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Ballard Roadside Raingardens

Phase 1 Hydrologic Monitoring Report

September 2012 through May 2013
Report Prepared January 2014

Seattle Public Utilities

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DUSTIN B. ATCHISON
STATE OF WASHINGTON
38291
REGISTERED
PROFESSIONAL ENGINEER

Seattle Public Utilities
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Term	Definition
bgs	below ground surface
BRR1	Ballard Roadside Raingarden, Phase 1
City	City of Seattle
CSS	combined sewer system
CSO	combined sewer overflow
DPP	drive point piezometer
ft	feet
gpm	gallons per minute
hr	hour
in	inches
LTCP	Long-Term Control Plan
MH	maintenance hole
NPDES	National Pollutant Discharge Elimination System
NW	Northwest
PVC	polyvinyl chloride
QAPP	quality assurance project plan
ROW	right-of-way
SPU	Seattle Public Utilities

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Summary

Two roadside raingardens were constructed in fall 2010 in the Ballard neighborhood of Seattle for Phase 1 of the Ballard Roadside Raingarden (BRR1) pilot project. BRR1 is Seattle Public Utilities' (SPU's) first application of bioretention for stormwater flow control facilities in a combined sewer overflow (CSO) basin. The purpose of the pilot project is to construct bioretention cells in the right-of-way to reduce the volume of stormwater entering the combined sewer system (CSS).

After they were constructed, the water levels and flow volumes through the raingardens were monitored to verify and refine the current performance of estimation tools (such as models) for roadside raingardens as a strategy for CSO control and provide an estimate of the average annual stormwater flow volume removed from the CSS. Two raingardens were monitored: (1) the 30th Avenue raingarden, on the southwest corner of the intersection of 30th Avenue Northwest (NW) and Loyal Way NW and (2) the 28th Avenue raingarden, on the west side of 28th Avenue NW between NW 66th and NW 67th streets.

These represent the two different types of raingardens constructed in this area, (1) those without underdrains and (2) those with underdrains. Underdrains consist of a perforated pipe in a gravel drain layer below the bioretention media. They facilitate drainage by routing some infiltrated water back to the local sewer system and are intended for areas where subsurface conditions are not ideal for infiltration.

The 30th Avenue raingarden was designed to capture and infiltrate over 95 percent of stormwater without use of underdrains and has drained adequately since installation. The 28th Avenue raingarden was originally constructed without underdrains but later retrofitted with underdrains.

Post-construction monitoring consisted of:

1. Continuous flow monitoring of the combined sewer or storm drain system immediately downstream of the raingardens
2. Continuous water level monitoring in the shallow subsurface soils and ponding areas within the raingarden or in maintenance holes (MHs) receiving flow from underdrains (28th Avenue raingarden only)

3. Controlled flow tests in September 2012 and April 2013

Continuous water level monitoring and flow monitoring began in September 2012 and ended in April 2013.

The results support the application of bioretention for CSO control in Seattle when these facilities are properly sited and designed. Data from controlled flow tests and from continuous monitoring are of good or excellent quality and therefore suitable for model calibration, and will support the development of a calibrated model of the raingardens and inform future raingarden designs. Results indicate the raingardens are functioning as anticipated by capturing and infiltrating flows that would otherwise enter the combined sewer system (CSS). Specifically, these monitoring results indicate that the 30th Avenue and 28th Avenue raingardens remove an average of 267,000 and 99,500 (respectively) gallons of stormwater flow from the CSS each year in the Ballard CSO Basin.

Flow tests at both raingardens indicated that inlet capacity may be a critical component of design. Discharge to the sewer can occur when the surface runoff from storms exceeds the inlet capacity of the raingardens. High flows can bypass the upstream inlets simply due to orientation along the roadway, but it also appears that minor variations in cross-slope, inlet shape, roadway slope, and presence of sediment or vegetation can have a significant impact on inlet capacity. Performance at the 30th Avenue raingarden could be improved by increasing inlet capacity at the upstream cells. The curb inlets at 28th Avenue have been retrofitted with asphalt berms, which have improved their capacity to capture flow.

Monitoring data showed that the 30th Avenue raingarden can handle up to the 15-year storm event and captured 98-99% of CSO-size storm volumes, outperforming its original design goal to capture 95 percent of CSO-size storms.

Monitoring at 28th Avenue showed that significant benefits for CSO reduction are possible even in a raingarden with an underdrain that directs flow to the sewer. The raingarden reduced peak flow rates by an average of 80-90 percent of CSO-size storm events. The 28th Avenue raingarden also provided delayed discharge to the sewer for an average of approximately 50-60 percent of the inflow (of the 20 storm events of the monitoring period). The raingarden fully infiltrated the remaining 40-50 percent, more than was expected from the retrofitted raingarden. This indicates that underdrains with flow restrictions can be an appropriate and effective design element in soils with low infiltration, and benefits can be maximized by optimizing the underdrain's orifice size and location for a given basin.

Per this analysis, the monitored raingardens could be downsized to reduce cost and still meet the performance objective of mitigating the CSO control target (one overflow per year). Sizing of raingardens is largely dependent on estimated design infiltration rates which can vary dramatically from site to site and based on existing hydrologic conditions at the time of exploration. The results suggest that infiltration rates may vary seasonally and potentially as facilities mature.

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SECTION 1

Purpose

This report presents the results of post-construction water level monitoring and flow monitoring conducted from September 2012 through April 2013 in two Ballard roadside raingardens. As part of the Ballard Roadside Raingarden Phase 1 (BRR1) project, stormwater bioretention facilities in the form of roadside raingardens were constructed for intercepting and infiltrating stormwater before it reaches the combined sewer system (CSS). BRR1 is Seattle Public Utilities' (SPU's) first application of bioretention for stormwater flow control facilities in a combined sewer overflow (CSO) basin. The purpose of the pilot project is to construct bioretention cells within the right-of-way to reduce the storage volume needed to control discharges to combined sewer overflows (CSOs).

The BRR1 project involved construction of roadside raingardens in the right-of-way (ROW) along approximately eight blocks in the northwest corner of the Ballard basin (see Figure 1). Specifically, raingardens were located along 28th Avenue Northwest (NW) from NW 65th Street to NW 73rd Street, along 30th Avenue NW from NW 80th Street to Loyal Way NW, and along 31st Avenue NW from NW 75th to NW 77th Street.

The raingardens were constructed in fall 2010. Raingardens are built by over-excavating an area of the ROW (typically the planting strip) and backfilling with bioretention soil, which is a special soil blend of sand and compost. A shallow depression is left to capture stormwater until it soaks into the soil. The soil surface is covered with a mulch layer and planted with native plants. Due to localized problems with inadequate infiltration and community concerns, raingardens along 28th Avenue NW were retrofitted in summer 2011 to include underdrains with orifices to reduce the period of surface ponding on the raingarden while still slowing the flow rate into the underdrain enough to continue to promote local infiltration. Underdrains consist of perforated pipe in a gravel drain layer. They are installed below the bioretention media to facilitate drainage by routing some infiltrated water back to the CSS. By retrofitting with underdrains, the focus of the 28th Avenue NW raingarden was shifted from complete infiltration of stormwater to retention and delay of stormwater to the CSS. The raingardens along 30th Avenue NW drained adequately and were not retrofitted. Elsewhere in the Ballard neighborhood, raingardens originally constructed in Phase 1 were decommissioned by backfilling or removing, due to poor performance or modified as "flow-thru" raingardens that did not allow surface ponding.

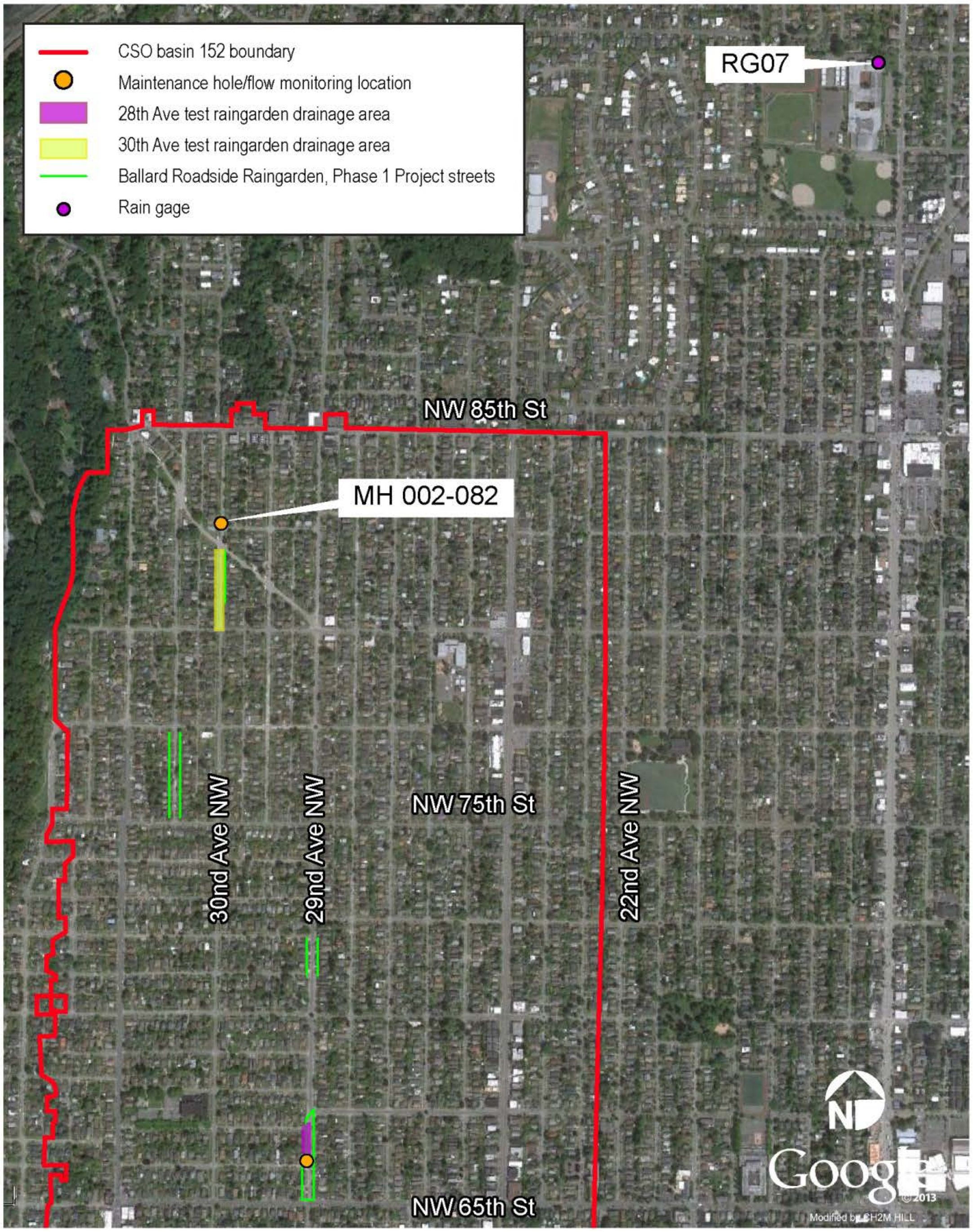

Figure 1. BRR1 Overview Map

The overall goals of performing post-construction hydrologic monitoring are to verify and refine the current performance of estimation tools (such as models) for roadside raingardens as a strategy for CSO control and provide an estimate of the average annual stormwater flow volume removed from the CSS. Using data collected under the Long-Term Control Plan (LTCP) flow monitoring program, a hydrologic and hydraulic model was developed for the CSO basin served by the BRR1 bioretention facilities. This report is intended to be a reference document for CSO basin modelers and others involved in CSO control and bioretention applications. An additional objective for this pilot project is to develop design templates for roadside raingardens in a CSO neighborhood. The results of the monitoring may also inform future design revisions to optimize performance of roadside raingardens.

Two raingardens were selected for monitoring to represent raingardens without and with underdrains: (1) the 30th Avenue raingarden (without underdrains), on the southwest corner of the intersection of 30th Avenue Northwest and Loyal Way Northwest and (2) the 28th Avenue raingarden (with underdrains), on the west side of 28th Avenue Northwest between Northwest 66th and Northwest 67th streets.

Water level monitoring and flow monitoring were conducted according to SPU’s *Quality Assurance Project Plan: Ballard Roadside Raingardens, Phase 1*, dated September 1, 2011. Hydrologic monitoring consisted of:

1. Continuous flow monitoring of the CSS or storm drain system immediately downstream of the raingardens
2. Continuous water level monitoring in the shallow subsurface soils and ponding areas within the raingarden or in maintenance holes (MHs) receiving flow from underdrains (28th Avenue raingarden only)
3. Controlled flow tests in September 2012 and April 2013

The controlled flow tests used simulated “design storms”— rainfall events with a specific pattern, depth, and duration to simulate performance under the target design objective, which in this case was CSO reduction per the regulatory standard of less than one overflow per year.

The objectives of the post-construction hydrologic monitoring and controlled flow tests were to:

- Adequately and accurately characterize the hydrologic performance of the roadside raingardens for:
    - The CSO design storm event(s) specific to the Ballard basin
    - A full wet season including real-time storm events and antecedent conditions
- Capture pre- and post-construction data for each of the simulated storm events.
- Determine saturated and unsaturated infiltration rates for the raingardens and other parameters necessary to model bioretention facilities
- Estimate total volume of runoff infiltrated and seasonal impacts on raingarden performance

Hydrologic performance for Ballard-specific design storm events was characterized by compressing and replicating the design storm flows (peak timing, volume, and pattern) with applied inflow water from a hydrant, and by collecting continuous level and velocity data in the downstream CSS during the simulated events.

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SECTION 2

Raingarden Description

Bioretention is an integrated stormwater management practice that has been used increasingly locally and nationwide over the last 10 years. “Raingarden” is the common name for one type of bioretention facility. For Seattle, roadside raingardens are a newer application of bioretention.

To construct a raingarden, a shallow depression is formed by over-excavating and backfilling with bioretention soil. Following City of Seattle (City) specifications, this special soil blend is 60 to 65 percent sand and 35 to 40 percent compost. The bioretention soil is covered with a mulch layer and planted with native plants. Figure 2 illustrates a typical raingarden cross-section such as the 30th Avenue raingarden.

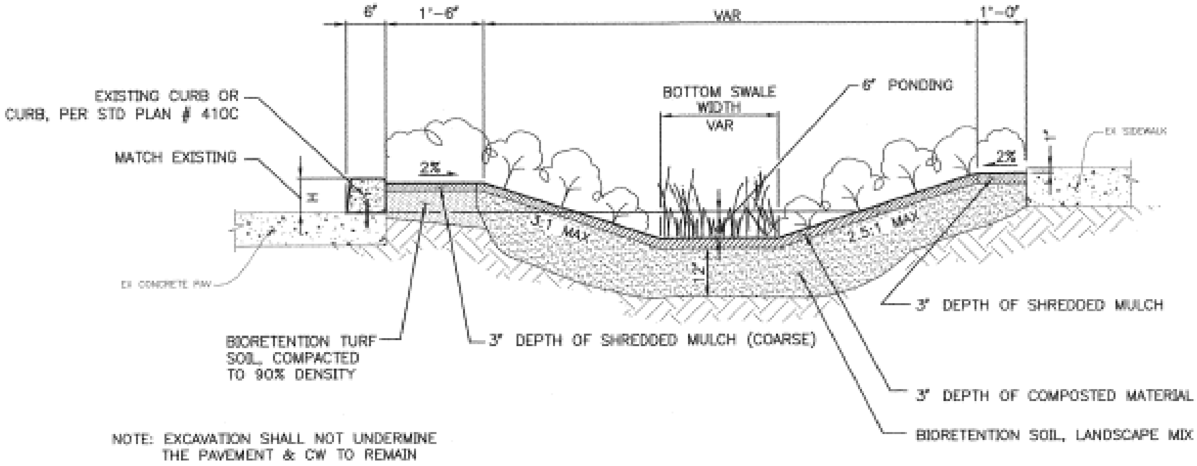

Figure 2. 30th Avenue Raingarden Cross-Section

Bioretention facilities manage stormwater by using capture-and-infiltrate approach. These processes reduce volume and peak flow and provide water quality treatment. SPU has mitigated stormwater flows from over 230 acres with bioretention in creek watersheds.

In CSO basins, roadside raingardens are located in one of two places, depending on site conditions: (1) within a curb extension (Figure 3), for which the curbline turns 90 degrees to run 5 feet into the roadway and then runs parallel to the road for a short length before turning back to rejoin the original curb, or (2) behind the curb in an existing planting strip between the curb and sidewalk (Figure 4). The 30th Avenue raingarden is of the latter design, and is located completely in the planting strip.

Figure 3. Curb Extension Design (31st Avenue NW)

Figure 4. Planting Strip Design (30th Avenue Raingarden)

Raingardens are generally placed between driveways or other obstructions at several locations along a block on either side of a street. For the CSO control target of limiting overflows to one per year, raingardens are designed to capture approximately 95 percent of the average annual volume of stormwater (which typically equates to infiltrating storms equal or less than the 1-year-recurrence-interval storm) through curb cuts as the water travels down the curbline. Up to 6 inches of ponding is allowed to provide additional storage and help with infiltration. With ponding greater than 6 inches, the water overflows the raingarden cell via a curb cut on the downstream end and either enters the next raingarden cell downstream or continues down the existing curbline, entering the CSS via an existing inlet. Figure 5 illustrates the typical flow path.

Figure 5. Typical Flow Pathway through the 30th Avenue Raingarden

30th Avenue Raingarden Description

The 30th Avenue raingarden includes cells on both sides of 30th Avenue NW south of Loyal Way NW. Only the cells located on the west of side of 30th Avenue were tested. This raingarden is of the typical SPU design (without underdrain), as described above. It has four individual cells, each with a trapezoidal curb cut inlet/outlet at the upstream and downstream ends. Flow that either slips by the curb cuts or overflows the cells enters the CSS through two inlets at the curb at the southwest corner of 30th and Loyal. Approximately 7,900 square feet of effective impervious area drains to the 30th Avenue raingarden, which has a total bottom area of 320 square feet.

An aerial view of the drainage basin for the 30th Avenue raingarden is shown in Figure 6.

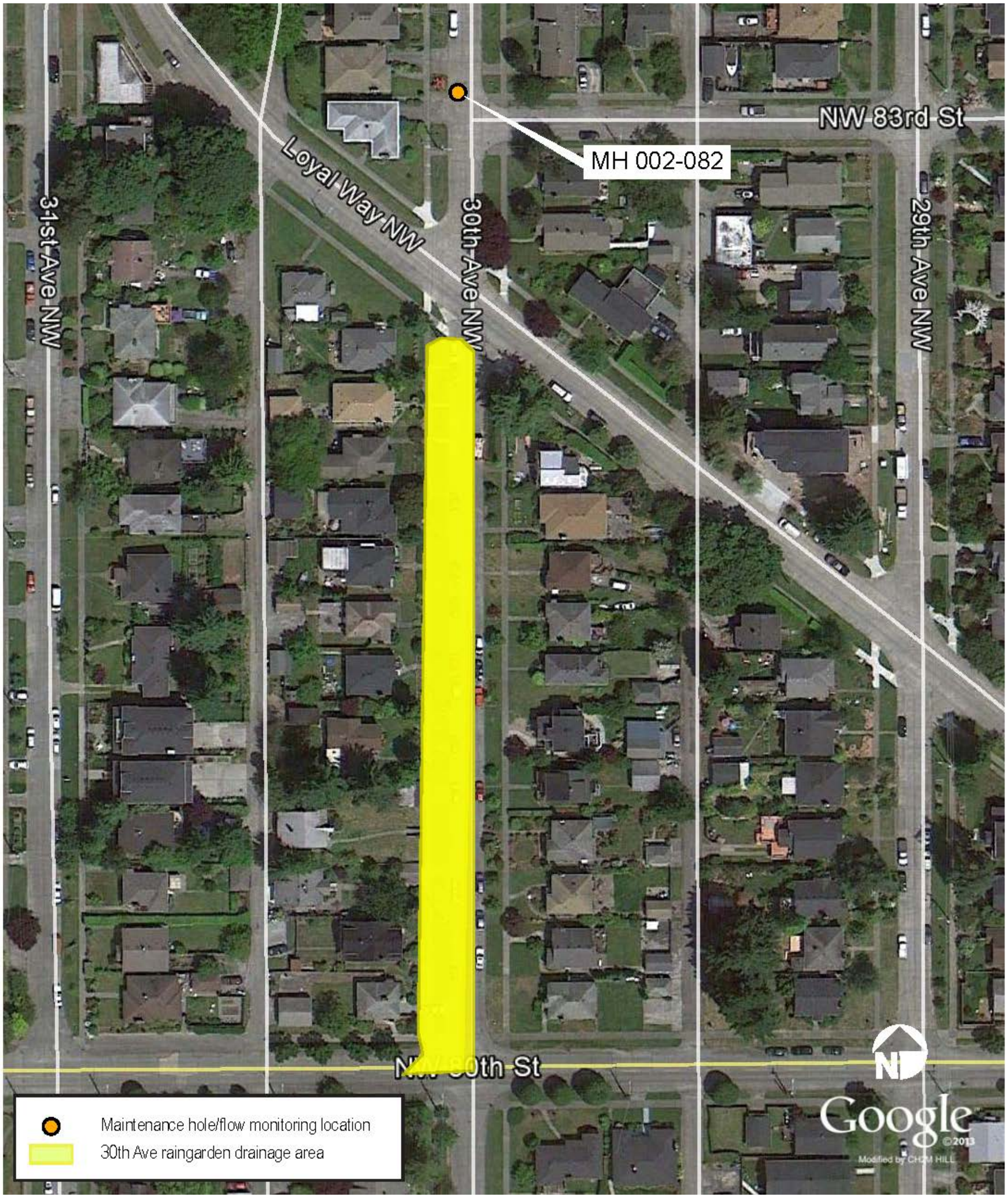

Figure 6. 30th Avenue Raingarden Drainage Area

28th Avenue Raingarden Description

The raingarden on the west side of 28th Avenue NW between NW 66th Street and NW 67th Street looks similar to the 30th Avenue raingarden, but functions quite differently. This raingarden is in an area underlain by a localized layer of shallow glacial till, which impedes infiltration, resulting in inadequate drainage and an unacceptable period of ponding after storm events. Therefore, this raingarden, originally built without an underdrain, was retrofitted in 2011 to include an underdrain, as shown in Figures 7 and 8. The underdrain gives stormwater that has passed through the bioretention soil a path out of the raingarden area so it does not pond on the surface. The underdrain consists of a 6-inch-diameter slotted polyvinyl chloride (PVC) pipe installed in gravel layer on top of the native soil.

As with the 30th Avenue raingarden, water enters the 28th Avenue raingarden cells from the curb through evenly distributed trapezoidal curb cuts. However, instead of providing a 6-inch-deep area for ponding, the retrofit design does not allow any visible ponding on the surface. This raingarden is backfilled nearly flush with the bottom of the curb cuts and has a sinuous layer of rounded river gravel/cobbles (referred to as a “stream gravel channel”) extending longitudinally down the center of the raingarden that varies in depth from 2 feet thick at the upstream end to approximately 0.5 feet thick at the bottom. Because the cobbles are uniform in size and diameter, there is a high volume of void space between them that allows the stormwater to quickly infiltrate. The cobbles also give the appearance of a dry river bed. After reaching the bottom of the cobble layer, stormwater infiltrates into the bioretention soil layer, which varies in depth from 5 feet at the upstream end to 3 feet at the downstream end. If, during a large storm event, stormwater cannot infiltrate into the subsurface fast enough, it can exit at the downstream end of each cell through a curb cut and then continue down to the next cell or into the existing storm drain inlet at the downstream end of the block. After infiltrating through the bioretention soil, the stormwater will either infiltrate into the native soil or enter the 6-inch-diameter underdrain pipe, where it is routed to a downstream MH and eventually back into the CSS.

The 28th Avenue raingarden has a 980-square-foot bottom area. It receives runoff from adjacent impervious areas under several conditions, as listed below in Table 1. The effective impervious area under saturated conditions (B) includes direct rainfall onto the raingarden footprint and sidewalk and parcel runoff.

Table 1. 28th Avenue Raingarden Tributary Areas

	Drainage Conditions	Area (square feet)
A	Directly connected impervious area from adjacent roadway, under normal conditions	5,400
B	Additional effective impervious area, under saturated conditions, from direct rainfall, adjacent sidewalk and private property	+2,800
C	Impervious area on NW 67th Street, connected to raingarden via inlet and flow splitter	+12,875
D	Total tributary area used for controlled flow test target flow rates	=21,075

In the original design, flow from 12,875 square feet along NW 67th Street was also plumbed to the raingarden series through an inlet and flow splitter. The sum of the tributary area used for calculation of the target flow rates for the controlled flow tests was therefore 21,075 square feet (conditions A + B + C in Table 1 above). Subsequent investigation of the raingarden revealed a plug in the system routing flow from NW 67th Street to the raingarden during the 2012 to 2013 wet season. This plug was removed in fall 2013. Along the center of the 28th Avenue NW raingarden are four MHs that access the underdrain piping. The underdrain pipe leaving each MH has a cap with a small orifice hole (0.8-inch diameter) on the upstream end that restricts the flow leaving the MH and thus the flow leaving the upstream cell, resulting in increased storage in the upstream cells and slowing discharge to downstream cells. This storage of stormwater in the raingardens, even those retrofitted with underdrains, is what provides the delay and reduction in storm volume and reduces the number of overflows from the basin. See Figure 7 for a cross-section of the 28th Avenue raingarden, and Figure 8 for an illustration of the monitoring points.

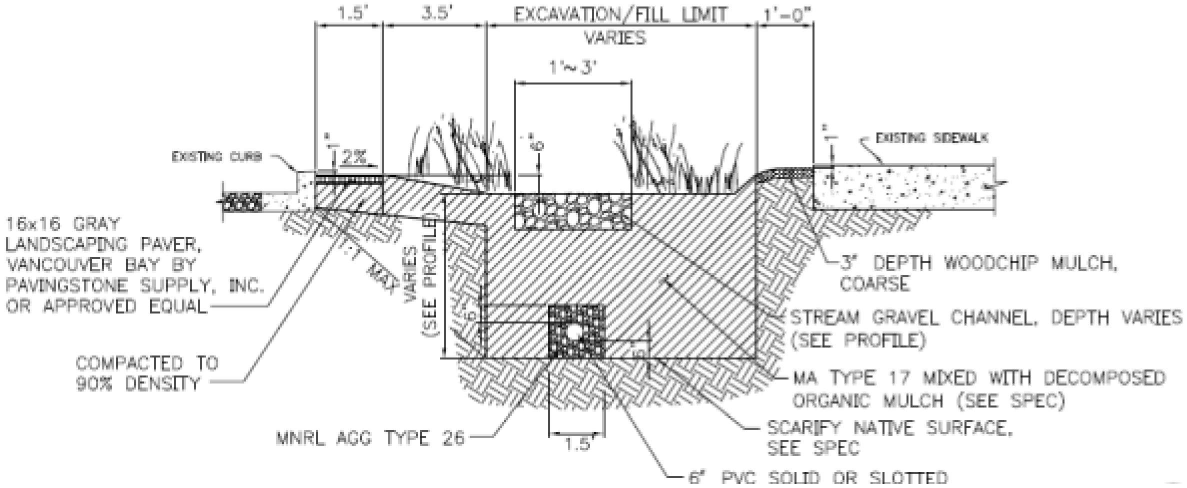

Figure 7. 28th Avenue Raingarden Cross-Section

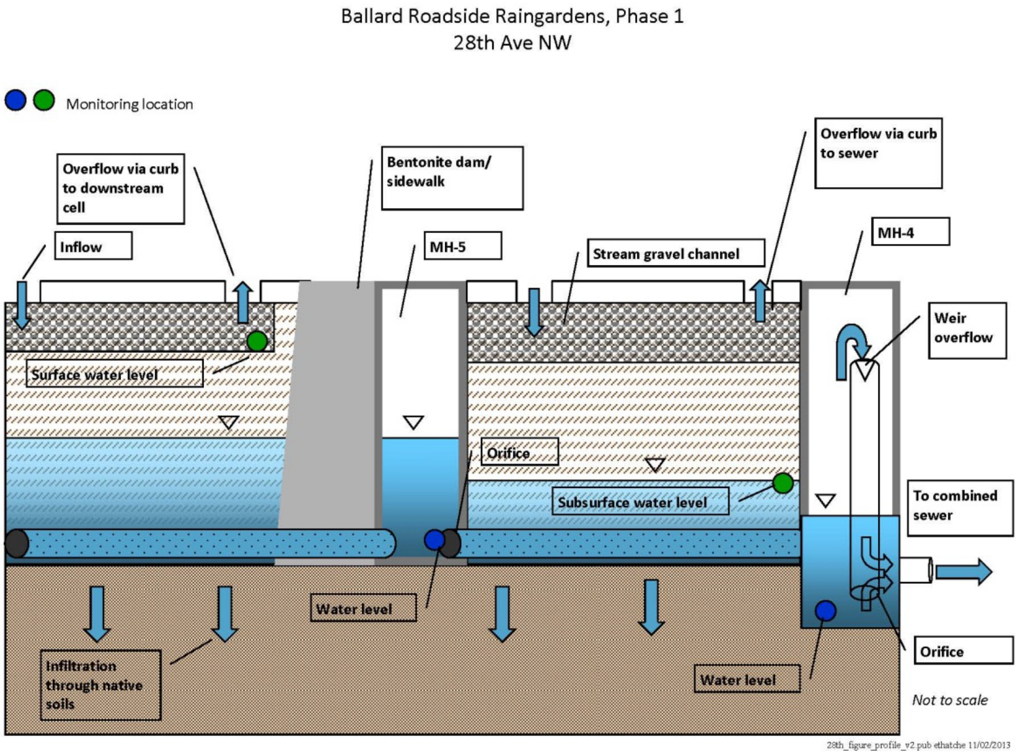

Figure 8. 28th Avenue Raingarden Cross-Section, with Monitoring Points

The most-downstream MH (MH 4) has a flow control structure consisting of an 8-inch-diameter riser pipe with a 0.5-inch-diameter orifice on the bottom that allows the stormwater to slowly enter the CSS. If MH 4 fills to near the surface, there is a high level overflow into the top of open riser pipe (see photos in the next section) at an elevation of about 2 inches below the ground surface.

An aerial view and the drainage basin for the 28th Avenue raingarden is shown in Figure 9.

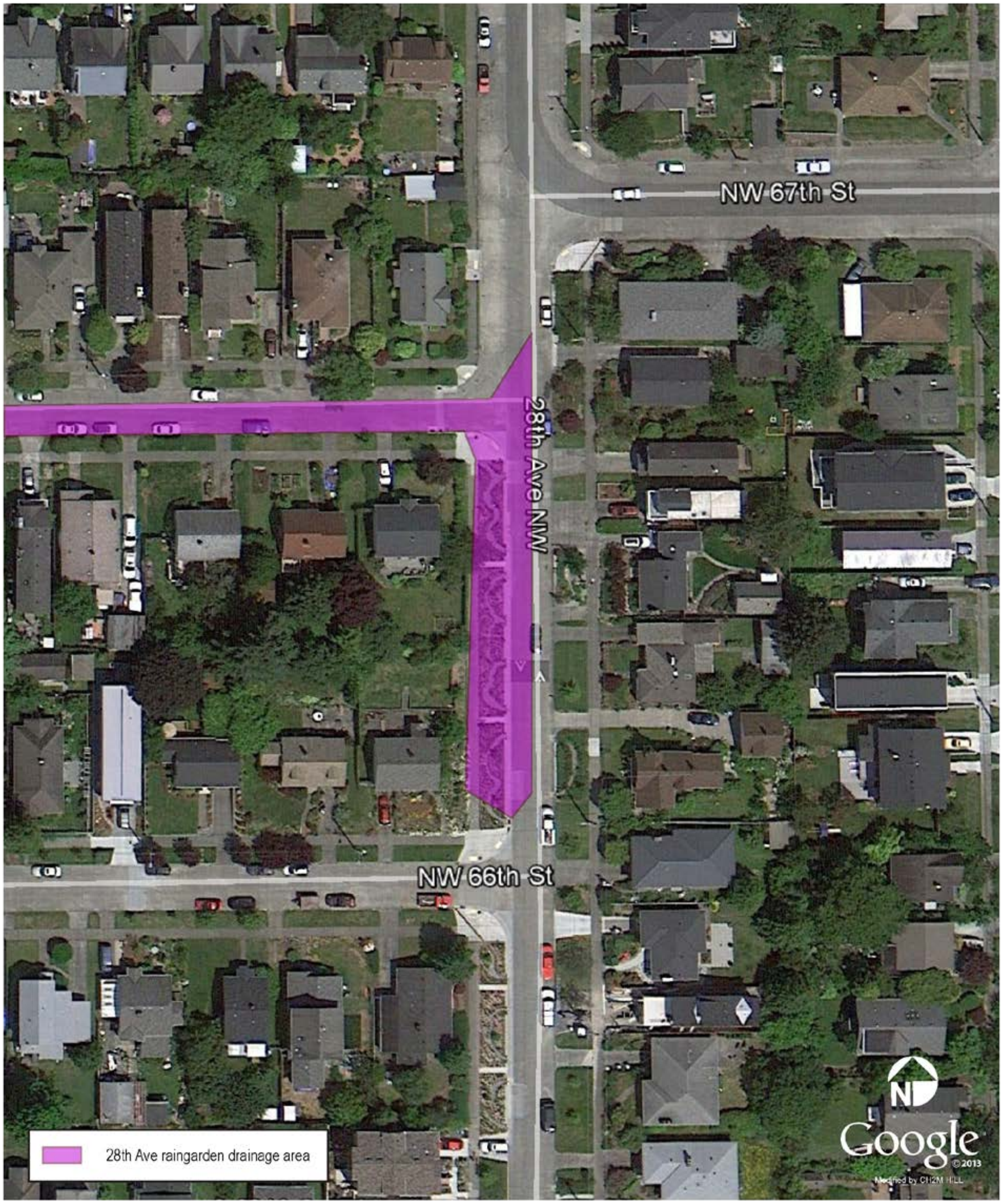

Figure 9. 28th Avenue Raingarden Drainage Area

SECTION 3

Monitoring Procedures

Pre-construction data were captured by running simulated storm flows down the roadway and bypassing the raingardens.

The post-construction data were captured by running the simulated storm flows down the roadway and allowing it to enter the raingardens. These tests were run during the late dry season (early September), while soil conditions were dry and base flows in the CSS were low, to allow for more accurate detection of the flows from the simulated storms. The tests were also run during the late wet season (early April), when base flows were higher and soil conditions were more saturated. Simulated storm tests were conducted on consecutive days to capture both dry (day one) and wet (following days) antecedent moisture conditions more typical of CSO events.

In addition, the raingardens were monitored throughout the 2012 to 2013 wet season (September through May).

Monitoring Locations

Water level and flow were monitored at several different points in and around the 30th Avenue and 28th Avenue raingardens. See Figure 1 for the location of all the Ballard raingardens, the two raingardens, and the project rain gage (RG07). Figures 10 and 11 show a plan view of the monitoring locations for the 30th Avenue and 28th Avenue raingardens.

Monitoring Equipment

Open-Channel (Downstream) Flow Monitors

ADS Environmental Services, Inc. (ADS) FlowShark open-channel flow monitors were installed in the first MH downstream of each raingarden to measure the surface overflow from the raingardens and/or the curb/gutter flow that slipped passed the raingarden inlets. FlowSharks are area-velocity flow monitors that can be configured to measure both depth (using multiple sensors) and velocity. Flow rate can then be calculated using these measurements and the channel dimensions. The ADS FlowShark flow monitors recorded depth and velocity at 5-minute intervals from September 2012 through April 2013. ADS installed and maintained the flow monitors.

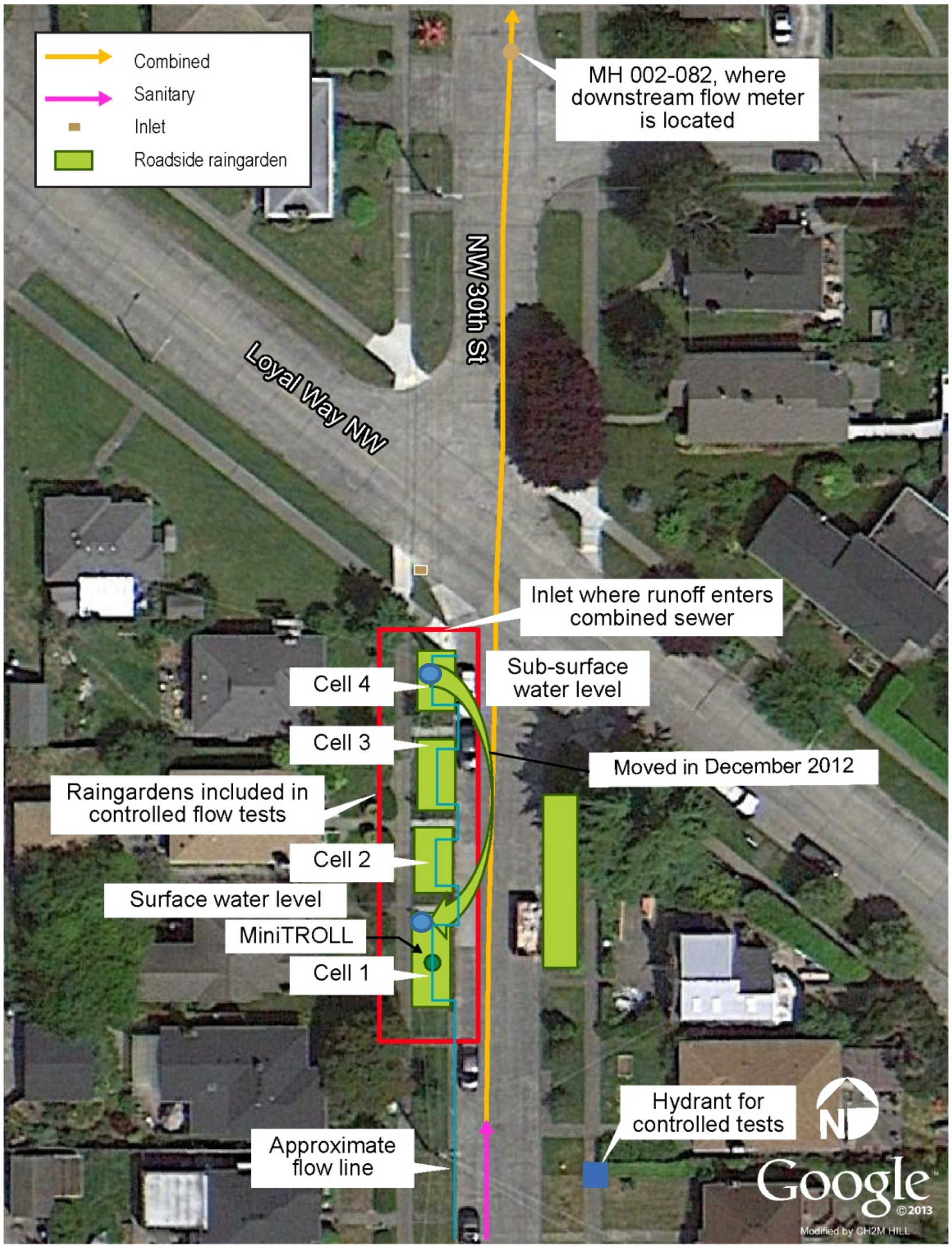

Figure 10. 30th Avenue Raingarden Monitoring Locations

Figure 11. 28th Avenue Raingarden Monitoring Locations

The downstream flow monitor at the 30th Avenue raingarden was in an 8-inch combined sewer immediately upstream of MH 002-082 (in 30th Avenue NW), in the block north of Loyal Way NW. This combined sewer receives both sanitary flow from adjacent residences and stormwater flow from roadway runoff from a basin area much larger than the basin draining to the raingarden. See Figure 12 for the entire basin boundary draining to this monitor location.

Figure 12. 30th Avenue Drainage Area to Flow Monitor in MH 002-082

Raingarden outflow and flow that bypasses the curb-cut raingarden inlets enters two inlets at the southwest corner of 30th Avenue NW and Loyal Way NW and drains to this combined sewer upstream of the flow-monitoring MH. This monitoring station is referred to as GSI_BAL_152-002-082A.

Due to expected low-level conditions, a low-flow dam (custom flume) was installed just downstream of the flow-monitoring sensor to back up the water level to a minimum depth of approximately 1 inch to improve the accuracy of the water level and velocity data. Level and velocity readings upstream of the low-flow dam were measured with an area-velocity sensor consisting of a submerged pressure transducer and a Doppler velocity sensor. Flow was calculated by multiplying area by velocity. See Figures 13a and 13b, respectively, for an area view and a close up of this monitoring station (GSI_BAL_152-002-082A).

Figures 13a and b. Overview and Close up Photo of Flow Monitoring Location GSI_BAL152-002-082A

The outlet flow monitor at the 28th Avenue raingarden was located in a 6-inch-diameter stormwater pipe receiving flow from two inlets in series at the northwest corner of 28th Avenue NW and NW 66th Street, which drains to a small MH/catch basin (MH 002-00535NW) in the sidewalk about 15 feet to the west. Due to expected low-level conditions, a Thel-Mar volumetric weir was installed in the downstream end of the 6-inch pipe just upstream of the monitoring MH. Water level behind (upstream of) this compound weir was measured with both ultrasonic and pressure depth sensors and level data were converted to flow using equations provided by the weir manufacturer. This monitoring station is referred to as GSI_BAL152-028-OUT. See Figures 14a and 14b, respectively, for an area view and a close up of this monitoring location.

Surface Ponding Level Monitors

A portable, logging pressure transducer (In-Situ Inc. MiniTROLL) was placed on the soil surface to measure surface ponding in Cell 4 (the most-downstream cell) of the 30th Avenue raingarden from September 2012 to December 2012. To capture more meaningful data, this monitor was moved to Cell 1 (upstream cell) in mid-December 2012, where it remained through April 2013. This sensor recorded pressure and translated to head (feet) measurements at 5-minute intervals. See Figure 15 for the MiniTROLL location.

Figures 14a and b. Overview and Close up Photo of Flow Monitoring Location GSI_BAL152-028-OUT

Subsurface Water Level Monitors

Two drive point piezometers (DPPs) were installed in the raingardens to measure groundwater levels in the bioretention media near the bottom of the raingardens, where the bioretention soil media contacts the underlying native soil. A 2½-inch-diameter hand auger was used to excavate boreholes for the piezometers. Logging pressure transducers (In-Situ Inc. LevelTROLL) were installed at 1.55 and 5.3 feet below ground surface (bgs) for the 30th Avenue (DPP-2) and 28th Avenue (DPP-1) raingardens, respectively. The boreholes were backfilled with bioretention soil after installation of the water level sensors. The DPP locations and surface elevations were surveyed after installation. The DPP at the 30th Avenue raingarden records data with a Geokon datalogger.

In addition, a temporary piezometer consisting of a LevelTROLL installed in a 2-inch-diameter, perforated, vertical PVC pipe was installed in the cobble “stream channel” layer in the 28th Avenue raingarden for the controlled flow test days only. This temporary transducer was located 0.8 feet bgs at the interface between the bottom of the cobble layer and the top of the bioretention soil.

All MiniTROLLS recorded pressure and level (feet) measurements at 5-minute intervals. See Figure 15 for the MiniTROLL and piezometer locations.

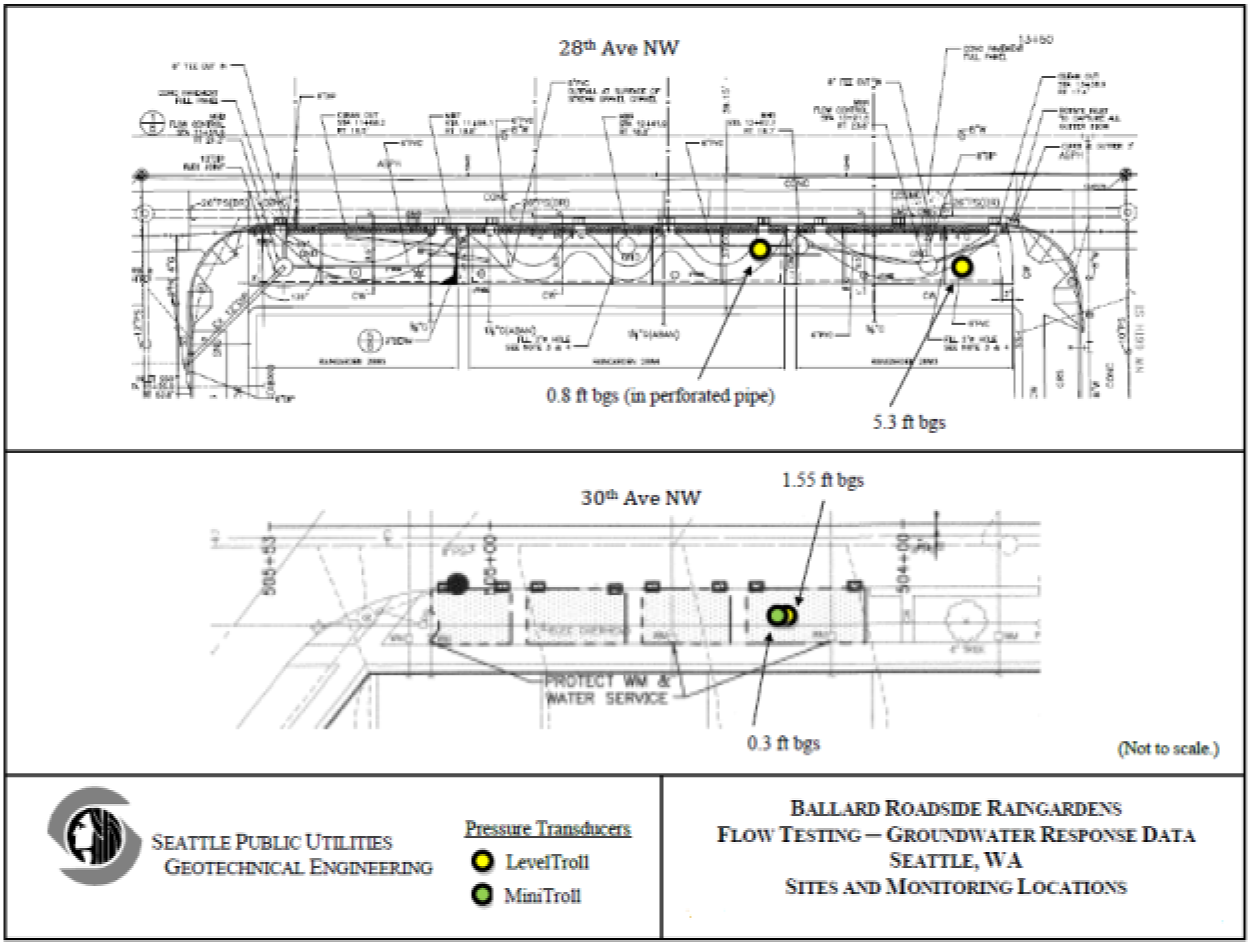

Figure 15. MiniTROLL and LevelTROLL Piezometer Locations

Maintenance Hole/Underdrain Level Monitors

At the 28th Avenue raingarden, two additional water level monitors were installed in MHs 4 and 5, which are located within the raingarden and used to access the underdrains. The water level monitors consisted of MiniTROLL piezoemeters (Model SSP-100) installed in stilling wells constructed of perforated 2-inch-diameter PVC pipe mounted vertically in each MH. These piezometers were used to measure water levels in the underdrain system and to calculate the underdrain flow discharged back to the combined sewer through a flow control structure/riser pipe in MH 4. Flow can enter the riser pipe through two pathways in MH 4: (1) normal or low flow enters through a 0.5-inch-diameter orifice at the bottom of an 8-inch-diameter riser pipe, and (2) high flow overflows into the top of a riser pipe located approximately 2 feet bgs. On October 26, 2012, a compound weir was cut into the top of the riser pipe to improve the accuracy of the high flow to the CSS. A weir equation was used to convert water level to flow. The flow control structure riser pipe is shown schematically in Figure 8 (above) and in Figures 16a and 16b. SPU staff surveyed the elevation of all underdrain monitors and key control points to the nearest 0.01 foot.

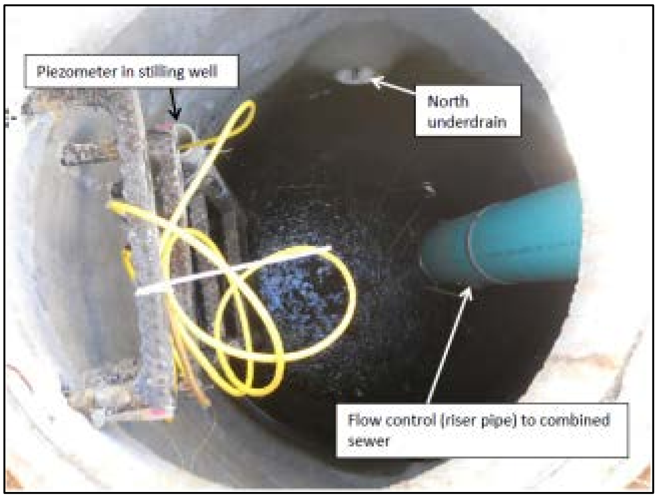

Figure 16a. MH 4 Piezometer

Figure 16b. MH 4 Flow Control Structure Riser Pipe

Closed-Channel (Upstream Inflow) Flow Meter

For the controlled flow testing performed during September 2012 and April 2013, inflow application rates were controlled by using a Sensus 1125-W closed-channel flow meter connected to a fire hydrant with a fire hose operated by staff from the SPU Meter Shop (Figures 17 and 18).

Figure 17. Controlled Flow Testing at the 30th Avenue Raingarden (looking north)

Figure 18. Controlled Flow Testing on 28th Avenue NW at NW 67th Street

Flow rates were controlled by throttling valves on the meter. Application rates were adjusted at predetermined times and rates based on the design storm rates. Water flowing through the meter causes a rotor with an attached magnet to turn, and the magnetic force is converted to velocity, or the speed of the flow. The velocity is multiplied by the known, constant area of the meter's channel to calculate the flow. The time and actual flow achieved was manually recorded for each change in rate and the inflow rate and volume was calculated from these recordings.

Precipitation Monitoring

SPU collects precipitation data from a network of 17 tipping bucket rain gages located throughout Seattle. Precipitation data are collected over 1-minute intervals and transmitted via wireless telemetry to a centralized server. The rain gage network is operated and maintained under contract by ADS.

SPU rain gauge RG07 was used to represent rainfall for both raingardens. RG07 is at Whitman Middle School, which is near the corner of 15th Avenue NW and NW 92nd Street, approximately 1.5 miles northeast of the project area.

Continuous Flow Monitoring versus Controlled Flow Testing

The post-construction flow monitoring used during this study consists of two elements: (1) continuous water level and flow monitoring to measure discharge from the raingardens back into the CSS during natural storms, and (2) controlled flow testing done by simulating storm flows during dry periods. The monitoring equipment mentioned above was used for the continuous monitoring element of this project and to measure outflow from the raingardens both from natural storms and during the controlled flow tests.

The continuous monitoring portion of this project relies on the occurrence of large, natural rainfall events. These results can be complicated by errors inherent in using rain gage data to calculate inflows and using open-channel flow monitors installed in collective systems, including inflow measurement error and outflow measurement error.

Inflow measurement error**.** Inflow during natural storm events is not measured directly but is calculated by multiplying rainfall by basin area. The project rain gage RG07 is over 1 mile from the raingardens. This distance can result in significant differences, especially during intense summer storms, between the rainfall measured by the gage and the rainfall actually occurring at the raingarden. In addition, delineating the actual drainage basin boundary can be difficult because it is not always possible to determine which areas drain to a specific monitor location. Variables such as flat topography, flow slipping past inlets, and inaccurate estimates of pervious versus impervious areas also complicate basin delineations.

Outflow measurement error. The outflow from each raingarden (flow that is not infiltrated) was quantified by flow monitors installed in the storm drain and combined sewer immediately downstream of each raingarden. The data collection interval was 5 minutes, so peak flows could have occurred between logged measurements. Open-channel flow data are subject to error from many sources such as debris in the sanitary and storm flow (which can foul the sensors), turbulence, technical limitations of the monitors, and equipment failure. In addition, it can be difficult to separate out the direct effect of the raingardens because the continuous flow data also include the sanitary flow and stormwater runoff that is not controlled by the raingardens (e.g., from areas not draining to the raingarden, flowing around the raingardens, or coming from downspouts, sidewalks, or driveways).

To control for the problems listed above, controlled flow testing (discussed below) was used to augment the continuous data for this project.

Controlled Flow Testing

Multiple controlled flow tests were conducted over several days in September 2012 (representing dry season conditions) and again in April 2013 (representing wet season conditions) by simulating a storm modified from a CSO-causing event, near the required regulatory threshold requiring an average of no more than one event per year. The controlled flow tests evaluated the performance of the raingardens and the city blocks on which they were built under simulated pre-construction and actual post-construction conditions, during a range of antecedent conditions and at full capacity.

Controlled flow testing involves metering the application of water from nearby hydrants to the raingardens during periods of dry weather to create “synthetic” storms. This type of testing mimics design storms while removing variables from the inflow and outflow measurements. To perform these tests, water from a nearby hydrant is applied at predetermined rates along the curbline of each raingarden, mimicking the way stormwater would flow by gravity. Since the inlet capacity of the 28th Avenue raingarden was much less than the peak synthetic flows, some flow slipped by the inlets instead of entering the raingarden. Sandbags were used to divert nearly all the applied hydrant flow along the curbline and into the target raingarden. No sandbags were needed at the 30th Avenue raingarden.

In addition to simulated design storms, two additional types of controlled tests were performed: (1) stress tests, in which the flow rate was slowly increased until water overflowed from the raingarden, at which point the flow rate was recorded, and (2) simulated “pre-construction” testing, in which inlets into the raingardens were blocked and the design storm flow was run down the curb to simulate the impact to the combined sewer before raingarden construction.

Design Storm Selection

Four potential storms from the last 32 years of the rainfall record for Seattle were screened for use (Table 2); the 32nd ranked overflow volume represents the event that must be “controlled” (i.e. no overflow), AKA the control volume. To be conservative (i.e., provide confidence that the raingardens can capture the required volume), the 31st ranked (October 15, 1996) storm was selected for the controlled flow tests (see Figure 19). The October 15, 1996, storm’s rainfall was converted to storm flows in gallons per minute (gpm) using a tributary impervious area of 7,900 square feet for the 30th Avenue raingarden and 8,200 square feet for the 28th Avenue raingarden.

Table 2. Storms Screened for Use as Design Storm for Controlled Flow Tests

<table>
<tr><th>Storm</th><th>CSO Volume Rank[a]</th><th>CSO Duration</th><th>Storm Duration</th><th>Rainfall 1 Week before Event</th><th>Rainfall during Event</th></tr>
<tr><td>8/18/1980</td><td>#49</td><td>4 hr</td><td>6 hr</td><td>0.00 in</td><td>1.02 in</td></tr>
<tr><td colspan="6">This short-duration storm had a rainfall record that approximated the 1-year return frequency for a 6-hour storm, according to a study by MGS (2003). This storm had dry antecedent conditions that could create a CSO overflow and likely had a higher, realistic intensity.</td></tr>
<tr><td>10/15/1996</td><td>#31</td><td>4 hr</td><td>6 hr</td><td>0.92 in</td><td>0.74 in</td></tr>
<tr><td colspan="6">A short-duration fall storm that occurred in two short spurts and resulted in a CSO volume ranking close to that of the control volume.</td></tr>
<tr><td>9/16/2010 (occurred over multiple days)</td><td>Unknown</td><td>66 hr</td><td>7 hr</td><td>0.61 in</td><td>0.40 in</td></tr>
<tr><td colspan="6">This was the first storm captured after a flow meter was installed at MH 002-082. This storm was not likely large enough to represent a control volume event, and it came a day after some previous rainfall.</td></tr>
</table>

Table 2. Storms Screened for Use as Design Storm for Controlled Flow Tests

Storm	CSO Volume Rank[a]	CSO Duration	Storm Duration	Rainfall 1 Week before Event	Rainfall during Event
As a design storm, this storm allows comparison with data from before the monitoring period. The controlled flow test is unlikely to be able to replicate these flows.					
Synthetic short-intensity storm	n/a	n/a	3 hr	n/a	0.91 in
Synthetic storm developed by MGS (2003) for the city-wide precipitation study. This is the 1-year recurrence interval, 6-hour storm for Ballard RG08.[b]					

[a] The CSO volume rank reflects the relative size of the CSO based on long-term monitoring in basin 152.

[b] Although RG08 was used for design storm selection, precipitation data from the nearby RG07 was used for monitoring data analysis because recurrence intervals for this rain gage were available (MGS 2003).

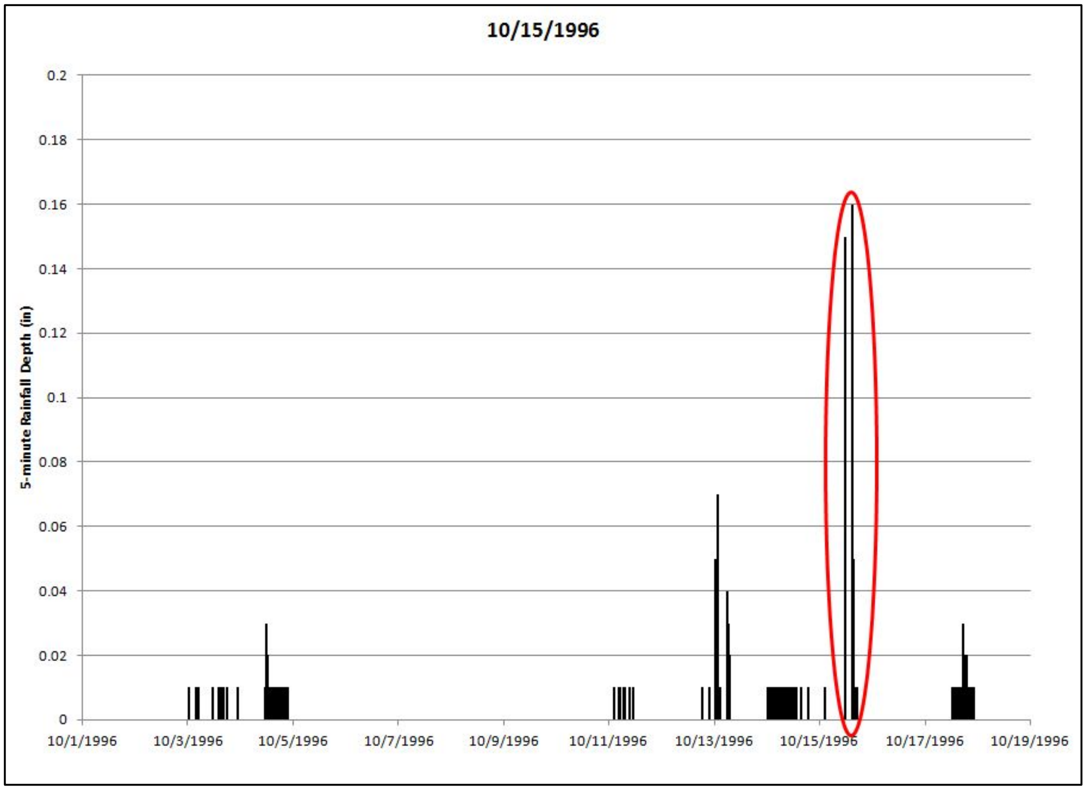

Figure 19. October 15, 1996, Rainfall Selected for Controlled Flow Tests

Design Storm Modifications

The project is tributary to NPDES CSO Outfall 152 which is most susceptible to long-duration events that are difficult to simulate in a controlled test. To allow for completion of testing during a normal work day and to minimize impacts to the neighborhood during testing, the design storm was modified by smoothing to prevent flows from simply bypassing the curb inlets, and a

3-hour gap in rainfall during the storm event was modified to a 2-hour gap, which also allowed for conservative test results by reducing the recovery time between inflow periods. Also, intermittent rainfall that occurred near the end of the actual storm was redistributed to the second peak of the simulated storm. In addition, the October 15, 1996 storm had high rainfall intensities are not typical of most wet season CSO events, resulting in additional conservative simulation of expected performance during target events.

In addition, the original measured rainfall data for this event was flashy in nature and difficult to replicate in the field. Therefore, minor modifications were made to the simulated storm hydrograph to provide smooth flow transitions while maintaining flow volume and duration for each peak of the simulated hydrograph (see Figures 20 and 21). The total design storm volume was 3,092 gallons for the 30th Avenue raingarden and 8,040 gallons for the 28th Avenue raingarden.

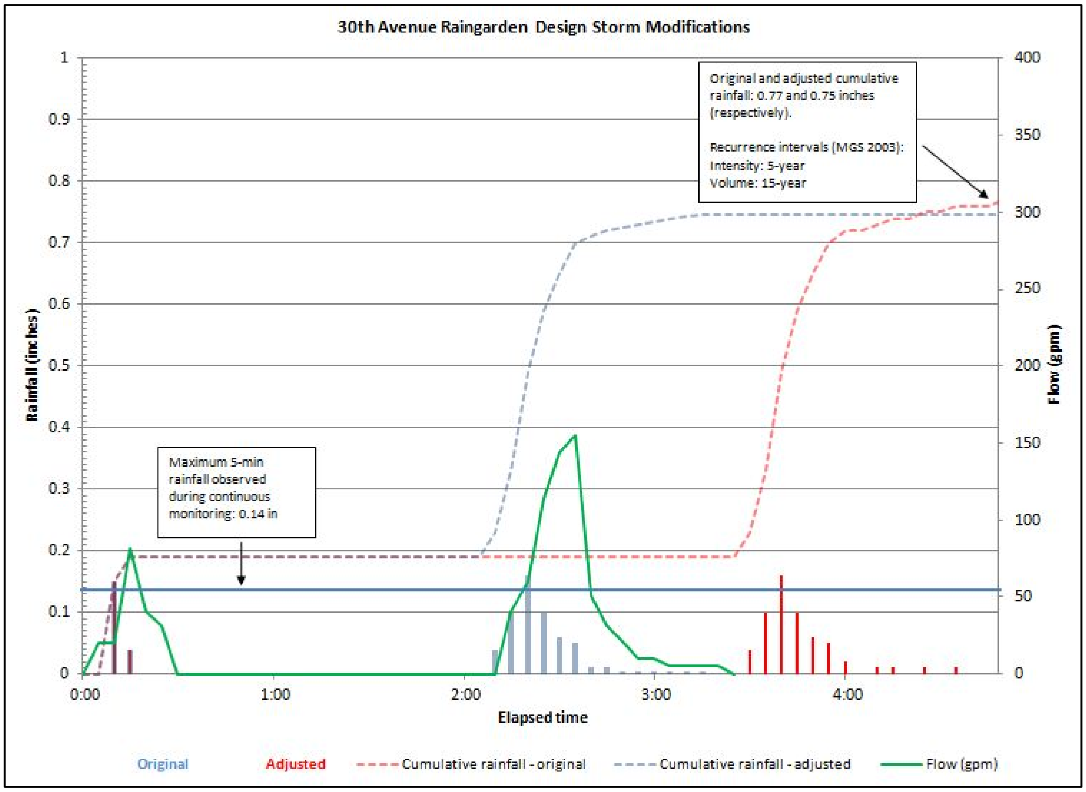

Figure 20. Design Storm Modifications for Controlled Flow Test at 30th Avenue

Controlled Flow Test Events

To simulate a range of antecedent and seasonal conditions, multiple flow tests were performed on both raingardens between September 11 and 14, 2012 (representing general dry season conditions) and again between April 9 and 11, 2013 (representing wet season conditions). Table 3 displays test dates, types of tests, and antecedent conditions.

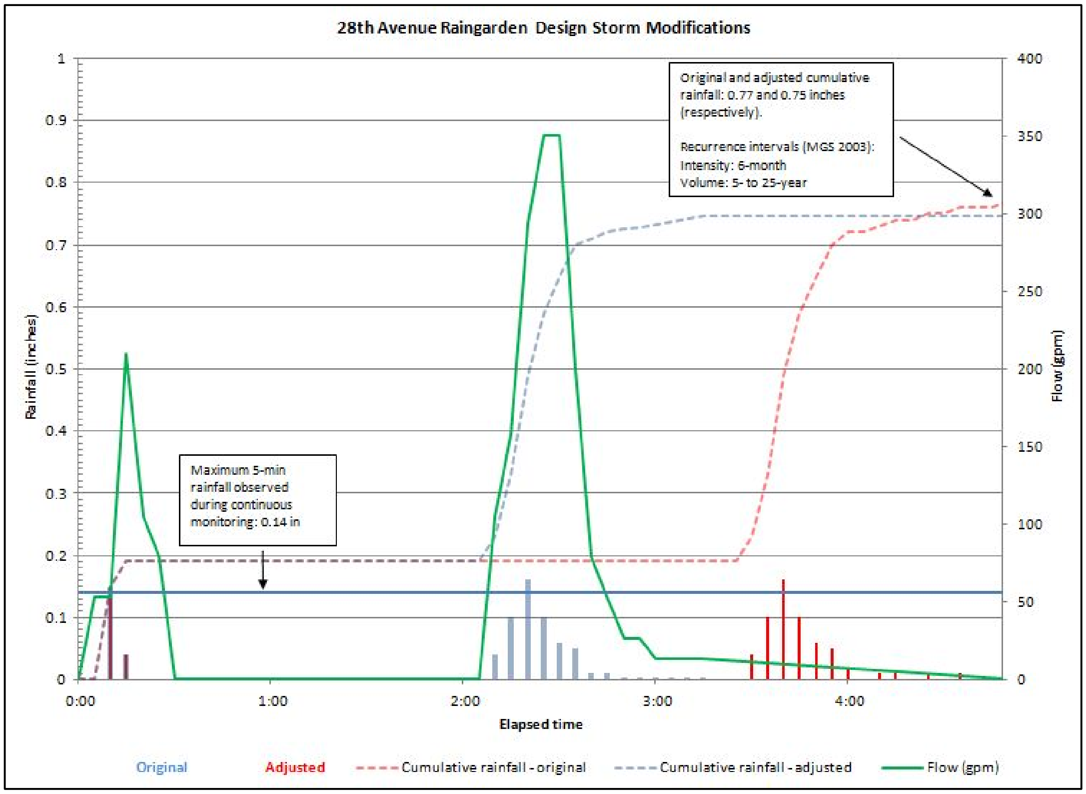

Figure 21. Design Storm Modifications for Controlled Flow Test at 28th Avenue

Table 3. Controlled Flow Tests – Types and Antecedent Conditions				
Date	**Rainfall 1 Week Prior to Test Event (in)**	**Rainfall 24 Hours Prior to Test Event (in)**	**30th Avenue Raingarden Event Type**	**28th Avenue Raingarden Event Type**
9/11/2012	0.35	0.00	Dry season, dry antecedent	Not tested
9/12/2012[a]	>0.35	>0.00	Dry season, wet antecedent Stress test	Not tested
9/13/2012[a]	>0.35	>0.00	“Preconstruction test” (inlets blocked)	Not tested
9/14/2012	0.35	0.00	Not tested	Dry season, dry antecedent
4/9/2013	2.70	0.00	Wet season, dry antecedent	Wet season, dry antecedent

Table 3. Controlled Flow Tests – Types and Antecedent Conditions

Date	Rainfall 1 Week Prior to Test Event (in)	Rainfall 24 Hours Prior to Test Event (in)	30th Avenue Raingarden Event Type	28th Avenue Raingarden Event Type
4/11/2013[a]	N/A[b]	N/A[b]	Wet season, saturated antecedent	Wet season, saturated antecedent

[a] *Antecedent rainfall is not applicable to one or both raingardens because the raingarden(s) was saturated by controlled flow testing on previous day(s).*

[b] *N/A – not applicable. As no testing was performed on 4/10/2013 due to intermittent rainfall, both raingardens were flooded with water the afternoon of 4/10/2013 to keep soils saturated.*

Continuous Monitoring Wet Season Storm Events

The continuous monitoring data at both the 30th Avenue and the 28th Avenue raingardens captured data during wet season storm events from October 2012 through May 2013. The top six storm events during this period are listed in Table 4.

The raingardens were not designed or expected to capture the volume from the November 19, 2012 storm, which was a 100-year event lasting 12 hours. The December 1, December 19, and October 31, 2012, storm events were similar to the target storm for the raingardens' design. The raingardens were expected to reach capacity and possibly overflow during events of this size. The April 5 and January 9, 2013, storm events were smaller than the target storm events the raingardens are intended to capture, and it was expected that the raingardens would infiltrate the entire volume.

The October 15, 1996, storm event was used for the controlled flow tests (described above), and reflects a CSO event close to the control volume.

Table 4. Continuous Monitoring Wet Season Storm Events

Event Date	CSO Volume (MG)	Peak Rainfall (in)	Duration (hr)	Recurrence Interval for Selected Duration
11/19/2012	15.24	2.75	12	100-year
12/1/2012	7.16	1.5	12	2-year
12/19/2012	5.52	1.9	24	2-year
10/31/2012	4.51	2.21	24	4-year
4/5/2013	2.75	0.73	6	0.4-year
1/9/2013	2.35	1.53	24	0.8-year
10/15/1996[a]	1.3	0.51	0.5	20-year

[a] *Selected control event storm used for testing.*

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SECTION 4

Analysis

30th Avenue Raingarden

Observations made by the testing team during the controlled flow test periods are described below.

Controlled Flow Test Surface Observations

Dry Season, Dry Antecedent Conditions (September 11, 2012)

The following observations were made during the controlled flow testing under dry antecedent conditions at the 30th Avenue raingarden:

- At 20 gpm, approximately 90 percent of flow was intercepted in the first inlet and all flow was captured by the first raingarden cell.
- At 80 gpm, flow entered the raingardens via the first five inlets only, discharging flow to the first three of the four total raingarden cells.
- At 113 gpm, flow reached the first seven inlets along the curbline and all four raingarden cells.
- At the peak flow of 154 gpm, flow entered all raingarden cells with minor bypass (water flowing past the inlet along the curbline) to the downstream inlets connecting to the CSS. It is estimated that approximately 140 to 150 gpm is the peak flow rate the 30th Avenue raingarden can accept without bypassing.
- Despite having the same design, some inlets appeared to be more effective than others due to micro-variations in conditions of the inlet, including the presence of cracked concrete panels (which increased the lateral slope of the roadway), variations in shaping of the depression at the inlet, street grade at inlet location, and presence of vegetation and sediment at the inlet.

Surface ponding during the flow test was minimal, consistent with dry antecedent conditions. Only minor ponding was observed in the first three cells, and no ponding was observed in the final cell. Initial runoff into each cell rapidly infiltrated near the inlet to each raingarden. Spot measurement of the drawdown of ponding at the end of the tests indicated an approximate drawdown of 1 inch of ponding within 5 to 6 minutes. No overflow (water exiting the raingarden through the curb inlet) from the raingardens was observed during this test.

Dry Season, Wet Antecedent Conditions (September 12, 2012)

The raingarden cells did not completely fill during the controlled flow test. Surface ponding observed during this test was consistent with expectations for wet antecedent conditions. Ponding was observed earlier and was more extensive (greater depth and duration) in each cell than for the dry conditions test on the prior day with the same flow rates. Cells 1, 2, and 4 ponded measurably during the peak period of the test but did not overflow. Cell 3 filled completely prior to the peak flow rate and began to bypass additional flow to Cell 4 downstream. Cell 3 began ponding prior to flow entering the cell via the curb inlets, which implies subsurface flow entered Cell 3 from upstream cells. Greater bypass was observed to the downstream inlets connecting to the CSS due to increased bypass flow to the last curb openings rather than overflow from the final raingarden cells.

Dry Season, Stress Test (September 12, 2012)

As noted during the wet antecedent conditions test, the raingardens did not completely fill during the controlled flow test. Therefore, the raingardens were allowed to drain for 1.5 hours after the wet antecedent conditions test (without additional inflow) and then a stress test was conducted to evaluate the duration of flow at the peak flow rate (140 to150 gpm) necessary to fully saturate all the cells. Similar to results of the wet antecedent conditions test, Cell 3 filled first, followed by Cell 2 and then Cell 4. Cell 1 at the top of the system was the last to fill, largely due to limited inflow through the curb inlets compared with the infiltration capacity of the cell.

Cell 1 Capacity (September 12, 2012)

To provide additional confirmation of the approximate flow capacity of a single cell versus the entire raingarden series, a final test was conducted to estimate the flow necessary to maintain a constant head on Cell 1 without overflow. Based on observations of the ponding depth and curbline downstream of the outlet curb opening in Cell 1, this flow rate was approximately 20 gpm.

Pre-Construction Conditions (September 13, 2012)

To simulate pre-construction conditions, the curb openings were blocked with sand bags and controlled flow was applied to the curbline using the same flow hydrograph as for the dry and wet antecedent conditions tests. During this test, no leakage through the sand bags into the raingardens was observed, and flow was collected in the downstream inlets connected to the CSS.

Wet Season, Dry Antecedent Conditions (April 9, 2013)

As noted in the dry season testing conducted in September, for the wet season-dry antecedent conditions test, prolonged flows in excess of 80 gpm flowed into the first three cells with a higher efficiency of flow through inlet 5 (into Cell 3). Because of the wetter antecedent conditions and the intensity of the design storm, Cell 3 overflowed earlier during the April (wet season, dry antecedent) controlled flow test, before Cells 1 and 2 reached capacity. When the capacity of Cell 3 was reached, the overflow from Cell 3 was enough to exceed capacity of the inlet to Cell

4. For a short time, the resulting flow then bypassed Cell 4, without filling that cell to capacity, and traveled along the curbline to discharge a small flow to the combined sewer system.

In the week before the spring flow tests, 2.7 inches of rain fell. Within 24 hours before the April 9 controlled flow test, no more than 0.01 inches of rain fell.

Wet Season, Saturated Antecedent Conditions (April 11, 2013)

The 30th Avenue raingarden’s performance during the wet season, saturated antecedent flow test on April 11, 2013, was similar to that during the dry antecedent test on April 9, but resulted in more overflow volume during the second inflow peak. Testing was cancelled on April 10 due to anticipated rainfall; however, flow was discharged to the raingardens during that day to maintain saturated conditions.

Continuous Monitoring Results (October 2012 to May 2013)

No signs of overflow from any of the raingardens were observed during the continuous monitoring period. Piezometers initially located in Cell 4 rarely indicated surface ponding, indicating that most flows were captured in the upstream cells during frequently occurring and smaller rainfall events. When the piezometers were relocated to Cell 1, the frequency and extent of ponding measured in Cell 1 were greater, but the cell did not reach the point of overflow. Review of storm intensities during this period suggests that curb flow was unlikely great enough to bypass the inlets to discharge to the CSS downstream. The cumulative 6-hour rainfall volume for each storm exceeded the volume of the controlled or stress tests only during the 100-year event. Therefore, it appears (with some degree of uncertainty) that the raingardens captured and contained all events other than the 100-year event. Due to inlet capacity restrictions, and considering stress tests conducted in summer 2012, it is likely that the raingarden did overflow (because Cells 1, 2, and 3 were filled to capacity) and then the flow bypassed the inlet to Cell 4 (where the piezometer was located).

The 30th Avenue raingarden captured all the flow for every storm except the November 2012 storm. Figures 22 and 23 show volume reduction provided by the 30th Avenue raingarden for the six largest storm events and for all storm events with total rainfall greater than 0.5 inches.

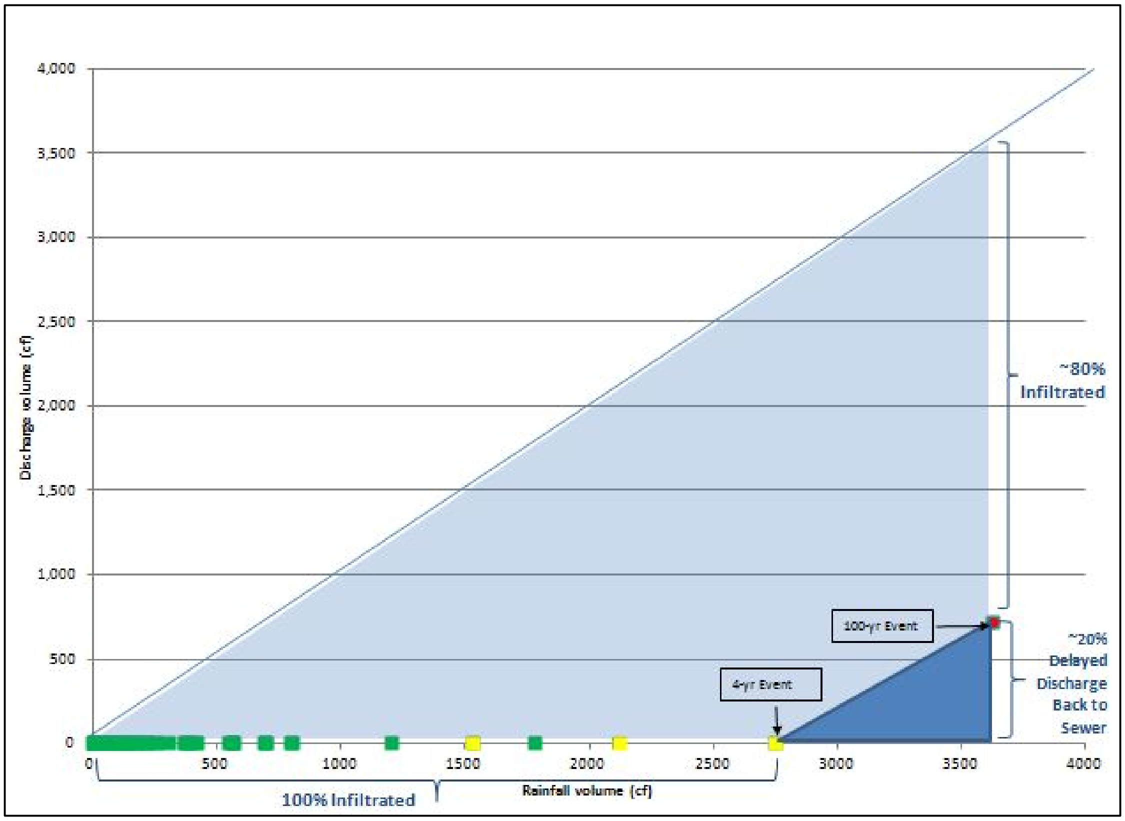

Figure 22. Volume Reduction by Event for the 30th Avenue Raingarden, October 2012 to May 2013

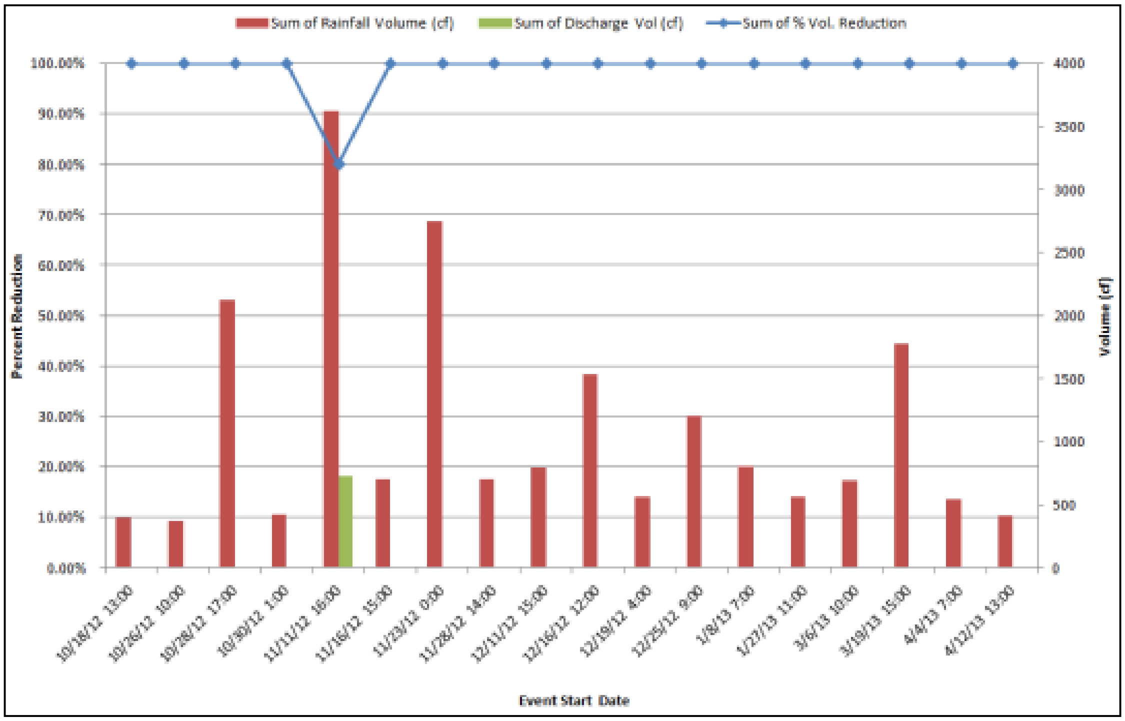

Figure 23. Volume Reduction by Event (>0.5 inches total rainfall) for the 30th Avenue Raingarden, October 2012 to May 2013

28th Avenue Raingarden

Controlled Flow Test Surface Observations

Dry Season, Dry Antecedent Conditions (September 14, 2012)

The 28th Avenue raingarden was tested on September 14, 2012 for performance during dry antecedent, dry season conditions. One day before the test, the calculated peak flows for the test were discharged from a nearby hydrant to the curbline to evaluate the inlet capacity of the system. Although there are nine curb inlets along this raingarden, the cumulative capacity of the inlets was only 50 gpm before flow bypassed the last inlet to the catch basin, discharging flow to the combined sewer. Therefore, it was determined that sand bags would be necessary to assure that test flows entered the raingarden during this and subsequent tests.

During the test, all curb inlet flows (directed by sand bags) initially infiltrated the surface of the bioretention soils via the streambed gravel channel. During the test, water levels within the bioretention cells slowly rose and eventually overflowed the downstream cell at MH 4 via the overflow riser approximately 30 minutes after the peak inflow. During the overflow period, it was discovered that the overflow riser was not plumb, which resulted in uneven weir flow over the top of the riser, making measurement of overflow rates difficult. The riser was retrofitted with a Thel-mar weir in October 2012 to enable more accurate measurement of overflows.

Wet Season, Dry and Saturated Antecedent Conditions (April 9 and 11, 2013)

Similar to results of the September tests, water from the 28th Avenue raingarden overflowed via the overflow weir during both dry and wet antecedent tests on April 9 and 11, 2013. The estimated total overflow volume (returned to the CSS) during both of these tests was just over 2,500 gallons, out of a total of just over 10,300 gallons of inflow. Due to artificial saturation of the raingardens on April 10th to maintain wet antecedent conditions, inflow into the upstream cell overflowed back to the curb and did not flow back into the raingarden through the last downstream inlet. This made it difficult to accurately assess the raingarden’s performance using the flow data.

Continuous Monitoring Results (October 2012 to May 2013)

The 28th Avenue raingarden provided peak flow reduction for an average of approximately 54 percent of the inflow (of the 20 storm events of the monitoring period) – see Figures 24 and 25. This peak flow reduction directed storm inflow into the CSS later and at a lower flow rate than would have been seen otherwise, which represents a benefit in terms of potential CSO reduction. The raingarden fully infiltrated the remaining 46 percent, more than was expected from a raingarden with an underdrain to the sewer.

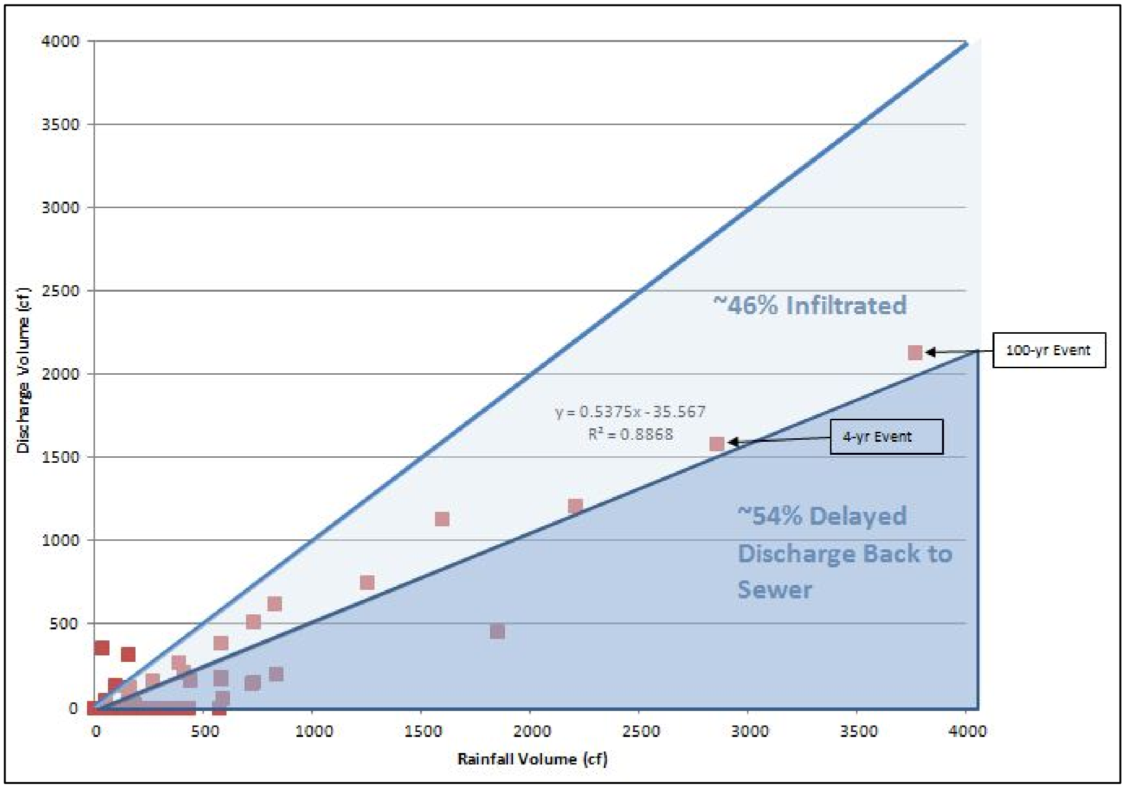

Figure 24. Volume Reduction by Event for the 28th Avenue Raingarden, October 2012 to May 2013

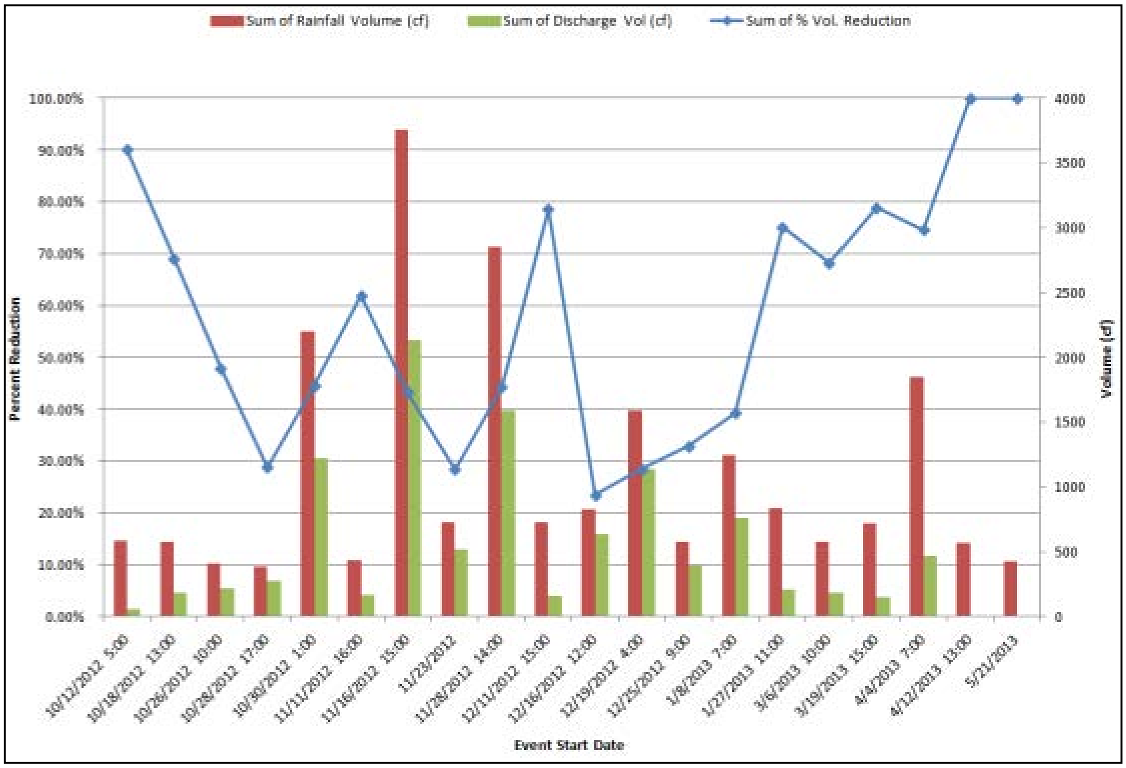

Figure 25. Volume Reduction by Event (>0.5 inches total rainfall) for the 28th Avenue Raingarden, October 2012 – May 2013

Data Quality

The quality of the data collected during the controlled flow tests was classified based on the usability of the data for modeling and as defined in Section 14 of the quality assurance project plan (QAPP). Data quality is classified as follows:

- **Excellent** – Data are reliable for modeling with no critical exceptions
- **Good** – Data are reliable for modeling with noted exceptions, noted edits, slight degree of error, or some missing data
- **Some Limitations** – Modeler must take into account the limitations of the data when calibrating; however, some important aspects of the data are still suitable for model calibration
- **Poor** – Data may provide some useful modeling information, but should be used with caution for calibration; sites with persistent poor ratings will be removed and alternative sites will be considered or alternative methods to provide relevant data will be explored

Table 5 summarizes the data quality of the data collected.

Table 5. Data Quality

Monitor	September 2012 Flow Test	April 2013 Flow Test	Continuous Monitoring
30th Avenue hydrant (inflow)	Excellent	Excellent	N/A
30th Avenue downstream flow (MH 002-082)	Excellent	Excellent	Good
30th Avenue subsurface water level (DPP-2)	Good	Excellent	Good
30th Avenue surface water level (MiniTROLL)	Good	Excellent	Good
28th Avenue hydrant (inflow)	Good	Excellent	N/A
28th Avenue MH 4 water level (overflow)	Some Limitations	Excellent	Excellent
28th Avenue MH 5 water level	Excellent	Excellent	Excellent
28th Avenue subsurface water level	N/A[a]	Excellent	Excellent
28th Avenue surface water level	Excellent	Excellent	Excellent
28th Avenue downstream flow (BAL 152-28-OUT)	Good	Excellent	Excellent

[a] *No data were recovered from this piezometer on September 14, 2012.*

Further details on the locations listed in Table 5 are:

- **30th Avenue and 28th Avenue Inflow (Hydrant).** The meters used to measure inflows are known to produce reliable results for industrial measurements and the results closely align with the data collected in the open-channel flow meter downstream, without data gaps.

- **30th Avenue Downstream Flow (MH 002-082).** The metered data in the downstream combined system align closely with the metered inflow data (generally within 5 to 10 percent) and are without data gaps. However, this meter is not ideal for continuous flow monitoring because the area of the raingardens is small relative to the size of the overall tributary area contributing to peak flows measured at this meter, so it is difficult to quantify how much flow was from the surrounding area or from overflow of the raingardens.
- **30th Avenue Subsurface Water Level (DPP-2).** No subsurface water level (DPP-2) data were recovered from the Geokon datalogger on September 11. There is also a small data gap on September 12, 2012. However, the data collected are considered reliable.

  Data from Cell 1 after mid-December 2012, when the meter was moved to Cell 1, are without data gaps and are considered reliable.
- **30th Avenue Surface Water Level (MiniTROLL).** MiniTROLL data on September 11 did not yield suitable results, as the meter was initially installed in Cell 4, which did not pond. The meter was moved to Cell 1 at the end of the test and captured ponding data for the September 12 flow test. However, the meter did not capture ponding during the September 13 flow test or the October 31, November 19, or December 1 storm events due to meter malfunction. There is also a small data gap on September 12, 2012. However, with these exceptions the data collected are considered generally reliable.
- **28th Avenue MH 4 Water Level.** The piezometer located in MH 4 from September 14, 2012, to April 2013 captured continuous water level data for the entire monitoring period without any significant data gaps. These data are considered reliable. However, due to the uneven overflow weir riser that was not replaced until October 2012, the data from the September 14, 2012 controlled flow test cannot provide accurate overflow measurements.
- **28th Avenue MH 5 Water Level.** The piezometer located in MH 5 from September 14, 2012, to April 2013 captured continuous water level data for the entire monitoring period without any significant data gaps. These data are considered reliable.
- **28th Avenue Subsurface Water Level.** Groundwater-level data were collected with a drive-point piezometer installed 5.3 feet bgs. Groundwater-level data collected beneath the raingarden cell just upstream of MH 4 are without significant data gaps for the continuous monitoring period (September 2012 to April 2013) and are considered reliable. This piezometer was installed but did not capture any data during the September 14, 2012 controlled flow test.
- **28th Avenue Surface Water Level.** Surface water level data at the 28th Avenue raingarden were collected on September 14, 2012 and April 9 to April 14, 2013 to capture data from the controlled flow tests. These data are without gaps and are considered reliable.
- **28th Avenue Downstream Flow (BAL 152-28-OUT).** The depth-velocity meter in the catch basin downstream of the 28th Avenue raingarden captured continuous flow data for the entire monitoring period without any significant data gaps. These data are considered reliable.

Data Summary

Figures A-1 through A-35 in Attachment A show water level and flow data for both raingardens for the controlled flow tests and the six largest storm events of the continuous monitoring period, as summarized in Table 5.

Table 6. Hydrograph and Water Level Data Graphs in Attachment A

	30th Ave		28th Ave	
Event	**Hydrograph**	**Water Levels**	**Hydrograph**	**Water Levels**
Sept 11 test	A-1	N/A[a]	N/A[a]	N/A[b]
Sept 12 test	A-2	A-3	N/A[c]	N/A[c]
Sept 13 test	A-4	N/A[a]	N/A[c]	N/A[c]
Sept 14 test	N/A	N/A	A-20	A-21
Event 1 -10/31	A-5	A-6	A-22	A-23
Event 2 -11/19	A-7	A-8	A-24	A-25
Event 3 -12/1	A-9	A-10	A-26	A-27
Event 4 -12/19	A-11	A-12	A-28	A-29
Event 5 -1/8	A-13	A-14	A-30	A-31
Event 6 -4/5	A-15	A-16	A-32	A-33
Apr 9 test	A-17	A-18	A-34	A-35
Apr 11 test	A-19	A-18	A-36	A-35

[a] *Data are not shown because the meter was not installed, the meter malfunctioned, or the data are unreliable. See the Data Quality section (above).*

[b] *Although the data from this location are considered reliable, without reliable data from MH 4 (overflow data for the hydrograph), these are not considered relevant.*

[c] *No controlled flow test occurred at the 28th Avenue raingarden on September 12 or 13, 2012.*

For the 30th Avenue raingarden, the graphs identified in Table 6 present the inflow, measured combined sewer flow at MH 002-082, and raingarden cell water-level data for each of the controlled flow tests and selected continuous monitoring data during key storm events.

For the 28th Avenue raingarden, the graphs identified in Table 5 present the inflow, total outflow (at MH 4), and raingarden cell water level data for each of the spring wet season controlled flow tests and selected continuous monitoring data during key storm events.

30th Avenue Raingarden

Downstream Flow (MH 002-082)

The first two flow peaks on September 12 are the simulated design storm flows (Figure A-2 in Attachment A). The third flow peak shown in the data is the stress test, in which approximately 8,055 gallons was required for the 30th Avenue raingarden to overflow. The fourth flow peak in Figure A-2 represents the Cell 1 capacity test. Figure A-4 in Attachment A shows the pre-construction conditions test performed on September 13, 2012, in which none of the design storm flow was allowed to reach the 30th Avenue raingarden.

Surface and Subsurface Water Levels

The subsurface piezometer was moved to Cell 1 (farthest upstream) in December 2012 to capture more information about the 30th Avenue raingarden's performance during storms. Figure A-12 in Attachment A shows the surface ponding and subsurface water level (LevelTroll – water level above cell bottom) in Cell 1 during the December 19, 2012 storm (a 2-year event).

Surface-water-level data did not measure any ponding in Cell 1 until the December 19, 2012, storm event. Data in Figure A-12 indicate that no overflow occurred in the raingarden.

Subsurface piezometer data from Cell 4 indicated that no overflow occurred during any of the storm events of the continuous monitoring period. Although the piezometer data in Figure A-8 indicate that Cell 4 did not overflow during the November 19 (100-year) storm, based on the controlled flow tests it is likely that curbline flow exceeded the capacity of the curb inlets to Cell 4 (due to filling the upstream cells) and may have resulted in discharge to the combined sewer without filling the most-downstream cell of the raingarden.

Surface- and subsurface-water-level data (Figure A-18) show that Cell 1 did not completely fill during the April 11, 2013, (wet antecedent) test, and that it drained quickly after inflow was stopped.

28th Avenue Raingarden

Outflow (BAL 152-28-OUT and MH 4)

Figure A-24 in Attachment A presents estimated inflow and outflow from the November 19, 2012, (100-year) storm event.

Surface and Subsurface Water Levels

Figure A-25 shows the overflow during the November 19, 2012, (100-year) storm event. Figure A-27 shows the water level in MH 4 during the December 1, 2012, (2-year) storm event, during which the 28th Avenue raingarden did not reach its full capacity.

30th Avenue Model Assumptions

Infiltration Rates

Bioretention Soil

The estimated bioretention soil infiltration rate is 14 inches per hour. This estimation is based on the rate of drop in surface ponding in Cell 1 after initial ponding on September 12 (wet antecedent conditions) according to the MiniTROLL data (see Figure A-3). Testing in April 2013 showed only a short period during which drawdown appeared to be limited by the bioretention soils only (saturation of the bioretention soils occurred more rapidly due to antecedent moisture conditions). However, calculations appear to confirm that during the initial wetting period the bioretention soil has a capacity equal to or greater than the rate measured in September.

The bioretention soil infiltration rate was also calculated at the end of the test to evaluate the rate when the system is fully saturated and controlled by the underlying native soils. The estimated infiltration rate under these conditions is approximately 7.3 inches per hour.

Native Soil

The observed native soil infiltration is approximately 2.8 inches per hour (controlled tests run in the springtime) to 7 inches per hour (controlled tests run in the summer), depending on the location and time of year. This is based on the drawdown rates observed in the subsurface water level (DPP-2) data throughout the continuous monitoring period, during the largest storm events (discussed above) and the controlled flow tests in the summer and spring. This value is consistent with the measured surface drawdown rate for the bioretention soils under saturated conditions reported above.

Perched Flow

Considering the observations of ponding in Cell 3 prior to flow through the inlet curbs and early saturation of that cell, it was hypothesized that some horizontal (or perched) groundwater flow occurs in the 30th Avenue raingarden, particularly between Cells 1, 2, and 3. The absence of observed ponding and subsurface ponding in Cell 4 until late in the wet antecedent conditions test indicates that the sidewalk break between Cells 3 and 4 may be providing an effective barrier (or dam) to perched flow between these two cells. More observations will be necessary to confirm these hypotheses.

Soil Storage Volume

A subsurface water level meter was initially installed only in the last cell in the raingarden series (Cell 4), however, the data did not indicate full saturation during the tests conducted (maximum head of 0.7 feet in 1 foot of soils on September 12, 2012). Due to unknown flow input into this last cell, the actual soil storage volume in this last cell cannot be calculated at this time. Evaluation of the drawdown rates (without inflow) in Cell 1 from controlled tests completed in the spring indicates the estimated drainable porosity of the soils is approximately 0.25 feet per foot, which is consistent with published values for bioretention soils (Rawls et al. 1998; SPU 2009).

28th Avenue Model Assumptions

A stormwater management model (SWMM) was developed with the ultimate goal of confirming design parameters for future raingarden designs. As the scope of the model development and calibration was limited, the model was only roughly calibrated to match the monitoring data. Thus, conclusions and values provided below are preliminary estimates only.

Infiltration Rates

Bioretention Soil

Bioretention soil infiltration rate was not estimated for the 28th Avenue raingarden because limited surface ponding measurements were made during the controlled tests and continuous monitoring. Because the ponding within the gravel stream channel at the surface of the bioretention facility is brief, the calculated infiltration rate is highly variable in the range between 8 and 20 inches per hour.

Native Soil

The estimated native soil infiltration rate is approximately 0.25 inches per hour according to rough model calibration.

Soil Storage Volume

Soil storage volume within the raingardens was not directly measured or monitored. The rough model calibration assumed typical published values (Rawls et al. 1998; SPU 2009) for drainable porosity of the bioretention soils (0.27 feet per foot, based on a total porosity of 0.4 feet per foot and field capacity of 0.13 feet per foot) and subsurface geometry based on the as-built drawings (width of excavated facility multiplied by the effective length and average depth based on slope of the subsurface). Based on the assumed values for bioretention cell geometry and iteration of the native soil infiltration rate, the rough model calibration yielded a reasonable match to the monitored data.

Inlet Capacity

Considering observations made during the tests, inlet capacity may be a critical component of design. The combined inlet capacity for the 28th Avenue test garden was only 50 gpm (whereas the cumulative inlet capacity of the 30th Avenue raingarden was an estimated 150 gpm prior to saturation). It was observed that distribution of flows to the raingardens through the curb openings is not uniform. The majority of flow enters the upstream cells at low flows while downstream cells only receive inflow during periods of high flow. This can cause water to bypass the upstream inlets, or cause overflow due to saturation in the upper raingarden cells. Additionally, minor variations in cross slope, shape of the curb opening depressions, roadway slope, and presence of sediment or vegetation also appear to have a large impact on inlet capacity.

Estimated Performance

Both raingardens provided peak flow reduction and volume reduction for each of the six significant storm events of the continuous monitoring period (see Table 7 below).

Table 7. Performance Summary for Ballard Raingardens, 2012-2013 Wet Season

Storm Event	Storm Recurrence Interval	30th Ave Peak Flow Reduction	30th Ave Volume Reduction	28th Ave Peak Flow Reduction	28th Ave Volume Reduction
11/19/2012	100-year	100%	80%	72%	43%
12/1/2012	2-year	100%	100%	89%	44%
12/19/2012	2-year	100%	100%	83%	29%
10/31/2012	4-year	100%	100%	86%	45%
4/5/2013	0.4-year	100%	100%	73%	75%
1/9/2013	0.8-year	100%	100%	81%	39%

Table 8 below lists each raingarden's performance in terms of CSO reduction as simulated by the basin model.

Table 8. CSO Reduction Performance Summary for Ballard Raingardens, 2012-2013 Wet Season

	CSO Performance			
	Basin Control Volume (gal)	**Control Volume Reduction (gal)**	**Average Annual Overflow Reduction (gal)**	**Average Annual System Flow Reduction (gal)**
30th Avenue	4.4 mil	13,500 – 20,500 16,500 average 1.05 gal/sf mitigated	117,300	267,100
28th Avenue		2,100 – 5,600 3,400 average 0.42 gal/sf mitigated	36,800	99,500

30th Avenue Raingarden

The inlet capacity of the 30th Avenue raingarden is approximately equal to a 5-year, short-duration storm event. The volume capacity of the 30th Avenue raingarden is approximately equal to a 15-year, moderate-duration storm event. The raingarden's performance (storm inflow removal) could be improved by increasing the inlet capacity of the upstream cells.

The 30th Avenue raingarden removed the entire controlled flow test volume from (approximately 4,254 gallons) from the CSS during the dry antecedent conditions on September 11, 2012 (see Figure A-1 in Attachment A).

During wet antecedent conditions on September 12, the 30th Avenue raingarden removed approximately 89 percent (3,793 gallons) of the total design storm inflow (4,260 gallons). Approximately 467 gallons of flow above baseflow was discharged to the combined sewer; baseflow was calculated by averaging the hourly flows at MH 002-082 on non-test dates between September 11 and September 17, 2012.

Total volume measured in the downstream flow meter was calculated as approximately 112 percent of the inflow from the hydrant meter, indicating a slight potential positive bias but relatively reasonable flow measurement results.

28th Avenue Raingarden

The initial inlet capacity of the 28th Avenue raingarden is estimated to be approximately equal to a 6-month, short duration storm event. Inlets have been retrofitted with asphalt berms to increase this capacity.

The approximate volume capacity of the 28th Avenue raingarden is between a 5- and 25-year, moderate duration storm event.

SECTION 5

Conclusions

Results from analysis of monitoring data indicate that both the 30th Avenue and the 28th Avenue raingardens are functioning as anticipated by capturing and infiltrating flows that would otherwise enter the CSS. The results support the application of bioretention for CSO control in Seattle when these facilities are properly sited and designed.

Data from controlled flow tests and from continuous monitoring are of good or excellent quality and therefore suitable for model calibration. Results from this data collection effort will support the development of a calibrated model of the raingardens, albeit with the limitations described below.

Performance

Monitoring data showed that the 30th Avenue raingarden can handle up to the 15-year storm event and captured 98-99% of CSO-size storm volumes, outperforming its original design goal to capture 95 percent of CSO-size storms. Infiltration rates at 30th Avenue were within the range (or greater) expected for outwash soils.

Monitoring at 28th Avenue showed that significant benefits for CSO reduction are possible even in a raingarden with an underdrain that directs flow to the sewer. The raingarden reduced peak flow rates by an average of 80-90% of CSO-size storm events. The raingarden reduced peak flow rates by an average of 80-90 percent of CSO-size storm events. The 28th Avenue raingarden provided delayed discharge to the sewer for approximately 54 percent of the inflow (of the 20 storm events of the monitoring period), meaning that while the inflow volume did reach the sewer it was delayed and at a lower flow. The raingarden fully infiltrated the remaining 46 percent, more than was expected from the retrofitted raingarden, which had an estimated native soil infiltration rate of 0.25 in/hr (based on model calibration).

Lessons Learned

Flow tests at both raingardens indicated that inlet capacity may be a critical component of design. High flows can bypass the upstream inlets simply due to orientation along the roadway, but it also appears that minor variations in cross-slope, inlet shape, roadway slope, and presence of sediment or vegetation can have a significant impact on inlet capacity.

Monitoring at 28th Avenue showed that significant benefits for CSO reduction are possible even with a raingarden with an underdrain that directs flow into the sewer. The delayed inflow and reduced peak flow rates provided by the 28th Avenue have CSO-reduction benefits. Also, the native soil infiltration rate at 28th Avenue indicates that underdrains with flow restrictions can be an appropriate and effective design element in soils with low infiltration, and benefits can be maximized by optimizing the underdrain's orifice size and location for a given basin. The performance of such raingardens is expected to be especially effective in basins with short duration CSOs (less than 2 to 6 hours).

Limitations

Monitoring data collected for this study does not represent all conditions within the raingardens and downstream system. Performance and design parameters may vary from the estimate provided herein due to a wide range of factors including, but not limited to, seasonal and climatic variation, non-stationarity of parameters (such as soil infiltration rates and porosity), maintenance, and measurement uncertainties.

Modeling conducted for this study was not rigorously calibrated and was limited to confirming rough estimates of design parameters based on monitoring data. More monitoring analysis and modeling would be necessary to determine these parameters and performance estimates with greater certainty.

SECTION 6

Acknowledgements

Key project personnel are listed below.

Seattle Public Utilities

Shanti Colwell, P.E. – monitoring study project manager, report author
Doug Hutchinson – field monitoring lead, report author
Ali Tabaei, Cody Nelson, and staff – water level monitoring technicians
Steve Zukaitas and Cam Tran – SPU Meter Shop hydrant flow monitor operators

CH2M HILL

Dustin Atchison, P.E. – modeler and report author
Erin Thatcher, E.I.T. – data analysis and report author

ADS Environmental Services

Flow and precipitation monitoring contractor

SECTION 7

References

CH2M HILL. 2012. Ballard Phase I/Retrofit Supplemental Monitoring Recommendations. August 17.

MGS Engineering Consultants, Inc. 2003. Analysis of Precipitation-Frequency and Storm Characteristics for the City of Seattle. December.

Rawls, W. J.; D. Giménez; and R. Grossman. 1998. *Use of soil texture, bulk density, and the slope of the water retention curve to predict saturated hydraulic conductivity*. Transactions American Society of Agricultural Engineers 41(4):983-988.

Seattle Public Utilities (SPU). 2009. *Stormwater Manual Vol. 3 Stormwater Flow Control & Water Quality Treatment Technical Requirements Manual*. 2009-005 SPU. November 2009.

Seattle Public Utilities (SPU). 2011. Quality Assurance Project Plan: Ballard Roadside Raingardens, Phase 1 Post-Construction Flow Monitoring – Summer 2012. Prepared for Washington Department of Ecology, September 1.

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Attachment A: Ballard Roadside Raingardens Continuous & Controlled Flow Test Monitoring Flow and Water Level Data

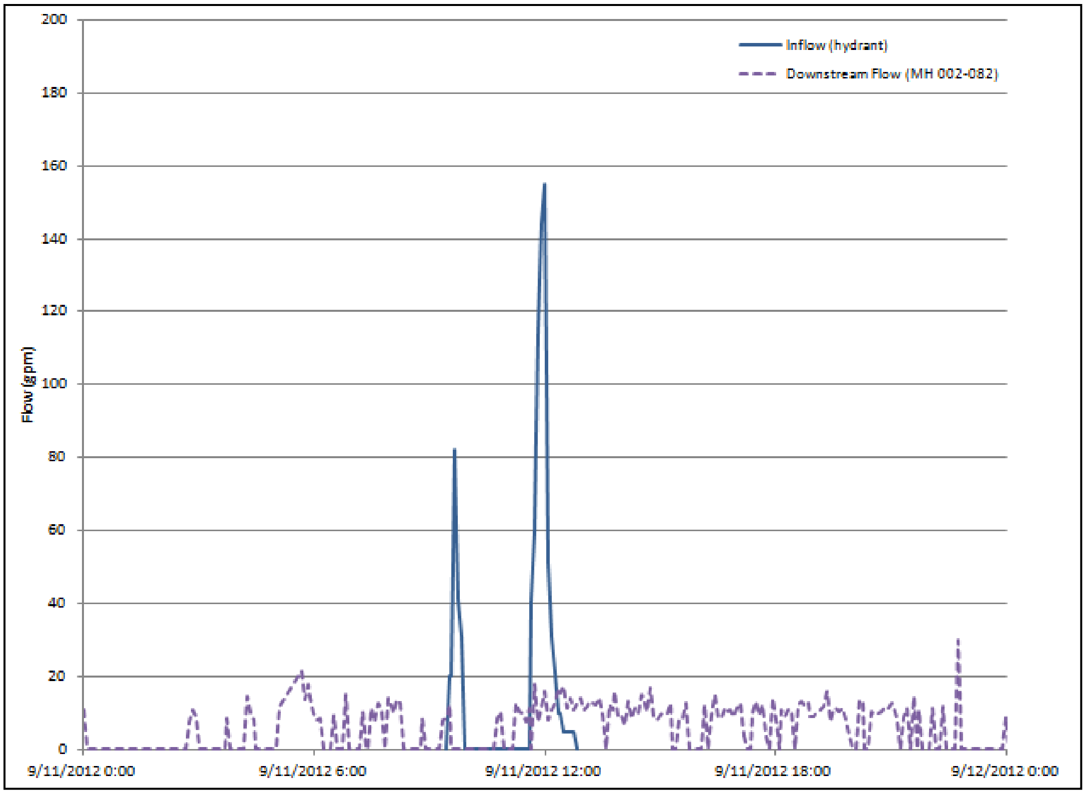


Figure A-1. 30th Avenue Raingarden, September 11, 2012 Controlled Flow Test Hydrograph

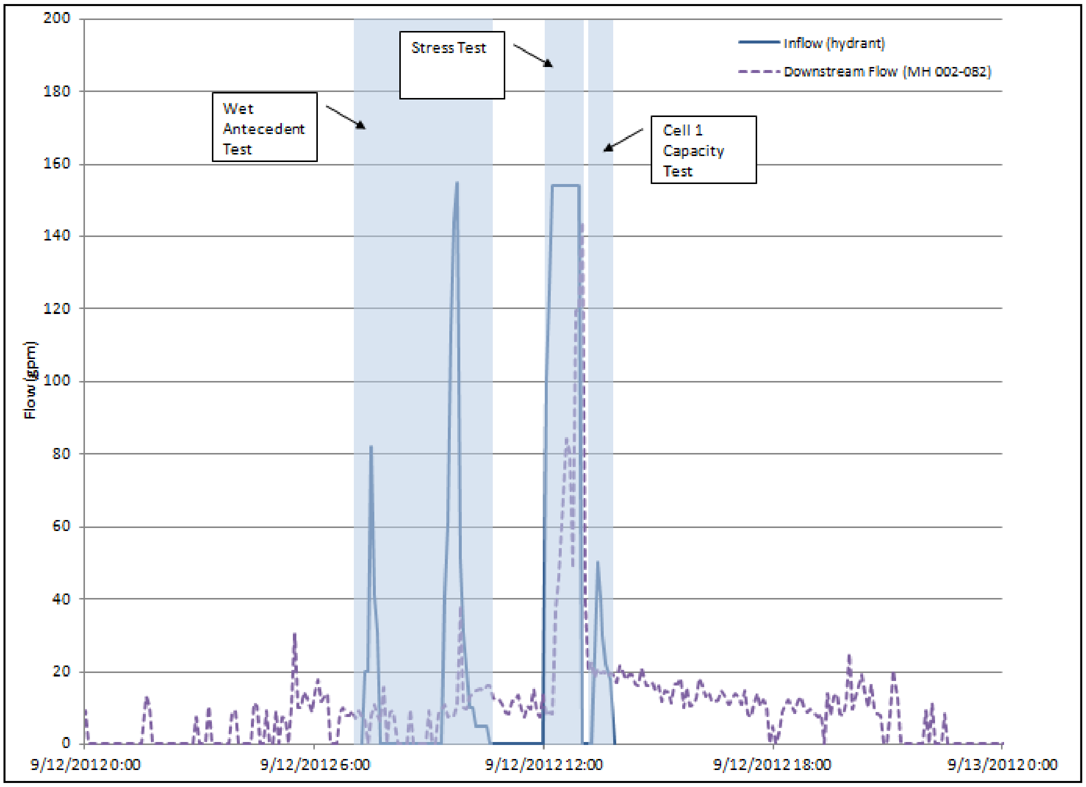


Figure A-2. 30th Avenue Raingarden, September 12, 2012 Controlled Flow Test Hydrograph

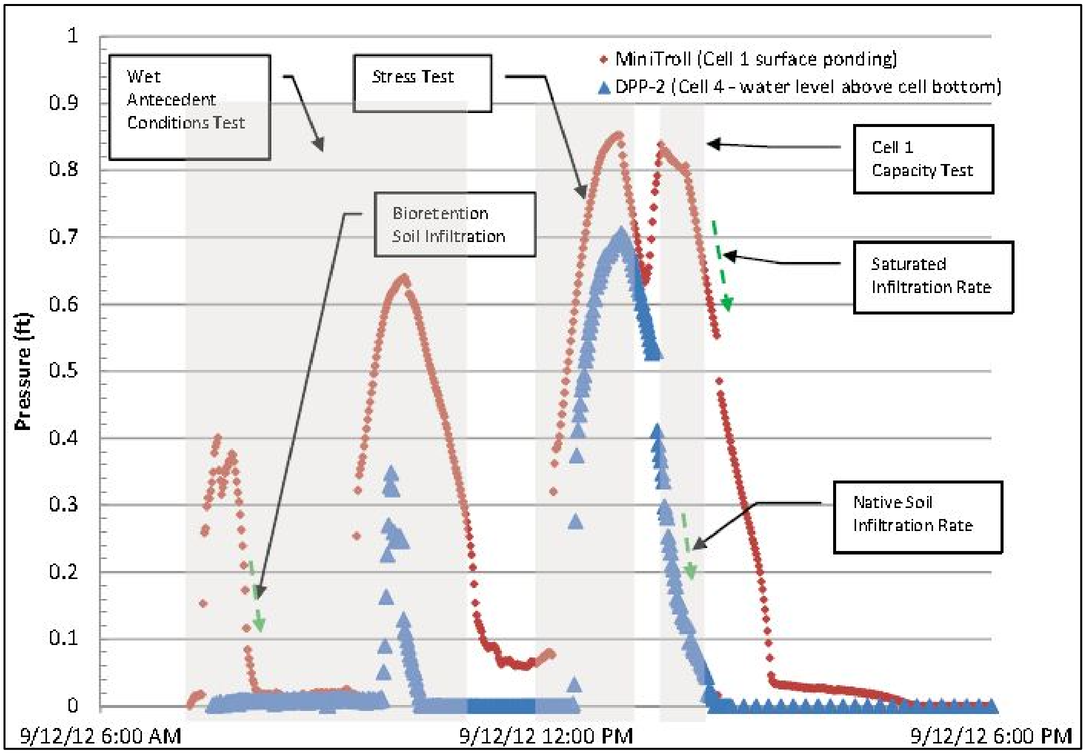


Figure A-3. 30th Avenue Raingarden, September 12, 2012 Controlled Flow Test Water Level

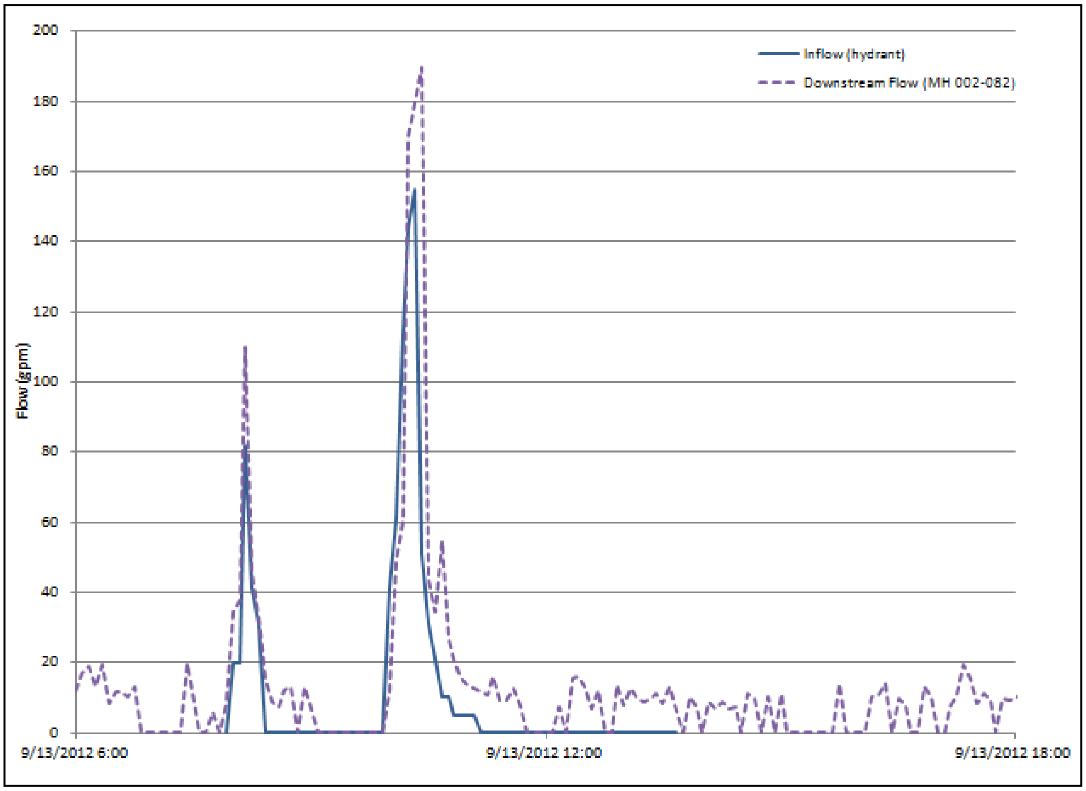


Figure A-4. 30th Avenue Raingarden, September 13, 2012 Controlled Flow Test Hydrograph

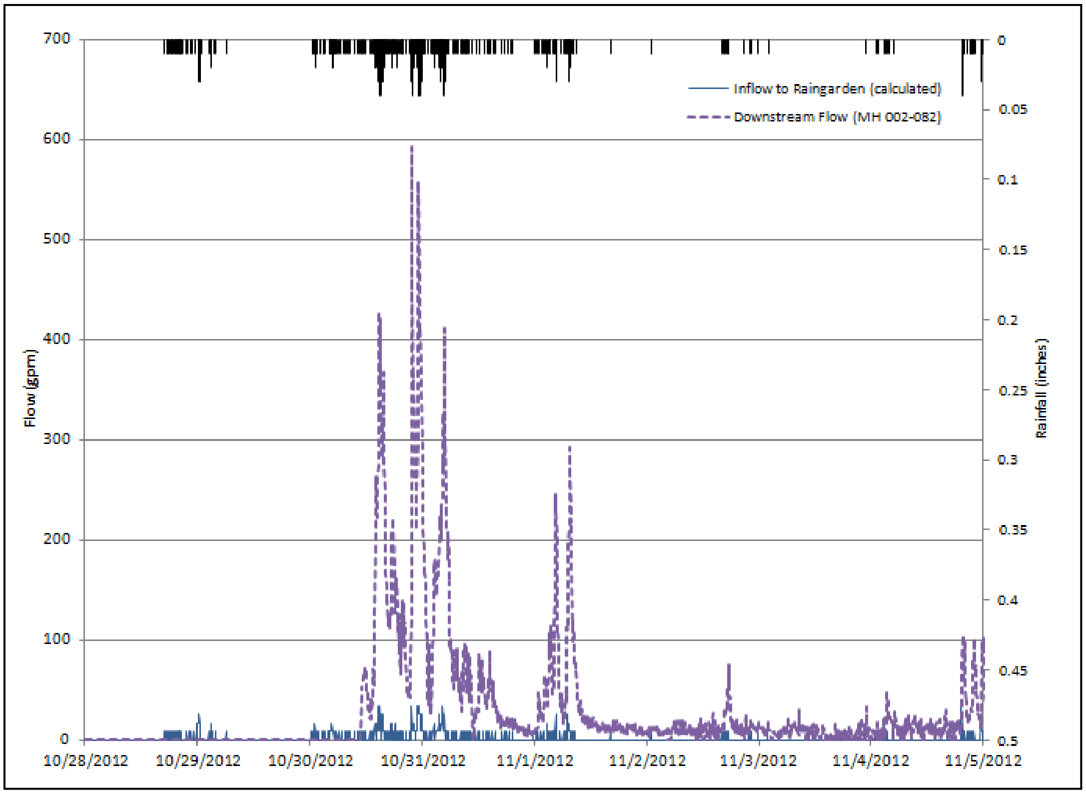


Figure A-5. 30th Avenue Raingarden, October 31, 2012 Storm Hydrograph

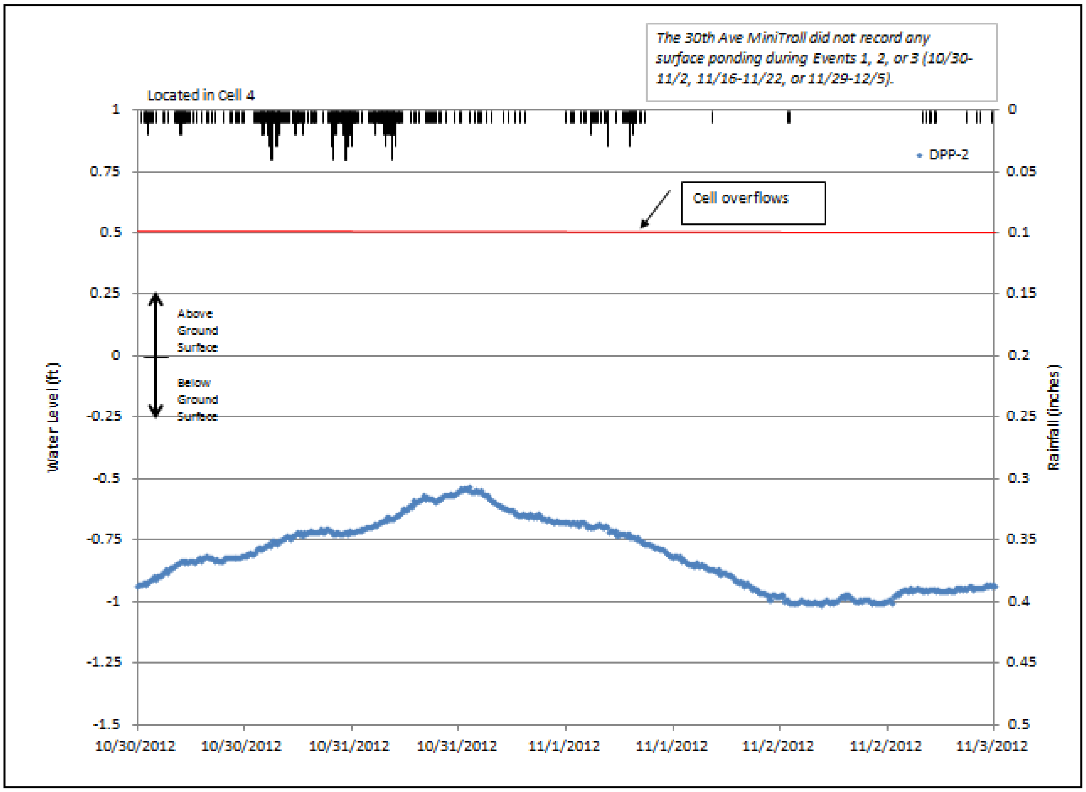


Figure A-6. 30th Avenue Raingarden, October 31, 2012 Storm Water Level (Cell 4)

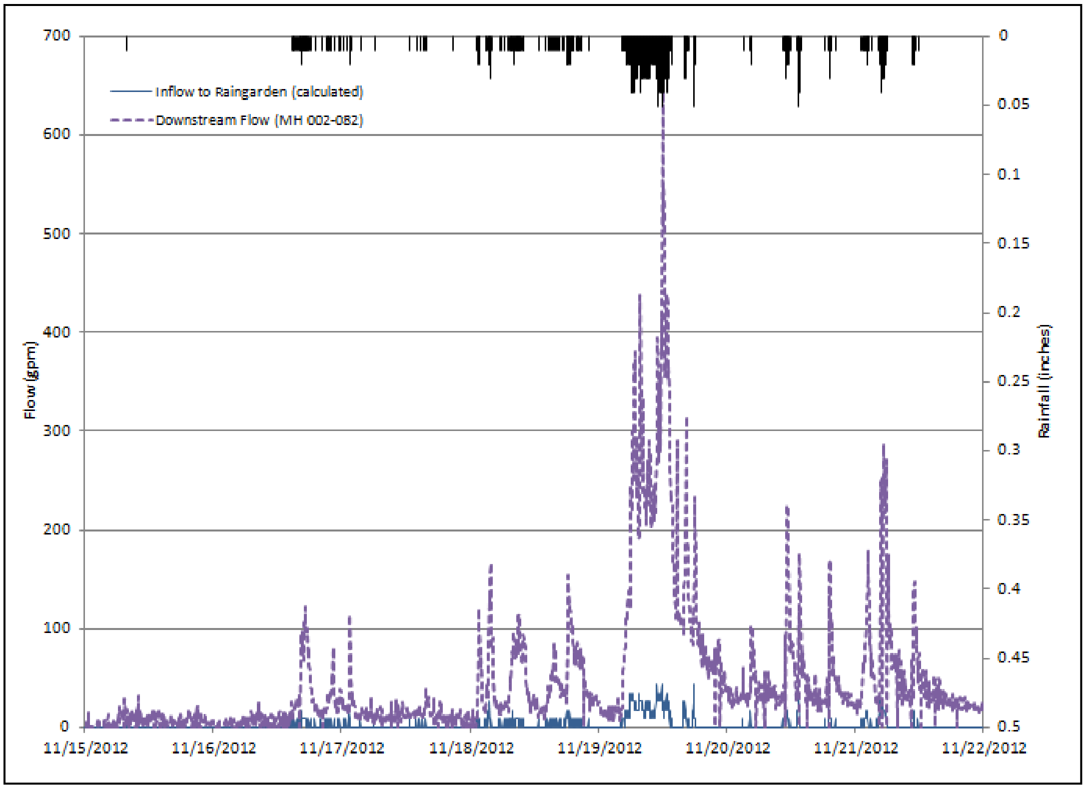
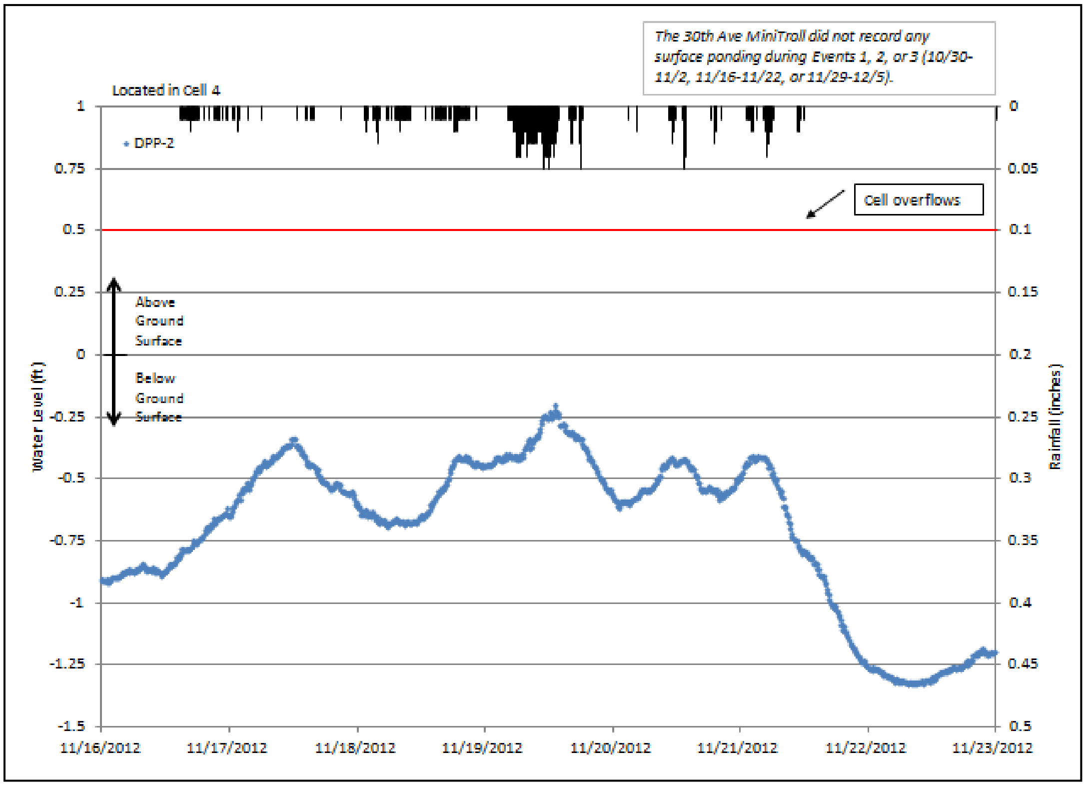


Figure A-7. 30th Avenue Raingarden, November 19, 2012 Storm Hydrograph



The 30th Ave MiniTroll did not record any surface ponding during Events 1, 2, or 3 (10/30-11/2, 11/16-11/22, or 11/29-12/5).

Figure A-8. 30th Avenue Raingarden, November 19, 2012 Storm Water Level (Cell 4)

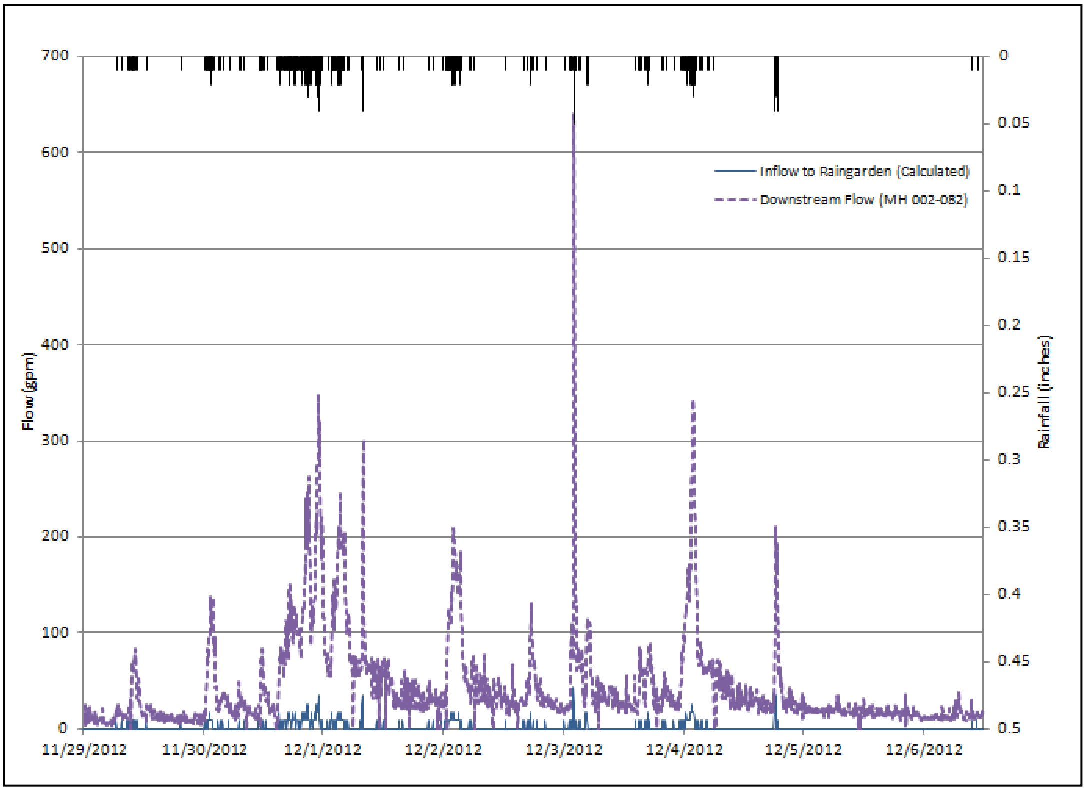


Figure A-9. 30th Avenue Raingarden, December 1, 2012 Storm Hydrograph

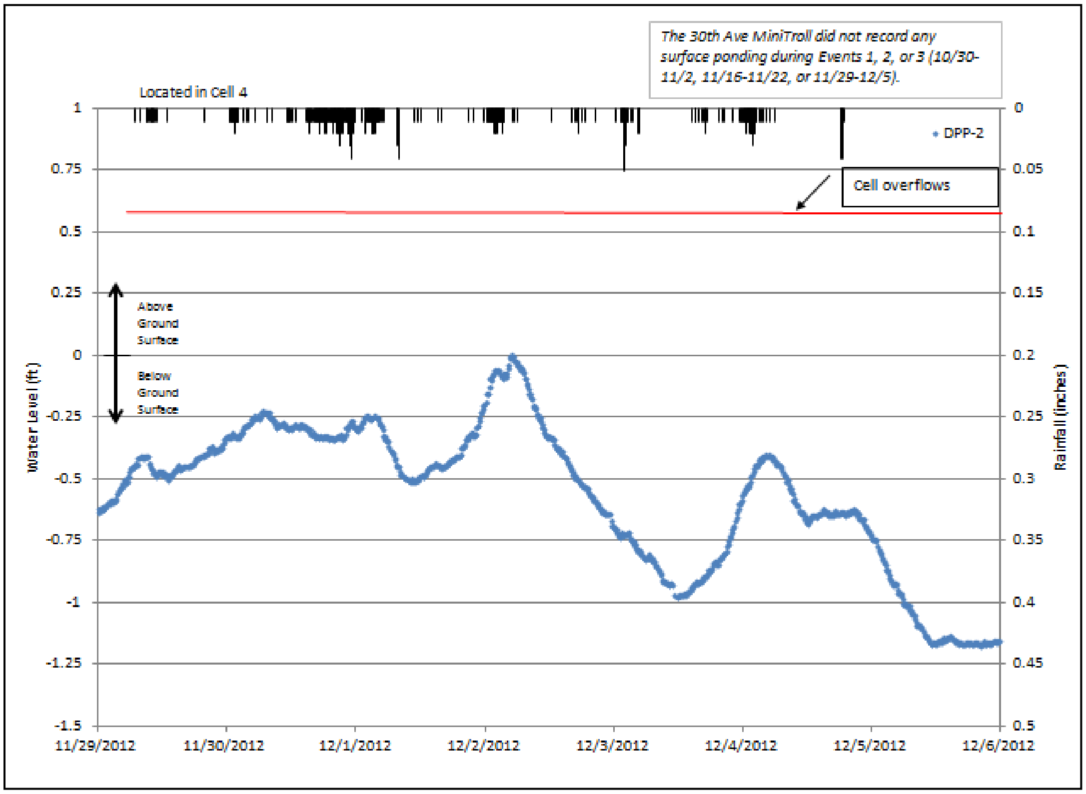


Figure A-10. 30th Avenue Raingarden, December 1, 2012 Storm Hydrograph (Cell 4)

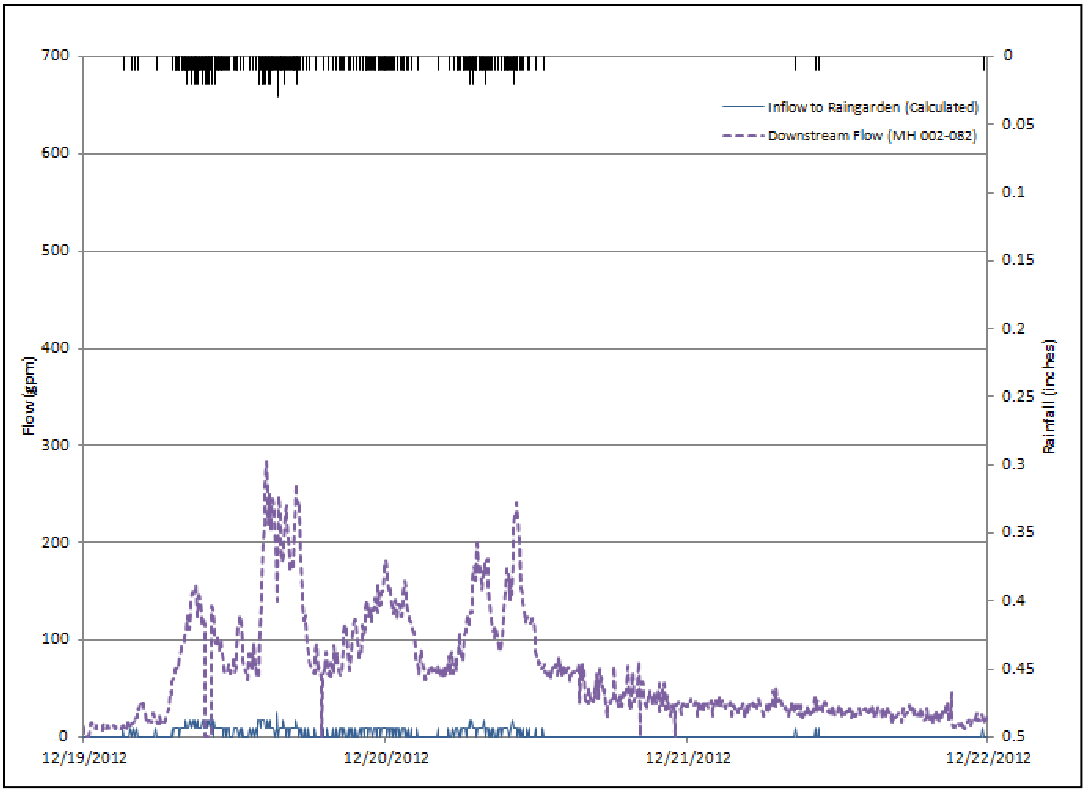


Figure A-11. 30th Avenue Raingarden, December 19, 2012 Storm Hydrograph

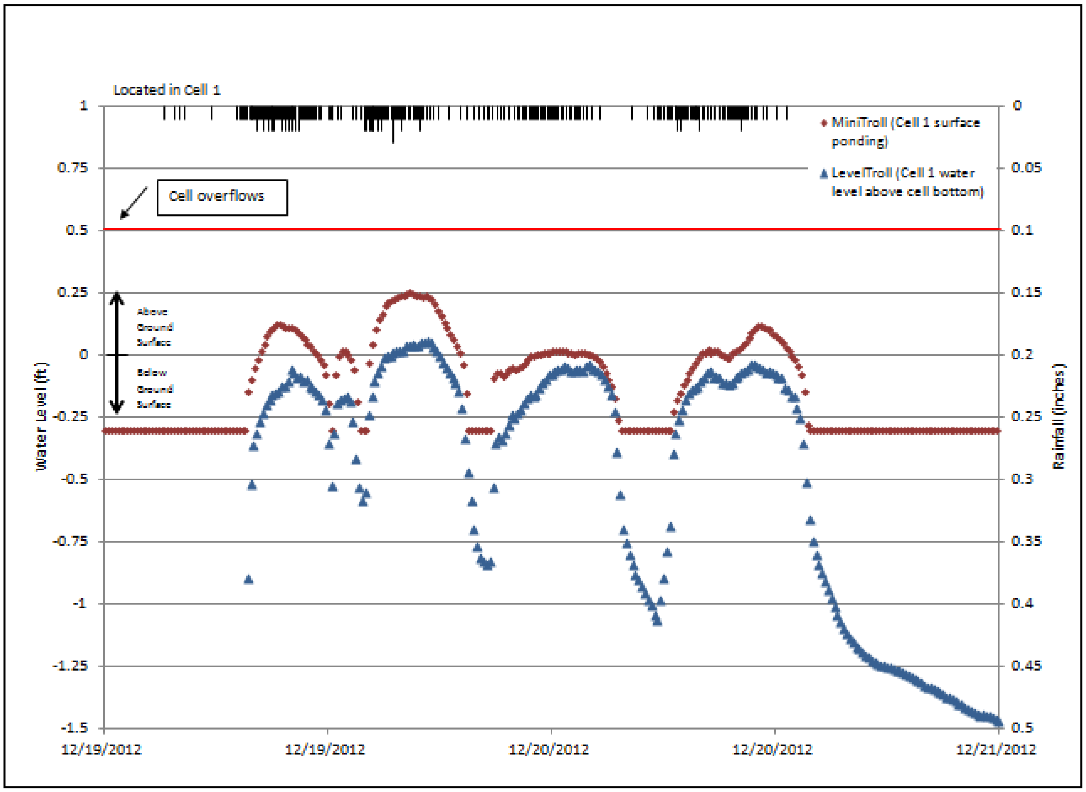


Figure A-12. 30th Avenue Raingarden, December 19, 2012 Storm Water Level (Cell 1)

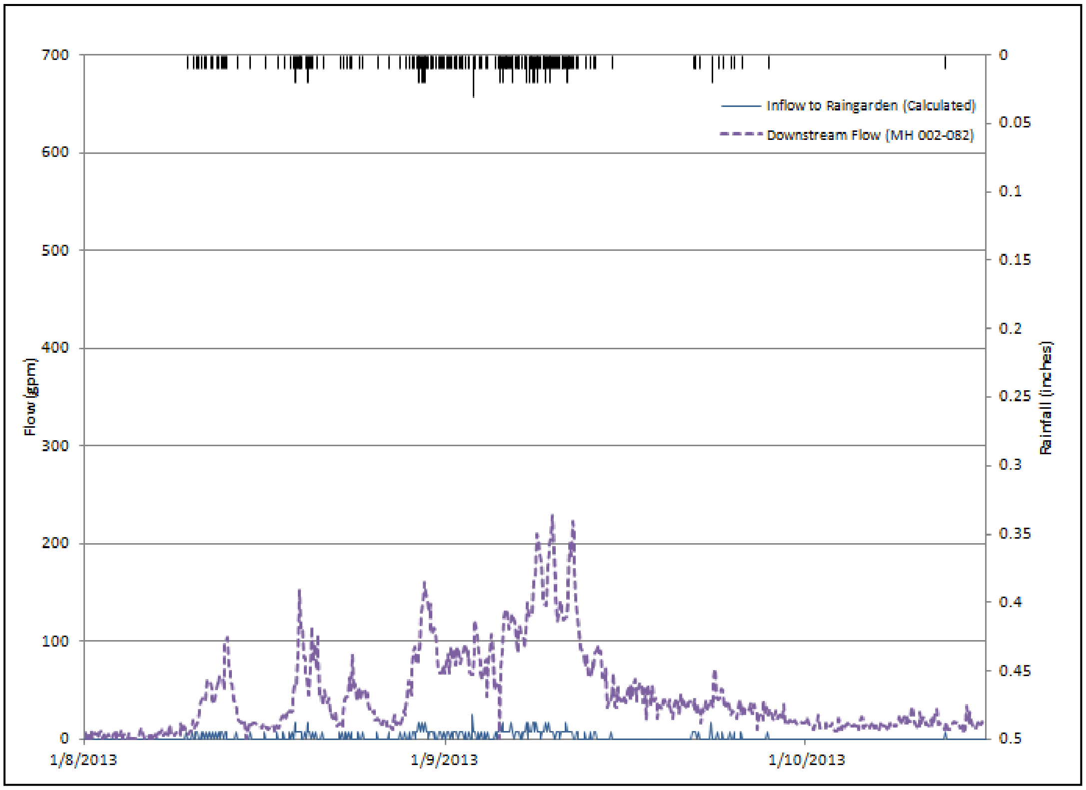


Figure A-13. 30th Avenue Raingarden, January 9, 2013 Storm Hydrograph

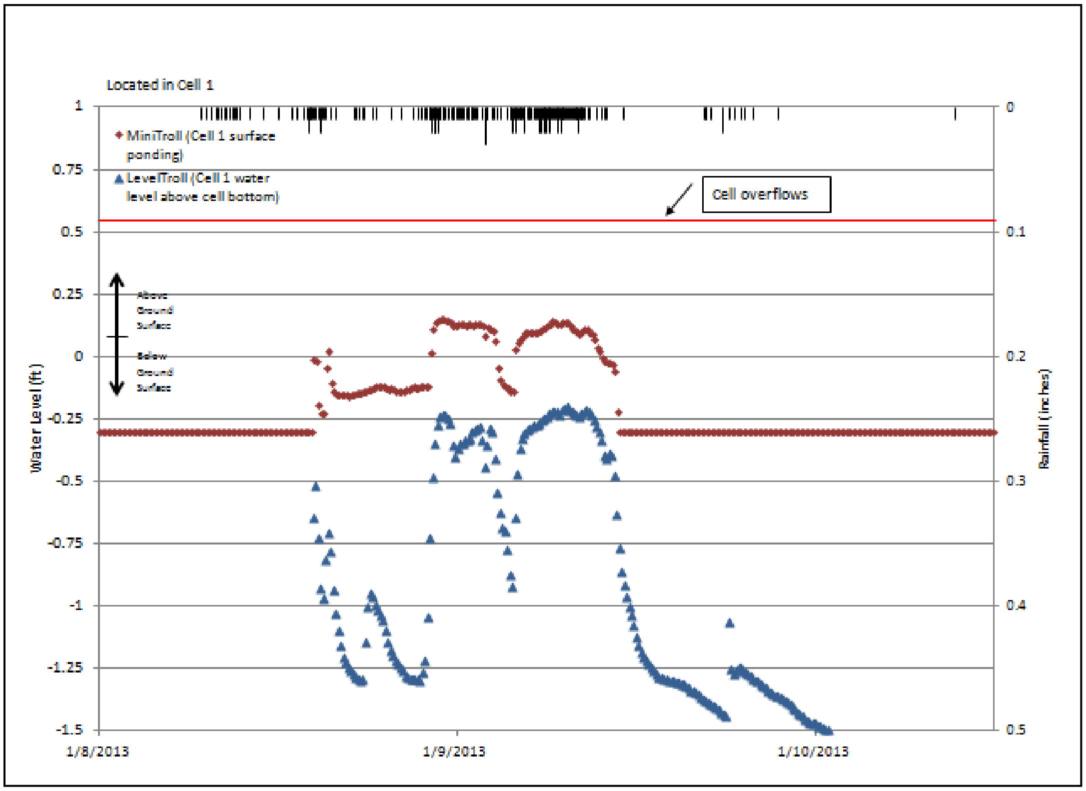


Figure A-14. 30th Avenue Raingarden, January 9, 2013 Storm Water Level (Cell 1)

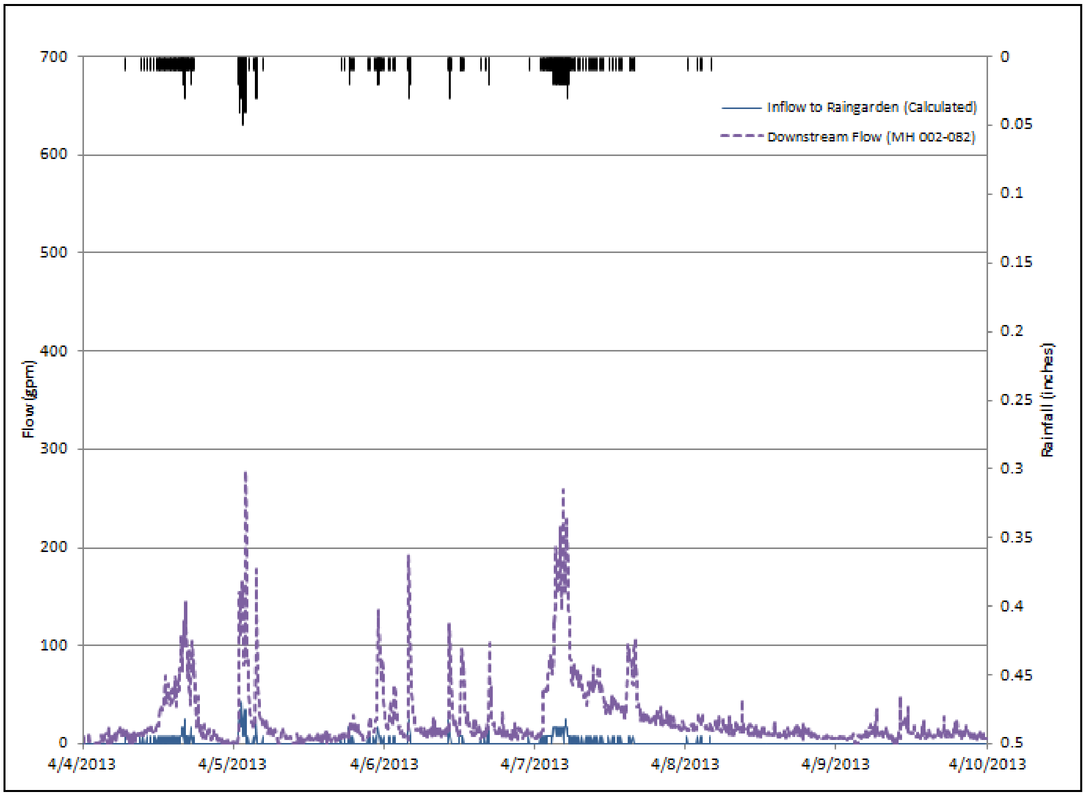


Figure A-15. 30th Avenue Raingarden, April 5, 2013 Storm Hydrograph

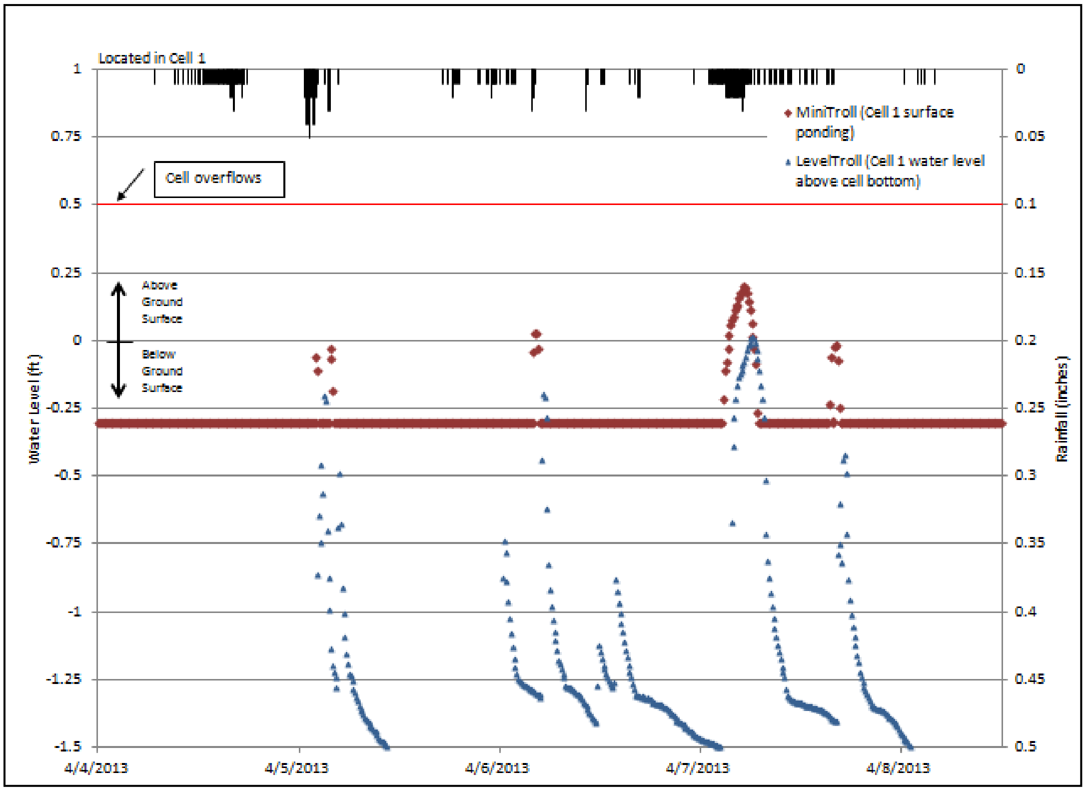


Figure A-16. 30th Avenue Raingarden, April 5, 2013 Storm Water Level (Cell 1)

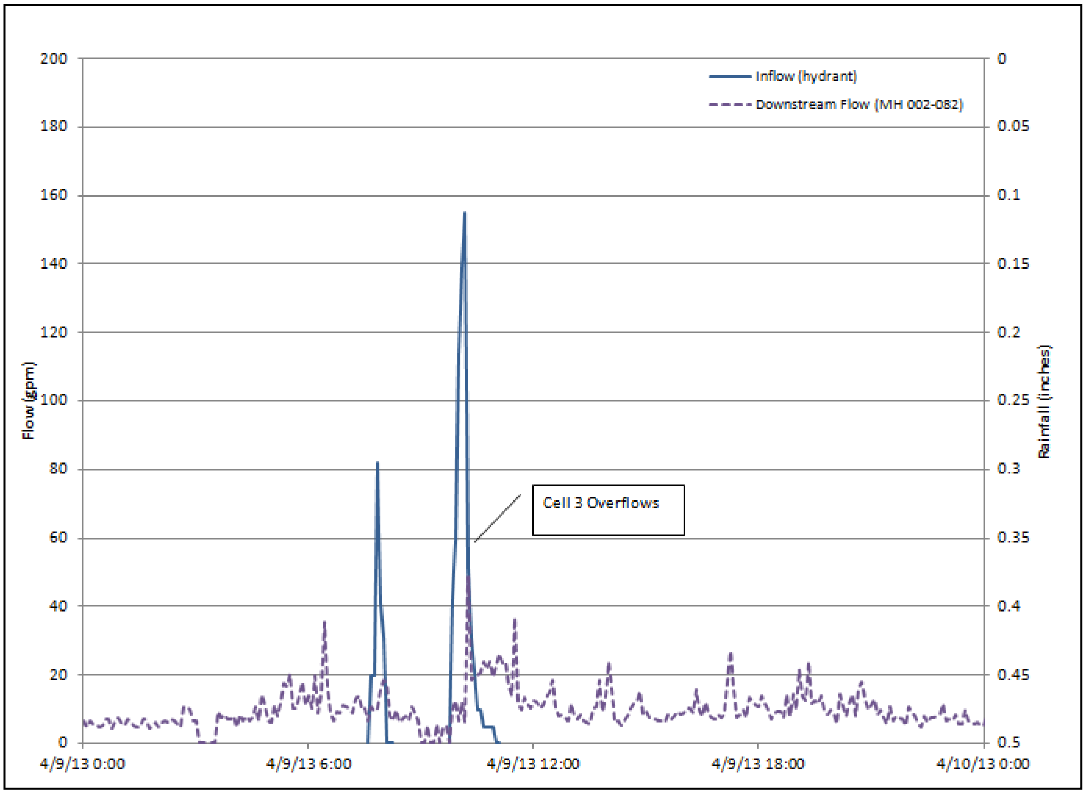


Figure A-17. 30th Avenue Raingarden, April 9, 2013 Controlled Flow Test Hydrograph

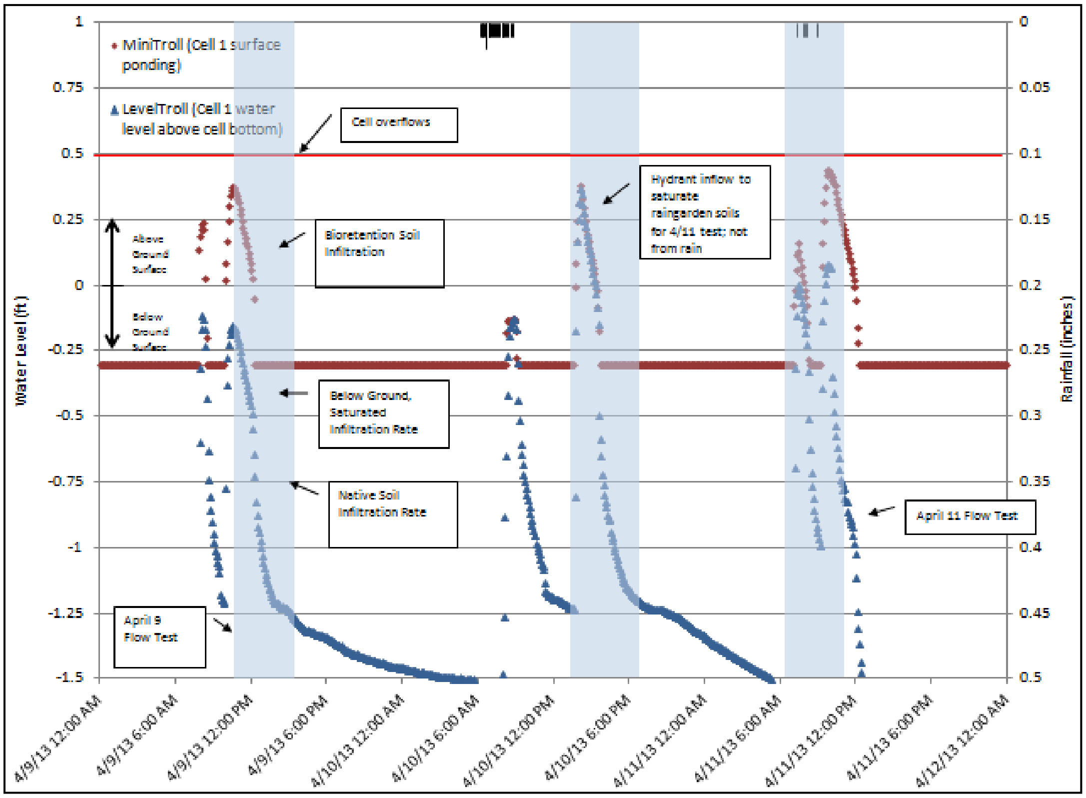


Figure A-18. 30th Avenue Raingarden, April 9 & 11 Controlled Flow Tests Water Level (Cell 1)

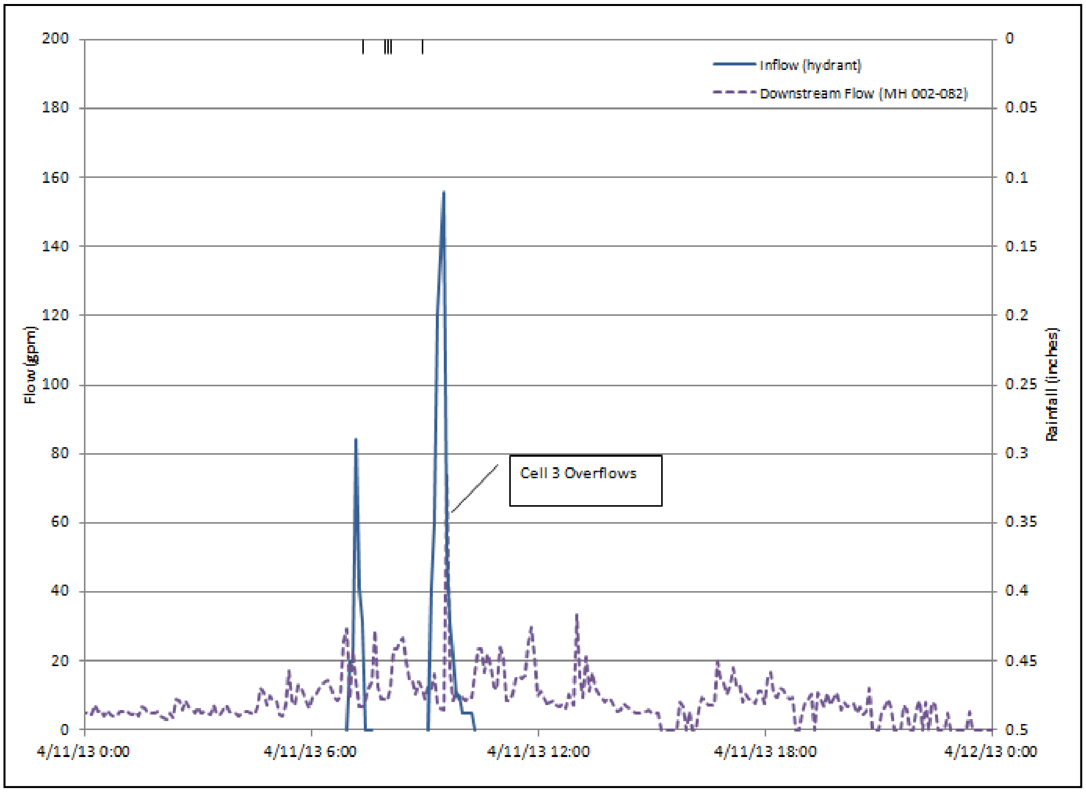


Figure A-19. 30th Avenue Raingarden, April 11, 2013 Controlled Flow Test Hydrograph

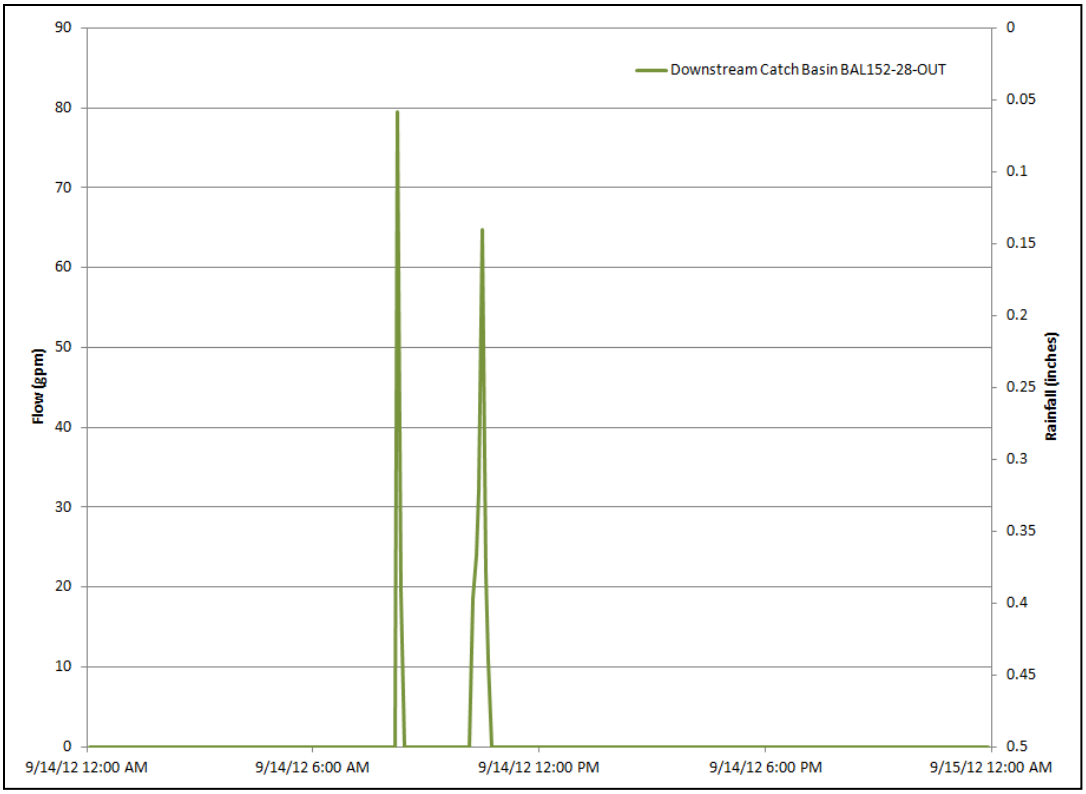


Figure A-20. 28th Avenue Raingarden, Outflow from Downstream Catch Basin, September 14, 2012 Controlled Flow Test

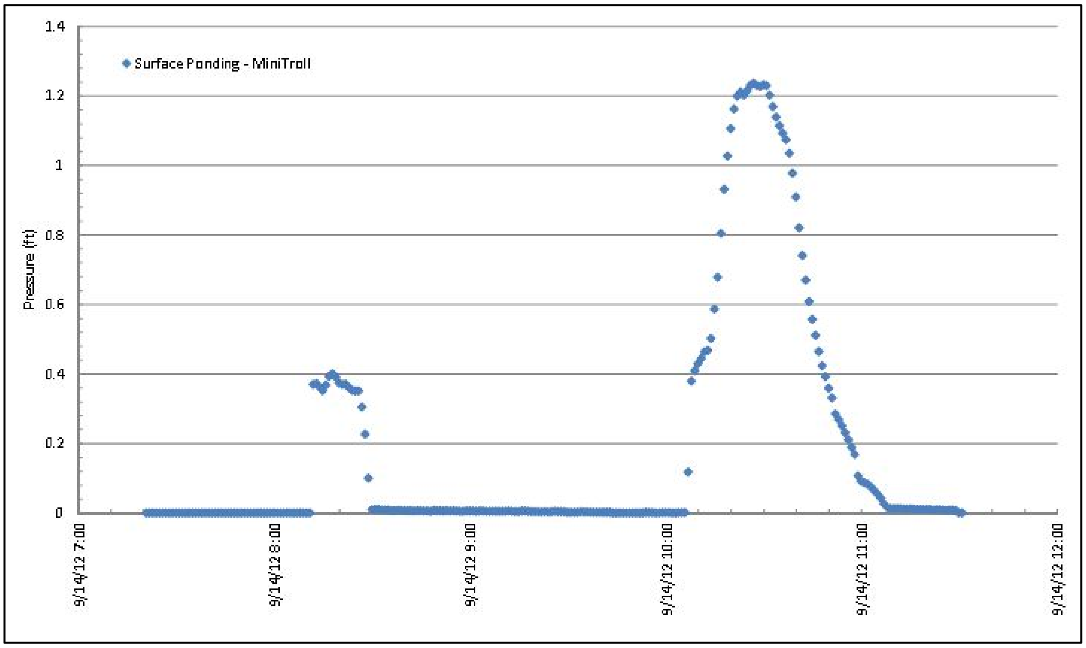


Figure A-21. 28th Avenue Raingarden, September 14, 2012 Controlled Flow Test Surface Water Level

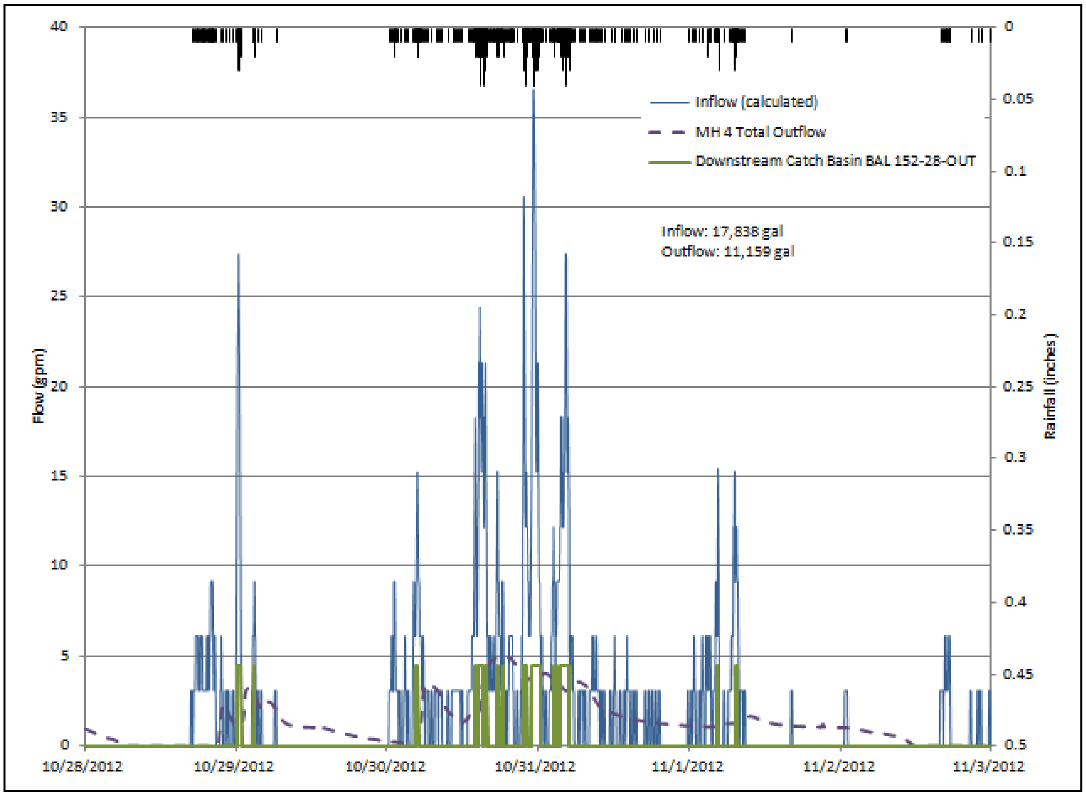


Figure A-22. 28th Avenue Raingarden, October 31, 2012 Storm Hydrograph

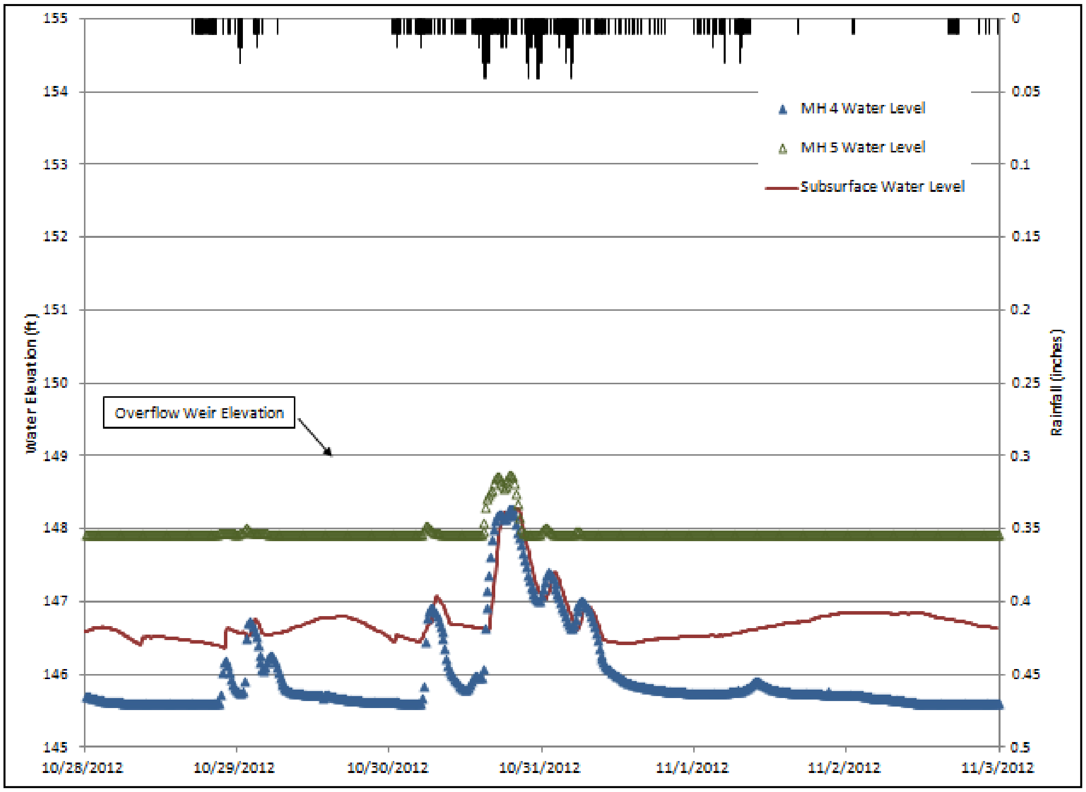


Figure A-23. 28th Avenue Raingarden, October 31, 2012 Storm Water Level

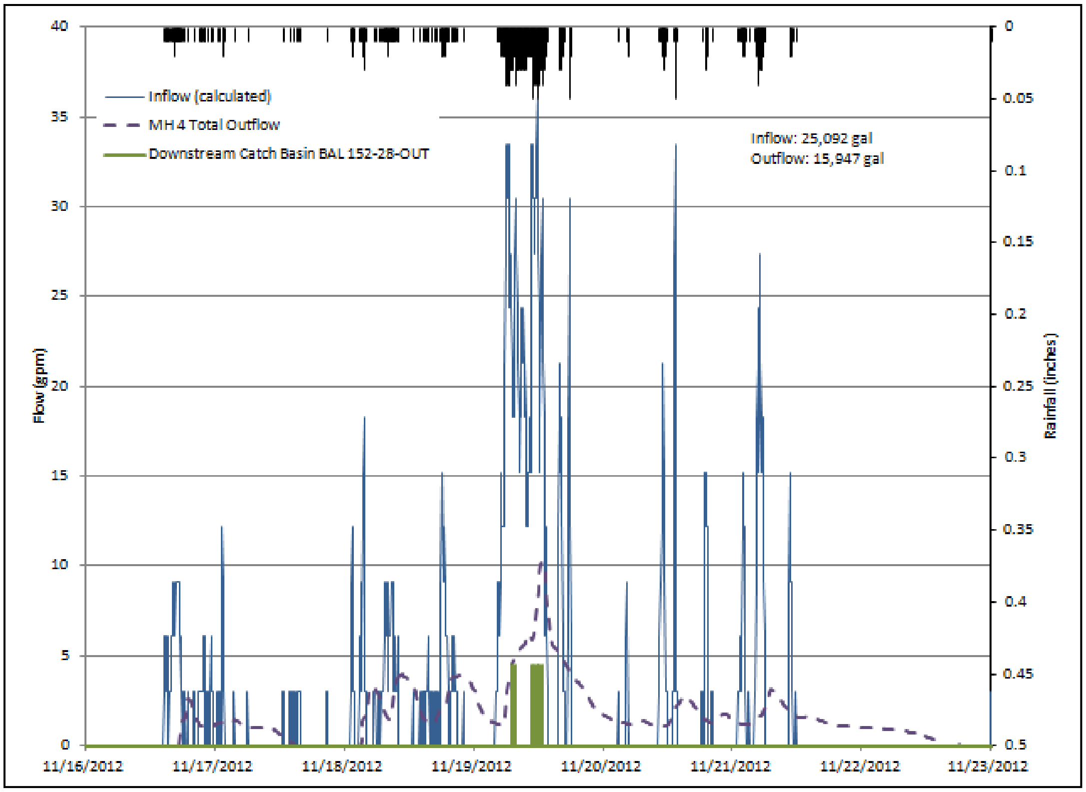


Figure A-24. 28th Avenue Raingarden, November 19, 2012 Storm Hydrograph

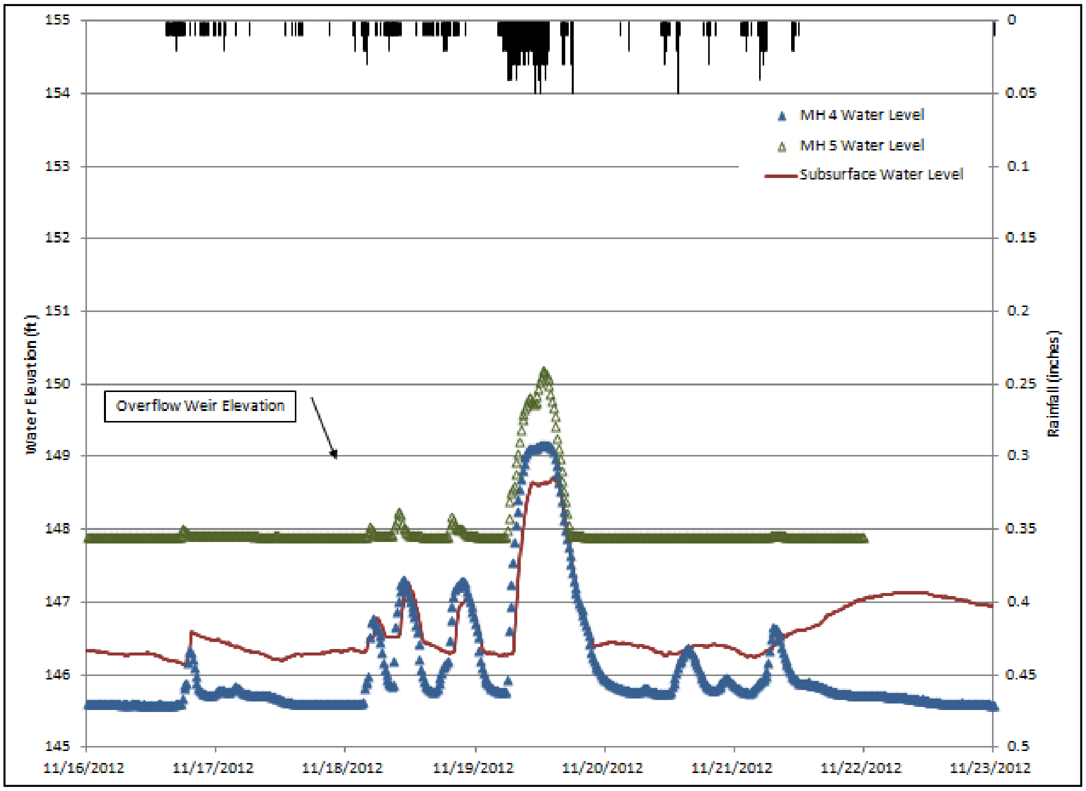


Figure A-25. 28th Avenue Raingarden, November 19, 2012 Storm Water Level

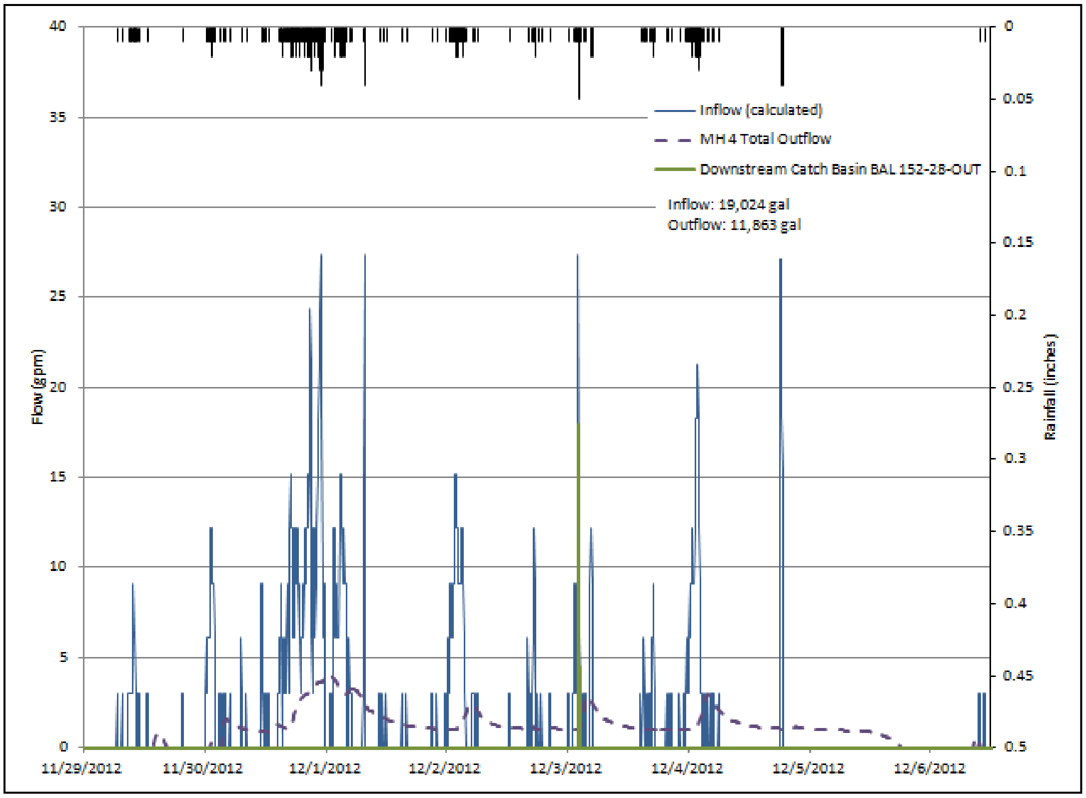


Figure A-26. 28th Avenue Raingarden, December 1, 2012 Storm Hydrograph

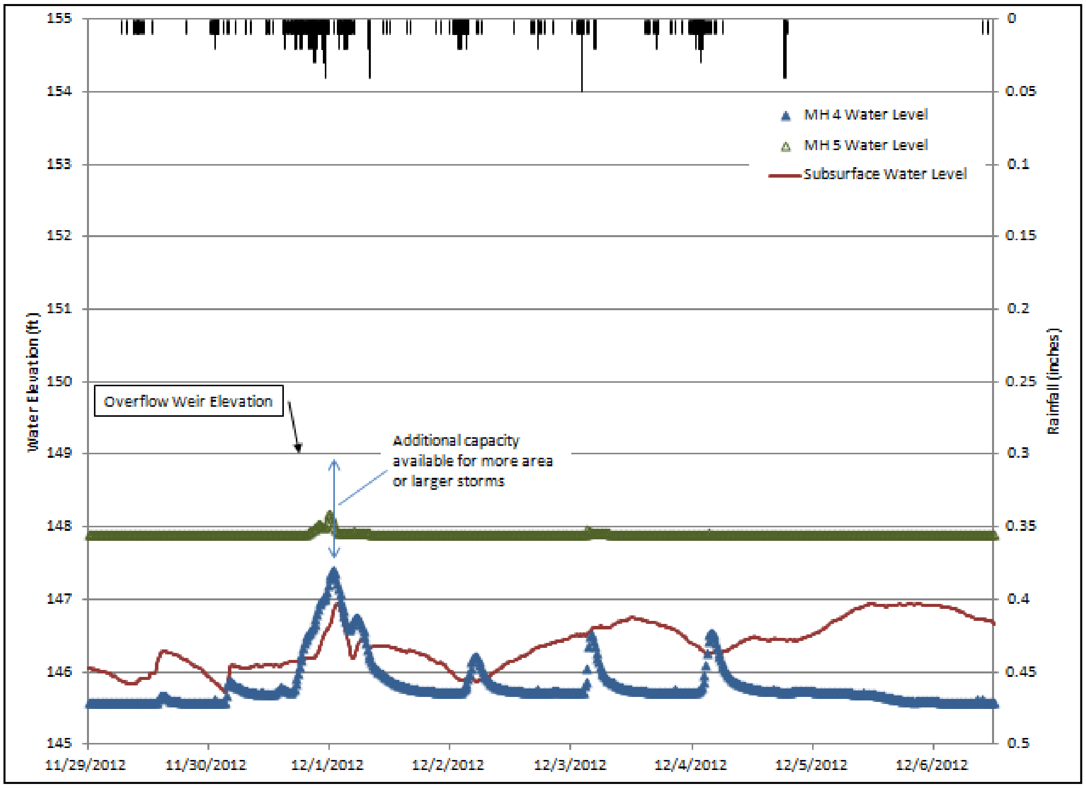


Figure A-27. 28th Avenue Raingarden, December 1, 2012 Storm Water Level

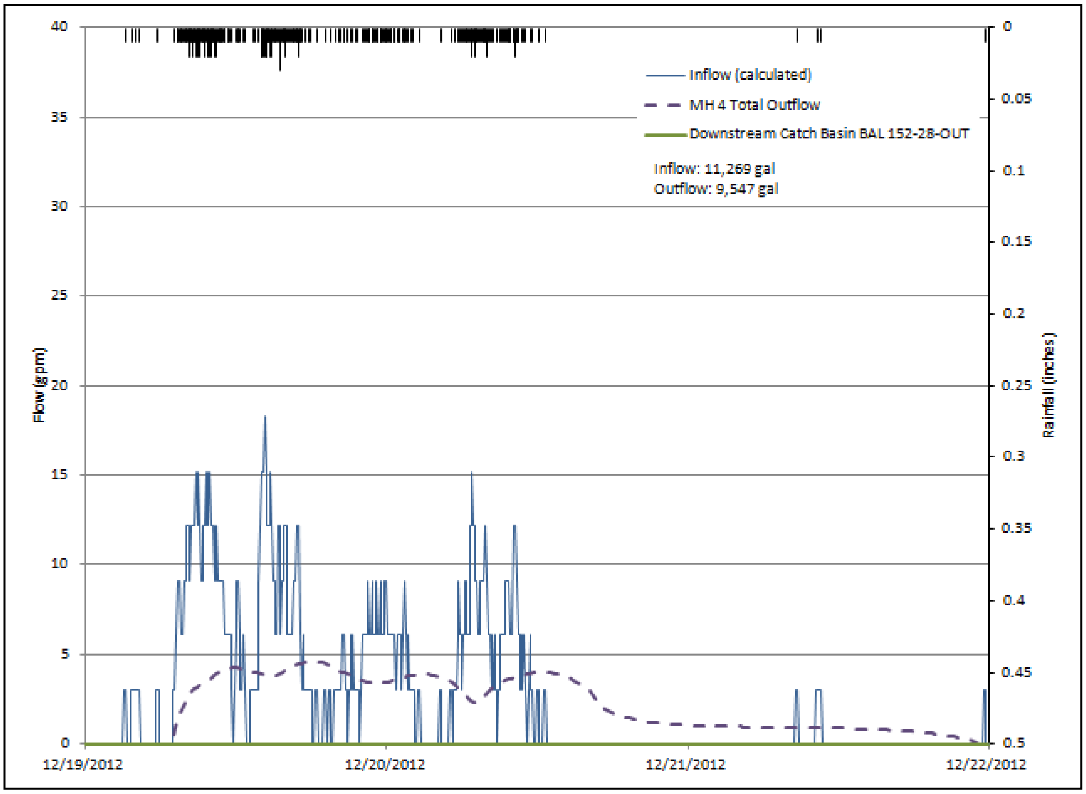


Figure A-28. 28th Avenue Raingarden, December 19, 2012 Storm Hydrograph

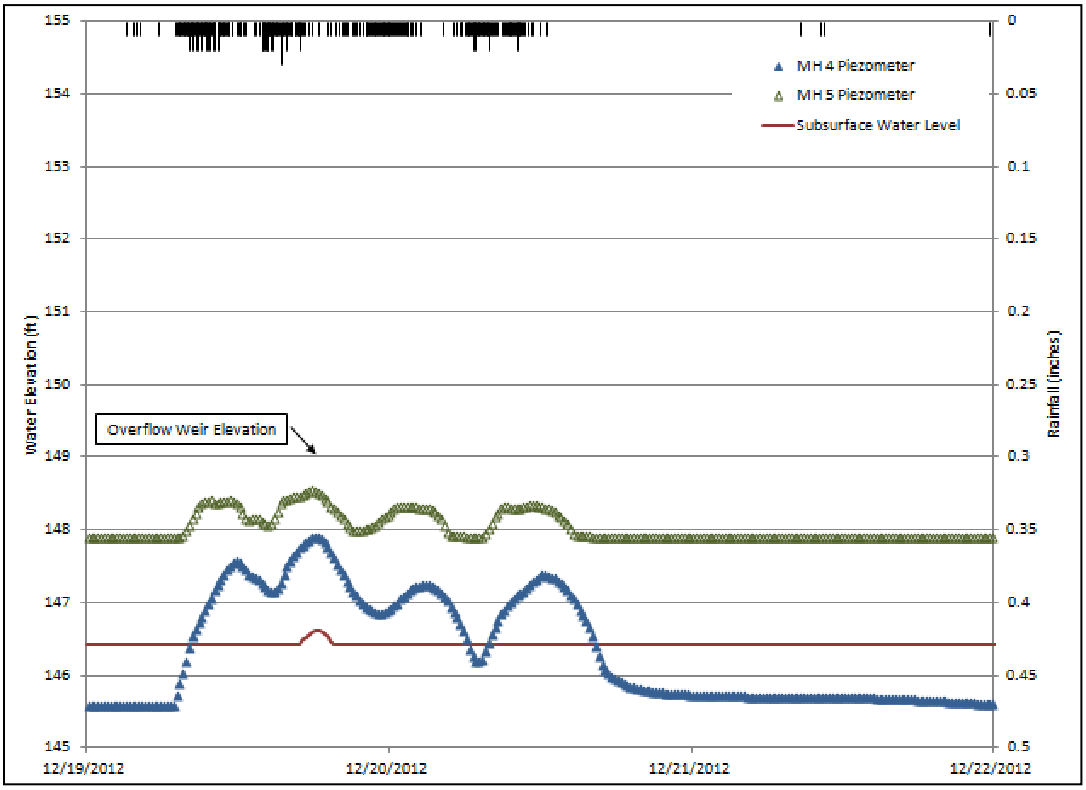


Figure A-29. 28th Avenue Raingarden, December 19, 2012 Storm Water Level

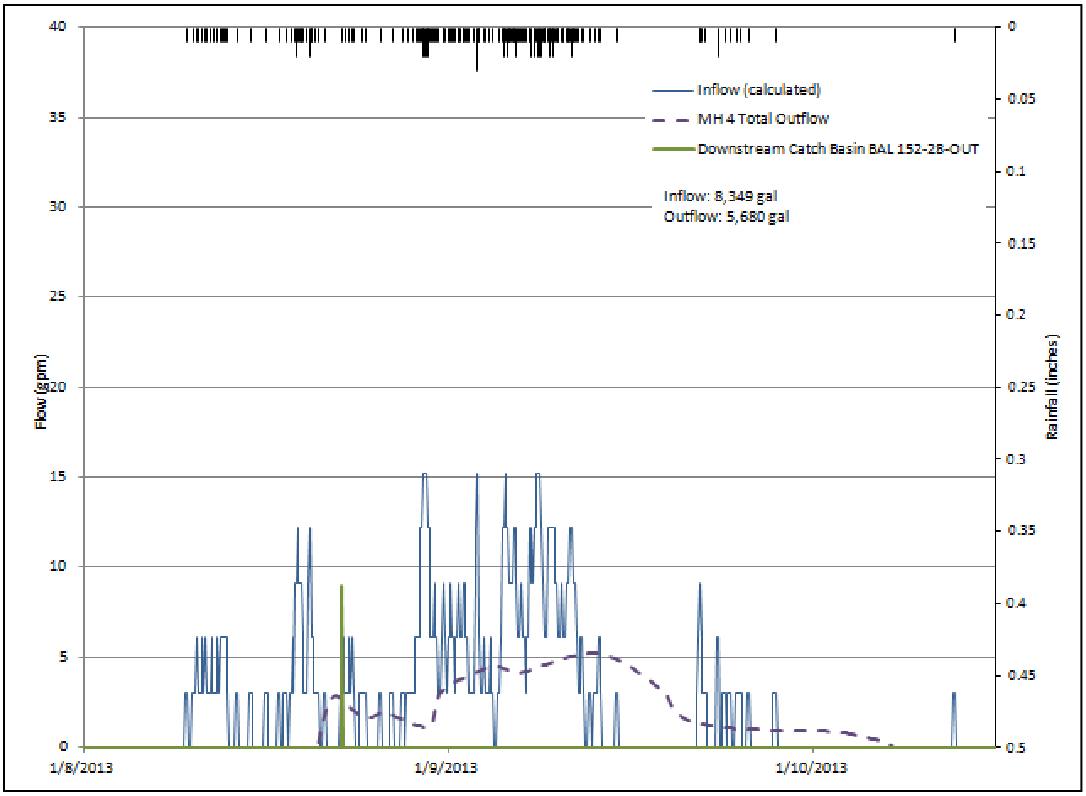


Figure A-30. 28th Avenue Raingarden, January 9, 2013 Storm Hydrograph

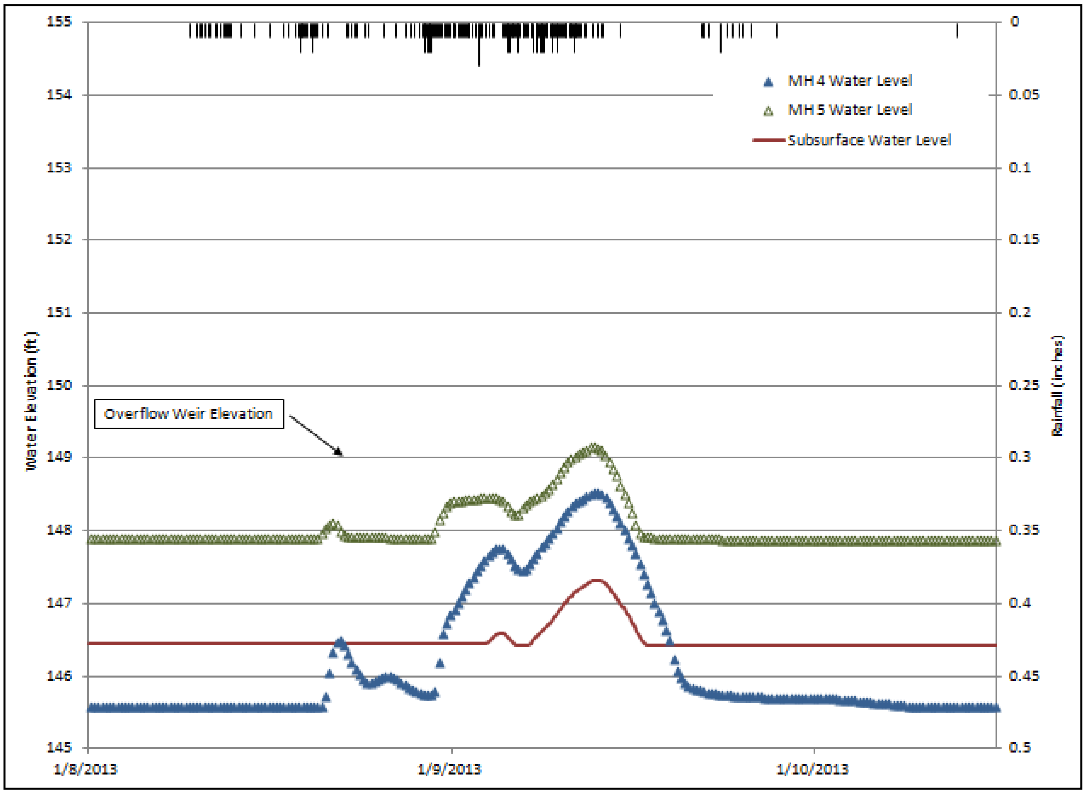


Figure A-31. 28th Avenue Raingarden, January 9, 2013 Storm Water Level

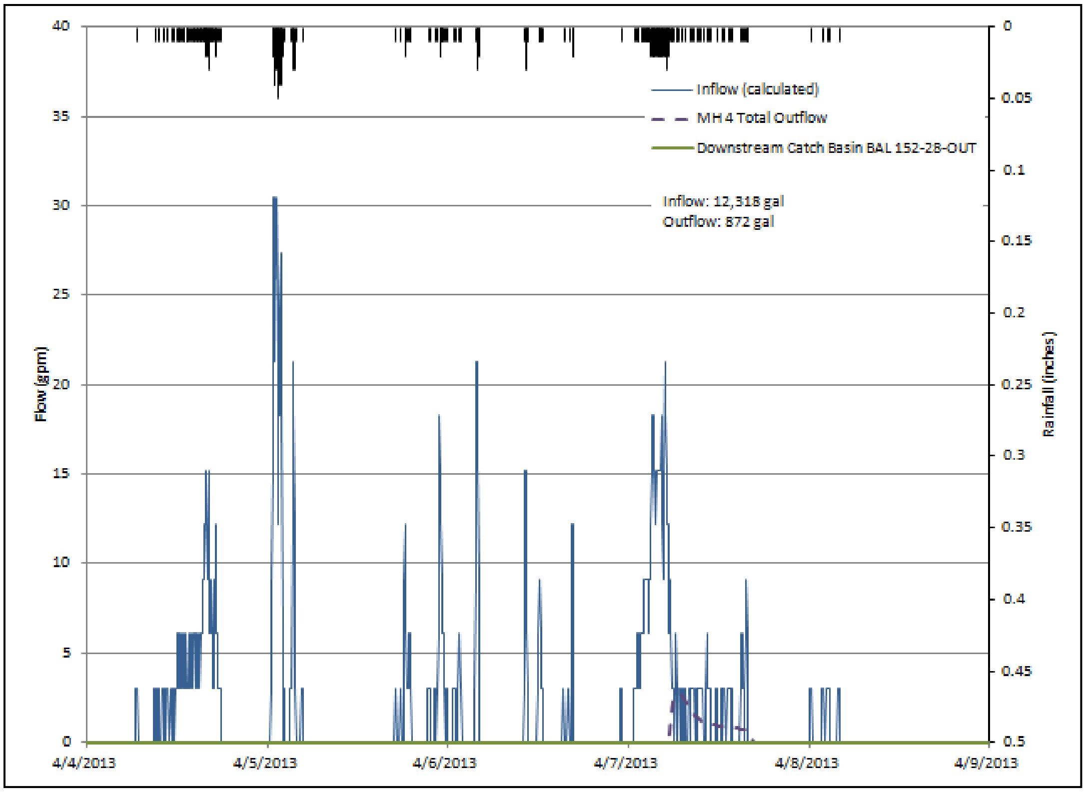


Figure A-32. 28th Avenue Raingarden, April 5, 2013 Storm Hydrograph

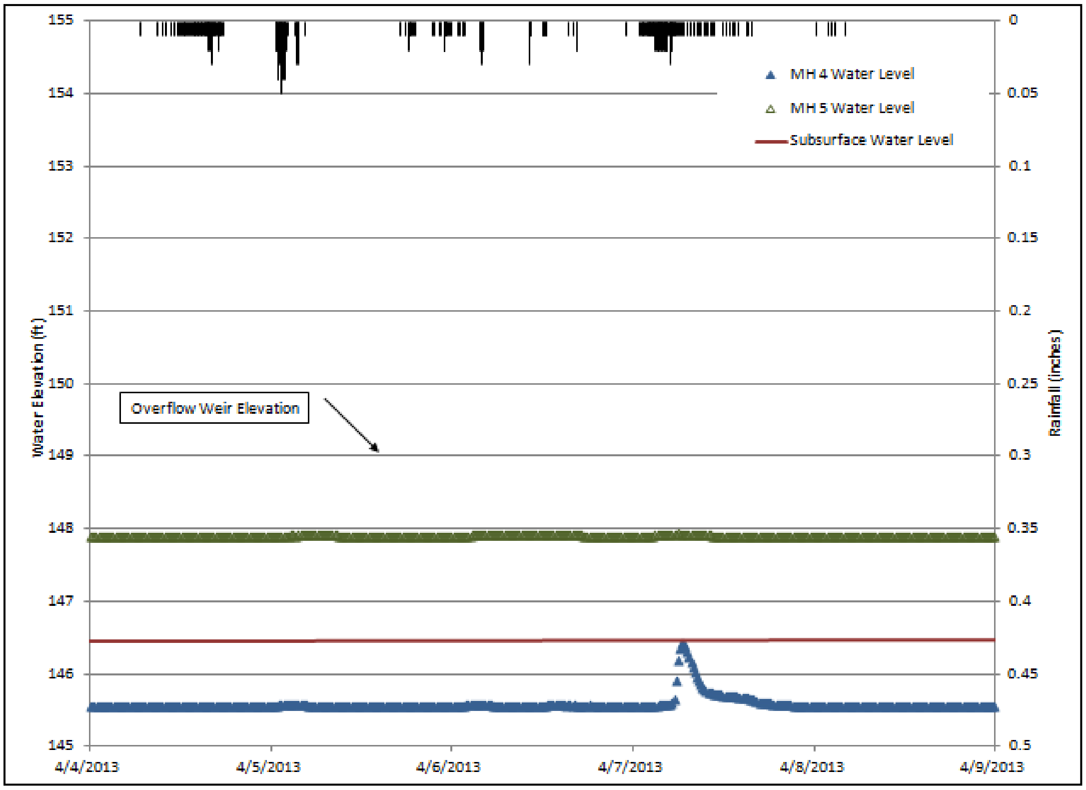


Figure A-33. 28th Avenue Raingarden, April 5, 2013 Storm Water Level

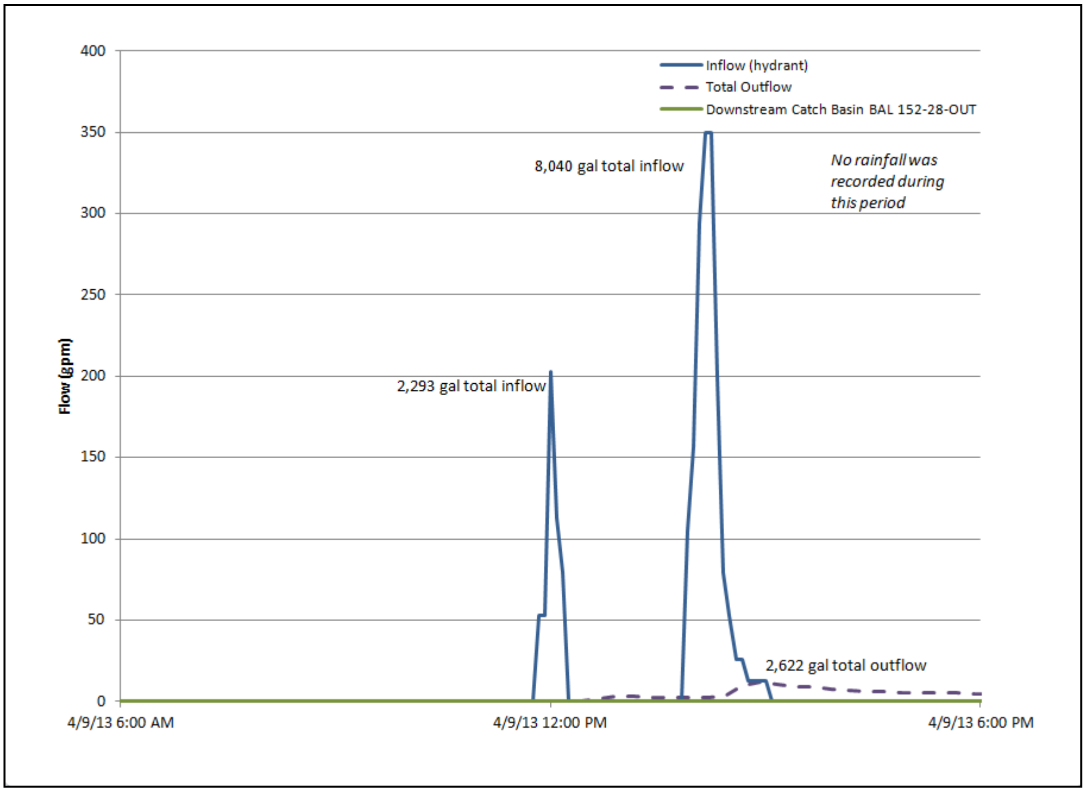


Figure A-34. 28th Avenue Raingarden, April 9, 2013 Controlled Flow Test Hydrograph

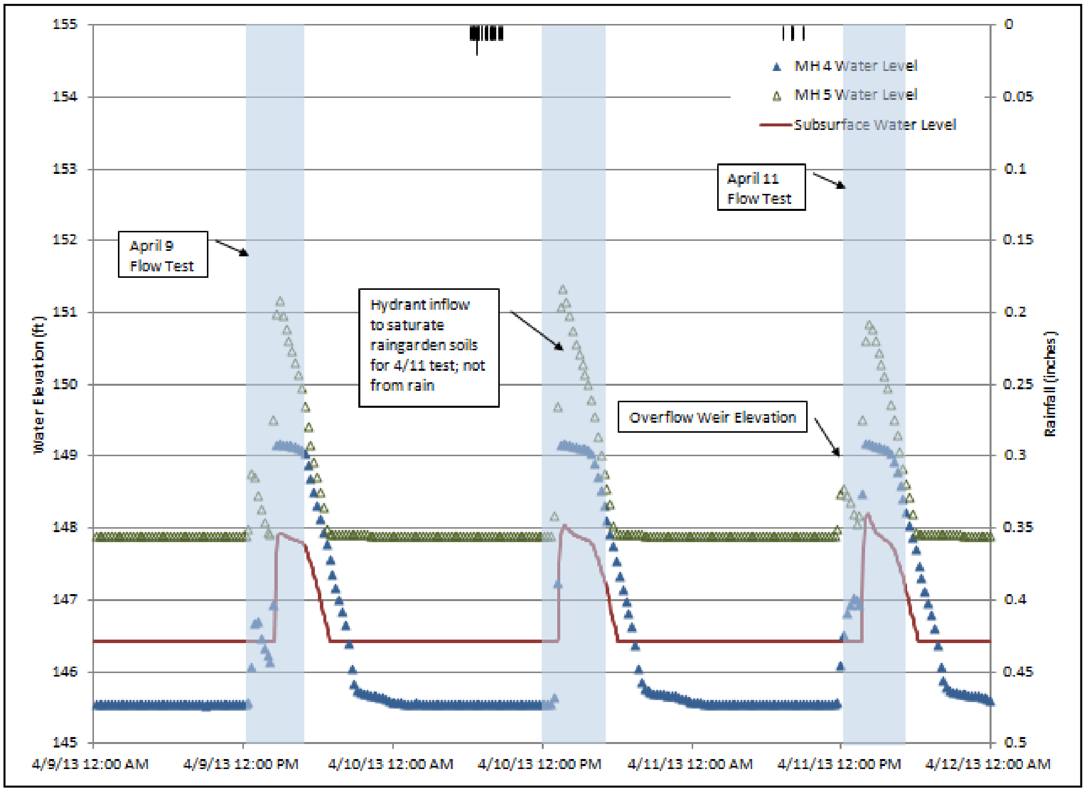


Figure A-35a. 28th Avenue Raingarden, April 9 & 11, 2013 Controlled Flow Tests Water Level

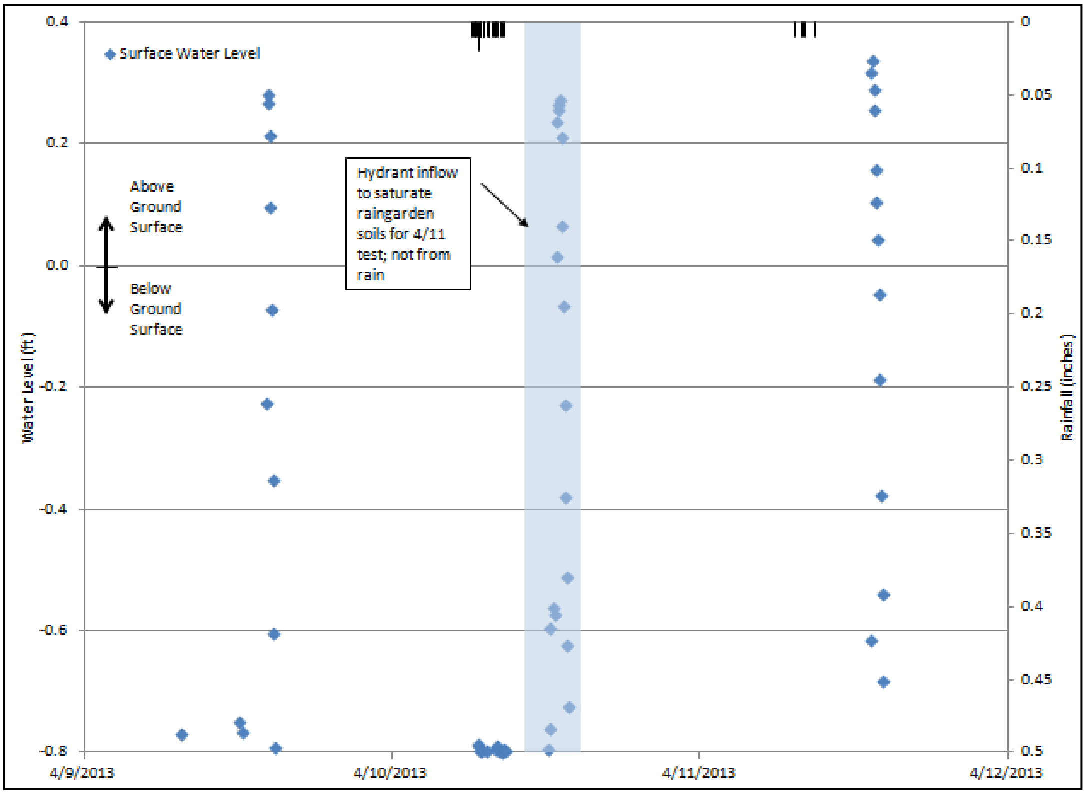


Figure A-35b. 28th Avenue Raingarden, April 9 & 11, 2013 Controlled Flow Test Surface Water Level

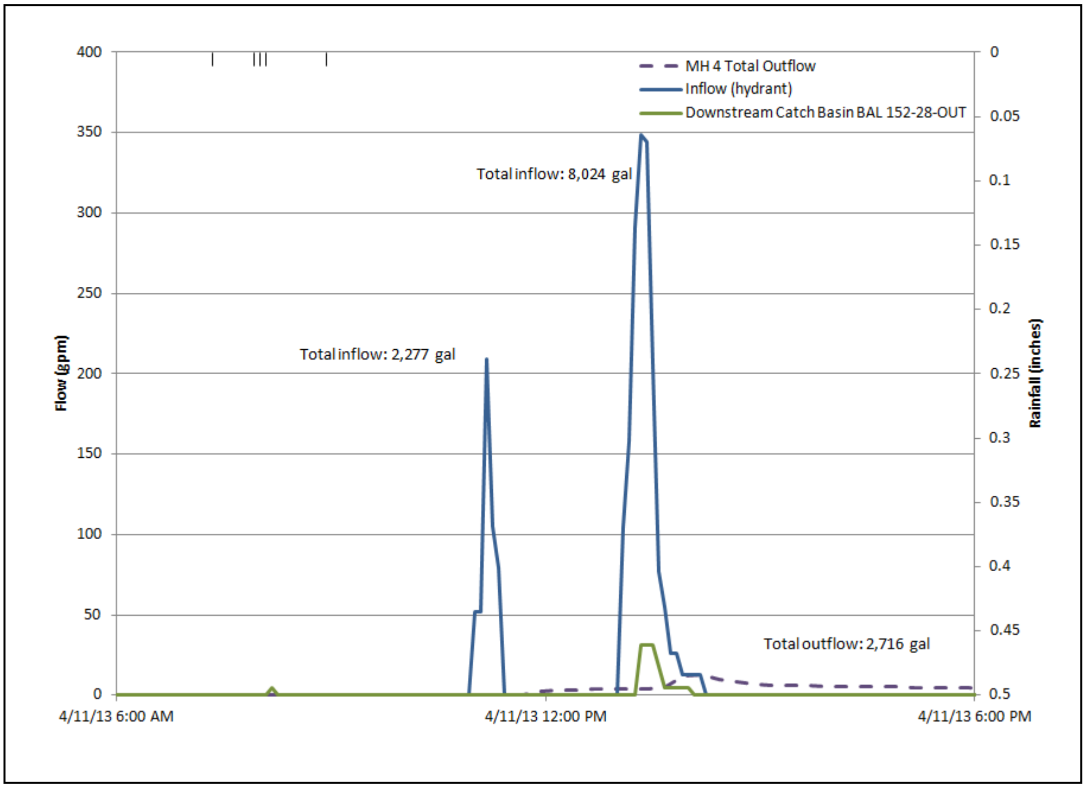


Figure A-36. 28th Avenue Raingarden, April 11, 2013 Controlled Flow Test Hydrograph

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Attachment B: Ballard Roadside Raingardens Summary of Data Analysis Methods

Attachment B Data Analysis Methods

Acronyms

ac	acre(s)
EPA	Environmental Protection Agency
ft	foot or feet
gpm	gallons per minute
hr	hour
in	inch
MG	million gallons
MH	maintenance hole
min	minute
RG	rain gage
sf	square feet
SPU	Seattle Public Utilities
SWMM	Storm Water Management Model

Precipitation and Inflow

Storm Events

The top six storm events of the September 2012 to May 2013 continuous monitoring period were identified by ranking the 24-hour peak rainfall of discreet storm events from City of Seattle rain gage (RG) 07. A period of 24 hours with 0.01 in or less of rainfall was used to separate each discreet storm event. The recurrence interval (e.g., 2-year, 100-year) of each of these storm events was determined by intensity-duration-frequency relationships reported in *Analyses of Precipitation-Frequency and Storm Characteristics for the City of Seattle* (MGS 2003).

Inflow Calculations

Controlled Flow Testing

Precipitation data from RG 07 was used to develop target inflows for controlled flow testing. The rational method was used to convert 5-min precipitation intensity from the October 15, 1996 storm to target inflow from the hydrants for each 5-min interval of the test.

$$Q = CIA$$

Where Q = flow, the runoff coefficient C = 0.9, rainfall intensity I = in/hr measured by RG 07 and area A = acres. The area for 30th Avenue testing was 7,900 sf based on delineation of the tributary impervious area during design by M. Lo of Seattle Public Utilities. The area for 28th Avenue testing was 21,075 sf based on delineation conducted by SPU of the total potential tributary area to the raingardens, including flow routed from NW 67th Street, curb flow from 28th Avenue NW (5,400 sf), direct precipitation on the raingardens, and sheet flow from adjacent properties.

Continuous Monitoring Analysis

The estimated storm inflow to the 30th Avenue and 28th Avenue raingardens was calculated with the rational formula for rainfall-runoff:

$$Q = CIA$$

Where Q = flow, the runoff coefficient C = 0.9, rainfall intensity I = in/hr measured by RG 07 and area A = ac. The area for 30th Avenue testing was 7,900 sf based on delineation of the tributary impervious area during design by M. Lo of Seattle Public Utilities. The area for 28th Avenue testing was 8,200 sf based on delineation conducted by SPU of the total potential tributary area to the raingardens, including curb flow from 28th Avenue NW, direct precipitation on the raingardens, and sheet flow from adjacent properties. *NOTE: During controlled flow testing conducted in September 2012, the routed flow from NW 67th Street was likely clogged due to the pipe being buried and backfilled with soil (resulting in collected flow being diverted directly to the combined sewer system) and therefore was excluded from the analysis.*

Raingarden Performance

Outflow Calculations

30th Avenue Raingarden

Total overflow from the 30th Avenue raingarden is the difference between total flow measured at the downstream MH (BAL 002-082) and the sum of inflow from the remaining basin impervious area and dry weather flow. Controlled tests occurred largely during periods of no rainfall and therefore the total overflow could be easily estimated as the difference between total flow and dry weather flow.

However, during the continuous monitoring period, the estimated inflow from the total contributing basin greatly exceeded the potential overflow from the 30th Avenue NW raingardens and therefore resulted in considerable uncertainty in calculating the overflow from the raingardens using this method.

Dry Weather Flow

Dry weather flow was based on the average hourly flow measured by the meter in MH 002-082 during dry weather periods. Dry weather flow was estimated for the September 2012 tests based on the continuous flow measurements in MH 002-082 between September 12 and 19, 2012. This dry weather flow was used to calculate the design storm volume infiltrated by the 30th Avenue raingarden, along with the measured hydrant inflow from the controlled flow test and the measured outflow in the downstream sewer (MH 002-082). See Figure B-1, where “Inflow (sewer)” represents the September 12, 2012 design storm and stress test flow from the raingarden back to the sewer (inflow = outflow – dry weather flow).

Dry weather flow was also calculated for the entire monitoring period by calculating an average hourly flow for selected dates/times for which the rainfall within the past 24 hours was less than 0.01 in (as measured by RG 07). This dry weather flow was used to calculate the volume infiltrated by the 30th Avenue raingarden during the storm events.

BAL002-082 Flow Meter

Flow data from the BAL002-082 FlowShark open-channel flow monitor was collected and summarized by ADS Environmental Services, Inc. FlowSharks are area-velocity flow monitors that can be configured to measure both depth (using multiple sensors) and velocity. Flow rate can then be calculated using these measurements and the channel dimensions. The ADS FlowShark flow monitors recorded depth and velocity at 5-min intervalS.

28th Avenue Raingarden

Total overflow from the 28th Avenue raingarden is the sum of the weir overflow, the flow through the orifice (see Figure B-2) and flow measured at the inlet connection collecting curb flow downstream of the raingardens (BAL152-28-OUT).

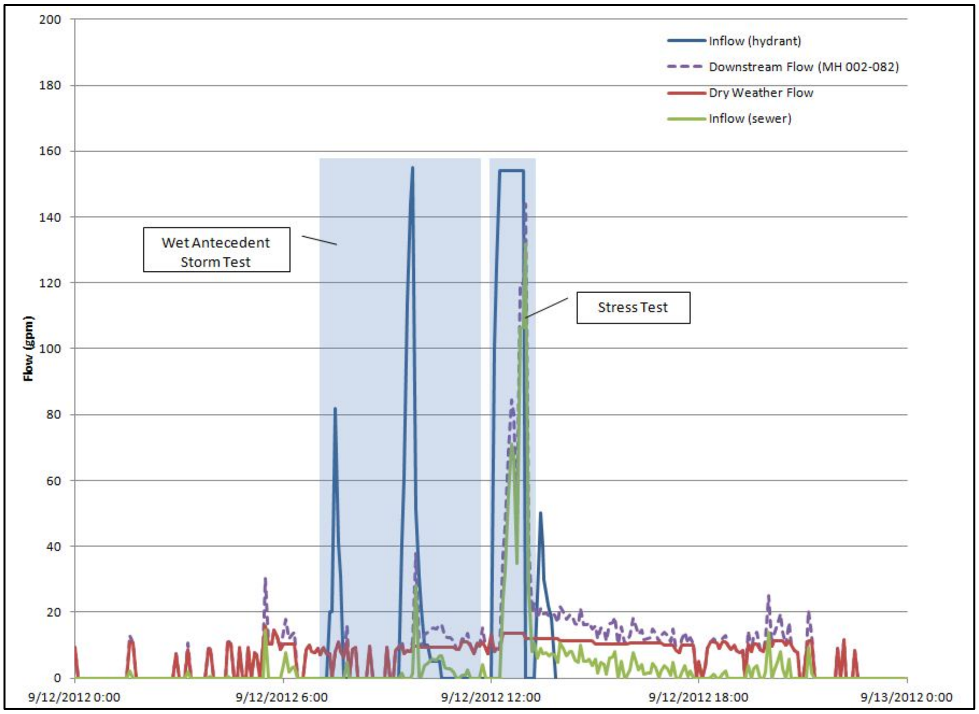


Figure B-1. September 12, 2012 Inflow vs. Outflow Calculations, 30th Avenue Raingarden

Figure B-2 – Thel-Mar Overflow Weir in MH 4 at the 28th Avenue Raingarden.

Weir Flow

Weir overflow from the 28th Avenue raingarden was calculated with the 8-in Thel-Mar weir equation, which is based on the flow (gpm) – head (ft) empirical relationship for an 8-in Thel-Mar weir shape:

$$y = 59412x^5 - 50580x^4 + 14050x^3 - 442.52x^2 - 0.6102x + 0.1839$$

Where y = overflow in gpm and x = feet of head above the weir notch. The surveyed weir notch elevation was 149.07 feet. Feet of head over the weir notch was calculated by subtracting this weir notch elevation from the water elevation measured by the MH 4 piezometer (installed at an elevation of 142.28 feet).

Orifice Flow

The overflow from the orifice was calculated by subtracting the water elevation measured by the MH 4 piezometer from the surveyed orifice invert elevation of 145.61 feet, giving feet of head above the orifice invert, then using the orifice equation for the 0.5-in diameter round orifice, where Cd = coefficient of discharge for a sharp orifice = 0.62; A = orifice area; and h = head over the orifice centerline:

$$Q = CdA\sqrt{2gh}$$

Dry Weather Flow

There are no relevant dry weather flow measurements or estimates for the 28th Avenue raingarden.

BAL152-28-OUT Flow Meter

As for the 30th Avenue raingarden, flow data from the BAL152-28-OUT FlowShark open-channel flow monitor were collected by ADS Environmental Services, Inc. at 5-min intervals based on depth and velocity measurements and channel dimensions. This meter captures flow that bypasses the raingarden and enters the storm sewer system via two downstream curb inlets.

Volume Reduction by Event

30th Avenue Raingarden

Monitoring during the 2012-2013 wet season did not directly indicate any overflows from the 30th Avenue raingardens (i.e., where measured ponding exceeded maximum ponding depth in the raingarden cells). Potential overflow was therefore estimated based on rainfall records and comparison to the volume and inlet capacity of the raingardens from the controlled flow tests.

The peak rainfall intensity measured at RG 07 was 0.14 in in 5 min on April 13, 2013. As this is less than the inlet capacity of the raingardens (see below), it is assumed that discharge to the combined sewer through bypass of the inlets alone did not occur during the monitoring period.

The next most intense rainfall intensity measured at RG 07 was 0.06 in in 5 min, which occurred on three occasions. Per the rational equation, the peak flow generated by this intensity is approximately 53 gpm. During the controlled flow tests, 80 gpm was necessary to generate flow that entered the third downstream raingarden cell. Therefore, it is assumed that most storms filled the upper cells initially and the potential overflow mode for the raingardens would be due to sustained flows that completely filled each cell to capacity. Per the analysis below, the volume capacity of the raingardens is estimated to be approximately a 15-year recurrence interval (or approximately 1.42 in of rainfall in 6 hours). Only the November 19, 2012 event (a 100-year recurrence interval) exceeded this rainfall volume. To estimate the potential overflow during this event, the accumulated rainfall prior to 1.42 in was estimated to be captured and/or infiltrated within the raingarden. Upon meeting this capacity, the remaining rainfall/runoff was estimated to overflow to the downstream combined sewer system. See Figure B-3 below.

To calculate the total volume infiltrated during each event, storm periods were first defined based on a 24-hour dry period. The total potential inflow volume for each event was calculated based on the total accumulated rainfall multiplied by the tributary impervious area (7,900 sf). As discussed above, it is assumed based on the performance of the raingardens during the controlled flow tests and rainfall records that the raingardens captured and infiltrated all runoff, except the November 19, 2012 event.

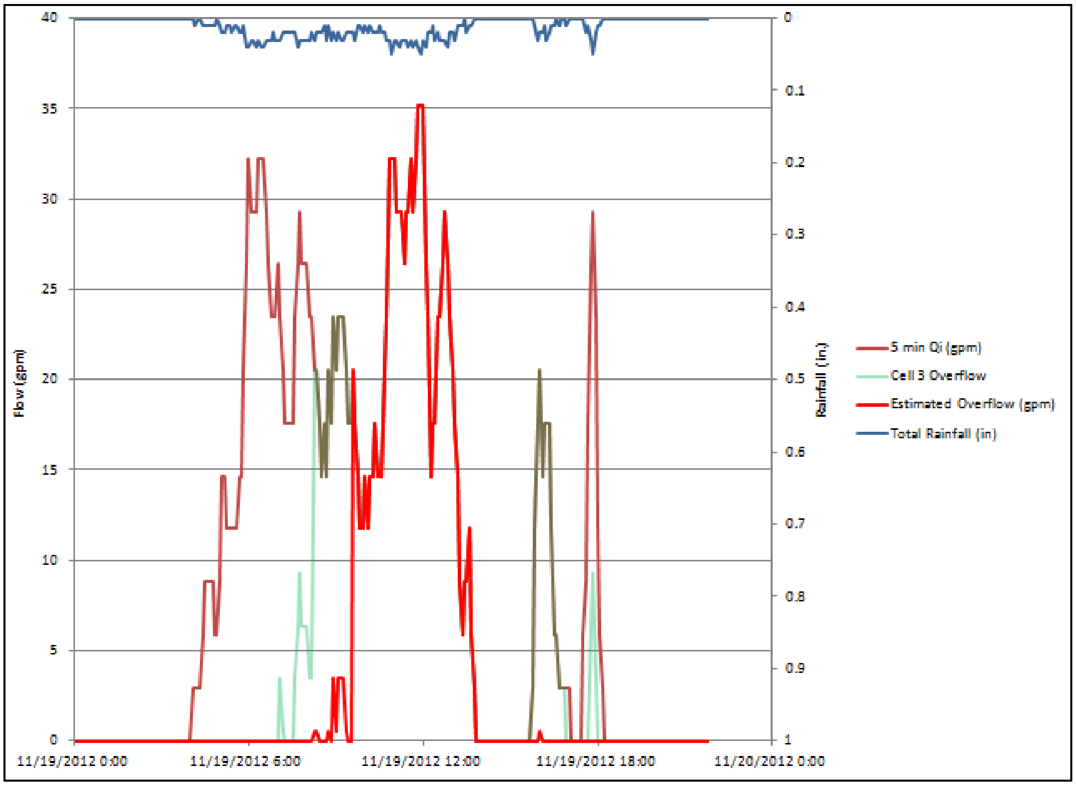


Figure B-3. Flows at the 30th Avenue Raingarden During the November 19, 2012 100-year Event

28th Avenue Raingarden

To calculate the total volume infiltrated during each event, storm periods were first defined based on a 24-hour dry period. The total potential inflow volume for each event was calculated based on the total accumulated rainfall multiplied by the tributary impervious area (8,200 sf).

Total outflow was calculated by the sum of the weir overflow, the flow through the orifice (see Figure B-2) and flow measured at the inlet connection collecting curb flow downstream of the raingardens (BAL152-28-OUT) during each storm period.

Equivalent Design Storm Capacity

30th Avenue Raingarden

Intensity

Observations and data recorded during the September 2012 controlled flow tests determined that inlet capacity may be limiting during intense storm events. The inlet capacity prior to bypass to the downstream combined sewer was estimated to be approximately 150 gpm. Using the raingarden’s tributary area and the rational method, the calculated rainfall intensity needed to generate the said flowrate is 2.04 in/hr (or 0.17 in in 5 min). Per MGS (2003) intensity-duration-frequency, this is equivalent to a **5-year recurrence interval.**

Table B-1. Intensity-Duration-Frequency Values; *reproduced from MGS (2003)*

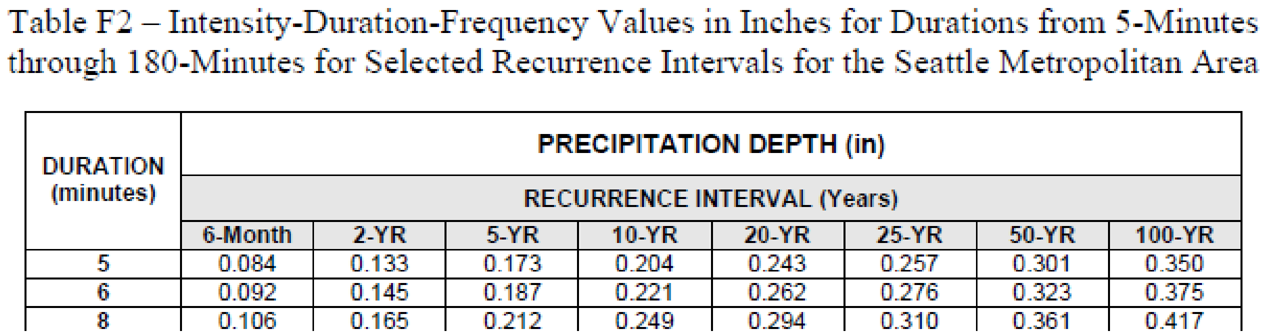


Table F2 – Intensity-Duration-Frequency Values in Inches for Durations from 5-Minutes through 180-Minutes for Selected Recurrence Intervals for the Seattle Metropolitan Area

DURATION (minutes)	PRECIPITATION DEPTH (in)							
	RECURRENCE INTERVAL (Years)							
	6-Month	2-YR	5-YR	10-YR	20-YR	25-YR	50-YR	100-YR
5	0.084	0.133	0.173	0.204	0.243	0.257	0.301	0.350
6	0.092	0.145	0.187	0.221	0.262	0.276	0.323	0.375
8	0.106	0.165	0.212	0.249	0.294	0.310	0.361	0.417

Volume

Observations and data recorded during the September 12, 2012 controlled flow tests determined that the 28th Avenue raingarden infiltrated 7,012 gallons in under 6 hours. For the raingarden's tributary area of 7,900 sf, this corresponds to approximately 1.42 in of precipitation.

Per MGS (2003), this is equivalent to **~15-year recurrence interval** for RG 07, assuming that rainfall intensity is less than the inlet capacity of the raingardens and all cells are saturated and filled completely prior to overflow.

Table B-2 & Figure B-4. Precipitation-Magnitude-Frequency Values; *table and figure reproduced from MGS (2003)*

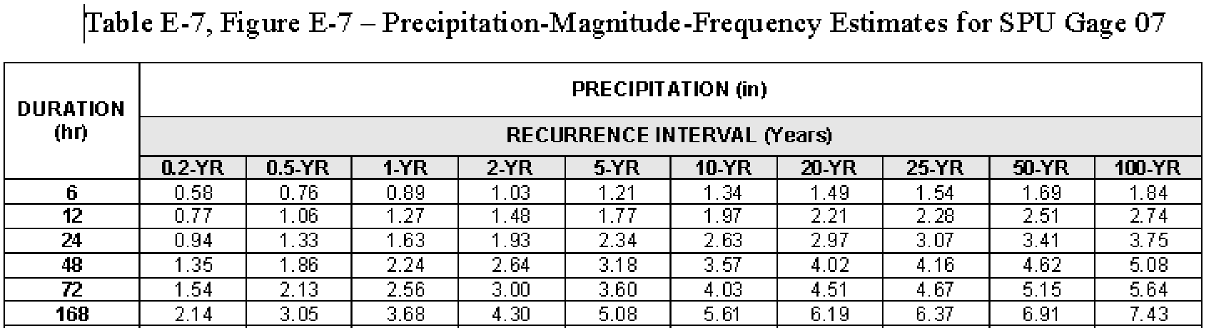
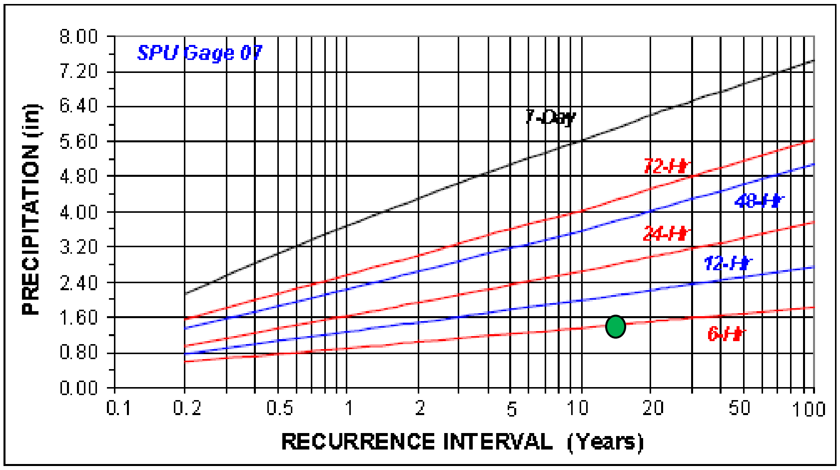


Table E-7, Figure E-7 – Precipitation-Magnitude-Frequency Estimates for SPU Gage 07

DURATION (hr)	PRECIPITATION (in)									
	RECURRENCE INTERVAL (Years)									
	0.2-YR	0.5-YR	1-YR	2-YR	5-YR	10-YR	20-YR	25-YR	50-YR	100-YR
6	0.58	0.76	0.89	1.03	1.21	1.34	1.49	1.54	1.69	1.84
12	0.77	1.06	1.27	1.48	1.77	1.97	2.21	2.28	2.51	2.74
24	0.94	1.33	1.63	1.93	2.34	2.63	2.97	3.07	3.41	3.75
48	1.35	1.86	2.24	2.64	3.18	3.57	4.02	4.16	4.62	5.08
72	1.54	2.13	2.56	3.00	3.60	4.03	4.51	4.67	5.15	5.64
168	2.14	3.05	3.68	4.30	5.08	5.61	6.19	6.37	6.91	7.43



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28th Avenue Raingarden

Intensity

As at the 30th Avenue raingarden, observations and data recorded during the September 2012 controlled flow tests determined that the 28th Avenue raingarden's inlet capacity may be limiting during intense storm events. The inlet capacity prior to bypass to the downstream combined sewer was estimated to be approximately 50 gpm. Using a tributary area for the roadway runoff (5,400 sf) and the rational method the calculated rainfall intensity to generate an equivalent flowrate is 1.00 in/hr (or 0.083 in in 5 min). Per MGS (2003) intensity-duration-frequency this is equivalent to a **6-month recurrence interval.** *NOTE: The curb inlets have recently been retrofitted with asphalt berms to increase the capacity of the inlets and capture additional flow.*

Table B-3. Five-Minute Intensity-Duration-Frequency Values; table reproduced from MGS (2003)

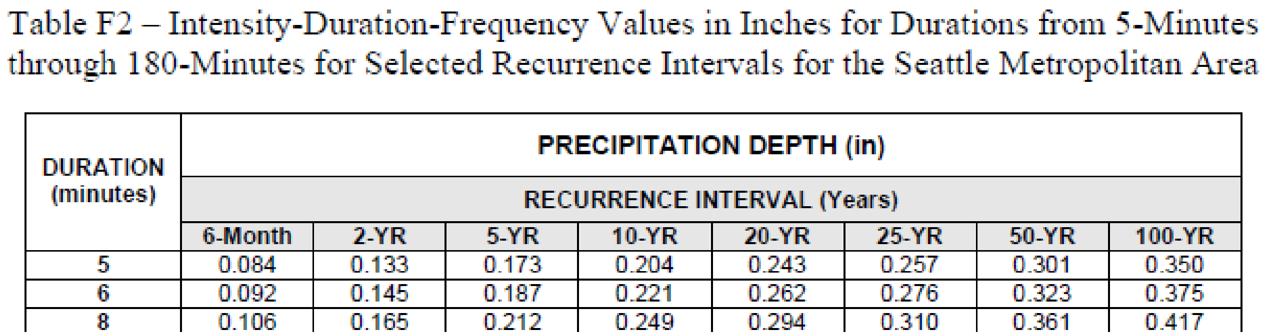


Table F2 – Intensity-Duration-Frequency Values in Inches for Durations from 5-Minutes through 180-Minutes for Selected Recurrence Intervals for the Seattle Metropolitan Area

DURATION (minutes)	PRECIPITATION DEPTH (in)							
	RECURRENCE INTERVAL (Years)							
	6-Month	2-YR	5-YR	10-YR	20-YR	25-YR	50-YR	100-YR
5	0.084	0.133	0.173	0.204	0.243	0.257	0.301	0.350
6	0.092	0.145	0.187	0.221	0.262	0.276	0.323	0.375
8	0.106	0.165	0.212	0.249	0.294	0.310	0.361	0.417

Volume

Based on continuous monitoring data, the raingardens were able to fully capture storms less than or equal to a 2 to 4-year recurrence interval (of a 12- to 24-hour duration) without overflow of the overflow riser. Overflow did occur during a 100-year event (12-hour duration). Therefore the estimated volume capacity of the raingardens (assuming all flow enters the curb inlets) is equal to approximately a **5 to 25 year recurrence interval.**

SWMM Modeling and Parameters

Model Development and Calibration

30th Avenue Raingarden

The 30th Avenue raingardens were added to the calibrated Ballard CSO model (EPA's SWMM) to simulate the performance during the wet season (October 1, 2012 to May 1, 2013), which included the April controlled flow tests. The model was constructed based primarily on record drawings, personal communications with SPU technical staff, and parameters estimated from the monitoring data described here.

Table B-4. SWMM Model Parameters for the 30th Avenue Raingarden			
Parameter	**Value**	**Unit**	**Basis/Notes**
Tributary Area	7900	sf	(M. Lo, personal communication, various dates 2011)
Bioretention Soil Infiltration Rate	12	in/hr	Monitoring Data (see below)
Bioretention Soil Depth	12	in	Record Drawings (Ballard Roadside Raingardens, Phase 1 Record Drawing, Sheet 20, July 6, 2012)
Native Soil Infiltration Rate	3	in/hr	Monitoring Data (see below)
Ponding Depth	8	in	Field Measurement
Porosity	0.4	ft/ft	(SPU 2009)
Field Capacity	0.13	ft/ft	(Rawls et al. 1998)
Wilting Point	0.05	ft/ft	(Rawls et al. 1998)
Basin Area	2.709	ac	Calibrated Model
% Impervious	49.54%	–	Calibrated Model
Total Impervious Mitigated	15,800	sf	(M. Lo, personal communication, various dates 2011)
% of Impervious Mitigated	27%	–	Calculation
Top Area	900	sf	Sizing Factor: 11.4%
Bottom Area	349	sf	Sizing Factor: 4.4%
Average Area	625	sf	Sizing Factor: 7.9%

Model geometry is simplified to a vertical walled facility (as limited by SWMM) by calculating the average area between the bottom area and top area of the bioretention cells. Note that the model simplifies the raingarden series by assuming they act as a single aggregate cell and that all flow is allowed to enter the facility via the curb cuts. In reality, cells fill independently and generally from the upstream to downstream and are limited by the capacity of the curb inlets.

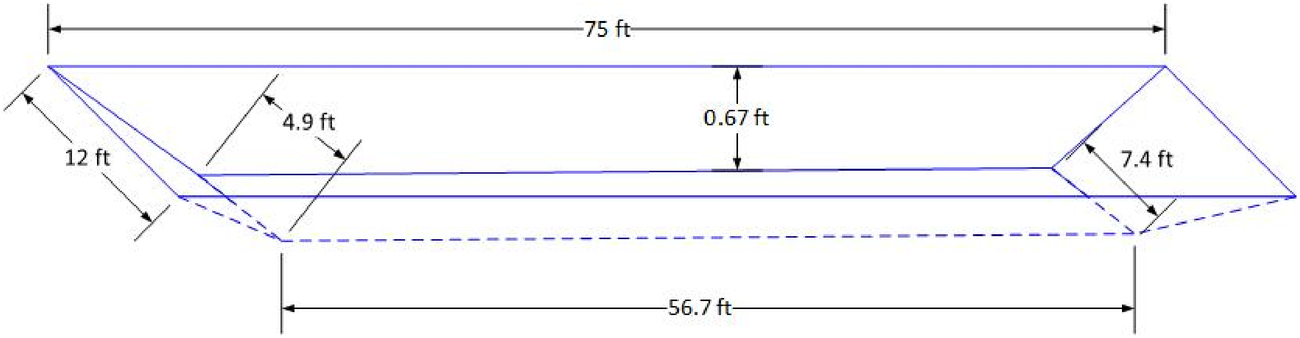


Figure B-5. Simplified Raingarden Cell Geometry for SWMM Model

Model runs using the record drawing geometry and soil parameters from the monitoring yielded results that were reasonably close to the monitoring data. As noted above, the only periods of modeled surface ponding were during the November 19, 2012 storm (a 100-year event) and the controlled flow tests in April. The April controlled flow tests did not overflow (with exceptions of minor bypass of the last cell prior to filling it to capacity). The November 19 event likely did overflow and nearly overflowed in the model simulation. Further calibration of this model would be necessary to refine the results, which would likely result in either a reduction in the following parameters:

- Effective ponding depth (ponding depth per the design was 6 in but measured as 8 in in Cell 1 in the field. Other cells may have shallower ponding depths.
- Native soil infiltration rate
- Effective raingarden area
- Soil storage (e.g. porosity relative to field capacity)

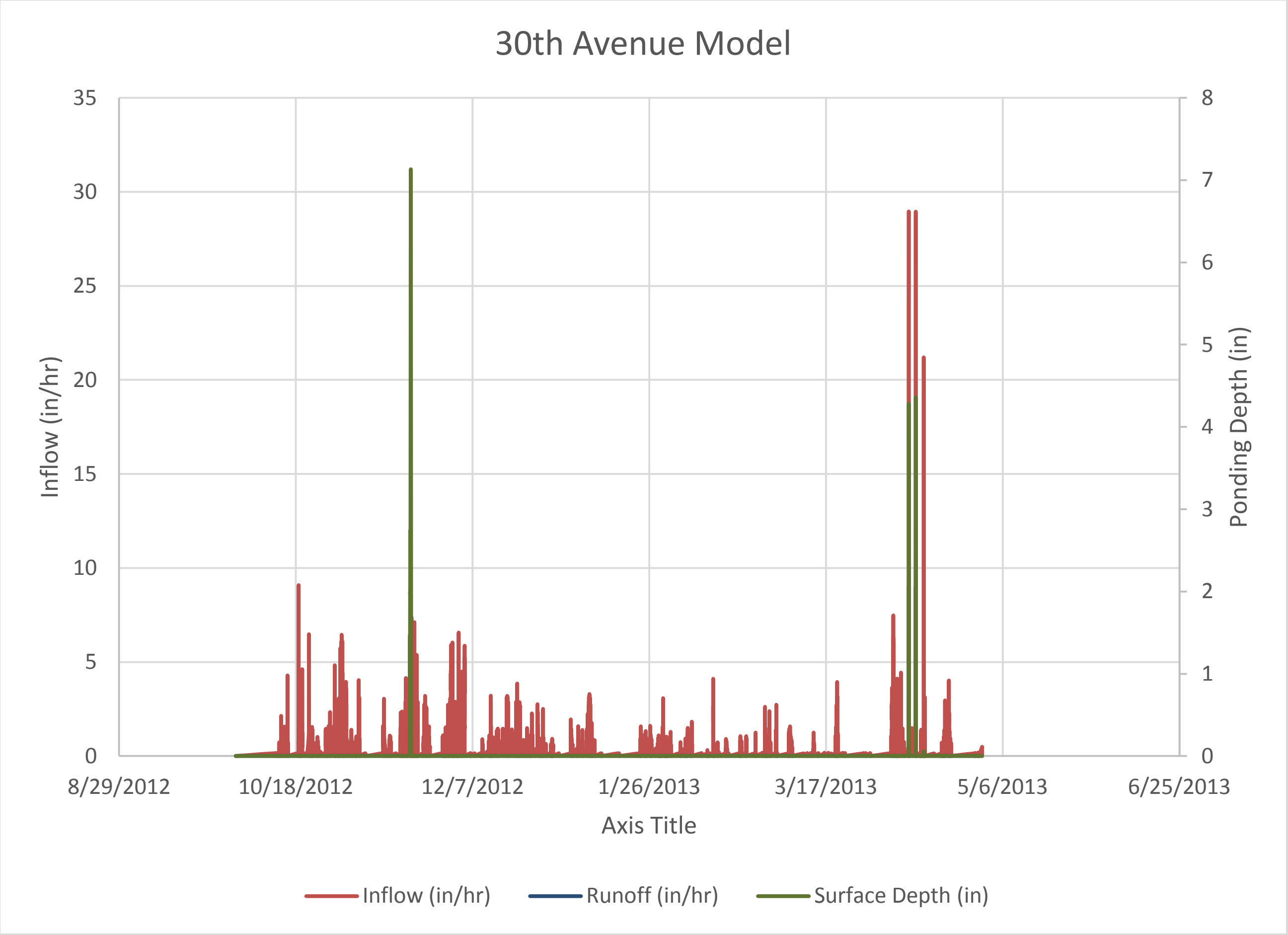


Figure B-6. 30th Avenue Raingarden Model

28th Avenue Raingarden

The 28th Avenue raingardens were also added to the calibrated Ballard CSO model to simulate the performance during the wet season (October 1, 2012 to May 1, 2013), which included the April controlled flow tests. As for the 30th Avenue raingarden modeling effort, the model was constructed based primarily on record drawings, personal communication with SPU technical staff, and parameters estimated from the monitoring data.

Table B-5. SWMM Model Parameters for the 28th Avenue Raingarden			
Parameter	**Value**	**Unit**	**Source, Notes**
Tributary Area	8200	sf	(M. Lo, personal communication, various dates 2011)
Bioretention Soil Infiltration Rate	12	in/hr	Monitoring Data (see below)
Native Soil Infiltration Rate	0.25	in/hr	Rough Calibration
Ponding Depth	1	in	Design is 0 but necessary for model stability
Porosity	0.4	ft/ft	(Rawls et al. 1998)
Field Capacity	0.13	ft/ft	(Rawls et al. 1998)
Wilting Point	0.05	ft/ft	(Rawls et al. 1998)
Bioretention Soil Depth[a]	5	in	Needed for model stability
Storage Depth	36	in	Maintain head on outlet orifice
Void Ratio (Storage)	0.16	ft/ft	Calculated, ~50% of eff. Porosity of Bioretention Soils
Drain Coefficient	0.083	in/hr	Calculated conversion from standard orifice equation to SWMM coefficient (Rossman 2009)
Drain Exponent	0.5	–	Orifice equation
Basin Area	1.198	ac	Calibrated model
% Impervious	44.68%	–	Calibrated model
% of Impervious Mitigated	35%	–	Calculation
Average Area	875	sf	Sizing Factor: 10.7%

[a] Actual depth is 42 in (Ballard Roadside Raingardens, Phase 1 Record Drawing, Sheet 23, July 5, 2012); however, for the model to simulate the underdrain flow correctly, this must be included in the storage depth layer.

Due to limitations in SWMM, model geometry is simplified to a vertical walled facility by calculating an effective footprint based on the total potential inundated depth (total depth from orifice to overflow riser plus an estimation of additional upstream ponding due to intermediate orifices). To maintain the approximate relationship of head on the outlet drain, the majority of storage is modeled as an underlying storage zone with an effective porosity equal to 50 percent of the bioretention soil.

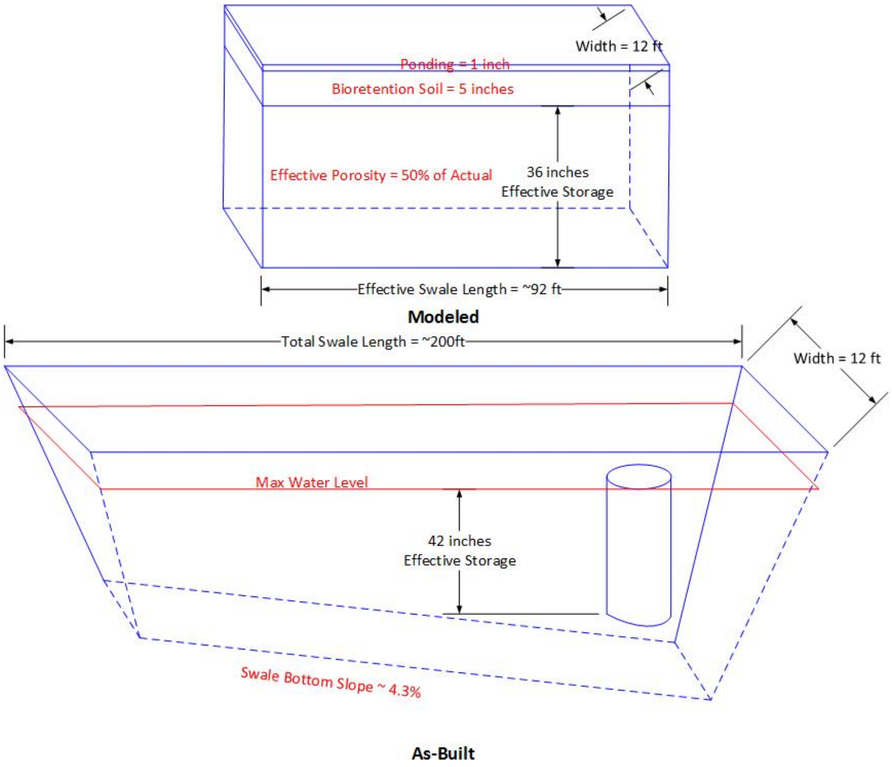


Figure B-7. Simplified Raingarden Cell Geometry for SWMM Model

Rough Calibration: 28th Avenue Raingarden

Qualitative evaluation of the simulation results indicates that the rough calibration is reasonable for most storms close to the control target of the 1-year recurrence interval. It appears that the model underestimates during the larger flow events (November 19, 2012 storm and April controlled tests), which is likely due to inability to account for additional storage in the bioretention soils due to intermediate orifices upstream. During larger events it is assumed that additional runoff is stored in the full length of the swale rather than just the downstream portion retained by the control structure in MH 4. See Figures B-8 through B-14 below.

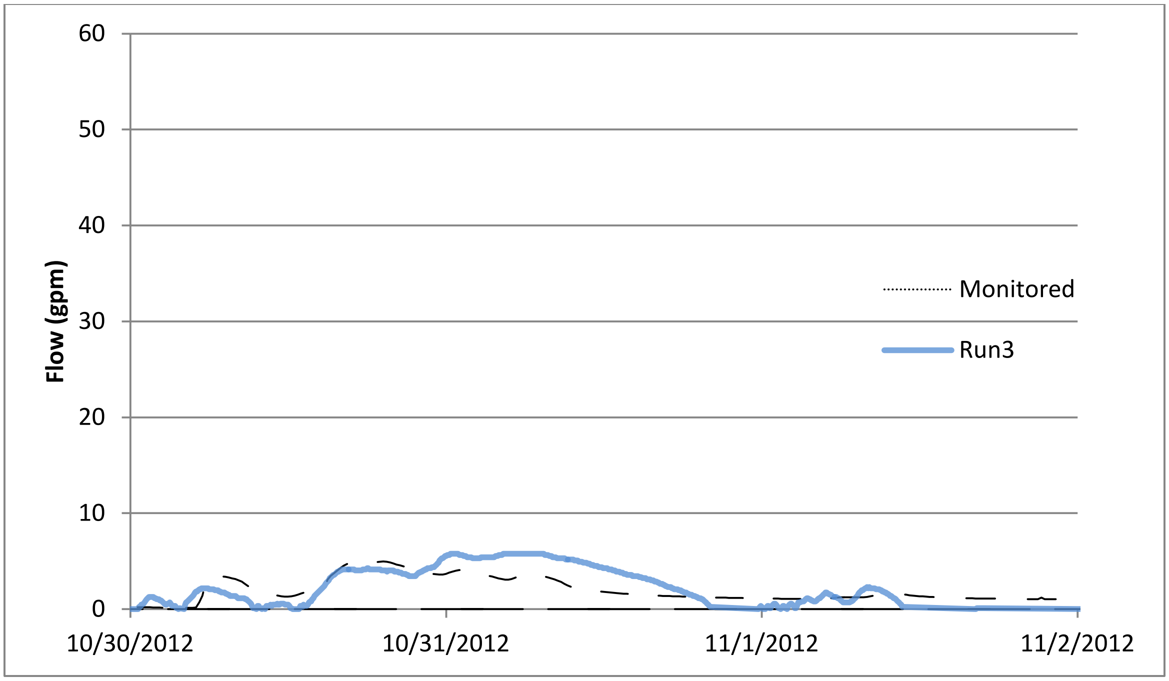


Figure B-8. Model Calibration, Event 1 (4.51 MG Overflow)

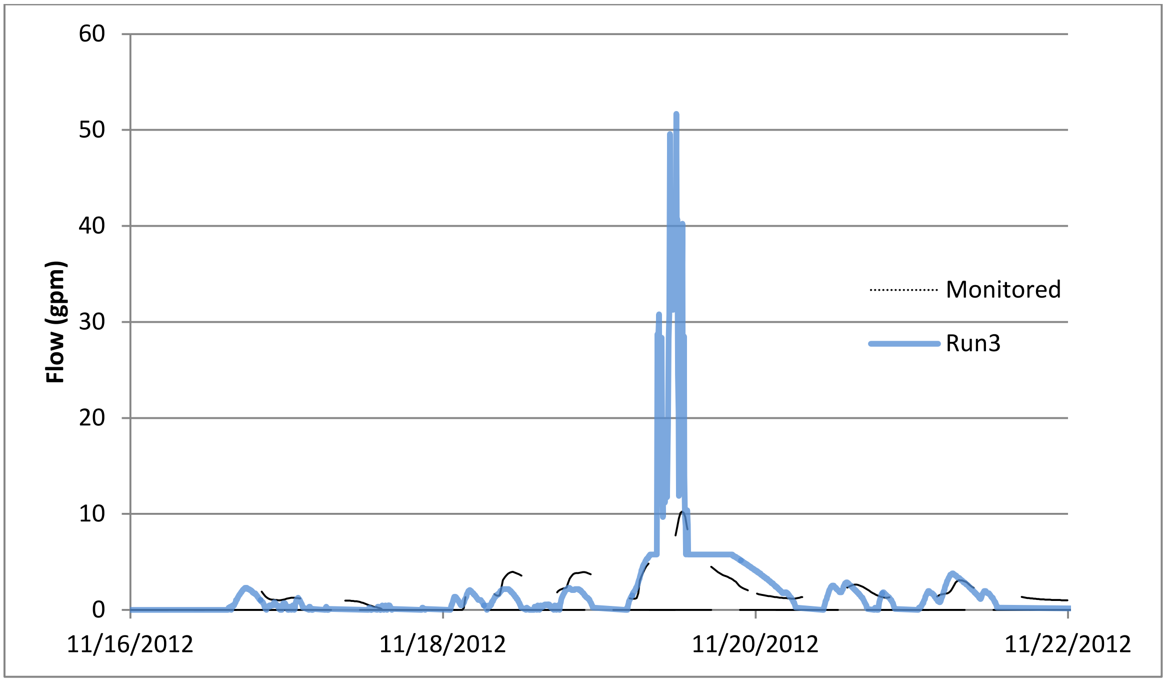


Figure B-9. Model Calibration, Event 2 (15.24 MG Overflow)

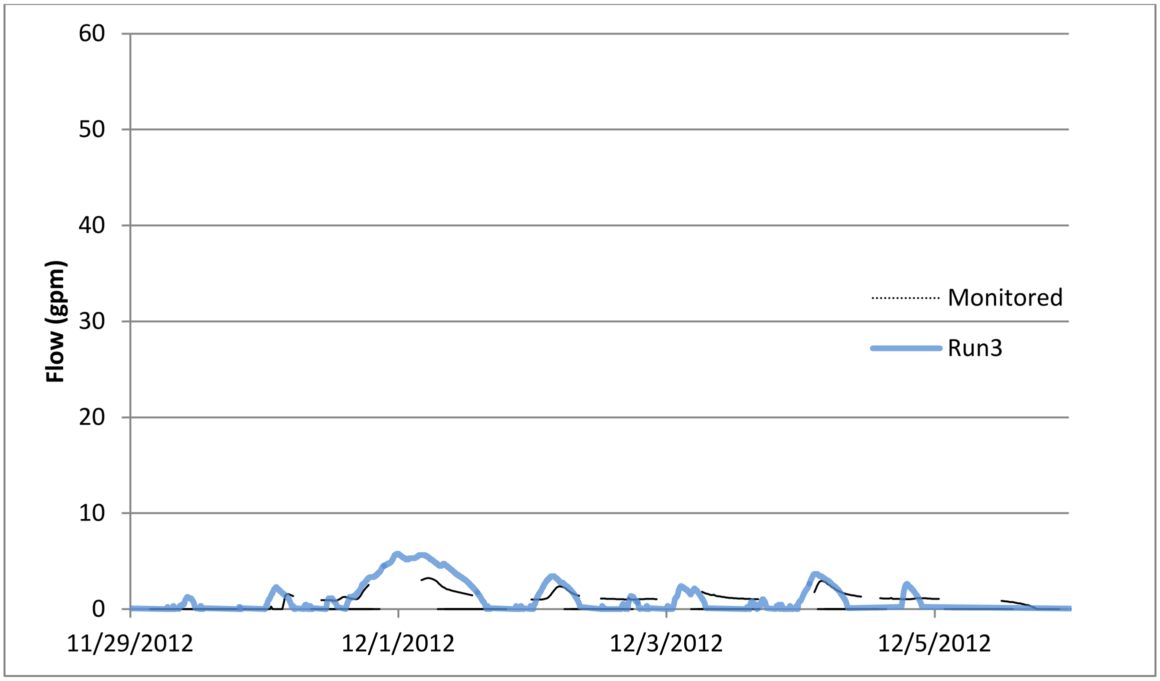


Figure B-10. Model Calibration, Event 3 (7.16 MG Overflow)

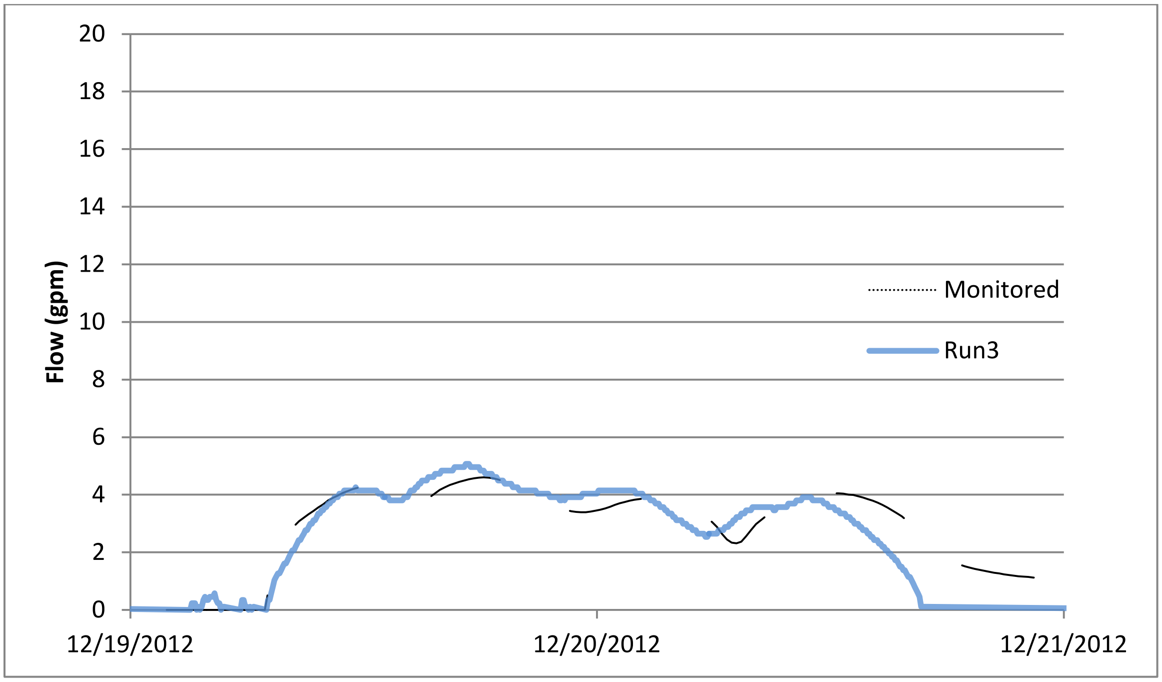


Figure B-11. Model Calibration, Event 4 (5.52 MG Overflow)

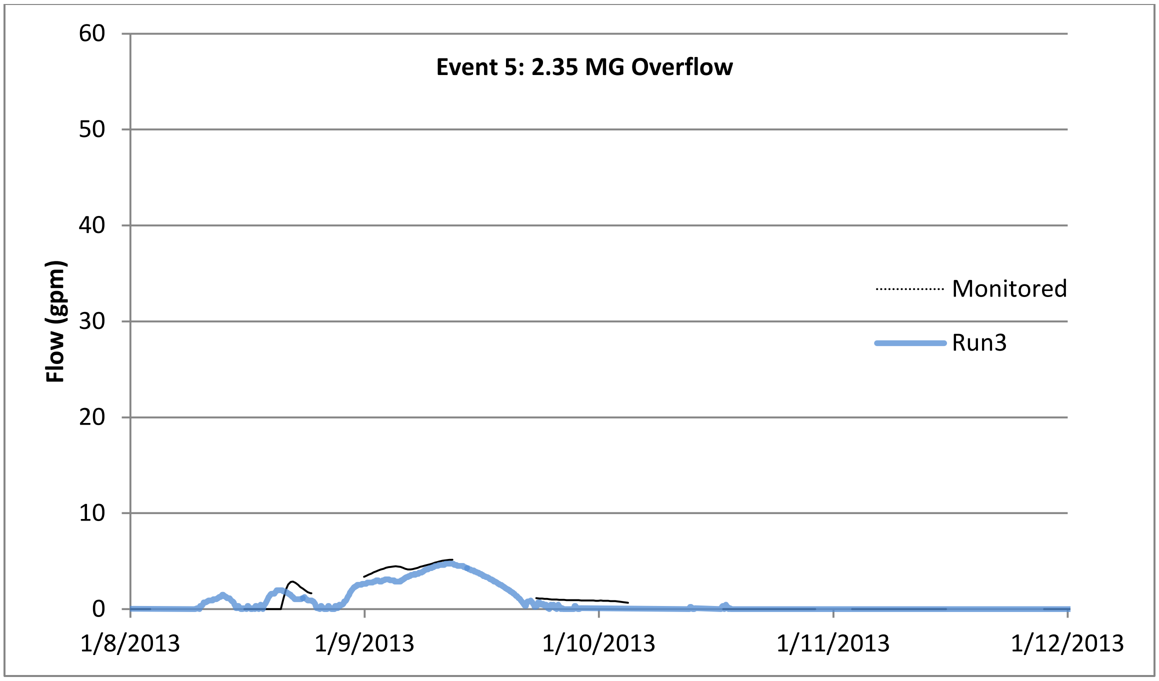


Figure B-12. Model Calibration, Event 5 (2.35 MG Overflow)

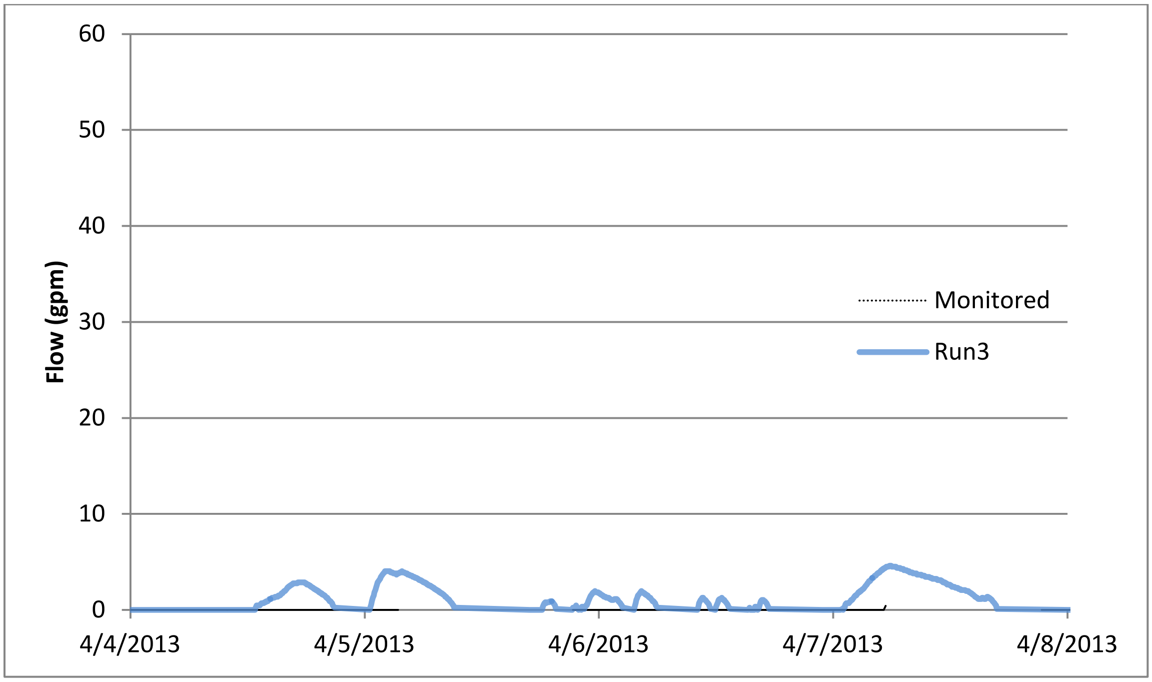


Figure B-13. Model Calibration, Event 6 (2.75 MG Overflow)

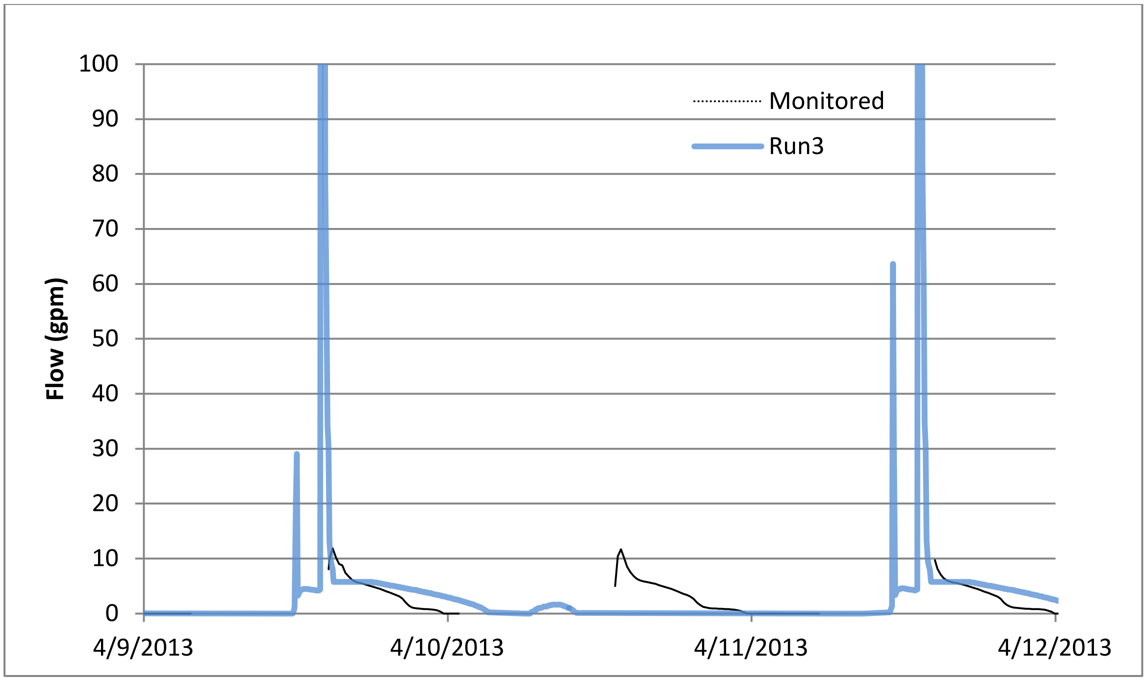


Figure B-14. Simulated Storm Test (With Inter-Event Saturation)

Infiltration Rates

Native Soil

The native soil infiltration rate for the 30th Avenue raingarden was estimated by calculating the rate of drop of surface ponding at the end of the controlled flow tests in September 2012 and April 2013 when the underlying bioretention soils are saturated and drawdown is controlled by the underlying native soils. This estimated infiltration rate is 3 to 7 in/hr.See Figures B-15 through B-17 below.

The native soil infiltration rate for the 28th Avenue raingarden is estimated through the rough modeling effort and the parameter that was necessary to match the monitoring data, approximately 0.25 in/hr.

Bioretention Soil

The infiltration rate of bioretention soil is estimated by measuring water level drop over time after the initial inflow during the controlled flow test, where the underlying soils are not saturated and infiltration is assumed to be controlled by the bioretention soil alone rather than the underlying native soils. Due to the high rate calculated, it is difficult to evaluate at other times during the continuous monitoring testing as it appears that the inflow rate is often less than the infiltration capacity of the bioretention soils and ponding was rarely measured without saturation from the bottom of the bioretention soils.

Soil Storage Volume

Soil storage volume was measured as the ratio of water level drop measured above the surface of the bioretention soils and measured below the soil surface.

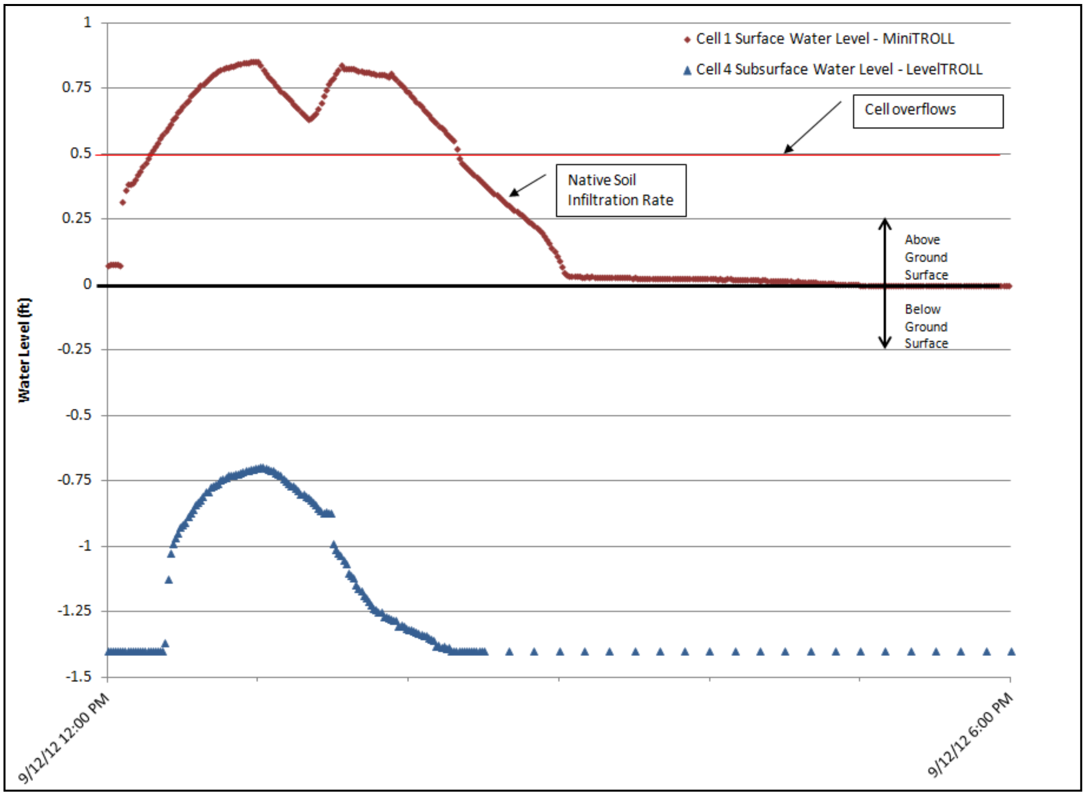


Figure B-15. September 12, 2012 Controlled Flow Test at the 30th Avenue Raingarden – Infiltration

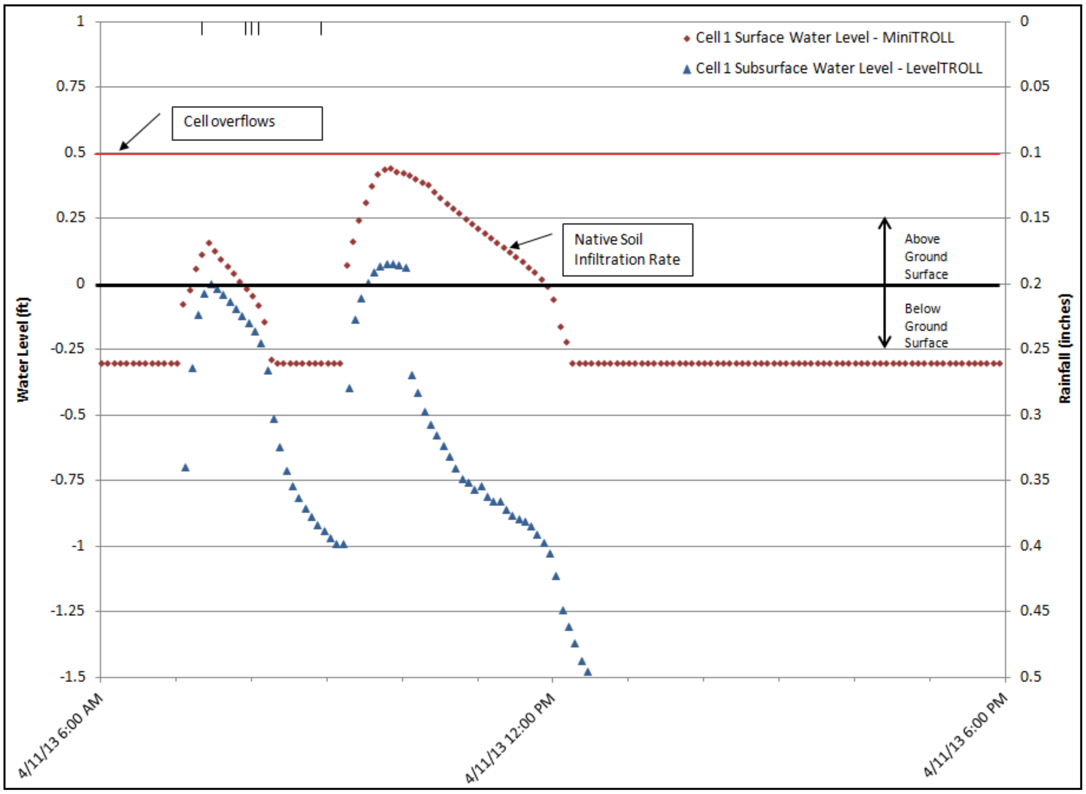


Figure B-16. April 11, 2013 Controlled Flow Test at the 30th Avenue Raingarden – Infiltration

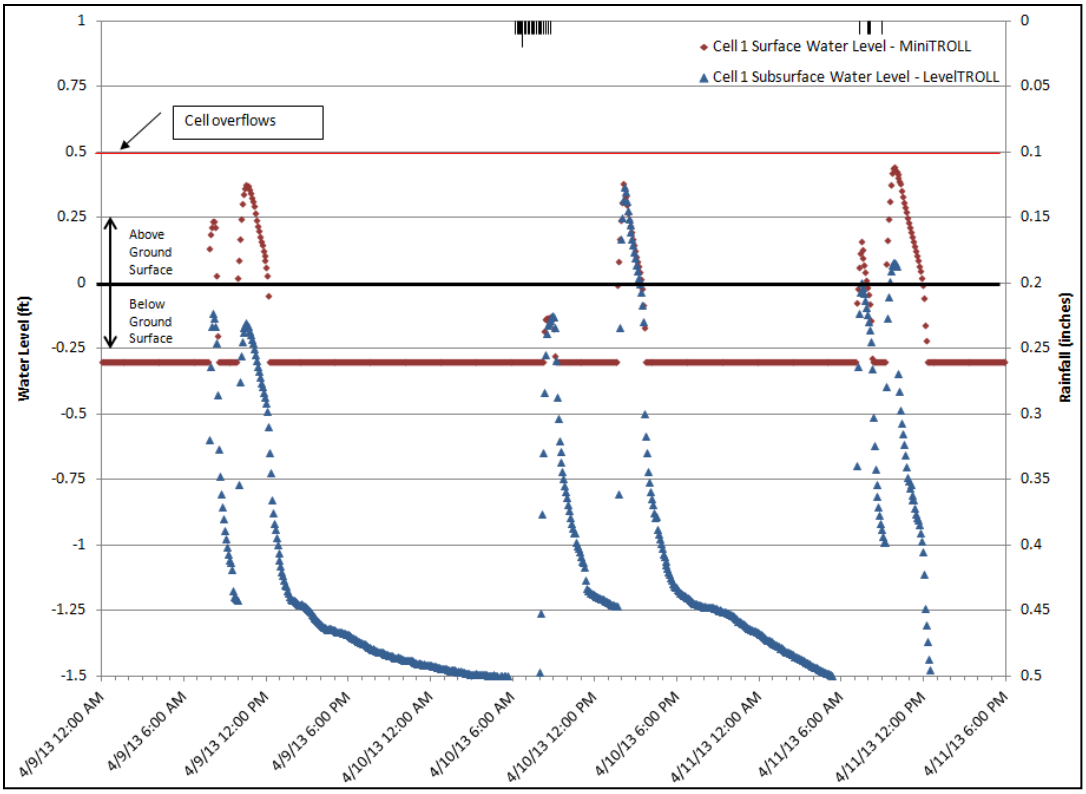


Figure B-17. April 2013 Controlled Flow Test at the 30th Avenue Raingarden – Infiltration

References

MGS Engineering Consultants, Inc. 2003. *Analyses of Precipitation-Frequency and Storm Characteristics for the City of Seattle.* Prepared for Seattle Public Utilities. December.

Rawls, W. J.; D. Giménez; and R. Grossman. 1998. *Use of soil texture, bulk density, and the slope of the water retention curve to predict saturated hydraulic conductivity*. Transactions American Society of Agricultural Engineers 41(4):983-988.

Rossman, Lewis A. *Storm Water Management Model User's Manual – BMP/LID Extensions.* Version 5.0. October 2009. United States Environmental Protection Agency.

Rossman, Lewis A. *Storm Water Management Model User's Manual* Version 5.0. July 2010. United States Environmental Protection Agency.

Seattle Public Utilities (SPU). 2009. *Stormwater Manual Vol. 3 Stormwater Flow Control & Water Quality Treatment Technical Requirements Manual.* 2009-005 SPU. November 2009.

Seattle Public Utilities
King County

Green Stormwater Infrastructure

Working Together to Protect our Waterways

Attachment C: Ballard Roadside Raingardens Field Monitoring Notes

Ballard Roadside Raingardens
Flow Test Field Data Sheet
Site: 30th Ave NW (west side) at NW Loyal
Test Date: 9/11/2011
Test Type: UNSATURATED - DAY 1

0735 - SEND 154gpm
~2 MINUTES TO ~35gpm
EAST SIDE.
INTO INLET | BYPASSED
SWALE.

Modified Low Intensity Event

		21075	
Elapsed Time	START Actual Time (PST)	Target Flow (gpm)	Actual Flow (gpm)
0:00	0930	20	20.1
0:05	0935	20	20.1
0:10	0940	82	82
0:15	0945	41	41
0:20	0950	31	31
0:25	0955	0	0
0:30	1000	0	0
0:35	1035	0	0
1 1/2 HOUR BREAK IN FLOW			
2:05	~~1135~~ 1140	41	41
2:10	1145	61	60
2:15	1150	114 ~~113~~ ~~82~~	114
2:20	1156	144 ~~133~~ ~~103~~ ~~82~~	144
2:25	1200	155 ~~144~~ 155 ~~82~~	155
2:30	1205	51 ~~61~~ 82	51
2:35	1210	31 ~~41~~ ~~61~~	31
2:40	1215	21 ~~31~~ ~~41~~	21
2:45	1220	10 10	10
2:50	1225	10	10
2:55	1230	5	5
3:00	1235	5	5
3:05	1240	5	5
3:10	1245	5	5
3:15	1250	5	5
3:20		~~5~~	STOP
3:25		5	
3:30		5	
3:35		5	
3:40		5	
3:45		5	
3:50		5	
3:55		5	
4:00		5	
4:05		5	
4:10		5	
4:15		5	
4:20		5	

→ 3RD INLET
5TH INLET

→ TO 3RD INLET
5TH INLET
7TH (LAST) INLET) PONDING IN FIRST CELL
BYPASS!! @150gpm

STOP TEST @ 1255

City of Seattle
Seattle Public Utilities

DAILY FIELD REPORT

FLOW TEST DAY 1

Page 1 of 3

Project BALLARD ROADSIDE RAIN GARDENS
Project No.
Location 30TH AVE NW @ LOYAL
Date 9/11/2012
Subject FLOW TESTING
By DJH

BACKGROUND - WILL PERFORM 3 DAYS OF SIMULATED FLOW TESTING AT EACH RAINGARDEN DAY 1 = DRY CONDITION TEST, DAY 2 = SATURATED CONDITION TEST, DAY 3 = PRE CONSTRUCTED TEST (PLUG INLETS)

0700 PST (ALL TIMES IN PST!!) DJH ARRIVES. ZUK/CAM OF METER SHOP PRESENT. DUSTIN OF CH$_2$M ARRIVES. LIZ (?) OF BALLARD STORMWATER ARRIVES

0735 PST - DO MOCK TEST ON EAST SIDE OF STREET TO SEE WHAT 154 gpm LOOKS LIKE. WE FLOW FOR ~2 MINUTES WATER ENTERS ALL CUTS AND ~30% SLIPS TO SEWER (THIS PULSE NEEDS TO BE CUT FROM FLOW RECORD). ALTHOUGH WE WILL DEFINETLY SEE SLIPPAGE, DUSTIN + I DECIDE TO STAY WITH ORIGINAL STORM.

0810 - CLAIRE + INTERN (GRANT) ARRIVE TO INSTALL SURFACE PIEZO

* DUSTIN DECIDES TO SWITCH TO MODIFIED EVENT TO LIMIT SLIPPAGE TO SEWER

Attachments

City of Seattle
Seattle Public Utilities

DAILY FIELD REPORT

Page 2 of 3

Project BALLARD ROADSIDE RAIN GARDENS

Project No.

Location 30TH AVE NW @ LOYAL

Date 9/11/2012

Subject

By DJH

M.T.L IS HAVING TROUBLE COMMUNICATING WITH THE BURIED LEVEL MONITOR. BY 0925 PST, CLAIRE TELLS ME TO START TEST AND THEY WILL KEEP TRYING

0930 PST - BEGIN FLOW @ 20gpm USING "MODIFIED LOW INTENSITY EVENT

AFTER 10 MINUTES OF FLOW, @ 20 gpm, WATER MAKES IT 3RD INLET

@ 82 gpm (PEAK) FLOW MAKES IT AS FAR AS 5TH INLET BUT NO BYPASS.
NO PONDING.

LULL FOR TWO HOURS

1140 RESUME FLOW

NEED TO INCREASE TO 150 gpm TO SEE BYPASS SO 150gpm IS INLET CAPACITY

MAX. PONDING ~3" IN CELLS

Attachments

City of Seattle
Seattle Public Utilities

DAILY FIELD REPORT

Page 3 of 3

Project

Project No.

Location

Date

Subject

By DJH

INFILTRATION TESTING

CELL 3 (NO INFLOW) PLACE ~~PIEZO~~ LEVEL MONIT
IN @ 1222 (DRY BY ~1225?)

CELL 1 PLACE LEVEL MONITOR @ 1228 PS
LEVEL STARTS @ 2", FLOW @ 5gpm
(DRY BY MONITOR BY ~1235 gpm
(CELL 1 AREA = 5' x 20')

1315 - OFFSITE TO CHECK 28TH RAIN GARDEN

TESTED CAPACITY OF PIPE CONNECTED
TO 67TH INLET (DRAINS TO MH W/ BYPASS)
= 0 gpm !! IS PIPE PLUGGED OR CAPPED?
NO FLOW OBSERVED DAYLIGHTING OR TO UNDERDRAIN

INLET CAPACITY = 50 gpm (THEN BYPASS)

Attachments

City of Seattle
Seattle Public Utilities

DAILY FIELD REPORT

Page 2 of 2

Project BALLARD ROADSIDE RAINGARDENS Project No.

Location NW 30TH

Date 9/12/2012

Subject FLOW TEST - DAY 2

By DJH

1205 - BEGIN "STRESS TEST" = FLOODING ALL CELLS

FLOW AT 100, 125, 150 gpm FOR FIVE MINUTES EACH

1233 = CELL 1 PONDING = 8" [illegible] NOT "FULL" BUT COULD BE AT EQUILIBRIUM)

1235 = CELL 4 PONDING = 5"

1238 = CELL 1 PONDING = 8.5"

1243 = CELL 4 PONDING = 6"

1245 - CELL 1 PONDING 9.25"

1247 - CELL 1 FILLS FINALLY!

1252 CELL 4 PONDING 6"

1300 - STOP STRESS TEST

1320 BEGIN CELL 1 CAPACITY TEST

PONDING = 7" AT START OF CAPACITY TEST

1329 PONDING = 8.6", 1334 PONDING = 9.25"

CELL 1 CAPACITY = $\boxed{20\text{gpm}}$ (20 gpm)

1351 - STOP FLOW FOR DAY

Attachments

City of Seattle
Seattle Public Utilities

DAY 2

ALL TIMES IN P.S.T.

DAILY FIELD REPORT

Page 1 of 2

Project BALLARD ROADSIDE RAIN GARDEN

Project No.

Location 30TH AVE NW

Date 9/12/2012

Subject FLOW TEST DAY TWO

By DJH

SCOPE - WILL ATTEMPT TWO TESTS TODAY: ① "SATURATED" TEST - USING SAME FLOW RATES AS YESTERDAY, ② "STRESS TEST" - AFTER DRAINING FOR ONE HOUR, WILL INCREASE FLOW UNTIL ALL CELLS FULL + OVERFLOWING

0700 PST - DJH ARRIVES. ZUK/CAM FROM METER SHOP + GRANT FROM M.T.L. JUST ARRIVED

WE WAIT FOR GRANT TO PROGRAM LOGGERS. HE PUTS ONE IN LOWEST POINT OF FIRST (SOUTH) CELL

0720 - BEGIN FLOW @ 20 gpm

0745-925 PST LULL

WE TEST BLOCKING INLETS ON EAST SIDE - NO WATER TO SEWER

0925-1039 - FINISH TEST 1

1040-1200 WRAP UP + OFF TO LUNCH

Attachments

Ballard Roadside Raingardens
Flow Test Field Data Sheet
Site: NW 30TH AVE @ LOYAL (WEST RAIN GARDEN)
Test Date: 9/12/2012 (DAY 2)
Test Type: SATURATED (?) - 2ND DAY USING SAME FLOW AS DAY 1

The 9/11 Storm = Actual Rates Used on Day 1

Elapsed Time	Actual Time (PST)	Target Flow (gpm)	Actual Flow (gpm)	Notes
0:00	0720	20	20	
0:05	0725	20	20	TO 3RD INLET, 2" PONDING CELL 1
0:10	0730	82	82	TO 6TH INLET, 2.75" PONDING CELL 1
0:15	0735	41	41	BACK TO 4TH INLET, UP TO 1" IN CELL 2+3
0:20	0740	31	31	
0:25	0745	0	0	
0:30	0750	0	0	
0:35	0755	0	0	
1 1/2 HOUR BREAK IN FLOW				
2:05	0925	41	41	TO 5TH INLET, 3" CELL 1
2:10	0930	61	61	
2:15	0935	114	114	
2:20	0940	144	144	BARELY BYPASSES TO INLET,
2:25	0945	155	155	6" PONDING CELL 1, CELL 3 FULL!
2:30	0950	51	51	
2:35	0955	31	31	
2:40	1000	21	21	
2:45	1005	10	10	
2:50	1010	10	10	
2:55	1015	5	↓	
3:00	1020	5		
3:05	1025	5		
3:10	1030	5		
3:15	1035	5		
	STOP 1039			

Comments:

Ballard Roadside Raingardens
Flow Test Field Data Sheet
Site: 30TH NW AVE @ LOYAL
Test Date: 9/12/2012
Test Type: STRESS TEST

Ad Hoc Storm

Elapsed Time	Actual Time (PST)	Actual Flow (gpm)	Notes
0:00	1205	100	FLOW TO 6TH INLET, 3" PONDING C1
0:05	1210	125	
0:10	1215	154	BYPASS TO INLET STARTS ~ 1211
0:15	1220	154	THIRD CELL FILLS ~1215
0:20	1225	154	~1228 2ND CELL FILLS
0:25	1230	154	
0:30	1235	154	
0:35	1240	154	1242 - CELL 4 FILLS
0:40	1245	154	1247 CELL 1 FILLS
0:45	1250	154	
0:50	1255	154	
0:55	1300	0	STOP TEST
1:00			
1:05			
1:10			
1:15			
1:20	CELL	1	CAPACITY TEST
1:25	1320	25	PONDING 7" AT START OF TEST
1:30	1323	50	(OVER CELL 1 CAPACITY)
1:35	1330	40	40 gpm STILL TOO HIGH
1:40	1332	30	30 STILL TOO HIGH
1:45	1338	22	22 STILL TOO HIGH
1:50	1344	18	TOO LOW. SAY 20 gpm
1:55	1351	0	STOP TEST
2:00			
2:05			
2:10			
2:15			
2:20			
2:25			
2:30			
2:35			
2:40			
2:45			
2:50			
2:55			

Comments:

Ballard Roadside Raingardens
Flow Test Field Data Sheet
Site: 30TH AVE NW @ LOYAL (WEST SIDE)
Test Date: 9/13/2013
Test Type: PRE-CONSTRUCTION (INLETS BLOCKED)

The 9/11 Storm = Actual Rates Used on Day 1

Elapsed Time	Actual Time (PST)	Target Flow (gpm)	Actual Flow (gpm)	Notes
0:00	0755	20	20	NO LEAKAGE
0:05	0800	20	20	NO LEAKAGE
0:10	0805	82	82	"
0:15	0810	41	41	"
0:20	0815	31	31	"
0:25	0820	0	–	
0:30	0825	0	–	
0:35	0830	0	–	
1 1/2 HOUR BREAK IN FLOW				
2:05	1000	41	41	NO LEAKAGE!
2:10	1005	61	61	↓
2:15	1010	114	114	
2:20	1015	144	144	
2:25	1020	155	~~155~~ 157	
2:30	1025	51	51	
2:35	1030	31	31	
2:40	1035	21	21	
2:45	1040	10	10	
2:50	1045	10	10	
2:55	1050	5	5	
3:00	1055	5	5	
3:05	1100	5	5	
3:10	1105	5	5	
3:15	1110	5	5	↓

Comments: NO LEAKAGE ~~UNTIL~~ THROUGH WHOLE TEST.

City of Seattle
Seattle Public Utilities

DAILY FIELD REPORT

DAY 3 - PRECONSTRUCTION

Page 1 of 1

Project BALLARD ROADSIDE RAINGARDEN
Location ~~NW~~ 30TH AVE NW
Subject DAY 3 TESTING
Project No.
Date 9/13/2012
By DJH

SCOPE - PERFORM PRE-CONSTRUCTION FLOW TEST BY BLOCKING INLETS AND RUNNING SAME FLOW FROM 9/11 DAY.

0730 PST - DJH ARRIVES. ZUK + CAM ONSITE AND INLETS BLOCKED WITH SAND BAGS

0755 - PST BEGIN FLOW TEST. ZERO LEAKAGE INTO RAINGARDEN AT 20gpm.

EVEN AT FIRST PULSE PEAK OF 82 gpm THERE IS NO LEAKAGE!

1000 - 1115 - 2ND HALF OF FLOW TEST. NO LEAKAGE INTO ANY CELL!

1115 - STOP TEST

Attachments

City of Seattle
Seattle Public Utilities

DAILY FIELD REPORT

SPRING TEST - DAY 1

ALL TIMES IN P.S.T.

Page 1 of 3

Project BALLARD ROAD SIDE RAIN GARDENS
Project No.
Location NW 30TH + NW 28TH RAIN GARDENS
Date 04/09/2013
Subject DAY 1 FLOW TESTS
By DJH

BACKGROUND - FIRST DAY OF "WET" WEATHER SIMULATED FLOW TESTING, OR ROUND 2 FOLLOWING ROUND 1 IN SEPTEMBER. LAST THURS → SUNDAY, REC'D 2" + OF RAIN.

0700 PST - DJH ARRIVES @ NW 30TH @ LOYAL DUSTIN OF CH2M + CAM + ZAK OF SPU METER SHOP ARRIVE SHORTLY.

I INSTALL A 6" Ø PVC PIPE ABOUT 0.8FT BELOW SURFACE OF DOWNSTREAM END OF CELL 3 FOR SHALLOW OBSERVATIONS.

0740 - START FLOW

0750 - AT 82 GPM, SOME FLOW BREAKS TO EAST AND DOESN'T GO TO W. SWALE SO WE INCREASE ACTUAL FLOW TO 92 gpm TO TRY TO GET 82 gpm INTO SWALE

0810-0910 OFFSITE DURING LULL IN TEST

0950 PST - RESUME FLOW

* CELL 3 FILLS SINCE INLET A (5) CAPTURES FLOW SO WELL

~~1200 - STOP TEST AT 30M~~ DJH 4/9/13

Attachments

City of Seattle
Seattle Public Utilities

DAILY FIELD REPORT

Page 2 of 3

Project BALLARD ROADSIDE RAIN
Location
Subject DAY 1 - UNSATURATED TEST
Project No.
Date 04/09/2013
By DJH

1027 PST - FLOW INSIDE CELL 3 WELL BEGINS TO DROP AND STILL ~6" BELOW SOIL SURFACE

1100 PST - STOP TEST AT 30TH

1115 - ARRIVE AT NW 28TH/67TH NO FLOW AT ADS MONITOR IN OUTLET MH.

1150 - PST - START TEST: PLACE SAND BAGS DOWNSTREAM OF EACH INLET TO DIVERT MORE FLOW INTO SWALE.

DID MUCH BETTER JOB OF KEEPING ALL FLOW AGAINST WEST CURB AND INTO SWALE (ONLY TRICKLE WENT INTO STORM INLET) THAN COMPARED TO SEPT 2012 TEST FOR FIRST HALF OF STORM (UP TO 210 GPM)

1215 - 1315 PST - OFFSITE DURING LULL

1355 RESUME TEST. UNDERDRAINS IN 2ND + 3RD DOWNSTREAM MHs NEVER STOPPED FLOWING IN 1.5 hr LULL

Attachments

City of Seattle
Seattle Public Utilities

DAILY FIELD REPORT

DAY 1 - UNSATURATED

Page 3 of 3

Project BRRG

Project No.

Location 28TH + 30TH NW RG.S

Date 4/9/13

Subject DAY 1 FLOW TEST

By DJH

1437 - FIRST FLOW LEAVES V-NOTCH WEIR IN RISER PIPE IN MH4

1505
~~1520~~ - STOP TEST

1517 - OFFSITE

Attachments

Ballard Roadside Raingardens
Flow Test Field Data Sheet
Site: 30th Ave NW (west side) at NW Loyal
Test Date: 04/09/2013
Test Type: "UNSATURATED" - DAY 1

9/11/2012 - Actual rates used

Elapsed Time	Actual Time (PST)	Target Flow (gpm)	Actual Flow (gpm)
0:00	0740	20	20
0:05	0745	20	20
0:10	0750	82	~82 EFFECTIVE/92
0:15	0755	41	41
0:20	0700	31	31
0:25	0805	0	0
0:30	0810	0	0
0:35	0815	0	0
1 1/2 HOUR BREAK IN FLOW			
2:10	0950	41	42
2:15	0955	60	59
2:20	1000	114	114
2:25	1005	144	139
2:30	1010	155	155
2:35	1015	51	51
2:40	1020	31	31
2:45	1025	21	21
2:50	1030	10	10
2:55	1035	10	10
3:00	1040	5	
3:05	1045	5	
3:10	1050	5	
3:15	1155	5	
3:20	1100	STOP	

0741 - FLOW TO 3RD INLET

- LOSE ~10 GPM TO EAST

TO C.S.

1006 - FIRST FLOW TO INLET #

1012 - MINOR BYPASS OF INLET TO CSS

1014 - CELL 3 FULL!

1020 - FLOW STOPS AT INLET ~~BUT STILL~~

1028 - FLOW ENTERING CELL H

Comments:

0741 FLOW TO 3RD INLET (CELL 2)
0742 - FLOW TO 4TH INLET (CELL 2)
0744 - ~1/2" PONDING IN CELL 1
0753 - FLOW TO 6TH INLET - CELL 3
0756 - PONDING IN CELL 2 ~1"
0756 - FLOW AT SURFACE OF PIPE IN CELL 3, BUT NONE IN INTERFLOW
0951 - FLOW AT INLET A (3) OF CELL 2
0952 - FLOW AT INLET A (5) CELL 3 - BEST INLET
0956 - PONDING IN CELL 2
1000 - FIRST SURFACE FLOW AT OBSERVATION PIPE IN CELL 3
1001 - FLOW INTO INLET B (7) - CELL 3
1002 - FLOW INTO INLET A (8) - CELL 4
1003 - FIRST FLOW INTO OBSERVATION WELL CELL 3

Ballard Roadside Raingardens
Flow Test Field Data Sheet
Site: 28th Ave NW (west side) at NW 66th St
Test Date: 4/9/2013
Test Type: "UNSATURATED - DAY 1

9/14/2012 - Actual rates used

		21075	
Elapsed Time	Actual Time (PST)	Target Flow (gpm)	Actual Flow (gpm)
0:00	1150	53	53
0:05	1155	53	53
0:10	1200	210	203
0:15	1205	105	113
0:20	1210	79	
0:25	1215	0	
0:30	1220	0	
0:35	1225	0	
1 1/2 HOUR BREAK IN FLOW			
2:05	1355	105	105
2:10	1400	158	157
2:15	1405	294	294
2:20	1410	350	350
2:25	1415	350	350
2:30	1420	200	200
2:35	1425	79	79
2:40	1430	53	53
2:45	1435	26	26
2:50	1440	26	26
2:55	1445	13	13
3:00	1450	13	13
3:05	1455	13	13
3:10	1500	13	13
3:15	1505	STOP	

1155 - FLOW TO 4TH INLET
1201 - FLOW TO LAST INLET
~1255 (BEFORE SEWER
↳ FIRST SURFACE FLOW AROUND 4TH INLET

1404 - FLOW EXITS SUBSURFACE
1413 - FLOW TO LAST CURB
↳ FLOW EXITING SECOND TO LAST CELL

Comments: Rates adjusted based on 09142012 test. 350 gpm was max rate possible without excessive flow to east side of 28th. USE SAND BAGS TO TRY TO INCREASE INLET CAPACITY

*1416 - FLOW ENTERS INLET TO STORM DRAIN - ABUNDANT FLOW LEAVING 2ND TO LAST CELL

1423 - ESTIMATE FLOW AT OUTLET FLOW METER AS ~1 gpm

*1437 - OVERFLOW OUT MH4 RISER'S V-NOTCH WEIR

City of Seattle
Seattle Public Utilities

DAILY FIELD REPORT

(NON-TEST DAY)

Page 1 of 2

Project BALLARD ROAD SIDE RAIN GARDENS Project No.

Location

Date 4/10/2013

Subject 28TH INLET TEST, SATURATATION By DJH

BACKGROUND - RAIN THIS MORNING - 0.22" FROM ~ 0600 - 1100 PST - CANCELLED FLOW TESTING. THIS AFTERNOON, THE GOAL IS TO: 28TH → ① DETERMINE INLET CAPACITY, ② DETERMINE IF 6" PIPE IN N. MH IS OPEN TO SWALE BY ADDING FLOW TO 67TH ST INLET ③ FLOODING SWALE TO SATURATE; AND 30TH - SATURATING FOR TOMORROW'S TEST.

1100 PST - DJH ARRIVES AT 28TH R.G. ZUK + CAM HERE

② - 6" PIPE TEST - WATER LEVEL ~4" BELOW WEIR IN FLOW CONTROL M.H. AND 6" PIPE IS COMPLETELY SUBMERGED INDICATING THIS PIPE IS STILL PLUGGED. WE ADD FLOW UNTIL OVERTOPPING WEIR AND THEN BACK DOWN TO 1 gpm (LOWEST WE CAN RECORD) AND STILL HAVE ~1 gpm OVER WEIR. CONCLUSION - PIPE IS STILL PLUGGED BUT COULD BE PLUGGED WITH DEBRIS

① 28TH INLET TEST RUN FLOW DOWN CURB TO TEST INLET

Attachments

City of Seattle
Seattle Public Utilities

DAILY FIELD REPORT

ALL TIMES IN P.S.T.

NON TEST DAY

Page 2 of 2

Project B.R.B.G

Project No.

Location

Date 4/10/2013

Subject INLET CAPACITY + SATURATION TEST By DJH

PST

~~1307~~ 1207-1208 - RUN 300 gpm BYPASSES ALL INLETS IN LESS THAN ONE MINUTE

1211-1213 - RUN 100 gpm - BYPASSES IN 90 SECS

1218-1220 - RUN 75 gpm - BYPASSESS ALL IN ~90 SECS

1225-1230 - RUN 50 gpm, FINAL SWALE INLET RETAINS ALL FLOW! (BARELY) - 49 gpm WAS ACTUAL RATE

1230-1232 - RUN 55 gpm AND GET ~5 gpm BYPASS

* CONCLUSION - $\boxed{\text{INLET CAPACITY IS 50 gpm}}$

③ SATURATION OF 28TH

1233 - 1310 RUN 270 gpm INTO HEAD OF SWALE AT 67TH SIDEWALK

1249 - FIRST FLOW OUT OF UNDERDRAIN IN UPPER (NORTHERN) M.H.

1251 - FLOW VISIBLE IN ALL UNDERDRAINS

1310 - STOP FLOW AS WATER IS W/I 2½' OF TOP OF RISER PIPE IN MH-1 + RISING FAST. I ASSUME THE SWALE WILL BE FAR MORE SATURATED THAN COMPARED TO YESTERDAY

1330 - ARRIVE AT 30TH RAINGARDEN

1337-1402 RUN 167 gpm TO SATURATE. WATER IS PONDED IN ALL CELLS HIGHER THAN DURING YESTERDAY'S TE

1405 - OFFSITE

Attachments

City of Seattle
Seattle Public Utilities

DAILY FIELD REPORT

ALL TIMES IN PST

Page 1 of 3

Project BALLARD ROADSIDE RAIN GARDENS
Project No.
Location
Date 4/11/2013
Subject SATURATED TESTS
By DJH

0650 PST - DJH ARRIVES AT 30TH. CAM + ZUK ALREADY HERE + SETUP. LIGHT MIST BUT NO RUNOFF

0700 PST - START FLOW TEST. TYPE = SATURATED

0725 - STOP FOR FIRST LULL

~0715 - 0900 - STEADY DRIZZLE BUT NO RUNOFF BEST GUESS IS ~0.05" OR LESS FELL

0910 - RESUME 30TH FLOW TEST

* TOTAL INLET CAPACITY = $\boxed{\sim 135\,\text{gpm}}$ BYPASS TO SEWER AT 137 gpm. PREVIOUS THOUGHT CAPACITY WAS 150 gpm WHICH IS PROBABLY BEST CASE. WITH SOME HYDRAULIC DAMMING (BUT NO OUTFLOW) 135 gpm IS BETTER

1020 - STOP TEST NO DRIZZLE SINCE ~920.

1200 PST - START TEST AT 28TH USE SAND BAGS TO REDUCE FLOW BYPASSING INLETS

Attachments

City of Seattle
Seattle Public Utilities

DAILY FIELD REPORT

Page 2 of 3

Project BALLARD ROADSIDE

Project No.

Location

Date 4/11/2013

Subject

By DJH

BY ~1330 WATER IS FLOWING PAST INLET TO SEWER AND IS BEING LOST DOWN STREET

WE ALSO ~~LOOSE~~ LOSE ~10 gpm TO EAST SIDE

THE THELMAR WEIR IS BASICALLY BLOCKED BY SLUG OF LEAVES WHEN I CHECK ~1335. I REMOVE LEAVES WITH MH HOOK BUT FLOW DATA WILL BE POOR FOR UNKNOWN PERIOD. IN ADDITION, WATER IS INFILTRATING RAPIDLY INTO THIS M.H. LAST CELL IS COMPLETELY FULL AND DISCHARGING LOTS OF WATER.

EXTRA WATER LEAVING OR BYPASSING SWALE DUE, TO TWO REASONS (COMPARED TO TUESDAY). ① MORE SATURATED SOILS AND ② WE DIDN'T GET ENOUGH FLOW INTO FIRST SWALE AND PUT TOO MUCH INTO DOWNSTREAM CELLS

Attachments

City of Seattle
Seattle Public Utilities

DAILY FIELD REPORT

Page 3 of 3

Project B. RRG

Location

Subject

Project No.

Date 4/11/2013

By DJH

SUMMARY - TODAY'S 28TH TEST IS OF POOR QUALITY DUE TO SO MUCH UNMEASORED FLOW. WE CANCELLED TOMORROW'S TEST TO HAVE TIME TO REGROUP.

Attachments

Ballard Roadside Raingardens
Flow Test Field Data Sheet
Site: 30th Ave NW (west side) at NW Loyal
Test Date: 4/11/2013
Test Type: SATURATED

9/11/2012 - Actual rates used

Elapsed Time	Actual Time (PST)	Target Flow (gpm)	Actual Flow (gpm)	Notes
0:00	0700	20	20	0702-FLOW TO INLET A/CELL 2 (AS)
0:05	0705	20	20	
0:10	0710	82	84	0711-FLOW TO BOTH INLETS OF CELL 3
0:15	0715	41	41	0712-PONDING BEGINS IN CELL 2
0:20	0720	31	31	0718-FIRST WATER IN CELL 3 OBSERVE WELL
0:25	0725	0	0	
0:30	0730	0	0	
0:35	0735	0	0	
1 1/2 HOUR BREAK IN FLOW				
2:10	0910	41	41	0912-FLOW REACHES INLET 5-CELL 3/A
2:15	0915	60	60	0915-FIRST PONDING IN CELL 3
2:20	0920	* 114	~~119~~ 120	0922. FIRST H_2O IN CELL 3 OBSERVE WELL
2:25	0925	144	137	BYPASS TO SEWER! ~~*~~ ~0926
2:30	0930	155	156	~0928-CELL 3 FULL
2:35	0935	51	51	
2:40	0940	31	31	
2:45	0945	21	21	
2:50	0950	10	10	
2:55	0955	10	10	
3:00	1000	5	5	
3:05	1005	5	↓	
3:10	1010	5		
3:15	1015	5		
3:20	1020	STOP		

Comments: LIGHT DRIZZLE AFTER 0700 BUT NO RUNOFF
*@ 114 gpm - WATER IN INLET A OF CELL 4 BUT NO BYPASS YET
** TOTAL INLET CAPACITY ~ 135 gpm UNDER SATURATED CONDITIONS

AT END OF TEST, ~2" MAX PONDED IN CELL 1
COMPARED TO 3" IN CELL 3.

2x ~ APRIL TUES / WED 23, 24th

Ballard Roadside Raingardens
Flow Test Field Data Sheet
Site: 28th Ave NW (west side) at NW 66th St
Test Date: 4/11/2013
Test Type: SATURATED

9/14/2012 - Actual rates used

		21075	
Elapsed Time	Actual Time (PST)	Target Flow (gpm)	Actual Flow (gpm)
0:00	1100	53	52
0:05	1105	53	52
0:10	1110	210	209
0:15	1115	105	105
0:20	1120	79	79
0:25	1125	0	0
0:30	1130	0	0
0:35	1135	0	0
1 1/2 HOUR BREAK IN FLOW			
2:05	1305	105	104
2:10	1310	158	158
2:15	1315	294	291
2:20	1320	350	349 (REALLY
2:25	1325	350	344 (~339) - 334
2:30	1330	200	206
2:35	1335	79	77
2:40	1340	53	55
2:45	1345	26	26
2:50	1350	26	26
2:55	1355	13	
3:00	1400	13	
3:05	1405	13	
3:10	1410	13	
3:15	1415	STOP	

1113 FLOW BEGINS EXITING CELL 1

1318 - FIRST FLOW TO SEWER INLET

~1344 MH4 RISER BEGINS OVERFLO

Comments: Rates adjusted based on 09142012 test. 350 gpm was max rate possible without excessive flow to east side of 28th. PLACE SAND BAGS TO DIVERT MAXIMUM FLOW INTO RAINGARDEN

WE LOSE ~10gpm TO EAST SIDE AT 349 gpm MAKING EFFECTIVE INFLOW RATE ~334 TO 339 gpm. ~~LOS~~ REASON FOR LOSS IS PROBABLY DUE TO ① MORE SATURATED CONDITIONS EQUAL LESS CAPACITY, AND ② WE DID NOT PUT ENOUGH FLOW INTO UPPER CELL SO DOWNSTREAM CELLS FILL FASTER THAN TUESDAY'S TEST

Seattle Public Utilities
King County

Green Stormwater Infrastructure

Working Together to Protect our Waterways

Attachment D: Ballard Roadside Raingardens Post-Construction Flow Monitoring Memorandum (Piezometers)

Seattle Public Utilities
Geotechnical Engineering

MEMORANDUM

Date: **September 20, 2012**

To: **Shanti Colwell, P.E.**
Utility Systems Management

From: **Claire Gibson, P.E.**
Grant Davenport, E.I.T.
SPU Geotechnical Engineering

Subject: **BALLARD ROADSIDE RAIN GARDENS POST-CONSTRUCTION FLOW MONITORING**

INTRODUCTION

In accordance with your request, Seattle Public Utilities (SPU) Geotechnical Engineering performed surface and groundwater monitoring for the Ballard Roadside Raingardens (RRG). This memorandum presents the data and results of our investigations. The study focused on two RRGs located near NW 66th Street and 28th Ave NW and Loyal Way NW and 30th Ave NW, hereafter referred to as 28th Ave NW and 30th Ave NW RRG, respectively. As part of this study, we installed and monitored three piezometers to measure surface ponding and groundwater levels during and after flow testing.

INSTRUMENT INSTALLATION

Two drive point piezometers (DPPs) (Geokon Model 4500DP) were installed in the RRGs on August 28, 2012. The DPPs were installed at the bottom of the raingardens, where the bioretention soil contacts the underlying native deposits. A 2½ inch hand auger was used to excavate to the installation depth. The piezometers were installed at 5.22 feet and 1.6 feet below ground surface (bgs), for 28th Ave NW and 30th Ave NW RRGs respectively. The piezometer sensor is located approximately 0.2 feet above the tip of the instrument. Therefore the corrected piezometer depths are 5.02 and 1.4 feet bgs, for 28th Ave NW and 30th Ave NW RRGs respectively. The auger holes were backfilled with bioretention soil after installation of the piezometers. The piezometer cables were then connected to Geokon dataloggers for semi-continuous reading of the groundwater levels.

The DPP locations and surface elevations were surveyed after installation. Table 1 below shows the surveyed locations and elevations.

Table 1 – DPP Surveyed Locations and Elevations

DPP Number (Location)	Northing	Easting	Surface Elevation (ft) (NAVD88)	Piezometer Sensor Elevation
DPP-1 (28th Ave NW)	250762.54	1256202.28	151.73	146.71
DPP-2 (30th Ave NW)	254948.78	1255607.78	286.93	285.53

FLOW TESTING AND MONITORING

The flow monitoring test occurred from September 11 – 14, 2012. The monitoring consisted of the two DPPs to measure groundwater buildup above the bottom of the cells and a movable MiniTroll to measure surface ponding during flow testing.

The data collected from the three piezometers are presented in Figures 1, 2, and 3. The MiniTroll results were corrected for a zero calibration offset. The DPP results were corrected for negative pressure values when the groundwater was not above the sensor location.

Several problems occurred with the Geokon data logger during testing. No data was recovered for DPP-2 on September 11 for the 30th Ave NW RRG, or for DPP-1 in the 28th Ave RRG on September 14. In addition, because the cells were draining too quickly, no relevant MiniTroll data was collected on September 11 for the 30th Ave NW RRG.

The approximate locations of the piezometers in each RRG are shown on Figure 4. On September 12, the MiniTroll was at ground surface in the 30th Ave NW RRG. On September 14 the MiniTroll was located approximately 1 foot below ground surface of Cell 2 in the 28th Ave NW RRG.

If you have any questions, please don’t hesitate to contact us: Claire (684-5914) or Grant (423-6022).

Figure 1:
MiniTroll Data
September 12, 2012
30th Ave NW RRG

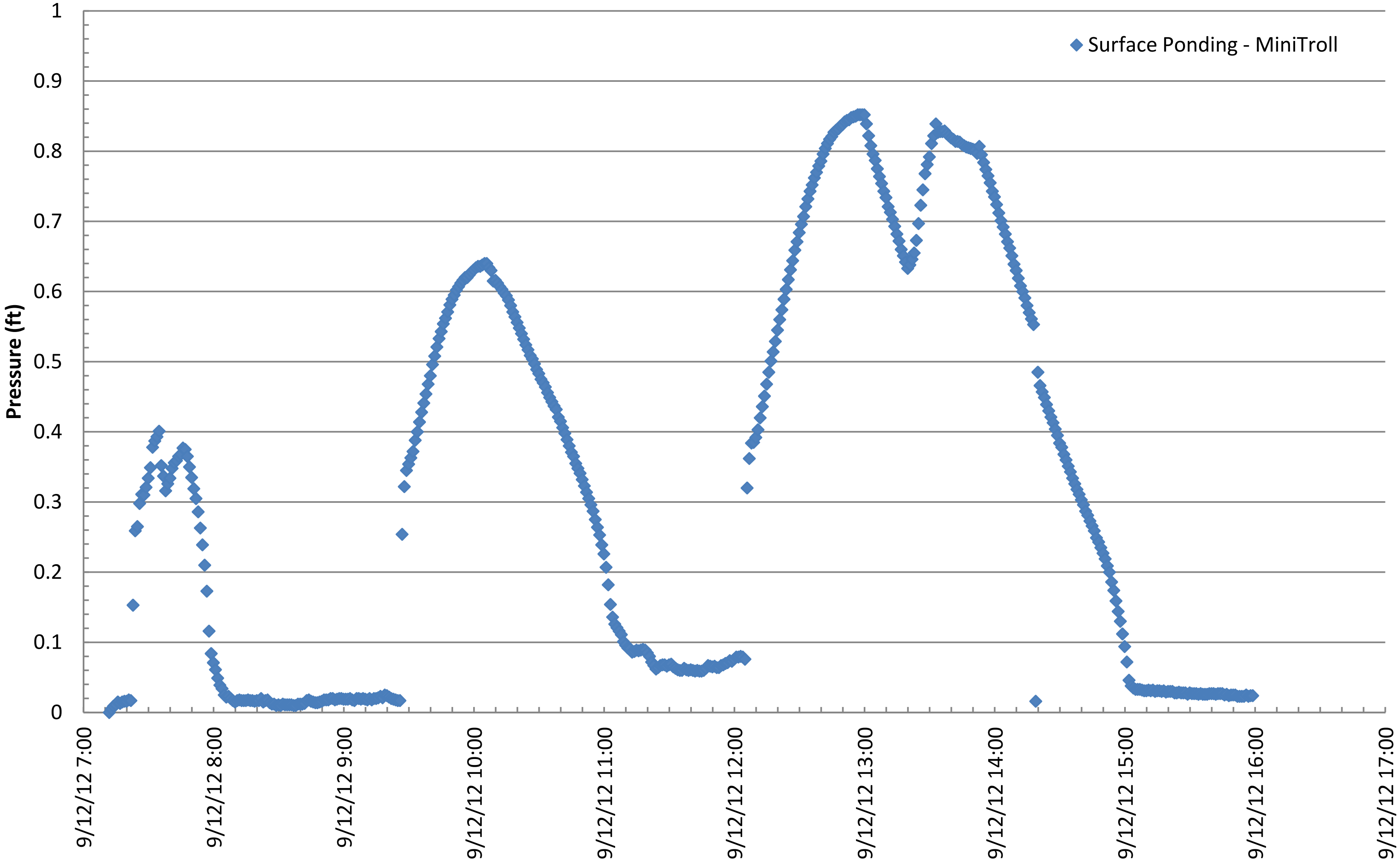


Figure 2:
DPP-2 Data
September 12, 2012
30th Ave NW RRG

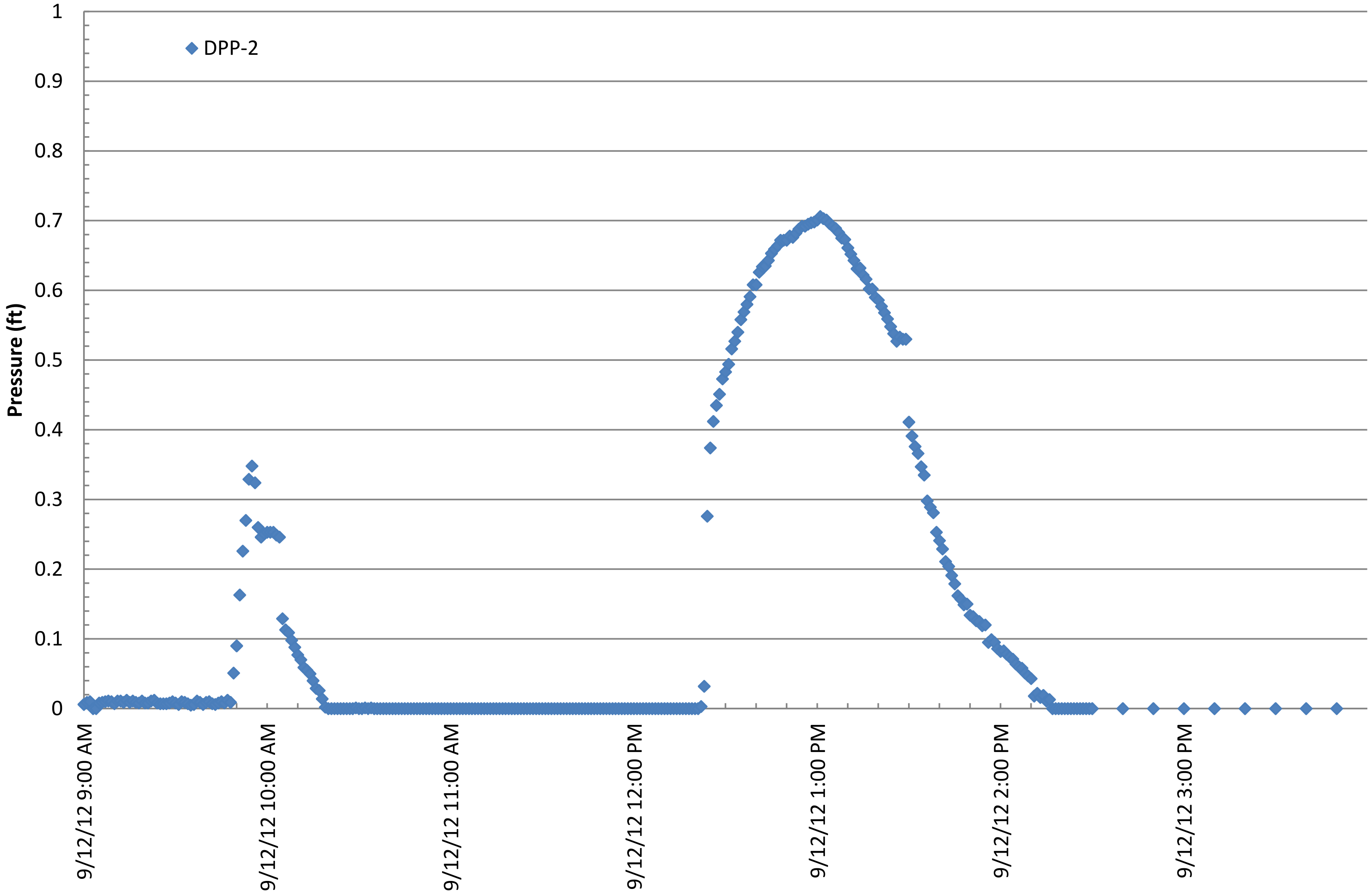
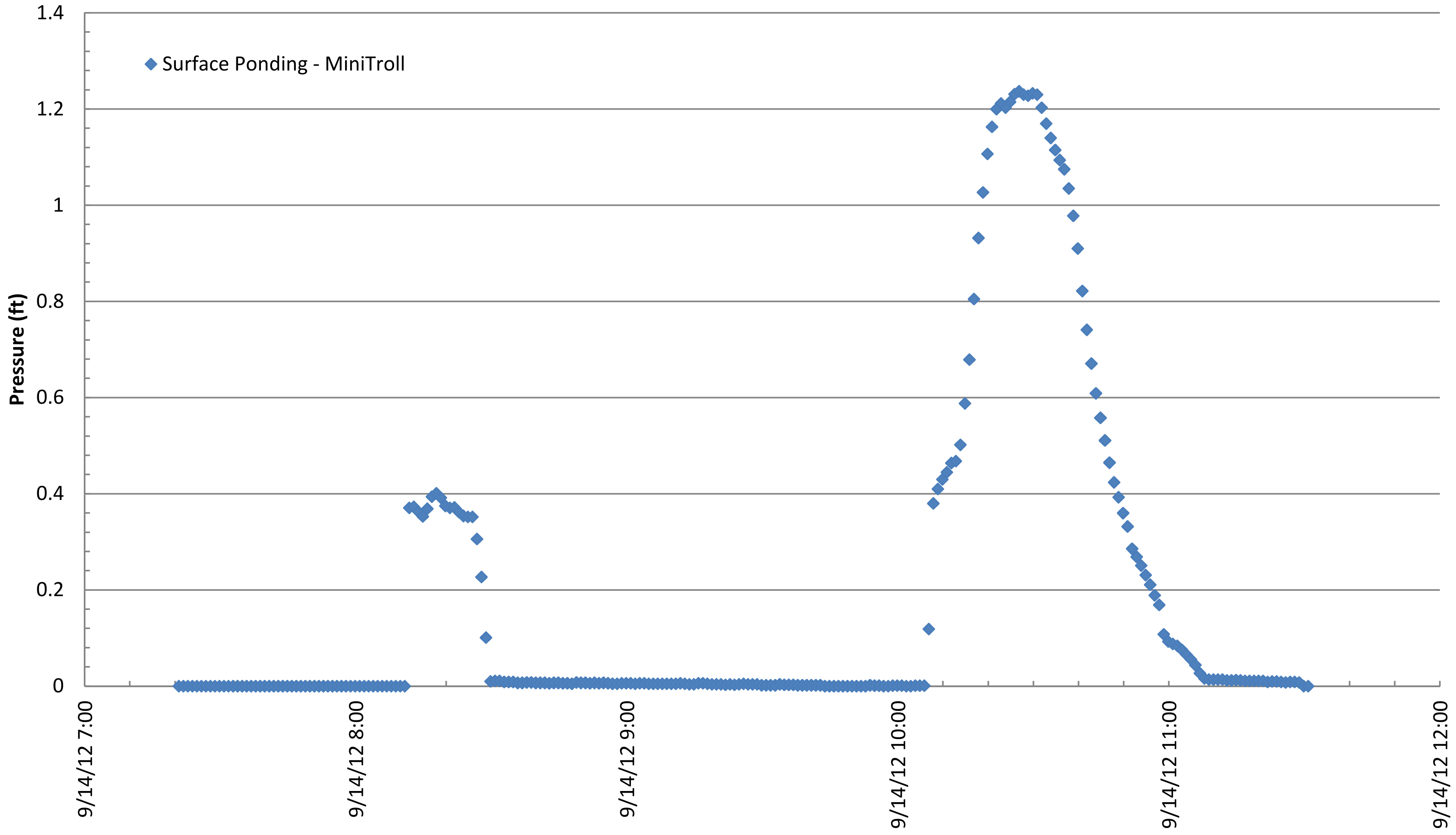
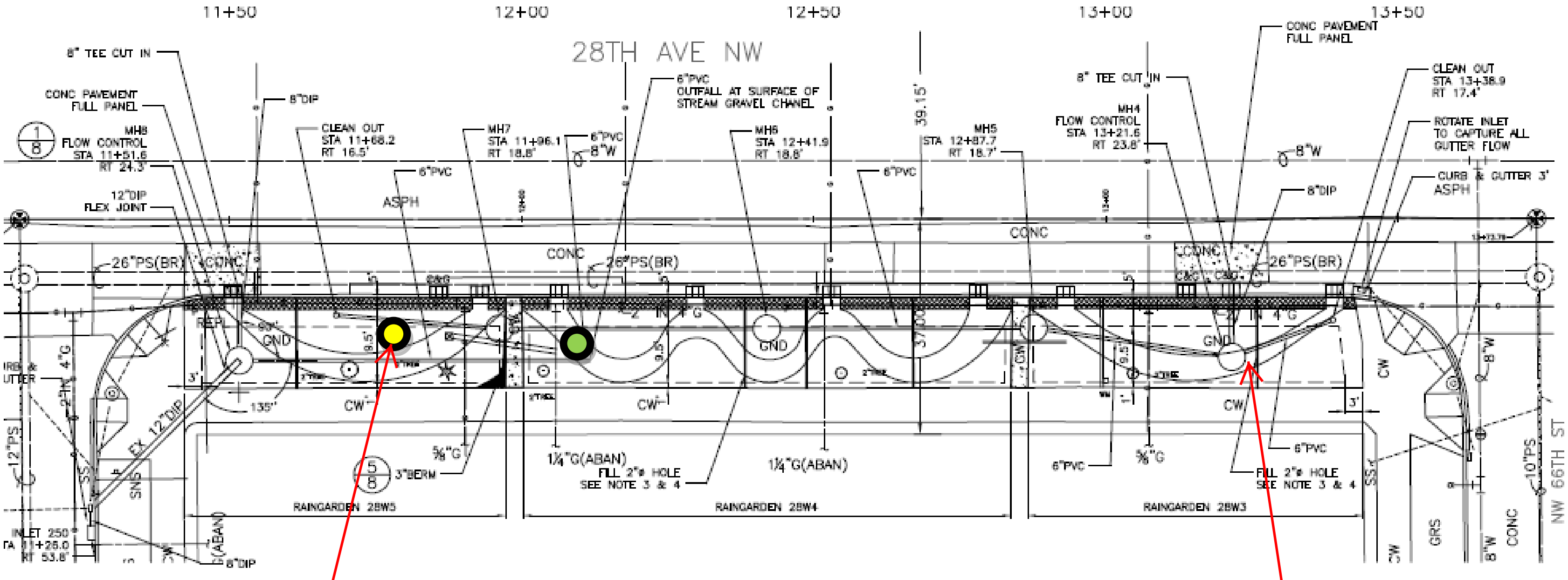


Figure 3:
MiniTroll Data
September 12, 2012
30th Ave NW RRG

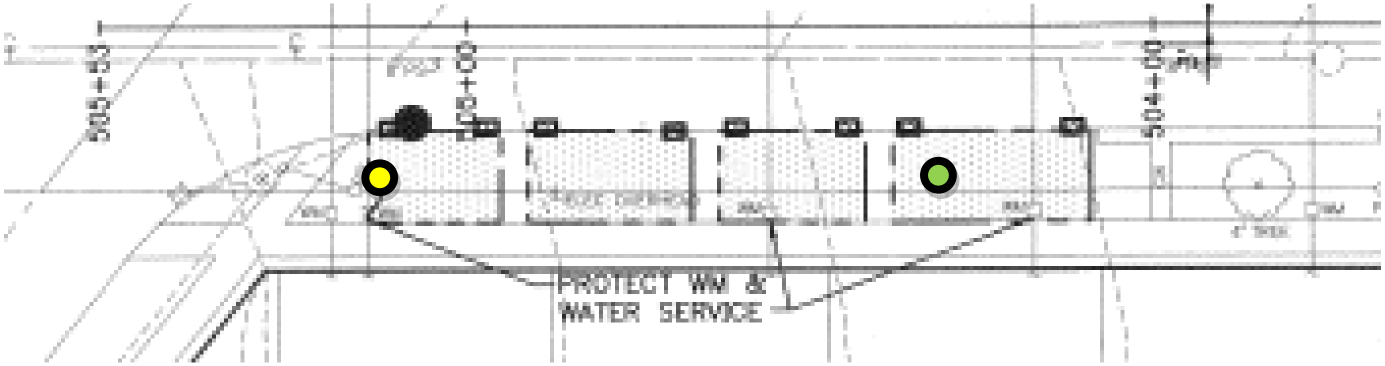




Incorrect location shown in original memo

Actual DPP location for entire monitoring period

30th Ave NW



● Drive Point Piezometer

● MiniTroll

SEATTLE PUBLIC UTILITIES
GEOTECHNICAL ENGINEERING

BALLARD ROADSIDE RAINGARDENS FLOW MONITORING
SEATTLE, WA
SITE AND MONITORING LOCATIONS

September 2012

FIGURE 4

Seattle Public Utilities
Geotechnical Engineering

MEMORANDUM

Date: **April 29, 2013**

To: **Shanti Colwell, P.E.**
Utility Systems Management

From: **Cody Nelson, L.G.**
SPU Geotechnical Engineering

Subject: **BALLARD ROADSIDE RAIN GARDENS CONTROLLED FLOW TESTING – GROUNDWATER RESPONSE DATA, 4/9 to 4/11/2013**

INTRODUCTION

In accordance with your request, Seattle Public Utilities (SPU) Geotechnical Engineering performed surface and groundwater monitoring for the Ballard Roadside Raingardens (RRG). The RRG were installed as part of the overall program to reduce combined sewer overflows (CSOs) to nearby waterbodies. This memorandum presents the data and results of our monitoring specifically during the controlled flow testing which occurred between April 9th and 11th, 2013. The flow testing was conducted by SPU crews under direction from Doug Hutchinson (SPU Field Technical Lead) and Dustin Atchinson (CH2MHill). The focus of this study was simulating conditions during a storm event and also to test the curb inlet capacity of each of the 28th Ave NW and 30th Ave NW roadside raingardens. As part of this study we installed one pressure transducer and monitored three previously installed pressure transducers to measure surface ponding and groundwater levels during and after flow testing.

INSTRUMENTATION

Two pressure transducers were installed previously in the 30th Ave NW RRG, and one pressure transducer was installed in the 28th Ave NW RRG. We have been monitoring groundwater pressures from these instruments for approximately the past 6 months. All pressure transducers are installed below the ground surface of the raingardens, and measure the water pressure rise at regular, programmed intervals with the idea of capturing water elevation before, during, and after rain events. The locations and depths of all instruments are shown on Figure 1.

The installation of one additional pressure transducer was completed to measure surface ponding during the flow testing within the 28th Ave RRG. The location of the pressure transducer was selected by Doug Hutchinson, who installed a vertical perforated PVC pipe within the gravel path near the south end of the raingarden (see Figure 1). Our pressure transducer was hung inside the pipe, with the pressure sensor approximately at 0.8 feet below ground surface (bgs). The instrument was removed after testing was completed. All pressure transducers were programmed to record data at 5 minute intervals, and set to Pacific Standard Time (PST).

FLOW TESTING AND MONITORING

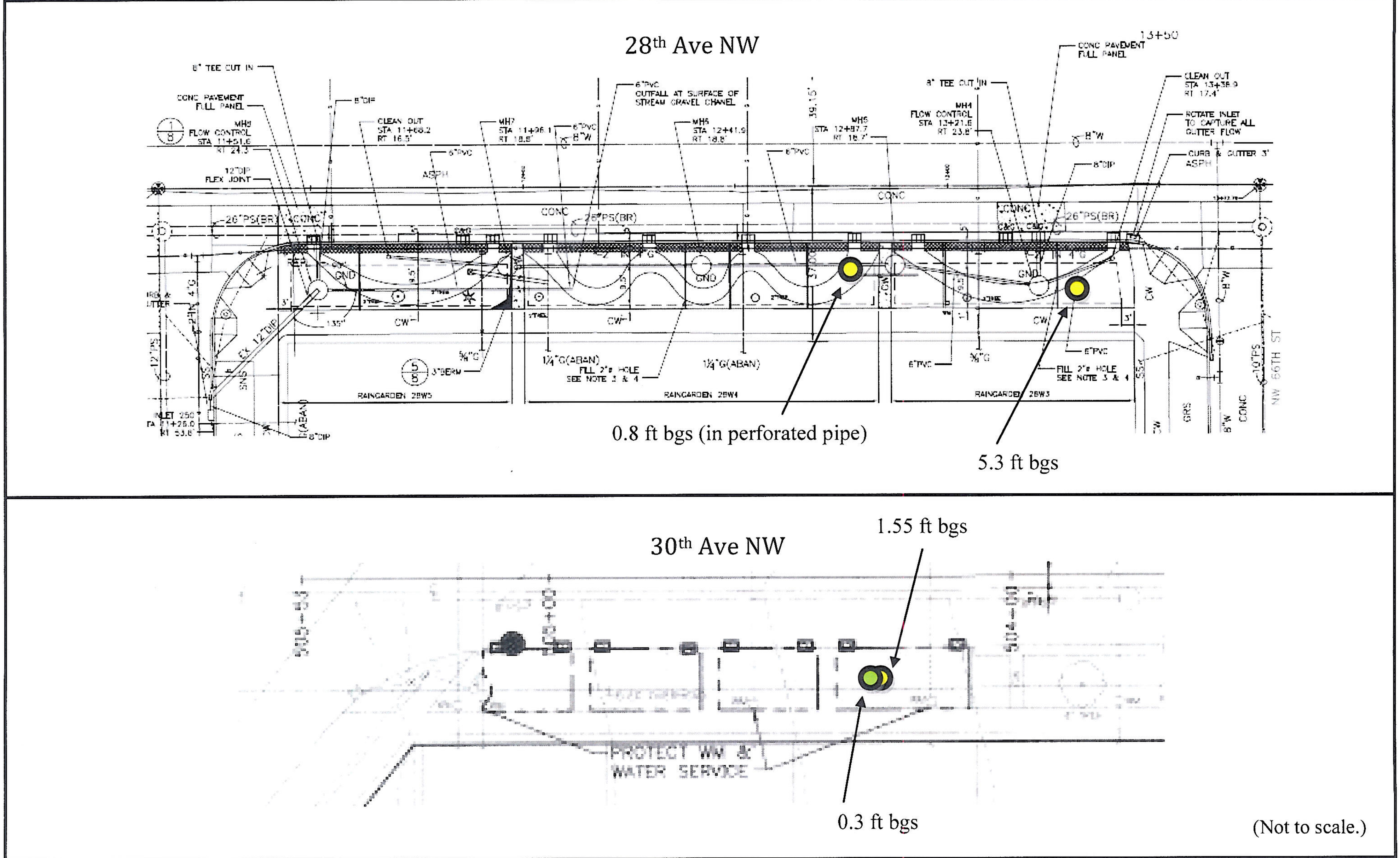
The controlled flow monitoring consisted of a series of tests designed to replicate varying degrees of storm events that are likely to mimic a CSO event. Testing began on April 9th by simulating a rain event following relatively unsaturated soil conditions first at the 30th Avenue NW RRG, then at the 28th Avenue NW RRG. On April 10th, slight rain caused the project team to decide to perform the inlet capacity testing at both locations; which consisted of monitoring the inlet capacity, but also saturated both raingarden cells. The simulated saturated soil conditions testing occurred on April 11th, first at the 30th Avenue NW RRG then at the 28th Avenue NW RRG.

The response of the pressure transducers for the 28th Avenue NW RRG are shown on Figure 2. Figure 2 shows a rapid rise and drop in surface ponding during all of the tests, and a fast and consistent drainage rate for water ponding that occurred below the ground surface.

The response of the pressure transducers for the 30th Avenue NW RRG are shown on Figures 3 and 4. These figures show the same data, but Figure 4 is shown at a larger scale. During the unsaturated and inlet capacity tests, the collected data show a relatively high drainage rate from the highest ponding level (approximately 0.4 feet above ground surface) to about 1.2 feet bgs. When the groundwater drops to about 1.2 feet bgs, the drainage rate appears to slow down. However, for the final test simulating saturated conditions, the rate of drainage from 1.2 feet bgs to the bottom of the raingarden was higher than the previous tests. The seepage velocity appears to have increased (the rate of movement of fluid particles through porous media) during this phase of the testing.

The pressure transducer data were corrected for negative pressure values when the groundwater was not above the sensor location. Following testing, the instruments were set to record at 10 minute intervals and we resumed our monthly schedule of data monitoring.

If you have any questions, please don't hesitate to contact me at 684-3066.



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GEOTECHNICAL ENGINEERING

Pressure Transducers

🟡 LevelTroll

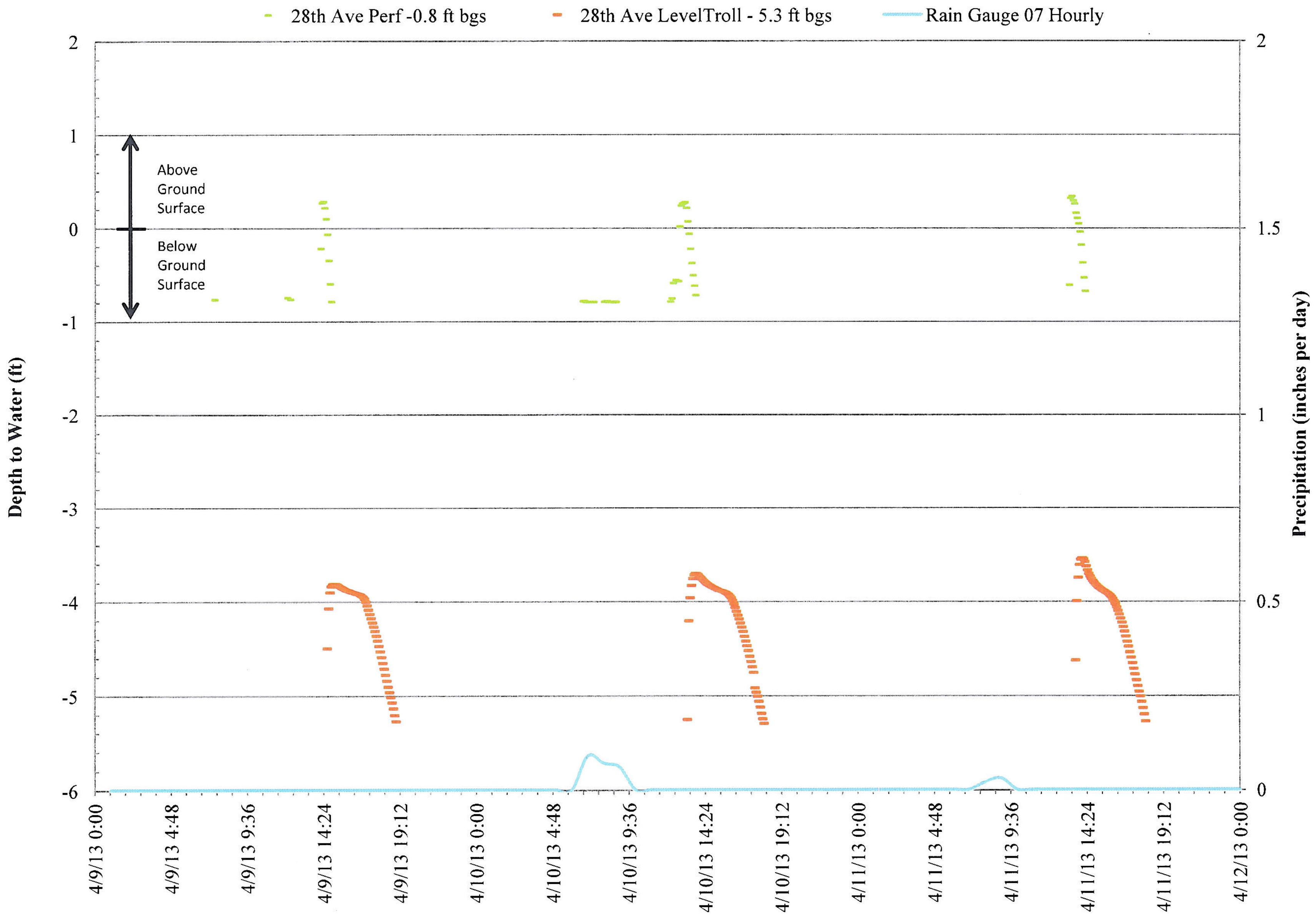
🟢 MiniTroll

BALLARD ROADSIDE RAINGARDENS
FLOW TESTING – GROUNDWATER RESPONSE DATA
SEATTLE, WA
SITES AND MONITORING LOCATIONS

2013

FIGURE 1

Ballard RRG Flow Testing — Groundwater Response Data 4/9 to 4/11/13
28th Ave NW

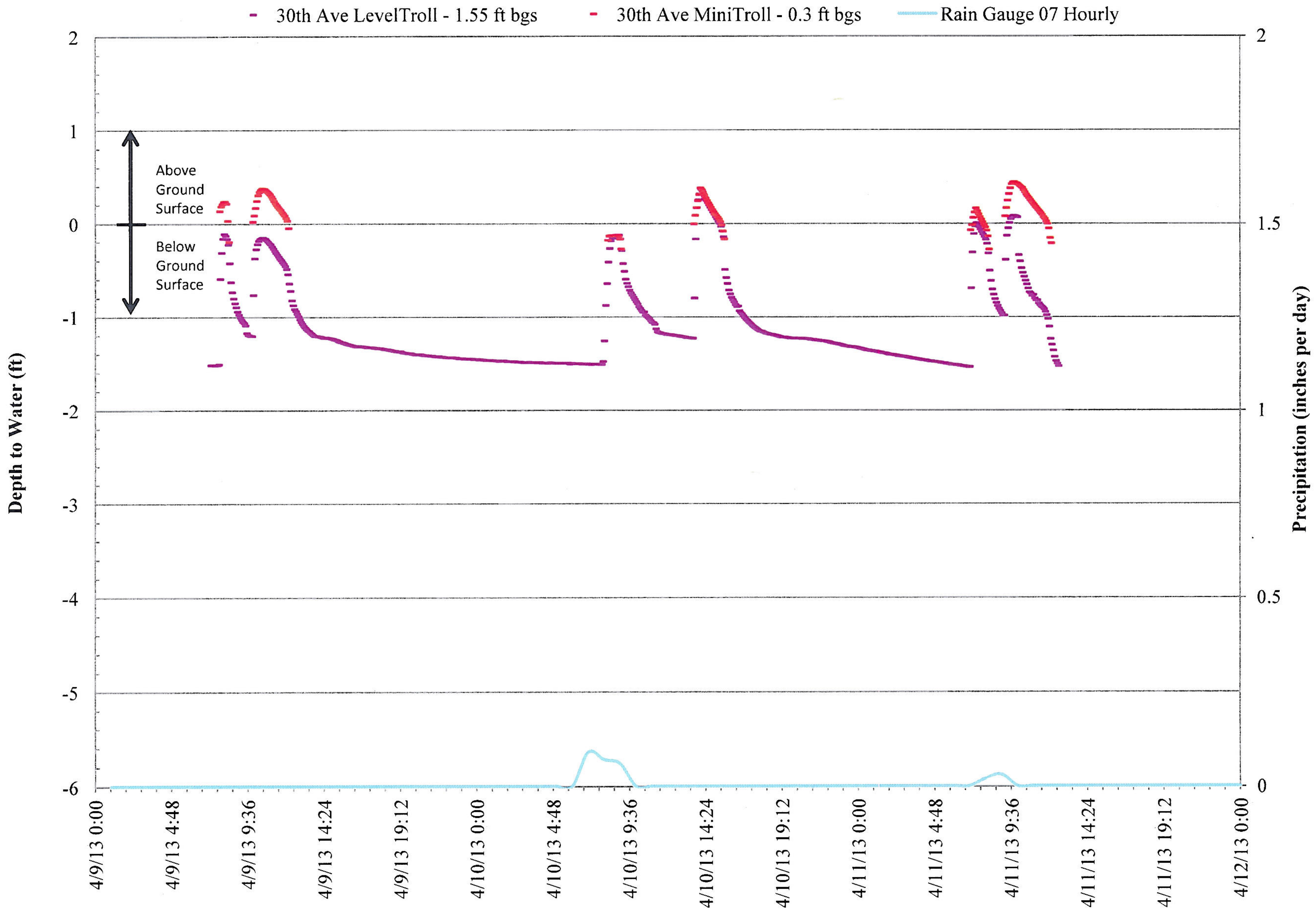


Ballard Roadside Raingardens
Flow Monitoring

Note: Transducer readings were obtained every 5 minutes during the length of the testing (Pacific Standard Time).

Figure 2
Transducer Data

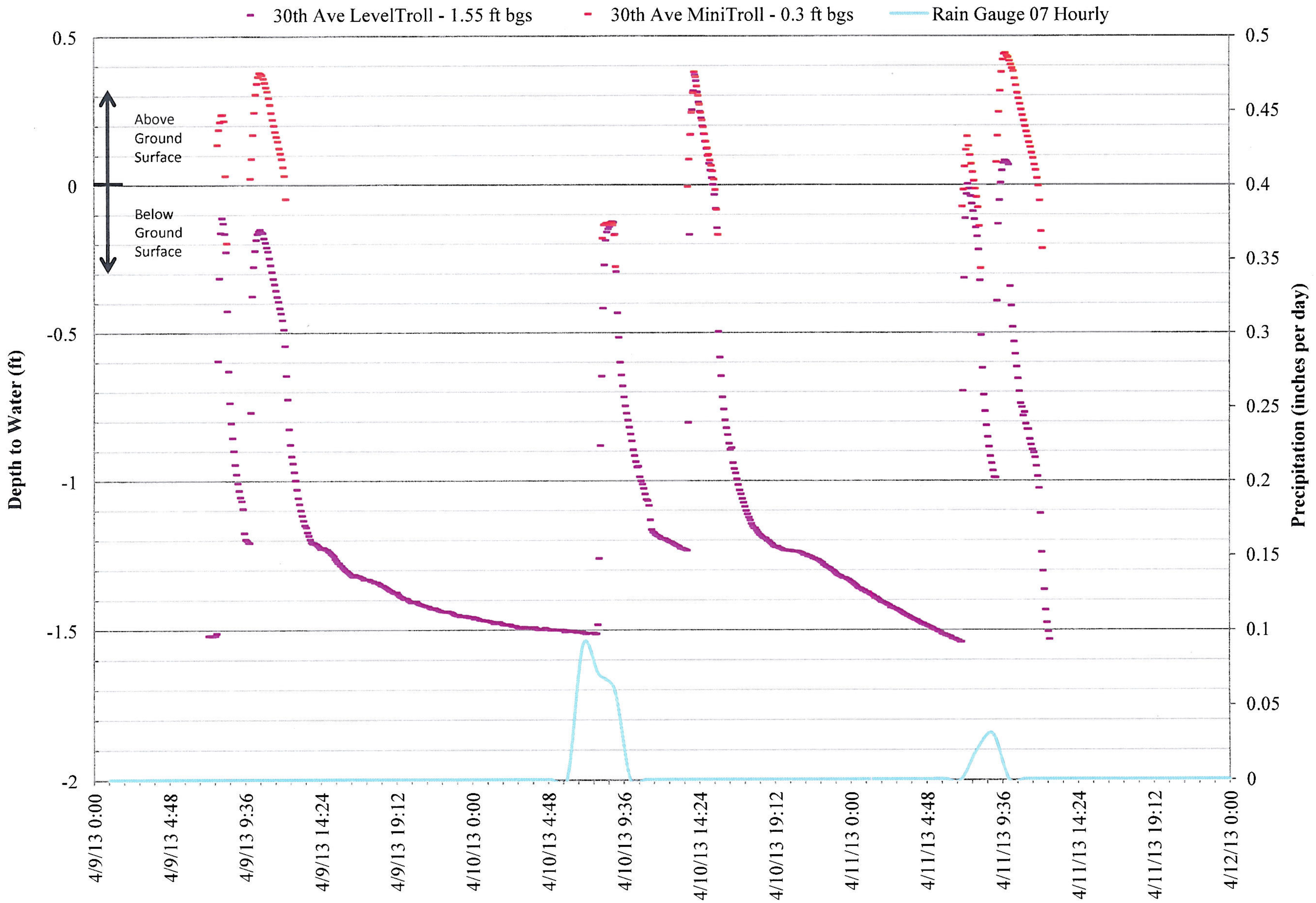
Ballard RRG Flow Testing — Groundwater Response Data 4/9 to 4/11/13
30th Ave NW



Note: Transducer readings were obtained every 5 minutes during the length of the testing (Pacific Standard Time).

Figure 3
Transducer Data

Ballard RRG Flow Testing — Groundwater Response Data 4/9 to 4/11/13
30th Ave NW



Note: Transducer readings were obtained every 5 minutes during the length of the testing (Pacific Standard Time).

Figure 4
Transducer Data