Hybrid BMP Project Final Report

June 2014

Prepared for:

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United States Forest Service
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Nevada Division of State Lands
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List of Acronyms

BMP	Best Management Practice
CHP	constant head permeameter
DI	drainage inlet
DRI	Desert Research Institute
EIP	Environmental Improvement Program
EPA	Environmental Protection Agency
FSP	fine sediment particle
GIS	Geographic Information System
ILA	Interlocal Agreement
LID	Low Impact Development
LPSA	Laser Particle Size Analysis
NDEP	Nevada Division of Environmental Protection
NDOT	Nevada Department of Transportation
NDSL	Nevada Division of State Lands
NTCD	Nevada Tahoe Conservation District
PLRM	Pollutant Load Reduction Model
PSD	Particle Size Distribution
QAPP	Quality Assurance Project Plan
QAQC	Quality Assurance/Quality Control
RAM	Rapid Assessment Methodology
ROW	right-of-way
TMDL	Total Maximum Daily Load
TRPA	Tahoe Regional Planning Agency
TSS	Total Suspended Solids
TU	Turbidity
USFS	United States Forest Service
WETLab	Western Environmental Testing Laboratory

EXECUTIVE SUMMARY

The Hybrid Best Management Practices (BMP) Project involved retrofitting a completed Environmental Improvement Program (EIP) Project along Village Boulevard in Incline Village, Washoe County, Nevada with low impact development (LID) stormwater treatment BMPs installed within the right-of-way (ROW). This project was a pilot project to demonstrate distributed, off-line, LID BMPs in the ROW could achieve fine sediment particle (FSP) load reduction for the Lake Tahoe Total Maximum Daily Load (TMDL). The project was also a pilot to test whether a biologically driven stormwater infiltration treatment could be effective in the Tahoe Basin's climatic and environmental conditions. The project resulted in the fall 2011 construction of 5 rain gardens, 2 underground infiltration systems and a bio-swale.

After installation of the BMPs, two years of monitoring and testing were used to characterize project effectiveness and gain insight on function and maintenance needs. The monitoring task produced data on stormwater runoff volume reduction as a result of the project, pollutant load treated by the LID BMPs, infiltration rate changes over time and vegetation establishment.

Although a two year monitoring period is too short to draw any conclusions regarding long-term effectiveness, asset lifespan or maintenance intervals, monitoring results suggest that biological driven LID BMPs relying on infiltration are an effective stormwater treatment alternative in the Tahoe Basin.

The project goals were to 1) reduce the stormwater runoff volume from the project area; 2) remove and sequester fine sediment mass from the project area and 3) sustain infiltration performance of distributed LID BMPs with minimal maintenance. The project treated 68% of the stormwater runoff generated in the project area with offline LID BMPs, which exceeded the project goal of 50%. Similarly, an estimated 68% of the FSP generated in the project area was treated through infiltration and biofiltration in the LID BMPs. Finally the BMPs exhibited no degradation in performance or accumulation of sediment in part due to effective use of pre-treatment sediment traps.

NTCD prepares this report, in part, to satisfy requirements specified in Attachment A (Work Plan) for the CWA Section 319 (h) grant project DEP-S 10-024, Hybrid BMP Retrofit.

INTRODUCTION

The Lake Tahoe Total Maximum Daily Load (TMDL) was approved by the United States Environmental Protection Agency (EPA) in August 2011 with the intent of providing a plan for restoring Lake Tahoe water clarity. The focus of the Lake Tahoe TMDL is on strategies to reduce fine sediment particles (FSP, defined as particles less than 16µm in diameter), nitrogen and phosphorus loads reaching Lake Tahoe from urban developments, including roads. To implement the Lake Tahoe TMDL, Nevada Tahoe jurisdictions of Washoe County, Douglas County and Nevada Department of Transportation (NDOT) entered into an Interlocal Agreement (ILA) with the Nevada Division of Environmental Protection (NDEP) for the purpose of committing to collectively engage in efforts to restore and protect Lake Tahoe's clarity.. As part of TMDL implementation, the jurisdictions are developing stormwater load reduction plans (SLRPs) that will propose cost effective strategies to reduce pollutants of concern, particularly FSP loads. This project was conceived as a pilot project to demonstrate the ability to retrofit an existing stormwater system with distributed off-line LID BMPs constructed in the Washoe County right-of-way (ROW) to achieve FSP load reduction for TMDL compliance.

The Nevada Tahoe Conservation District (NTCD) partnered with Washoe County, Tahoe Regional Planning Agency (TRPA), Nevada Division of State Lands (NDSL), United States Forest Service (USFS) and NDEP to design and construct the project in the ROW along Village Boulevard in Incline Village, Nevada. The project resulted in the first rain gardens installed in the Tahoe Basin and served as a LID pilot project. According to information collected by the EPA regarding stormwater management, capital and operation and maintenance requirements of rain gardens and other green infrastructure BMPs typically are more cost effective than comparable structural BMPs. Rain gardens and other bio-infiltration BMPs take advantage of natural biological processes such as vegetation growth (annual root growth and senescence) and soil organisms (burrowing, humus aggregates) to maintain soil porosity and infiltration. Rain gardens are being widely implemented across the United States to effectively treat stormwater runoff. Portland, Oregon has rain gardens that are over 15 years old and still functioning satisfactorily with routine maintenance of sediment trap cleaning (Maria Cahill, pers. comm.). As presented in this final project report, the project has yielded useful information about siting, design, construction, revegetation, and maintenance that will be available for the design and implementation of future LID BMP projects in the Tahoe Basin. The Hybrid BMP Project was awarded the 2012 TRPA Best in Basin erosion control project.

PROJECT LOCATION

The Hybrid BMP Project is located in Incline Village, Washoe County, Nevada, along an approximately 1,000 foot length of Village Boulevard. The project area is within the Washoe County ROW along the southeastern side of Village Boulevard from just below Ace Court to just above Golfers Pass Drive (Figure 1). The project area is entirely within the Third Creek watershed, which is ranked by TRPA as a Priority 1 watershed. The project area lies within the catchment identified in Washoe County's TMDL Stormwater Load Reduction Plan as Fairway/Fairview Phase III Water Quality Improvement Project Rosewood Creek (FF3 RWC), which is ranked in the 60-80 percentile for FSP loading of

43 lbs/year/acre in the existing condition scenario. Adjacent developments include the Incline Village neighborhood along Village Boulevard and its side streets.

PROJECT GOALS AND OBJECTIVES

The Hybrid BMP Project goals were as follows:

1. Reduce the stormwater runoff volume from Washoe County's impervious area in the project area.
2. Remove and sequester fine sediment mass within the project area.
3. Sustain seasonal and longer term infiltration performance with minimal maintenance

The project planned to meet the goals through the following objectives:

A. Treat 50 percent of the stormwater runoff generated in the project area with offline LID BMPs.
B. Employ infiltration or biofiltration LID BMPs to remove 50 percent of fine sediment particles from stormwater generated in the project area.
C. Install sediment traps to pre-treat runoff before entering the BMPs, such that Washoe County does not incur an additional maintenance load compared to current practices.

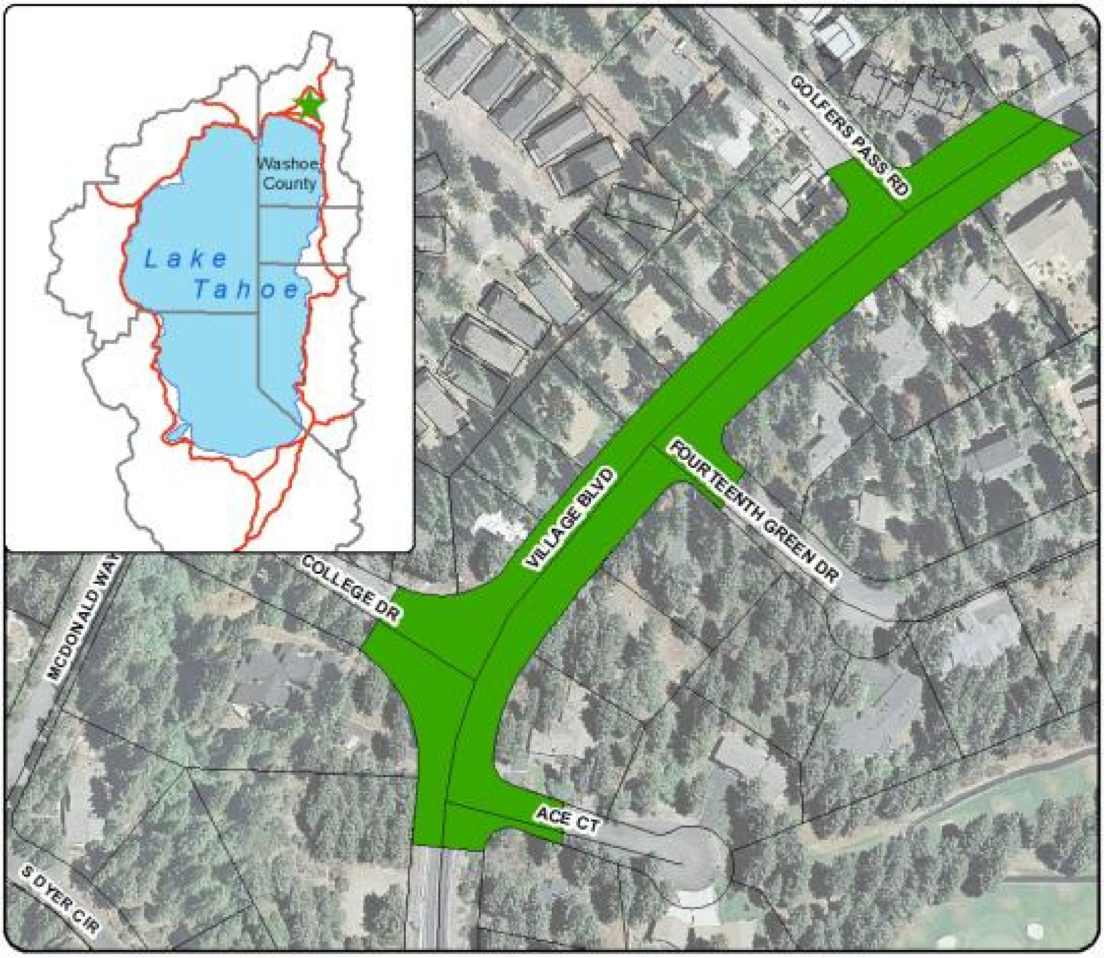
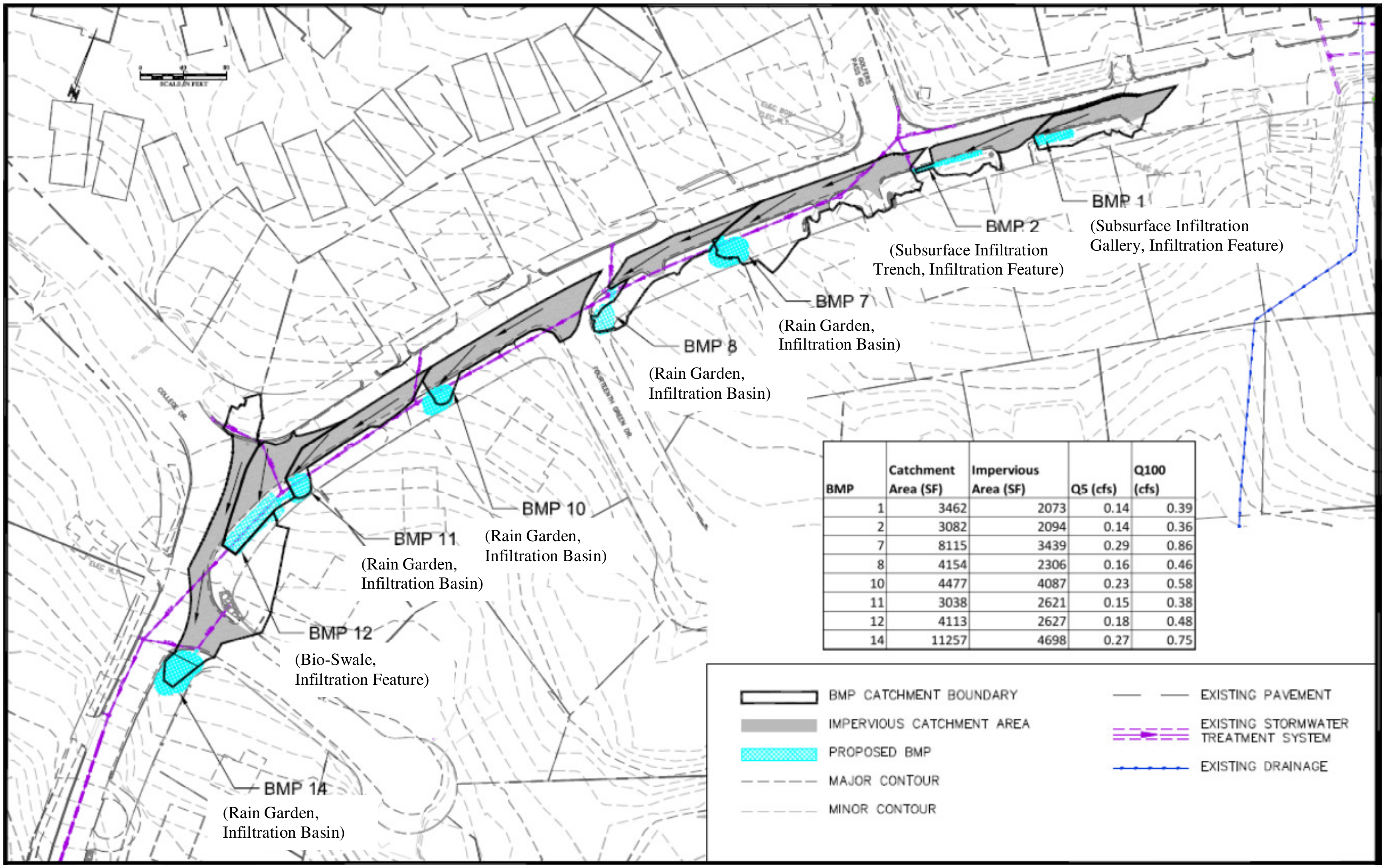


Figure 1. Hybrid BMP Project area along Village Boulevard in Incline Village, NV.

PROJECT DESCRIPTION

The Hybrid BMP Project resulted in the installation of 5 rain gardens, 2 subsurface infiltration systems and a bio-swale in the Washoe County ROW along Village Boulevard. NTCD worked closely with Washoe County and the other project partners (NDEP, NDSL, USFS and TRPA) to select three basic types of LID BMPs. Following is a qualitative overview of the installed LID BMP treatment systems (see Figure 2). Table 1 presents a summary of the characteristics and features according to BMP type.



BMP	Catchment Area (SF)	Impervious Area (SF)	Q5 (cfs)	Q100 (cfs)
1	3462	2073	0.14	0.39
2	3082	2094	0.14	0.36
7	8115	3439	0.29	0.86
8	4154	2306	0.16	0.46
10	4477	4087	0.23	0.58
11	3038	2621	0.15	0.38
12	4113	2627	0.18	0.48
14	11257	4698	0.27	0.75

Figure 2. LID BMPs along Village Boulevard in the upper portion of the project area contrasted for the Hybrid BMP Project.

Rain Gardens: BMPs 7, 8, 10, 11 and 14 were designed with flat basin bottoms and engineered soils up to 36 inches deep. Stormwater runoff that exceeds the infiltration rate will pond to a designed maximum depth (6”-12”). Stormwater is treated through infiltration, which sequesters FSP and other pollutants. The rain gardens were designed to pond at the designed depth in one of two ways:

- Backwater in the BMP hydraulically isolates the BMP (BMPs 7, 10, and 14) from accepting additional flow. BMP 14 has an additional emergency overflow conveyance above the maximum ponding depth, should extreme circumstances cause the ponded depth to exceed the maximum design depth.
- Overflow at design depth elevation conveys excess stormwater runoff out of the BMP. Due to topography, it was not possible for some BMPs to utilize the principle of hydrologic isolation (BMPs 8 and 11). Instead, stormwater that exceeds the ponded depth overflows through a conveyance either back into the road (BMP 8) or into additional downstream treatment (BMP 11)

Subsurface Infiltration Systems: Two subsurface infiltration systems were installed. A subsurface infiltration gallery (BMP 1) allows stormwater runoff to fill a subsurface void (StormTech® SC-310 Chambers and surrounding drain rock) until infiltration into in-situ soils. Stormwater volume that exceeds void space will hydraulically isolate the inlet to the gallery from accepting additional flow. A subsurface infiltration trench (BMP 2) allows stormwater runoff to access a subsurface void (drain rock filled trench) for infiltration into surrounding soils. Stormwater volume that exceeds void space will hydraulically isolate the system from accepting additional flow.

Bio-Swale: This linear swale (BMP 12) was designed to slowly convey stormwater runoff. The BMP was configured as a series of terraced, nearly level cells of engineered soil to 36 inches deep, separated by rock weirs to maximize infiltration. This BMP was designed to store vast quantities of snow removed from the intersection of College Drive and Village Boulevard. Stormwater runoff accesses the entire length of the BMP without pre-treatment. Stormwater flow that exceeds the infiltration capacity of the swale continues to flow downhill into the existing stormwater infrastructure to BMP 14.

Table 1. BMP type characteristics

BMP #	Type of BMP	BMP RAM Name*	Flow Through	Sediment Trap	Engineered Soils	Design Storm Recurrence Interval (yrs)
1	Subsurface infiltration gallery	Infiltration feature	No	Yes	No	20
2	Subsurface infiltration trench	Infiltration feature	No	Yes	Yes	27
7	Rain garden	Infiltration basin	No	Yes	Yes	56
8	Rain garden	Infiltration basin	Yes	Yes	Yes	57
10	Rain garden	Infiltration basin	No	Yes	Yes	8
11	Rain garden	Infiltration basin	Yes	Yes	Yes	1
12	Bio-swale	Infiltration feature	Yes	No	Yes	324
14	Rain garden	Infiltration basin	No	Yes	Yes	141

*BMP RAM discussed under ***Long Term Performance Measurements***

BMP type and location were selected after assessing relevant technical and site factors, such as estimated potential pollutant load reduction, topography, runoff volume, engineering, and hydro-geologic considerations which are documented in the *Final Design Report for Hybrid BMP Project* (NTCD 2011). The installed LID BMPs accommodate stormwater runoff from at least a one year event (0.41 inch, one hour storm) (Table 1) and treat approximately 50% of Village Boulevard between Ace Court and Golfers Pass Road as shown in Figure 2. Statistical analysis of 7 years of precipitation at Diamond Peak in Incline Village, NV (Figure 3) reveals that 91% of daily water-equivalent precipitation was 0.5 inches or less.

Table 2. Minimum runoff accommodated by the Hybrid BMPs.

Year Event	Precipitation (1 hr)	Precipitation (24 hr)
2	0.54 inches	3.29 inches

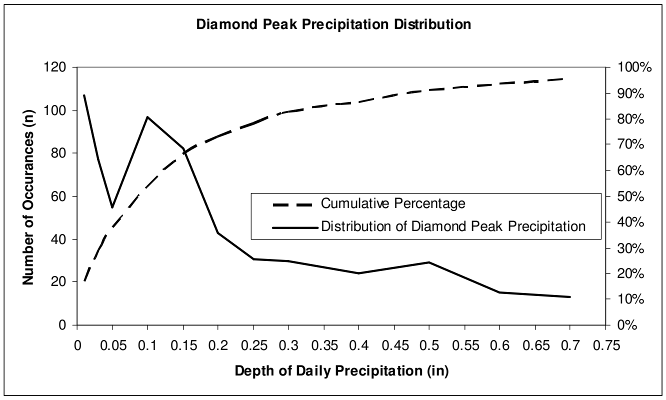


Figure 3. Distribution of precipitation events for the meteorological station at Diamond Peak, Incline Village, NV for the seven year period of record (http://www.wrcc.dri.edu/weather/incc.html).

This project was a pilot to determine the ability of distributed, off-line LID BMPs constructed in the Washoe County ROW to achieve FSP load reduction for Lake Tahoe TMDL compliance. The project was also a pilot to test whether a biologically driven (annual root growth and senescence, microorganism burrowing, humus aggregate) stormwater infiltration treatment could be effective in Nevada-Tahoe's challenging environment of granitic soils which are rapidly draining and poor in nutrients and organic matter, dry summers, and winters of high snow fall and associated application of traction control material. The BMPs were configured with various design elements to prolong asset life, lengthen maintenance intervals and to inform future LID BMP projects in terms of effectiveness and maintenance requirements.

Preferred design elements included:

1. Off-line configuration: Most of the BMPs were designed and installed without an outlet except via infiltration or emergency overflow. Most were designed and installed to hydraulically isolate from additional inflow when full. As a result, sequestered FSP and other pollutants could not be flushed into the stormwater system by a subsequent large flow event. In the event stormwater bypasses the BMPs, excess stormwater was conveyed in the existing stormwater system.
2. Pre-treatment sediment traps: A common feature of all but one of the installed BMPs was a pre-treatment sediment trap or Type 4R catch basin with a sump that captures the coarse fraction of sediment. Existing sediment traps were utilized where possible. A double sediment trap with a 200 micron sock filter was also used to reduce sediment input to the subsurface infiltration gallery.

3. Deep amended soils: Soils were amended for the rain gardens and bio-swale in order to establish vegetation and improve infiltration. The amendment recipe was constant across all sites. Soil amendment depth varied between 30 and 36 inches.
4. Vegetation: Native and adapted plants were established in the rain gardens and bio-swale. Establishment methods included seeding, transplanting t-pots and supercells and transplanting containerized landscape plants from 1 pint to 1 gallon sized containers. Plants were irrigated for a two-year establishment period.

Expenses

The project was funded through grants and funds from the USFS Southern Nevada Public Land Management Act (SNPLMA) Round 10, NDEP Clean Water Act Section 319, NDSL Lake Tahoe License Plate, Washoe County TRPA water quality mitigation funds and Washoe County in-kind match labor as shown in Table 3.

Table 3. Project funding souces

Funding Source	Amount
NDSL License Plate	$86,100
USFS SNPLMA Round 10	$123,539
NDEP 319	$85,200
TRPA Mitigation (Washoe County WQ)	$97,417
In-Kind Contribution	$25,222
TOTAL	**$417,478**

Project expenses are shown in Table 4. Due to the pilot project nature of the project, many of the costs for the line items are higher than typical Tahoe Basin water quality construction projects. It is expected that future rain garden projects may cut costs in the Design & Engineering, Project Management and Monitoring categories.

Table 4. Project expenses

Project Expenses	Amount
Project Management	$47,970
Design & Engineering	$100,264
Construction	$134,035
Revegetation	$23,171
Monitoring	$87,141
Coordination & Permitting	$24,897
TOTAL	**$417,478**

MONITORING PROGRAM

To determine whether the project met the goals and objectives, and to obtain monitoring data to evaluate effects of the various design elements, a monitoring plan was developed as detailed in the *Monitoring Plan/Quality Assurance Project Plan* (QAPP) (NTCD 2011). The monitoring focus was to evaluate the performance of the BMPs over time and evaluate the suitability of the maintenance interval for the Tahoe region as stated in the *Hybrid BMP Project Final Maintenance Plan* (NTCD 2011) included in Appendix A. The available budget limited monitoring to two years, but longer performance monitoring would be necessary to validate the design and construction and to estimate the frequency and significance of maintenance efforts. Monitoring criteria and methods are fully discussed in the QAPP.

The monitoring objectives were to:

1. Measure infiltration rate at the surface of the engineered soils.
2. Measure exfiltration rate from the LID BMPs to the native soils.
3. Estimate the volume of stormwater infiltrated by the LID BMPs.
4. Estimate the mass of fine sediment sequestered by the LID BMPs.

Effectiveness of the LID BMPs was monitored in four ways:

1. Artificial washoff tests were performed to estimate the percent runoff reduction resultant from the project.
2. Load of fine sediment entering two BMPs was estimated by collecting water quality grab samples during precipitation events.
3. Pressure transducers in observation wells were installed in 6 BMPs to monitor the stage of runoff within the BMPs from natural precipitation events as well as controlled experiments.
4. Two types of surface infiltration tests were performed to characterize changes in the LID BMP soil surface infiltration rates over time due to sediment deposition, compaction, and/or vegetation establishment.

METHODS AND MATERIALS

Sampling Process Design

The sample design collected data on two spatial scales: a catchment-scale (i.e., project-scale) and a BMP-scale (i.e., rain garden-scale). The sample design was further divided into three temporal scales: scheduled project tests, precipitation event data collection, and long term assessment of BMP performance as part of the Lake Tahoe TMDL program using the appropriate BMP Rapid Assessment Methodology (RAM) field observation protocols. All water samples collected were "grab" samples, except those project-scale samples collected at the Harold Basin monitoring site where an ISCO autosampler was utilized. At the BMP-scale, samples were collected from the pre-treatment sediment trap, just below the water surface and near the outlet to the LID BMP.

Changes to Sampling and Analysis Design

The three monitoring sites, Harold Basin, Ace Court and Golfers Pass DI, were installed to monitor stormwater runoff volumes that would help determine the the amount of stormwater runoff captured by the project. The Harold Basin monitoring site collected stormwater runoff volume for the entire catchment, including the project treatment area, the Golfers Pass catchment and the Lower catchment (Figure 4). The Ace Court monitoring site collected runoff volume for the project treatment area and Golfers Pass catchment and the Golfers Pass DI collected runoff volume from the Golfers Pass catchment. With stormwater runoff volumes from all three locations both pre-project (Incline Village Sweeper Study data) and post-project, the runoff volume infiltrated by the project would have been a simple subtraction equation.

Unfortunately, after the QAPP was created and monitoring commenced, Desert Research Institute (DRI) concluded (while processing the data collected during the Incline Village Sweeper Study) that the Ace Court monitoring site collected unreliable data due to slope of the installed flume being too great and causing turbulence in water flow. Thus, the Ace Court monitoring site data was ultimately not used in this monitoring effort.

The Golfers Pass monitoring site, consisting of a pressure transducer installed in a drainage inlet (DI), overestimated the stage height during the winter months when the transducer was submerged in ice (residual stormwater runoff in the DI froze). The stormwater runoff volume was then overestimated which rendered the data unusable for determining the stormwater runoff volume infiltrated by the project's rain gardens and infiltration feature BMPs. This was a known issue from the Incline Village Sweeper Study, but was worth collecting the data and trying to manually adjust for the transducer overestimating by visually observing and recording the dates of the frozen water in the DI. Unfortunately, applying a correction factor was too difficult and the Golfers Pass monitoring site data was not utilized.

With only the Harold Basin monitoring site functioning properly, NTCD used each individual BMP's surface area, average annual porosity and change in stage height provided by the pressure transducers to estimate the volume infiltrated by the project (see Flood Capacity Test; Volume Infiltrated Estimate below).

Sampling System Overview

<u>Location</u>

Figure 4 shows the BMP, sediment traps and monitoring site locations for the catchment. The Harold Basin monitoring site collects stormwater runoff from the entire catchment, including the lower catchment, project treatment and Golfers Pass catchment.

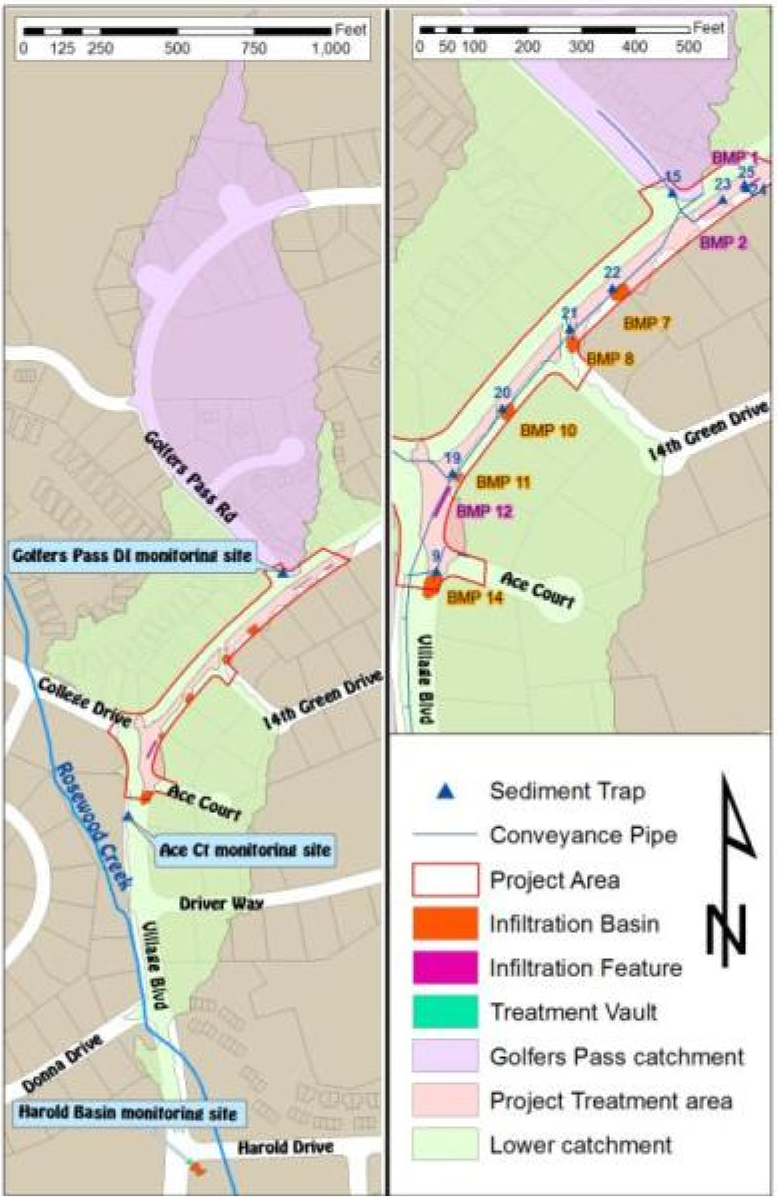


Figure 4. BMP, sediment trap and catchment-scale monitoring locations. Data from Golfers Pass and Ace monitoring sites was not utilized.

<u>Hardware</u>

Catchment-scale hardware configuration:
The Harold Basin monitoring site (Figure 5) consisted of an ISCO autosampler measuring stage with a flume and pressure transducer which collected.continuous water temperature, conductivity, and turbidity data.

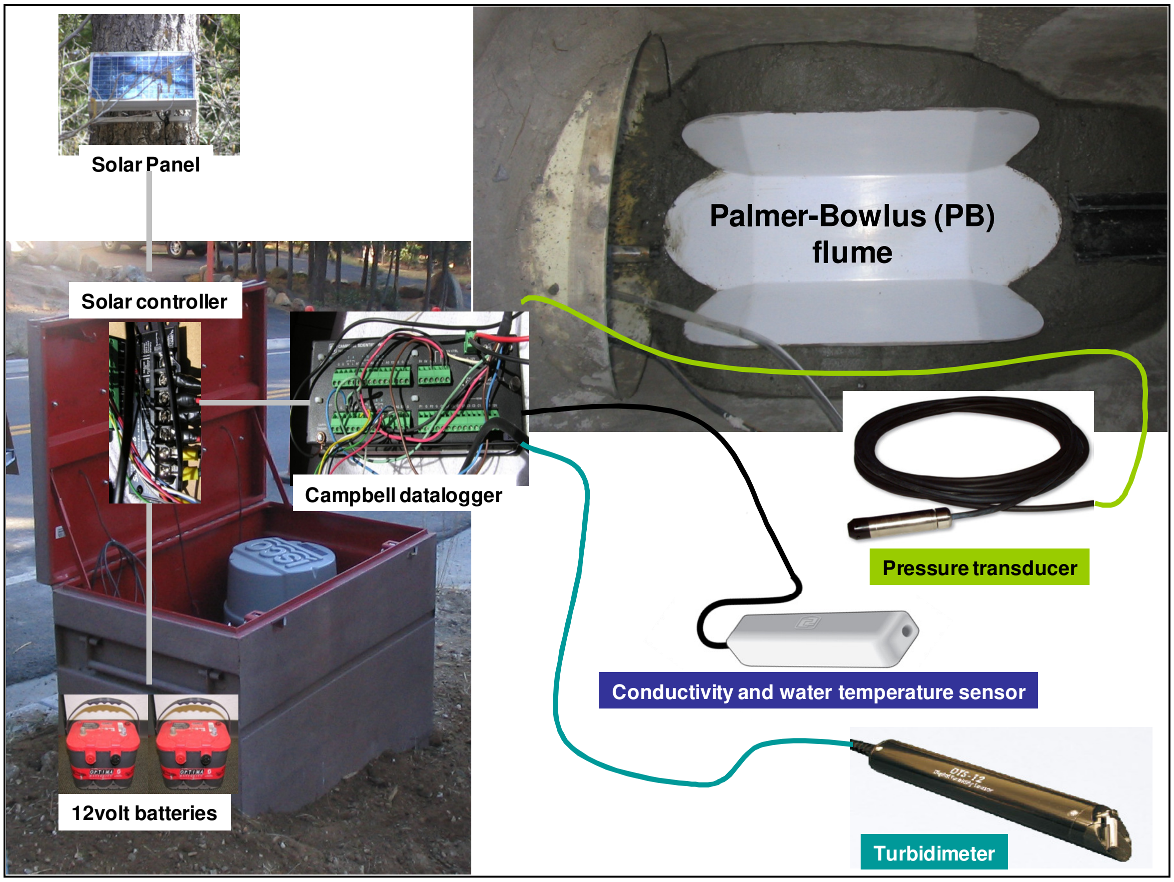


Figure 5. Schematic of the water quality sampling configuration used at the Harold Basin monitoring sites.

BMP scale hardware configuration:
After construction of the LID BMPs, an observation well consisting of a 2 inch PVC pipe was installed vertically in the middle of each rain garden (Figure 6). The pipe was perforated starting 6 inches below the soil for the length of the PVC (Figure 7). A self-contained pressure transducer was suspended in the well, approximately 4 feet below the soil surface. This configuration permitted the depth of water in saturated soil to be monitored. Data was recovered monthly by removing the transducer from the observation well and downloaded to a computer in the field. The data was subsequently adjusted using barometric data corrections. Stage was measured at BMP 1 by suspending the pressure transducer through the BMP inspection port since it was designed as a subsurface infiltration gallery.

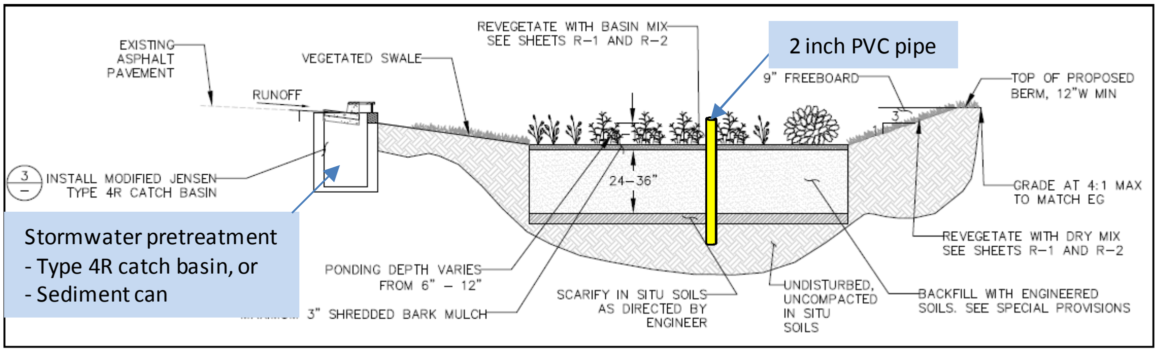


Figure 6. Sample location for Hybrid BMP (i.e., basin) scale sampling. Water quality samples were typically collected from the stormwater pretreatment asset. A pressure transducer was installed in an observation well in the middle of the basin.

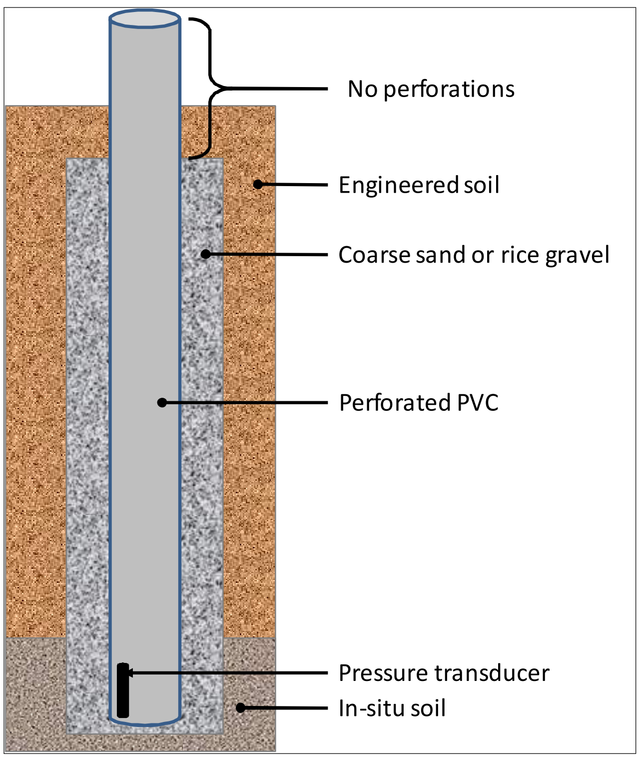


Figure 7. Schematic of the observation well and pressure transducer configuration for the LID BMPs.

Precipitation

The Tahoe-Truckee Airport weather data provided by Weather Underground (http://www.wunderground.com/weatherstation/WXDailyHistory.asp?ID=KTRK) was utilized to provide a hyetograph for the monitoring period. Although the Truckee-Tahoe Airport site is lower in elevation by 700 feet and greater than 10 miles away, it was the closest site with consistent and complete data. Both the Tahoe-Truckee Airport and the Incline Creek weather station operated by the Western Regional Climate Center (http://www.wrcc.dri.edu/weather/incc.html) were utilized to provide daily summer and winter precipitation totals and provide context for stormwater runoff data collected in the study area. The Incline Creek weather station data was used when available for specific results as discussed in the Results for the individual sections. The Incline Creek station, while located higher in elevation than the project area, is located closer to the project area than the Tahoe-Truckee Airport station and Tahoe storms can be geographically localized.

The precipitation events were categorized as rain or snowmelt events by NTCD personnel on site. Snowmelt events were categorized as periods of runoff from melting snowfall and melting snowpack. Rain events were categorized as all other precipitation.

Project Tests

This project performed three different experiments: the washoff test, the flood capacity test and the surface infiltration tests. Table 5 provides a summary of the different project tests performed.

Table 5. Project Tests Summary Table

Project Test Name	Brief Description	Test Purpose	Test Location	Water Volume	Water Quality
Washoff Test	Artificial test that applied 12,000 gallons of water to project area	Determine runoff volume reduction as a result of project	Harold Basin, BMP 7, BMP 11	Yes	Yes
Flood Capacity Test	Add known water volume to a BMP until maximum ponding depth achieved, assuming saturated soil conditions attained at BMP capacity	Determine an infiltration rate into the engineered soils and an exfiltration rate out of the engineered soil and into the native soil. Also obtained estimated volume infiltrated.	BMPs 7, 8, 10, 11 and 14; BMP 1 tested for exfiltration rate only	Yes	No
Surface Infiltration Test	Perform surface infiltration tests using the CHP and double ring infiltrometer	Characterize changes in the BMP soil surface infiltration rates over time due to sediment deposition, compaction and/or vegetation establishment	BMPs 7, 8, 10, 11 and 14	No	No
Precipitation Event Data	Collect continuous stage data over the two year monitoring period; collect grab samples during rain/snowmelt events during which runoff entered the BMPs*	Determine if the project BMPs successfully removed 50% of the fine sediment particles from stormwater generated in the project area	Harold Basin, Golfers Pass, BMPs 1, 7, 8, 10, 11 and 14	Yes	BMP 7, BMP 11*
Long Term Performance Measurements	Collect BMP RAM, revegetation and plant mortality data	Install sediment stormwater pre-treatment systems such that Washoe County does not incur an additional maintenance load compared to current practices	BMPs 1, 7, 8, 10, 11 and 14	No	No

*Grab samples and water quality data collected at BMP 7 and BMP 11, water quality data extrapolated to BMPs 1, 8, 10 and 11.

Washoff Test

The washoff test is a low cost method of applying water to a catchment in a controlled, repeatable method that allowed runoff volumes to be compared before and after installation of the BMPs. Before the washoff tests were performed, Washoe County vactored all the sediment traps within the project area. One pre-project and three post-project washoff experiments were conducted. Each washoff test involved 6 discharges of 2,000 gallons (12,000 gallons total) of water from the Washoe County water truck over a 2 hour period. The tests were performed when there was no ice or snow in the road and ideally when sediment mass per unit area was great (like at the end of winter).

A washoff test was performed in September 2011, prior to the LID BMP installation, establishing pre-project conditions for post-project comparison purposes. The water volume measured at the Harold Basin monitoring site from the pre-project test was noted. The difference between the volume applied and measured at Harold was the system "loss" and was considered constant throughout the monitoring period (12,000 gallons applied – 11,388 gallons discharged at the Harold Basin monitoring site = 612 gallons lost). NTCD performed three different washoff tests after the project was constructed and compared the volume recorded at the Harold Basin monitoring site to the pre-rain garden installation volume to calculate the water volume reduction due to the project installation. Village Boulevard was micro-surfaced in August 2011 and no further surfacing occurred during the monitoring period.

Catchment-scale washoff test water volume:
Flow from the washoff tests was measured at the Harold Basin monitoring site. Because each test applied 12,000 gallons of water, the water volume measured at the Harold Basin monitoring site during the pre-project test represented the water volume being stored within the catchment conveyance system and road surface and was assumed to remain constant to estimate the reduction in runoff volume with BMPs installed. The percent volume reduction due to project installation is represented by the equation:

$$\%\ \text{Volume Reduction} = 1 - (\text{post-project volume} \,/\, \text{pre-project volume})$$

NTCD expected a 50% runoff volume reduction as the LID BMPs were designed to capture approximately 50% of the runoff from the project area (Figure 4). A third post-project test was conducted October 15, 2013 to improve confidence in the runoff volume measurement. The Harold Basin monitoring site measured flow every 15 seconds during the first year tests, but was changed to every two minutes for year two to remove the 'noise' associated with the 15 second data.

Experiment:	**Washoff Test** (Harold Basin monitoring site water volume)
Test Period:	Record stage every 15 seconds (year 1) or 2 minutes (year 2) until flow ends (about 180 minutes)
Test Occasions:	One pre-project experiment and three post-project experiments
Test Locations:	Water was applied to the project area. The Harold Basin monitoring site collected stage data.
Analyses:	Calculate water volume from the measured stage
Assumptions/ Conditions	No ice, snow or snowmelt in the road, and loss of water volume to pavement and conveyance assets assumed to remain constant between tests.

Catchment-scale washoff test water quality:
ISCO autosampler water quality samples were collected at the Harold Basin monitoring site during the washoff tests. The ISCO samples were composited (volume-weighted) to establish a single representative sample from which an event mean concentration and total mass washed from the road was calculated. A one-time first flush sample was collected via a grab sample and analyzed in year 2, May 2013. For the purposes of this monitoring effort, the first flush concept, refers to capturing the concentration of pollutants associated with the first wave of stormwater runoff compared with the pollutant concentration in the remaining stormwater runoff. No water quality samples were collected or analyzed during the third post-project test, October 15, 2013. The washoff tests represent the only occasion to sample water quality at the catchment-scale and allow FSP load comparisons between the catchment and BMP-scale. Samples were analysed for Turbidity, Total Suspended Solids (TSS) and Particle Size Distribution (PSD) by the Western Environmental Testing Laboratory (WETLab); however WETLab subcontracted the PSD analysis to DRI who utilized a Micromeritics Saturn DigiSizer for the analysis.

Experiment:	**Washoff Test** (Harold Basin monitoring site water quality)
Sampling Period:	ISCO autosampler collected water quality samples for about 180 minutes. First flush grab sample Year 2, May 2013.
Sampling Occasions:	One pre-project (September 2011) and two post-project during the washoff tests
Sampling Locations:	The Harold Basin monitoring site.
Analyses:	Turbidity, TSS, and PSD
Assumptions/ Conditions:	No recent street sweeping and a relatively heavy sediment mass per unit area on Village Blvd. Road RAM performed before washoff test.

BMP-scale washoff test water volume:
To estimate water volume at the BMP-scale, pressure transducer stage data from the post-project washoff tests was obtained. The pressure transducers were reprogrammed before the washoff tests to obtained data every 30 seconds. Water volume infiltrated was estimated using the individual BMP stage data, porosity and surface area data (see section Flood Capacity Test: Volume Infiltrated Estimate below). The water volume was utilized to estimate the fine sediment particle load sequestered during the washoff tests.

Experiment:	**Washoff Test** (BMP water volume)
Test Period:	Record stage every 30 seconds until water infiltrated out of rain gardens (about 180 minutes to 4 days depending on rain garden)
Test Occasions:	One pre-project experiment and three post-project experiments
Test Locations:	Water was applied to the project area. BMPs 1, 7, 8, 10, 11 and 14 collected stage data.
Analyses:	Calculate water volume from the measured stage, porosity, surface area
Assumptions/ Conditions	No ice, snow or snowmelt in the road, and loss of water volume to pavement and conveyance assets assumed to remain constant between tests.

BMP-scale washoff test water quality:
During the washoff tests, water quality grab samples were collected approximately every 5 minutes from the sediment trap, just below the water surface and near the outlet of BMPs 7 and 11 until inflow to the basin ceased (average 20 samples collected per washoff test). The grab samples were equal-volume composited to establish an approximate mean concentration. A one-time first flush grab sample was analyzed at BMP 7, BMP 11 and the Harold Basin monitoring site for year 2, May 2013. The washoff tests represent the only occasion to sample water quality at the catchment-scale and allow FSP load comparisons between the catchment and BMP-scale.

Experiment:	**Washoff Test** (BMP water quality)
Sampling Period:	Grab samples once every 5 minutes (approximately) for about 90 minutes during washoff tests
Sampling Occasions:	One pre-project (September 2011) and two post-project during the washoff tests
Sampling Locations:	From pre-treatment sediment traps of BMPs 7 and 11
Analyses:	Turbidity, TSS, and PSD
Assumptions/ Conditions:	No recent street sweeping and a relatively heavy sediment mass per unit area on Village Blvd. Road RAM performed before washoff test.

<u>Road Rapid Assessment Methodology (RAM):</u>

NTCD performed Road Rapid Assessment Methodology (RAM) prior to the washoff tests to establish road condition. The Road RAM protocols outlined in the Road RAM Technical Document and User Manual were followed (2NDNATURE LLC *et. al* 2010). The Lake Tahoe jurisdictions are currently participating in a basin-wide *Stormwater Tools Improvement Project* to improve the Lake Clarity Crediting Program tools. As part of that project, Road RAM may undergo changes; however, at the time of monitoring, Road RAM was the accepted road condition assessment protocol.

Three transects representative of the project area based on road risk, abrasive application, and location were established to perform Road RAM. Scores from each transect were calculated and then compared to the washoff test water quality data from similarly located BMP 7, BMP 11 and the Harold Basin monitoring site.

Experiment:	Road RAM
Sampling Period:	Perform Road RAM prior to conducting washoff tests
Sampling Occasions:	Two post-project prior to the washoff tests
Sampling Locations:	Three transects to represent the project area road condition
Analyses:	Calculate Road RAM scores based on the field data collected
Assumptions/ Conditions:	No recent street sweeping and a relatively heavy sediment mass per unit area on Village Blvd.

Bulk Density:

DRI collected bulk density samples (Blake 1965) annually, once immediately after construction and again each monitoring year prior to performing the flood capacity tests. Samples were collected annually at 3 different locations within BMPs 7, 8, 10, 11 and 14. The three discrete bulk density results were averaged by year. The soil samples were obtained with a 1.9 inch (48.5 mm) diameter by 5.0 inch (127.0 mm) high sample sleeve (229.7 cm^3) in a sliding hammer. At the lab, the soil core was dried in the oven at 221°F (105°C) for at least 24 hours. The samples were then removed from the oven and weighed to establish dry mass. Particle density was not measured, but assumed to be 2.65 g/cm^3 to represent a sandy soil. Utilizing the following two equations, both bulk density and soil porosity were calculated annually for the rain gardens.

$$\text{Soil Bulk Density } (\rho_b) = \text{dry mass of soil / total volume of soil (V)}$$

$$\text{Porosity } (\phi) = 1 - \text{bulk density } (\rho_b) \text{ / particle density } (\rho_p)$$

Experiment:	Bulk Density
Test Period:	Follow the guidance in Blake 1965
Sampling Occasions:	Three experiments: once immediately after construction and again on the first and second year anniversary prior to the flood capacity tests
Sampling Locations:	At every basin installed for this project except BMPs 1, 2 and 12.
Analyses:	Obtain samples of known volume and dry in oven.
Assumptions/ Conditions:	Particle density for calculating porosity was assumed to be 2.65 g/ cm^3 based on sandy soil .

Flood Capacity Tests

BMP-scale water volume:

The flood capacity tests consisted of adding known volume of water to an LID BMP from a fire hydrant, without causing erosion, until maximum ponding depth (BMP capacity) was achieved. It was assumed that saturated soil conditions were attained when the BMPs were at capacity. The pressure transducer within each BMP was configured prior to testing to continuously record stage at 30 second intervals until the engineered soils in the BMP are no longer saturated. The pressure transducer data was downloaded after the LID BMPs drained completely. In the lab, the transducer data was analyzed and an infiltration rate (inches per hour) was calculated for both the infiltration from the free standing water to the engineered soils and the exfiltration from the engineered soil to the native soil. A percolation calculation was performed on the transducer data to measure the infiltration rate because it allows water movement through both the bottom and sides of the BMP, thus the measured rate of water level drop in percolation calculation must be adjusted to represent the discharge that is occurring on both the bottom and sides of the BMP (Godwin et al.). That adjustment is called the reduction factor. The percolation rates were established by viewing the stage data hydrograph and locating the peak (start) and low (end) stage height and times for each the infiltration and exfiltration rates. The infiltration rate into the engineered soil was faster than the exfiltration rate into the native soil, thus the start and end points are identifiable on the hydrograph.

$$\text{Infiltration Rate} = \text{Percolation Rate}/\text{Reduction Factor}$$

Where the Percolation Rate is:

$$\mathrm{Pr} = \frac{Hp - Hl}{(Tp - Tl)}$$

With:

Hp = Peak stage height (inches)

Hl = low stage height (inches)

Tp = peak time (minutes)

Tl = low time (minutes)

Where the Reduction Factor is:

$$Rf = \frac{2di - \Delta d}{DIA} + 1$$

With:

di = Initial Water Depth (inches)

Δd = Average/Final Water Level Drop (inches)

DIA = Diameter of the Percolation Hole (inches) or length of rain garden

Three flood capacity tests were performed in the fall following BMP RAM and surface infiltration tests.

Experiment:	**Flood Capacity Test**
Test Period:	Record stage every 30 seconds until stage falls below the lowest elevation of the engineered soil
Test Occasions:	Three tests: once immediately after construction and again on the first and second year anniversary (the same day, but after the double ring infiltrometer tests). Prior to the infiltrometer tests, sample soil to determine bulk density and porosity.
Test Locations:	At every BMP installed for this project except BMPs 2 and 12.
Analyses:	Establish a relationship between the change in water volume as a function of time (dV/dt) to calculate an infiltration and exfiltration rate.
Assumptions/ Conditions:	No ice or snow in the basin and at least 7 days since the last stormwater event.

Volume Infiltrated Estimate:

Estimating the stormwater runoff volume infiltrated per BMP utilized the individual BMP's stage data from the flood test experiments, annual average porosity and surface area. The surface area of each BMP was calculated as an ellipse.

DRI calculated porosity of the engineered soils based on bulk density samples (*Bulk Density* section above). Annual average soil porosity values were applied to the water volume equation during the corresponding year. The continuous stage data recorded at each BMP is the last component of estimating the runoff volume infiltrated; however, the volume equation changes according to the recorded stage within the rain garden. When the stage was below the engineered soil and within the native soil, the volume equation was the change in pressure transducer over time multiplied by the BMP surface area multiplied by the native porosity. The native porosity was 0.472 based on the above porosity equation assuming a particle density of 2.65 g/cm3 and a native bulk density of 1.4 g/cm^3 (NRCS Soil Survey). When the stage was within the engineered soil, the volume equation was the change in pressure transducer over time multiplied by the BMP surface area multiplied by the engineered annual average soil porosity. Lastly, when the water level was above the soil surface, the volume equation was the change in pressure transducer multiplied by the BMP surface area. Total water volume in the BMP was the sum of the three different profiles.

$$\text{Water Volume}_{\text{native soil}} = \Delta\text{d} * \text{SA} * \phi_{\text{native}}$$
$$\text{Water Volume}_{\text{engineered soil}} = \Delta\text{d} * \text{SA} * \phi_{\text{engineered}}$$
$$\text{Water Volume}_{\text{above surface}} = \Delta\text{d} * \text{SA}$$
$$\text{Water Volume}_{\text{total}} = \text{Volume}_{\text{native}} + \text{Volume}_{\text{engineered}} + \text{Volume}_{\text{abv surface}}$$

With:

$$\Delta\text{d} = \text{change in pressure transducer over change in time } (\Delta\text{pressure transducer}/\Delta\text{time})$$
$$\text{SA} = \text{BMP surface area of an ellipse}$$
$$\phi = \text{porosity}$$

Calculation:	**Volume Infiltrated Estimate**
Test Data:	Utilizing data from the Bulk Density and Flood Capacity Tests
Sampling Data Occasions:	Three calculations: once immediately after construction and again on the first and second year anniversary utilizing data from the bulk density and flood capacity tests
Sampling Data Locations:	At every basin installed for this project except BMPs 1, 2 and 12.
Analyses:	Utilize the above equation with the average annual porosity, surface area and stage data to estimate the volume infiltrated in each BMP.
Assumptions/ Conditions:	Flood Capacity test volumes are representative of the actual volume infiltrated.

Surface Infiltration Tests

Surface infiltration tests measured changes in the LID BMP soil surface infiltration rates over time due to sediment deposition and/or vegetation establishment. Infiltration was measured with both a constant head permeameter (CHP) and a double ring infiltrometer. The CHP is the recommended BMP RAM method for measuring the infiltration rate (BMP RAM Technical Document) in infiltration basins, but CHPs do not measure infiltration rates at the soil surface as they are installed 4 inches deep within the soil profile. Thus, double ring infiltrometers were also used to calculate the infiltration rate at the surface of the engineered soils. Three CHP tests per rain garden were conducted following the BMP RAM User's Manual guidance (2NDNATURE *et al.* 2009). Three double ring infiltrometer tests per rain garden were conducted following modified ASTM 3385 09 Standards as described in Appendix E of *Low Impact Development Manual for Michigan* (SEMCOG 2008). The three tests were averaged to provide an infiltration rate for the CHP and double ring infiltrometer at each rain garden. The tests were not performed on BMPs 1, 2 or 12. The CHP and double ring infiltrometer tests were performed three times; first, immediately after the BMPs were constructed (November 2011), second, after one calendar year, and third, after two calendar years.

Experiment:	**Surface Infiltration Test**
Test Period:	Follow the modified ASTM 3385-09 & BMP RAM User's Manual
Sampling Occasions:	Three experiments: once immediately after construction and again on the first and second year anniversary
Sampling Locations:	At every basin installed for this project except BMPs 1, 2 and 12.
Analyses:	Follow modified ASTM 3385-09 to determine the saturated infiltration rate at the surface of the engineered soils. Follow the BMP RAM User's Manual for CHP use. Perform three tests each occasion and average the results.
Assumptions/ Conditions:	No ice or snow in the basin and at least 7 days since the last stormwater event.

Precipitation Event Data Collection

This subsection describes the data that was routinely collected during precipitation events (rainfall or snowmelt) over the course of the two year monitoring period.

Catchment-scale routine water volume:
The Harold Basin monitoring site, located at the bottom of the catchment, continually measured stormwater runoff volumes from the entire catchment area (Golfers Pass, Project Treatment, Lower catchment) for the two years of this project and for the two years prior to this project (Figure 4). The annual stormwater volume totals allow for pre and post-LID BMP installation stormwater runoff comparison. Figure 8 depicts the runoff flow diagram and the monitoring site locations in relation to the stormwater sources and conveyance system.

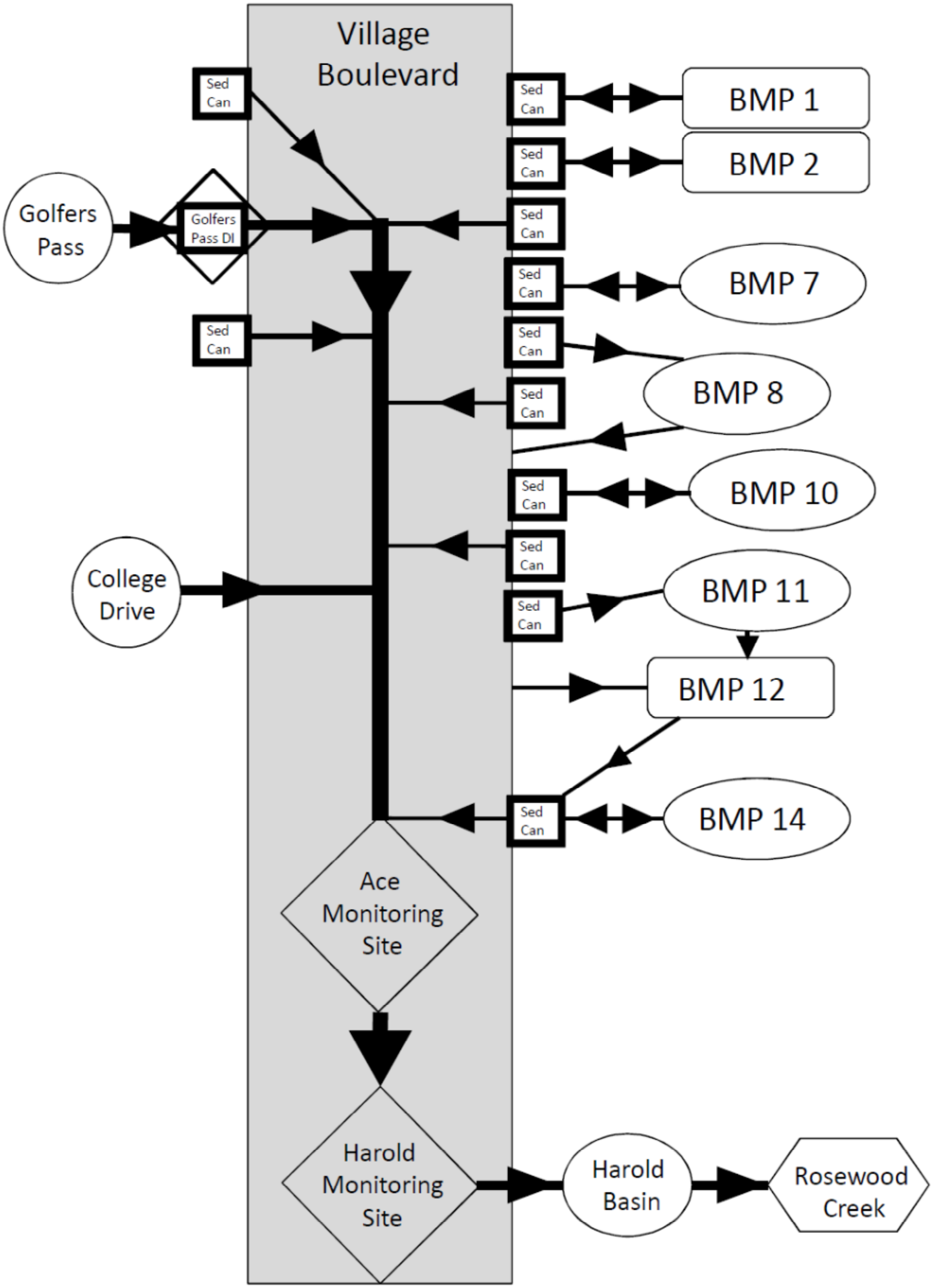


Figure 8. Runoff flow diagram and monitoring site locations. Data from Golfers Pass and Ace monitoring sites was not utilized.

The Golfers Pass catchment provides a significant source of stormwater to Village Boulevard that conveys to the Harold Basin monitoring site, but it has no impact on the project area as the stormwater runoff is within subsurface stormwater conveyance pipes.

Experiment:	**Precipitation Event** (Harold Basin monitoring site water volume)
Test Period:	Continuous 10 minute stage data
Test Occasions:	Process the data every 3 months
Test Locations:	The Harold sampling site
Analyses:	Compare the Harold annual pre verse post-BMP volume
Assumptions/ Conditions:	The Harold volume was reduced due to the BMPs installation

BMP-scale routine water volume:
Continuous stage was measured with a pressure transducer programmed to a 5 minute time step at all BMPs except BMP 2 and 12. The volume of water infiltrated in the rain gardens and BMP 1 was estimated using the surface area of the LID BMP, annual average porosity and stage data as described in the Volume Infiltrated Estimate section above. The volume infiltrated was calculated per precipitation event and on an annual basis.

Experiment:	**Precipitation Event** (BMP water volume)
Test Period:	Continuously record 5 minute stage
Test Occasions:	Process data monthly
Test Locations:	All LID BMPs except BMPs 2 and 12.
Analyses:	Stormwater infiltrated on a 5 minute time step and total volume reported per precipitation event and annually
Assumptions/ Conditions:	Direct stormwater inputs to the basin from snow, rain, and cast-off constitute a negligible volume

BMP-scale routine water quality:
Precipitation event driven stormwater water quality samples were periodically collected to establish a range of TSS concentrations, FSP, and turbidity values. These data provided an estimated range of mass sequestered by the LID BMPs. Stormwater samples were collected as grab samples when runoff volume was entering the sampled BMPs. Event hydrographs (Appendix C) indicate that samples were collected at all times along the hydrograph.

BMPs 7 and 11 were sampled and the water quality analyzed over the two year period. Samples were collected for precipitation events: 8 rain and 3 snowmelt runoff events per BMP in 2012 and 6 rain and 4 snowmelt events per BMP in 2013. A total of 42 grab samples were collected. During the monitoring period, NTCD personnel witnessed no significant stormwater overflow or bypass from any BMP.

Experiment:	**Precipitation Event** (BMP water quality)
Sampling Period:	Precipitation: rain or snowmelt
Sampling Occasions:	Precipitation event samples per BMP annually 2012: 8 rain and 3 snowmelt event samples 2013: 6 rain and 4 snowmelt event samples
Sampling Locations:	BMPs 7 and 11

Analyses:	Turbidity, TSS, and PSD
Assumptions/ Conditions:	There is no significant flux of stormwater or suspended sediment out of the BMP except by infiltration.

Long Term Performance Measurements

BMP RAM:
The BMP RAM, a long term BMP performance testing program, has been established as part of the Lake Tahoe TMDL program and Lake Clarity Crediting Program. The BMP RAM protocols outlined in the BMP RAM Technical Document and User Manual V.1 were followed (2NDNATURE *et. al* 2009). The BMP RAM is currently undergoing changes as part of the *Stormwater Tools Improvement Project*, but at the time of monitoring, BMP RAM was accepted stormwater treatment BMP monitoring protocol.

During the two year monitoring period, BMP RAM was performed twice annually on the BMPs and the sediment traps. It is expected that Washoe County will continue to perform BMP RAM on the *key* or *essential* (as defined in the Lake Clarity Crediting Program Handbook) BMPs per the BMP RAM User's Manual specifications.

All Treatment BMPs listed in the BMP RAM Technical Document have different evaluation criteria with a benchmark value having been established at installation or following complete maintenance to represent desired or baseline conditions. The BMP RAM also establishes a default threshold, for each evaluation criteria, which triggers maintenance action.

BMP 1, 2 and 12 were considered "infiltration features" for the purposes of this monitoring. BMP 1 is an underground infiltration gallery with limited evaluation access, thus only conveyance obstruction was evaluated. BMP 2 and 12 were evaluated according to BMP RAM for percent vegetation cover, conveyance obstruction and infiltration, measured by the presence of standing water 20 seconds following application of 1 liter of water (2NDNATURE LLC *et. al.* 2009 User Manual, pg 41). A 10% maximum percent coverage of any vegetation species is the default threshold for infiltration features. Infiltration tests are performed based on the size of the feature (minimum 3 tests). Tests are a pass/fail test based on the presence of standing water for 20 seconds or longer. Default maintenance trigger threshold for infiltration tests is any failed test. "Infiltration features" may be classified as *supporting* or *key* BMPs according to the Lake Clarity Crediting Program Handbook (Environmental Incentives 2011).

The remaining rain gardens were considered "infiltration basins" and evaluated for percent vegetation composition, conveyance obstruction and infiltration rate using the CHP. A 20% infiltration rate decline from the benchmark and a 20% maximum percent coverage of wetland and riparian species are the default maintenance trigger threshold values for infiltration basins because the overall load reduction capability of an infiltration basin is directly dependent on the rate at which it infiltrates stormwater runoff. "Infiltration basins" may be classified *key* or *essential* BMPs according to the Lake Clarity Crediting Program Handbook (Environmental Incentives 2011).

Sediment traps and drop inlets with 12 inches or greater of sump capacity were considered "sediment traps" according to the *BMP RAM Technical Document* and evaluated for capacity (2NDNATURE LLC *et. al.* 2009). Less than 12 inches of sump capacity remaining is the default maintenance trigger threshold established by the BMP RAM. "Sediment traps" are classified as *supporting* BMPs according to the Lake Clarity Crediting Program Handbook, thus do not require that BMP RAM be performed and tracked as part of the Lake Clarity Crediting Program (Environmental Incentives 2011).

Experiment:	**BMP RAM**
Test Period:	Twice annually for the first two monitoring years.
Test Occasions:	Before winter (likely in conjunction with the flood capacity test) And in the spring (likely in conjunction with the washoff test)
Test Locations:	All LID BMPs plus all pre-treatment sediment traps.
Analyses:	Provide data to BMP RAM
Assumptions/ Conditions:	None

Water Quality Sampling Methods

The sampling methods as described in "Monitoring Plan/Quality Assurance Project Plan for the Hybrid BMP Retrofit for a Primary Roadway" were followed to ensure all samples were verified by standard techniques to assure accuracy and precision of measurements and analyses. All samples were collected using standard methods employed by NTCD and DRI. WETLab, a state of Nevada certified laboratory, processed all samples.

Quality Control

A quality assurance/quality control (QA/QC) program was followed for all aspects of the investigations conducted to ensure accuracy in field data collection, laboratory analysis, and data management. This program included review of datasets and removal of suspect data based on a priori data acceptance guidelines, consistent labeling of samples in the field, archival of laboratory samples and development, use of chain of custody forms, adherence to holding time requirements, and adopted standard protocols for performance of tests and sub-sampling. All field and laboratory results were recorded in electronic spreadsheets and immediately transmitted from WETLab to NTCD. The spreadsheet includes the collection location, time, date, and individual, sample number, analysis date, time, equipment, operator, an indication of field or lab replicates, and analysis results.

NTCD verified that all samples were analyzed appropriately and all data results were provided. NTCD searched for potential data entry errors by graphing the data. NTCD used all water quality data for analysis without removing outlier data due to the small sample size. Field notes and WETLab QA/QC reports do not indicate irregularities or issues with data collection and analysis.

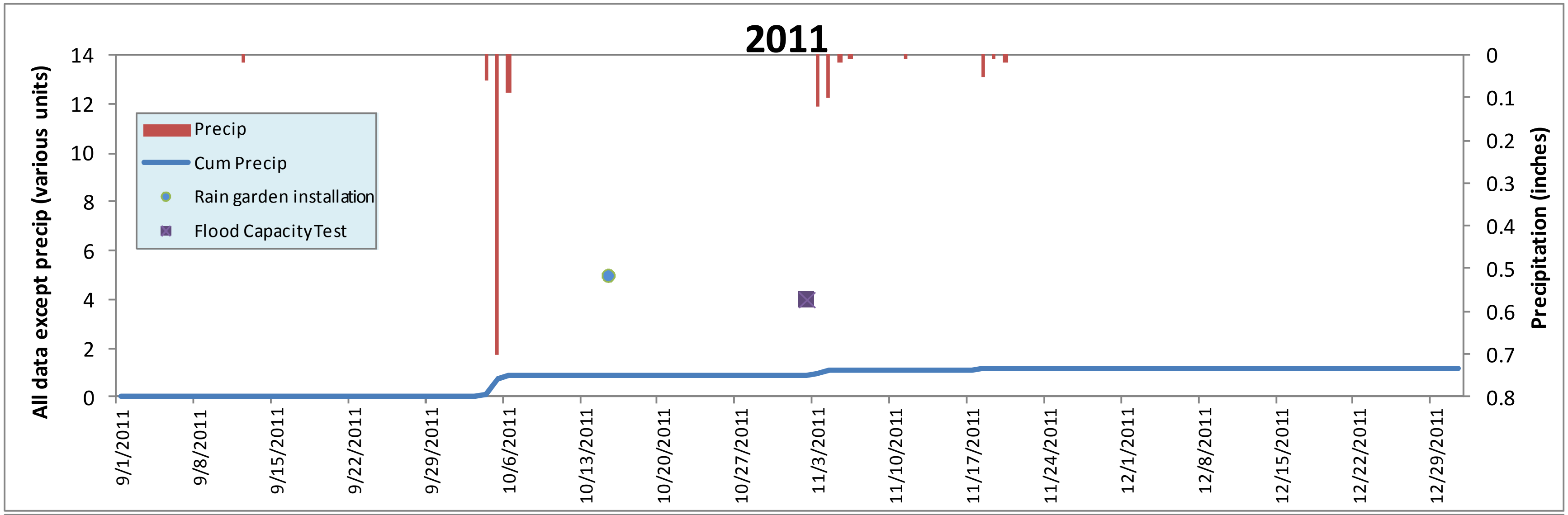
Field QA/QC procedures were followed to ensure sample integrity and assess precision of field sampling techniques. Specific requirements include field decontamination to prevent cross-contamination, thus, the collection of field blanks (distilled water) were collected and analyzed to evaluate sample container integrity and decontamination technique. Field blanks constituted 5% of the total sample count and were submitted to the analytical laboratory in blind form. An additional 14% of samples were duplicates and submitted for evaluation (Table 6).

Table 6. Summary of original, QA/QC samples, and total samples analyzed.

Sample Origin	Scale	Samples	QA/QC samples	Total samples analyzed
Washoff	Basin	4 composited (2 washoff tests collected from BMP 7 & BMP 11)	None	4 composites
	Catchment	2 composited (2 washoff tests collected at Harold)	None	2 composites
Routine	Basin	42 grab samples (11 in 2012 and 10 in 2013 samples from one basin; sample BMP 7 & BMP 11)	- Six duplicate samples (4 in 2012, 2 in 2013) - Two field blank	50 (42 normal, six duplicates, and two field blanks)
	Catchment	None	None	None
Totals		48 samples	8 (above 10% required for QA/QC)	56 total individual samples analyzed

CHRONOLOGY OF MONITORING ACTIVITIES

To better appreciate the context of the data that is presented in the following Results section, a chronology of samples and precipitation is provided in Figure 9. Figure 8 represents a hyetograph of data collected by Weather Underground from the Truckee-Tahoe Airport (KTRK) at an elevation of 5899 feet for part of 2011 and all of 2012 and 2013. The precipitation represents daily accumulation of both rain and snowfall events. The collection dates for rain and snowmelt events indicate grab samples collected and analyzed for total suspended solids (TSS), turbidity and particle size distribution (PSD).


2011
All data except precip (various units)
Precipitation (inches)
Precip
Cum Precip
Rain garden installation
Flood Capacity Test
9/1/2011
9/8/2011
9/15/2011
9/22/2011
9/29/2011
10/6/2011
10/13/2011
10/20/2011
10/27/2011
11/3/2011
11/10/2011
11/17/2011
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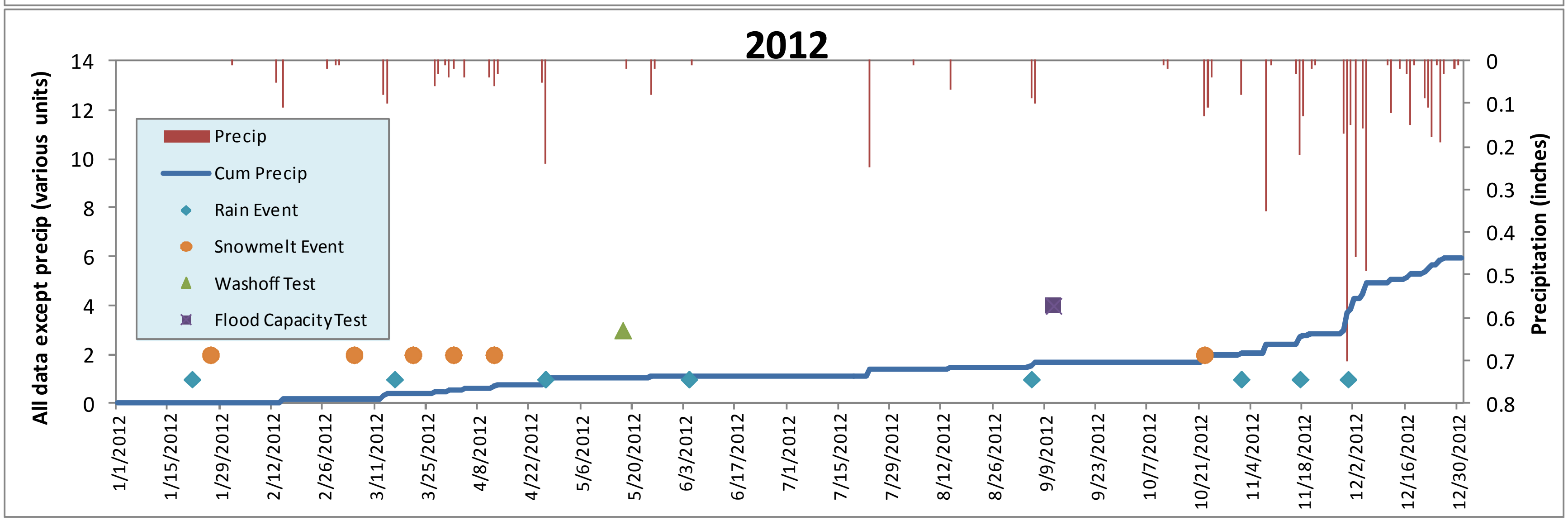
12/15/2011
12/22/2011
12/29/2011


2012
All data except precip (various units)
Precipitation (inches)
Precip
Cum Precip
Rain Event
Snowmelt Event
Washoff Test
Flood Capacity Test
1/1/2012
1/15/2012
1/29/2012
2/12/2012
2/26/2012
3/11/2012
3/25/2012
4/8/2012
4/22/2012
5/6/2012
5/20/2012
6/3/2012
6/17/2012
7/1/2012
7/15/2012
7/29/2012
8/12/2012
8/26/2012
9/9/2012
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12/2/2012
12/16/2012
12/30/2012

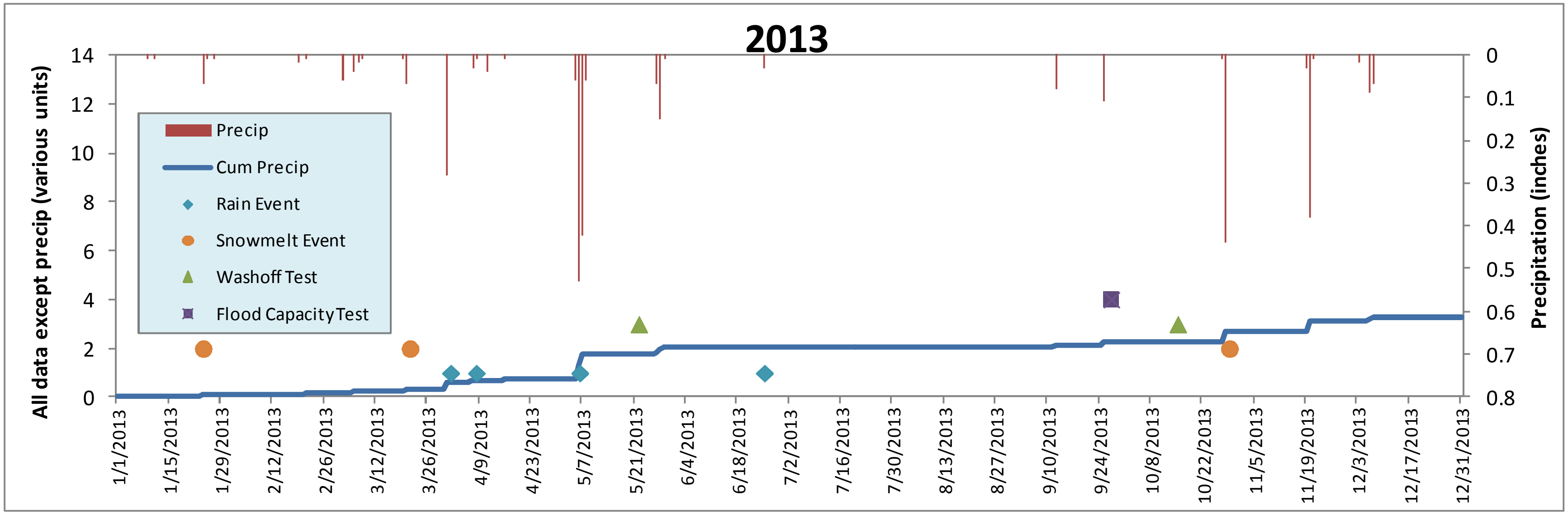


Figure 9. Chronology of events in 2011, 2012 and 2013. Note 2011 is from September to December only.

RESULTS

Project Tests

<u>Road RAM</u>

The Nevada Tahoe Conservation District performed Road RAM once a year on the Hybrid BMP Project prior to the washoff tests to establish road condition. After performing Road RAM on a 10,000 square foot section of road and entering the field observations into the Road RAM database (http://www.tahoeroadram.com), the resulting RAM score was used to express road condition using a continuous 0-5 scale (Table 7).

Table 7. Road RAM scores relative to road condition and relative risk to downslope water quality.

Road RAM Score	Condition	FSP Concentration (mg/L) range	• Description
0 - 1.0	Poor	1,592-680	• Significant potential risk to downslope water quality should runoff event occur • Road maintenance practices require immediate improvements • Capital improvement projects downslope may need to be considered to capture road generated pollutants
>1.0 - ≤ 2.0	Degraded	679-291	• Likely potential risks to downslope water quality • Road maintenance practices require immediate improvements • Capital improvement projects downslope may need to be considered to capture road generated pollutants
> 2.0 - ≤ 3.0	Fair	290-124	• Road condition is closer to degraded than desired, may pose downstream water quality risk • Road maintenance should be prioritized as needed if time and resources permit
> 3.0 - ≤ 4.0	Acceptable	123-53	• No immediate risk to downslope water quality should runoff event occur • Minimal need to improve road maintenance practices
> 4.0 – 5.0	Desired	52-23	• Maximum achievable road condition • No need to improve road maintenance practices

Village Boulevard ranged in road condition from Fair to Desired depending on the year and section of road (Table 8). Washoe County performed street sweeping each year prior to Road RAM. Precipitation events of varying intensity and duration also occurred both years prior to Road RAM being performed. The May 22, 2013 higher scores indicate slightly better overall road conditions. NTCD anticipated higher Road RAM scores based on recent Washoe County street sweeping activity, precipitation events which may effectively wash roads and the lack of visual observation of sediment accumulation along the road matrix.

Table 8. Road RAM results for the two year monitoring period.

Road Segment	Year	Date	Road RAM Score	Condition	Notes
Village/Golfers Pass	Year 1	5/16/2012	2.9	Fair	Washoe County swept on May 11th, rain event May 15th
Village/Golfers Pass	Year 2	5/22/2013	3.3	Acceptable	Rain event May 5th-8th, sprinkles May 9th-10th, Washoe County swept May 14th
Village/14th Green	Year 1	5/16/2012	3.6	Acceptable	Washoe County swept on May 11th, rain event May 15th
Village/14th Green	Year 2	5/22/2013	3.1	Acceptable	Rain event May 5th-8th, sprinkles May 9th-10th, Washoe County swept May 14th
Village/Ace	Year 1	5/16/2012	2.6	Fair	Washoe County swept on May 11th, rain event May 15th
Village/Ace	Year 2	5/22/2013	4.8	Desired	Rain event May 5th-8th, sprinkles May 9th-10th, Washoe County swept May 14th

Washoff Test

The post-project percent water volume reduction was calculated using 11,388 gallons as the total gallons possible to reach the Harold Basin monitoring site. Table 9 shows the percent water volume reduction recorded during each truck washoff with an overall post-project average of 68% water volume reduction. Figure 10 shows the water volume runoff hydrograph; the blue line represents the pre-project volume, which shows higher peaks than subsequent years, representing greater water volume.

$$\%\,Volume\ Reduction = 1 - \frac{Post-project\ Harold\ volume}{11{,}388}$$

Table 9. Washoff test results representing percent volume reduction.

Date	Harold Basin (Gallons)	Percent Volume Reduction
Pre-Project	11388	
Year 1, Spring	2043	82%
Year 2, Spring	5315	53%
Year 2, Fall	3596	68%
Overall Average ->		**68%**

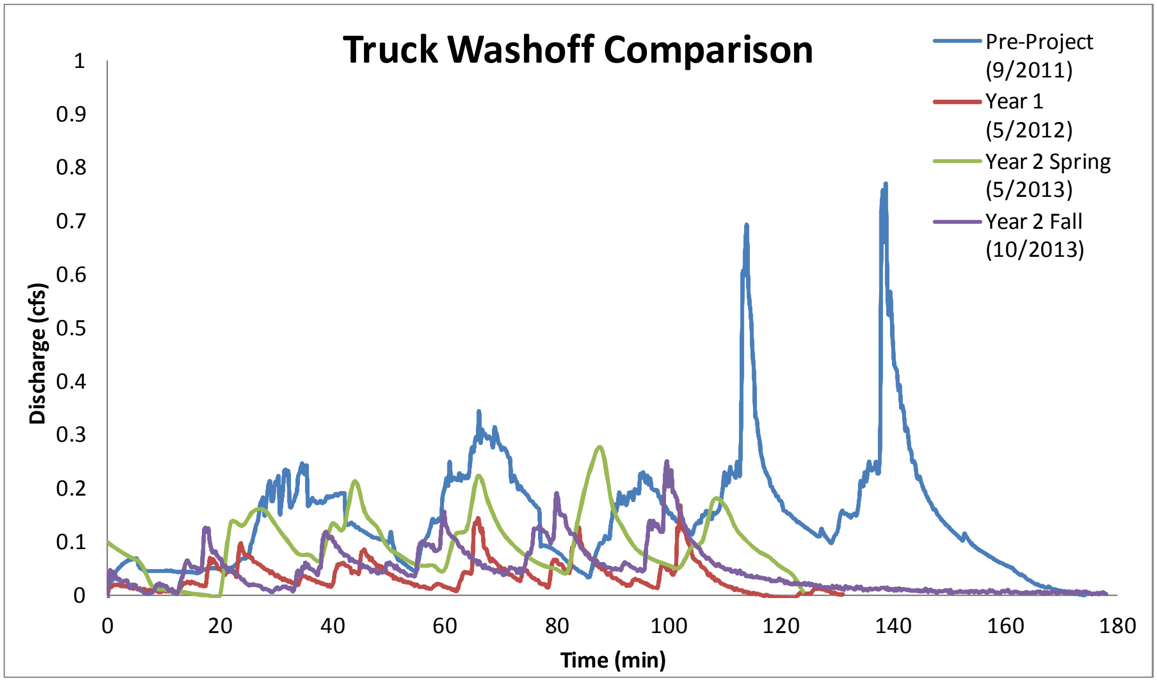


Figure 10. Washoff test comparison hydrographs at the Harold monitoring site.

NTCD collected water quality data (TSS, turbidity and PSD) at BMP 7, BMP 11 and the Harold Basin monitoring site during the 2012 and 2013 spring washoff tests. On average 20 grab samples per washoff test from each BMP 7 and BMP 11 were equal volume composited and analyzed. Samples collected by the autosampler at Harold Basin were flow-weighted composites and event mean concentrations analyzed. First flush samples were collected and analyzed for Year 2 Spring (5/2013). Water quality results are displayed in Table 10 below.

Table 10. Washoff test water quality results, fine sediment load and Road RAM score.

Year	Site	Turbidity (NTU)	TSS (mg/L)	% Finer than 16 µm	Estimated Volume per Site (gallons)	Fine Sediment Load (lbs)	Road RAM score
Year 1	BMP 7	92	320	33	2002	1.7	2.9
Year 1	BMP 11	91	750	39	926	2.3	3.6
Year 1	Harold	180	520	53	2043	4.7	2.6
Year 2	BMP 7	770	550	11	2521	1.2	3.3
Year 2	BMP 11	270	470	22	1182	1.0	3.3
Year 2	Harold	140	382	40	5315	6.8	4.8
Year 2	BMP 7 1st Flush	330	957	25			
Year 2	BMP 11 1st Flush	490	1850	32			
Year 2	Harold 1st Flush	222	600	30			

Turbidity and TSS results are shown in Figures 11 and 12. Using the PSD results, the % Finer than 16 µm was calculated by summarizing the percent frequency of the phi particle size bins from 0.24 µm to 16 µm. The estimated volume per site was calculated using the pressure transducer stage data, surface area and BMP porosity as described in the *Volume Infiltrated Estimate* section.

The TSS result was multiplied by the % Finer than 16µm to estimate the amount of TSS that is comprised of less than 16 µm particles. The Fine Sediment Load (lbs) for the washoff test was calculated by multiplying the TSS by the % Finer than 16 µm and by the estimated volume per site and converted to pounds.

Fine Sediment Load (lbs) = TSS (mg/L) * % Finer than 16µm * Volume (gallons) * 8.3454E-6

A Fine Sediment Load was calculated for the washoff test samples collected in Year 1 and Year 2 (Figure 13). The Harold Basin results are consistently greater than the BMP 7 and BMP 11 results and the Year 1 BMP 7 and BMP 11 results are greater than the Year 2 results. For each site, both years exceeded the 250 mg/L TSS Surface Water Discharge Limit, but not the 200 Nephelometric Turbidity Units (NTU) turbidity Groundwater Discharge Limit. The turbidity Groundwater Discharge Limit is used for comparison because there is no Surface Water Discharge Limit for turbidity. With so few data points, it is difficult to compare the corresponding Road RAM score to the fine sediment load and draw any conclusions.

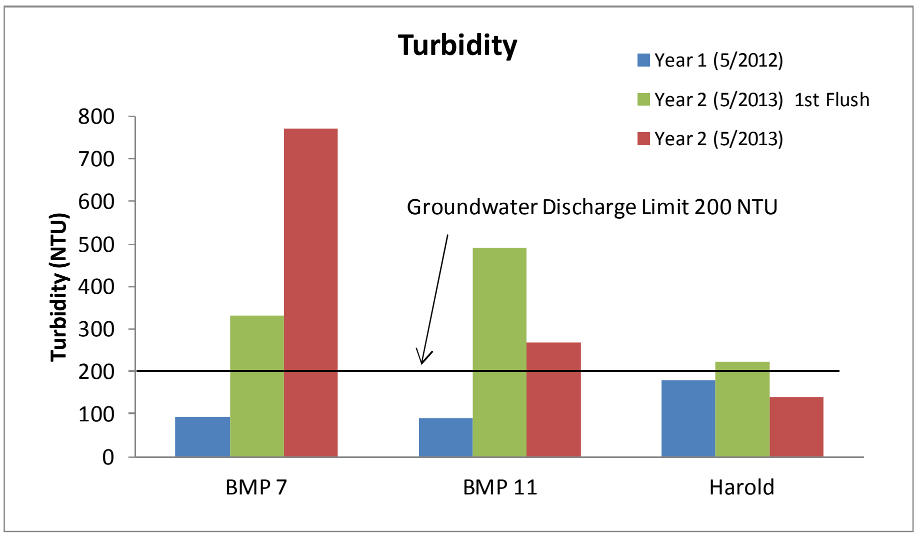


Figure 11. Turbidity results for the washoff tests.

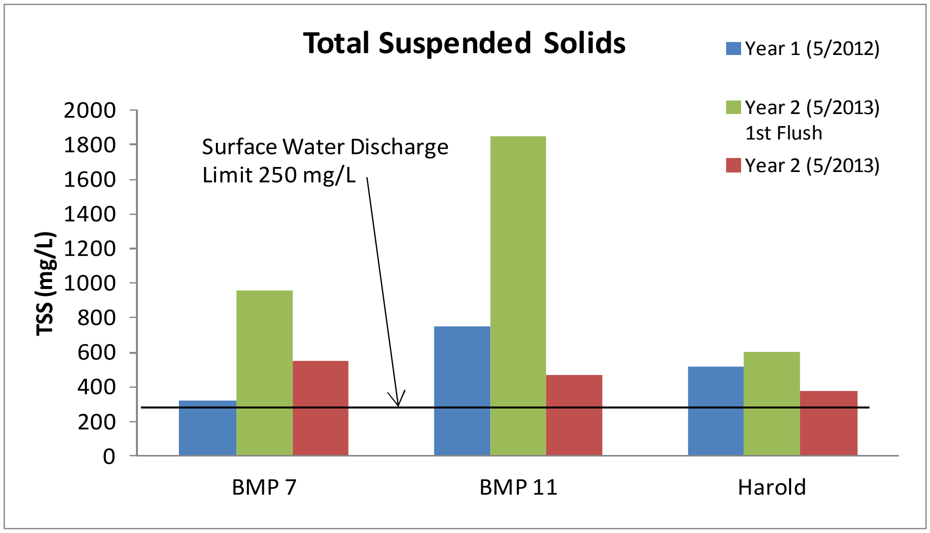


Figure 12. Total suspended solids (TSS) results for the washoff tests.

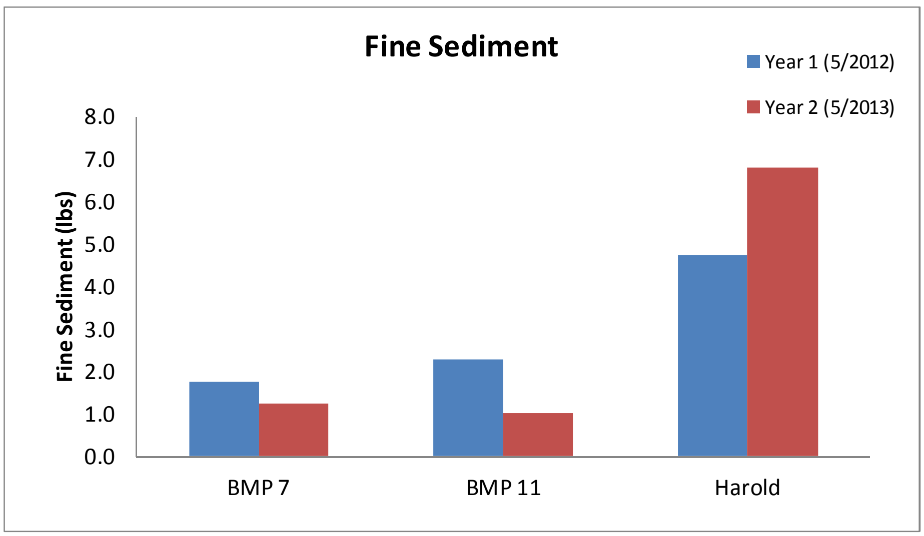


Figure 13. Fine sediment load results for the washoff tests.

Figure 14 shows the PSD profiles representing each water quality sample from each sampling site for the washoff tests. The graph demonstrates the percent volume concentration within each particle bin size. Obviously there are variations in these PSDs, but other than the BMP 7 Yr 2 profile (large spike from 63 µm to 250 µm), visualizing the relevant differences is difficult. Thus, Figure 15 shows the PSD profile for two sites: Harold Year 1 sample with the largest % Finer than 16 µm of 53% and BMP 7 Year 2 sample with the lowest % Finer than 16 µm of only 15%. The area under the curve that is less than 16 µm represents the % Finer than 16 µm (the blue area for BMP 7 Year 2 and the green area for Harold Year 1)

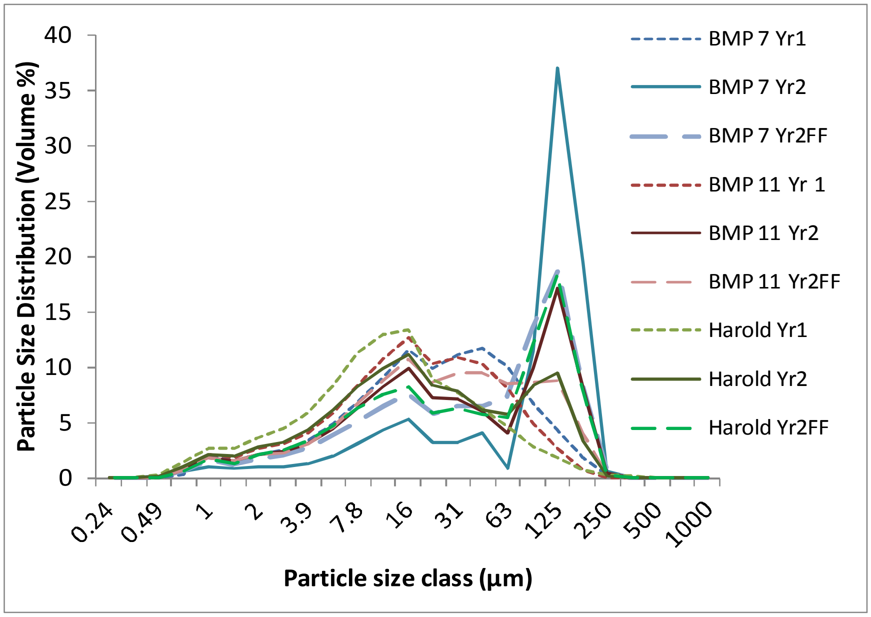


Figure 14. The washoff test particle size distributions of each water quality sample

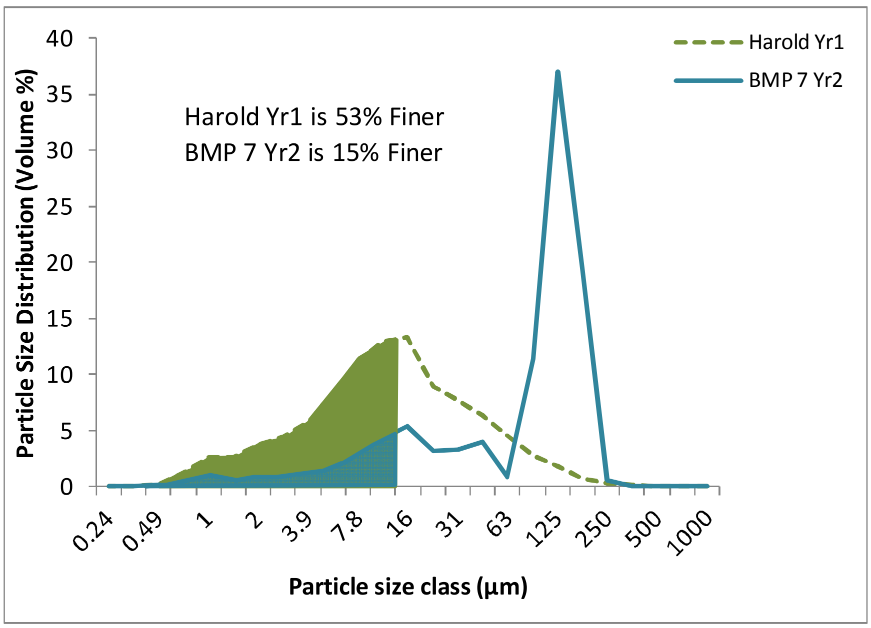


Figure 15. The washoff test particle size distributions for Harold Yr1 and BMP 7 Yr2 comparison.

<u>Bulk Density</u>

Bulk density increased at each BMP compared to the initial installation measurement and porosity decreased. This was expected as the engineered soils in the rain gardens had not been compacted by the flood capacity test prior to bulk density measurements. Additionally, soil compaction was expected as the soils settled and received snow loading. The porosity of each rain garden's engineered soil still remains greater than the 0.472 porosity of the native soil. A major component of rain garden functionality is ensuring the porosity of the engineered soil remains higher than the native soil for infiltration performance which is accomplished with natural processes such as vegetation growth (annual root growth and senescence) and soil organisms (burrowing, humus aggregates). Table 11 shows the averaged bulk density and porosity; Figures 16 and 17 show the bulk density and porosity.

Table 11. Bulk density measurements at each BMP. Native soil bulk density and porosity are 1.4 g/cm^3 and 0.472 respectively.

BMP	Installation (11/2011) BMP Avg. Bulk Density (g/cm3)	Installation (11/2011) Porosity (ϕ)	Year 1 (9/2012) BMP Avg. Bulk Density (g/cm3)	Year 1 (9/2012) Porosity (ϕ)	Year 2 (9/2013) BMP Avg. Bulk Density (g/cm3)	Year 2 (9/2013) Porosity (ϕ)
7	0.659	0.751	1.298	0.510	0.959	0.638
8	0.618	0.767	0.718	0.729	1.083	0.591
10	0.747	0.718	1.013	0.618	1.009	0.619
11	0.836	0.685	1.221	0.539	1.153	0.565
14	0.671	0.747	0.918	0.654	1.065	0.598

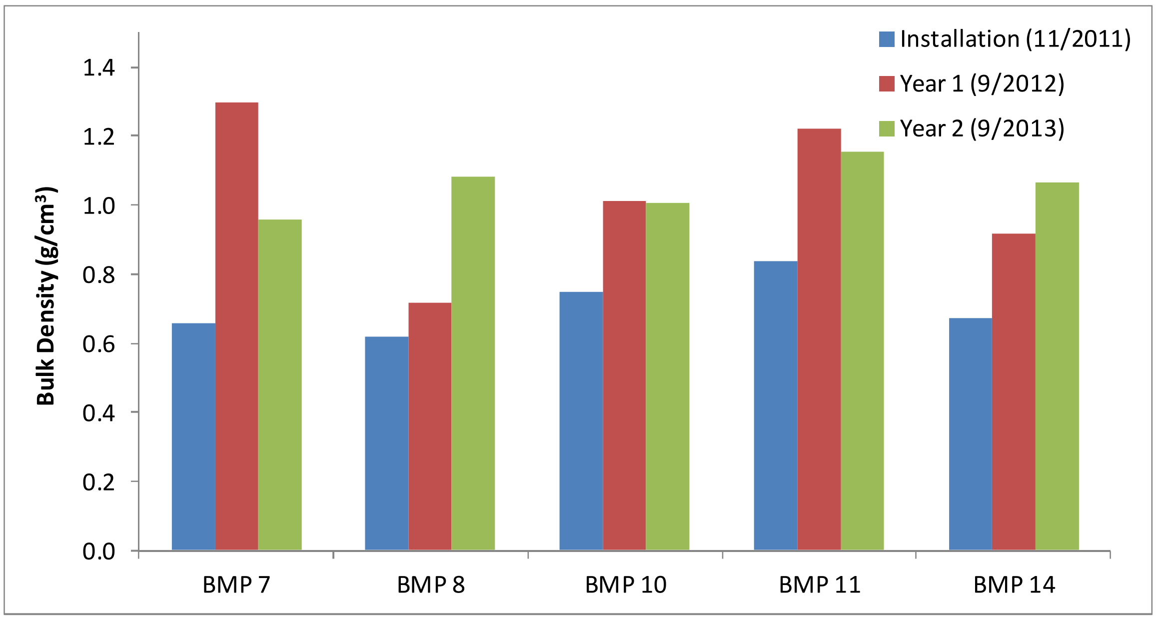


Figure 16. Bulk density comparison at each BMP.

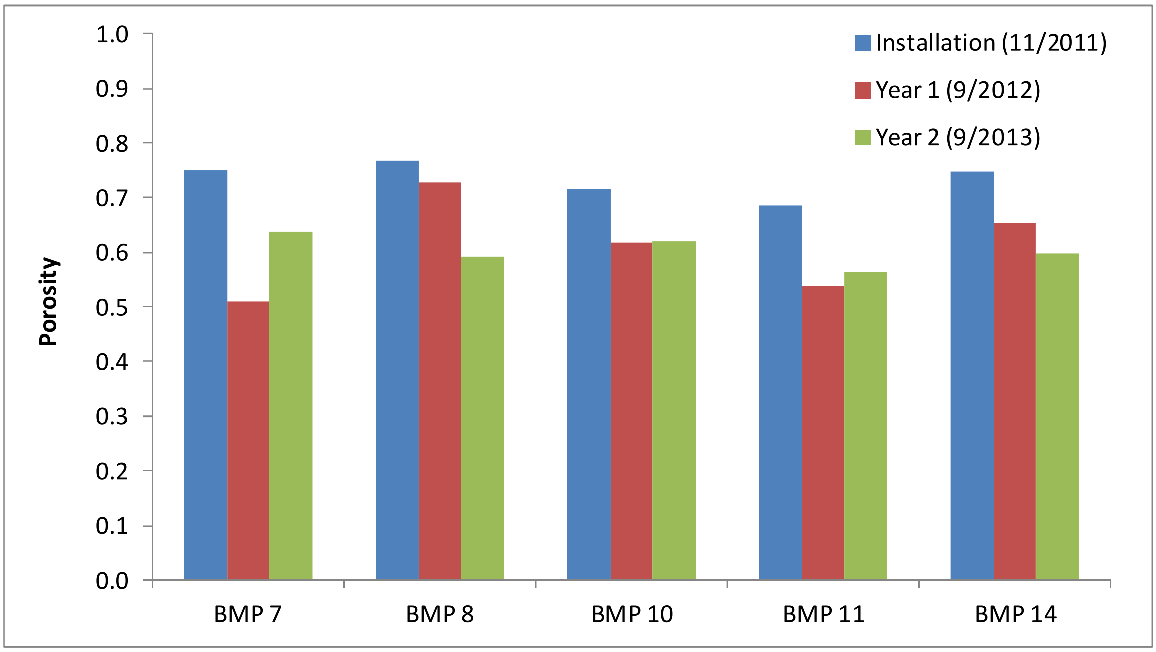


Figure 17. Porosity comparison at each BMP.

Flood Capacity Tests

Flood capacity tests were performed on BMPs 1, 7, 8, 10, 11 and 14 three times over the two year monitoring period: once after installation in November 2011 and once each subsequent year in September. Flood capacity tests provided NTCD with three different sets of data:

1. Water volume (gallons) each BMP could withhold at a certain fill rate before bypassing the system or overflowing.
2. Estimated stormwater runoff volume each BMP removed from the existing EIP conveyance system.
3. Infiltration rate/exfiltration rate of each BMP.

The volume and time it took to fill each BMP to capacity varied for each of the three test events. The volume needed to fill each BMP varied depending on the antecedent soil moisture content, infiltration rate, overall soil porosity and rate of fill. The flood capacity tests documented the known water volume (gallons) each BMP could withhold at that fill rate before bypassing the system or overflowing (Table 12).

Table 12. Flood capacity test results.

Site	11/2011 Fill Height (inches)	11/2011 Gallons to Fill	9/2012 Fill Height (inches)	9/2012 Gallons to Fill	9/2013 Fill Height (inches)	9/2013 Gallons to Fill
BMP 1	24	3060	24	3235	24	2869
BMP 7	6	4000	9.25	5119	11	3680
BMP 8	12	4657	12	4312	11	4480
BMP 10	5.8	979	10.4	1722	10	794
BMP 11	9.5	1649	11.6	2149	11.3	3545
BMP 14	12	6915	12	5692	14	9318

Comparing the known water volume of each BMP obtained from the volume needed to fill the BMPs from the flood capacity test to an estimated water volume infiltrated from the flood capacity tests (using the continuous stage data, surface area and porosity), provided the basis for extrapolating the estimated water volume equation (page 21) to all stormwater runoff events over the two year monitoring period. Using Table 13 below, the first column represents the date of each flood capacity test and column 2 represents the BMP tested. Column 3 (Actual Meter Vol.) shows the water volume capacity of each BMP for each flood capacity test recorded by the water meter. Est. Calculated Vol (column 4) shows the estimated water volume infiltrated based on the continuous stage data.

To determine the accuracy of the estimates and validity of assumptions which were later used to estimate stormwater volume reduction from natural precipitation events, a comparison between the known water volume documented during the flood capacity tests and the estimated stage data water volume was performed per BMP. The actual metered volume and the estimated calculated volume provide a range of volume each BMP can withhold along with providing a percent difference which indicates whether the estimated calculated volume overestimates or underestimates. Figure 18 shows the flood capacity test known water volumes compared to the estimated water volume infiltrated for each BMP.

Table 13. Flood capacity test volumes and Estimated Volume Infiltrated comparison.

Date	BMP	Actual Meter Vol (gallons)	Est. Calculated Vol (gallons)	Percent Difference*
11/10/2011	BMP 1	3060	1688	45%
9/22/2012		3235	1519	53%
9/27/2013		2869	1849	36%
	Average->	**3055**	**1685**	**45%**
11/10/2011	BMP 7	4000	3687	8%
9/22/2012		5119	3393	34%
9/27/2013		3680	3857	-5%
	Average->	**4266**	**3646**	**15%**
11/10/2011	BMP 8	4657	3089	34%
9/22/2012		4312	3263	24%
9/27/2013		4480	3078	31%
	Average->	**4483**	**3143**	**30%**
11/10/2011	BMP 10	979	1867	-91%
9/22/2012		1722	1548	10%
9/27/2013		794	1727	-118%
	Average->	**1165**	**1714**	**-47%**
11/10/2011	BMP 11	1649	1475	11%
9/22/2012		2149	1109	48%
9/27/2013		3545	1324	63%
	Average->	**2448**	**1303**	**47%**
11/10/2011	BMP 14	6915	7145	-3%
9/22/2012		5692	6722	-18%
9/27/2013		9318	8128	13%
	Average->	**7308**	**7331**	**0%**

*Negative percent difference indicates the estimated calculated volume is greater than the actual metered volume

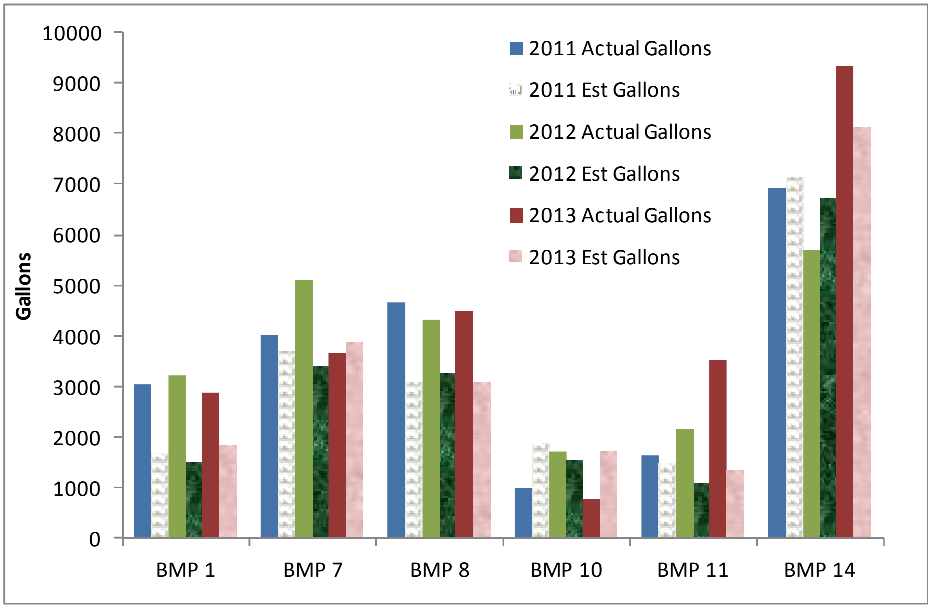


Figure 18. Flood capacity test volume comparison: known volume vs. estimated volume.

The relatively lower volume infiltrated estimates could be a result of how the pressure transducers were installed in the rain gardens. Due to discrepancies between transducer data and field observed stage and suspicions of continually under reporting the stage height, the individual BMP pressure transducers were removed from the PVC after the first year of data collection and tested for accuracy. A manufacturer pressure test determined the pressure transducers were functioning properly. Subsequent investigations revealed that the pressure transducers were reporting the stage height accurately as the manufacturer tests concluded, but that observed water levels within the observation well and rain garden were different. Thus, because the stage height directly correlates to the volume infiltrated, a stage height that was under reporting as compared to observed conditions, resulted in an under estimated volume infiltrated.

This difference in stage height was likely the result of two situations: 1) the rain gardens never achieved full saturation and 2) the stage in the observation well was below the rain garden surface stage due to a lag time caused by the pore space differences between the soil media (40%) and the observation well (100%).

For the water level observed within the rain garden and within the PVC pipe to be equal, the rain garden must be saturated. Considering the variables associated with each rain garden (porosity, vegetation, compaction, engineered/native soil differences), the chances of the stormwater infiltrating uniformly within the rain garden and creating fully saturated conditions were slim. It may have been impossible to achieve saturation during the flood capacity tests. Thus, the stage height recording lower than the observed water level in the rain garden may have been unavoidable.

Alternatively, stage height discrepancies between the ponded rain garden and the observation wells may be explained by the engineered soil porosity and the inherent lag time it creates in transmitting flow. The runoff infiltrates through the engineered soil with voids spaces of approximately 40% before it enters the observation well. The observation well, with 100% void space infiltrates into native soil. Thus, the porosity difference may create a limitation to flow as the observation well has a 100% porosity and infiltrates to native soil. This may help explain the stage height differences and the lag time, as BMP 1 (with no engineered soils or observation well) did not exhibit the stage height differences.

Subtracting the total runoff volume estimates from the real-time runoff volume recorded at the Harold Basin monitoring site yields the project-scale volume reduction results. Figure 4 above showed the project and subsequent catchments; Table 14 below shows the area (0.97 acres) and percent (3%) of the project catchment treated by the LID BMPs.

Table 15 shows the natural precipitation event annual stormwater volume infiltrated estimate over the two year monitoring period at BMPs 1, 7, 8, 10, 11 and 14, along with providing the overall annual sum of the BMPs- *Total BMP Volume*. The *Harold Basin Volume* shows the annual total runoff volume recorded at the Harold Basin monitoring site for 2012 and 2013, and *Total* is the sum of *Total BMP Volume* and *Harold Basin Volume*, thus *Total BMP Volume* divided by *Total* equals the *% Volume Reduction at Harold Basin*. The Hybrid BMP Project reduced the stormwater volume at the Harold Basin monitoring site by 3% and 5% respectively in 2012 and 2013; which corresponds to the project design of the project treating 3% of the overall catchment stormwater runoff volume.

Table 14. Project area as a percentage of catchment (Figure 4).

	Acres	% Area
Project Treatment area	0.97	3%
Golfers Pass catchment	15.36	47%
Lower catchment	16.58	50%
Project catchment	**32.91**	**100%**

Table 15. Stormwater volume reduction at the Harold Basin monitoring site.

Year	BMP 1 (gallons)	BMP 7 (gallons)	BMP 8 (gallons)	BMP 10 (gallons)	BMP 11 (gallons)	BMP 14 (gallons)	Total BMP Volume (gallons)	Harold Basin Volume (gallons)	Total (gallons)	% Volume Reduction at Harold Basin
2012	1,755	21,042	48,933	81,680	20,852	129,128	**303,390**	11,027,123	11,330,513	**3%**
2013	597	7,987	17,279	49,418	3,581	78,687	**157,549**	3,000,297	3,157,846	**5%**

Flood capacity tests, through the continuous stage data, also provided an infiltration rate and an exfiltration rate into the native soil. See the following Surface Infiltration Tests and Exfiltration Test sections for results.

Surface Infiltration Tests

NTCD performed two infiltration tests on the five rain gardens (BMPs 7, 8, 10, 11 and 14). NTCD calculated an infiltration rate from the flood capacity test stage data using the reduction factor associated with a percolation test (Godwin et. al). NTCD also performed: 1) CHP tests; 2) double ring infiltrometer tests and 3) flood capacity tests. Table 16 below shows the infiltration rate results for all three tests at each BMP, while Figure 19 compares the three different infiltration rate analysis methods per BMP. From the table, the CHP results were typically lower than the percolation test and double ring infiltrometer results, except for BMP 14 where the percolation test and CHP measurements were similar. BMP 11 measurements fluctuate the most which correlates with the flood capacity test challenges of not being able to fill the basin to maximum capacity because it drained quickly. Infiltration rates in soils have a high level of natural variability due to soil textures, micro-site characteristics such as root channels, insect burrows, voids around rocks, and soil water repellency, thus analyzing the different infiltration rate methods is a project all its own (NTCD 2014). It is worth mentioning that BMP 14 has the slowest infiltration rate and it received the most stormwater runoff, thus it should be carefully monitored for sediment buildup or performance degradation. BMP 8, having a slow infiltration rate as well, received irrigation from the homeowner's irrigation system, thus the infiltration rate may be reduced due to high soil moisture content. Appendix B shows the individual rain garden hydrographs for the flood capacity tests.

Table 16. Surface Infiltration Test results for each BMP

		BMP 7	BMP 8	BMP 10	BMP 11	BMP 14
Date	Instrument	*Infiltration Rate (in/hr)*				
11/1/2011	CHP	6.32	8.28	8.87	3.75	2.98
9/10/2012	CHP	4.01	3.90	6.13	1.26	1.74
5/21/2013	CHP	3.84	4.38	4.53	3.10	1.95
9/25/2013	CHP	6.74	1.26	3.79	4.84	3.99
11/1/2011	Dbl Ring	10.76	7.91	4.90	8.94	9.22
9/10/2012	Dbl Ring	17.02	3.43	15.67	12.11	6.92
5/21/2013	Dbl Ring	20.87	8.06	9.34	19.93	15.10
9/25/2013	Dbl Ring	14.05	11.58	5.20	8.42	15.06
11/1/2011	Perc Test	18.48	5.31	12.38	19.87	2.10
9/10/2012	Perc Test	13.09	7.56	13.19	43.04	3.26
5/21/2013	Perc Test	-	-	-	-	-
9/27/2013	Perc Test	12.87	11.86	11.75	28.26	2.85
Average (in/hr)=		11.64	6.68	8.70	13.96	5.92
Std Dev =		5.85	3.35	4.08	12.83	5.06
CV =		0.50	0.50	0.47	0.92	0.85

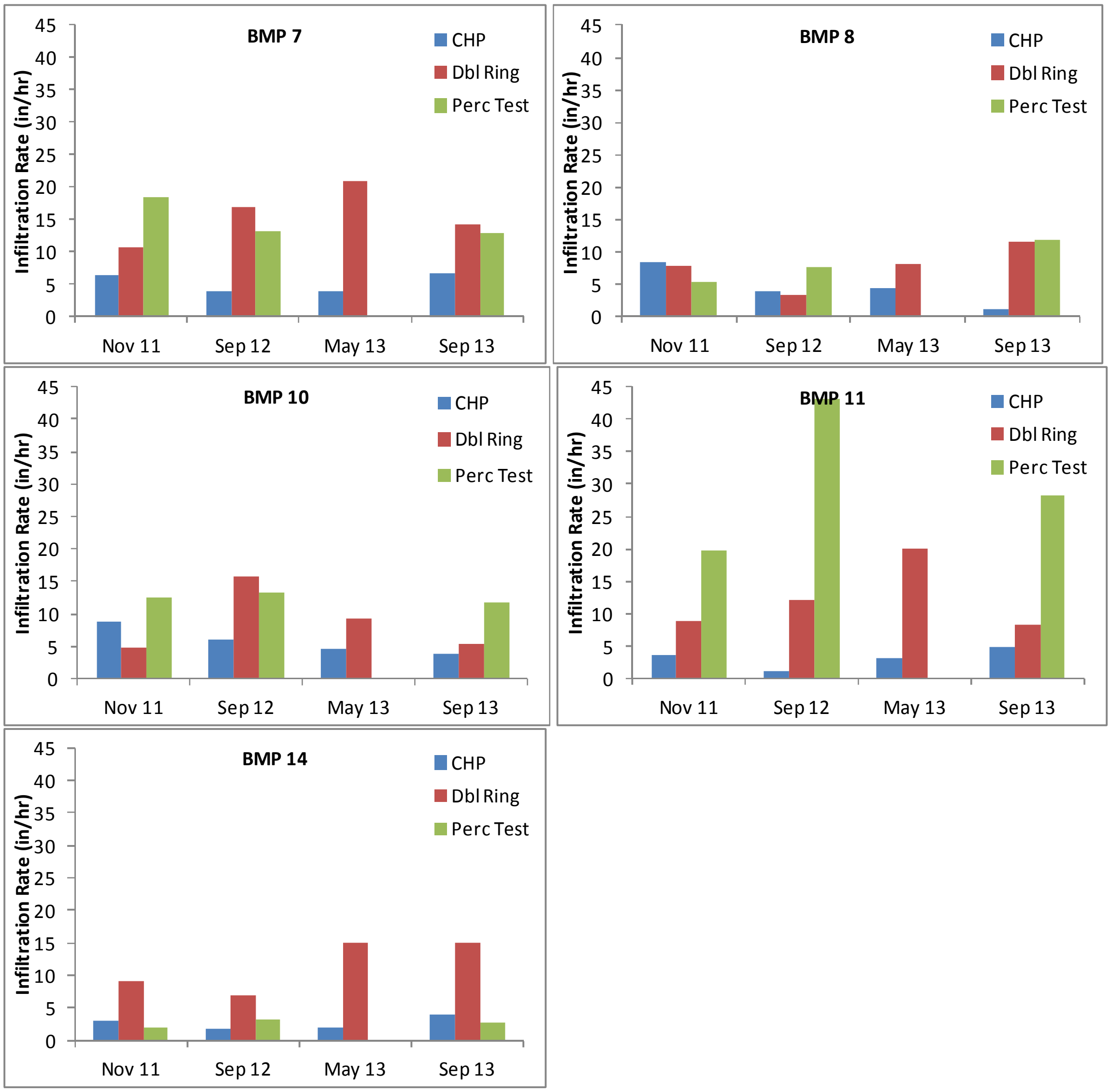


Figure 19. Surface infiltration rates at each BMP.

Exfiltration Test

An exfiltration rate was calculated for each BMP from the flood capacity test stage data using the reduction factor method percolation calculation (page 20)(Godwin et. al). Table 17 and Figure 20 show the exfiltration rates remained quite similar per individual BMP over the two year period, aside from BMP 11 which fluctuated similar to the infiltration rate. It is expected that the exfiltration rate should remain constant since the native soil interface is at depth and not subject to major environmental changes or pollutant loads. As with the infiltration rates, BMP 14 and BMP 8 have the slowest exfiltration rates.

Table 17. Exfiltration rate into the native soil for each BMP.

BMP	Date	Exfiltration Rate (in/hr)
1	11/2/2011	11.28
	9/10/2012	10.23
	9/27/2013	12.63
7	11/2/2011	8.97
	9/10/2012	13.98
	9/27/2013	11.35
8	11/2/2011	3.14
	9/10/2012	3.83
	9/27/2013	4.33
10	11/2/2011	4.75
	9/10/2012	10.08
	9/27/2013	9.04
11	11/2/2011	9.16
	9/10/2012	26.08
	9/27/2013	14.17
14	11/2/2011	1.69
	9/10/2012	1.94
	9/27/2013	2.32

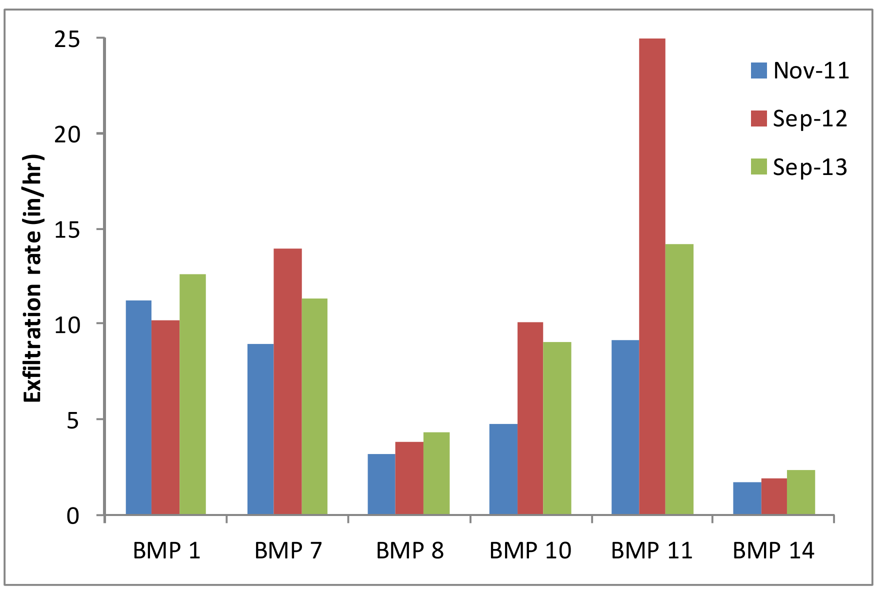


Figure 20. Exfiltration rate comparison for each BMP.

Precipitation Event Data

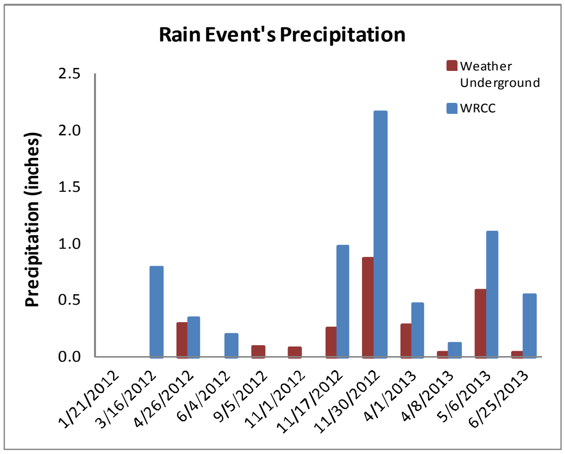
NTCD monitored BMPs 1, 7, 8, 10, 11 and 14 for continuous stage data over the two year monitoring period along with collecting grab samples at BMPs 7 and 11 during precipitation events. The size of the precipitation event did not trigger a sample; but rather, when stormwater runoff filled the pretreatment sediment trap to capacity and flowed into the rain garden, then samples were collected. The grab samples were analyzed for turbidity, TSS and PSD. The precipitation events were categorized as rain or snowmelt events by NTCD personnel collecting the sample. Precipitation records were collected from both the Tahoe-Truckee Airport Weather Underground location and the Western Regional Climate Center Incline Creek location (Tables 18 and 19, Figure 21).

Table 18. Rain event data for routine data collection.

Date	Weather Underground Tahoe-Truckee Airport, Truckee, CA Precipitation (inches)	Western Regional Climate Center Incline Creek, Diamond Peak Incline Village, NV Precipitation (inches)	Notes
1/21/2012	0.00	0.00	rain, but not enough to register
3/16/2012	0.00	0.79	
4/26/2012	0.29	0.34	rain
6/4/2012	0.00	0.20	rain, thunderstorm
9/5/2012	0.09	0.00	rain
11/1/2012	0.08	0.00	rain
11/17/2012	0.25	0.97	rain, including precipitation from 11/16
11/30/2012	0.87	2.16	rain, slush, including precipitation from 11/29
4/1/2013	0.28	0.46	rain, thunderstorm, snow 3/31, melted 4/1
4/8/2013	0.04	0.11	rain, thunderstorm, snow late evening 4/7/13, early morning 4/8/13
5/6/2013	0.59	1.1	rain, thunderstorm
6/25/2013	0.03	0.55	rain

Table 19. Snowmelt event data for routine data collection. Data represents snow water equivalent.

Date	Weather Underground Tahoe-Truckee Airport, Truckee, CA Precipitation (inches)	Western Regional Climate Center Incline Creek, Diamond Peak Incline Village, NV Precipitation (inches)	Notes
1/26/2012	0.00	0.00	
3/5/2012	0.00	0.00	
3/21/2012	0.00	0.00	
4/1/2012	0.02	0.02	snow
4/12/2012	0.10	0.34	snow
10/22/2012	0.13	0.00	rain, thunderstorm, snow
1/24/2013	0.07	0.13	fog, rain
3/21/2013	0.08	0.42	rain, snow
10/29/2013	0.45	0	rain late evening 10/27, snow/slush 10/28



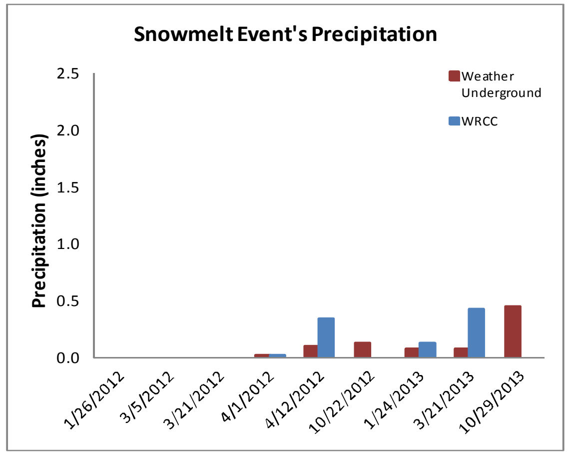
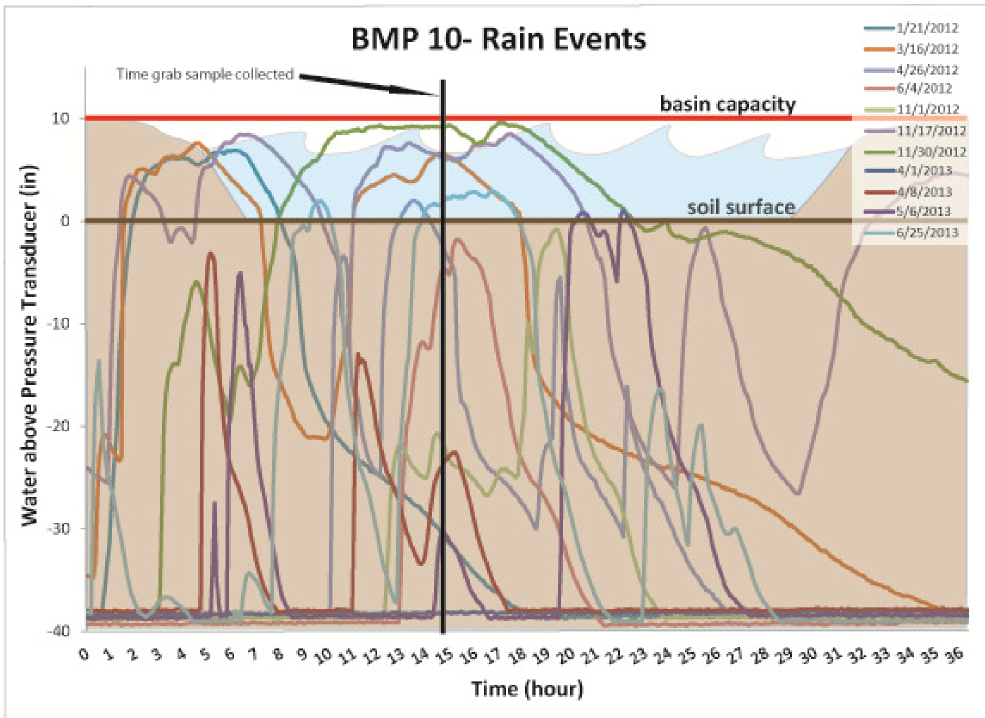


Figure 21. Precipitation event graph comparing both Weather Underground and Western Regional Climate Centers (WRCC) data.

Continuous stage data collection at each BMP allowed for the creation of hydrographs for each sampled rain and snowmelt event. Figure 22 shows the hydrograph for each sampled rain and snowmelt event at BMP 10. Appendix C contains the hydrographs for the other monitored BMPs. The red horizontal line in the graph represents the maximum height the water level was recorded during the flood capacity test (i.e. the rain garden runoff volume capacity). The brown horizontal line represents the rain garden's soil surface.

The black vertical line represents when the grab samples were collected compared to the first flush, rising limb or falling limb of the hydrograph. The first flush differs from the rising and falling limbs in that the first flush is the relatively higher concentration of pollutants associated with the first wave of stormwater runoff compared with the relatively lower pollutant concentration in the remaining stormwater runoff. Ideally, grab samples were collected after the first flush to represent the average water quality, but due to a lack of precipitation events, grab samples were collected when runoff was entering the BMP from the sediment trap.



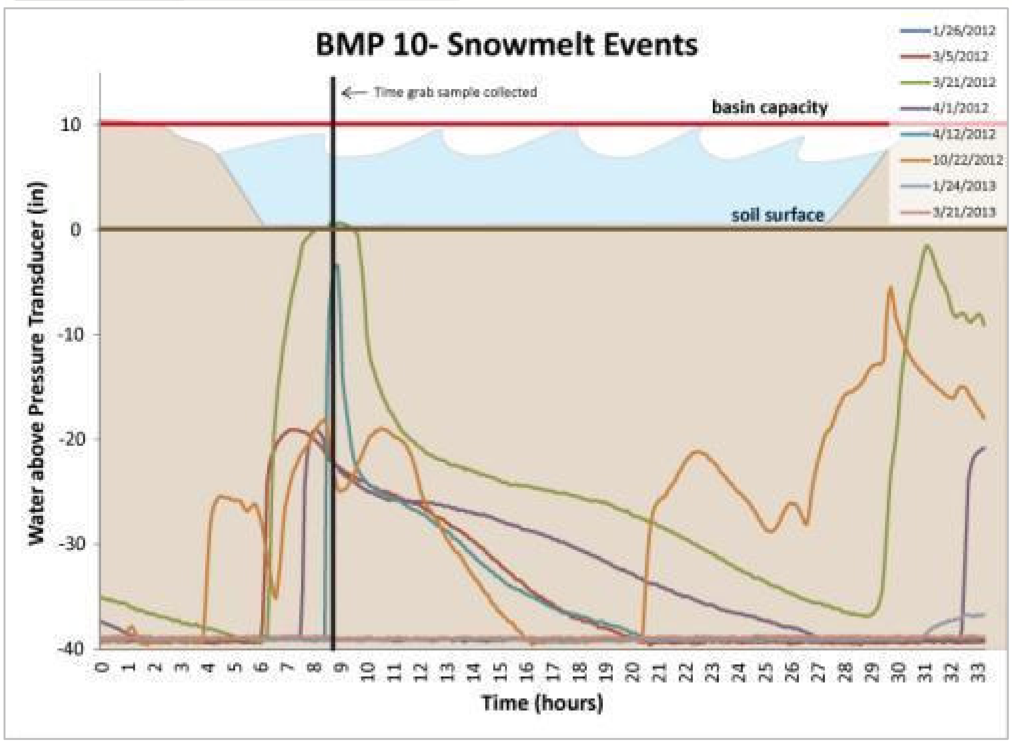


Figure 22. Rain and snowmelt event hydrographs for BMP 10.

The water quality data collected at BMP 7 and BMP 11 during the rain and snowmelt events is shown below in Tables 18 and 19. Due to the small sample size (8 rain and 3 snowmelt in 2012 and 6 rain and 4 snowmelt in 2013), no outlier data was removed. Table 20 shows the average turbidity, TSS and % Finer than 16 µm results for BMP 7 and BMP 11 during rain events were quite similar, only a slight difference in % Finer of 53% and 56% respectively between the two sample sites.

Table 20. Routine data results for BMP 7 and BMP 11 rain events.

		BMP 7 Rain Events			BMP 11 Rain Events		
Count	Event Date	Turbidity (NTU)	TSS (mg/L)	% Finer than 16µm	Turbidity (NTU)	TSS (mg/L)	% Finer than 16µm
1	1/21/2012	58	280	25	16	82	20
2	3/16/2012	86	75	92	150	160	36
3	4/26/2012	57	72	52	66	97	67
4	6/4/2012	48	40	41	38	40	66
5	9/5/2012	100	120	55	98	190	34
6	11/1/2012	18	8	47	20	23	51
7	11/17/2012	51	44	68	43	36	81
8	11/30/2012	26	52	47	16	38	53
9	4/8/2013	55	53	63	39	34	77
10	5/6/2013	120	100	74	150	160	70
11	6/25/2013	28	31	23	25	16	65
	Average	**59**	**80**	**53**	**60**	**80**	**56**
	Std Dev	32	74	21	51	63	20
	CV	0.54	0.92	0.39	0.84	0.79	0.35

The average snowmelt event water quality data at BMP 7 are 137 NTU and 128 mg/L for turbidity and TSS and 103 NTU and 102 mg/L at BMP 11 for turbidity and TSS. BMP 7 and BMP 11 have average % Finer than 16 µm of 62% and 63% respectively (Table 21). The coefficient of variance for BMP 7 snowmelt events is quite large which is due to the January 24, 2013 event results. The January 24, 2013 turbidity and TSS results could be due to the seven week time interval between precipitation events- November 30, 2012 was the previous precipitation event that produced stormwater runoff, meaning there was a seven week time interval for build-up of sediment and debris on the road.

Table 21. Routine data results for BMP 7 and BMP 11 snowmelt events.

		BMP 7 Snowmelt Events			BMP 11 Snowmelt Events		
Count	Event Date	Turbidity (NTU)	TSS (mg/L)	% Finer than 16µm	Turbidity (NTU)	TSS (mg/L)	% Finer than 16µm
1	1/26/2012	77	63	36	94	73	64
2	3/5/2012	13	70	60	6.4	38	35
3	3/21/2012	68	100	43	48	64	63
4	4/1/2012	90	96	76	140	160	86
5	4/12/2012	180	250	61	330	300	74
6	10/22/2012	43	14	28	100	36	81
7	1/24/2013	710	540	90	140	140	69
8	3/21/2013	140	100	86	89	57	91
9	4/1/2013	33	25	85	56	58	37
10	10/29/2013	19	24	60	25	98	29
	Average	**137**	**128**	**62**	**103**	**102**	**63**
	Std Dev	208	160	22	91	81	22
	CV	1.52	1.24	0.35	0.89	0.79	0.35

Figure 23 shows the rain and snowmelt event turbidity and TSS results for BMP 7 and BMP 11. The figures show the highest concentrations in water quality were found during snow events based on the applicable Groundwater and Surface Discharge Limit thresholds.

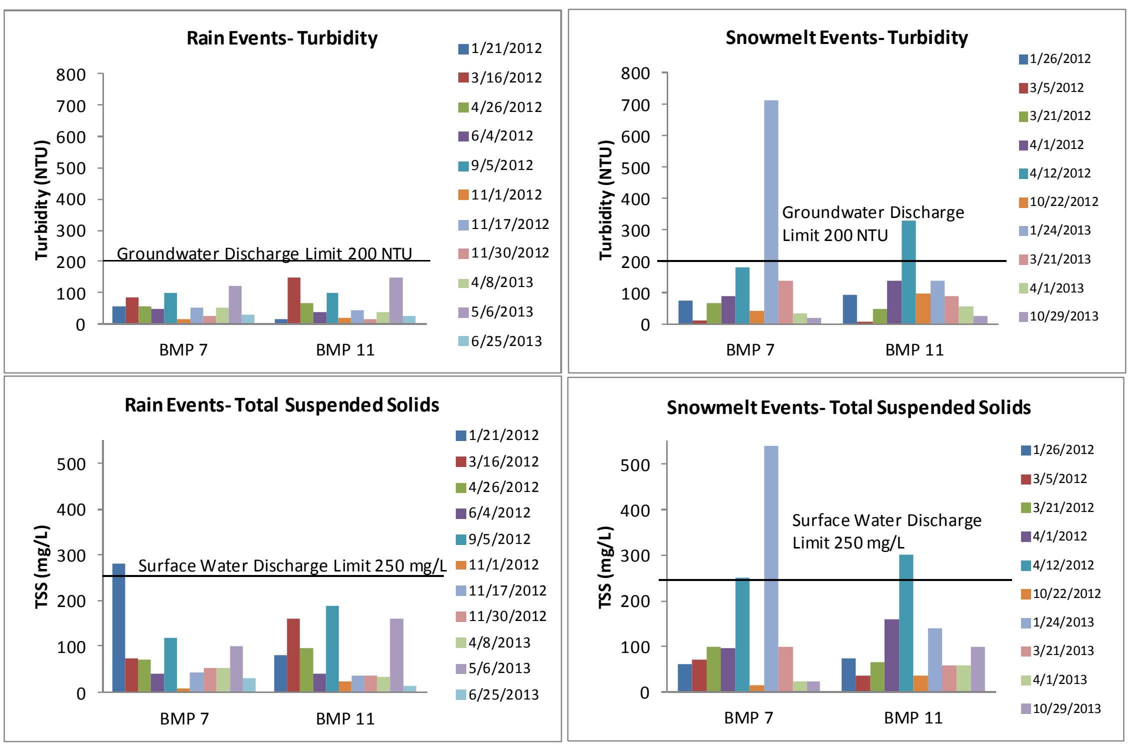


Figure 23. Routine rain and snowmelt result comparisons for turbidity and TSS.

Figure 24 below shows the PSD profiles for all the rain and snowmelt events for BMP 7 and BMP 11. Again, a fair amount of variation exists between the sites, but it is difficult to discern the relevant differences between event samples. Thus, Figure 25 shows the average rain and snowmelt events for BMP 7 and BMP 11, making it easier to identify the PSD differences between the four sites. For example, the BMP 7 average had the highest large particle concentration seen by the large blue arch on the right side of the graph, hence the smallest FSP concentration of the four sets of data at 53%. As described above for Figure 15, the area beneath the curve from 0 to 16 µm represents the % Finer than 16 µm.

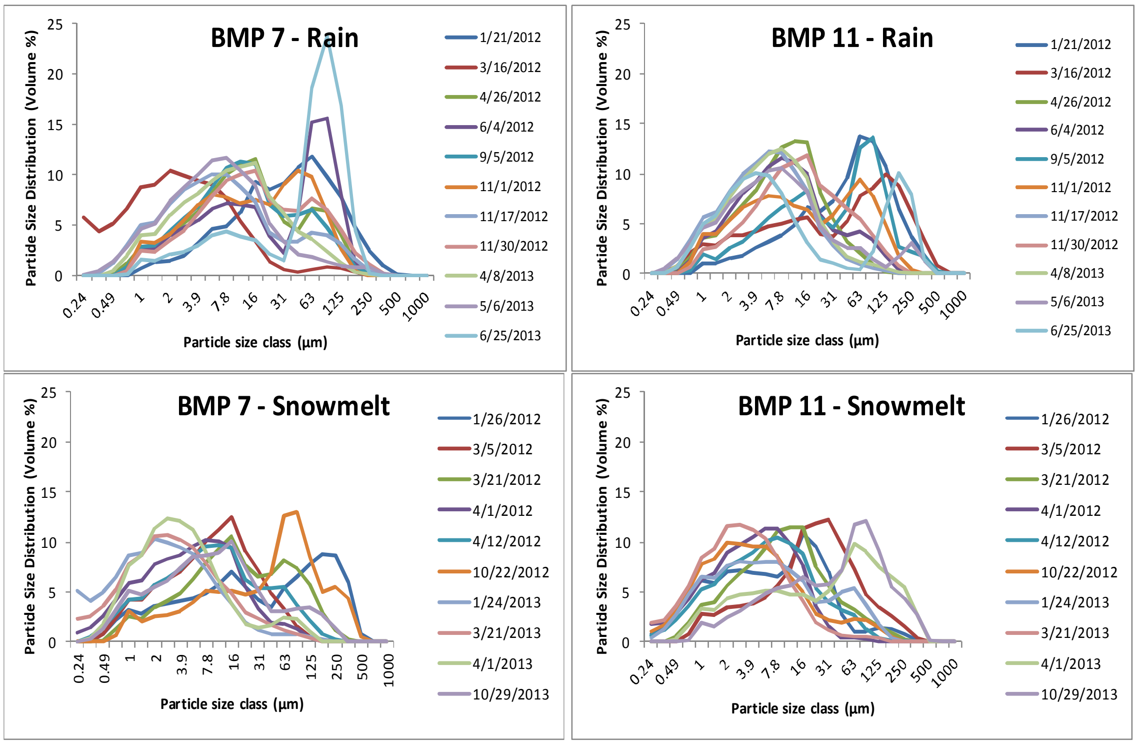


Figure 24. Particle size distribution profiles for BMP 7 and BMP 11 rain and snowmelt events.

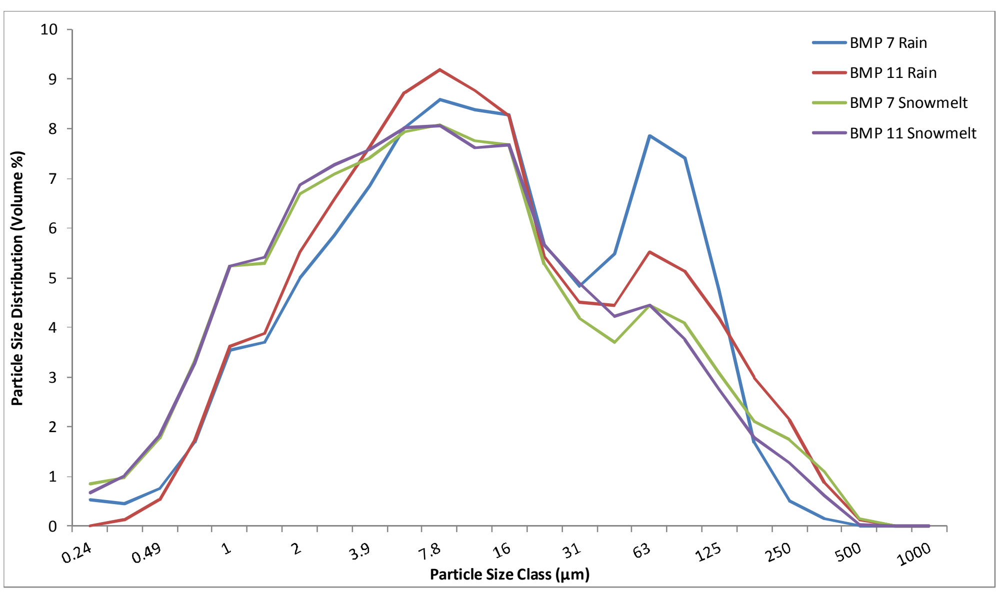


Figure 25. Particle size distribution profiles for the averages of BMP 7 and BMP 11 rain and snowmelt events.

Neither the rain or snowmelt data results show a pattern or similarity between events, which may be attributed to duration and intensity of the event, differences in road conditions (particle accumulation, particle flushing, sediment in the curb, snow/ice present in the curb, ice dams at the pretreatment sediment traps), road operations (sweeping), abrasive application, vehicular traffic, solar radiation, the number of days between precipitation events and when in the hydrograph the sample was collected. The variables are too many to explain water quality differences between events, but the overall averages provide a good picture of project area water quality.

Volume of Stormwater Infiltrated

NTCD estimated the volume of stormwater infiltrated in each BMP using the continuous stage data, porosity, and surface area. Based on the flood capacity test comparisons, the infiltrated stormwater volume is a good estimate and likely underestimated infiltrated stormwater volume by 17%. The volume of stormwater infiltrated and estimated pounds of FSP sequestered are best shown together, see section *Estimated FSP Sequestered* below for volume of stormwater infiltrated results per BMP. The following section will show volume of stormwater and FSP sequestered per BMP per precipitation event sampled and per BMP per annual year.

Estimated FSP sequestered

The estimated volume of water infiltrated per BMP must be calculated first in order to estimate the pounds of FSP sequestered per BMP, thus the data is displayed together in this section. Two different sets of data are displayed, the estimated volume of water infiltrated and estimated pounds of FSP sequestered are shown per BMP per sampling event and annually per BMP.

As mentioned, for each runoff event the volume of water infiltrated was estimated for each individual BMP (1, 7, 8, 10, 11 and 14) using the pressure transducer stage data, the BMP surface area and the soil porosity. The estimated fine sediment load sequestered during each precipitation sampling event was calculated using the following equation:

$$\text{Fine Sediment Load (lbs)} = \text{TSS (mg/L)} * \text{\% Finer than } 16\mu\text{m} * \text{Volume (gallons)} * 8.3454\text{E-}6$$

The estimated water volume infiltrated and the estimated pounds of FSP sequestered at BMP 7 and BMP 11 per precipitation event are shown below in Tables 22, 23, 24 and 25.

Table 22. Estimated water volume infiltrated and pounds of FSP sequestered for BMP 7 rain events.

Count	Event Date	TSS (mg/L)	% Finer than 16µm	Estimated Volume per Site (gallons)	Fine Sediment (lbs)
1	1/21/2012	***280***	25	5	0.00
2	3/16/2012	75	92	9	0.01
3	4/26/2012	72	52	24	0.01
4	6/4/2012	40	41	22	0.00
5	9/5/2012*	120	55	36	0.02
6	11/1/2012	8	47	18	0.00
7	11/17/2012	44	68	5797	1.46
8	11/30/2012	52	47	4159	0.85
9	4/8/2013	53	63	9	0.00
10	5/6/2013	100	74	2469	1.53
11	6/25/2013	31	23	299	0.02
	Average	**80**	**53**		
	Std Dev	74	21		
	CV	0.92	0.39		

*9/5/2012- no stage data available, est. volume based on 11/1/2012 stage data

Table 23. Estimated water volume infiltrated and pounds of FSP sequestered for BMP 7 snowmelt events.

Count	Event Date	TSS (mg/L)	% Finer than 16µm	Estimated Volume per Site (gallons)	Fine Sediment (lbs)
1	1/26/2012	63	36	7	0.00
2	3/5/2012	70	60	44	0.02
3	3/21/2012	100	43	363	0.13
4	4/1/2012	96	76	328	0.20
5	4/12/2012	***250***	61	7	0.01
6	10/22/2012	14	28	15	0.00
7	1/24/2013	***540***	90	9	0.04
8	3/21/2013	100	86	172	0.12
9	4/1/2013	25	85	1513	0.27
10	10/29/2013	24	60	11	0.00
	Average	**128**	**62**		
	Std Dev	160	22		
	CV	1.24	0.35		

Table 24. Estimated water volume infiltrated and pounds of FSP sequestered for BMP 11 rain events.

Count	Event Date	TSS (mg/L)	% Finer than 16μm	Estimated Volume per Site (gallons)	Fine Sediment (lbs)
1	1/21/2012	82	20	981	0.13
2	3/16/2012	160	36	1990	0.96
3	4/26/2012	97	67	673	0.36
4	6/4/2012	40	66	924	0.20
5	9/5/2012*	190	34	6	0.00
6	11/1/2012	23	51	3	0.00
7	11/17/2012	36	81	4443	1.08
8	11/30/2012	38	53	2199	0.37
9	4/8/2013	34	77	5	0.00
10	5/6/2013	160	70	224	0.21
11	6/25/2013	16	65	6	0.00
	Average	**80**	**56**		
	Std Dev	63	20		
	CV	0.79	0.35		

*9/5/2012- no stage data available, est. volume based on 11/1/2012 stage data

Table 25. Estimated water volume infiltrated and pounds of FSP sequestered for BMP 11 snowmelt events.

Count	Event Date	TSS (mg/L)	% Finer than 16μm	Estimated Volume per Site (gallons)	Fine Sediment (lbs)
1	1/26/2012	73	64	4	0.00
2	3/5/2012	38	35	5	0.00
3	3/21/2012	64	63	450	0.15
4	4/1/2012	160	86	550	0.63
5	4/12/2012	***300***	74	419	0.77
6	10/22/2012	36	81	3	0.00
7	1/24/2013	140	69	4	0.00
8	3/21/2013	57	91	4	0.00
9	4/1/2013	58	37	1502	0.27
10	10/29/2013	98	29	4	0.00
	Average	**102**	**63**		
	Std Dev	81	22		
	CV	0.79	0.35		

To estimate the FSP sequestered at BMPs 8, 10 and 14 during the precipitation events, the water quality data (TSS and PSD) from BMP 7 and BMP 11 was extrapolated to those BMPs. Based on similar road operations and road risk, BMP 7 water quality data was used to estimate FSP sequestered at BMPs 1, 8 and 10, while BMP 11 data was used to estimate FSP sequestered at BMP 14. Due to a lack of stage data at BMP 1 during most precipitation events, there is no estimated FSP sequestered per event. The tables below show the estimated water volume infiltrated and estimated pounds of FSP sequestered at BMPs 8, 10 and 14 for rain and snowmelt events (Tables 26, 27, 28 and 29). Figure 26 summarizes the amount of fine sediment sequestered by each BMP during the precipitation events.

Table 26. Estimated water volume infiltrated and pounds of FSP sequestered for BMP 8 and BMP 10 rain events.

				BMP 8		BMP 10	
Count	Event Date	TSS (mg/L)	% Finer than 16µm	Estimated Volume per Site (gallons)	Fine Sediment (lbs)	Estimated Volume per Site (gallons)	Fine Sediment (lbs)
1	1/21/2012	***280***	25	2219	1.28	2084	1.20
2	3/16/2012	75	92	1542	0.89	1381	0.79
3	4/26/2012	72	52	1091	0.34	4285	1.34
4	6/4/2012	40	41	1439	0.20	1654	0.23
5	9/5/2012*	120	55	16	0.01	3396	1.86
6	11/1/2012	8	47	8	0.00	1698	0.05
7	11/17/2012	44	68	9743	2.45	4653	1.17
8	11/30/2012	52	47	5332	1.09	2866	0.58
9	4/8/2013	53	63	10	0.00	2758	0.77
10	5/6/2013	100	74	6614	4.11	3901	2.42
11	6/25/2013	31	23	11	0.00	4507	0.27
	Average	**80**	**53**				
	Std Dev	74	21				
	CV	0.92	0.39				

*9/5/2012- no stage data available, est. volume based on 11/1/2012 stage data

Table 27. Estimated water volume infiltrated and pounds of FSP sequestered for BMP 8 and BMP 10 snowmelt events.

				BMP 8		BMP 10	
Count	Event Date	TSS (mg/L)	% Finer than 16µm	Estimated Volume per Site (gallons)	Fine Sediment (lbs)	Estimated Volume per Site (gallons)	Fine Sediment (lbs)
1	1/26/2012	63	36	5	0.00	5	0.00
2	3/5/2012	70	60	118	0.04	861	0.30
3	3/21/2012	100	43	513	0.18	1818	0.65
4	4/1/2012	96	76	2332	1.42	882	0.54
5	4/12/2012	***250***	61	5	0.01	1720	2.19
6	10/22/2012	14	28	10	0.00	1736	0.06
7	1/24/2013	***540***	90	8	0.03	6	0.02
8	3/21/2013	100	86	5	0.00	1638	1.17
9	4/1/2013	25	85	11	0.00	3321	0.59
10	10/29/2013	24	60	16	0.00	2016	0.24
	Average	**128**	**62**				
	Std Dev	160	22				
	CV	1.24	0.35				

Table 28. Estimated water volume infiltrated and pounds of FSP sequestered for BMP 14 rain events.

				BMP 14	
Count	Event Date	TSS (mg/L)	% Finer than 16µm	Estimated Volume per Site (gallons)	Fine Sediment (lbs)
1	1/21/2012	82	20	6520	0.89
2	3/16/2012	160	36	3034	1.46
3	4/26/2012	97	67	4012	2.17
4	6/4/2012	40	66	4098	0.91
5	9/5/2012*	190	34	3164	1.69
6	11/1/2012	23	51	1582	0.15
7	11/17/2012	36	81	7536	1.83
8	11/30/2012	38	53	4755	0.79
9	4/8/2013	34	77	2191	0.48
10	5/6/2013	160	70	8409	7.89
11	6/25/2013	16	65	2933	0.26
	Average	**80**	**56**		
	Std Dev	63	20		
	CV	0.79	0.35		

*9/5/2012- no stage data available, est. volume based on 11/1/2012 stage data

Table 29. Estimated water volume infiltrated and pounds of FSP sequestered for BMP 14 snowmelt events.

				BMP 14	
Count	Event Date	TSS (mg/L)	% Finer than 16µm	Estimated Volume per Site (gallons)	Fine Sediment (lbs)
1	1/26/2012	73	64	946	0.37
2	3/5/2012	38	35	1384	0.15
3	3/21/2012	64	63	2215	0.74
4	4/1/2012	160	86	1854	2.12
5	4/12/2012	***300***	74	3538	6.53
6	10/22/2012	36	81	2172	0.53
7	1/24/2013	140	69	1264	1.02
8	3/21/2013	57	91	4437	1.91
9	4/1/2013	58	37	6508	1.18
10	10/29/2013	98	29	4442	1.06
	Average	**102**	**63**		
	Std Dev	81	22		
	CV	0.79	0.35		

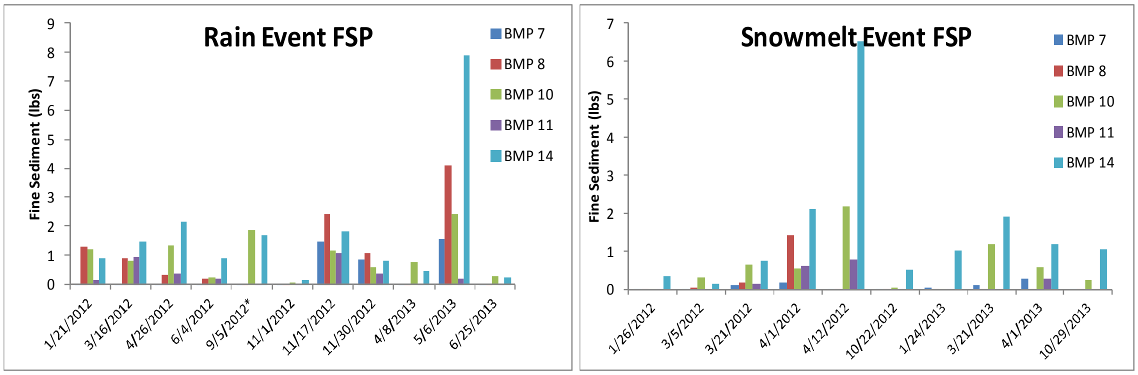


Figure 26. Pounds of estimated fine sediment sequestered by each BMP during the precipitation sampling events.

To estimate the annual water volume infiltrated and pounds of FSP sequestered, BMP 7 and BMP 11 TSS and % Finer than 16 µm data was averaged annually and applied to the other BMPs. Due to the small number of samples and the fact that water quality data was collected as grab samples that were not collected at the same time during the hydrograph, all data was utilized for analysis. The annual average TSS and % Finer than 16µm are shown in Tables 30 and 31 and Table 32 shows the total fine sediment captured by BMPs 1, 7, 8, 10, 11 and 14 per monitoring year.

Table 30. BMP 7 annual average data applied to BMPs 1, 8 and 10 for estimated annual FSP sequestered.

BMP 7	2012			2013			
Count	Event Date	TSS (mg/L)	% Finer than 16µm	Count	Event Date	TSS (mg/L)	% Finer than 16µm
1	1/21/2012	280	25	9	4/8/2013	53	63
2	3/16/2012	75	92	10	5/6/2013	100	74
3	4/26/2012	72	52	11	6/25/2013	31	23
4	6/4/2012	40	41	7	1/24/2013	540	90
5	9/5/2012	120	55	8	3/21/2013	100	86
6	11/1/2012	8	47	9	4/1/2013	25	85
7	11/17/2012	44	68	10	10/29/2013	24	60
8	11/30/2012	52	47		**Average**	**125**	**69**
1	1/26/2012	63	36		Std Dev	186	23
2	3/5/2012	70	60		CV	1.49	0.34
3	3/21/2012	100	43				
4	4/1/2012	96	76				
5	4/12/2012	250	61				
6	10/22/2012	14	28				
	Average	**92**	**52**				
	Std Dev	80	18				
	CV	0.87	0.35				

Table 31. BMP 11 annual average data applied to BMP 14 for estimated annual FSP sequestered.

BMP 11	2012			2013			
Count	Event Date	TSS (mg/L)	% Finer than 16µm	Count	Event Date	TSS (mg/L)	% Finer than 16µm
1	1/21/2012	82	20	9	4/8/2013	34	77
2	3/16/2012	160	36	10	5/6/2013	160	70
3	4/26/2012	97	67	11	6/25/2013	16	65
4	6/4/2012	40	66	7	1/24/2013	140	69
5	9/5/2012	190	34	8	3/21/2013	57	91
6	11/1/2012	23	51	9	4/1/2013	58	37
7	11/17/2012	36	81	10	10/29/2013	98	29
8	11/30/2012	38	53		Average	**80**	**68**
1	1/26/2012	73	64		Std Dev	54	18
2	3/5/2012	38	35		CV	0.67	0.26
3	3/21/2012	64	63				
4	4/1/2012	160	86				
5	4/12/2012	300	74				
6	10/22/2012	36	81				
	Average	**96**	**58**				
	Std Dev	80	20				
	CV	0.84	0.35				

Table 32. Annual pounds of FSP sequestered by BMPs 1, 7, 8, 10, 11 and 14.

	TSS (mg/L)	Convert to lbs/L	Convert to lbs/gallon	Multiple by Annual Runoff Volume (gallons)	TSS by weight (lbs)	% Finer than 16µm	FSP by weight (lbs)
2012							
BMP 1	92	0.000202	0.00077	1755	1.3	52	0.7
BMP 7	92	0.000202	0.00077	21042	16.1	52	8.4
BMP 8	92	0.000202	0.00077	48933	37.5	52	19.6
BMP 10	92	0.000202	0.00077	81680	62.5	52	32.6
BMP 11	96	0.000211	0.00080	20852	16.6	58	9.6
BMP 14	96	0.000211	0.00080	129128	102.9	58	59.5
			Total Fine Sediment Captured (lbs) 2012->				**130**
2013							
BMP 1	125	0.000275	0.00104	597	0.6	69	0.4
BMP 7	125	0.000275	0.00104	7987	8.3	69	5.7
BMP 8	125	0.000275	0.00104	17279	18.0	69	12.3
BMP 10	125	0.000275	0.00104	49418	51.4	69	35.3
BMP 11	80	0.000177	0.00067	3581	2.4	68	1.6
BMP 14	80	0.000177	0.00067	78687	52.8	68	36.1
			Total Fine Sediment Captured (lbs) 2013->				**92**
Conversion = (mg/L)*(gallons)*(1gram/1000mg)*(3.7854 L/1 gallon)*(1 lb/453.592 gram)							
1 Lake Clarity Credit = 200.42 lbs FSP							

Table 32 shows that the estimated quantity of fine sediment sequestered in 2012 as 130 pounds and in 2013 as 92 pounds. The Lake Clarity Crediting Program equates one clarity credit to approximately 200 pounds of FSP. According to the fine sediment sequestered estimates above, over the two year monitoring period, the project area sequestered 222 lbs FSP, which is just over one clarity credit. NTCD performed PLRM for both pre and post-project conditions, PLRM results estimated a 3.75 FSP annual credit (751.5 lbs FSP) reduction for post-project conditions. It's important to note that PLRM utilizes an 18 year annual average precipitation amount to determine modeled results, and the project data was collected during two drought years, with 2013 being the driest year on record (Lake Tahoe News 2013).

Long Term Performance Measurements

Vegetation

Each BMP installed was revegetated with the containerized plants and/or seed mix as shown in Tables 33 and 34. The revegetation was irrigated for two years (except BMP 1). NTCD negotiated right-of-entries with adjacent homeowners to supply the irrigation water for the two year vegetation establishment period. NTCD performed routine maintenance for plant establishment such as weeding, reseeding or replanting and maintaining the irrigation system. NTCD worked with the homeowner adjacent to BMP 8 to establish a visually aesthetic rain garden acceptable to both the homeowner and Washoe County by installing potted plants. Table 35 shows the plant mortality at BMP 8 specifically and Table 36 shows the overall containerized plant survival at the other BMPs. Winter 2011 was a very dry winter with no precipitation or snow cover until January 2012. The winter drought conditions are believed the reason for the plant mortality as the plants were not watered beyond the planting date. BMP 8 deceased plants were replaced, while the plugs (due to unavailability) were replaced with a seed mix containing those species.

BMP 8 is expected to receive continued irrigation per the maintenance agreement with the adjacent homeowner, while the other BMPs will receive no further irrigation beyond the two year establishment period. It is expected that vegetation percent cover will decrease in response to irrigation termination, but it is unknown whether the expected decrease in vegetation percent cover will retain sufficient vegetation to sustain natural processes (annual root growth and senescence, microorganism burrowing, humus aggregate) for continued infiltration.

Table 33. Project containerized plants and species composition.

	PLUGS				
Location	Common Name	Species	Height	Size	Quantity
BMP 7, BMP 10, BMP 11, BMP 14	Mountain Pride Penstemon	*Penstemon newberryi*	1'	Supercell	7
	Slender Cinquefoil	*Potentilla gracilus*	6"	Supercell	28
	Slender Cinquefoil	*Potentilla gracilus*	2.5'	D-pot	6
	Mountain Spirea	*Spiraea densiflora*	2'	Supercell	7
	Showy Penstemon	*Penstemon speciosus*	2'	Supercell	9
	POTS				
Location	Common Name	Species	Height	Size	Quantity
BMP 8	Arctic Willow	*Salix purpurea 'Nana'*	3'	1 gallon	3
	Alpine Currant	*Ribes alpinum*	3'	1 gallon	2
	Spirea	*Spirea japonica 'Little Princess'*	3'	1 gallon	2
	Potentilla	*Potentilla parvifolia 'Goldfinger'*	3'	1 gallon	2
	Lavender	*Lavendula angustifolia 'Munstead'*	2'	1 quart	3
	Salvia	*Salvia nemorosa 'East Friesland'*	2'	1 quart	5
	Catmint	*Nepeta x faassenii 'Walker's Low'*	2'	1 quart	5
	Bee Balm	*Monarda didyma 'Petite Delight'*	18"	1 quart	3
	Fuschia	*Zauschneria californica*	12"	1 pint	5
	Strawberry	*Fragaria x 'Lipstick'*	6"	1 quart	3
	Bearberry	*Arctostaphylos uva-ursi*	6"	1 quart	7

Table 34. Project seed mix type and species composition

UPLAND MIX				
Location	Common Name	Species	Height	Lbs/Acre
BMP 1, BMP 2, BMP 7, BMP 10, BMP 11, BMP 12, BMP 14	Sheep Fescue 'Covar'	*Festuca trachyphylla 'Covar'*	6"	4.00
	Streambank Wheatgrass 'Soda	*Elymus lanceolatus ssp. psammophilu*	12-18"	6.00
	Showy Penstemon	*Penstemon speciosus*	1-3'	0.50
	Sulfur-flower Buckwheat	*Eriogonum umbellatum*	1'	0.50
	Yarrow	*Achillea millefolium*	1-2'	0.25
	Blue Flax	*Linum perenne*	18-24"	2.00
	California Poppy	*Eschscholzia californica*	16"	3.00
	Slender Wheatgrass	*Elymus trachycaulus 'Revenue'*	2-2.5'	6.00

GRASS FILTER STRIP				
Location	Common Name	Species	Height	Lbs/Acre
BMP 2,	Blue Wildrye	*Elymus glaucus*	2-3'	6.00
BMP 7,	Sheep Fescue 'Covar'	*Festuca trachyphylla 'Covar'*	6"	4.00
BMP 10,	Creeping Wildrye	*Elymus triticoides*	3'	2.00
BMP 11,	Streambank Wheatgrass 'Soda	*Elymus lanceolatus ssp. psammophilu*	12-18"	7.00
BMP 12,	Slender Wheatgrass	*Elymus trachycaulus 'Revenue'*	2-2.5'	10.00
BMP 14	Hard Fescue	*Festuca trachyphylla 'Durar'*	1-2'	4.00

BASIN MIX				
Location	Common Name	Species	Height	Lbs/Acre
BMP 2, BMP 7, BMP 10, BMP 11, BMP 12, BMP 14	Blue Wildrye	*Elymus glaucus*	2-3'	5.00
	Sheep Fescue 'Covar'	*Festuca trachyphylla 'Covar'*	6"	4.00
	Hard Fescue	*Festuca trachyphylla 'Durar'*	1-2'	4.00
	Baltic Rush	*Juncus balticus*	8-32"	0.15
	Creeping Wildrye	*Elymus triticoides*	3'	6.00
	Nebraska Sedge	*Carex nebrascensis*	3'	0.35
	Slender Wheatgrass	*Elymus trachycaulus 'Revenue'*	2-2.5'	1.00
	Sierra Wildflower Mix	*Various species: See Appendix D*	6"-3'	1.00

Table 35. Plant mortality at BMP 8 only.

Plant Mortality				
Species	No. Planted	No. Deceased 2012	Replaced (Y/N)	No. Deceased 2013
Arctic Willow	3			
Alpine Currant	2			
Spirea	2			
Potentilla	2			
Lavender	3	2	Y	
Salvia	5			
Catmint	5			
Bee Balm	3			
Fuschia	5	1	Y	
Strawberry	3	2	Y	
Bearberry	7			

Table 36. Overall containerized plant survival at all BMPs.

Plant Mortality			
Species	No. Planted	No. Deceased 2012	Replaced (Y/N)
Mtn Pride Penstemon	7	7	seeded spring 2013
Cinquefoil	34	13	seeded spring 2013
Spirea	7	2	N
Penstemon	9	7	seeded spring 2013

No invasive weeds were found in the project area over the two year monitoring period, but NTCD did remove common weeds from the rain gardens as shown in Table 37. Percent vegetative cover is reported in the following section as part of BMP RAM.

Table 37. Weeds removed from the rain gardens over the two year period.

BMP	Date	Lamb's Quarters	Prickly Lettuce	Tumbleweed	White Sweetclover
1	9/10/2012	1	1		
1	9/25/2013	1	2		
2	9/10/2012		2		1
2	9/25/2013		3		4
7	9/10/2012	3	5		2
7	9/25/2013	3	4		6
8	9/10/2012	2	4		3
8	9/25/2013	3	10		2
10	9/10/2012		1		2
10	9/25/2013		1		1
11	9/10/2012	1			1
11	9/25/2013		2		
12	9/10/2012	20	2		
12	9/25/2013	8	2		4
14	9/10/2012	5	3	1	16
14	9/25/2013	2	7		9

BMP RAM

The Nevada Tahoe Conservation District performed BMP RAM three times over the two year monitoring project. It was difficult to classify the project BMPs into 1 of the 12 'Treatment BMP Types' defined in the BMP RAM Technical Document. As mentioned earlier, BMP RAM may be changed as part of the *Stormwater Tools Improvement Project* that is currently (March 2014) underway. It is unknown what changes will be made to the BMP RAM. NTCD staff utilized the field observations described in BMP RAM User Manual V.1 (2009) and classified the project BMPs into the defined BMP RAM 'Treatment BMP Types' using their best professional judgment after consultation with NDEP, DRI and Washoe County.

Due to ongoing updates to the Lake Clarity Crediting Tools and the fact that the catchment registration process has not commenced, the BMP RAM database is not being utilized; thus, BMP RAM scores for the project BMPs could not be attained. The raw data for the field observations are reported below to illustrate changes over time in the BMPs and to provide Washoe County with the data when the catchment is registered.

BMP 1 was designed and constructed as a subsurface infiltration system (infiltration gallery), therefore BMP 1 was considered an 'infiltration feature' for purposes of applying

BMP RAM. Infiltration features require the following field observation protocols be performed: *Conveyance*, *Runoff*, and *Vegetation Cover.* However, due to the underground infiltration gallery design of BMP 1, it is not possible to perform the *Runoff*, and *Vegetation Cover* field observation protocols. NTCD noted that the revegetation was established on the disturbed soils to help minimize erosion and that the inlet conveyance remained clear and free of debris. Pressure transducer data indicates that the BMP is draining properly.

BMP 2 was constructed as a subsurface infiltration trench, while BMP 12 was constructed as a bio-swale, yet both BMPs were considered 'infiltration features' for BMP RAM purposes. BMP 2 was classified as an infiltration feature for similar reasons as discussed for BMP 1, while BMP 12's design tried to maximize infiltration and minimize conveyance with nearly level cells of engineered soils to augment infiltration and rock weirs to slow and spread conveyance. Infiltration features require the following field observation protocols be performed: *Conveyance*, *Runoff*, and *Vegetation Cover.* It's important to note that for performing the *Runoff* field observation protocol NTCD used 20 seconds as the threshold. The BMP RAM User Manual has conflicting information regarding the threshold; page 41 reads 30 seconds, while page 58 and the field observation datasheet for infiltration feature on page 84 both read 20 seconds. BMP RAM data collected for BMP 2 and BMP 12 is shown in Table 38 below. BMP 12 failed the *Runoff* field observation protocol on September 10, 2012 as water was present on the soil surface for longer than 20 seconds.

Table 38. BMP RAM *Vegetation Cover, Runoff* and *Conveyance* field observation protocols results for BMP 2 and BMP 12.

BMP	Year	Date	% Wetland Vegetation Cover	% Riparian Vegetation Cover	% Tree Vegetation Cover	% Grass Vegetation Cover	% No Vegetation Cover	Water after 20 sec? (Y/N)	Conveyance Inlet Functioning (Y/N)	Conveyance Outlet Functioning (Y/N)
2	Install	11/1/2011								
	1	9/10/2012	0	0	0	75	25	NO	Y	n/a
	2	5/21/2013	0	0	0	95	5	NO	Y	n/a
	2	9/25/2013	0	0	0	95	5	NO	Y	n/a
12	Install	11/1/2011								
	1	9/10/2012	0	0	0	70	30	YES	Y	Y
	2	5/21/2013	0	0	0	75	25	NO	Y	Y
	2	9/25/2013	0	0	0	75	25	NO	Y	Y

The remaining rain gardens (BMPs 7, 8, 10, 11 and 14) were considered 'infiltration basins' for BMP RAM purposes. The following BMP RAM field observation protocols were performed on the project rain gardens: *Conveyance*, *Infiltration*, and *Vegetation Cover.* BMP RAM data collected for BMPs 7, 8, 10, 11, and 14 is shown in Table 39 below.

Table 39. BMP RAM *Vegetation Cover*, *Infiltration* and *Conveyance* field observation protocols results for BMP 7, BMP 8, BMP 10, BMP 11 and BMP 14.

BMP	Year	Date	% Wetland Vegetation cover	% Riparian Vegetation Cover	% Tree Vegetation Cover	% Grass Vegetation Cover	% No Vegetation Cover	CHP K_{sat} (in/hr)	Conveyance Inlet Functioning (Y/N)	Conveyance Outlet Functioning (Y/N)
7	Install	11/1/2011						6.32		
	1	9/10/2012	0	1	0	85	14	4.08	Y	Y
	2	5/21/2013	0	0	0	75	25	3.84	Y	Y
	2	9/25/2013	0	0	0	97	3	6.74	Y	Y
8	Install	11/1/2011						8.28		
	1	9/10/2012	0	0	25	40	35	3.90	Y	Y
	2	5/21/2013	0	0	10	5	85	3.98	Y	Y
	2	9/25/2013	0	0	30	45	25	1.05	Y	Y
10	Install	11/1/2011						8.87		
	1	9/10/2012	0	0	0	70	30	6.24	Y	Y
	2	5/21/2013	0	0	0	70	30	4.43	Y	Y
	2	9/25/2013	0	0	0	97	3	2.64	Y	Y
11	Install	11/1/2011						3.75		
	1	9/10/2012	0	0	0	60	40	0.88	Y	Y
	2	5/21/2013	0	0	0	20	80	3.14	Y	Y
	2	9/25/2013	0	0	0	80	20	4.84	Y	Y
14	Install	11/1/2011						2.98		
	1	9/10/2012	0	5	0	85	10	1.80	Y	Y
	2	5/21/2013	0	0	0	80	20	1.73	Y	Y
	2	9/25/2013	0	0	0	90	10	3.99	Y	Y

All BMPs exhibited acceptable revegetation establishment of 75% cover by the end of the two year monitoring period.

BMP RAM was performed on the sediment traps and drainage inlets with more than 12" sump installed as part of this project. *Sediment Trap Capacity* and *Conveyance* field observation protocols were performed per BMP RAM. There were no issues found while performing the *Conveyance* field observation protocol. The *Sediment Trap Capacity* results are presented in Table 40 below. Sediment trap 25 was just under the 12 inch capacity at 11.8 inches in year 2, September 2013 and would trigger maintenance activity to restore capacity per BMP RAM.

Table 40. Sediment trap RAM data results.

Sediment Trap	Sump Depth (inches)	Pre-Project (9/2011) Sediment Depth (inches)	Pre-Project (9/2011) Available Capacity (inches)	Year 1 (5/2012) Sediment Depth (inches)	Year 1 (5/2012) Available Capacity (inches)	Year 2 (5/2013) Sediment Depth (inches)	Year 2 (5/2013) Available Capacity (inches)	Year 2 (9/2013) Sediment Depth (inches)	Year 2 (9/2013) Available Capacity (inches)
9	40.5	0	40.5	1.5	39.0	2.5	38.0	2.5	38.0
15	26	0	26.0	10	16.0	4.5	21.5	12.5	13.5
19	20	n/a	n/a	0	20.0	0	20.0	1.5	18.5
20	35	n/a	n/a	0.5	34.5	0	35.0	2.5	32.5
21	20	n/a	n/a	0	20.0	0	20.0	1.25	18.8
22	38	n/a	n/a	0.5	37.5	0	38.0	4.5	33.5
23	20	n/a	n/a	0	20.0	0.25	19.8	0.25	19.8
24	24	n/a	n/a	1	23.0	0.5	23.5	2.25	21.8
25	12	n/a	n/a	0	12.0	0	12.0	0.25	11.8

n/a - corresponding sediment traps not installed until November 2011

It should be noted that the default maintenance triggers in BMP RAM for the *Vegetation Cover* field observation protocol for 'infiltration features' stipulates that vegetative cover in excess of 10% indicates non-functioning condition; however, vegetation is a desired component of this project's BMPs.

For 'infiltration basins', the *Infiltration* field observation protocol has a default maintenance trigger of 20% infiltration rate decline from the benchmark. BMP RAM User's Manual defines 'benchmark' as: the highest, best achievable value for each respective observation for a specific Treatment BMP. Using this guidance, the September 2012 CHP readings represent benchmark as they were obtained once the vegetation established; however, NTCD recommends that the default maintenance trigger be set at a value of 1"/hour, as the rain gardens are designed to operate and drain satisfactory at .8"/hour (20% decline from suggested 1"/hr benchmark).

For 'infiltration basins', the *Vegetation Cover* field observation protocol has a default maintenance trigger of 20% cover of wetland and riparian species. Although none of the 'infiltration basins' exceeded this threshold, all of the seed mixes and container plants established in the rain gardens included riparian and wetland species as a component of the revegetation. NTCD has monitored other infiltration and dry basins which exceeded the 20% riparian and wetland species threshold, yet exhibited satisfactory infiltration based on CHP, double ring infiltrometer and modified Philip-Dunne infiltrometer results (NTCD 2014). Thus NTCD recommends that any exceedance of 20% riparian and wetland species cover be evaluated in light of *Infiltration* results and overall performance and not alone trigger maintenance activities. As mentioned earlier, BMP RAM may be changed as part of the *Stormwater Tools Improvement Project* that is currently (March 2014) underway. As the BMP RAM is currently configured, NTCD recommends that Washoe County negotiate the above changes in default maintenance triggers upon catchment registration to better suit the project design.

Maintenance

Maintenance performed on the BMPs during the monitoring period included weeding and irrigation upkeep and the routine vactoring of the sediment traps twice a year by Washoe County. Also, NTCD staff removed a handful of trash items and plant debris (pine cones) within the BMPs during monitoring activities. NTCD and Washoe County Roads staff performed some adjustments to the construction during 2012 to achieve improved flow into BMP 7, BMP 10 and BMP 12, but these improvements are not expected to be required again.

CONCLUSIONS

The Hybrid BMP Project goals were to 1) reduce the stormwater runoff volume from Washoe County's impervious area in the project area; 2) remove and sequester fine sediment mass from the project area and 3) sustain infiltration performance with minimal maintenance. The project met the goals through its objectives of treating 50% of the stormwater runoff generated in the project area with offline LID BMPs; removing 50% of the FSP generated in the project area through infiltration and biofiltration LID BMPs; and installing pre-treatment sediment traps to minimize maintenance and prolong asset life.

This project was conceived as a pilot project to demonstrate the ability to retrofit an existing stormwater EIP project with distributed, off-line, LID BMPs in the ROW to achieve FSP load reduction for TMDL compliance. The project was also a pilot to test whether a biologically driven (annual root growth and senescence, microorganism burrowing, humus aggregate) stormwater infiltration treatment could be effective in the Tahoe Basin's climatic and environmental conditions. Monitoring results suggest that a biological driven infiltration treatment is effective in Nevada-Tahoe, but it's important to note that the BMPs were irrigated during the monitoring period. No data exists for non-irrigated sites, thus the long-term viability of non-irrigated sites in Tahoe conditions remains unknown.

Over the two year monitoring period, the pollutant loads treated by the LID BMPs were characterized. The average TU, TSS and FSP for BMP 7 and BMP 11 rain events were 59 NTU, 80 mg/L and 53% and 60 NTU, 80 mg/L and 56% respectively. The average TU, TSS and FSP for BMP 7 and BMP 11 snowmelt events were 137 NTU, 128 mg/L and 62% and 103 NTU, 102 mg/L and 63% respectively. PLRM modeling and pollutant load reduction estimates based on monitoring data indicate the project achieved relatively small FSP load reductions for Lake Tahoe TMDL's Lake Clarity Crediting Program as the project treats only 3% of the catchment, but was significant relative to project area (50%).

The runoff volume reduction was determined through controlled water pour experiments. The project was designed to treat 50% of the impervious surface within the project area. Monitoring results suggest that the project was effective at reducing stormwater runoff volumes by 68%. Additionally the catchment-scale volume reduction resulted in a 3% and 5% volume reduction in 2012 and 2013 respectively; the project was designed to treat 3% of the entire catchment area.

Pressure transducers in observation wells of the LID BMPs monitored stage of runoff from natural and controlled experiments. The data was used to calculate an infiltration and exfiltration rate and plot hydrographs for the precipitation events. Infiltration rate was also measured with CHP and double ring infiltrometers. Soil samples were taken to track changes to bulk density and porosity in the engineered soils of the LID BMPs. Soil samples indicate a decrease in porosity and increase in bulk density over the monitoring period, which was expected as the soils settled and consolidated. The porosity remains higher and the bulk density lower than the surrounding native soils. No infiltration trends can be seen in the data which is not surprising as the measurements were taken at different locations within the BMP each year and soil conditions are highly variable.

Flood capacity testing provided a runoff volume capacity of the LID BMPs, infiltration and exfiltration rates and justified using the volume infiltrated estimate equation.

NTCD coordinated with adjacent homeowners to obtain right-of-entries for irrigation water during the two year vegetation establishment period. Vegetation exhibited satisfactory establishment with at least 75% cover in LID BMPs at the end of the two year monitoring period.

BMP RAM was performed on the LID BMPs and their associated pre-treatment sediment traps. No trends are apparent in the data. If the rain garden BMPs become part of the maintained stormwater treatment BMPs for tracking FSP load reductions under the LakeTahoe TMDL, NTCD recommends that NDEP consider changes to the default BMP RAM thresholds and maintenance triggers to align with the project design intent.

The project met the goals and is considered successful. It provides an example of LID BMPs installed within the ROW that rely on the maintenance of vegetation to support natural processes that can maintain infiltration. Although two years of monitoring data is not sufficient to assess BMP effectiveness over the long term, the obtained data indicates continued infiltration success of the BMPs and suggests current maintenance actions and frequency are adequate at this time.

ACKNOWLEDGEMENTS

The Hybrid BMP Project was made possible through grants from the USDA Forest Service Lake Tahoe Basin Management Unit, Nevada Division of State Lands Lake Tahoe License Plate Grant Program and from the Nevada Division of Environmental Protection's Clean Water Act Section 319 grant program. Additionally, funding was provided by Washoe County through the TRPA water quality mitigation funds. Washoe County also provided in-kind labor as grant match in the form of assistance and support throughout the design, construction and monitoring phases of the project. NTCD would like to thank Washoe County Public Works and Washoe County Roads Department for their participation, support and insight throughout the project. Kris Klein, P.E. deserves a special thank you for her guidance, patience, dedication throughout the project and her diligence in tracking and reporting Washoe County in-kind efforts. Desert Research Institute was a trusted partner throughout the project and was leaned on heavily during the monitoring period for planning, equipment installation and data collection and analysis.

Numerous individuals and agencies provided advice, assistance and supplies to ensure the success of the project, including: Incline Village General Improvement District, Tahoe Douglas Fire Protection District, Nevada Division of Forestry's Washoe Nursery, High Sierra Gardens, Full Circle Compost, Ed Kleiner of Comstock Seeds, Michael Hogan of Integrated Environmental Restoration Services, Maria Cahill of Green Girl Land Development Solutions, Mikael Isensee of the Dakota County Soil and Water Conservation District, Brian McCrae of Lumos and Associates, Gradex Construction Company, Schlumberger Water Services, Linda Burdick of Burdick Excavating and Juan Luna of Luna Enterprises.

Lastly, special thanks are due to Paul Moresi, Art Strosberg and Jeofrey Wyrick for providing support and irrigation water access during the revegetation period.

This publication was made possible through a grant from the USDA Forest Service.

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APPENDICES

Appendix A: Hybrid BMP Project Final Maintenance Plan

Nevada Tahoe Conservation District
400 Dorla Ct.
PO Box 915
Zephyr Cove, NV 89448
(775) 586-1610

HYBRID BMP PROJECT

FINAL

MAINTENANCE PLAN

June 2011

Washoe County
Department of Public Works
1001 E. Ninth Street
PO Box 11130
Reno, NV 89520

Rain Garden Maintenance Plan

Properly designed and installed rain gardens require little maintenance once established.

Sediment Traps: Each LID feature will include sediment traps at each inlet to capture coarse sediment before it enters the feature. The traps are designed to be cleaned with a Vactor truck. The traps will be located either in or just behind the curb so that regular street sweeping removes accumulated pine needles from their inlet grates and pans. Installation of the LID features is not expected to increase street sweeping or Vactoring frequency as the overall sediment load will be the same but more distributed with the additional assets. Sediment traps will reduce the amount of coarse sediment that enters each LID feature and therefore increase their lifespan by limiting surficial sediment accumulation.

Vegetation: The LID features will be planted with low-maintenance, native vegetation approved by Washoe County for sight safety concerns. Regular irrigation is required for the first growing season and occasional irrigation the second year (performed by NTCD). Once vegetation is established, maintenance of the LID feature consists of periodic trash and debris removal. The LID features will also require removal of invasive weeds similar to other stormwater facilities and County right-of-ways. Thick vegetation in the LID features and a natural pine needle mulch supply from surrounding trees will obviate the need for mulch replenishment. BMP RAM protocols to determine vegetative cover should be followed annually as the LID features will be classified as 'infiltration basins' according to BMP RAM. Desired percentage of vegetation differs from BMP RAM default values in that ideal vegetation percent cover in the LID features should be between 50 and 80 percent.

Infiltration Performance: The City of Portland has experienced acceptable infiltration rates over the life of their rain gardens, some of which are 10 to 15 years old[1]. Once vegetation is established, it is expected that biological activity will maintain or even increase infiltration rates of the soil. Other municipalities have experienced increased infiltration rates five years following construction, likely due to soil biological activity and the annual cycle of plant root growth and senescence[2]. Thus, replacement of the amended soils in the LID features is not anticipated.

The maintenance trigger for infiltration performance is ponding water for longer than 3 days or unsatisfactory infiltration performance using BMP RAM protocols for infiltration basins. Loosening of the soil profile with a broadfork is the first step of soil reconditioning. If desired infiltration performance is not achieved, removal of the top inch of soil in late summer or aerating or tilling the top few inches of soil may restore desired infiltration. Revegetation is not necessary if care is taken not to destroy vegetation or remove the seed bank. If major soil reconditioning is performed (soil replacement), then vegetation would have to be reestablished.

<u>Inspection and Maintenance:</u> Maintenance of the rain gardens is required when inspections reveal the following:

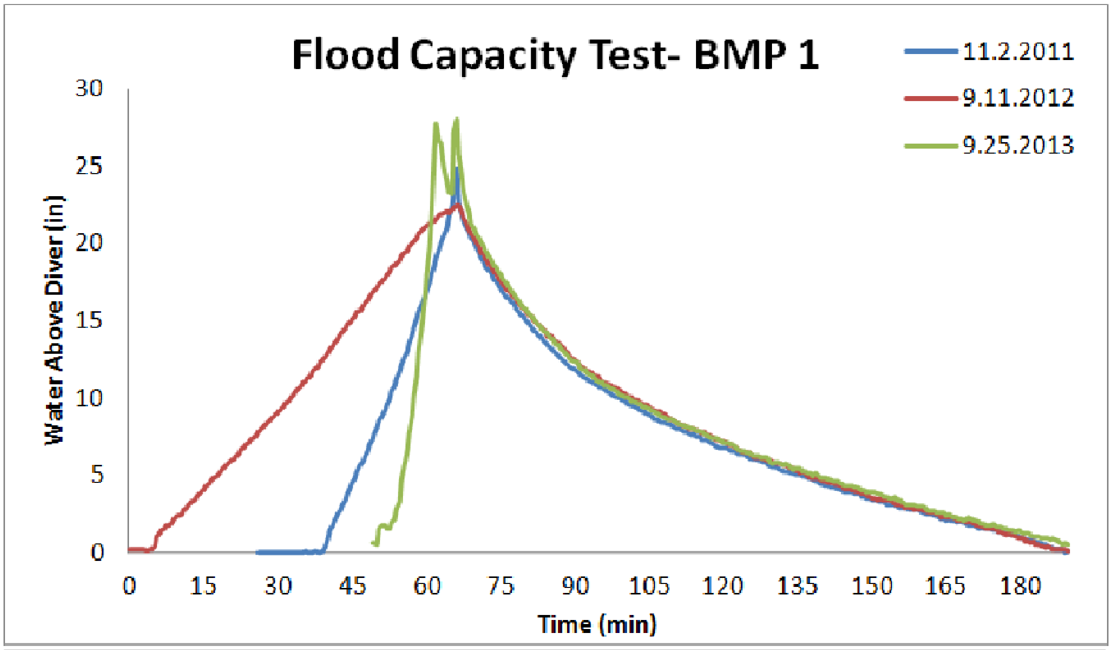
- Trash, debris or sediment accumulation (determined visually, inspect twice annually)
    - Remove trash, debris and dispose of properly
    - Remove accumulated sediment and dispose of properly (ensure design depth of rain gardens is maintained)
- Weeds (use the same protocol and frequency for all county right-of-ways)
    - Remove invasive weeds and any tree seedlings to prevent their establishment
- Full sediment traps (inspect and maintain at the same frequency as existing catch basins using BMP RAM protocols)
    - Empty sediment traps and dispose of properly
- Pine needle obstruction of inlets
    - Remove pine needles from entry via regular street sweeping
- Ponding water for longer than 3 days or poor infiltration (using BMP RAM protocols for infiltration basins)
    - Loosen soil profile with broadfork **or** remove top inch of soil in gardens **or** aerate/till the top few inches of soil in late summer.

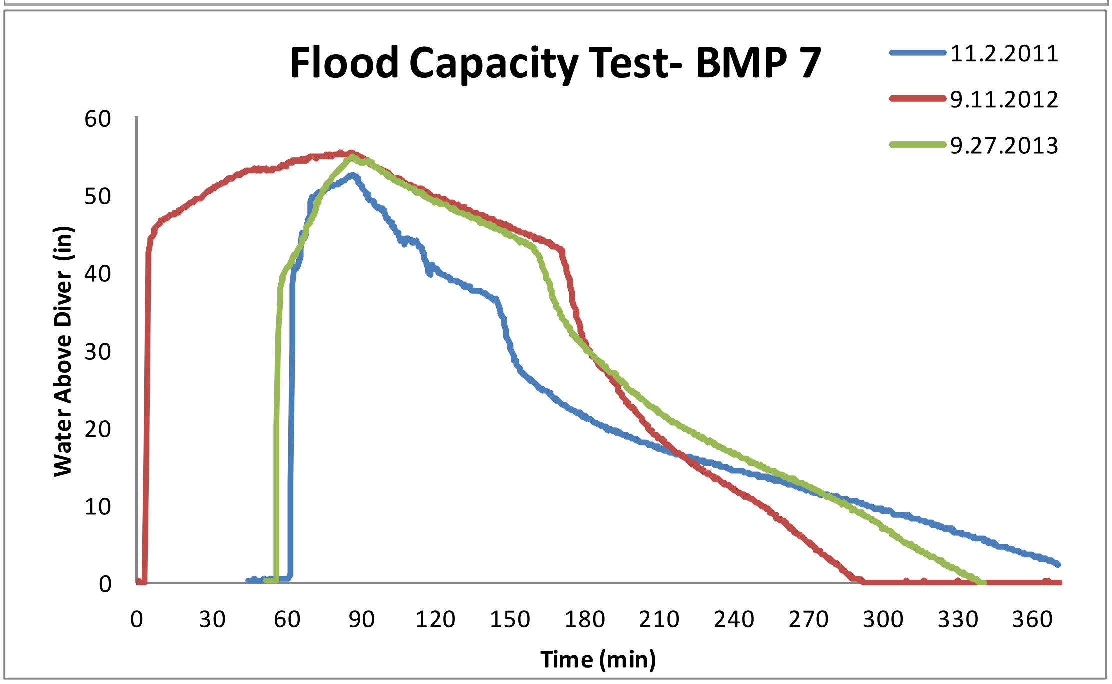
Inspection and Maintenance Schedule

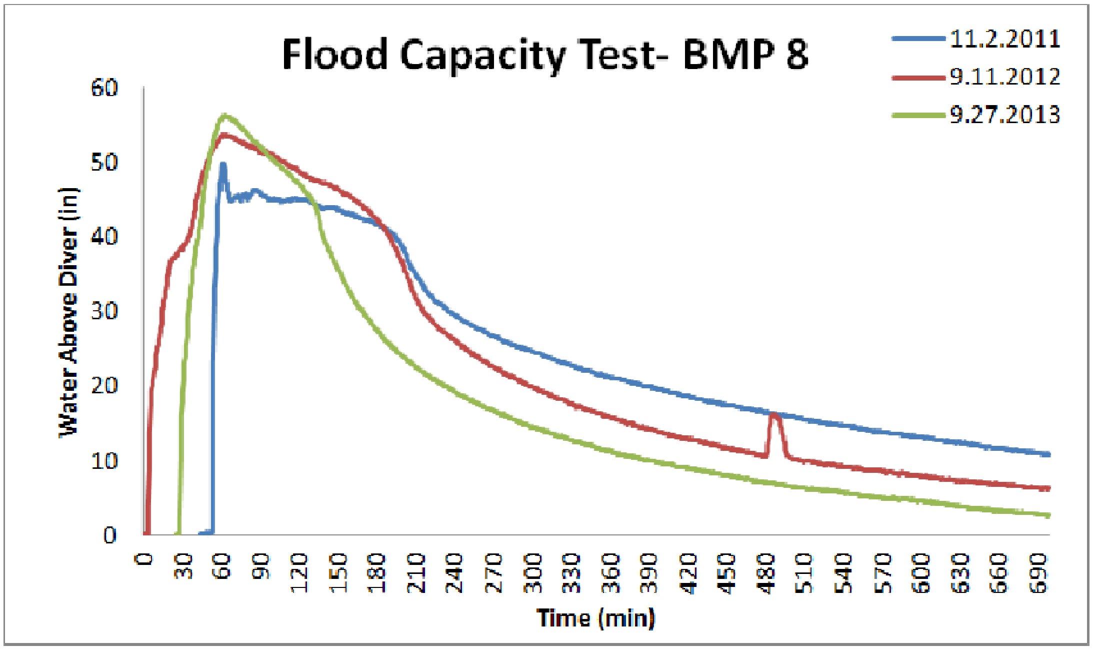
Anticipated Rain Garden Inspection and Maintenance		
Task	Schedule	Responsibility
Irrigation	1" of water per week during the first growing season to establish vegetation. Possibly additional irrigation the second year.	NTCD (first 2 years)
Weeding	The LID features will be planted with native vegetation to improve infiltration and nutrient up take. Invasive weeds and tree seedlings are not desired in the LID features. Invasive weeds must be managed as in any stormwater treatment facility or County Right-of-Way.	NTCD (first 2 years) Washoe County thereafter
Street Sweeping	Four times a year and before and after major storm events. Removing pine needles from the drainage inlets is key for stormwater entry to the gardens.	Washoe County
Empty Sediment Traps	Follow the current schedule of twice a year. (Spring and Fall)	Washoe County
Remove Trash/Debris	Annually (same schedule as any other stormwater basin).	NTCD (first 2 years) Washoe County thereafter
BMP RAM	Use BMP RAM Field Observation Protocols for Infiltration Basins. Percent cover vegetation should be between 50 and 80 percent. Conduct annually, or as often as condition scores are desired	NTCD (first 2 years) Washoe County thereafter
Soil Reconditioning	Not Anticipated[1]. The experience of other municipalities is that reconditioning of bioretention basins is a very rare maintenance requirement. The vegetation is expected to maintain porosity and infiltration. Rain gardens often have a higher infiltration rate five years after construction, likely due to soil biological activity and the annual cycle of root growth and senescence[2]. In the unlikely event that desired infiltration is not maintained, loosening of the soil profile with a broad fork is recommended. Removal of the top inch of soil or aerating or tilling the top few inches of soil may in late summer also be performed to restore function.	Washoe County

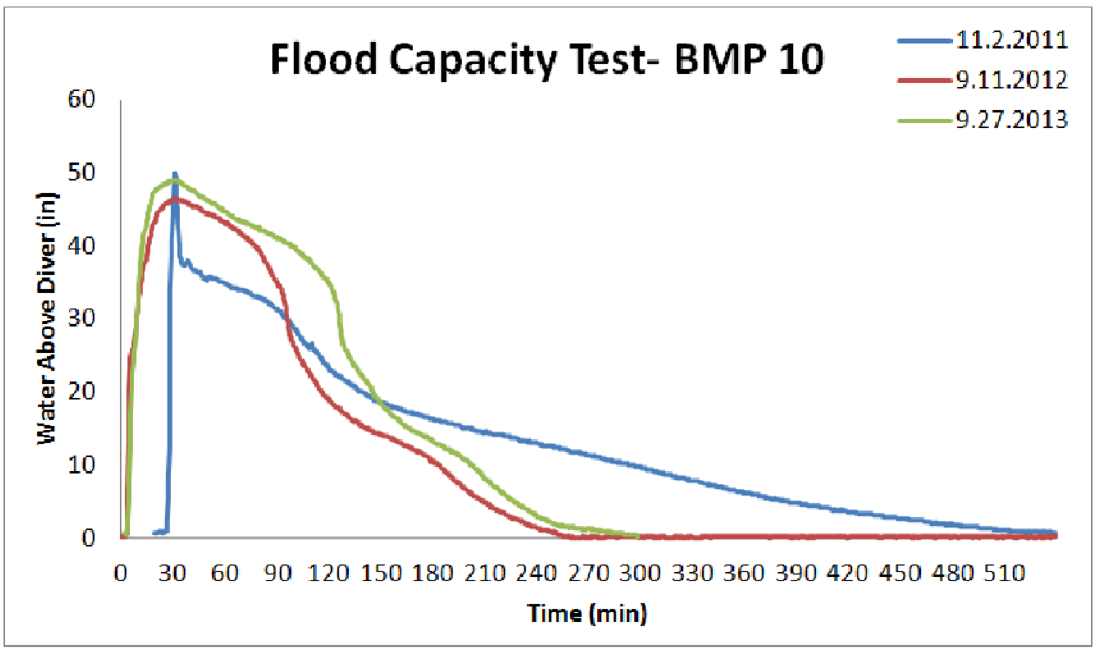
[1] 7/20/10 Conversation with Maria Cahill of Green Girl Land Development Solutions.
[2] 7/22/10 Conversation with Mike Isensee of Dakota County Soil and Water Conservation District.

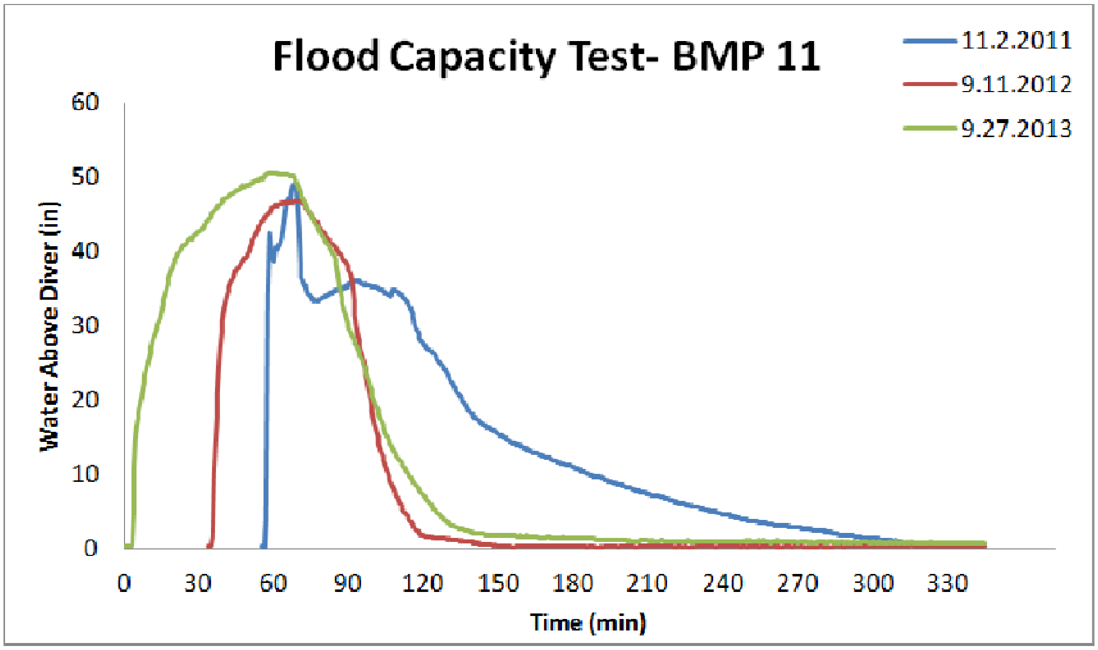
Appendix B: Individual BMP Flood Capacity Test Hydrographs

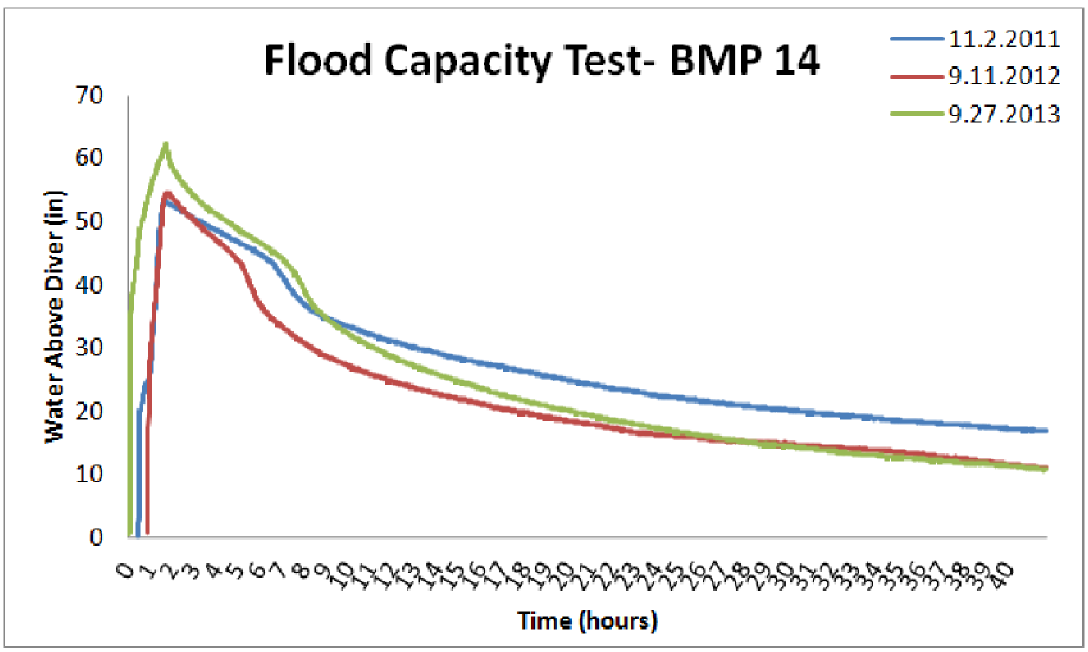

Flood Capacity Test- BMP 1
11.2.2011
9.11.2012
9.25.2013
Water Above Diver (in)
0
5
10
15
20
25
30
0
15
30
45
60
75
90
105
120
135
150
165
180
Time (min)


Flood Capacity Test- BMP 7
11.2.2011
9.11.2012
9.27.2013
Water Above Diver (in)
0
10
20
30
40
50
60
0
30
60
90
120
150
180
210
240
270
300
330
360
Time (min)

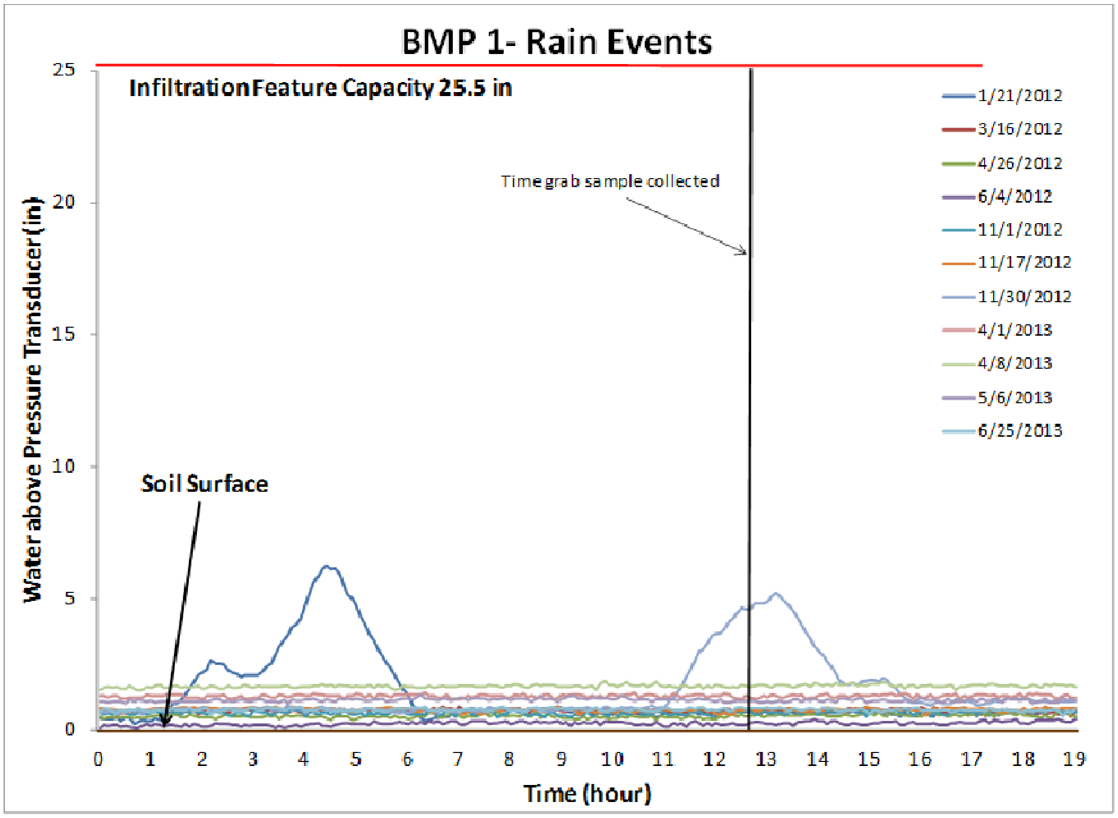

Flood Capacity Test- BMP 8
11.2.2011
9.11.2012
9.27.2013
Water Above Diver (in)
0
10
20
30
40
50
60
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
480
510
540
570
600
630
660
690
Time (min)


Flood Capacity Test- BMP 10
11.2.2011
9.11.2012
9.27.2013
Water Above Diver (in)
0
10
20
30
40
50
60
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
480
510
Time (min)

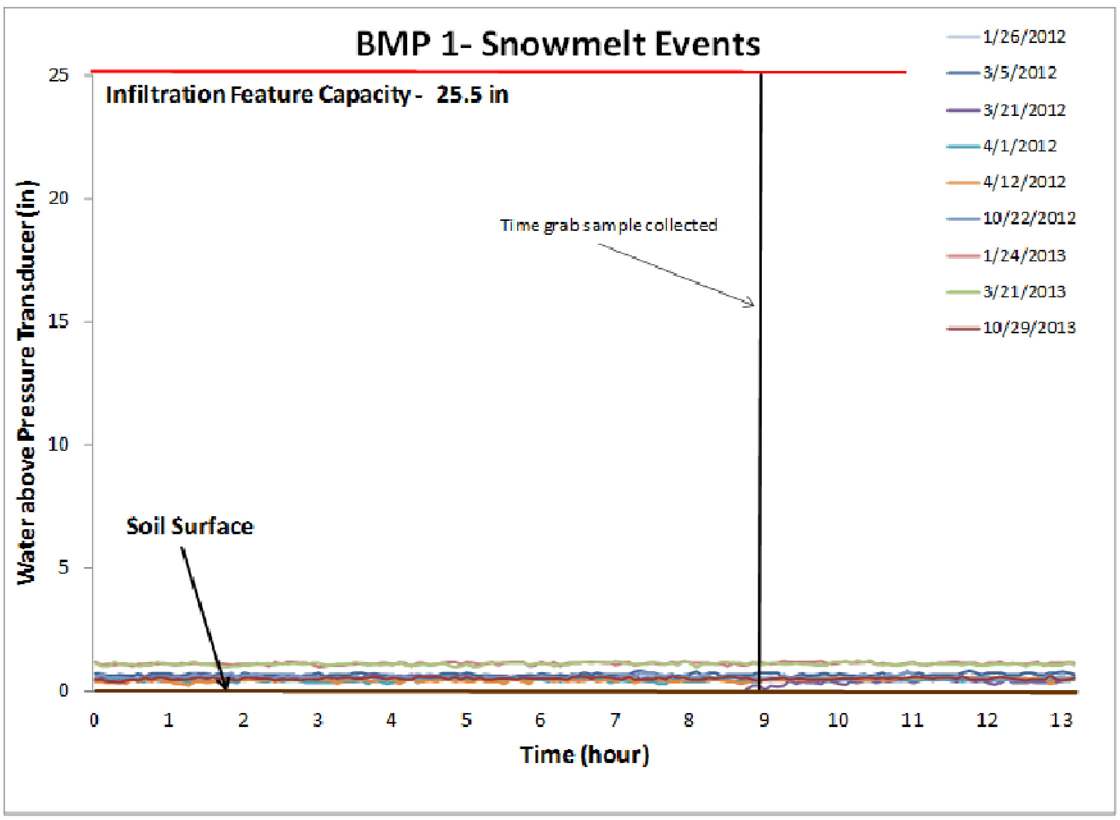

Flood Capacity Test- BMP 11
11.2.2011
9.11.2012
9.27.2013
Water Above Diver (in)
Time (min)


Flood Capacity Test- BMP 14
11.2.2011
9.11.2012
9.27.2013
Water Above Diver (in)
Time (hours)

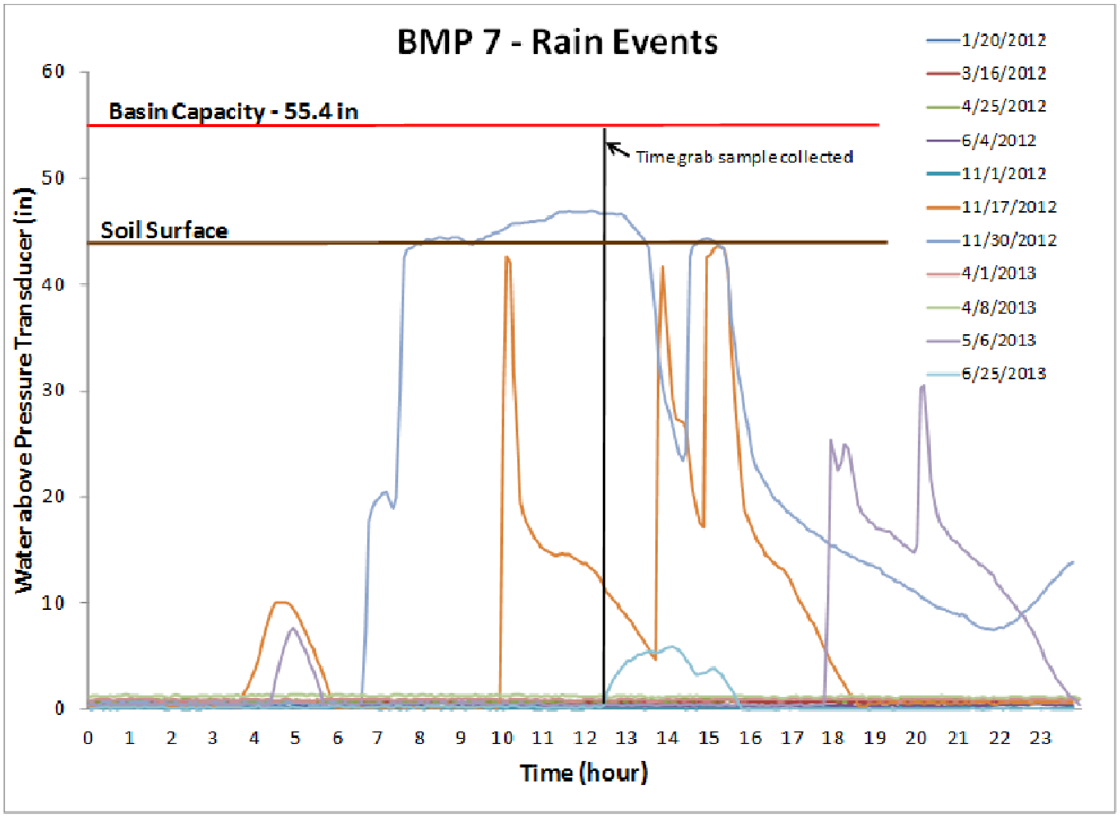
Appendix C: Individual BMP Precipitation Event Hydrographs



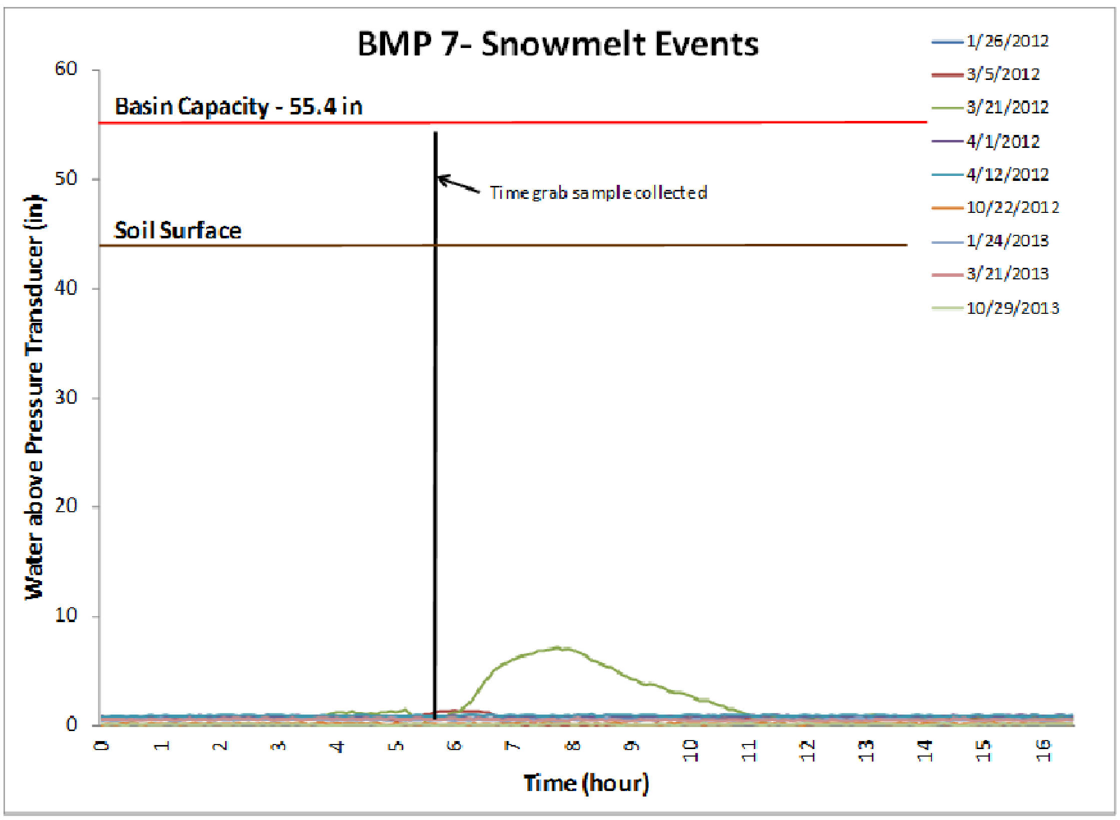
BMP 1- Rain Events
Infiltration Feature Capacity 25.5 in
Time grab sample collected
Soil Surface
Water above Pressure Transducer (in)
Time (hour)
1/21/2012
3/16/2012
4/26/2012
6/4/2012
11/1/2012
11/17/2012
11/30/2012
4/1/2013
4/8/2013
5/6/2013
6/25/2013



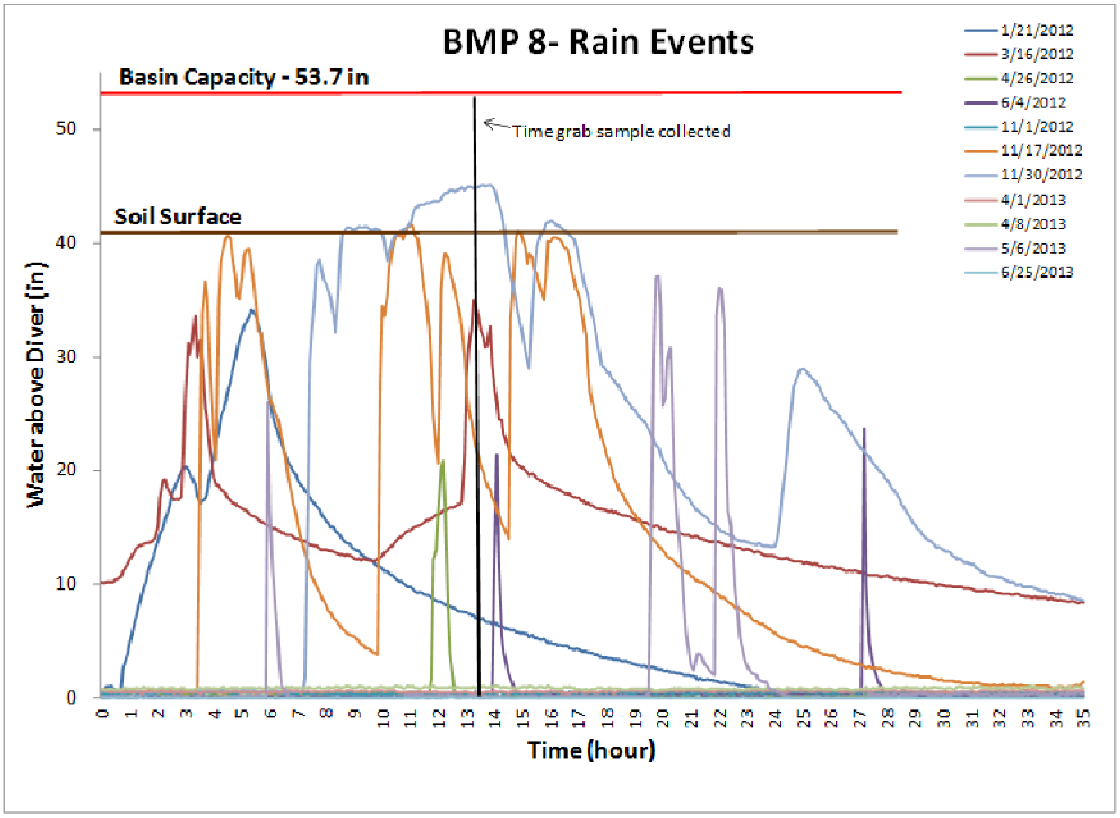
BMP 1- Snowmelt Events
Infiltration Feature Capacity - 25.5 in
Time grab sample collected
Soil Surface
Water above Pressure Transducer (in)
Time (hour)
1/26/2012
3/5/2012
3/21/2012
4/1/2012
4/12/2012
10/22/2012
1/24/2013
3/21/2013
10/29/2013

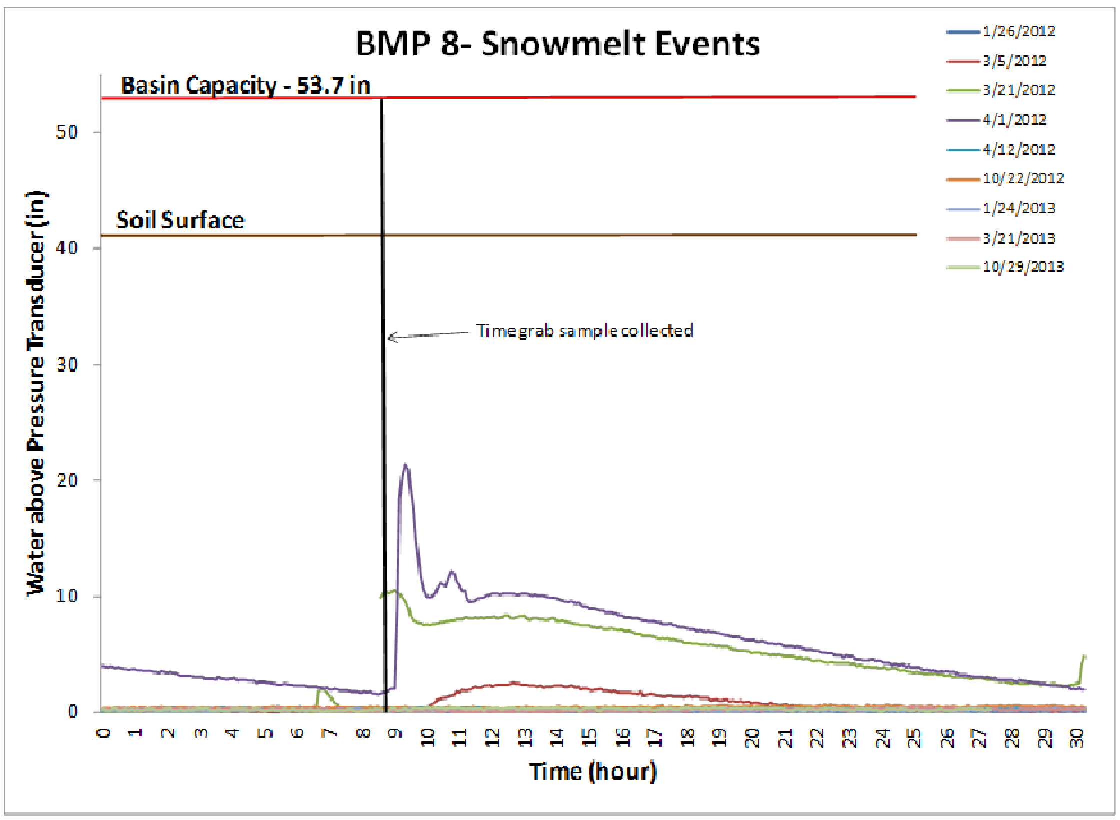


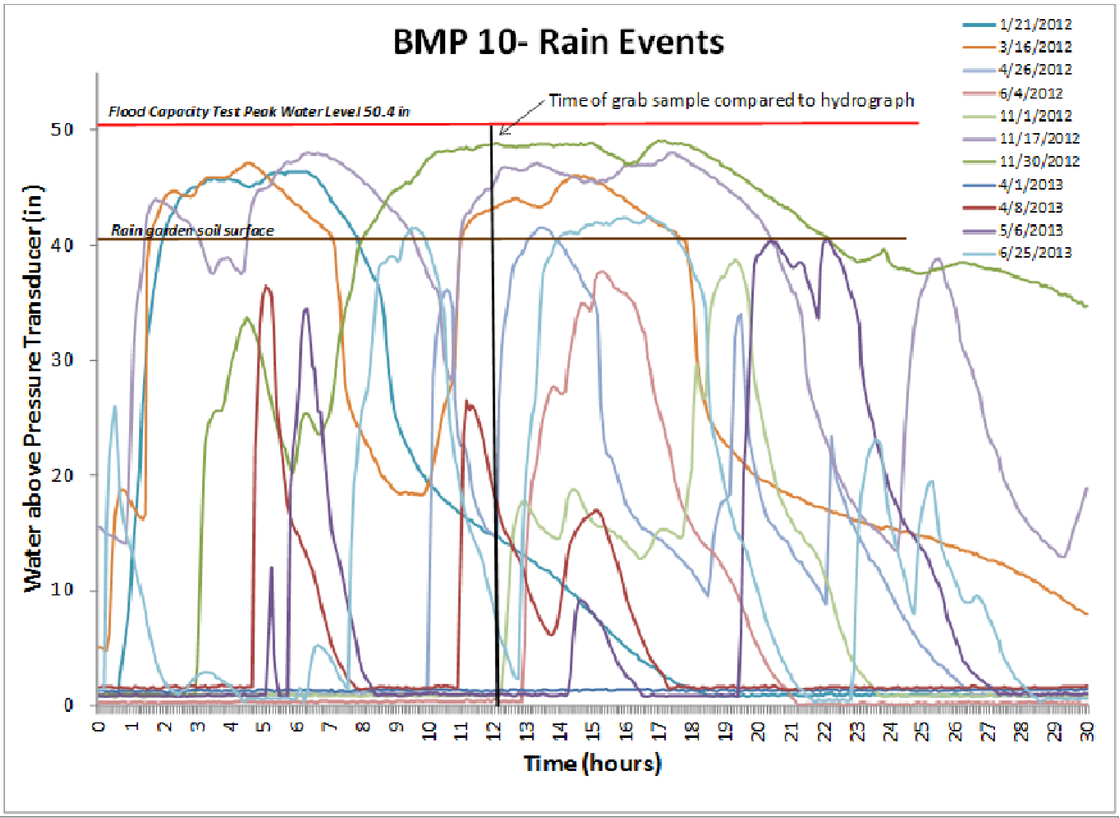
BMP 7 - Rain Events
Basin Capacity - 55.4 in
Time grab sample collected
Soil Surface
Water above Pressure Transducer (in)
Time (hour)
1/20/2012
3/16/2012
4/25/2012
6/4/2012
11/1/2012
11/17/2012
11/30/2012
4/1/2013
4/8/2013
5/6/2013
6/25/2013



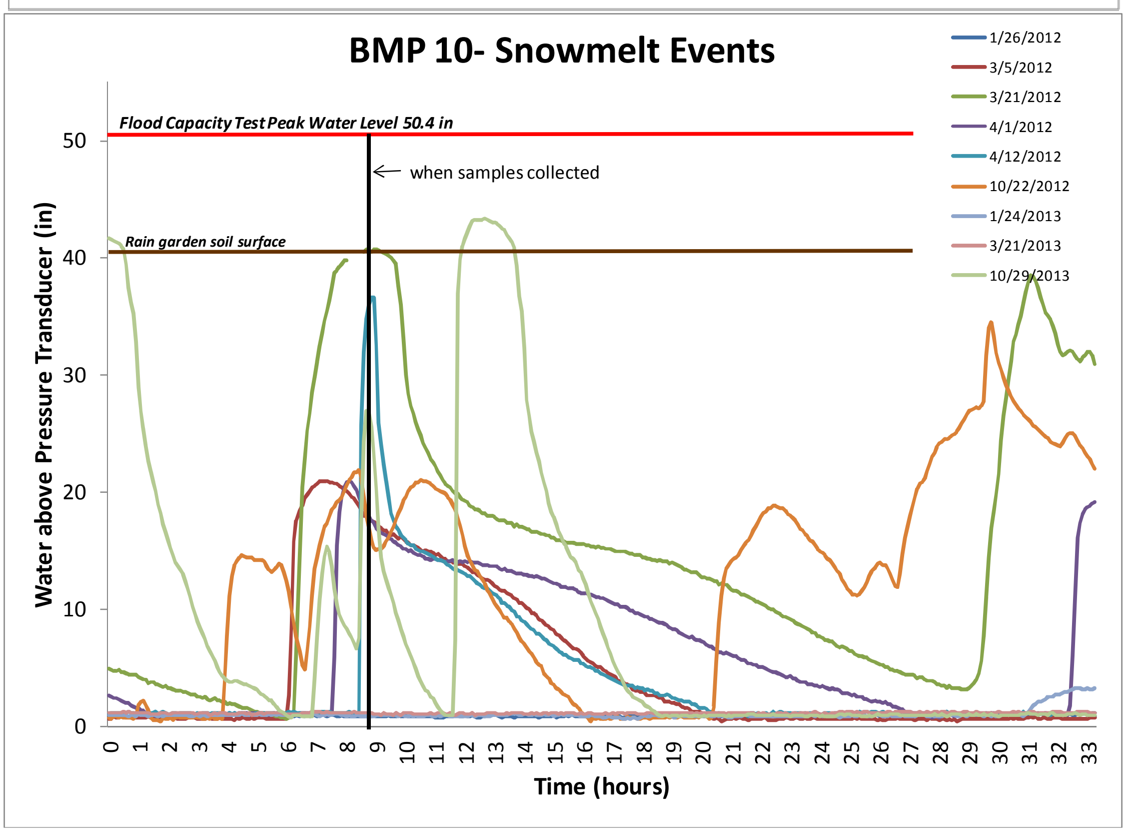
BMP 7- Snowmelt Events
Basin Capacity - 55.4 in
Time grab sample collected
Soil Surface
Water above Pressure Transducer (in)
Time (hour)
1/26/2012
3/5/2012
3/21/2012
4/1/2012
4/12/2012
10/22/2012
1/24/2013
3/21/2013
10/29/2013


BMP 8- Rain Events
Basin Capacity - 53.7 in
Soil Surface
Time grab sample collected
Water above Diver (in)
Time (hour)
1/21/2012
3/16/2012
4/26/2012
6/4/2012
11/1/2012
11/17/2012
11/30/2012
4/1/2013
4/8/2013
5/6/2013
6/25/2013

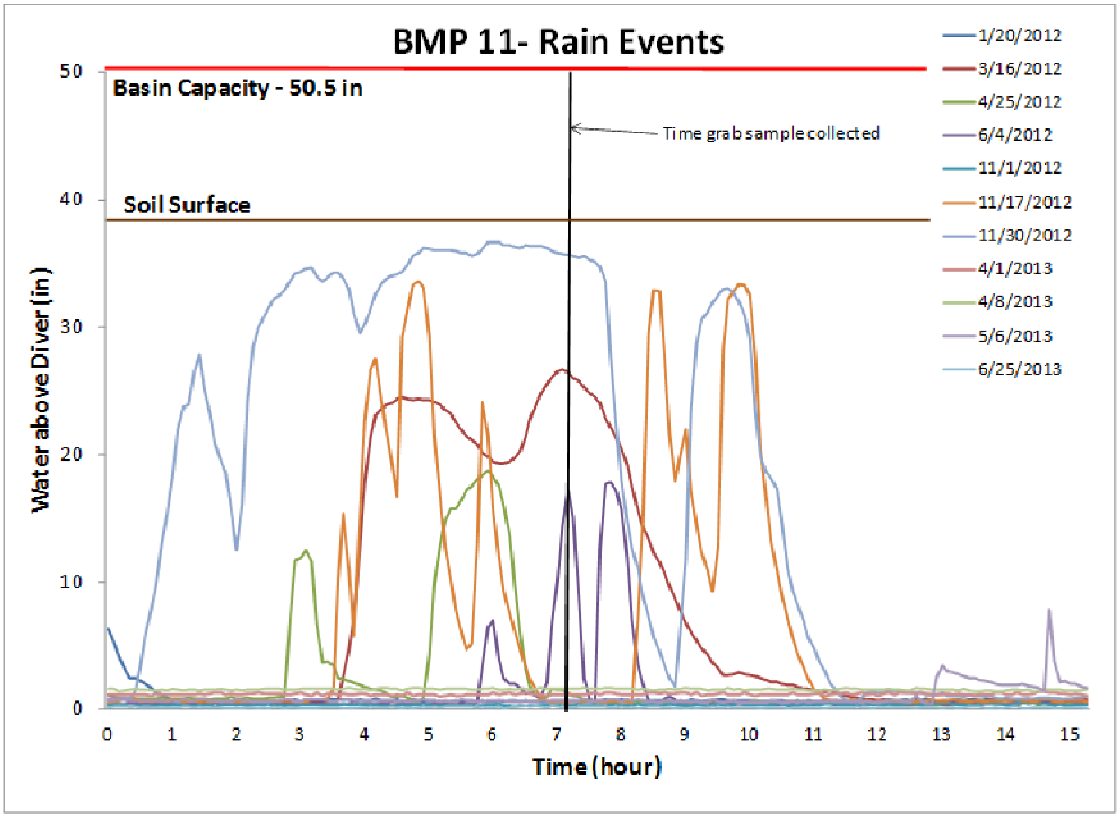

BMP 8- Snowmelt Events
Basin Capacity - 53.7 in
Soil Surface
Time grab sample collected
Water above Pressure Transducer (in)
Time (hour)
1/26/2012
3/5/2012
3/21/2012
4/1/2012
4/12/2012
10/22/2012
1/24/2013
3/21/2013
10/29/2013

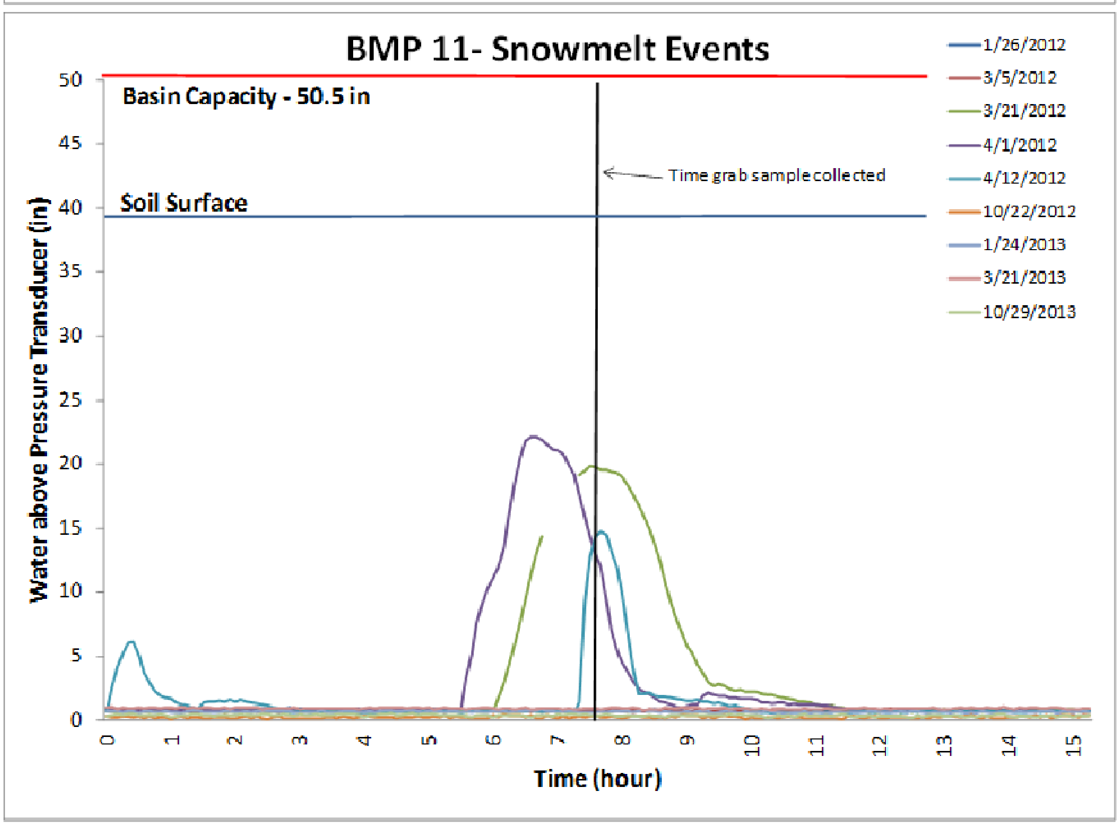


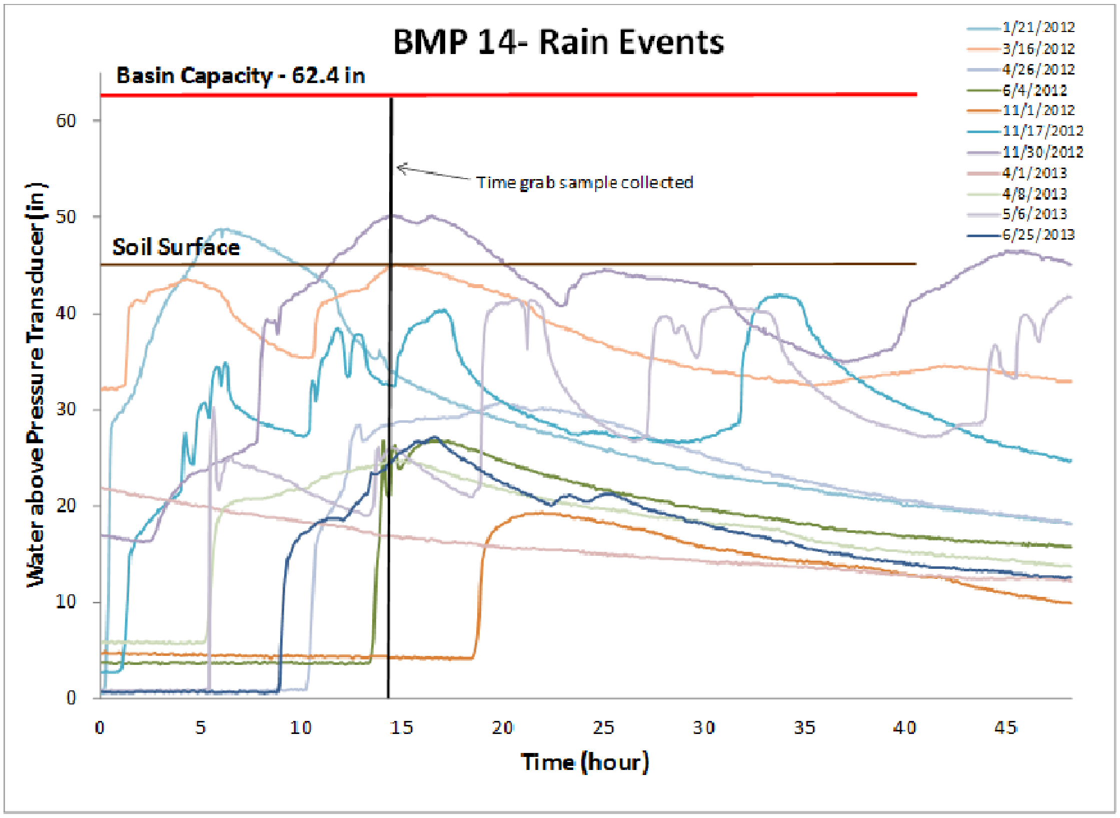
BMP 10- Rain Events
Flood Capacity Test Peak Water Level 50.4 in
Time of grab sample compared to hydrograph
Rain garden soil surface
Water above Pressure Transducer (in)
Time (hours)
1/21/2012
3/16/2012
4/26/2012
6/4/2012
11/1/2012
11/17/2012
11/30/2012
4/1/2013
4/8/2013
5/6/2013
6/25/2013

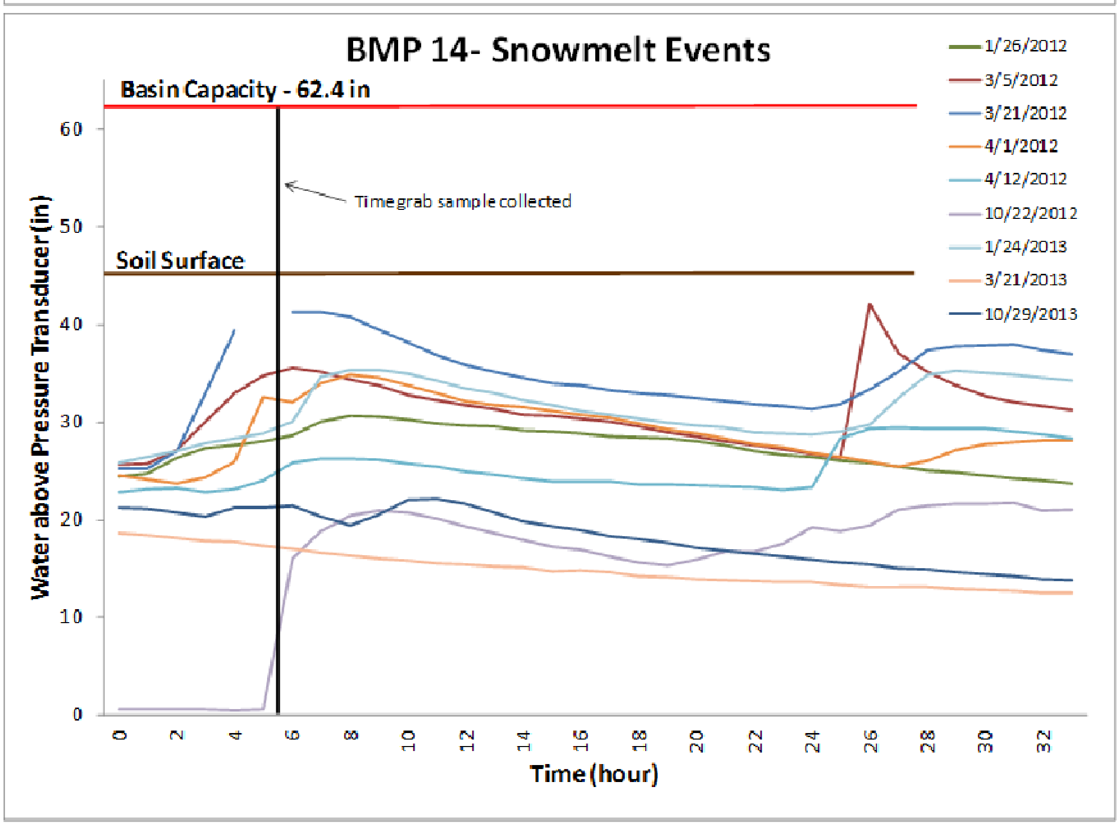


BMP 10- Snowmelt Events
Flood Capacity Test Peak Water Level 50.4 in
when samples collected
Rain garden soil surface
Water above Pressure Transducer (in)
Time (hours)
1/26/2012
3/5/2012
3/21/2012
4/1/2012
4/12/2012
10/22/2012
1/24/2013
3/21/2013
10/29/2013


BMP 11- Rain Events
Basin Capacity - 50.5 in
Time grab sample collected
Soil Surface
Water above Diver (in)
Time (hour)
1/20/2012
3/16/2012
4/25/2012
6/4/2012
11/1/2012
11/17/2012
11/30/2012
4/1/2013
4/8/2013
5/6/2013
6/25/2013


BMP 11- Snowmelt Events
Basin Capacity - 50.5 in
Time grab sample collected
Soil Surface
Water above Pressure Transducer (in)
Time (hour)
1/26/2012
3/5/2012
3/21/2012
4/1/2012
4/12/2012
10/22/2012
1/24/2013
3/21/2013
10/29/2013


BMP 14- Rain Events
Basin Capacity - 62.4 in
Soil Surface
Time grab sample collected
Water above Pressure Transducer (in)
Time (hour)
1/21/2012
3/16/2012
4/26/2012
6/4/2012
11/1/2012
11/17/2012
11/30/2012
4/1/2013
4/8/2013
5/6/2013
6/25/2013


BMP 14- Snowmelt Events
Basin Capacity - 62.4 in
Soil Surface
Time grab sample collected
Water above Pressure Transducer (in)
Time (hour)
1/26/2012
3/5/2012
3/21/2012
4/1/2012
4/12/2012
10/22/2012
1/24/2013
3/21/2013
10/29/2013

Appendix D: Sierra Wildflower Mix

WILDFLOWER MIX SIERRA	
Arnica Mollis	*Arnica mollis*
Black-eyed Susan	*Rudbeckia hirta*
Buckwheat Sulphur	*Eriogonum umbellatum*
Candytuft	*Iberis sempervirens*
Catchfly	*Silene armeria*
Cinquefoil	*Potentilla gracilis*
Columbine, red	*Aquilegia formosa*
Coreopsis Lanceleaf	*Coreopsis lanceolata*
Coreopsis Plains	*Coreopsis tinctoria*
Flax, blue	*Linum perenne*
Flax, scarlet	*Linum grandiflorum*
Geum	*Geum macrophyllum*
Gilia, golden	*Linanthus aureus*
Gilia, scarlet	*Ipomopsis aggregata*
Indian Blanketflower	*Gaillardia aristata*
Iris missouriensis	*Iris missouriensis*
Keckellia	*Keckiella breviflora*
Lupine, argentus	*Lupinus argenteus*
Lupine, perennis	*Lupinus perennis*
Monkeyflower, yellow	*Mimulus guttatus*
Monkeyflower, Lewis	*Mimulus lewisii*
Penstemon, rydbergii	*Penstemon rydbergii*
Penstemon, strictus	*Penstemon strictus*
Poppy, California	*Eschscholzia californica*
Poppy, Flanders	*Papaver rhoeas*
Shasta Daisy	*Leucanthemum x superbum*
Showy Goldeneye	*Viguiera multiflora*
Snow in Summer	*Cerastium tomentosum*
Wallflower	*Erysimum asperum*