HYDROLOGIC ANALYSIS OF RAIN GARDEN PERFORMANCE

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ANALYSIS OF RAIN GARDEN HYDROLOGY PERFORMANCE

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ABSTRACT

Urban flooding became a significant issue for many cities worldwide due to rapid urbanization and increased impervious areas over the past two decades ([1]). Rain gardens are considered to be an economically-friendly solution for addressing this extensive urban storm water problem. The Marlborough neighborhood, in an urban (and older) area of Kansas City, MO (USA) was selected as a large study area with dense rain garden construction opportunities and applicability. The City of Kansas City introduced the rain garden project into this neighborhood to see if the rain gardens could perform well in reducing inflow to the collection system, thus reducing combined sewer system capacity issues.

Regular and ongoing system monitoring is needed to quantify design parameters and long-term performance of rain gardens. There are seven rain gardens (part of 135 rain gardens in this six block neighborhood) that were monitored by the UMKC research team. The monitoring data reveals that the seven rain gardens have different performance responses during the same rain event. There are many candidate factors which may affect rain gardens' hydrological performance, such as watershed area, street slope, watershed slope, impervious area, precipitation depth, precipitation duration peak precipitation intensity, and antecedent dry day. There were a total 57 rain events that were captured between June 2012 and June 2014 for seven monitored locations. This study presents which factors are the most significant to affect the gardens' hydrological performance for future design. Therefore, a data-driven PCA and MLR model was developed from this study. Internal and external data validation have been processed to assess this model. Future site monitoring and design recommendation have been identified.

Rain gardens' hydrology characteristics research has been done for many years by different research groups nationwide. However, few studies show the detailed rain garden performance characteristics based on actual and varying field data. Most studies are limited to short monitoring periods and/or only one or two rain gardens. This study results can validate rain gardens' hydrology features. Thus, it can provide valuable support for future engineering site design guidance and new data analysis approach to research work based on more robust and extensive data.

APPROVAL PAGE

The faculty listed below, appointed by the Dean of the School of Graduate Studies have examined a dissertation titled "Analysis of Rain Garden Hydrology Performance" presented by Yanan Ma, candidate for Doctor of Philosophy degree and certify that in their opinion is worthy of acceptance.

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CHAPTER 1

LITERATURE REVIEW

1.1. Urban Area Stormwater Challenges

The hydrologic cycle is continuous, but every human habitat has a significant impact on it. As population increases and spreads across the land surface, people disregard the local environment and the natural limits for each place ([2]). One of the natural behaviors of water is to infiltrate into the ground and to evaporate back into the atmosphere. However, human development significantly changes the patterns of water movement, especially in urban areas where there are many impervious surfaces, such as parking lots, streets and houses. Human development will significantly impact on the natural hydrological cycle. The potential hydrological impacts of human behavior include the following ([3]):

1. Changes to stream flow, which will change stream geomorphology
2. Increased urban runoff volume
3. Increased urban peak runoff discharges
4. Increased urban runoff velocities
5. Increased frequency of bank-full or near bank-full events
6. Increased urban flooding events.
7. Reduced base flow, increased stream temperatures and loss of pool-riffle structures will have negative impacts on aquatic habitat.

Pollutants from urban runoff are also an increasing concern for the urban areas. The potential effects on water quality include the followings:

(1) Pathogenic bacteria/viruses from fecal material in combined sewer overflows (CSOs)

(2) Nuisance algal growth from excess nutrients in the runoff

(3) Toxicity from ammonia, heavy metal, organic compounds, pesticides and other contaminants.

(4) Higher temperature runoff into natural streams reduce dissolved oxygen levels in natural water bodies.

(5) Contamination of groundwater

Stormwater is classified as rainwater and melted snow that runs off streets, sidewalks, parking lots and other areas. Due to the increase in impervious areas, street runoff cannot always soak into the ground naturally. Instead, it stays on road surfaces, or rapidly runs into storm drains, sewer systems and drainage ditches ([4]). Runoff from urban areas contains grease, oil, nutrients (nitrogen and phosphorous), sediment, and heavy metals (Pb, Zn, Cr) ([5];[6]; [7]). The highest pollutant loadings occur during the "first flush" (first ½ inch) of runoff ([6]). The traditional solution for stormwater is to discharge the water using large drainage systems that flow to the receiving rivers. The large amount of polluted discharge that flows into the downstream river causes downstream flooding, CSO in combined sewer systems, stream bank erosion and also contaminated streams, rivers and coastal water. In additional, conventional or structural control solutions come with a higher construction and maintenance input than the green solution ([6]).

1.2. LID/GI Method

Low Impact Development (LID) has been considered to be an eco-friendly solution that can both provide natural storage and infiltration for runoff and treat pollution on site in a watershed ([8]). It is a decentralized micro-scale control measure for stormwater management ([8]; [9]; [10]). The LID strategy treats the stormwater on site in each LID unit instead of conveying it to centralized waste water treatment ([11]). The LID could capture and treat stormwater runoff onsite. It is a non-structural stormwater management solution rather than the conventional methods ([12]). LID types are varied for stormwater, and can consist of rain gardens and constructed wetlands, rain barrels and cisterns to collect water runoff from building roofs, green roofs to reduce the volume of runoff, and permeable pavement surfaces ([13]). Some scholars also considers Green Infrastructure (GI) as a subset under LID system ([14]). LIDs have infiltration units and filtration units. Infiltration units are designed to infiltrate runoff into the subsoils layers, like bioswales, bioretention cells and permeable pavement. Filtration units are not intended to infiltrate runoff into the subsoil, but to function as a storage facility for runoff. All filtration unites are required to have an underdrain system, such as a planter box, a green roof and a sand filter. Bioswales are narrow vegetated channels that are suitable for curbs and gutters with an infiltration function ([11]). The State of Florida Department of Environmental Protection suggests three categories of LIDs: (1) the retention LIDs which are designed for runoff storage, (2) Detention LIDs, which are designed to reduce the peak discharge, and (3) Source control LIDs which are nonstructural units designed to minimize the stormwater volume and pollutants ([15]). There are several types of LIDs.

(1) Pervious pavement, permeable pavement and porous pavers have been used interchangeably very often. However, these three pavements have their distinct characteristics. Permeable pavers allow water to pass around the bricks. The permeable pavers are composed of a layer of concrete or fired clay brick that is separated by joints filled with crushed aggregate. Porous pavers are cellular grids filled with dirt, sand or gravel. Grass will grow up and reinforce

the ground stabilization. So that rain water can infiltrate through the grass. Pervious pavement has a pervious surface while allows water to filter through. The pervious surface can filter urban storm runoff pollutants. Although permeable pavers and porous pavers have been around since the 1940s, pervious pavement is a relatively new technology addition to the LID category ([16]). There are pervious parking lots, pervious sidewalks and pervious driveways. Reducing the amount of impervious area in these high runoff area by pervious pavement technology is efficient in reducing both urban runoff and the amount of pollution in the runoff. Design criteria for pervious pavement requires that the travel distance of runoff should not be more than 100 ft. Level the street slope before intercept by permeable pavement to ensure a good performance. Usually, impermeable surfaces make up no more than 2/3 of the total area.

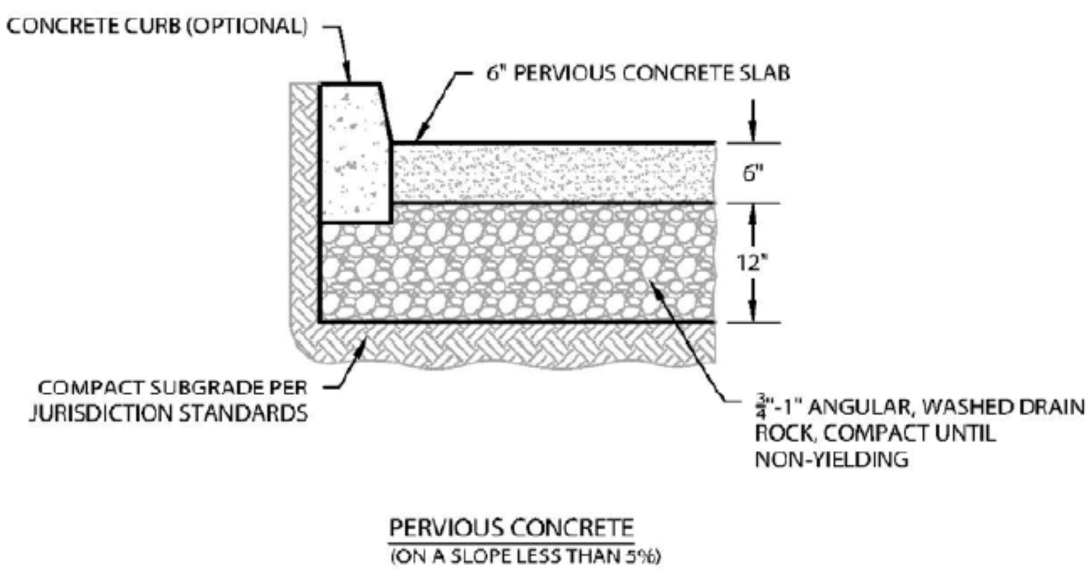


Figure 1 Typical Pervious Concrete (Source: Tahoe BMP[17])

(2) Infiltration Trench

The goal for infiltration trenches is to collect flush runoff and to improve the runoff water quality. The infiltration trenches have worked well for removal of solids and pollutant. The design restricts the contributing drainage area to any infiltration basin to 2 acres or less. Generally, locate basins at least 150 feet away from drinking water wells to limit the possibility of groundwater contamination, and at least 10 feet down gradient and 100 feet up gradient from building foundations to avoid potential seepage problems. The length-to-width ratio for an infiltration basin should be 3:1 or greater.

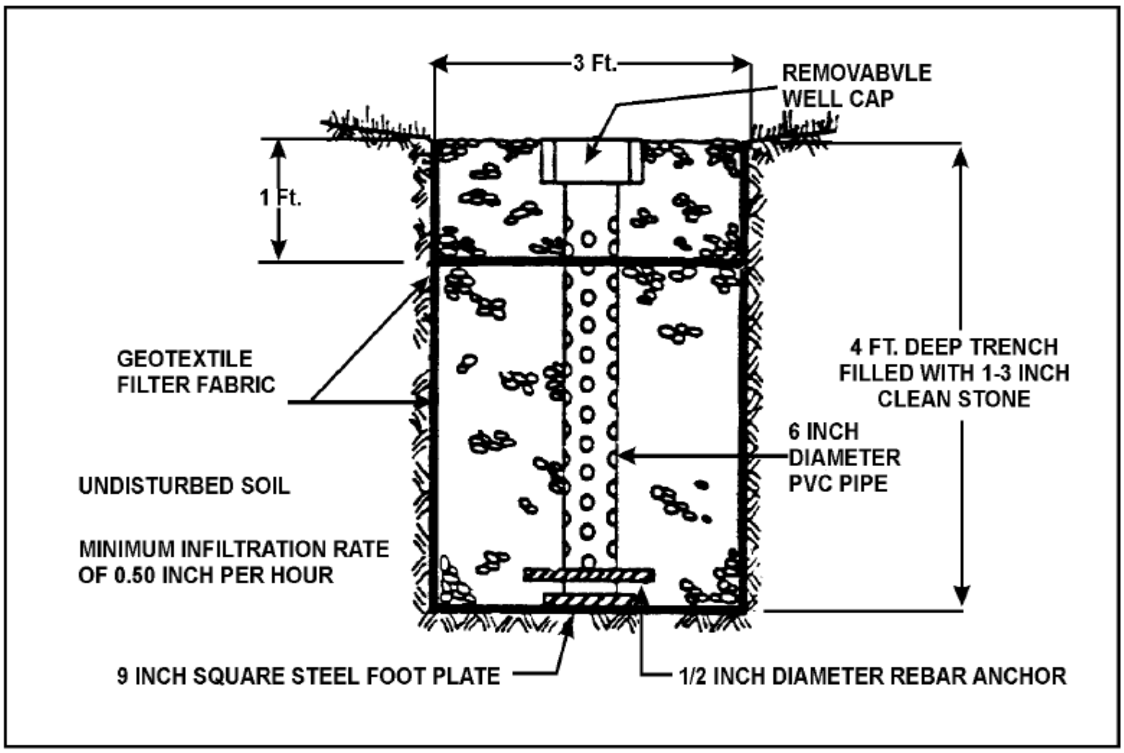


Figure 2 Typical Infiltration Trench (Source: Southeastern

Wisconsin Regional Planning Commission 1991[18])

(3) Extended Detention Wetland

Generally a detention wetland or pond is located at the downstream of an industrial area to treat the runoff from upstream. It also provides wildlife habitat and recreational benefits for that area.

The maximum depth is 6 to 12 feet, requiring a large area for retaining water for detention time.

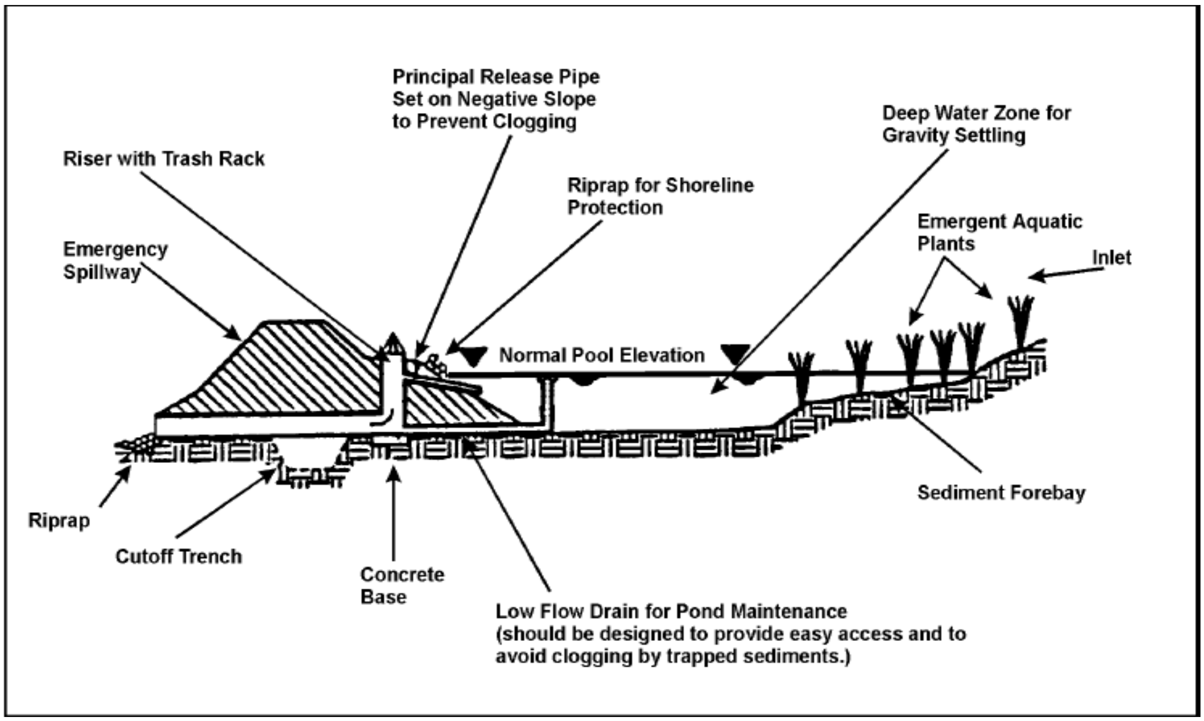


Figure 3 Typical Extended detention wetland

(Source: Maryland Department of Environment 1986[19])

(4) Green Roofs

Green roofs can be applied on the industrial, commercial and residential building roof to reduce total stormwater runoff volume and peak flows. Green roofs have the ability to remove the air pollutants like SO_2 (7%), NO_2 (27%), PM_{10}(14%) and O_3(52%) ([20]). Deeper growing media can be applied. The deeper growing media is usually greater than 6 inches and small trees, shrubs ([21]). The design reduction of stormwater volume is 50% to 85%, where this reduction depends on the depth of planting medium and the amount of maintenance needed. A green roof may be categorized as an extensive green roof, a semi-intensive green roof or an intensive green roof. The details are summarized in Table 1 ([22]). The unique function of green roofs is that they can help reduce the heat island effect in dense urban areas. The thermal function can keep the building cooling during the summer time. Thus, green roofs can help buildings save energy. In 2003, a thermal performance study of green roof based on field evaluation was been done by the National Research Council in Canada. This study showed a test area roof can reduce average daily energy demand by more than 75% in the summer time ([23]). More recently, a study in New York found that, during summer times, a green roof can provides 15-25 % energy savings, cuts rate of heat absorption through the green roof by 84%, and captures 40-60 % of the roof runoff ([24]).

Table 1 Green Roofs Categories

	Extensive Green Roofs	Semi-Intensive Green Roofs	Intensive Green Roofs
Overfall Depth	3-5 inches	5-7 inches	7-24+ inches
Weight Max.	15-25lb/square ft.	25-40lb/square ft.	35-80lb/square ft.
Maintenance	Low	Medium	High

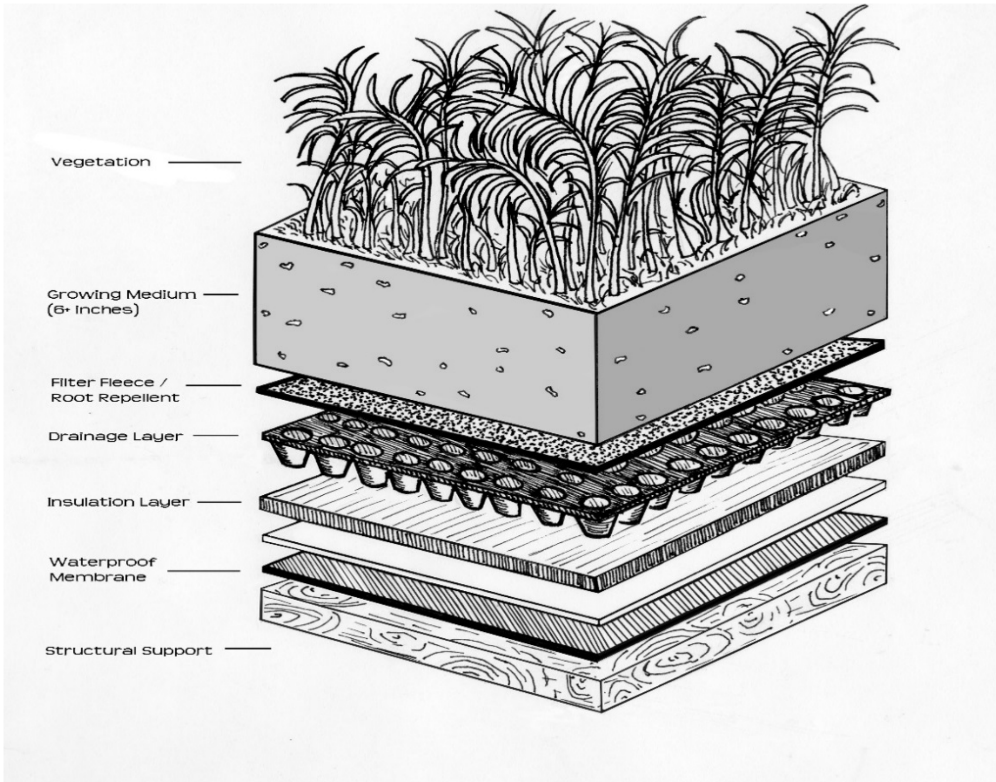


Figure 4 Typical Design of Intensive Green Roof (Source: Green Roof Plan 2010[25])

(5) Bioretention cells or rain gardens

Generally, bioretention cells work well with underdrains. Most will have an engineered soil layer. The goal of the engineered layer is to increase the infiltration rate on the garden soil bed. It is recommended that native plants, preferably the bioretention cells or rain gardens, plants with deep roots and a high tolerance for wet condition be planted([26]).

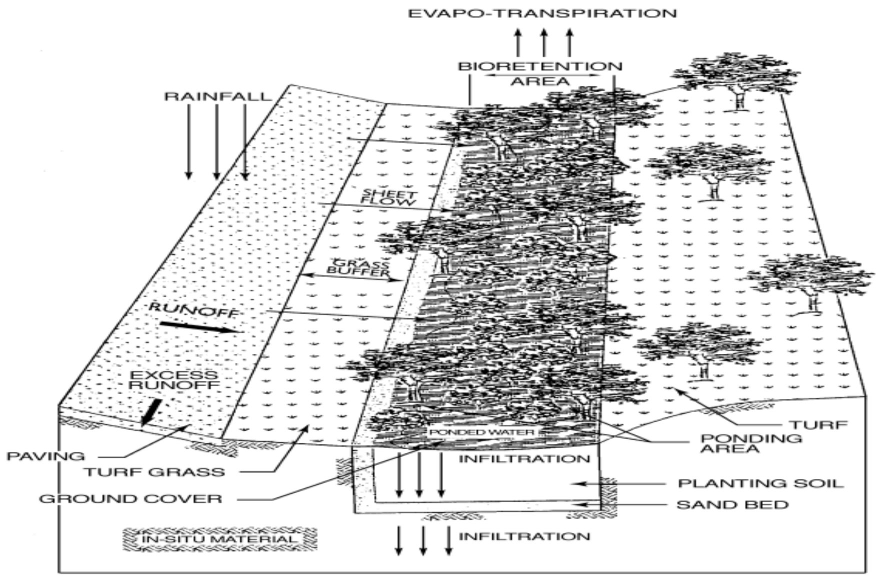


Figure 5 Typical Bioretention Cell or Rain Garden(Source: PGDER 1983[27])

Rain gardens, also referred to as bioretention practices, are shallow, vegetated depressions that are designed to receive stormwater runoff from impervious surfaces such as parking lots, roofs, and roads. Rain gardens and bioretention practices are the same type of LID [11]. Rain gardens systems have the potential to reduce peak runoff flow and improve water quality [20].

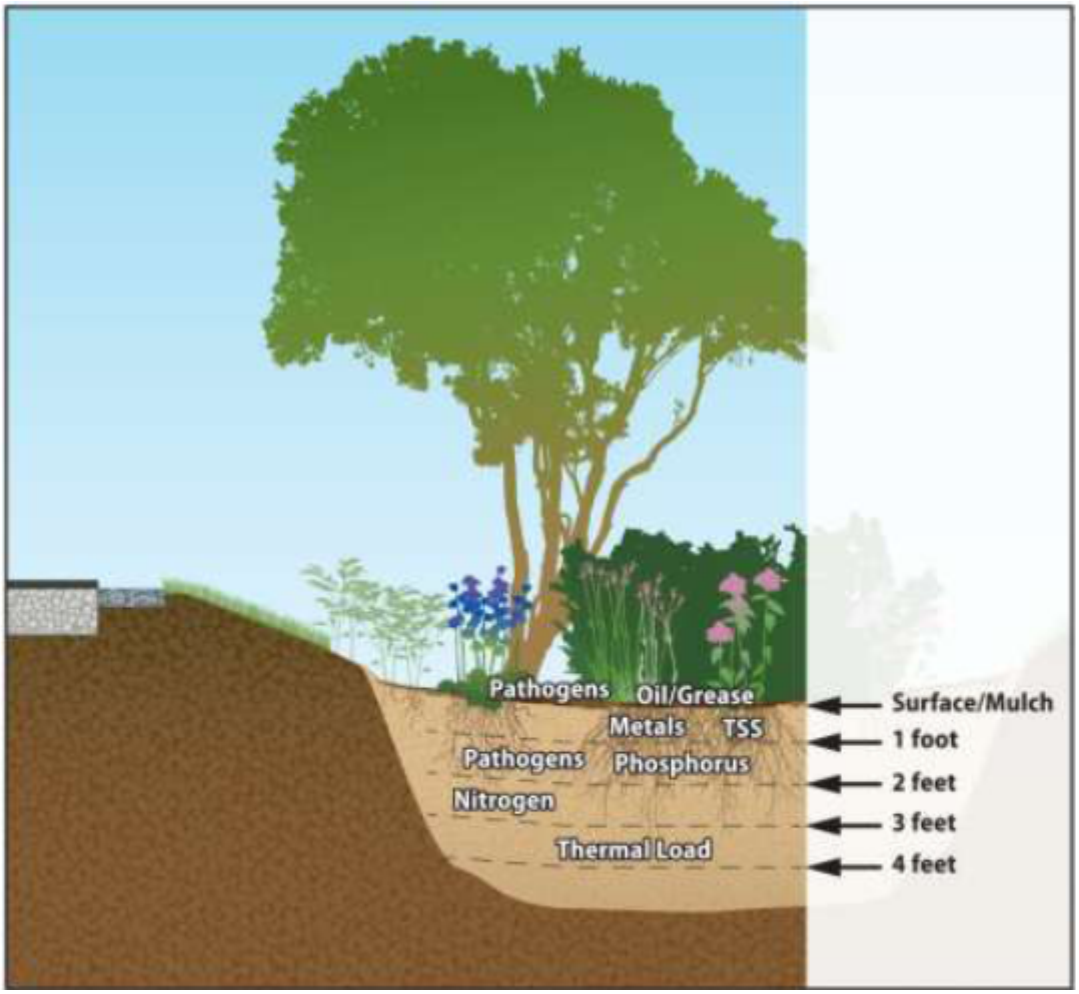


Figure 6 Bioretention Cell Pollutant Removal Layers (Source: Tetra Tech 2013[11])

1.3. Current GI Practices and Guidance

Several urban areas have implemented GI programs, including New York, Cincinnati, and Kansas City.

In 2010, the original New York Green Infrastructure Plan was released ([28]), and it was updated in 2012 . The plan was aimed at developing a long-term plan to manage the stormwater issues, which affect the water quality in New York harbor and its tributaries. This plan has indicated the green solution is a cost effective water management system that which could save billions of dollars over the traditional solutions. The proposed $1.5 billion budget will be spent on construction over the next 20 years. The sustainability benefits from the GI plan were as follows ([29]):

(1) Construct $2 million of GI in three neighborhood demonstration areas.

(2) Construct $3.4 billion in traditional solution.

(3) Manage 10% of the runoff from impervious areas in combined sewer system serviced area. The New York City Department of Environmental Protection proposed achieving the goal of capturing 1.5% of the impervious area by 2015, an additional 2.5% by 2020, an additional 3% by 2025 and the remaining 3% by 2030.

(4) Publish 11 Long Term Control Plans for the control of combined sewer overflow by 2017

In 2015, New York City published the monitoring results on Civil Engineering in May 2015. The three demonstration locations had total tributary drainage area of 24.1, 22.7 and 19.3 acres, and the monitoring results showed the runoff reduction was between 20% and 23 %. The GIs were found to be able to manage the first inch of rainfall that fell on more than14.3% of the demo impervious area surface. This exceeded the expectation of the 10% target. The impervious percentage is between 81% to 92% in those three demo areas. A total of 79 curbside bioswales were constructed. The bioswales were excavated to a depth of 5 ft and they were then backfilled with stone and engineered soil. They were designed to capture 1,100 to 2,200 gallons per storm. The construction cost for a 20 ft by 5 ft bioswale is approximately $16,500. The City of New York has added approximately 300 curbside bioswales throughout the city ([30]).

In 2011, The City of Philadelphia released the Green City Clean Waters report, which is their combined sewer overflow control program summary. The City of Philadelphia has one of the oldest sewer systems in the US and much of that original infrastructure is still operational.

Forty-eight percent of the city's 64 square miles lies within the combined sewer system serviced area. Based on this program summary document, beginning of 2009, in the future 25-year implementation period, Philadelphia Water Service Department will invest approximately $2.4 billion ($1.2 billion in 2009 dollars) to initiate a large scale green infrastructure program. This program was aimed at capturing 85% of the stormwater collected flow. The components of the large scale green program include 38% of green streets, 2% of green schools, 3% of green public facilities, 5% of green parking, 10% of green open space,16% of green industry, business, commerce and institutions, 6% of green alleys, driveways and walkways, and 20% of green homes. The City believes that in 45 years, the Green City, Clean Waters program will generate more benefits than the cost ([31]).

In Chicago, a rain event of 0.67 inches within 24 hours can trigger a CSO in the Chicago River. From 2007 to 2012, CSO events occurred 314 times, which means an average of one CSO event per week. According to the Green Stormwater Infrastructure strategy released by the City in April 2014, large-scale GI stormwater management is the key to solving this problem. This program includes the following actions:

(1) Installation of 350 green roofs over 126 acres of surface area.

(2) 7.5 acres of permeable pavement which can detain approximately 17 million gallons of runoff each year.

(3) More citywide tree planting.

(4) Engaging with communities and citizens to disconnect the downspouts from the sewer and connect them to a rain barrel, yard or garden.

(5) Help Chicago residents manage their backyard by distributing over 3,000 rain barrels per year.

Chicago will demonstrate a GI program by $50 million for the next five years. This program contains adopting permeable streets and increase the usage of bioswales. A GI cost-effective study and flooding risk analysis will be conducted for future decision-making purposes ([32]).

In July 2015, Seattle released a draft Green stormwater infrastructure strategy. The goal from this recently released plan is to manage 400 million gallons of stormwater runoff annually with GIs by the year of 2020. In this strategy, roadside bioretention swales, street trees, rain gardens, green roofs and permeable pavement will be adopted ([33]).

In 2007, Oregon Health and Science University developed a stormwater management plan that employed several LID techniques, including ecoroofs, bioretention cells and rainwater harvesting utilities. This comprehensive plan will reduce the impervious area by 21%, and this will lead significant reduction in campus watershed runoff, The plan will also improve the water quality ([34]). LID have also been applied as a way to recharge the groundwater table in Santa Cruz County, CA ([35]). A LID restoration master plan for town of Centreville, MD has been developed to reduce the runoff volume, to restore groundwater recharge and to optimize pollutant removal from urban runoff ([36]).

A Minneapolis watershed organization has constructed a living laboratory for the purpose of conducting research into stormwater management techniques. The Mississippi Watershed Management Organization (MWMO) would like to use this facility to determine the different function of various LIDs. This facility which is located beside the Mississippi River, includes various of LIDs such as rain gardens, green roof, cistern, permeable pavement and tree trench. MWMO would also take this opportunity to test different filter media to determine which is the most effective one to remove dissolved phosphorus. ([37])

1.4. Research Condition and Need

Numbers of studies have been conducted to find rain garden or bioretention cell performance in runoff pollution removal. Six year monitoring at a 8.3 acres LID residential subdivision in North Carolina found the total nitrogen (TN), total phosphorus (TP), and total suspended solids (TSS) exports from two LID sites are 23 to 92% lower than a control site ([38]). One highway median swale in Virginia and an agricultural test farm in Taiwan have been monitored and studied to find the average pollutant removal efficiencies on total suspended solids, chemical oxygen demand (COD), total nitrogen (TN) and total phosphorus (TP) are range from 14 to 99%. Data analysis indicated that a generally gradual slope for grass swales will have a better performance on pollutant removal ([39]). The table below summaries typical bioretention cells or rain garden pollution removal ability results: the data are summarized from released EPA reports ([40];[41];[42];[43]).

Table 2 Typical Bioretention Cell or Rain Garden Pollution Removal Ability

Pollutant	LID Types	Removal Rate
Total Phosphorus	Bioretention	70%-83%
	Rain Garden	70%-83%
Metals (Cu, Zn, Pb)	Bioretention	93%-98%
	Rain Garden	93%-98%
Total Nitrogen	Bioretention	68%-80%
	Rain Garden	68%-80%
	Bioretention	90%

Total Suspended Solids	Rain Garden	90%
Organics	Bioretention	90%
	Rain Garden	90%
Bacteria	Bioretention	90%
	Rain Garden	90%

Maintenance costs have also been compared with conventional stormwater management. A study examined seven LID types for 2 to 4 years and found that LID systems generally have lower maintenance costs than the conventional solutions ([44]). Bioretention cells have excellent performance for small rain events, but have a weaker performance for extremely large events ([45]). Generally, bioretention cells or rain gardens require twice-per-year routine cleanups including trash, sediment, debris and weed cleaning. The regular inspection is also recommended to make sure the gardens can drain ponding water within 72 hours to prevent mosquito breeding ([46]).

Hydrology performance of rain gardens has been studied by different researchers. Field data based simulation results from Case Western Reserve University indicated that infiltration dominates garden behavior more than evaporation and evapotranspiration ([47]). A field study at University of Maryland campus captured 49 runoff events. There were two parallel bioretention cells which can receive runoff from 0.24 ha asphalt surface parking lot. The results showed that there are significant peak flow delays and peak flow reductions for the two sites ([48]). A three-year study in Twin Cities, MN found that the bioretention system performed well in that cold climate area. The frost type has the most significant impact on the bioretention performance by affecting the infiltration rates ([49]). A seven year monitoring study has been conducted on a Villanova campus rain garden, and this study indicated that the accumulated fine materials do not have significant impact in garden infiltration potential.([50])

The bioretention abstraction volume(BAV) concept has been defined by Davis in 2012 ([51]). The BAV has been defined as the available storage volume in the bioretention cell. The BAV includes the garden surface bowl volume, media depth region volume, root zone region volume, lower median zone volume, and internal water storage. Figure 7 shows the concept of the BAV model.

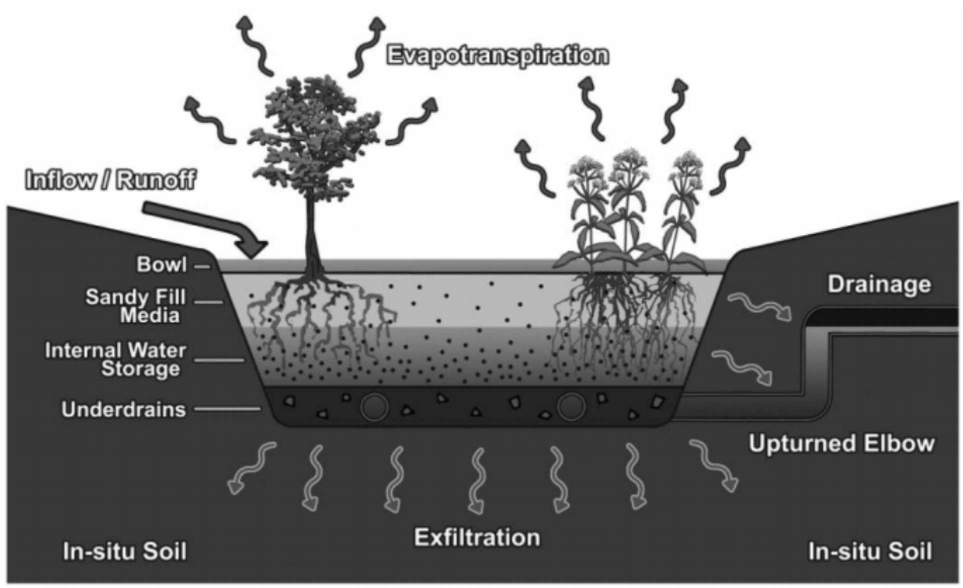


Figure 7 Cross Section of Bioretention Cell

(Source: Shawn Kennedy, NC State University)

For different types or bioretention cells, the BAV are calculated differently as below.

(1) For bioretention cells without an underdrain, BAV=Bowl Volume.+RZMS(SAT-WP)

(2) For bioretention cells with an underdrain but no internal storage,

BAV=RZMS(SAT-WP)+LMS(SAT-FC)

(3) For bioretention cells with internal storage

BAV=Bowl Volume.+RZMS(SAT-WP)+LMS(SAT-FC).

Where BAV= Bioretention abstraction volume

RZMS=root-zone media storage volume

SAT=saturation point

WP=wilting point

LMS=Lower media-storage volume (Deeper than plant roots)

FC=field capacity.

However, due to the soil permeability, water table depths and street slope or other site characteristics, placement of LID needs to be carefully planned ([6]). A study was conducted by Stander's team. This study monitored six gardens which have been categorized into three different groups. The results showed that the rain garden sizes don't have as significant impact on the garden hydrology performance as the soil layers in the garden([52]).

This study focus on the bioretention cell or rain garden hydrology performance. Therefore, in order to understand current bioretention cell or rain garden design guidance and criteria, some existing technical guidance have been reviewed and listed in tables below

Table 3 Bioretention Cell or Rain Garden Technology Guidance Summary Table

Manual	Authors	Garden Size	Soil	Drainage area (DA)	Existing groundwater table	Watershed Slope	Impervious area	Street Slope	Curb inlet width	Catch Basin	Garden basin design	Mulch	Maintenance	Ponding depths and drawdown time
LID Technical Guidance Manual for Puget Sound (2012)[53]	Washington State University Extension & Puget Sound partnership	GSI-Cal sizing tool	Highly permeable layer, sandy	0.75 ac is a threshold to change infiltration reduction factor in the design		<10%	0.23 ac is a threshold to change infiltration reduction factor in the design	NA	18 inches is recommended, 12 inches is the minimum	Forebays are necessary to capture debris and sediment	Side slope 3H:1V.	2-3 inches	frequent maintenance during the first three years. Include watering, mulch/soil replace, sediment removal, plants care.	6-12 inches 24-48 hours
LID manual for Southern California (2010)[54]	The low impact development center, Inc.		Infiltration min is 0.5in/hr., sandy. Group A B without undrain, group C D with under-drain	Max tributary area should be less than 5 acres	at least 10 ft.	5-15%							Semi-annual planting inspection, occasional sediment and debris removal	
LID Standards Manual (2014)[55]	County of Los Angeles Dept. of Public Works	3-5% of DA	in-situ infiltration rate of 0.3 in/hr. or higher	<10 ac		Recommend gently sloped site <20%					Side slope 3H:1V.		Medium frequent maintenance	18 inches 96 hrs.
LID manual (2013)[56]	Metropolitan Nashville Division County	3% to 10% of the DA	Infiltration rate greater than 0.5 in/hr. otherwise consider underdrain		Minimum 2 feet away	1-5% or terraced to slow flow	Impervious area from 0.1 ac to 2.5 ac					3 inches	First 6 months, site inspection at least twice for storm greater than 0.5 inch. Regular irrigation and trash removal are required.	Maximum ponding depth is 6 inches
LID Manual for Michigan (2008)[57]	Southeast Michigan Council of Governments			No more than 1 acre	Minimum 2 feet away, 4 feet is recommended	Median slope	Impervious area/ bioretention area should be smaller than 5:1				Maximum Side slope 3H:1V.	2-3 inches	Biannual health evaluation	6-18 inches 48 hours

Manual	Authors	Garden Size	Soil	Drainage area	Existing groundwater table	Watershed Slope	Impervious area	Street Slope	Curb inlet width	Catch Basin	Garden basin design	Mulch	Maintenance	Ponding depths and drawdown time

San Antonio River Basin LID Technical Guidance Manual(2013)[11]	Tetra Tech		Greater than 0.5in/hr. Otherwise underdrain pipes are needed 0.5 to 6 inch/hr.	Smaller than 5 acres	Minimum 3 ft. away	Smaller than 15%					Maximum Side slope 3H:1V.	3 inches	Medium frequent maintenance	Average 9 inches. Surface draw down in 12-24 hrs, subsurface drain in 48-72 hrs.
LID Practices Design & Implementation Guidelines Manual (2014)[15]	Geosyntec Consultants	Maximum is 1 acre	Typically designed with underdrain or overflow spillway.		At least 2 ft.					Sediment trap will be designed		2-3 inches	Medium to high level frequent maintenance	Maximum ponding depth is 6 inches
New York State Stormwater Management Design Manual (2015)[58]	New York State Dept. of Environmental Conservation		Soil type A B without underdrain, soil C D with underdrain				Smaller than 1000 square feet. Impervious area to infiltration area ratio cannot exceed 5:1				Maximum Side slope 3H:1V			Maximum ponding depth is 6 inches
Manual of BMP for Stormwater Quality (2012)[46]	APWA & Mid-America Regional Council		If infiltration rate is less than 0.1 in/hr. then amended soil layer will needed	Smaller than 1 acre	10 ft. from building foundations		Rain garden surface area from 10% to 40% of catchment area					3 inches		Maximum ponding depth is 6 inches. Drain 24 to 48 hrs.
LID Strategies an Integrated Design Approach (1999)[59]	Prince George's County, Maryland		Infiltration rate needs to be greater than 0.27 in/hr.	Garden surface from 50 to 200 sq. ft.	2 to 4 ft. above ground water table/bedrock 10 ft. down gradient from foundations								Low maintenance	6 inches

As discussed before, few large-scale GI programs have been completed in US or even in the world. The Kansas City Middle Blue River Pilot Study has a very unique dataset with various data collected. This study has a three year combined sewer data period that has been analyzed by Ma ([60]) in her master's thesis and Leila ([61])in her PhD dissertation. Both found the post construction period in the study area shared a more than 30% reduction of the watershed runoff after GI construction. Beyond the watershed level data, individual gardens were monitored from 2011 to 2015. The monitoring initially started from 2011 and ended in 2013. Another funding source from University of Missouri Kansas City School of Graduate Studies supported the monitoring program from August 2014 to June 2015 to extend the monitoring period. Therefore, a detailed rain garden/bioretention cell hydrology performance data analysis can be conducted based on this robust dataset. A data-driven model can be developed based on advanced statistical methods. It can quickly predict the runoff reduction from proposed rain garden plan at the early stage of a conceptual design.

1.5. Proposed Research

For monitored gardens, the total inflow to the garden and the infiltrated volume for each rain event can be calculated by the 0.5H flume conversion equation and the V-notch overflow equation. Different variables may affect the garden inflow and the infiltration rate. The potential influences for total storm volume into a garden are watershed area, street slope, watershed slope, garden length slope, flume width, whether or not the garden inlet has grooves, rainfall depths and rainfall duration, rainfall intensity and antecedent dry days before each event. The potential influences for infiltration rate are whether or not garden has an underdrain, rainfall depths, rainfall duration rainfall intensity, peak rainfall intensity and antecedent dry days before each event. Statistical analysis based on the field data will be conducted to address the following questions.

Question I: Which factors impact the total inflow for each individual garden? Which factors have no statistically significant impact on inflow for each garden? Is there any interaction among those factors based on statistical analysis?

Question II: Which factors impact the infiltration rate of each individual garden? Which factors have no statistically significant impact on the infiltration rate? Is there any interaction among those factors based on statistical analysis?

Question III: Will the gardens have different performances in different rain events?

Question IV: What design/monitoring suggestions result from the research results based on statistical analysis?

Question V: Is there a data-driven regression model can be constructed to estimate how much of runoff rain garden can capture?

The dataset will be analyzed by two different statistical approaches. The first approach will use factorial analysis in Minitab to determine factors impact the responses and whether there are any interactions among the factors ([62]). During this process, the numerical values will be assigned as either high and low (digital) values and analyzed as discrete values. The data will be analyzed as a binomial dataset. The second approach will use the software R to do a multivariate analysis based on continuous numerical values. For the garden performance analysis, principal component analysis (PCA) will be adopted to reduce the factor dimensions and to find a regression equation from those principal factors. Cross validation will be applied to the model validation process ([63]). For the entire dataset, analysis of similarities (ANOSIM) will be adopted to group the similar rain events and analyze the impact of engineering design characteristics on the total volume and infiltration rate. All of the statistical analysis results will provide a comprehensive understanding of the rain garden field monitoring data.

Prior to the input of data into Minitab, careful data review was done. It included incomplete dataset removal, removal of data due to equipment failure removal, and removal of outliers. The high level values used in the factorial analysis in Minitab were assigned manually. The numerical values of each factor were divided into a high group and low group based on the mean. The high group values are +1, low group values are -1. The backward elimination method with $\alpha=0.05$ has been used for factor selection process. In order to meet the normality assumption of the T test and F test, the response numerical value has been square root - transformed.

After the proper data analysis, the questions will be answered based on the results as in the followings ways:

Question I: Which factors impact the total inflow for each individual garden? Which factor are not statistically significant impact on inflow for each garden? Is there any interaction among those factors based on statistical analysis?

The Design of Experiments (DOE) analysis using Minitab is widely available to engineers. The results from factorial analysis will identify and explain the significance on each factor. Factorial analysis reveals interactions between each factors and explores the influence of the factors on the inflow.

Question II: Which factors impact the infiltration rate of each individual garden? Which factors are not statistically significant impact on the infiltration rate? Is there any interaction among those factors based on statistical analysis?

Factorial analysis will also be applied in the infiltration data. The results will explain the impact of each factor on rain garden infiltration. It will also display the interaction impact within each factors.

Question III: Will the gardens have different performances in different rain events?

The ANOSIM will group similar rain events based on total rainfall depth, rain duration, peak intensity and antecedent dry days. Three groups are expected from this analysis: small event, medium event, and large event. Comparison analysis between groups will be conducted to find the impact of factors in rain garden response to rain events. Comparison of the results from different approaches will be made in the summary section.

Question IV: What design suggestions result from the research results based on statistical analysis?

Based on the significant factors analysis results, some detailed design values may consider to be overly conservative. The results from this study will evaluate existing design criteria. For instance, the LID manual for Kansas City area suggests that the rain garden surface area should be from 10% to 40% of its catchment area. The study monitored sites have an average garden surface area to drainage area ratio of 52%. These gardens' great performance indicates that the design values may need to loosen to have an efficient design.

Question V: There is a data-driven regression model can be built up to estimate how much of runoff rain garden can capture.

Based on the factorial analysis and PCA analysis results, a data-driven statistical regression model is expected. A high level resolution estimation of rain garden performance can be made from this model. The field data from Nov 2012 to May 2013 will be used for model validation.

Many physically-based models have been constructed to simulate the rain garden performance, including SWMM, SUSTAIN and WinSLAMM ([64], [65]). The case study in South Korea uses Storm Water Management Model (SWMM 5.0) to evaluate the LID performance on flood runoff mitigation ([64]). Many studies have adapted different models to simulate various scenarios to optimize rain garden design plan. System for Urban Stormwater Treatment and Integration (SUSTAIN) has been used to obtain the most cost-effective rain garden design plan in Foshan City, China ([65]).

However, few studies involved in statistical approaches. The data-driven statistical model will provide a simpler and faster approach to estimate the runoff reduction from a large area. The study by Khan's team in 2013 provides a garden size design guide tool based on a multiple linear regression model. However, the work herein has unique and significant differences from Khan's work. A comparison table between this study and Khan's work is summarized in Table 3 (Khan et al. 2013).

Table 4 Khan's Work

	Khan(2013)	This Study
Similarity	Data Driven Model	Data Driven Model
Difference	Simulated rain event	Natural rain event
	Experimental purpose garden design, not operate and no runoff drains.	Operating rain garden with runoff drains.
	Only study on infiltration volume	Study on inflow volume and drawdownrate

	Focus on cold climate	Common climate condition

From the data-driven regression model, the water volume captured by each rain garden can be estimated. This model will be applied to the remaining rain gardens in the study area to achieve a total watershed level reduction of runoff for given rain event values. The field data from the total watershed draining to the combined sewer can be used to do the model validation. There were eight rain events that used to do this validation (Table 4). The eight rain events will be excluded from model development. Table 5 summarizes the two categories of LIDs in the test area. The fundamental theory for this validation is shown in equation 1.

$$\text{Rainfall(gal)} = \text{Captured Water Volume(gal)} + \text{Pipeflow(gal)} \qquad \text{Equation 1}$$

Table 5 Monitored Watershed Runoff from Study Area

(Source :Ma 2013)

Starting Time	Ending Time	Rainfall (inch)	Test (gallons)
11/11/2012 4:35	11/11/2012 12:30	1.45	430,000
4/7/2013 19:09	4/8/2013 0:46	0.97	180,000
4/9/2013 20:58	4/10/2013 8:58	0.8	320,000
4/17/2013 21:08	4/18/2013 8:58	0.9	210,000
4/26/2013 14:28	4/27/2013 9:18	0.87	170,000
5/2/2013 2:00	5/3/2013 3:00	1.02	200,000
5/27/2013 8:18	5/27/2013 12:03	2.36	360,000
5/29/2013 22:48	5/30/13 14:13	1.30	570,000

Table 6 Summary Table for Characteristics of Test Area

Design Plan Component	Number of this Type of Stormwater Control Units in Test(pilot) Area	Drainage Area for Each Unit(ac)	Total Area Treated by These Devices (ac)
Rain Garden without underdrain	83	0.33	27.03
Bioretention with underdrain	47	0.45	21.03
Shallow Bioretention Cell with SmartDrain®	5	0.25	1.26
Total number of control units:	135	Total area treated	49.32

1.6. Literature Review of Design of Experiments and Hybrid PCA and MLR Model

Factorial analysis has been applied for storm surge flooding in Barrow, Alaska to gain a comprehensive understanding of the occurrence of flooding. The research team adapted simulation flow from a numerical weather prediction model and a storm surge inundation model. They found that the most significant predictor for severe flooding is winds exceeding 13mph for at least 20hr [66]. In the water quality area, a three-way factorial design was used to evaluate the significant factors to contribution to nitrogen removal in a rain garden. The factorial design results also found there were no significant interaction among the tested factors ([67]).

Currently, there are different model tools can be used for LID/GI design or location. Models can be generally categorized in to three groups ([68]).

(1) Group 1 can provide an approximate and quick screening and planning results that require low input and effort, such as Water Environment Research Foundation (WERF) BMP select and WERF Whole Life Costing Tool.

(2) Group 2 can provide better approximate screening and planning results. This group includes Long-Term Hydrologic Impact Assessment (L-THIA-LID), developed by Purdue University, and the EPA National SW Calculator. L-THIA-LID is an easy use screening tool. It can estimate runoff volumes, depths, and expected pollution loadings for a group of LID practices that includes bioretention cell, rain garden, grass swale, porous pavement, green roof etc. ([69];[70];[71]). A one -dimension finite difference model, Bioretention Hydrologic Model (BHM) has been developed to simulate the hydrologic behavior in bioretention system. In this study, ten storm events monitored inflow and overflow data have been used for this analysis. The main model variables are total rainfall depth, rainfall duration, average rainfall intensities, 5 min rainfall intensity, and antecedent moisture condition which is treated as category data. The evapotranspiration rate was calculated based on Penman-Monteith equation ([72]). A Two dimensional Finite Richards equation based model has been developed and validated on one experimental designed purpose rain garden to estimate infiltration and recharge ability ([73]).

(3) Group 3 can provide advanced planning and sizing results. It is more accurate, but requires high effort and data input. For example, the Storm Water Management Model (SWMM) developed by the EPA, has been applied for various urban storm strategizing process, Field data

have been used for model validation and calibration ([74]). Recently, the LID components have been combined into the original model as vertical layers ([71]). SUSTAIN can integrate mapping and modeling. SUSTAIN is a decision making assistant model made by the USEPA. It supports a variety of LID units to simulate the storage, infiltration, evapotranspiration and pollutant transportation ([75]). RECARGA, developed by University of Wisconsin-Madison, is limited to rain garden design. It can simulate groundwater recharge through bioretention. However, it has not been validated against field data. Source Loading and Management Model for Windows (WinSLAMM), developed at University of Alabama-Tuscaloosa by Dr. Robert Pitt and John Voorhees.

All of the models are described above based on same physical mechanism of urban hydrology. Field monitored data can be used to do the model calibration and justification to improve the accuracy. For instance, the Kansas City data have been used for a WinSLAMM model calibration by Dr.Pitt.

The pilot area design of this study was originally analyzed by SWMM. The goal for the city of Kansas City is to reduce peak flow by 76% and reduce sewer runoff volume by 292,000 gallons ([76]). This goal applied to combined sewer outfall No.069, which captures runoff from 475 acres. The 100-acre pilot area ultimately drains to outfall No.069. The final design can provide approximately 372,000 gallons of storage volume ([76]).

Many collected variable data have correlated variables. High correlation between variables decrease the accuracy on the regression model. The Principal Component Analysis (PCA) has been applied to transfer the original dataset into uncorrelated principal component scores which forms the bais for new variables for analysis([77],[78], [79], [80], [81]) PCA and multiple linear regression (MLR) have been used for the forecasting on stream flows based on hydrologic predictors, atmospheric predictors, and oceanic predictors. Potential predictors of the flow data have been selected based on the significant correlations coefficient r. A 95% confidence level have been used as the criterion. The PCA and MLR approach has been applied the model built-up for individual sites with a good performance ([80]). The PCA and MLR hybrid model has been compared with general multiple linear model in a long-range forecasting study on Nile River flow using climate data. This study proved the hybrid model from PCA and MLR approached have a higher accuracy of forecast lead time of the Nile River. The correlation among predictors may impact the precision of the model because the correlation between variables impacts the coefficients of individual variables, and this may decrease the regression equation accuracy. PCA can determine orthogonal variables from the original variables to remove the correlation ([79]). The combination of PCA and MLR has applied in food science area. The effect of E-bean irradiation on food has been evaluated by this approach. The PCA on the chemicals, was followed by an MLR with a response term of nitrate and nitrite content ([78])

Cluster analysis has been applied in water quality assessment in Hong Kong. Linkage distance has been calculated on both water quality temporal and spatial variations to group the monitoring periods and monitoring sites ([82]). Bioretention cells have excellent performance for small rain events but have a weaker performance on extremely large event ([45]).

Measured and monitored data can help define or modify LID guidelines. However, a sufficient data analysis framework has not been developed. A part of the future work for the LID research is to develop an easy decision tool that can incorporate LID units ([9]).

CHAPTER 2

PROJECT BACKGROUND

2.1. Overflow Control Program

In response to Kansas City's City Council Resolution 030764, which passed on July 10, 2003, the City of Kansas City, Missouri (the City) Water Service Department (WSD) submitted a comprehensive approach to managing the runoff water issues in the City. The Wet Weather Solutions Program contains three major components: (1) A comprehensive stormwater management plan that includes the City's stormwater management framework for 35 watersheds, (2) Develop and implement major flood control in the City with the U.S. Army Corps of Engineers, and (3) Develop a long-term plan to control the overflows from the City's wastewater collection and treatment system. In 2009, the KCMO Water Service Department submitted the overflow control plan to the United States Environmental Protection Agency (USEPA) and to the Missouri Department of Natural Resources (MDNR). On Sept. 27, 2010, the United States District for the Western District of Missouri Federal Court approved the plan and entered the Consent Decree. The Consent Decree stipulate that for the City's combined sewer system (CSS) and separate sanitary sewer system (SSS), the overflow frequency, volume and duration need to be decreased ([83]). The CSO Control Policy was issued by the USEPA in 1994. The EPA policy was meant to utilize the National Pollutant Discharge Elimination System (NPDES) permit program by establishing a consistent management approach to control the national combined sewer discharges to national waters. WSD worked with regulatory agencies for several years to meet the requirements of the Clean Water Act (CWA). The plan outlines control plans for the City's CSS and SSS ([83]).

2.2. Kansas City Combined Sewer System

Combined sewer systems are widely used for the United States' earliest city constructed. CSOs became a major water pollution concern in over 700 cities and for approximately 40 million people around Northeast, Great Lakes, and Pacific Northwest regions in the United States ([32]).

Conventional stormwater approaches have focused on removing stormwater from a site as quickly as possible, as well as on transfering the flow of stormwater into a centralized collection system. The traditional approaches convey the runoff as fast as possible to the drainage pipe system ([84]).

Kansas City has combined sewers in many areas that were constructed before 1945. In a typical year, the estimated total overflow volume from the city's combined sewer system south of the Missouri River was 6.4 billion gallons. The CSO condition varies for different locations. Some outfalls have no CSOs expected in a typical year. However, some outfalls are expected to have several CSOs per month. An estimation of overflow frequency at the 89 outfalls south of the Missouri River exceeds 18 times per year ([83]). Table 7 shows the details of the CSO extent in Kansas City area. There were 36 sewer overflows per year when a rain event yielded over 0.6 inches of rain. Therefore, green solutions and conventional source reduction techniques will play significant roles in the CSO control plan. The goals for the city are (1) to reduce CSO frequency by 65%, which turns out to be 1.4 billion gallons of the runoff from the entire combined sewer service area, (2) to reduce inflow and infiltration in the sanitary sewer system, and (3) to provide adequate capacity for runoff storage, transportation, and treating the remaining wet-weather flows area within Kansas City that is served by the combined sewer system ([83]). Figure 8 shows the combined sewer service area in Kansas City. The total combined sewer system serviced area within Kansas City is approximately 56 square miles.

Table 7 Combined Sewer System Performance in Typical Year

KCMOWSD 2012[83]

Basin	Typical Year Wet Weather Flow (billion gallons)	Existing Overflow Volume (billion gallons)	Capture of Wet Weather Flow (%)
MISSOURI RIVER CSS BASINS			
Downtown Airport	Data not Available		
Turkey Creek/Central Industrial District	2.99	2.66	11%
Northeast Industrial District	1.12	0.89	21%
Subtotal, Missouri River Basins	**4.11**	**3.55**	**14%**
BLUE RIVER CSS BASINS			
Town Fork Creek	0.88	0.34	61%
Brush Creek	1.83	1.46	20%
Subtotal, Brush Creek CSS Basins	**2.71**	**1.80**	**34%**
Gooseneck Creek	1.02	0.68	34%
Lower Blue River	0.62	0.21	66%
Middle Blue River	0.62	0.15	76%
Subtotal, All Blue River CSS Basins	**4.97**	**2.83**	**43%**
SSS Wet Weather from 87th Street	2.07	N/A	N/A
SSS Wet Weather from Round Grove	0.50	N/A	N/A
Subtotal, SSS Inflows to BRIS	**2.56**	N/A	N/A
CITY-WIDE TOTALS	***11.64***	***6.38***	***45%***

Table 8 Middle Blue River Existing and Future Land Use Details

	Single Family	Multifamily	Commercial	Industrial	Institutional
Existing	39.5	4.5	4.3	8.6	4.2
Future	49.0	4.7	5.5	13.9	3.8
	Transportation	Mass Assembly	Leisure Activities	Natural Resources	Unclassifiable
Existing	2.6	1.0	16.7	1.0	18
Future	0.3	0.9	18.7	0.0	4.2

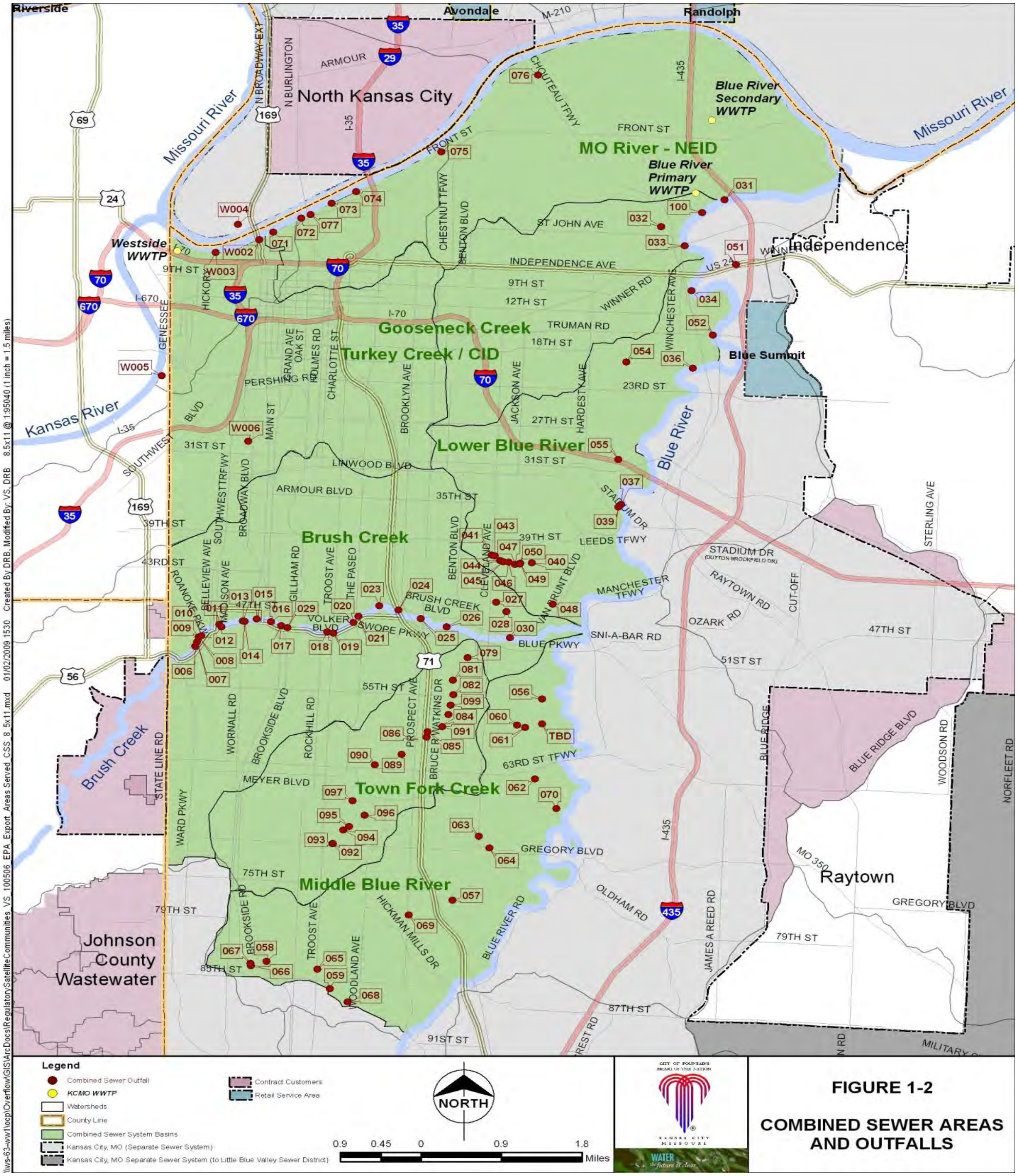


Figure 8 Combined Sewer Areas And Outfalls

Source: KCMOWSD 2012[83]

2.3. Blue River Watershed

In the Blue River Watershed, monitoring data demonstrate that the CSO receiving streams do not meet current state water quality standards for bacteria level. The major pollution sources in the receiving CSOs are (1) upstream stormwater runoff, (2) adjacent area from both SSS and CSS to the streams, (3) effluent from wastewater treatment plan, and (4) untreated waste water overflow from the combined sewer. The reduction of CSOs in the Blue River Watershed will benefit the receiving stream water quality, resulting in the meeting of current state water quality standards. The Post Construction Monitoring Program (PCMP) is also a part of the City's Overflow Control Plan. This program includes installation of flow meters and level sensors in both CSS and SSS to do the flow monitoring and to capture the pre/post construction change inflow. The GI pilot project in the CSS basin is a large scale project that will benefit the downstream of the GI area significantly. Corresponding public education and outreach are also in planning. In the entire Blue River Watershed, different solutions have been applied at different locations. Map 2 shows the plans for the entire watershed. The GI pilot area is located at the Middle Blue River watershed upstream of outfalls of 059 and 069. The GI projects has an estimated cost of $21 million from capital and $1.04 million from additional annual operation and maintenance (O&M), both in 2008 dollars ([83]). The CSO control plan for the Blue River Watershed is identified as the "demonstration approach". The development and implementation of the program includes a suite of CSO control that is sufficient to meet the state water quality standards ([83]).

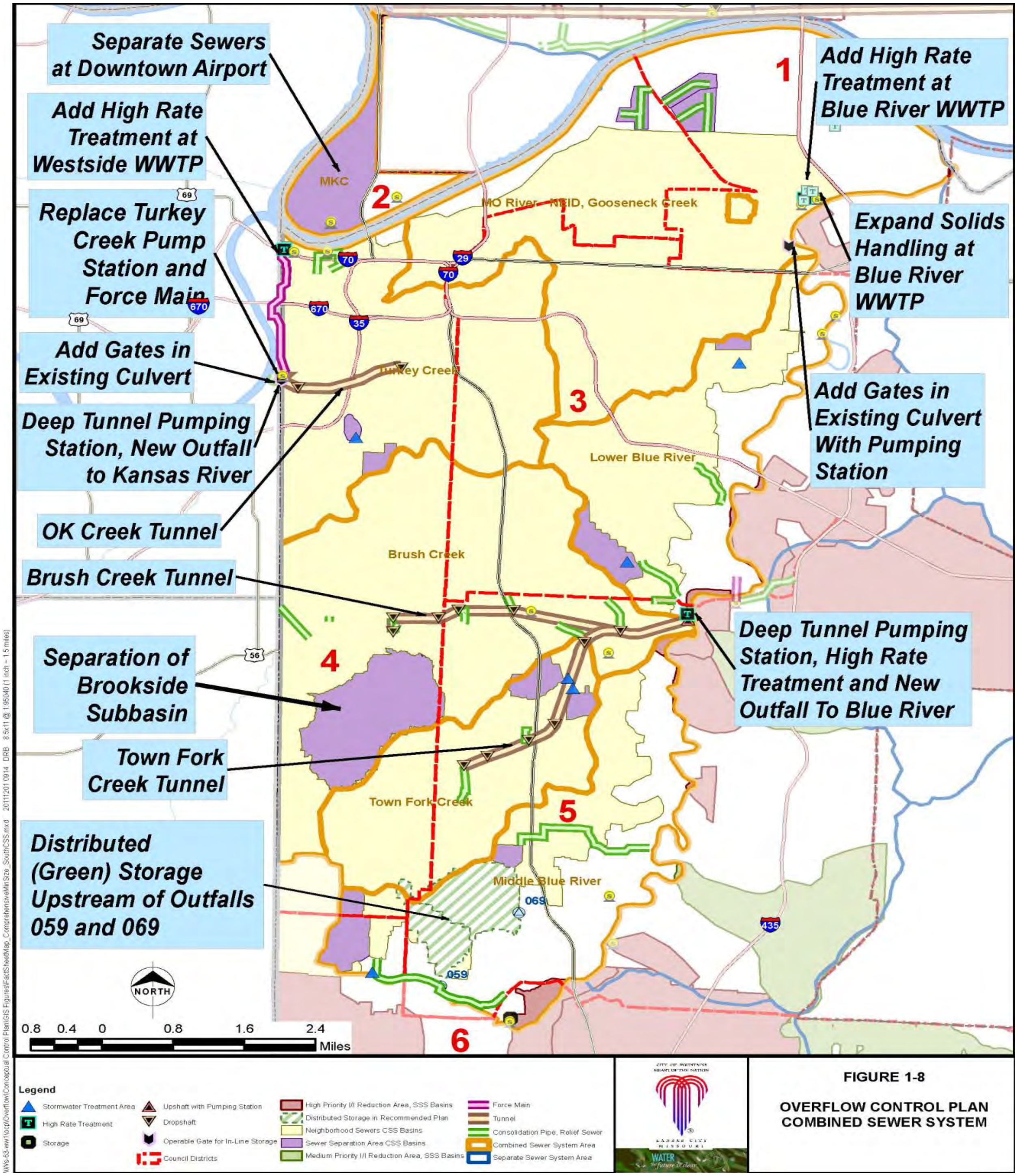


Figure 9 Overflow Control Plan Combined Sewer System

Source: KCMOWSD 2012[83]

The Middle Blue River basin study was completed by HDR in 2005. The Middle Blue River basin has a total drainage area of 24,575 acres, and its service population is 154,858. There are 33 diversion structures and 16 outfalls ([83]). In a typical year, the Middle Blue River basin has a wet weather flow of 0.62 billion gallons, and the existing overflow volume is 0.15 billion gallons. Figure 10 shows the original overflow control plan for middle blue river basin.

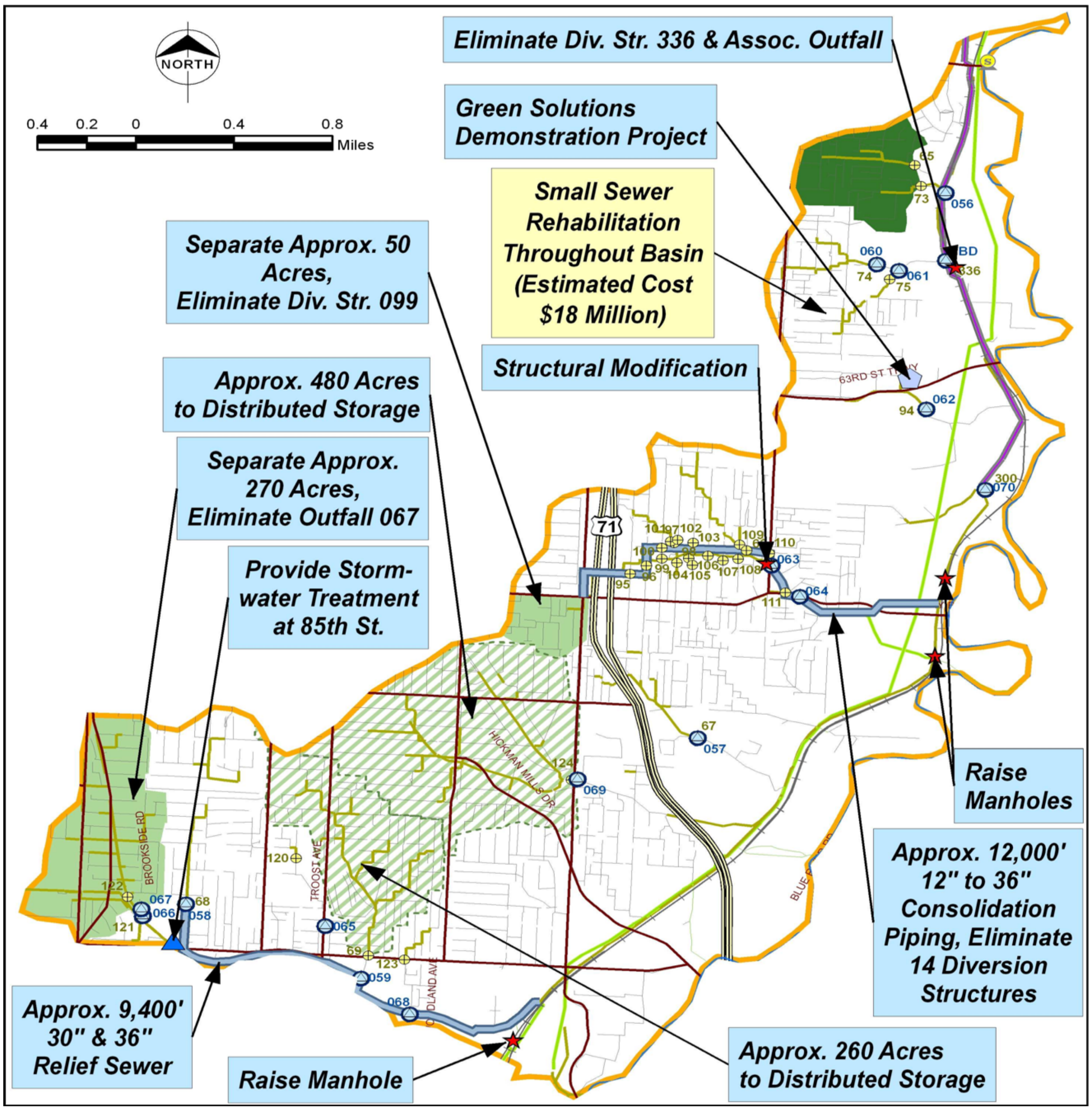
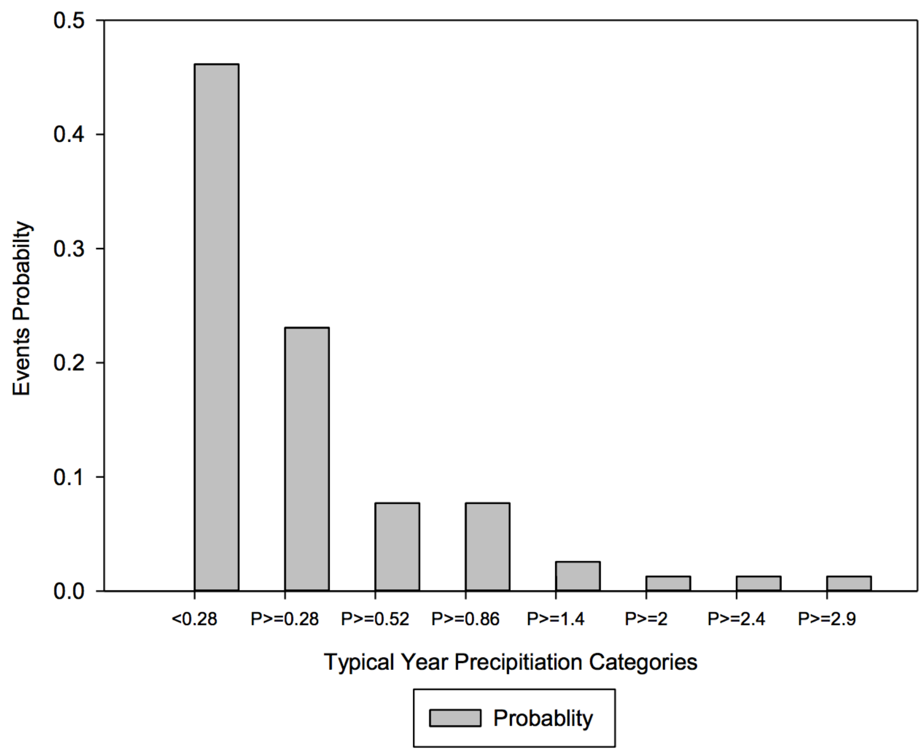


Figure 10 Middle Blue River CSO Control Original Plan([83])

A typical year in Kansas City has been determined by historical rain events statistical analysis. Figure 10 shows the events probability distribution with approximate long-term average annual rainfall as 36.5 inches.

Figure 11 Typical Year Precipitation Chart



2.4. Pilot Area

The Marlborough neighborhood, which is in an urban area of Kansas City, MO, was selected as the study area. This is one of the largest GI projects in United States that provides a unique opportunity for assessing the GI performance both on large scales and a small scales ([85]). The tributary area to Outfalls 059 and 069 have been chosen for placement of the GI units, which can provide storage space. The goal for this GI development project is to reduce the frequency of overflow from the combined sewer system to no more than six events in a typical year. This Overflow Controlled Program (OCP) adopted storm D (1.4 inches of rainfall in one day) as the design storm ([86]). The drainage area to Outfall 059 is approximately 269 acres. The pilot area has approximately 100 acres and drains to the combined sewer outfall No.069, as shown in Figure 2. The total tributary area to outfall 069 is approximately 475 acres. The goal for outfalls 059 and 069 is less than 3.5 million gallons of GI storage be in the 744 acres of drainage area to both outfalls ([83]).

A total of 135 rain gardens were completed in the test area, and there is also a control area next to the test area. Field soil surveys were performed in November 2008. There were total of 29 soil samples collected using hand soil sampling probe. All of the samples were collected from areas between 6 and 24 inches into the soil column ([86]). The soil test results indicated that the domain soil type in this area is clay. The description of soil contains the consistency (relative density), moisture, color, modifier, and soil type. The KCMO boring logs indicated that the 29 sites have similar soil descriptions in the first two feet: silt clay with dark brown or reddish brown color, soft, and low plastic. The vegetation condition varies from low to dense, and most vegetation consists of plant root hairs ([87]). Smoke testing was performed to ensure the connection with private and public to the sewer system ([86]).

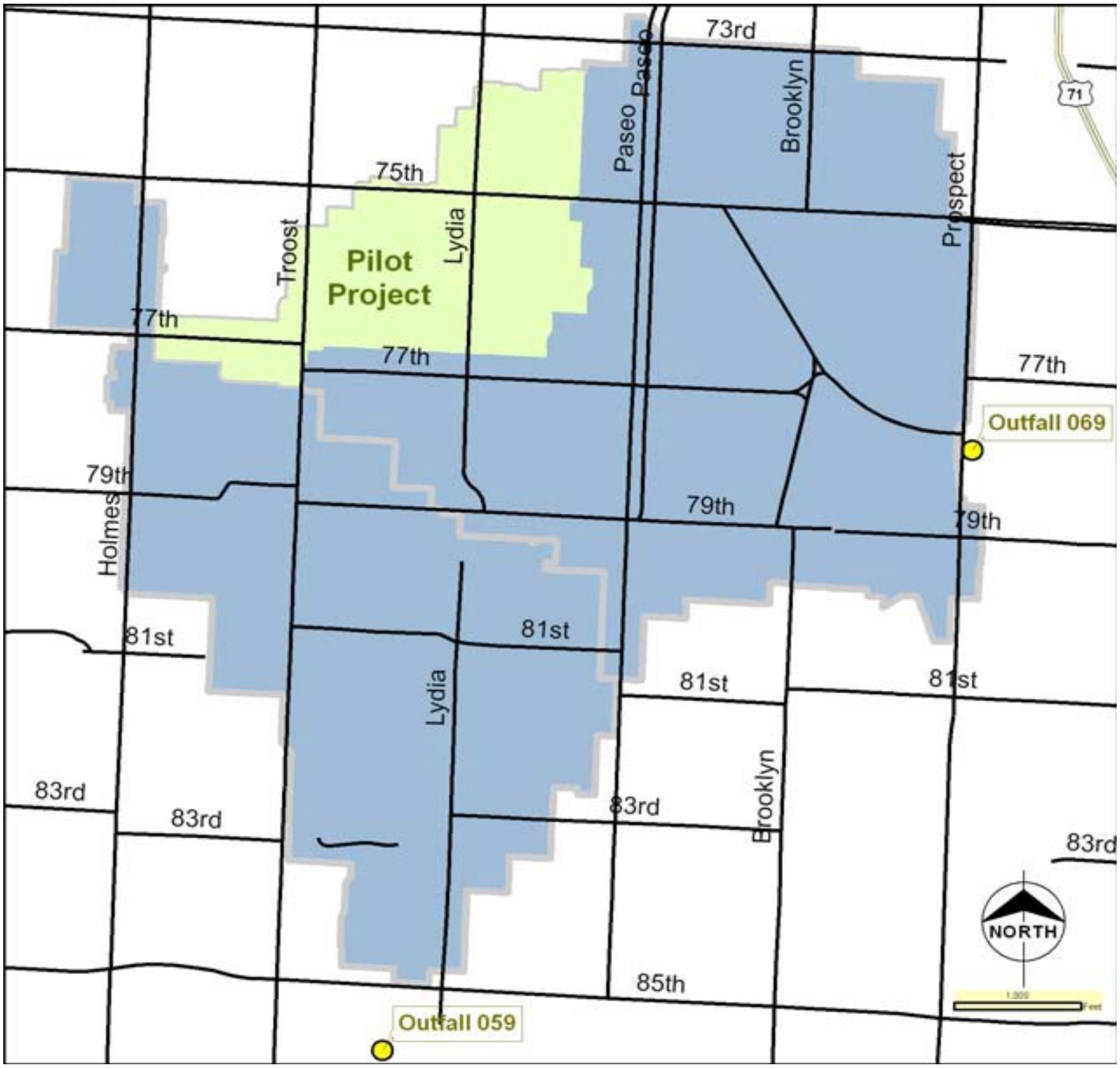


Figure 12 Outfalls 069 Sewer Boundaries (Source: Burns & McDonnell 2009[86])

XPSWMM 9.50 has been used to model the collection system. ArcGIS 9.1 has been used to estimate the hydrologic parameters ([86]). The large watershed has been divided into subbasins in order to place the GI units in detail. Based on the rainfall data from city rain gauges 5100 and 5110, the design storm of this pilot area has a total rain depth of 1.4 inches, peak intensity of 0.6 in/hr, and a duration of 16.75 hours ([86], [88]).

CHAPTER 3

DATA PREPARATION

3.1. Individual Sites Monitoring

Little insight into rain garden design with multiple measurement sites over several rainy seasons is available in the design literature. The watershed in Kansas City was designed and built to answer many of these design questions. The total inflow of each garden and the infiltration ability have been selected as the two indicators of garden behaviors. Seven rain gardens that were monitored from 2011 to 2015. Figure 13 shows the locations of the monitored gardens along E.76th St and E.76th Terrace.

Figure 13 Study Area and Monitored Rain Gardens

The monitoring data reveal that the seven rain gardens have different responses from the same rain event. There are many factors may affect different responses from the same event, including garden types, size, street slope, watershed slope, flume width, garden length slope, precipitation duration, precipitation depths, peak precipitation intensity, and antecedent dry days before the event. Statistical approaches were applied to determine the importance of these factors. A comprehensive report of rain garden hydrology characteristics can be generated for use by engineers, planners and homeowners in future design of rain gardens. Research into the rain gardens' hydrology characteristics research has been undertaken over many years by various research. However, few studies show the detailed statistical analysis of rain garden hydrology characteristics based on field data. Most studies lack the detail, site redundancy and longevity of the Kansas City study. Thus, a systematic application of multivariate statistics can help unlock this rich data set.

Each garden had a 0.5H flume installed to measure its inflow. For sites 1222, 1324, 1325 and 1140, the ISCO 6712 type flow sensor was used for inflow water depth monitoring from June 2012 to June 2013. After June 2013, the Global Water WL16 water level logger was used exclusively for water level monitoring. For sites 1112, 1336 and 1612, the Global Water WL16 water level logger was been installed at the flume to measure the water depths for flow calculation.

Figure 14 ISCO Sampler

Figure 15 Global Water Level Sensor

3.2. Methodology of Inflow and Infiltration Calculation

Of the seven monitored gardens, two are constructed with Smartdrain® pipes. A 22° V-notch weir was installed in the outlet pipe of the drainage system for those two gardens. Figure 17 shows the V-notch weir. Based on the weir overflow equation, the outflow can be calculated using equation 2 ([89]). Each garden had a 0.5 H flume installed to measure its inflow (Figure 18). The Global Water WL16 water level logger has been installed at the flume to measure the water depths. The inflow volume can be calculated by the following 0.5 H flume conversion equation:

$$Flow\left(\frac{gallons}{min}\right) = 718.1318\times\ depth(feet)^{2.2001} \qquad \text{Equation 2}$$

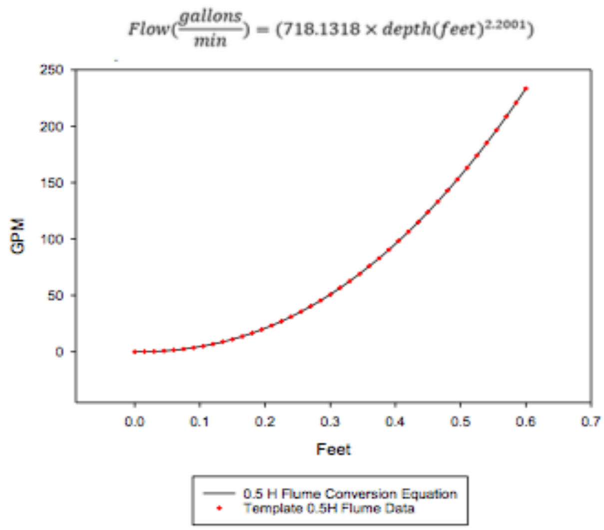


Figure 16 Calibration of 0.5H Flume

Figure 17 22◦ V-notch Weir

Figure 18 0.5H Flume Inlet

$$Q = 4.28 \times Ce \tan(\frac{\theta}{2})(H + K)^{\frac{5}{2}}$$ Equation 3

Where $Ce = 0.607165052 - (0.000874466963)\theta + (6.10393334\, x\, 10 - 6)\theta^{2}$

$K = 0.0144902648 - (0.00033955535)\theta + (3.29819003\ x\ 10\text{-}6)\ \theta^{2} - (1.06215442\ x\ 10\text{-}8)\ \theta^{3}$

The infiltration volume is calculated for each of these two gardens by subtracting the outflow from the inflow. Figure 19 shows a typical graph generated from each event. For the five rain gardens without Smartdrain® pipes, no overflow occurred during the monitored period. All of the inflow was infiltrated during a known time that can also be calculated. A similar analysis graph can be generated as Figure 20.

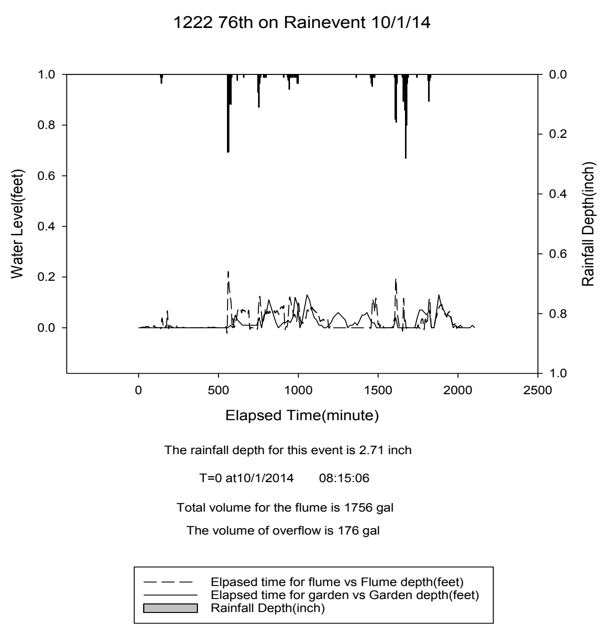


Figure 19 Typical Hydrograph for Bioretention Cells with SmartDrain®

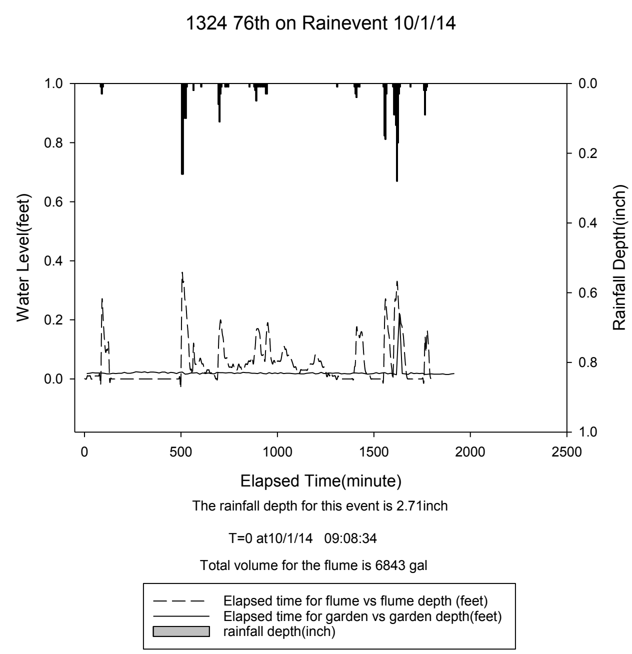


Figure 20 Typical Hydrograph for Raingardens

The monitoring began in from 2011 and ended in 2013. From 2012 to 2013, Kansas City was in a drought. The University of Missouri Kansas City School of Graduate Studies supported the monitoring program from August 2014 to June 2015 so that the monitoring period could be extended. A rain gauge was installed near the study area to measure the rainfall data (Figure 22). The average distance from the rain gauge to monitored sites is 0.37 miles. The city rain gauge ID 5110, which is located at Troost Avenue and 75th St, was used for data validation. Figure 21 shows the UMKC rain gauge location relative to the monitored sites. Following the removal of invalid data, 57 rain events, shown in Figure 22, were used to do the analysis. Discrete rainfall events are defined as having an intermittent dry period of more than 10 hours.

Figure 21 Monitored Sites and Rain Gauge Location

The entire monitoring period started on 06/11/2012 ended on 6/17/2015. Seven gardens were monitored from June, 2012 to October, 2013, with the monitoring of four of these gardens having been extended to include the period from August, 2014 to June, 2015.

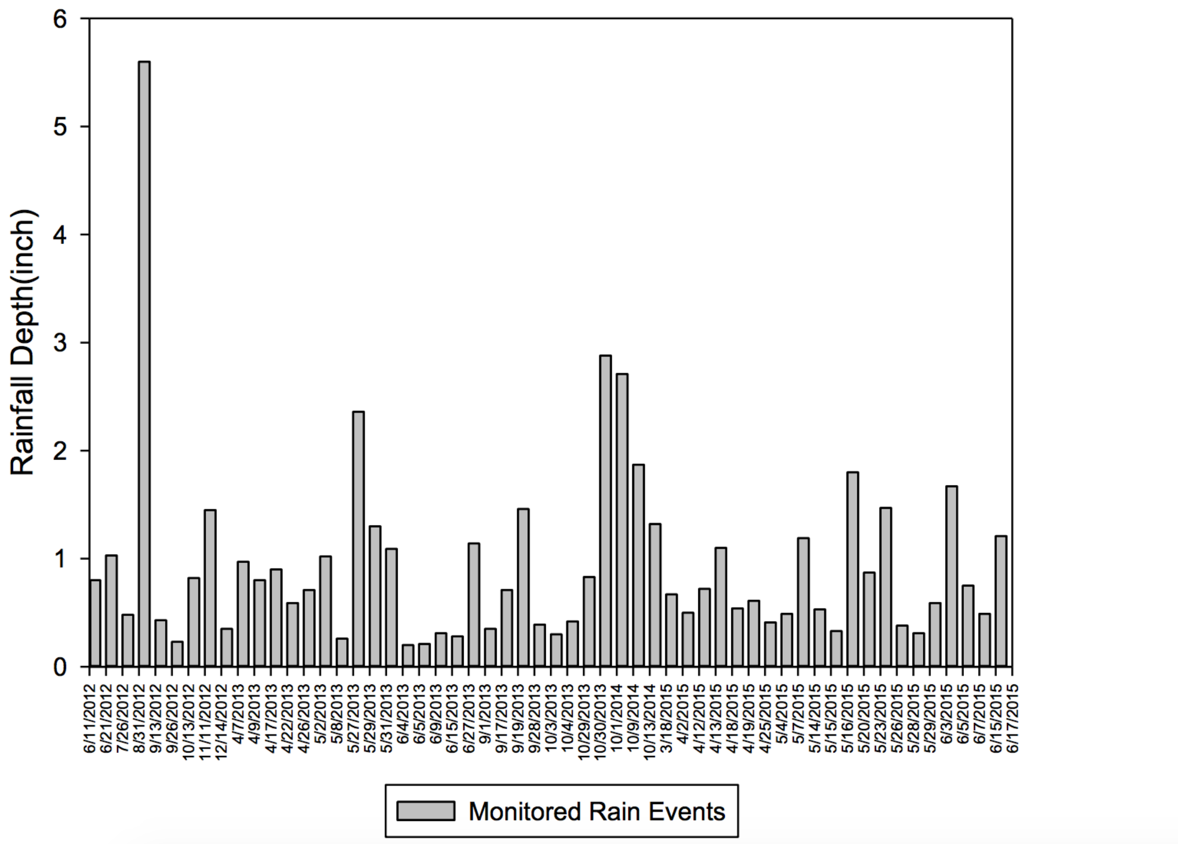


Figure 22 Monitored Rain Events From June/2012 to June 2015

Table 9 Monitored Rain Events Features

	Total Rainfall Depth(inch)	Rainfall Duration(min)	Antecedent Dry Day(days)	Peak Intensity(inch/hour)
Average	0.94	540	7	1.27

3.3. Flooding Issues on the Data and Solution

During the monitoring period, flume inlet flooding situation occurred as shown in Figure 23. Therefore, the H-flume could not function as a free outfall to use the 0.5 H flowrate conversion equation. Field validation measures the height of flume inlet. When the ponding depth is higher that the height of the flume inlet, it indicates that there is a flume flooding occurred. Flooding check work was done, resulting that five data points having been from site 1336. There was some inflow before a short flooding period. Therefore, some of these data were retained. The inflow volume during the flooding period has been counted as zero.

Figure 23

Flume Inlet Flooding

Table 10 Monitored data details

Site	Total monitored rain events	Total captured data	Inflow Sensor issue bad data due to equipment failure	bad data due to inflow flooding	Ponding/outflow Sensor bad data due to equipment failure/clogging
1324	57	51	3	0	1
1325	57	49	6	0	1
1336	32	24	0	5	0
1612	32	18	0	2	0
1112	32	29	0	0	0
1222	57	53	2	0	8
1140	57	52	1	0	12
Total	324	276	12	7	22

Figure 23 is an example to show how to determine whether an inlet flooding situation occurred during monitoring. For Site 1336, 0.2 feet is the relative height from inlet mouth to the graden sensor. Therefore, when the inflow depth is greater than 0.2 feet, it indicates that inflow flooding occurs. The volume corresponding to an inflow depth larger than 0.2 feet has been subtracted from the total inflow volume calculation process to achieve the real inflow.

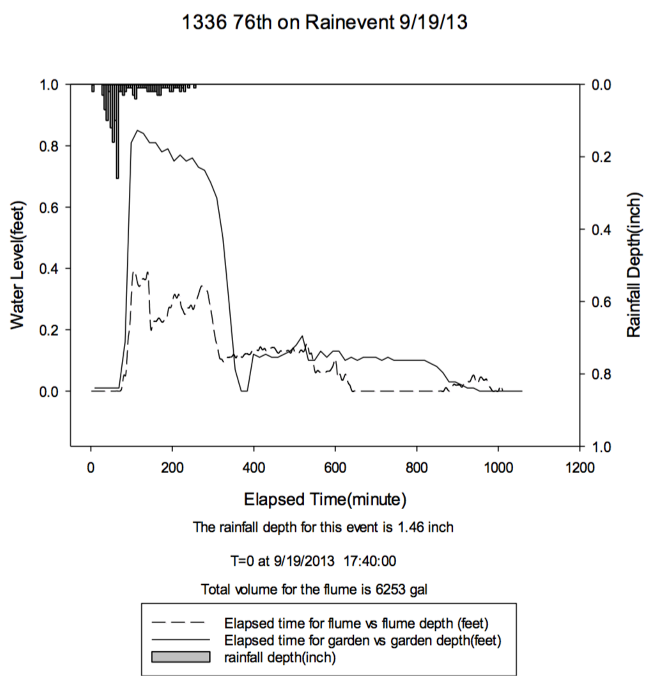


Figure 24 Example of flume inlet flooding hydrograp

CHAPTER 4

FACTORIAL ANALYSIS ON RAIN GARDEN PERFORMANCE

This chapter examines the impact of several factors on the rain garden performance based on a Minitab Design of Experiment (DOE) analysis. This factorial analysis is used to investigate the effects of input variables on an output variable. The numerical input values need to be split as high and low values in order to create a factorial design that can be analyzed in this study. For this study, the two indicators for rain garden performance are inflow volume and infiltration ability.

4.1. Inflow Factorial Analysis

The inflow volume of each garden is a major indicator of garden performance. The potential influences on total volume into the garden are watershed area, street slope, watershed slope, whether the garden inlet has grooves (Figure 25), rainfall depths, and rainfall duration, rainfall peak intensity, and the number of antecedent dry days before the rain. After each rain event, a hydrograph (Figure 18) and Table 11 were made for each monitored site.

Figure 25 Grooves at Inlet

Table 11 Typical variables for rain garden without underdrain

Site NO.	Garden Type(*)	Event Date	Rainfall Depth (inch)	Rainfall Duration (min)	Average Intensity (in/hr.)	Peak Intensity (in/hr.)	Antecedent Dry Day (days)
1324	1	1/10/2014	2.71	1570	0.1	3.36	14
	Watershed Area (ac)	Street Slope (%)	Watershed Slope (%)	Grooves or not	Impervious %	Infiltration Volume (gal)	Total Volume (gal)
	0.08	1.65	3.64	No	65.93	6843	6843

Several data points were removed due to equipment failure. There are 254 data points, where each data point is a garden/rain set that included in the factorial analysis. Since the groove variable is a categorical variable, all of the numerical data have been split into high and low values based on if it is higher or lower than the mean. Values above the mean were assigned a value of +1, otherwise, and the values below the mean assigned a value of -1. Figure 26 and 27 showed the details of high-low data split, which indicates that the data split is, an even split on the dataset.

Normality and constant variances, as well as independent observations, are the basic assumptions of the factorial analysis test. After the square root transformation on the inflow, the residual plots indicate that the dataset satisfies the basic assumptions for the factorial analysis test. Therefore, the inflow volume has been applied with a square root transformation.

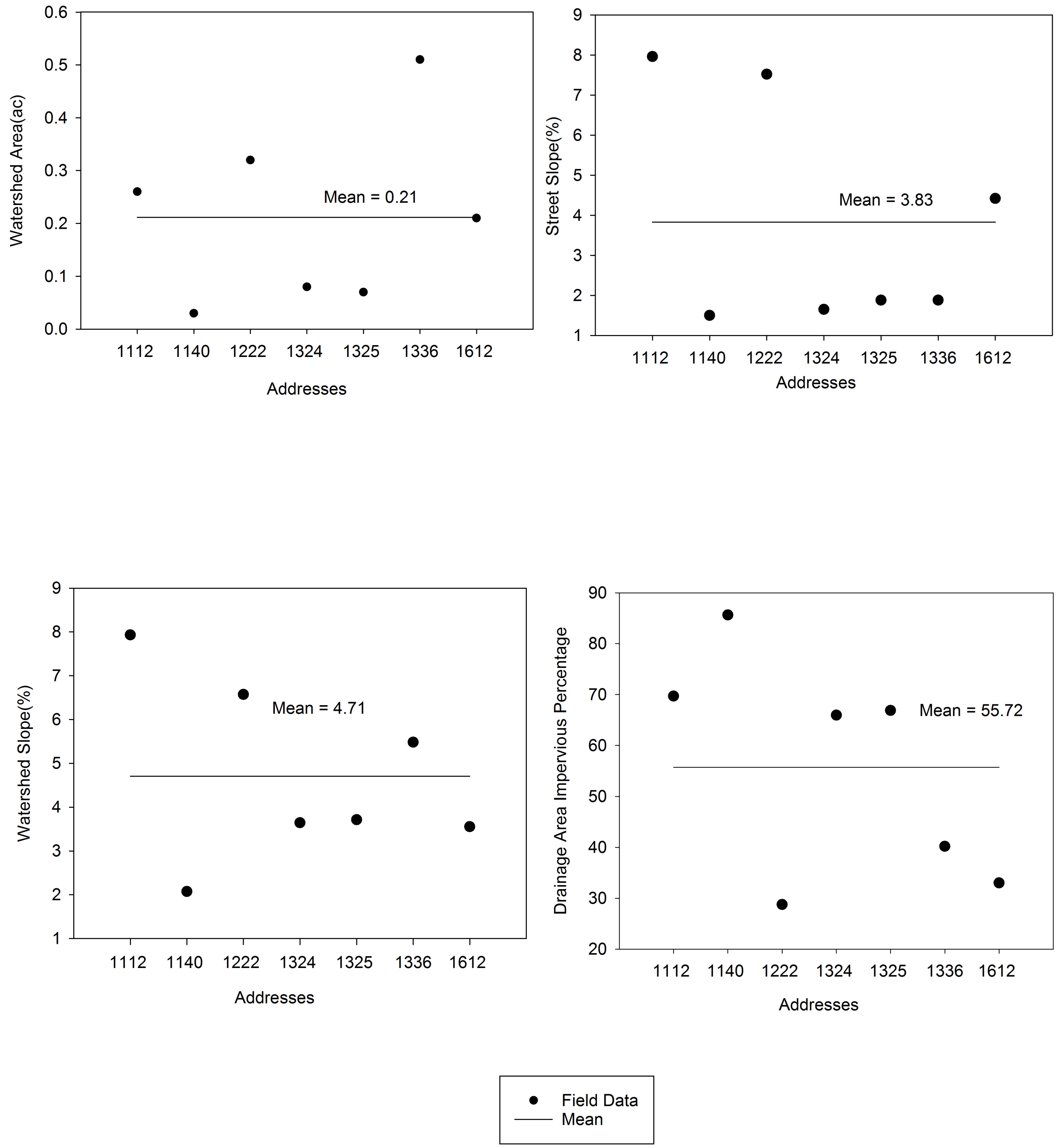


Figure 26 Scatter Plots of Garden Feature Data

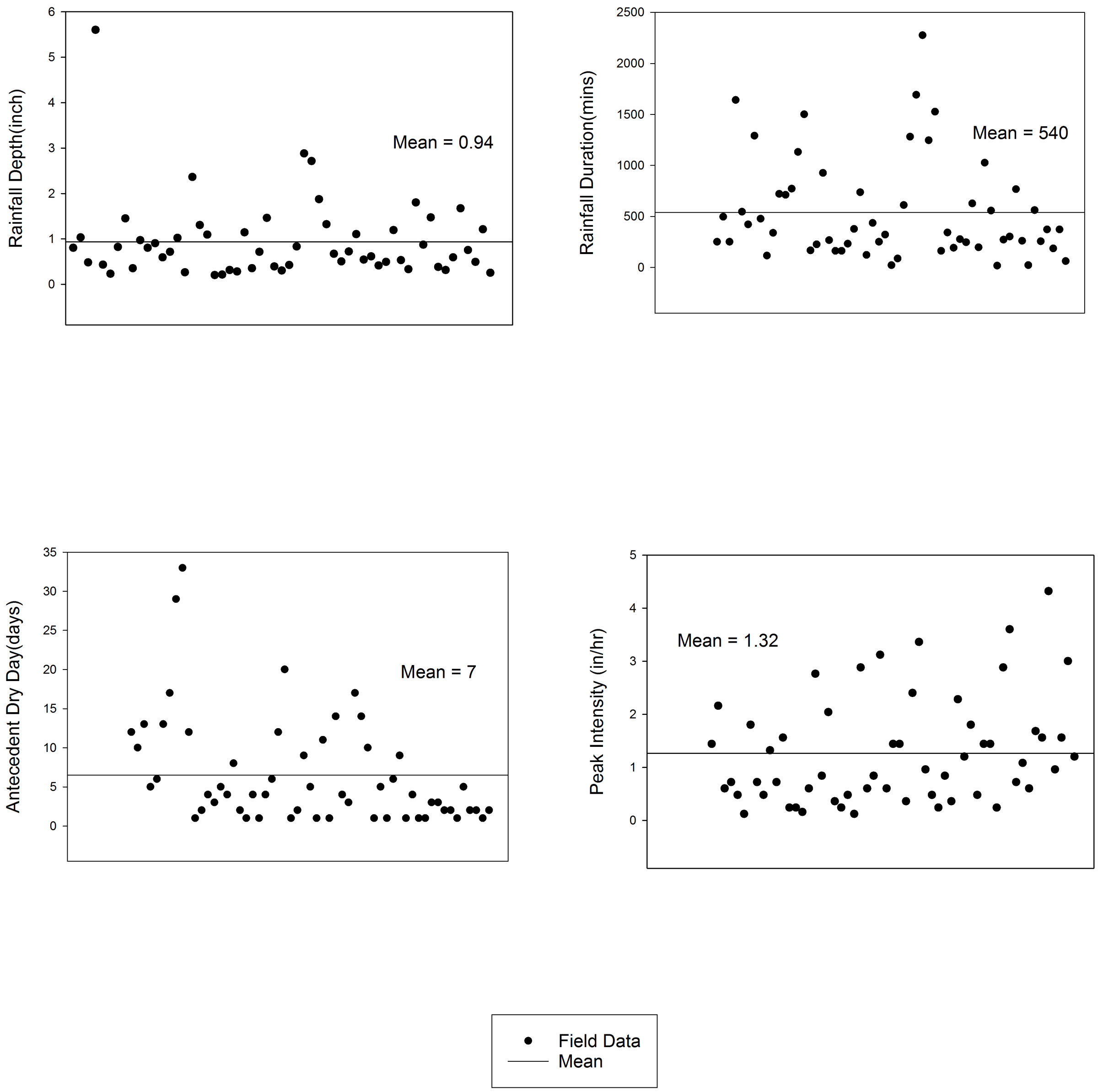


Figure 27 Scatter Plots of Rainfall Data

The experimental design is a 2-level fractional factorial designs, 2^9 experiment. T-tests and F-tests were used for the One Way Analysis of Variance (ANOVA) procedure to determine which factors are significant based on significance level $\alpha = 0.05$. α is defined as $\alpha = P(Type\ I\ error) = P((reject\ H_0|H_0\ is\ true)$. The null hypothesis for ANOVA is that the means for all groups are equal. If any two group means are not equal, then the null hypothesis is false. A significance level of 0.05 means that, by chance, the null hypothesis will be rejected when it is true once in every 20 tests. A significance level of 0.05 is a common convention in statistical analysis ([90]). Response values have been square root-transformed in order to ensure satisfaction of the normality assumption. A backward elimination method has been chosen.

The residual plots are presented in Figure 27. The residual is defined as $\epsilon = \text{y (observed value)} - \hat{y}\text{ (predicted value)}$. A linear normal probability plot indicates that the error terms are roughly normal. Figure 29 shows the three significant factors at the alpha=0.05 level are impervious area, total rainfall depth and rain duration.

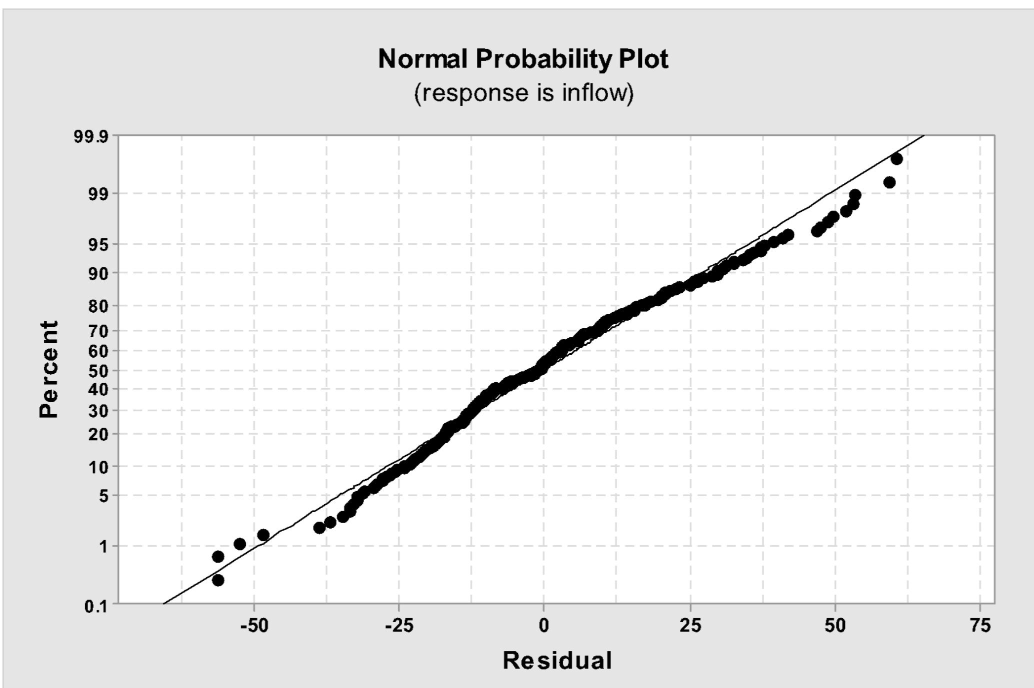


Figure 28 Inflow(square root transformed) Normal Probability Plot

KS value is 0.061 with P-value of 0.3

I. Main Effect Analysis

Figure 29 (main effect plot) illustrates that the two main factors have a positive impact on the inflow. The impervious percentage and the total rainfall depth have significant impact on the inflow.

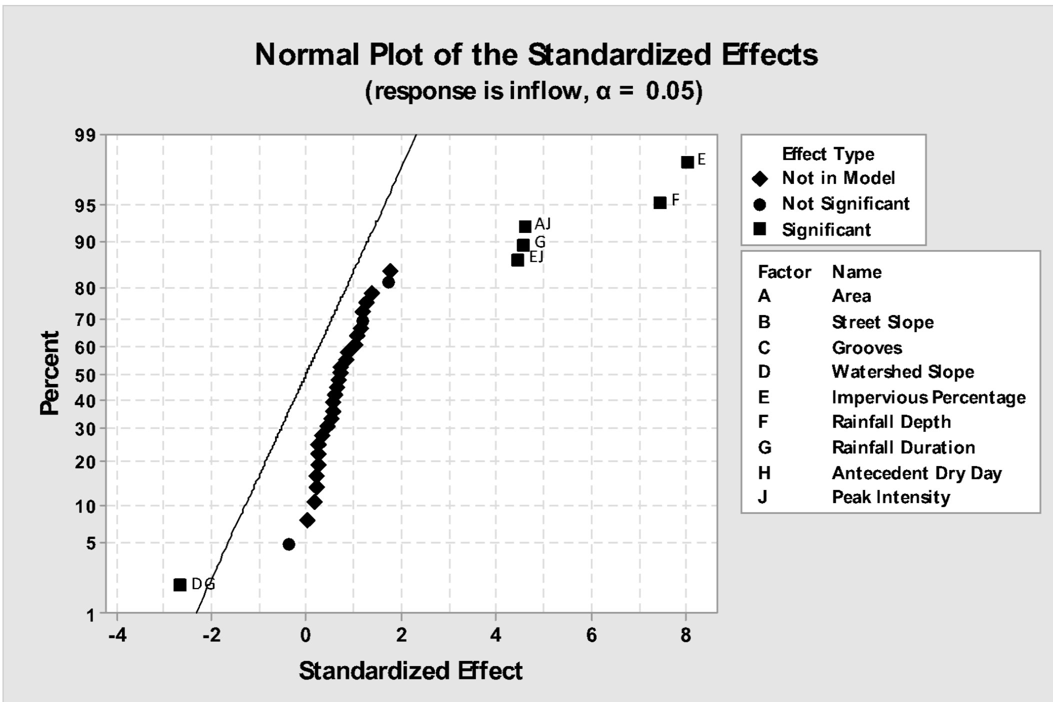


Figure 29 Normal Plot of Standardized Effects

Table 12 is the ANOVA table for this analysis.

Table 12 Inflow Factorial Analysis ANOVA Table

Source	DF	Adjusted SS	Adjusted MS	F-Value	P-Value
Model	9	106451	11827.8	25.32	0.000
Linear	6	95106	15851.0	33.94	0.000
Area	1	1424	1423.8	3.05	0.082
Watershed Slope	1	647	647.3	1.39	0.240

Impervious Percentage	1	29907	29907.5	64.03	0.000
Rainfall Depth	1	25829	25829	55.30	0.000
Rainfall Duration	1	9722	9722.2	20.82	0.000
Peak Intensity	1	59	59.0	0.13	0.723
2-Way Interactions					
Watershed Slope *Rainfall Duration	1	9844	9844.5	21.08	0.000
Watershed Slope*Rainfall Duration	1	3310	3310.4	7.09	0.008
Impervious Percentage*Peak Intensity	1	9244	9243.7	19.79	0.000
Error	243	113495	467.1		
Lack-of-fit	61	27625	452.9	0.96	0.564
Pure Error	182	85870	471.8		
Total	252	219946			

Table 12 shows those factors or interaction terms have a P-value, which is smaller than the alpha = 0.05, have significant impact on the inflow. The impervious area and total rainfall depths show a significant impact on the inflow. Figure 30 is the main effects plot. All of the grey cells in the main effect plot and interaction plot indicate that the corresponding factor or interaction does not have a significant impact on the response. Therefore, those terms are not included in the model. But drainage area, watershed slope, rainfall duration and peak intensity don not show significant influence on the inflow based on Table 12. These factors are still included in the model because there are significant interactions with these variables.

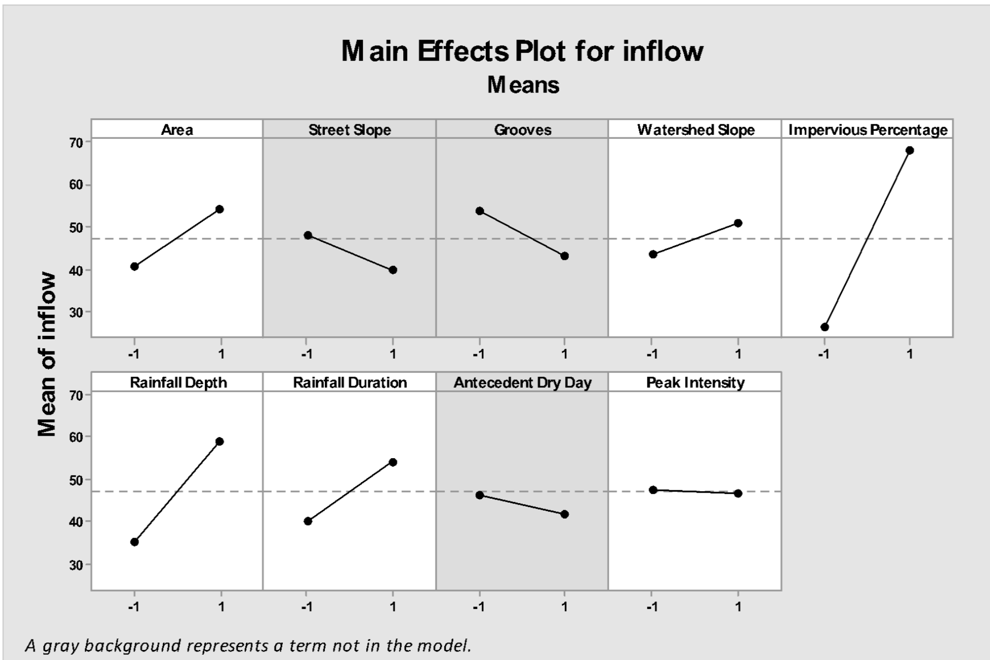


Figure 30 Main Effects Plot for Inflow

II. Interaction Effects Analysis

Figure 31 (interaction plot) shows the interaction between watershed area and peak intensity, the interaction between impervious area and peak intensity, and the interaction between watershed slope and rainfall duration also have significant impact on the response. The interpretation of the three interaction terms is listed below:

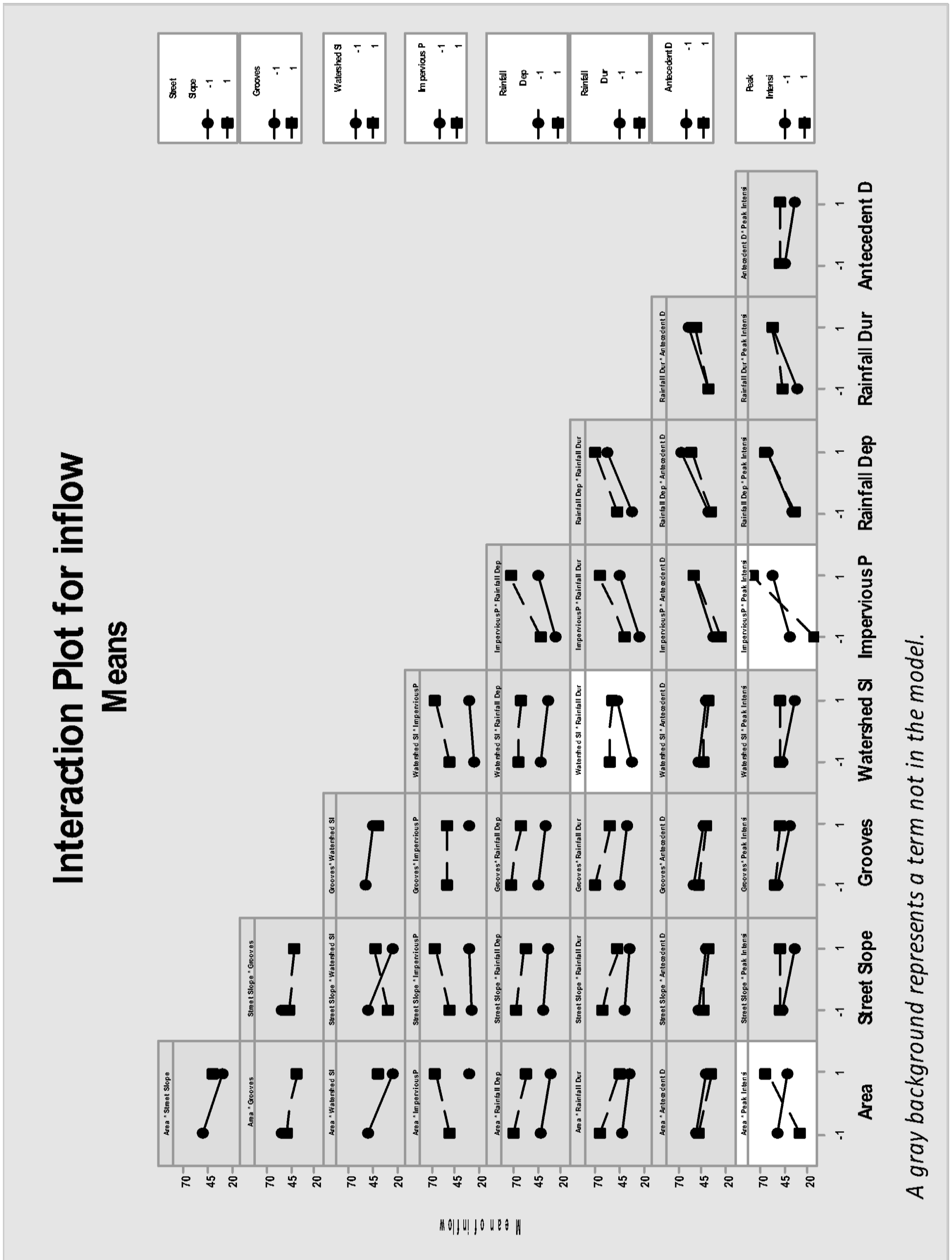


Figure 31 Interaction Plot for Inflow

(1) The interaction between rainfall duration and watershed slope:

When the rainfall duration is at a low level, the watershed slope has a positive effect on the garden inflow volume. However, when the rainfall duration is at a high level, the watershed slope has a slightly negative effect on inflow volume. The rainfall duration already showed the significant positive main effect on the inflow. This means that longer rainfall durations are associated with a higher inflow into the garden. When the rainfall duration is at a low level, a steeper watershed slope is associated with a higher inflow into the garden. This happens because a steeper watershed slope contributes to a faster surface runoff velocity, thus it reduces the natural infiltration volume in the runoff routing period.

(2) The interaction between area and peak intensity

The plot indicates that when the peak intensity is at a low level, the drainage area has a slightly negative impact on the inflow volume. When the peak intensity is at a high level, the drainage area has a positive effect on the inflow. When the peak intensity is low, the runoff from the drainage area will tend to infiltrate more during the routing process. A larger drainage area will intercept more runoff, which results in less inflow to the garden. A smaller area intercepts less runoff and more storm runoff will drain to gardens. However, when the peak intensity is at a high level, the runoff velocity increases and the natural soil infiltration is relatively low. Runoff will tend to flow more to the gardens. Therefore, more drainage area will contribute more inflow volume to the garden.

(3) The interaction between impervious percentage on the drainage area and peak intensity

The plot shows that when the peak intensity is at a low level, the impervious percentage has a slightly positive effect on the inflow. When the peak intensity is at high level, the impervious percentage shows a significant positive effect on inflow. From the main effects plots, the impervious percentage has a positive effect on the inflow. And the interaction term enhances this positive effects from the two factors.

In summary, the most influential factor is impervious percentage in the drainage area which has a significant positive effect on the inflow. Rainfall depth and rainfall duration both show positive and significant effects on the response. The peak intensity, area, and watershed slope themselves were not show significance in the main factor analysis. However, peak intensity interacts with watershed area and impervious percentage. When peak intensity is at a low level, watershed area has a negative impact, and impervious percentage has a positive impact on the response. When peak intensity is at a high level, watershed area has a positive impact, and impervious percentage has a significant positive impact on the response. For example, when peak intensity is high, higher impervious percentage, larger rainfall depth, longer rainfall duration, steeper watershed slope and a larger watershed area will contribute the most inflow volume to a garden.

4.2. Infiltration Data Analysis

For the analysis of infiltration, there are three different datasets. The first group is the SmartDrain® group: site 1222 and site 1140. The only available infiltration data for SmartDrain® sites are the infiltration volumes in gallons. The outflow volume was monitored at the V-notch weir (Figure 17) installed at each SmartDrain® pipe outlet. Outflow discharge was calculated using equation 4 for a 22° V-notch. Infiltration volume can be subtracted from total inflow to obtain the outflow volume. An example of SmartDrain® rain event analysis graph is shown in section 3.1 Figure 19.

Table 13 Data variables for bioretention cells with SmartDrain® installed

Site NO.	Garden Type(*)	Event Date	Rainfall Depth(inch)	Rainfall Duration (min)	Average Intensity(in/hr.)	Peak Intensity(in/hr.)	Antecedent Dry Day(days)
1222	2	1/10/2014	2.71	1570	0.1	3.36	14
	Watershed Area (ac)	Street Slope (%)	Watershed Slope (%)	Grooves or not	Impervious %	Infiltration Volume (gal)	Inflow Volume (gal)
	0.32	3.7.52	6.57	Yes	28.74	1580	1756

The second group includes sites 1112 and 1336, where the response term is drawdown rate in inch/hour. The third group includes site 1324 and 1325, where the response term is infiltration volume in gal. The third group did not have pooling during the monitoring period. Therefore, the inflow volume is the same as the infiltration volume.

Once the data are split, each dataset has a fairly small number of observations. The small sample size limited the number of factors that could be analyzed in factorial analysis. Additionally, for the garden features, watershed area, watershed slope, street slope, and impervious percentage are confounded with each other. Individual impact analysis cannot be processed within those four variables. Based on the previous inflow analysis results, the impervious percentage has a significant impact on infiltration volume. Therefore, in the infiltration analysis, the analyzed factors are impervious percentage, rainfall depth, rainfall duration, antecedent dry day and peak intensity.

4.2.1. Factor Analysis for the SmartDrain® Group

The response term is infiltration volume, which is obtained by substracting the outflow volume from inflow volume. The outflow volume can be calculated from equation 2.

$$Q = 4.28 \times Ce \tan(\frac{\theta}{2})(H + K)^{\frac{5}{2}} \qquad \text{Equation 4}$$

Where

$$Ce = 0.607165052 - (0.000874466963)\theta + (6.10393334 \; x \; 10 - 6)\theta^{2}$$

$$K = 0.0144902648 - (0.00033955535)\theta + (3.29819003 \; x \; 10\text{-}6)\,\theta^{2} - (1.06215442 \; x \; 10\text{-}8)\,\theta^{3}$$

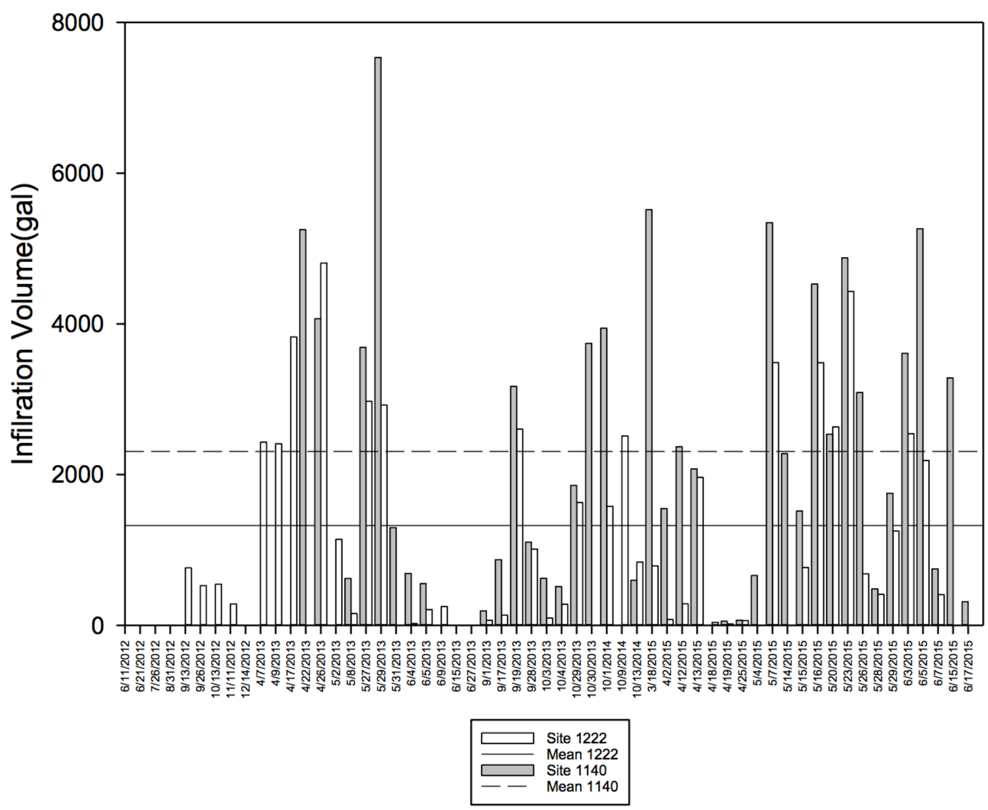


Figure 32 Monitored Infiltration Volumes for Site 1222 and 1140

In section 3.1, Figure 19 shows a typical hydrograph for SmartDrain® group data. The following factors have been analyzed in this dataset, total rainfall depths, rainfall duration, antecedent dry day and rainfall peak intensity. The response term is infiltration volume. The backward regression method has been applied here to determine the significant variables.

I. Main Effect Analysis

A square root transformation has been applied to the response in order make residuals that satisfy the assumption of normality. Figure 33 indicates that the residuals roughly follow a normal distribution after data transformation. Figure 34 shows that the main effects from impervious percentage, total rainfall depth, rainfall duration and antecedent dry days show significantly impact the infiltration volume. There are two interaction terms also show significant effects on the response.

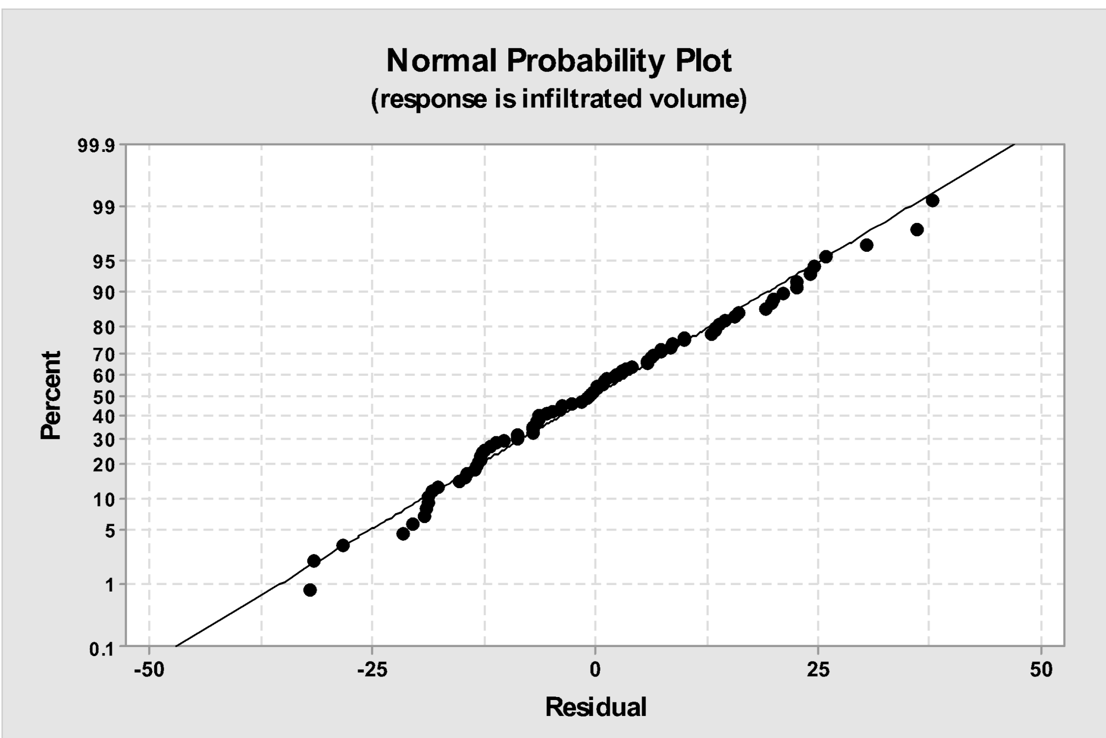


Figure 33 Normal Probability Plot

KS value is 0.061 with a P-value larger than 0.15

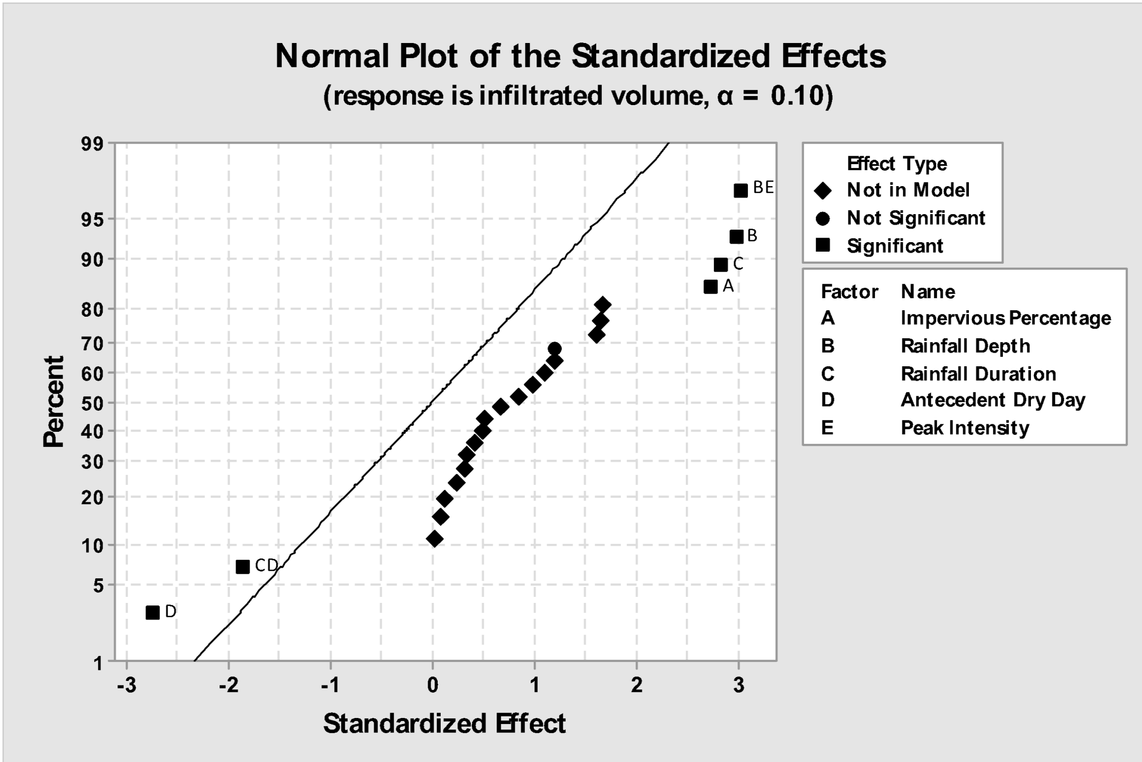


Figure 34 Normal Plot of the Standardized Effects

Figure 35 shows the main effects plot for this test. The number of antecedent dry day shows a significantly negative impact on the infiltration volume. Because a longer antecedent dry day, the soil tends to be unsaturated before an event. Then more runoff infiltrates in sites drainage path to the sites.

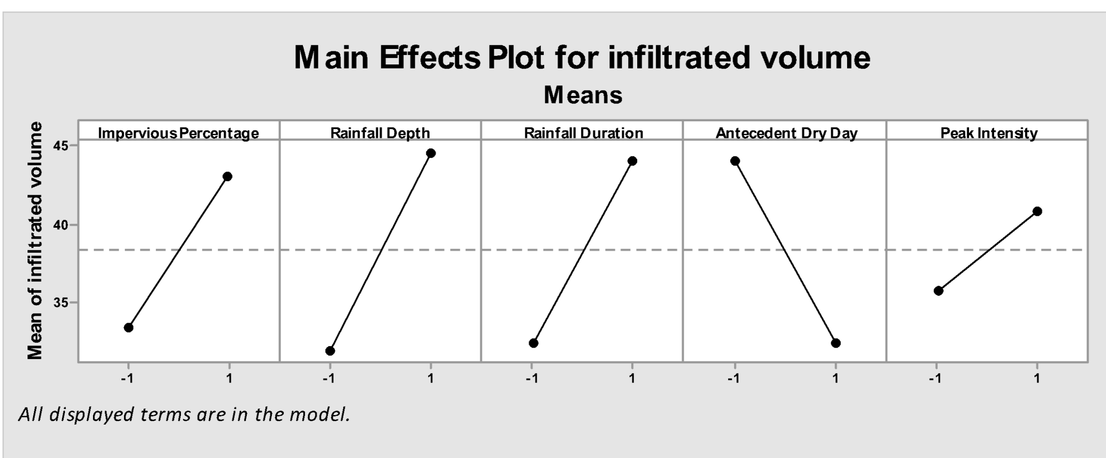


Figure 35 Main Effects Plot for Infiltrated Volume

Table 14 is the ANOVA table for this group analysis.

Table 14 Infiltration Factorial Analysis ANOVA Table for for SmartDrain® group

Source	DF	Adjusted SS	Adjusted MS	F-Value	P-Value
Model	7	15474.0	2210.6	8.72	0.000
Linear	5	12480.3	2496.1	9.85	0.000
Impervious Percentage	1	1886.5	1886.5	7.45	0.008
Rainfall Depth	1	2255.0	2255.0	8.90	0.004
Rainfall Duration	1	2033.5	2033.5	8.03	0.006
Antecedent Dry Day	1	1908.4	1908.4	7.53	0.008
Peak Intensity	1	362.2	362.2	1.43	0.236
2-Way Interactions					
Rainfall Depth *Peak Intensity	1	2330.6	2330.6	9.20	0.003
Rainfall Duration*Antecedent Dry Day	1	880.4	880.4	3.47	0.066
Error	74	18750.9	253.4		
Lack-of-fit	17	2544.5	149.7	0.53	0.928
Pure Error	57	16206.4	284.3		
Total	81	34224.9			

II. Interaction Effects Analysis

Figure 35 shows the details of the interaction between factors.

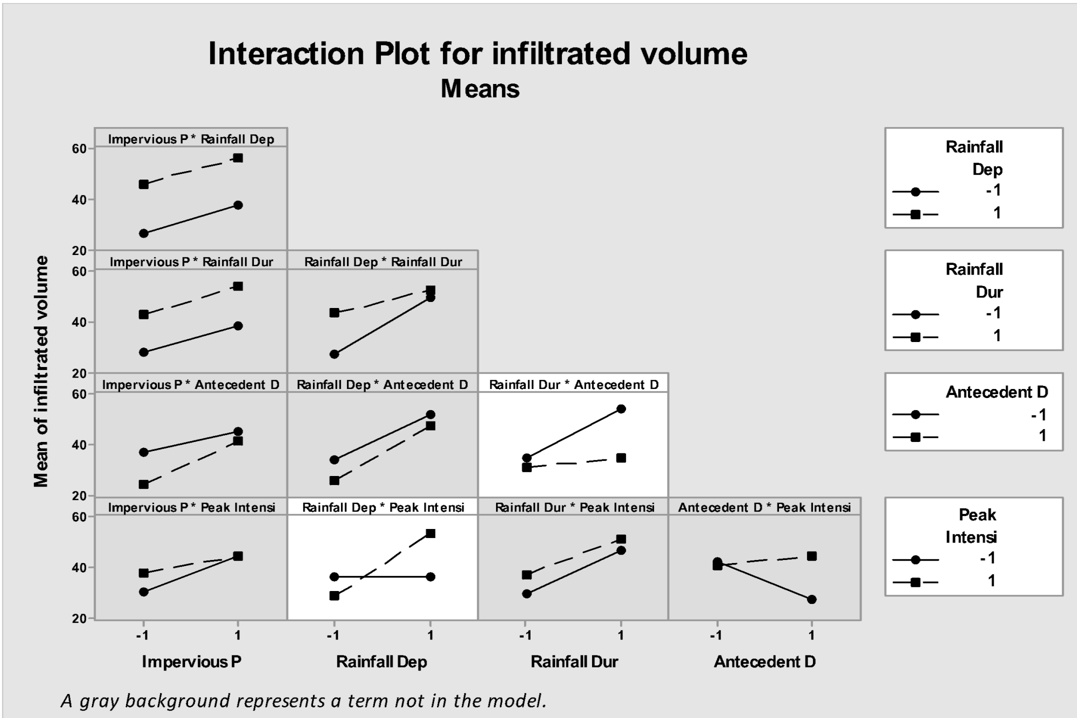


Figure 36 Interaction Plot for Infiltrated Volume

(1) Interaction between rainfall duration and antecedent dry day

When the number of antecedent dry days is at a high level, rainfall duration has a slightly positive effect on the infiltration volume. This happens because, large number of antecedent dry days indicates that soil is likely to be unsaturated before the event. In this situation, rainfall duration has a slightly impact on the infiltrated volume since less inflow makes it to the garden. When the number of antecedent dry days is at a low level, the rainfall duration has a significant positive effect on infiltration volume. This means that when soil is more likely to be saturated, more runoff arrives in the garden site. This leads to higher infiltration volume.

(2) Interaction between rainfall depth and peak intensity

When the peak intensity is at a high level, higher rainfall depth is associated with higher infiltration volume. On the other hand, when peak intensity is at a low level, the rainfall depth does not significantly affect the infiltration volume. In a similar fashon to the interactions described previously, high peak intensity causes more runoff from the drainage area. This causes an increase in infiltration volume for those two sites.

The infiltration volume from the SmartDrain® group is calculated from the inflow volume by subtracting the outflow volume from the pipe. Table 13 summarizes the average outflow from the two sites.

Table 15 SmartDrain® group Monitored Outflow Frequency

Site	Average Outflow Percentage
1222	9%
1140	3%

Table 15 indicates that very little outflow has been monitored during the three-year period from those two sites. Based on the factor analysis above, the infiltration volume is the most significantly impacted the inflow volume. However, other factors also have a significant impact on the inflow volume, but the analysis cannot be conducted on inflow and other factors. Clearly, the amount of water that reaches to the garden has a large effect on the infiltration volume. This indicates that the SmartDrain® group gardens had a great infiltration performance with a very low outflow percentage during the monitored period.

4.2.2. Factor Analysis on Raingardens

Site 1336 and site 1112 are two raingardens that have neither an underdrain pipe to the street nor underdrain system. Consequently, the sensors that are located at the bottom of these two gardens can measure the ponding depths and time. The drawdown rate for the two sites can be calculated by peak ponding depths over the infiltration duration. For some of the events, there are several ponding peaks. In such cases, the drawdown rate is defined as the average drawdown rate for each event. The tolerance level for slope calculation is a peak depth of no less than 0.1 ft. Furthermore, there must be at least have 3 data points on the decreasing trend.

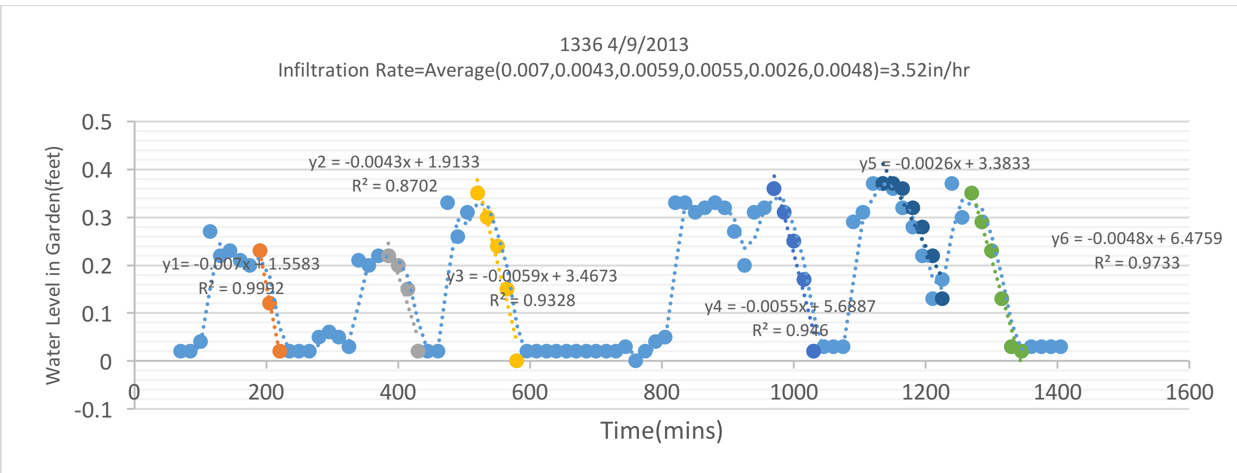


Figure 37 Example of drawdown rate calculation

Table 14 gives the calculated drawdown rate for sites 1112 and 1336.

Table 16 Calculated Drawdown Rate for Site 1336 and 1112

Date	Drawdown rate 1336 (in/hr.)	Date	Drawdown rate 1112(in/hr.)
6/11/12	4.97	8/31/12	4.43
6/21/12	1.22	9/13/12	6.05

Date	Drawdown rate 1336 (in/hr.)	Date	Drawdown rate 1112(in/hr.)
7/26/12	0.65	9/26/12	4.82
8/31/12	1.37	11/11/12	2.52
9/13/12	0.89	12/14/12	4.75
11/11/12	8.93	4/7/13	3.28
4/9/13	3.96	4/9/13	3.46
6/27/13	5.83	4/26/13	2.81
9/17/13	7.52	5/27/13	1.87
9/19/13	2.16	5/29/13	2.62
9/28/13	1.84	5/31/13	1.87
10/3/13	2.38	9/1/13	0.94
10/4/13	4.18	9/17/13	0.50
10/29/13	3.67	9/19/13	4.61
10/30/13	3.47	9/28/13	0.65
		10/3/13	3.53
		10/4/13	5.69
		10/29/13	2.23
		10/30/13	3.01
Average	3.75	Average	3.14

I. Main Effects Analysis

Figure 38 indicates that the residuals follows a distribution that is roughly normal after square root transformation is carried out.

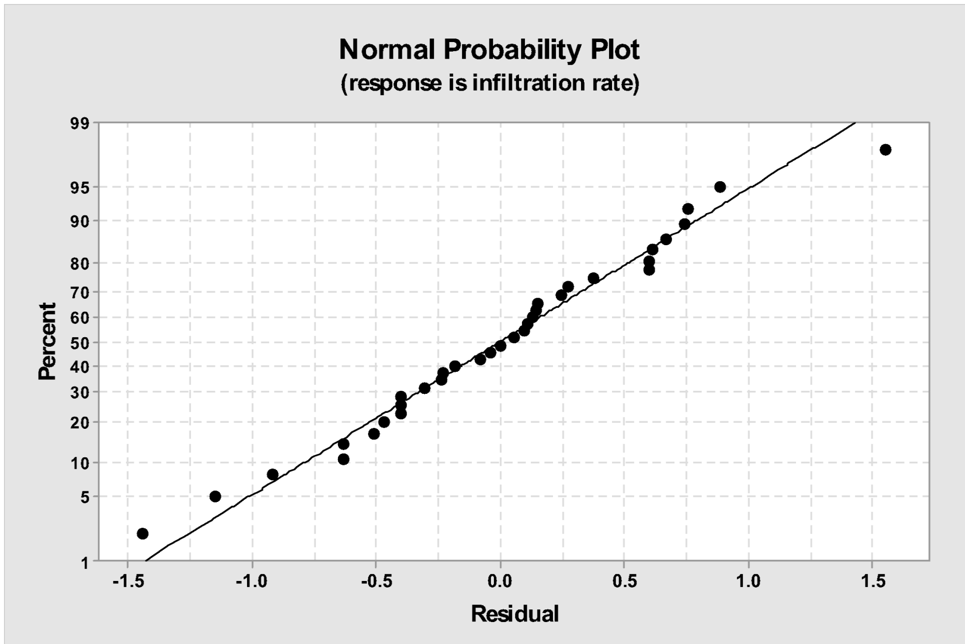


Figure 38 Normal Probability Plot

KS values is 0.061 with a P-value larger than 0.15

Figure 39 indicates that interaction between rainfall duration and the number of antecedent dry days is the factor that most significantly impacts the drawdown rate.

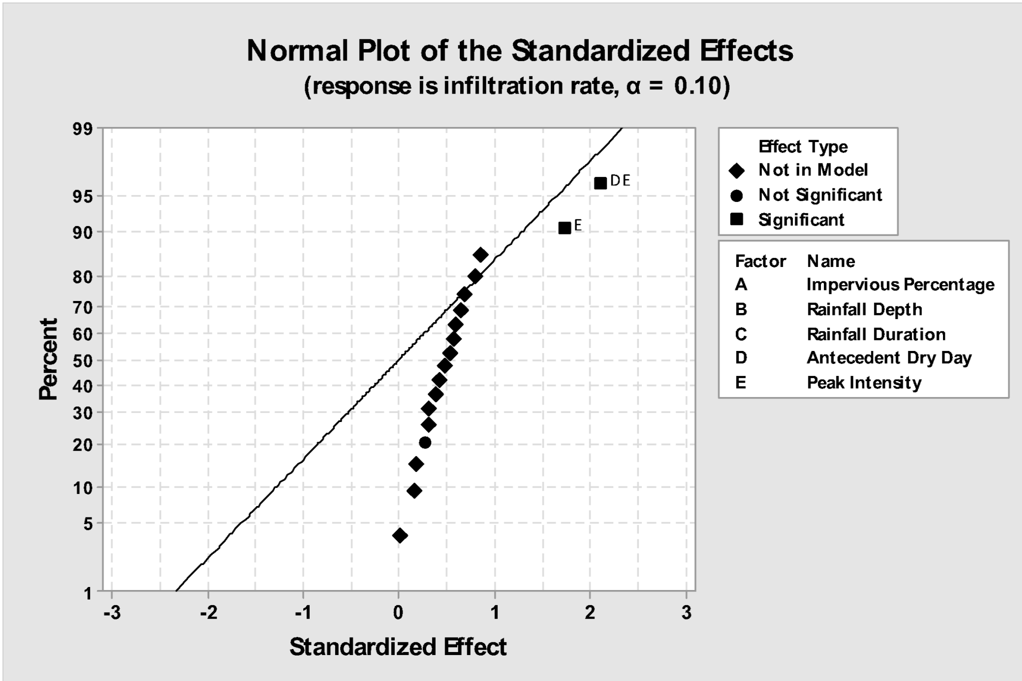


Figure 39 Normal Plot of Standardized Effects

The peak intensity is another significant factor. Figure 40 illustrates that, the effects of both the number of antecendent dry days and the peak intensity are both positive.

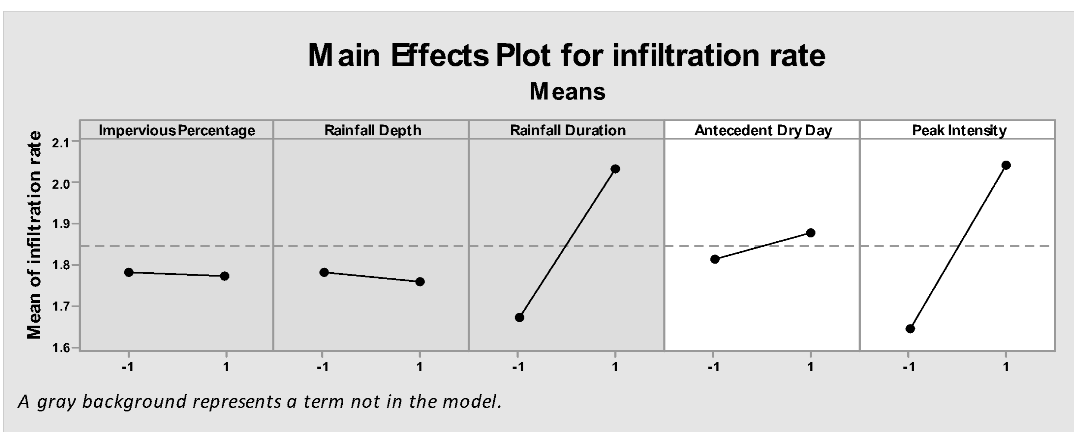


Figure 40 Main Effects Plot for Rain Garden Drawdown Rate

Table 17 is the ANOVA table for this group analysis.

Table 17 Infiltration Factorial Analysis ANOVA Table for for Rain Garden group

Source	DF	Adjusted SS	Adjusted MS	F-Value	P-Value
Model	3	2.6754	0.89178	2.15	0.115
Linear	2	1.2358	0.61790	1.49	0.242
Antecedent Dry Day	1	0.0326	0.0326	0.08	0.781
Peak Intensity	1	1.2356	1.2356	2.98	0.095
2-Way Interactions	1	1.823	1.823	4.39	0.045
Antecedent Dry Day*Peak Intensity	1	1.823	1.823	4.39	0.045
Error	30	12.4582	0.41527		
Lack-of-fit	15	1.3893	0.09262	0.13	1.0
Pure Error	15	11.0689	0.73793		
Total	33	15.1335			

II. Interaction Effects Analysis

Figure 41 is the interaction plot, which shows the most significant interaction for drawdown rates.

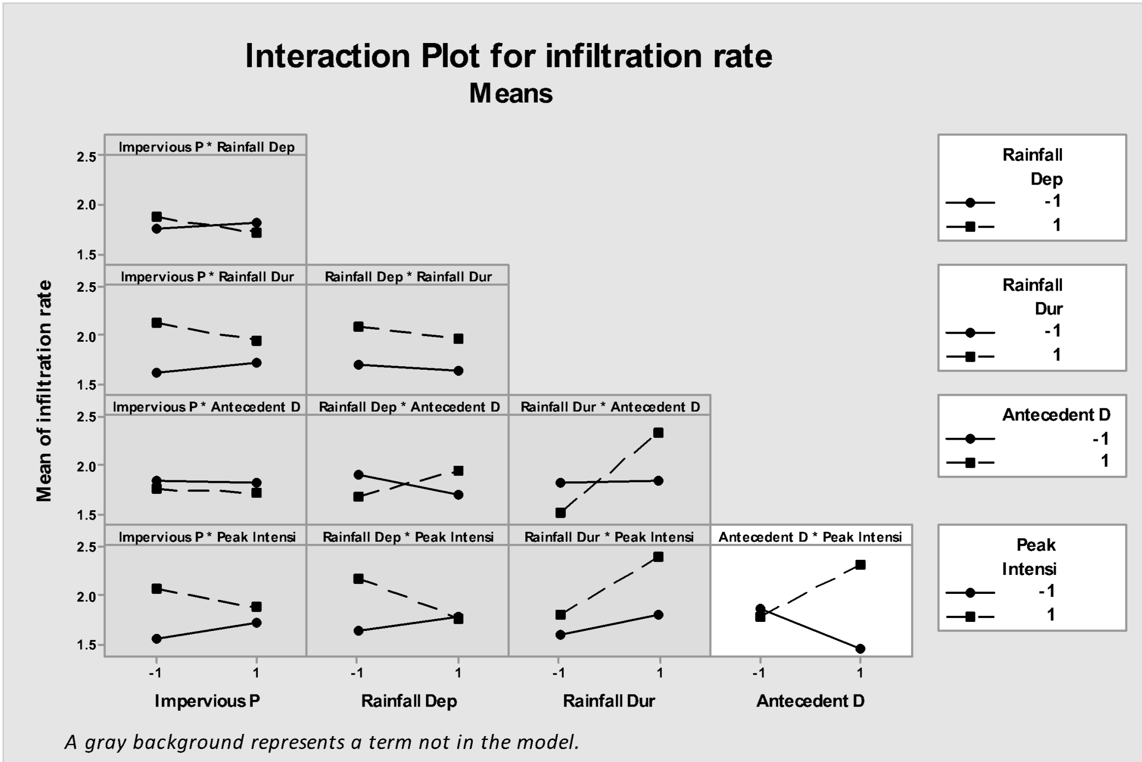


Figure 41 Interaction Plot for Rain Garden Drawdown Rate

When the peak intensity is at a high level, the number of antecedent dry days has a significant positive impact on the drawdown rate. However, when the peak intensity has a low value, the number of antecedent dry days has a negative impact on the drawdown. This illustrates the difference in how water infiltrates based on whether the soil is saturated or unsaturated. The results indicate that when soil is saturated (the number of antecedent dry days is at low level) before an event, the peak intensity has negative impact on the inflow volume. Since the soil layer is saturated, water tends to accumulate on the surface instead of infiltrating through the soil. Furthermore, a higher peak intensity is associated with an even lower drawdown rate in this situation. In contrast, when the soil layer is unsaturated (the number of antecedent dry days is at high level) before an event. Higher peak intensity causes more precipitation during a certain period. It makes the drawdown rate higher since the soil is not saturated yet. However, there will be a threshold for this impact. Discovery of such a threshold requires monitored data to be obtained from extremely large rain events which is in excess of an average rain fall intensity of 1.32 inch/hour rain event from our study.

4.2.3. Factor Analysis on Flat Events

For monitored sites 1324 and 1325, 80% and 75%, respectively, of rain events had a flat garden water level of zero. Since no overflow events occurred during the monitoring period, only the infiltration volume for each rain event can be determined. The infiltration volume is equal to the inflow volume, therefore they can both be used because they are identical. The factorial analysis analyzed factors that are analyzed in the factorial analysis are drainage area, garden length slope, total rainfall depth, rainfall duration, the number of antecedent dry days and rainfall peak intensity. The response term is infiltration volume.

I. Main Effects Analysis

Figure 42 indicates that the distribution of the residuals after the square root transformation on the response is carried out is roughly normal.

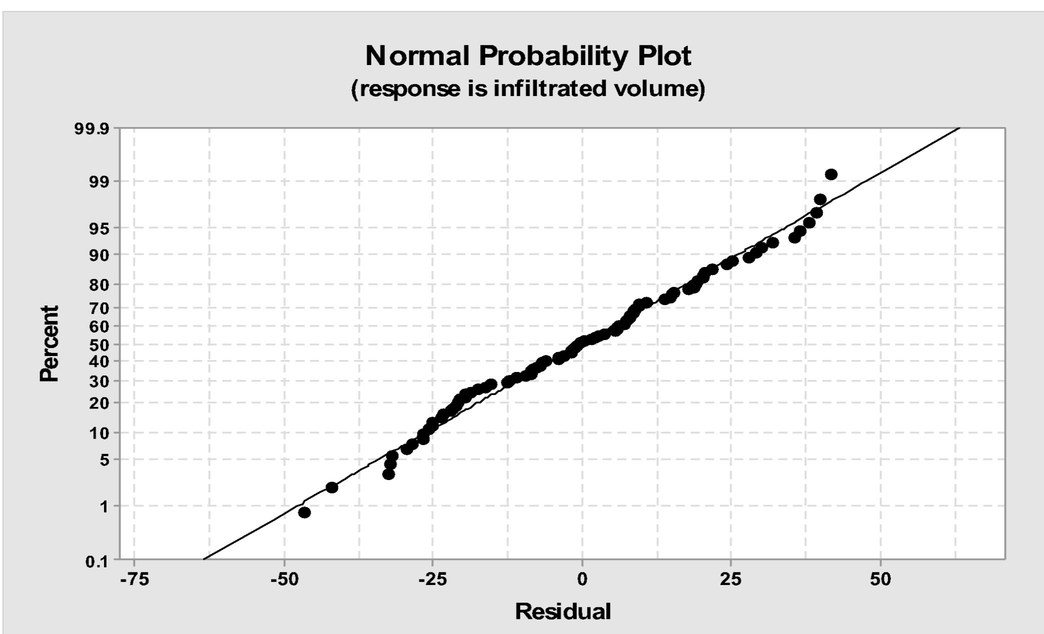


Figure 42 Normal Probablity Plot for Flat Events Group

KS value is 0.061 with a P-value larger than 0.15

Figure 43 indicates that total rainfall depth and rainfall duration are the two factors that most significantly impact the infiltration. Both of these two factors have a positive impact on the infiltration volume. Since the response for this group is the same as the inflow, the results of this are very similar to those produced by the inflow factor analysis in section 4.1.

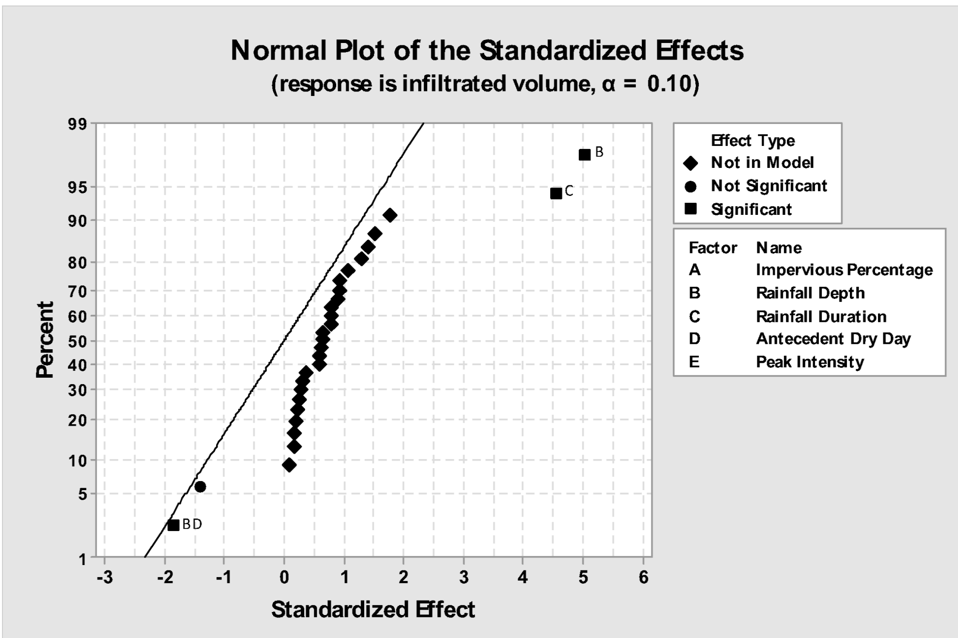


Figure 43 Normal Plot of the Standardized Effects

Figure 44 indicates that the number of antecedent dry days has a negative impact on the infiltration volume for this group.

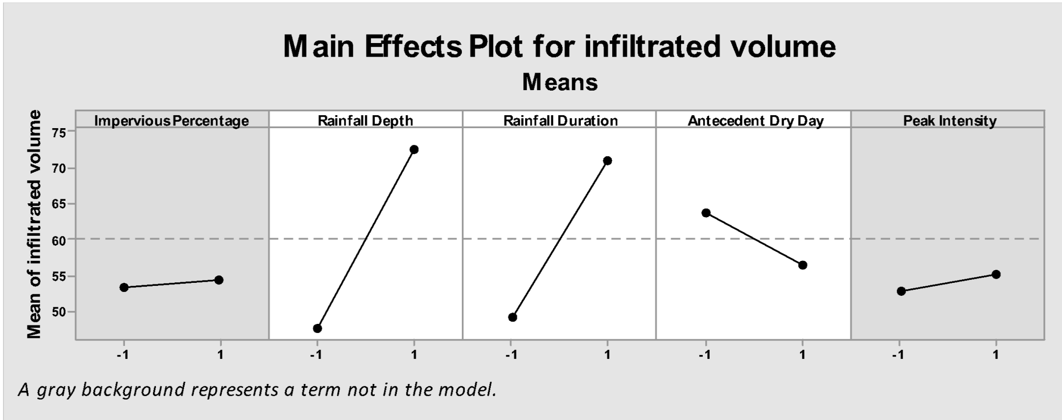


Figure 44 Main Effects Plot for Infiltration Volume

Table 18 is the ANOVA table for this group analysis.

Table 18 Infiltration Factorial Analysis ANOVA Table for flat response group

Source	DF	Adjusted SS	Adjusted MS	F-Value	P-Value
Model	4	32288.9	8072.2	18.33	0.000
Linear	3	24216.3	8072.1	18.33	0.000
Rainfall Depth	1	11162.2	11162.2	25.35	0.000
Antecedent Dry Day	1	886.5	886.5	2.01	0.160
Rainfall Duration	1	9075.6	9075.6	20.61	0.000
2-Way Interactions	1	1532.9	1532.9	3.48	0.066
Rainfall Depth * Antecedent Dry Day	1	1532.9	1532.9	3.48	0.066
Error	84	36987.2	440.3		
Lack-of-fit	25	6995.0	279.8	0.55	0.949
Pure Error	59	29992.3	508.3		

Total	88	69276.2			

II. Interaction Effects Analysis

Figure 45 gives the interaction plots. The interaction between rainfall depth and the number of antecedent dry days has a significant impact on the infiltration volume. When the number of antecedent dry days is at high level, the rainfall depth has a slightly positive effect on the infiltration volume. However, when the number of antecedent dry days is low, the rainfall depth has a significant positive effect on the infiltration volume.

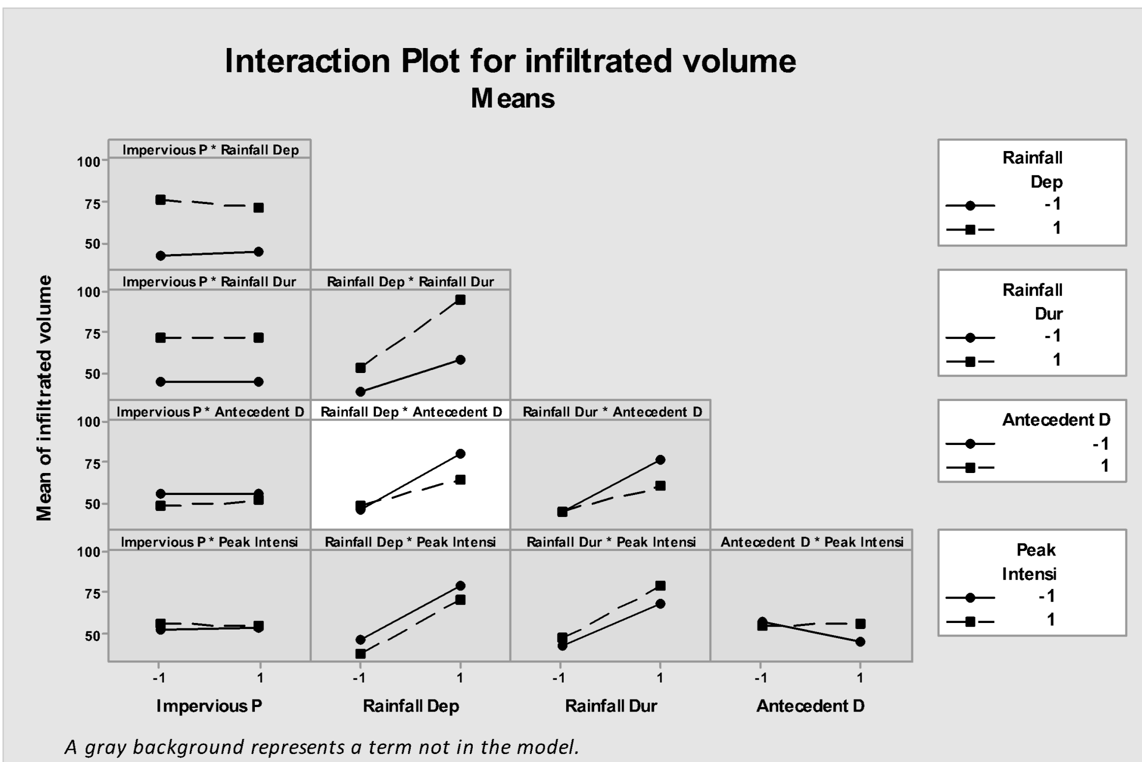


Figure 45 Interaction Plot for Infiltrated Volume

From the three groups analysis on the infiltration, the summary table can be generated as below.

Table 19 Infiltration Factorial Analysis Analysis Results

Groups	Significant Factors	Analysis Response
SmartDrain® Drain Group	Interaction of rainfall and peak intensity, total rainfall depths, rainfall duration, impervious percentage, antecedent dry days, and the interaction of duration and antecedent dry days.	Monitored infiltration volume
Raingarden with real drawdown rate(in/hr.)	The interaction of antecedent dry day of peak intensity and Peak intensity	Calculated drawdown rate(in/hr.)
Raingarden with flat response	Rainfall total depth, rainfall duration and the interaction of total rainfall and antecedent dry day	Inflow volume which is the total infiltrated volume

Overall, the most important factor actually is antecedent dry days. Different levels of antecedent dry days have different interactions with other terms and then turns to negative impacts or positive impacts on the response. When the soil is saturated, the rain gardens tend to receive more inflow and infiltrate more runoff. The sampling period did not measure the threshold limit of drawdown for less than an event with an average intensity of 1.32 inch/hour.

CHAPTER 5

PCA and MLR MODEL

5.1. Data Preparation for Model

There are two types of monitored GI units. The raingarden units in this study refer to the GI units that do not connect to a combined sewer pipe system underground. The bioretention units in this study refer to the GI units that are connected to the combined sewer pipe system. For monitored raingarden cells, the water volume captured equals inflow volume since no overflows were observed in 2013-2015. For the bioretention cells, the water volume captured is equal to the infiltration volume. Data from four gardens of the raingarden type and two of the bioretention type were used to construct the model. Two separate models were constructed. One is a model that uses data from raingardens without underdrain (Model 1), and the other one is a model that uses data from SmartDrain® system, which do have an underdrain model (Model 2).

Garden site 1612 has not been used for this model. Technically, this site is a raingarden and is not connected to a city sewer pipe. However, it has a two inches diameter drain pipes that drains to the street which can drain into the sewer pipe through a drop inlet. Therefore, the assumption that the inflow is infiltrated on site is not valid for this location.

During the monitoring period, flume inlet flooding situations occurred occasionally as the photo shows. Therefore, the H-flume did not function as a free outfall, so it is not possible to use the 0.5 H flowrate conversion equation. From the hydrograhs for each site at each event, the flooding events can been determined comparing the ponding depths in the garden with the flume inlet elevation. Flooding check

work has been done, which led to the removal of five data points from site 1336 due to inlet flooding.

The variables used in each of the two models, are watershed drainage area, watershed slope, street slope, impervious area percentage for each GI unit, rainfall total depths, rainfall duration, rainfall peak intensity and the number of antecedent dry days. The goal of the model is to predict the volume of water captured by the GI water captured volume. Model 1 was built based on site 1324, 1325, 1336 and 1112. The response variable for model 1 is total inflow volume for each garden for each event. Model 2 was built based on data from site 1140 and 1222. The response variable in model 2 is infiltration volume from monitored data.

Table 20 Data Details for Models

Data details for Raingarden (without underdrain) Model

Site	Total monitored events	Neglected data due to equipment failure	Neglected data due to flooding	Reserved Data points for validation	Model used data points
1324	51	3	0	6	42
1325	49	6	0	7	36
1336	24	0	5	2	17
1112	29	0	0	8	21
Total Points					116

Data details for Raingarden (SmartDrain®) Model

Site	Total monitored events	Neglected data due to equipment failure	Neglected data due to flooding	Reserved Data points for validation	Model used data points
1222	51	2	4	8	37
1140	51	1	10	3	37
Total Points					74

5.2. Correlation Coefficient Analysis on Variables

The variables used in model1 are watershed drainage area (Warea), watershed slope (Wslope), street slope (Sslope), impervious area percentage for each GI unit (Im), rainfall total depths (rain), rainfall duration (duration), rainfall peak intensity (I_peak) and the number of antecedent dry days (ADD). The first step was to run the correlation coefficient analysis for all of the variables. Pearson's correlation coefficient (r), which takes a value between -1 and +1 and measures the strength of the liner relationship between two variables was used. If the absolute value of the coefficients is high, it indicates the two variables have a strong linear relationship ([91]). For one dataset$\{x_1, x_2 \cdots x_n\}$and other dataset $\{y_1, y_2 \cdots y_n\}$, the correlation coefficient is obtained by the formula below ([92]):

$$r = r_{xy} = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2}} \quad \text{Equation 5}$$

where $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$, $\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$

After rearranging this equation,

$$r = r_{xy} = \frac{\sum_{i=1}^{n} x_i y_i - n\bar{x}\bar{y}}{(n-1)S_x S_y} \quad \text{Equation 6}$$

Where $S_x = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$, $S_y = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(y_i - \bar{y})^2}$, are the sample standard deviation.

For a collection of matrix with q variables, the covariance matrix can be illustrated as

$$\Sigma = \begin{pmatrix} \sigma_1^2 & \cdots & \sigma_{1q} \\ \vdots & \ddots & \vdots \\ \sigma_{q1} & \cdots & \sigma_q^2 \end{pmatrix} \quad \text{Equation 7}$$

Where $\sigma_i^2 = E((X_i - \mu_i))^2, \sigma_{ij} = E(X_i - \mu_i)(X_j - \mu_j)$

μ is the sample mean for each variable

For a sample from some population, the matrix Σ is estimated by:

$$\mathbf{S} = \frac{1}{n-1}\sum_{i=1}^{n}(X_i - \bar{X})(X_i - \bar{X})^T \quad \text{Equation 8}$$

Where $X_i = (x_{i1}, x_{i2}, \cdots x_{iq})^T, \bar{X} = n^{-1}\sum_{i=1}^{n} X_i$. Therefore, the diagonal of $\mathbf{S}$ contains the sample variances, which are denoted as s_{ii}, the correlation coefficient matrix can be illustrated as

$$R = D^{-1/2}\boldsymbol{S}D^{-1/2} \quad \text{Equation 9}$$

Where $D^{-1/2} = diag\left(\frac{1}{s_1}, \cdots, \frac{1}{s_q}\right)$, s_i is the sample standard deviation of variable i

The scatterplot of the eight variables for rain garden and SmartDrain® dataset are displayed below.

Figure 47 Scatterplot of Raingarden Variables

Figure 48 Scatterplot of Bioretentions with Smartdrain® Installed Variable

Figure 47 and Figure 48 display the correlation coefficient matrix for two models' variables. Both of the figures show that the rainfall depth has a strong correlation with rainfall duration and the peak intensity. From Figure 48, since there are only two sites, the garden features values became naturally strongly correlated with each other.

The following interpretation of correlation coefficient in terms of the strength of a linear association has been recommended by Evans in 1996. The absolute value of r that is smaller than 0.2 indicates a "very weak" linear association. If the absolute value of r is between 0.2 to 0.39 is "weak", then the linear relationship is weak, etc ([93]). Table 18 lists the details.

Table 21 Linear Association Level

Absolute Value of r	Linear Association Level
<0.2	Very weak
0.2 to 0.39	Weak
0.4 to 0.59	Moderate
0.6 to 0.79	Strong
0.8 to 1.0	Very strong

Model 1, makes use of data from four sites. The predictors are watershed area (Warea), street slope (Sslope), watershed slope (Wslope), impervious area percentage (Im), total rainfall depth (Rainfall), rainfall duration (Duration), number of antecedent dry days (ADD), and rainfall peak intensity (I_peak). The correlation coefficients matrix is displayed below.

Table 22 Correlation Coefficient Matrix (Without Underdrain Model)

	Warea	Sslope	Wslope	Im	Rainfall	Duration	ADD	I_peak
Warea	1	0.28	0.61	-0.83	-0.11	-0.11	0.24	-0.14
Sslope	0.28	1	0.93	0.31	0.07	0	0.1	-0.1
Wslope	0.61	0.93	1	-0.06	0.02	-0.04	0.17	-0.14
Im	-0.83	0.31	-0.06	1	0.15	0.11	-0.18	0.08
Rain	-0.11	0.07	0.02	0.15	1	0.61	-0.08	0.47
Duration	-0.11	0	-0.04	0.11	0.61	1	0.15	0.05
ADD	0.24	0.1	0.17	-0.18	-0.08	0.15	1	-0.16
I_peak	-0.14	-0.1	-0.14	0.08	0.47	0.05	-0.16	1

For model 2, the analysis variables are the same as model 1, however, only two sites' data have been used.

Table 23 Correlation Coefficient Matrix (With Underdrain Model)

	Warea	Sslope	Wslope	Im	Rainfall	Duration	ADD	I_peak
Warea	1	1	1	-1	-0.05	0.06	0.1	-0.06
Sslope	1	1	1	-1	-0.05	0.06	0.1	-0.06
Wslope	1	1	1	-1	-0.05	0.06	0.1	-0.06
Im	-1	-1	-1	1	0.05	-0.06	-0.1	0.06
Rain	-0.05	-0.05	-0.05	0.05	1	0.6	-0.02	0.61
Duration	0.06	0.06	0.06	-0.06	0.6	1	0.28	-0.04
ADD	0.1	0.1	0.1	-0.1	-0.02	0.28	1	-0.23
I_peak	-0.06	-0.06	-0.06	0.06	0.61	-0.04	-0.23	1

Based on the values Evans suggested, in model 1, the watershed slope has a very strong correlation with impervious area percentage and with area. Street slope and watershed slope also have a very high linear correlation. Total rainfall depth has a strong linear relationship with duration. Finally, the peak intensity has a moderate relationship with total rainfall depths.

In model 2, since data from only two sites are used for this analysis, there are only two different values in watershed area, street slope, watershed slope and impervious area percentage. Those four variables show very strong linear relationships. The total rainfall depth also has a high correlation with peak intensity. A common threshold for multicollinearity is absolute value of r that exceeds 0.5 ([94]). Therefore, collinearity exists among predictors in both model 1 and model 2. This means that using a multiple linear regression with those variables as predictors may impact the model precision. In a linear regression model, a set of predictors are used to estimate the relationship between the response and the predictors. In order to use the linear regression model properly, the predictors need to be independent. The significance of predictors is often in explaining variation in the response examined through hypothesis testing. If high collinearity exists between predictors, it is difficult to distinguish the real impact from each individual variable. This leads to inflated standard errors of those coefficients, and this makes the model unstable. Consequently, it is difficult to assess the significance of each variable ([94]). Principal Components Analysis (PCA) is a common way to accommodate the collinearity among the variables.

5.3. Principal Components Analysis (PCA)

The PCA could be understood as a data transformation method to transform the original data to uncorrelated and independent variables. The new dataset which is the PCA scores should capture the entire dataset's variance. For instance, for a dataset with two variables, $x_1, and\ x_2$.

S is the covariance matrix $S = \begin{bmatrix} cov(x_1, x_1) & cov(x_1, x_2) \\ cov(x_2, x_1) & cov(x_2, x_2) \end{bmatrix}$ is a symmetrical matrix.

The eigenvector is also called the characteristic vector. For a certain linear transformation, the eigenvector does not change the direction, while the vector length may change. If there is a given transformation matrix A, then the eigenvectors γ will satisfy such that $A\gamma = \lambda\gamma$, where λ is the eigenvalue. In order to get the value of λ. Matrix algebra will be applied to solve this equation.

$$A\gamma = \lambda\gamma \qquad \text{Equation 10}$$

$$A\gamma - \lambda\gamma = 0 \qquad \text{Equation 11}$$

$$(A - \lambda I)\gamma = 0 \qquad \text{Equation 12}$$

For two variables, S=$\begin{pmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{pmatrix}$, in order to get the eigenvalues of the covariance matrix

S

$$\left| S - \begin{pmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{pmatrix} \right| = 0 \qquad \text{Equation 13}$$

$$\begin{pmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{pmatrix} - \begin{pmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{pmatrix} = 0 \qquad \text{Equation 14}$$

Then two eigenvalues λ_1 *and* λ_2 can be obtained.

Write the eigenvector as $\gamma = \begin{pmatrix} X_1 \\ X_2 \end{pmatrix}$ Equation 15

Substitute the values of λ_1 *and* λ_2,

$$\begin{pmatrix} s_{11}-\lambda_1 & s_{12} \\ s_{21} & s_{22}-\lambda_1 \end{pmatrix}\begin{pmatrix} X_1 \\ X_2 \end{pmatrix} = 0 \qquad \text{Equation 16}$$

$$\begin{pmatrix} s_{11}-\lambda_2 & s_{12} \\ s_{21} & s_{22}-\lambda_2 \end{pmatrix}\begin{pmatrix} X_1 \\ X_2 \end{pmatrix} = 0 \qquad \text{Equation 17}$$

since $\begin{pmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{pmatrix}$, λ_1 and λ_2 are known values, the $\begin{pmatrix} X_1 \\ X_2 \end{pmatrix}$ which is the eigenvectors can be obtained.

$\boldsymbol{a}_1$ is the eigenvector or characteristic vector of the sample covariance matrix, and $\boldsymbol{a}_1$ must be the one which contains the most variance, **S**. The eigenvector**.** counts both the common and unique variance of the variables: matrix $\mathbf{A} = (\boldsymbol{a}_1, \boldsymbol{a}_2, \cdots, \boldsymbol{a}_q)$. Then for each principle component, there is an eigenvalues $\boldsymbol{\lambda}_i$ associated with it. The eigenvalue is the variance of all of the variables which accounted for that principle component.

For q variables, it will satisfy that

$$\sum_{i=1}^{q} \lambda_i = s_1^2 + s_2^2 \cdots + s_q^2, \text{where } s_i^2 \text{ is the sample variance of } x_i. \qquad \text{Equation 18}$$

Λ is the main diagonal matrix of $\lambda_1, \lambda_2, \cdots, \lambda_q$. Thus, the covariance matrix of the original variables is given by: $\mathbf{S} = \mathbf{A}\boldsymbol{\Lambda}\mathbf{A}^T$.This process has been known as the spectral decomposition of $\mathbf{S}$,

Then the proportion of each Principal Component (PC) value can be determined as below:

$P_i = \frac{\lambda_i}{trace(\boldsymbol{S})}$ then the cumulative proportion for m principal components , where m<q, can be determined from $P^m = \frac{\sum_{i=1}^{m} \lambda_i}{trace(\boldsymbol{S})}$

The most commonly application for PCA are (1) reduce variable dimensions, and (2) remove the high correlation among the variables. The principle component is a linear combination of original variables. A two principal component calculation process is used here as an example to illustrate the principle of PCA. The first principal component has the greatest variance among all of the principal component groups.

$$\text{PC1} = a_{11}x_1 + a_{12}x_2 + \cdots + a_{1q}x_q \quad \text{Equation 19}$$

$$\text{PC2} = a_{21}x_1 + a_{22}x_2 + \cdots + a_{2q}x_q \quad \text{Equation 20}$$

$$\boldsymbol{a}_1^T = (a_{11}, a_{12}, \cdots, a_{1q}), \boldsymbol{a}_2^T = (a_{21}, a_{22}, \cdots, a_{2q}) \quad \text{Equation 21}$$

There are restrictions applied on those coefficients, $\boldsymbol{a}_1^T\boldsymbol{a}_1 = 1.\ \boldsymbol{a}_2^T\boldsymbol{a}_2 = 1, \boldsymbol{a}_2^T\boldsymbol{a}_1 = 0$. The first two restrictions guarantee the transformation keeps the same data variance during the axis rotation process. The last restriction ensures that PC1 and PC2 are uncorrelated. Figure 49 is an example of the PCA transformation of the original dataset ($x_1$and x_2). The slope of the major axis is the ratio of eigenvector of the largest eigenvalue (λ_1). Slope of minor axis is the ratio of the eigenvector of the second largest eigenvalue (λ_2).

For more than two variables, the similar process but the method of LaGrangian multipliers is used.

R is a free download and open source statistical software. However, it is not very user friendly. All of the calculation and graphing need to be coded. The PCA can be processed by R in-built function: princomp(). This function returns the following information.

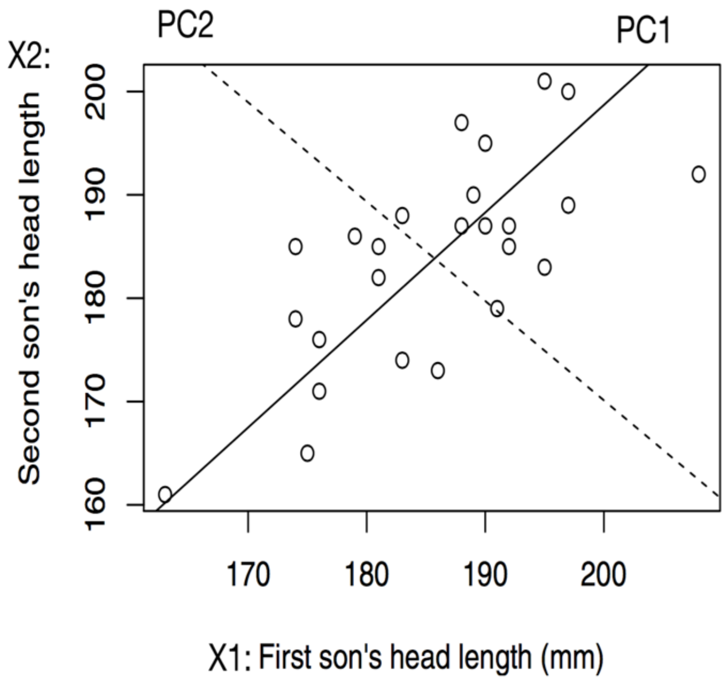


Figure 49 Principle Component Graphical Depiction

Source: Everitt and Hothorn 2011([91]).

Table 24 Princomp() Interpretation Table

Code Name	Interpretation
sdev	Standard deviations of each column of the rotated data
Loadings	Principal components $[T]_{\cdot n \times m}$
Center	Mean for each variable
Scale	The scale factor applied on the original data
Scores	The rotated data (new data) $[P]_{m \times m}$
N.obs	Number of each variable
call	The call to princomp() that created the object

For returned results values from princomp() function. The scaled original data matrix $[X]$satisfies the following relationship with the loading values.

$$[X][P] = [T] \qquad \text{Equation 22}$$

$[X]_{n\times m}$ is scaled original data matrix

$[T]_{n\times m}$ is the matrix of principal components scores, which are the new data points after axis rotation

$[P]_{m\times m}$ is square matrix of loading matrix

5.4. PCA and MLR Hybrid Model

Because of the collinearity in the model 1 and model 2 datasets, PCA is applied to the predictors before the multiple linear regression (MLR) is carried out. For each model dataset, the data points have been randomly split as training datasets and test datasets. The training dataset is 80% of the original data points, while the test dataset uses 20% of the original data. Different split attempts will return a different training and test dataset. Therefore, this process was repeated 20 times until the regression returned the highest R^2value. The dataset which returns the highest R^2value is considered to return the best performance model, it will be a bit biased, however, using an independent test dataset to validation the regression will help to solve this problem ([95], [96]).

The PCA process is the pre step for MLR. However, the results from MLR will affect the PCA. The results from MLR will diagnose the high leverage points as well as outliers that may need to be removed from the analysis. After the removal of outliers, the PCs need to be recalculated to obtain the new dataset PCA scores. The criteria to remove outlier and leverage points are (1) check the normal probability plot to maintain a straight line and (2) Residual plot lacks a potential pattern. For model 1, the response is total inflow volume into each garden. In order to ensure that the residuals are roughly normally distributed, the square root of the response is applied on the principal components. High leverage points or influential points in the values of the predictors will also decrease model precision.

The diagnostic plots for Model 1 are below. Point 88, 107 and 114 have large residuals and are removed from the dataset in order to improve fit.

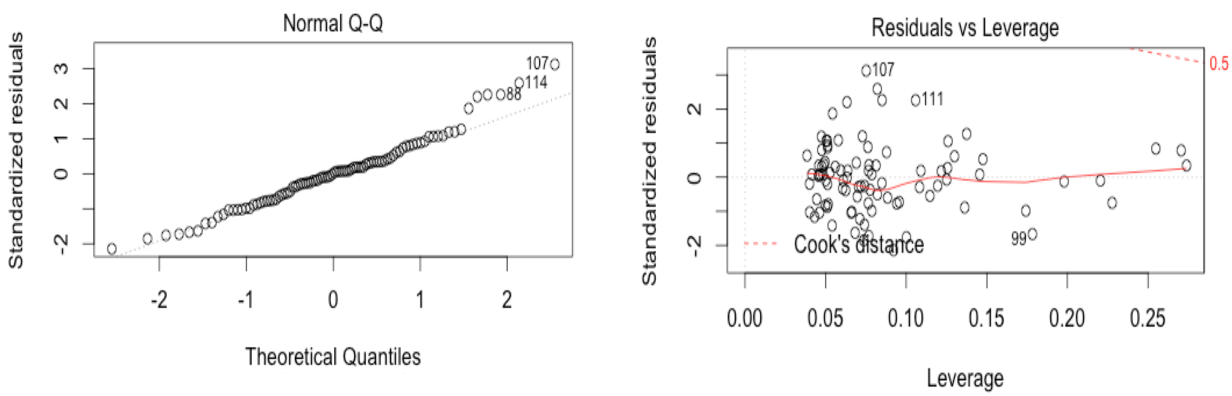


Figure 50 Diagnostic Plots of First Run MLR of Model 1

The normal probability plot indicates that the residuals follow a normal distribution. The leverage plot indicates that there are high leverage points in this dataset that need to be removed. A common threshold for a high leverage point is a point having a Cook's distance of at least 0.5 ([97]). Equation 23 is the Cooke's distance equation.

$$D_i = \frac{\sum_{j=1}^{n}(\hat{y}_i - \widehat{y_{J(i)}})^2}{(k+1)MS_E} \quad \text{Equation 23}$$

$\widehat{y_{J(i)}}$ is the prediction of y_i by the revised regression model when the point $(x, \ldots, x_{ik}, y_i)$is removed from the sample.

Those points have been removed from the training dataset. PCA has been run the second time to obtain the new PC scores. The second MLR on PC scores after removal the outliers, shows a better fit to the responses.

After the second run of MLR. Points 65 and 111 have high residuals. Therefore, the two points needed to be removed.

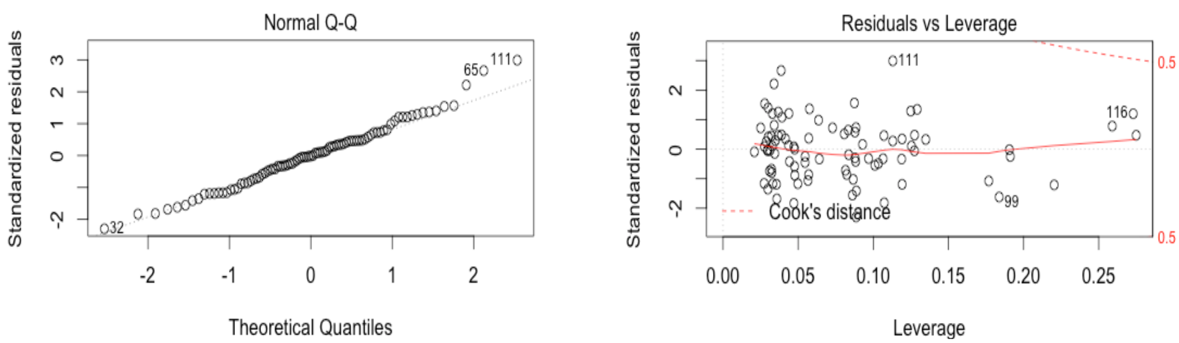


Figure 51 Diagnostic Plots for Second Run MLR of Model 1

After points of 65 and 111 are removed, the diagnostic plots suggested that the residuals follow an approximate normal distribution without large residual points. This data set is used as the training set.

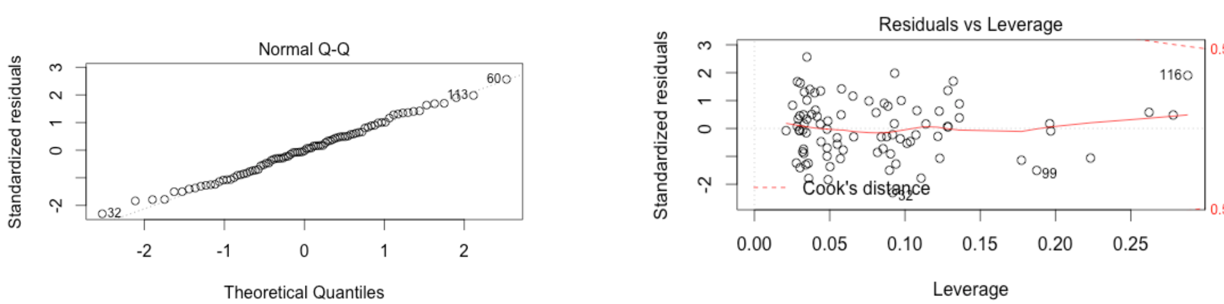


Figure 52 Diagnostic Plots for Final MLR of Model 1

The five removed points are listed in table 25. It indicates that the five points have usual inflow comparing to the average inflow for this site. It is possible caused by flume pressure sensor clogging during the data collection period.

Table 25 Large Residual Points Details

Data Points	Monitored Inflow(gal)	Site Location	Average Inflow For This Site(gal)
88	6748	1336	1300
107	20762	1112	9200
114	16158	1112	9200
65	17372	1325	3700
111	22043	1112	9200

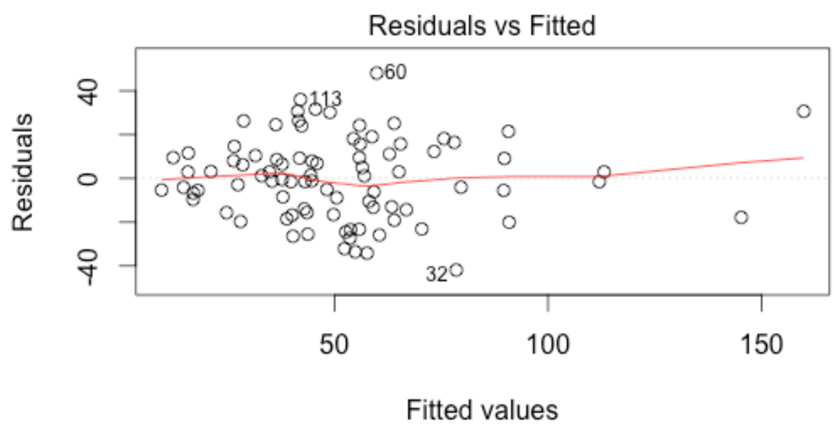


Figure 53 Values vs Residual Plot

Figure 53 indicates that the data set roughly has a constant variance because the values vs residual does not follow a certain pattern.

Correlation matrix has been suggested to use for PCA when the data set is in different scales. The correlation coefficient matrix for the training data for Model 1 is shown in Table 20.

Table 26 Correlation Coefficient Matrix After Outliers Removal

(Without Underdrain Model)

	Warea	Sslope	Wslope	Im	Rainfall	Duration	ADD	I_peak
Warea	1	0.25	0.61	-0.85	-0.17	-0.11	0.32	-0.1
Sslope	0.25	1	0.92	0.29	-0.05	-0.02	0.18	-0.09
Wslope	0.61	0.92	1	-0.11	-0.11	-0.06	0.27	-0.12
Im	-0.85	0.29	-0.11	1	0.15	0.1	-0.22	0.05
Rain	-0.17	-0.05	-0.11	0.15	1	0.54	-0.22	0.56
Duration	-0.11	-0.02	-0.06	0.1	0.54	1	0.1	-0.09
ADD	0.32	0.18	0.27	-0.22	-0.22	0.1	1	-0.25
I_peak	-0.1	-0.09	-0.12	0.05	0.56	-0.09	-0.25	1

In order for PCA to work properly, the original data need to be standarized by subtracting the mean, and then dividing the standard deviation of each variable. This step will produce a dataset with mean=0 and standard deviation of 1([98]). The PCA loadings have been calculated for each of the two models respectively.

Table 27 PCA Loadings (Without Underdrain Model)

	Comp. 1	Comp. 2	Comp. 3	Comp. 4	Comp. 5	Comp. 6	Comp. 7	Comp. 8
Warea	-0.514	0.155	0.383		-0.166		-0.386	0.616
Sslope	-0.352	-0.592	-0.156	0.118			0.622	0.312
Wslope	-0.497	-0.421		0.135	-0.103		-0.396	-0.623
Im	0.318	-0.472	-0.462		0.141		-0.555	0.366
Rain	0.289	-0.355	0.559			-0.69		
Duration	0.139	-0.269	0.338	-0.68	-0.258	0.515		
ADD	-0.324			-0.46	0.819	-0.108		

I_peak	0.235	-0.16	0.434	0.531	0.451	0.496	

The PCA can be understood as a data transformation process. It will create new independent uncorrelated predictors for analysis. In order to ensure that the new principal component datasets captured the variation in the original data, the proportion of variability can be calculated for each principal component. The tables below summarize the details for the variables.

Table 28 Cumulative Captured Original Data Variances (Without Underdrain Model)

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Cumulative Proportion	0.33	0.55	0.74	0.89	0.97	1.00	1.00	1.00

For model 1, six principal components can explain 100% of the original data variances. Principal component scores have been defined as $[X][P] = [T]$. The first six principal components(PC) scores are the predictors for model 1. The four diagnostic plots for model 1 indicate that the residuals satisfy the normality assumption.

Multiple linear regression coefficients for each PC values for model 1 are displayed below:

Table 29 MLR Coefficients (Without Underdrain Model)

	Estimate	Std. Error	t value	P-Value	Significance
(Intercept)	51.553	2.05	25.165	<2.00E-16	***
pc1	7.695	1.28	6.027	4.86E-08	***
pc2	-13.9	1.57	-8.86	1.66E-13	***
pc3	6.262	1.67	3.751	0.000332	***
pc4	-6.06	1.90	-3.193	0.002015	**
pc5	-6.421	2.49	-2.576	0.011821	*

pc6	-23.543	5.08	-4.637	1.36E-05	***

Residual standard error: 19.11 on 82 degrees of freedom

Multiple R-squared: 0.6691. Adjusted R-squared: 0.6443.

Table 23 lists the MLR results. Two tail T-test has been used to determine the significance of each variable. For a family wide hypothesis test, the statistical significance level needs to be corrected using the Bonferroni correction. Then the corrected statistical significance level for this analysis is 0.1/7=0.014. When the P-value is smaller than the significance level 0.014, it means the null hypothesis has been rejected and this variable has significant effect on the response. Therefore, this variable needs to be in the final model. R-squared represents how much percentage of variation from the original dataset can be explained by the liner regression when there are multiple variables. Every time a new variable is introduced to a model, the R-square will increase. When a model has multiple variables, it will give a misleading high R-square. Therefore, the Adjusted R value is used to determine whether the model is a good fit ([99]).

$$\text{Adjusted R} - \text{squared} = 1 - \frac{\text{Mean Square Error}}{\text{Total Mean Square}} \qquad \text{Equation 24}$$

64% of the variation in the responses can be explained by regression on the principal components in model 1.

The only difference between the way the analyses for model 1 and model 2 are carried out is that the response term is infiltration volume instead the inflow volume to each site. Sites 1140 and 1222 data were used for model development. Linear regression diagnostic plots are used to identify outliers and high leverage values. The first run regression diagnostic plots indicate that points 38, 57 and 58 have large residuals. Therefore, these three points have been removed from the data set.

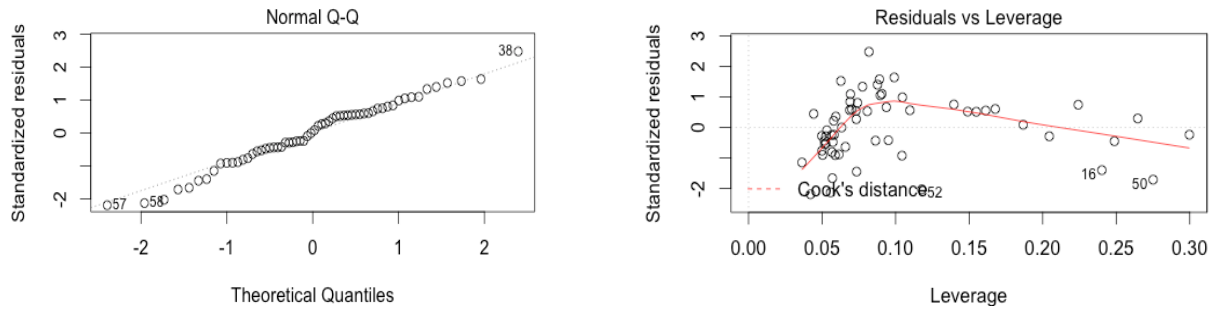
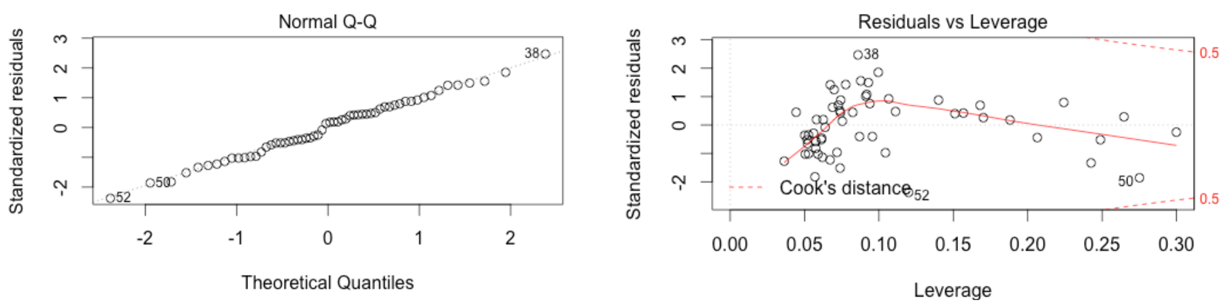


Figure 54 Diagnostic Plots of First Run MLR of Model 2

After the larger residual points been removed, the diagnostic plots below indicate the residual of new data set roughly follows a



normal distribution, which satisfies the assumption of multiple linear regression.

Figure 55 Diagonal Plots of Final Run MLR of Model 2

The five removed points are listed in table 30. It indicates that the two points have usual inflow comparing to the average infiltration for this site. It is possible caused by flume pressure sensor reading failure during the data collection period.

Table 30 Large Residual Points Details

Data Points	Monitored Inflow(gal)	Site Location	Average Inflow For This Site(gal)
57	4	1140	3600
58	54	1140	3600

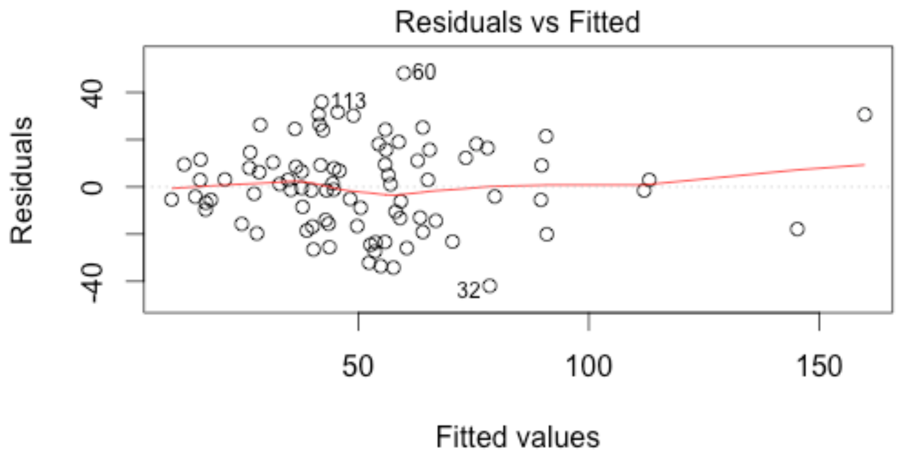


Figure 56 Values vs Residual Plot

Figure 56 indicates that the data set roughly has a constant variance because the values vs residual does not follow a certain pattern.

Similar to model 1, PCA was applied to the correlation matrix from the variables for model 2. The correlation coefficient matrix of the training dataset on Model 2 can be generated in Table 24.

Table 31 After Outlier Removal Correlation Coefficient Matrix

(With Underdrain Model)

	Warea	Sslope	Wslope	Im	Rainfall	Duration	ADD	I_peak
Warea	1	1	1	-1	-0.12	0.1	0.11	-0.17
Sslope	1	1	1	-1	-0.12	0.1	0.11	-0.17
Wslope	1	1	1	-1	-0.12	0.1	0.11	-0.17
Im	-1	-1	-1	1	0.12	-0.1	-0.11	0.17
Rain	-0.12	-0.12	-0.12	0.12	1	0.63	-0.07	0.59
Duration	0.1	0.1	0.1	-0.1	0.63	1	0.21	-0.04
ADD	0.11	0.11	0.11	-0.11	-0.07	0.21	1	-0.28
I_peak	-0.17	-0.17	-0.17	0.17	0.59	-0.04	-0.28	1

As in the analysis of model 1, the original data are standized before the PCA is carried out.

Table 32 PCA Loadings (With Underdrain Model):

	Comp. 1	Comp. 2	Comp. 3	Comp. 4	Comp. 5	Comp. 6	Comp. 7	Comp. 8
Warea	-0.492					-0.727	-0.598	
Sslope	-0.492					0.734	0.351	0.295
Wslope	-0.492					-0.231	-0.660	0.511
Im	0.492					-0.123	-0.290	0.807
Rain		-0.708			0.700			
Duration		-0.519	0.511	0.437	-0.526			
ADD			0.682	-0.724				
I_peak	0.117	-0.466	-0.502	-0.534	-0.481			

Table 33 Cumulative Captured Original Data Variances (With Underdrain Model)

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Cumulative Proportion	0.51	0.74	0.90	0.99	1	1	1	1

For model 2, five principal components can explain 100% of the original data variances. PC scores have been defined as $[X][P] = [T]$. The five PC scores are the predictor for model 2.

Table 34 MLR Coefficients (With Underdrain Model)

	Estimate	Std. Error	t value	Pr (>|t|)	Significance
(Intercept)	34.997	1.7169	19.508	<2.00E-16	***
pc1	3.392	0.947	3.582	0.00075	**
pc2	-8.603	1.351	-6.366	5.06E-09	***
pc3	-2.40	1.604	-1.496	0.14068	.
pc4	4.603	2.197	2.095	0.04110	
pc5	7.059	5.433	1.299	0.19955	

Residual standard error:13.66 on 52 degrees of freedom

Multiple R-squared: 0.5812

Adjusted R-squared: 0.541

In a similar fashion as in model 1, the multiple linear regression model 2 can explain 57% of the original dataset. Table 27 lists the significant PC values are pc1 and pc2. For a family wide hypothesis test, the corrected statistical significance level for this analysis is 0.1/5=0.02. Then the final equation should only keep the intercept, pc1 and pc2.

Based on the significance of each PC scores regressors, the regression equation for model 1 and model 2 are:

$$\text{Y(square root of inflow volume)} = 51.55 + 7.70\text{PC1} - 13.9\text{PC2} + 6.26\text{PC3} - 6.06\text{PC4} - 6.421\text{PC5} - 23.543\text{PC6} \quad \text{Equation 25}$$

$$\text{Y(square root of infiltration volume)} = 34.997 + 3.392\text{PC1} - 8.803\text{PC2} \quad \text{Equation 26}$$

The underlying idea of a linear regression is that the regression line is an average value of response of the selected predictors. It means that when $\alpha = 0.05$, there is 95% probability that this 95% confident interval could capture the true population mean. When the predictor values are $X_p = (1, X_{p,1}, X_{p,2}, \ldots, X_{h,p-1})^T$, the mean response is μ_Y. The standard error of the fit at a given X_p is given by $\text{se}(\hat{y}_h) = \sqrt{MSE(X_h^T(X^TX)^{-1}X_h}$, then a 100% confidence interval for Y is

$$\hat{y}_h \pm t_{(\alpha/2, n-p)} \times Se(\hat{y}_h) \quad \text{Equation 27}$$

where

$\hat{y}_h$ is the "fitted value" when the predictors are X_p

$t_{(\alpha/2, n-p)}$ is the t-multiplier. $1 - \alpha$ is the confident level, n is the total number of observations in the dataset, and p is the predictors' number ([100]).

One of the primary goal of regression model is to make accurate predictions. Therefore the prediction interval for a new response y_{new} will be important to study. For a known predictor value $X_p = (1, X_{p,1}, X_{p,2}, \ldots, X_{h,p-1})^T$, the prediction interval of y_{new} is defined as:

$$\hat{y}_{new} \pm t_{(\alpha/2, n-p)} \times \sqrt{MSE + Se(\hat{y}_h)^2} \quad \text{Equation 28}$$

Where

$\hat{y}_{new}$ is the "fitted value" when the predictors are $X_p([101])$.

$t_{(\alpha/_{2},n-p)}$ is the t-multiplier Therefore, the 95% confident interval and 95% prediction interval can be calculated for the two models.

For both of the models, internal validation has been performed. The test datasets are randomly selected during the data training and test set split process.

5.5. Model Verification

As a preliminary step for model development, the test dataset variables were standardized before the PCA loading was applied.

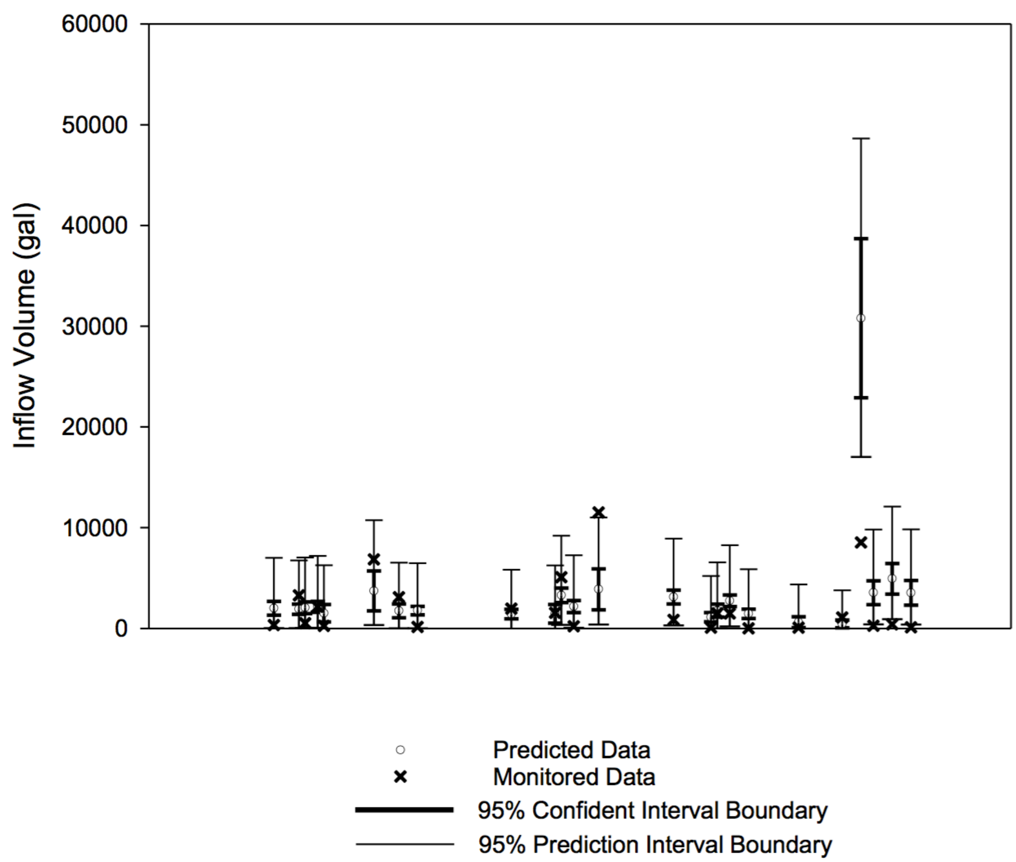


Figure 57 Raingarden Model Test Dataset Validation

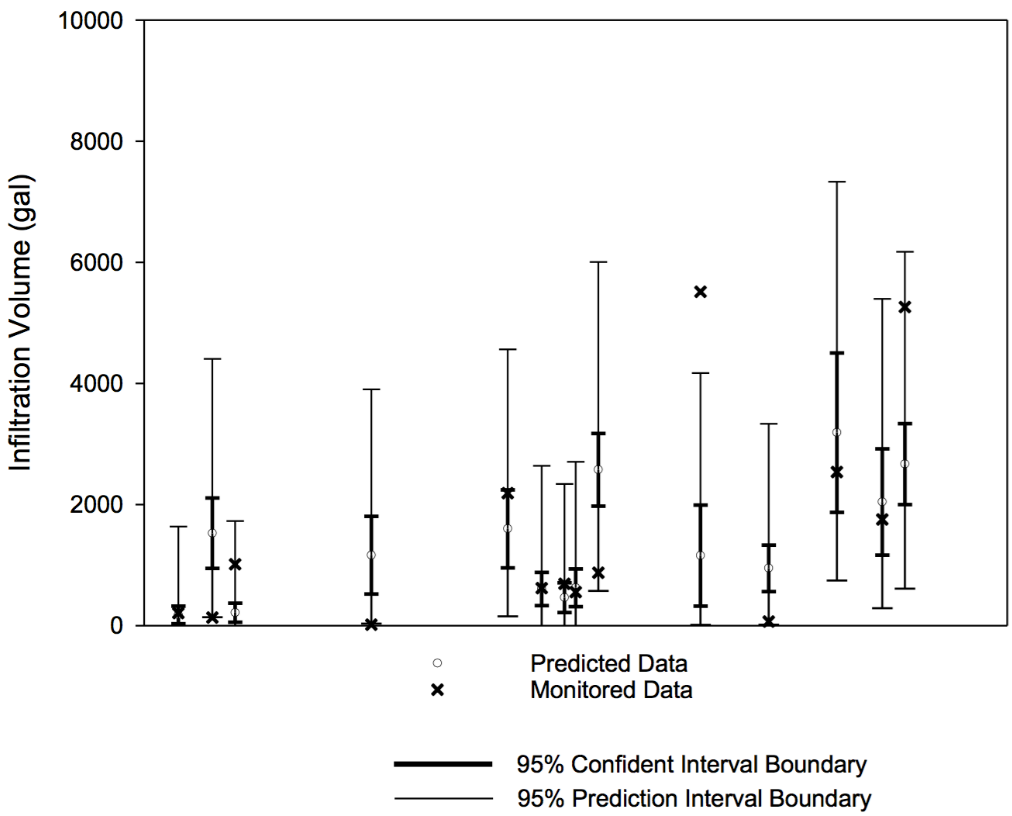


Figure 58 SmartDrain® Model Test Dataset Validation

From the results, for model 1, 92% of the test data points are within the 95% prediction interval. For model 2, 93% of the test data points are within the 95% prediction interval. 80% has been recommended to use as a threshold to determine whether the model has a good prediction. This suggests that the two models have a good prediction value.

Overall, internal validation suggests that the two models fit the monitored data well. The next step is to perform an external validation to see how this regression models work on data prediction.

CHAPTER 6

WATERSHED LEVEL PREDICTION AND MODEL VALIDATION

6.1. Data Preparation for Prediction

The entire watershed contains 135 green infrastructure units. The watershed is a largely-residential urban area, and the following table summarizes the raingarden watershed characteristics. Each raingarden has its own drainage area. Parts of the 100 acres are not treated by GI solutions: about half of the pilot area are not treated by GIs.

Table 35 Summary of Watershed Characteristics

	Drainage Area(ac)	Impervious Percentage	Watershed Slope	Street Slope
Average	0.37	48.44	6.57	7.52

Total treated area is 49.32 ac.

There are 81 rain gardens without an underdrain that are connected to the sewer system, and there are 53 bioretention cells that are connected to sewer system, 1 bioswale, 200 square feet of porous concrete sidewalk and 5070 square feet of permeable paver sidewalk. Bioretention units have an engineered soil layer. The layer is a mixture of sand, topsoil and compost, with the concentration of sand no less than 50% of the mixture. Bioretention cells have underdrains that are connected to a below grade storage pipe. This drainage system functions as a detention system, where the water infiltrated from the garden is stored in the pipe and then slowly overflows through a small orifice into the combined sewer system. And it was not detected in the storm hydrographs. Since the detention function delays the runoff discharge to the sewer pipe, it can reduce the combined sewer peak flow ([102], [103]).

Figure 59 Test Watershed Map

The GI units have various names in original design plan. Bioretention without curb, curb extensions with bioretention, shallow bioretention, bioswale, cascade, and rain garden are examples of these names. This study groups the units into three different categories. One is rain garden without an underdrain, the second is bioretention cells with lower grade storage, and the third group is the shallow bioretention cell with a SmartDrain® pipe connected directly to the combined sewer system. Table 29 summaries the details of the three categories.

Table 36 Three Categories of GIs in Test Area

Design Plan Component	Number of this type of stormwater control units in test (pilot) area	Drainage area for each unit (ac)	Total Area treated by these devices (ac)
Rain Garden without underdrain	83	0.33	27.03
Bioretention with underdrain	47	0.45	21.03
Shallow Bioretention Cell with SmartDrain®	5	0.25	1.26
Total number of control units:	135	Total area treated	49.32

The eight variables analyzed in the previous section are drainage area to each GI unit, watershed slope, street slope, impervious area percentage of each drainage area, rainfall total depths, rainfall duration, rainfall peak intensity and antecedent dry days. The first four characteristics can be determined from the garden design details.

The original hydrology design on the entire watershed was done by HDR, Inc ([86]). A SWMM model was used to determine how much of the water volume needed to be captured in order to achieve the goal of reducing the combined sewer overflow frequency by 65%. This frequency reduction turns out to reduce the runoff from the outfall 069 by 292,000 gal and lower the peak flow by 76%. The hydrology model by HDR adopted design storm D (1.4 inches) which has peak intensity of 0.6 in/hr and duration of 16.75 hours. The original concept plan indicated that the GIs installed in the pilot area should store or infiltrate approximately 56 % of the pilot area runoff from design storm D. The entire storage volume from the GIs was expected to be 300,000 gallons from a design storm event. A total of 344 total GIs were recommended in the conceptual plan.

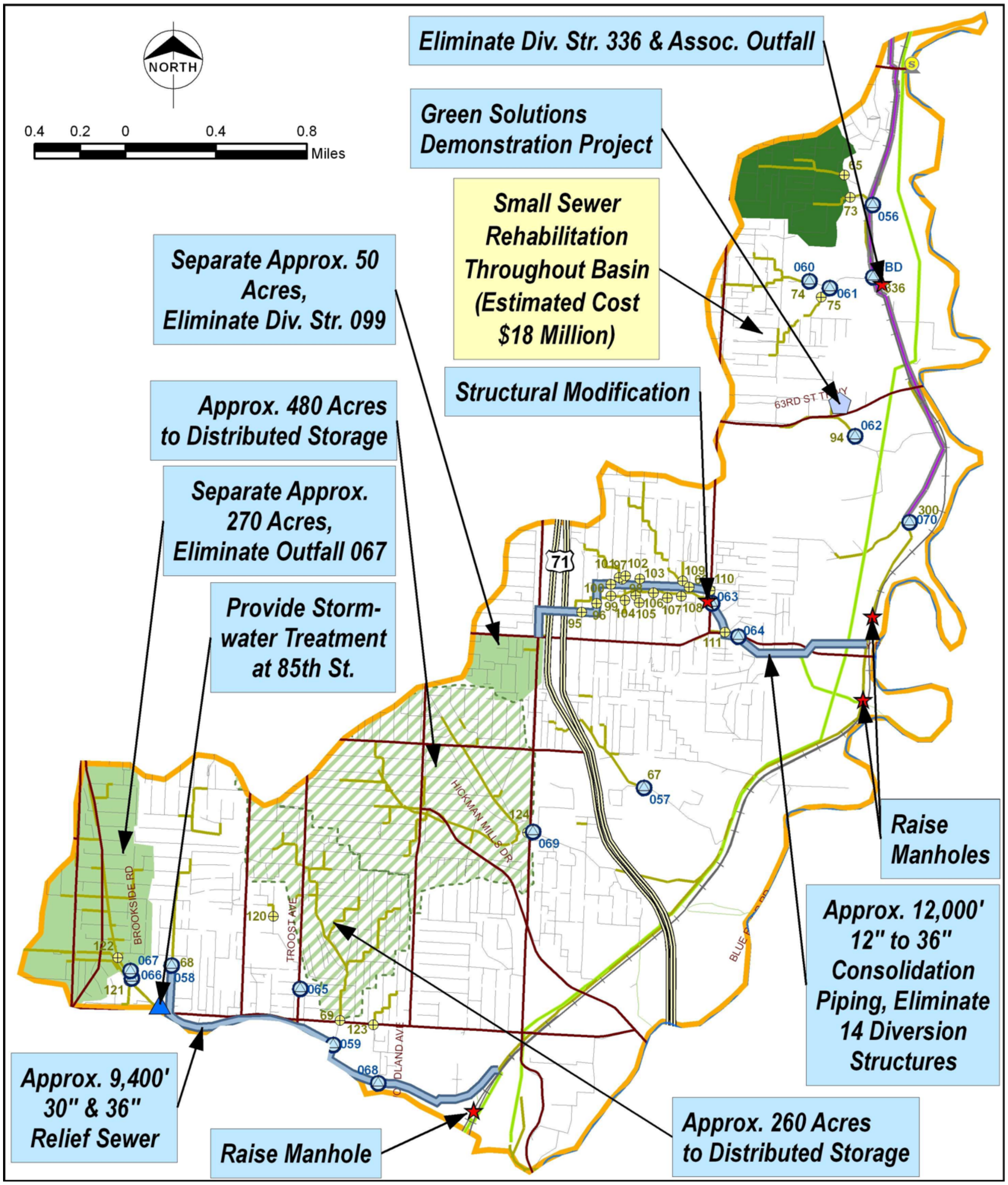


Figure 60 Original Middle Blue River Overflow Control Plan ([83])

Due to the conflicts with utility lines, driveways, sidewalks, bus stops, parking, trees, and access, some of the original GI locations were changed. The subbasin delineation is based on the terrain geometry. The original design of the GI location had one single GI per subbasin. Within the 54 bioretention cells, several cells share the same drainage area, watershed slope, street slope and impervious area percentage. Therefore, those cells were combined for this analysis. Then the total number of bioretention cells for prediction will be 49 rather than 54. The following sites share the same subbasin, and they will be combined as one unit for the analysis. Sites 126, 127 and 129 have been combined, as are sites 131 and 132, sites 36 and 59, and sites 74 and 119. The map below shows the GI units with their drainage area.

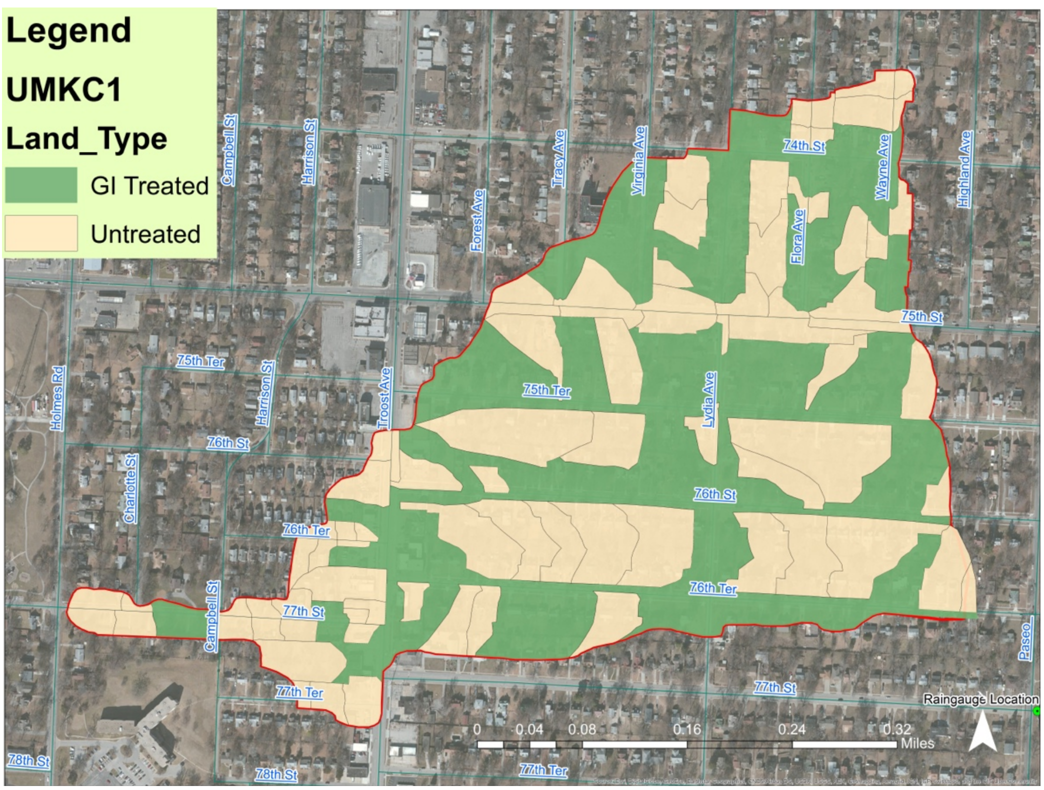


Figure 61 Subwatershed For Each GI Unit in Test Area

The eight events that have monitored watershed flow data during the post-construction period are reserved for model validation and were not used in the model calibration.

Figure 62 Photo of Bioretention Cell with Below Grade Storage on Troost Street (Source: Dods, 2012)

For the rain garden group, model 1 is used for prediction and validation. For rain garden sites, it is assumed that all of the inflow will eventually be infiltrated and thus does not contribution to the sewer flow. Therefore, the inflow volume predicted from the model is the captured volume from those rain gardens.

Figure 63 Photo of Bioretention Cell with Smart Drain® (Source: Dods, 2012)

For the bioretention cell with below-grade storage, which includes the underground cubic storage units along Troost Street, model 1 is also used for prediction and validation. Since the bioretention all has an underdrain pipe connected to combined sewer system, the below grade storage functions as a detention pond. This storage pipe contains the infiltrated flow from the bioretention cell, temporarily stores it in the pipe, and slowly release to the sewer pipe. This reduces the peak flow discharge, and does not contribute to the hydrograph.

The calculation for outfall volume is based on each storm's natural starting and ending points. Therefore, there is a time difference between when the bioretention cells release the storage and when the sewer peak flow occurs. From the outfall monitored hydrograph, one can barely tell that there was another peak after the rain event ended. This means that, the sewer flow data did not account for this volume that the bioretention cells store during a rain event.

Therefore, the bioretention category can use model 1 to predict the inflow, where the inflow is represented by the captured or temporarily stored volume. Figures 45 and 46 show the below grade storage pipe and the cubic storage units ([103]).

Figure 64 Photo of Bioretention Cell with Cubic Storage(Source: Dods, 2012)

For the shallow bioretention cells that are installed with a SmartDrain® pipe, model 2 will be used for prediction and validation. This model was built based on data from site 1140 and 1222, both of which have shallow bioretention cells with SmartDrain® pipes. There is no underground storage; any noninfiltrated water in the raingarden soil layer will migrate to the sewer system. Model 2 can predict the infiltrated volume from a shallow bioretention cell, that is the volume captured by a shallow bioretention unit. Figure 45 shows the installation of a Smart Drain® pipe.

6.2. Monitored Site Validation

Eight rain events are used for water mass balance validation. Those rain events have been removed from the model construction process.

Table 37 Model Validation Rain Events

Date	Total Depth (inch)	Duration (mins)	Antecedent Dry Day	Peak Intensity(in/hr.)
11/11/2012	1.45	475	29	0.72
4/7/2013	0.97	337	12	1.32
4/9/2013	0.80	720	1	0.72
4/17/2013	0.90	710	2	1.56
4/26/2013	0.71	1130	3	0.24
5/2/2013	1.02	1500	5	0.16
5/27/2013	2.36	225	8	2.76
5/29/2013	1.30	925	2	0.84

The prediction inflow volume and infiltration volume can be predicted from the two models. Since monitored inflow and infiltration volume are available for those locations, the prediction value and monitored value can be compared from each site.

For model 1, data from sites 1112, 1324, 1325, 1336 and 1612 data are used for model construction, excluding the eight events that are reserved for the validation process. The match between the model and inflow for each of these locations follows in Figures 63-67.

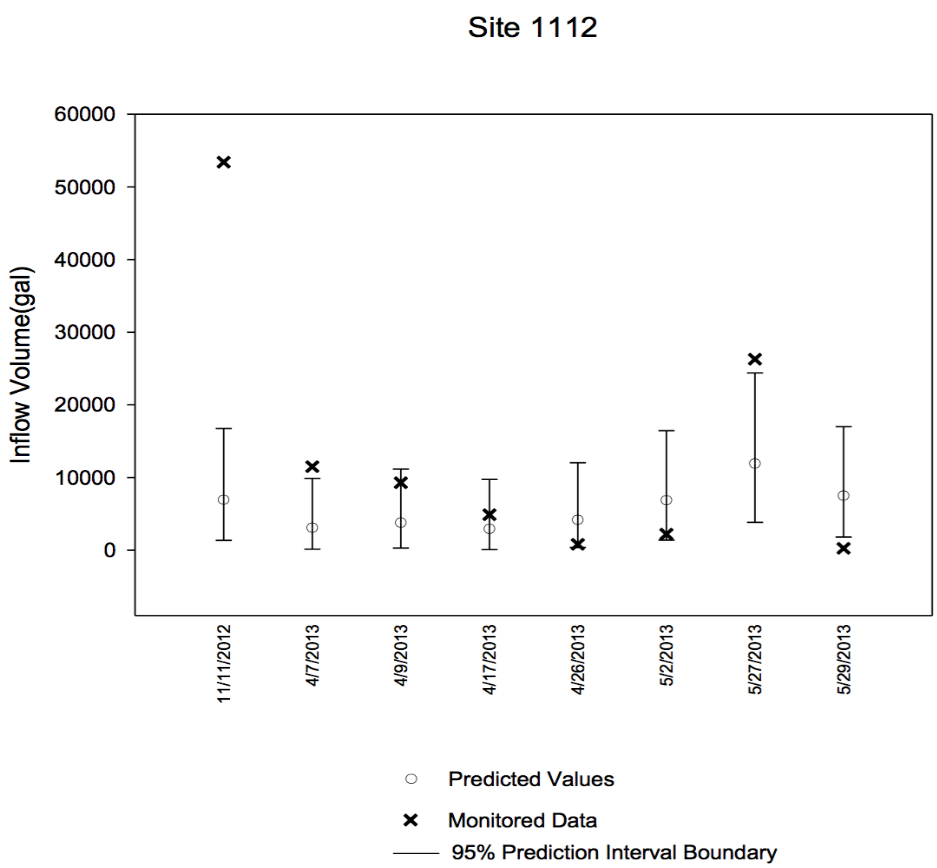


Figure 65 Site 1112 Monitored Data Validation

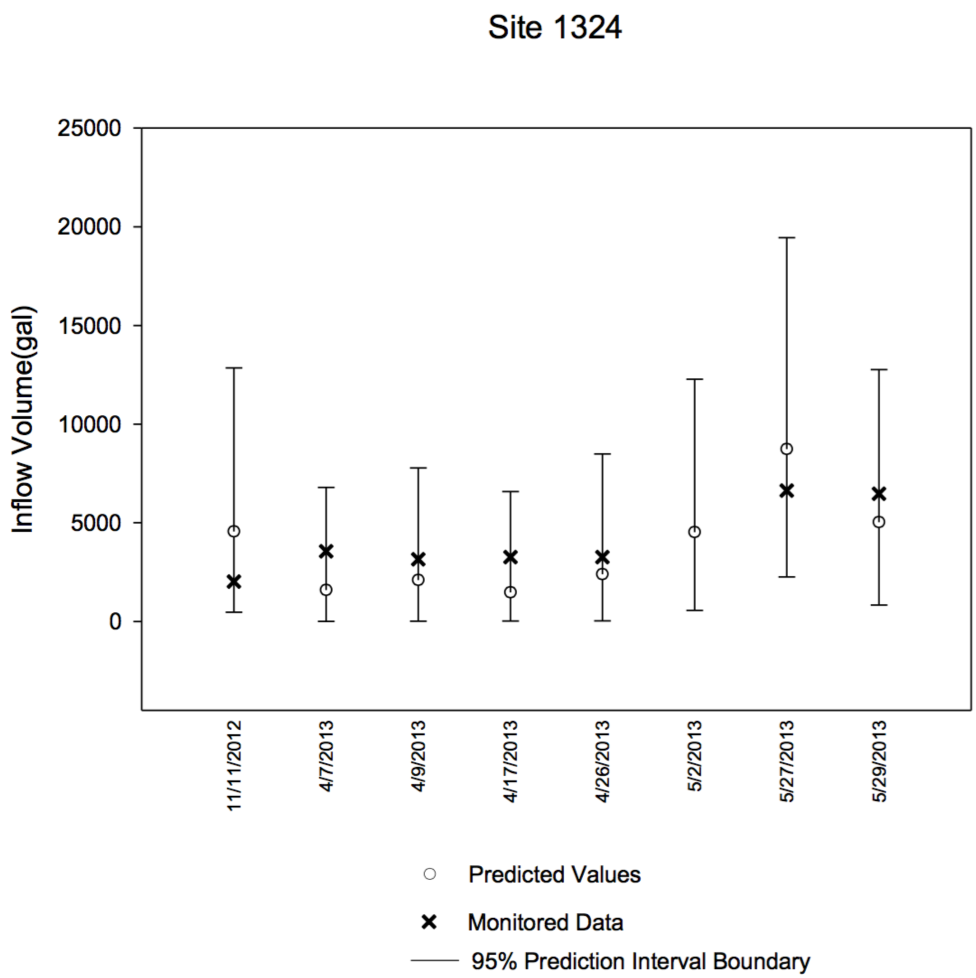


Figure 66 Site 1324 Monitored Data Validation

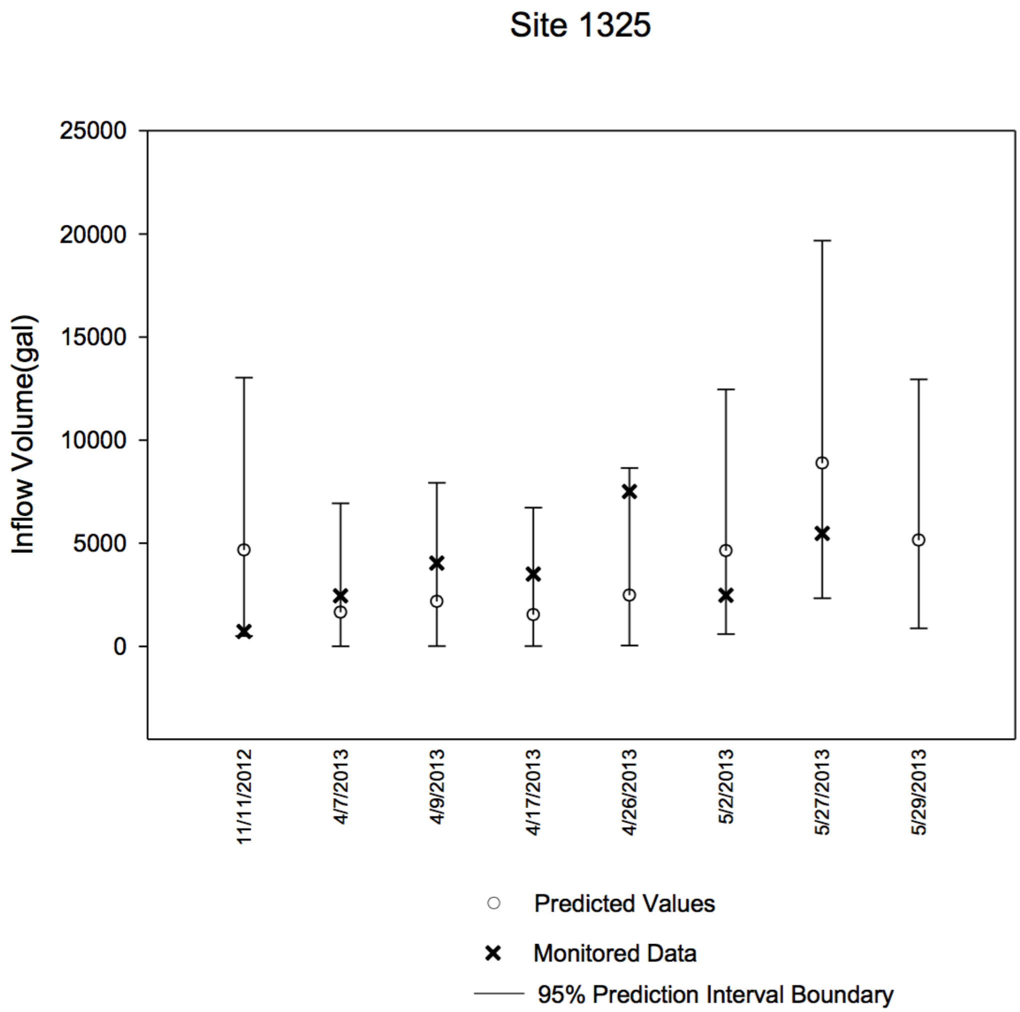


Figure 67 Site 1325 Monitored Data Validation

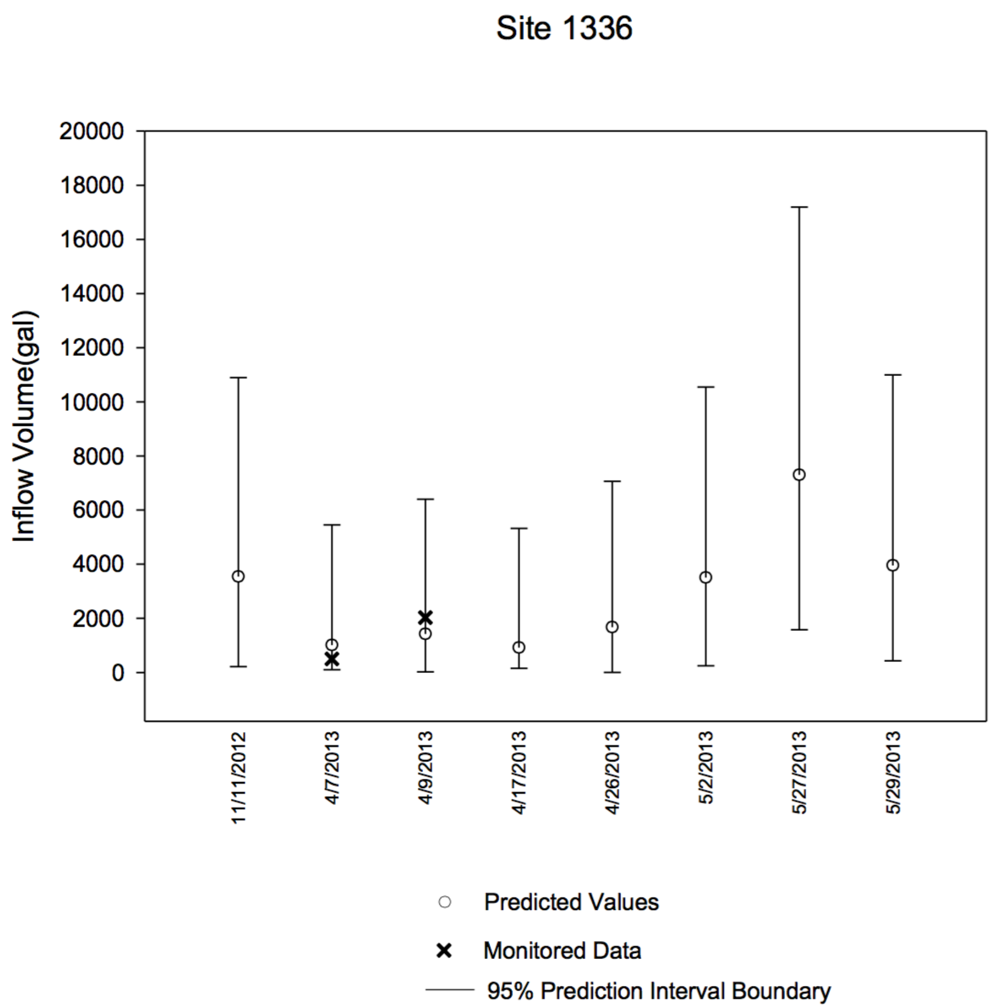


Figure 68 Site 1336 Monitored Data Validation

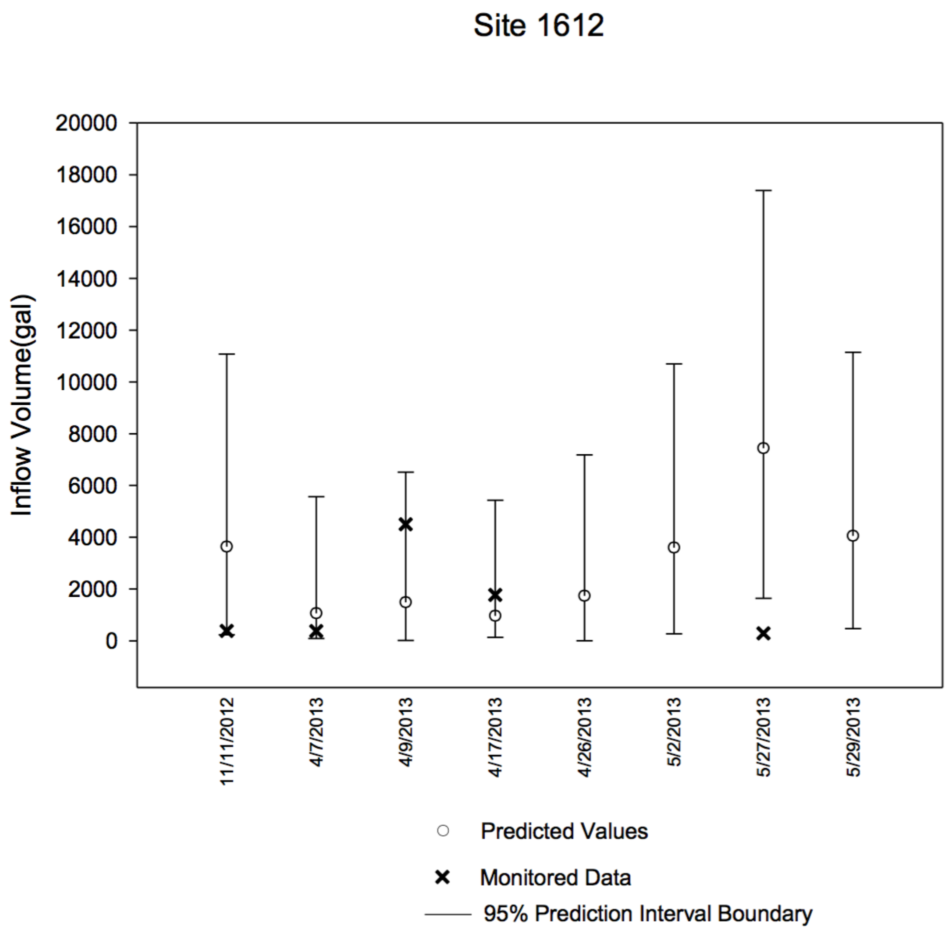


Figure 69 Site 1612 Monitored Data Validation

When the monitored values fall within the 95% prediction interval boundary from the model, it indicates that computed point is a good prediction value. So a good prediction is defined as when the monitored value is within 95% prediction interval of the prediction value. Table 37 lists the good prediction rate for each location. Overall, an average good prediction rate is 86%.

Table 38 Monitored Site Validation Results

Site	Total Monitored Points	Within PI Boundary Points	Good Prediction Rate
1112	8	4	50%
1324	7	7	100%
1325	7	7	100%
1336	2	2	100%
1612	5	4	80%
Weighted Average			83%

For model 2, sites 1222 and 1140 data are used for model construction. However, the eight events for the validation process have not been used for model built-up. Therefore, the eight events monitored infiltration volume can be used for validation.

For model 2, sites 1222 and 1140 data are used for model development. Except for, the eight events reserved for the validation process. The comparison between model prediction values and monitored values for each of these locations follows in Figure 68-69.

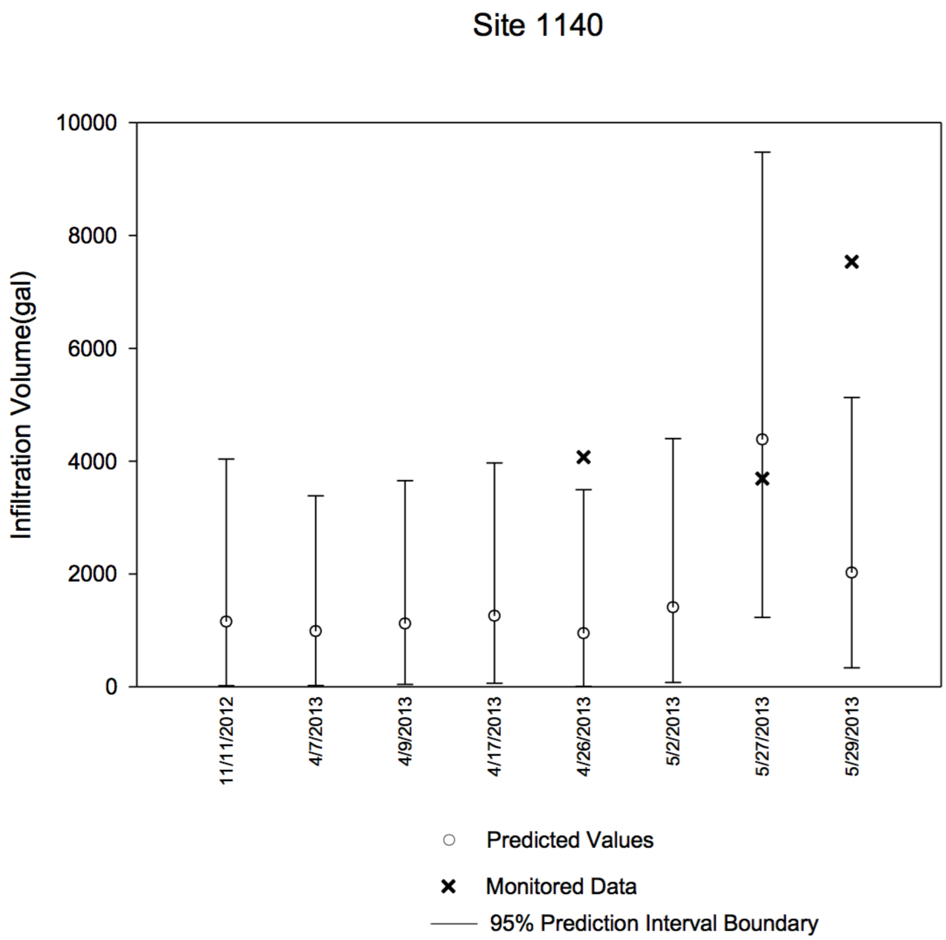


Figure 70 Site 1140 Monitored Data Validation

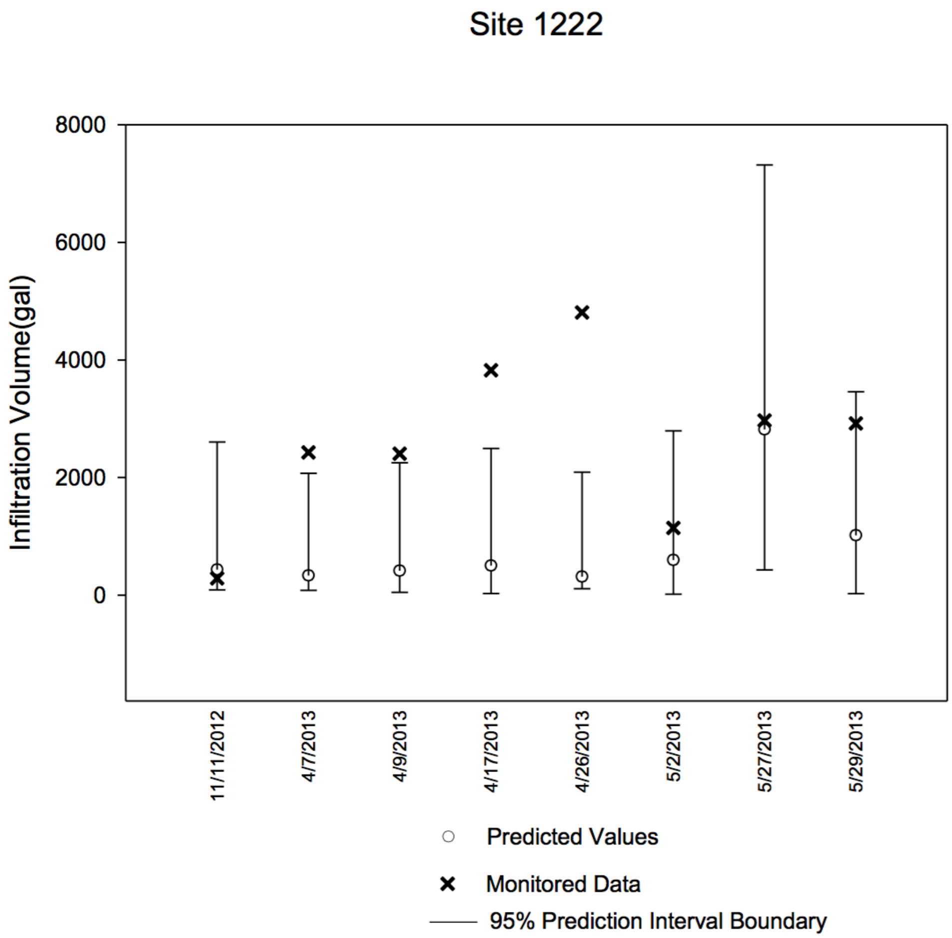


Figure 71 Site 1222 Monitored Data Validation

Table 39 Monitored Site Validation Results

Site	Total Monitored Points	Within PI Boundary Points	Good Prediction Rate
1222	3	1	33%
1140	8	4	50%
Weighted Average			45%

From the comparison on model 1 and model 2 validation, the results also indicated that if there are more sites monitored in model 2 group, the prediction values will more closely to match the monitored data.

6.3. Watershed Level Model Prediction

For the entire watershed, the water mass balance follows the equation below:

$$\text{Total rainfall volume} = V_{\text{Raingarden captured}} + V_{\text{Bioretention captured}} + V_{\text{combined Sewer flow}}$$

Equation 29

Before all of the GI units were constructed, the runoff coefficient was 42% with 1% error bar. During the raingarden pre-construction period, the flow monitoring equipment from the outfall location only report velocity values after two rain events. A flow rate data reconstruction based on the velocity data was done in 2013([60]). Due to the data reconstruction, there is an error range for the pre-construction period sewer runoff volume.

Table 40 Monitored Rain Events Flow Details

Date	Rainfall (inch)	UMKC1 (gal)	UMKC1 (Depth)	UMKC1 (Depth) Lower	UMKC1 (Depth) Upper	Runoff %	Runoff % lower	Runoff % upper
2/27/11	1.73	1,600,000	0.60	0.60	0.60	0.35	0.35	0.35
11/25/11	1.14	1,100,000	0.39	0.39	0.39	0.34	0.34	0.34
12/21/11	1.54	2,400,000	0.90	0.83	0.98	0.58	0.54	0.64
2/6/12	1.57	2,200,000	0.83	0.79	0.86	0.53	0.50	0.55
3/20/12	1.77	1,900,000	0.69	0.66	0.71	0.39	0.37	0.40
5/8/12	1.85	1,500,000	0.57	0.46	0.68	0.31	0.25	0.37
Average						0.42	0.39	0.44

This table indicates that a natural infiltration from the watershed is (1-42%)×50.68%(untreated area) = 30% ±1%. All of the eight events occurred between Nov/2012 to May/2013. In Kansas City, this period has a similar evapotranspiration behavior, this natural infiltration value will be used for each event mass balance. Total rainfall volume is obtained by monitored data and the combined sewer flow is obtained through monitored data from the outfall location of this watershed.

Table 41 Predicted Watershed Captured Runoff by GIs

Event	UMKC1 (Monitored Flow)	Raingarden Captured (81) Model	Bio_storage (44)Model	SmartDrain® Captured(only 5 sites) Model
11/11/2012	11%	8%±16%	4%±8%	0%±0%
4/7/13	7%	4%±14%	1%±5%	0%±1%
4/9/13	15%	6%±19%	2%±6%	0%±0%
4/17/13	9%	4%±15%	1%±5%	0%±1%
4/26/13	9%	8%±24%	2%±6%	0%±0%
5/2/13	7%	11%±21%	4%±8%	0%±0%
5/27/13	6%	10%±13%	8%±11%	0%±0%
5/29/13	17%	10%±17%	5%±8%	0%±0%

Table 42 Predicted Watershed Captured Runoff by GIs

Event	UMKC1 (Monitored Flow)	Raingarden Captured (81) Model	Bio_storage (44)Model	SmartDrain® Captured(only 5 sites) Model
11/11/2012	430,000	46,000 to 914,000	23,000 to 487,000	128 to 17,000

4/7/13	180,000	6,800 to 442,000	4,000 to 233,00	134 to 15,000
4/9/13	320,000	5,500 to 477,000	3,300 to 252,000	123 to 14,000
4/17/13	210,000	11,400 to 402,000	7,200 to 212,000	130 to 16,000
4/26/13	170,000	5,300 to 511,000	3,000 to 270,100	166 to 17,000
5/2/13	200,000	28,000 to 771,000	14,000 to 409,000	192 to 19,000
5/27/13	360,000	191,000 to 1,425,000	99,000 to 761,000	4,600 to 43,000
5/29/13	570,000	51,000 to 837,000	26,000 to 445,000	1,000 to 22,000

After calculation, the table below summaries the details for each event.

Table 43 Mass Balance For Monitored Events

	GI captured	Natural infiltration	Sewer flow	Sum (low boundary)	Sum (high boundary)	Mass Sum
11/11/2012	12%±25%	30%±1%	7%	30%	78%	54%
4/7/13	5%±20%	30%±1%	15%	21%	64%	43%
4/9/13	8%±26%	30%±1%	9%	26%	80%	53%
4/17/13	5%±21%	30%±1%	9%	22%	65%	44%
4/26/13	10%±30%	30%±1%	7%	17%	81%	49%
5/2/13	15%±30%	30%±1%	6%	23%	82%	52%
5/27/13	18%±30%	30%±1%	17%	32%	71%	51%
5/29/13	15%±24%	30%±1%	10%	37%	84%	60%

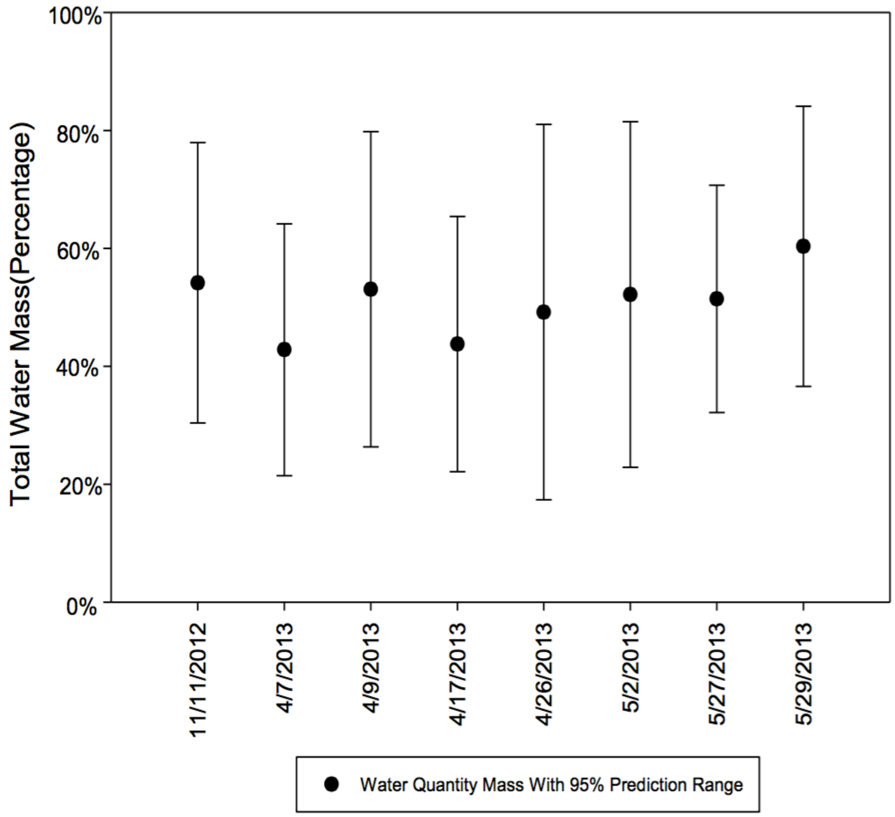


Figure 72 Mass Balance with 95% Prediction Interval For Monitored Events

From the watershed level mass balance analysis, the model prediction is very conservative on the garden performance. The average prediction values can only explain half of the water mass balance from the entire watershed. However, the 95% prediction upper boundary can explain about 80% mass balance. One of the possible reason for this lower prediction is that, the monitored sites received lower than average inflows and are not representative of other gardens. It means, those monitored sites have a below average performance in intercepting runoff.

Table 44 Comparison between Predicted GI Captured Volume and Design Value

Date	Monitored Rainfall Depth(inch)	Predicted GI Captured(gal)
11/11/2012	1.45	521,374
4/7/13	0.97	156,432
4/9/13	0.8	181,808
4/17/13	0.9	126,450
4/26/13	0.71	201,084
5/2/13	1.02	414,662
5/27/13	2.36	1,033,527
5/29/13	1.3	499,484

Design Storm is 1.4 inch, GI design capture volume is 292,000gals.

Even though the predicted model value can only explain half of the watershed mass balance, the predicted GI captured volume exceeds the original design goal, which is to reduce 292,000 gal runoff from outfall 069 at a design storm (1.4inch) event ([76]). Table 35 gives the predicted GI capture volume from the eight validation events. The rainevent at 11/11/2012 and 5/29/2013 have 1.45 inches and 1.3 rainfall depth which are similar to the design storm, and both have predicted GI captured volume of over 500,000 gals from the entire watershed. The original design goal was 292,000 gal runoff reduction from outfall 069. Figure 10 shows the pilot area in inside of the drainage area to outfall 069. The predicted GI captured volume shows only the 49% of the 100 acres been treated with GI solutions has already exceeding the goal.

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

7.1. Conclusions and Discussion

During the monitoring period, June 2012 to June 2015, 57 rain events occured. Sites 1112, 1336 and 1612 were monitored until October 2013. Sites 1222, 1324, 1325, and 1140 were monitored for the entire period. Table 36 displays the average inflow volume for each site. Site 1112 has the highest average inflow volume, while site 1612 has the lowest average inflow volume. The factorial analysis was conducted in order to discover which factors have the highest impact on inflow volume.

Table 45 Average Monitored Inflow Volume for Each Site

Monitored Location	1112	1324	1325	1336	1612	1222	1140
Average Inflow Volume (gal)	9,200	3,500	3,700	1,300	840	1,400	3,600

From the factor analysis on the gardens' hydrology, the most important factor on the inflow is impervious area percentage, and the second most important factor is the total rainfall depth.

Most of the current design manuals suggest a maximum value for rain garden drainge area. The lowest guidance from Michigan and MARC LID manual is less than 1 acre ([46];[57]). However, the monitored sites all have a watershed area that is smaller than 1 acre. Therefore, it cannot be determined from this study whether the 1 acre criterion is too conservative. The watershed area does show a positive impact on the inflow volume for the monitored site, which indicates that for the small catchment area site gardens, larger subbasin area contributes more inflow into the gardens, and the gardens can infiltrate the flow.

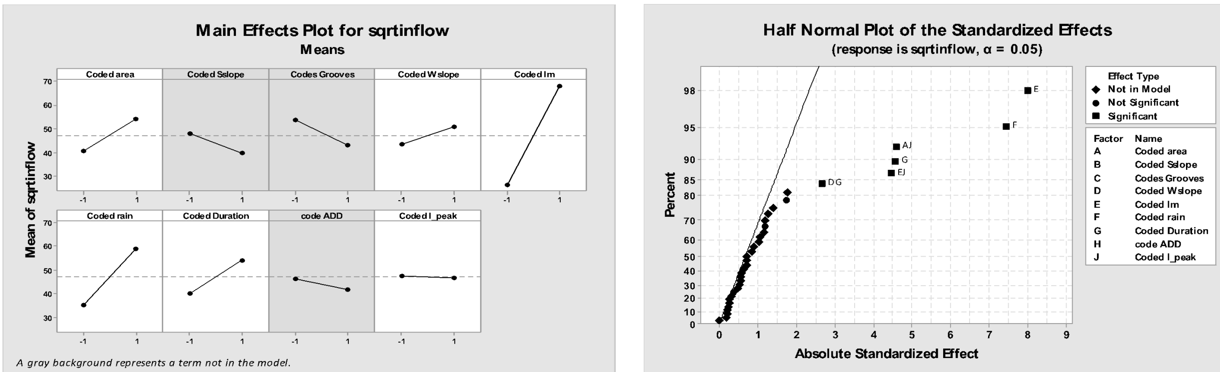


Figure 73 Inflow Factorial Analysis Results

Table 45 lists different design features of the monitored gardens and the average value. Site 1112 has a higher drainage area, impervious percentage and watershed slope than the mean, therefore, this site tends to have a higher inflow volume. In contrast, site 1612 has a lower impervious percentage and watershed slope than the mean, and it has a steeper street slope than the average. Thus, site 1612 tends to have a lower inflow draining into it.

Table 46 Monitored Site Design Features

Site	Drainage Area (ac)	Impervious Percentage	Watershed Slope Percentage
Watershed Average	0.37	49	3.51
Monitored Average	0.21	56	4.7
1324	0.08	66	3.6
1325	0.07	67	3.7
1336	0.51	40	5.5
1612	0.21	33	3.6
1112	0.26	70	7.9
1140	0.03	86	2.1
1222	0.32	29	6.6

Table 47 summarizes the analysis results each of the infiltration data groups. In fact, only site 1112 and 1336 have a measureable drawdown rate, in inch/hour. This set of results reveals that the number of antecedent dry days, peak intensity and their interaction terms have positive effects on the drawdown rate. When the number of antecedent dry days is higher, the soil tends to be unsaturated before an event. Therefore, the soil will have more capacity for infiltration. An increase in peak intensity means that more precipitation occurs during a given period of time. The interaction term between peak intensity and the number of antecedent dry days shows strong significance. Figure 74 is the factor interaction plot. When the the number of antecedent dry days is lower, and the peak intensity is higher, the mean drawdown rate is slightly lower than when the peak intensity is lower. When the number of antecedent dry days has a higher value, and the soil is more likely to be unsaturated, and the peak intensity increases gets higher the mean response will be higher. The results indicate that when soil is saturated before an event, peak intensity has little impact on the inflow volume. Since the soil layer is saturated, water tends to accumulate on the surface instead of infiltrating into the soil. Additionally, a higher peak intensity makes the drawdown rate even lower in this situation. A higher peak intensity means more inflow during a given time period. In this situation, a higher drawdown rate is observed because the soil is not yet saturated. However, there is a probably threshold beyond which this impact begins to decrease. In order to discover this threshold, it is necessary to monitor larger rain events.

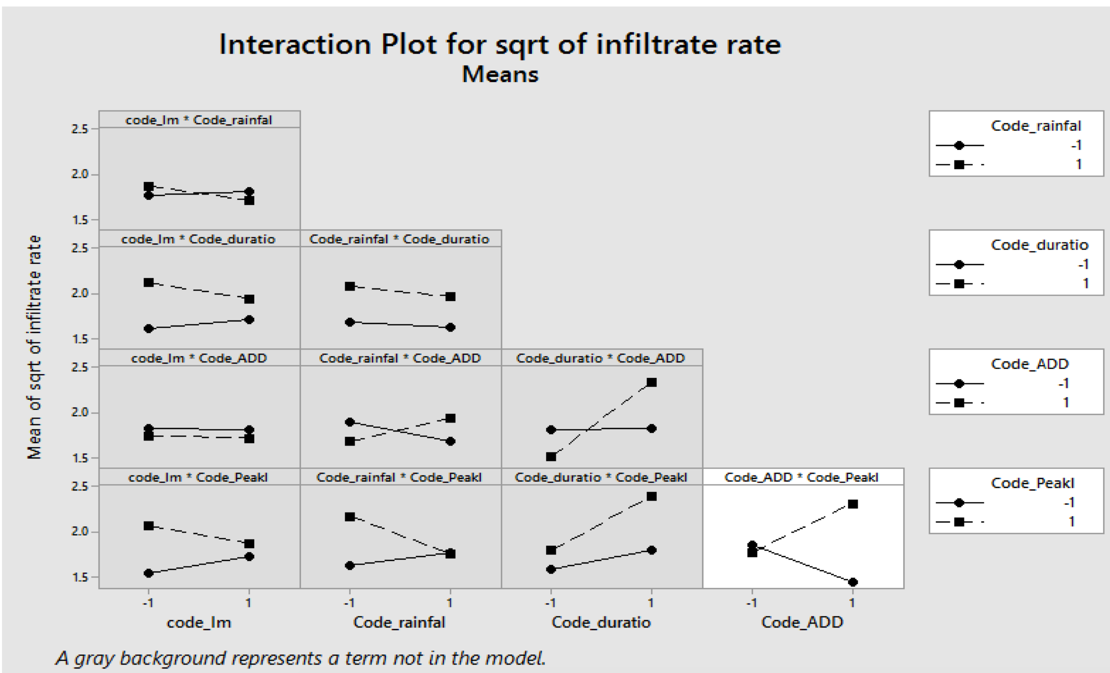


Figure 74 Interaction Plot of Site 1112 and 1336

Table 47 Infiltration Factorial Analysis Results

Groups	Significant Factors	Analysis Response
SmartDrain® Drain Group	Interaction of rainfall and peak intensity, total rainfall depths, rainfall duration, impervious percentage, antecedent dry days, and the interaction of duration and antecedent dry days.	Monitored infiltration volume
Raingarden with real drawdown rate(in/hr.)	The antecedent dry day of peak intensity, peak intensity and their interaction	Calculated drawdown rate(in/hr.)
Raingarden with flat response	Rainfall total depth, rainfall duration and the interaction of total rainfall and antecedent dry day	Inflow volume which is the total infiltrated volume

Overall, the most important factor is antecedent dry days. Different levels of antecedent dry days change the impact of other terms on the response. When the soil is saturated, the rain gardens tend to receive more inflow and infiltrate more runoff. This study does not contain enough data to to find the maximum capacity of those rain gardens. Extreme largely events may be able to return a threshold value for those rain gardens.

The PCA and MLR hybrid model were developed based on the field data. The interval validation fit was good based on the test dataset cross validation results in Section 5.5. When the model is used to predict a watershed-level response, the model validation among the monitored sites also indicates good model performance based an internal monitored data validation. However, the mass balance explained by these two models is not satisfied. This means the prediction values from the two models are very conservative. Conservative engineering design is safe but may not be economically efficient. Overly conservative design criteria may lead to higher costs for design, construction and maintenance.

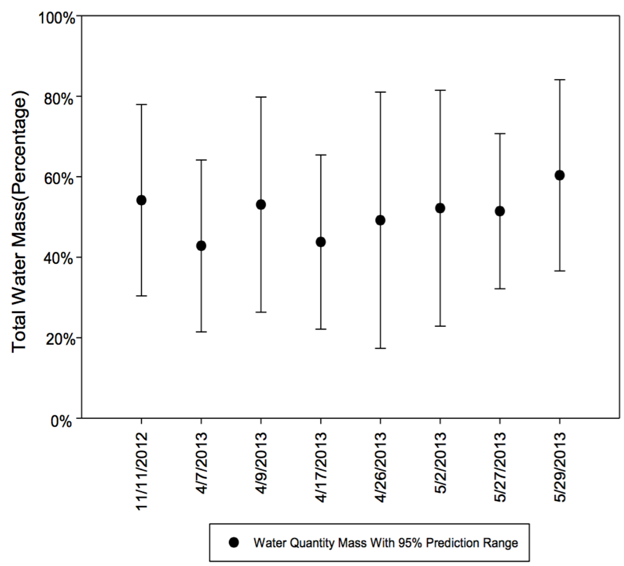


Figure 75 Mass Balance with 95% Prediction Interval For Monitored Events

From the watershed level mass balance analysis, the model prediction is very conservative based on the measured garden performance. The average prediction values can only explain half of the water mass balance from the entire watershed. However, the 95% upper boundary a prediction interval boundary can explain about 80% mass balance. One possible reason for this lower prediction is that the monitored sites are not representative of the other gardens. This means that those monitored sites have a below average inflow.

Table 48 Monitored Sites Feature Comparison with Entire Watershed

Site	Drainage Area (ac)	Impervious Percentage	Watershed Slope Percentage	Street Slope Percentage
Watershed Average	0.37	48	3.5	2.9
Sampled Average	0.21	56	4.7	3.8
1324	0.08	66	3.6	1.7
1325	0.07	67	3.7	1.9
1336	0.51	40	5.5	1.9
1612	0.21	33	3.6	4.4
1112	0.26	70	7.9	8.0
1140	0.03	86	2.1	1.5
1222	0.32	29	6.6	7.5

The seven monitored sites have a drainage area that is relatively small compared to the average drainage area from the entire pilot area. Some have a slightly higher impervious percentage than the average value, but a lower watershed slope and a higher street slope than the entire watershed. Based on the factorial analysis results, the impervious percentage and total rainfall depth have a positive impact on the inflow volume, and street slope have a negative impact on the inflow. Therefore, it is possible that those seven monitored sites are not representative of the other 128 units based on these garden features.

Table 49 Comparison between Predicted GI Captured Volume and Design Value

Date	Monitored Rainfall Depth(inch)	Predicted GI Captured(gal)
11/11/2012	1.45	520,000
4/7/13	0.97	156,000
4/9/13	0.8	182,000
4/17/13	0.9	126,000
4/26/13	0.71	201,000
5/2/13	1.02	415,000
5/27/13	2.36	1,034,000
5/29/13	1.3	500,000

Design Storm is 1.4 inch, GI capture goal is 292,000gals.([76])

Even though the predicted model value can only explain half of the watershed mass balance, the predicted GI captured volume already exceeds the original design goal, which is to reduce the amount of 292,000 gal runoff from the watershed in a design storm (1.4 inch) event ([76]). Table 40 lists the predicted GI capture volume from the eight validation events. For instance, the rain event on 11/11/2012 and 5/29/2013 resulted in 1.45 inches and 1.3 inches of rain, which is similar to the design storm. The predicted GI captured volume from the entire watershed is 520,000 gals. Goal was a GI capture volume of 292,000 gals. Table 43 shows the comparison for the runoff reduction from the calibrated BMP model and the PCA/MLR model from this study in a design storm of 1.4 inches. The runoff reduction from the statistical model is about 1.8 times the expected reduction volume from the pilot area ([76]). The largest total rainfall monitored occurred on 8/31/2012 with 5.6 inches of rain. This event has a duration of 1640 minutes and an average intensity of 0.2 in/hr. This event is still smaller than a 2-year return period event in Kansas City. Therefore, the monitoring for a rainfall event is equal or larger than 2-year event may help to improve the results.

Table 50 Comparison of Runoff Reduction from Calibrated BMP Model and PCA MLR Model in Pilot Area

Location	Pre-Existing Condition Total Volume (gallons)([76])	Calibrated BMP Model Total Volume (gallons) ([76])	Reduction
Pilot Area	812,000	520,000	36%
Location	Pre-Existing Condition Total Volume (gallons)	PCA MLR Model Total Volume (gallons)	Reduction
Pilot Area	812,000	292,000	64%

This indicates that the current design is very conservative. It is possible to loosen the design criteria and make the design more efficient ([104]).

The novel discovery from this research is that this study established a new approach for hydrologic rain garden performance analysis. The PCA and MLR are well-developed and widely used data analysis methods in the area of biology, medicine, environmental pollution, etc. Since a dataset that includes multiple variables is not common in the area of civil engineering, this study is the first one applied this well-established statistical approach into civil engineering area. It reveals several recommendations for rain garden site monitoring and data analysis in the future research activities.

7.2. Future Work

7.2.1. Rainfall Events Similarity Analysis

Clustering methods fall into the class of unsupervised learning techniques, while classification is a term of supervised learning. In contrast with classification, there are no predefined groups for cluster analysis which is difference with classification ([105]).Several methods can be used to do this analysis, including agglomerative hierarchical techniques, k-means clustering, and model-based clustering. The hierarchical method only requires the measure of the similarity between the groups ([106]). K-means approach requires recalculation of the group centroid and reassignment of data points into groups ([107]).

The agglomerative hierarchical techniques can divided the data into groups based on the Euclidean distance as defined below.

$$d_{ij} = \sqrt{\sum_{k=1}^{q} (x_{ik} - x_{jk})^2} \qquad \text{Equation 30}$$

d_{ij} is the Euclidean distance between individual I with variable values of $x_{i1}, x_{i2},\ldots, x_{iq}$ and individual j with variable values of $x_{j1}, x_{j2},\ldots, x_{jq}$. The Euclidean distance is the indicator of the similarity between data points. The determination of which group data should merged in the agglomerative hierarchical clustering can be done using any of three different linkage approach.

The single linkage method was applied by Sneath on the taxonomy research. The dendrograms (phylogenetic tree) have been used as a convenient way to visualize the groups into which bacterial strains are placed ([108], [109])

The Dendrogram below shows the groups details on the rainfall data monitored for this study.

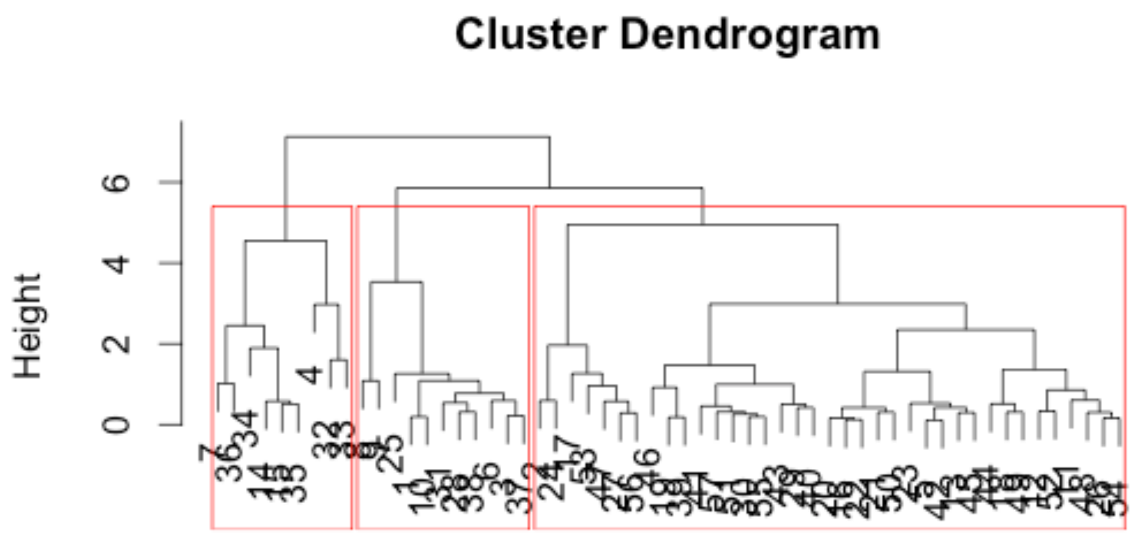


Figure 76 Cluster Dendrogram For Monitored Rain Events

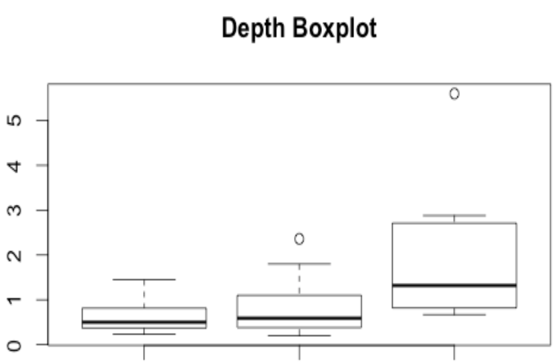
Rain events can be placed into three groups based on total rainfall depths, rainfall duration, peak intensity, and the number of antecedent dry days.

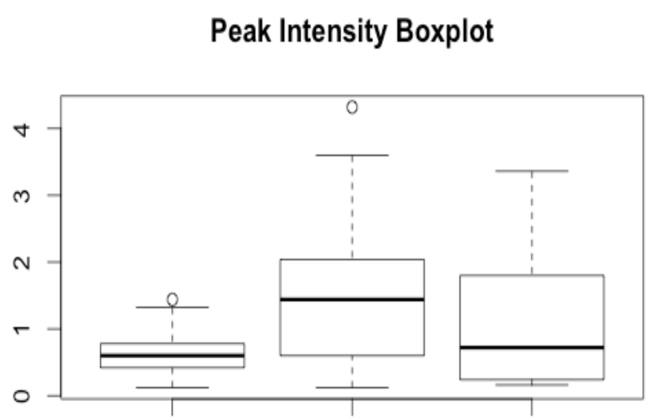
Table 51 Rain Event Categories Details

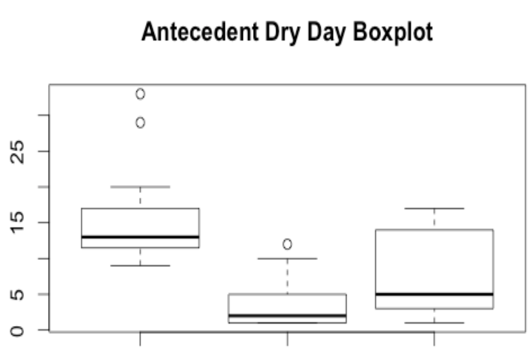
	D_Ave (inch)	Dur_Ave (min)	ADD_Ave (day)	Peak_I_Ave (in/hr.)
Group 1	1.90	1587.22	7.78	1.43
Group 2	1.31	848.22	4.53	1.51
Group 3	1.46	1367.19	9.24	1.08

Group1 consists of the rain events with the highest total depths, the longest rainfall duration, a median long antecedent dry days and a median large peak intensity. Group 2 consists of the rain events with the smallest total depths, the shortest duration, the shortest antecedent dry day and the largest peak intensity. Group 3 consists of the rain events with a moderate level of total rainfall depth, a moderate level long rainfall duration period, the longest antecedent dry day and the smallest peak intensity. The inflow volume from those monitored evens and sites have been plotted as below to illustrate the gardens' different performance under different types of rain events.

Generally, rain gardens received the highest inflow during type 3 rain event. Moderate level of inflow during rain events that fall into group 2. The lowest inflow volume during group 1 rain events. Current 57 events are all smaller than a 2-year return period in Kansas City. Therefore, events that equal or larger of 2-year event may help to make this analysis more precise.







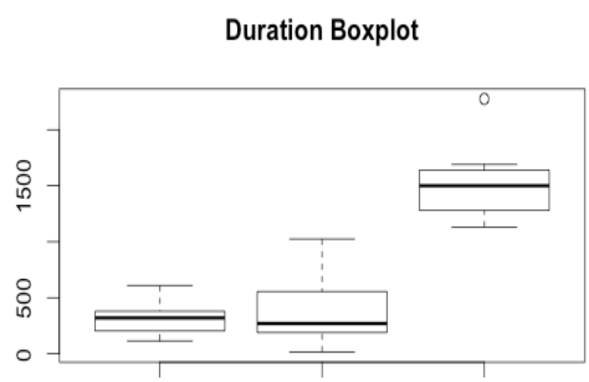


Figure 77 Boxplots for Three Rain Events Categories

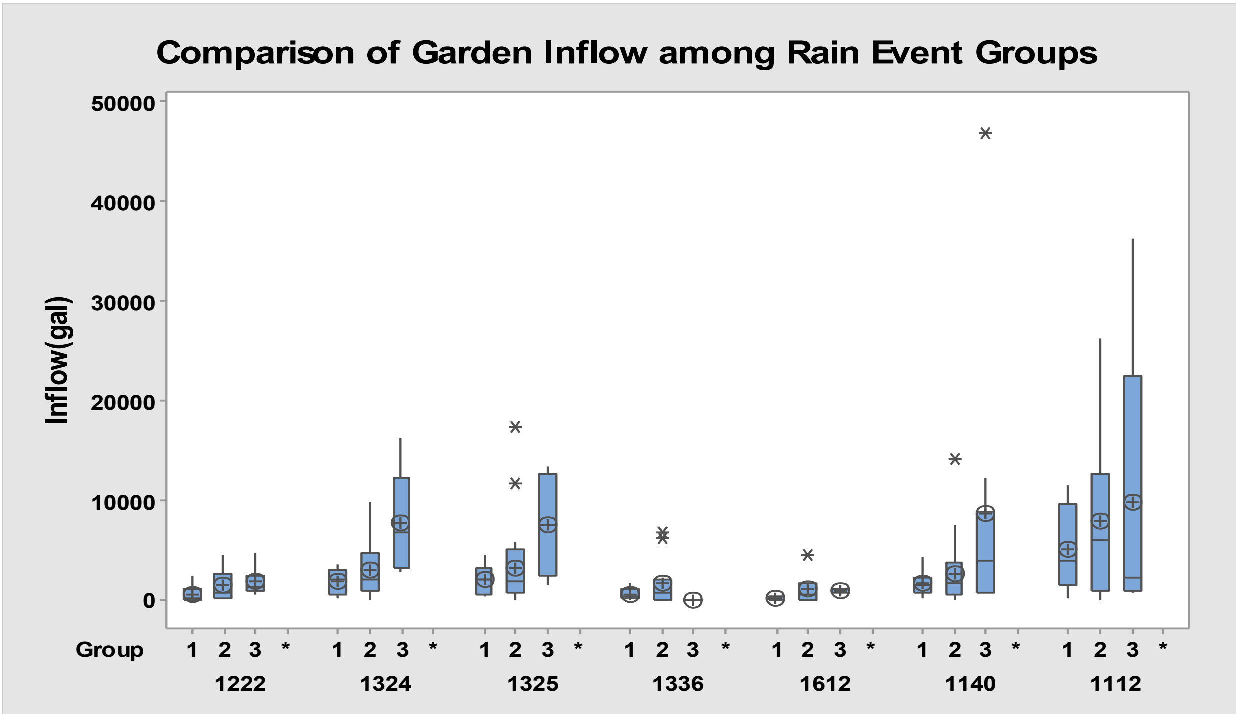


Figure 78 Comparison of Garden Inflow Among Rain Events Groups

7.2.2. Rain Garden Performance Change Trend

Much research suggests that a rain garden's performance improves once two years have passed since the rain gardens' construction and the plants have matured. One possible reason is that the plant roots are deeper, which helps build micro-channels in the soil layer. This building of microchannels helps water infiltrate into the soil. Another possible reason is that when the micro-ecology system has been matured, the worms living in the soil also help in building micro-channels.

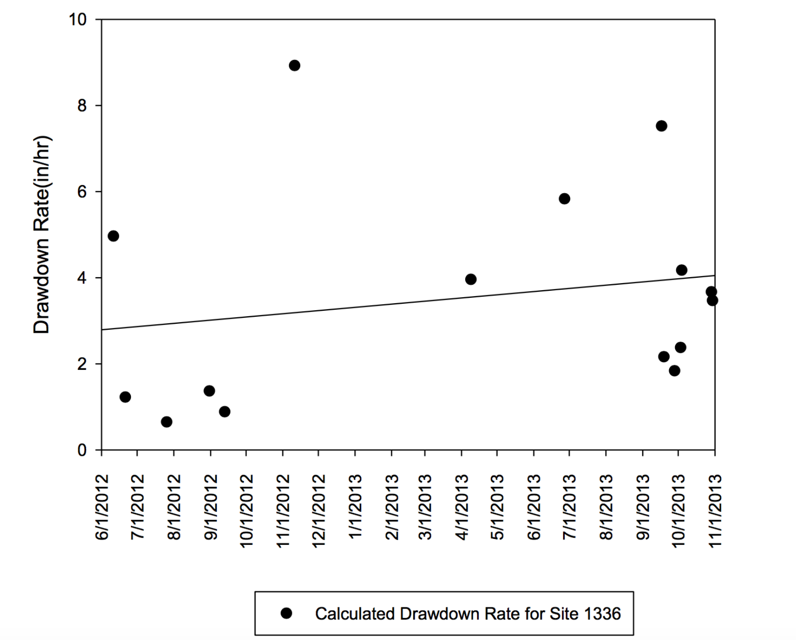


Figure 79 1336 Drawdown Rate vs Time

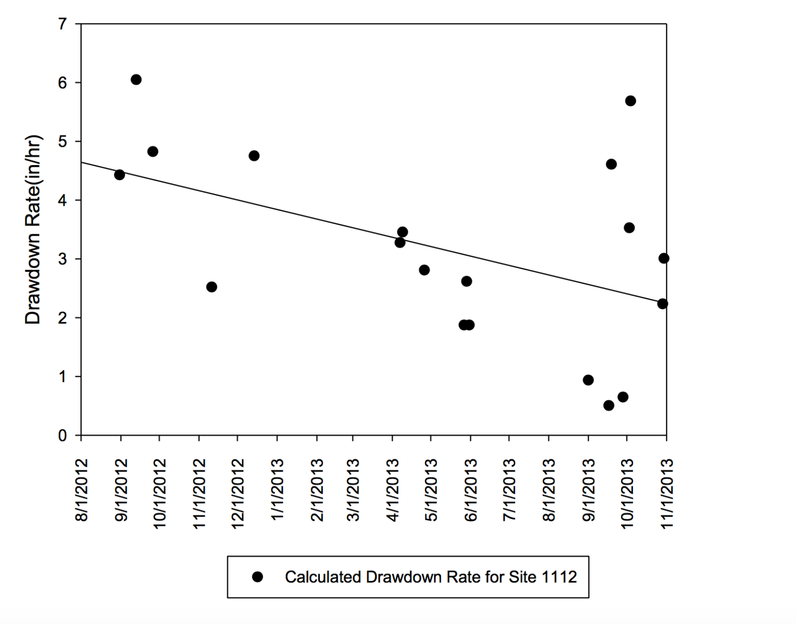


Figure 80 1112 Drawdown Rate vs Time

Site 1336, there is a slightly increasing trend in the drawdown rate. However, for 1112 location, the drawdown rate decreases with time. Routine maintenance is very important to ensuring continuous performance. Therefore, extending monitoring to site 1336 may yield better more detailed research data. For future research, it is recommended that a different rain garden location without an underdrain be chosen and monitored in the same way in order to easy interpretation.

7.3. Recommendations for Future Monitoring and Design

(1) List the potential garden features, such as drainage area, watershed slope, street slope, impervious area percentage, inlet condition, etc. for all sites.

(2) Select representative sites based on an average garden features, this would make those monitored sites more representative.

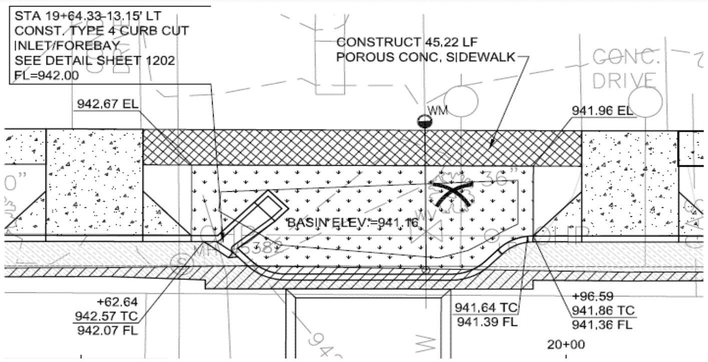
(3) Inspect equipment frequently. Check the flume inlet to ensure no flooding occurred during rain events, and check the monitoring equipment.

(4) Draw a hydrograph after each event. It may be difficult early onto determine where a sensor should be placed. The first several hydrographs can help to determine whether the sensors have been placed at a correctly

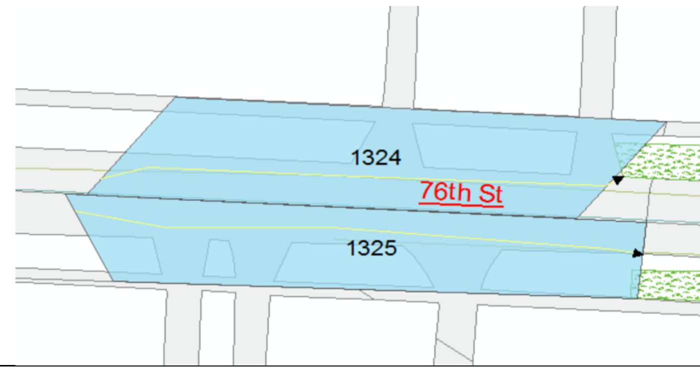
(5) The current engineering design on rain gardens is very conservative. It is possible to loosen the design criteria and make the design more effcient.

APPENDIX A: Monitored Sites Descriptions

Site Location	Watershed Area	Impervious Percentage	Watershed Slope(%)	Street Slope(%)	Street Slope(%)	GI Type	Grooves	Sediment Basin(inch)
76th Street House No. 1324	0.08	65.93	3.64	2.85	1.65	Rain Garden	No	30*18*5



Design Detail of Site 1324

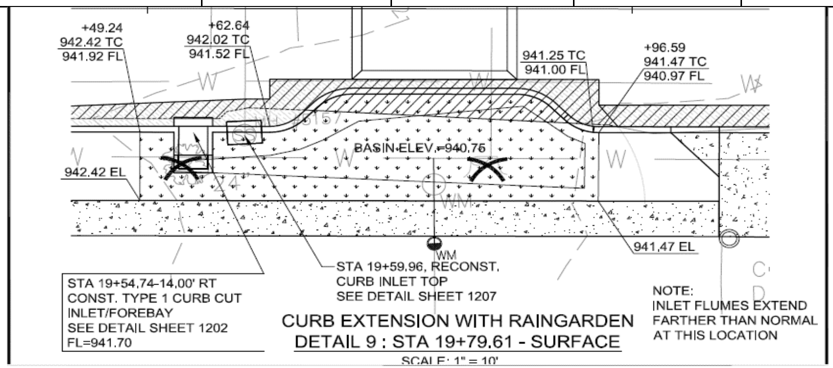


Field Validated Watershed Area for Site 1324

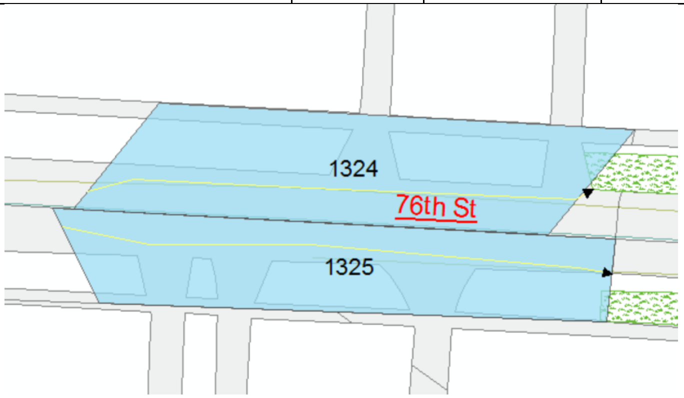
As-built Schematic of Monitoring Installation *for Site 1324*

Site 1324 Photo

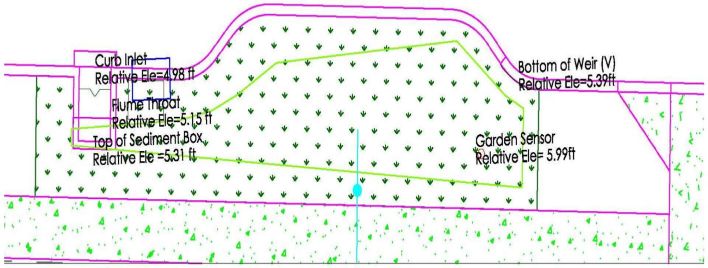
Site Location	Watershed Area(ac)	Impervious Percentage	Watershed Slope(%)	Street Slope(%)	GI Type	Grooves	Sediment Basin(inch)	Flume Inlet Width(inch)
76th Street House No. 1325	0.07	66.86	3.71	1.88	Rain Garden	Yes	36*18*5	32



Design Detail of Site 1325



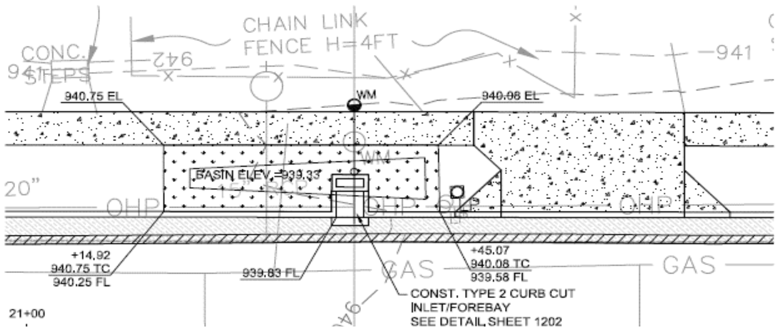
Field Validated Watershed Area for Site 1325



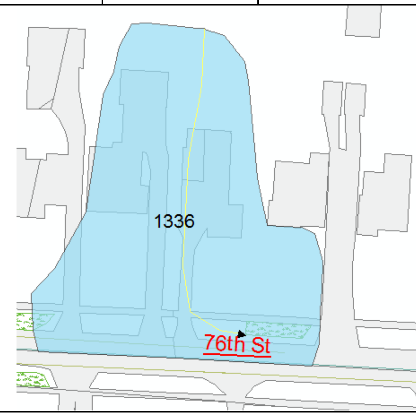
As-built Schematic of Monitoring Installation for Site 1325

Site 1325 Photo

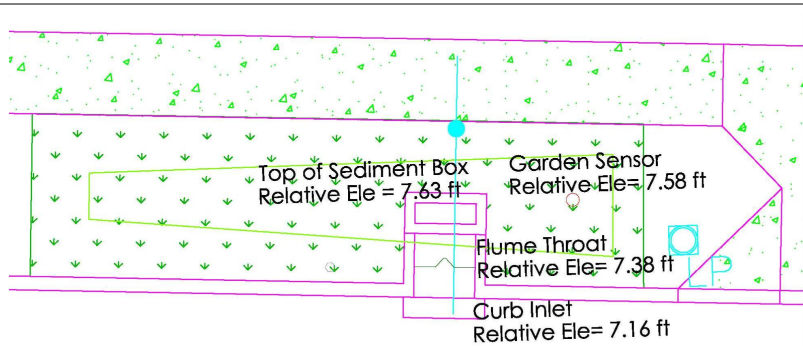
Site Location	Watershed Area(ac)	Impervious Percentage	Watershed Slope(%)	Street Slope(%)	GI Type	Grooves	Sediment Basin(inch)	Flume Inlet Width(inch)
76th Street House No. 1336	0.51	40.18	5.48	1.88	Rain Garden	Yes	12*36*10	46



Design Detail of Site 1336



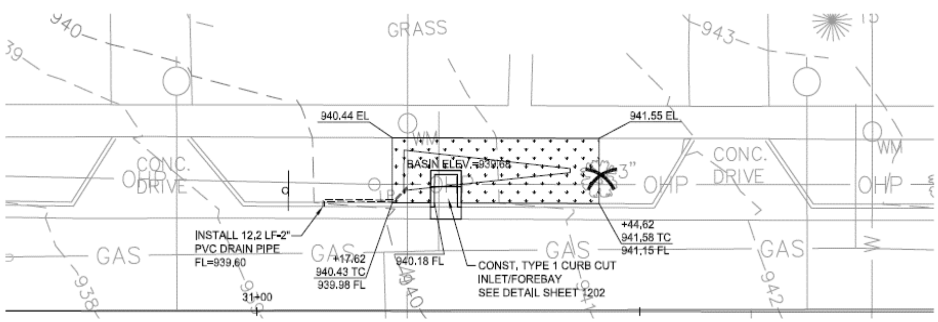
Field Validated Watershed Area for Site 1336



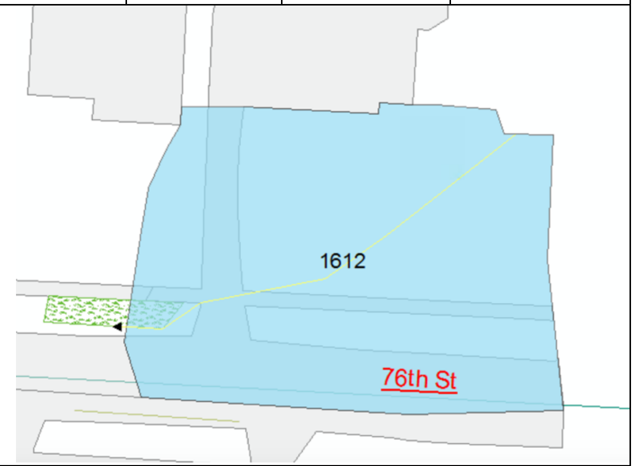
As-built Schematic of Monitoring Installation for Site 1336

Site 1336 Photo

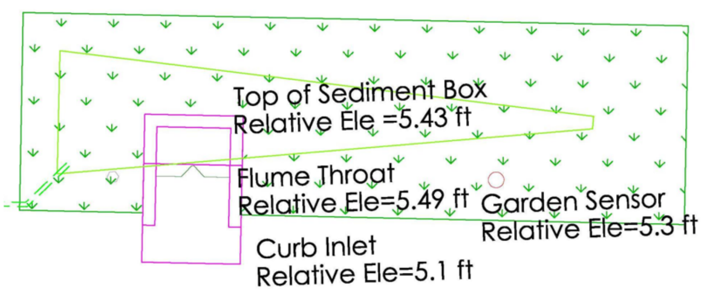
Site Location	Watershed Area(ac)	Impervious Percentage	Watershed Slope(%)	Street Slope(%)	GI Type	Grooves	Sediment Basin(inch)	Flume Inlet Width(inch)
76th Street House No. 1612	0.21	33.00	3.55	4.42	Rain Garden	Yes	36*18*5	34



Design Detail of Site 1612



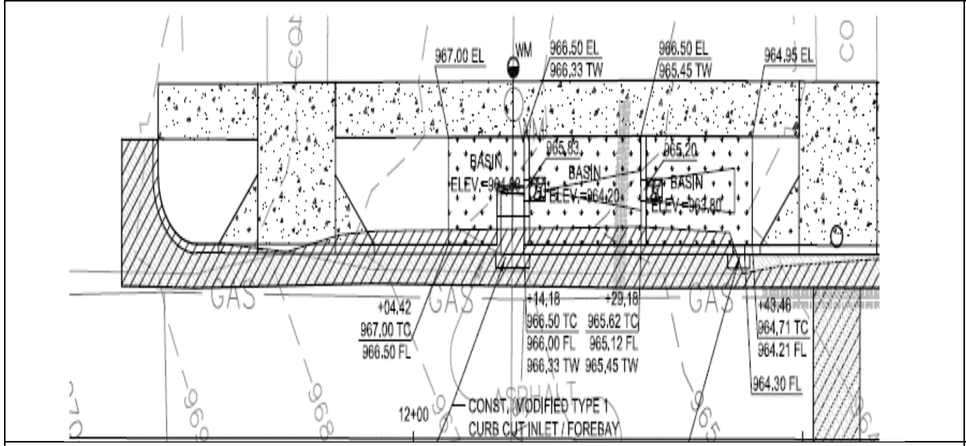
Field Validated Watershed Area for Site 1612



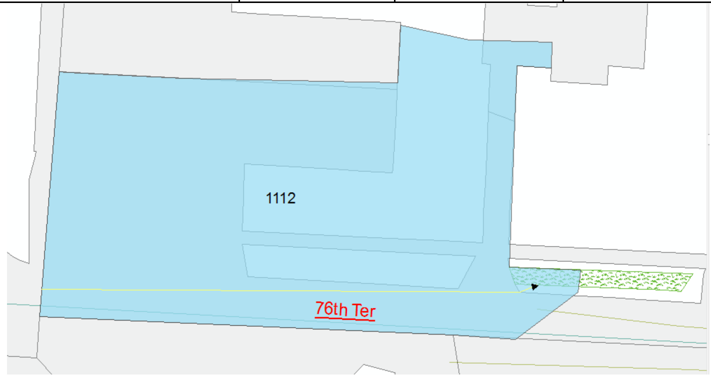
As-built Schematic of Monitoring Installation for Site 1612

Site 1612 Photo

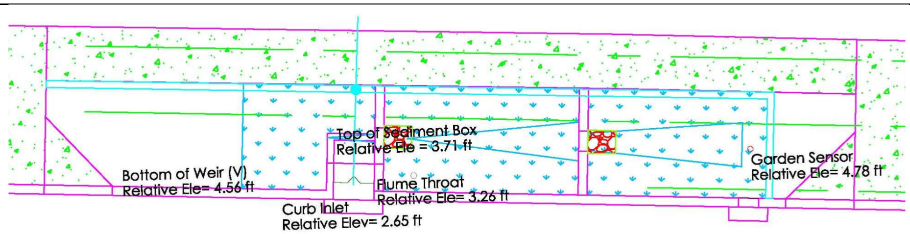
Site Location	Watershed Area(ac)	Impervious Percentage	Watershed Slope(%)	Street Slope(%)	GI Type	Grooves	Sediment Basin(inch)	Flume Inlet Width(inch)
76th Terrace Street House No. 1112	0.26	69.69	7.93	7.96	Rain Garden	Yes	36*18*5	36



Design Detail of Site 1112



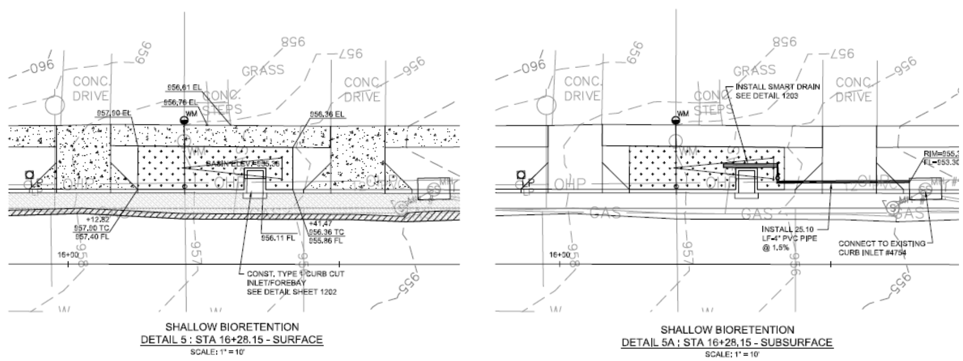
Field Validated Watershed Area for Site 1112



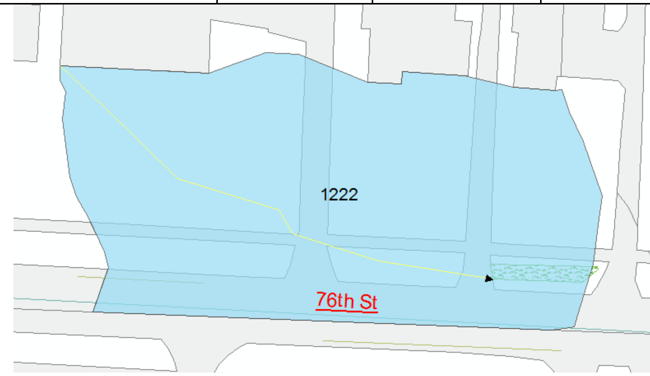
As-built Schematic of Monitoring Installation for Site 1112

Site 1112 Photo

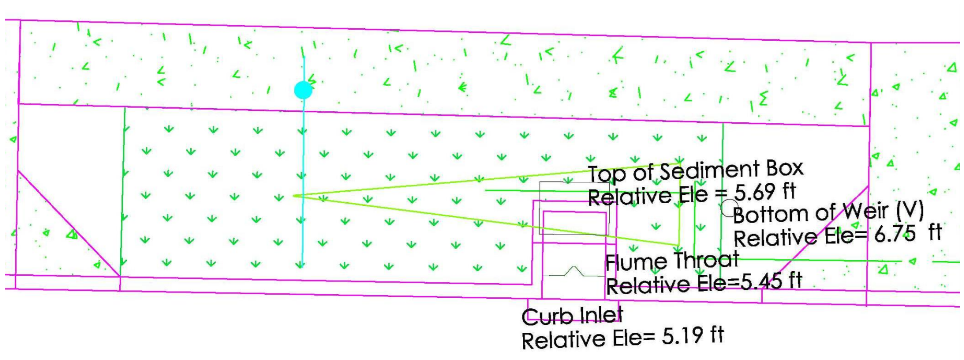
Site Location	Watershed Area(ac)	Impervious Percentage	Watershed Slope(%)	Street Slope(%)	GI Type	Grooves	Sediment Basin(inch)	Flume Inlet Width(inch)
76th Street House No. 1222	0.32	28.74	6.57	7.52	Bioretention with SmartDrain® Pipe	Yes	36*18*5	35



Design Detail of Site 1222



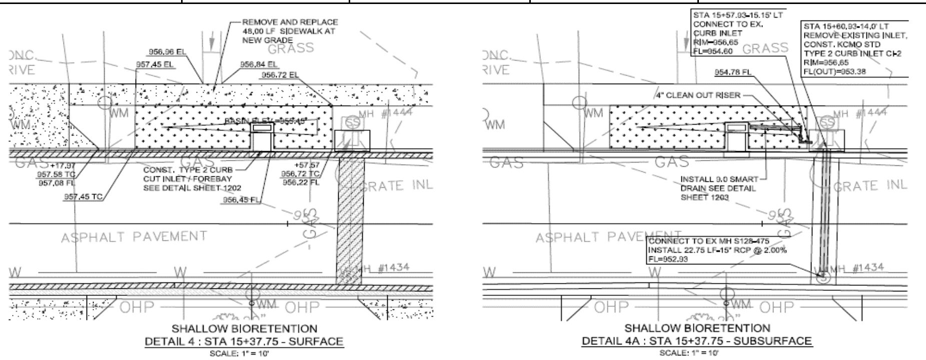
Field Validated Watershed Area for Site 1222



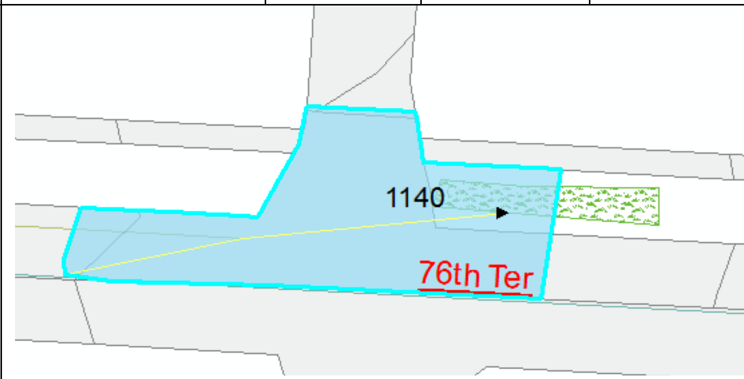
As-built Schematic of Monitoring Installation for Site 1222

Site 1222Photo

Site Location	Watershed Area(ac)	Impervious Percentage	Watershed Slope(%)	Street Slope(%)	GI Type	Grooves	Sediment Basin(inch)	Flume Inlet Width(inch)
76th Terrace Street House No. 1140	0.03	85.61	2.07	1.50	Bioretention with SmartDrain® Pipe	Yes	12*36*10	46



Design Detail of Site 1140



Field Validated Watershed Area for Site 1140

Data Not Available

As-built Schematic of Monitoring Installation for Site 1140

Site 1140 Photo

APPENDIX B: Rain Gage Data

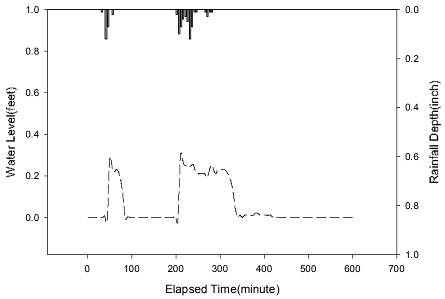
Date	Begin time	End Time	Total Depth (inch)	Duration (mins)	Antecedent Dry Day(days)	Peak Intensity (in/hr.)
6/11/12	6/11/12 2:35	6/11/12 6:45	0.80	250.00	12	1.44
6/21/12	6/21/12 0:30	6/21/12 8:45	1.03	495.00	10	2.16
7/26/12	7/26/12 0:25	7/26/12 4:34	0.48	249.00	13	0.60
8/31/12	8/31/12 11:00	9/1/12 14:20	5.60	1640.00	5	0.72
9/13/12	9/13/12 14:20	9/13/12 23:25	0.43	545.00	6	0.48
9/26/12	9/26/12 0:23	9/26/12 7:23	0.23	420.00	13	0.12
10/13/12	10/13/12 0:28	10/13/12 21:58	0.82	1290.00	17	1.80
11/11/12	11/11/12 4:35	11/11/12 12:30	1.45	475.00	29	0.72
12/14/12	12/14/12 22:25	12/15/12 0:20	0.35	115.00	33	0.48
4/7/13	4/7/13 19:09	4/8/13 0:46	0.97	337.00	12	1.32
4/9/13	4/9/13 20:58	4/10/13 8:58	0.80	720.00	1	0.72
4/17/13	4/17/13 21:08	4/18/13 8:58	0.90	710.00	2	1.56
4/22/13	4/22/13 23:23	4/23/13 12:13	0.59	770.00	4	0.24
4/26/13	4/26/13 14:28	4/27/13 9:18	0.71	1130.00	3	0.24
5/2/13	5/2/13 2:00	5/3/13 3:00	1.02	1500.00	5	0.16
5/8/13	5/8/13 23:13	5/9/13 1:58	0.26	165.00	4	0.60
5/27/13	5/27/13 8:18	5/27/13 12:03	2.36	225.00	8	2.76
5/29/13	5/29/13 22:48	5/30/13 14:13	1.30	925.00	2	0.84
5/31/13	5/31/13 4:48	5/31/13 9:13	1.09	265.00	1	2.04

6/4/13	6/4/13 10:43	6/4/13 13:23	0.20	160.00	4	0.36
6/5/13	6/5/13 8:43	6/5/13 11:23	0.21	160.00	1	0.24
6/9/13	6/9/13 0:08	6/9/13 3:58	0.31	230.00	4	0.48
6/15/13	6/15/13 15:43	6/15/13 21:58	0.28	375.00	6	0.12
6/27/13	6/27/13 11:23	6/27/13 23:38	1.14	735.00	12	2.88
9/1/13	9/1/13 6:35	9/1/13 8:35	0.35	120.00	20	0.60
9/17/13	9/17/13 7:15	9/17/13 14:30	0.71	435.00	1	0.84
9/19/13	9/19/13 17:45	9/19/13 21:55	1.46	250.00	2	3.12
9/28/13	9/28/13 7:15	9/28/13 12:35	0.39	320.00	9	0.60
10/3/13	10/3/13 10:10	10/3/13 10:30	0.30	20.00	5	1.44
10/4/13	10/4/13 21:45	10/4/13 23:10	0.42	85.00	1	1.44
10/29/13	10/29/13 1:50	10/29/13 12:00	0.83	610.00	11	0.36
10/30/13	10/30/13 11:15	10/31/13 8:35	2.88	1280.00	1	2.40
10/1/14	10/1/14 10:33	10/2/14 14:43	2.71	1690.00	14	3.36
10/9/14	10/9/14 7:13	10/10/14 21:08	1.87	2275.00	4	0.96
10/13/14	10/13/14 2:43	10/13/14 23:28	1.32	1245.00	3	0.48
3/18/15	3/18/15 12:43	3/19/15 14:08	0.67	1525.00	17	0.24
4/2/15	4/2/15 3:53	4/2/15 6:33	0.50	160.00	14	0.84
4/12/15	4/12/15 3:53	4/12/15 9:33	0.72	340.00	10	0.36
4/13/15	4/13/15 0:03	4/13/15 3:13	1.10	190.00	1	2.28
4/18/15	4/18/15 9:43	4/18/15 14:18	0.54	275.00	5	1.20
4/19/15	4/19/15 0:48	4/19/15 4:53	0.61	245.00	1	1.80
4/25/15	4/25/15 3:03	4/25/15 13:28	0.41	625.00	6	0.48
5/4/15	5/4/15 20:33	5/4/15 23:48	0.49	195.00	9	1.44

5/7/15	5/7/15 11:48	5/8/15 4:53	1.19	1025.00	1	1.44
5/14/15	5/14/15 0:43	5/14/15 9:58	0.53	555.00	4	0.24
5/15/15	5/15/15 12:48	5/15/15 13:03	0.33	15.00	1	2.88
5/16/15	5/16/15 22:18	5/17/15 2:48	1.80	270.00	1	3.60
5/20/15	5/20/15 2:48	5/20/15 7:48	0.87	300.00	3	0.72
5/23/15	5/23/15 19:08	5/24/15 7:53	1.47	765.00	3	1.08
5/26/15	5/26/15 1:58	5/26/15 6:18	0.38	260.00	2	0.60
5/28/15	5/28/15 6:53	5/28/15 7:13	0.31	20.00	2	1.68
5/29/15	5/29/15 5:58	5/29/15 15:18	0.59	560.00	1	1.56
6/3/15	6/3/15 8:43	6/3/15 12:58	1.67	255.00	5	4.32
6/5/15	6/5/15 0:33	6/5/15 6:43	0.75	370.00	2	0.96
6/7/15	6/7/15 22:38	6/8/15 1:43	0.49	185.00	2	1.56
6/15/15	6/15/15 14:28	6/15/15 20:38	1.21	370.00	1	3.00
6/17/15	6/17/15 1:13	6/17/15 2:13	0.25	60.00	2	1.20

APPENDIX C: Garden Performance Hydrographs

1140 76th terr on Rainevent 6/11/12



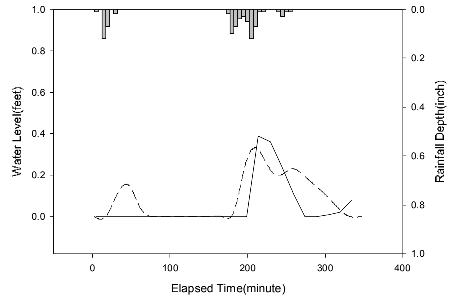
The rainfall depth for this event is 0.80 inch.

T=0 at 6/11/2012 02:03:12

The total volume of water into the garden during this event is 4305 gal.

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1336 76th on Rainevent 6/11/12



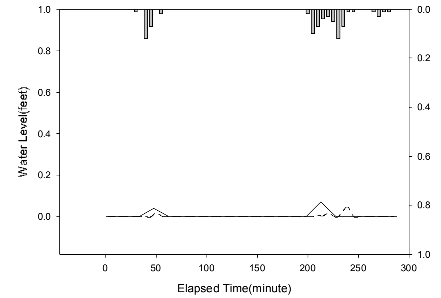
The rainfall depth for this event is 0.80 inch

T=0 at 6/11/2012 02:30:00

Total volume for the flume is 3472 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1222 76th on Rainevent 6/11/12



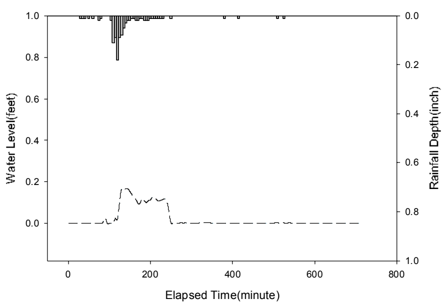
The rainfall depth for this event is 0.80 inch.

T=0 at 6/11/2012 02:05:00

The total volume of water into the garden during this event is 6.7gal.

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1324 76th on Rainevent 6/21/12



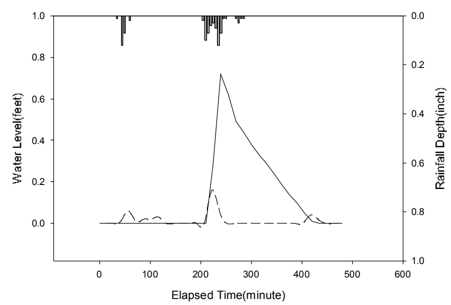
The rainfall depth for this event is 1.03 inch

T=0 at 6/21/2012 00:00:00

Total volume for the flume is 916 gal
The water level in Garden is always zero.

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1612 76th on Rainevent 6/11/12



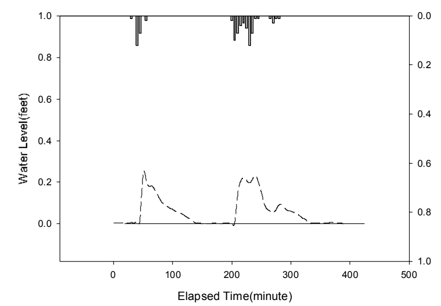
The rainfall depth for this event is 0.80 inch

T=0 at 6/11/2012 02:00:52

Total volume for the flume is 85 al

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1325 76th on Rainevent 6/5/13



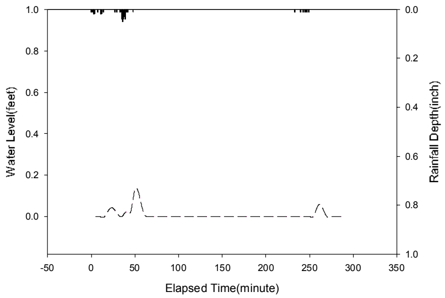
The rainfall depth for this event is 0.80 inch

T=0 at 6/11/2012 2:05:00

Total volume for the flume is 1731 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1222 76th on Rainevent 7/26/12



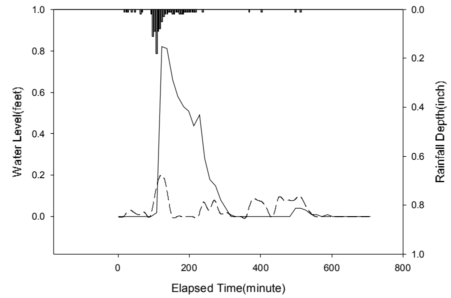
The rainfall depth for this event is 0.48 inch

T=0 at 7/26/2012 00:25:00

Total volume for the flume is 82 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1612 76th on Rainevent 6/21/12



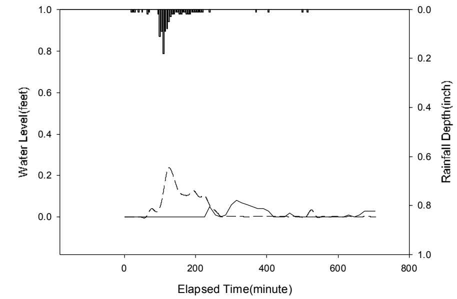
The rainfall depth for this event is 1.03 inch

T=0 at6/21/2012 00:12:33

Total volume for the flume is 1061 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1325 76th on Rainevent 6/21/12



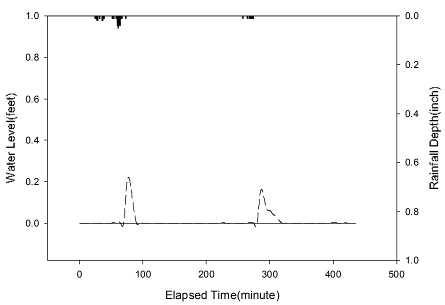
The rainfall depth for this event is 1.03 inch

T=0 at 6/21/2012 00:09:22

Total volume for the flume is 453 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1324 76th on Rainevent 7/26/12



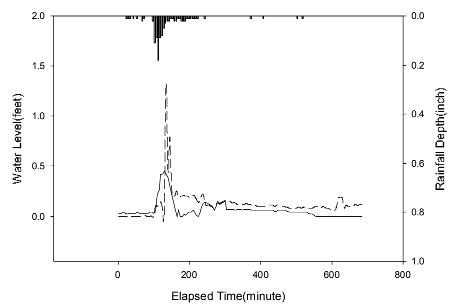
The rainfall depth for this event is 0.48 inch

T=0 at 7/26/2012 00:00:00

Total volume for the flume is 337 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1140 76th terr on Rainevent 6/21/12



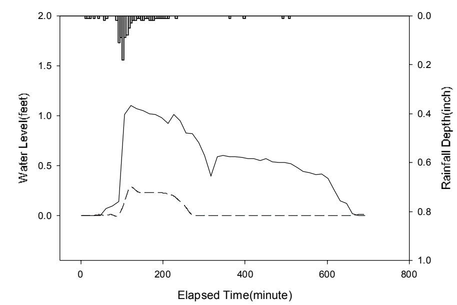
The rainfall depth for this event is 1.03 inch

T=0 at6/21/2012 00:07:24

Total volume for the flume is 14203 gal

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1336 76th on Rainevent 6/21/12

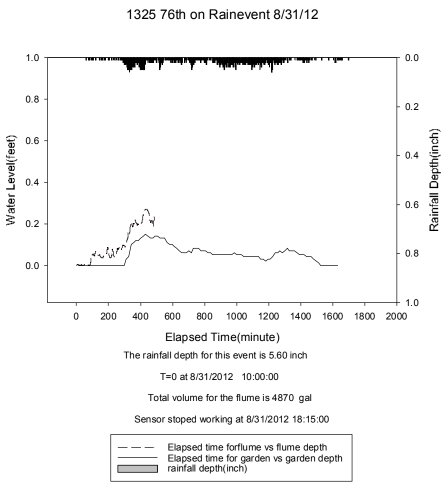


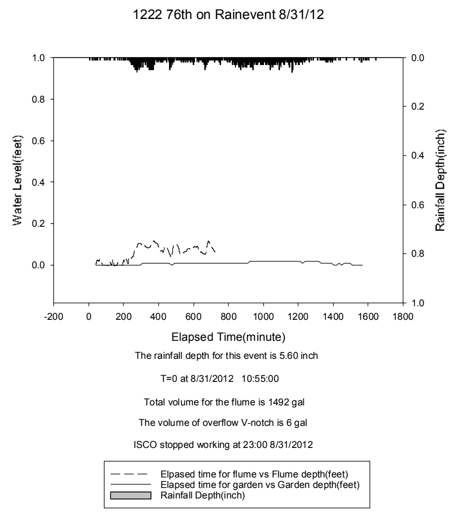
The rainfall depth for this event is 1.03 inch

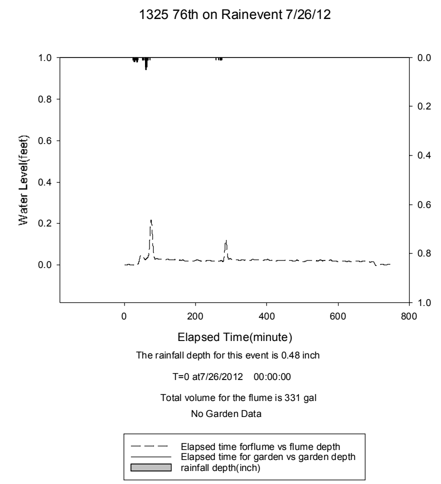
T=0 at 6/21/2012 00:17:19

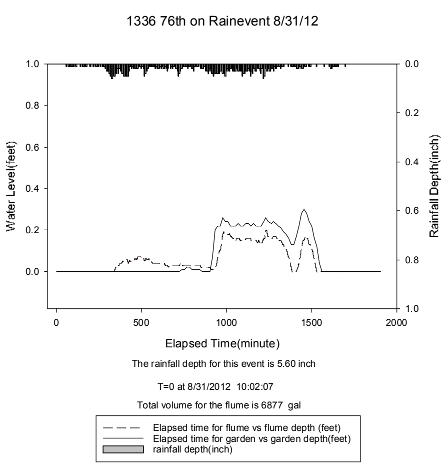
Total volume for the flume is 3884 gal

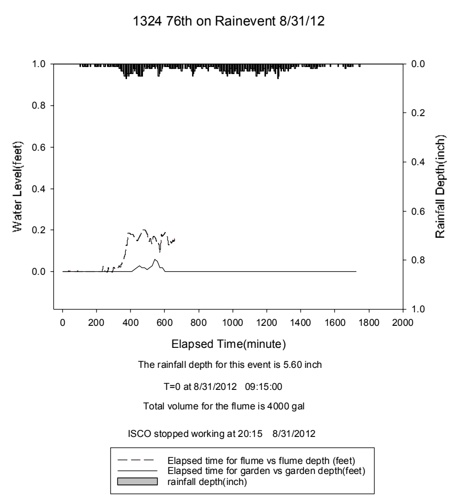
Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

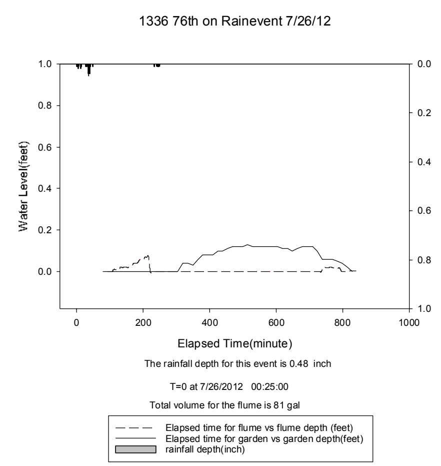

1325 76th on Rainevent 8/31/12
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 5.60 inch
T=0 at 8/31/2012 10:00:00
Total volume for the flume is 4870 gal
Sensor stoped working at 8/31/2012 18:15:00
Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)


1222 76th on Rainevent 8/31/12
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 5.60 inch
T=0 at 8/31/2012 10:55:00
Total volume for the flume is 1492 gal
The volume of overflow V-notch is 6 gal
ISCO stopped working at 23:00 8/31/2012
Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

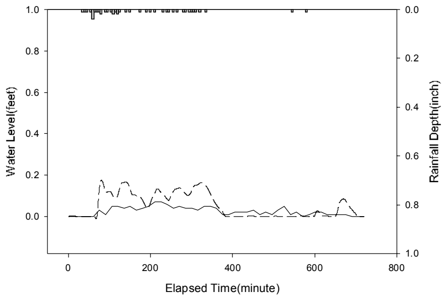

1325 76th on Rainevent 7/26/12
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 0.48 inch
T=0 at7/26/2012 00:00:00
Total volume for the flume is 331 gal
No Garden Data
Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)


1336 76th on Rainevent 8/31/12
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 5.60 inch
T=0 at 8/31/2012 10:02:07
Total volume for the flume is 6877 gal
Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)


1324 76th on Rainevent 8/31/12
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 5.60 inch
T=0 at 8/31/2012 09:15:00
Total volume for the flume is 4000 gal
ISCO stopped working at 20:15 8/31/2012
Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)


1336 76th on Rainevent 7/26/12
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 0.48 inch
T=0 at 7/26/2012 00:25:00
Total volume for the flume is 81 gal
Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1324 76th on Rainevent 9/13/12



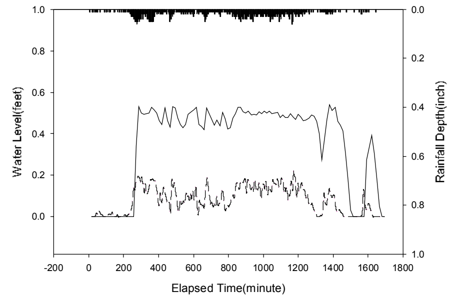
The rainfall depth for this event is 0.43inch

T=0 at 9/13/2012 13:45:00

Total volume for the flume is 2101 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1112 76th on Rainevent 8/31/12



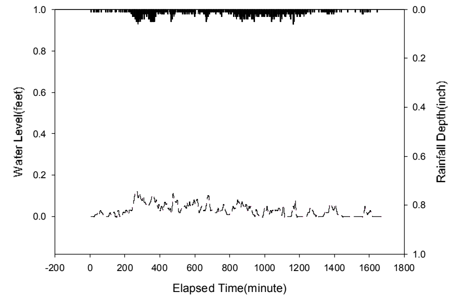
The rainfall depth for this event is 5.60 inch

T=0 at 8/31/2012 10:55:00

Total volume for the flume is 8533 gal

Elapsed time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1612 76th on Rainevent 8/31/12



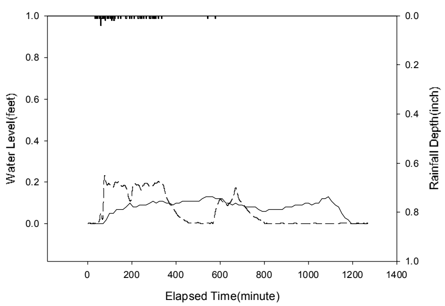
The rainfall depth for this event is5.60 inch

T=0 at 8/31/2012 10:55:00

Total volume for the flume is 1194 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1325 76th on Rainevent 9/13/12



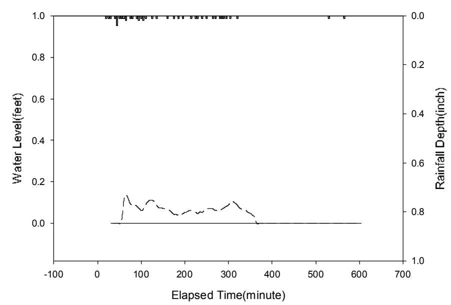
The rainfall depth for this event is 0.43 inch

T=0 at 9/13/2012 13:45:00

Total volume for the flume is 5954 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1222 76th on Rainevent 9/13/12



The rainfall depth for this event is 0.43 inch

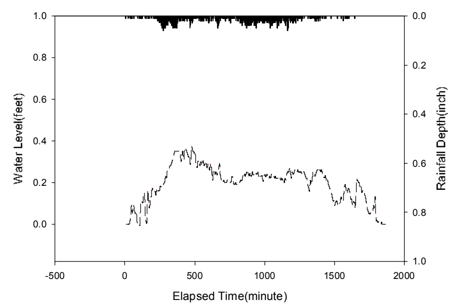
T=0 at 9/13/2012 14:00:00

Total volume for the flume is 762 gal

The volume of overflow V-notch is 0 gal

Elapsed time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1140 76th terr on Rainevent 8/31/12



The rainfall depth for this event is 5.60 inch

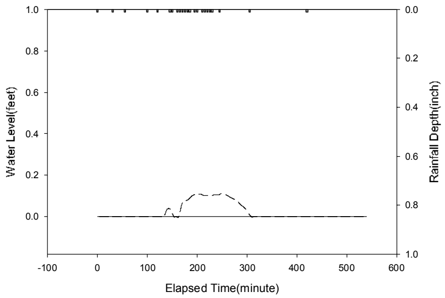
T=0 at8/31/2012 10:55:00

Total volume for the flume is 46827 gal

There is no garden data

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1222 76th on Rainevent 9/26/12



The rainfall depth for this event is 0.23 inch.

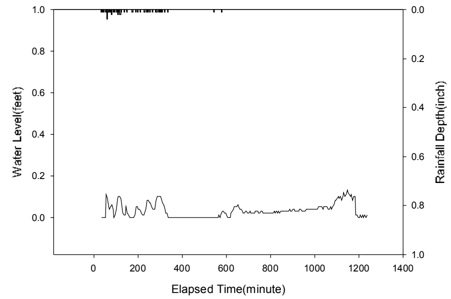
T=0 at 9/26/2012 02:00:00

The total volume of water into the garden during this event is 527gal.

The volume of overflow V-notch is 0 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1140 76th terr on Rainevent 9/13/12



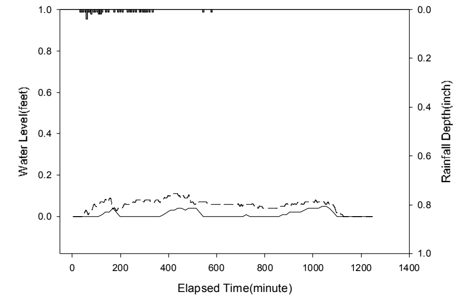
The rainfall depth for this event is 0.43 inch

T=0 at9/13/2012 14:00:00

NO Flume data for this Rainevent

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1336 76th on Rainevent 9/13/12



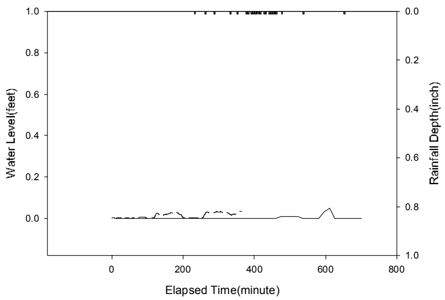
The rainfall depth for this event is 0.43 inch

T=0 at9/13/2012 14:00:00

Total volume for the flume is 1692 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1325 76th on Rainevent 9/26/12



The rainfall depth for this event is 0.23 inch.

T=0 at 9/25/2012 20:30:00

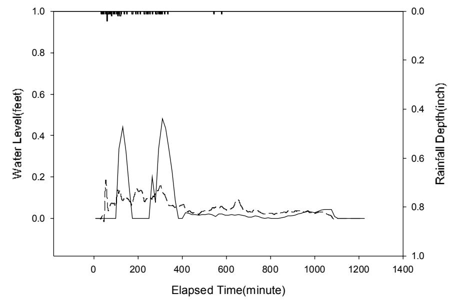
The total volume of water into the garden during this event is 42gal.

The garden data is always zero during this period

ISCO flume stopped at 9/26/2012 3 am

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1112 76th on Rainevent 9/13/12



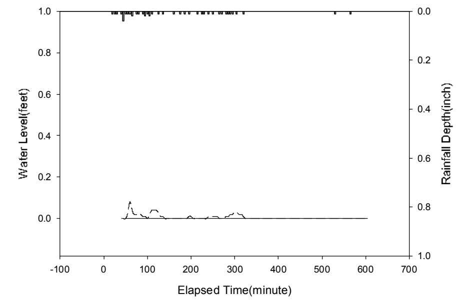
The rainfall depth for this event is 0.43 inch

T=0 at 9/13/2012 14:00:00

Total volume for the flume is 2098 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1612 76th on Rainevent 9/13/12



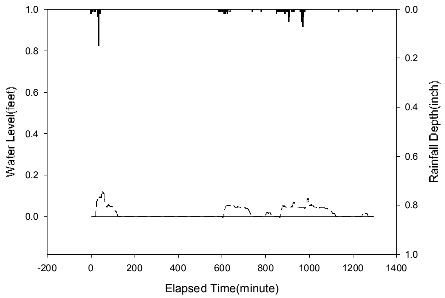
The rainfall depth for this event is 0.43 inch

T=0 at 9/13/2012 14:00:00

Total volume for the flume is 40 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1222 76th on Rainevent 10/13/12



The rainfall depth for this event is 0.82 inch.

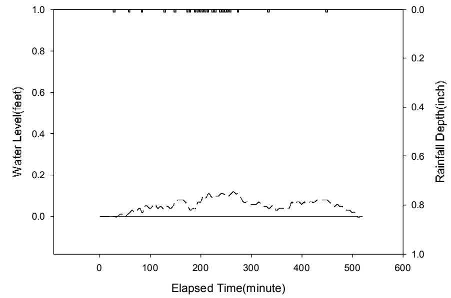
T=0 at10/13/2012 00:30:00

Total volume for the flume is 547 gal

The volume of overflow V-notch is 0 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1140 76th terr on Rainevent 9/26/12



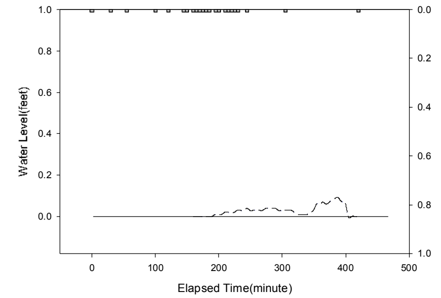
The rainfall depth for this event is 0.23 inch.

T=0 at 9/25/2012 23:54:34

Total volume for the flume is 869 gal

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1336 76th on Rainevent 9/26/12



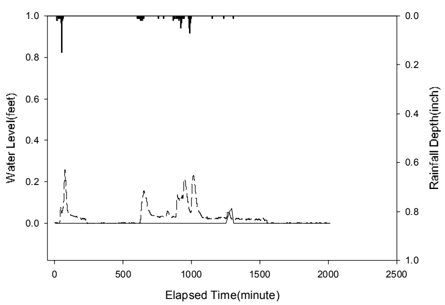
The rainfall depth for this event is 0.23 inch.

T=0 at 9/26/2012 03:02:07

Total volume for the flume is 156 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1324 76th on Rainevent 10/13/12



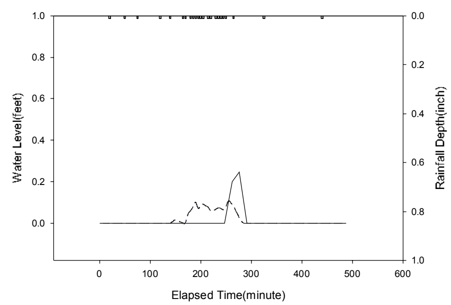
The rainfall depth for this event is 0.82 inch.

T=0 at10/12/2012 21:00:00

Total volume for the flume is 2775 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1112 76th on Rainevent 9/26/12



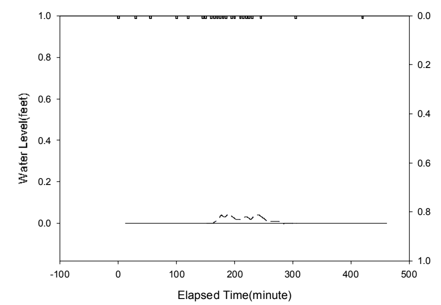
The rainfall depth for this event is 0.23 inch.

T=0 at 9/26/2012 02:08:23

Total volume for the flume is 261gal

Elapsed time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1612 76th on Rainevent 9/26/12



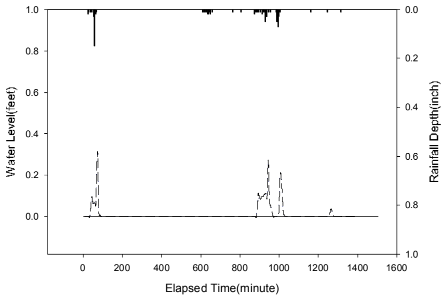
The rainfall depth for this event is 0.23 inch.

T=0 at 9/26/2012 02:55:54

Total volume for the flume is 30 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1112 76th on Rainevent 10/13/12



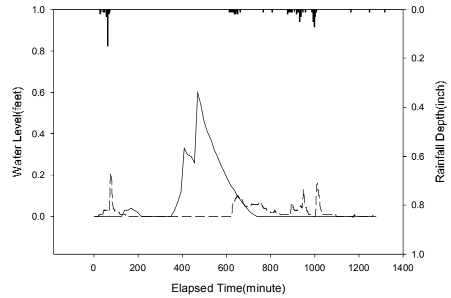
The rainfall depth for this event is 0.82 inch

T=0 at 10/13/2012 00:03:23

Total volume for the flume is 1197 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1612 76th on Rainevent 10/13/12



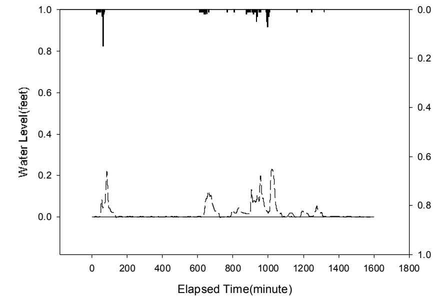
The rainfall depth for this event is 0.82 inch

T=0 at 10/13/2012 00:00:54

Total volume for the flume is 754 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1325 76th on Rainevent 10/13/12



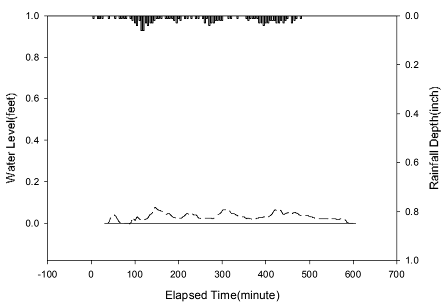
The rainfall depth for this event is 0.82 inch.

T=0 at10/12/2012 19:00:00

Total volume for the flume is 1553 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1222 76th on Rainevent 11/11/12



The rainfall depth for this event is 1.45 inch.

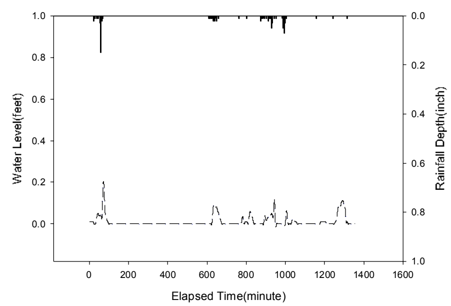
T=0 at 11/11/2012 05:00:00

Total volume for the flume is 284 gal

The volume of overflow V-notch is 0 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1140 76th terr on Rainevent 10/13/12



The rainfall depth for this event is 0.82 inch.

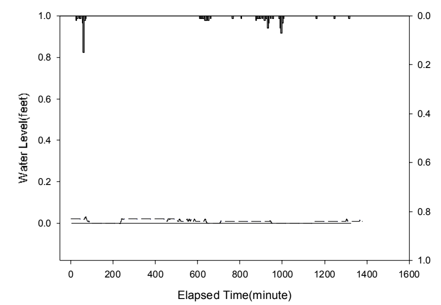
T=0 at10/12/2012 20:59:34

Total volume for the flume is 536 gal

No Garden Data during these period due to batteries

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1336 76th on Rainevent 10/13/12



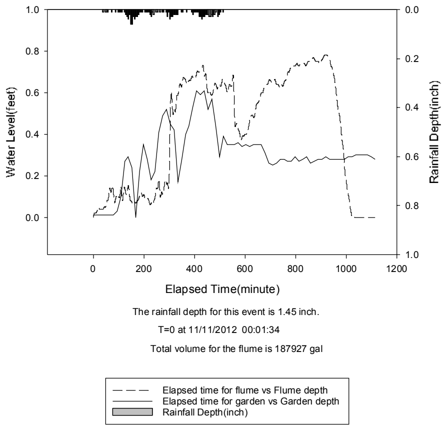
The rainfall depth for this event is 0.82 inch.

T=0 at10/13 2012 00:02:07

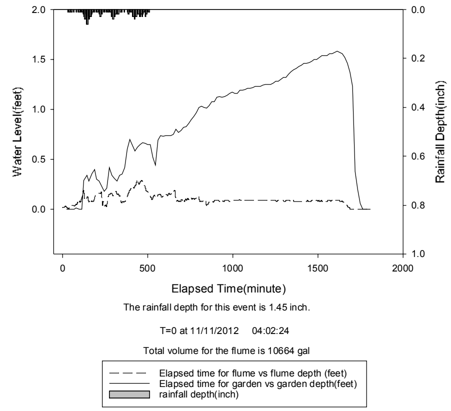
Total volume for the flume is 68 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

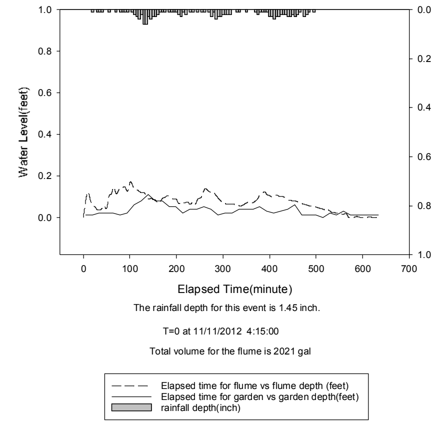
1140 76th terr on Rainevent 11/11/12



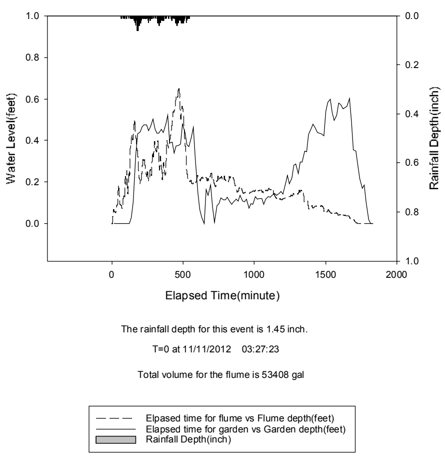
1336 76th on Rainevent 11/11/12



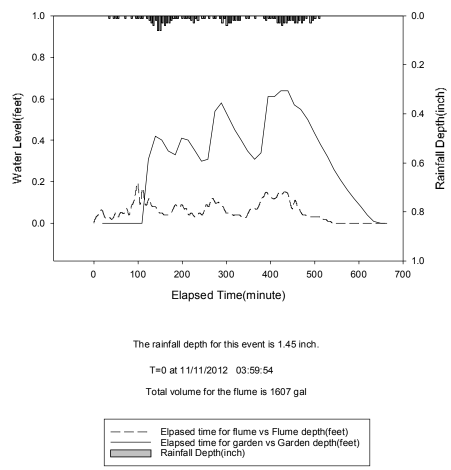
1324 76th on Rainevent 11/11/12



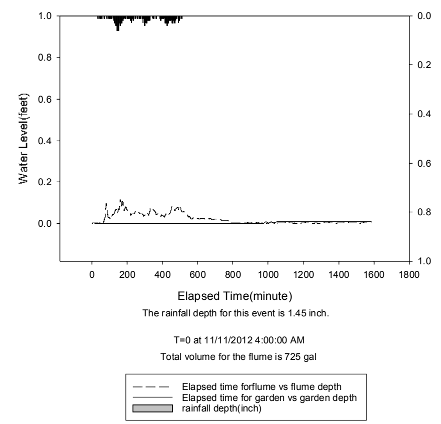
1112 76th on Rainevent 11/11/12



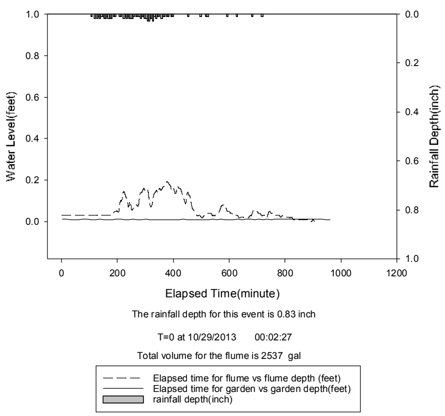
1612 76th on Rainevent 11/11/12



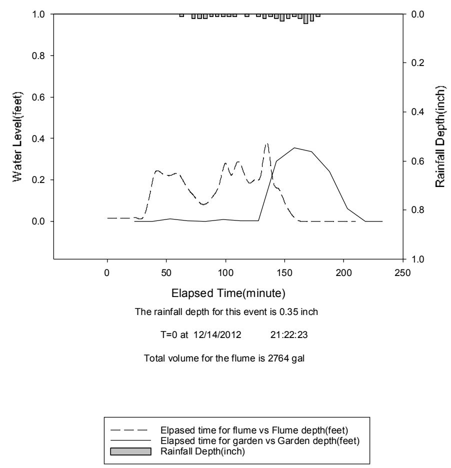
1325 76th on Rainevent 11/11/12



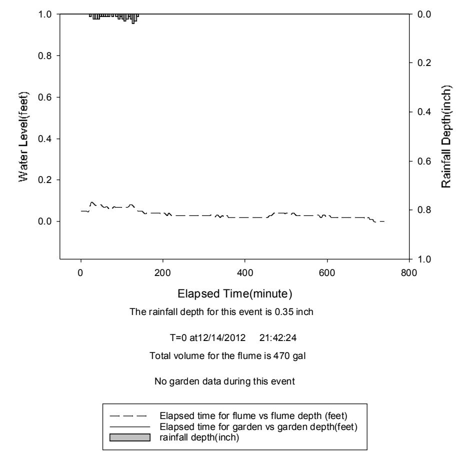
1324 76th on Rainevent 10/29/13



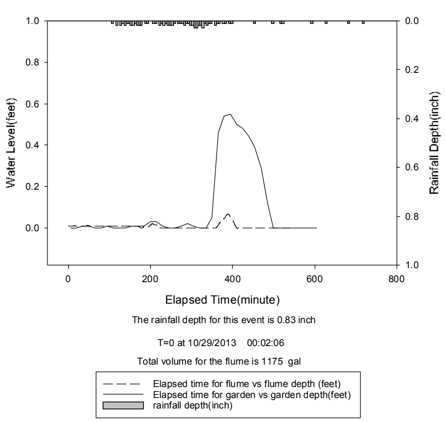
1112 76th on Rainevent 12/14/12



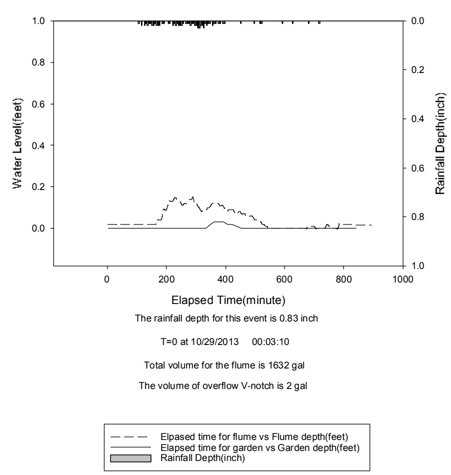
1336 76th on Rainevent 12/14/12



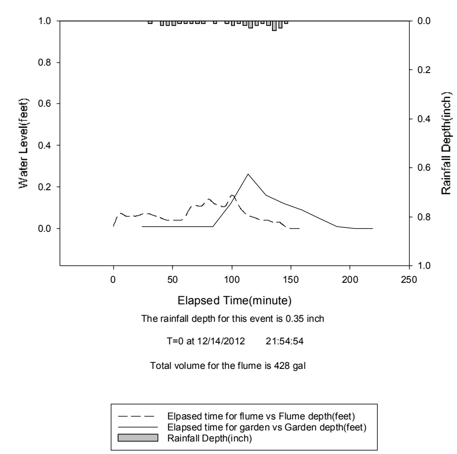
1336 76th on Rainevent 10/29/13



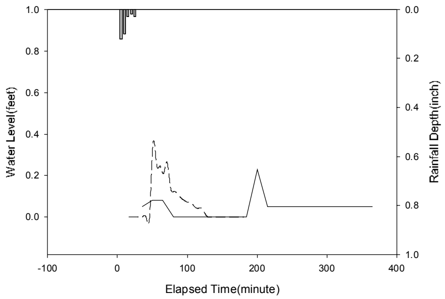
1222 76th on Rainevent 10/29/13



1612 76th on Rainevent 12/14/12



1325 76th on Rainevent 10/3/13



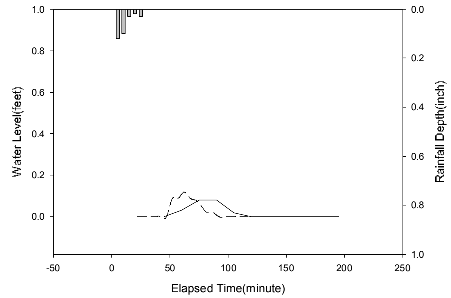
The rainfall depth for this event is 0.30 inch

T=0 at 10/3/2013 10:05:00

Total volume for the flume is 1204 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1222 76th on Rainevent 10/3/13



The rainfall depth for this event is 0.30 inch

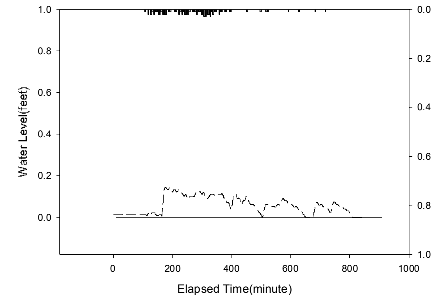
T=0 at 10/3/2013 10:05:00

Total volume for the flume is 108gal

The volume of overflow V-notch is 12 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1140 76th terr on Rainevent 10/29/13



The rainfall depth for this event is 0.83 inch

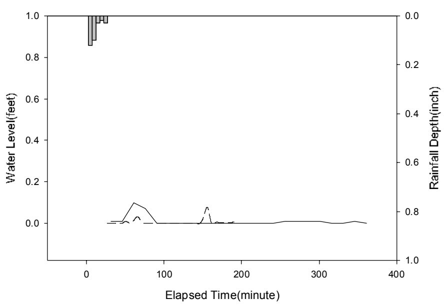
T=0 at10/29/2013 00:02:01

Total volume for the flume is 1856 gal

The volume of overflow V-notch is 0 gal

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1336 76th on Rainevent 10/3/13



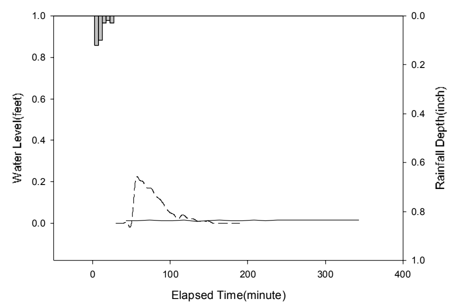
The rainfall depth for this event is 0.30 inch

T=0 at 10/3/2013 10:05:00

Total volume for the flume is 17 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1324 76th on Rainevent 10/3/13



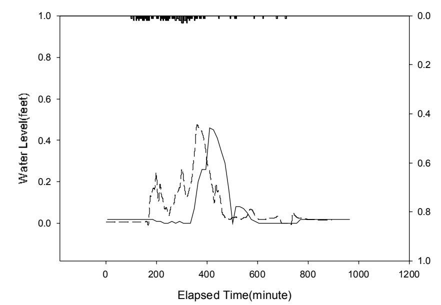
The rainfall depth for this event is 0.30 inch

T=0 at 10/3/2013 10:05:00

Total volume for the flume is 599 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1112 76th on Rainevent 10/29/13



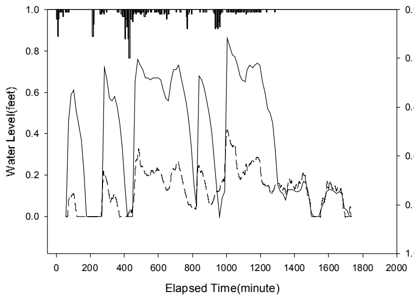
The rainfall depth for this event is 0.83 inch

T=0 at 10/29/2013 00:08:30

Total volume for the flume is 8924 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1336 76th on Rainevent 10/30/13



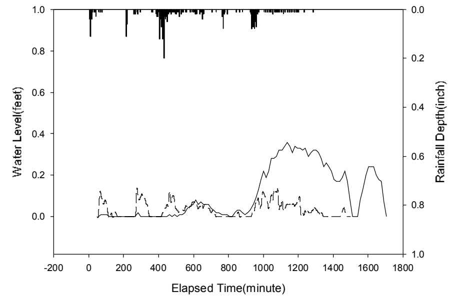
The rainfall depth for this event is 2.88 inch

T=0 at 10/30/2013 11:10:00

Total volume for the flume is 24372 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1222 76th on Rainevent 10/30/13



The rainfall depth for this event is 2.88 inch

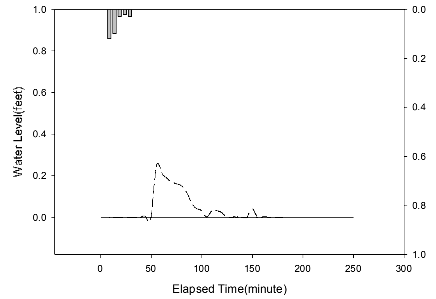
T=0 at 10/30/2013 11:10:00

Total volume for the flume is 1536 gal

The volume of overflow V-notch is 5206 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1140 76th terr on Rainevent 10/3/13



The rainfall depth for this event is 0.30 inch

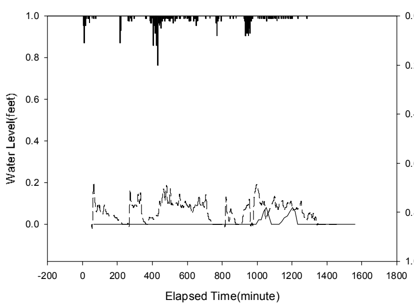
T=0 at10/3/2013 10:01:01

Total volume for the flume is 624 gal

The volume of overflow V-notch is 0 gal

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1140 76th terr on Rainevent 10/30/13



The rainfall depth for this event is 2.88inch

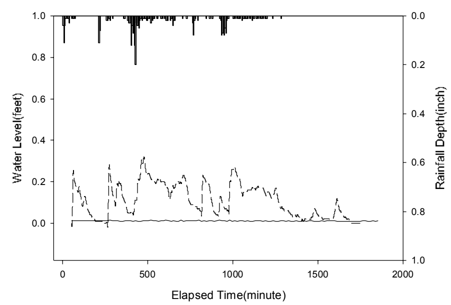
T=0 at 10/30/2013 11:10:00

Total volume for the flume is 3767 gal

The volume of overflow V-notch is 23 gal

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1324 76th on Rainevent 10/30/13



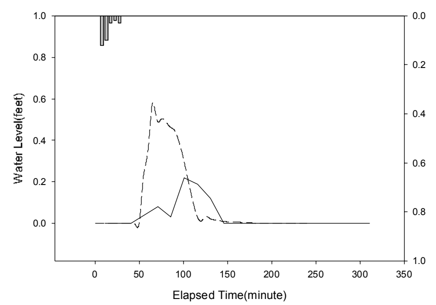
The rainfall depth for this event is 2.88 inch

T=0 at 10/30/2013 11:10:00

Total volume for the flume is 16226 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1112 76th on Rainevent 10/3/13



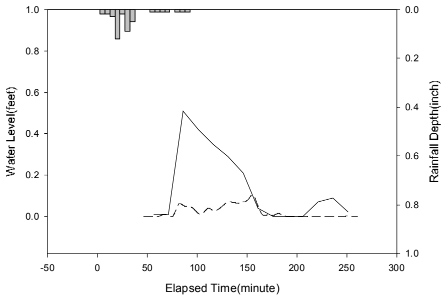
The rainfall depth for this event is 0.30 inch

T=0 at10/3/2013 10:02:55

Total volume for the flume is 6091 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1336 76th on Rainevent 10/4/13



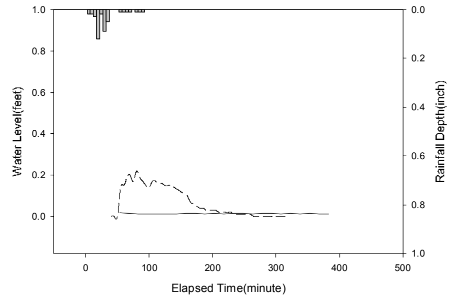
The rainfall depth for this event is 0.42 inch

T=0 at 10/4/2013 21:40:00

Total volume for the flume is 117 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1324 76th on Rainevent 10/4/13



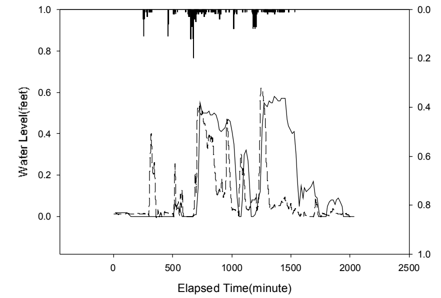
The rainfall depth for this event is 0.42 inch

T=0 at 10/4/2013 21:40:00

Total volume for the flume is 1419 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1112 76th on Rainevent 10/30/13



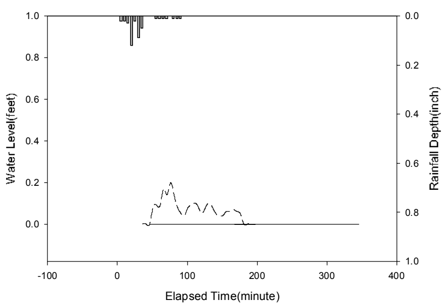
The rainfall depth for this event is 2.88 inch

T=0 at 10/30/2013 07:03:30

Total volume for the flume is 36295 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1140 76th terr on Rainevent 10/4/13



The rainfall depth for this event is 0.42 inch

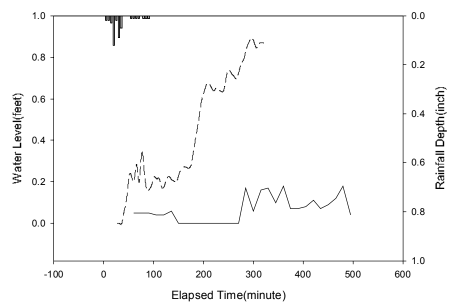
T=0 at10/4/2013 21:40:00

Total volume for the flume is 515 gal

The volume of overflow V-notch is 0 gal

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1325 76th on Rainevent 10/4/13



The rainfall depth for this event is 0.42 inch

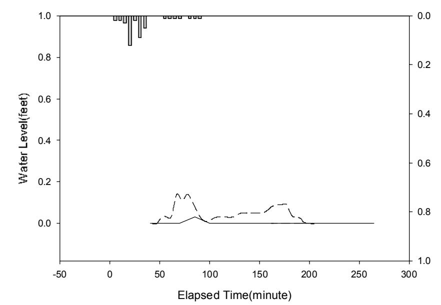
T=0 at 10/4/2013 21:40:00

Total volume for the flume is 54731 gal

There must something wrong with this dataset, the water depths cannot be that high

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1222 76th on Rainevent 10/4/13



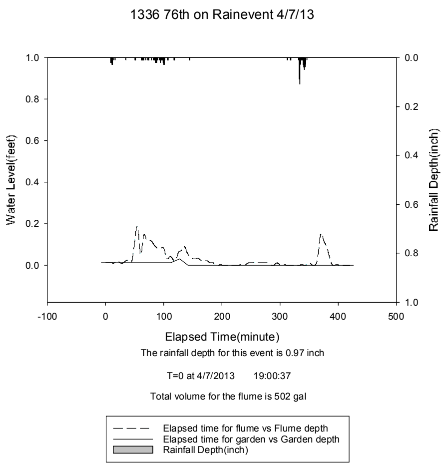
The rainfall depth for this event is 0.42 inch

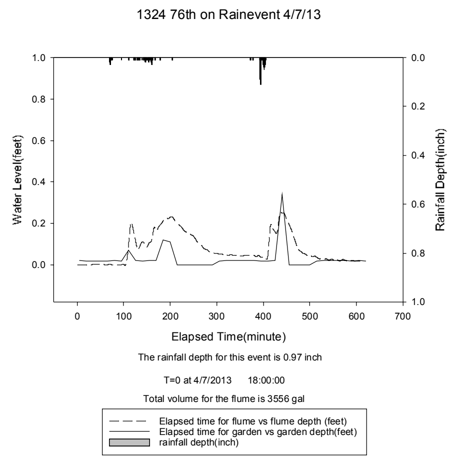
T=0 at 10/4/2013 21:40:00

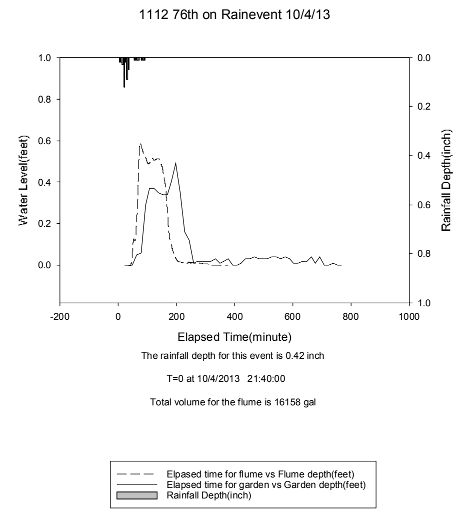
Total volume for the flume is 280 gal

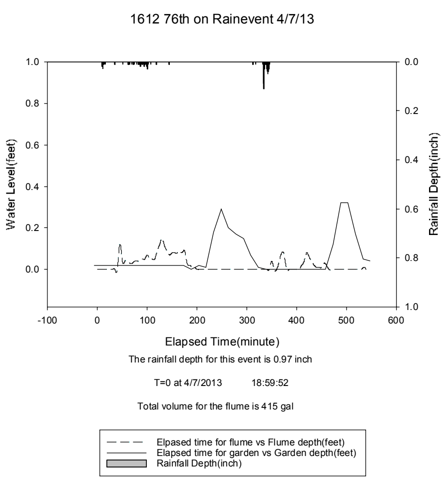
The volume of overflow V-notch is 0 gal

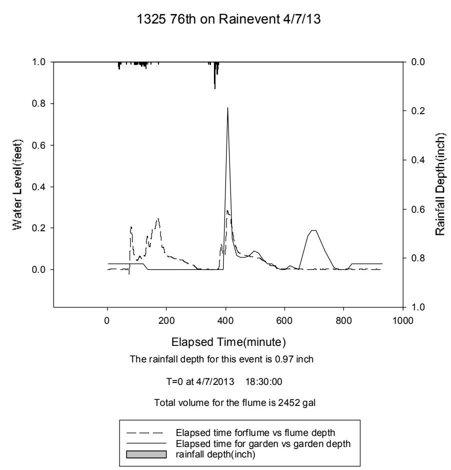
Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

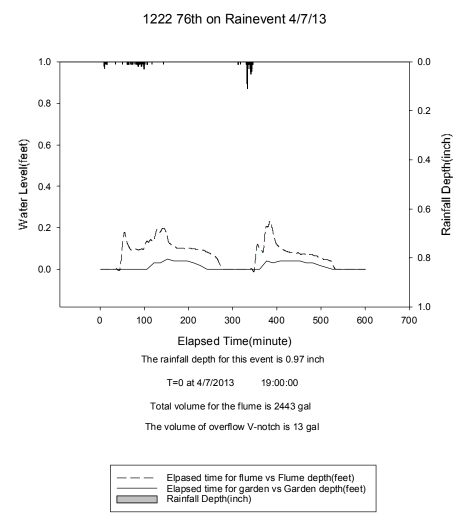

1336 76th on Rainevent 4/7/13
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 0.97 inch
T=0 at 4/7/2013 19:00:37
Total volume for the flume is 502 gal
Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)


1324 76th on Rainevent 4/7/13
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 0.97 inch
T=0 at 4/7/2013 18:00:00
Total volume for the flume is 3556 gal
Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

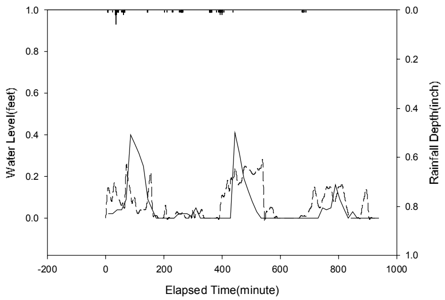

1112 76th on Rainevent 10/4/13
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 0.42 inch
T=0 at 10/4/2013 21:40:00
Total volume for the flume is 16158 gal
Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)


1612 76th on Rainevent 4/7/13
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 0.97 inch
T=0 at 4/7/2013 18:59:52
Total volume for the flume is 415 gal
Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)


1325 76th on Rainevent 4/7/13
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 0.97 inch
T=0 at 4/7/2013 18:30:00
Total volume for the flume is 2452 gal
Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)


1222 76th on Rainevent 4/7/13
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 0.97 inch
T=0 at 4/7/2013 19:00:00
Total volume for the flume is 2443 gal
The volume of overflow V-notch is 13 gal
Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1612 76th on Rainevent 4/9/13



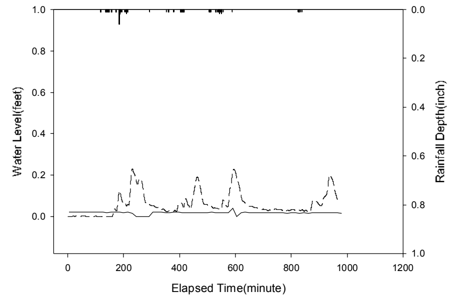
The rainfall depth for this event is 0.80 inch

T=0 at 4/9/2013 21:30:52

Total volume for the flume is 5171 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1324 76th on Rainevent 4/9/13



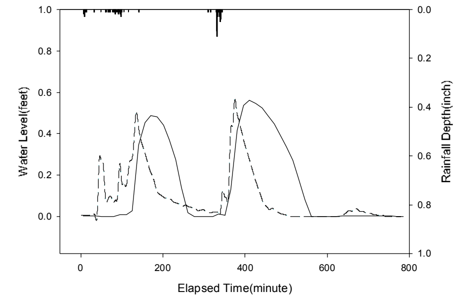
The rainfall depth for this event is 0.97 inch

T=0 at 4/9/2013 19:00:00

Total volume for the flume is 3151 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1112 76th Terr on Rainevent 4/7/13



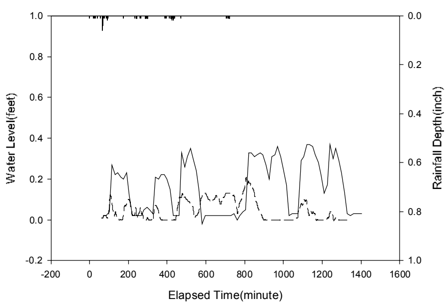
The rainfall depth for this event is 0.97 inch

T=0 at 4/7/2013 18:02:03

Total volume for the flume is 11502 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1336 76th terr on Rainevent 4/9/13



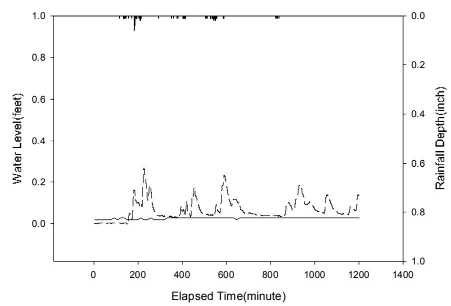
The rainfall depth for this event is 0.80inch

T=0 at 4/9/2013 20:58:00

Total volume for the flume is 2934 gal

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1325 76th on Rainevent 4/9/13



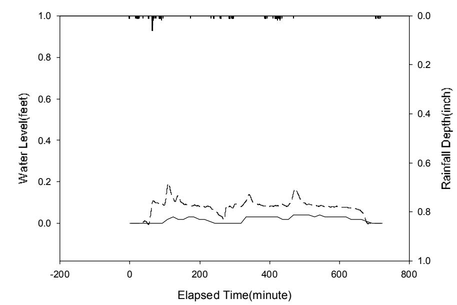
The rainfall depth for this event is 0.80 inch

T=0 at 4/9/2013 19:00:00

Total volume for the flume is 4033 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1222 76th on Rainevent 4/9/13



The rainfall depth for this event is 0.80 inch

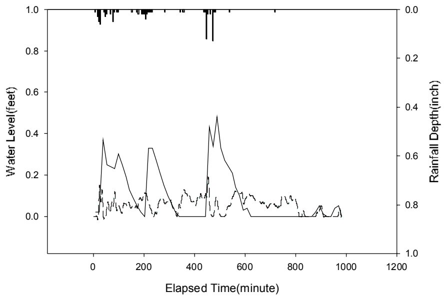
T=0 at 4/9/2013 21:00:00

Total volume for the flume is 2422 gal

The volume of overflow V-notch is 14 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1612 76th on Rainevent 4/17/13



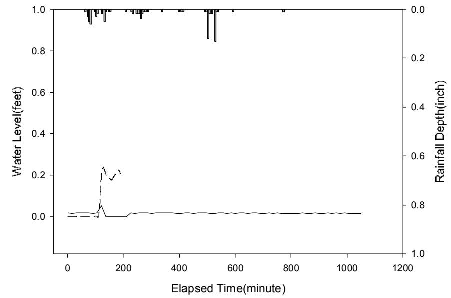
The rainfall depth for this event is 0.90 inch

T=0 at 4/17/2013 21:30:52

Total volume for the flume is 1947 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1324 76th on Rainevent 4/17/13



The rainfall depth for this event is 0.9 inch

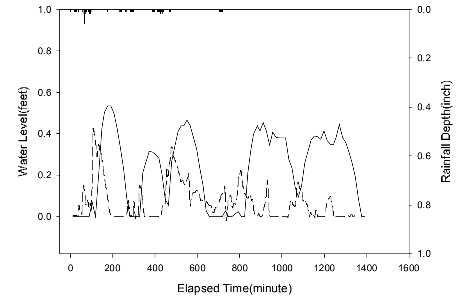
T=0 at 4/17/2013 20:05:00

Total volume for the flume is 1644 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

ISCO Flume Stoped working at 4/17/2013 11:15 pm

1112 76th Terr on Rainevent 4/9/13



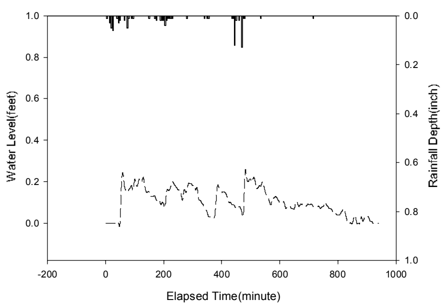
The rainfall depth for this event is 0.80 inch

T=0 at 4/9/2013 21:03:03

Total volume for the flume is 9278 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1140 76th terr on Rainevent 4/17/13



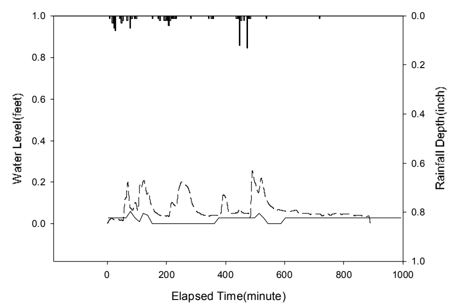
The rainfall depth for this event is 0.90 inch

T=0 at 4/17/2013 21:03:56

Total volume for the flume is 6685gal

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1325 76th on Rainevent 4/17/13



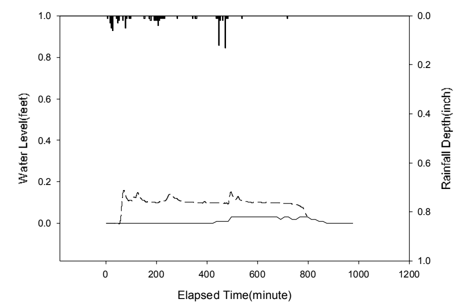
The rainfall depth for this event is 0.9 inch

T=0 at 4/17/2013 21:00:00

Total volume for the flume is 3506 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1222 76th on Rainevent 4/17/13



The rainfall depth for this event is 0.9 inch

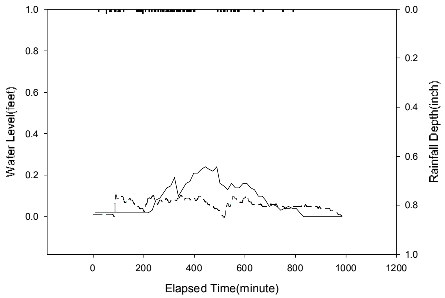
T=0 at 4/17/2013 21:00:00

Total volume for the flume is 3836 gal

The volume of overflow V-notch is 10 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1612 76th on Rainevent 4/22/13



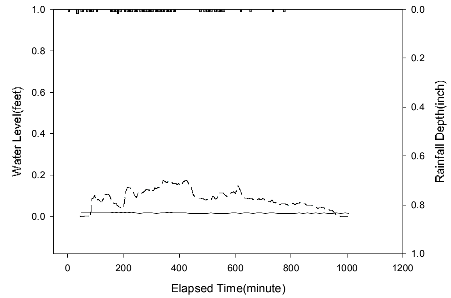
The rainfall depth for this event is 0.59inch

T=0 at 4/22/2013 23:01:57

Total volume for the flume is 1681 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1324 76th on Rainevent 4/22/13



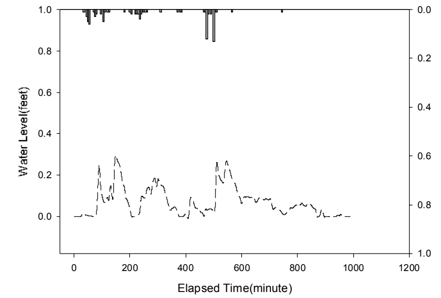
The rainfall depth for this event is 0.59 inch

T=0 at 4/22/2013 23:18:00

Total volume for the flume is 4265 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1112 76th Terr on Rainevent 4/17/13



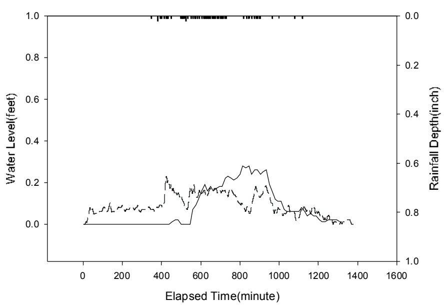
The rainfall depth for this event is 0.90 inch

T=0 at 4/17/2013 20:33:03

Total volume for the flume is 4885 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1140 76th terr on Rainevent 4/22/13



The rainfall depth for this event is 0.59 inch

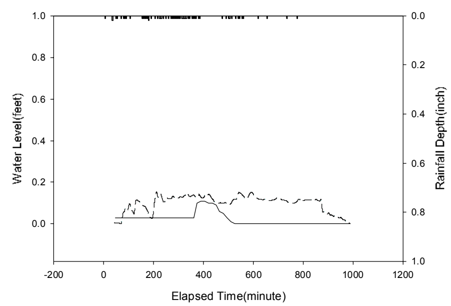
T=0 at 4/22/2013 17:33:56

Total volume for the flume is 6954 gal

The volume of overflow V-notch is 1703 gal

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1325 76th on Rainevent 4/22/13



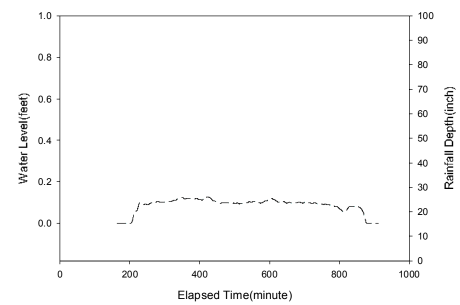
The rainfall depth for this event is 0.59 inch

T=0 at 4/22/2013 23:18:00

Total volume for the flume is 5082 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1222 76th on Rainevent 4/22/13



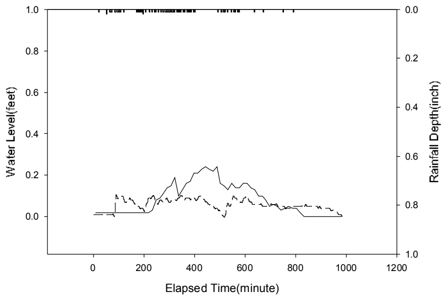
The rainfall depth for this event is 0.59 inch

T=0 at 4/23/2013 02:00:00

Total volume for the flume is 3007 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1612 76th on Rainevent 4/23/13



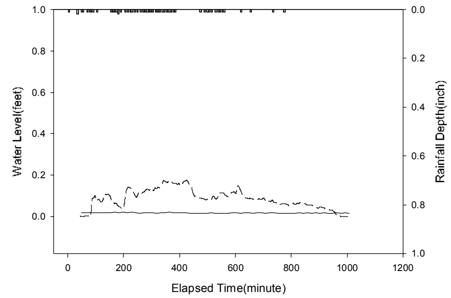
The rainfall depth for this event is 0.59inch

T=0 at 4/22/2013 23:01:57

Total volume for the flume is 1681 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1324 76th on Rainevent 4/23/13



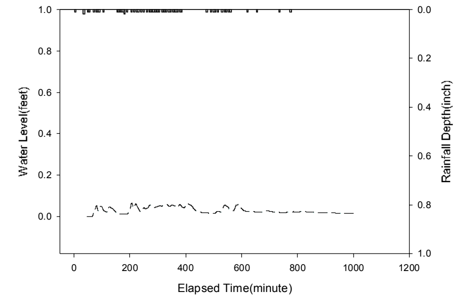
The rainfall depth for this event is 0.59 inch

T=0 at 4/22/2013 23:18:00

Total volume for the flume is 4265 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1112 76th Terr on Rainevent 4/22/13



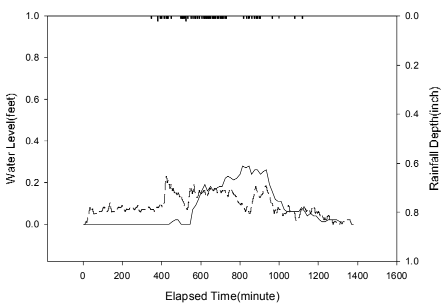
The rainfall depth for this event is 0.59 inch

T=0 at 4/22/2013 23:18:00

Total volume for the flume is 402 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1140 76th terr on Rainevent 4/23/13



The rainfall depth for this event is 0.59 inch

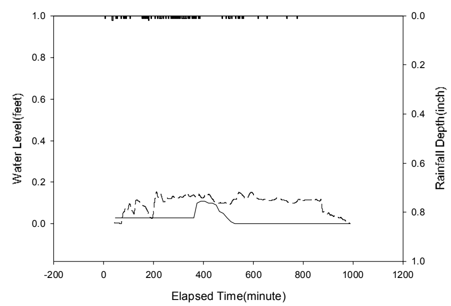
T=0 at 4/23/2013 17:33:56

Total volume for the flume is 6954 gal

The volume of overflow V-notch is 1703 gal

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1325 76th on Rainevent 4/23/13



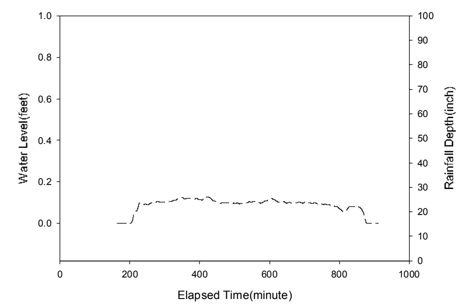
The rainfall depth for this event is 0.59 inch

T=0 at 4/22/2013 23:18:00

Total volume for the flume is 5082 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1222 76th on Rainevent 4/23/13



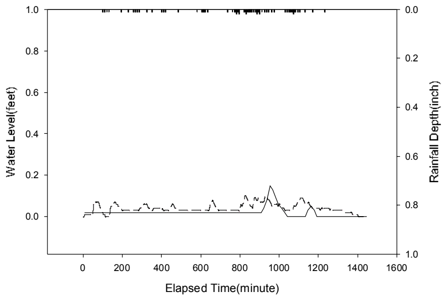
The rainfall depth for this event is 0.59 inch

T=0 at 4/23/2013 02:00:00

Total volume for the flume is 3007 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1612 76th on Rainevent 4/26/13



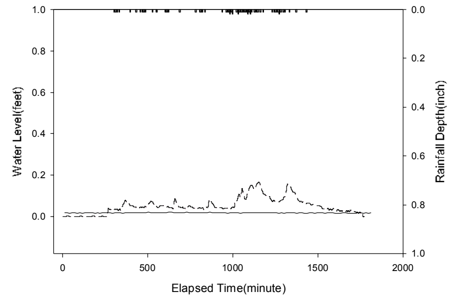
The rainfall depth for this event is 0.71 inch

T=0 at 4/26/2013 12:46:57

Total volume for the flume is 1220 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1324 76th on Rainevent 4/26/13



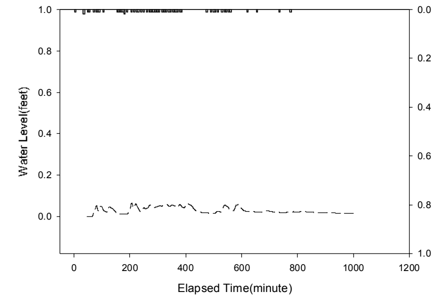
The rainfall depth for this event is 0.71 inch

T=0 at 4/26/2013 09:25:00

Total volume for the flume is 3260 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1112 76th Terr on Rainevent 4/23/13



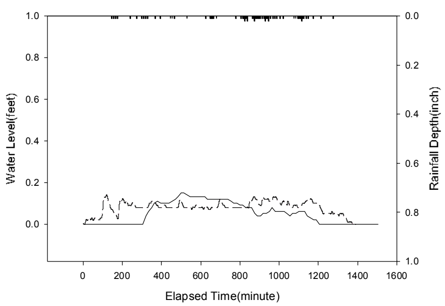
The rainfall depth for this event is 0.59 inch

T=0 at 4/22/2013 23:18:00

Total volume for the flume is 402 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1140 76th terr on Rainevent 4/26/13



The rainfall depth for this event is 0.71 inch

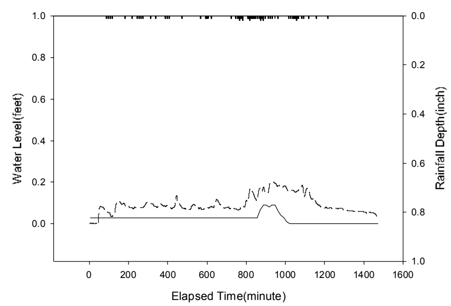
T=0 at 4/26/2013 12:03:56

Total volume for the flume is 4585 gal

The volume of overflow V-notch is 515 gal

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1325 76th on Rainevent 4/26/13



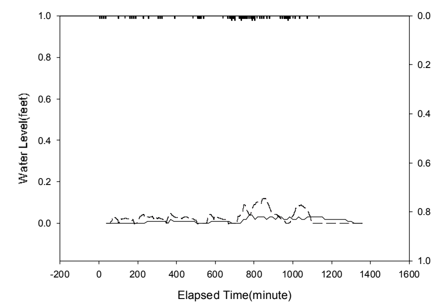
The rainfall depth for this event is 0.71 inch

T=0 at 4/26/2013 13:00:00

Total volume for the flume is 7504 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1222 76th on Rainevent 4/26/13



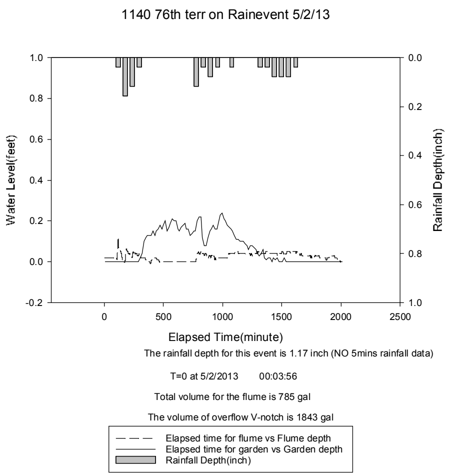
The rainfall depth for this event is 0.71 inch

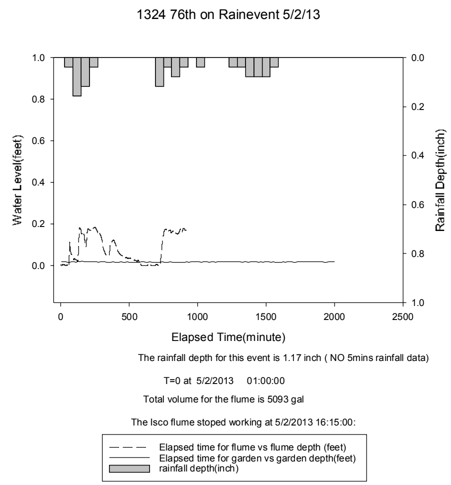
T=0 at 4/26/2013 14:23:00

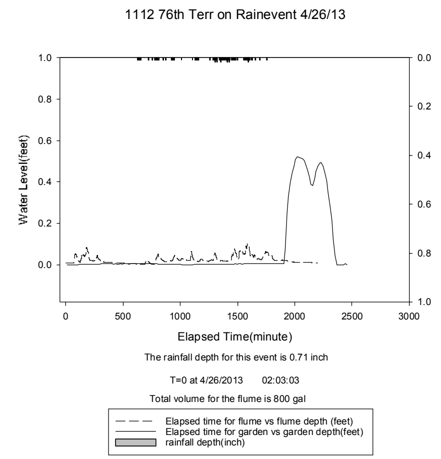
Total volume for the flume is 4821 gal

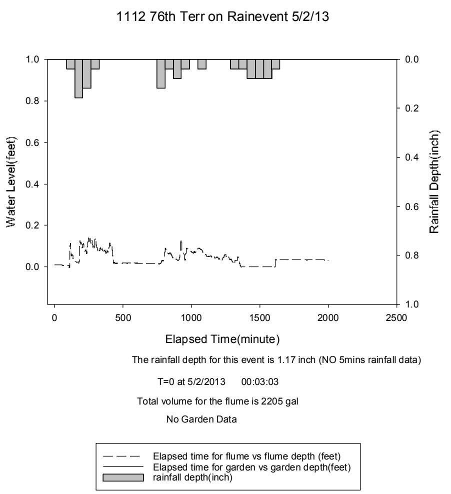
The volume of overflow V-notch is 12 gal

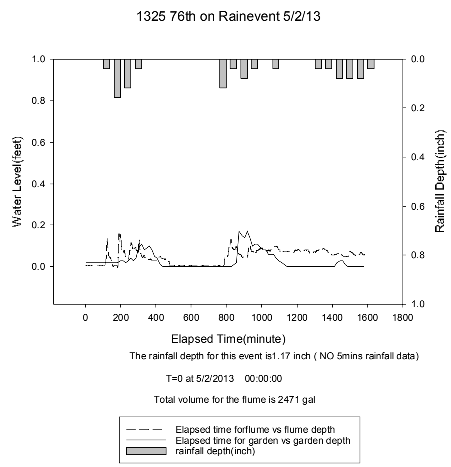
Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

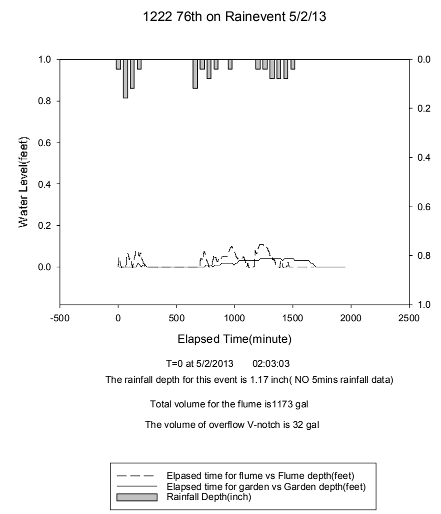

1140 76th terr on Rainevent 5/2/13
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 1.17 inch (NO 5mins rainfall data)
T=0 at 5/2/2013 00:03:56
Total volume for the flume is 785 gal
The volume of overflow V-notch is 1843 gal
Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)


1324 76th on Rainevent 5/2/13
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 1.17 inch (NO 5mins rainfall data)
T=0 at 5/2/2013 01:00:00
Total volume for the flume is 5093 gal
The Isco flume stoped working at 5/2/2013 16:15:00:
Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

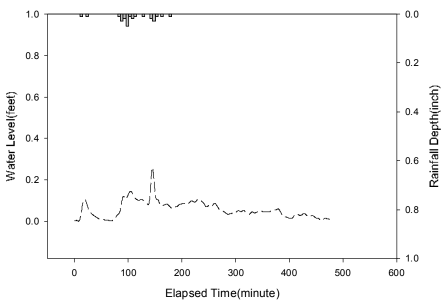

1112 76th Terr on Rainevent 4/26/13
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 0.71 inch
T=0 at 4/26/2013 02:03:03
Total volume for the flume is 800 gal
Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)


1112 76th Terr on Rainevent 5/2/13
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 1.17 inch (NO 5mins rainfall data)
T=0 at 5/2/2013 00:03:03
Total volume for the flume is 2205 gal
No Garden Data
Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)


1325 76th on Rainevent 5/2/13
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is1.17 inch (NO 5mins rainfall data)
T=0 at 5/2/2013 00:00:00
Total volume for the flume is 2471 gal
Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)


1222 76th on Rainevent 5/2/13
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
T=0 at 5/2/2013 02:03:03
The rainfall depth for this event is 1.17 inch(NO 5mins rainfall data)
Total volume for the flume is1173 gal
The volume of overflow V-notch is 32 gal
Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1112 76th Terr on Rainevent 5/8/13



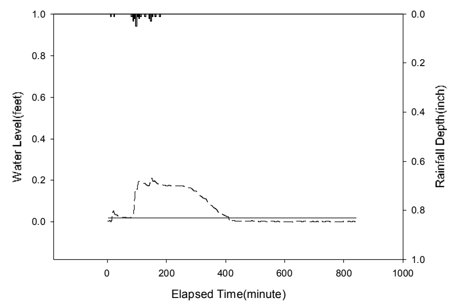
The rainfall depth for this event is 0.26 inch

T=0 at 5/8/2013 23:00:03

Total volume for the flume is 1099 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1325 76th on Rainevent 5/8/13



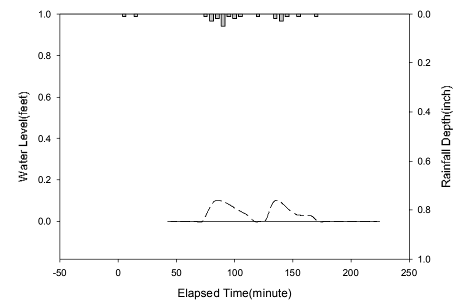
The rainfall depth for this event is 0.26 inch

T=0 at 5/8/2013 23:00:00

Total volume for the flume is 3696 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1222 76th on Rainevent 5/8/13



The rainfall depth for this event is 0.26 inch

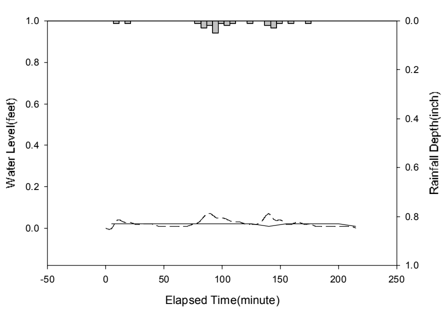
T=0 at 5/8/2013 23:08:00

Total volume for the flume is 156 gal

The volume of overflow V-notch is 0 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1612 76th on Rainevent 5/8/13



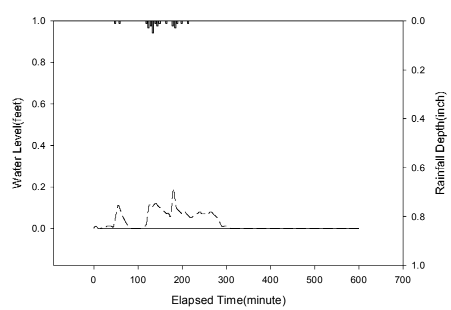
The rainfall depth for this event is 0.26 inch

T=0 at 5/8/2013 23:04:28

Total volume for the flume is 78 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1140 76th terr on Rainevent 5/8/13



The rainfall depth for this event is 0.26 inch

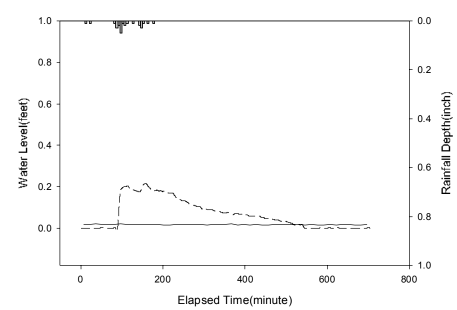
T=0 at5/8/2013 22:24:56

Total volume for the flume is 620 gal

The volume of overflow V-notch is 0 gal

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1324 76th on Rainevent 5/8/13

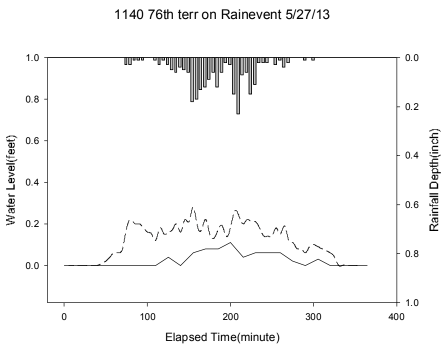


The rainfall depth for this event is 0.26 inch

T=0 at 5/8/2013 23:00:00

Total volume for the flume is 3280 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)



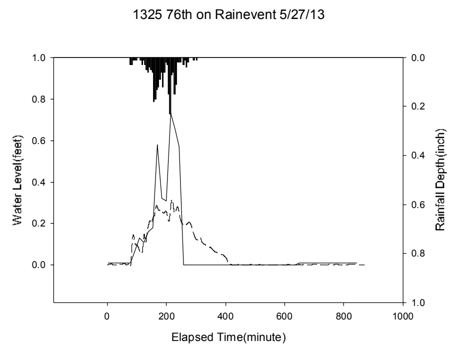
The rainfall depth for this event is 2.36 inch

T=0 at 5/27/2013 07:04:56

Total volume for the flume is 3728 gal

The volume of overflow V-notch is 39 gal

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

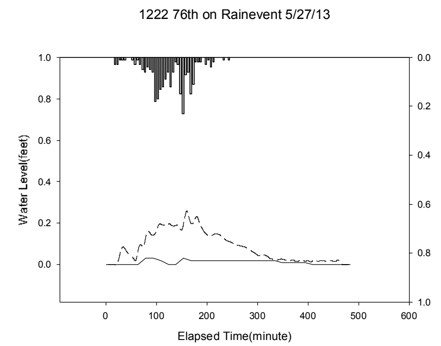


The rainfall depth for this event is 2.36 inch

T=0 at 5/27/2013 07:00:00

Total volume for the flume is 5473 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)



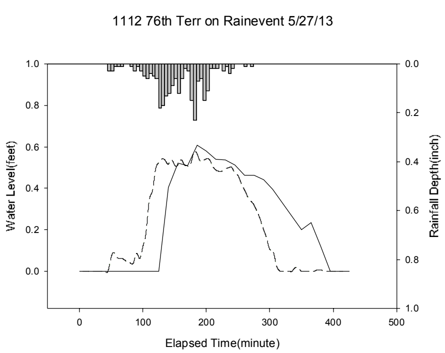
The rainfall depth for this event is 2.36 inch

T=0 at 5/27/2013 08:00:00

Total volume for the flume is 2973 gal

The volume of overflow V-notch is 1 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

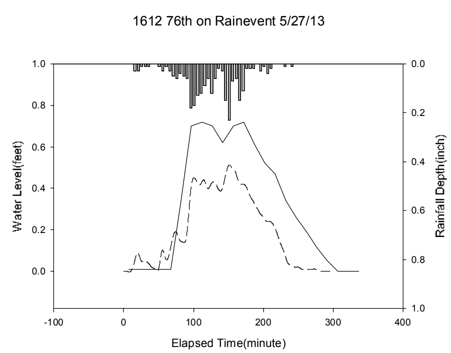


The rainfall depth for this event is 2.36 inch

T=0 at 5/27/2013 07:31:03

Total volume for the flume is 26303 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

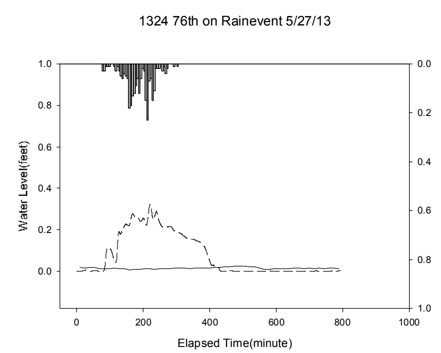


The rainfall depth for this event is 2.36 inch

T=0 at 5/27/2013 08:04:32

Total volume for the flume is 12126 gal

Elapsed time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)



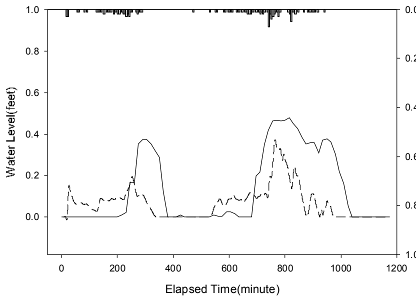
The rainfall depth for this event is 2.36 inch

T=0 at 5/27/2013 07:00:00

Total volume for the flume is 6634 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1112 76th Terr on Rainevent 5/29/13



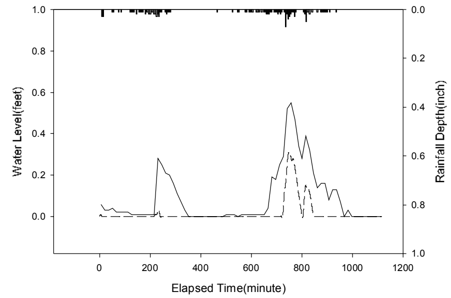
The rainfall depth for this event is 1.3 inch

T=0 at 5/29/2013 22:31:03

Total volume for the flume is 6264 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1612 76th on Rainevent 5/29/13



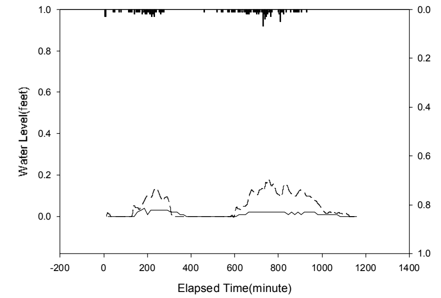
The rainfall depth for this event is 1.3 inch

T=0 at 5/29/2013 22:49:32

Total volume for the flume is 2049 gal

Elapsed time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1222 76th on Rainevent 5/29/13



The rainfall depth for this event is 1.3 inch

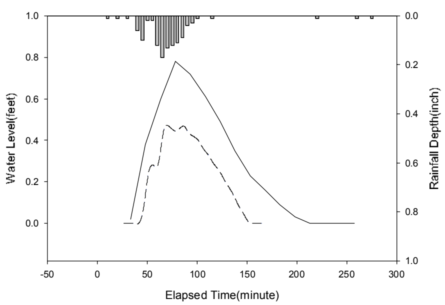
T=0 at 5/29/2013 22:43:00

Total volume for the flume is 2930 gal

The volume of overflow V-notch is 8 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1612 76th on Rainevent 5/31/13



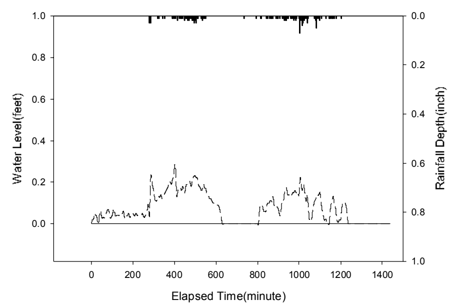
The rainfall depth for this event is 1.09 inch

T=0 at 5/31/2013 05:04:32

Total volume for the flume is 6809 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1140 76th terr on Rainevent 5/29/13



The rainfall depth for this event is 1.3 inch

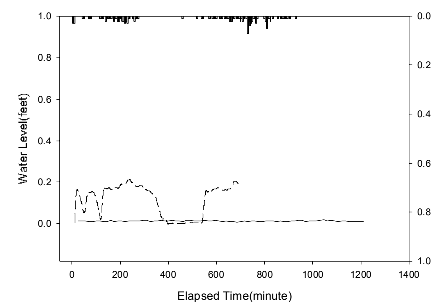
T=0 at 5/29/2013 18:09:56

Total volume for the flume is 7535 gal

The volume of overflow V-notch is 0 gal

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1324 76th on Rainevent 5/29/13



The rainfall depth for this event is 1.3 inch

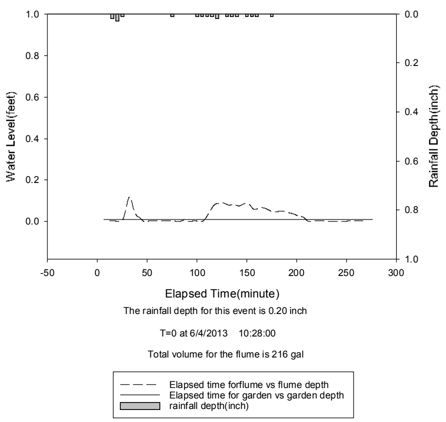
T=0 at 5/29/2013 22:43:00

Total volume for the flume is 6471 gal

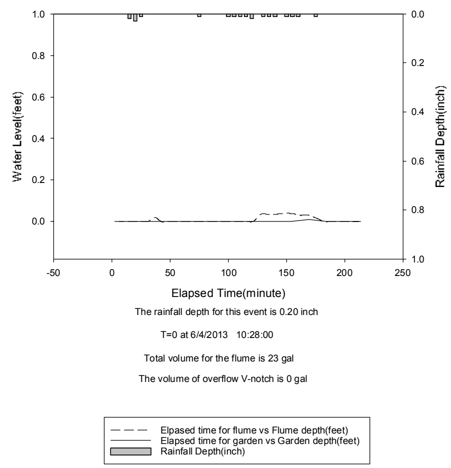
The flume ISCO stopped working at 5/30/2013 10:15

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

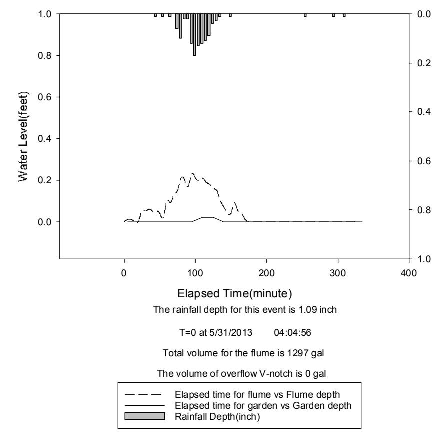
1325 76th on Rainevent 6/4/13



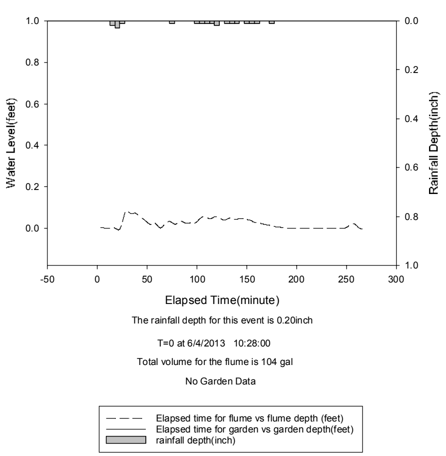
1222 76th on Rainevent 6/4/13



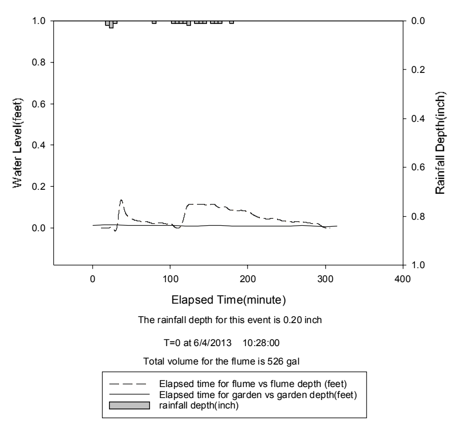
1140 76th terr on Rainevent 5/31/13



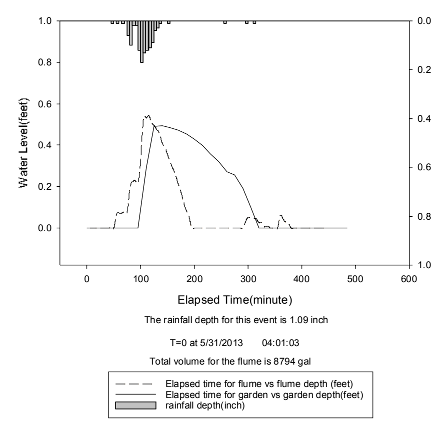
1336 76th on Rainevent 6/4/13



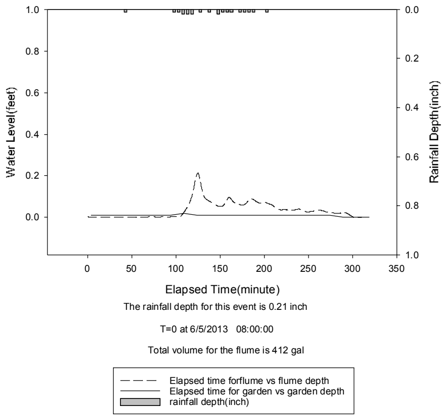
1324 76th on Rainevent 6/4/13



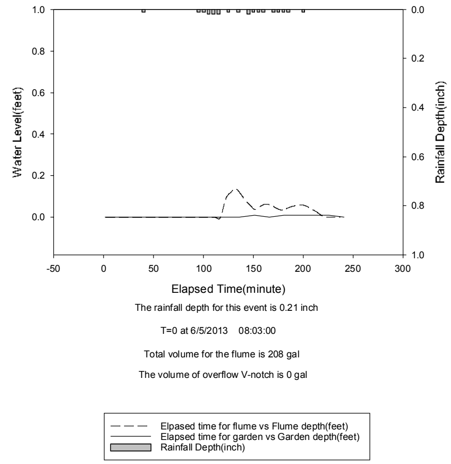
1112 76th Terr on Rainevent 5/31/13



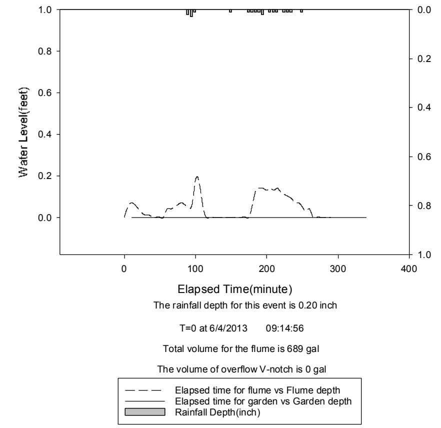
1325 76th on Rainevent 6/5/13



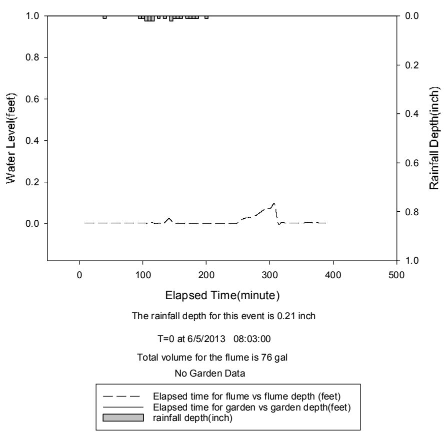
1222 76th on Rainevent 6/5/13



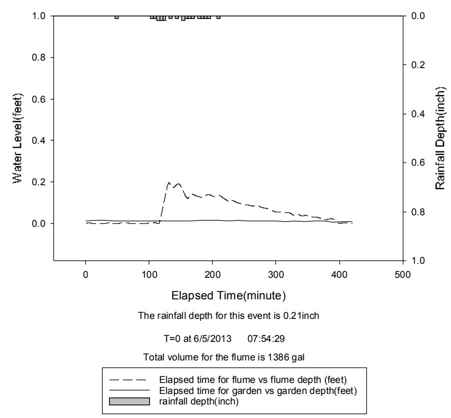
1140 76th terr on Rainevent 6/4/13



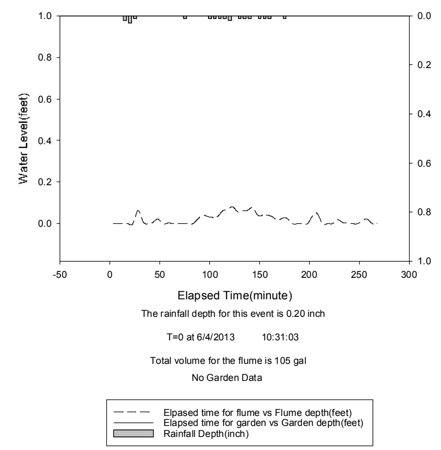
1336 76th on Rainevent 6/5/13



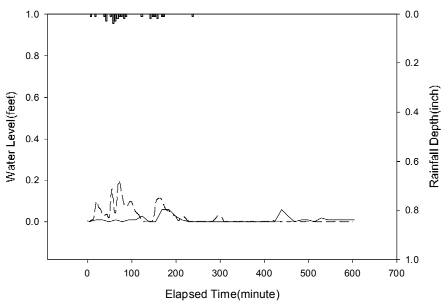
1324 76th on Rainevent 6/5/13



1112 76th on Rainevent 6/4/13



1325 76th on Rainevent 6/9/13



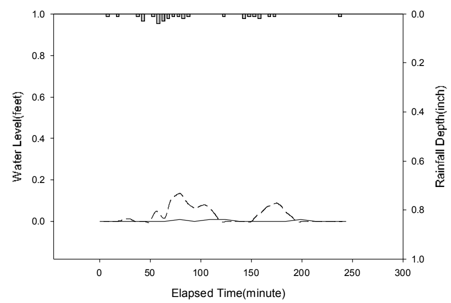
The rainfall depth for this event is 0.31 inch

T=0 at 6/9/2013 00:00:00

Total volume for the flume is 540 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1222 76th on Rainevent 6/9/13



The rainfall depth for this event is 0.31 inch

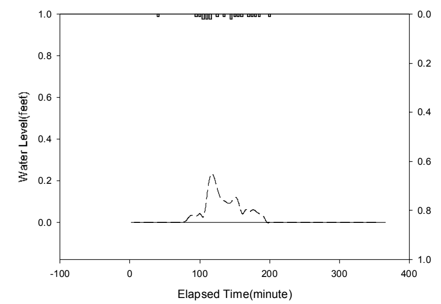
T=0 at 6/9/2013 00:00:00

Total volume for the flume is 249gal

The volume of overflow V-notch is 0 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1140 76th terr on Rainevent 6/5/13



The rainfall depth for this event is 0.21 inch

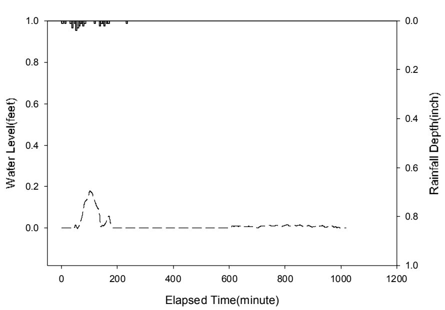
T=0 at6/5/2013 08:03:00

Total volume for the flume is 553gal

The volume of overflow V-notch is 0 gal

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1336 76th on Rainevent 6/9/13



The rainfall depth for this event is 0.31 inch

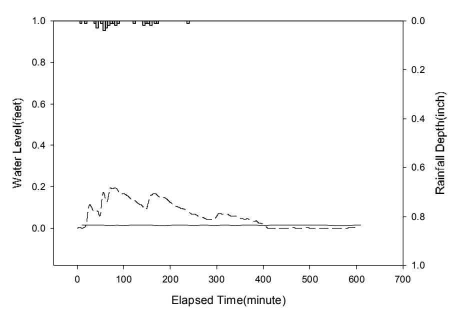
T=0 at 6/9/2013 00:01:06

Total volume for the flume is 583 gal

No Garden Data

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1324 76th on Rainevent 6/9/13



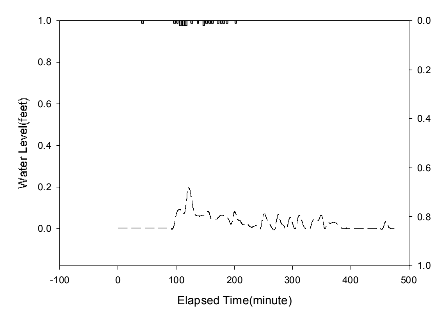
The rainfall depth for this event is 0.31inch

T=0 at 6/9/2013 00:00:00

Total volume for the flume is 2151 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1112 76th terr on Rainevent 6/5/13



The rainfall depth for this event is 0.21 inch

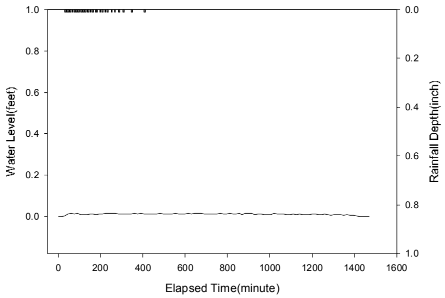
T=0 at6/5/2013 08:01:03

Total volume for the flume is 409 gal

No Garden Data

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1324 76th on Rainevent 6/15/13



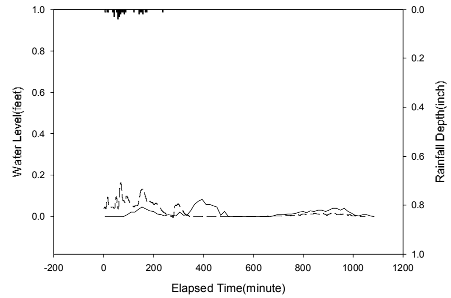
The rainfall depth for this event is 0.28 inch

T=0 at 6/15/2013 15:10:29

Flume ISCO stopped working on 6/14/2013 due to the low battery

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1112 76th on Rainevent 6/9/13



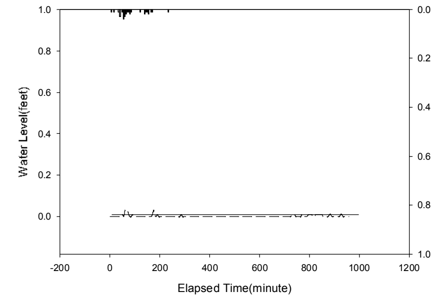
The rainfall depth for this event is 0.31 inch

T=0 at 6/9/2013 00:01:03

Total volume for the flume is 686 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1612 76th on Rainevent 6/9/13



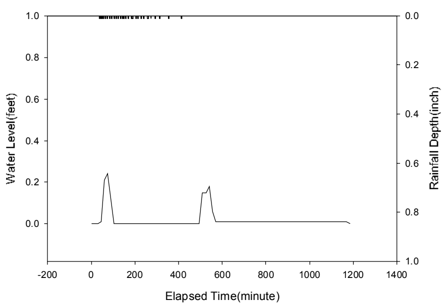
The rainfall depth for this event is 0.31 inch

T=0 at 6/9/2013 00:03:46

Total volume for the flume is 10 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1325 76th on Rainevent 6/15/13



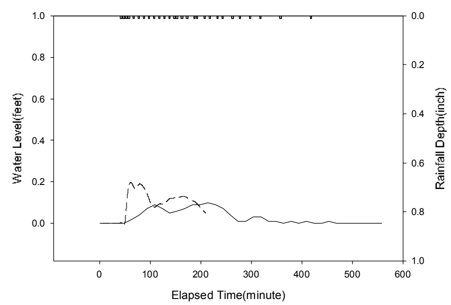
The rainfall depth for this event is 0.28 inch

T=0 at 6/15/2013 15:04:58

Flume ISCO stopped working on 6/14/2013 due to the low battery

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1222 76th on Rainevent 6/15/13



The rainfall depth for this event is 0.28 inch

T=0 at 6/15/2013 15:00:00

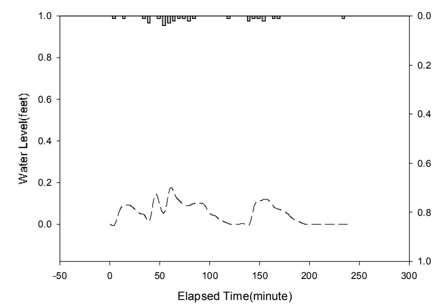
Total volume for the flume is 1253 gal

The volume of overflow V-notch is 66 gal

ISCO stopped working at 6/15/2013 18:30

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1140 76th terr on Rainevent 6/9/13



The rainfall depth for this event is 0.31 inch

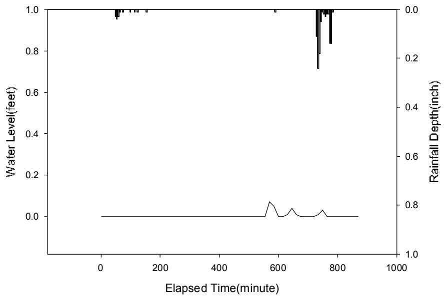
T=0 at6/9/2013 00:04:56

Total volume for the flume is 537 gal

No Garden Data

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1222 76th on Rainevent 6/27/13



The rainfall depth for this event is 1.14 inch

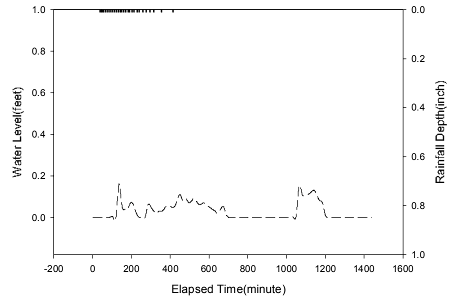
T=0 at 6/27/2013 10:34:03

There is no flume data due to removal of ISCO sampler

The volume of overflow V-notch is 8 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1140 76th terr on Rainevent 6/15/13



The rainfall depth for this event is 0.28 inch

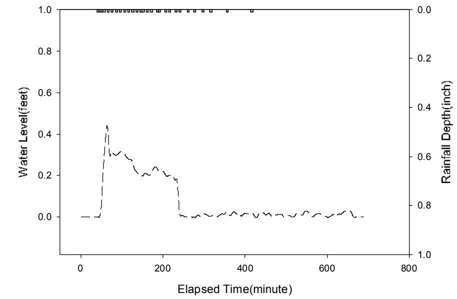
T=0 at6/15/2013 15:04:56

Total volume for the flume is 568 gal

There is no garden data from this location due to broked sensor

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1336 76th on Rainevent 6/15/13



The rainfall depth for this event is 0.28 inch

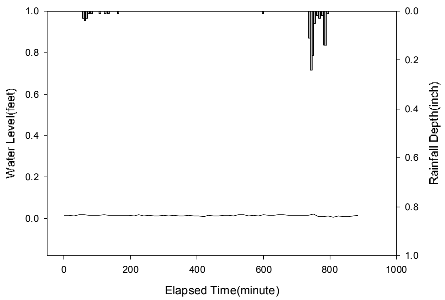
T=0 at 6/15/2013 15:01:06

Total volume for the flume is 6748 gal

There is no garden data from this location

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1324 76th on Rainevent 6/27/13



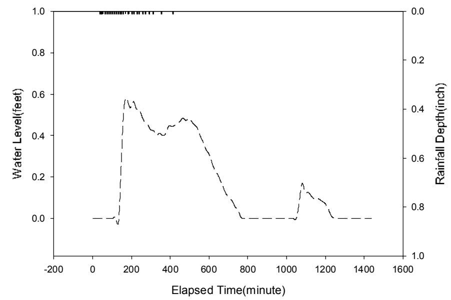
The rainfall depth for this event is 1.14 inch

T=0 at 6/27/2013 10:25:29

There is no flume data due to removal of ISCO sampler

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1112 76th on Rainevent 6/15/13



The rainfall depth for this event is 0.28 inch

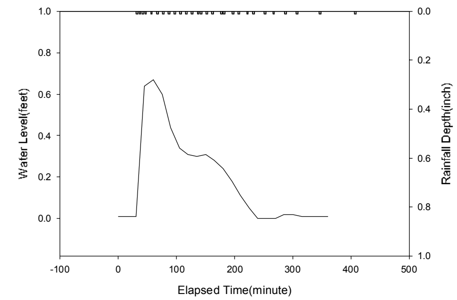
T=0 at 6/15/2013 15:01:03

Total volume for the flume is 20762 gal

There is no garden data from this location due to bad sensor

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1612 76th on Rainevent 6/15/13



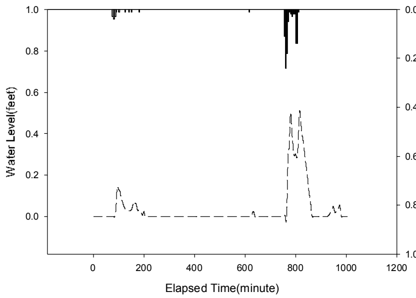
The rainfall depth for this event is 0.28inch

T=0 at 6/15/2013 15:11:49

There is no Flume data from this location due to bad battery

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1112 76th on Rainevent 6/27/13



The rainfall depth for this event is 1.14 inch

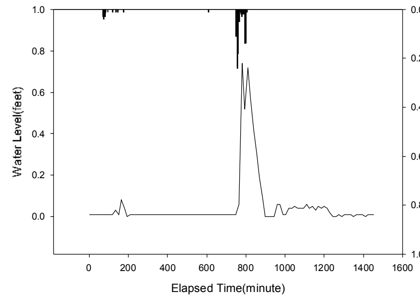
T=0 at 6/27/2013 10:06:03

Total volume for the flume is 6584 gal

There is no garden data from this location due to broken sensor

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1612 76th on Rainevent 6/27/13



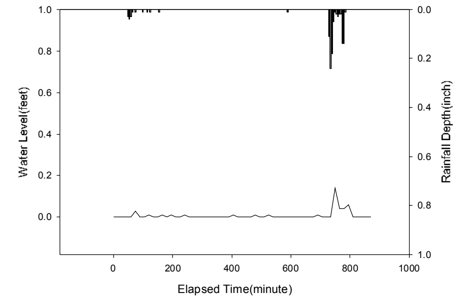
The rainfall depth for this event is 1.14 inch

T=0 at 6/27/2013 10:12:49

There is no flume data from this location due to bad batteries in sensor

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1325 76th on Rainevent 6/27/13



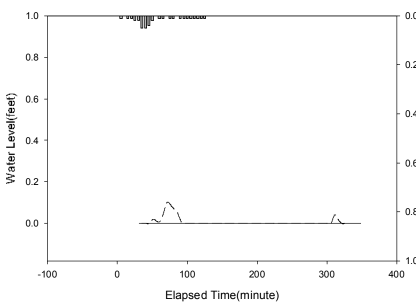
The rainfall depth for this event is 1.14 inch

T=0 at 6/27/2013 10:34:58

There is no flume data due to removal of ISCO sampler

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1222 76th on Rainevent 9/1/13



The rainfall depth for this event is 0.35 inch

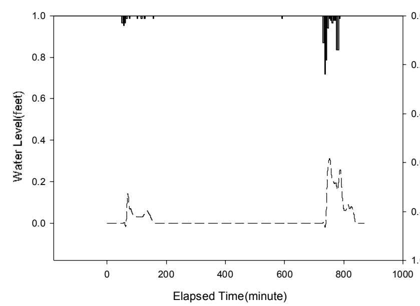
T=0 at 9/1/2013 07:01:09

Total volume for the flume is 66 gal

The volume of overflow V-notch is 0 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1140 76th terr on Rainevent 6/27/13



The rainfall depth for this event is 1.14 inch

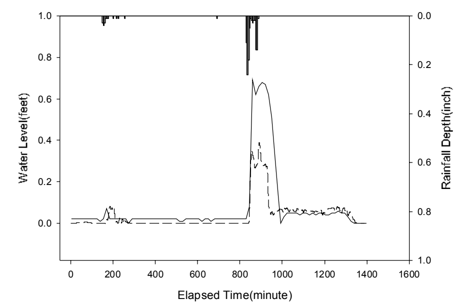
T=0 at6/27/2013 10:31:46

Total volume for the flume is 1676 gal

There is no garden data from this location due to broken sensor

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1336 76th on Rainevent 6/27/13



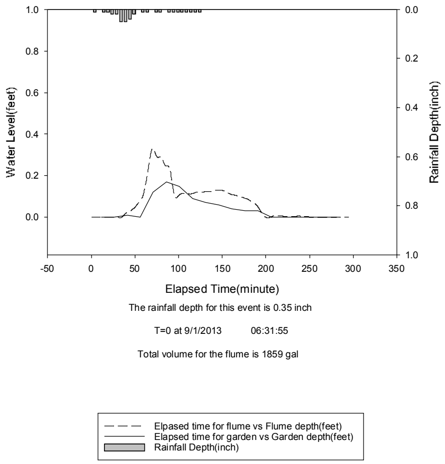
The rainfall depth for this event is 1.14 inch

T=0 at 6/27/2013 08:52:06

Total volume for the flume is 5041 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1112 76th on Rainevent 9/1/13

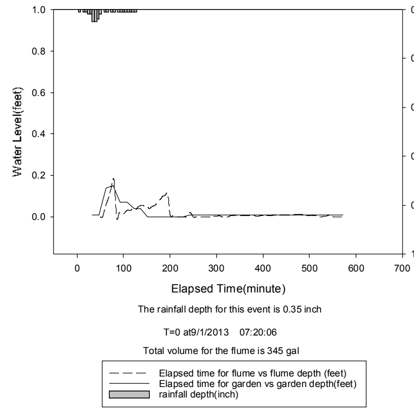


The rainfall depth for this event is 0.35 inch

T=0 at 9/1/2013 06:31:55

Total volume for the flume is 1859 gal

1336 76th on Rainevent 9/1/13

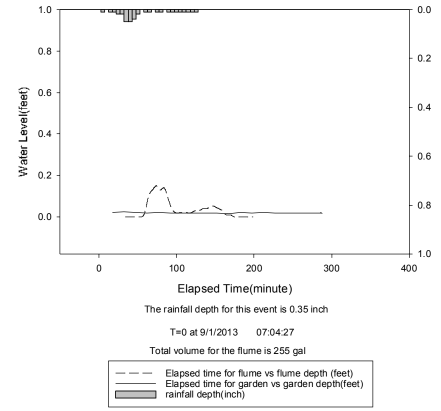


The rainfall depth for this event is 0.35 inch

T=0 at9/1/2013 07:20:06

Total volume for the flume is 345 gal

1324 76th on Rainevent 9/1/13

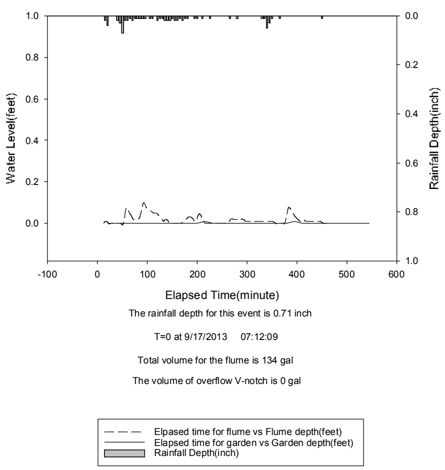


The rainfall depth for this event is 0.35 inch

T=0 at 9/1/2013 07:04:27

Total volume for the flume is 255 gal

1222 76th on Rainevent 9/17/13



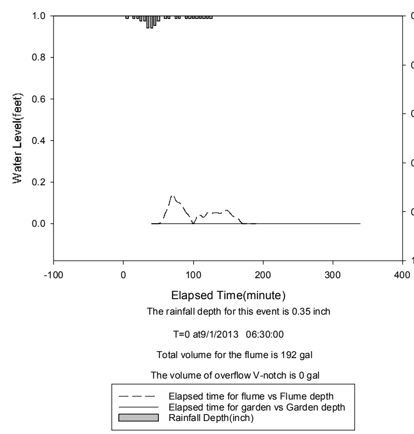
The rainfall depth for this event is 0.71 inch

T=0 at 9/17/2013 07:12:09

Total volume for the flume is 134 gal

The volume of overflow V-notch is 0 gal

1140 76th terr on Rainevent 9/1/13



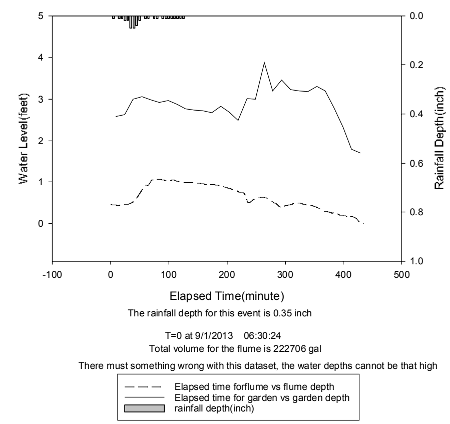
The rainfall depth for this event is 0.35 inch

T=0 at9/1/2013 06:30:00

Total volume for the flume is 192 gal

The volume of overflow V-notch is 0 gal

1325 76th on Rainevent 9/1/13



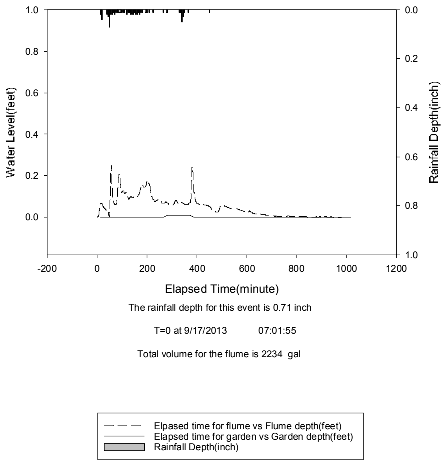
The rainfall depth for this event is 0.35 inch

T=0 at 9/1/2013 06:30:24

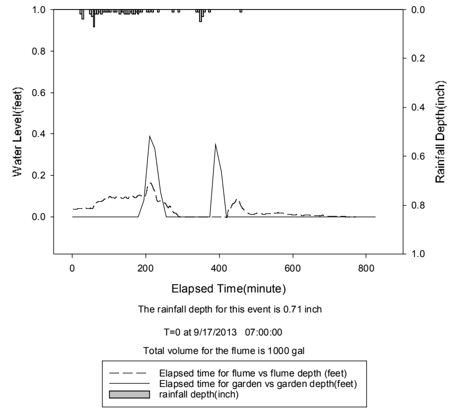
Total volume for the flume is 222706 gal

There must something wrong with this dataset, the water depths cannot be that high

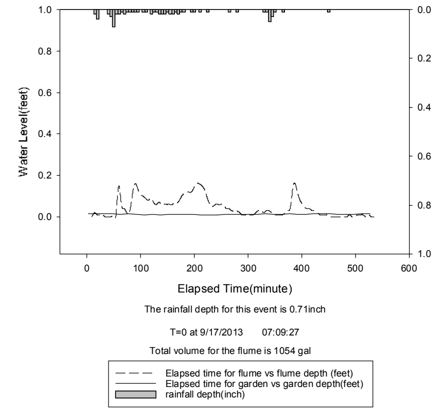
1112 76th on Rainevent 9/17/13



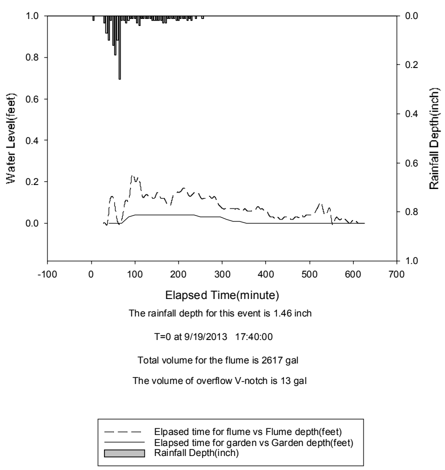
1336 76th on Rainevent 9/17/13



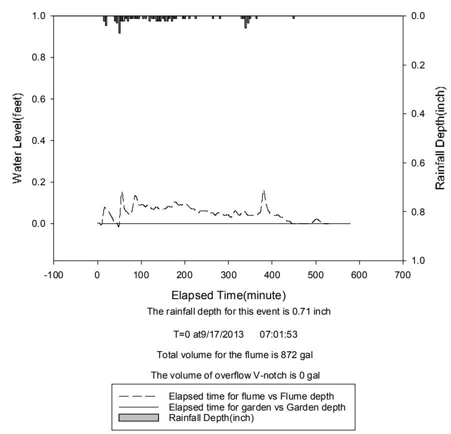
1324 76th on Rainevent 9/17/13



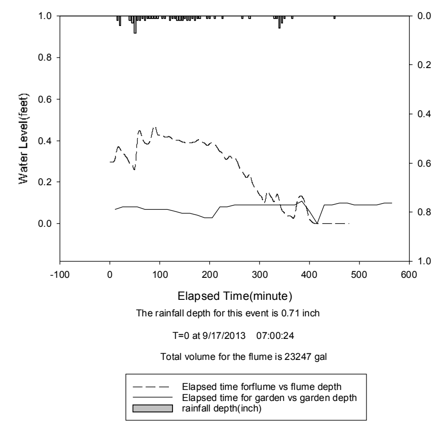
1222 76th on Rainevent 9/19/13

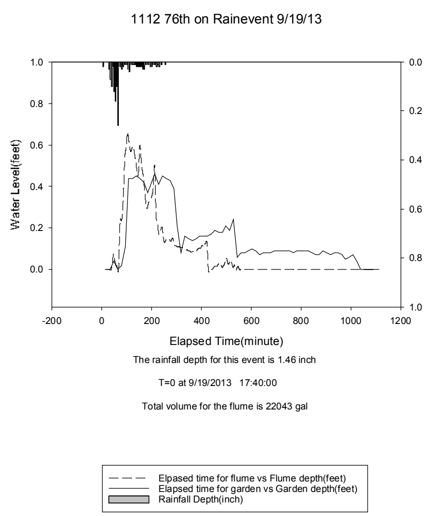


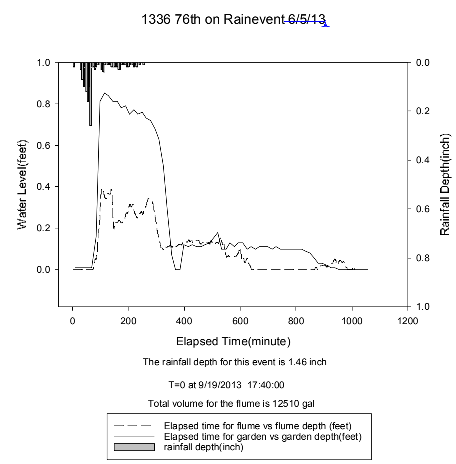
1140 76th terr on Rainevent 9/17/13

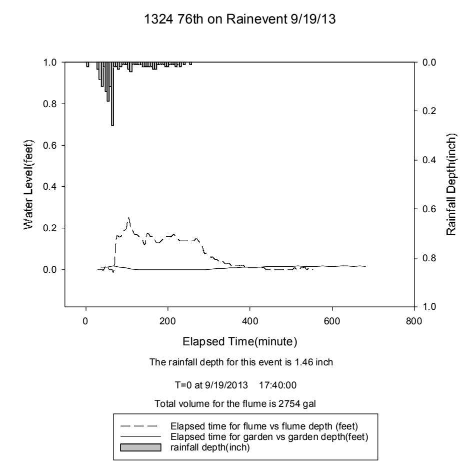


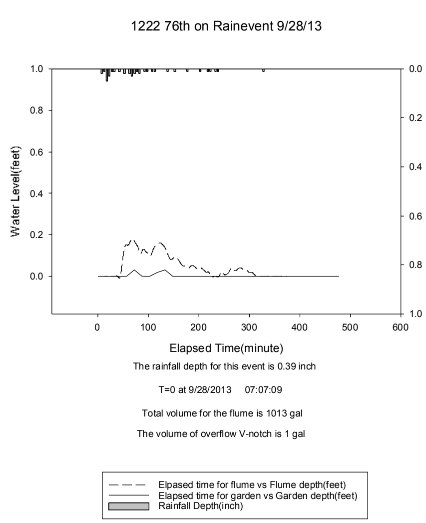
1325 76th on Rainevent 9/17/13

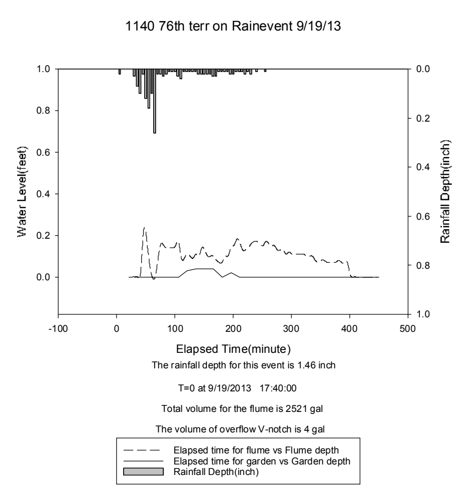


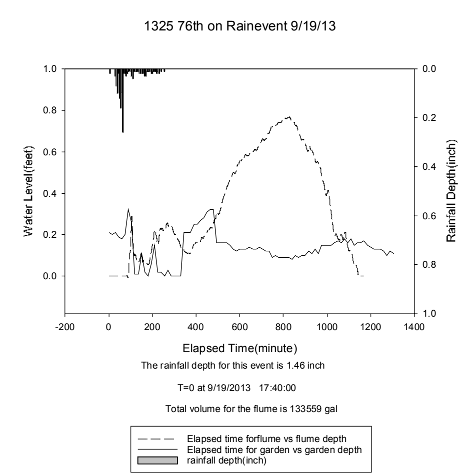

1112 76th on Rainevent 9/19/13
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 1.46 inch
T=0 at 9/19/2013 17:40:00
Total volume for the flume is 22043 gal
Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)


1336 76th on Rainevent 6/5/13
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 1.46 inch
T=0 at 9/19/2013 17:40:00
Total volume for the flume is 12510 gal
Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

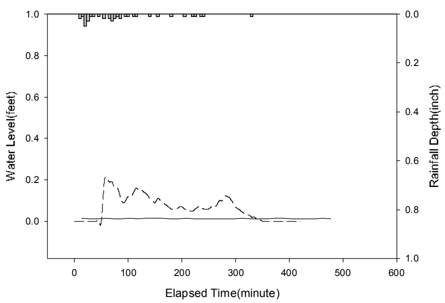

1324 76th on Rainevent 9/19/13
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 1.46 inch
T=0 at 9/19/2013 17:40:00
Total volume for the flume is 2754 gal
Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)


1222 76th on Rainevent 9/28/13
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 0.39 inch
T=0 at 9/28/2013 07:07:09
Total volume for the flume is 1013 gal
The volume of overflow V-notch is 1 gal
Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)


1140 76th terr on Rainevent 9/19/13
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 1.46 inch
T=0 at 9/19/2013 17:40:00
Total volume for the flume is 2521 gal
The volume of overflow V-notch is 4 gal
Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)


1325 76th on Rainevent 9/19/13
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 1.46 inch
T=0 at 9/19/2013 17:40:00
Total volume for the flume is 133559 gal
Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1324 76th on Rainevent 9/28/13



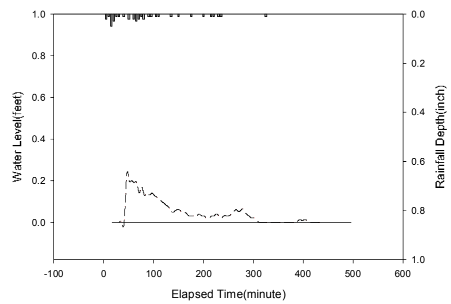
The rainfall depth for this event is 0.39 inch

T=0 at 9/28/2013 07:05:27

Total volume for the flume is 1466 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1140 76th terr on Rainevent 9/28/13



The rainfall depth for this event is 0.39 inch

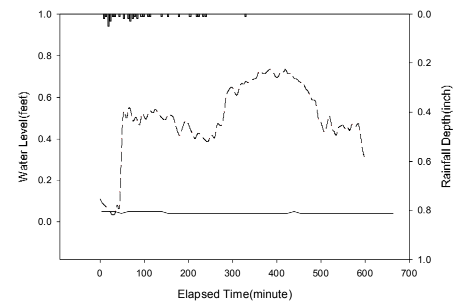
T=0 at 9/28/2013 07:10:00

Total volume for the flume is 1105 gal

The volume of overflow V-notch is 0 gal

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1325 76th on Rainevent 9/28/13



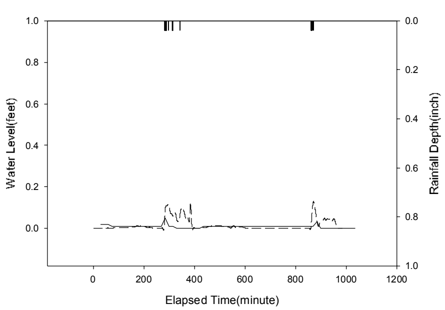
The rainfall depth for this event is 0.39 inch

T=0 at 9/28/2013 07:06:24

Total volume for the flume is 110159 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1222 76th on Rainevent 8/29/14



The rainfall depth for this event is 0.39 inch

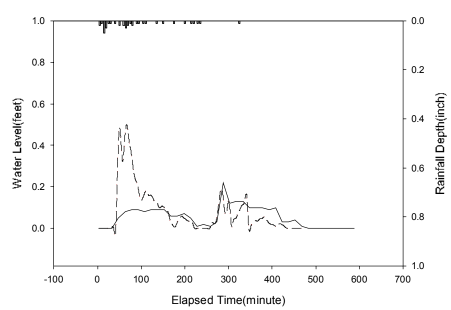
T=0 at 8/29/2014 06:35:06

Total volume for the flume is 422 gal

The volume overflow from V-notch is 4 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1112 76th on Rainevent 9/28/13



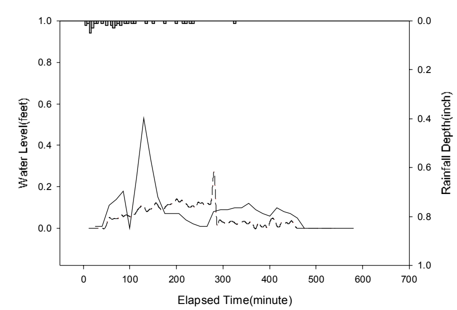
The rainfall depth for this event is 0.39 inch

T=0 at9/28/2013 07:10:00

Total volume for the flume is 5259 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1336 76th on Rainevent 9/28/13



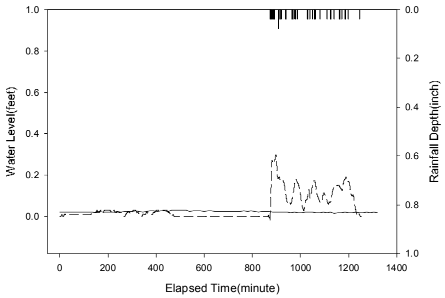
The rainfall depth for this event is 0.39 inch

T=0 at 9/28/2013 07:10:00

Total volume for the flume is 1293 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1324 76th on Rainevent 8/31/14



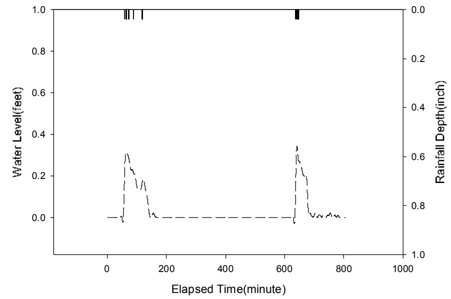
The rainfall depth for this event is 1.42 inch

T=0 at 8/31/14 08:02:34

Total volume for the flume is 3610 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1140 76th terr on Rainevent 8/29/14



The rainfall depth for this event is 0.39 inch

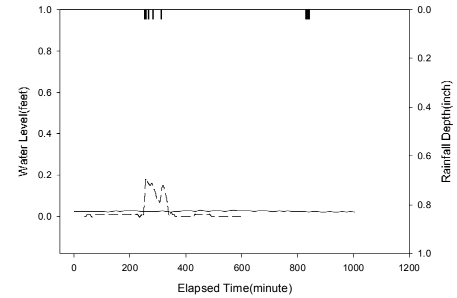
T=0 at 8/29/2014 10:19:59

Total volume for the flume is 3153 gal

No Garden Data for this event

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1324 76th on Rainevent 8/29/14



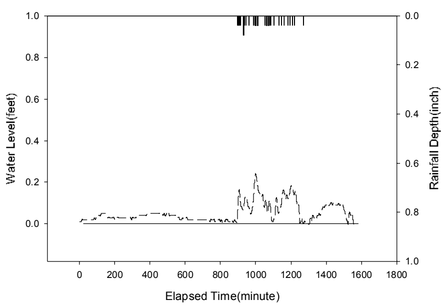
The rainfall depth for this event is 0.39 inch

T=0 at 8/29/14 07:05:10

Total volume for the flume is 701 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1325 76th on Rainevent 8/31/14



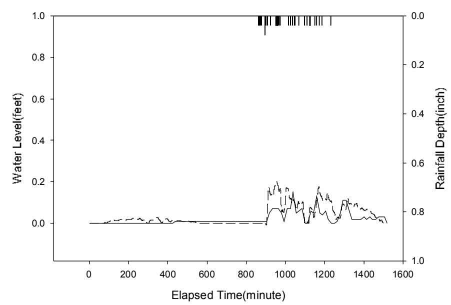
The rainfall depth for this event is 1.42 inch

T=0 at 8/31/2014 07:39:06

Total volume for the flume is 3370gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1222 76th on Rainevent 8/31/14



The rainfall depth for this event is 1.42 inch

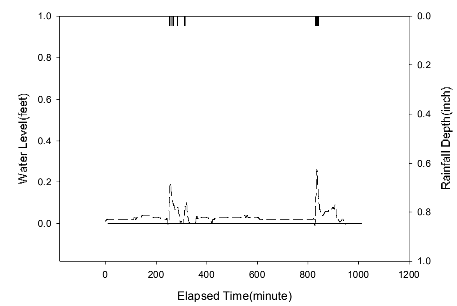
T=0 at 8/31/2014 07:30:06

Total volume for the flume is 2751 gal

The volume overflow from V-notch is 129 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1325 76th on Rainevent 8/29/14



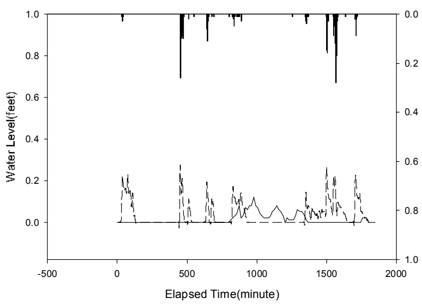
The rainfall depth for this event is 0.39 inch

T=0 at 8/29/2014 07:04:06

Total volume for the flume is 841 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1140 76th terr on Rainevent 10/1/14



The rainfall depth for this event is 2.71 inch

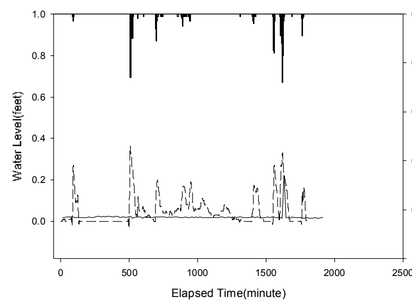
T=0 at 10/1/2014 10:04:59

Total volume for the flume is 4024 gal

The volume of overflow V-notch is 80gal

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1324 76th on Rainevent 10/1/14



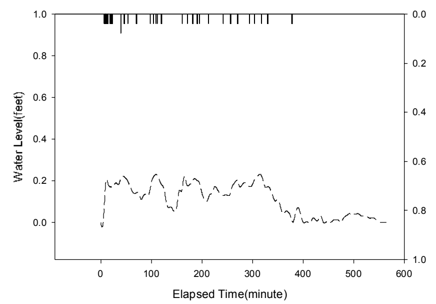
The rainfall depth for this event is 2.71inch

T=0 at10/1/14 09:08:34

Total volume for the flume is 6843 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1140 76th terr on Rainevent 8/31/14



The rainfall depth for this event is 1.42inch

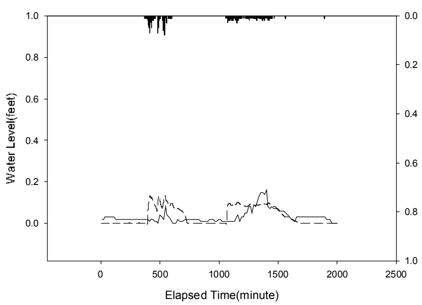
T=0 at 8/31/2014 22:29:59

Total volume for the flume is 4957 gal

No Garden Data for this event

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1222 76th on Rainevent 10/9/14



The rainfall depth for this event is 1.87 inch

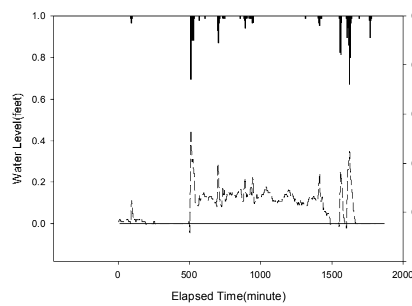
T=0 at10/9/2014 01:00:06

Total volume for the flume is 2831 gal

The volume of overflow V-notch is 317 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1325 76th on Rainevent 10/1/14



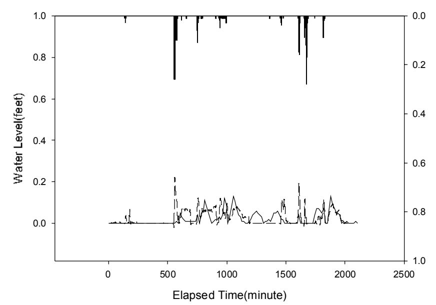
The rainfall depth for this event is 2.71inch

T=0 at10/1/2014 09:04:06

Total volume for the flume is 11503 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1222 76th on Rainevent 10/1/14



The rainfall depth for this event is 2.71 inch

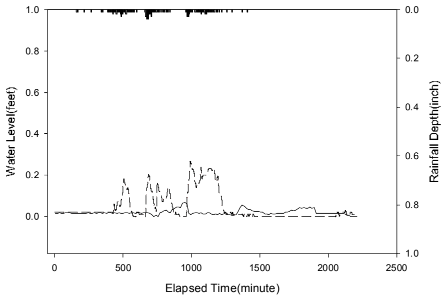
T=0 at10/1/2014 08:15:06

Total volume for the flume is 1756 gal

The volume of overflow is 176 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1324 76th on Rainevent 10/13/14



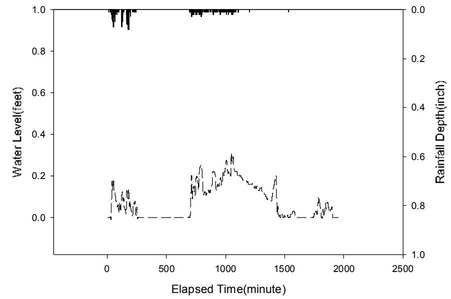
The rainfall depth for this event is 1.32 inch

T=0 at10/13/14 00:00:34

Total volume for the flume is 7072 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1140 76th terr on Rainevent 10/9/14



The rainfall depth for this event is 1.87inch

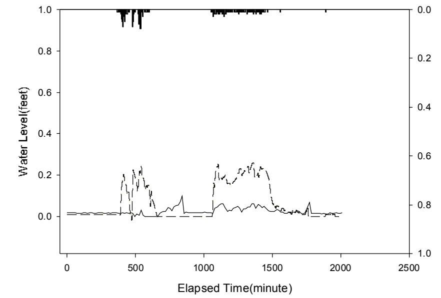
T=0 at 10/9/2014 07:00:59

Total volume for the flume is 12195 gal

The batteries were dead for garden sensors for this event

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1324 76th on Rainevent 10/9/14



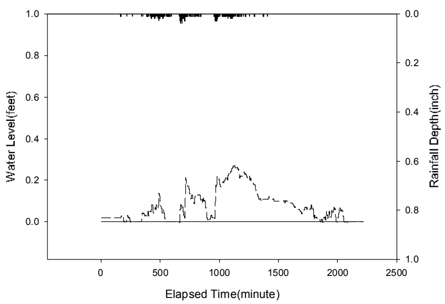
The rainfall depth for this event is1.87 inch

T=0 at10/9/14 01:04:34

Total volume for the flume is 12198 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1325 76th on Rainevent 10/13/14



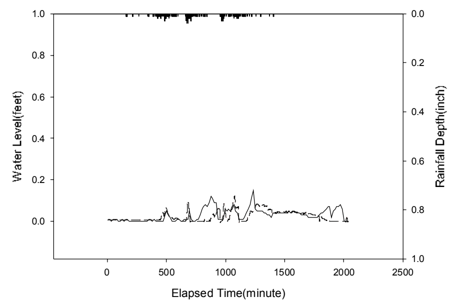
The rainfall depth for this event is 1.32inch

T=0 at10/13/2014 00:00:06

Total volume for the flume is 12583 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1222 76th on Rainevent 10/13/14



The rainfall depth for this event is 1.32inch

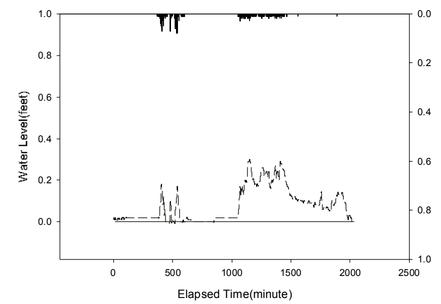
T=0 at10/13/2014 00:01:06

Total volume for the flume is 1051 gal

The volume of overflow V-notch is 212 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1325 76th on Rainevent 10/9/14



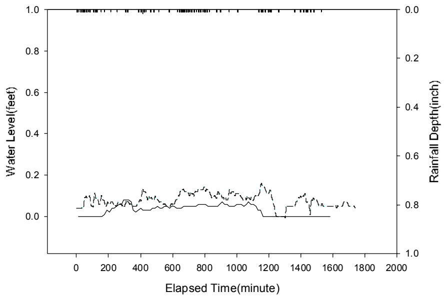
The rainfall depth for this event is 1.87 inch

T=0 at10/9/2014 01:04:06

Total volume for the flume is 13466 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1140 76th terr on Rainevent 3/18/15



The rainfall depth for this event is 0.67 inch

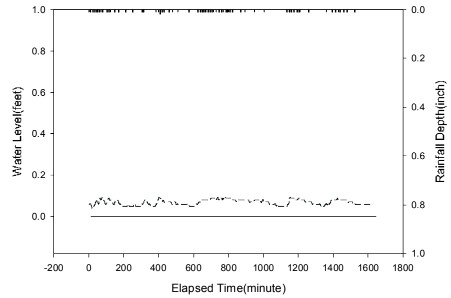
T=0 at 3/18/2015 12:39:31

Total volume for the flume is 5637 gal

The volume of overflow V-notch is 120 gal

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1325 76th on Rainevent 3/18/15



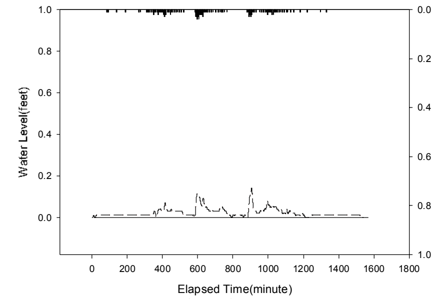
The rainfall depth for this event is 0.67inch

T=0 at 3/18/2015 12:43:12

Total volume for the flume is 3371 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1140 76th terr on Rainevent 10/13/14



The rainfall depth for this event is 1.32 inch

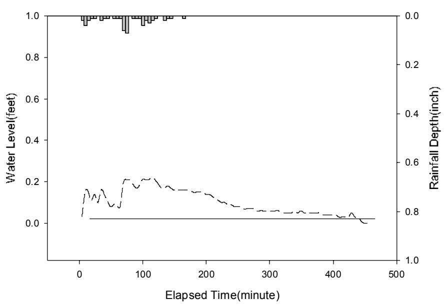
T=0 at 10/13/2014 01:17:59

Total volume for the flume is 598 gal

The volume of overflow V-notch is 0 gal

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1324 76th on Rainevent 4/2/15



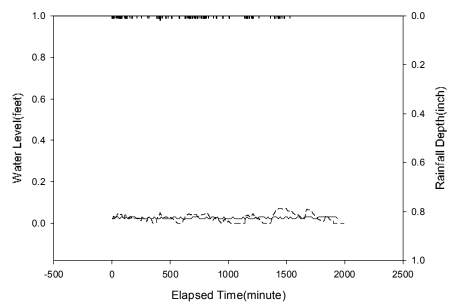
The rainfall depth for this event is 0.50 inch

T=0 at 3/2/14 03:52:24

Total volume for the flume is 3094gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1222 76th on Rainevent 3/18/15



The rainfall depth for this event is 0.67inch

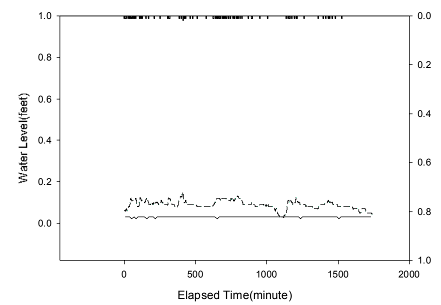
T=0 at3/18/2015 12:41:18

Total volume for the flume is 851 gal

The volume of overflow V-notch is 61 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1324 76th on Rainevent 3/18/15



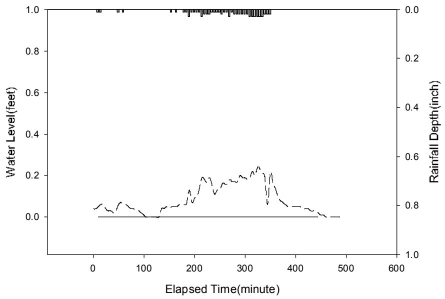
The rainfall depth for this event is 0.67 inch

T=0 at 3/18/14 12:42:24

Total volume for the flume is 6414 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1325 76th on Rainevent 4/12/15



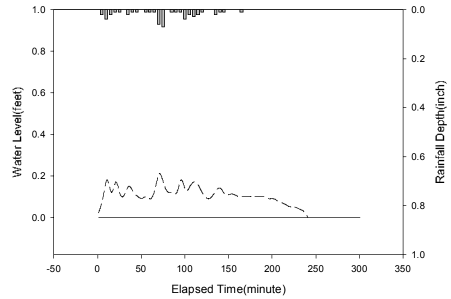
The rainfall depth for this event is 0.72 inch

T=0 at 4/12/2015 03:44:12

Total volume for the flume is 2814 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1140 76th terr on Rainevent 4/2/15



The rainfall depth for this event is 0.50 inch

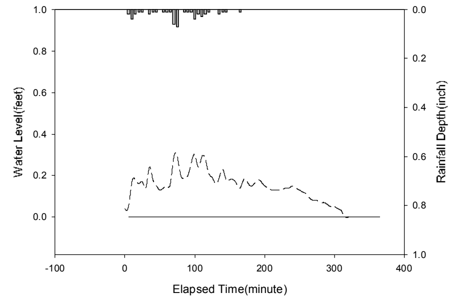
T=0 at 4/2/2015 03:49:31

Total volume for the flume is 1549gal

The volume of overflow V-notch is 0 gal

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1325 76th on Rainevent 4/2/15



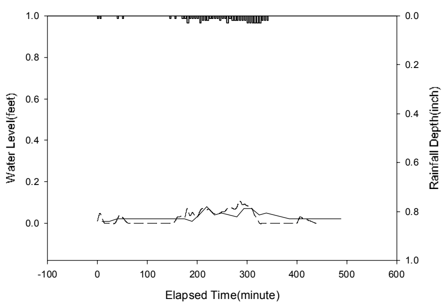
The rainfall depth for this event is 0.50 inch

T=0 at 4/2/2015 03:48:12

Total volume for the flume is 4616 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1222 76th on Rainevent 4/12/15



The rainfall depth for this event is 0.72inch

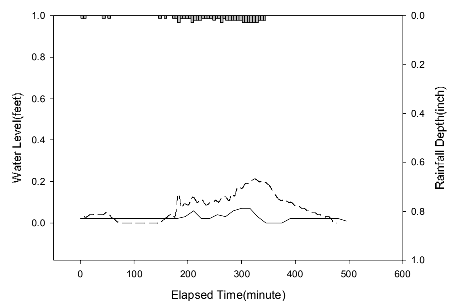
T=0 at4/12/2015 03:52:18

Total volume for the flume is 285 gal

The volume of overflow V-notch is 0.2 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1324 76th on Rainevent 4/12/15



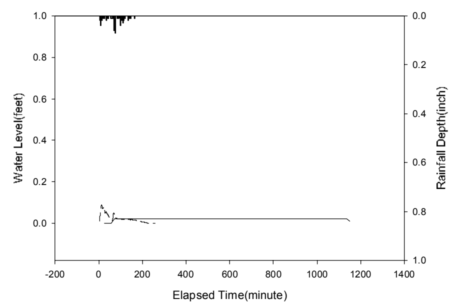
The rainfall depth for this event is 0.72 inch

T=0 at 3/12/15 03:50:25

Total volume for the flume is 2266 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1222 76th on Rainevent 4/2/15



The rainfall depth for this event is 0.50inch

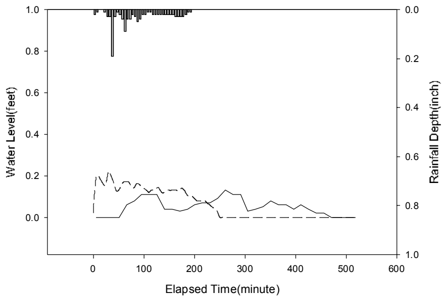
T=0 at4/2/2015 12:41:18

Total volume for the flume is 89 gal

The volume of overflow V-notch is 11 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1140 76th terr on Rainevent 4/13/15



The rainfall depth for this event is 1.10inch

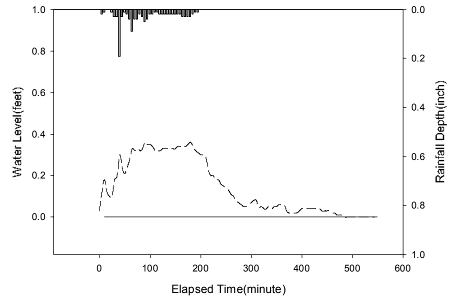
T=0 at 4/13/2015 00:00:31

Total volume for the flume is 2211 gal

The volume of overflow V-notch is 136 gal

Elapsed time for flume vs Flume depth
Elapsed Time for garden vs Garden depth
Rainfall Depth(inch)

1325 76th on Rainevent 4/13/15



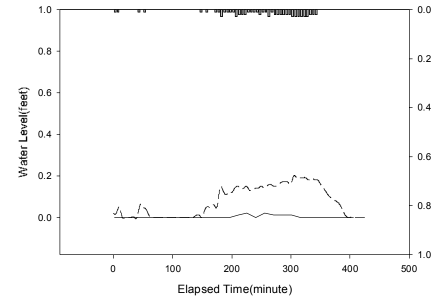
The rainfall depth for this event is 1.10inch

T=0 at 4/12/2015 23:59:12

Total volume for the flume is 11663 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1140 76th terr on Rainevent 4/12/15



The rainfall depth for this event is 0.72 inch

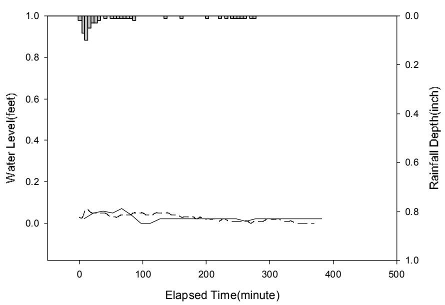
T=0 at 4/12/2015 03:50:31

Total volume for the flume is 2369 gal

The volume of overflow V-notch is 0.4 gal

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1324 76th on Rainevent 4/18/15



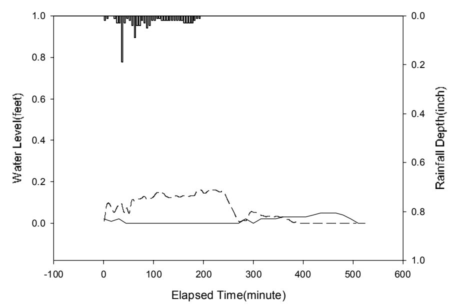
The rainfall depth for this event is 0.54 inch

T=0 at 3/19/15 09:42:24

Total volume for the flume is 148gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1222 76th on Rainevent 4/13/15



The rainfall depth for this event is 1.10 inch

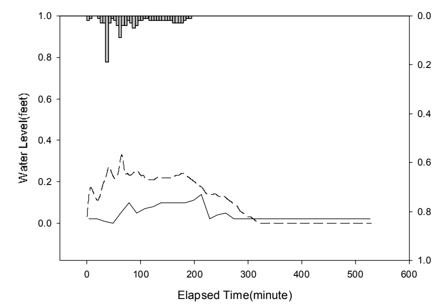
T=0 at4/13/2015 00:01:41

Total volume for the flume is 1973 gal

The volume of overflow V-notch is 10 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1324 76th on Rainevent 4/13/15



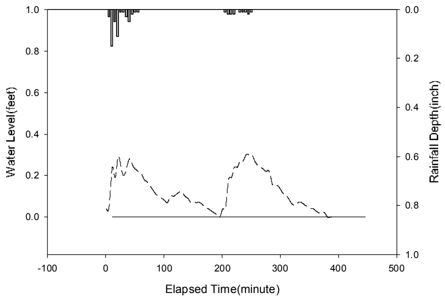
The rainfall depth for this event is 1.10 inch

T=0 at 3/13/15 00:02:24

Total volume for the flume is 6051 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1325 76th on Rainevent 4/18/15



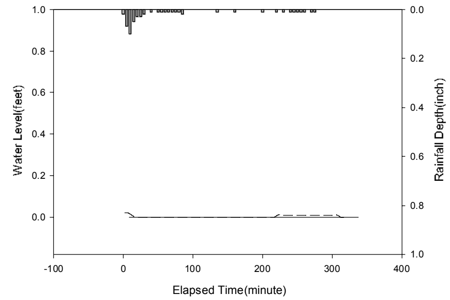
The rainfall depth for this event is 0.61 inch

T=0 at 4/19/2015 00:44:12

Total volume for the flume is 5188 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1140 76th terr on Rainevent 4/18/15



The rainfall depth for this event is 0.54inch

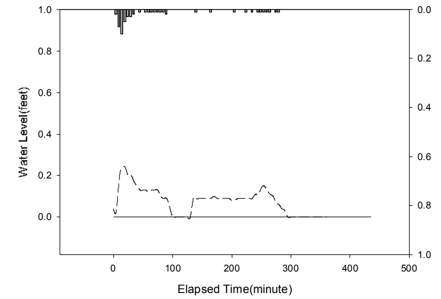
T=0 at 4/18/2015 9:43:00

Total volume for the flume is 4 gal

The volume of overflow V-notch is 0

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1325 76th on Rainevent 4/18/15



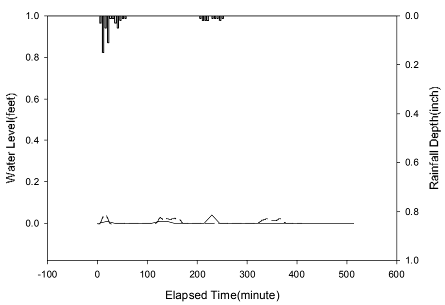
The rainfall depth for this event is 0.54 inch

T=0 at 4/18/2015 09:39:12

Total volume for the flume is 1730 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1222 76th on Rainevent 4/19/15



The rainfall depth for this event is 0.61 inch

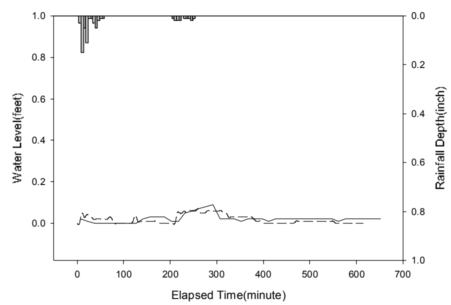
T=0 at4/19/2015 00:42:18

Total volume for the flume is 18 gal

The volume of overflow V-notch is 1 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1324 76th on Rainevent 4/19/15



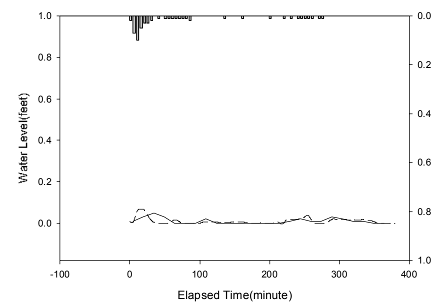
The rainfall depth for this event is 0.61 inch

T=0 at 3/19/15 00:42:24

Total volume for the flume is 190 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1222 76th on Rainevent 4/18/15



The rainfall depth for this event is 0.54 inch

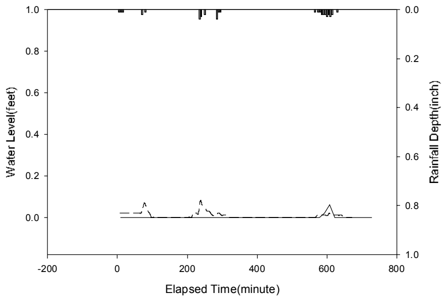
T=0 at4/18/2015 09:42:18

Total volume for the flume is 44 gal

The volume of overflow V-notch is 4 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1140 76th terr on Rainevent 4/25/15



The rainfall depth for this event is 0.41inch

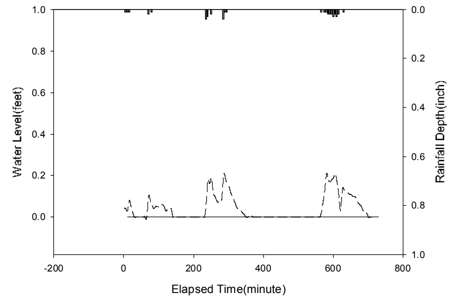
T=0 at 4/25/2015 2:58:00

Total volume for the flume is 70 gal

The volume of overflow V-notch is 3

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1325 76th on Rainevent 4/25/15



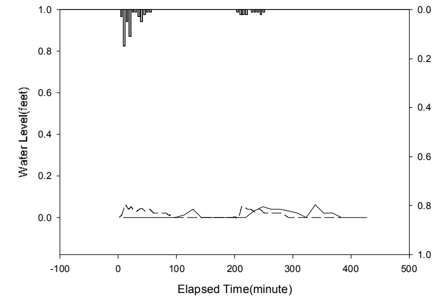
The rainfall depth for this event is 0.41 inch

T=0 at 4/25/2015 2:58:00

Total volume for the flume is 1891 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1140 76th terr on Rainevent 4/19/15



The rainfall depth for this event is 0.61inch

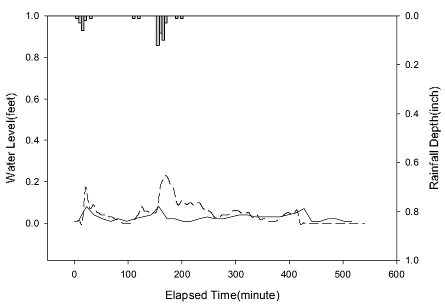
T=0 at 4/19/2015 00:43:00

Total volume for the flume is 63 gal

The volume of overflow V-notch is 9

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1324 76th on Rainevent 5/4/15



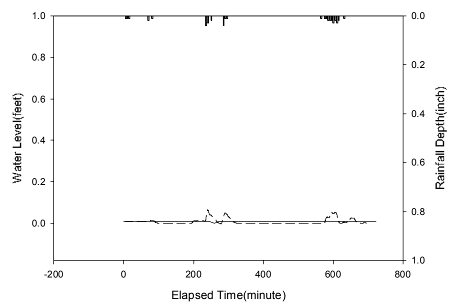
The rainfall depth for this event is 0.49 inch

T=0 at 5/4/2015 20:28:24

Total volume for the flume is 1163 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1222 76th on Rainevent 4/25/15



The rainfall depth for this event is 0.41 inch

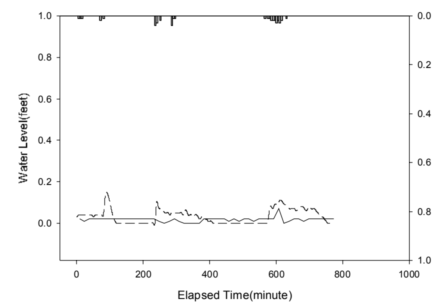
T=0 at4/25/2015 02:57:18

Total volume for the flume is 63 gal

The volume of overflow V-notch is 1 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1324 76th on Rainevent 4/25/15



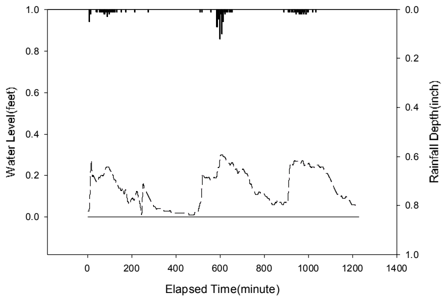
The rainfall depth for this event is 0.41 inch

T=0 at 4/25/15 02:57:24

Total volume for the flume is 778 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1325 76th on Rainevent 5/7/15



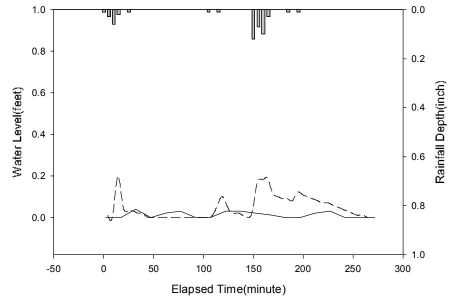
The rainfall depth for this event is 1.19 inch

T=0 at 5/7/2015 11:40:12

Total volume for the flume is 17372 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1140 76th terr on Rainevent 5/4/15



The rainfall depth for this event is 0.49inch

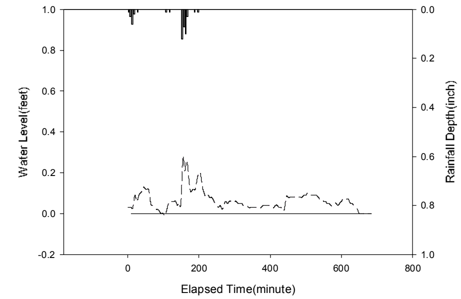
T=0 at 5/4/2015 22:07:31

Total volume for the flume is 664gal

The volume of overflow V-notch is 3.5 gal

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1325 76th on Rainevent 5/4/15



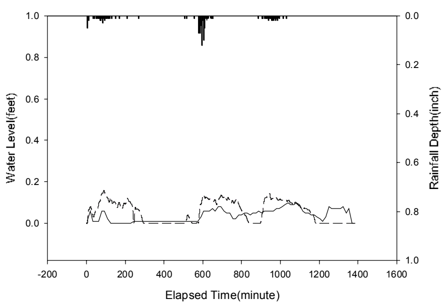
The rainfall depth for this event is 0.49 inch

T=0 at 5/4/2015 22:30:12

Total volume for the flume is 2026 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1222 76th on Rainevent 5/7/15



The rainfall depth for this event is 1.19 inch

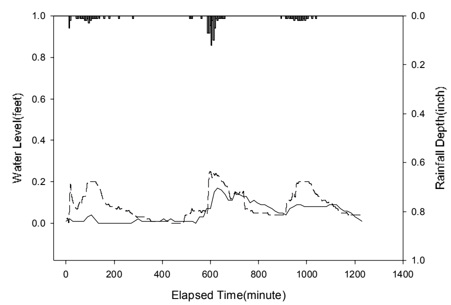
T=0 at 5/7/2015 11:43:18

Total volume for the flume is 3656 gal

The volume of overflow V-notch is 168 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1324 76th on Rainevent 5/7/2015



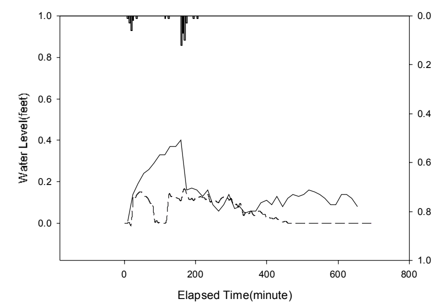
The rainfall depth for this event is 1.19 inch

T=0 at 5/7/2015 11:38:24

Total volume for the flume is 7324 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1222 76th on Rainevent 5/4/15



The rainfall depth for this event is 0.49inch

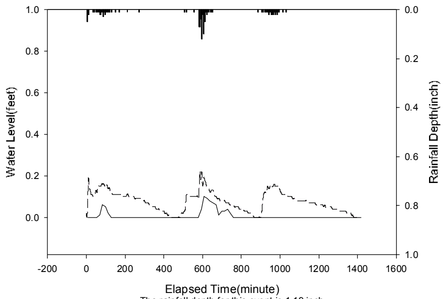
T=0 at 5/4/2015 20:38:18

Total volume for the flume is 1927 gal

The volume of overflow V-notch is 2270 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1140 76th terr on Rainevent 5/7/15



The rainfall depth for this event is 1.19 inch

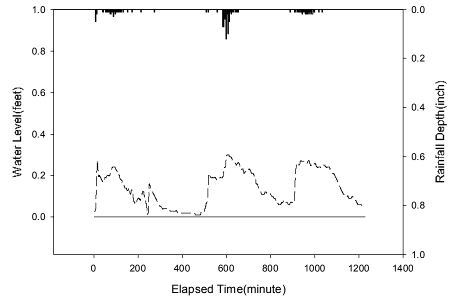
T=0 at 5/7/2015 11:42:31

Total volume for the flume is 5381 gal

The volume of overflow V-notch is 36 gal

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1325 76th on Rainevent 5/7/15



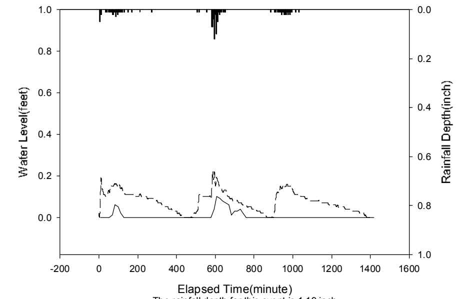
The rainfall depth for this event is 1.19 inch

T=0 at 5/7/2015 11:40:12

Total volume for the flume is 17372 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1140 76th terr on Rainevent 5/7/15



The rainfall depth for this event is 1.19 inch

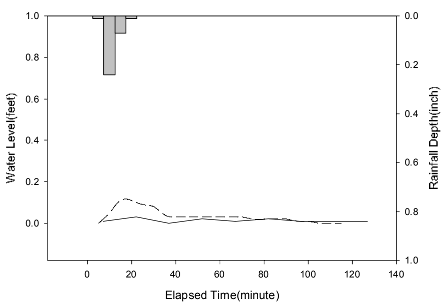
T=0 at 5/7/2015 11:42:31

Total volume for the flume is 5381 gal

The volume of overflow V-notch is 36 gal

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1324 76th on Rainevent 5/15/15



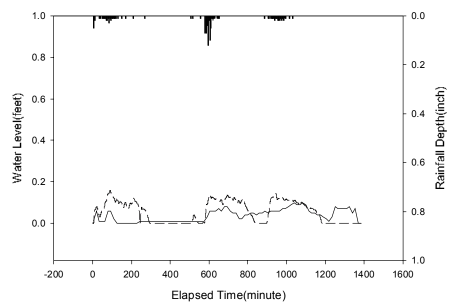
The rainfall depth for this event is 0.33inch

T=0 at5/15/2015 12:48:24

Total volume for the flume is 110 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1222 76th on Rainevent 5/7/15



The rainfall depth for this event is 1.19 inch

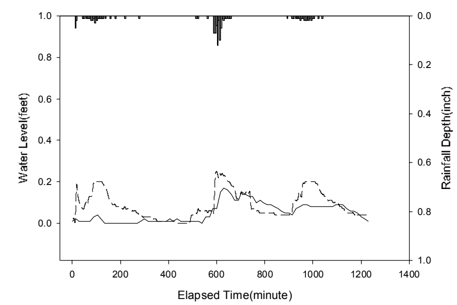
T=0 at 5/7/2015 11:43:18

Total volume for the flume is 3656 gal

The volume of overflow V-notch is 168 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1324 76th on Rainevent 5/7/2015



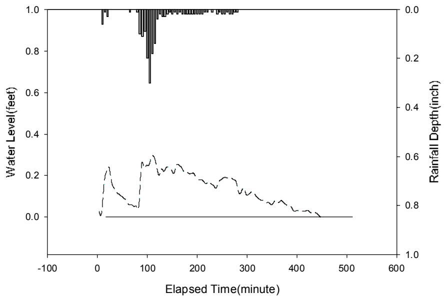
The rainfall depth for this event is 1.19 inch

T=0 at 5/7/2015 11:38:24

Total volume for the flume is 7324 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1325 76th on Rainevent 5/16/15



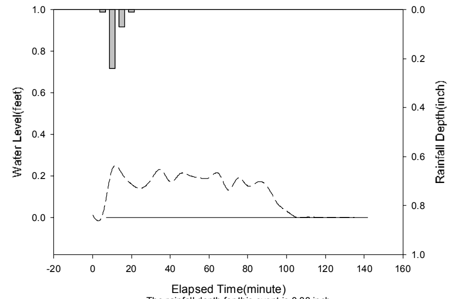
The rainfall depth for this event is 1.80 inch

T=0 at 5/16/2015 22:11:12

Total volume for the flume is 5708 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1140 76th terr on Rainevent 5/15/15



The rainfall depth for this event is 0.33 inch

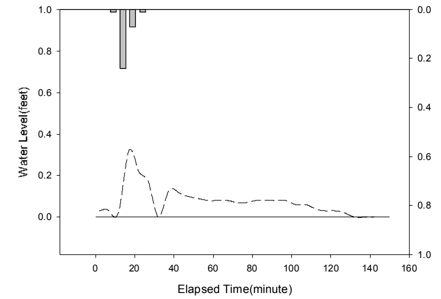
T=0 at 5/15/2015 12:43:31

Total volume for the flume is 1516 gal

The volume of overflow V-notch is 0 gal

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1325 76th on Rainevent 5/15/15



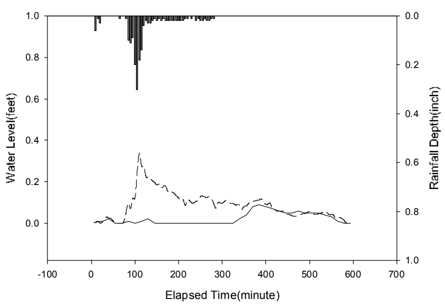
The rainfall depth for this event is 0.33 inch

T=0 at 5/15/2015 12:41:12

Total volume for the flume is 746 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1222 76th on Rainevent 5/16/15



The rainfall depth for this event is 1.80 inch

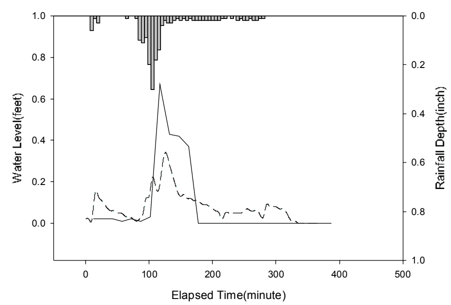
T=0 at 5/16/2015 22:13:18

Total volume for the flume is 3525 gal

The volume of overflow V-notch is 41 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1324 76th on Rainevent 5/16/15



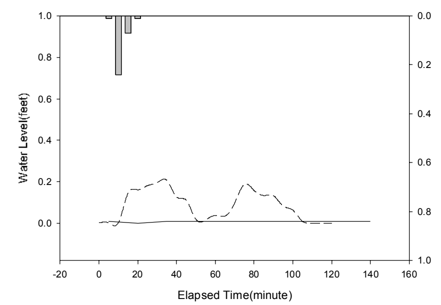
The rainfall depth for this event is 1.80 inch

T=0 at 5/16/2015 22:08:24

Total volume for the flume is 1946 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1222 76th on Rainevent 5/15/15



The rainfall depth for this event is 0.33 inch

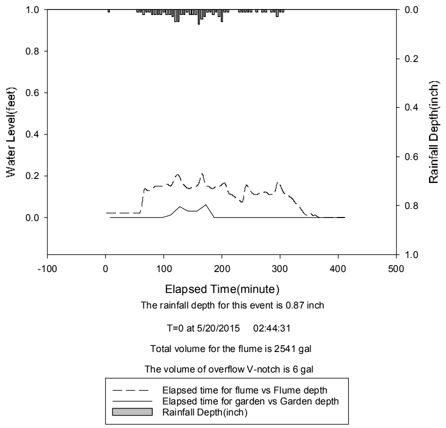
T=0 at 5/15/2015 12:43:18

Total volume for the flume is 766 gal

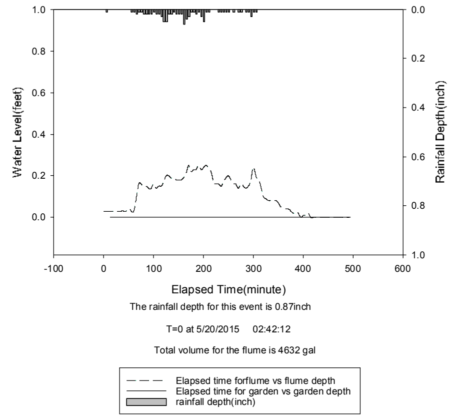
The volume of overflow V-notch is 0.24 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

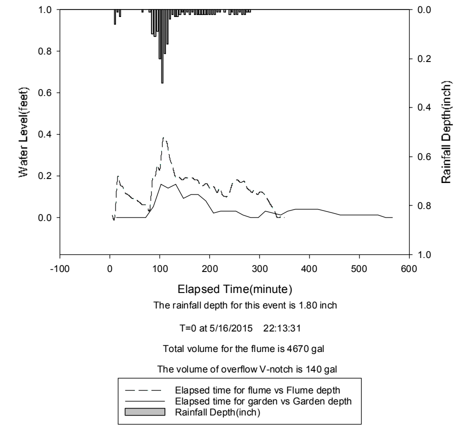
1140 76th terr on Rainevent 5/20/15



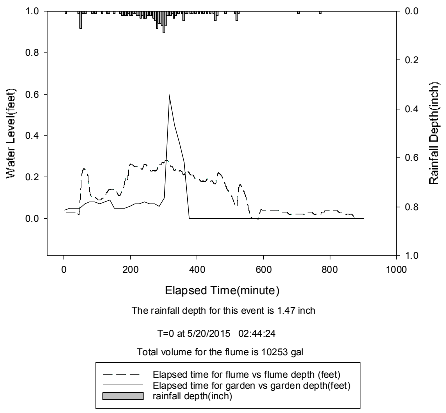
1325 76th on Rainevent 5/20/15



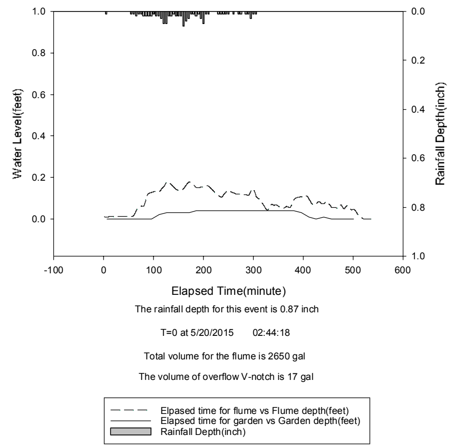
1140 76th terr on Rainevent 5/16/15



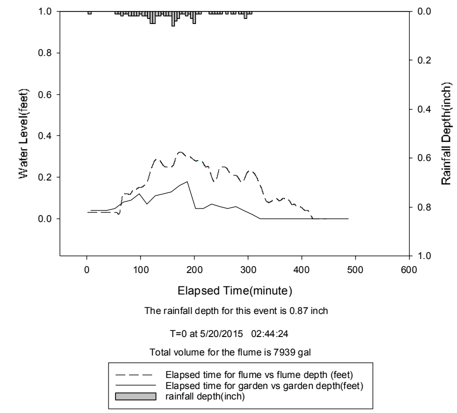
1324 76th on Rainevent 5/23/15



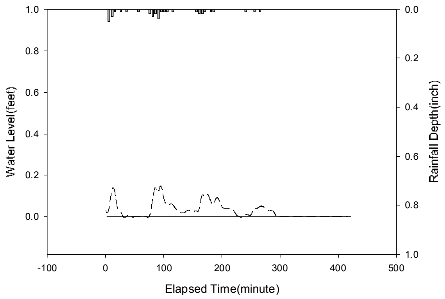
1222 76th on Rainevent 5/20/15



1324 76th on Rainevent 5/20/15



1325 76th on Rainevent 5/26/15



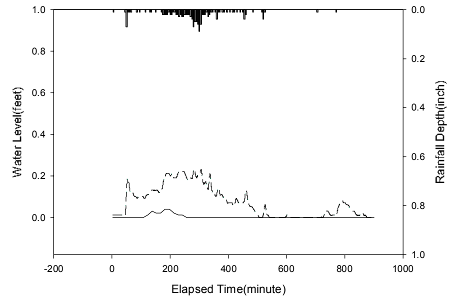
The rainfall depth for this event is 0.38 inch

T=0 at 5/26/2015 01:52:12

Total volume for the flume is 449 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1140 76th terr on Rainevent 5/23/15



The rainfall depth for this event is 1.47 inch

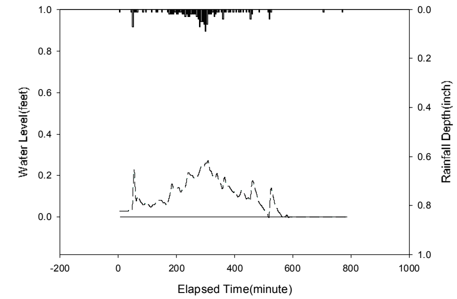
T=0 at 5/23/2015 19:04:31

Total volume for the flume is 4881 gal

The volume of overflow V-notch is 3 gal

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1325 76th on Rainevent 5/23/15



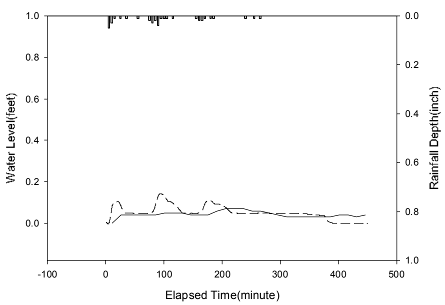
The rainfall depth for this event is 1.47inch

T=0 at 5/23/2015 19:07:12

Total volume for the flume is 5013 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1222 76th on Rainevent 5/26/15



The rainfall depth for this event is 0.38 inch

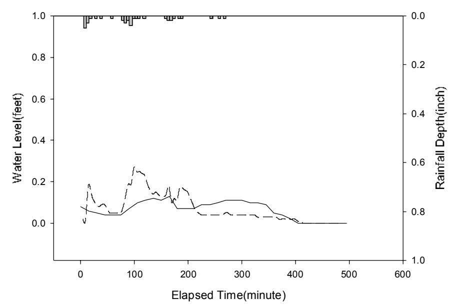
T=0 at 5/26/2015 01:54:18

Total volume for the flume is 728 gal

The volume of overflow V-notch is 43 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1324 76th on Rainevent 5/26/15



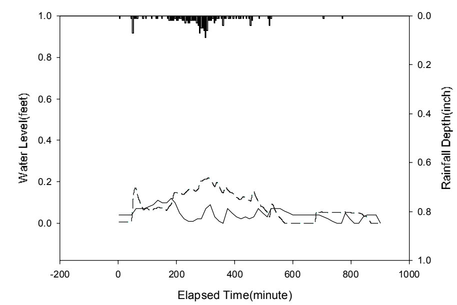
The rainfall depth for this event is 0.38 inch

T=0 at 5/26/2015 01:54:24

Total volume for the flume is 2371 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1222 76th on Rainevent 5/23/15



The rainfall depth for this event is 1.47 inch

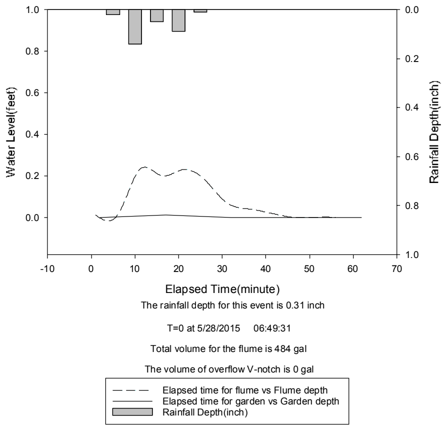
T=0 at 5/23/2015 19:04:18

Total volume for the flume is 4579 gal

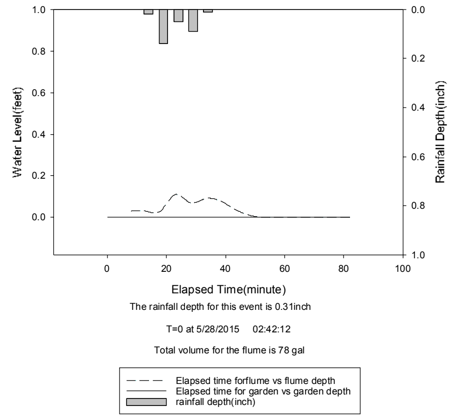
The volume of overflow V-notch is 147 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

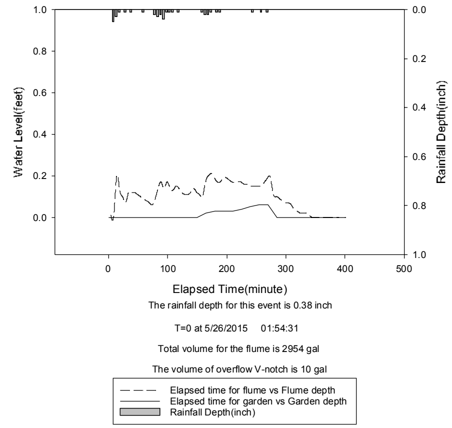
1140 76th terr on Rainevent 5/28/15



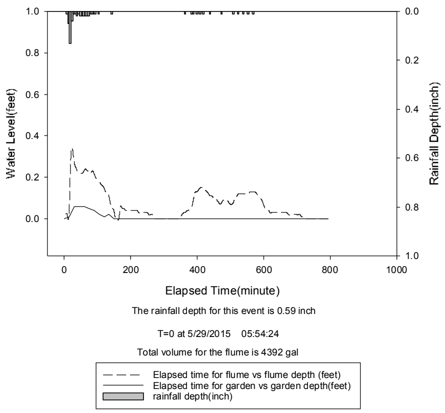
1325 76th on Rainevent 5/28/15



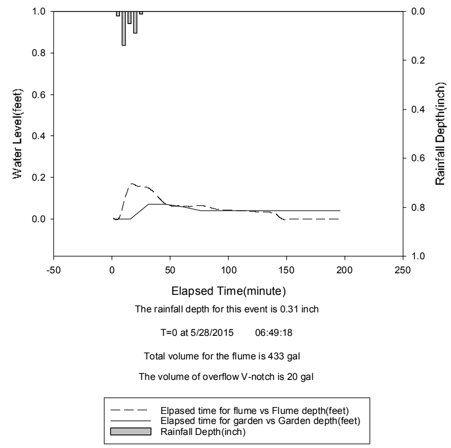
1140 76th terr on Rainevent 5/26/15



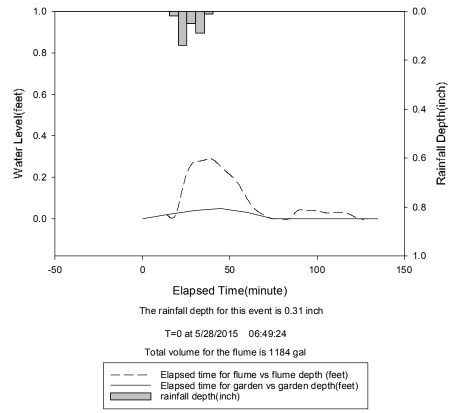
1324 76th on Rainevent 5/29/15



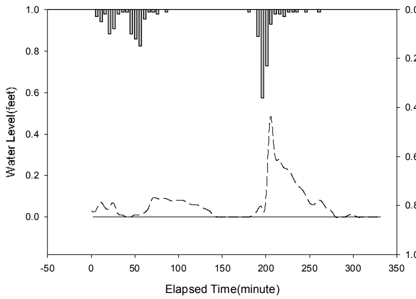
1222 76th on Rainevent 5/28/15



1324 76th on Rainevent 5/28/15



1325 76th on Rainevent 6/3/15



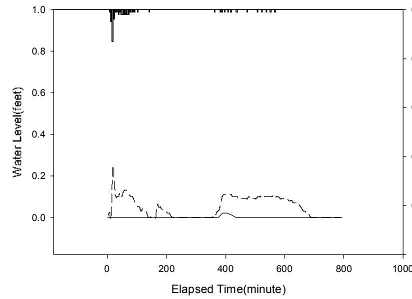
The rainfall depth for this event is 1.67 inch

T=0 at 6/3/2015 08:37:12

Total volume for the flume is 2012 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1140 76th terr on Rainevent 5/29/15



The rainfall depth for this event is 0.59 inch

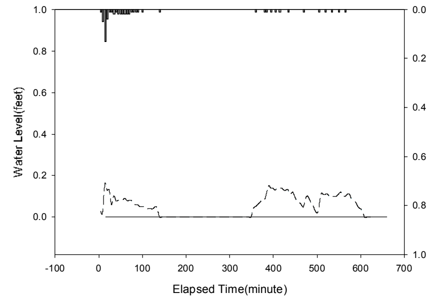
T=0 at 5/29/2015 05:54:31

Total volume for the flume is 1754 gal

The volume of overflow V-notch is 0 gal

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

1325 76th on Rainevent 5/29/15



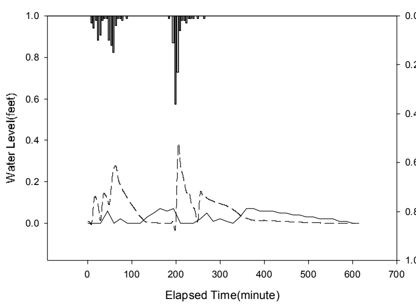
The rainfall depth for this event is 0.59inch

T=0 at 5/29/2015 05:57:12

Total volume for the flume is 1500 gal

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

1222 76th on Rainevent 6/3/15



The rainfall depth for this event is 1.67 inch

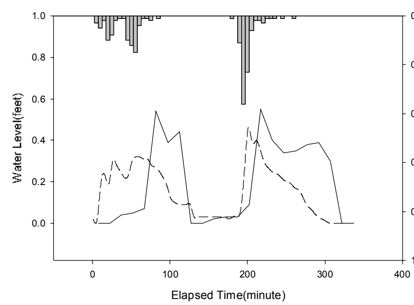
T=0 at 6/3/2015 08:34:18

Total volume for the flume is 2586 gal

The volume of overflow V-notch is 43 gal

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

1324 76th on Rainevent 6/3/15



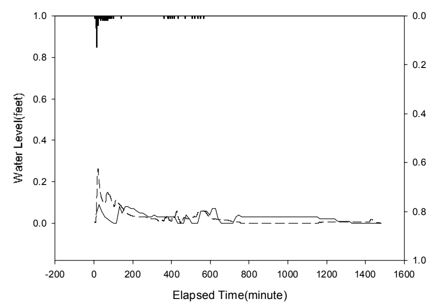
The rainfall depth for this event is 1.67 inch

T=0 at 6/3/2015 08:39:24

Total volume for the flume is 7170 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

1222 76th on Rainevent 5/29/15



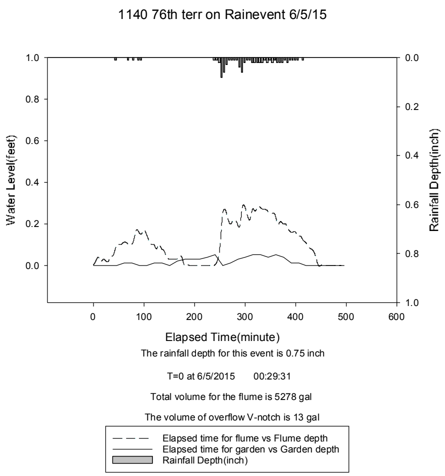
The rainfall depth for this event is 0.59 inch

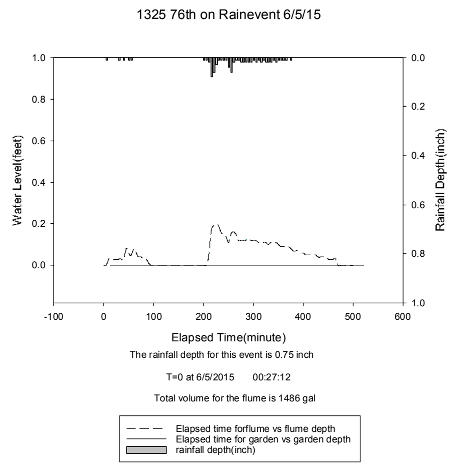
T=0 at 5/29/2015 05:54:18

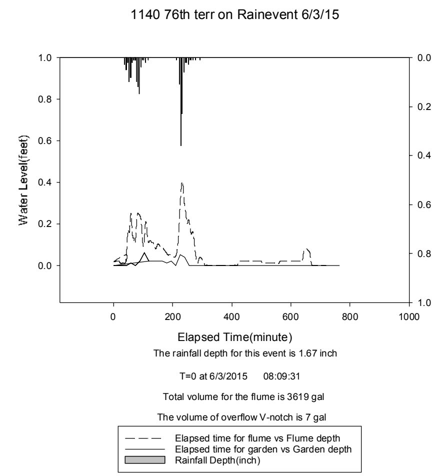
Total volume for the flume is 1333 gal

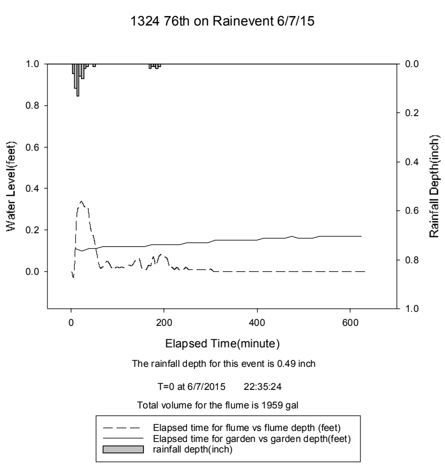
The volume of overflow V-notch is 83 gal

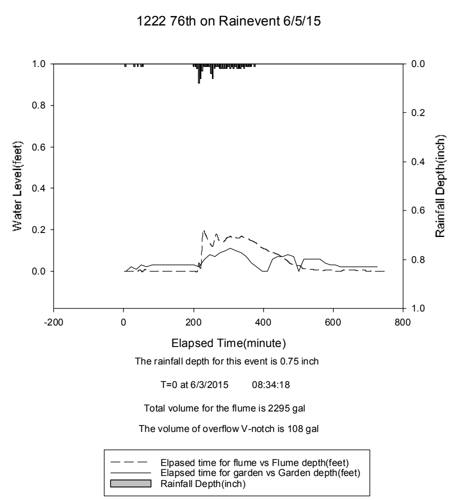
Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

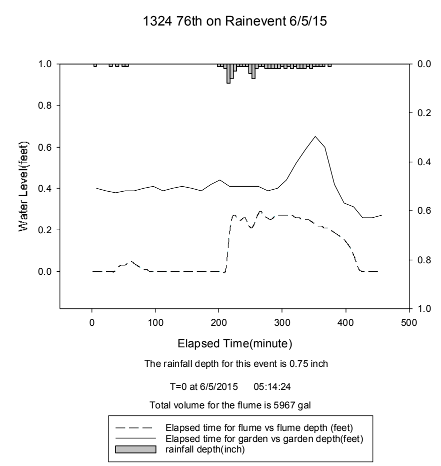

1140 76th terr on Rainevent 6/5/15
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 0.75 inch
T=0 at 6/5/2015 00:29:31
Total volume for the flume is 5278 gal
The volume of overflow V-notch is 13 gal
Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

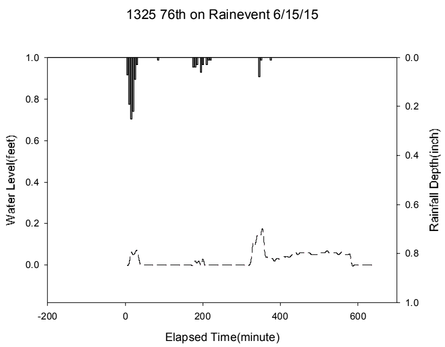

1325 76th on Rainevent 6/5/15
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 0.75 inch
T=0 at 6/5/2015 00:27:12
Total volume for the flume is 1486 gal
Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)


1140 76th terr on Rainevent 6/3/15
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 1.67 inch
T=0 at 6/3/2015 08:09:31
Total volume for the flume is 3619 gal
The volume of overflow V-notch is 7 gal
Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)


1324 76th on Rainevent 6/7/15
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 0.49 inch
T=0 at 6/7/2015 22:35:24
Total volume for the flume is 1959 gal
Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)


1222 76th on Rainevent 6/5/15
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 0.75 inch
T=0 at 6/3/2015 08:34:18
Total volume for the flume is 2295 gal
The volume of overflow V-notch is 108 gal
Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)


1324 76th on Rainevent 6/5/15
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 0.75 inch
T=0 at 6/5/2015 05:14:24
Total volume for the flume is 5967 gal
Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)



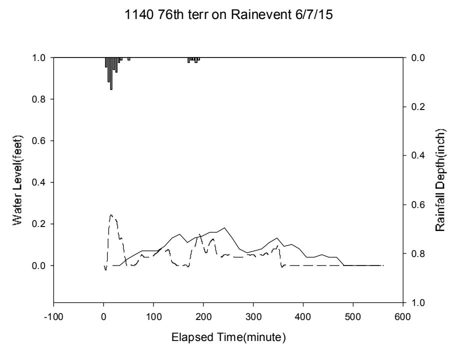
The rainfall depth for this event is 1.21 inch

T=0 at 6/15/2015 14:28:12

Total volume for the flume is 548 gal

No Garden Data for this event

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)



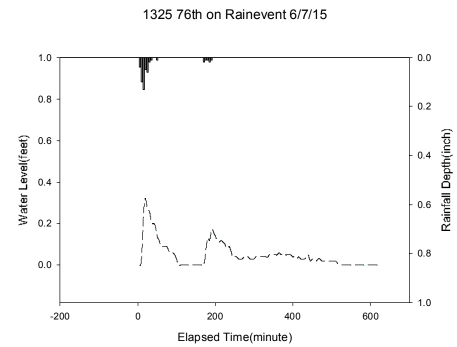
The rainfall depth for this event is 0.49 inch

T=0 at 6/7/2015 22:34:31

Total volume for the flume is 1090 gal

The volume of overflow V-notch is 341 gal

Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)



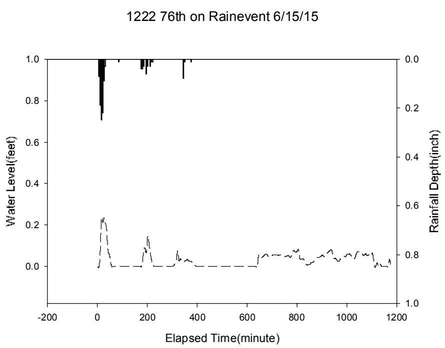
The rainfall depth for this event is 0.49 inch

T=0 at 6/7/2015 22:38:12

Total volume for the flume is 1952 gal

No Garden Data for this event

Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)



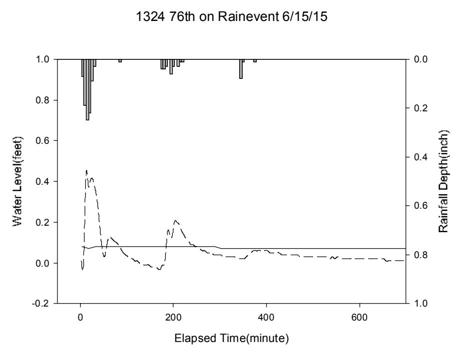
The rainfall depth for this event is 1.21 inch

T=0 at 6/15/2015 14:23:00

Total volume for the flume is 1323 gal

No Garden Data Due to Low Battery

Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

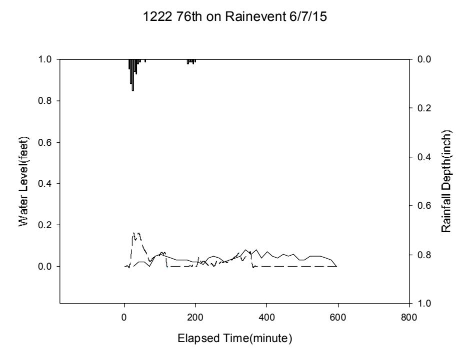


The rainfall depth for this event is 1.21 inch

T=0 at 6/15/2015 14:25:24

Total volume for the flume is 3775 gal

Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)



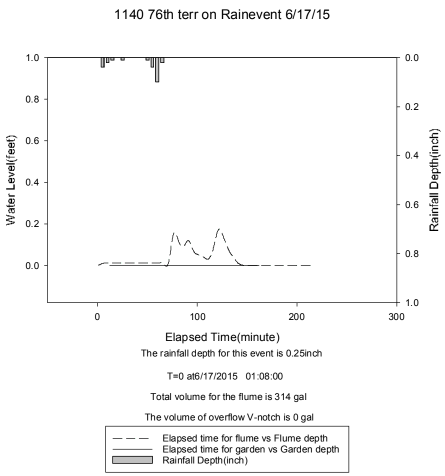
The rainfall depth for this event is 0.49 inch

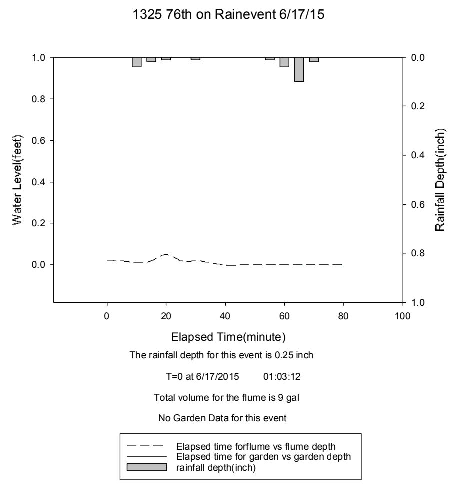
T=0 at 6/7/2015 22:24:18

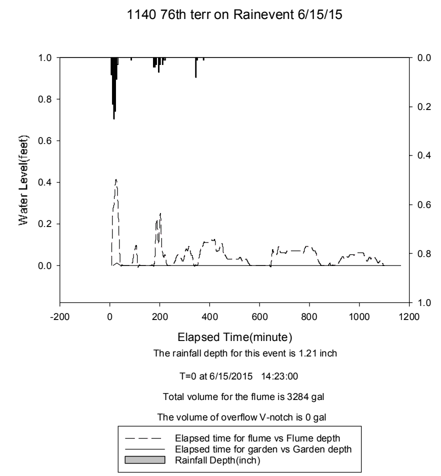
Total volume for the flume is 461 gal

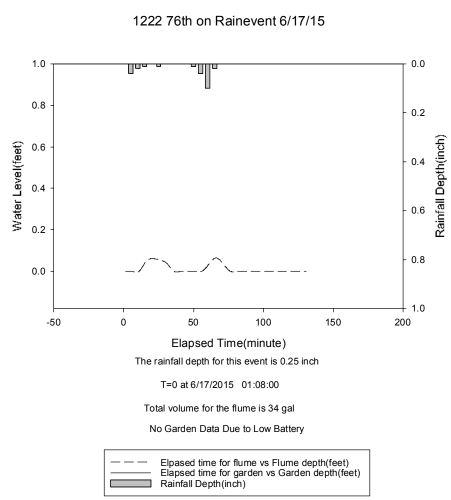
The volume of overflow V-notch is 54 gal

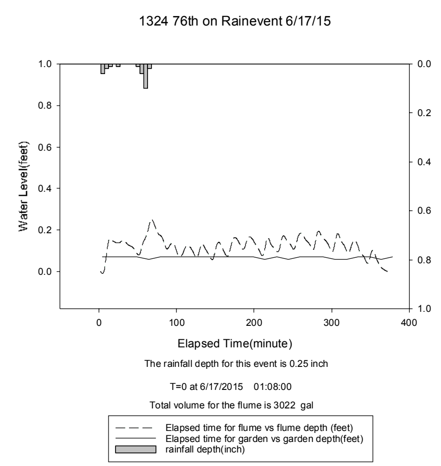
Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)


1140 76th terr on Rainevent 6/17/15
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 0.25inch
T=0 at6/17/2015 01:08:00
Total volume for the flume is 314 gal
The volume of overflow V-notch is 0 gal
Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

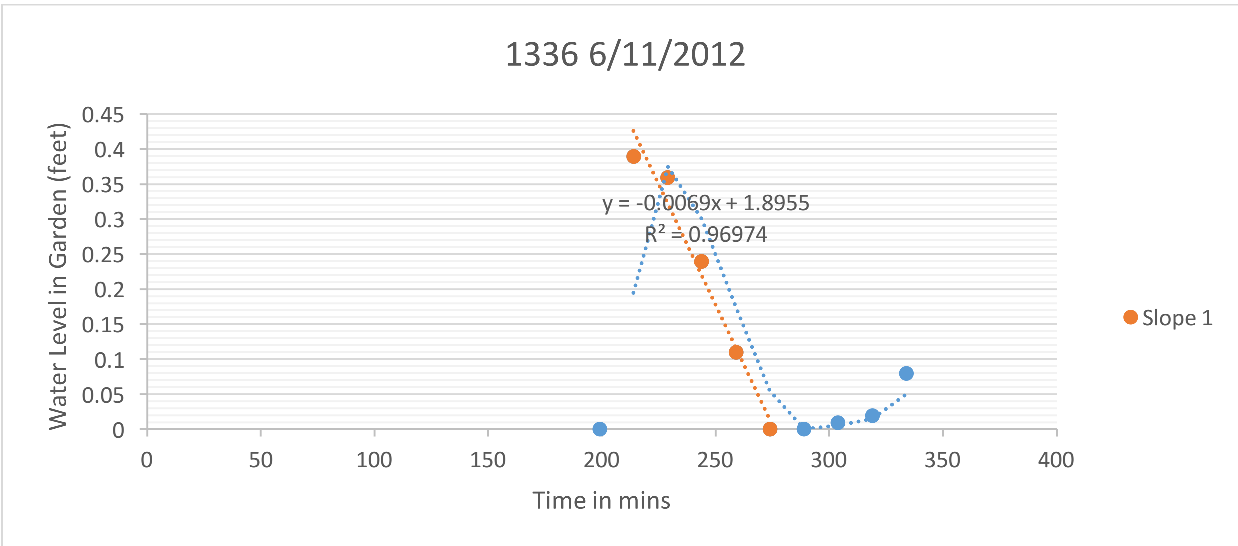

1325 76th on Rainevent 6/17/15
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 0.25 inch
T=0 at 6/17/2015 01:03:12
Total volume for the flume is 9 gal
No Garden Data for this event
Elapsed time forflume vs flume depth
Elapsed time for garden vs garden depth
rainfall depth(inch)

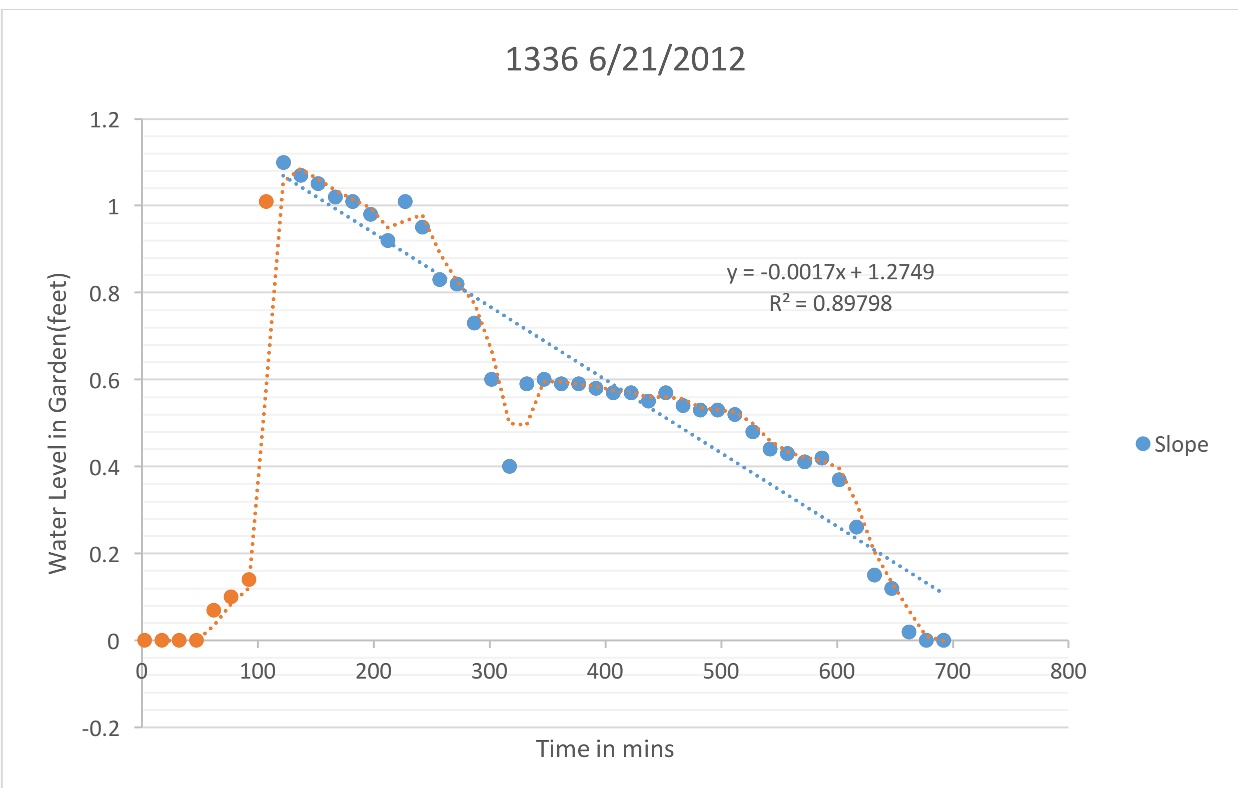

1140 76th terr on Rainevent 6/15/15
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 1.21 inch
T=0 at 6/15/2015 14:23:00
Total volume for the flume is 3284 gal
The volume of overflow V-notch is 0 gal
Elapsed time for flume vs Flume depth
Elapsed time for garden vs Garden depth
Rainfall Depth(inch)

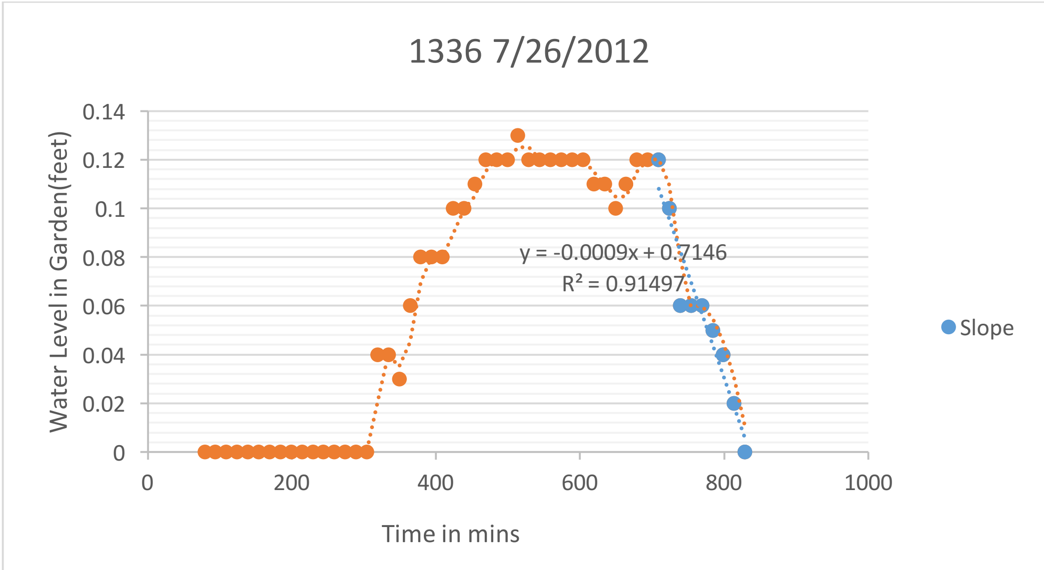

1222 76th on Rainevent 6/17/15
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 0.25 inch
T=0 at 6/17/2015 01:08:00
Total volume for the flume is 34 gal
No Garden Data Due to Low Battery
Elpased time for flume vs Flume depth(feet)
Elapsed time for garden vs Garden depth(feet)
Rainfall Depth(inch)

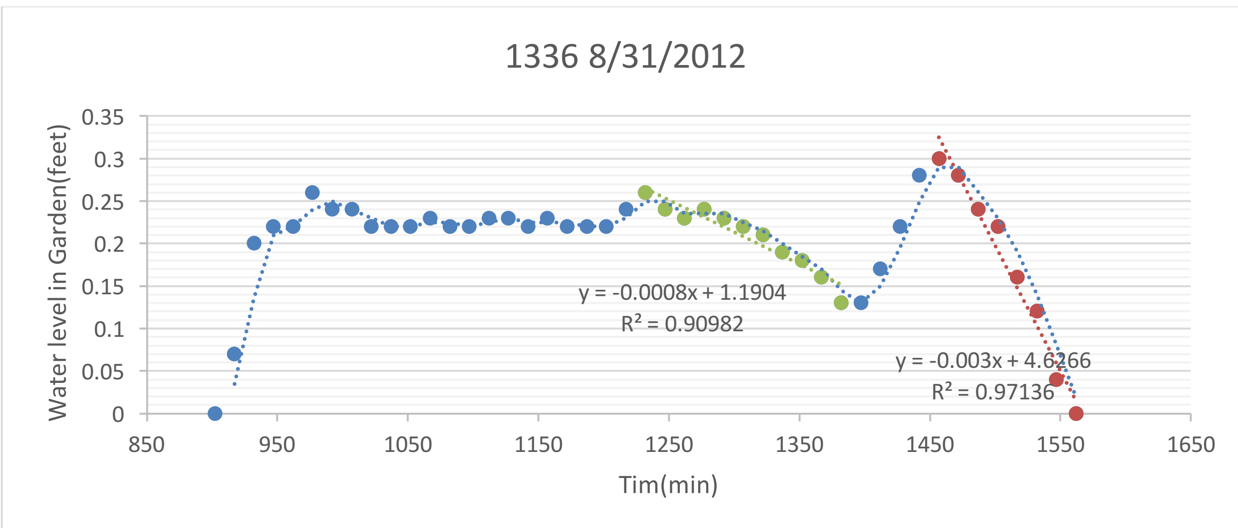

1324 76th on Rainevent 6/17/15
Water Level(feet)
Rainfall Depth(inch)
Elapsed Time(minute)
The rainfall depth for this event is 0.25 inch
T=0 at 6/17/2015 01:08:00
Total volume for the flume is 3022 gal
Elapsed time for flume vs flume depth (feet)
Elapsed time for garden vs garden depth(feet)
rainfall depth(inch)

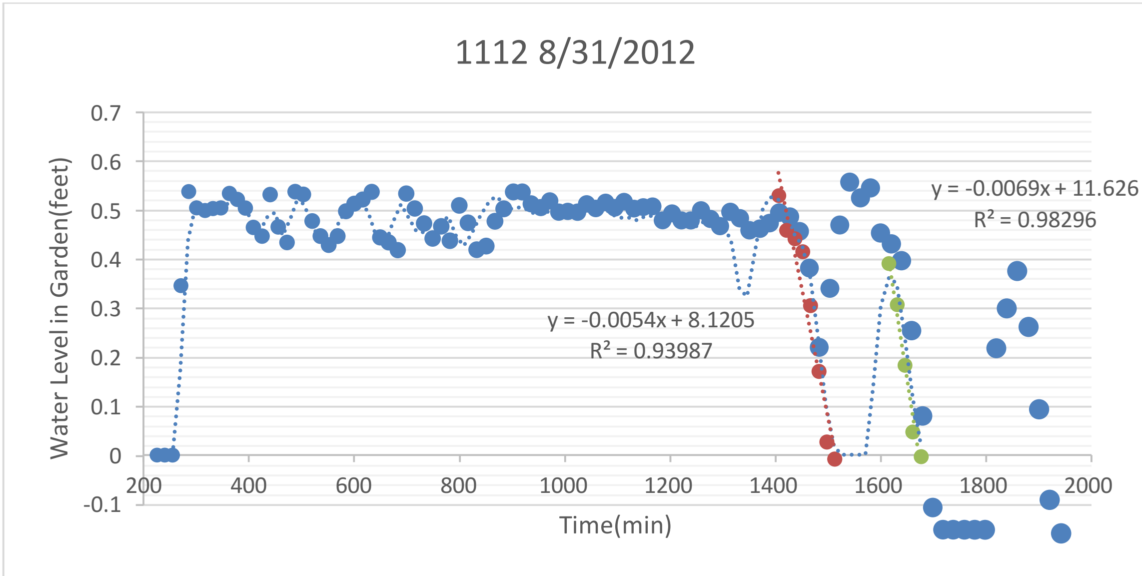
APPENDIX D: Drawdown Rate Calculation Graphs for Site 1336 and 1112



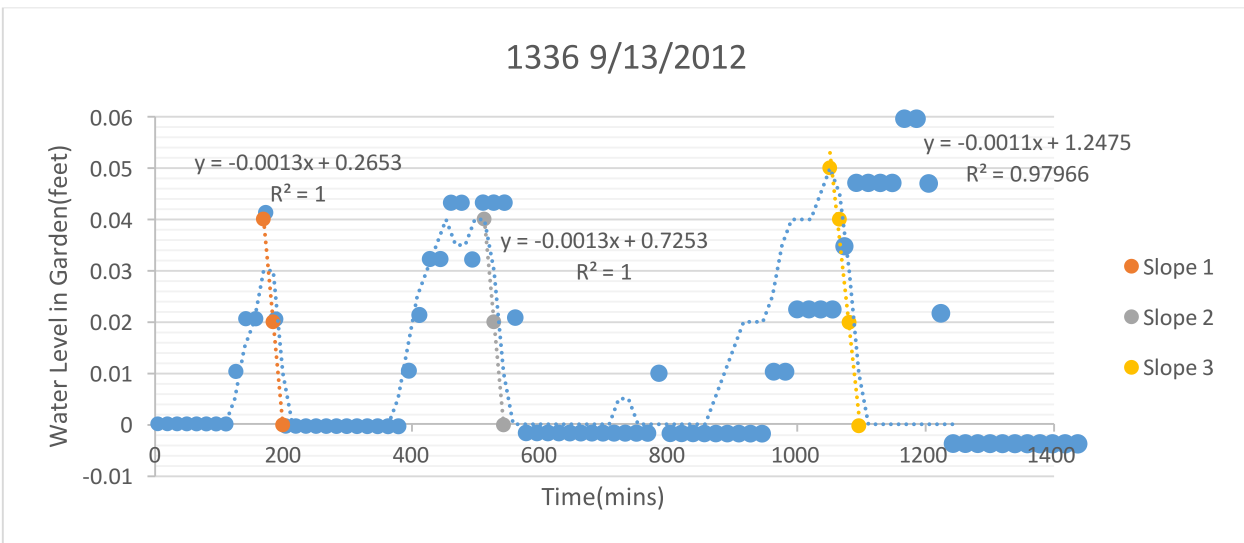



1336 7/26/2012
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Water Level in Garden(feet)
0
200
400
600
800
1000
Time in mins
y = -0.0009x + 0.7146
R² = 0.91497
Slope

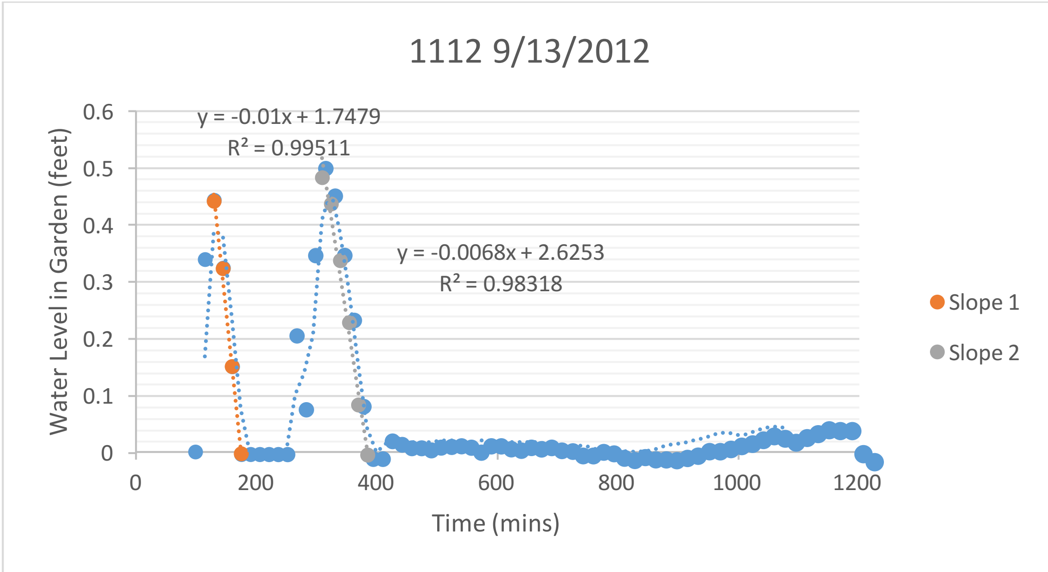

1336 8/31/2012
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Water level in Garden(feet)
850
950
1050
1150
1250
1350
1450
1550
1650
Tim(min)
y = -0.0008x + 1.1904
R² = 0.90982
y = -0.003x + 4.6266
R² = 0.97136

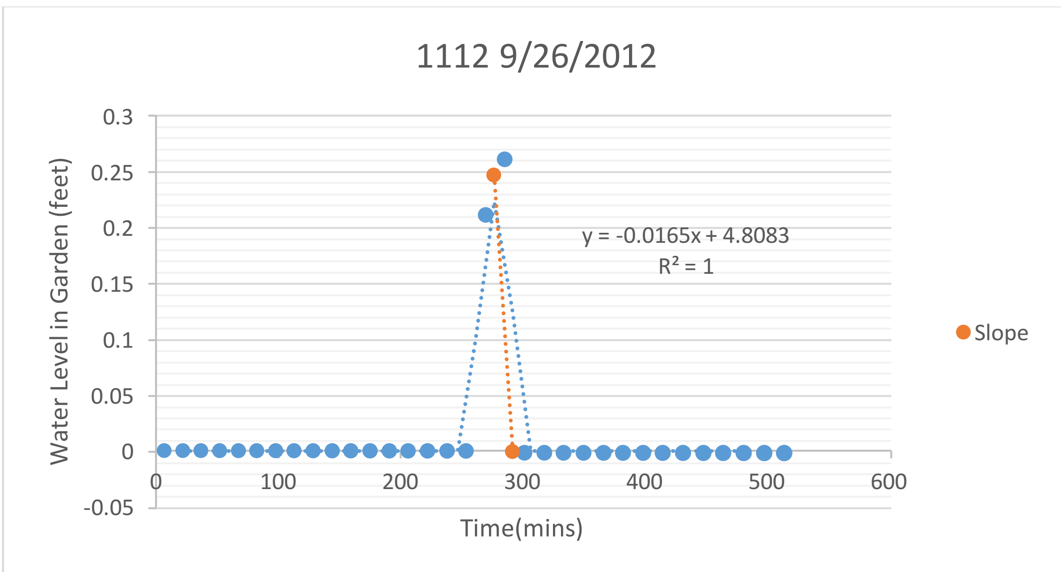


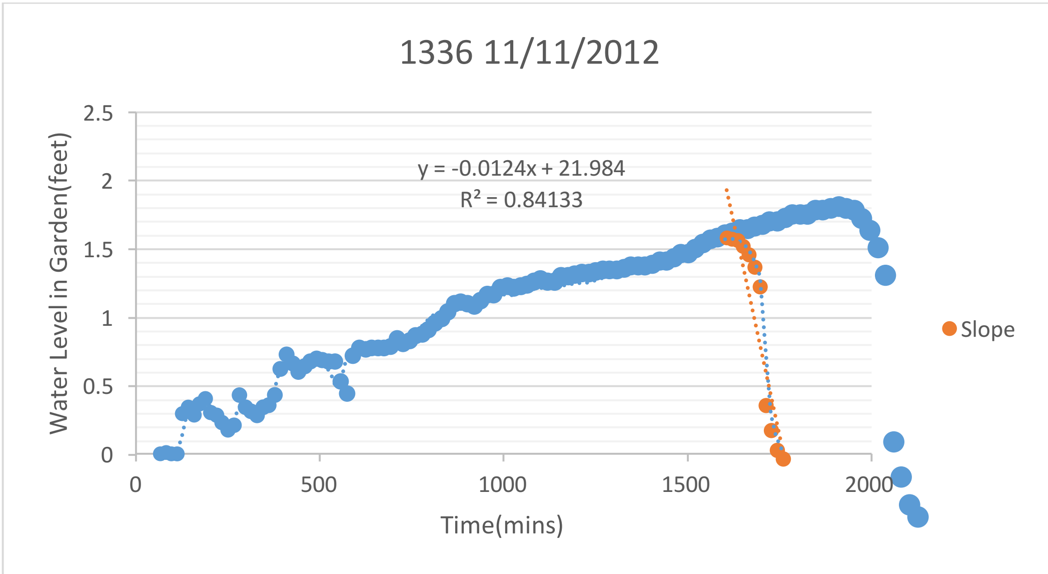
1112 8/31/2012
y = -0.0069x + 11.626
R² = 0.98296
y = -0.0054x + 8.1205
R² = 0.93987
Water Level in Garden(feet)
Time(min)

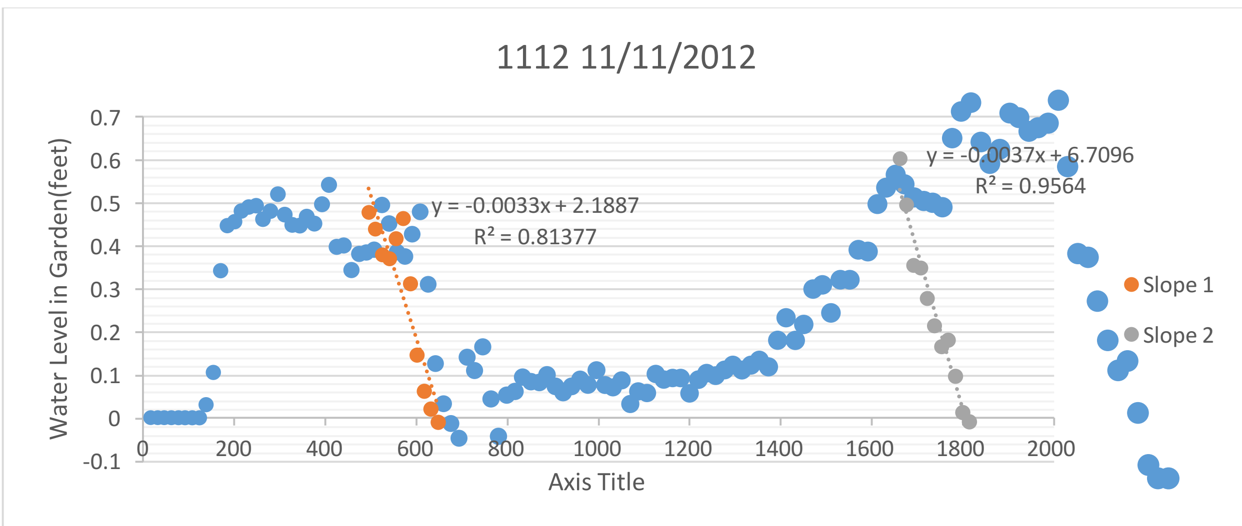


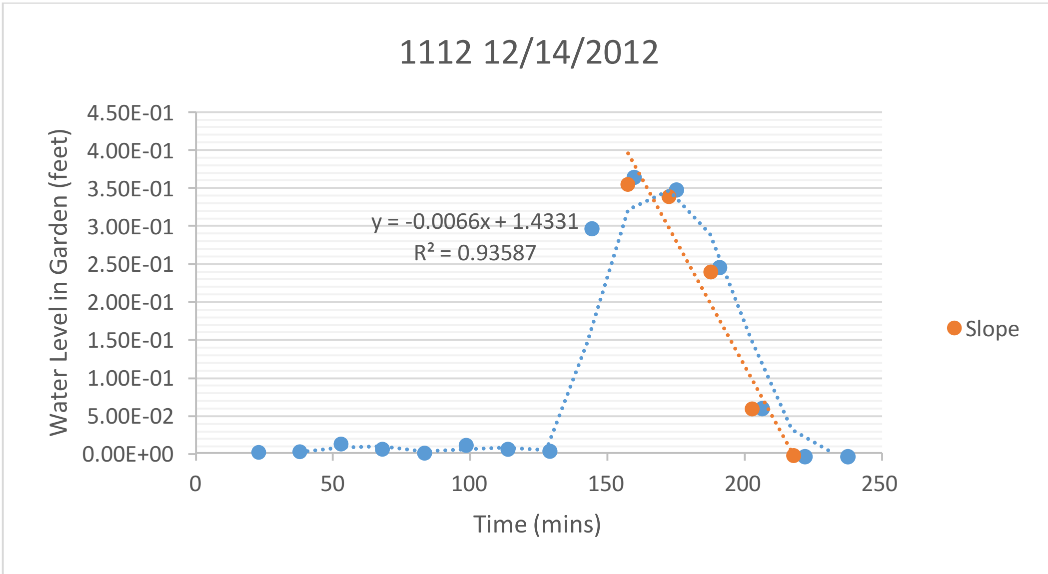
1336 9/13/2012
y = -0.0013x + 0.2653
R² = 1
y = -0.0013x + 0.7253
R² = 1
y = -0.0011x + 1.2475
R² = 0.97966
Slope 1
Slope 2
Slope 3
Water Level in Garden(feet)
Time(mins)

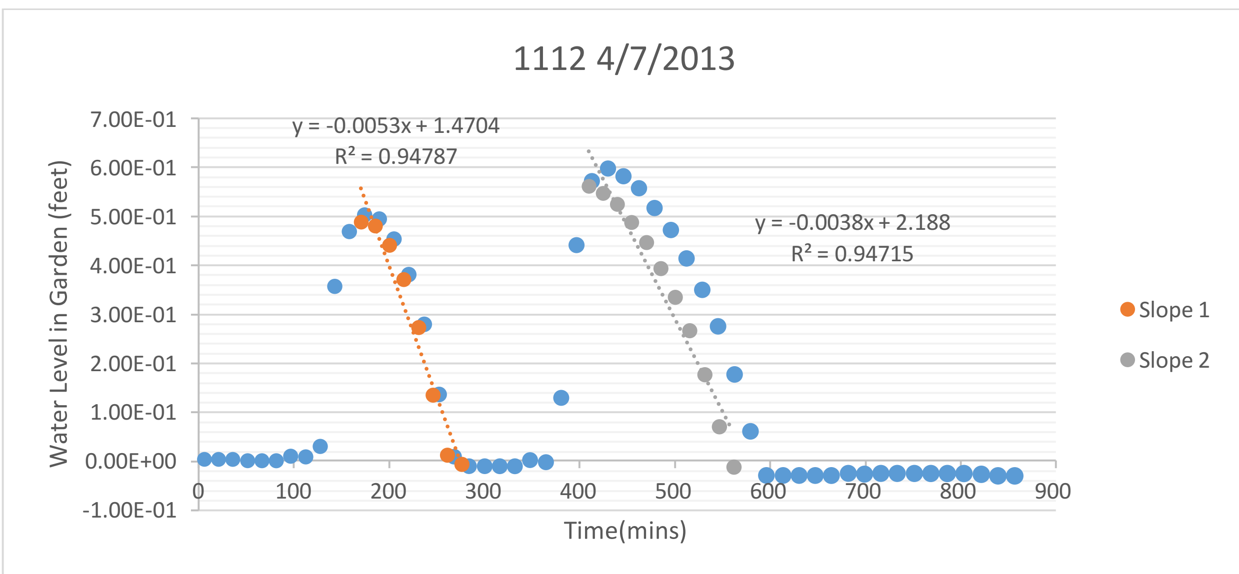

1112 9/13/2012
y = -0.01x + 1.7479
R² = 0.99511
y = -0.0068x + 2.6253
R² = 0.98318
Water Level in Garden (feet)
0.6
0.5
0.4
0.3
0.2
0.1
0
0
200
400
600
800
1000
1200
Time (mins)
Slope 1
Slope 2

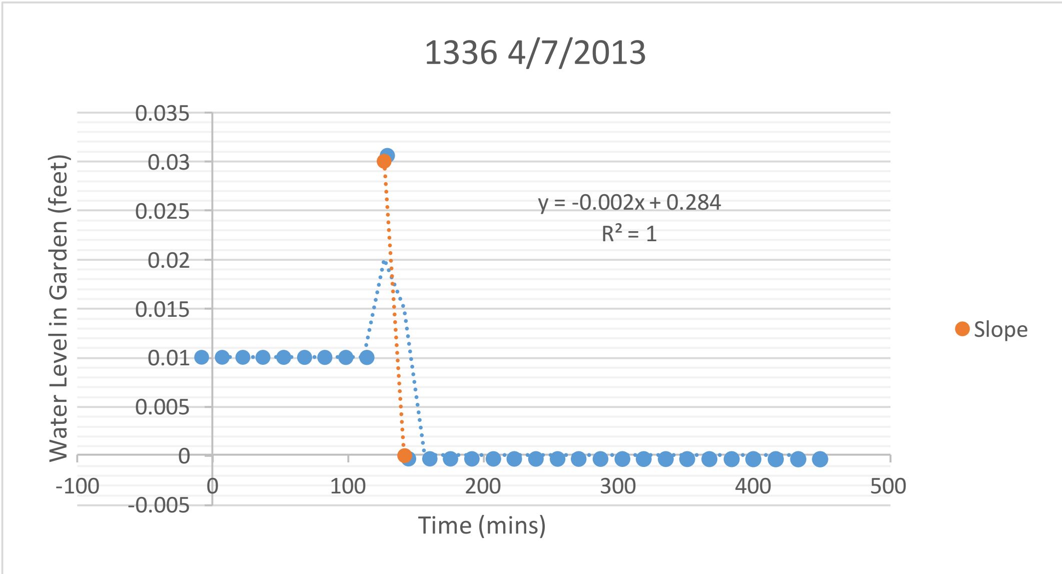

1112 9/26/2012
y = -0.0165x + 4.8083
R² = 1
Water Level in Garden (feet)
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
0
100
200
300
400
500
600
Time(mins)
Slope

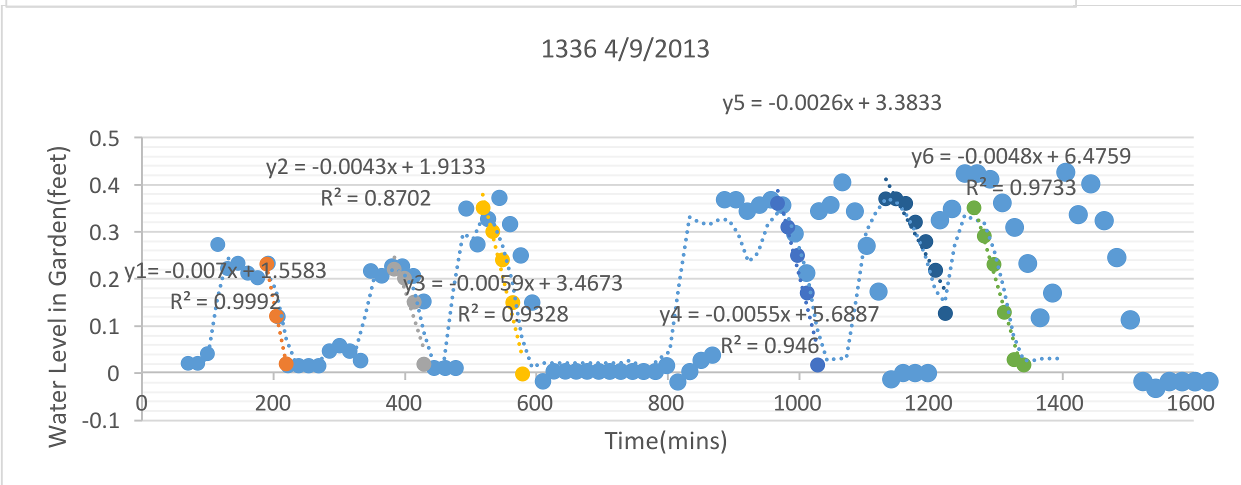

1336 11/11/2012
y = -0.0124x + 21.984
R² = 0.84133
Water Level in Garden(feet)
Time(mins)
Slope
2.5
2
1.5
1
0.5
0
0
500
1000
1500
2000

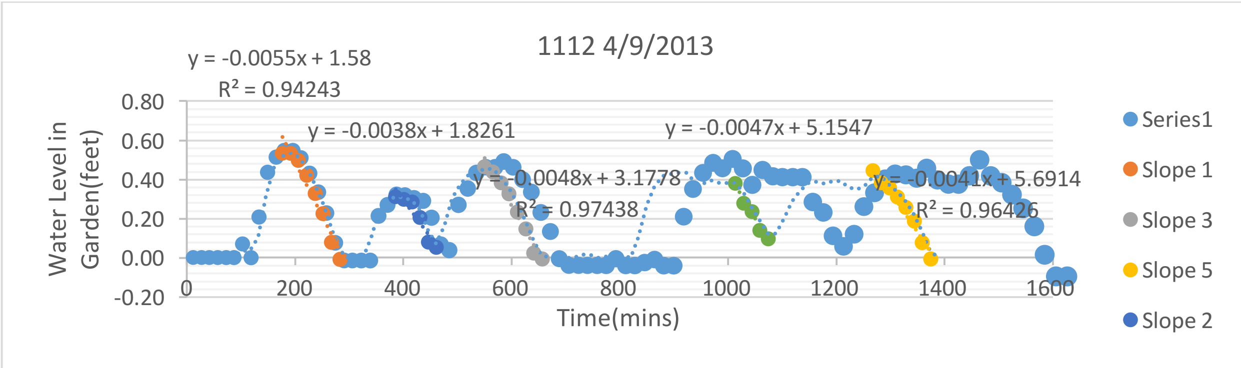

1112 11/11/2012
y = -0.0033x + 2.1887
R² = 0.81377
y = -0.0037x + 6.7096
R² = 0.9564
Water Level in Garden(feet)
Axis Title
Slope 1
Slope 2
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
0
200
400
600
800
1000
1200
1400
1600
1800
2000

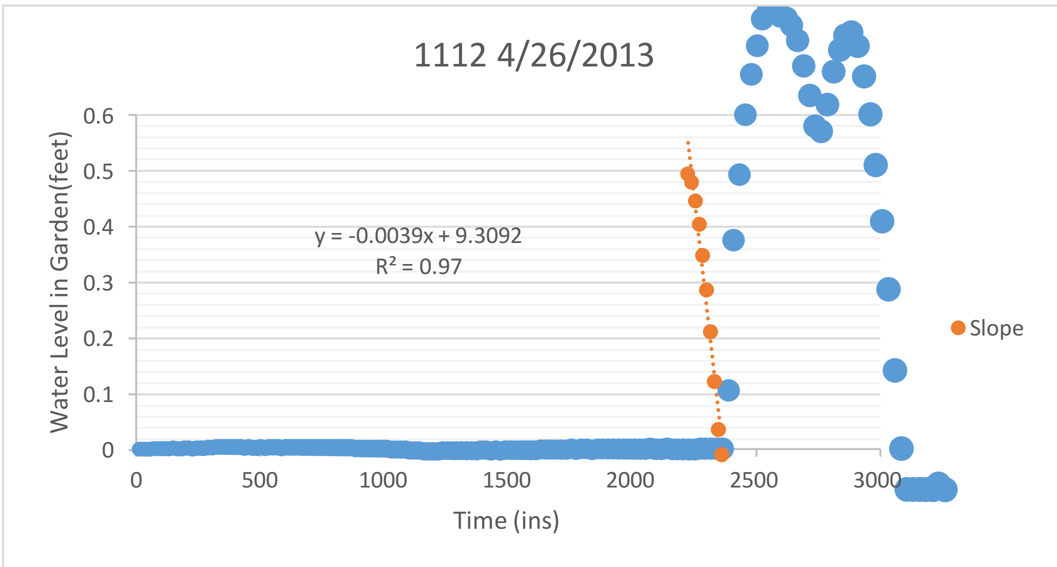

1112 12/14/2012
Water Level in Garden (feet)
4.50E-01
4.00E-01
3.50E-01
3.00E-01
2.50E-01
2.00E-01
1.50E-01
1.00E-01
5.00E-02
0.00E+00
y = -0.0066x + 1.4331
R² = 0.93587
0
50
100
150
200
250
Time (mins)
Slope

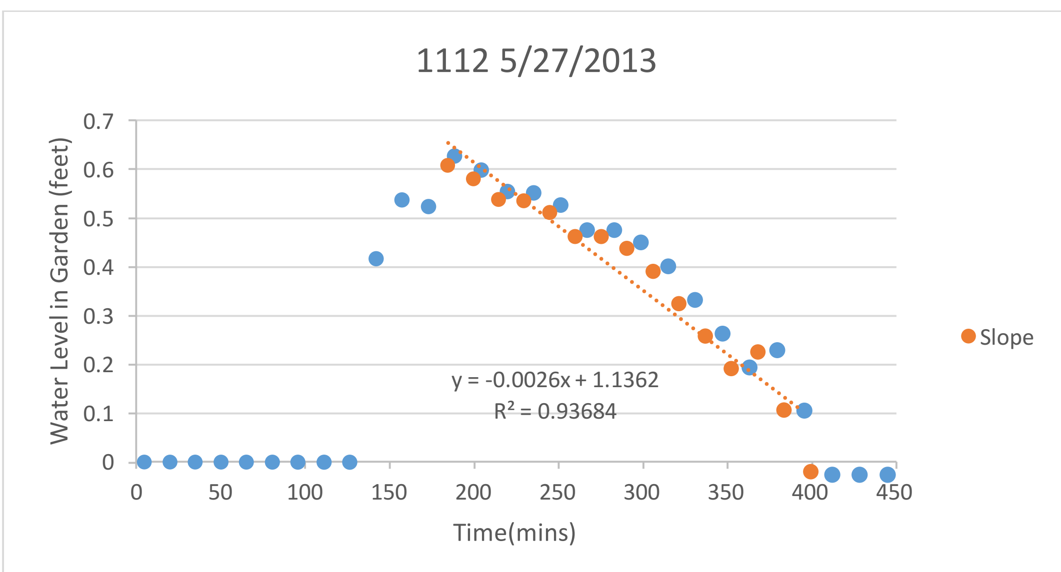

1112 4/7/2013
Water Level in Garden (feet)
7.00E-01
6.00E-01
5.00E-01
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
-1.00E-01
y = -0.0053x + 1.4704
R² = 0.94787
y = -0.0038x + 2.188
R² = 0.94715
0
100
200
300
400
500
600
700
800
900
Time(mins)
Slope 1
Slope 2

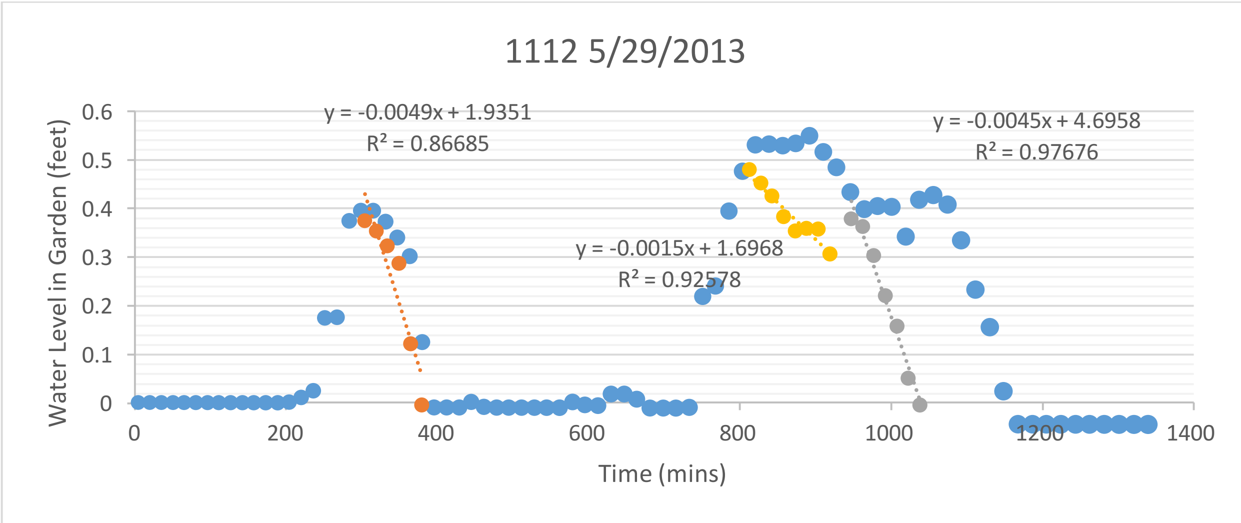

1336 4/7/2013
Water Level in Garden (feet)
Time (mins)
y = -0.002x + 0.284
R² = 1
Slope

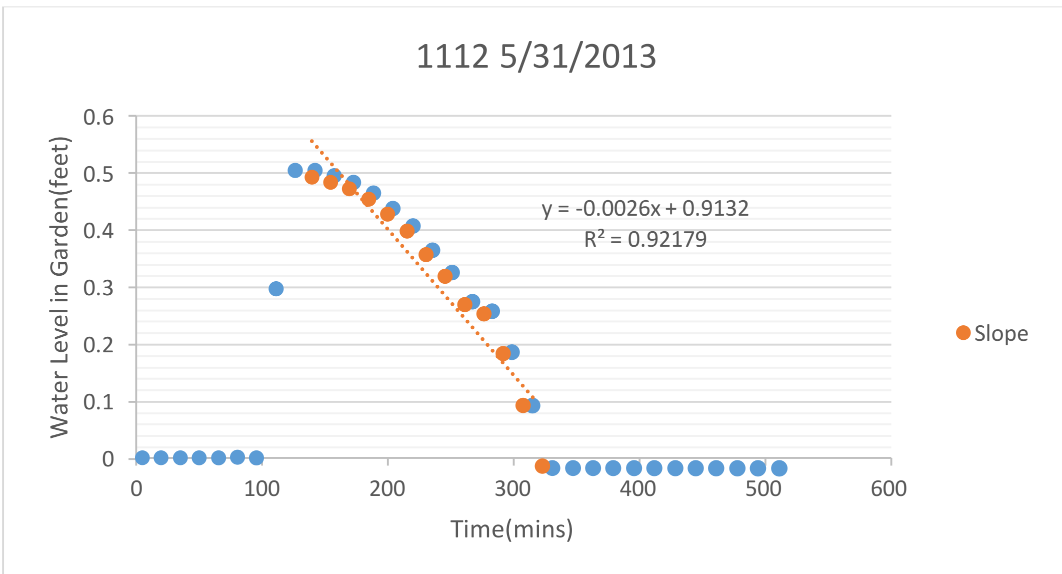

1336 4/9/2013
Water Level in Garden(feet)
Time(mins)
y1= -0.007x + 1.5583
R² = 0.9992
y2 = -0.0043x + 1.9133
R² = 0.8702
y3 = -0.0059x + 3.4673
R² = 0.9328
y4 = -0.0055x + 5.6887
R² = 0.946
y5 = -0.0026x + 3.3833
y6 = -0.0048x + 6.4759
R² = 0.9733

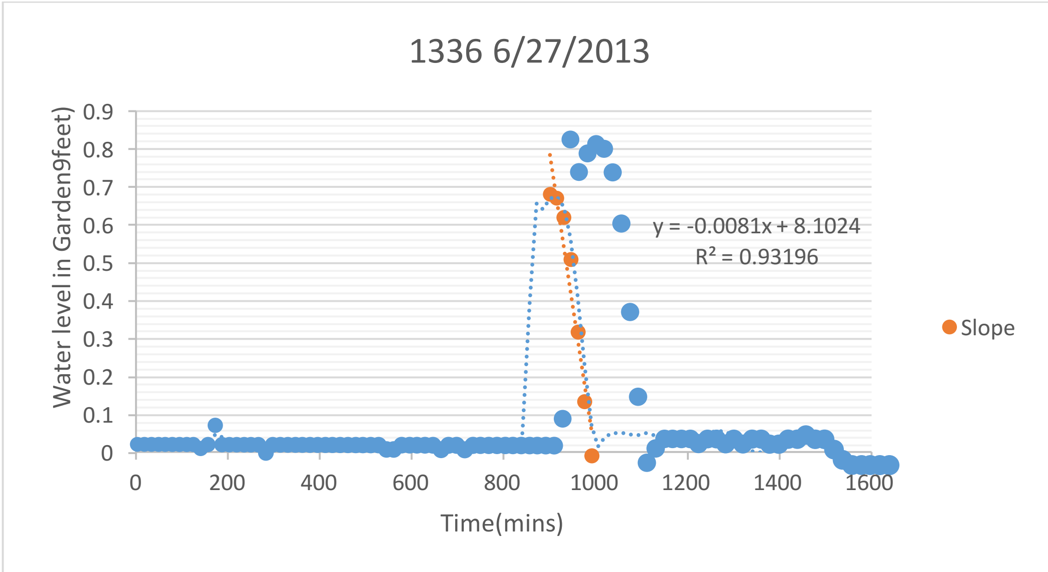

1112 4/9/2013
y = -0.0055x + 1.58
R² = 0.94243
y = -0.0038x + 1.8261
y = -0.0047x + 5.1547
y = -0.0048x + 3.1778
R² = 0.97438
y = -0.0041x + 5.6914
R² = 0.96426
Water Level in Garden(feet)
Time(mins)
0.80
0.60
0.40
0.20
0.00
-0.20
0
200
400
600
800
1000
1200
1400
1600
Series1
Slope 1
Slope 3
Slope 5
Slope 2

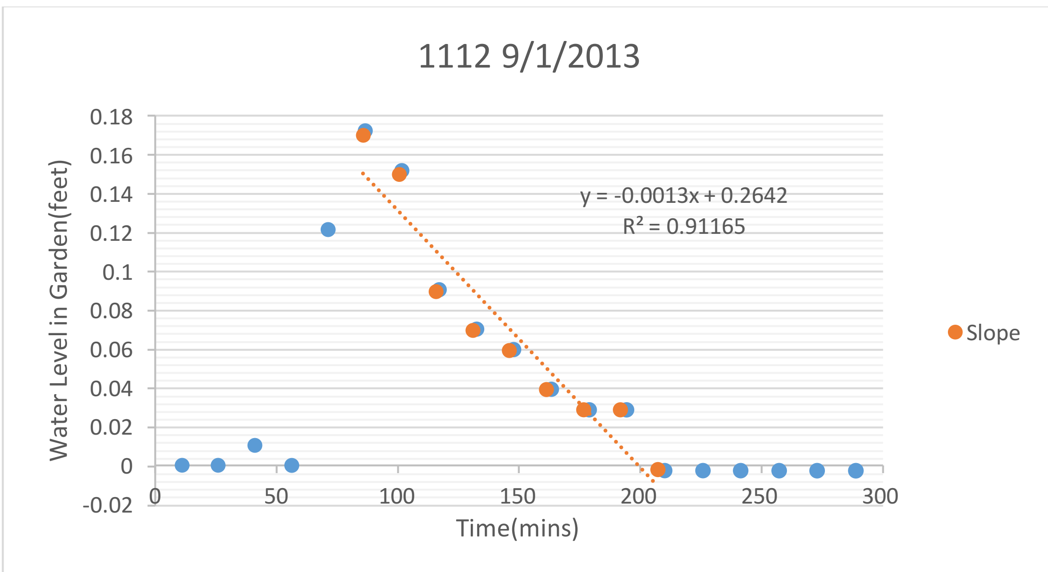

1112 4/26/2013
y = -0.0039x + 9.3092
R² = 0.97
Water Level in Garden(feet)
Time (ins)
0.6
0.5
0.4
0.3
0.2
0.1
0
0
500
1000
1500
2000
2500
3000
Slope

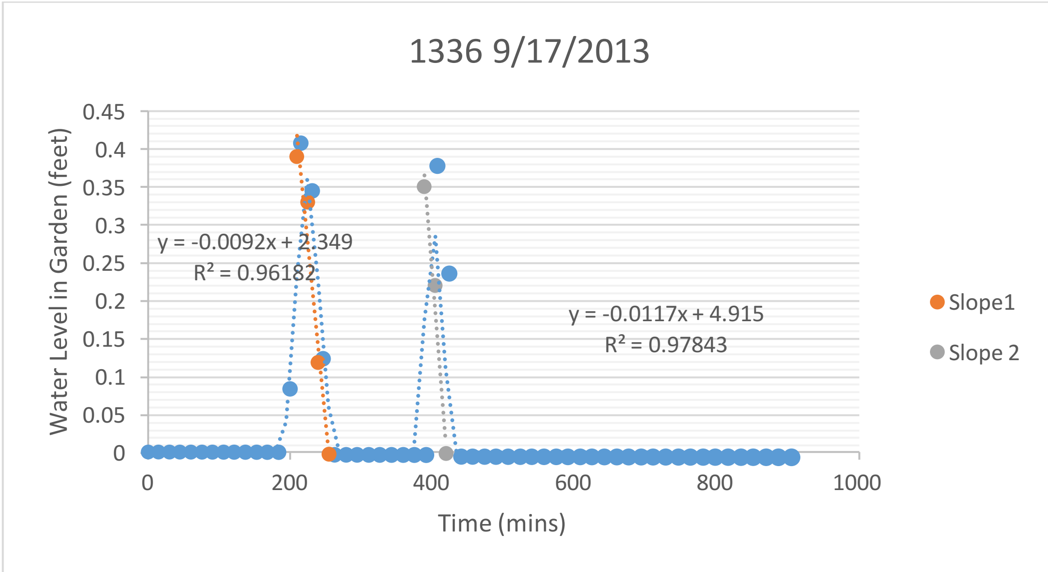

1112 5/27/2013
y = -0.0026x + 1.1362
R² = 0.93684
Water Level in Garden (feet)
Time(mins)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
400
450
Slope

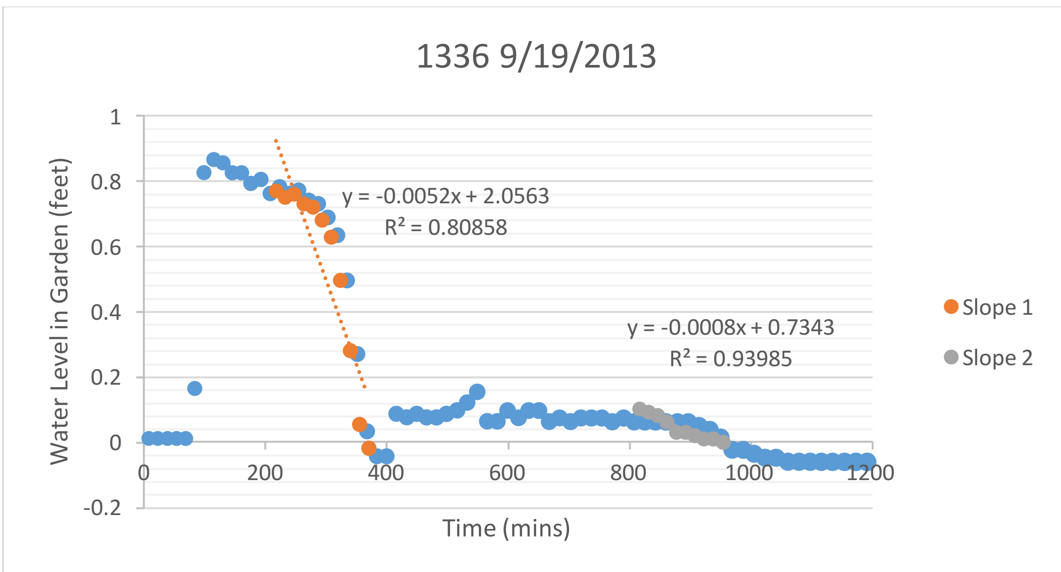

1112 5/29/2013
Water Level in Garden (feet)
Time (mins)
y = -0.0049x + 1.9351
R² = 0.86685
y = -0.0015x + 1.6968
R² = 0.92578
y = -0.0045x + 4.6958
R² = 0.97676
0.6
0.5
0.4
0.3
0.2
0.1
0
0
200
400
600
800
1000
1200
1400

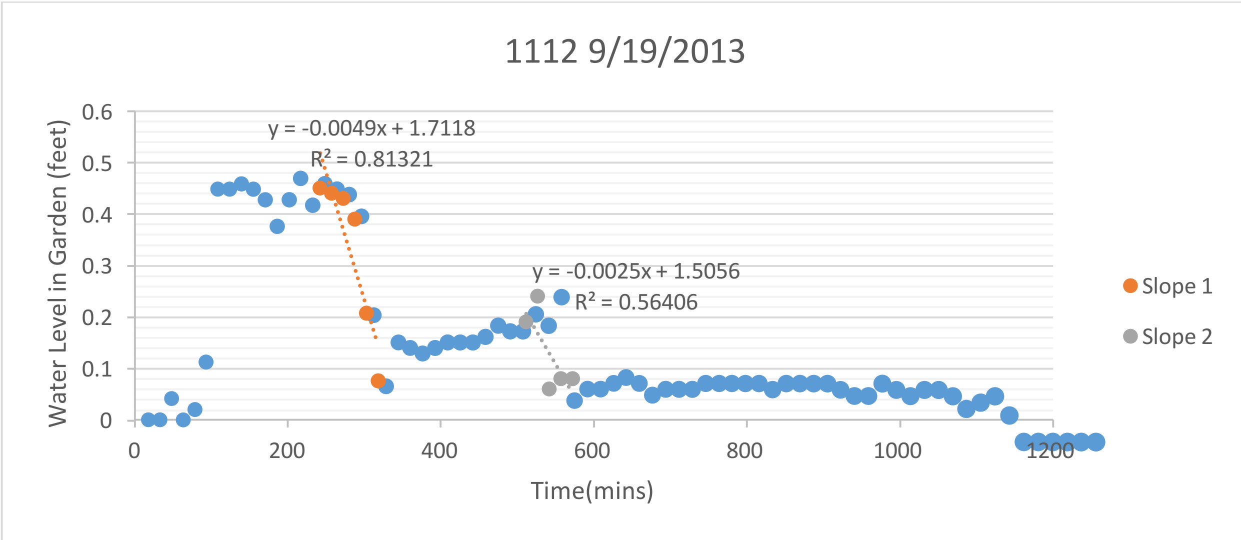

1112 5/31/2013
Water Level in Garden(feet)
Time(mins)
y = -0.0026x + 0.9132
R² = 0.92179
Slope
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
600

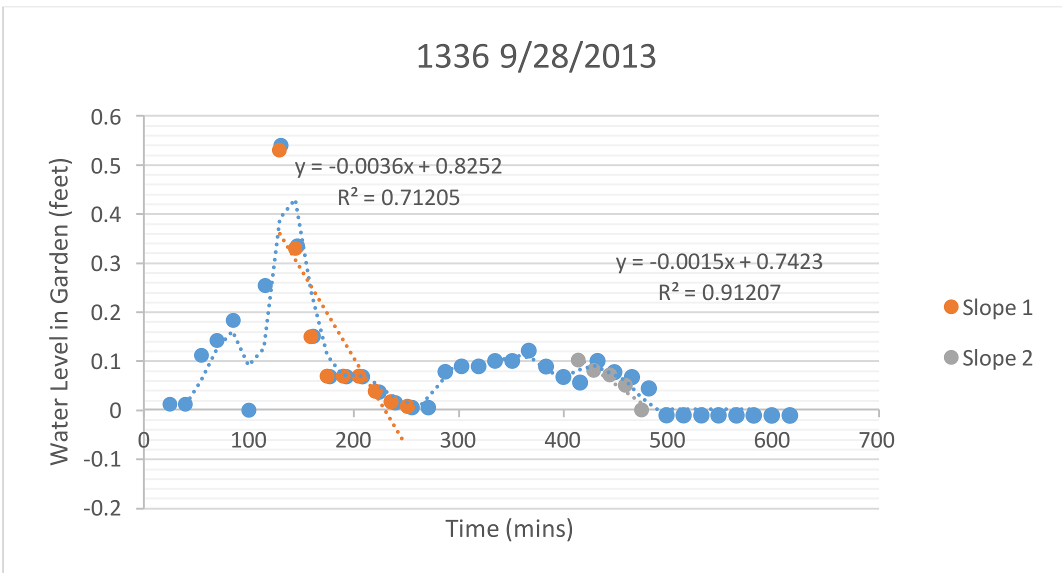

1336 6/27/2013
Water level in Garden9feet)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
200
400
600
800
1000
1200
1400
1600
Time(mins)
y = -0.0081x + 8.1024
R² = 0.93196
Slope

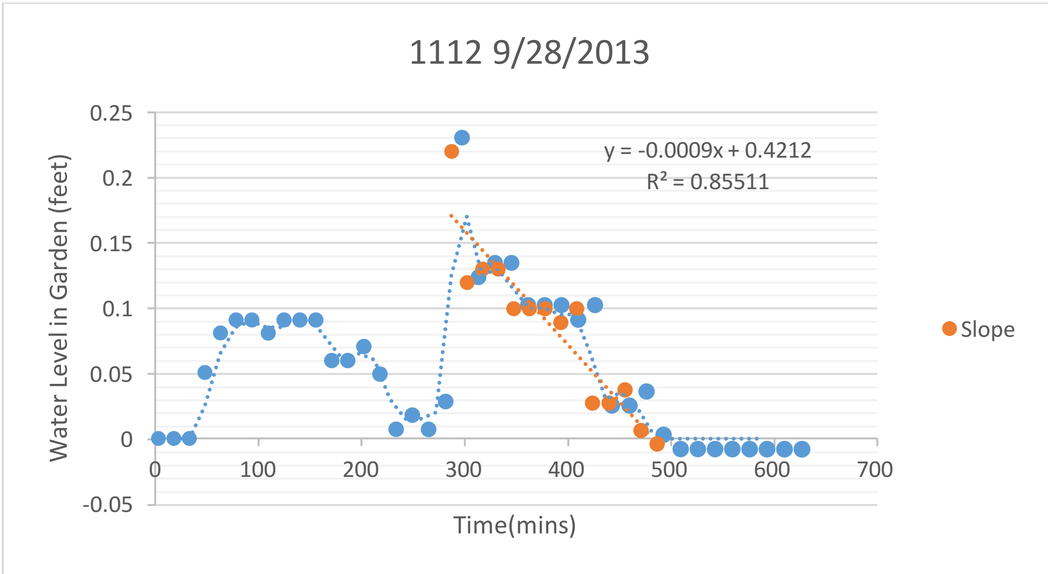

1112 9/1/2013
Water Level in Garden(feet)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
0
50
100
150
200
250
300
Time(mins)
y = -0.0013x + 0.2642
R² = 0.91165
Slope

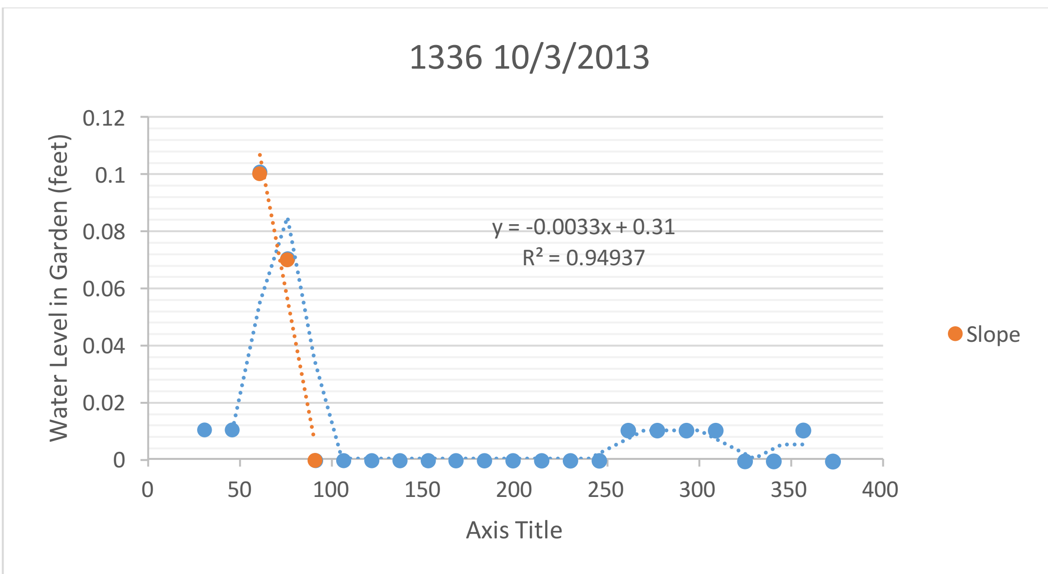

1336 9/17/2013
Water Level in Garden (feet)
Time (mins)
y = -0.0092x + 2.349
R² = 0.96182
y = -0.0117x + 4.915
R² = 0.97843
Slope1
Slope 2
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
200
400
600
800
1000

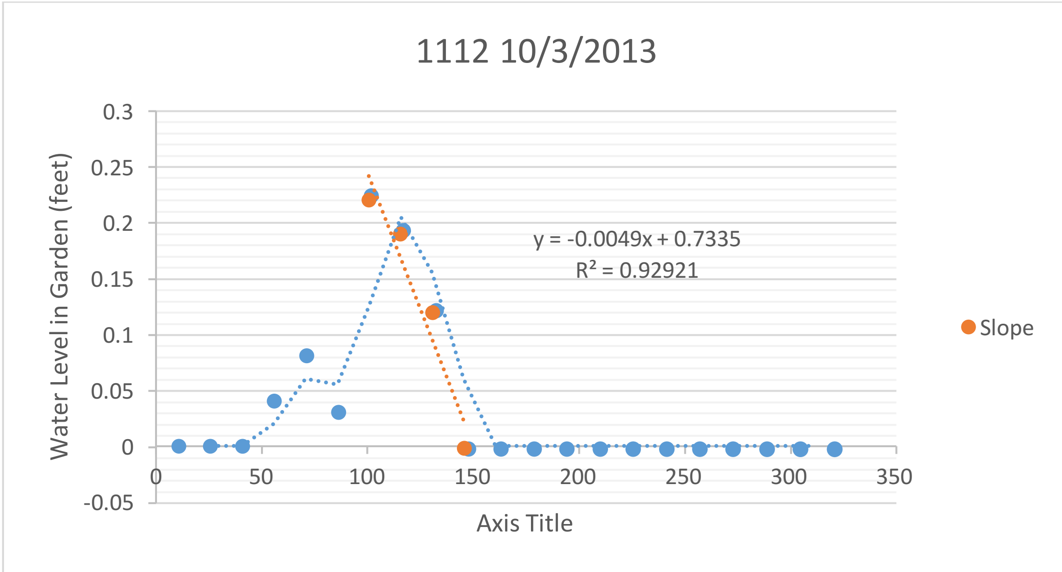

1336 9/19/2013
Water Level in Garden (feet)
Time (mins)
y = -0.0052x + 2.0563
R² = 0.80858
y = -0.0008x + 0.7343
R² = 0.93985
Slope 1
Slope 2
1
0.8
0.6
0.4
0.2
0
-0.2
0
200
400
600
800
1000
1200

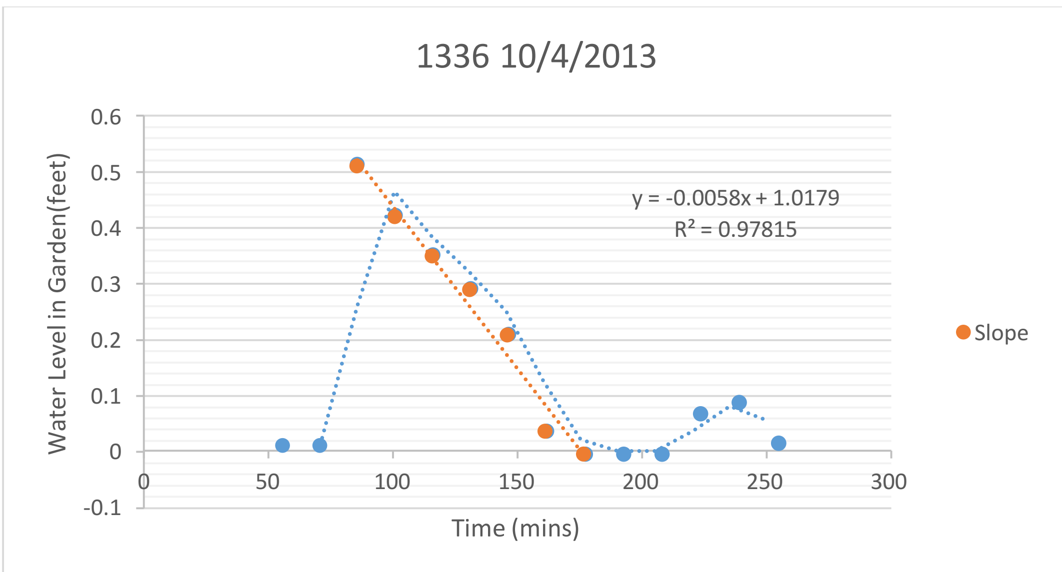

1112 9/19/2013
Water Level in Garden (feet)
Time(mins)
y = -0.0049x + 1.7118
R² = 0.81321
y = -0.0025x + 1.5056
R² = 0.56406
Slope 1
Slope 2
0.6
0.5
0.4
0.3
0.2
0.1
0
0
200
400
600
800
1000
1200

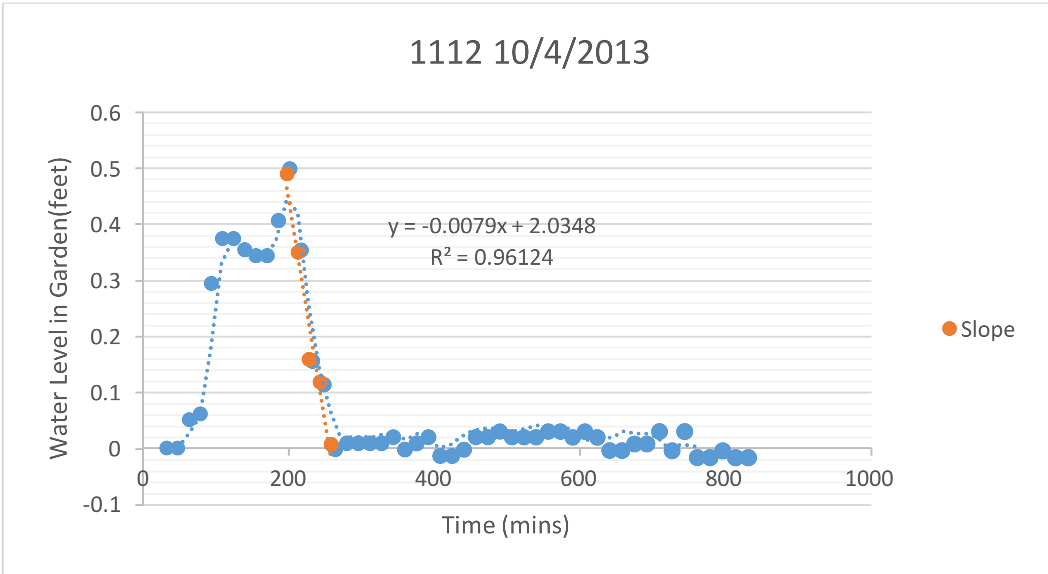

1336 9/28/2013
Water Level in Garden (feet)
Time (mins)
y = -0.0036x + 0.8252
R² = 0.71205
y = -0.0015x + 0.7423
R² = 0.91207
Slope 1
Slope 2
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
0
100
200
300
400
500
600
700

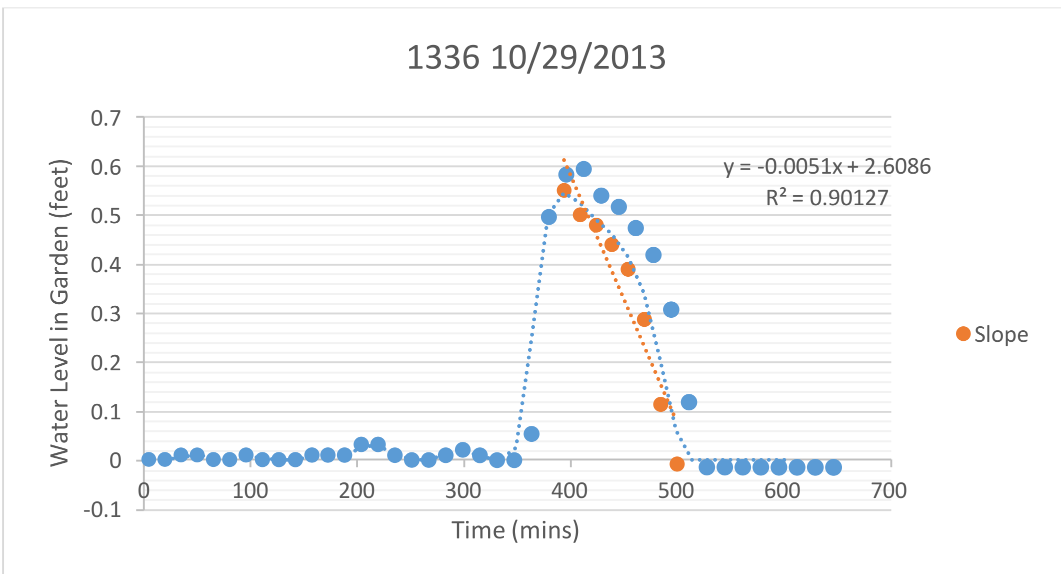

1112 9/28/2013
y = -0.0009x + 0.4212
R² = 0.85511
Water Level in Garden (feet)
Time(mins)
Slope
0.25
0.2
0.15
0.1
0.05
0
-0.05
0
100
200
300
400
500
600
700

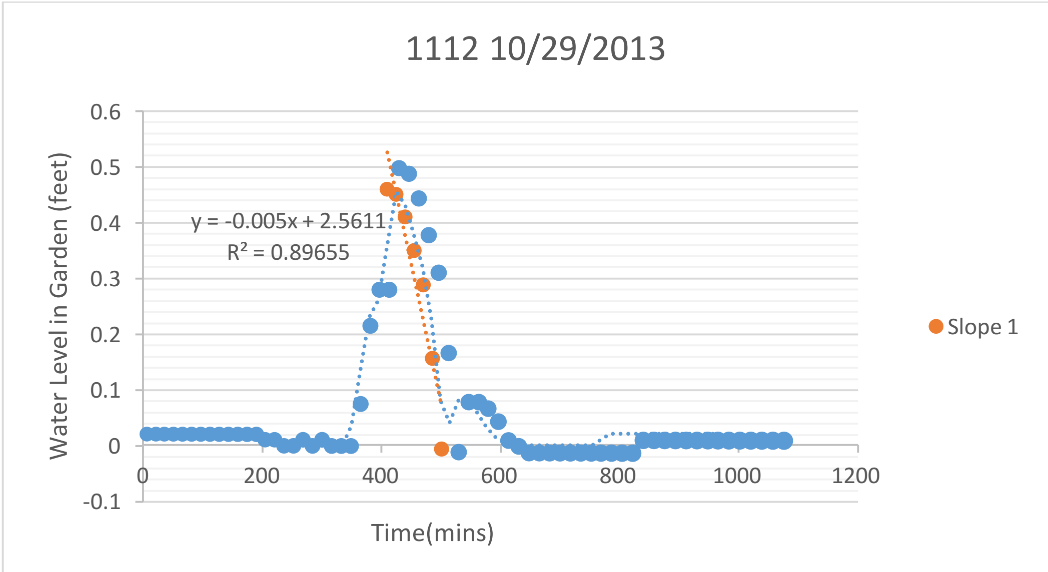

1336 10/3/2013
y = -0.0033x + 0.31
R² = 0.94937
Water Level in Garden (feet)
Axis Title
Slope
0.12
0.1
0.08
0.06
0.04
0.02
0
0
50
100
150
200
250
300
350
400

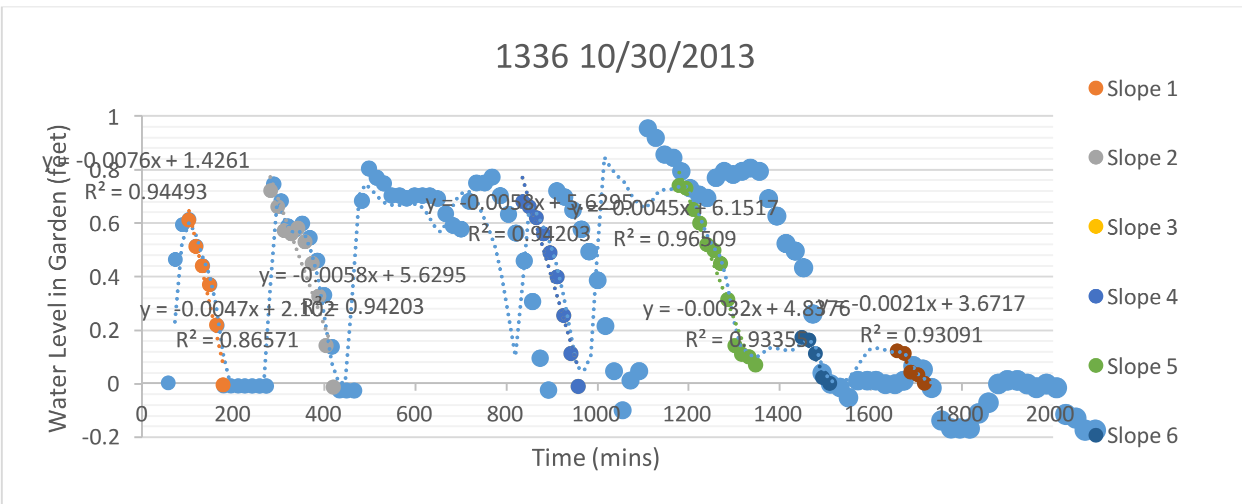

1112 10/3/2013
Water Level in Garden (feet)
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
0
50
100
150
200
250
300
350
Axis Title
y = -0.0049x + 0.7335
R² = 0.92921
Slope

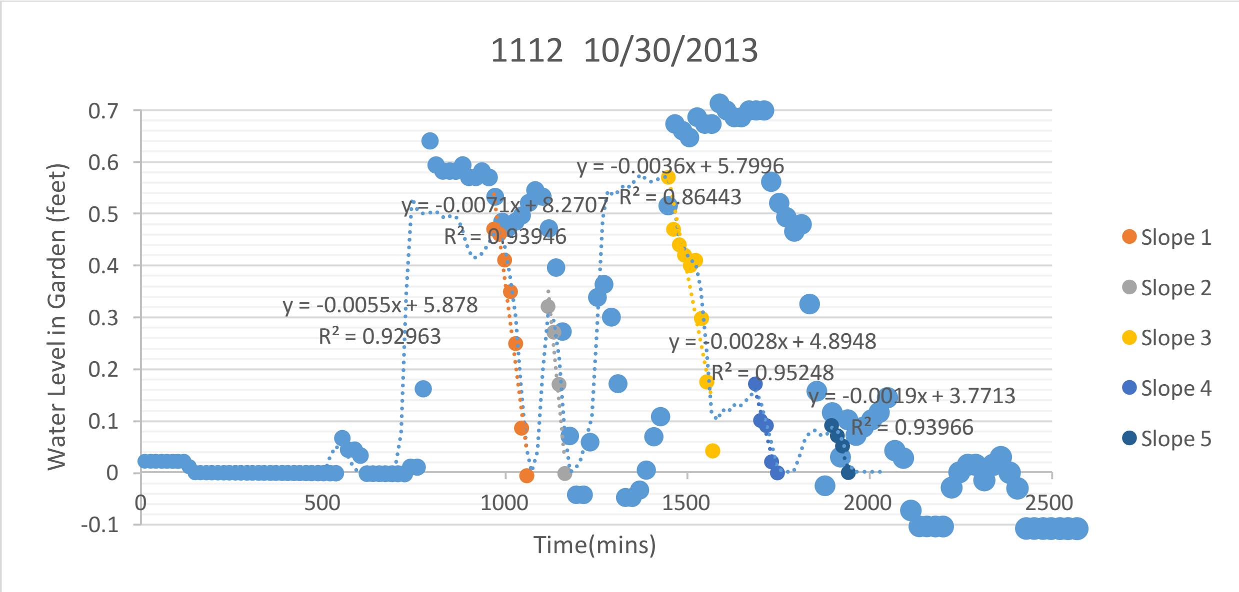

1336 10/4/2013
Water Level in Garden(feet)
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
0
50
100
150
200
250
300
Time (mins)
y = -0.0058x + 1.0179
R² = 0.97815
Slope


1112 10/4/2013
Water Level in Garden(feet)
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
0
200
400
600
800
1000
Time (mins)
y = -0.0079x + 2.0348
R² = 0.96124
Slope


1336 10/29/2013
Water Level in Garden (feet)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
0
100
200
300
400
500
600
700
Time (mins)
y = -0.0051x + 2.6086
R² = 0.90127
Slope


1112 10/29/2013
Water Level in Garden (feet)
Time(mins)
y = -0.005x + 2.5611
R² = 0.89655
Slope 1
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
0
200
400
600
800
1000
1200


1336 10/30/2013
Water Level in Garden (feet)
Time (mins)
y = -0.0076x + 1.4261
R² = 0.94493
y = -0.0047x + 2.102
R² = 0.86571
y = -0.0058x + 5.6295
R² = 0.94203
y = -0.0045x + 6.1517
R² = 0.96509
y = -0.0032x + 4.8376
R² = 0.93358
y = -0.0021x + 3.6717
R² = 0.93091
Slope 1
Slope 2
Slope 3
Slope 4
Slope 5
Slope 6
1
0.8
0.6
0.4
0.2
0
-0.2
0
200
400
600
800
1000
1200
1400
1600
1800
2000



Filter the Max depth <0.1 ft. and difference <0.1 ft.							
	total rainfall (inch)		Drawdown rate(inch/hour)				
Date	UMKC	City	1324	1325	1336	1612	1112
6/11/12	0.80	0.79	NA	Flat	4.97	2.52	NA
6/21/12	1.03	0.98	NA	Flat	1.22	3.17	NA
7/26/12	0.48	0.32	Flat	NA	0.65	NA	NA
8/31/12	5.60	5.91	Flat	2.88	1.37	NA	4.43
9/13/12	0.41	0.39	Flat	0.86	0.89	Flat	6.05
9/26/12	0.23	0.20	NA	Flat	Flat	Flat	4.82
10/13/12	0.82	0.87	Flat	Flat	Flat	1.51	Flat
11/11/12	1.45	1.50	Flat	Flat	8.93	2.30	2.52
12/14/12	0.35	0.35	NA	NA	NA	1.94	4.75
4/7/13	0.97	NA	9.58	6.30	NA	3.46	3.28
4/9/13	0.80	NA	Flat	Flat	3.53	3.10	3.31
4/17/13	0.90	1.14	Flat	Flat	NA	2.23	NA
4/22/13	0.59	0.59	Flat	0.72	NA	0.43	NA
4/26/13	0.71	0.87	Flat	Flat	NA	1.22	2.81
5/2/13	1.02	1.02	Flat	0.72	NA	NA	NA

Filter the Max depth <0.1 ft. and difference <0.1 ft.							
	total rainfall (inch)		Drawdown rate(inch/hour)				
Date	UMKC	City	1324	1325	1336	1612	1112
5/8/13	0.26	0.28	Flat	Flat	NA	Flat	NA
5/27/13	2.36	2.72	Flat	10.87	NA	3.89	1.87
5/29/13	1.30	1.14	Flat	NA	NA	1.66	2.62
5/31/13	1.09	1.30	NA	NA	NA	4.54	1.87
6/4/13	0.20	0.16	Flat	Flat	NA	NA	NA
6/5/13	0.21	0.28	Flat	Flat	NA	NA	NA
6/9/13	0.31	0.35	Flat	Flat	NA	Flat	Flat
6/15/13	0.28	1.10	Flat	4.93	NA	3.24	NA
6/27/13	1.14	1.30	Flat	1.22	5.83	4.46	NA
9/1/13	0.35	0.55	Flat	Bad Data	na	NA	0.94
9/17/13	0.71	0.67	Flat	2.66	7.52	NA	NA
9/19/13	1.46	1.85	Flat	1.80	2.16	NA	2.66
9/28/13	0.39	0.51	Flat	NA	1.84	NA	0.65
10/3/13	0.30	0.28	Flat	6.23	2.38	NA	3.53
10/4/13	0.42	0.39	Flat	5.74	4.18	NA	5.69
10/29/13	0.83	0.91	Flat	NA	3.67	NA	3.60
10/30/13	2.88	2.68	Flat	NA	3.47	NA	3.01
8/29/14	na	0.39	Flat	Flat	NA	NA	NA
8/31/14	na	1.26	Flat	Flat	NA	NA	NA
10/1/14	2.71	2.99	Flat	Flat	NA	NA	NA
10/9/14	1.90	1.85	0.58	Flat	NA	NA	NA
10/13/14	1.32	1.30	Flat	Flat	NA	NA	NA
3/18/15	0.67	0.67	Flat	Flat	NA	NA	NA
4/2/15	0.50	0.55	Flat	Flat	NA	NA	NA
4/12/15	0.72	0.63	Flat	Flat	NA	NA	NA
4/13/15	1.10	1.20	5.76	Flat	NA	NA	NA
4/18/15	0.54	0.47	Flat	Flat	NA	NA	NA

Filter the Max depth <0.1 ft. and difference <0.1 ft.							
	total rainfall (inch)		Drawdown rate(inch/hour)				
Date	UMKC	City	1324	1325	1336	1612	1112
4/19/15	0.61	0.51	Flat	Flat	NA	NA	NA
4/25/15	0.41	0.35	Flat	Flat	NA	NA	NA
5/4/15	0.49	0.32	Flat	Flat	NA	NA	NA
5/7/15	1.19	1.02	0.36	Flat	NA	NA	NA
5/14/15	0.53	0.47	Flat	Flat	NA	NA	NA
5/15/15	0.33	0.20	Flat	Flat	NA	NA	NA
5/16/15	1.80	2.05	6.41	Flat	NA	NA	NA
5/20/15	0.87	0.95	6.26	Flat	NA	NA	NA
5/23/15	1.47	1.73	6.55	Flat	NA	NA	NA
5/26/15	0.38	0.39	0.79	Flat	NA	NA	NA
5/28/15	0.31	0.32	Flat	Flat	NA	NA	NA
5/29/15	0.59	0.87	Flat	Flat	NA	NA	NA
6/3/15	1.67	2.29	5.98	Flat	NA	NA	NA
6/5/15	0.75	0.91	Bad Data	Flat	NA	NA	NA
6/7/15	0.49	0.59	NA	Flat	NA	NA	NA
6/15/15	1.21	0.91	NA	Flat	NA	NA	NA
6/17/15	0.25	0.35	NA	Flat	NA	NA	NA
Average			4.70	3.75	3.51	2.64	3.24
Max			9.58	10.87	8.93	4.54	6.05
NA-Data Not Available Bad Data: Senor reading error Flat: Garden depth are always < 0.1ft.							

APPENDIX E: Watershed Level Data

Layer	Drainage area (ac)	Impervious Percentage	Watershed Slope	Street Slope	Type Valid	Applied Model	Comments
Bioretention	0.21	47.11	5.69	6.34	House NO.7446 Bioretention	Model 1	
Bioretention	0.31	46.94	2.84	2.41	House NO.7442 bioretention	Model 1	
Bioretention	0.20	56.63	2.65	3.23	House NO.7401 bioretention	Model 1	
Bioretention	0.55	46.63	3.51	3.27	House NO.7348 bioretention	Model 1	
Bioretention	0.09	51.94	0.98	0.96	House NO.7345 bioretention	Model 1	
Bioretention	0.21	46.10	4.30	0.73	House NO.7348 bioretention	Model 1	
Bioretention	0.39	36.92	3.20	2.42	House NO.7441 bioretention	Model 1	
Bioretention	0.42	37.77	6.64	5.49	House NO.7445 Bioretention	Model 1	
Bioretention	0.40	47.46	4.88	3.97	House NO.7445 bioretention	Model 1	
Bioretention	0.25	53.67	1.47	1.04	House NO.1332 bioretention	Model 1	
Bioretention	0.43	64.85	4.02	0.67	House NO.1460 bioretention	Model 1	
Bioretention	0.42	42.67	3.61	0.69	House NO.1459 bioretention	Model 1	
Bioretention	0.35	22.87	4.38	0.71	House NO.1344 bioretention	Model 1	
Bioretention	0.40	35.60	4.60	4.01	House NO.1346 bioretention	Model 1	
Bioretention	0.39	45.33	3.36	4.97	House NO.1400 bioretention	Model 1	
Bioretention	0.00	88.54	0.00	0.73	Troost&76th ter bioretention	Model 1	Combined with 127 and 129
Bioretention	0.00	88.54	0.00	0.73	Troost&76th ter bioretention	Model 1	Combined with 126 and 129
Bioretention	0.59	67.34	2.14	0.93	Troost & 76th ter NO.7616 bioretention	Model 1	

Bioretention	0.41	88.54	0.65	0.87	Troost & 76th ter bioretention	Model 1	
Bioretention	0.63	86.12	2.26	0.85	Troost &77th NO.7702 bioretention	Model 1	
Bioretention	0.00	77.47	0.00	1.61	Troost & 76th Ter bioretention	Model 1	Combined with 132
Bioretention	0.39	77.47	1.07	1.61	Troost & 76th Ter bioretention	Model 1	
Bioretention	0.48	83.59	3.14	0.31	Troost & 76th ter NO.7630 bioretention	Model 1	
Bioretention	0.64	32.75	5.13	2.68	House NO.7444 Bioretention	Model 1	
bioswale	1.19	77.03	2.65	1.44	House NO.1300 raingarden with underdrain?	Model 1	
cascade	0.30	60.65	3.92	7.96	House NO.1111 raingarden	Model 1	
cascade	0.32	32.75	5.13	4.47	House NO.7435 raingarden	Model 1	
cascade	0.25	44.62	5.03	6.03	House NO.7433 raingarden	Model 1	
cascade	0.29	32.47	5.97	5.49	House NO.7434 Raingarden	Model 1	
cascade(1112)	0.26	69.69	7.93	7.96	House NO.1112 Raingarden	Model 1	
Curb Extension w BR	1.36	22.80	5.71	4.06	House NO 1436 Bioretention	Model 1	
Curb Extension w BR	0.34	32.10	4.13	2.24	House NO.1187 Bioretention	Model 1	
Curb Extension w BR	0.08	60.65	5.56	4.58	House NO.1119 Bioretention/porous	Model 1	
Curb Extension w BR	0.09	58.57	1.74	2.29	House NO.1160 Bioretention	Model 1	
Curb Extension w BR	0.59	27.60	5.51	2.48	House NO.1159 Bioretention	Model 1	
Curb Extension w BR	0.81	25.74	4.27	4.20	House NO.1344 bioretention	Model 1	
Curb Extension w BR	0.87	34.42	4.82	1.23	House NO.1346 bioretention	Model 1	

Curb Extension w BR	0.09	61.90	1.35	1.23	House NO.1347 bioretention	Model 1	
Curb Extension w BR	0.28	61.47	4.37	5.39	House NO.1523 bioretention	Model 1	
Curb Extension w BR	0.97	29.29	4.98	5.55	House NO.1522 bioretention	Model 1	
Curb Extension w BR	0.31	38.18	5.25	3.53	House NO.1418 bioretention	Model 1	
Curb Extension w BR	0.80	61.33	4.23	4.34	House NO.1122 Bioretention	Model 1	
Curb Extension w BR	0.40	44.75	3.91	4.65	House NO.1123 Bioretention	Model 1	
Curb Extension w BR	0.33	45.51	1.65	4.07	House NO.1191 bioretention	Model 1	
Curb Extension w BR	2.19	23.68	3.15	0.86	House NO.1420 bioretention	Model 1	
Curb Extension w BR	0.22	49.40	4.32	0.84	House NO.1425 bioretention	Model 1	
Curb Extension w BR	0.27	55.60	3.05	2.03	House NO.1190 bioretention	Model 1	
Curb Extension w BR	0.10	62.47	7.80	4.52	House NO.1118 bioretention	Model 1	
Curb Extension w BR	0.28	61.47	2.12	3.17	House NO.1419 bioretention with porous	Model 1	
Curb Extension w BR	0.24	55.72	3.25	1.39	House NO.932 bioretention	Model 1	
Curb Extension w BR	0.22	44.95	4.20	1.37	House NO.933 bioretention	Model 1	
Curb Extension w BR	0.18	46.87	0.64	0.57	House NO.820 bioretention	Model 1	
Curb Extension w BR	0.55	29.74	1.74	0.96	House NO.845 bioretention	Model 1	

Curb Extension w RG	0.21	53.16	4.04	4.07	House NO.1437 Raingarden with underdrain	Model 1	
Curb Extension w RG	1.10	32.77	4.25	4.98	House NO.1146 raingarden with porous sidewalk	Model 1	
Curb Extension w RG	0.00	33.87	0.00	4.68	House NO.1141 raingarden with porous sidewalk	Model 1	Combined with NO.36
Curb Extension w RG	0.22	64.85	4.02	2.18	House NO.1422 raingarden with underdrain/porous	Model 1	
Curb Extension w RG	0.00	61.47	0.00	2.23	House NO.1403 raingarden with underdrain	Model 1	This garden doesn't really has a drainage area
Curb Extension w RG	0.00	49.40	0.00	6.54	House NO.1401 raingarden with underdrain	Model 1	This garden doesn't really has a drainage area
Curb Extension w RG	0.15	33.70	5.17	5.55	House NO.1400 raingarden with underdrain/ porous	Model 1	
Curb Extension w RG	0.56	41.46	5.10	2.23	House NO.1419 raingarden/porous	Model 1	
Curb Extension w RG	0.40	64.85	4.02	3.21	House NO.1400 flower bed, not a raingarden	Model 1	
Curb Extension w RG	0.37	29.43	3.60	3.38	House NO.1401 raingarden/porous	Model 1	
Curb Extension w RG	0.00	36.02	0.00	3.25	House NO.1400 raingarden with underdrain/porous	Model 1	Combined with NO.74
Curb Extension w RG(1324)	0.08	65.93	3.64	1.65	House NO.1324 raingarden with porous sidewalk	Model 1	
Curb Extension w RG(1325)	0.07	66.86	3.71	1.88	House NO.1325 raingarden	Model 1	

raingarden	0.45	33.34	5.91	1.56	House NO.7506 raingarden but has underdrain	Model 1	
raingarden	0.09	61.90	1.35	1.04	House NO.1337 raingarden	Model 1	
raingarden	1.00	50.38	3.72	1.50	House NO.1126 raingarden	Model 1	
raingarden	0.21	50.38	3.72	1.50	House NO.1136 raingarden with underdrain	Model 1	
raingarden	1.00	29.36	5.55	1.76	House NO.1151 raingarden	Model 1	
raingarden	0.34	32.10	4.13	3.49	House NO.1187 raingarden with underdrain	Model 1	
raingarden	0.18	55.60	3.05	3.20	House NO.1184 raingarden/porous	Model 1	
raingarden	0.29	64.85	4.02	2.98	House NO.1434 raingarden/porous	Model 1	
raingarden	1.36	22.80	4.46	3.81	House NO.1452 Raingarden with underdrain	Model 1	
raingarden	0.11	45.37	0.89	0.87	House NO.1157 Raingarden	Model 1	
raingarden	0.06	45.37	0.89	0.87	House NO.1165 Raingarden with underdrain	Model 1	
raingarden	0.30	33.87	5.39	5.35	House NO.1127 Raingarden with underdrain	Model 1	
raingarden	0.35	48.67	3.14	1.65	House NO.1106 Raingarden	Model 1	
raingarden	0.31	53.67	1.47	1.53	House NO.7425 raingarden	Model 1	
raingarden	0.25	49.45	4.26	5.95	House NO.7409 Raingarden	Model 1	
raingarden	0.31	54.63	3.30	5.98	House NO.7404 Raingarden with underdrain	Model 1	
raingarden	0.28	51.46	1.45	4.96	House NO.7404 raingarden with underdrain	Model 1	
raingarden	0.37	52.67	5.77	6.29	House NO.7409 raingarden	Model 1	
raingarden	0.26	50.16	3.65	5.43	House NO.7416 raingarden with underdrain	Model 1	
raingarden	0.70	35.32	1.85	1.80	House NO.1300 raingarden	Model 1	

raingarden	0.39	50.93	1.96	1.76	House NO.7417 raingarden	Model 1	
raingarden	0.09	58.57	1.74	1.81	House NO.1150 raingarden/porous	Model 1	
raingarden	0.91	23.00	5.42	1.76	House NO.1145 raingarden	Model 1	
raingarden	0.09	55.60	3.05	2.49	House NO.1174 raingarden	Model 1	
raingarden	0.40	44.75	3.91	3.89	House NO.1115 raingarden with underdrain	Model 1	
raingarden	0.25	47.80	6.27	4.76	House NO.1210 raingarden with underdrain	Model 1	
raingarden	0.18	56.07	4.51	7.52	House NO.1245 raingarden with underdrain	Model 1	
raingarden	0.18	56.07	4.51	3.79	House NO.1301 raingarden with underdrain	Model 1	
raingarden	0.05	65.87	4.28	4.95	House NO.1309 raingarden	Model 1	
raingarden	0.51	43.64	4.70	4.67	House NO.1316 raingarden with underdrain	Model 1	
raingarden	0.09	61.47	2.14	3.10	House NO,1407 raingarden	Model 1	
raingarden	0.42	36.02	4.83	3.72	House NO.1412 raingarden	Model 1	
raingarden	0.47	55.62	2.22	2.29	House NO.1111 Raingarden	Model 1	
raingarden	0.67	32.29	4.51	0.62	House NO 1158 Raingarden with porous sidewalk	Model 1	
raingarden	0.67	32.29	4.51	0.62	House NO1162 Raingarden with underdrain	Model 1	
raingarden	0.34	32.68	3.56	0.62	House NO1176 Raingarden with porous sidewalk	Model 1	
raingarden	0.17	45.51	1.65	0.87	House NO.1185 Raingarden with underdrain	Model 1	
raingarden	0.56	30.19	2.79	0.77	House NO.1403 raingarden	Model 1	
raingarden	0.28	30.19	3.85	0.77	House NO.1400 raingarden	Model 1	
raingarden	0.37	29.50	4.55	1.32	Hose NO.1190 E 76th Ter raingarden with underdrain	Model 1	

raingarden	0.70	22.87	4.38	0.71	House NO.7506 raingarden but has underdrain	Model 1	
raingarden	0.75	47.82	3.29	5.04	House NO.1126 Raingarden with underdrain	Model 1	
raingarden	0.11	53.16	3.31	4.71	House NO.1451 Raingarden	Model 1	
raingarden	0.11	56.64	4.95	5.81	House NO.7426 raingarden with underdrain	Model 1	
raingarden	0.18	44.62	4.69	5.60	House NO.7425 raingarden	Model 1	
raingarden	0.89	36.89	1.56	0.42	House NO.7345 raingarden	Model 1	
raingarden	0.15	45.45	1.48	0.44	House NO.7401 raingarden	Model 1	
raingarden	0.07	45.45	1.48	0.44	House NO.7404 raingarden	Model 1	
raingarden	0.32	36.89	7.38	0.42	House NO.7342 raingarden	Model 1	
raingarden	0.24	41.62	6.01	5.68	House NO. 7416 Raingarden with underdrain	Model 1	
raingarden	0.28	42.01	8.72	4.79	House NO.7439 Raingarden	Model 1	
raingarden	0.21	61.71	0.99	1.17	House NO.1300 raingarden	Model 1	
raingarden	0.19	24.80	3.24	1.46	House NO.7420 Raingarden	Model 1	
raingarden	0.20	51.36	1.65	1.30	House NO.7424 raingarden	Model 1	
raingarden	0.69	35.52	2.11	1.40	House NO.7410 raingarden	Model 1	
raingarden	0.16	70.06	0.51	1.18	House NO.7411 raingarden	Model 1	
raingarden	0.20	52.26	7.39	2.82	House NO.7421 Raingarden with underdrain	Model 1	
raingarden	0.52	34.54	7.51	0.67	House NO.1462 raingarden	Model 1	
raingarden	0.19	61.47	4.37	4.42	House NO.1613 Raingarden with underdrain	Model 1	
raingarden	0.15	33.70	5.17	5.63	House NO.1410 Raingarden	Model 1	
raingarden	0.13	57.36	2.15	2.34	House NO.1471 raingarden with underdrain	Model 1	
raingarden	0.12	56.53	0.67	0.83	House NO.1400 raingarden	Model 1	
raingarden(1336)	0.51	40.18	5.48	1.88	House NO.1336 Raingarden	Model 1	

raingarden(1612)	0.21	33.00	3.55	4.42	House NO.1612 raingarden with underdrain	Model 1	
SBR	0.11	67.72	0.55	0.16	House NO.1401 bioretention	Model 2	
SBR	0.38	42.30	2.40	1.22	House NO.7440 bioretention	Model 2	
SBR	0.42	61.71	0.99	1.17	House NO.1300 bioretention	Model 2	
SBR(1140)	0.03	85.61	2.07	1.50	House NO.1140 Bioretention	Model 2	
SBR(1222)	0.32	28.74	6.57	7.52	House NO.1222 Bioretention	Model 2	
Total Treated Area= 49.32 ac. Average Impervious Percentage = 48.44 ,Average Watershed Slope= 3.51, Average Street Slope= 2.85.							

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[3] City of New Hampshire, "New Hampshire Stormwater Manual," 2015.

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VITA

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Yanan married with Mr. Wei Jin in 2013 and live in South Kansas City. Besides work and study, she records online radio shows and songs as a hobby. She loves traveling to national parks with family.