MONITORING WATER BALANCE OF A RAIN GARDEN BY INSTALLATION OF FLOW MONITORING DEVICES ON A RESIDENTIAL PROPERTY

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MASTER OF SCIENCE

by
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MONITORING WATER BALANCE OF A RAIN GARDEN

BY INSTALLATION OF FLOW MONITORING

DEVICES ON A RESIDENTIAL PROPERTY

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ABSTRACT

Rain gardens are infiltration best management practices that are installed in existing and new construction for the purposes of water quality in receiving waters and stormwater volume reduction. Nationally, rain gardens are transitioning from landscaping features with beneficial environmental effects to facultative engineered systems for meeting water quality standards or providing peak flow attenuation in combined sewersheds. The objectives of this study were to site, design, install, and monitor the hydraulic characteristics of a typical rain garden installation on a private residential property. Infiltration tests by infiltrometer and full-inundation methods were conducted yielding results that indicate infiltration rates in current rain garden design guidance may be too conservative. Guidance for the design and installation of rain gardens are provided that may improve their large-scale implementation as part of a watershed management plan.

APPROVAL PAGE

The faculty listed below, appointed by the Dean of the School of Computing and Engineering have examined a thesis titled "Monitoring Water Balance of a Rain Garden by Installation of Flow Monitoring Devices on a Residential Property," presented by Jason F. Nall, candidate for Master of Science degree, and certify that in their opinion is worthy of acceptance.

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CHAPTER 1

INTRODUCTION

Stormwater management is trending toward decentralizing traditional end-of-pipe best management practices (BMPs). Traditional centralized BMPs include: detention/retention ponds, infiltration basins, and rapid-treatment systems. The functionality of centralized BMPs is largely dependent on substantial conveyance structures whose location and size are designed for expedient removal of stormwater runoff from transportation facilities and properties. When stormwater detention structures are utilized for peak flow attenuation, these structures result in either an increase or decrease from the pre-development peak flow at a given point downstream of the basin depending on the watershed characteristics (Sloat and Hwang, 2010). While stormwater detention is an effective flood-control practice through peak flow attenuation immediately downstream of the basin, uniform design and use result in peak flow rates higher than the pre-development peak flow rate, which results in stream bank degradation (Goff and Gentry, 2005). Detention ponds designed for water quality increase the size of the detention facility, decreasing available usable land space and provide diminishing pollutant removal for the cost of construction (Guo and Urbonas, 1996). Infiltration basins are believed to be highly effective centralized

BMP for nutrient removal (EPA 2012). Infiltration basins also provide storage, peak flow attenuation, and volume reduction.

While infiltration basins are believed to be an effective centralized BMP, infiltration basins are also difficult to site, design, and install (EPA 2012). Located at the terminus of a sewershed basin, infiltration basins are installed at the lowest point in the sub-catchment of a watershed, where there is an increased likelihood high groundwater tables that can potentially inhibit the infiltration capacity of the absorption area. Locations of high groundwater tables minimize the depth of the vadose zone exasperating groundwater mounding effects. The infiltrative surface of the absorption area is also sensitive to clogging by the suspended solids loading (EPA, 2012). Installation of infiltration basins also presents difficulties when impact forces are applied to the soil by the operation of the bucket compacting the soils, thus reducing porosity and hydraulic conductivity (R. Bannerman, Pers. Comm., 2010). When the soil structure matix is intact, infiltration and percolation, occur through available void space in the soil. Compaction of the soil results in a decrease in the size of the voids and the loss of void space available for water flow (Das, 2006).

Rain gardens are decentralized BMPs that collect and infiltrate stormwater runoff from small contributing areas. The purpose of rain garden installations is similar to infiltration basins, but can offer advantages not found with infiltration basins. The size of rain gardens allow them to be installed near the source of the runoff, which leads to installations located in the upper portions of the catchment, which are recharge areas and ideal for infiltration practices. The highlands are recharge areas and lowlands are discharge areas (Freeze and Cherry, 1979). The increased depth to the groundwater allows rain gardens to sustain design infiltration rates over extended periods and accelerated dissipation of groundwater mounding. When groundwater mounds under an infiltration BMP, the mounding results in groundwater flow that is in a saturated condition, resulting in slower infiltration rates for fine-grained soils (Fetter, 2001). The infiltration capacity of the absorption area can be restored between storm events by burrowing animals and available soil capacity through evapo-transpiration and percolation. The smaller size of the rain garden retention volume and absorption area requires smaller, low-impact equipment, such as small wide-tracked excavators, that would not typically be utilized in the installation of an infiltration basin, thus protecting the existing soil matrix structure.

The size, performance, and benefits of rain gardens are directing design and implementation on an individual lot basis, where a significant portion of the stormwater runoff generated on a lot can be treated at the source (Ports, 2009). A source treatment control system spatially distributes small depressions to attenuate peak flows and reduce volume of runoff to mimic nature's storage systems prior to urbanization (Andoh and Declerck, 1997). Treating runoff at the source also means: maximizing depression storage and infiltration, minimizing discharge by minimizing directly connected impervious area, maximizing flow paths and time of concentration, and maximizing evapotranspiration (Lee and Struck, 2009). This type of decentralized implementation versus a centralized installation for the treatment of stormwater runoff is similar to onsite wastewater treatment systems versus wastewater treatment plants, where rain gardens, when installed on individual properties for the treatment of runoff generated on those properties, should be designed for site-specific for performance. While rain gardens when used exclusively will not likely meet peak flow attenuation requirements in most developed watersheds, they may be used as part of an overall stormwater management chain that reduces runoff volume and attenuates peak flow (Williams and Wise, 2006). Rain gardens should not be singularly designed for broad application over the entire watershed, or multiple watersheds. The infiltration rate established by testing for a particular location and elevation of the absorption area should control areal size and available storage volume.

Implementation of rain gardens as a major control method for stormwater management is slow because the effects and the reliability of these structures have not been quantified to a great extent (Fujita, 2010). This quantification requires performance monitoring of field installations to build a knowledge base on the implementation of rain gardens.

The installation and performance monitoring of the rain garden demonstrates the rain garden's capabilities of treating stormwater at the source, resulting in significant reductions in the discharge of the stormwater runoff from building structures, with the potential to also capture runoff from other surfaces.

1.1 Project Overview

The ultimate objective for this project was to collect data on the water balance of a residential rain garden by monitoring real-time inflow and outflow in an isolated, well-controlled, system. This objective resulted in a number of smaller objectives that included the siting, rain garden design, rain garden installation, and development of an innovative flow monitoring device to monitor inflow to the rain garden that is compact, unobtrusive, and capable of dependably recording the large range of flows that can be expected from storm events of varying intensity. As it is desirable to extend the duration of the project over a longer duration, a three-year access agreement was signed by the owner of the property, which would also allow monitoring of the rain garden as it matures. The scope of this projected is limited to the design and installation of the rain garden and monitoring appurtenances and the first year's observations, which occurred late September 2010 through mid-November 2010.

1.2 Experimental Plan

There were a couple of controlling factors that had to be considered in developing the monitoring program for the rain garden. The primary factor was the large range of flows that were expected to be discharged to the garden. One of the difficulties with flume installations is recording small flows. Low flows have been a problem for other studies of infiltration BMP's. In a study by Furumai, et al (2005), the research group was unable to record flow less than 0.01 m^3/s (0.353 cfs). The maximum design flow from the contributing roof area of the residence was calculated to be 0.17 cfs, which comes from the 100-year, five-minute duration storm intensity for the Kansas City area. The minimum flow would be much less, particularly at the beginning and the ends of the inflow hydrographs. A small Palmer-Bowlus flume may have been sufficient to cover the range of flows, but this would require the approach to be subcritical flow. The momentum of the water falling twenty feet and being discharged to a rain garden ten feet from the house precluded the use of a flume. To accommodate the large range of flows, a compound orifice-controlled device was designed and fabricated. A small orifice is provided to control and measure small flows. A larger 2.25 in. diameter orifice was provided to measure flows nearly up to the 100-year peak intensity flow of 0.17 cfs. The size of the orfice was minimized to provide varying flow depths for recording, while allowing enough head space without overflow. A level logger in the barrel recorded the water level for calculating discharge from the orifices. Turbulence of the water level within the barrel was a concern, which was addressed with a screened inlet. The screened inlet also provided a secondary benefit by filtering leaf clutter, preventing blockage of the orifices. A simple v-notch weir was designed for the outlet of the rain garden to record discharge flows, if they occur.

Additional planning included discussions with the property owner on the aesthetics of the flow monitoring devices and the rain garden itself. The location of the rain garden and monitoring appurtenances were discussed at length and overall appearance. Throughout the design and construction, the research team was able to satisfactorily accommodate the owner with color scheme of the monitoring equipment and appearance of the rain garden.

CHAPTER 2

SITING

The site selected for the private rain garden installation had ample area for a ten (10) foot setback from foundation wall, adequate lawn space to design the rain garden absorption area, room next to the residential structure to isolate inflow for metering, and positive drainage for conveyance of overflow discharge away from structures and the property, following existing drainage patterns. An aerial view of the residence with the contributing roof drainage area and approximate location of the rain garden is provided in

Figure 2.1.

Figure 2.1 Aerial view of private rain garden installation residence. (Mid-America Regional Council)

2.1 Siting Methods

A field soil inspection was conducted following the selection of the potential site, and, by visual inspection, the soil appeared to be a silty clay loam. A rough percolation test was conducted for site suitability (Bannerman & Considine, 2003). The percolation test yielded results that were favorable for locating the rain garden. The water infiltrated the soil in less than eight (8) minutes. The test was conducted by digging a six (6) inch hole and filling it with water to a depth of five (5) inches. The estimated initial permeability of the soil from the test was 37.5 inches per hour. While this rough infiltration method for siting the rain garden is not a standard method for measuring infiltration, it does give an indication of the suitability of the soils for an infiltration BMP. A thorough soil investigation of the absorption area subsoils was conducted following the siting of the garden, which is discussed in Section 6.3.

CHAPTER 3

DESIGN

The rain garden was designed for a residential installation per discussions with Dr. Scott Struck, where storage volume is provided based on the size of the contributing area for a water quality volume of a one (1) inch rainfall event and an allowable ponding depth of six (6) inches (S. Struck, Pers. Comm., 2010). The contributing area to the rain garden was estimated by visual inspection of the arrangement of the gutter and roof leader system and measuring the perimeter of contributing area of the roof to the gutter and roof leader system. Conclusions drawn from those observations were that it was possible to collect stormwater runoff from the southwest quadrant of the residential structure and the west half of the attached covered front porch. The combined contributing area is 671 square feet split between two roof leaders, one for the southwest quadrant of the residential structure and one for the west portion of the covered front porch. The required storage volume for a rainfall event depth of one (1) inch with a contributing area of 671 square feet is 56 cubic feet. The area required for the rain garden with a storage depth of six inches is 112 square feet. The designed absorption area is approximately 17% of the contributing area. Published guidance for sizing the absorption area for residential private rain garden installations ranges from 25-30% for a silty clay loam to a broad 30% for any type of soil (Bannerman & Considine, 2003).

CHAPTER 4

INSTALLATION

A concerted effort was made to construct the rain garden using tools that a typical resident would have available, or be able to purchase at a reasonable cost. Tools for the installation were limited to a drain spade, square point shovel, carpenter's line, wood stakes, line levels, rope, bow rake, and a tarp.

4.1 Excavation

The excavation of the rain garden absorption area and installation of a berm required careful construction techniques to ensure a flat absorption area and a stable berm to retain water for monitoring pool elevations.

- The boundary of the absorption area was delineated by a rope.
- Sod was then removed from the absorption area and stockpiled.
- Following sod removal from the absorption area, a two-foot boundary was marked outside the absorption area for sod removal and placement of the berm.
- Two string lines with levels were strewn taut across the absorption area as guides to gauge depth of the excavation.
- Soil excavated from the absorption area was placed and compacted by firm tapping of a foot for placement of the berm.
- Excess soil not used for construction of the berm was placed with the stockpiled sod for use by the homeowner in other areas of the property.

- Fine adjustments to the elevation of absorption area were made using a tape measure, balanced string line, and rake.
- Excavation was only performed during dry conditions to minimize disturbance to the soils in the absorption area.

4.2 Planting

Planting of the rain garden was a cooperative effort between the Mid-America Regional Council (MARC) and the Target Green Team from the University of Missouri-Kansas City. Plants were selected by MARC through a vendor historically used by MARC for other similar BMP installations. The first planting of the rain garden was delayed by rain and time allowances that were made to allow the absorption area to dry before the planting commenced. At this stage of construction, a change was made to the design depth of six (6) inches to allow for the placement of two (2) inches of compost, modifying the design ponding depth to four (4) inches, to aid in the establishment of the vegetation. A second planting was required to amend the first planting, providing the homeowner with a denser, more aesthetically appealing rain garden during the establishment of vegetation. The homeowner was instructed on supplemental watering of the rain garden during plant establishment. The supplemental watering program provided to the homeowner prescribed 1.0-1.5 inches water depth per week (Bannerman & Considine, 2003).

CHAPTER 5

INSTALLATION AND INSTRUMENTATION OF FLOW MONITORING DEVICES AND STRUCTURES

Two (2) roof leaders were connected to a flow monitoring device. The flow monitoring device consists of a 55-gallon high-density polyethylene drum for stormwater collection and an orifice plate for controlled discharge from the barrel to the rain garden (R. Pitt, Pers. Comm., 2010). A schematic of the orifice-controlled inlet flow monitoring device is shown in Appendix A. A Global Water WL16U Water Level Logger measures and records the depth of the water in the barrel, which is correlated with the theoretical discharges from the orifices. The device does not measure the real-time discharge from the roof directly to the rain garden, as there are some storage effects inherent in the barrel-orifice design, but does measure real-time inflow to the rain garden. The storage effects result from the runoff filling the available volume with the variation of the height above the orifices.

Figure 5.1 is the theoretical height-discharge curve for the inlet flow monitoring device. The equation for flow through an orifice is $Q(cfs)=0.61*A*(2gH)^{0.5}$, where A is the area of the orifice in square feet, g is the acceleration of gravity, 32 ft/s^2, and H is the height of the water in feet from the midpoint of the orifice.

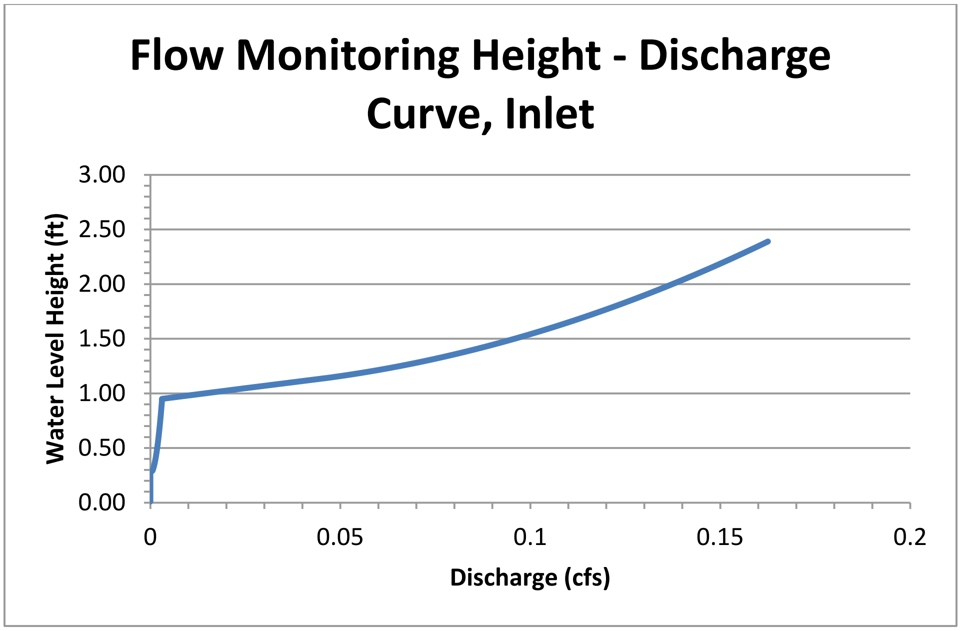


Figure 5.1 Theoretical height-discharge curve for orifice-controlled inlet flow monitoring device.

Any discharge from the rain garden is measured by a 1/8 in. thick stainless steel 22.5 degree sharp-crested v-notch weir at a protected outlet. Head above the crest is measured in the pool of the rain garden by a second Global Water WL16U Water Level Logger in a perforated PVC casing. The logger also measures rain garden ponding depth and infiltration response of the absorption area to various hydraulic loadings and recurrence intervals. The theoretical height-discharge curve for the weir-controlled outlet is provided in Figure 5.2. The equation for flow through the weir is $Q(cfs)=0.676*H^{2.5}$, where H is the height in feet above the crest of the weir. Figure 5.3 shows the weir outlet structure.

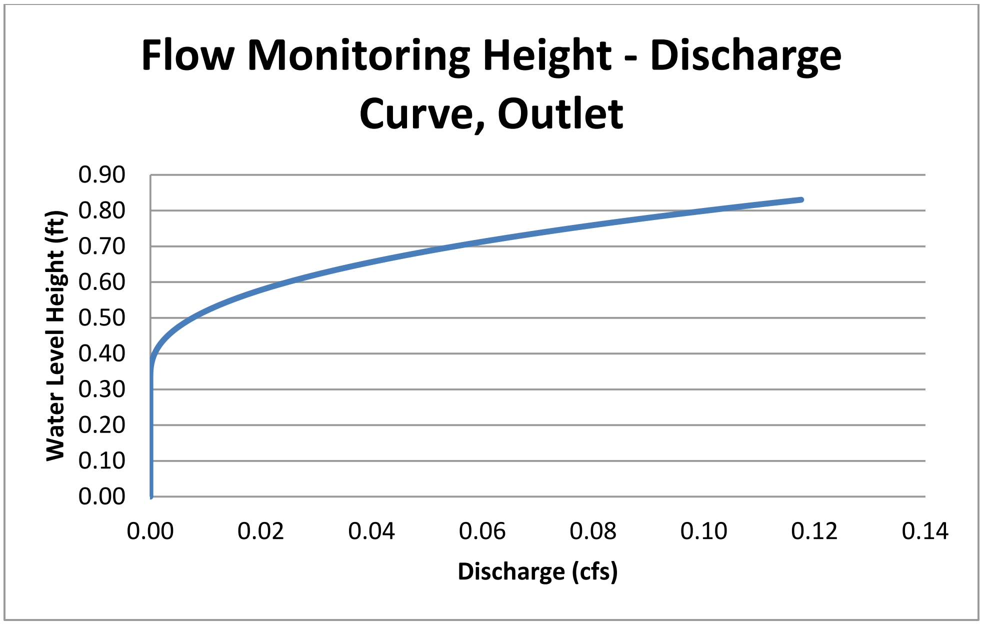


Figure 5.2 Theoretical height-discharge curve for weir outlet.

Figure 5.3 Weir outlet structure, shown at center.

The Global Water WL16U Water Level Loggers have a storage capacity of 81,759 stamped data points and are programmed to sample depth on a one (1) second interval. When storage space is exceeded, the logger wraps the collected data, replacing the oldest data sequential in chronological order with the new data samples. The available storage capacity of the level loggers require that data be collected within approximately 22.5 hours of the beginning of a precipitation event to record the entire rain garden inflow hydrograph and rain garden ponding depths.

CHAPTER 6

INFILTRATION TESTING

Infiltration testing of the absorption area was performed utilizing a full-inundation test, where a high rate of flow was used to fill the garden and time the drawdown. Additional infiltration testing was performed using Turf-Tec infiltrometers. The testing with the infiltrometers was performed a day prior to the full-inundation tests.

6.1 Turf-Tec Infiltrometer Infiltration Testing

Three Turf-Tec infiltrometers were used to measure infiltration rates of the absorption area. The Turf-Tec infiltrometers are double-ringed, where the water level in the outer ring is maintained while the drop in the water level of the inner ring is observed and recorded with time. The water level in the inner ring if periodically filled to continue the test for a duration where the sustained infiltration rate can be observed. The infiltrometer tests were conducted the day before each of the full-inundation tests. Figure 6.1 shows the collection of data from the three (3) infiltrometers. Figure 6.2 is a close-up of the double rings of the infiltrometer.

Figure 6.1 Data collection from infiltrometers.

Figure 6.2 Infiltrometer rings.

6.2 Full-Inundation Infiltration Testing

Full-inundation infiltration tests of the rain garden were conducted on September 6, 2011, and October 28, 2011. The September 6, 2011, test is shown in Figure 6.3. The full-inundation tests are advantageous for measuring the real capacity of the rain garden to infiltrate stormwater runoff. The full-inundation tests are more representative of the performance of the rain garden in the inundated condition that the absorption area is subjected to during a storm event.

Figure 6.3 Water pool during full-inundation infiltration test.

Measurements of the depth of ponding in the rain garden absorption area with respect to time were recorded utilizing a stop watch and staff gauge. Measurements were recorded every minute for the first five minutes of the test following the initial filling of the rain garden, then in five-minute increments for the remaining duration of the test. Depth measurements were not recorded while the garden was filled during initial filling and subsequent refilling activities. Inspections of the berm and the ground surrounding the rain garden did not indicate seepage was occurring during the test. Seepage evident by flow through the berm or surface on the ground surrounding the rain garden would have affected the water balance, resulting in lower infiltration rates for the absorption area of the rain garden than those observed during the tests.

Pitt, et al (2002), noted that infiltration in pervious areas is controlled by three (3) mechanisms, rate of entry of water through the soil/plant surface, flow rate through the vadose zone, and rate of drainage from the vadose zone to the saturated zone. The absorption area of the rain garden is also abundant with burrowing organisms. The voids created by the organisms also provide an entry location for water to infiltrate. The full-inundation tests provides a means to the measure the effects of macro features of the absorption area that would allow additional storage and direct access to additional soil surface area, which increases the effective area of the rain garden absorption area. The macro features are voids in the surface and subsurface of the soil that are larger than the void space between soil particles. The effective surface area is the surface of the rain garden absorption area, surface area within holes that were dug by borrowing annelids, and surface area next to the root structure. While the Turf-Tec infiltrometers are effective at measuring the infiltration at the surface of a soil, the infiltrometers are not effective at measuring the effect of macro features in a rain garden on infiltration.

Sustained infiltration rates of both, infiltrometers and full-inundation are provided in Table 6.1. The sustained infiltration rates were calculated from the average of the data points in range of the data sets where the infiltration rate appears to level off. Figure 6.4 shows a comparative view of the two inundation tests. The total duration of the full-inundation tests ranged from 90 to 105 minutes. The full inundation tests demonstrate that macro-features in the soil have a strong influence on the effective infiltration rate of the absorption area. A unique observation of the full-inundation tests is the first sharp peak of higher infiltration, which occurred during both tests at approximately ten minutes into the test. The infiltrometer tests are not included in the Figure 6.4 because of difficulties with the second installation of the Turf-Tec infiltrometers due to increased density of the rain garden vegetation, where the infiltrometers may not have been installed in a soil structure similar to the soil structure of the first infiltrometer test.

Table 6.1 Infiltration Tests – Sustained Infiltration Rates

Infiltration Test	Date	Sustained Infiltration Rate (in/hr)
Infiltrometer	8/18/2010	1.5
Infiltrometer	10/27/2010	7.2
Full-Inundation	9/2/2010	10.4
Full-Inundation	10/28/2010	9.3

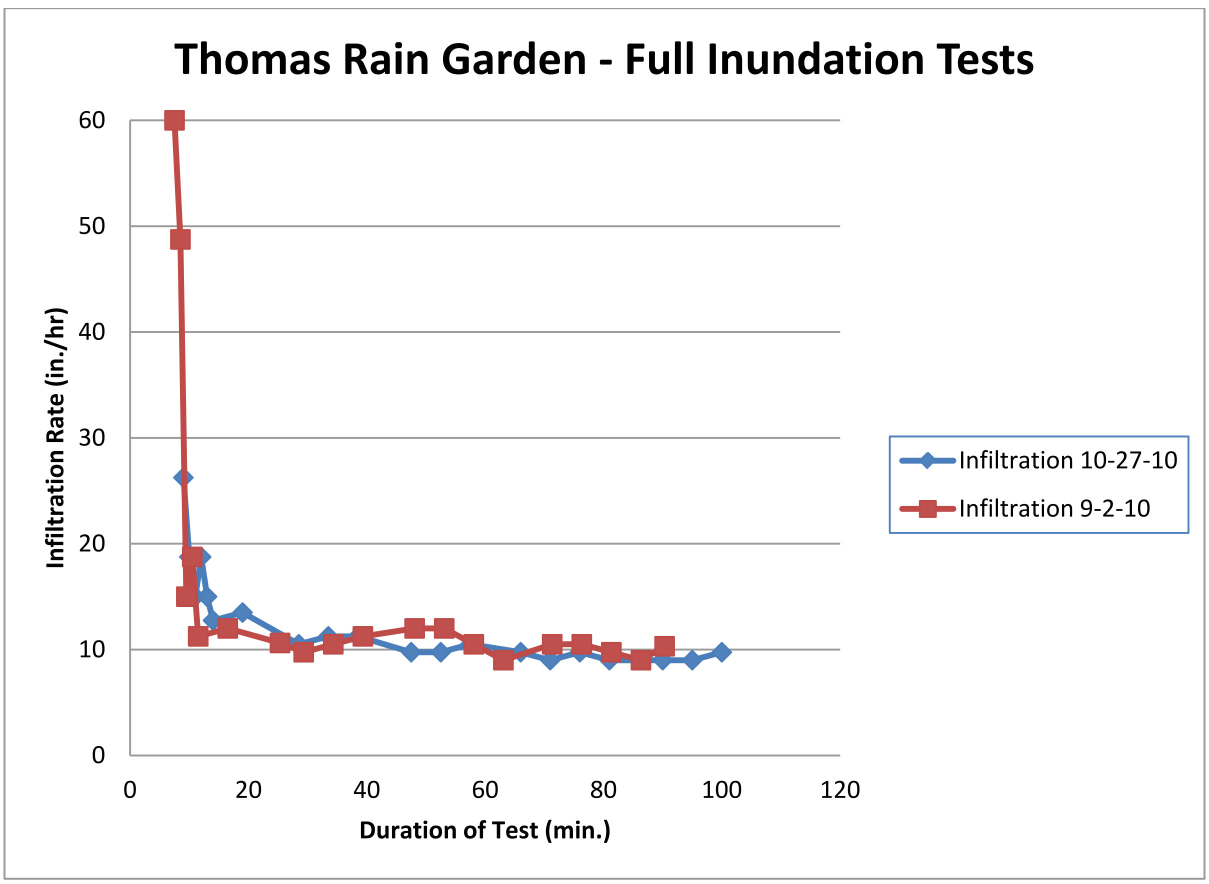


Figure 6.4 Infiltration rates from full-inundation infiltration tests.

6.3 Soils Investigation

The preliminary investigation during siting of the rain garden included a field soil texture and visual description, which identified the soil as a silty clay loam, brown in coloration. Additional soil tests were conducted following the selection of rain garden site for a more detailed characterization of the in situ soils. The detailed soil characterization tests were not a consideration for the design or location of the rain garden. The tests selected for soil investigation were based solely on the characteristics of the soils that may affect its hydraulic properties. The tests included particle size distribution, Atterberg limits, sand-cone density, and specific gravity. The results of the tests, shown in Table 6.2, were in strong agreement between three of the major soil classification systems, US Department of Agriculture, the American Association of State Highway and Transportation Officials, and the Unified Soil Classification System. The soil classifications for the three major soil classification systems are shown in Table 6.2.

Table 6.2 Soils Report

Particle Size Distribution	
Sand Retained on No. 10:	0.20%
Sand Retained on No. 200:	2.30%
Silt (0.005-0.074 mm):	53.30%
Clay (< 0.005 mm):	44.30%

Soil Classifications	-
USDA	Silty Clay
AASHTO	A-7-6
USCS	Lean Clay

Atterberg Limits	
Liquid Limit:	44
Plastic Limit:	21
Plasticity Index:	23

Sand-Cone Density (Date of Test: 8-18-10)	
ρ_{DRY}:	1.507 g/cm^3 (1507g/l)
ρ_{WET}:	1.934 g/cm^3 (1934 g/l)
ω:	28.30%

Specific Gravity of Soil Solids	
G_t:	2.69
G_{20}:	2.69

CHAPTER 7

FLOW MONITORING RESULTS

Fabrication of the orifice-controlled barrel flow monitoring device, fabrication of the outlet weir, and installation of the flow monitoring devices allowed flow monitoring to commence late September 2010. The first precipitation event was recorded on October 11, 2010, and the last was recorded November 12, 2010, prior to winterization of the flow monitoring device and restoration of the roof leaders on the residential property to discharge directly to the rain garden. Connecting the roof leaders to the rain garden maintained its functionality, similar to a typical residential rain garden installation, where the rain garden would be collecting snow melt and other precipitation during the winter months, though precipitation depths and snowmelt were not recorded. Figure 7.1 is the installed inlet flow monitoring device at the residence. Figure 7.2 is a photo of the level logger in a screened pipe in the absorption area of the rain garden. The metal tube resting on the berm is the housing for the batteries and the data collector. Figure 7.3 is the V-notch weir used to measure discharge from the garden.

Figure 7.1 Rain garden inlet orifice-controlled flow monitoring device in barrel casing at the southwest corner of the residence.

Figure 7.2 Level logger in rain garden absorption area.

Figure 7.3 V-notch weir at rain garden outlet.

Figures 7.4-7.7 demonstrate the capacity of the rain garden to react to precipitation events of varying intensity and duration. The events shown in the figures had recordings of minor or light precipitation that either preceded the time span shown in the figures or immediately followed the time span shown in the figures. The precipitation event durations are shortened from the total events for the sake of meaningful visual representation.

The response of the pooling depths the rain garden in Figure 7.4 to the inflow hydrograph is consistent and reflective of the peak inflow and duration of the precipitation event. The infiltration of the absorption area is estimated during the periods of low inflow to the garden. The infiltration rate for this event was maintained following the peak inflow at about 7.4 in/hr.

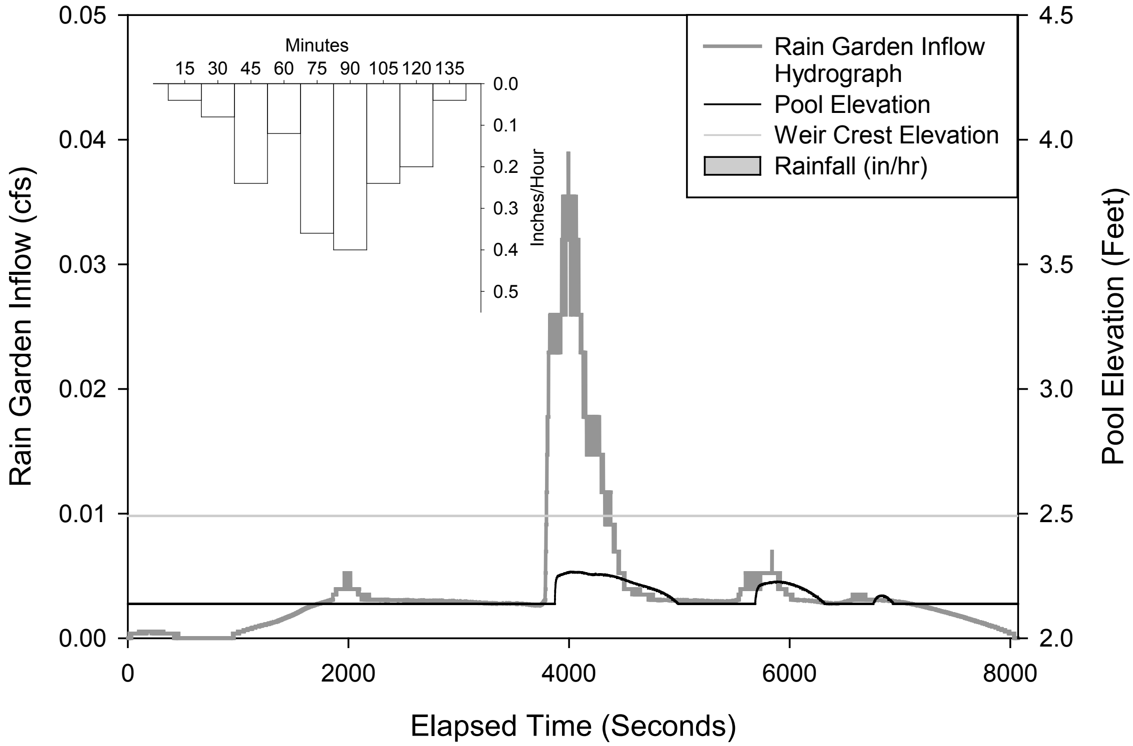


Figure 7.4 Rain garden response to precipitation event on October 11, 2010.

Note rain garden absorption area is at elevation of 2.11 feet.

In Figure 7.5, there is a slight delay between the beginning of the first peak of the inflow hydrograph and the beginning of the pooling depth peak. This is attributable to the infiltration rate of the garden initially exceeding the inflow rate. An infiltration rate is maintained between 7.0 and 8.5 in/hr through the duration of the event.

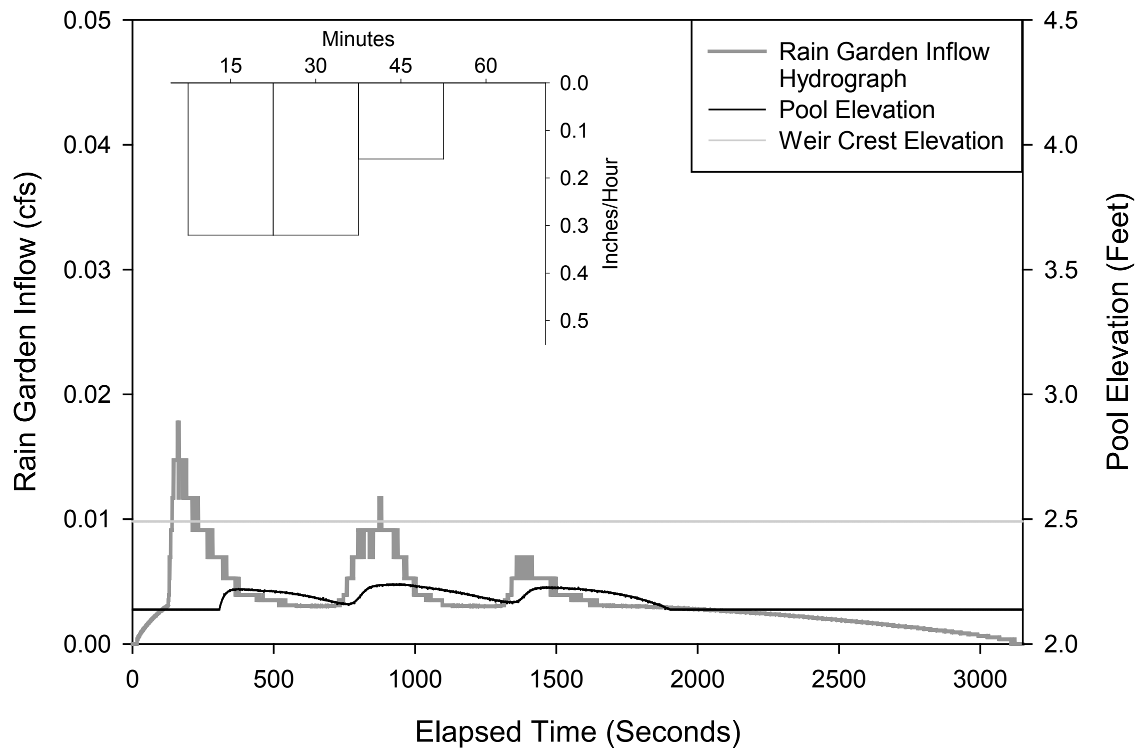


Figure 7.5 Rain garden response to precipitation event on October 12, 2010. Note rain garden absorption area is at elevation of 2.11 feet.

The inflow hydrograph for the precipitation event shown in Figure 7.6 is higher in intensity and of shorter duration than the events shown in Figures 7.4 and 7.5. The infiltration capacity of the absorption area significantly exceeds the rate of the inflow, resulting in a zero change in the pooling depth.

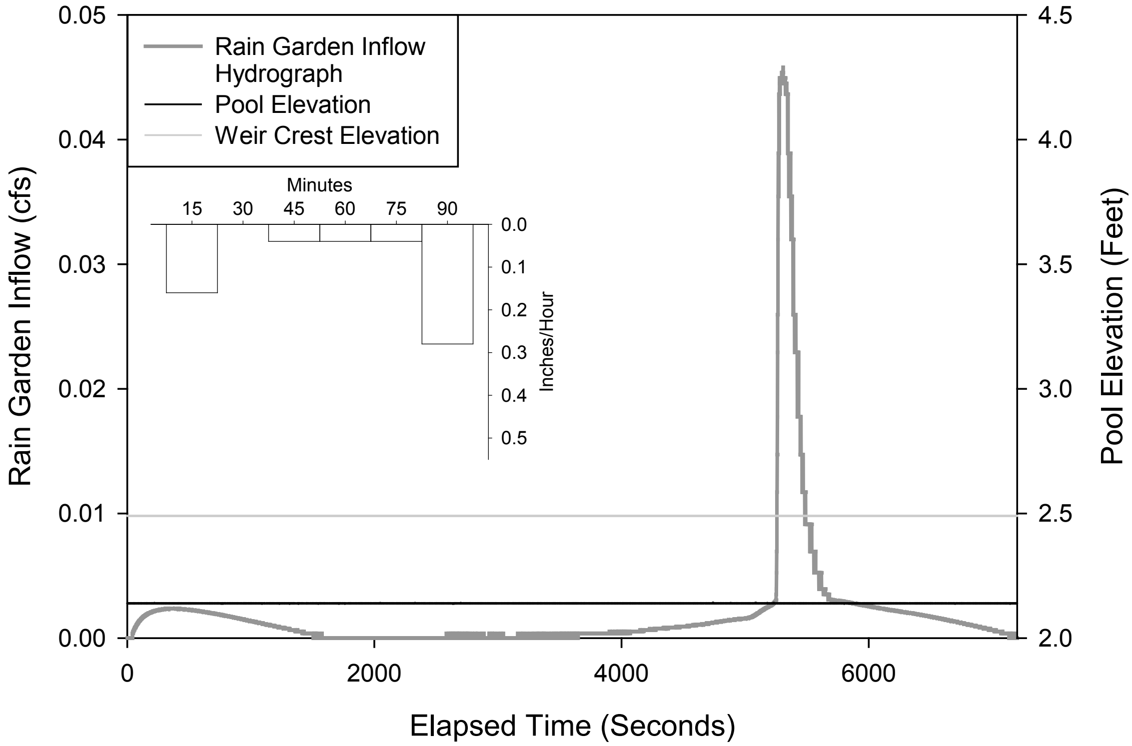


Figure 7.6 Rain garden response to precipitation event on October 22, 2010. Note rain garden absorption area is at elevation of 2.11 feet.

The largest event recorded at the rain garden in 2010 is shown in Figure 7.7. The precipitation event had a total depth of about 1.63 in., which resulted in a total discharge volume to the rain garden of approximately 134 cubic feet. During the event, the pooling depth of the rain garden did not exceed the height of the crest of the weir and the garden maintained an infiltration rate of greater than 5.0 in/hr during this extended event with high peak flow discharges to the rain garden.

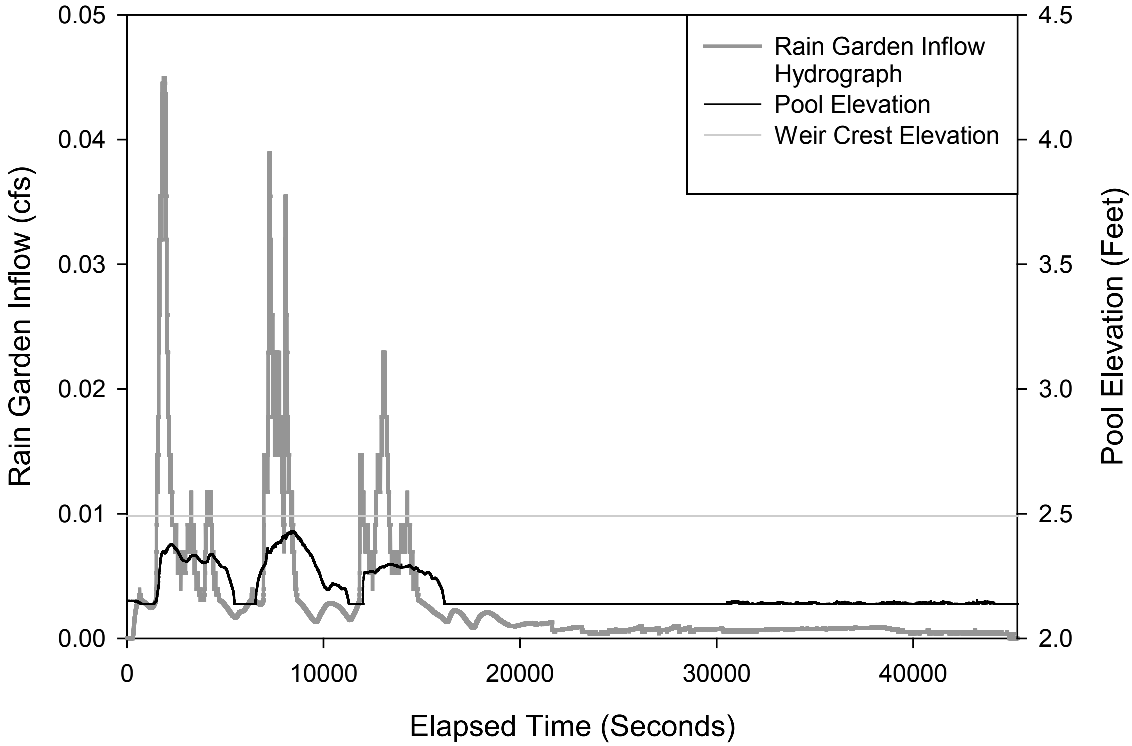


Figure 7.7 Rain garden response to precipitation event on November 12, 2010.

Note hyetograph not presented in Figure 7.7 due to rain gauge equipment failure and rain garden absorption area is at elevation of 2.11 feet.

CHAPTER 8

CONCLUSIONS

The study met its objectives in establishing a monitoring program for a private rain garden installation. The flow data for the inlet of the rain garden and the pool level data provided simultaneous real-time data, which gives a visual representation of the performance of the rain garden during events of varying intensities. Additionally, the orifice-controlled flow monitoring device provides a compact and unobtrusive method for measuring flows from roof runoff on private residences. Observations of the performance of the rain garden and the infiltration tests also lead to insights on the implementation and the performance of the absorption area in volume reduction and peak flow attenuation.

In the few precipitation events recorded in 2010, the private rain garden demonstrated peak flow attenuation by volume reduction through its ability to intercept, store, and infiltrate the total runoff volume from the storm events that were recorded. The total volume of stormwater runoff intercepted by the rain garden for the four events as estimated from the inlet hydrographs was 206 cubic feet. Implementation of rain gardens on a large scale in residential areas may prove to be an effective means to mitigate peak stormwater flows through volume reduction.

The garden was installed in clayey soils that would typically be considered unsuitable for an infiltration BMP without the installation of an underdrain to assist in draining captured runoff from under the infiltration surface. The infiltrative capacity of the absorption area at this particular site may be attributable to an intact soil matrix that was not disturbed and remolded during construction of the house on this lot and the minimally disruptive construction techniques that did not cause compaction of the upper 6-12 inches of the soil in the absorption area that can be caused by even light excavation equipment.

The higher than expected infiltration rates for this rain garden installation exhibit the necessity of individual site investigations for each rain garden installation and that current guidance for these installations do not result in efficient or appropriate installation for sites that can vary spatially, even on the same residential lot. The approaches to the installation of these infiltration practices for stormwater management require similar siting considerations to those in practice for onsite wastewater treatment systems (OWTs). OWTs are, in many counties, subject to strict specifications of the county health department in the design and location of the absorption field for the septic tank effluent. Additionally, technical manuals for the design and will be needed to promote infiltration methods for stormwater management (Fujita, 1997). Rain gardens will require the same attention to design from a regulatory perspective to perform effectively in meeting stormwater treatment goals for individual watersheds.

CHAPTER 9

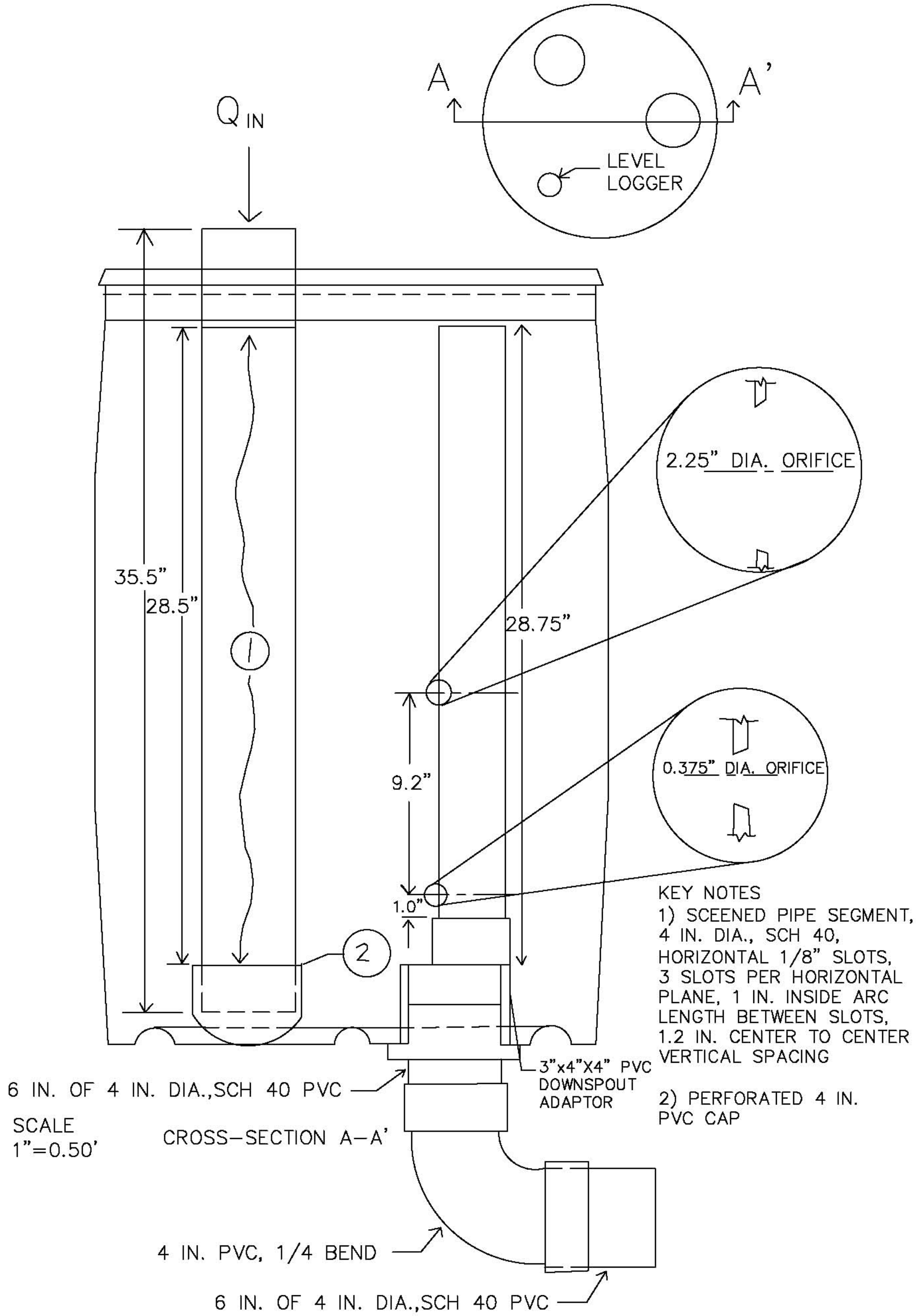
FUTURE RESEARCH

Future research in the area of monitoring rain gardens will include expanding water balance monitoring programs with equipment that is relatively simple to install and compact, similar to the orifice-controlled barrel flow monitoring device. Expanding water balance monitoring programs will advance both the understanding of rain gardens on an individual lot basis and allow for the development of the implementation of rain gardens on a large scale as part of a comprehensive watershed management plan.

The performance of the rain garden in fine-grained soils with clay exceeded typically expected infiltration rate. Future research should include the review of design and sizing of rain gardens that is based on the performance of in situ soils to infiltrate water on an individual lot basis, particularly in unsaturated flow conditions. This would be in contrast to many existing publications that base rain garden sizing on soil type rather than hydraulic characteristics.

APPENDIX A

SCHEMATIC OF INLET FLOW MONITORING DEVICE


Q IN
A
A'
LEVEL LOGGER
2.25" DIA. ORIFICE
0.375" DIA. ORIFICE
35.5"
28.5"
28.75"
9.2"
1.0"
1
2
KEY NOTES
1) SCEENED PIPE SEGMENT, 4 IN. DIA., SCH 40, HORIZONTAL 1/8" SLOTS, 3 SLOTS PER HORIZONTAL PLANE, 1 IN. INSIDE ARC LENGTH BETWEEN SLOTS, 1.2 IN. CENTER TO CENTER VERTICAL SPACING
2) PERFORATED 4 IN. PVC CAP
3"x4"X4" PVC DOWNSPOUT ADAPTOR
6 IN. OF 4 IN. DIA.,SCH 40 PVC
SCALE 1"=0.50'
CROSS-SECTION A-A'
4 IN. PVC, 1/4 BEND
6 IN. OF 4 IN. DIA.,SCH 40 PVC

APPENDIX B

FULL-INUNDATION TEST DATA

Full Inundation Infiltration Test

Test #: 2
Date of Test: 9-2-10
Test Site Location: Private Rain Garden - Thomas Property
Exact Location of Test: Full Inundation Infiltration Test
Rain Gauge Site ID: UMKC Rain Gauge No. 1 - Paseo
Last Rainfall Event: 8-31-10: 0.62 in., 9-1-10: 0.42 in.
Moisture Content (%): SE Corner of Absorption Area: 28.3, SW Corner of Absorption Area: 32.4
In-Place Dry Density (g/l): 1507

Table 2

Time (min)	Reading (inch)	Reading (inch)	Incremental Infiltration Rate (in/min)	Incremental Infiltration Rate (in/hr)	Ring Refill Level (inch)	Fill/Refill Duration (Minutes)
0	6	6.0000	-	-	-	6:30
1	7	7.0000	1.0000	60.00	-	-
2	7 13/16	7.8125	0.8125	48.75	-	-
3	8 1/16	8.0625	0.2500	15.00	-	-
4	8 6/16	8.3750	0.3125	18.75	-	-
5	8 9/16	8.5625	0.1875	11.25	-	-
10	9 9/16	9.5625	0.2000	12.00	6.0625	2:50
16	7 2/16	7.1250	0.1771	10.63	-	-
20	7 15/16	7.9375	0.1625	9.75	-	-
25	8 13/16	8.8125	0.1750	10.50	-	-
30	9 12/16	9.7500	0.1875	11.25	5.875	3:45
35	6 14/16	6.8750	0.2000	12.00	-	-
40	7 14/16	7.8750	0.2000	12.00	-	-
45	8 12/16	8.7500	0.1750	10.50	-	-
50	9 8/16	9.5000	0.1500	9.00	6	3:25
55	6 14/16	6.8750	0.1750	10.50	-	-
60	7 12/16	7.7500	0.1750	10.50	-	
65	8 9/16	8.5625	0.1625	9.75	-	-
70	9 5/16	9.3125	0.1500	9.00	-	-
74	10	10.0000	0.1719	10.31	-	-
80						-
85						
90						
95						
100						
105						
110						
115						
120						

Full Inundation Infiltration Test
Test #: 4
Date of Test: 10-28-10
Test Site Location: Private Rain Garden - Thomas Property
Exact Location of Test: Full Inundation Infiltration Test
Rain Gauge Site ID: UMKC Rain Gauge No. 1 - Paseo
Last Rainfall Event: 10-22-10: 0.21 in.
Moisture Content (%): North Center of Absorption Area: 26.5, South Center of Absorption Area: 40.4
In-Place Dry Density (g/l): 1507

Table 2

Time (min)	Reading (inch)	Reading (inch)	Incremental Infiltration Rate (in/min)	Incremental Infiltration Rate (in/hr)	Ring Refill Level (inch)	Fill/Refill Duration (Minutes)
0	8 8/16	8.5000	-	-	-	9:00
1	8 15/16	8.9375	0.4375	26.25	-	-
2	9 4/16	9.2500	0.3125	18.75	-	-
3	9 8/16	9.5000	0.2500	15.00	-	-
4	9 13/16	9.8125	0.3125	18.75	-	-
5	10 1/16	10.0625	0.2500	15.00	-	-
10	11 2/16	11.1250	0.2125	12.75	8.5625	4:30
15	9 11/16	9.6875	0.2250	13.50	-	-
20	10 9/16	10.5625	0.1750	10.50	-	-
25	11 8/16	11.5000	0.1875	11.25	8.5625	4:00
30	9 8/16	9.5000	0.1875	11.25	-	-
35	10 5/16	10.3125	0.1625	9.75	-	-
40	11 2/16	11.1250	0.1625	9.75	8.5625	3:30
45	9 7/16	9.4375	0.1750	10.50	-	-
50	10 4/16	10.2500	0.1625	9.75	-	-
55	11	11.0000	0.1500	9.00	-	-
60	11 13/16	11.8125	0.1625	9.75	8.625	4:00
65	9 6/16	9.3750	0.1500	9.00	-	-
70	10 2/16	10.1250	0.1500	9.00	-	-
75	10 14/16	10.8750	0.1500	9.00	-	-
80	11 11/16	11.6875	0.1625	9.75	-	-
85						
90						
95						
100						
105						
110						
115						
120						

APPENDIX C

INFILTROMETER DATA

Infiltration Test with Turf-Tec Infiltrometer
Test #: 1-A
Date of Test: 8-18-10
Test Site Location: Private Rain Garden - Thomas Property
Exact Location of Test: south side of garden, ~2 ft. from berm, located near center east-west
Rain Gauge Site ID: UMKC Rain Gauge No. 1 - Paseo
Last Rainfall Event: 8-17-10: 0.08 in.
Moisture Content (%): 26.5
In-Place Dry Density (g/l): 1507

Table 1-A

Time (min)	Reading (inch)	Reading (inch)	Incremental Infiltration Rate (in/min)	Incremental Infiltration Rate (in/hr)	Ring Refill Level (inch)
0	5/16	0.3125	0	0.00	-
1	6/16	0.3750	0.0625	3.75	-
2	7/16	0.4375	0.0625	3.75	-
3	7/16	0.4375	0.0000	0.00	-
4	7/16	0.4375	0.0000	0.00	-
5	7/16	0.4375	0.0000	0.00	-
10	9/16	0.5625	0.0250	1.50	-
15	10/16	0.6250	0.0125	0.75	-
20	11/16	0.6875	0.0125	0.75	-
25	13/16	0.8125	0.0250	1.50	-
30	14/16	0.8750	0.0125	0.75	-
35	15/16	0.9375	0.0125	0.75	-
40	1	1.0000	0.0125	0.75	-
45	1 1/16	1.0625	0.0125	0.75	-
50	1 2/16	1.1250	0.0125	0.75	-
55	1 3/16	1.1875	0.0125	0.75	-
60	1 4/16	1.2500	0.0125	0.75	-
65	1 4/16	1.2500	0.0000	0.00	-
70	1 5/16	1.3125	0.0125	0.75	-
75	1 7/16	1.4375	0.0250	1.50	-
80	1 7/16	1.4375	0.0000	0.00	-
85	1 8/16	1.5000	0.0125	0.75	-
90	1 9/16	1.5625	0.0125	0.75	-
95	1 10/16	1.6250	0.0125	0.75	-
100	1 11/16	1.6875	0.0125	0.75	-
105	1 12/16	1.7500	0.0125	0.75	-
110	1 13/16	1.8125	0.0125	0.75	-
115	1 13/16	1.8125	0.0000	0.00	-
120	1 14/16	1.8750	0.0125	0.75	-

Infiltration Test with Turf-Tec Infiltrometer
Test #: 1-B
Date of Test: 8-18-10
Test Site Location: Private Rain Garden - Thomas Property
Exact Location of Test: east side of garden, ~2 ft. from east berm, ~2 ft. from south berm
Rain Gauge Site ID: UMKC Rain Gauge No. 1 - Paseo
Last Rainfall Event: 8-17-10: 0.08 in.
Moisture Content (%): 26.5
In-Place Dry Density (g/l): 1507

Table 2-B

Time (min)	Reading (inch)	Reading (inch)	Incremental Infiltration Rate (in/min)	Incremental Infiltration Rate (in/hr)	Ring Refill Level (inch)
0	8/16	0.5000	0	0.00	-
1	9/16	0.5625	0.0625	3.75	-
2	10/16	0.6250	0.0625	3.75	-
3	11/16	0.6875	0.0625	3.75	-
4	14/16	0.8750	0.1875	11.25	-
5	14/16	0.8750	0.0000	0.00	-
10	1 1/16	1.0625	0.0375	2.25	-
15	1 4/16	1.2500	0.0375	2.25	-
20	1 6/16	1.3750	0.0250	1.50	-
25	1 8/16	1.5000	0.0250	1.50	-
30	1 10/16	1.6250	0.0250	1.50	-
35	1 13/16	1.8125	0.0375	2.25	-
40	1 15/16	1.9375	0.0250	1.50	-
45	2 1/16	2.0625	0.0250	1.50	-
50	2 3/16	2.1875	0.0250	1.50	-
55	2 5/16	2.3125	0.0250	1.50	-
60	2 7/16	2.4375	0.0250	1.50	-
65	2 9/16	2.5625	0.0250	1.50	0.1875
70	5/16	0.3125	0.0250	1.50	-
75	9/16	0.5625	0.0500	3.00	-
80	12/16	0.7500	0.0375	2.25	-
85	14/16	0.8750	0.0250	1.50	-
90	1 1/16	1.0625	0.0375	2.25	-
95	1 3/16	1.1875	0.0250	1.50	-
100	1 6/16	1.3750	0.0375	2.25	-
105	1 8/16	1.5000	0.0250	1.50	-
110	1 11/16	1.6875	0.0375	2.25	-
115	1 14/16	1.8750	0.0375	2.25	-
120	2 1/16	2.0625	0.0375	2.25	-

Infiltration Test with Turf-Tec Infiltrometer
Test #: 1-C
Date of Test: 8-18-10
Test Site Location: Private Rain Garden - Thomas Property
Exact Location of Test: north side of garden, ~1 ft. from north berm, located near center east-west
Rain Gauge Site ID: UMKC Rain Gauge No. 1 - Paseo
Last Rainfall Event: 8-17-10: 0.08 in.
Moisture Content (%): 29.7
In-Place Dry Density (g/l): 1507

Table 2-C

Time (min)	Reading (inch)	Reading (inch)	Incremental Infiltration Rate (in/min)	Incremental Infiltration Rate (in/hr)	Ring Refill Level (inch)
0	5/16	0.3125	0	0.00	-
1	7/16	0.4375	0.1250	7.50	-
2	9/16	0.5625	0.1250	7.50	-
3	10/16	0.6250	0.0625	3.75	-
4	10/16	0.6250	0.0000	0.00	-
5	11/16	0.6875	0.0625	3.75	-
10	13/16	0.8125	0.0250	1.50	-
15	1 1/16	1.0625	0.0500	3.00	-
20	1 3/16	1.1875	0.0250	1.50	-
25	1 5/16	1.3125	0.0250	1.50	-
30	1 8/16	1.5000	0.0375	2.25	-
35	1 11/16	1.6875	0.0375	2.25	-
40	1 13/16	1.8125	0.0250	1.50	-
45	2	2.0000	0.0375	2.25	-
50	2 2/16	2.1250	0.0250	1.50	-
55	2 4/16	2.2500	0.0250	1.50	-
60	2 6/16	2.3750	0.0250	1.50	-
65	2 9/16	2.5625	0.0375	2.25	0.25
70	7/16	0.4375	0.0375	2.25	-
75	9/16	0.5625	0.0250	1.50	-
80	12/16	0.7500	0.0375	2.25	-
85	15/16	0.9375	0.0375	2.25	-
90	1 1/16	1.0625	0.0250	1.50	-
95	1 4/16	1.2500	0.0375	2.25	-
100	1 6/16	1.3750	0.0250	1.50	-
105	1 9/16	1.5625	0.0375	2.25	-
110	1 11/16	1.6875	0.0250	1.50	-
115	1 13/16	1.8125	0.0250	1.50	-
120	1 15/16	1.9375	0.0250	1.50	-

Infiltration Test with Turf-Tec Infiltrometer

Test #: 3-A
Date of Test: 10-27-10
Test Site Location: Private Rain Garden - Thomas Property
Exact Location of Test: NW Corner of Garden, ~2 FT from N Berm, ~2.5 FT from W Berm
Rain Gauge Site ID: UMKC Rain Gauge No. 1 - Paseo
Last Rainfall Event: 10-22-10: 0.21 in.
Moisture Content (%): N Center of Garden: 26.5%, S. Center of Garden: 40.4%
In-Place Dry Density (g/l): 1507

Table 3-A

Time (min)	Reading (inch)	Reading (inch)	Incremental Infiltration Rate (in/min)	Incremental Infiltration Rate (in/hr)	Ring Refill Level (inch)
0	4/16	0.2500	0	0.00	-
1	7/16	0.4375	0.1875	11.25	-
2	9/16	0.5625	0.1250	7.50	-
3	11/16	0.6875	0.1250	7.50	-
4	13/16	0.8125	0.1250	7.50	-
5	14/16	0.8750	0.0625	3.75	-
10	1 7/16	1.4375	0.1125	6.75	-
15	1 14/16	1.8750	0.0875	5.25	-
20	2 6/16	2.3750	0.1000	6.00	-
25	2 13/16	2.8125	0.0875	5.25	-
30	3 3/16	3.1875	0.0750	4.50	0.25
35	12/16	0.7500	0.1000	6.00	-
40	1 4/16	1.2500	0.1000	6.00	-
45	1 13/16	1.8125	0.1125	6.75	-
50	2 2/16	2.1250	0.0625	3.75	-
55	2 8/16	2.5000	0.0750	4.50	-
60	2 14/16	2.8750	0.0750	4.50	0.3125
65	13/16	0.8125	0.1000	6.00	-
70	1 4/16	1.2500	0.0875	5.25	-
75	1 10/16	1.6250	0.0750	4.50	-
80	2	2.0000	0.0750	4.50	-
85	2 7/16	2.4375	0.0875	5.25	-
90	2 12/16	2.7500	0.0625	3.75	-
95	3 1/16	3.0625	0.0625	3.75	0.25
100	13/16	0.8125	0.1125	6.75	-
105	1 1/16	1.0625	0.0500	3.00	-
110	1 8/16	1.5000	0.0875	5.25	-
115	1 13/16	1.8125	0.0625	3.75	-
120	2 3/16	2.1875	0.0750	4.50	-

Infiltration Test with Turf-Tec Infiltrometer
Test #: 3-B
Date of Test: 10-27-10
Test Site Location: Private Rain Garden - Thomas Property
Exact Location of Test: SW Corner of Garden, ~1 FT from W Berm, ~0.5 FT from S Berm
Rain Gauge Site ID: UMKC Rain Gauge No. 1 - Paseo
Last Rainfall Event: 10-22-10: 0.21 in.
Moisture Content (%): N Center of Garden: 26.5%, S. Center of Garden: 40.4%
In-Place Dry Density (g/l): 1507

Table 3-B

Time (min)	Reading (inch)	Reading (inch)	Incremental Infiltration Rate (in/min)	Incremental Infiltration Rate (in/hr)	Ring Refill Level (inch)
0	2/16	0.1250	0	0.00	-
1	7/16	0.4375	0.3125	18.75	-
2	15/16	0.9375	0.5000	30.00	-
3	1 1/16	1.0625	0.1250	7.50	-
4	1 5/16	1.3125	0.2500	15.00	-
5	1 7/16	1.4375	0.1250	7.50	-
10	2 6/16	2.3750	0.1875	11.25	0.125
15	1	1.0000	0.1750	10.50	-
20	1 12/16	1.7500	0.1500	9.00	-
25	2 7/16	2.4375	0.1375	8.25	0.1875
30	15/16	0.9375	0.1500	9.00	-
35	1 10/16	1.6250	0.1375	8.25	-
40	2 3/16	2.1875	0.1125	6.75	-
45	2 12/16	2.7500	0.1125	6.75	-
50	3 3/16	3.1875	0.0875	5.25	0.125
55	8/16	0.5000	0.0750	4.50	-
60	1 4/16	1.2500	0.1500	9.00	-
65	1 13/16	1.8125	0.1125	6.75	-
70	2 4/16	2.2500	0.0875	5.25	-
75	2 12/16	2.7500	0.1000	6.00	-
80	3 3/16	3.1875	0.0875	5.25	0.125
85	8/16	0.5000	0.0750	4.50	-
90	1 2/16	1.1250	0.1250	7.50	-
95	1 8/16	1.5000	0.0750	4.50	-
100	1 15/16	1.9375	0.0875	5.25	-
105	2 6/16	2.3750	0.0875	5.25	-
110	2 12/16	2.7500	0.0750	4.50	-
115	3 2/16	3.1250	0.0750	4.50	-
120	3 7/16	3.4375	0.0625	3.75	-

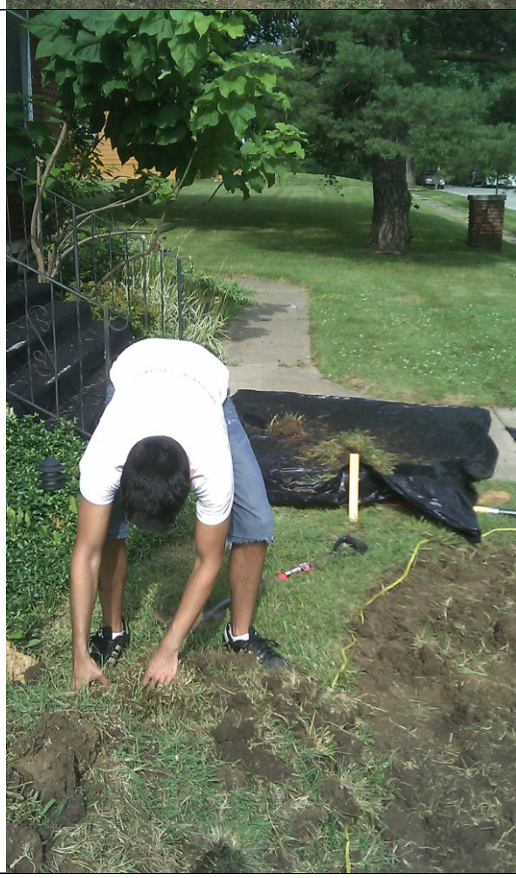
Infiltration Test with Turf-Tec Infiltrometer
Test #: 3-C
Date of Test: 10-27-10
Test Site Location: Private Rain Garden - Thomas Property
Exact Location of Test: SE Corner of Garden, ~1 FT from S Berm, ~2.5 FT from E Berm
Rain Gauge Site ID: UMKC Rain Gauge No. 1 - Paseo
Last Rainfall Event: 10-22-10: 0.21 in.
Moisture Content (%): N Center of Garden: 26.5%, S. Center of Garden: 40.4%
In-Place Dry Density (g/l): 1507

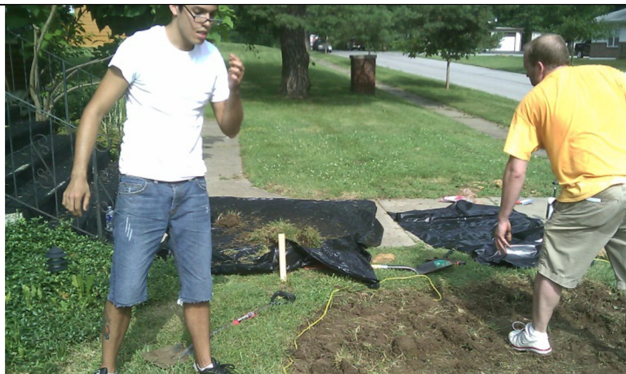
Table 3-C

Time (min)	Reading (inch)	Reading (inch)	Incremental Infiltration Rate (in/min)	Incremental Infiltration Rate (in/hr)	Ring Refill Level (inch)
0	3/16	0.1875	0	0.00	-
1	1 12/16	1.7500	1.5625	93.75	-
2	2 15/16	2.9375	1.1875	71.25	-
3	3 8/16	3.5000	0.5625	33.75	0.375
4	1 3/16	1.1875	0.8125	48.75	-
5	2	2.0000	0.8125	48.75	0.1875
10	3 6/16	3.3750	0.6375	38.25	0.1875
15	2 13/16	2.8125	0.5250	31.50	0.375
20	2 8/16	2.5000	0.4250	25.50	0.1875
25	2 3/16	2.1875	0.4000	24.00	0.1875
30	1 15/16	1.9375	0.3500	21.00	0.1875
35	1 13/16	1.8125	0.3250	19.50	0.1875
40	1 11/16	1.6875	0.3000	18.00	-
45	3 2/16	3.1250	0.2875	17.25	0.125
50	1 10/16	1.6250	0.3000	18.00	-
55	2 14/16	2.8750	0.2500	15.00	0.125
60	1 7/16	1.4375	0.2625	15.75	-
65	2 10/16	2.6250	0.2375	14.25	0.25
70	1 5/16	1.3125	0.2125	12.75	-
75	2 6/16	2.3750	0.2125	12.75	0.0625
80	1	1.0000	0.1875	11.25	-
85	2 2/16	2.1250	0.2250	13.50	-
90	3 1/16	3.0625	0.1875	11.25	0.1875
95	1 1/16	1.0625	0.1750	10.50	-
100	1 15/16	1.9375	0.1750	10.50	-
105	2 13/16	2.8125	0.1750	10.50	-
110	3 9/16	3.5625	0.1500	9.00	3.1875
115	1 1/16	1.0625	-0.4250	-25.50	-
120	1 15/16	1.9375	0.1750	10.50	-

APPENDIX D

PROJECT PHOTOGRAPHS

Project: Private Rain Garden Installation - Thomas Property	Date: 06/10/10-06/11/10
	Created By: JN
	Figure 1. Sod removal in stormwater absorption area of rain garden. Also shown, perimeter of rain garden marked by rope. 06/10/10
	Figure 2. Removal of sod from construction area. Also shown, black plastic sheet for transport of sod to location selected by homeowner for storage/compost. 06/10/10

	Figure 3. Removal of sod from construction area. Also shown, black plastic sheet for transport of sod to location selected by homeowner for storage/compost. 06/10/10
	Figure 4. Removal of sod from construction area. 06/10/10
	Figure 5. Sod removal in stormwater absorption area of rain garden. Also shown, perimeter of rain garden marked by rope. 06/10/10

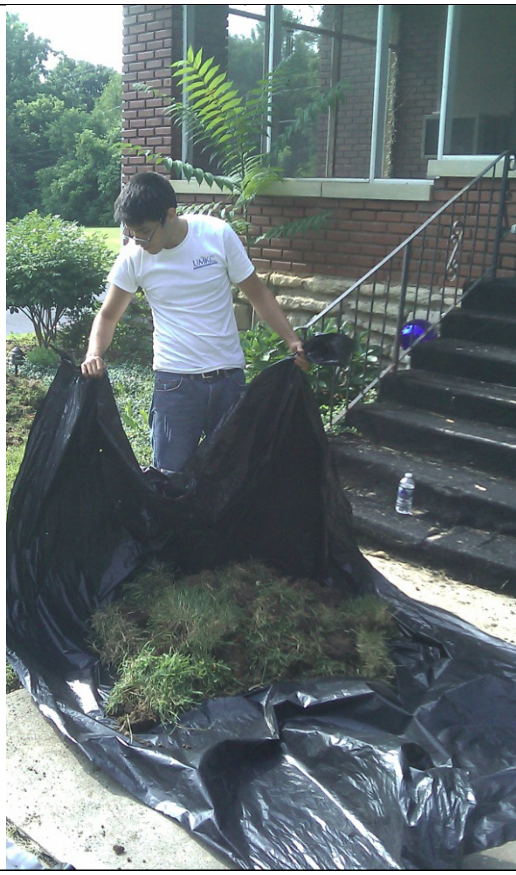


Figure 6. Removal of sod from construction area. 06/10/10

Figure 7. Removal of sod from construction area. 06/10/10

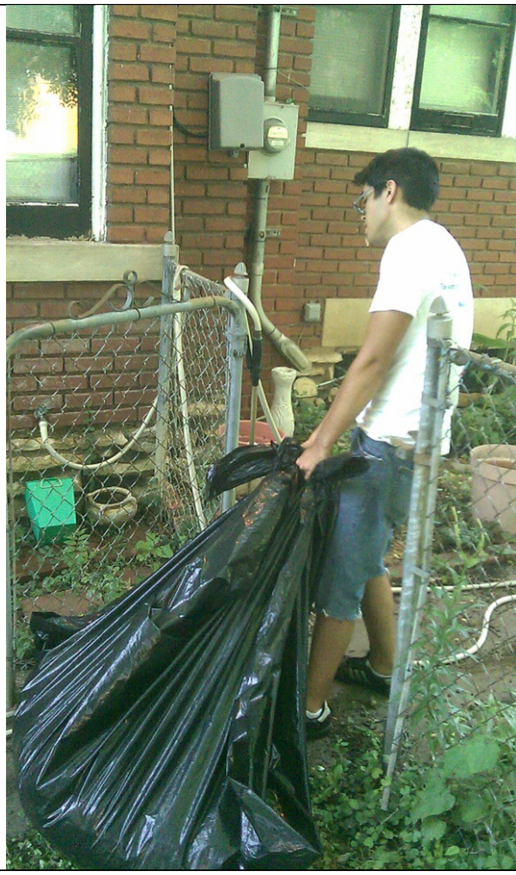
	Figure 8. Removal of sod from construction area. 06/10/10

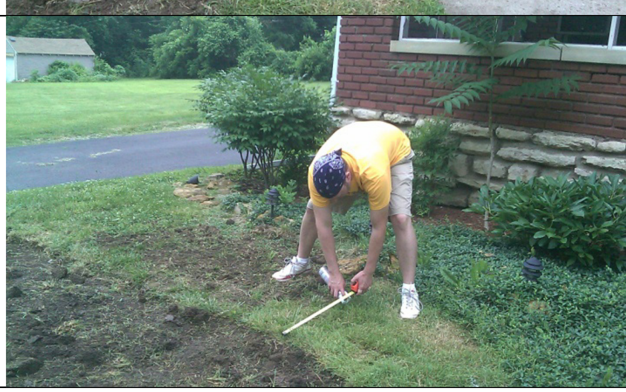
	Figure 9. Sod removal in stormwater absorption area of rain garden. Also shown, perimeter of rain garden marked by rope. 06/10/10
	Figure 10. Marking exterior perimeter of berm for sod removal. 06/11/10
	Figure 11. Marking exterior perimeter of berm for sod removal. 06/11/10

Figure 12. Marking exterior perimeter of berm for sod removal. 06/11/10

Figure 13. Marking exterior perimeter of berm for sod removal. 06/11/10

Figure 14. Marking exterior perimeter of berm for sod removal. 06/11/10

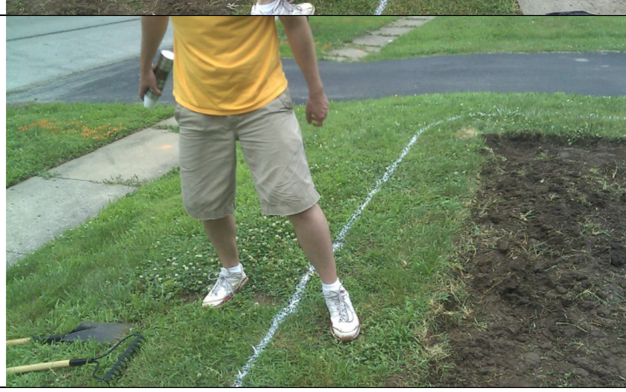


Figure 15. Exterior perimeter of berm for sod removal. 06/11/10

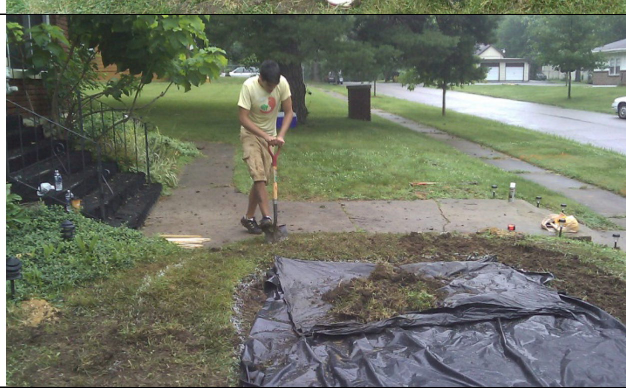
	Figure 16. Exterior perimeter of berm for sod removal. 06/11/10
	Figure 17. Sod removal in berm area of rain garden. 06/11/10
	Figure 18. Sod removal in berm area of rain garden. 06/11/10
	Figure 19. Sod removal in berm area of rain garden. 06/11/10

	Figure 20. Excavation of soil from stormwater absorption area of rain garden for use in construction of berm. Unsuitable berm construction materials have been removed. Also shown, string lines with line levels for depth guidance and compacted berm, ~2 in. lifts. 06/11/10
	Figure 21. Excavation of soil from stormwater absorption area of rain garden for use in construction of berm. Unsuitable berm construction materials have been removed. Also shown, string lines with line levels for depth guidance. 06/11/10

Project: Private Rain Garden Installation - Thomas Property	Date: 07/21/10
	Created By: JN
	Figure 1. Planting additional vegetation. 07/21/10

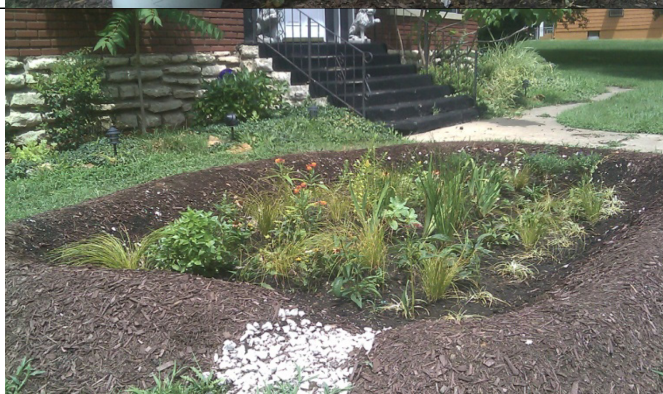
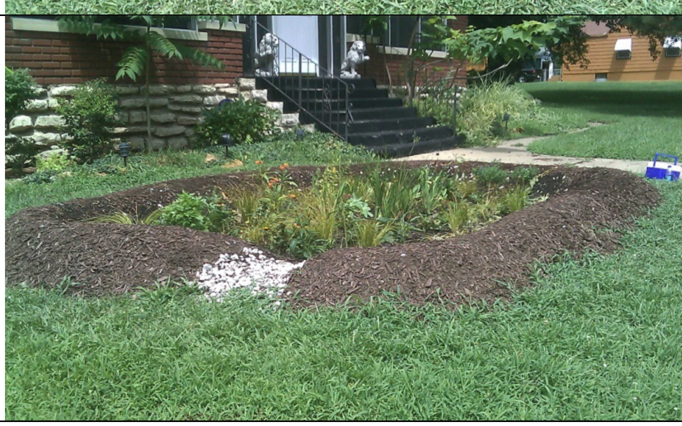
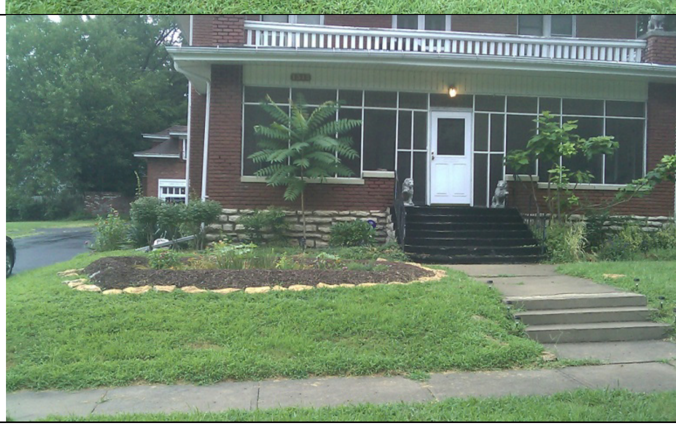
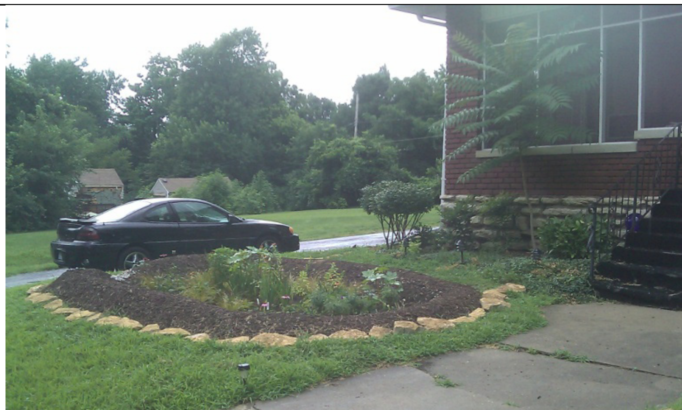
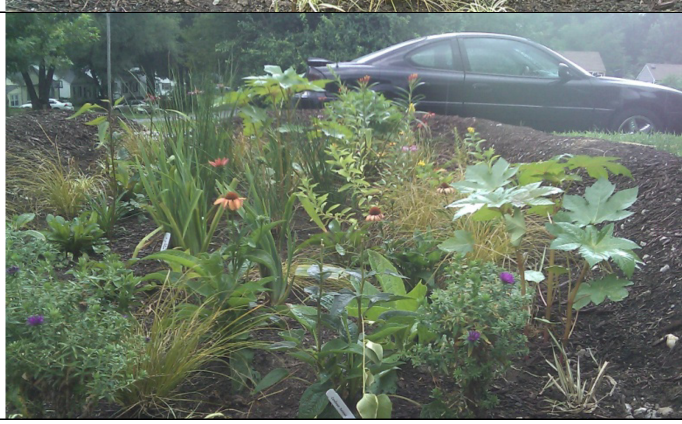
	Figure 2. Planting additional vegetation. 07/21/10
	Figure 3. Rain garden, looking east. 07/21/10
	Figure 4. Rain garden, looking north. 07/21/10
	Figure 5. Rain garden, looking northeast. 07/21/10

	Figure 6. Rain garden. 07/21/10

Project: Private Rain Garden Installation - Thomas Property	Date: 07/29/10
	Created By: JN
	Figure 1. Rain garden, looking east. 07/29/10
	Figure 2. Rain garden, looking north. 07/29/10

		Figure 3. Rain garden, looking west. 07/29/10
		Figure 4. Rain garden, looking north. 07/29/10
		Figure 5. Rain garden, looking west. 07/29/10

Project: Private Rain Garden Installation - Thomas Property	Date: 08/18/10 and 09/02/10
	Created By: JN
	Figure 1. Turf-Tec infiltration test. 08/18/10
	Figure 2. Turf-Tec infiltration test. 08/18/10
	Figure 3. Turf-Tec infiltration test. 08/18/10

		Figure 4. Turf-Tec infiltration test, showing locations of the three (3) infiltrometer set-up. 08/18/10
		Figure 5. Full-inundation infiltration test hydrant connection. 09/02/10
		Figure 6. Full-inundation infiltration test traffic control. 09/02/10

		Figure 7. Full-inundation infiltration test set-up. 09/02/10
		Figure 8. Full-inundation infiltration test fill. 09/02/10
		Figure 9. Full-inundation infiltration test maximum water height controlled by temporary weir. 09/02/10

	Figure 10. Full-inundation infiltration test. 09/02/10
	Figure 11. Full-inundation infiltration test reading staff gauge. 09/02/10
	Figure 12. Full-inundation infiltration test close-up of filling procedure. 09/02/10

Project: Private Rain Garden Installation - Thomas Property	Date: 09/21/10 - 09/23/10
	Created By: JN

Figure 1. Trellis fabrication. 09/21/10

Figure 2. Trellis fabrication. 09/21/10

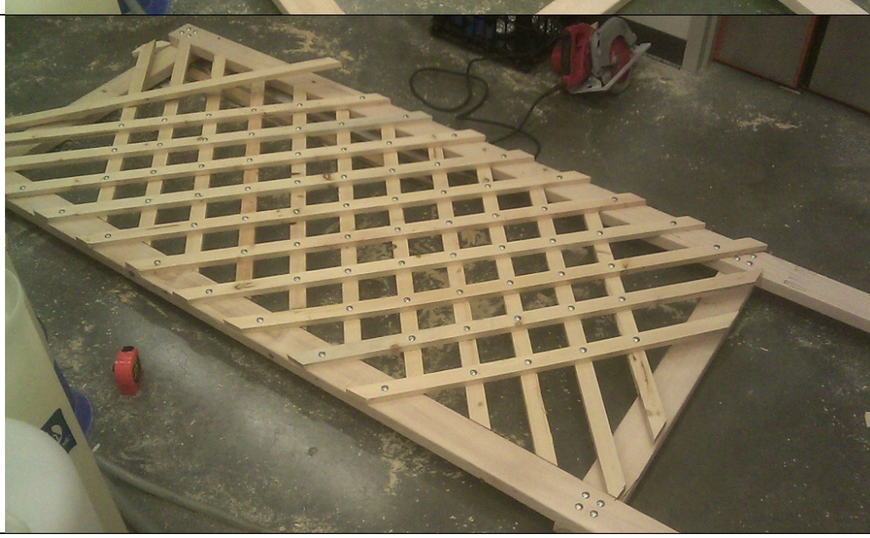
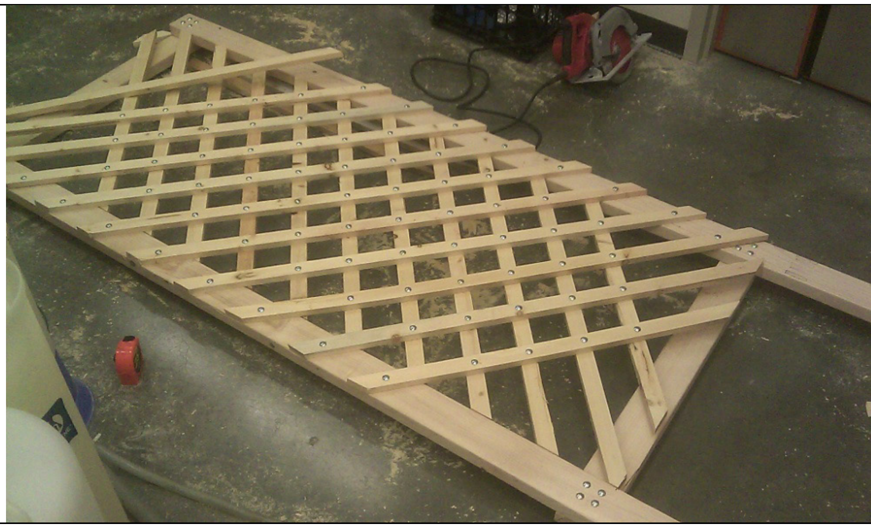
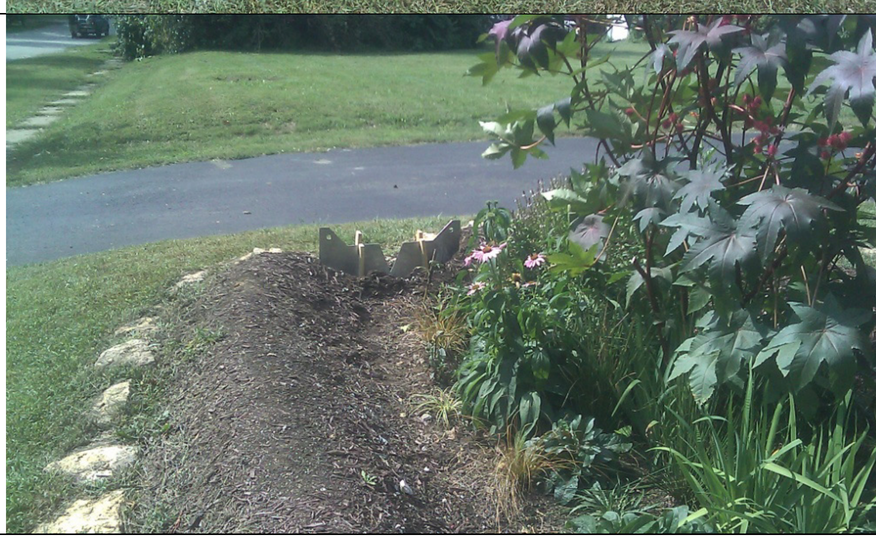


Figure 3. Trellis fabrication. 09/22/10

	Figure 4. Trellis fabrication. 09/23/10

Project: Private Rain Garden Installation - Thomas Property	Date: 09/23/10
	Created By: JN
	Figure 1. Weir installation. 09/23/10
	Figure 2. Weir installation. 09/23/10

	Figure 3. Weir installation. 09/23/10
	Figure 4. Weir installation. 09/23/10
	Figure 5. Weir installation. 09/23/10

Project: Private Rain Garden Installation - Thomas Property	Date: 09/25/10-09/30-10
	Created By: JN
	Figure 1. Locate bounds of excavation for barrel block supports. 09/25/10
	Figure 2. Paint pipe connections. 09/25/10
	Figure 3. Trellis installation to carry pipe from disconnected roof leader. 09/28/10

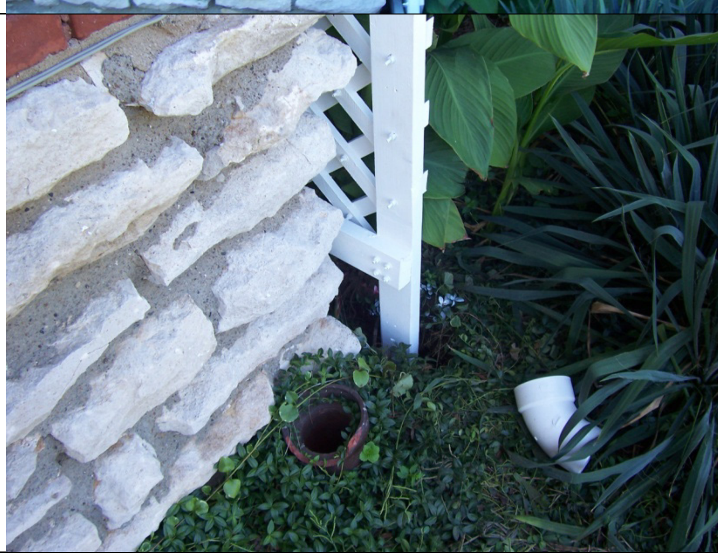
		Figure 4. View of barrel and connecting pipes, looking NE. 09/28/10
		Figure 5. Rood leader disconnect. 09/28/10
		Figure 6. Rood leader disconnect. Not shown, 4 in. test plug. 09/28/10

	Figure 7. Paint pipe connections. 09/28/10
	Figure 8. View of barrel and connecting pipes, looking NE. 09/28/10

Figure 9. Paint pipe connections. 09/28/10

Figure 10. Rood leader disconnect. 09/28/10

Figure 11. SW corner roof leader connection. 09/28/10

	Figure 12. Outlet protection. 09/28/10
	Figure 13. Installation complete, looking east. 09/28/10
	Figure 14. Installation complete, looking NE. 09/28/10

	Figure 15. Installation complete, looking north. 09/28/10
	Figure 16. Installation complete, looking NE. 09/30/10
	Figure 17. Installation complete, looking north. 09/30/10
Project: Private Rain Garden Installation - Thomas Property	Date: 10/08/10-10/11/10
	Created By: JN

Figure 1. Instrumentation of barrel flow monitor. 10/08/10

Figure 2. Instrumentation of rain garden. 10/08/10

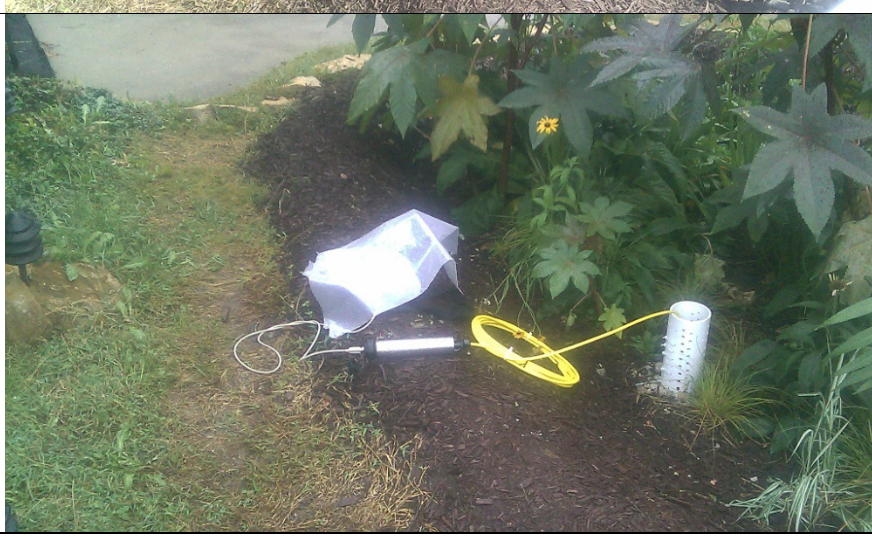
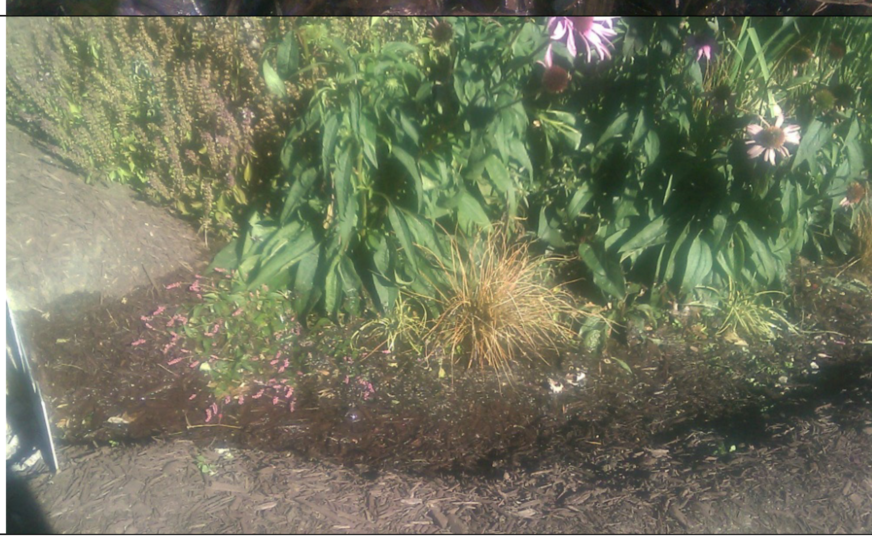
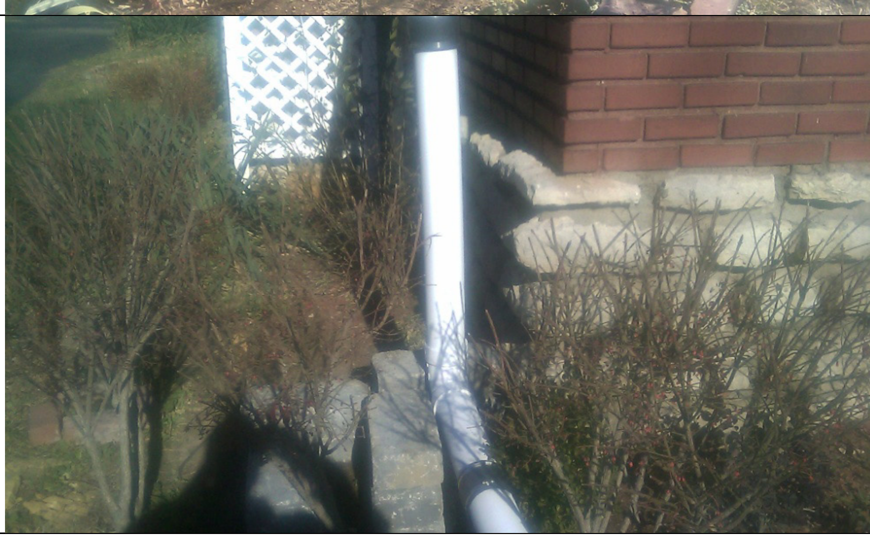


Figure 3. Data collection from rain garden Global Water Level Logger WL16. 10/11/10

Project: Private Rain Garden Installation - Thomas Property	Date: 10/27/10-10/28/10
	Created By: JN
	Figure 1. Borrowing invertebrates pictured in soil from rain garden absorption area. 10/27/10
	Figure 2. Air displacement during 2nd inundation test. 10/28/10
	Figure 3. Rain garden absorption area following 2nd inundation test. 10/28/10

Project: Private Rain Garden Installation - Thomas Property	Date: 12/02/10
	Created By: JN
	Figure 1. Leaf clutter and debris removed by PVC screen in barrel flow monitor. 12/02/10
	Figure 2. Winterized rain garden connection, looking southeast. 12/02/10
	Figure 3. Winterized rain garden connection, looking north. 12/02/10

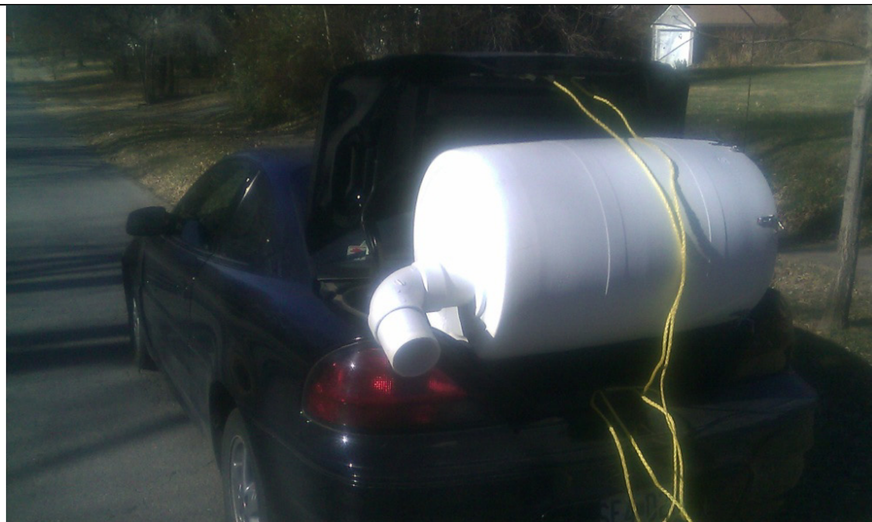


Figure 4. Transport of rain barrel from Thomas property to UMKC. 12/02/10

Figure 5. Winterized rain garden connection, looking north. 12/02/10

Figure 6. Winterized rain garden connection, looking north. 12/02/10

APPENDIX E

GLOBAL WL16 SPECIFICATIONS

Water Level Loggers

Global WL16 Water Level Data Loggers

Size: Datalogging Unit 1 7/8" diameter, 11.5" length (fits inside 2" well). Stainless steel UV protected PVC vented for barometric pressure compensation. Probe 5.7" length, .77" diameter

Material of Cable Covering Marine grade polyurethane jacket, polyethylene vent tube, full foil shield. Outside Diameter: 3/16".

Cable Wiring 3 wire (input, output, ground)

Weight 1.6 lbs

Recording Interval Programmable Linear fixed intervals from 1/second to once every 32,000 seconds (also 0-32,000 minutes, hours and days) and Logarithmic test (for pump and slug tests).

Sample Modes High Speed (10 samples per second), Fixed Interval (programmable from 1 sec to >1 year), Logarithmic, Exception.

Memory Storage Capacity Non-volatile flash memory. 81,759 time and date stamped data points including battery voltage. Type of memory Data Overwrite: Select memory wrap or unwrap (unwrap will stop logging data once memory is full)

Clock Synchronizes to the time and date of user's computer. Clock Accuracy 0.0025% or 1 minute in 1 month. Clock Format Month/Day/Year, Hour/Minute/Second

Power Two Lithium 9 VDC batteries. Battery life up to 1 year (depending on recording intervals).

Input Analog 0-4 VDC

Resolution 12 bit

Moisture Protection Silicon coating (prevents damage to electronics from condensation).

Temperature -40° to +185° F

Humidity 0 – 95% non-condensing

Linearity 0.1% Full Scale

Accuracy 0.1% Full Scale at constant temperature, 0.2% over 35º F to 70º F range. 0.25% Full Scale for temperature greater than 85º F.

Pressure Ranges 0-3', 0-15', 0-30', 0-60', 0-120', 250' and 0-500' are available.

Communication Port WL16S RS-232 4-pin circular connector WL16U USB Type B Selectable Baud Rates 9600, 19200, 28800, 38400, 57600, 115200

Software Compatible with Microsoft's Windows 95, 98, ME, 2000, NT, and XP. Windows and Excel are trademarks of the Microsoft Corporation.

Software Features Programmable record interval, scaling for engineering units, output in spreadsheet format, real-time monitoring.

Operating Temperature -40° to 170° F (Datalogger) Overpressure: 2 x full scale range Burst Pressure: 10 x full scale range

Geotech Environmental Equipment, Inc.
2650 East 40th Avenue • Denver, Colorado 80205
(303) 320-4764 • **(800) 833-7958** • FAX (303) 322-7242
email: sales@geotechenv.com website: www.geotechenv.com

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VITA

Jason Frank Nall was born in Sheboygan, Wisconsin. He received his Bachelor of Science in Civil Engineering from the University of Wisconsin - Platteville in May 2004. During the following years, he was employed as a consulting engineer. In January of 2009, he entered the University of Missouri - Kansas City to pursue the degree of Master of Science in Civil Engineering. He is employed as a project manager at Aquaterra Environmental Solutions, Inc. Jason is a professional engineer, licensed in Wisconsin, and is a Leadership in Energy and Environmental Design Accredited Professional (LEED AP).