47**	**0.01**
	maximum					**36.60**	**64.47**	**3.50**	**1.90**	**0.67**
	average					**6.31**	**12.49**	**0.77**	**0.89**	**0.10**
	median					**4.00**	**9.57**	**0.49**	**0.95**	**0.07**
	standard deviation					**7.23**	**11.39**	**0.74**	**0.42**	**0.11**
	COV					**1.15**	**0.91**	**0.96**	**0.47**	**1.15**

Large-Scale Rainfall and Runoff Monitoring from Combined Sewer System for Test (Pilot) Area UMKC01 Monitoring Location before Construction of Green Infrastructure Controls (raw data from KCMO, UMKC, and Tetra Tech, calculations by UA)

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
1	**3/23/2009**	**21:40**	**3/24/2009**	**17:00**	**19.33**	**24,910**	**0.069**	**3.81**	**0.34**	**0.29**	**0.12**	**1.99**
2	**3/26/2009**	**12:25**	**3/27/2009**	**8:45**	**20.33**	**16,603**	**0.046**	**1.02**	**0.25**	**4.07**	**0.16**	**3.17**
3	**3/28/2009**	**9:20**	**3/30/2009**	**3:00**	**41.67**	**167,283**	**0.461**	**3.95**	**0.94**	**4.20**	**0.49**	**1.39**
4	**3/30/2009**	**23:20**	**3/31/2009**	**13:25**	**14.08**	**81,600**	**0.225**	**4.95**	**1.65**	**3.00**	**0.94**	**6.93**
5	**4/2/2009**	**5:50**	**4/2/2009**	**23:55**	**18.08**	**29,159**	**0.080**	**0.92**	**0.45**	**2.05**	**0.67**	**2.65**
6	**4/9/2009**	**20:20**	**4/10/2009**	**23:55**	**27.58**	**99,913**	**0.275**	**2.78**	**0.51**	**5.45**	**0.29**	**1.52**
7	**4/12/2009**	**14:05**	**4/13/2009**	**17:55**	**27.83**	**51,172**	**0.141**	**1.46**	**0.46**	**3.21**	**0.33**	**1.48**
8	**4/18/2009**	**7:00**	**4/19/2009**	**0:45**	**17.75**	**28,145**	**0.078**	**5.31**	**0.44**	**12.07**	**0.14**	**3.26**
9	**4/19/2009**	**3:25**	**4/19/2009**	**19:00**	**15.58**	**34,316**	**0.095**	**5.70**	**0.61**	**9.34**	**0.34**	**4.37**
10	**4/26/2009**	**22:55**	**4/29/2009**	**2:15**	**51.33**	**281,137**	**0.774**	**10.66**	**1.52**	**7.02**	**0.36**	**3.59**
11	**4/29/2009**	**14:50**	**4/30/2009**	**9:15**	**18.42**	**171,573**	**0.473**	**12.83**	**1.54**	**8.31**	**0.22**	**0.61**
12	**5/8/2009**	**5:30**	**5/8/2009**	**21:15**	**15.75**	**17,772**	**0.049**	**2.08**	**0.31**	**6.71**	**0.15**	**4.82**
13	**5/13/2009**	**18:10**	**5/13/2009**	**23:55**	**5.75**	**7,971**	**0.022**	**10.63**	**0.70**	**15.19**	**0.08**	**4.06**
14	**5/15/2009**	**17:15**	**5/16/2009**	**10:00**	**16.75**	**60,959**	**0.168**	**17.14**	**1.05**	**16.32**	**0.13**	**3.51**
15	**6/2/2009**	**13:25**	**6/3/2009**	**7:00**	**17.58**	**52,209**	**0.144**	**12.57**	**0.91**	**13.80**	**0.37**	**2.67**
16	**6/8/2009**	**2:25**	**6/8/2009**	**4:50**	**2.42**	**3,430**	**0.009**	**1.79**	**0.38**	**4.69**	**0.05**	**1.79**
17	**6/9/2009**	**11:20**	**9/10/2009**	**12:05**	**2232.7**	**186,479**	**0.514**	**39.29**	**2.09**	**18.80**	**0.25**	**179.82**

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
					5							
18	6/11/2009	2:40	6/11/2009	17:00	14.33	62,008	0.171	22.01	1.19	18.50	0.40	5.70
19	6/15/2009	5:10	6/16/2009	19:15	38.08	498,449	1.373	32.10	3.63	8.84	0.54	1.33
20	6/23/2009	23:20	6/24/2009	13:20	14.00	8,229	0.023	2.85	0.16	17.81	0.06	7.64
21	7/3/2009	8:25	7/4/2009	18:15	33.83	103,103	0.284	2.59	0.32	8.03	0.18	1.55
22	7/10/2009	5:05	7/10/2009	8:45	3.67	5,482	0.015	3.25	0.40	8.13	0.09	3.28
23	7/12/2009	7:55	7/13/2009	6:00	22.08	57,620	0.159	31.16	0.75	41.55	0.20	2.04
24	7/20/2009	16:30	7/21/2009	14:50	22.33	30,191	0.083	3.56	0.39	9.12	0.13	2.06
25	7/27/2009	21:40	7/29/2009	4:40	31.00	59,273	0.163	15.02	0.53	28.34	0.10	1.63
26	8/1/2009	4:00	8/1/2009	18:45	14.75	15,742	0.043	2.34	0.29	8.07	0.14	5.33
27	8/4/2009	6:00	8/4/2009	15:50	9.83	16,568	0.046	10.29	0.43	23.93	0.08	3.60
28	8/10/2009	1:40	8/10/2009	15:30	13.83	8,562	0.024	4.77	0.17	28.03	0.12	5.32
29	8/15/2009	19:50	8/16/2009	22:50	27.00	123,747	0.341	13.20	1.22	10.82	0.15	1.78
30	8/17/2009	7:05	8/18/2009	1:00	17.92	88,033	0.243	28.15	1.36	20.70	0.22	3.38
31	8/19/2009	7:00	8/20/2009	12:00	29.00	81,969	0.226	12.04	0.76	15.84	0.25	1.60
32	8/27/2009	1:55	8/27/2009	15:00	13.08	9,272	0.026	0.70	0.19	3.68	0.21	2.47
33	9/4/2009	10:00	9/5/2009	5:50	19.83	17,945	0.049	2.79	0.25	11.16	0.13	1.10
34	9/8/2009	15:15	9/9/2009	22:00	30.75	18,026	0.050	1.92	0.15	12.80	0.16	1.24
35	9/21/2009	10:15	9/22/2009	7:00	20.75	33,845	0.093	2.71	0.45	6.01	0.15	1.64
36	9/26/2009	0:30	9/26/2009	17:45	17.25	15,980	0.044	3.89	0.26	14.97	0.13	1.83
37	10/1/2009	3:45	10/1/2009	17:30	13.75	4,233	0.012	0.58	0.08	7.25	0.10	4.08
38	10/6/2009	2:25	10/6/2009	10:00	7.58	3,432	0.009	1.00	0.16	6.25	0.08	4.64
39	10/8/2009	2:20	10/9/2009	9:00	30.67	102,567	0.283	7.94	0.86	9.23	0.19	1.49
40	10/13/2009	17:25	10/14/2009	12:00	18.58	18,413	0.051	2.36	0.30	7.87	0.25	2.91
41	10/20/2009	5:30	10/20/2009	12:40	7.17	11,219	0.031	5.86	0.40	14.65	0.13	5.81
42	10/21/2009	15:45	10/23/2009	2:25	34.67	89,206	0.246	2.49	0.57	4.37	0.31	1.54
43	10/25/2009	14:00	10/26/2009	2:10	12.17	54,858	0.151	4.35	0.90	4.84	0.26	1.15
44	10/29/2009	5:50	10/29/2009	11:25	5.58	55,455	0.153	6.80	0.62	10.97	0.24	0.45
45	11/14/2009	22:30	11/18/2009	5:00	78.50	83,045	0.229	1.37	0.29	4.72	0.12	1.22
46	12/23/2009	0:00	12/24/2009	23:00	47.00	67,248	0.185	4.68	0.43	10.88	0.11	1.19
47	12/28/2009	4:35	12/28/2009	22:15	17.67	9,612	0.026	0.28	0.13	2.10	0.22	1.82
48	12/30/2009	5:55	12/30/2009	23:55	18.00	8,385	0.023	0.22	0.12	1.83	0.05	1.33
49	2/5/2010	10:25	2/5/2010	23:55	13.50	10,497	0.029	0.33	0.09	3.67	0.10	0.74
50	2/7/2010	11:25	2/7/2010	0:55	13.50	13,563	0.037	0.33	0.13	2.54	0.31	0.75
51	2/19/2010	6:55	2/20/2010	1:25	18.50	22,778	0.063	1.55	0.34	4.57	0.15	1.78
52	2/21/2010	5:15	2/22/2010	23:50	42.58	93,882	0.259	2.66	0.77	3.44	0.47	1.32
53	3/8/2010	20:45	3/9/2010	4:55	8.17	8,546	0.024	0.95	0.10	9.50	0.12	0.45
54	3/10/2010	19:00	3/11/2010	14:20	19.33	49,894	0.137	6.13	0.68	9.02	0.15	2.29

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
55	3/21/2010	12:00	3/22/2010	1:40	13.67	9,836	0.027	0.44	0.21	2.10	0.14	4.25
56	3/24/2010	12:00	3/25/2010	9:00	21.00	17,628	0.049	0.91	0.23	3.96	0.24	2.52
57	3/27/2010	7:20	3/27/2010	22:00	14.67	5,113	0.014	0.78	0.19	4.11	0.12	4.49
58	4/2/2010	9:55	4/2/2010	20:00	10.08	14,035	0.039	5.53	0.39	14.30	0.10	2.56
59	4/5/2010	7:30	4/5/2010	22:00	14.50	54,142	0.149	18.91	1.03	18.36	0.21	7.50
60	4/6/2010	20:10	4/7/2010	11:40	15.50	98,750	0.272	9.47	1.76	5.38	0.49	3.26
61	4/22/2010	10:25	4/23/2010	19:35	33.17	214,933	0.592	10.01	1.78	5.63	0.23	1.49
62	4/24/2010	11:15	4/25/2010	20:30	33.25	94,125	0.259	2.07	0.78	2.65	0.35	1.39
63	4/30/2010	6:30	4/30/2010	23:50	17.33	40,157	0.111	11.39	0.64	17.78	0.20	2.41
64	5/15/2010	7:15	5/16/2010	20:00	36.75	91,855	0.253	2.44	0.63	3.87	0.43	1.33
65	5/19/2010	12:20	5/20/2010	7:00	18.67	169,204	0.466	9.44	1.07	8.82	0.38	0.59
66	6/8/2010	8:50	6/9/2010	8:20	23.50	92,351	0.254	27.25	1.09	25.00	0.12	0.84
67	6/12/2010	10:15	6/13/2010	1:40	15.42	251,228	0.692	47.13	4.68	10.07	0.32	4.30
68	6/13/2010	7:10	6/15/2010	0:05	40.92	780,680	2.151	106.67	5.29	20.16	0.61	1.39
69	6/16/2010	18:25	6/17/2010	6:40	12.25	109,484	0.302	29.04	2.45	11.85	0.43	11.67
70												
71	2/24/2011	9:00	2/25/2011	3:00	9.00	49,932	0.138	1.98	0.73	2.72	0.39	1.50
72	2/26/2011	13:50	2/28/2011	8:00	28.33	146,655	0.404	16.83	0.88	19.12	0.33	1.70
73	3/4/2011	11:15	3/4/2011	22:45	11.50	21,625	0.060	6.14	0.47	13.06	0.25	4.60
74	3/8/2011	8:10	3/9/2011	1:10	8.83	23,355	0.064	2.06	0.41	5.02	0.16	1.77
75	3/13/2011	22:30	3/14/2011	20:15	21.75	11,802	0.033	0.66	0.12	5.50	0.21	1.62
76	3/19/2011	13:30	3/19/2011	22:10	8.67	12,464	0.034	2.44	0.38	6.42	0.11	4.95
	count				75	75	75	75	75	75	75	75
	sum				3,772	5,584,861	15.39					
	minimum				2.42	3,430	0.01	0.22	0.08	0.29	0.05	0.45
	maximum				2232.75	780,680	2.15	106.67	5.29	41.55	0.94	179.82
	average				50.29	74,465	0.21	9.25	0.79	10.06	0.24	5.11
	median				17.92	40,157	0.11	3.89	0.46	8.13	0.20	1.99
	standard deviation				255.71	114,061	0.31	15.03	0.93	7.51	0.16	20.54
	COV				5.08	1.53	1.53	1.62	1.17	0.75	0.67	4.02

Large-Scale Rainfall and Runoff Monitoring from Combined Sewer System for Test (Pilot) Area UMKC01 Monitoring Location after Construction of Green Infrastructure Controls (raw data from KCMO, UMKC, and Tetra Tech, calculations by UA)

	Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
After Construction	77	4/7/2013	19:52	4/8/2013	2:25		6.55	1.10	1.42	0.17
	78	4/9/2013	21:56	4/10/2013	18:30	1.62	20.57	1.62	1.42	0.08
	79	4/14/2013	19:02	4/15/2013	7:08	4.02	12.10	0.39	0.47	0.03
	80	4/17/2013	11:00	4/18/2013	20:41	2.16	33.68	1.10	0.47	0.03
	81	4/23/2013	1:34	4/23/2013	10:53	4.20	9.32	0.39	0.47	0.04
	82	4/26/2013	4:19	4/27/2013	11:02	2.73	30.72	0.95	0.95	0.03
	83	5/2/2013	3:08	5/4/2013	4:11	4.67	49.05	1.42	0.47	0.03
	84	5/8/2013	7:21	5/9/2013	2:36	4.13	19.25	0.28	0.47	0.01
	85	5/19/2013	2:21	5/20/2013	1:44	9.99	23.38	0.83	1.42	0.04
	86	5/27/2013	8:31	5/27/2013	12:35	7.28	4.07	2.01	1.90	0.49
	87	5/29/2013	22:53	5/30/2013	15:17	2.43	16.40	1.62	1.42	0.10
	88	5/31/2013	5:26	5/31/2013	9:21	0.59	3.92	1.34	1.90	0.34
	89	6/4/2013	10:55	6/4/2013	14:19	4.07	3.40	0.24	0.47	0.07
	90	6/5/2013	9:44	6/5/2013	12:47	0.81	3.05	0.47	0.47	0.15
	91	6/9/2013	0:54	6/9/2013	3:53	3.50	2.98	0.39	0.95	0.13
	92	6/15/2013	15:50	6/15/2013	22:05	6.50	6.25	1.26	1.42	0.20
	93	6/27/2013	11:46	6/28/2013	0:49	11.57	13.05	0.83	1.90	0.06
	94	7/3/2013	17:54	7/3/2013	21:36	5.71	3.70	1.50	0.95	0.41
	95	7/25/2013	17:00	7/26/2013	11:00	21.81	18.00	0.24	0.47	0.01
	96	7/29/2013	6:27	7/30/2013	9:41	2.81	27.23	0.91	0.95	0.03
	97	8/2/2013	3:46	8/2/2013	8:10	2.75	4.40	0.32	0.47	0.07
	98	8/4/2013	11:38	8/4/2013	13:58	2.14	2.33	0.12	0.47	0.05
	99	8/6/2013	3:24	8/6/2013	4:59	1.56	1.58	0.55	1.42	0.35
	100	8/7/2013	4:13	8/7/2013	8:45	0.97	4.53	0.87	0.95	0.19
	101	8/12/2013	7:07	8/12/2013	10:18	4.93	3.18	0.67	1.42	0.21
	102	9/1/2013	7:42	9/1/2013	9:02	19.89	1.33	0.16	0.95	0.12
	103	9/16/2013	2:13	9/16/2013	4:10	14.72	1.95	0.12	0.95	0.06
	104	9/17/2013	7:04	9/17/2013	15:14	1.12	8.17	0.79	0.95	0.10
	105	9/19/2013	19:00	9/19/2013	22:23	2.16	3.38	1.89	2.85	0.56
	106	9/28/2013	8:29	9/28/2013	11:29	8.42	3.00	0.28	0.47	0.09
	107	10/3/2013	11:04	10/3/2013	11:24	4.98	0.33	0.16	0.47	0.47
	108	10/4/2013	22:36	10/5/2013	3:48	1.47	5.20	0.87	0.47	0.17
	109	10/11/2013	23:08	10/12/2013	2:29	6.81	3.35	0.12	0.47	0.04
	110	10/14/2013	15:10	10/15/2013	1:23	2.53	10.22	0.12	0.47	0.01
	111	10/18/2013	14:03	10/18/2013	17:05	3.53	3.03	0.12	0.47	0.04

	Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
	112	10/29/2013	2:52	10/29/2013	9:41	10.41	6.82	0.83	0.95	0.12
	113	10/30/2013	12:09	10/31/2013	11:46	1.10	23.62	3.43	1.42	0.15
	count					36	37	37	37	37
	sum						393	30.29		
	minimum					0.59	0.33	0.12	0.47	0.01
	maximum					21.81	49.05	3.43	2.85	0.56
	average					5.28	10.62	0.82	0.97	0.14
	median					3.78	5.20	0.79	0.95	0.09
	standard deviation					5.06	11.12	0.70	0.57	0.15
	COV					0.96	1.05	0.86	0.59	1.03

Large-Scale Rainfall and Runoff Monitoring from Combined Sewer System for Test (Pilot) Area UMKC01 Monitoring Location after Construction of Green Infrastructure Controls (raw data from KCMO, UMKC, and Tetra Tech, calculations by UA)

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
77	4/7/2013	19:50	4/8/2013	9:45	13.92	66,609	0.183	19.33	1.44	13.42	0.17	2.12
78	4/9/2013	21:45	4/11/2013	6:30	32.75	137,860	0.380	13.28	1.19	11.16	0.23	1.59
79	4/14/2013	19:15	4/15/2013	17:20	22.08	7,939	0.022	1.26	0.13	9.69	0.06	1.83
80	4/17/2013	11:00	4/19/2013	8:20	45.33	131,126	0.361	4.72	0.80	5.90	0.33	1.35
81	4/23/2013	1:30	4/23/2013	22:00	20.50	27,952	0.077	0.96	0.43	2.23	0.20	2.20
82	4/26/2013	4:25	4/27/2013	23:00	42.58	64,499	0.178	1.51	0.43	3.51	0.19	1.39
83	5/2/2013	2:10	5/4/2013	13:00	58.83	149,222	0.411	1.51	0.70	2.16	0.29	1.20
84	5/8/2013	7:20	5/9/2013	13:00	29.67	19,890	0.055	2.45	0.21	11.67	0.20	1.54
85	5/19/2013	3:20	5/20/2013	13:00	33.67	57,570	0.159	8.01	0.47	17.04	0.19	1.44
86	5/27/2013	8:35	5/27/2013	23:50	15.25	210,046	0.579	36.40	3.81	9.55	0.29	3.75
87	5/29/2013	23:05	5/31/2013	3:00	27.92	124,377	0.343	5.54	1.28	4.33	0.21	1.70
88	5/31/2013	5:00	5/31/2013	21:15	16.25	199,276	0.549	26.37	3.55	7.43	0.41	4.15
89	6/4/2013	10:45	6/4/2013	21:05	10.33	7,607	0.021	0.84	0.20	4.20	0.09	3.04
90	6/5/2013	9:00	6/5/2013	22:50	13.83	12,604	0.035	2.47	0.26	9.50	0.07	4.54
91	6/9/2013	0:30	6/9/2013	15:05	14.58	17,051	0.047	3.14	0.32	9.81	0.12	4.89
92	6/15/2013	15:55	6/16/2013	9:00	17.08	71,491	0.197	12.57	1.16	10.84	0.16	2.73

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
93	6/27/2013	11:50	6/28/2013	11:00	23.17	60,903	0.168	19.07	0.73	26.12	0.20	1.78
94	7/3/2013	17:55	7/4/2013	6:55	13.00	30,333	0.084	11.24	0.64	17.56	0.06	3.51
95	7/25/2013	17:05	7/26/2013	13:15	20.17	3,066	0.008	0.05	0.01	5.00	0.04	1.12
96	7/29/2013	6:30	7/30/2013	20:00	37.50	51,803	0.143	7.40	0.38	19.47	0.16	1.38
97	8/2/2013	3:00	8/2/2013	20:30	0.83	13,547	0.037	1.23	0.21	5.86	0.12	0.19
98	8/4/2013	11:40	8/4/2013	19:20	7.67	3,923	0.011	0.58	0.14	4.14	0.09	3.29
99	8/6/2013	3:45	8/6/2013	6:45	3.00	8,752	0.024	4.96	0.79	6.28	0.04	1.89
100	8/7/2013	4:20	8/7/2013	13:45	9.42	23,841	0.066	6.87	0.70	9.81	0.08	2.08
101	8/12/2013	7:10	8/12/2013	20:40	13.50	35,350	0.097	11.82	0.76	15.55	0.15	4.24
102	9/1/2013	7:40	9/1/2013	16:05	8.42	6,846	0.019	3.54	0.50	7.08	0.12	6.31
103	9/16/2013	0:30	9/16/2013	6:05	5.58	1,155	0.003	0.39	0.06	6.50	0.03	2.86
104	9/17/2013	8:05	9/17/2013	23:55	15.83	22,378	0.062	2.27	0.39	5.82	0.08	1.94
105	9/19/2013	19:00	9/20/2013	12:00	17.00	93,701	0.258	2.92	0.06	48.67	0.14	5.02
106	9/28/2013	8:05	9/28/2013	23:50	15.75	17,316	0.048	3.02	0.30	10.07	0.17	5.25
107	10/3/2013	11:00	10/3/2013	13:40	2.67	5,226	0.014	3.37	0.53	6.36	0.09	8.00
108	10/4/2013	22:00	10/5/2013	9:35	11.58	16,374	0.045	4.54	0.39	11.64	0.05	2.23
109	10/11/2013	23:00	10/12/2013	7:45	8.75	2,687	0.007	1.92	0.08	24.00	0.06	2.61
110	10/14/2013	15:30	10/15/2013	6:30	15.00	2,628	0.007	0.48	0.05	9.60	0.06	1.47
111	10/18/2013	14:00	10/18/2013	22:15	8.25	3,198	0.009	0.53	0.11	4.82	0.07	2.72
112	10/29/2013	3:05	10/29/2013	22:00	18.92	33,023	0.091	2.11	0.48	4.40	0.11	2.78
113	10/30/2013	12:15	10/31/2013	23:45	35.50	219,477	0.605	18.02	1.71	10.54	0.18	1.50
	count				37	37	37	37	37	37	37	37
	sum				706	1,960,646	5.40					
	minimum				0.83	1,155	0.00	0.05	0.01	2.16	0.03	0.19
	maximum				58.83	219,477	0.60	36.40	3.81	48.67	0.41	8.00
	average				19.08	52,990	0.15	6.67	0.69	10.59	0.14	2.75
	median				15.75	23,841	0.07	3.14	0.43	9.55	0.12	2.20
	standard deviation				12.91	62,642	0.17	8.15	0.83	8.56	0.09	1.64
	COV				0.68	1	1.18	1.22	1.22	0.81	0.62	0.60

Large-Scale Rainfall and Runoff Monitoring from Combined Sewer System for Control Area UMKC02a Monitoring Location (raw data from KCMO, UMKC, and Tetra Tech, calculations by UA)

	Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
Initial Baseline	1	3/23/2009	21:14	3/24/2009	6:57		9.72	0.55	0.47	0.06
	2	3/26/2009	19:55	3/27/2009	2:20	2.54	6.42	0.28	0.95	0.04
	3	3/28/2009	9:19	3/29/2009	15:14	1.29	29.92	0.95	0.95	0.03
	4	3/30/2009	23:23	3/31/2009	1:25	1.34	2.03	0.24	0.95	0.12
	5	4/2/2009	5:53	4/2/2009	12:42	2.19	6.82	0.12	0.47	0.02
	6	4/9/2009	20:05	4/10/2009	14:16	7.31	18.18	0.95	1.42	0.05
	7	4/12/2009	14:07	4/13/2009	8:59	1.99	18.87	0.43	0.47	0.02
	8	4/18/2009	7:17	4/18/2009	12:44	4.93	5.45	0.55	0.47	0.10
	9	4/19/2009	3:15	4/19/2009	6:49	0.60	3.57	0.28	0.47	0.08
	10	4/26/2009	22:48	4/27/2009	13:06	7.67	14.30	2.17	1.42	0.15
	11	4/29/2009	14:51	4/30/2009	21:14	2.07	30.38	2.13	0.95	0.07
	12	5/8/2009	6:00	5/8/2009	9:16	7.37	3.27	0.32	0.47	0.10
	13	5/13/2009	18:07	5/13/2009	19:32	5.37	1.42	0.28	0.47	0.20
	14	5/15/2009	17:14	5/15/2009	22:00	1.90	4.77	1.34	1.90	0.28
	15	6/2/2009	13:12	6/2/2009	19:47	17.63	6.58	0.39	0.47	0.06
	16	6/8/2009	2:38	6/8/2009	3:59	5.29	1.35	0.20	0.95	0.15
	17	6/9/2009	10:37	6/9/2009	23:02	1.28	12.42	2.09	1.42	0.17
	18	6/11/2009	2:42	6/11/2009	5:13	1.15	2.52	0.43	1.42	0.17
	19	6/15/2009	2:38	6/16/2009	7:15	3.89	28.62	2.52	1.42	0.09
	20	6/23/2009	23:33	6/24/2009	1:23	7.68	1.83	0.35	0.95	0.19
	21	7/3/2009	8:24	7/4/2009	6:17	9.29	21.88	1.62	1.42	0.07
	22	7/10/2009	5:13	7/10/2009	6:20	5.96	1.12	0.16	0.47	0.14
	23	7/12/2009	7:58	7/12/2009	18:48	2.07	10.83	0.79	0.95	0.07
	24	7/20/2009	16:47	7/21/2009	3:39	7.92	10.87	0.63	0.95	0.06
	25	7/27/2009	21:38	7/28/2009	16:41	6.75	19.05	1.69	0.95	0.09
	26	8/1/2009	4:02	8/1/2009	6:48	3.47	2.77	0.32	0.95	0.12
	27	8/4/2009	5:59	8/4/2009	8:43	2.97	2.73	0.55	0.47	0.20
	28	8/10/2009	1:19	8/10/2009	3:55	5.69	2.60	0.20	0.47	0.08
	29	8/15/2009	19:42	8/16/2009	10:50	5.66	15.13	2.29	0.95	0.15
	30	8/17/2009	7:39	8/17/2009	12:57	0.87	5.30	1.10	1.42	0.21
	31	8/19/2009	7:00	8/20/2009	1:05	1.75	18.08	0.91	0.95	0.05
	32	8/27/2009	1:31	8/27/2009	6:49	7.02	5.30	0.12	0.47	0.02
	33	9/4/2009	12:04	9/5/2009	6:06	8.22	18.03	0.39	0.47	0.02
	34	9/8/2009	17:16	9/9/2009	18:08	3.47	24.87	0.32	0.47	0.01
	35	9/21/2009	10:37	9/21/2009	23:14	11.69	12.62	0.63	0.47	0.05
	36	9/26/2009	1:42	9/26/2009	11:08	4.10	9.43	0.35	0.47	0.04

	Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
	37	10/1/2009	4:27	10/1/2009	7:49	4.72	3.37	0.12	0.47	0.04
	38	10/6/2009	2:40	10/6/2009	4:18	4.79	1.63	0.12	0.47	0.07
	39	10/8/2009	0:38	10/8/2009	21:16	1.85	20.63	1.46	0.95	0.07
	40	10/13/2009	17:56	10/14/2009	0:19	4.86	6.38	0.20	0.47	0.03
	41	10/20/2009	5:27	10/20/2009	6:41	6.21	1.23	0.24	0.95	0.19
	42	10/21/2009	15:36	10/22/2009	14:06	1.37	22.50	0.79	0.47	0.04
	43	10/25/2009	14:11	10/26/2009	0:47	3.00	10.60	0.59	0.47	0.06
	44	10/29/2009	6:01	10/29/2009	18:30	3.22	12.48	0.63	0.95	0.05
	45	11/14/2009	23:22	11/17/2009	15:50	16.20	64.47	1.97	1.42	0.03
	46	12/22/2009	21:27	12/24/2009	12:59	35.23	39.53	1.73	1.42	0.04
	47	12/28/2009	4:32	12/28/2009	14:16	3.65	9.73	0.12	0.47	0.01
	48	12/30/2009	6:01	12/30/2009	19:35	1.66	13.57	0.43	1.42	0.03
	49	2/5/2010	9:55	2/6/2010	4:05	36.60	18.17	0.28	0.47	0.02
	50	2/7/2010	19:35	2/8/2010	13:33	1.65	17.97	0.12	0.47	0.01
	51	2/19/2010	6:56	2/19/2010	17:21	10.72	10.42	0.43	0.47	0.04
	52	2/21/2010	5:32	2/22/2010	13:46	1.51	32.23	0.55	1.42	0.02
	53	3/8/2010	20:41	3/9/2010	14:54	14.29	18.22	0.20	0.95	0.01
	54	3/10/2010	18:53	3/11/2010	3:20	1.17	8.45	0.94	1.42	0.11
	55	3/21/2010	12:21	3/21/2010	15:34	10.38	3.22	0.20	1.42	0.06
	56	3/24/2010	12:55	3/24/2010	21:15	2.89	8.33	0.20	0.47	0.02
	57	3/27/2010	8:04	3/27/2010	11:20	2.45	3.27	0.12	0.95	0.04
	58	4/2/2010	9:51	4/2/2010	13:47	5.94	3.93	0.39	1.90	0.10
	59	4/5/2010	7:28	4/5/2010	9:24	2.74	1.93	0.71	0.95	0.37
	60	4/6/2010	20:04	4/7/2010	0:49	1.44	4.75	0.55	0.95	0.12
	61	4/22/2010	10:20	4/23/2010	8:34	15.40	22.23	2.52	1.42	0.11
	62	4/24/2010	11:39	4/25/2010	11:36	1.13	23.95	0.75	0.47	0.03
	63	4/30/2010	7:03	4/30/2010	14:15	4.81	7.20	0.55	0.47	0.08
	64	5/10/2010	10:09	5/11/2010	2:21	10.25	18.45	1.22	2.36	0.07
	65	5/12/2010	17:09	5/13/2010	9:17	1.81	19.30	1.54	2.83	0.08
	66	5/15/2010	7:21	5/16/2010	11:01	14.71	27.67	0.59	0.95	0.02
	67	5/19/2010	12:20	5/20/2010	20:02	3.05	31.70	1.22	0.95	0.04
	68	6/8/2010	8:30	6/9/2010	12:30	18.52	28.00	2.06	0.95	0.07
	69	6/12/2010	10:05	6/12/2010	13:40	2.90	3.58	2.13	0.95	0.59
	70	6/13/2010	7:15	6/14/2010	12:45	0.73	29.50	3.50	1.90	0.12
	71	6/16/2010	18:23	6/16/2010	19:26	2.23	1.05	0.71	1.42	0.67
After Relining	72	1/22/2011	12:20	1/22/2011	15:40		3.33	0.12		0.04
	73	2/24/2011	9:00	2/24/2011	15:00	32.58	6.00	0.35	0.47	0.06
	74	2/26/2011	13:50	2/27/2011	20:20	2.15	16.67	1.22	1.42	0.07
	75	3/4/2011	11:10	3/4/2011	13:40	5.08	2.50	0.24	0.95	0.09

	Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
	76	**3/8/2011**	**8:10**	**3/8/2011**	**13:10**	**3.65**	**5.00**	**0.39**	**0.47**	**0.08**
	77	**3/13/2011**	**23:00**	**3/14/2011**	**12:25**	**5.07**	**13.42**	**0.16**	**0.47**	**0.01**
	78	**3/19/2011**	**14:30**	**3/19/2011**	**16:15**	**5.69**	**1.75**	**0.32**	**0.95**	**0.18**
After Construction	**79**	**4/7/2013**	**19:52**	**4/8/2013**	**2:25**		**6.55**	**1.10**	**1.42**	**0.17**
	80	**4/9/2013**	**21:56**	**4/10/2013**	**18:30**	**1.62**	**20.57**	**1.62**	**1.42**	**0.08**
	81	**4/14/2013**	**19:02**	**4/15/2013**	**7:08**	**4.02**	**12.10**	**0.39**	**0.47**	**0.03**
	82	**4/17/2013**	**11:00**	**4/18/2013**	**20:41**	**2.16**	**33.68**	**1.10**	**0.47**	**0.03**
	83	**4/23/2013**	**1:34**	**4/23/2013**	**10:53**	**4.20**	**9.32**	**0.39**	**0.47**	**0.04**
	84	**4/26/2013**	**4:19**	**4/27/2013**	**11:02**	**2.73**	**30.72**	**0.95**	**0.95**	**0.03**
	85	**5/2/2013**	**3:08**	**5/4/2013**	**4:11**	**4.67**	**49.05**	**1.42**	**0.47**	**0.03**
	86	**5/8/2013**	**7:21**	**5/9/2013**	**2:36**	**4.13**	**19.25**	**0.28**	**0.47**	**0.01**
	87	**5/19/2013**	**2:21**	**5/20/2013**	**1:44**	**9.99**	**23.38**	**0.83**	**1.42**	**0.04**
	88	**5/27/2013**	**8:31**	**5/27/2013**	**12:35**	**7.28**	**4.07**	**2.01**	**1.90**	**0.49**
	89	**5/29/2013**	**22:53**	**5/30/2013**	**15:17**	**2.43**	**16.40**	**1.62**	**1.42**	**0.10**
	90	**5/31/2013**	**5:26**	**5/31/2013**	**9:21**	**0.59**	**3.92**	**1.34**	**1.90**	**0.34**
	91	**6/4/2013**	**10:55**	**6/4/2013**	**14:19**	**4.07**	**3.40**	**0.24**	**0.47**	**0.07**
	92	**6/5/2013**	**9:44**	**6/5/2013**	**12:47**	**0.81**	**3.05**	**0.47**	**0.47**	**0.15**
	93	**6/9/2013**	**0:54**	**6/9/2013**	**3:53**	**3.50**	**2.98**	**0.39**	**0.95**	**0.13**
	94	**6/15/2013**	**15:50**	**6/15/2013**	**22:05**	**6.50**	**6.25**	**1.26**	**1.42**	**0.20**
	95	**6/27/2013**	**11:46**	**6/28/2013**	**0:49**	**11.57**	**13.05**	**0.83**	**1.90**	**0.06**
	96	**7/3/2013**	**17:54**	**7/3/2013**	**21:36**	**5.71**	**3.70**	**1.50**	**0.95**	**0.41**
	97	**7/25/2013**	**17:00**	**7/26/2013**	**11:00**	**21.81**	**18.00**	**0.24**	**0.47**	**0.01**
	98	**7/29/2013**	**6:27**	**7/30/2013**	**9:41**	**25.37**	**27.23**	**0.91**	**0.95**	**0.03**
	99	**8/2/2013**	**3:46**	**8/2/2013**	**8:10**	**6.70**	**4.40**	**0.32**	**0.47**	**0.07**
	100	**8/4/2013**	**11:38**	**8/4/2013**	**13:58**	**5.08**	**2.33**	**0.12**	**0.47**	**0.05**
	101	**8/6/2013**	**3:24**	**8/6/2013**	**4:59**	**3.80**	**1.58**	**0.55**	**1.42**	**0.35**
	102	**8/7/2013**	**4:13**	**8/7/2013**	**8:45**	**2.59**	**4.53**	**0.87**	**0.95**	**0.19**
	103	**8/12/2013**	**7:07**	**8/12/2013**	**10:18**	**6.09**	**3.18**	**0.67**	**1.42**	**0.21**
	104	**9/1/2013**	**7:42**	**9/1/2013**	**9:02**	**19.89**	**1.33**	**0.16**	**0.95**	**0.12**
	105	**9/16/2013**	**2:13**	**9/16/2013**	**4:10**	**14.72**	**1.95**	**0.12**	**0.95**	**0.06**
	106	**9/17/2013**	**7:04**	**9/17/2013**	**15:14**	**1.12**	**8.17**	**0.79**	**0.95**	**0.10**
	107	**9/19/2013**	**19:00**	**9/19/2013**	**22:23**	**2.16**	**3.38**	**1.89**	**2.85**	**0.56**
	108	**9/28/2013**	**8:29**	**9/28/2013**	**11:29**	**8.42**	**3.00**	**0.28**	**0.47**	**0.09**
	109	**10/3/2013**	**11:04**	**10/3/2013**	**11:24**	**4.98**	**0.33**	**0.16**	**0.47**	**0.47**
	110	**10/4/2013**	**22:36**	**10/5/2013**	**3:48**	**1.47**	**5.20**	**0.87**	**0.47**	**0.17**
	111	**10/11/2013**	**23:08**	**10/12/2013**	**2:29**	**6.81**	**3.35**	**0.12**	**0.47**	**0.04**
	112	**10/14/2013**	**15:10**	**10/15/2013**	**1:23**	**2.53**	**10.22**	**0.12**	**0.47**	**0.01**
	113	**10/18/2013**	**14:03**	**10/18/2013**	**17:05**	**3.53**	**3.03**	**0.12**	**0.47**	**0.04**
	114	**10/29/2013**	**2:52**	**10/29/2013**	**9:41**	**10.41**	**6.82**	**0.83**	**0.95**	**0.12**

	Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
	115	10/30/2013	12:09	10/31/2013	11:46	1.10	23.62	3.43	1.42	0.15
		count				112	115	115	114	115
		sum				703	1,380	92		
		minimum				0.59	0.33	0.12	0.47	0.01
		maximum				36.60	64.47	3.50	2.85	0.67
		average				6.28	12.00	0.80	0.95	0.11
		median				4.12	8.17	0.55	0.95	0.07
		standard deviation				6.76	11.22	0.72	0.52	0.12
		COV				1.08	0.94	0.91	0.55	1.11

Large-Scale Rainfall and Runoff Monitoring from Combined Sewer System for Control Area UMKC02a Monitoring Location (raw data from KCMO, UMKC, and Tetra Tech, calculations by UA)

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
1	3/23/2009	21:00	3/24/2009	13:00	16.00	15,945	0.244	1.56	0.28	0.29	0.44	1.65
2	3/26/2009	20:10	3/27/2009	6:10	10.00	822	0.013	0.37	0.02	18.50	0.04	1.56
3	3/28/2009	8:05	3/30/2009	14:20	54.25	23,335	0.357	2.32	0.21	11.05	0.38	1.81
4	3/30/2009	23:30	3/31/2009	13:00	13.50	16,690	0.255	0.79	0.35	0.47	1.06	6.64
5	4/2/2009	5:35	4/2/2009	23:50	18.25	3,625	0.055	0.20	0.05	4.00	0.46	2.68
6	4/9/2009	19:25	4/10/2009	20:35	25.17	23,021	0.352	0.96	0.25	3.84	0.37	1.38
7	4/12/2009	11:50	4/13/2009	20:00	32.17	1,096	0.017	0.12	0.01	12.00	0.04	1.70
8	4/18/2009	6:55	4/19/2009	23:45	40.83	4,733	0.072	1.15	0.05	23.00	0.13	7.49
9	4/19/2009	3:15	4/19/2009	18:45	15.50	34,052	0.521	2.26	0.62	3.65	1.89	4.35
10	4/26/2009	22:50	4/28/2009	1:00	26.17	292,467	4.476	9.13	3.09	2.95	2.06	1.83
11	4/29/2009	14:50	4/30/2009	23:55	33.08	61,072	0.935	5.76	0.51	11.29	0.44	1.09
12	5/8/2009	6:10	5/8/2009	13:50	7.67	4,067	0.062	1.31	0.15	8.73	0.19	2.35
13	5/13/2009	18:10	5/13/2009	21:00	2.83	10,902	0.167	4.52	1.04	4.35	0.60	2.00
14	5/15/2009	17:15	5/16/2009	9:00	15.75	163,805	2.507	11.18	2.87	3.90	1.87	3.30
15	6/2/2009	13:10	6/2/2009	19:35	6.42	14,196	0.217	6.12	0.61	10.03	0.56	0.97
16	6/8/2009	1:45	6/8/2009	5:45	4.00	1,415	0.022	1.24	0.10	12.40	0.14	2.96
17	6/9/2009	10:30	6/9/2009	18:15	7.75	95,197	1.457	20.39	3.38	6.03	0.91	0.62
18	6/11/2009	2:35	6/11/2009	17:15	14.67	87,774	1.343	10.86	1.65	6.58	3.12	5.83
19	6/15/2009	5:10	6/16/2009	18:35	37.42	160,447	2.456	17.89	1.14	15.69	0.97	1.31

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
20	6/23/2009	23:55	6/24/2009	6:45	6.83	1,261	0.019	1.37	0.05	27.40	0.06	3.73
21	7/3/2009	8:20	7/4/2009	8:15	23.92	30,474	0.466	5.91	0.35	16.89	0.29	1.09
22	7/10/2009	5:00	7/10/2009	8:00	3.00	1,115	0.017	1.29	0.10	12.90	0.11	2.69
23	7/12/2009	7:45	7/13/2009	6:45	23.00	14,639	0.224	9.90	0.18	55.00	0.28	2.12
24	7/20/2009	16:45	7/21/2009	3:15	10.50	4,353	0.067	1.11	0.11	10.09	0.11	0.97
25	7/27/2009	21:35	7/28/2009	17:40	20.08	12,699	0.194	6.52	0.17	38.35	0.11	1.05
26	8/1/2009	3:35	8/1/2009	6:30	2.92	3,150	0.048	0.83	0.29	2.86	0.15	1.05
27	8/4/2009	6:00	8/4/2009	20:45	14.75	7,089	0.108	3.71	0.13	28.54	0.20	5.40
28	8/10/2009	1:20	8/10/2009	15:55	14.58	5,976	0.091	1.74	0.11	15.82	0.46	5.61
29	8/15/2009	19:45	8/16/2009	10:50	15.08	24,261	0.371	4.73	0.44	10.75	0.16	1.00
30	8/17/2009	7:35	8/17/2009	23:55	16.33	27,760	0.425	9.70	0.47	20.64	0.39	3.08
31	8/19/2009	7:00	8/20/2009	13:05	30.08	17,584	0.269	3.59	0.16	22.44	0.30	1.66
32	8/27/2009	1:25	8/27/2009	12:50	11.42	2,244	0.034	0.16	0.05	3.20	0.29	2.15
33	9/4/2009	12:00	9/5/2009	18:15	30.25	3,816	0.058	0.80	0.03	23.82	0.15	1.68
34	9/8/2009	17:00	9/9/2009	17:45	24.75	4,452	0.068	0.96	0.05	19.20	0.22	1.00
35	9/21/2009	10:00	9/22/2009	11:15	25.25	13,576	0.208	1.91	0.15	12.73	0.33	2.00
36	9/26/2009	1:50	9/26/2009	23:00	21.17	6,049	0.093	1.43	0.08	17.88	0.26	2.24
37	10/1/2009	4:50	10/1/2009	19:50	15.00	1,636	0.025	0.38	0.03	12.67	0.21	4.46
38	10/6/2009	1:00	10/6/2009	4:20	3.33	826	0.013	0.36	0.07	5.14	0.11	2.04
39	10/8/2009	0:55	10/9/2009	4:15	27.33	12,524	0.192	3.41	0.13	26.23	0.13	1.32
40	10/13/2009	16:00	10/14/2009	2:10	10.17	2,917	0.045	1.01	0.09	11.22	0.22	1.59
41	10/20/2009	5:30	10/20/2009	18:40	13.17	5,349	0.082	2.83	0.11	25.73	0.34	10.68
42	10/21/2009	15:15	10/23/2009	2:05	34.83	18,988	0.291	1.17	0.15	7.80	0.37	1.55
43	10/25/2009	14:00	10/26/2009	12:45	22.75	20,720	0.317	1.53	0.25	6.12	0.54	2.15
44	10/29/2009	6:00	10/30/2009	6:30	24.50	18,121	0.277	2.65	0.20	13.25	0.44	1.96
45	11/15/2009	1:30	11/18/2009	3:50	74.33	24,369	0.373	0.85	0.09	9.44	0.19	1.15
46	12/22/2009	21:30	12/24/2009	23:45	50.25	15,127	0.232	1.41	0.08	17.63	0.13	1.27
47	12/28/2009	4:05	12/29/2009	1:55	21.83	5,211	0.080	0.18	0.07	2.57	0.66	2.24
48	12/30/2009	6:00	12/31/2009	7:00	25.00	4,448	0.068	0.13	0.05	2.60	0.16	1.84
49	2/5/2010	9:55	2/6/2010	7:40	21.75	4,292	0.066	0.20	0.05	4.00	0.23	1.20
50	2/7/2010	19:45	2/8/2010	23:00	27.25	6,355	0.097	0.15	0.06	2.50	0.81	1.52
51	2/19/2010	6:40	2/19/2010	20:40	14.00	11,432	0.175	0.93	0.22	4.23	0.41	1.34
52	2/21/2010	5:15	2/22/2010	23:50	42.58	25,973	0.398	1.04	0.17	6.12	0.72	1.32
53	3/8/2010	20:35	3/10/2010	2:55	30.33	8,276	0.127	0.85	0.08	10.63	0.64	1.67
54	3/10/2010	18:55	3/11/2010	15:15	20.33	15,274	0.234	2.51	0.20	12.55	0.25	2.41
55	3/21/2010	11:45	3/21/2010	23:50	12.08	1,865	0.029	0.24	0.05	4.80	0.14	3.76
56	3/24/2010	11:10	3/25/2010	8:55	21.75	7,802	0.119	0.39	0.10	3.90	0.60	2.61
57	3/27/2010	7:15	3/27/2010	15:05	7.83	2,518	0.039	0.27	0.04	6.75	0.32	2.40

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
58	4/2/2010	9:55	4/2/2010	23:55	14.00	13,507	0.207	6.34	0.27	23.48	0.53	3.56
59	4/5/2010	7:30	4/5/2010	20:45	13.25	16,089	0.246	11.23	0.42	26.74	0.35	6.85
60	4/6/2010	20:05	4/7/2010	12:00	15.92	16,506	0.253	3.04	0.25	12.16	0.46	3.35
61	4/22/2010	10:20	4/23/2010	20:30	34.17	61,201	0.937	3.46	0.50	6.92	0.37	1.54
62	4/24/2010	11:35	4/25/2010	23:35	36.00	42,831	0.656	0.91	0.33	2.76	0.87	1.50
63	4/30/2010	7:30	4/30/2010	20:15	12.75	8,719	0.133	3.52	0.15	23.47	0.24	1.77
64	5/10/2010	9:55	5/11/2010	12:00	28.33	26,199	0.401	8.71	0.33	26.39	0.33	1.54
65	5/12/2010	17:00	5/13/2010	21:20	31.50	79,652	1.219	12.40	0.78	15.90	0.79	1.63
66	5/15/2010	7:20	5/16/2010	23:00	39.67	14,422	0.221	0.61	0.09	6.78	0.37	1.43
67	5/19/2010	12:30	5/20/2010	8:00	19.50	54,087	0.828	4.15	0.34	12.21	0.68	0.62
68	6/8/2010	8:30	6/9/2010	20:40	36.17	27,560	0.422	7.97	0.26	30.65	0.20	1.29
69	6/12/2010	10:10	6/13/2010	1:40	15.50	75,083	1.149	11.93	1.34	8.90	0.54	4.33
70	6/13/2010	7:15	6/14/2010	23:55	40.67	274,075	4.195	47.29	1.87	25.29	1.20	1.38
71	6/16/2010	18:25	6/17/2010	7:30	13.08	36,391	0.557	7.49	0.76	9.86	0.79	12.46
72												
73	2/24/2011	9:00	2/25/2011	19:05	25.08	9,617	0.147	1.19	0.26	4.58	0.42	4.18
74	2/27/2011	8:35	2/28/2011	11:00	26.42	45,905	0.703	5.69	0.47	12.11	0.58	1.59
75	3/4/2011	11:10	3/4/2011	17:40	6.50	5,069	0.078	2.64	0.21	12.57	0.33	2.60
76	3/8/2011	8:10	3/9/2011	1:10	8.83	6,114	0.094	1.01	0.10	10.10	0.24	1.77
77	3/13/2011	22:30	3/14/2011	23:45	25.25	5,370	0.082	0.33	0.05	6.60	0.52	1.88
78	3/19/2011	13:30	3/20/2011	4:15	0.25	3,013	0.046	0.62	0.05	12.40	0.15	0.14
79	4/7/2013	19:45	4/8/2013	12:25	16.67	15,187	0.232	5.80	0.25	23.20	0.21	2.54
80	4/9/2013	21:55	4/10/2013	6:30	8.58	107,090	1.639	6.11	0.91	6.71	1.01	0.42
81	4/14/2013	19:00	4/15/2013	19:10	24.17	15,546	0.238	1.23	0.18	6.83	0.61	2.00
82	4/17/2013	11:00	4/19/2013	8:35	45.58	66,975	1.025	4.61	0.41	11.24	0.93	1.35
83	4/23/2013	1:30	4/23/2013	20:50	19.33	8,444	0.129	0.46	0.12	3.83	0.33	2.08
84	4/26/2013	4:25	4/27/2013	23:05	42.67	20,436	0.313	0.95	0.13	7.31	0.33	1.39
85	5/2/2013	3:00	5/4/2013	13:45	58.75	29,465	0.451	0.60	0.14	4.29	0.32	1.20
86	5/8/2013	23:25	5/9/2013	9:05	9.67	3,154	0.048	1.21	0.09	13.44	0.17	0.50
87	5/19/2013	2:20	5/20/2013	13:40	35.33	40,650	0.622	5.05	0.32	15.78	0.75	1.51
88	5/27/2013	8:20	5/27/2013	23:55	15.58	198,341	3.036	20.41	3.57	5.72	1.51	3.83
89	5/29/2013	22:45	5/31/2013	3:15	28.50	76,739	1.174	3.35	0.75	4.47	0.72	1.74
90	5/31/2013	5:15	5/31/2013	20:40	15.42	69,172	1.059	9.71	1.19	8.16	0.79	3.94
91	6/4/2013	10:40	6/4/2013	21:40	11.00	1,164	0.018	0.35	0.03	11.67	0.07	3.24
92	6/5/2013	9:50	6/5/2013	16:10	6.33	3,383	0.052	1.86	0.14	13.29	0.11	2.08
93	6/9/2013	0:55	6/9/2013	15:45	14.83	25,635	0.392	1.40	0.49	2.86	1.01	4.97
94	6/15/2013	15:45	6/16/2013	9:30	17.75	12,366	0.189	6.42	0.20	32.10	0.15	2.84
95	6/27/2013	11:35	6/28/2013	0:25	12.83	6,406	0.098	5.73	0.14	40.93	0.12	0.98

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
96	7/3/2013	17:35	7/4/2013	9:35	16.00	120,340	1.842	3.62	1.91	1.90	1.23	4.32
97	7/25/2013	17:00	7/26/2013	17:50	24.83	5,138	0.079	0.20	0.06	3.33	0.33	1.38
98	7/29/2013	6:30	7/30/2013	21:50	39.33	17,615	0.270	4.62	0.12	38.50	0.30	1.44
99	8/2/2013	3:45	8/2/2013	19:20	0.83	7,202	0.110	0.33	0.12	2.75	0.34	0.19
100	8/4/2013	11:40	8/4/2013	23:30	11.83	4,611	0.071	0.27	0.11	2.45	0.59	5.07
101	8/6/2013	3:25	8/6/2013	16:05	12.67	3,489	0.053	0.24	0.08	3.00	0.10	8.00
102	8/7/2013	4:20	8/7/2013	15:40	11.33	10,735	0.164	2.42	0.26	9.31	0.19	2.50
103	8/12/2013	5:00	8/12/2013	18:25	13.42	20,839	0.319	2.55	0.51	5.00	0.48	4.21
104	9/1/2013	5:45	9/1/2013	9:00	3.25	2,701	0.041	1.99	0.44	4.52	0.26	2.44
105	9/15/2013	20:00	9/16/2013	3:55	7.92	397	0.006	0.07	0.01	7.00	0.05	4.06
106	9/17/2013	6:40	9/17/2013	12:00	5.33	2,711	0.041	0.42	0.12	3.50	0.05	0.65
107	9/19/2013	17:20	9/20/2013	4:55	11.58	12,213	0.187	7.78	0.30	25.93	0.10	3.42
108	9/28/2013	6:45	9/28/2013	23:50	17.08	2,160	0.033	0.70	0.03	23.33	0.12	5.69
109	10/3/2013	6:00	10/3/2013	13:15	7.25	1,370	0.021	0.99	0.05	19.80	0.13	21.75
110	10/4/2013	21:10	10/5/2013	6:05	8.92	2,590	0.040	1.66	0.08	20.75	0.05	1.71
111	10/11/2013	17:00	10/12/2013	2:15	9.25	968	0.015	0.78	0.09	8.67	0.13	2.76
112	10/14/2013	14:00	10/15/2013	3:40	13.67	577	0.009	0.18	0.01	18.00	0.07	1.34
113	10/18/2013	10:30	10/18/2013	23:40	13.17	576	0.009	0.21	0.01	21.00	0.07	4.34
114	10/29/2013	1:40	10/29/2013	8:55	7.25	3,208	0.049	0.41	0.08	5.13	0.06	1.06
115	10/30/2013	10:50	10/31/2013	21:00	34.17	43,090	0.659	7.22	0.32	22.56	0.19	1.45
					114	114	114	114	114	114	114	114
					2,291	3,193,275	49					
					0.25	397	0.01	0.07	0.01	0.29	0.04	0.14
					74.33	292,467	4.48	47.29	3.57	55.00	3.12	21.75
					20.09	28,011	0.43	3.76	0.39	12.64	0.45	2.72
					15.96	12,289	0.19	1.48	0.15	10.37	0.33	1.86
					13.10	48,752	0.75	5.81	0.65	9.87	0.46	2.67
					0.65	1.74	1.74	1.55	1.69	0.78	1.03	0.98

APPENDIX J

LARGE-SCALE COMBINED AND SEPARATE SEWER MONITORING DATA AT CINCINNATI, OH

Rainfall characteristics for downstream flow monitoring location at Cincinnati State College combined sewer system (Manhole 29612032)

Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
1	8/5/2012	16:10	8/5/2012	16:15		0.08	0.04	0.48	0.48
2	8/10/2012	2:05	8/10/2012	4:30	4.41	2.42	0.32	0.96	0.13
3	8/17/2012	7:50	8/17/2012	7:55	7.14	0.08	0.04	0.48	0.48
4	8/27/2012	16:50	8/27/2012	17:10	10.37	0.33	0.08	0.48	0.24
5	10/1/2012	16:15	10/1/2012	21:05		4.83	0.74	1.43	0.15
6	10/5/2012	19:45	10/6/2012	0:30	3.94	4.75	0.44	0.66	0.09
7	10/14/2012	16:50	10/14/2012	19:20	8.68	2.50	0.19	0.52	0.08
8	10/19/2012	13:25	10/20/2012	0:20	4.75	10.92	0.25	0.23	0.02
9	10/20/2012	13:15	10/20/2012	13:30	0.54	0.25	0.01	0.06	0.04
10	10/26/2012	12:00	10/27/2012	0:55	5.94	12.92	0.78	0.32	0.06
11	10/30/2012	0:55	10/31/2012	17:50	3.00	40.92	0.48	0.11	0.01
12	11/3/2012	10:45	11/3/2012	16:10	2.70	5.42	0.12	0.13	0.02
13	11/12/2012	3:50	11/12/2012	13:45	8.49	9.92	0.77	0.32	0.08
14	11/26/2012	22:55	11/27/2012	2:15	14.38	3.33	0.10	0.05	0.03
15	12/2/2012	7:25	12/2/2012	11:30	5.22	4.08	0.52	0.77	0.13
16	12/4/2012	15:35	12/4/2012	19:25	2.17	3.83	0.25	0.70	0.07
17	12/7/2012	0:15	12/7/2012	18:20	2.20	18.08	0.99	0.39	0.05
18	12/9/2012	16:50	12/10/2012	0:25	1.94	7.58	1.38	2.64	0.18
19	12/15/2012	11:55	12/15/2012	15:00	5.48	3.08	0.09	0.17	0.03
20	12/17/2012	12:35	12/18/2012	4:40	1.90	16.08	0.57	1.90	0.04
21	12/20/2012	7:15	12/20/2012	19:55	2.11	12.67	0.86	0.47	0.07

Runoff characteristics for downstream flow monitoring location at Cincinnati State College combined sewer system (Manhole 29612032)

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avgpipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
1	8/5/2012	14:55	8/5/2012	16:20	1.42	5,580	0.004	3.51	1.09	3.22	0.11	17.00
2	8/10/2012	2:05	8/10/2012	9:20	7.25	37,919	0.029	4.4	1.45	3.03	0.09	3.00
3	8/17/2012	8:00	8/17/2012	10:50	2.83	12,666	0.010	2.96	1.21	2.45	0.24	34.00
4	8/27/2012	15:30	8/27/2012	18:50	3.33	13,314	0.010	2.64	1.11	2.38	0.13	10.00
5	10/1/2012	17:45	10/2/2012	20:35	26.83	114,691	0.088	6.33	1.19	5.32	0.12	5.55
6	10/5/2012	21:00	10/6/2012	12:30	15.50	82,501	0.063	6.31	1.48	4.26	0.14	3.26
7	10/14/2012	18:00	10/15/2012	0:40	6.67	21,651	0.017	4.29	0.9	4.77	0.09	2.67
8	10/19/2012	15:20	10/20/2012	7:15	15.92	64,368	0.049	3.79	1.12	3.38	0.20	1.46
9						0	0.000					
10	10/26/2012	12:25	10/28/2012	2:30	38.08	241,875	0.185	4.76	1.76	2.70	0.24	2.95
11	10/30/2012	4:30	10/31/2012	23:55	43.42	270,276	0.207	5.17	1.73	2.99	0.43	1.06
12	11/3/2012	15:20	11/3/2012	23:25	8.08	23,054	0.018	3.5	0.79	4.43	0.14	1.49
13	11/12/2012	4:15	11/12/2012	23:40	19.42	141,016	0.108	5.29	2.02	2.62	0.14	1.96
14	11/27/2012	0:50	11/27/2012	3:15	2.42	10,919	0.008	2.72	1.21	2.25	0.08	0.72
15	12/2/2012	8:10	12/2/2012	14:30	6.33	37,313	0.029	6.33	1.64	3.86	0.05	1.55
16	12/4/2012	16:20	12/5/2012	0:20	8.00	56,994	0.044	14.25	1.94	7.35	0.17	2.09
17	12/7/2012	0:30	12/9/2012	16:40	64.17	587,551	0.449	7.88	2.54	3.10	0.45	3.55
18	12/9/2012	16:45	12/12/2012	1:20	56.58	494,906	0.378	71.21	2.43	29.30	0.27	7.46
19	12/15/2012	12:25	12/15/2012	16:55	4.50	20,043	0.015	3.52	1.21	2.91	0.17	1.46
20	12/17/2012	13:35	12/18/2012	10:45	21.17	128,178	0.098	14.98	1.68	8.92	0.17	1.32
21	12/20/2012	7:40	12/22/2012	7:35	47.92	295,040	0.226	9.26	1.71	5.42	0.26	3.78

Rainfall characteristics for upstream flow monitoring location at Cincinnati State College combined sewer system (Manhole 29612050)

Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
1	8/5/2012	16:10	8/5/2012	16:15		0.08	0.04	0.48	0.48
2	8/10/2012	2:05	8/10/2012	4:30	4.41	2.42	0.32	0.96	0.13
3	8/17/2012	7:50	8/17/2012	7:55	7.14	0.08	0.04	0.48	0.48
4	8/27/2012	16:50	8/27/2012	17:10	10.37	0.33	0.08	0.48	0.24
5	10/1/2012	16:15	10/1/2012	21:05		4.83	0.74	1.43	0.15
6	10/5/2012	19:45	10/6/2012	0:30	3.94	4.75	0.44	0.66	0.09
7	10/14/2012	16:50	10/14/2012	19:20	8.68	2.50	0.19	0.52	0.08
8	10/19/2012	13:25	10/20/2012	0:20	4.75	10.92	0.25	0.23	0.02
9	10/20/2012	13:15	10/20/2012	13:30	0.54	0.25	0.01	0.06	0.04
10	10/26/2012	12:00	10/27/2012	0:55	5.94	12.92	0.78	0.32	0.06
11	10/30/2012	0:55	10/31/2012	17:50	3.00	40.92	0.48	0.11	0.01
12	11/3/2012	10:45	11/3/2012	16:10	2.70	5.42	0.12	0.13	0.02
13	11/12/2012	3:50	11/12/2012	13:45	8.49	9.92	0.77	0.32	0.08
14	11/26/2012	22:55	11/27/2012	2:15	14.38	3.33	0.10	0.05	0.03
15	12/2/2012	7:25	12/2/2012	11:30	5.22	4.08	0.52	0.77	0.13
16	12/4/2012	15:35	12/4/2012	19:25	2.17	3.83	0.25	0.70	0.07
17	12/7/2012	0:15	12/7/2012	18:20	2.20	18.08	0.99	0.39	0.05
18	12/9/2012	16:50	12/10/2012	0:25	1.94	7.58	1.38	2.64	0.18
19	12/15/2012	11:55	12/15/2012	15:00	5.48	3.08	0.09	0.17	0.03
20	12/17/2012	12:35	12/18/2012	4:40	1.90	16.08	0.57	1.90	0.04
21	12/20/2012	7:15	12/20/2012	19:55	2.11	12.67	0.86	0.47	0.07

Runoff characteristics for upstream flow monitoring location at Cincinnati State College combined sewer system (Manhole 29612050)

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avgpipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
1	8/5/2012	14:55	8/5/2012	16:25	1.50	2,658	0.002	2.12	0.49	4.33	0.05	18.00
2	8/10/2012	1:55	8/10/2012	9:30	7.58	19,238	0.016	2.58	0.7	3.69	0.05	3.14
3	8/17/2012	8:00	8/17/2012	10:50	2.83	3,196	0.003	1.14	0.3	3.80	0.07	34.00
4	8/27/2012	16:50	8/27/2012	18:50	2.00	3,715	0.003	1.33	0.50	2.66	0.04	6.00
5	10/1/2012	17:45	10/2/2012	18:45	25.00	55,455	0.046	5.67	0.61	9.30	0.06	5.17
6	10/5/2012	22:50	10/6/2012	7:55	9.08	27,531	0.023	4.21	0.84	5.01	0.05	1.91
7	10/14/2012	18:00	10/14/2012	19:00	1.00	5,352	0.004	3.16	1.49	2.12	0.02	0.40
8	10/19/2012	15:20	10/20/2012	7:10	15.83	17,044	0.014	1.12	0.3	3.73	0.06	1.45
9						0	0.000					
10	10/26/2012	12:45	10/27/2012	8:30	19.75	71,266	0.059	2.08	1	2.08	0.08	1.53
11	10/30/2012	4:30	10/31/2012	23:55	43.42	77,841	0.064	2.00	0.5	4.00	0.13	1.06
12	11/3/2012	15:40	11/3/2012	23:25	7.75	8,454	0.007	1.26	0.3	4.20	0.06	1.43
13	11/12/2012	4:15	11/12/2012	23:40	19.42	62,831	0.052	3.02	0.9	3.36	0.07	1.96
14	11/27/2012	1:10	11/27/2012	2:25	1.25	945	0.001	0.43	0.2	2.15	0.01	0.38
15	12/2/2012	8:15	12/2/2012	12:00	3.75	17,841	0.015	4.8	1.29	3.72	0.03	0.92
16	12/4/2012	16:20	12/4/2012	23:55	7.58	19,736	0.016	4.86	0.71	6.85	0.06	1.98
17	12/7/2012	0:35	12/8/2012	18:45	42.17	123,758	0.102	4.27	0.81	5.27	0.10	2.33
18	12/9/2012	17:40	12/10/2012	8:35	14.92	72,882	0.060	18.7	1.36	13.75	0.04	1.97
19	12/15/2012	12:35	12/15/2012	16:55	4.33	2,682	0.002	0.7	0.17	4.12	0.02	1.41
20	12/17/2012	13:55	12/18/2012	10:45	20.83	39,588	0.033	4.97	0.53	9.38	0.06	1.30
21	12/20/2012	7:45	12/22/2012	7:35	47.83	143,887	0.118	5.59	0.84	6.65	0.14	3.78

Rainfall characteristics during different flow monitoring periods for Cincinnati State College separate sewer system (manhole number 29606027)

Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain [a] (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
1	3/11/2010	9:00	3/11/2010	9:10		0.17	0.08	0.48	0.48
2	3/11/2010	16:00	3/11/2010	16:05	0.28	0.08	0.04	0.48	0.48
3	3/12/2010	17:40	3/12/2010	20:55	1.07	3.25	0.84	2.89	0.26
4	3/13/2010	9:15	3/13/2010	19:25	0.51	10.17	0.44	0.48	0.04
5	3/21/2010	23:25	3/22/2010	5:05	8.17	5.67	0.60	0.48	0.11
6	3/25/2010	15:10	3/26/2010	1:10	3.42	10.00	1.20	0.96	0.12
7	3/28/2010	14:15	3/28/2010	14:35	2.55	0.33	0.08	0.48	0.24
8	4/8/2010	0:55	4/8/2010	8:20	10.43	7.42	0.52	0.96	0.07
9	4/23/2010	10:50	4/23/2010	14:10	15.10	3.33	0.28	0.96	0.08
10	4/24/2010	17:00	4/24/2010	22:25	1.12	5.42	0.72	1.45	0.13
11	4/25/2010	15:00	4/25/2010	18:00	0.69	3.00	0.12	0.48	0.04
12	5/2/2010	3:20	5/2/2010	21:45	6.39	18.42	1.36	1.45	0.07
13	5/11/2010	4:40	5/11/2010	8:30	8.29	3.83	0.32	1.45	0.08
14	5/12/2010	7:40	5/12/2010	13:15	0.97	5.58	0.88	1.45	0.16
15	5/16/2010	20:40	5/16/2010	22:50	4.31	2.17	0.12	0.48	0.06
16	5/17/2010	5:25	5/17/2010	6:55	0.27	1.50	0.20	0.48	0.13
17	5/21/2010	2:00	5/21/2010	3:20	3.80	1.33	0.12	0.48	0.09
18	5/21/2010	16:20	5/21/2010	17:45	0.54	1.42	0.36	0.96	0.25
19	6/6/2010	8:25	6/6/2010	8:50	15.61	0.42	0.24	1.45	0.58
20	6/9/2010	5:50	6/9/2010	6:10	2.88	0.33	0.24	0.96	0.72
21	6/12/2010	7:40	6/12/2010	12:25	3.06	4.75	2.84	3.37	0.60
22	6/13/2010	3:20	6/13/2010	3:30	0.62	0.17	0.12	0.96	0.72
23	6/14/2010	22:30	6/14/2010	23:50	1.79	1.33	0.40	2.41	0.30
24	6/15/2010	20:40	6/15/2010	22:10	0.87	1.50	0.56	1.93	0.37
25	6/19/2010	7:15	6/19/2010	8:55	3.38	1.67	0.52	1.45	0.31
26	6/21/2010	12:30	6/21/2010	14:20	2.15	1.83	0.28	1.93	0.15
27	6/27/2010	23:30	6/28/2010	4:20	6.38	4.83	1.20	3.86	0.25
28	7/9/2010	11:05	7/9/2010	12:40	11.28	1.58	0.48	1.93	0.30
29	7/17/2010	17:20	7/17/2010	17:55	8.19	0.58	0.60	2.89	1.03
30	7/20/2010	20:00	7/20/2010	22:10	3.09	2.17	0.32	0.96	0.15
31	8/11/2010	15:05	8/11/2010	15:10	21.70	0.08	0.24	2.88	2.88
32	8/15/2010	16:55	8/15/2010	17:25	4.07	0.50	0.24	0.96	0.48
33	9/11/2010	10:25	9/11/2010	10:40	26.71	0.25	0.12	0.96	0.48
34	9/16/2010	3:00	9/16/2010	6:20	4.68	3.33	0.20	0.96	0.06
35	10/13/2010	18:55	10/13/2010	22:15	27.52	3.33	0.08	0.48	0.02
36	10/26/2010	12:30	10/26/2010	16:50	12.59	4.33	1.52	5.78	0.35
37	11/16/2010	11:10	11/16/2010	21:45	20.76	10.58	1.16	1.45	0.11
38	11/23/2010	1:35	11/23/2010	4:05	6.16	2.50	0.92	2.89	0.37
39	11/24/2010	13:20	11/24/2010	23:00	1.39	9.67	1.04	0.96	0.11
40	11/25/2010	6:10	11/25/2010	23:25	0.30	17.25	2.72	1.45	0.16
41	11/29/2010	22:00	11/30/2010	4:10	3.94	6.17	1.00	0.96	0.16
42	1/1/2011	1:25	1/1/2011	8:40	31.89	7.25	0.48	0.48	0.07

Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain [a] (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
43	1/18/2011	8:55	1/18/2011	15:55	17.01	7.00	0.32	0.48	0.05
44	1/24/2011	19:35	1/25/2011	9:40	6.15	14.08	0.28	0.48	0.02
45	2/1/2011	5:10	2/2/2011	0:10	6.81	19.00	1.24	0.96	0.07
46	2/5/2011	5:55	2/5/2011	11:50	3.24	5.92	0.24	0.48	0.04
47	2/21/2011	9:05	2/21/2011	18:50	15.89	9.75	2.08	0.96	0.21
48	2/24/2011	17:40	2/25/2011	4:25	2.95	10.75	1.96	1.45	0.18
49	2/27/2011	18:55	2/27/2011	20:45	2.60	1.83	0.36	1.45	0.20
50	2/28/2011	5:20	2/28/2011	8:40	0.36	3.33	0.40	1.45	0.12
51	3/4/2011	6:25	3/5/2011	9:55	3.91	27.50	1.64	0.96	0.06
52	3/5/2011	16:30	3/5/2011	20:30	0.27	4.00	0.24	0.48	0.06
53	3/8/2011	21:55	3/9/2011	19:55	3.06	22.00	1.64	1.45	0.07
54	3/18/2011	17:35	3/18/2011	18:50	8.90	1.25	0.32	0.96	0.26
55	4/1/2011	20:45	4/1/2011	21:15	14.08	0.50	0.20	0.96	0.40
56	4/4/2011	14:15	4/4/2011	17:50	2.71	3.58	1.08	1.45	0.30
57	4/9/2011	11:40	4/9/2011	15:00	4.74	3.33	0.76	1.45	0.23
58	4/11/2011	8:10	4/12/2011	6:30	1.72	22.33	2.28	0.96	0.10
59	4/15/2011	22:15	4/16/2011	3:55	3.66	5.67	1.84	1.93	0.32
60	4/19/2011	1:15	4/19/2011	11:40	2.89	10.42	2.72	3.37	0.26
61	4/20/2011	1:30	4/20/2011	8:05	0.58	6.58	1.08	1.45	0.16
62	4/22/2011	17:20	4/22/2011	19:40	2.39	2.33	0.60	2.89	0.26
63	4/23/2011	1:30	4/23/2011	6:50	0.24	5.33	0.68	0.96	0.13
64	4/23/2011	14:20	4/23/2011	19:00	0.31	4.67	1.48	2.89	0.32
65	4/24/2011	18:20	4/24/2011	22:10	0.97	3.83	0.24	0.48	0.06
66	4/25/2011	4:00	4/25/2011	8:55	0.24	4.92	0.56	1.45	0.11
67	4/27/2011	4:50	4/27/2011	10:45	1.83	5.92	0.92	2.41	0.16
68	4/28/2011	18:50	4/28/2011	19:50	1.34	1.00	0.20	0.96	0.20
69	5/2/2011	1:30	5/2/2011	8:50	3.24	7.33	0.88	0.96	0.12
70	5/2/2011	16:35	5/3/2011	10:10	0.32	17.58	1.76	0.96	0.10
71	5/7/2011	23:50	5/8/2011	0:25	4.57	0.58	0.32	0.96	0.55
72	5/13/2011	15:50	5/13/2011	16:35	5.64	0.75	1.00	4.34	1.33
73	5/15/2011	20:45	5/15/2011	22:25	2.17	1.67	0.20	0.96	0.12
74	5/17/2011	20:30	5/18/2011	4:45	1.92	8.25	0.20	0.96	0.02
75	5/23/2011	5:40	5/23/2011	7:25	5.04	1.75	0.48	0.96	0.27
76	5/23/2011	19:20	5/23/2011	23:40	0.50	4.33	0.68	2.41	0.16
77	5/26/2011	0:30	5/26/2011	3:25	2.03	2.92	0.60	1.45	0.21
78	5/26/2011	14:10	5/26/2011	14:45	0.45	0.58	0.40	1.93	0.69
79	6/10/2011	12:55	6/10/2011	20:15	14.92	7.33	5.16	19.76	0.70
80	6/11/2011	3:55	6/11/2011	7:25	0.32	3.50	1.08	3.37	0.31
81	6/15/2011	11:15	6/15/2011	16:05	4.16	4.83	0.64	0.96	0.13
82	6/19/2011	9:50	6/19/2011	15:55	3.74	6.08	0.24	0.48	0.04
83	6/20/2011	10:10	6/20/2011	12:35	0.76	2.42	2.04	4.34	0.84
84	6/21/2011	15:15	6/21/2011	17:10	1.11	1.92	0.80	1.93	0.42
85	6/22/2011	22:35	6/23/2011	4:20	1.23	5.75	0.76	2.89	0.13

Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain [a] (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
86	6/26/2011	5:10	6/26/2011	10:30	3.03	5.33	0.92	1.45	0.17
87	6/27/2011	10:05	6/27/2011	11:10	0.98	1.08	0.24	1.45	0.22
88	7/8/2011	2:40	7/8/2011	7:40	10.65	5.00	0.76	1.45	0.15
89	8/3/2011	5:10	8/3/2011	11:55	25.90	6.75	0.32	0.96	0.05
90	8/7/2011	5:40	8/7/2011	7:30	3.74	1.83	1.28	3.37	0.70
91	8/8/2011	19:25	8/8/2011	23:25	1.50	4.00	0.72	1.93	0.18
92	8/14/2011	2:25	8/14/2011	4:10	5.13	1.75	0.12	0.96	0.07
93	8/21/2011	15:20	8/21/2011	17:55	7.47	2.58	0.52	2.41	0.20
94	9/4/2011	1:05	9/4/2011	2:20	13.30	1.25	0.60	2.89	0.48
95	9/4/2011	20:20	9/4/2011	22:55	0.75	2.58	0.64	1.93	0.25
96	9/7/2011	7:40	9/7/2011	23:10	2.36	15.50	0.80	0.48	0.05
97	9/14/2011	22:25	9/15/2011	2:15	6.97	3.83	0.56	0.96	0.15
98	9/19/2011	9:05	9/19/2011	15:55	4.28	6.83	0.84	1.45	0.12
99	9/21/2011	9:50	9/21/2011	13:50	1.75	4.00	0.16	0.48	0.04
100	9/23/2011	2:25	9/23/2011	9:50	1.52	7.42	0.80	0.96	0.11
101	9/26/2011	0:00	9/26/2011	8:35	2.59	8.58	3.36	2.41	0.39
102	9/29/2011	19:30	9/29/2011	22:15	3.45	2.75	0.28	0.96	0.10
103	10/13/2011	9:40	10/13/2011	15:20	13.48	5.67	0.60	1.45	0.11
104	10/19/2011	0:00	10/19/2011	4:10	5.36	4.17	0.36	0.48	0.09
105	10/19/2011	11:00	10/20/2011	11:35	0.28	24.58	2.00	0.96	0.08
106	10/26/2011	20:35	10/27/2011	3:55	6.38	7.33	1.36	0.96	0.19
107	11/3/2011	12:45	11/4/2011	2:15	7.37	13.50	1.56	0.48	0.12
108	11/14/2011	20:25	11/15/2011	6:40	10.76	10.25	2.28	6.27	0.22
109	11/16/2011	6:00	11/16/2011	10:55	0.97	4.92	0.60	0.48	0.12
110	11/21/2011	6:40	11/21/2011	12:00	4.82	5.33	0.92	0.96	0.17
111	12/4/2011	14:50	12/6/2011	0:05	13.12	33.25	3.32	0.96	0.10
112	12/15/2011	3:05	12/15/2011	12:00	9.13	8.92	0.48	0.48	0.05
113	12/19/2011	19:05	12/20/2011	0:25	4.30	5.33	0.32	0.96	0.06
114	12/21/2011	3:25	12/21/2011	7:50	1.13	4.42	0.68	0.96	0.15
115	12/22/2011	12:10	12/22/2011	19:55	1.18	7.75	0.84	0.96	0.11
116	12/27/2011	2:25	12/27/2011	15:35	4.27	13.17	0.80	0.96	0.06
117	1/11/2012	7:30	1/11/2012	13:00	14.66	5.50	0.48	0.48	0.09
118	1/12/2012	13:40	1/12/2012	15:45	1.03	2.08	0.16	0.48	0.08
119	1/17/2012	3:15	1/17/2012	14:40	4.48	11.42	1.76	2.41	0.15
120	1/20/2012	23:20	1/21/2012	0:35	3.36	1.25	0.16	0.96	0.13
121	1/22/2012	12:05	1/22/2012	15:10	1.48	3.08	0.24	0.48	0.08
122	1/22/2012	23:50	1/23/2012	5:25	0.36	5.58	0.44	0.96	0.08
123	1/25/2012	17:55	1/25/2012	19:15	2.52	1.33	0.12	0.48	0.09
124	1/26/2012	4:00	1/26/2012	10:35	0.36	6.58	0.80	0.96	0.12
125	1/26/2012	17:25	1/27/2012	5:40	0.28	12.25	1.08	0.96	0.09
126	2/16/2012	3:35	2/16/2012	7:10	19.91	3.58	0.20	0.48	0.06
127	2/29/2012	3:15	2/29/2012	9:10	12.84	5.92	0.56	0.48	0.09
128	3/2/2012	9:35	3/2/2012	16:50	2.02	7.25	0.40	0.96	0.06

Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain [a] (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
129	3/8/2012	7:40	3/8/2012	17:25	5.62	9.75	1.08	0.96	0.11
130	3/15/2012	10:15	3/15/2012	12:05	6.70	1.83	1.00	4.50	0.55
131	3/23/2012	11:05	3/23/2012	17:50	7.96	6.75	0.44	0.48	0.07
132	3/24/2012	0:50	3/24/2012	1:50	0.29	1.00	0.40	1.45	0.40
133	4/1/2012	23:45	4/2/2012	0:50	8.91	1.08	0.24	0.96	0.22
134	4/14/2012	9:40	4/14/2012	17:40	12.37	8.00	1.08	0.96	0.14
135	4/25/2012	23:45	4/26/2012	0:00	11.25	0.25	0.32	2.89	1.28
136	4/28/2012	12:25	4/28/2012	13:15	2.52	0.83	0.68	1.93	0.82
137	4/28/2012	20:20	4/28/2012	22:20	0.30	2.00	0.16	0.48	0.08
138	4/30/2012	20:30	4/30/2012	23:15	1.92	2.75	0.72	1.93	0.26
139	5/1/2012	17:35	5/1/2012	22:45	0.76	5.17	0.80	2.41	0.15
140	5/5/2012	1:05	5/5/2012	3:30	3.10	2.42	0.20	0.96	0.08
141	5/8/2012	0:05	5/8/2012	8:35	2.86	8.50	0.48	0.48	0.06
142	5/13/2012	3:50	5/13/2012	16:00	4.80	12.17	1.36	0.48	0.11
143	5/29/2012	8:50	5/29/2012	10:50	15.70	2.00	0.20	0.48	0.10
144	6/1/2012	0:35	6/1/2012	7:55	2.57	7.33	1.00	1.45	0.14
145	6/11/2012	7:30	6/11/2012	10:15	9.98	2.75	0.20	0.48	0.07
146	6/18/2012	6:35	6/18/2012	6:50	6.85	0.25	0.32	2.41	1.28
147	6/29/2012	17:50	6/29/2012	18:05	11.46	0.25	0.24	1.45	0.96
148	7/1/2012	19:25	7/1/2012	19:40	2.06	0.25	0.20	0.96	0.80
149	7/15/2012	13:20	7/15/2012	13:55	13.74	0.58	0.32	0.96	0.55
150	7/18/2012	16:45	7/18/2012	17:00	3.12	0.25	0.52	3.37	2.08
151	7/26/2012	15:25	7/26/2012	18:55	7.93	3.50	0.28	1.93	0.08
152	7/27/2012	17:15	7/27/2012	18:45	0.93	1.50	0.56	2.41	0.37
154	10/5/2012	19:45	10/6/2012	0:30	3.94	4.75	0.45	0.66	0.09
155	10/14/2012	16:50	10/14/2012	19:20	8.68	2.50	0.19	0.52	0.08
156	10/19/2012	13:25	10/20/2012	0:20	4.75	10.92	0.25	0.23	0.02
157	10/26/2012	12:00	10/27/2012	0:55	6.49	12.92	0.78	0.32	0.06
158	10/30/2012	0:55	10/31/2012	17:50	3.00	40.92	0.48	0.11	0.01
159	11/3/2012	10:45	11/3/2012	16:10	2.70	5.42	0.12	0.13	0.02
160	11/12/2012	3:50	11/12/2012	13:45	8.49	9.92	0.77	0.32	0.08
161	11/26/2012	22:55	11/27/2012	2:15	14.38	3.33	0.10	0.05	0.03
162	12/2/2012	7:25	12/2/2012	11:30	5.22	4.08	0.52	0.77	0.13
163	12/4/2012	15:35	12/4/2012	19:25	2.17	3.83	0.25	0.70	0.07
164	12/7/2012	0:15	12/7/2012	18:20	2.20	18.08	0.99	0.39	0.05
165	12/9/2012	16:50	12/10/2012	0:25	1.94	7.58	1.38	2.64	0.18
166	12/15/2012	11:55	12/15/2012	15:00	5.48	3.08	0.09	0.17	0.03
167	12/17/2012	12:35	12/18/2012	4:40	1.90	16.08	0.57	1.90	0.04
168	12/20/2012	7:15	12/20/2012	19:55	2.11	12.67	0.86	0.47	0.07
169	12/26/2012	3:15	12/26/2012	18:45	5.31	15.50	1.27	0.47	0.08

Runoff characteristics during different flow monitoring periods for Cincinnati State College separate sewer system (manhole number 29606027)

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
1	3/11/2010	9:10	3/11/2010	14:05	4.92	1,143	0.022	1.32	0.06	22.00	0.28	29.50
2	3/11/2010	14:30	3/11/2010	17:25	2.92	918	0.018	1.66	0.09	18.44	0.45	35.00
3	3/12/2010	17:35	3/13/2010	1:40	8.08	15,336	0.298	2.39	0.52	4.60	0.35	2.49
4	3/13/2010	9:15	3/14/2010	3:10	17.92	10,672	0.207	0.84	0.16	5.25	0.47	1.76
5	3/21/2010	21:00	3/22/2010	9:05	12.08	11,191	0.217	2.12	0.26	8.15	0.36	2.13
6	3/25/2010	14:00	3/26/2010	14:45	24.75	26,828	0.520	2.06	0.31	6.65	0.43	2.48
7	3/28/2010	14:25	3/28/2010	20:55	6.50	824	0.016	0.65	0.03	21.67	0.20	19.50
8	4/8/2010	0:55	4/8/2010	11:30	10.58	7,489	0.145	1.25	0.20	6.41	0.28	1.43
9	4/23/2010	9:40	4/23/2010	15:35	5.92	4,900	0.095	1.07	0.23	4.72	0.34	1.77
10	4/24/2010	17:00	4/25/2010	2:50	9.83	11,038	0.214	1.90	0.31	6.15	0.30	1.82
11	4/25/2010	14:45	4/25/2010	19:00	4.25	1,565	0.030	0.74	0.10	7.36	0.25	1.42
12	5/2/2010	3:05	5/2/2010	5:50	2.75	13,699	0.266	1.15	0.15	7.64	0.20	0.15
13	5/11/2010	4:35	5/11/2010	18:35	14.00	2,459	0.048	1.16	0.05	23.18	0.15	3.65
14	5/12/2010	7:40	5/12/2010	18:40	11.00	4,986	0.097	1.53	0.13	12.24	0.11	1.97
15	5/16/2010	21:05	5/17/2010	3:20	6.25	1,192	0.023	0.59	0.05	11.28	0.19	2.88
16	5/17/2010	4:50	5/17/2010	14:50	10.00	1,596	0.031	0.75	0.04	16.95	0.15	6.67
17	5/21/2010	2:10	5/21/2010	6:35	4.42	1,231	0.024	0.54	0.08	7.14	0.20	3.31
18	5/21/2010	16:20	5/22/2010	0:35	8.25	4,251	0.082	2.35	0.14	16.56	0.23	5.82
19	6/6/2010	8:15	6/6/2010	10:50	2.58	3,973	0.077	4.20	0.41	10.24	0.32	6.20
20	6/9/2010	5:20	6/9/2010	9:05	3.75	2,946	0.057	2.07	0.21	9.73	0.24	11.25
21	6/12/2010	7:35	6/12/2010	15:55	8.33	35,166	0.682	4.74	1.16	4.09	0.24	1.75
22	6/13/2010	3:25	6/13/2010	8:30	5.08	1,359	0.026	1.84	0.07	26.33	0.22	30.50
23	6/14/2010	22:35	6/15/2010	5:10	6.58	4,061	0.079	4.18	0.17	24.74	0.20	4.94
24	6/15/2010	20:30	6/15/2010	23:50	3.33	1,025	0.020	1.44	0.08	18.05	0.04	2.22
25	6/19/2010	7:20	6/19/2010	11:00	3.67	6,900	0.134	3.38	0.51	6.61	0.26	2.20
26	6/21/2010	11:30	6/21/2010	15:30	4.00	3,919	0.076	2.06	1.20	1.72	0.27	2.18
27	6/27/2010	23:15	6/28/2010	11:15	12.00	20,649	0.401	6.12	0.47	12.91	0.33	2.48
28	7/9/2010	11:00	7/9/2010	18:25	7.42	4,077	0.079	1.89	0.15	12.60	0.16	4.68
29	7/17/2010	17:25	7/17/2010	18:55	1.50	2,089	0.041	2.17	0.37	5.87	0.07	2.57
30	7/20/2010	21:35	7/20/2010	23:00	1.42	3,797	0.074	1.91	0.70	2.72	0.23	0.65
31	8/11/2010	14:50	8/11/2010	18:15	3.42	1,385	0.027	2.03	0.11	18.45	0.11	41.00
32	8/15/2010	16:45	8/15/2010	19:10	2.42	2,464	0.048	1.09	0.27	4.04	0.20	4.83
33	9/11/2010	10:15	9/11/2010	11:00	0.75	904	0.018	0.80	0.30	2.67	0.15	3.00
34	9/16/2010	2:55	9/16/2010	5:05	2.17	1,283	0.025	1.20	0.16	7.50	0.12	0.65
35	10/13/2010	18:05	10/13/2010	21:40	3.58	1,092	0.021	0.54	0.08	6.75	0.26	1.08
36	10/26/2010	12:20	10/26/2010	17:55	5.58	3,485	0.068	1.29	0.17	7.59	0.04	1.29
37	11/16/2010	11:25	11/16/2010	23:45	12.33	10,358	0.201	1.66	0.24	6.92	0.17	1.17
38	11/23/2010	1:25	11/23/2010	6:10	4.75	7,603	0.148	2.29	0.44	5.20	0.16	1.90
39	11/24/2010	13:40	11/25/2010	1:40	12.00	10,681	0.207	1.70	0.25	6.80	0.20	1.24
40	11/25/2010	6:15	11/26/2010	5:15	23.00	42,160	0.818	2.65	0.51	5.20	0.30	1.33
41	11/29/2010	22:00	11/30/2010	8:00	10.00	14,689	0.285	1.80	0.40	4.50	0.28	1.62

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
42	1/1/2011	1:25	1/1/2011	10:55	9.50	5,213	0.101	0.93	0.15	6.20	0.21	1.31
43	1/18/2011	9:30	1/18/2011	16:30	7.00	2,115	0.041	0.71	0.08	8.88	0.13	1.00
44	1/24/2011	14:15	1/25/2011	18:05	27.83	2,859	0.055	1.18	0.03	39.33	0.20	1.98
45	2/1/2011	5:05	2/2/2011	15:00	33.92	19,968	0.387	1.45	0.16	9.06	0.31	1.79
46	2/5/2011	4:00	2/5/2011	17:35	13.58	2,037	0.040	0.63	0.04	15.75	0.16	2.30
47	2/21/2011	8:15	2/22/2011	11:30	27.25	39,235	0.761	2.39	0.40	5.98	0.37	2.79
48	2/24/2011	17:55	2/25/2011	23:05	29.17	47,914	0.930	2.68	0.46	5.83	0.47	2.71
49	2/27/2011	19:10	2/27/2011	21:35	2.42	3,087	0.060	1.68	0.34	4.94	0.17	1.32
50	2/28/2011	5:20	2/28/2011	12:45	7.42	8,045	0.156	4.40	0.30	14.67	0.39	2.22
51	3/4/2011	8:55	3/5/2011	11:05	26.17	29,592	0.574	1.49	0.31	4.81	0.35	0.95
52	3/5/2011	16:25	3/6/2011	5:45	13.33	9,062	0.176	1.12	0.49	2.29	0.73	3.33
53	3/8/2011	22:05	3/10/2011	1:25	27.33	37,339	0.724	1.28	0.38	3.37	0.44	1.24
54	3/18/2011	16:25	3/19/2011	0:05	7.67	4,446	0.086	1.85	0.16	11.56	0.27	6.13
55	4/1/2011	20:45	4/2/2011	1:55	5.17	1,595	0.031	1.26	0.08	15.75	0.15	10.33
56	4/4/2011	12:00	4/5/2011	9:30	21.50	11,123	0.216	1.38	0.14	9.86	0.20	6.00
57	4/9/2011	11:50	4/10/2011	0:20	12.50	7,948	0.154	2.16	0.18	12.00	0.20	3.75
58	4/11/2011	7:00	4/12/2011	17:05	34.08	37,686	0.731	1.03	0.31	3.32	0.32	1.53
59	4/15/2011	22:20	4/16/2011	9:30	11.17	17,364	0.337	1.60	0.43	3.72	0.18	1.97
60	4/19/2011	1:35	4/19/2011	23:55	22.33	22,398	0.435	4.93	0.28	17.61	0.16	2.14
61	4/20/2011	1:30	4/21/2011	9:50	32.33	19,611	0.380	1.88	0.17	11.06	0.35	4.91
62	4/22/2011	17:10	4/23/2011	0:05	6.92	7,107	0.138	2.29	0.28	8.18	0.23	2.96
63	4/23/2011	1:35	4/23/2011	14:00	12.42	12,478	0.242	2.21	0.28	7.89	0.36	2.33
64	4/23/2011	14:20	4/24/2011	0:40	10.33	13,068	0.254	2.58	0.35	7.37	0.17	2.21
65	4/24/2011	18:20	4/25/2011	3:00	8.67	4,015	0.078	0.84	0.13	6.46	0.32	2.26
66	4/25/2011	4:00	4/25/2011	21:20	17.33	3,421	0.066	0.78	0.05	15.60	0.12	3.53
67	4/27/2011	3:30	4/27/2011	17:00	13.50	10,343	0.201	1.85	0.21	8.81	0.22	2.28
68	4/28/2011	17:30	4/29/2011	4:30	11.00	2,930	0.057	0.99	0.07	14.14	0.28	11.00
69	5/2/2011	1:25	5/2/2011	12:50	11.42	9,778	0.190	1.10	0.24	4.58	0.22	1.56
70	5/2/2011	15:40	5/3/2011	19:55	28.25	25,776	0.500	1.41	0.25	5.64	0.28	1.61
71	5/7/2011	23:20	5/8/2011	1:55	2.58	2,871	0.056	1.09	0.30	3.63	0.17	4.43
72	5/13/2011	15:55	5/14/2011	1:55	10.00	8,402	0.163	4.77	0.23	20.74	0.16	13.33
73	5/15/2011	19:25	5/16/2011	2:20	6.92	2,989	0.058	1.73	0.12	14.42	0.29	4.15
74	5/17/2011	20:25	5/18/2011	12:20	15.92	4,702	0.091	0.78	0.08	9.75	0.46	1.93
75	5/23/2011	5:50	5/23/2011	12:45	6.92	5,949	0.115	1.45	0.24	6.04	0.24	3.95
76	5/23/2011	19:20	5/24/2011	0:45	5.42	6,720	0.130	2.18	0.34	6.41	0.19	1.25
77	5/26/2011	0:30	5/26/2011	10:00	9.50	8,056	0.156	1.07	0.23	4.65	0.26	3.26
78	5/26/2011	14:15	5/26/2011	21:05	6.83	4,160	0.081	1.31	0.17	7.71	0.20	11.71
79	6/10/2011	13:20	6/11/2011	1:35	12.25	11,864	0.230	2.47	0.27	9.15	0.04	1.67
80	6/11/2011	4:05	6/11/2011	17:45	13.67	14,709	0.285	4.29	0.30	14.30	0.26	3.90
81	6/15/2011	11:10	6/15/2011	18:00	6.83	7,177	0.139	1.23	0.29	4.24	0.22	1.41
82	6/19/2011	10:40	6/19/2011	18:00	7.33	3,084	0.060	1.02	0.12	8.50	0.25	1.21
83	6/20/2011	10:05	6/20/2011	15:30	5.42	7,667	0.149	2.33	0.39	5.97	0.07	2.24

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
84	6/21/2011	14:40	6/21/2011	20:40	6.00	4,226	0.082	1.62	0.15	10.80	0.10	3.13
85	6/22/2011	21:50	6/23/2011	5:40	7.83	3,073	0.060	2.17	0.18	12.06	0.08	1.36
86	6/26/2011	5:05	6/26/2011	11:10	6.08	2,801	0.054	0.66	0.13	5.08	0.06	1.14
87	6/27/2011	9:40	6/27/2011	13:55	4.25	1,500	0.029	1.20	0.10	12.00	0.12	3.92
88	7/8/2011	5:50	7/8/2011	17:00	11.17	2,262	0.044	1.20	0.06	20.00	0.06	2.23
89	8/3/2011	8:05	8/3/2011	15:40	7.58	1,060	0.021	1.58	0.04	39.50	0.06	1.12
90	8/7/2011	5:45	8/7/2011	9:00	3.25	1,548	0.030	1.08	0.13	8.31	0.02	1.77
91	8/8/2011	20:00	8/9/2011	14:00	18.00	11,198	0.217	1.90	0.17	11.18	0.30	4.50
92	8/14/2011	2:25	8/14/2011	5:40	3.25	211	0.004	0.13	0.02	6.50	0.03	1.86
93	8/21/2011	17:45	8/21/2011	19:15	1.50	282	0.005	0.26	0.05	5.20	0.01	0.58
94	9/4/2011	1:15	9/4/2011	5:40	4.42	1,137	0.022	0.82	0.07	11.71	0.04	3.53
95	9/4/2011	20:15	9/4/2011	22:45	2.50	234	0.005	0.20	0.03	6.67	0.01	0.97
96	9/7/2011	1:50	9/8/2011	5:30	27.67	1,211	0.023	0.26	0.01	26.00	0.03	1.78
97	9/14/2011	23:50	9/15/2011	7:10	7.33	1,013	0.020	0.43	0.04	10.75	0.04	1.91
98	9/19/2011	8:40	9/19/2011	21:35	12.92	696	0.013	0.43	0.01	43.00	0.02	1.89
99						0	0.000	0.00	0.00	0.00	0.00	0.00
100	9/23/2011	2:30	9/23/2011	20:45	18.25	1,192	0.023	0.31	0.02	15.50	0.03	2.46
101	9/26/2011	1:05	9/26/2011	21:25	20.33	14,794	0.287	2.39	0.20	11.95	0.09	2.37
102	9/29/2011	19:25	9/30/2011	1:45	6.33	718	0.014	0.43	0.03	14.33	0.05	2.30
103	10/13/2011	9:50	10/13/2011	14:35	4.75	351	0.007	0.19	0.02	9.50	0.01	0.84
104	10/19/2011	5:25	10/19/2011	5:55	0.50	11	0.000	0.01	0.01	1.00	0.00	0.12
105	10/19/2011	11:40	10/20/2011	15:30	27.83	3,077	0.060	0.48	0.03	16.00	0.03	1.13
106	10/26/2011	20:45	10/27/2011	18:30	21.75	3,009	0.058	0.54	0.04	13.50	0.04	2.97
107	11/3/2011	12:30	11/4/2011	22:20	33.83	4,461	0.087	0.51	0.04	12.75	0.06	2.51
108	11/14/2011	21:25	11/15/2011	10:50	13.42	9,723	0.189	2.74	0.20	13.70	0.08	1.31
109	11/16/2011	6:00	11/17/2011	11:40	29.67	7,309	0.142	2.80	0.07	40.00	0.24	6.03
110	11/21/2011	7:10	11/21/2011	22:35	15.42	3,001	0.058	2.74	0.20	13.70	0.06	2.89
111	12/4/2011	20:05	12/6/2011	0:20	28.25	13,948	0.271	0.69	0.14	4.93	0.08	0.85
112	12/15/2011	4:55	12/15/2011	16:50	11.92	167	0.003	0.05	0.01	5.00	0.01	1.34
113	12/19/2011	23:25	12/19/2011	23:30	0.08	14	0.000	0.02	0.02	1.00	0.00	0.02
114	12/21/2011	6:15	12/21/2011	17:15	11.00	2,539	0.049	0.52	0.06	8.67	0.07	2.49
115	12/22/2011	13:45	12/23/2011	3:35	13.83	2,145	0.042	0.24	0.04	6.00	0.05	1.78
116	12/27/2011	4:45	12/27/2011	21:30	16.75	2,143	0.042	0.59	0.04	14.75	0.05	1.27
117	1/11/2012	8:35	1/11/2012	14:55	6.33	528	0.010	0.25	0.02	12.50	0.02	1.15
118	1/12/2012	14:05	1/12/2012	16:40	2.58	124	0.002	0.02	0.01	2.00	0.02	1.24
119	1/17/2012	3:55	1/18/2012	15:50	35.92	7,792	0.151	1.47	0.06	24.50	0.09	3.15
120	1/20/2012	23:20	1/21/2012	4:45	5.42	286	0.006	0.05	0.01	5.00	0.03	4.33
121						0	0.000	0.00	0.00	0.00	0.00	0.00
122	1/22/2012	0:30	1/23/2012	20:45	44.25	2,083	0.040	0.67	0.03	22.33	0.09	7.93
123						0	0.000	0.00	0.00	0.00	0.00	
124	1/26/2012	5:00	1/26/2012	17:20	12.33	2,897	0.056	0.99	0.06	16.50	0.07	1.87
125	1/26/2012	17:25	1/27/2012	11:25	18.00	4,179	0.081	0.26	0.03	8.67	0.08	1.47

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
126	2/16/2012	3:55	2/16/2012	8:55	5.00	110	0.002	0.03	0.01	3.00	0.01	1.40
127	2/29/2012	3:15	2/29/2012	12:30	9.25	369	0.007	0.13	0.01	13.00	0.01	1.56
128	3/2/2012	12:10	3/2/2012	20:45	8.58	1,096	0.021	0.75	0.04	18.75	0.05	1.18
129	3/8/2012	8:30	3/8/2012	18:30	10.00	640	0.012	0.19	0.02	9.50	0.01	1.03
130	3/15/2012	9:20	3/15/2012	18:00	8.67	5,891	0.114	1.16	0.19	6.11	0.11	4.73
131	3/23/2012	12:00	3/23/2012	18:25	6.42	670	0.013	1.02	0.03	34.00	0.03	0.95
132	3/24/2012	1:00	3/24/2012	5:35	4.58	879	0.017	0.44	0.05	8.80	0.04	4.58
133	4/1/2012	23:55	4/2/2012	1:40	1.75	583	0.011	0.68	0.09	7.56	0.05	1.62
134	4/14/2012	9:55	4/15/2012	7:25	21.50	1,783	0.035	0.66	0.02	33.00	0.03	2.69
135	4/25/2012	23:45	4/26/2012	5:50	6.08	1,907	0.037	1.94	0.09	21.56	0.12	24.33
136	4/28/2012	12:20	4/28/2012	14:30	2.17	1,991	0.039	0.87	0.25	3.48	0.06	2.60
137	4/29/2012	21:10	4/29/2012	22:05	0.92	32	0.001	0.01	0.01	1.00	0.00	0.46
138	4/30/2012	20:40	4/30/2012	23:55	3.25	2,291	0.044	0.81	0.19	4.26	0.06	1.18
139	5/1/2012	17:40	5/2/2012	17:50	24.17	6,011	0.117	1.95	0.07	27.86	0.15	4.68
140	5/5/2012	1:40	5/5/2012	2:20	0.67	35	0.001	0.02	0.01	2.00	0.00	0.28
141						0	0.000	0.00	0.00	0.00	0.00	0.00
142						0	0.000	0.00	0.00	0.00	0.00	0.00
143	5/29/2012	8:55	5/29/2012	10:20	1.42	97	0.002	0.04	0.02	2.00	0.01	0.71
144	6/1/2012	0:40	6/1/2012	12:55	12.25	4,904	0.095	1.49	0.11	13.55	0.10	1.67
145	6/11/2012	12:45	6/11/2012	12:55	0.17	156	0.003	0.52	0.52	1.00	0.02	0.06
146	6/18/2012	6:15	6/18/2012	8:40	2.42	496	0.010	0.71	0.06	11.83	0.03	9.67
147	6/29/2012	17:50	6/29/2012	18:25	0.58	474	0.009	0.68	0.20	3.40	0.04	2.33
148						0	0.000	0.00	0.00	0.00	0.00	0.00
149						0	0.000	0.00	0.00	0.00	0.00	0.00
150	7/18/2012	16:40	7/19/2012	3:50	11.17	1,477	0.029	0.84	0.04	21.00	0.06	44.67
151	7/26/2012	15:30	7/26/2012	19:10	3.67	179	0.003	0.28	0.01	28.00	0.01	1.05
152	7/27/2012	17:20	7/27/2012	18:45	1.42	585	0.011	0.69	0.11	6.27	0.02	0.94
153	10/1/2012	18:25	10/1/2012	23:00	4.58	1,102	0.021	0.64	0.07	9.14	0.03	0.95
154	10/5/2012	23:45	10/6/2012	2:20	2.58	906	0.018	0.45	0.09	5.00	0.04	0.54
155	10/14/2012	18:00	10/14/2012	18:40	0.67	142	0.003	0.14	0.05	2.80	0.01	0.27
156	10/19/2012	21:50	10/19/2012	22:10	0.33	8	0.000	0.02	0.01	2.00	0.00	0.03
157	10/26/2012	14:30	10/27/2012	4:40	14.17	645	0.013	0.05	0.01	5.00	0.02	1.10
158	10/30/2012	6:05	10/30/2012	18:35	12.50	641	0.012	0.06	0.01	6.00	0.03	0.31
159						0	0.000	0	0	0.00	0.00	0.00
160	11/12/2012	7:35	11/12/2012	14:55	7.33	899	0.017	0.8	0.03	26.67	0.02	0.74
161	11/27/2012	6:20	11/27/2012	9:30	3.17	371	0.007	0.65	0.03	21.67	0.07	0.95
162	12/2/2012	8:10	12/2/2012	10:55	2.75	852	0.017	0.85	0.08	10.63	0.03	0.67
163	12/4/2012	16:25	12/4/2012	18:20	1.92	575	0.011	0.69	0.08	8.63	0.04	0.50
164	12/7/2012	0:50	12/9/2012	20:20	67.50	1,817	0.035	0.95	0.03	31.67	0.04	3.73
165	12/9/2012	20:25	12/10/2012	16:05	19.67	6,020	0.117	2.76	0.08	34.50	0.08	2.59
166						0	0.000	0	0	0.00	0.00	0.00
167	12/17/2012	14:00	12/17/2012	18:25	4.42	1,198	0.023	0.9	0.07	12.86	0.04	0.27

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
168	12/20/2012	7:55	12/20/2012	17:45	9.83	2,357	0.046	0.36	0.07	5.14	0.05	0.78
169	12/26/2012	5:30	12/28/2012	11:05	53.58	4,515	0.088	1.17	0.04	29.25	0.07	3.46

Rainfall characteristics for main entrance of the Cincinnati zoo separate sewer line (manhole number 338162022)

Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain [a] (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
1	2/5/2010	9:50	2/6/2010	4:35		18.75	0.93	0.60	0.05
2	2/12/2010	10:10	2/12/2010	16:55	6.23	6.75	0.27	0.24	0.04
3	2/18/2010	14:55	2/18/2010	18:30	5.92	3.58	0.13	0.36	0.04
4	2/22/2010	3:05	2/22/2010	9:55	3.36	6.83	0.07	0.24	0.01
5	3/12/2010	17:45	3/12/2010	22:10	18.33	4.42	0.81	1.08	0.18
6	3/13/2010	7:05	3/13/2010	20:40	0.37	13.58	0.45	0.12	0.03
7	3/21/2010	22:05	3/22/2010	5:10	8.06	7.08	0.61	0.48	0.09
8	3/25/2010	11:35	3/26/2010	1:15	3.27	13.67	1.28	0.48	0.09
9	4/8/2010	0:55	4/8/2010	8:10	12.99	7.25	0.54	0.96	0.07
10	4/24/2010	16:55	4/25/2010	3:25	16.36	10.50	0.91	0.60	0.09
11	5/2/2010	3:00	5/2/2010	20:15	6.98	17.25	1.36	0.72	0.08
12	5/11/2010	4:35	5/11/2010	10:15	8.35	5.67	0.40	0.96	0.07
13	5/16/2010	21:20	5/16/2010	23:55	5.46	2.58	0.13	0.12	0.05
14	5/17/2010	5:00	5/17/2010	8:05	0.21	3.08	0.16	0.12	0.05
15	5/21/2010	2:10	5/21/2010	3:50	3.75	1.67	0.16	0.24	0.10
16	5/21/2010	16:20	5/21/2010	18:35	0.52	2.25	0.86	2.29	0.38
17	6/5/2010	14:45	6/5/2010	15:05	14.84	0.33	0.22	1.33	0.66
18	6/6/2010	8:15	6/6/2010	8:50	0.72	0.58	0.30	1.33	0.51
19	6/12/2010	3:10	6/12/2010	11:25	5.76	8.25	2.64	2.05	0.32
20	6/14/2010	22:35	6/14/2010	23:20	2.47	0.75	0.50	2.65	0.67
21	6/19/2010	7:15	6/19/2010	9:20	4.33	2.08	0.70	1.81	0.34
22	6/21/2010	11:55	6/21/2010	14:45	2.11	2.83	0.59	2.17	0.21
23	6/27/2010	23:10	6/28/2010	5:50	6.35	6.67	1.70	3.37	0.26
24	7/9/2010	11:00	7/9/2010	12:50	11.22	1.83	0.22	0.48	0.12
25	7/13/2010	9:00	7/13/2010	16:25	3.84	7.42	0.25	0.72	0.03
26	7/17/2010	17:35	7/17/2010	18:05	4.05	0.50	0.29	1.20	0.58
27	7/20/2010	20:05	7/20/2010	22:45	3.08	2.67	0.48	1.33	0.18
28	8/11/2010	14:55	8/11/2010	15:10	21.67	0.25	0.11	0.96	0.44
29	8/14/2010	17:25	8/14/2010	18:55	3.09	1.50	0.50	1.20	0.33
30	8/15/2010	16:50	8/15/2010	17:25	0.91	0.58	0.18	0.60	0.31

Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain [a] (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
31	9/16/2010	4:10	9/16/2010	6:40	31.45	2.50	0.15	0.72	0.06
32	9/27/2010	12:45	9/27/2010	16:50	11.25	4.08	0.09	0.12	0.02
33	10/13/2010	18:10	10/13/2010	19:40	16.06	1.50	0.14	0.36	0.09
34	10/26/2010	12:30	10/26/2010	17:25	12.70	4.92	0.72	2.05	0.15
35	11/16/2010	11:10	11/16/2010	22:05	20.74	10.92	0.99	0.84	0.09
36	11/23/2010	1:30	11/23/2010	5:00	6.14	3.50	0.64	0.96	0.18
37	11/25/2010	6:05	11/26/2010	1:05	2.05	19.00	2.61	1.08	0.14
38	11/30/2010	9:20	11/30/2010	20:40	4.34	11.33	0.83	0.60	0.07
39	12/11/2010	16:55	12/12/2010	4:55	10.84	12.00	0.52	0.24	0.04
40	12/18/2010	13:25	12/18/2010	15:30	6.35	2.08	0.09	0.12	0.04
41	12/20/2010	12:30	12/20/2010	14:25	1.88	1.92	0.08	0.24	0.04
42	12/30/2010	0:55	12/30/2010	12:35	9.44	11.67	0.30	0.24	0.03
43	1/1/2011	1:20	1/1/2011	9:50	1.53	8.50	0.50	0.36	0.06
44	1/18/2011	3:25	1/18/2011	11:50	16.73	8.42	0.29	0.24	0.03
45	1/24/2011	22:25	1/25/2011	10:10	6.44	11.75	0.20	0.24	0.02
46	2/1/2011	1:45	2/2/2011	0:40	6.65	22.92	1.10	0.36	0.05
47	2/5/2011	5:20	2/5/2011	12:05	3.19	6.75	0.23	0.24	0.03
48	2/21/2011	8:10	2/21/2011	19:15	15.84	11.08	2.13	1.20	0.19
49	2/24/2011	17:45	2/25/2011	5:05	2.94	11.33	1.80	0.60	0.16
50	2/27/2011	19:05	2/27/2011	20:50	2.58	1.75	0.19	0.48	0.11
51	2/28/2011	5:15	2/28/2011	11:45	0.35	6.50	0.43	1.33	0.07
52	3/4/2011	6:35	3/5/2011	21:55	3.78	39.33	1.77	0.48	0.04
53	3/8/2011	21:55	3/9/2011	19:55	3.00	22.00	1.62	0.48	0.07
54	3/15/2011	10:40	3/15/2011	18:20	5.61	7.67	0.11	0.36	0.01
55	3/18/2011	16:00	3/18/2011	18:55	2.90	2.92	0.60	1.33	0.21
56	4/1/2011	20:40	4/2/2011	4:00	14.07	7.33	0.14	0.48	0.02
57	4/4/2011	13:30	4/4/2011	18:00	2.40	4.50	1.15	2.65	0.26
58	4/9/2011	11:45	4/9/2011	15:25	4.74	3.67	0.57	1.45	0.16
59	4/11/2011	8:00	4/12/2011	7:00	1.69	23.00	2.42	1.45	0.11
60	4/15/2011	22:15	4/16/2011	10:25	3.64	12.17	1.58	0.96	0.13
61	4/19/2011	1:35	4/19/2011	12:00	2.63	10.42	2.59	2.53	0.25
62	4/20/2011	1:35	4/20/2011	8:10	0.57	6.58	0.81	1.08	0.12
63	4/22/2011	16:45	4/22/2011	19:55	2.36	3.17	0.83	2.53	0.26
64	4/24/2011	19:30	4/25/2011	9:35	1.98	14.08	0.37	0.24	0.03
65	4/27/2011	4:00	4/27/2011	11:45	1.77	7.75	0.79	2.17	0.10
66	4/27/2011	17:00	4/28/2011	2:50	0.22	9.83	0.24	0.24	0.02
67	4/28/2011	17:45	4/28/2011	19:55	0.62	2.17	0.26	0.72	0.12
68	5/1/2011	20:30	5/3/2011	11:35	3.02	39.08	2.47	0.60	0.06
69	5/7/2011	23:25	5/8/2011	2:05	4.49	2.67	0.31	0.48	0.12

Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain [a] (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
70	5/13/2011	15:55	5/13/2011	16:55	5.58	1.00	1.01	3.73	1.01
71	5/15/2011	12:00	5/15/2011	14:10	1.80	2.17	0.10	0.12	0.05
72	5/15/2011	19:50	5/16/2011	2:05	0.24	6.25	0.18	0.60	0.03
73	5/17/2011	13:30	5/18/2011	7:00	1.48	17.50	0.33	0.24	0.02
74	5/22/2011	17:45	5/22/2011	17:55	4.45	0.17	0.10	0.84	0.60
75	5/23/2011	5:45	5/23/2011	7:50	0.49	2.08	0.32	0.48	0.15
76	5/23/2011	19:20	5/24/2011	0:25	0.48	5.08	0.53	1.08	0.10
77	5/26/2011	0:30	5/26/2011	18:20	2.00	17.83	0.79	1.45	0.04
78	6/4/2011	22:25	6/4/2011	22:35	9.17	0.17	0.09	0.72	0.54
79	6/10/2011	17:15	6/10/2011	21:15	5.78	4.00	1.05	1.08	0.26
80	6/11/2011	4:05	6/11/2011	8:45	0.28	4.67	0.74	1.57	0.16
81	6/15/2011	11:10	6/15/2011	15:35	4.10	4.42	0.54	0.48	0.12
82	6/18/2011	8:15	6/18/2011	13:05	2.69	4.83	0.10	0.12	0.02
83	6/19/2011	10:35	6/19/2011	11:35	0.90	1.00	0.13	0.24	0.13
84	6/20/2011	9:10	6/20/2011	12:35	0.90	3.42	0.73	1.45	0.21
85	6/21/2011	14:35	6/21/2011	17:00	1.08	2.42	0.62	1.57	0.26
86	6/22/2011	22:30	6/23/2011	4:25	1.23	5.92	0.36	1.08	0.06
87	6/26/2011	4:25	6/26/2011	10:40	3.00	6.25	0.81	0.36	0.13
88	6/27/2011	10:10	6/27/2011	11:15	0.98	1.08	0.17	1.08	0.16
89	7/4/2011	8:50	7/4/2011	9:10	6.90	0.33	0.18	0.36	0.54
90	7/8/2011	2:35	7/8/2011	8:05	3.73	5.50	0.64	1.81	0.12
91	7/13/2011	14:00	7/13/2011	14:10	5.25	0.17	0.11	0.84	0.66
92	7/23/2011	13:05	7/23/2011	13:30	9.95	0.42	0.97	5.90	2.33
93	8/3/2011	8:05	8/3/2011	8:35	10.77	0.50	0.43	2.53	0.86
94	8/7/2011	5:40	8/7/2011	7:30	3.88	1.83	0.74	2.29	0.40
95	8/8/2011	20:00	8/8/2011	21:40	1.52	1.67	1.15	2.17	0.69
96	8/14/2011	2:20	8/14/2011	4:15	5.19	1.92	0.12	0.36	0.06
97	8/21/2011	17:40	8/21/2011	17:55	7.56	0.25	0.20	1.69	0.80
98	9/4/2011	1:10	9/4/2011	3:30	13.30	2.33	0.54	2.05	0.23
99	9/4/2011	20:10	9/4/2011	21:55	0.69	1.75	0.28	0.84	0.16
100	9/7/2011	10:40	9/8/2011	3:05	2.53	16.42	0.49	0.36	0.03
101	9/14/2011	22:30	9/15/2011	2:10	6.81	3.67	0.43	0.36	0.12
102	9/19/2011	9:25	9/19/2011	16:30	4.30	7.08	0.48	0.36	0.07
103	9/23/2011	5:10	9/23/2011	10:00	3.53	4.83	0.58	0.36	0.12
104	9/25/2011	23:25	9/26/2011	9:00	2.56	9.58	3.38	1.69	0.35
105	9/29/2011	19:20	9/29/2011	21:30	3.43	2.17	0.37	1.45	0.17
106	10/18/2011	2:10	10/20/2011	15:25	18.19	61.25	2.27	0.96	0.04
107	10/26/2011	20:35	10/27/2011	4:10	6.22	7.58	0.92	0.60	0.12
108	11/3/2011	12:55	11/4/2011	2:50	7.36	13.92	1.37	0.48	0.10

Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain [a] (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
109	11/14/2011	20:20	11/15/2011	7:10	10.73	10.83	1.59	1.69	0.15
110	11/16/2011	5:45	11/16/2011	11:05	0.94	5.33	0.32	0.24	0.06
111	11/21/2011	6:30	11/21/2011	9:25	4.81	2.92	0.36	2.05	0.12
112	11/21/2011	15:10	11/21/2011	23:30	0.24	8.33	0.16	0.24	0.02
113	11/22/2011	6:50	11/22/2011	15:30	0.31	8.67	0.83	0.60	0.10
114	11/27/2011	2:05	11/29/2011	5:00	4.44	50.92	2.33	0.36	0.05
115	11/29/2011	17:35	11/29/2011	21:55	0.52	4.33	0.13	0.12	0.03
116	12/4/2011	14:20	12/6/2011	2:15	4.68	35.92	3.17	0.60	0.09
117	12/15/2011	3:10	12/15/2011	12:15	9.04	9.08	0.32	0.36	0.04
118	12/19/2011	19:20	12/20/2011	1:35	4.30	6.25	0.24	0.24	0.04
119	12/20/2011	18:25	12/21/2011	7:55	0.70	13.50	0.74	0.84	0.05
120	12/22/2011	12:00	12/22/2011	20:10	1.17	8.17	0.66	0.24	0.08
121	12/27/2011	2:20	12/27/2011	17:25	4.26	15.08	0.66	0.36	0.04
122	12/28/2011	3:20	12/28/2011	18:25	0.41	15.08	1.66	0.36	0.11
123	1/11/2012	7:45	1/11/2012	12:55	13.56	5.17	0.36	0.48	0.07
124	1/17/2012	3:00	1/17/2012	14:20	5.59	11.33	1.76	2.41	0.16
125	1/20/2012	23:40	1/21/2012	0:35	3.39	0.92	0.12	0.48	0.13
126	1/23/2012	0:35	1/23/2012	5:55	2.00	5.33	0.44	0.96	0.08
127	1/26/2012	4:50	1/26/2012	9:50	2.95	5.00	0.72	0.96	0.14
128	1/26/2012	17:25	1/27/2012	5:40	0.32	12.25	0.96	0.96	0.08
129	2/16/2012	0:20	2/16/2012	7:10	19.78	6.83	0.28	0.48	0.04
130	2/29/2012	3:20	2/29/2012	5:40	12.84	2.33	0.24	0.48	0.10
131	2/29/2012	8:30	2/29/2012	9:15	0.12	0.75	0.12	0.48	0.16
132	3/2/2012	11:15	3/2/2012	17:05	2.08	5.83	0.52	1.45	0.09
133	3/8/2012	8:25	3/8/2012	17:00	5.64	8.58	0.64	0.48	0.07
134	3/12/2012	7:20	3/12/2012	11:55	3.60	4.58	0.12	0.48	0.03
135	3/15/2012	10:25	3/15/2012	12:10	2.94	1.75	0.80	1.93	0.46
136	3/23/2012	12:00	3/23/2012	18:30	7.99	6.50	0.44	0.96	0.07
137	3/24/2012	1:00	3/24/2012	2:00	0.27	1.00	0.36	1.93	0.36
138	3/30/2012	20:20	3/30/2012	22:20	6.76	2.00	0.32	1.45	0.16
139	4/1/2012	23:40	4/2/2012	0:35	2.06	0.92	0.40	0.96	0.44
140	4/14/2012	9:50	4/14/2012	17:35	12.39	7.75	1.32	1.45	0.17
141	4/20/2012	20:35	4/21/2012	3:20	6.13	6.75	0.16	0.48	0.02
142	4/25/2012	22:55	4/25/2012	23:55	4.82	1.00	0.72	3.37	0.72
143	4/28/2012	11:55	4/28/2012	14:20	2.50	2.42	0.80	1.93	0.33
144	5/1/2012	17:35	5/1/2012	20:00	3.14	2.42	1.52	5.30	0.63
145	5/4/2012	16:35	5/4/2012	16:40	2.86	0.08	0.16	1.93	1.92
146	5/5/2012	1:10	5/5/2012	3:05	0.35	1.92	0.20	0.48	0.10
147	5/7/2012	20:25	5/8/2012	8:30	2.72	12.08	0.80	2.89	0.07

Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain [a] (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
148	5/13/2012	5:15	5/13/2012	21:30	4.86	16.25	1.40	0.96	0.09
149	5/29/2012	8:55	5/29/2012	10:00	15.48	1.08	0.28	0.96	0.26
150	6/1/2012	0:40	6/1/2012	8:10	2.61	7.50	1.12	1.93	0.15
151	6/11/2012	7:40	6/11/2012	10:30	9.98	2.83	0.16	0.48	0.06
152	6/17/2012	13:40	6/17/2012	14:05	6.13	0.42	0.12	0.96	0.29
153	6/29/2012	17:45	6/29/2012	18:05	12.15	0.33	0.40	1.45	1.20
154	7/14/2012	9:00	7/14/2012	10:30	14.62	1.50	0.36	1.45	0.24
155	7/18/2012	16:40	7/18/2012	17:55	4.26	1.25	0.92	1.93	0.74
156	7/19/2012	11:50	7/19/2012	12:35	0.75	0.75	0.32	1.93	0.43
157	7/23/2012	15:30	7/23/2012	21:45	4.12	6.25	0.36	1.93	0.06
158	7/27/2012	14:00	7/27/2012	18:50	3.68	4.83	0.36	1.45	0.07
159	10/1/2012	18:50	10/1/2012	23:25		4.58	0.76	1.23	0.17
160	10/5/2012	18:25	10/6/2012	0:40	3.79	6.25	0.40	0.58	0.06
161	10/14/2012	13:15	10/14/2012	22:45	8.52	9.50	0.36	1.02	0.04
162	10/19/2012	13:25	10/20/2012	0:30	4.61	11.08	0.28	0.17	0.03
163	10/26/2012	9:50	10/27/2012	3:30	6.39	17.67	0.82	0.36	0.05
164	10/30/2012	2:10	10/30/2012	10:30	2.94	8.33	0.45	0.11	0.05
165	11/3/2012	10:50	11/3/2012	16:10	4.01	5.33	0.11	0.12	0.02
166	11/12/2012	3:50	11/12/2012	13:55	8.49	10.08	0.77	0.35	0.08
167	11/26/2012	22:55	11/27/2012	2:20	14.38	3.42	0.10	0.05	0.03
168	12/2/2012	7:35	12/2/2012	11:30	5.22	3.92	0.48	0.59	0.12
169	12/4/2012	15:35	12/4/2012	19:30	2.17	3.92	0.22	0.27	0.06
170	12/7/2012	7:55	12/7/2012	18:20	2.52	10.42	0.83	0.28	0.08
171	12/9/2012	20:05	12/10/2012	0:25	2.07	4.33	0.98	1.59	0.23
172	12/15/2012	11:55	12/15/2012	15:00	5.48	3.08	0.09	0.14	0.03
173	12/17/2012	12:30	12/17/2012	16:20	1.90	3.83	0.51	1.54	0.13
174	12/20/2012	7:20	12/20/2012	16:20	2.63	9.00	0.86	0.51	0.10
175	12/26/2012	3:10	12/26/2012	15:15	5.45	12.08	1.18	0.37	0.10
176	12/28/2012	21:00	12/29/2012	6:10	2.24	9.17	0.12	0.08	0.01

Runoff characteristics for main entrance of the Cincinnati Zoo separate sewer line (manhole number 338162022)

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
1						0	0.000	0.00	0.00		0.00	0.00
2						0	0.000	0.00	0.00		0.00	0.00
3						0	0.000	0.00	0.00		0.00	0.00
4	2/22/2010	14:45	2/22/2010	23:35	8.83	140	0.016	0.02	0.00	5.00	0.22	1.29
5	3/12/2010	19:00	3/12/2010	20:15	1.25	132	0.015	0.11	0.03	3.67	0.02	0.28
6	3/13/2010	14:00	3/14/2010	0:35	10.58	261	0.029	0.04	0.01	5.71	0.06	0.78
7	3/22/2010	2:10	3/22/2010	2:35	24.42	37	0.004	0.08	0.02	3.33	0.01	3.45
8	3/25/2010	17:55	3/26/2010	8:50	14.92	1,107	0.124	0.11	0.02	5.24	0.10	1.09
9					0.00	0	0.000	0.00	0.00		0.00	0.00
10	4/24/2010	20:05	4/24/2010	21:30	1.42	327	0.037	0.19	0.07	2.79	0.04	0.13
11	5/2/2010	4:55	5/3/2010	1:15	20.33	586	0.066	0.09	0.01	9.00	0.05	1.18
12						0	0.000	0.00	0.00		0.00	0.00
13						0	0.000	0.00	0.00		0.00	0.00
14						0	0.000	0.00	0.00		0.00	0.00
15						0	0.000	0.00	0.00		0.00	0.00
16	5/21/2010	15:50	5/21/2010	16:40	0.83	203	0.023	0.20	0.06	3.23	0.03	0.37
17	6/5/2010	13:55	6/5/2010	14:40	0.75	189	0.021	0.19	0.07	2.71	0.10	2.25
18	6/6/2010	7:20	6/6/2010	8:40	1.33	5,144	0.576	4.34	1.072	1.25	1.92	2.29
19	6/12/2010	7:00	6/12/2010	19:15	12.25	6,295	0.705	0.74	0.143	5.17	0.27	1.48
20	6/14/2010	21:45	6/14/2010	23:00	1.25	449	0.050	0.63	0.1	6.30	0.10	1.67
21						0	0.000	0.00	0.00		0.00	0.00
22						0	0.000	0.00	0.00		0.00	0.00
23						0	0.000	0.00	0.00		0.00	0.00
24						0	0.000	0.00	0.00		0.00	0.00
25						0	0.000	0.00	0.00		0.00	0.00
26						0	0.000	0.00	0.00		0.00	0.00
27	7/20/2010	20:45	7/20/2010	21:05	0.33	130	0.015	0.43	0.108	3.98	0.03	0.12
28						0	0.000	0.00	0.00		0.00	0.00
29	8/14/2010	17:55	8/14/2010	18:05	0.17	9	0.001	0.02	0.015	1.33	0.00	0.11
30						0	0.000	0	0		0.00	0.00
31						0	0.000	0	0		0.00	0.00
32						0	0.000	0	0		0.00	0.00
33						0	0.000	0	0		0.00	0.00
34	10/26/2010	11:35	10/26/2010	15:30	3.92	668	0.075	0.4	0.047	8.51	0.10	0.80
35						0	0.000	0.00	0.00		0.00	0.00
36						0	0.000	0.00	0.00		0.00	0.00
37	11/25/2010	12:15	11/26/2010	3:10	14.92	43,925		9.88	0.818	12.08	0.00	0.79

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
38	11/30/2010	16:15	11/30/2010	20:55	4.67	110	0.012	0.19	0.01	19.00	0.01	0.41
39						0	0.000	0	0		0.00	0.00
40						0	0.000	0	0		0.00	0.00
41						0	0.000	0	0		0.00	0.00
42						0	0.000	0	0		0.00	0.00
43						0	0.000	0	0		0.00	0.00
44						0	0.000	0	0		0.00	0.00
45						0	0.000	0	0		0.00	0.00
46	2/1/2011	17:55	2/2/2011	9:45	15.83	1,150	0.129	0.23	0.02	11.50	0.12	0.69
47	2/5/2011	12:00	2/6/2011	2:35	14.58	32	0.004	0.01	0.001	10.00	0.02	2.16
48	2/21/2011	11:20	2/22/2011	10:30	23.17	2,282	0.255	0.25	0.027	9.26	0.12	2.09
49	2/24/2011	21:00	2/26/2011	6:40	33.67	3,091	0.346	0.24	0.025	9.60	0.19	2.97
50	2/27/2011	20:15	2/27/2011	21:25	1.17	143	0.016	0.17	0.034	5.00	0.08	0.67
51	2/28/2011	5:20	2/28/2011	17:55	12.58	577	0.065	0.37	0.013	28.46	0.15	1.94
52	3/4/2011	11:10	3/6/2011	12:10	49.00	2,817	0.315	0.16	0.016	10.00	0.18	1.25
53	3/8/2011	23:05	3/10/2011	2:20	27.25	2,251	0.252	0.2	0.023	8.70	0.16	1.24
54	3/15/2011	11:35	3/15/2011	19:10	7.58	31	0.003	0.02	0.002	10.00	0.03	0.99
55	3/18/2011	17:35	3/18/2011	21:45	4.17	316	0.035	0.25	0.021	11.90	0.06	1.43
56						0	0.000	0	0		0.00	0.00
57	4/4/2011	14:35	4/4/2011	22:35	8.00	526	0.059	0.41	0.018	22.78	0.05	1.78
58	4/9/2011	12:40	4/9/2011	20:10	7.50	458	0.051	0.18	0.017	10.59	0.09	2.05
59	4/11/2011	8:40	4/13/2011	5:00	44.33	2,337	0.262	0.06	0.015	4.00	0.11	1.93
60	4/15/2011	23:05	4/17/2011	4:30	29.42	822	0.092	0.05	0.008	6.25	0.06	2.42
61	4/19/2011	1:55	4/19/2011	16:50	14.92	968	0.108	0.06	0.018	3.33	0.04	1.43
62	4/20/2011	2:00	4/21/2011	12:00	34.00	694	0.078	0.05	0.006	8.33	0.10	5.16
63	4/22/2011	16:55	4/23/2011	1:50	8.92	275	0.031	0.04	0.009	4.44	0.04	2.82
64	4/24/2011	19:45	4/25/2011	9:40	13.92	657	0.074	0.04	0.013	3.08	0.20	0.99
65	4/27/2011	4:00	4/27/2011	15:30	11.50	237	0.026	0.04	0.006	6.67	0.03	1.48
66	4/27/2011	18:20	4/28/2011	4:55	10.58	127	0.014	0.04	0.003	13.33	0.06	1.08
67						0	0.000	0	0		0.00	0.00
68	5/2/2011	18:25	5/4/2011	9:00	38.58	1,846	0.207	0.12	0.013	9.23	0.08	0.99
69	5/8/2011	0:15	5/8/2011	2:05	1.83	66	0.007	0.03	0.01	3.00	0.02	0.69
70	5/13/2011	16:50	5/14/2011	0:55	8.08	143	0.016	0.03	0.005	6.00	0.02	8.08
71	5/15/2011	11:45	5/15/2011	16:55	5.17	118	0.013	0.03	0.006	5.00	0.13	2.38
72	5/15/2011	19:35	5/16/2011	4:55	9.33	106	0.012	0.03	0.003	10.00	0.07	1.49
73	5/17/2011	13:50	5/18/2011	12:05	22.25	182	0.020	0.02	0.002	10.00	0.06	1.27
74	5/22/2011	17:55	5/22/2011	20:15	2.33	30	0.003	0.02	0.004	5.00	0.03	14.00
75	5/23/2011	7:05	5/23/2011	9:20	2.25	70	0.008	0.04	0.009	4.44	0.02	1.08

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
76	5/23/2011	20:55	5/24/2011	9:35	12.67	247	0.028	0.03	0.005	6.00	0.05	2.49
77	5/26/2011	0:50	5/27/2011	0:40	23.83	353	0.039	0.04	0.004	10.00	0.05	1.34
78	6/4/2011	22:50	6/4/2011	23:45	0.92	65	0.007	0.14	0.018	7.78	0.08	5.50
79	6/10/2011	18:25	6/10/2011	23:30	5.08	155	0.017	0.04	0.008	5.00	0.02	1.27
80	6/11/2011	4:15	6/11/2011	13:15	9.00	166	0.019	0.13	0.005	26.00	0.03	1.93
81						0	0.000	0	0		0.00	0.00
82						0	0.000	0	0		0.00	0.00
83						0	0.000	0	0		0.00	0.00
84	6/20/2011	10:35	6/20/2011	18:15	7.67	234	0.026	0.04	0.008	5.00	0.04	2.24
85	6/21/2011	15:45	6/21/2011	21:20	5.58	185	0.021	0.05	0.009	5.56	0.03	2.31
86	6/22/2011	23:05	6/23/2011	8:15	9.17	148	0.017	0.05	0.004	12.50	0.05	1.55
87	6/26/2011	6:05	6/26/2011	14:30	8.42	380	0.043	0.05	0.013	3.85	0.05	1.35
88	6/27/2011	10:30	6/27/2011	16:20	5.83	105	0.012	0.04	0.005	8.00	0.07	5.38
89						0	0.000	0	0		0.00	0.00
90	7/8/2011	6:00	7/8/2011	8:30	2.50	176	0.020	0.05	0.02	2.50	0.03	0.45
91						0	0.000	0	0		0.00	0.00
92						0	0.000	0	0		0.00	0.00
93	8/3/2011	8:30	8/3/2011	8:50	0.33	25	0.003	0.03	0.021	1.43	0.01	0.67
94	8/7/2011	5:55	8/7/2011	7:55	2.00	298	0.033	0.25	0.041	6.10	0.05	1.09
95	8/8/2011	20:10	8/9/2011	0:05	3.92	539	0.060	0.32	0.038	8.42	0.05	2.35
96						0	0.000	0	0		0.00	0.00
97	8/21/2011	18:00	8/21/2011	18:35	0.58	17	0.002	0.03	0.008	3.75	0.01	2.33
98	9/4/2011	2:25	9/4/2011	3:20	0.92	38	0.004	0.05	0.012	4.17	0.01	0.39
99	9/4/2011	20:25	9/4/2011	21:55	1.50	156	0.017	0.11	0.029	3.79	0.06	0.86
100	9/7/2011	12:55	9/8/2011	23:25	34.50	396	0.044	0.04	0.01	4.00	0.09	2.10
101	9/15/2011	0:00	9/15/2011	2:30	2.50	185	0.021	0.04	0.021	1.90	0.05	0.68
102	9/19/2011	14:55	9/19/2011	16:20	1.42	215	0.024	0.07	0.009	7.78	0.05	0.20
103	9/23/2011	5:55	9/23/2011	10:10	4.25	301	0.034	0.09	0.02	4.50	0.06	0.88
104	9/26/2011	1:20	9/26/2011	7:15	5.92	3,279	0.367	0.45	0.031	14.52	0.11	0.62
105	9/29/2011	19:35	9/29/2011	22:20	2.75	141	0.016	0.08	0.014	5.71	0.04	1.27
106	10/19/2011	5:30	10/20/2011	9:30	28.00	1,067	0.119	0.06	0.011	5.45	0.05	0.46
107	10/26/2011	21:20	10/27/2011	5:25	8.08	689	0.077	0.09	0.024	3.75	0.08	1.07
108	11/3/2011	16:45	11/4/2011	3:40	10.92	908	0.102	0.06	0.023	2.61	0.07	0.78
109	11/14/2011	20:30	11/15/2011	15:20	18.83	1,621	0.181	0.2	0.024	8.33	0.11	1.74
110	11/16/2011	6:05	11/16/2011	15:55	9.83	331	0.037	0.06	0.009	6.67	0.12	1.84
111	11/21/2011	6:40	11/21/2011	10:20	3.67	113	0.013	0.07	0.009	7.78	0.04	1.26
112	11/21/2011	14:30	11/22/2011	0:50	10.33	223	0.025	0.04	0.006	6.67	0.16	1.24
113	11/22/2011	6:45	11/22/2011	22:15	15.50	962	0.108	0.14	0.017	8.24	0.13	1.79

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
114	11/27/2011	5:20	11/29/2011	14:05	56.75	3,136	0.351	0.05	0.015	3.33	0.15	1.11
115	11/29/2011	17:35	11/30/2011	2:35	9.00	202	0.023	0.04	0.006	6.67	0.17	2.08
116	12/4/2011	16:20	12/7/2011	0:45	56.42	3,372	0.377	0.14	0.017	8.24	0.12	1.57
117	12/15/2011	5:45	12/15/2011	12:55	7.17	114	0.013	0.03	0.004	7.50	0.04	0.79
118	12/19/2011	23:45	12/20/2011	1:20	1.58	9	0.001	0.003	0.001	3.00	0.00	0.25
119	12/21/2011	4:00	12/21/2011	12:25	8.42	451	0.050	0.082	0.015	5.47	0.07	0.62
120	12/22/2011	13:00	12/23/2011	2:00	13.00	634	0.071	0.045	0.014	3.21	0.11	1.59
121	12/27/2011	4:45	12/27/2011	17:25	12.67	499	0.056	0.043	0.011	3.91	0.08	0.84
122	12/28/2011	5:45	12/28/2011	18:25	12.67	500	0.056	0.043	0.011	3.91	0.03	0.84
123	1/11/2012	11:15	1/11/2012	14:10	2.92	47	0.005	0.028	0.004	7.00	0.01	0.56
124	1/17/2012	7:55	1/17/2012	21:25	13.50	1,491	0.167	0.285	0.025	11.40	0.09	1.19
125	1/20/2012	23:45	1/21/2012	2:55	3.17	143	0.016	0.032	0.012	2.67	0.13	3.45
126	1/23/2012	0:45	1/23/2012	10:25	9.67	363	0.041	0.155	0.01	15.50	0.09	1.81
127	1/26/2012	4:55	1/26/2012	15:30	10.58	791	0.089	0.152	0.021	7.24	0.12	2.12
128	1/26/2012	17:25	1/27/2012	21:30	28.08	1,474	0.165	0.204	0.015	13.60	0.17	2.29
129	2/16/2012	7:05	2/16/2012	7:40	0.58	38	0.004	0.043	0.018	2.39	0.02	0.09
130	2/29/2012	6:00	2/29/2012	6:15	0.25	17	0.002	0.032	0.019	1.68	0.01	0.11
131	2/29/2012	8:50	2/29/2012	10:25	1.58	130	0.015	0.105	0.023	4.57	0.12	2.11
132	3/2/2012	12:20	3/2/2012	19:35	7.25	554	0.062	0.223	0.021	10.62	0.12	1.24
133	3/8/2012	8:55	3/8/2012	18:55	10.00	659	0.074	0.085	0.018	4.72	0.12	1.17
134	3/12/2012	9:30	3/12/2012	10:35	1.08	12	0.001	0.008	0.003	2.67	0.01	0.24
135	3/15/2012	9:35	3/15/2012	15:05	5.50	600	0.067	0.19	0.03	6.33	0.08	3.14
136	3/23/2012	12:05	3/23/2012	19:10	7.08	593	0.066	0.118	0.023	5.13	0.15	1.09
137	3/24/2012	1:00	3/24/2012	5:15	4.25	434	0.049	0.303	0.028	10.82	0.14	4.25
138	3/30/2012	20:40	3/30/2012	23:50	3.17	199	0.022	0.067	0.017	3.94	0.07	1.58
139	4/2/2012	0:00	4/2/2012	2:00	2.00	729	0.082	1.343	0.097	13.85	0.20	2.18
140	4/14/2012	10:20	4/14/2012	22:45	12.42	1,393	0.156	0.215	0.031	6.94	0.12	1.60
141	4/20/2012	22:45	4/21/2012	12:20	13.58	267	0.030	0.036	0.005	7.20	0.19	2.01
142	4/25/2012	23:45	4/26/2012	6:45	7.00	787	0.088	1.536	0.031	49.55	0.12	7.00
143	4/28/2012	12:25	4/28/2012	18:10	5.75	473	0.053	0.204	0.023	8.87	0.07	2.38
144	5/1/2012	17:45	5/2/2012	5:55	12.17	2,095	0.235	1.038	0.048	21.63	0.15	5.03
145	5/4/2012	16:40	5/4/2012	18:45	2.08	84	0.009	0.056	0.011	5.09	0.06	25.00
146	5/5/2012	1:10	5/5/2012	19:45	18.58	246	0.028	0.051	0.009	5.67	0.14	9.70
147	5/7/2012	20:40	5/8/2012	12:00	15.33	807	0.090	0.152	0.015	10.13	0.11	1.27
148	5/13/2012	7:50	5/13/2012	23:10	15.33	1,680	0.188	0.149	0.03	4.97	0.13	0.94
149						0	0.000	0	0		0.00	0.00
150						0	0.000	0	0		0.00	0.00
151						0	0.000	0	0		0.00	0.00

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
152						0	0.000	0	0		0.00	0.00
153						0	0.000	0	0		0.00	0.00
154						0	0.000	0	0		0.00	0.00
155	7/18/2012	17:30	7/18/2012	18:40	1.17	17	0.002	0.036	0.04	0.90	0.00	0.93
156						0	0.000	0	0		0.00	0.00
157						0	0.000	0	0		0.00	0.00
158						0	0.000	0	0		0.00	0.00
159	10/1/2012	18:50	10/1/2012	23:25	4.58	802	0.090	0.234	0.049	4.78	0.12	1.00
160	10/6/2012	1:05	10/6/2012	2:35	1.50	261	0.029	0.139	0.048	2.90	0.07	0.24
161	10/14/2012	18:25	10/14/2012	19:25	1.00	133	0.015	0.176	0.037	4.76	0.04	0.11
162	10/20/2012	1:05	10/20/2012	2:15	1.17	60	0.007	0.039	0.014	2.79	0.02	0.11
163	10/26/2012	14:45	10/27/2012	3:35	12.83	1,148	0.128	0.08	0.025	3.20	0.16	0.73
164	10/30/2012	7:15	10/30/2012	11:35	4.33	512	0.057	0.063	0.032	1.97	0.13	0.52
165						0	0.000	0	0		0.00	0.00
166	11/12/2012	8:30	11/12/2012	14:25	5.92	710	0.079	0.139	0.033	4.21	0.10	0.59
167						0	0.000	0	0		0.00	0.00
168						0	0.000	0	0		0.00	0.00
169	12/4/2012	18:00	12/4/2012	18:45	0.75	43	0.005	0.019	0.007	2.71	0.02	0.19
170	12/7/2012	9:55	12/7/2012	19:50	9.92	1,208	0.135	0.13	0.034	3.82	0.16	0.95
171	12/9/2012	20:40	12/10/2012	5:20	8.67	1,431	0.160	0.339	0.046	7.37	0.16	2.00
172						0	0.000	0	0		0.00	0.00
173	12/17/2012	15:40	12/17/2012	16:50	1.17	166	0.019	0.128	0.039	3.28	0.04	0.30
174	12/20/2012	9:05	12/20/2012	17:05	8.00	1,112	0.124	0.122	0.039	3.13	0.14	0.89
175	12/26/2012	6:50	12/26/2012	15:05	8.25	535	0.060	0.104	0.018	5.78	0.05	0.68
176						0	0.000	0	0		0.00	0.00

Rainfall characteristics for African Savannah zoo combined sewer line

Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain [a] (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
1	1/17/2010	10:30	1/17/2010	17:15		6.75	0.13	0.12	0.02
2	1/21/2010	4:15	1/22/2010	0:15	3.46	20.00	0.65	0.36	0.03
3	1/24/2010	4:35	1/24/2010	14:50	2.18	10.25	0.54	0.60	0.05
4	2/5/2010	9:50	2/6/2010	4:40	11.79	18.83	0.93	0.60	0.05
5	2/12/2010	10:10	2/12/2010	17:00	6.23	6.83	0.27	0.24	0.04
6	2/18/2010	14:05	2/18/2010	18:35	5.88	4.50	0.13	0.36	0.03
7	3/12/2010	17:45	3/13/2010	20:40	21.97	26.92	1.32	1.08	0.05
8	3/21/2010	22:05	3/22/2010	5:10	8.06	7.08	0.61	0.48	0.09
9	3/25/2010	13:55	3/26/2010	1:15	3.36	11.33	1.27	0.48	0.11
10	3/29/2010	6:15	3/29/2010	9:35	3.21	3.33	0.08	0.12	0.02
11	4/5/2010	19:30	4/5/2010	20:55	7.41	1.42	0.11	0.48	0.08
12	4/8/2010	0:55	4/8/2010	8:05	2.17	7.17	0.54	0.96	0.08
13	4/23/2010	11:00	4/23/2010	15:10	15.12	4.17	0.14	0.24	0.03
14	4/24/2010	16:55	4/25/2010	3:20	1.07	10.42	0.91	0.60	0.09
15	4/25/2010	14:35	4/25/2010	19:25	0.47	4.83	0.16	0.36	0.03
16	5/2/2010	3:00	5/2/2010	20:15	6.32	17.25	1.36	0.72	0.08
17	5/11/2010	4:35	5/11/2010	10:15	8.35	5.67	0.40	0.96	0.07
18	5/12/2010	7:45	5/12/2010	13:40	0.90	5.92	0.50	1.20	0.08
19	5/16/2010	20:00	5/16/2010	23:55	4.26	3.92	0.14	0.12	0.04
20	5/17/2010	5:00	5/17/2010	8:05	0.21	3.08	0.16	0.12	0.05
21	5/21/2010	2:10	5/21/2010	3:55	3.75	1.75	0.16	0.36	0.09
22	5/21/2010	12:45	5/21/2010	18:35	0.37	5.83	0.93	2.41	0.16
23	6/5/2010	14:45	6/5/2010	15:05	14.84	0.33	0.22	1.33	0.66
24	6/6/2010	8:15	6/6/2010	8:50	0.72	0.58	0.30	1.33	0.51
25	6/12/2010	7:30	6/12/2010	12:20	5.94	4.83	2.64	2.05	0.55
26	6/14/2010	22:35	6/14/2010	23:20	2.43	0.75	0.50	2.65	0.67
27	6/19/2010	7:15	6/19/2010	9:20	4.33	2.08	0.70	1.81	0.34
28	6/21/2010	11:55	6/21/2010	14:45	2.11	2.83	0.59	2.17	0.21
29	6/27/2010	23:10	6/28/2010	5:50	6.35	6.67	1.70	3.37	0.26
30	7/9/2010	11:00	7/9/2010	12:50	11.22	1.83	0.22	0.48	0.12
31	7/13/2010	9:00	7/13/2010	16:25	3.84	7.42	0.25	0.72	0.03
32	7/17/2010	17:35	7/17/2010	18:05	4.05	0.50	0.29	1.20	0.58
33	7/20/2010	18:05	7/20/2010	22:45	3.00	4.67	0.52	1.33	0.11
34	8/11/2010	14:55	8/11/2010	15:10	21.67	0.25	0.20	1.20	0.80
35	8/14/2010	17:25	8/14/2010	18:55	3.09	1.50	0.50	1.20	0.33
36	8/15/2010	16:50	8/15/2010	17:25	0.91	0.58	0.18	0.60	0.31
37	9/16/2010	4:10	9/16/2010	6:40	31.45	2.50	0.15	0.72	0.06
38	10/13/2010	18:10	10/13/2010	19:40	27.48	1.50	0.14	0.36	0.09

Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain[a] (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
39	10/26/2010	12:30	10/26/2010	17:25	12.70	4.92	0.72	2.05	0.15
40	11/16/2010	11:10	11/16/2010	22:05	20.74	10.92	0.99	0.84	0.09
41	11/23/2010	1:30	11/23/2010	5:00	6.14	3.50	0.64	0.96	0.18
42	11/25/2010	6:05	11/26/2010	1:05	2.05	19.00	2.61	1.08	0.14
43	11/30/2010	0:00	11/30/2010	20:40	3.95	20.67	1.53	0.60	0.07
44	1/1/2011	1:20	1/1/2011	9:50	31.19	8.50	0.50	0.36	0.06
45	1/18/2011	3:25	1/18/2011	18:10	16.73	14.75	0.29	0.24	0.02
46	1/24/2011	22:25	1/25/2011	10:10	6.18	11.75	0.20	0.24	0.02
47	2/1/2011	1:45	2/2/2011	0:40	6.65	22.92	1.10	0.36	0.05
48	2/5/2011	5:20	2/5/2011	12:05	3.19	6.75	0.23	0.24	0.03
49	2/21/2011	8:10	2/21/2011	19:15	15.84	11.08	2.13	1.20	0.19
50	2/24/2011	17:45	2/25/2011	5:05	2.94	11.33	1.80	0.60	0.16
51	2/27/2011	19:05	2/27/2011	20:50	2.58	1.75	0.19	0.48	0.11
52	2/28/2011	5:15	2/28/2011	11:45	0.35	6.50	0.43	1.33	0.07
53	3/4/2011	6:35	3/5/2011	21:55	3.78	39.33	1.77	0.48	0.04
54	3/8/2011	21:55	3/9/2011	19:55	3.00	22.00	1.62	0.48	0.07
55	3/15/2011	10:40	3/15/2011	18:20	5.61	7.67	0.11	0.36	0.01
56	3/18/2011	16:00	3/18/2011	18:55	2.90	2.92	0.60	1.33	0.21
57	4/1/2011	20:40	4/2/2011	4:00	14.07	7.33	0.14	0.48	0.02
58	4/4/2011	13:30	4/4/2011	18:00	2.40	4.50	1.15	2.65	0.26
59	4/9/2011	11:45	4/9/2011	15:25	4.74	3.67	0.57	1.45	0.16
60	4/11/2011	8:00	4/12/2011	7:00	1.69	23.00	2.42	1.45	0.11
61	4/15/2011	22:15	4/16/2011	10:25	3.64	12.17	1.58	0.96	0.13
62	4/19/2011	1:35	4/19/2011	12:00	2.63	10.42	2.59	2.53	0.25
63	4/20/2011	1:35	4/20/2011	8:10	0.57	6.58	0.81	1.08	0.12
64	4/22/2011	16:45	4/22/2011	19:55	2.36	3.17	0.83	2.53	0.26
65	4/24/2011	18:35	4/25/2011	9:35	1.94	15.00	0.39	0.24	0.03
66	4/27/2011	4:00	4/27/2011	11:45	1.77	7.75	0.79	2.17	0.10
67	4/27/2011	17:00	4/28/2011	2:50	0.22	9.83	0.24	0.24	0.02
68	4/28/2011	17:45	4/28/2011	19:55	0.62	2.17	0.26	0.72	0.12
69	5/1/2011	20:30	5/3/2011	11:35	3.02	39.08	2.47	0.60	0.06
70	5/7/2011	23:25	5/8/2011	2:05	4.49	2.67	0.31	0.48	0.12
71	5/13/2011	15:55	5/13/2011	16:55	5.58	1.00	1.01	3.73	1.01
72	5/15/2011	12:00	5/15/2011	14:10	1.80	2.17	0.10	0.12	0.05
73	5/15/2011	19:50	5/16/2011	2:05	0.24	6.25	0.18	0.60	0.03
74	5/17/2011	13:30	5/18/2011	7:00	1.48	17.50	0.33	0.24	0.02
75	5/22/2011	17:45	5/22/2011	17:55	4.45	0.17	0.10	0.84	0.60
76	5/23/2011	5:45	5/23/2011	7:50	0.49	2.08	0.33	0.48	0.16
77	5/23/2011	19:20	5/24/2011	0:25	0.48	5.08	0.53	1.08	0.10

Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain [a] (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
78	5/26/2011	0:30	5/26/2011	18:20	2.00	17.83	0.79	1.45	0.04
79	6/4/2011	22:25	6/4/2011	22:35	9.17	0.17	0.09	0.72	0.54
80	6/10/2011	13:15	6/10/2011	21:15	5.61	8.00	1.12	1.08	0.14
81	6/11/2011	4:05	6/11/2011	8:45	0.28	4.67	0.74	1.57	0.16
82	6/15/2011	11:10	6/15/2011	15:35	4.10	4.42	0.54	0.48	0.12
83	6/18/2011	8:15	6/18/2011	13:05	2.69	4.83	0.10	0.12	0.02
84	6/19/2011	10:35	6/19/2011	11:35	0.90	1.00	0.13	0.24	0.13
85	6/20/2011	9:10	6/20/2011	12:35	0.90	3.42	0.73	1.45	0.21
86	6/21/2011	14:35	6/21/2011	17:00	1.08	2.42	0.62	1.57	0.26
87	6/22/2011	22:30	6/23/2011	4:25	1.23	5.92	0.36	1.08	0.06
88	6/26/2011	4:25	6/26/2011	10:40	3.00	6.25	0.81	0.36	0.13
89	6/27/2011	10:10	6/27/2011	11:15	0.98	1.08	0.17	1.08	0.16
90	7/4/2011	2:35	7/4/2011	8:00	6.64	5.42	0.64	1.81	0.12
91	7/8/2011	2:35	7/8/2011	8:05	3.77	5.50	0.64	1.81	0.12
92	7/23/2011	13:05	7/23/2011	13:30	15.21	0.42	0.97	5.90	2.33
93	8/3/2011	5:10	8/3/2011	11:40	10.65	6.50	0.66	2.53	0.10
94	8/7/2011	5:40	8/7/2011	7:30	3.75	1.83	0.74	2.29	0.40
95	8/8/2011	20:00	8/8/2011	21:40	1.52	1.67	1.15	2.17	0.69
96	8/14/2011	2:20	8/14/2011	4:15	5.19	1.92	0.12	0.36	0.06
97	8/21/2011	17:40	8/21/2011	17:55	7.56	0.25	0.20	1.69	0.80
98	9/4/2011	1:10	9/4/2011	3:30	13.30	2.33	0.54	2.05	0.23
99	9/4/2011	20:10	9/4/2011	23:25	0.69	3.25	0.29	0.84	0.09
100	9/7/2011	10:40	9/8/2011	3:05	2.47	16.42	0.49	0.36	0.03
101	9/14/2011	22:30	9/15/2011	2:10	6.81	3.67	0.43	0.36	0.12
102	9/19/2011	9:25	9/19/2011	16:30	4.30	7.08	0.48	0.36	0.07
103	9/23/2011	5:10	9/23/2011	12:15	3.53	7.08	0.59	0.36	0.08
104	9/25/2011	23:25	9/26/2011	9:00	2.47	9.58	3.38	1.69	0.35
105	9/29/2011	19:20	9/29/2011	21:30	3.43	2.17	0.37	1.45	0.17
106	10/18/2011	19:00	10/20/2011	15:25	18.90	44.42	2.27	0.96	0.05
107	10/26/2011	20:35	10/27/2011	4:10	6.22	7.58	0.92	0.60	0.12
108	11/3/2011	12:55	11/4/2011	2:50	7.36	13.92	1.37	0.48	0.10
109	11/14/2011	20:20	11/15/2011	7:10	10.73	10.83	1.61	1.69	0.15
110	11/16/2011	5:45	11/16/2011	11:05	0.94	5.33	0.32	0.24	0.06
111	11/21/2011	6:30	11/21/2011	9:25	4.81	2.92	0.36	2.05	0.12
112	11/21/2011	15:10	11/21/2011	23:30	0.24	8.33	0.16	0.24	0.02
113	11/22/2011	6:50	11/22/2011	15:30	0.31	8.67	0.83	0.60	0.10
114	11/27/2011	2:05	11/29/2011	5:00	4.44	50.92	2.33	0.36	0.05
115	12/4/2011	14:20	12/6/2011	2:15	5.39	35.92	3.17	0.60	0.09
116	12/15/2011	3:10	12/15/2011	12:15	9.04	9.08	0.32	0.36	0.04

Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain [a] (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
117	12/19/2011	19:20	12/20/2011	1:35	4.30	6.25	0.24	0.24	0.04
118	12/20/2011	18:25	12/21/2011	7:55	0.70	13.50	0.74	0.84	0.05
119	12/22/2011	12:00	12/22/2011	20:10	1.17	8.17	0.66	0.24	0.08
120	12/27/2011	2:20	12/27/2011	17:25	4.26	15.08	0.66	0.36	0.04
121	1/11/2012	7:45	1/11/2012	12:55	14.60	5.17	0.36	0.48	0.07
122	1/17/2012	3:00	1/17/2012	14:20	5.59	11.33	1.76	2.41	0.16
123	1/20/2012	23:40	1/21/2012	0:35	3.39	0.92	0.12	0.48	0.13
124	1/23/2012	0:35	1/23/2012	5:55	2.00	5.33	0.44	0.96	0.08
125	1/26/2012	4:50	1/26/2012	9:50	2.95	5.00	0.72	0.96	0.14
126	1/26/2012	17:25	1/27/2012	5:40	0.32	12.25	0.96	0.96	0.08
127	2/16/2012	0:20	2/16/2012	7:10	19.78	6.83	0.28	0.48	0.04
128	2/29/2012	3:20	2/29/2012	9:15	12.84	5.92	0.36	0.48	0.06
129	3/2/2012	11:15	3/2/2012	17:05	2.08	5.83	0.52	1.45	0.09
130	3/8/2012	8:25	3/8/2012	17:00	5.64	8.58	0.64	0.48	0.07
131	3/12/2012	7:20	3/12/2012	11:55	3.60	4.58	0.12	0.48	0.03
132	3/15/2012	10:25	3/15/2012	12:10	2.94	1.75	0.80	1.93	0.46
133	3/23/2012	12:00	3/23/2012	18:30	7.99	6.50	0.44	0.96	0.07
134	3/24/2012	1:00	3/24/2012	2:00	0.27	1.00	0.36	1.93	0.36
135	3/30/2012	20:20	3/30/2012	22:20	6.76	2.00	0.32	1.45	0.16
136	4/1/2012	23:40	4/2/2012	0:35	2.06	0.92	0.40	0.96	0.44
137	4/14/2012	9:50	4/14/2012	17:35	12.39	7.75	1.32	1.45	0.17
138	4/20/2012	20:35	4/21/2012	3:20	6.13	6.75	0.16	0.48	0.02
139	4/25/2012	22:55	4/25/2012	23:55	4.82	1.00	0.72	3.37	0.72
140	4/28/2012	11:55	4/28/2012	14:20	2.50	2.42	0.80	1.93	0.33
141	5/1/2012	17:35	5/1/2012	20:00	3.14	2.42	1.52	5.30	0.63
142	5/4/2012	16:35	5/4/2012	16:40	2.86	0.08	0.16	1.93	1.92
143	5/5/2012	1:10	5/5/2012	3:05	0.35	1.92	0.20	0.48	0.10
144	5/7/2012	20:25	5/8/2012	8:30	2.72	12.08	0.80	2.89	0.07
145	5/13/2012	5:15	5/13/2012	21:30	4.86	16.25	1.40	0.96	0.09
146	5/29/2012	8:55	5/29/2012	10:00	15.48	1.08	0.28	0.96	0.26
147	6/1/2012	0:40	6/1/2012	8:10	2.61	7.50	1.12	1.93	0.15
148	6/11/2012	7:40	6/11/2012	10:30	9.98	2.83	0.16	0.48	0.06
149	6/17/2012	13:40	6/17/2012	14:05	6.13	0.42	0.12	0.96	0.29
150	6/29/2012	17:45	6/29/2012	18:05	12.15	0.33	0.40	1.45	1.20
151	7/14/2012	9:00	7/14/2012	10:30	14.62	1.50	0.36	1.45	0.24
152	7/18/2012	16:40	7/18/2012	17:55	4.26	1.25	0.92	1.93	0.74
153	7/19/2012	11:50	7/19/2012	12:35	0.75	0.75	0.32	1.93	0.43
154	7/27/2012	14:00	7/27/2012	18:50	8.06	4.83	0.36	1.45	0.07
155	10/1/2012	16:15	10/1/2012	23:25		7.17	0.76	1.23	0.11

Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain [a] (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
156	10/5/2012	18:25	10/6/2012	0:40	3.79	6.25	0.40	0.58	0.06
157	10/14/2012	13:15	10/14/2012	22:45	8.52	9.50	0.36	1.02	0.04
158	10/19/2012	13:25	10/20/2012	0:30	4.61	11.08	0.28	0.17	0.03
159	10/26/2012	9:50	10/27/2012	3:30	6.39	17.67	0.82	0.36	0.05
160	10/30/2012	2:10	10/30/2012	10:30	2.94	8.33	0.45	0.11	0.05
161	11/3/2012	10:50	11/3/2012	16:10	4.01	5.33	0.11	0.12	0.02
162	11/12/2012	3:50	11/12/2012	13:55	8.49	10.08	0.77	0.35	0.08
163	11/26/2012	22:55	11/27/2012	2:20	14.38	3.42	0.10	0.05	0.03

Runoff characteristics for African Savannah zoo combined sewer line

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
1	1/17/2010	10:15	1/17/2010	19:05	8.83	1,050	0.017	0.10	0.05	2.00	0.13	1.31
2	1/21/2010	14:25	1/22/2010	8:45	90.33	16,066	0.257	2.81	0.24	11.71	0.40	4.52
3	1/24/2010	5:30	1/24/2010	16:40	11.17	12,146	0.195	3.91	0.27	14.48	0.36	1.09
4	2/5/2010	12:40	2/6/2010	10:15	21.58	6,768	0.108	0.21	0.09	2.33	0.12	1.15
5	2/12/2010	11:10	2/12/2010	19:40	8.50	1,023	0.016	0.22	0.03	7.33	0.06	1.24
6	2/18/2010	16:20	2/18/2010	19:10	2.83	22	0.000	0.03	0.00	15.00	0.00	0.63
7	3/12/2010	17:50	3/14/2010	4:15	34.42	39,670	0.635	2.78	0.32	8.69	0.48	1.28
8	3/21/2010	22:20	3/22/2010	11:30	13.17	13,052	0.209	2.07	0.28	7.39	0.34	1.86
9	3/25/2010	14:15	3/26/2010	7:05	16.83	39,993	0.641	3.10	0.74	4.19	0.50	1.49
10	3/29/2010	6:25	3/29/2010	10:10	3.75	756	0.012	0.16	0.06	2.67	0.15	1.12
11	4/5/2010	19:40	4/5/2010	20:15	0.58	442	0.007	0.59	0.21	2.81	0.06	0.41
12	4/8/2010	1:00	4/8/2010	10:05	9.08	9,497	0.152	1.71	0.29	5.90	0.28	1.27
13	4/23/2010	11:30	4/23/2010	16:40	5.17	7,779	0.125	2.93	0.42	6.98	0.89	1.24
14	4/24/2010	17:05	4/25/2010	4:10	11.08	22,198	0.356	2.35	0.56	4.20	0.39	1.06
15	4/25/2010	14:45	4/25/2010	20:50	6.08	1,153	0.018	0.40	0.05	8.00	0.12	1.26
16	5/2/2010	3:00	5/3/2010	8:20	29.33	47,466	0.760	1.96	0.45	4.36	0.56	1.70
17	5/11/2010	4:45	5/11/2010	12:30	7.75	2,122	0.034	1.59	0.08	19.88	0.08	1.37
18	5/12/2010	8:00	5/12/2010	16:40	8.67	7,229	0.116	1.05	0.23	4.57	0.23	1.46
19	5/16/2010	21:10	5/17/2010	0:55	3.75	1,386	0.022	0.36	0.05	7.20	0.16	0.96
20	5/17/2010	5:20	5/18/2010	8:35	27.25	1,760	0.028	0.45	0.15	3.00	0.18	8.84
21	5/21/2010	2:10	5/21/2010	4:55	2.75	545	0.009	0.29	0.06	4.83	0.05	1.57
22	5/21/2010	12:10	5/21/2010	22:35	10.42	5,636	0.090	2.16	0.15	14.40	0.10	1.79
23	6/5/2010	14:50	6/5/2010	16:45	1.92	3,993	0.064	4.38	0.58	7.55	0.29	5.75
24	6/6/2010	8:15	6/6/2010	10:30	2.25	3,417	0.055	2.58	0.42	6.14	0.18	3.86
25	6/12/2010	7:40	6/12/2010	21:30	13.83	83,555	1.338	7.36	1.67	4.41	0.51	2.86
26	6/14/2010	21:45	6/15/2010	5:45	8.00	10,908	0.175	7.12	0.42	16.84	0.35	10.67
27	6/19/2010	7:15	6/19/2010	12:55	5.67	8,284	0.133	2.19	0.41	5.40	0.19	2.72
28	6/21/2010	12:10	6/21/2010	22:40	10.50	3,530	0.057	1.97	0.09	21.05	0.10	3.71
29	6/27/2010	21:50	6/28/2010	11:35	13.75	35,363	0.566	4.61	0.71	6.46	0.33	2.06
30	7/9/2010	10:45	7/9/2010	14:05	3.33	5,198	0.083	3.51	0.43	8.11	0.38	1.82
31	7/13/2010	7:00	7/13/2010	17:40	10.67	6,511	0.104	2.14	0.17	12.65	0.42	1.44
32	7/17/2010	16:40	7/17/2010	23:05	6.42	5,242	0.084	3.02	0.22	13.49	0.29	12.83
33	7/20/2010	17:40	7/21/2010	5:30	11.83	6,781	0.109	2.49	0.21	11.62	0.21	2.54
34	8/11/2010	13:25	8/11/2010	21:00	7.58	2,770	0.044	2.37	0.10	23.37	0.22	30.33
35	8/14/2010	15:40	8/15/2010	6:30	14.83	17,790	0.285	2.83	0.33	8.54	0.57	9.89
36	8/15/2010	16:50	8/15/2010	23:55	7.08	2,877	0.046	1.10	0.11	9.91	0.26	12.14
37	9/16/2010	4:10	9/16/2010	12:00	7.83	1,551	0.025	1.37	0.05	27.40	0.17	3.13

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
38	10/13/2010	15:20	10/13/2010	23:25	8.08	885	0.014	0.39	0.03	13.00	0.10	5.39
39	10/26/2010	12:10	10/26/2010	20:05	7.92	15,278	0.245	4.51	0.53	8.51	0.34	1.61
40	11/16/2010	12:20	11/17/2010	5:00	16.67	17,488	0.280	1.97	0.29	6.79	0.28	1.53
41	11/23/2010	1:30	11/23/2010	14:15	12.75	25,732	0.412	4.44	0.56	7.93	0.64	3.64
42	11/25/2010	15:10	11/26/2010	23:05	31.92	144,779	2.319	4.11	1.03	3.99	0.89	1.68
43	11/30/2010	0:00	11/30/2010	23:55	23.92	65,363	1.047	2.62	0.38	6.89	0.68	1.16
44	1/1/2011	0:00	1/1/2011	14:10	14.17	15,176	0.243	1.19	0.30	4.00	0.49	1.67
45	1/18/2011	3:25	1/18/2011	19:30	16.08	6,472	0.104	0.46	0.11	4.18	0.36	1.09
46	1/24/2011	22:25	1/25/2011	8:00	9.58	1,778	0.028	0.14	0.05	2.75	0.14	0.82
47	2/1/2011	1:40	2/2/2011	9:30	31.83	40,229	0.644	1.75	0.35	4.99	0.59	1.39
48	2/5/2011	5:45	2/5/2011	18:25	12.67	2,701	0.043	0.31	0.06	5.20	0.19	1.88
49	2/21/2011	7:00	2/21/2011	23:55	16.92	101,883	1.632	4.29	1.66	2.58	0.77	1.53
50	2/24/2011	19:45	2/25/2011	15:00	19.25	108,532	1.738	4.59	1.56	2.94	0.97	1.70
51	2/27/2011	19:05	2/27/2011	22:40	3.58	3,995	0.064	2.12	0.30	7.01	0.34	2.05
52	2/28/2011	5:20	2/28/2011	12:00	6.67	15,148	0.243	5.11	0.35	14.55	0.56	1.03
53	3/4/2011	6:35	3/5/2011	23:00	40.42	55,126	0.883	2.32	0.38	6.13	0.50	1.03
54	3/8/2011	23:20	3/9/2011	23:55	24.58	53,640	0.859	2.77	0.37	7.53	0.53	1.12
55	3/15/2011	9:30	3/15/2011	17:05	7.58	974	0.016	0.44	0.04	12.39	0.14	0.99
56	3/18/2011	17:25	3/18/2011	20:25	3.00	5,075	0.081	2.72	0.46	5.94	0.14	1.03
57	4/1/2011	20:00	4/2/2011	5:20	9.33	4,166	0.067	1.25	0.05	23.27	0.48	1.27
58	4/4/2011	14:20	4/4/2011	23:55	9.58	42,351	0.678	2.88	1.22	2.36	0.59	2.13
59	4/9/2011	11:50	4/9/2011	17:20	5.50	11,909	0.191	2.66	0.60	4.43	0.33	1.50
60	4/11/2011	7:35	4/12/2011	15:50	32.25	114,039	1.826	2.94	0.98	3.00	0.75	1.40
61	4/15/2011	23:00	4/16/2011	17:00	18.00	69,906	1.120	4.75	1.08	4.40	0.71	1.48
62	4/19/2011	1:35	4/19/2011	21:15	19.67	96,529	1.546	2.72	0.46	5.94	0.60	1.89
63	4/20/2011	1:35	4/20/2011	11:40	10.08	49,954	0.800	3.19	1.51	2.11	0.99	1.53
64	4/22/2011	16:45	4/22/2011	23:45	7.00	19,591	0.314	5.49	0.77	7.15	0.38	2.21
65	4/24/2011	18:40	4/25/2011	12:00	17.33	31,262	0.501	5.22	0.50	10.47	1.28	1.16
66	4/27/2011	4:05	4/27/2011	15:55	11.83	32,382	0.519	7.19	0.76	9.46	0.66	1.53
67	4/27/2011	17:20	4/28/2011	4:40	11.33	6,271	0.100	0.95	0.15	6.18	0.42	1.15
68	4/28/2011	17:15	4/28/2011	21:20	4.08	8,413	0.135	2.30	0.56	4.10	0.52	1.88
69	5/1/2011	21:15	5/3/2011	17:25	44.17	113,436	1.817	2.30	3.29	0.71	0.74	1.13
70	5/7/2011	23:25	5/8/2011	2:15	2.83	8,020	0.128	2.42	0.76	3.17	0.41	1.06
71	5/13/2011	15:55	5/13/2011	23:00	7.08	33,037	0.529	8.93	1.30	6.89	0.52	7.08
72	5/15/2011	12:25	5/15/2011	15:00	2.58	1,819	0.029	0.51	0.20	2.62	0.29	1.19
73	5/15/2011	20:30	5/16/2011	2:20	29.83	4,719	0.076	2.43	0.22	10.81	0.42	4.77
74	5/17/2011	13:40	5/18/2011	7:15	17.58	4,082	0.065	0.59	0.06	9.23	0.20	1.00
75	5/22/2011	17:50	5/22/2011	18:25	0.58	1,153	0.018	2.38	0.55	4.33	0.18	3.50

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
76	5/23/2011	5:45	5/23/2011	9:10	3.42	14,137	0.226	2.87	1.15	2.49	0.69	1.64
77	5/23/2011	19:25	5/24/2011	1:15	5.83	23,787	0.381	3.15	1.12	2.82	0.72	1.15
78	5/26/2011	0:35	5/26/2011	23:10	22.58	47,071	0.754	3.13	0.58	5.41	0.95	1.27
79	6/4/2011	22:30	6/4/2011	23:55	1.42	3,209	0.051	2.23	0.12	18.58	0.57	8.50
80	6/10/2011	13:30	6/11/2011	0:50	11.33	40,568	0.650	6.64	0.99	6.73	0.58	1.42
81	6/11/2011	4:05	6/11/2011	10:55	6.83	38,479	0.616	7.43	1.56	4.76	0.83	1.46
82	6/15/2011	11:15	6/15/2011	18:25	7.17	19,238	0.308	2.77	0.75	3.69	0.57	1.62
83	6/18/2011	8:35	6/18/2011	14:05	5.50	476	0.008	0.39	0.02	19.50	0.08	1.14
84	6/19/2011	10:10	6/19/2011	12:55	2.75	3,324	0.053	1.01	0.34	2.97	0.41	2.75
85	6/20/2011	9:50	6/20/2011	19:10	9.33	38,870	0.623	4.69	1.15	4.08	0.85	2.73
86	6/21/2011	15:20	6/21/2011	19:45	4.42	13,962	0.224	4.98	0.88	5.66	0.36	1.83
87	6/22/2011	22:30	6/23/2011	5:20	6.83	18,675	0.299	4.38	0.76	5.76	0.83	1.15
88	6/26/2011	5:10	6/26/2011	14:25	9.25	31,408	0.503	2.74	0.94	2.91	0.62	1.48
89	6/27/2011	10:10	6/27/2011	14:30	4.33	9,269	0.148	3.74	0.59	6.34	0.87	4.00
90	7/4/2011	2:45	7/4/2011	11:05	8.33	38,931	0.624	3.94	1.28	3.08	0.97	1.54
91	7/8/2011	12:10	7/8/2011	16:30	4.33	9,271	0.148	3.74	0.59	6.34	0.23	0.79
92	7/23/2011	10:40	7/23/2011	18:05	7.42	16,264	0.260	1.96	0.61	3.21	0.27	17.80
93	8/3/2011	5:10	8/3/2011	14:45	9.58	12,774	0.205	3.54	0.37	9.57	0.31	1.47
94	8/7/2011	5:40	8/7/2011	15:45	10.08	32,743	0.524	4.32	0.89	4.85	0.71	5.50
95	8/8/2011	20:25	8/8/2011	22:00	1.58	21,648	0.347	9.08	3.14	2.89	0.30	0.95
96	8/14/2011	2:20	8/14/2011	5:50	3.50	3,535	0.057	1.58	0.28	5.64	0.47	1.83
97	8/21/2011	17:45	8/21/2011	19:25	1.67	4,168	0.067	2.31	0.69	3.35	0.33	6.67
98	9/4/2011	1:15	9/4/2011	6:10	4.92	8,088	0.130	2.55	0.46	5.54	0.24	2.11
99	9/4/2011	20:15	9/4/2011	23:55	3.67	16,852	0.270	2.97	1.25	2.38	0.93	1.13
100	9/7/2011	10:25	9/8/2011	3:40	17.25	15,452	0.247	1.77	0.25	7.08	0.51	1.05
101	9/14/2011	22:10	9/15/2011	4:10	6.00	11,396	0.183	1.46	0.53	2.75	0.42	1.64
102	9/19/2011	9:45	9/19/2011	20:00	10.25	17,407	0.279	2.86	0.47	6.09	0.58	1.45
103	9/23/2011	4:55	9/23/2011	15:40	10.75	23,411	0.375	4.79	0.60	7.98	0.64	1.52
104	9/25/2011	22:55	9/26/2011	13:00	14.08	157,097	2.516	12.13	3.59	3.38	0.74	1.47
105	9/29/2011	19:25	9/29/2011	22:00	2.58	8,002	0.128	2.41	0.69	3.49	0.35	1.19
106	10/18/2011	19:05	10/20/2011	15:25	44.33	95,034	1.522	3.06	0.60	5.13	0.67	1.00
107	10/26/2011	20:35	10/27/2011	8:10	11.58	54,908	0.879	3.05	1.32	2.32	0.96	1.53
108	11/3/2011	13:10	11/4/2011	7:00	17.83	62,888	1.007	3.05	2.93	0.98	0.74	1.28
109	11/14/2011	20:25	11/15/2011	10:40	14.25	80,137	1.284	3.93	1.56	2.51	0.80	1.32
110	11/16/2011	6:15	11/16/2011	11:35	5.33	4,613	0.074	0.85	0.24	3.55	0.23	1.00
111	11/21/2011	6:50	11/21/2011	9:50	3.00	2,314	0.037	1.73	0.21	8.06	0.10	1.03
112	11/21/2011	16:05	11/21/2011	23:55	7.83	12,553	0.201	2.54	0.70	3.64	1.26	0.94
113	11/22/2011	6:55	11/22/2011	17:15	10.33	37,521	0.601	3.05	1.32	2.32	0.72	1.19

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
114	11/27/2011	3:00	11/29/2011	7:10	52.17	158,234	2.534	2.84	0.84	3.37	1.09	1.02
115	12/4/2011	18:45	12/6/2011	2:10	31.42	222,056	3.557	5.51	1.96	2.81	1.12	0.87
116	12/15/2011	4:55	12/15/2011	12:50	7.92	3,065	0.049	0.91	0.11	8.49	0.15	0.87
117	12/19/2011	21:30	12/20/2011	2:00	4.50	3,418	0.055	0.87	0.21	4.12	0.23	0.72
118	12/20/2011	21:35	12/21/2011	11:50	14.25	17,639	0.283	2.60	0.34	7.59	0.38	1.06
119	12/22/2011	15:30	12/22/2011	22:40	7.17	27,696	0.444	2.23	1.07	2.08	0.67	0.88
120	12/27/2011	4:45	12/27/2011	18:00	13.25	10,032	0.161	1.49	0.21	7.11	0.24	0.88
121	1/11/2012	10:25	1/11/2012	14:05	3.67	2,533	0.041	0.88	0.19	4.60	0.11	0.71
122	1/17/2012	4:10	1/17/2012	15:25	11.25	56,945	0.912	4.49	1.41	3.19	0.52	0.99
123	1/20/2012	23:40	1/21/2012	23:55	24.25	269	0.004	0.55	0.30	1.84	0.04	26.45
124	1/23/2012	3:50	1/23/2012	6:10	2.33	1,056	0.017	0.62	0.12	5.13	0.04	0.44
125	1/26/2012	5:05	1/26/2012	12:00	6.92	6,383	0.102	1.33	0.26	5.17	0.14	1.38
126	1/26/2012	19:35	1/27/2012	3:50	8.25	36,632	0.587	3.61	1.23	2.93	0.61	0.67
127	2/16/2012	0:30	2/16/2012	7:25	6.92	777	0.012	0.24	0.03	7.53	0.04	1.01
128	2/29/2012	3:20	2/29/2012	10:05	6.75	3,562	0.057	0.95	0.15	6.49	0.16	1.14
129	3/2/2012	12:15	3/2/2012	17:30	5.25	1,954	0.031	1.48	0.10	14.28	0.06	0.90
130	3/8/2012	5:20	3/8/2012	21:00	15.67	8,445	0.135	0.54	0.17	3.15	0.21	1.83
131	3/12/2012	7:50	3/12/2012	11:20	3.50	3,255	0.052	0.48	0.28	1.73	0.43	0.76
132	3/15/2012	9:30	3/15/2012	14:05	4.58	14,443	0.231	2.91	0.86	3.39	0.29	2.62
133	3/23/2012	12:10	3/23/2012	18:40	6.50	1,754	0.028	0.36	0.07	4.78	0.06	1.00
134	3/24/2012	1:00	3/24/2012	4:15	3.25	3,336	0.053	2.75	0.29	9.65	0.15	3.25
135	3/30/2012	20:20	3/30/2012	23:20	3.00	426	0.007	0.17	0.04	4.31	0.02	1.50
136	4/1/2012	23:55	4/2/2012	3:35	3.67	6,340	0.102	2.79	0.48	5.81	0.25	4.00
137	4/14/2012	10:20	4/14/2012	20:25	10.08	10,640	0.170	2.67	0.29	9.10	0.13	1.30
138	4/20/2012	20:30	4/21/2012	4:00	7.50	433	0.007	0.18	0.02	11.38	0.04	1.11
139	4/25/2012	23:45	4/26/2012	3:45	4.00	15,764	0.252	4.47	1.07	4.17	0.35	4.00
140	4/28/2012	13:00	4/28/2012	17:20	4.33	6,250	0.100	1.33	0.40	3.31	0.13	1.79
141	5/1/2012	17:45	5/1/2012	23:45	6.00	33,981	0.544	3.92	1.51	2.60	0.36	2.48
142	5/4/2012	15:00	5/4/2012	19:20	4.33	371	0.006	0.35	0.14	2.55	0.04	52.00
143	5/5/2012	1:25	5/5/2012	3:35	2.17	949	0.015	0.27	0.12	2.19	0.08	1.13
144	5/7/2012	20:30	5/8/2012	10:35	14.08	5,296	0.085	0.69	0.10	6.62	0.11	1.17
145	5/13/2012	5:40	5/13/2012	23:55	18.25	22,251	0.356	1.33	0.40	3.31	0.25	1.12
146	5/29/2012	19:00	5/29/2012	23:20	4.33	353	0.006	0.23	0.04	6.19	0.02	4.00
147						0	0.000				0.00	
148	6/11/2012	7:25	6/11/2012	11:35	4.17	1,601	0.026	3.06	0.11	28.65	0.16	1.47
149	6/17/2012	13:40	6/17/2012	15:50	2.17	915	0.015	1.50	0.12	12.80	0.12	5.20
150	6/29/2012	16:55	6/29/2012	20:05	3.17	687	0.011	0.14	0.06	2.39	0.03	9.50
151	7/14/2012	17:55	7/14/2012	21:05	3.17	96	0.002	0.11	0.02	6.01	0.00	2.11

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
152	7/18/2012	16:45	7/18/2012	20:30	3.75	6,511	0.104	1.76	0.48	3.64	0.11	3.00
153	7/19/2012	19:55	7/19/2012	23:05	3.17	196	0.003	0.44	0.08	5.37	0.01	4.22
154	7/27/2012	14:20	7/27/2012	21:10	6.83	7,765	0.124	2.80	0.32	8.88	0.35	1.41
155	10/1/2012	16:40	10/1/2012	23:40	7.00	9,251	0.148	2.73	0.37	7.45	0.20	0.98
156	10/5/2012	18:35	10/6/2012	2:35	8.00	3,475	0.056	1.11	0.12	9.33	0.14	1.28
157	10/14/2012	13:10	10/14/2012	23:00	9.83	5,935	0.095	2.85	0.17	17.00	0.27	1.04
158	10/19/2012	12:55	10/20/2012	0:35	11.67	4,724	0.076	3.11	0.12	26.01	0.27	1.05
159	10/26/2012	9:40	10/27/2012	4:45	19.08	18,679	0.299	0.65	0.27	2.38	0.36	1.08
160	10/30/2012	2:20	10/30/2012	13:45	11.42	3,553	0.057	0.40	0.09	4.65	0.13	1.37
161	11/3/2012	10:50	11/3/2012	16:45	5.92	897	0.014	0.20	0.04	4.74	0.13	1.11
162	11/12/2012	3:50	11/12/2012	17:25	13.58	8,107	0.130	1.07	0.17	6.46	0.17	1.35
163	11/26/2012	23:10	11/27/2012	4:35	5.42	242	0.004	0.06	0.01	5.01	0.04	1.59

Rainfall characteristics for Clark Montessori High School combined sewer line

Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain [a] (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
1	3/10/2010	3:05	3/10/2010	11:50		8.75	0.12	0.96	0.01
2	3/11/2010	9:35	3/11/2010	11:00	0.91	1.42	0.08	0.48	0.06
3	3/12/2010	17:35	3/13/2010	19:40	1.27	26.08	1.56	1.45	0.06
4	3/14/2010	6:50	3/14/2010	8:30	0.47	1.67	0.12	0.48	0.07
5	3/21/2010	22:00	3/22/2010	5:00	7.56	7.00	0.60	0.48	0.09
6	3/25/2010	13:40	3/26/2010	1:20	3.36	11.67	1.12	0.96	0.10
7	3/28/2010	11:15	3/28/2010	23:10	2.41	11.92	0.24	0.48	0.02
8	3/29/2010	7:20	3/29/2010	7:50	0.34	0.50	0.08	0.48	0.16
9	4/5/2010	19:40	4/5/2010	19:50	7.49	0.17	0.36	3.86	2.16
10	4/8/2010	1:10	4/8/2010	7:55	2.22	6.75	0.40	0.96	0.06
11	4/23/2010	11:00	4/23/2010	13:55	15.13	2.92	0.24	0.48	0.08
12	4/24/2010	16:45	4/24/2010	22:40	1.12	5.92	1.04	1.45	0.18
13	4/25/2010	15:50	4/25/2010	18:15	0.72	2.42	0.12	0.48	0.05
14	5/16/2010	19:35	5/16/2010	23:30		3.92	0.20	0.48	0.05
15	5/17/2010	5:05	5/17/2010	7:35	0.23	2.50	0.24	0.48	0.10
16	5/21/2010	12:45	5/21/2010	18:35	4.22	5.83	0.36	2.41	0.06
17	5/31/2010	21:05	5/31/2010	23:25	10.10	2.33	0.12	0.48	0.05
18	6/14/2010	22:45	6/14/2010	23:10		0.42	0.44	2.89	1.06
19	6/15/2010	20:55	6/15/2010	23:55	0.91	3.00	0.44	1.45	0.15
20	6/19/2010	7:20	6/19/2010	10:00	3.31	2.67	0.52	0.96	0.20
21	6/21/2010	12:35	6/21/2010	14:45	2.11	2.17	0.24	0.96	0.11
22	6/27/2010	23:45	6/28/2010	4:10	6.38	4.42	1.56	5.78	0.35
23	7/20/2010	18:20	7/20/2010	22:10		3.83	0.32	0.48	0.08
24	8/11/2010	15:00	8/11/2010	15:20	21.70	0.33	0.63	3.82	1.90
25	8/14/2010	17:50	8/14/2010	18:00	3.10	0.17	0.12	0.95	0.71
26	9/16/2010	4:20	9/16/2010	6:30		2.17	0.16	0.96	0.07
27	9/20/2010	10:00	9/20/2010	10:05	4.15	0.08	0.32	3.86	3.84
28	11/16/2010	11:05	11/17/2010	0:10	57.04	13.08	0.84	0.96	0.06
29	11/23/2010	1:45	11/23/2010	5:25	6.07	3.67	0.56	2.41	0.15
30	11/24/2010	13:50	11/24/2010	23:00	1.35	9.17	0.80	0.48	0.09
31	11/25/2010	6:15	11/25/2010	23:45	2.03	17.50	2.56	2.41	0.15
32	11/29/2010	22:00	11/30/2010	20:00	3.93	22.00	1.40	0.96	0.06
33	12/11/2010	17:15	12/12/2010	5:35	10.89	12.33	0.48	0.48	0.04
34	12/18/2010	11:55	12/18/2010	15:15	6.26	3.33	0.16	0.96	0.05
35	12/30/2010	2:00	12/30/2010	11:35	11.45	9.58	0.32	0.96	0.03
36	1/1/2011	1:50	1/1/2011	9:00	1.59	7.17	0.44	0.96	0.06
37	1/18/2011	9:40	1/18/2011	18:35	17.03	8.92	0.32	0.48	0.04
38	1/24/2011	15:30	1/24/2011	22:50	5.87	7.33	0.16	0.48	0.02

Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain [a] (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
39	2/5/2011	7:50	2/5/2011	12:00	11.38	4.17	0.16	0.48	0.04
40	2/21/2011	8:55	2/21/2011	19:00	15.87	10.08	2.08	1.45	0.21
41	2/24/2011	17:30	2/25/2011	5:25	2.94	11.92	1.44	0.96	0.12
42	2/27/2011	17:20	2/27/2011	20:50	2.50	3.50	0.68	1.45	0.19
43	2/28/2011	5:25	2/28/2011	7:05	0.36	1.67	0.32	0.96	0.19
44	3/4/2011	11:05	3/5/2011	19:25	4.17	32.33	1.40	1.45	0.04
45	3/8/2011	22:05	3/9/2011	20:05	3.11	22.00	1.44	1.45	0.07
46	3/15/2011	4:55	3/15/2011	16:20	5.37	11.42	0.20	0.48	0.02
47	3/18/2011	17:45	3/18/2011	18:55	3.06	1.17	0.40	2.41	0.34
48	4/1/2011	20:55	4/1/2011	21:20	14.08	0.42	0.16	0.96	0.38
49	4/4/2011	14:20	4/4/2011	17:45	2.71	3.42	1.08	1.45	0.32
50	4/9/2011	11:55	4/9/2011	15:30	4.76	3.58	0.48	0.96	0.13
51	4/11/2011	8:20	4/12/2011	8:05	1.70	23.75	1.92	1.93	0.08
52	4/15/2011	23:10	4/16/2011	10:15	3.63	11.08	0.92	0.96	0.08
53	4/19/2011	1:30	4/19/2011	11:35	2.64	10.08	2.04	0.16	0.20
54	4/20/2011	1:35	4/20/2011	8:15	0.58	6.67	1.08	2.41	0.16
55	4/22/2011	17:30	4/22/2011	19:50	2.39	2.33	0.64	2.89	0.27
56	4/23/2011	1:45	4/23/2011	6:40	0.25	4.92	0.56	0.96	0.11
57	4/23/2011	13:15	4/23/2011	20:15	0.27	7.00	1.16	2.89	0.17
58	4/24/2011	8:10	4/24/2011	10:45	0.50	2.58	0.20	0.48	0.08
59	4/27/2011	5:45	4/27/2011	9:55	3.40	4.17	0.56	1.45	0.13
60	4/27/2011	17:30	4/27/2011	20:55	0.32	3.42	0.16	0.48	0.05
61	4/28/2011	18:55	4/28/2011	20:00	0.92	1.08	0.16	0.96	0.15
62	5/1/2011	20:25	5/2/2011	7:50	3.02	11.42	0.76	0.96	0.07
63	5/2/2011	16:50	5/3/2011	10:35	0.38	17.75	1.48	0.96	0.08
64	5/7/2011	23:25	5/8/2011	0:40	4.53	1.25	0.32	0.96	0.26
65	5/13/2011	16:00	5/13/2011	16:15	5.64	0.25	0.12	0.48	0.48
66	5/14/2011	7:40	5/14/2011	15:50	0.64	8.17	0.16	0.48	0.02
67	5/15/2011	20:15	5/15/2011	21:10	1.18	0.92	0.16	0.96	0.17
68	5/17/2011	12:45	5/18/2011	4:35	1.65	15.83	0.33	0.24	0.02
69	5/22/2011	18:10	5/22/2011	18:15	4.57	0.08	0.12	1.45	1.44
70	5/23/2011	1:00	5/23/2011	6:55	0.28	5.92	1.08	4.34	0.18
71	5/23/2011	19:30	5/24/2011	0:35	0.52	5.08	0.72	1.45	0.14
72	5/26/2011	0:35	5/26/2011	18:40	2.00	18.08	1.12	1.45	0.06
73	6/10/2011	18:20	6/10/2011	20:50	14.99	2.50	2.72	7.23	1.09
74	6/11/2011	4:05	6/11/2011	8:05	0.30	4.00	1.20	1.45	0.30
75	6/15/2011	11:25	6/15/2011	16:05	4.14	4.67	0.52	0.96	0.11
76	6/19/2011	10:40	6/19/2011	16:25	3.77	5.75	0.16	0.48	0.03
77	6/20/2011	10:30	6/20/2011	12:35	0.75	2.08	0.84	1.93	0.40

Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain [a] (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
78	6/21/2011	11:35	6/21/2011	19:25	0.96	7.83	1.76	3.86	0.22
79	6/22/2011	22:50	6/23/2011	4:30	1.14	5.67	0.64	1.93	0.11
80	6/26/2011	5:15	6/26/2011	10:35	3.03	5.33	0.60	0.96	0.11
81	7/4/2011	9:20	7/4/2011	9:40	7.95	0.33	0.24	0.96	0.72
82	7/8/2011	3:25	7/8/2011	7:50	3.74	4.42	1.20	1.93	0.27
83	7/23/2011	12:15	7/23/2011	13:30	15.18	1.25	0.28	2.41	0.22
84	8/3/2011	5:15	8/3/2011	8:35	10.66	3.33	0.68	1.93	0.20
85	8/7/2011	5:55	8/7/2011	7:30	3.89	1.58	0.84	2.41	0.53
86	8/8/2011	19:55	8/8/2011	20:30	1.52	0.58	0.36	1.45	0.62
87	8/21/2011	17:50	8/21/2011	18:05	12.89	0.25	0.24	1.45	0.96
88	9/4/2011	1:10	9/4/2011	2:30	13.30	1.33	0.48	1.45	0.36
89	9/4/2011	20:35	9/4/2011	22:50	0.75	2.25	0.40	1.45	0.18
90	9/7/2011	9:30	9/8/2011	22:05	2.44	36.58	0.44	0.96	0.01
91	9/14/2011	23:45	9/15/2011	1:35	6.07	1.83	0.44	0.96	0.24
92	9/19/2011	9:55	9/19/2011	15:05	4.35	5.17	0.36	0.48	0.07
93	9/23/2011	2:50	9/23/2011	10:20	3.49	7.50	0.52	0.96	0.07
94	9/25/2011	23:55	9/26/2011	9:55	2.57	10.00	2.76	3.37	0.28
95	9/29/2011	19:35	9/29/2011	21:20	3.40	1.75	0.32	1.45	0.18
96	10/13/2011	9:50	10/13/2011	14:45	13.52	4.92	0.32	0.48	0.07
97	10/19/2011	0:45	10/20/2011	12:15	5.42	35.50	2.28	1.45	0.06
98	10/26/2011	20:40	10/27/2011	3:35	6.35	6.92	1.36	0.96	0.20
99	11/3/2011	13:05	11/4/2011	1:00	7.40	11.92	0.96	0.96	0.08
100	11/14/2011	20:30	11/15/2011	7:10	10.81	10.67	1.96	0.96	0.18
101	11/16/2011	5:40	11/16/2011	10:25	0.94	4.75	0.40	0.48	0.08
102	11/20/2011	15:50	11/20/2011	20:40	4.23	4.83	0.20	0.48	0.04
103	11/21/2011	6:50	11/21/2011	7:20	0.42	0.50	0.40	2.89	0.80
104	11/21/2011	16:20	11/21/2011	21:10	0.38	4.83	0.20	0.48	0.04
105	11/22/2011	6:45	11/22/2011	11:55	0.40	5.17	0.80	0.96	0.15
106	11/27/2011	4:10	11/29/2011	4:30	4.68	48.33	2.24	0.96	0.05
107	11/29/2011	17:55	11/29/2011	21:35	0.56	3.67	0.24	0.96	0.07
108	12/4/2011	15:00	12/6/2011	0:40	4.73	33.67	3.16	0.96	0.09
109	12/15/2011	3:55	12/15/2011	11:50	9.14	7.92	0.40	0.48	0.05
110	12/19/2011	18:40	12/20/2011	0:30	4.28	5.83	0.32	0.48	0.05
111	12/21/2011	1:55	12/21/2011	12:10	1.06	10.25	0.52	0.48	0.05
112	12/22/2011	12:10	12/22/2011	20:15	1.00	8.08	0.76	0.96	0.09
113	12/27/2011	2:35	12/27/2011	15:30	4.26	12.92	0.76	0.96	0.06
114	1/11/2012	7:35	1/11/2012	11:30	14.67	3.92	0.36	0.96	0.09
115	1/12/2012	14:05	1/12/2012	16:10	1.11	2.08	0.20	0.48	0.10
116	1/17/2012	3:10	1/17/2012	12:15	4.46	9.08	1.68	3.37	0.18

Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain [a] (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
117	1/22/2012	23:25	1/23/2012	5:40	5.47	6.25	0.44	0.96	0.07
118	1/26/2012	4:20	1/26/2012	23:30	2.94	19.17	1.64	0.96	0.09
119	2/16/2012	0:00	2/16/2012	11:20	20.02	11.33	0.28	0.48	0.02
120	2/29/2012	3:25	2/29/2012	12:55	12.67	9.50	0.56	0.48	0.06
121	3/2/2012	13:10	3/2/2012	17:15	2.01	4.08	0.24	0.96	0.06
122	3/8/2012	7:50	3/8/2012	16:50	5.61	9.00	0.60	0.48	0.07
123	3/12/2012	7:05	3/12/2012	13:45	3.59	6.67	0.12	0.48	0.02
124	3/15/2012	10:25	3/15/2012	20:50	2.86	10.42	1.64	5.30	0.16
125	3/23/2012	12:15	3/23/2012	19:00	7.64	6.75	1.16	1.45	0.17
126	3/24/2012	1:05	3/24/2012	2:15	0.25	1.17	0.28	1.45	0.24
127	4/14/2012	10:20	4/14/2012	17:40	21.34	7.33	0.92	0.96	0.13
128	4/20/2012	23:55	4/21/2012	5:05	6.26	5.17	0.32	0.96	0.06
129	4/25/2012	20:00	4/26/2012	0:10	4.62	4.17	0.76	6.27	0.18
130	4/28/2012	5:05	4/28/2012	13:25	2.20	8.33	1.00	2.89	0.12
131	5/4/2012	21:20	5/5/2012	7:25	6.33	10.08	0.52	0.96	0.05
132	5/8/2012	0:35	5/8/2012	9:20	2.72	8.75	0.40	0.48	0.05
133	5/13/2012	3:40	5/13/2012	18:55	4.76	15.25	1.04	0.96	0.07
134	5/29/2012	8:55	5/29/2012	10:00	15.58	1.08	0.28	0.96	0.26
135	6/1/2012	1:50	6/1/2012	9:10	2.66	7.33	1.04	2.89	0.14
136	6/11/2012	7:35	6/11/2012	10:35	9.93	3.00	0.16	0.48	0.05
137	6/29/2012	9:15	6/29/2012	11:00	17.94	1.75	0.20	0.48	0.11
138	7/1/2012	6:40	7/1/2012	7:50	1.82	1.17	0.16	0.48	0.14
139	7/1/2012	19:35	7/1/2012	21:55	0.49	2.33	0.12	0.48	0.05
140	7/15/2012	13:55	7/15/2012	14:15	13.67	0.33	0.20	0.96	0.60
141	7/18/2012	16:00	7/18/2012	18:05	3.07	2.08	1.96	8.19	0.94
142	7/19/2012	9:45	7/19/2012	12:30	0.65	2.75	0.36	1.93	0.13
143	7/20/2012	12:35	7/20/2012	12:55	1.00	0.33	0.60	3.86	1.80
144	7/26/2012	15:40	7/26/2012	22:00	6.11	6.33	0.60	2.41	0.09
145	7/27/2012	17:30	7/27/2012	20:55	0.81	3.42	0.40	1.45	0.12
146	8/9/2012	16:45	8/9/2012	17:20	12.83	0.58	0.16	0.96	0.27
147	8/10/2012	2:35	8/10/2012	4:25	0.39	1.83	0.36	0.96	0.20
148	8/27/2012	10:10	8/27/2012	17:20	17.24	7.17	0.28	1.45	0.04
149	10/1/2012	16:00	10/1/2012	21:45		5.75	0.79	1.07	0.14
150	10/5/2012	18:20	10/6/2012	1:30	3.86	7.17	0.50	0.60	0.07
151	10/19/2012	13:25	10/19/2012	21:00	13.50	7.58	0.14	0.17	0.02
152	10/26/2012	9:55	10/27/2012	1:35	6.54	15.67	0.85	0.33	0.05
153	10/30/2012	2:10	10/30/2012	10:00	3.02	7.83	0.41	0.11	0.05
154	11/3/2012	12:00	11/3/2012	16:25	4.08	4.42	0.12	0.16	0.03
155	11/12/2012	3:50	11/12/2012	13:50	8.48	10.00	0.78	0.35	0.08

Event #	Rain start date	Rain start time	Rain end date	Rain end time	Antecedent dry days	Rain dur. (hrs)	Total rain [a] (in)	5-minute peak rain intensity (in/hr)	Avg rain int. (in/hr)
156	11/26/2012	22:55	11/27/2012	2:10	14.38	3.25	0.08	0.05	0.02
157	12/2/2012	7:20	12/2/2012	11:25	5.22	4.08	0.49	0.69	0.12
158	12/4/2012	15:40	12/4/2012	18:45	2.18	3.08	0.18	0.41	0.06
159	12/6/2012	19:00	12/7/2012	1:40	2.01	6.67	0.29	0.37	0.04
160	12/7/2012	7:55	12/7/2012	18:20	2.55	10.42	0.71	0.28	0.07
161	12/9/2012	19:50	12/10/2012	3:50	2.06	8.00	0.98	1.59	0.12
162	12/15/2012	12:00	12/15/2012	16:05	5.34	4.08	0.08	0.14	0.02
163	12/17/2012	12:45	12/17/2012	16:05	1.86	3.33	0.54	0.96	0.16
164	12/20/2012	7:15	12/20/2012	20:00	2.63	12.75	0.94	0.48	0.07
165	12/26/2012	3:50	12/26/2012	14:35	5.33	10.75	1.33	0.47	0.12
166	12/28/2012	21:00	12/29/2012	6:05	2.27	9.08	0.12	0.08	0.01

Runoff characteristics for Clark Montessori High School combined sewer line

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
1	3/10/2010	3:45	3/10/2010	15:10	11.42	2,417	0.045	0.83	0.06	13.83	0.38	1.30
2	3/11/2010	7:00	3/11/2010	18:25	11.42	1,227	0.023	0.46	0.03	15.33	0.29	8.06
3	3/12/2010	17:50	3/14/2010	3:30	33.67	30,726	0.573	2.21	0.25	8.84	0.37	1.29
4	3/14/2010	3:40	3/14/2010	23:55	20.25	2,367	0.044	0.24	0.03	8.00	0.37	12.15
5	3/21/2010	17:50	3/22/2010	9:10	15.33	24,469	0.457	1.88	0.44	4.27	0.76	2.19
6	3/25/2010	13:55	3/26/2010	11:40	21.75	44,445	0.829	4.22	0.57	7.40	0.74	1.86
7	3/28/2010	2:45	3/29/2010	2:25	23.67	791	0.015	0.27	0.01	27.00	0.06	1.99
8	3/29/2010	6:15	3/29/2010	9:15	3.00	475	0.009	0.16	0.04	4.00	0.11	6.00
9	4/5/2010	18:30	4/6/2010	1:10	6.67	3,407	0.064	5.77	0.14	41.21	0.18	40.00
10	4/8/2010	0:55	4/8/2010	12:45	11.83	3,540	0.066	0.77	0.08	9.63	0.17	1.75
11	4/23/2010	11:20	4/23/2010	16:20	5.00	934.01	0.017	0.27	0.05	5.40	0.07	1.71
12	4/24/2010	16:50	4/25/2010	1:40	8.83	17,913	0.334	2.64	0.56	4.71	0.32	1.49
13	4/25/2010	15:10	4/25/2010	23:30	8.33	965	0.018	0.51	0.04	12.75	0.15	3.45
14	5/16/2010	18:15	5/17/2010	2:45	8.50	1,050	0.020	0.23	0.03	7.67	0.10	2.17
15	5/17/2010	5:10	5/18/2010	17:35	36.42	3,570	0.067	1.18	0.08	14.75	0.28	14.57
16	5/21/2010	12:30	5/21/2010	23:55	11.42	2,825	0.053	1.52	0.07	21.71	0.15	1.96
17	5/31/2010	14:50	5/31/2010	23:55	9.08	2,582	0.048	1.46	0.08	18.25	0.40	3.89
18	6/14/2010	22:50	6/15/2010	2:40	3.83	5,061	0.094	7.07	0.37	19.11	0.21	9.20
19	6/15/2010	20:55	6/16/2010	5:20	8.42	6,089	0.114	2.6	0.2	13.00	0.26	2.81
20	6/19/2010	6:00	6/19/2010	14:30	8.50	7,932	0.148	2.77	0.26	10.65	0.28	3.19
21	6/21/2010	12:20	6/21/2010	23:05	10.75	6,739	0.126	3.88	0.17	22.82	0.52	4.96
22	6/27/2010	22:40	6/28/2010	8:35	9.92	23,602	0.440	8.09	0.66	12.26	0.28	2.25
23	7/20/2010	18:35	7/21/2010	2:40	8.08	4,300	0.080	2.55	0.15	17.00	0.25	2.11
24	8/11/2010	14:05	8/11/2010	17:00	2.92	1,772	0.033	1.44	0.17	8.47	0.05	8.75
25	8/14/2010	17:40	8/14/2010	19:30	1.83	2,332	0.044	2.3	0.34	6.76	0.37	11.00
26	9/16/2010	4:25	9/16/2010	9:50	5.42	1,635	0.031	1.63	0.08	20.38	0.19	2.50
27	9/20/2010	9:45	9/20/2010	14:20	4.58	267	0.005	0.1	0.02	5.00	0.02	55.00
28	11/16/2010	11:05	11/17/2010	1:40	14.58	10,791	0.201	1.84	0.21	8.76	0.24	1.11
29	11/23/2010	1:40	11/23/2010	9:00	7.33	8,600	0.161	3.32	0.33	10.06	0.29	2.00
30	11/24/2010	13:20	11/25/2010	1:40	12.33	12,770	0.238	1.05	0.29	3.62	0.30	1.35
31	11/25/2010	6:15	11/26/2010	6:30	24.25	48,686	0.909	3.39	0.76	4.46	0.35	1.39
32	11/29/2010	22:05	11/30/2010	23:55	25.83	32,292	0.603	1.74	0.35	4.97	0.43	1.17
33	12/11/2010	16:55	12/12/2010	12:20	19.42	6,855	0.128	0.36	0.1	3.60	0.27	1.57
34	12/18/2010	11:35	12/18/2010	17:35	6.00	68	0.001	0.03	0.00	10.72	0.01	1.80
35	12/30/2010	1:00	12/30/2010	16:35	15.58	3,644	0.068	0.26	0.06	3.96	0.21	1.63
36	1/1/2011	1:10	1/1/2011	12:45	11.58	9,803	0.183	1.21	0.25	4.84	0.42	1.62
37	1/18/2011	9:20	1/18/2011	18:35	9.25	4,058	0.076	0.29	0.12	2.42	0.24	1.04

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
38	1/24/2011	14:25	1/25/2011	4:15	13.83	990	0.018	0.18	0.02	9.00	0.12	1.89
39	2/5/2011	5:20	2/5/2011	13:20	8.00	617	0.012	0.28	0.02	14.00	0.07	1.92
40	2/21/2011	8:15	2/21/2011	23:55	15.67	39,691	0.741	3.2	0.7	4.57	0.36	1.55
41	2/24/2011	17:45	2/25/2011	21:25	27.67	45,743	0.854	4.43	0.46	9.63	0.59	2.32
42	2/27/2011	19:00	2/27/2011	23:20	4.33	1,837	0.034	0.99	0.12	8.25	0.05	1.24
43	2/28/2011	5:20	2/28/2011	15:40	10.33	6,830	0.127	4.6	0.18	25.56	0.40	6.20
44	3/4/2011	11:10	3/5/2011	23:55	36.75	27,595	0.515	1.88	0.2	9.40	0.37	1.14
45	3/8/2011	22:15	3/10/2011	7:55	33.67	32,593	0.608	3.4	0.27	12.59	0.42	1.53
46	3/15/2011	4:10	3/15/2011	17:30	13.33	923	0.017	0.57	0.02	28.50	0.09	1.17
47	3/18/2011	13:55	3/18/2011	23:10	9.25	4,967	0.093	2.73	0.15	18.20	0.23	7.93
48	4/1/2011	21:00	4/1/2011	23:35	2.58	1,198	0.022	0.81	0.12	6.75	0.14	6.20
49	4/4/2011	13:05	4/4/2011	20:30	7.42	13,370	0.250	2.18	0.5	4.36	0.23	2.17
50	4/9/2011	11:10	4/9/2011	16:35	5.42	6,363	0.119	1.03	0.33	3.12	0.25	1.51
51	4/11/2011	8:15	4/12/2011	18:35	34.33	44,225	0.825	2.76	0.36	7.67	0.43	1.45
52	4/15/2011	23:00	4/17/2011	13:20	38.33	17,157	0.320	2.5	0.33	7.58	0.35	3.46
53	4/19/2011	0:00	4/19/2011	21:00	21.00	51,250	0.956	8.05	0.51	15.78	0.47	2.08
54	4/20/2011	1:30	4/20/2011	20:45	19.25	28,646	0.535	3.83	0.41	9.34	0.50	2.89
55	4/22/2011	17:00	4/23/2011	23:45	30.75	12,045	0.225	5.94	0.5	11.88	0.35	13.18
56	4/23/2011	1:40	4/23/2011	11:50	10.17	21,031	0.393	4.78	0.57	8.39	0.70	2.07
57	4/23/2011	13:45	4/24/2011	6:15	16.50	31,109	0.581	6.61	0.52	12.71	0.50	2.36
58	4/24/2011	8:00	4/24/2011	15:15	7.25	2,910	0.054	0.73	0.11	6.64	0.27	2.81
59	4/27/2011	2:30	4/27/2011	15:10	12.67	8,524	0.159	3.87	0.19	20.37	0.28	3.04
60	4/27/2011	16:30	4/27/2011	23:20	6.83	3,152	0.059	0.97	0.13	7.46	0.37	2.00
61	4/28/2011	18:00	4/28/2011	21:20	3.33	2,397	0.045	1.78	0.2	8.90	0.28	3.08
62	5/1/2011	19:50	5/2/2011	13:40	17.83	11,663	0.218	2.08	0.18	11.56	0.29	1.56
63	5/2/2011	15:20	5/3/2011	20:00	28.67	41,510	0.775	2.01	0.4	5.03	0.52	1.62
64	5/7/2011	23:25	5/8/2011	4:10	4.75	6,303	0.118	2.32	0.37	6.27	0.37	3.80
65	5/13/2011	16:05	5/13/2011	18:15	2.17	1,148	0.021	1.45	0.15	9.67	0.18	8.67
66	5/14/2011	7:05	5/14/2011	17:20	10.25	905	0.017	0.4	0.02	20.00	0.11	1.26
67	5/15/2011	18:00	5/15/2011	23:55	5.92	1,760	0.033	1.04	0.03	34.67	0.21	6.45
68	5/17/2011	10:00	5/18/2011	10:45	24.75	3,792	0.071	0.51	0.04	12.75	0.21	1.56
69	5/22/2011	18:00	5/22/2011	23:25	5.42	1,240	0.023	1.99	0.05	39.80	0.19	65.00
70	5/23/2011	1:10	5/23/2011	13:20	12.17	14,576	0.272	8.32	0.33	25.21	0.25	2.06
71	5/23/2011	19:30	5/24/2011	7:20	11.83	8,333	0.156	1.78	0.19	9.37	0.22	2.33
72	5/26/2011	0:35	5/26/2011	22:50	22.25	14,658	0.274	2.83	0.18	15.72	0.24	1.23
73	6/10/2011	18:25	6/11/2011	2:55	8.50	24,064	0.449	9.06	0.7	12.94	0.17	3.40
74	6/11/2011	4:05	6/11/2011	13:00	8.92	24,074	0.449	8.43	0.74	11.39	0.37	2.23
75	6/15/2011	11:25	6/15/2011	20:45	9.33	4,722	0.088	1.1	0.14	7.86	0.17	2.00

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
76	6/19/2011	10:50	6/19/2011	17:55	7.08	252	0.005	0.08	0.01	8.00	0.03	1.23
77	6/20/2011	10:25	6/20/2011	17:45	7.33	17,360	0.324	4.54	0.66	6.88	0.39	3.52
78	6/21/2011	11:45	6/22/2011	7:30	19.75	25,995	0.485	8.86	0.37	23.95	0.28	2.52
79	6/22/2011	22:40	6/23/2011	11:45	13.08	9,473	0.177	7.89	0.2	39.45	0.28	2.31
80	6/26/2011	4:40	6/26/2011	16:20	11.67	10,131	0.189	0.99	0.24	4.13	0.32	2.19
81	7/4/2011	9:15	7/4/2011	10:55	1.67	2,312	0.043	2.26	0.39	5.79	0.18	5.00
82	7/8/2011	2:45	7/8/2011	12:25	9.67	11,740	0.219	1.96	0.34	5.76	0.18	2.19
83	7/23/2011	8:40	7/23/2011	15:20	6.67	2,434	0.045	3.38	0.1	33.80	0.16	5.33
84	8/3/2011	3:00	8/3/2011	11:10	8.17	4,594	0.086	1.67	0.16	10.44	0.13	2.45
85	8/7/2011	5:50	8/7/2011	10:05	4.25	10,575	0.197	4.7	0.69	6.81	0.23	2.68
86	8/8/2011	20:15	8/8/2011	23:55	3.67	7,498	0.140	2.81	0.22	12.77	0.39	6.29
87	8/21/2011	16:55	8/21/2011	20:20	3.42	1,910	0.036	2.14	0.16	13.38	0.15	13.67
88	9/4/2011	1:15	9/4/2011	6:10	4.92	8,629	0.161	5.78	0.48	12.04	0.34	3.69
89	9/4/2011	20:25	9/4/2011	23:55	3.50	6,519	0.122	2.22	0.25	8.88	0.30	1.56
90	9/7/2011	9:05	9/8/2011	23:50	38.75	6,807	0.127	0.61	0.13	4.69	0.29	1.06
91	9/14/2011	23:25	9/15/2011	5:50	6.42	5,369	0.100	1.35	0.24	5.63	0.23	3.50
92	9/19/2011	9:55	9/19/2011	20:20	10.42	7,349	0.137	0.96	0.2	4.80	0.38	2.02
93	9/23/2011	3:05	9/23/2011	16:10	13.08	8,345	0.156	1.36	0.18	7.56	0.30	1.74
94	9/26/2011	0:00	9/26/2011	15:20	15.33	39,920	0.745	5.72	0.72	7.94	0.27	1.53
95	9/29/2011	19:30	9/29/2011	23:50	4.33	2,366	0.044	1.2	0.15	8.00	0.14	2.48
96	10/13/2011	9:50	10/13/2011	17:55	8.08	4,986	0.093	1.62	0.17	9.53	0.29	1.64
97	10/19/2011	0:00	10/20/2011	16:35	40.58	38,659	0.721	1.85	0.22	8.41	0.32	1.14
98	10/26/2011	20:40	10/27/2011	9:55	13.25	21,346	0.398	1.79	0.45	3.98	0.29	1.92
99	11/3/2011	13:10	11/4/2011	8:45	19.58	17,529	0.327	1.43	0.25	5.72	0.34	1.64
100	11/14/2011	21:25	11/15/2011	13:20	15.92	31,730	0.592	3.06	0.55	5.56	0.30	1.49
101	11/16/2011	6:55	11/16/2011	16:20	9.42	8,757	0.163	1.14	0.26	4.38	0.41	1.98
102	11/20/2011	14:40	11/20/2011	23:20	8.67	2,806	0.052	0.32	0.09	3.56	0.26	1.79
103	11/21/2011	6:25	11/21/2011	12:10	5.75	3,612	0.067	1.82	0.17	10.71	0.17	11.50
104	11/21/2011	14:35	11/22/2011	2:35	12.00	5,181	0.097	1.39	0.12	11.58	0.48	2.48
105	11/22/2011	5:15	11/22/2011	21:40	16.42	24,224	0.452	2.67	0.41	6.51	0.57	3.18
106	11/27/2011	3:40	11/29/2011	12:00	56.33	57,151	1.067	0.93	0.28	3.32	0.48	1.17
107	11/29/2011	17:35	11/30/2011	9:00	15.42	3,584	0.067	0.33	0.06	5.50	0.28	4.20
108	12/4/2011	14:45	12/6/2011	12:05	45.33	97,119	1.813	3.2	0.6	5.33	0.57	1.35
109	12/15/2011	3:40	12/15/2011	16:45	13.08	8,867	0.165	1.15	0.19	6.05	0.41	1.65
110	12/19/2011	18:15	12/20/2011	9:55	15.67	6,065	0.113	0.91	0.11	8.27	0.35	2.69
111	12/21/2011	1:35	12/21/2011	14:15	12.67	13,419	0.250	2.25	0.29	7.76	0.48	1.24
112	12/22/2011	12:10	12/22/2011	23:55	11.75	19,099	0.356	1.19	0.45	2.64	0.47	1.45
113	12/27/2011	2:25	12/27/2011	20:25	18.00	11,894	0.222	1.26	0.19	6.63	0.29	1.39

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
114	1/11/2012	7:20	1/11/2012	14:45	7.42	3,348	0.062	0.85	0.13	6.54	0.17	1.89
115	1/12/2012	12:40	1/12/2012	18:50	6.17	1,305	0.024	0.44	0.06	7.33	0.12	2.96
116	1/17/2012	1:40	1/17/2012	20:55	19.25	41,980	0.783	4.56	0.61	7.48	0.47	2.12
117	1/22/2012	23:50	1/23/2012	15:30	15.67	7,091	0.132	1.77	0.13	13.62	0.30	2.51
118	1/26/2012	3:45	1/27/2012	11:20	31.58	54,795	1.023	2.93	0.48	6.10	0.62	1.65
119	2/16/2012	0:10	2/16/2012	14:25	14.25	3,137	0.059	0.52	0.06	8.67	0.21	1.26
120	2/29/2012	3:30	2/29/2012	17:20	13.83	6,658	0.124	2.02	0.13	15.54	0.22	1.46
121	3/2/2012	11:35	3/2/2012	20:55	9.33	3,534	0.066	2.02	0.11	18.36	0.27	2.29
122	3/8/2012	6:05	3/8/2012	19:15	13.17	8,094	0.151	1.07	0.17	6.29	0.25	1.46
123	3/12/2012	6:00	3/12/2012	17:00	11.00	1,101	0.021	0.43	0.03	14.33	0.17	1.65
124	3/15/2012	10:30	3/15/2012	23:15	12.75	17,451	0.326	4.66	0.4	11.65	0.20	1.22
125	3/23/2012	11:35	3/23/2012	23:55	12.33	22,756	0.425	6.1	0.51	11.96	0.37	1.83
126	3/24/2012	1:05	3/24/2012	5:45	4.67	4,140	0.077	1.48	0.23	6.43	0.28	4.00
127	4/14/2012	10:00	4/14/2012	23:05	13.08	17,820	0.333	0.215	2.5	0.38	0.36	1.78
128	4/20/2012	23:45	4/21/2012	4:35	4.83	1,225	0.023	0.39	0.03	13.00	0.07	0.94
129	4/25/2012	23:55	4/26/2012	0:50	0.92	681	0.013	2.05	0.21	9.76	0.02	0.22
130	4/28/2012	4:50	4/28/2012	18:20	13.50	8,561	0.160	2.19	0.18	12.17	0.16	1.62
131	5/4/2012	21:15	5/5/2012	9:40	12.42	7,265	0.136	2.42	0.16	15.13	0.26	1.23
132	5/8/2012	0:35	5/8/2012	12:45	12.17	6,231	0.116	1.43	0.14	10.21	0.29	1.39
133	5/13/2012	5:15	5/13/2012	23:55	18.67	25,177	0.470	2.19	0.37	5.92	0.45	1.22
134	5/29/2012	9:15	5/29/2012	12:00	2.75	1,408	0.026	0.65	0.14	4.64	0.09	2.54
135	6/1/2012	0:45	6/1/2012	15:05	14.33	21,744	0.406	6.49	0.42	15.45	0.39	1.95
136	6/11/2012	6:40	6/11/2012	14:05	7.42	2,186	0.041	0.28	0.08	3.50	0.25	2.47
137	6/29/2012	17:35	6/29/2012	20:35	3.00	4,175	0.078	2.28	0.39	5.85	0.39	1.71
138	7/1/2012	5:20	7/1/2012	7:50	2.50	200	0.004	0.12	0.02	6.00	0.02	2.14
139	7/1/2012	15:20	7/1/2012	23:05	7.75	277	0.005	0.2	0.01	20.00	0.04	3.32
140	7/15/2012	11:20	7/15/2012	20:50	9.50	261	0.005	0.11	0.01	11.00	0.02	28.50
141	7/18/2012	16:00	7/18/2012	23:30	7.50	23,232	0.434	6.68	0.86	7.77	0.22	3.60
142	7/19/2012	9:40	7/19/2012	15:35	5.92	2,116	0.039	1.24	0.1	12.40	0.11	2.15
143	7/20/2012	12:35	7/20/2012	16:30	3.92	400	0.007	0.36	0.03	12.00	0.01	11.75
144	7/26/2012	15:25	7/26/2012	23:50	8.42	6,704	0.125	3.93	0.22	17.86	0.21	1.33
145	7/27/2012	17:30	7/27/2012	22:25	4.92	1,899	0.035	1.61	0.11	14.64	0.09	1.44
146	8/9/2012	17:05	8/9/2012	23:50	6.75	32	0.001	0.01	0.00	11.35	0.00	11.57
147	8/10/2012	1:50	8/10/2012	6:30	4.67	4,892	0.091	0.76	0.29	2.62	0.25	2.55
148	8/27/2012	10:15	8/27/2012	18:15	8.00	2,016	0.038	0.92	0.07	13.14	0.13	1.12
149	10/1/2012	18:05	10/1/2012	23:55	5.83	13,418	0.250	0.234	0.049	4.78	0.32	1.01
150	10/5/2012	21:25	10/6/2012	7:30	10.08	6,509	0.121	1.79	0.18	9.94	0.24	1.41
151	10/19/2012	14:35	10/19/2012	23:20	8.75	4,583	0.086	0.6	0.15	4.00	0.62	1.15

Event #	Pipeflow start date	Pipeflow start time	Pipeflow end date	Flow end time	Flow dur. (hrs)	Total pipeflow discharge volume (ft3)	Total disch. (in)	5-minute Peak flow disch. rate (CFS)	5-minute Avg flow disch. rate (CFS)	Peak/avg pipeflow rate ratio	Rv (Runoff Depth/Rain Depth)	flow/ rain dur. ratio
152	10/26/2012	10:40	10/27/2012	9:20	22.67	19,307	0.360	1.06	0.24	4.42	0.43	1.45
153	10/30/2012	4:30	10/30/2012	14:55	10.42	8,647	0.161	0.63	0.23	2.74	0.39	1.33
154	11/3/2012	12:20	11/3/2012	20:25	8.08	2,596	0.048	0.57	0.09	6.33	0.40	1.83
155	11/12/2012	4:30	11/12/2012	16:35	12.08	14,058	0.262	1.46	0.32	4.56	0.34	1.21
156	11/26/2012	0:50	11/27/2012	5:00	28.17	254	0.005	0.08	0.02	4.00	0.06	8.67
157	12/2/2012	8:05	12/2/2012	14:15	6.17	6,148	0.115	2.15	0.23	9.35	0.23	1.51
158	12/4/2012	16:05	12/4/2012	23:20	7.25	5,472	0.102	1.9	0.19	10.00	0.57	2.35
159	12/6/2012	17:05	12/7/2012	0:55	31.83	3,850	0.072	0.92	0.1	9.20	0.25	4.77
160	12/7/2012	7:15	12/7/2012	23:55	16.67	18,898	0.353	1.14	0.13	8.77	0.50	1.60
161	12/9/2012	20:35	12/10/2012	6:10	9.58	18,773	0.350	4.49	0.54	8.31	0.36	1.20
162	12/15/2012	12:25	12/15/2012	14:30	2.08	115	0.002	0.07	0.02	3.50	0.03	0.51
163	12/17/2012	14:05	12/17/2012	20:35	6.50	3,845	0.072	1.49	0.16	9.31	0.13	1.95
164	12/20/2012	7:55	12/20/2012	21:15	13.33	14,302	0.267	2.1	0.3	7.00	0.28	1.05
165	12/26/2012	4:50	12/26/2012	23:30	18.67	12,990	0.242	0.87	0.19	4.58	0.18	1.74
166	12/28/2012	21:05	12/29/2012	12:05	15.00	1,091	0.020	0.15	0.02	7.50	0.17	1.65