Pennsylvania

Villanova University Stormwater Best Management Practice
Section 319
National Monitoring Program Project

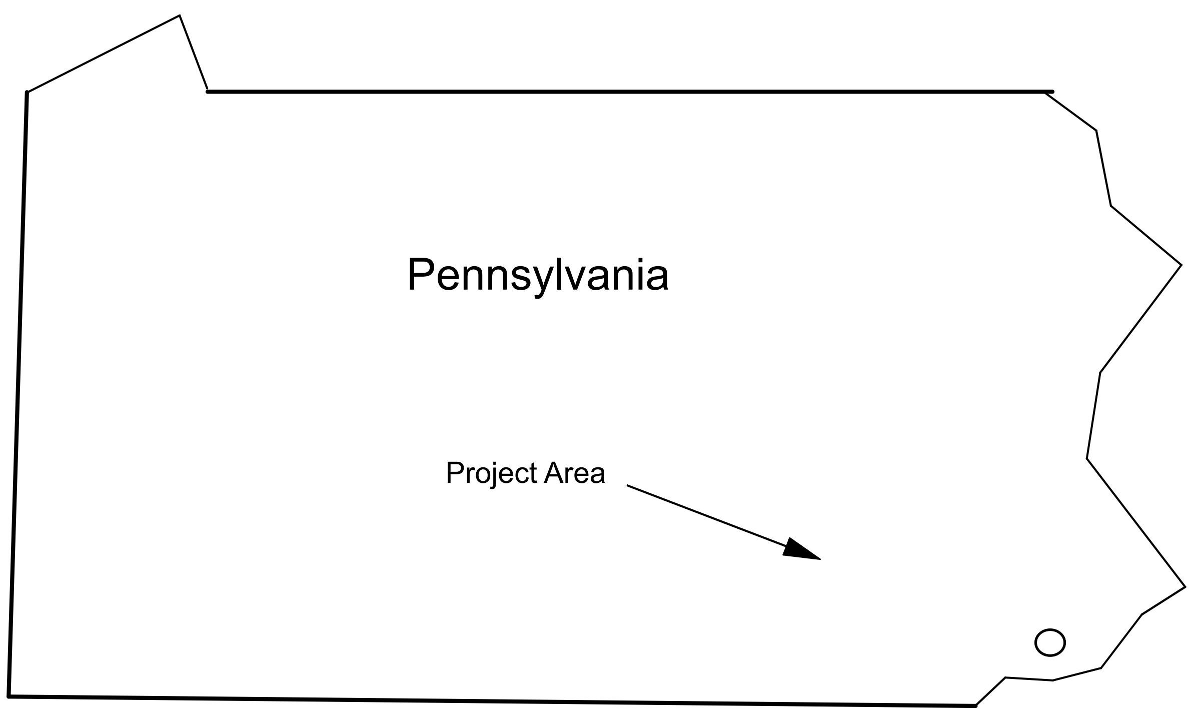


Figure 44: Villanova University Stormwater Best Management Practice (BMP) Monitoring Project.

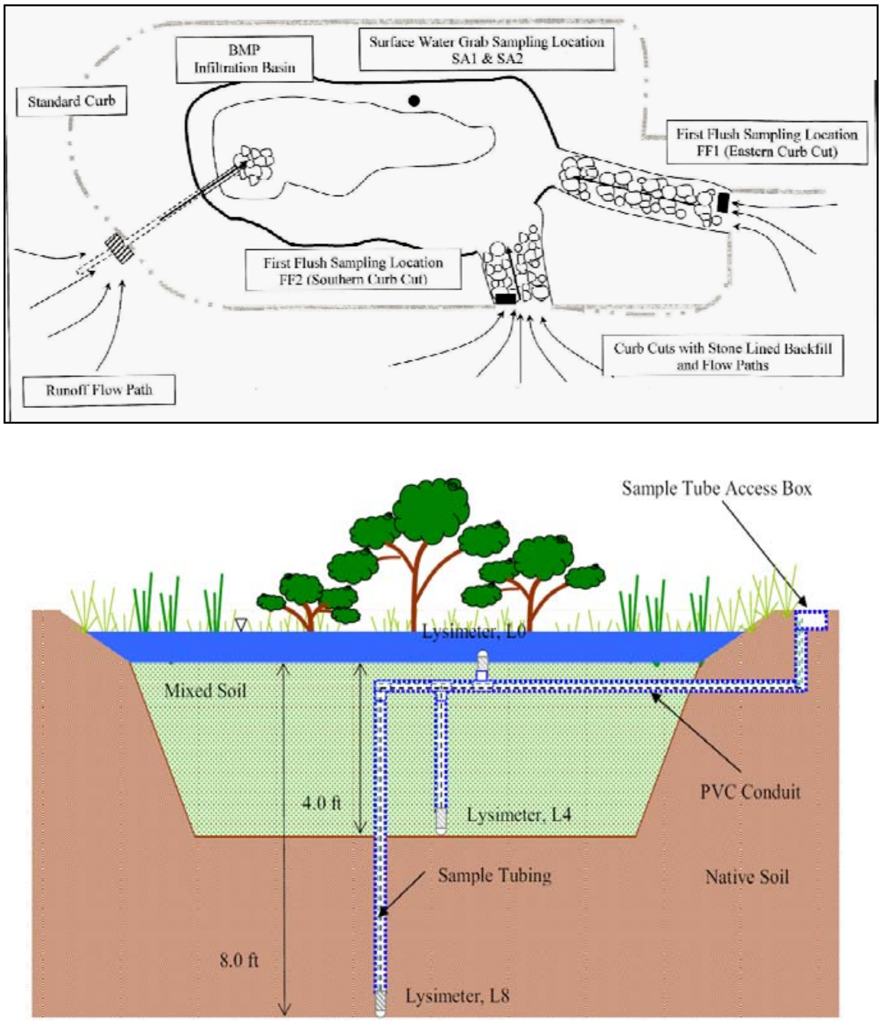


Figure 45a. Bioinfiltration Rain Garden (formally called Bioinfiltration Traffic Island)- Monitoring Setup.

(top) Schematic of surface sampling locations (Ermillo, 2005)

(bottom) Diagram of subsurface lysimeters sampling locations

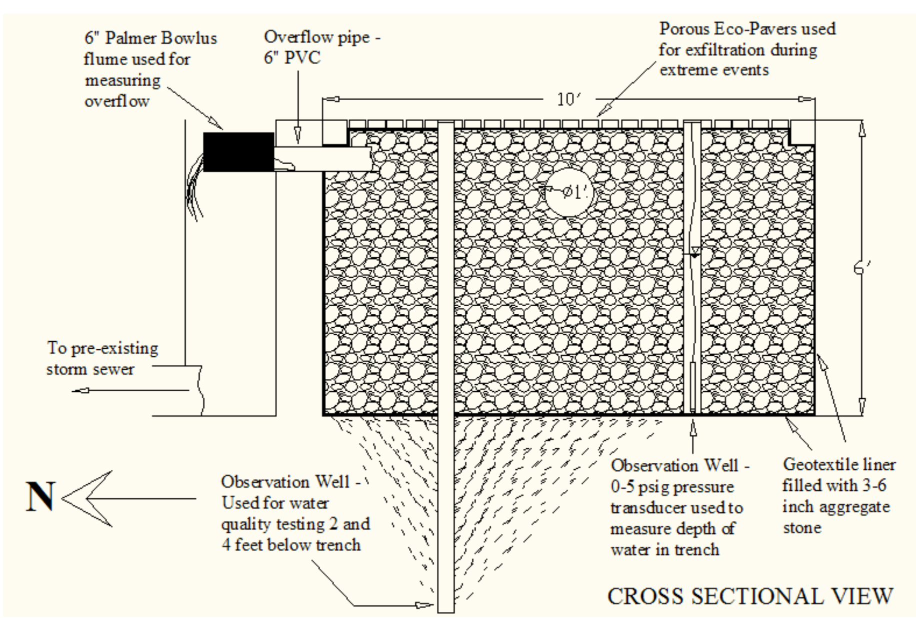


Figure 45b. Diagram of the infiltration trench cross with subsurface monitoring locations

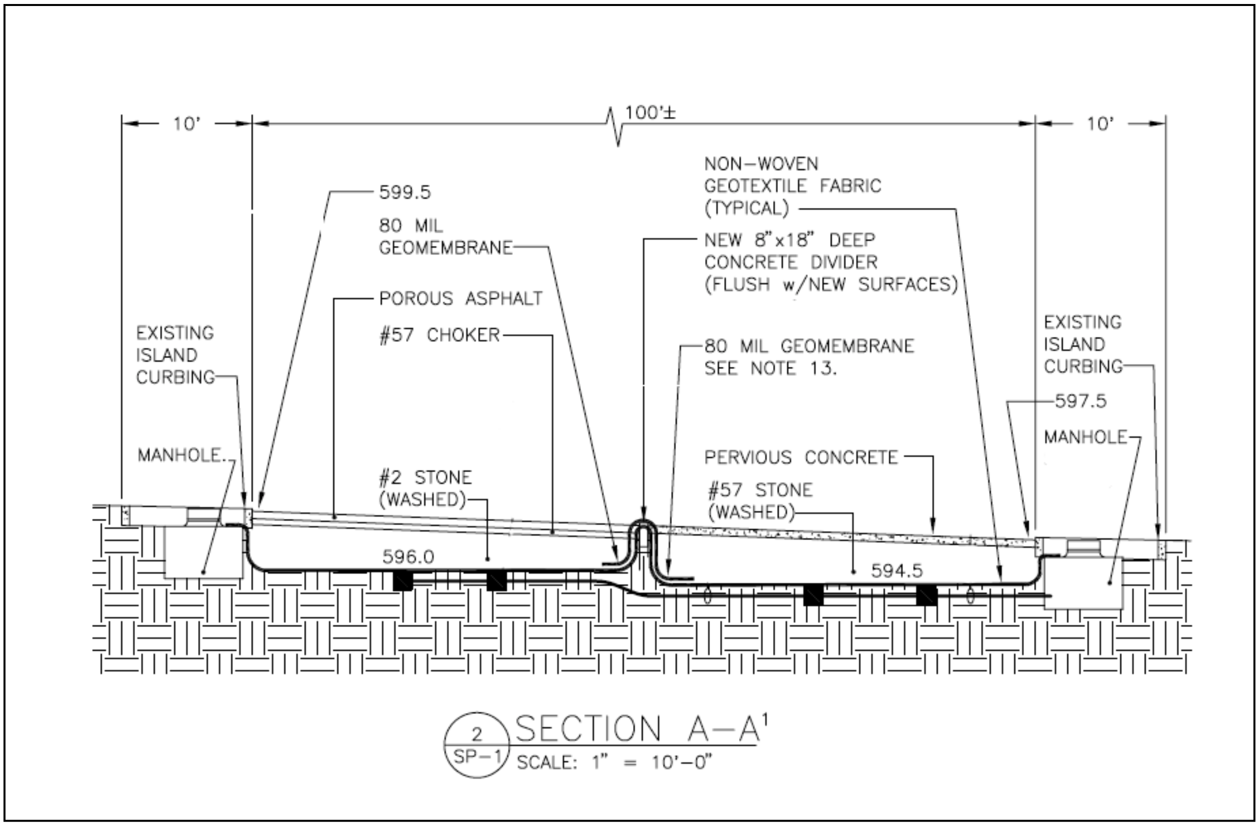


Figure 45c. (top) Diagram of the Pervious Concrete/ Porous Asphalt (PCPA)

(bottom) Photograph of the GKY First Flush Sampler, a passive stormwater sampler that can hold up to 5 L of water.

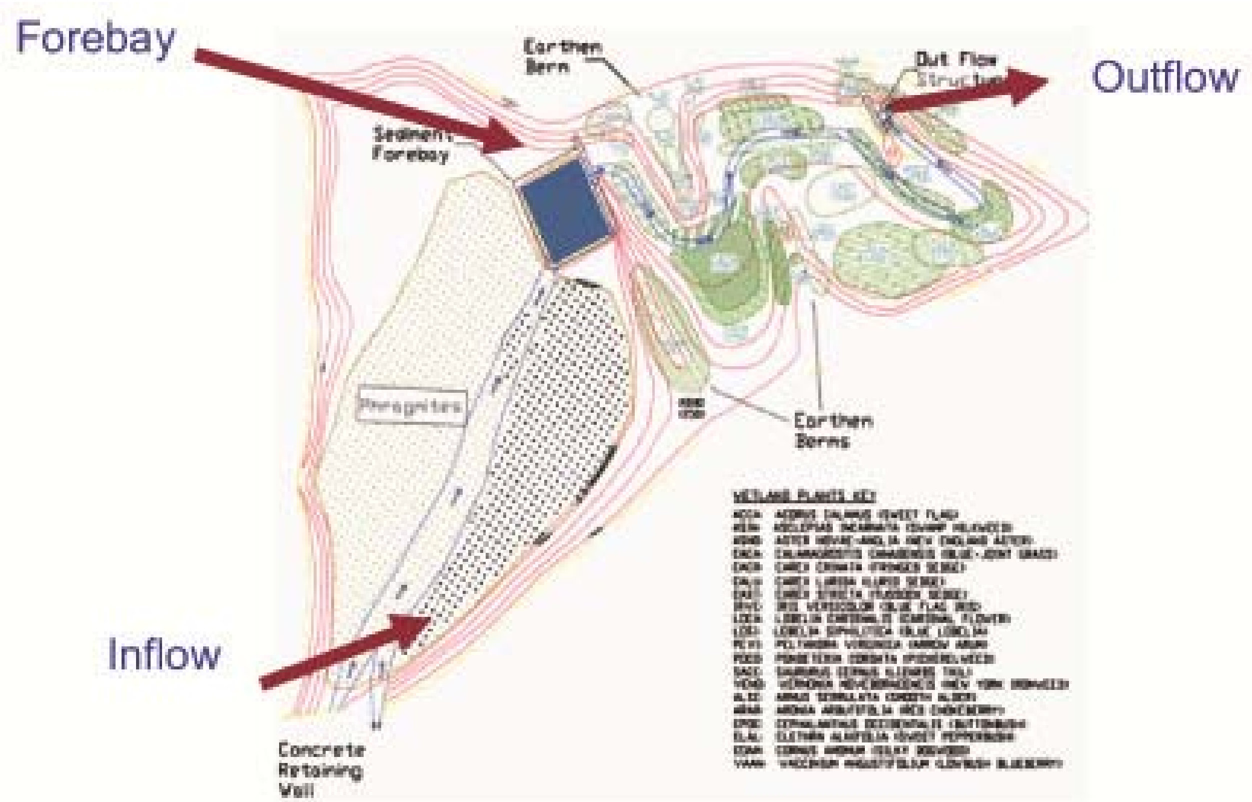


Figure 46. Stormwter Wetland - Monitoring Setup

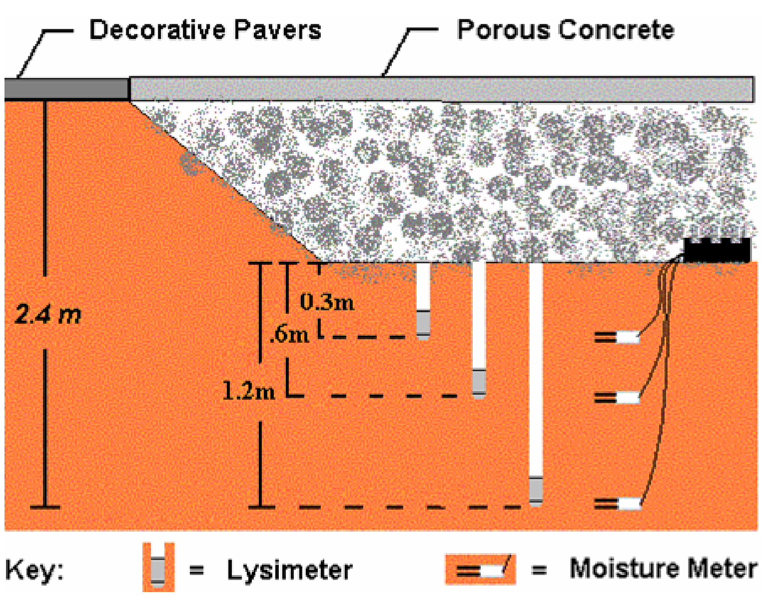


Figure 47. Porous Concrete –Cross Section of Monitoring Instrumentation (Kwiatkowski 2003)

PROJECT OVERVIEW

This project was accepted into the U.S. EPA NNPSMP in 2003. The goals of the EPA National Nonpoint Source Monitoring Program (NNPSMP) project and the Villanova University Stormwater Best Management Practice Park Research and Demonstration Park are:

1) To improve our understanding of nonpoint source pollution;

2) To scientifically evaluate the effectiveness of watershed technologies designed to control nonpoint source pollution; and

3) To export results and lessons learned to the stormwater community

During the last decade there has been a dramatic shift in the practice of stormwater management. The field has moved away from a single-minded flood prevention approach to one that embraces both water quality and quantity. A new suite of control measures termed Best Management Practices (BMPs) using on-site infiltration and treatment approaches have been developed to treat various forms of water pollution including runoff volume and peak flows from urban stormwater. These practices are still evolving, as recognized by the National Academies report entitled Urban Stormwater Management in the United States (National Research Council 2008).

Recognizing the need for research and public education, Villanova University, in collaboration with the Pennsylvania Department of Environmental Protection (PaDEP), formed the Villanova Urban Stormwater Partnership (VUSP) in 2002 and created a Stormwater Best Management Practice Research and Demonstration Park on its campus near Philadelphia, PA.

Since 1999, VUSP has constructed and monitored multiple innovative BMP devices including a stormwater wetland, bioinfiltration and bioretention rain gardens, pervious concrete/ porous asphalt installations, an infiltration trench, and a green roof. Other practices on campus include both wet and dry ponds, rain barrels, a bioswale and a seepage pit estimated to have been built in the 1890s.

By monitoring wet weather flows and pollution entering and exiting each BMP, the effectiveness of these technologies can be measured and evaluated. As the research ends on a specific site, a new one is brought on line. Each site is instrumented to facilitate study of runoff volume, peak flow and quality.

PROJECT BACKGROUND

Project Area

Bioinfiltration Traffic Island	Watershed – 0.53 hectares
Infiltration Trench	Watershed – 0.16 hectares
Pervious Concrete / Porous Asphalt	Watershed - 0.07hectares
Porous Concrete	Watershed - 0.52 hectares

Relevant Hydrologic, Geologic, and Meteorologic Factors

All BMPs are in the Philadelphia region. Rainfall is approximately 114 centimeters per year, with about 50% of the total volume falling in storms less then 2.5 cm. The soils are underlain by undisturbed sandy silt.

Land Use

Bioinfiltration Traffic Island - The watershed includes a student parking lot, roadway and lawn areas. It is approximately 50% impervious..

Infiltration Trench - The watershed consists of an elevated parking deck. It is 100% impervious.

Pervious Concrete / Porous Asphalt – Faculty / Staff Parking area – 100% impervious

Water Resources of Concern

All sites are built to mitigate the effects of urban stormwater runoff on the area streams and groundwater. This includes water quality, baseflow recharge, and stream bank protection. The Bioinfiltration Traffic Island is at the headwaters of the Darby Creek Watershed, while the other sites are in the headwaters of Mill Creek, which eventually reaches the Schuylkill River.

Water Uses and Impairments

Both Darby and Mill Creeks are degraded and listed on the 303d list, with urban runoff listed as the cause. Note that urban runoff is rated as the Nation's third highest leading source of water pollution (EPA, 1998 and 2002b). The EPA Region III website lists stormwater as the second highest cause of stream impairment as measured by river miles.

Pollutant Sources

Unlike many types of polluted water, stormwater typically is characterized by rapidly changing and widely fluctuating flows; in some instances high flow periods are accompanied by high concentrations of pollutants, leading to exceptionally elevated short-term loads to receiving waters. In addition to suspended solids, nitrogen and phosphorus, stormwater runoff may contain elevated concentrations of lead and zinc, which also have the potential to affect receiving waters adversely.

Pre-Project Water Quality

For this project, inflow to the stormwater BMP sites is treated as the pre-project water quality.

Water Quality Objectives

All projects are developed to mitigate the effects of urban runoff. The infiltration projects are designed to remove the first flush and infiltrate it into the ground, thus recharging baseflow and treating the first flush, as well as reducing volumes and peak flows.

Project Time Frame

The project time frame is to monitor most sites for six to ten years. Initial monitoring for water quality and quantity for the Bioinfiltration Traffic Island commenced October 1, 2003. During this first year of monitoring, it was discovered that sampling from the traffic island bowl and the porous concrete rock bed did not adequately represent the inflow conditions so first flush samplers were installed for both these practices. It was also discovered that unexpected extremely large levels of chloride increased the minimum detection level of the laboratory instruments for dissolved nutrients. These issues have been addressed through development of new laboratory techniques and purchase of new equipment.. Multiple wells were added to the Bioinfiltration site to facilitate monitoring of Groundwater.. The Infiltration Trench monitoring started in August 2004. One problem on the site is small rainfall events overflow the site and are difficult to monitor. Therefore an overflow weir and an automated sampler were added to the project during July/August of 2006. It was also determined that the grab sampler was not properly categorizing the inflows, so a composite sampler was added and previous inflow data was discarded. Sampling on the Pervious Concrete / Porous Asphalt site initiated in 2008.

Due to the experiences with these sites, the startup work is termed the "Initial Monitoring Period." Note that as all the original sampling locations are continued, the data collected during this first year will be used in analysis.

PROJECT DESIGN

Nonpoint Source Control Strategy

"Green Infrastructure" infiltration BMPs have been the focus of much research at Villanova University (VU). Each of the sites described below has been under study since construction. Websites for each stormwater BMP project can be viewed through the following link: http://www.villanova.edu/ vusp.

The control strategy is to assess flow volumes, rates and pollutant loads for wet weather flows entering and exiting the BMPs. The inflow and outflow of individual BMPs are examined. The BMPs considered to be part of the NNPSMP are summarized below.

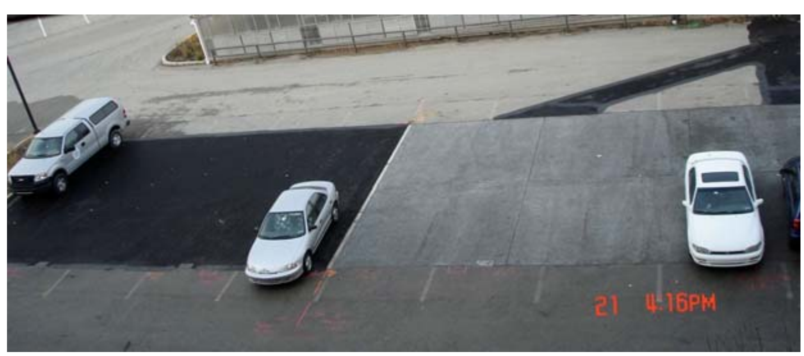
Bioinfiltration Rain Garden (BRG) (formally called Bioinfiltration Traffic Island). (PA Growing Greener Grant, constructed summer 2001). This bioinfiltration BMP (previously termed Bioinifiltration Traffic Island) was created by retrofitting an existing traffic island on Villanova's campus as shown in Figure 2. The facility intercepts runoff from a highly impervious (50%) student parking area and road (0.53 ha) that previously would be collected by inlets and delivered through culverts to a dry detention basin. The BMP is designed to control runoff from smaller storms (1- 3 cm) through capture and infiltration of the first flush. Capture of these small storms treats more than 80% of the annual rainfall, thus improving water quality, reducing downstream bank erosion and maintaining baseflow.

VU Bioinfiltration Rain Garden BMP (photo bottom taken 2007)

Infiltration Trench (IT). (319 Grant – Constructed August 2004). The project is designed to capture runoff from an elevated parking deck and then infiltrate it through a rock bed into the ground. The project presents some unique possibilities. As the water is piped through storm drains to the site, filtration devices can be used and tested at this site. This BMP has a very large drainage area to infiltration area ratio to stress the capacity of the BMP. It is designed to capture approximately the first 0.6 cm of runoff from an elevated parking deck (0.16 ha) and infiltrate it through a rock bed into the ground. The rock bed has a surface area of approximately 7.2 m2, and is 3 m deep (under the influent box and picnic table - see photo). Overflow from the trench first exits through a pipe at the surface to the inlet pictured (far left of Figure 3). During extreme events, if the overflow pipe is full, any additional runoff exits through the porous pavers placed above the infiltration trench (Figure 3). Of the demonstration sites under study, this site is the only one with a 100% impervious drainage area. The drainage area receives continuous use by faculty and staff vehicles.

VU Infiltration Trench, (left) completion of trench excavation with geotextile fabric lining (note locations of the two monitoring wells) (right) completed infiltration trench (2005)

Pervious Concrete / Porous Asphalt (PCPA). (EPA Section 319 grant, National Ready-Mixed Concrete Association – Prince Georges County, constructed October 2007). This BMP captures runoff from a campus parking area, passes the flow through either a pervious concrete or porous asphalt surface course, and infiltrates it through a rock bed into the ground. The site, formerly a standard asphalt paved area, is located behind Mendel Hall at the Villanova campus. The site consists of an infiltration bed overlain by a 15.2 x 9.1 m pervious concrete surface and an adjacent, equally sized porous asphalt surface. The site receives continuous use by faculty and staff vehicles. The site is designed to capture and infiltrate storms of up to five cm of rainfall. From these events there is no runoff from the site. The pervious pavements receive water solely from parking areas. The infiltration beds are level and range from 0.9 to 1.5 m deep and are filled with washed stone, with approximately 40% void space. In extreme events when the capacity of the storage beds is exceeded, flows are permitted to exit the site and flow out to the original storm sewer system. This overflow eventually makes its way to a stormwater wetland. The project presents some unique possibilities, to include comparing the performance from both a hydrologic and environmental view of the technologies. Hydrocarbon testing was in 2008.



VU Pervious Concrete / Porous Asphalt BMP

Stormwater Wetland. (EPA Section 319 grant, NOAA Coastal Zone Program grant, construction 1998). An existing stormwater detention basin on Villanova University property was converted into an extended detention Stormwater Wetland BMP (Center for Watershed Protection, 1996) using the design concepts presented in the Pennsylvania Handbook of Best Management Practices for Developing Areas (PACD, 1998). The wetland was designed to treat water quality and to reduce erosive peak flows from runoff from large parking lots, university buildings and dormitories, roadways and train tracks. The watershed draining to the wetland is approximately 40% impervious. The project has been published in EPA 319 Success Stories Part III (EPA, 2002a). Some limited unfunded flow studies was conducted at this site prior to 2005; additional monitoring was conducted after 2005 under a NOAA Coastal Zone Program grant. Monitoring has ended.

VU Stormwater Wetland Outlet (2004)

Porous Concrete Demonstration Site PaDEP 319 grant, construction 2002) The creation of a porous concrete infiltration facility was in an existing central paved area on the Villanova University campus.. Rock beds underlie three large paved areas, with porous concrete strips (the darkest gray edging around the white concrete) surrounding the beds. The rock beds capture runoff directly from the surrounding roof drains and also from drainage through the porous concrete strips. This site was first built in 2002, but the initial concrete pour failed. The surface was replaced in the summer of 2003, but again some material problems reemerged which were addressed through replacement of some of the surfaces in October 2004. Similar to the concept of the Bioinfiltration Traffic Island, runoff from the site and surrounding buildings (approximately 64% impervious) are captured and infiltrated, decreasing the flows and pollution to a high priority stream segment on the 303(d) list. The site has a much higher capacity then the Bioinfiltration Traffic Island as it overlies the large rock holding beds.

(left) Construction of porous concrete infiltration beds with #4 baffle stone in place.
(middle) Runoff being infiltrated by porous concrete.
(right) Porous Concrete Demonstration Site.

Project Schedule

Site	Monitoring TimeframeStatus	Initial Monitoring Phase	Notes
Bio-Infiltration Traffic Island	Monitoring Underway 10/01/04-09/30/14	10/01/03-09/30/04	IMP - added first flush samplers + bowl lysimeter. GW Well added 2006 Additional GW Wells added 2007
Infiltration Trench	12/01/04-09/30/10	09/01/04-09/30/05	2006 added Automated inflow sampler Overflow Weir
Pervious Concrete / Porous Asphalt	1/1/2009- 9/1/2013	1/1/2008-12/31/2008	Constructed Oct 2007
Stormwater Wetland	Monitoring concluded Baseflow monitoring 6/1/04-9/30/10 Wet weather monitoring 2/1/05-9/30/10	2005-2008	Constructed 1998
Porous Concrete	Monitoring concluded 10/1/04-9/30/10	10/1/03-9/30/04	Construction 2002

Water Quality Monitoring

Variables Measured

pH
Conductivity
Total Suspended Solids (surface samples)
Dissolved Solids (depending on volume collected)
Chlorides
Nutrients - N, P (Dissolved - Various Forms)
Metals - Various (Dissolved - Various Forms)
Hydrocarbons (start 2008)

This list is adjusted based upon what is found at the site and the direction of the research governing board. Note that some of these tests are only applicable to the surface or ground water samples (currently, spectrophometry, ion chromatography, and atomic adsorption equipment is in use - QAPP plan is in place).Unexpected extreme values of high chlorides from road salt interfered with the nitrates, nitrites, and orthophosphate HPLC analysis for the first several years. A new analysis technique was developed to address this situation.

The samples are analyzed in Villanova University’s Civil and Environmental Engineering Water Resources Laboratory, beginning within 30 minutes of sample collection; all analyses are typically completed within 24 hours of sample collection. Any samples not analyzed within 24 hours are preserved according to appropriate protocols established for each analysis.

Sampling / Flow Monitoring Scheme

See figures 45, 46, and 47 for sampling locations.

Infiltration Sites – Each site has rain gages, water sampling devices, and flow or level recorders as appropriate. Pressure transducers are also used to measure the depth of water in the rock beds or surface bowls. First flush samplers are used to capture runoff inflow for water quality testing. Flow leaving the site is split into infiltration and overflow for large storm events. As sampling is conducted from the vadose zone, soil lysimeters were used to collect water samples under the beds (treated as a composite sample). Note that only dissolved fractions are collected from the vadose zone samples and that the sample size is limited, occasionally limiting the number of tests performed.

Lysimeters were used to measure subsurface flow. Lysimeters work by overcoming soil water tension or negative pressure created by capillary forces. By creating a vacuum or negative pressure greater than the soil suction holding the water within the capillary spaces, a hydraulic gradient is established for the water to flow through the porous ceramic cup into the sampler.

Bioinfiltration Rain Garden (formally Bioinfiltration Traffic Island) – A level detector is used to measure the rate of infiltration from the surface bowl, and outflow is measured using a weir in the culvert leaving the site. Soil moisture meters and lysimeters have been placed under the bed. For the past year, inflow water samples for quality analysis were taken from the water bowl above the bed. As considerable removal in the stone beds leading to this BMP has been observed, "first flush" flow samplers have been installed to better represent the inflows to the site. These devices are installed to capture water samples where the runoff enters the site through curb cuts. Ground water quality (outflow) is measured using lysimeters located at the bottom of the made soil (multiple depths and locations). Surface water outflow (only large storms) grab samples are taken from the bowl. A well was added to the site in 2006 to learn more about the site interaction with the groundwater. In 2007 several more were drilled, and pressure transducers with conductivity meters were added to allow for study of the groundwater hydrology from both the hydrology and environmental perspective. More specifically:

<u>Stormwater quantity</u>: The bioinfiltration rain garden has been equipped to accept runoff entering the system via two inlets (north and south), and from a culvert that intercepts runoff from an adjacent culvert.

- Rainfall is measured in 5-minute intervals with a tipping bucket rain gage.
- Overflow is measured through use of a combination V notch weir / pressure transducer.
- Depth within the bowl is measured directly, initially using an ultrasonic level recorder and later a pressure transducer.

  Inflow is determined from a calibrated hydrologic model using all data mentioned previously.
- Multiple Pressure Transducers are installed in surrounding wells. This arrangement is still preliminary.

<u>Stormwater quality</u>: Surface runoff and sub-surface vadose zone samples are collected for approximately 12-18 storms/year.

- Two first-flush samplers catch the first two L of direct runoff from the impervious surface and the grass area adjacent to the basin.
- Initially, a grab sample was collected of surface water during the storm event, with a second sample collected at the conclusion of rainfall, if ponding had occurred. This has been replaced by an automated composite sampler.
- A composite grab sample is taken from the outflow weir.
- Lysimeters are located at depths of 0, 1.2, and 2.4 m beneath the surface. The sample is

extracted from the soil through the use of a pressure-vacuum soil water sampler.

- Grab samples have been taken of the groundwater from surrounding wells. These samples are part of another project that is still at a preliminary stage.

Sample locations for the Bioinfiltration Rain Garden:

- “first flush #1” (FF1) – located on the perimeter of the basin. Assumed to collect the first segment of runoff from the surrounding landscape to the south and east of the basin
- “first flush #2” (FF2) – located on the perimeter of the basin. Assumed to collect the first segment of runoff from the surrounding landscape to the north of the basin.
- “grab sample 1” (GS1) – Sample taken during the rain storm from the ponded water within the basin. Assumed to represent surface water inflow into the site.
- “grab sample 2” (GS2) – Sample taken once the rain has ended from the ponded water within the basin – Assumed to represent outflow leaving the site as either surface water if the depth is above the weir or infiltration into the ground.
- “L0” – lysimeter located at ground level within the drainage bowl. Assumed to represent water infiltrating into the bed.
- “L4” – lysimeter located within the bowl approximately 4 feet beneath the ground surface.
- “L8” – lysimeter located within the bowl approximately 8 feet beneath the ground surface.

Infiltration Trench – As the site is unique in categorizing the nonpoint pollutant contribution of a paved area, this site is treated differently. A rain gage is on site, and runoff inflow is measured using a pressure transducer and V-notch weir. An automated sampler has been added to measure the inflow water quality at the V notch weir. Pressure transducers and soil lysimeters are used to evaluate the depth within the rock bed, volume of infiltration (outflow), and pollutant loadings (Outflow). An overflow weir was added to improve outflow measurements for larger storm events. Again, as the overflow outflows are essentially untreated, the outflow surface water quality is considered the same as the inflow. More specifically:

Stormwater Quantity: The infiltration trench has been equipped to measure and sample runoff entering the system, storage within the system, and overflow. All data are recorded continuously and downloaded weekly.

- Rainfall is measured in 1-minute intervals using a tipping bucket rain gage.
- Runoff entering the site is measured using two V-notch type weirs with corresponding pressure transducers.
- Depth of runoff stored in the rock bed is measured using a pressure transducer.
- Overflow is measured using a manufactured weir and a pressure transducer.

Stormwater Quality: Event-based samples of surface runoff and soil moisture are collected from an average of 12-18 storms/ year.

- An autosampler takes rainfall-weighted discrete samples of surface water inflow.
- Lysimeters are located at 0.6 and 1.2 m depths beneath the surface to extract vadose zone water samples.
- A grab sample co collector is used to capture overflow water quality samples.

Sample locations for the Infiltration Trench:

- “In” – Sequential samples entering the BMP. Samples are taken after ¼”, ½” and 1” of runoff.

- “Overflow” – Grab Sample of overflow from the Infiltration Trench - captures the first segment of overflow.
- “L2” lysimeter located approximately 2 feet below the bottom of the bed.
- “L4” lysimeter located approximately 4 feet below the bottom of the bed

Pervious Concrete / Porous Asphalt — Inflow water quality is measured using first flush and lysimeters for both the asphalt and concrete sections. Overflow outflow (large storms only) from each site is measured at weirs in and overflow structure adjacent to the rock bed. Composite water samples for quality measurement of the surface water overflows are taken through a port in the rock bed. More specifically:

Note: Sampling was reduced in 2009 to focus on flow and temperature following conclusion of the water quality study. Notes below are on the original instrumentation.

<u>Stormwater Quantity</u>: The PC/PA has been equipped to monitor runoff entering the system through the porous surface. These flows are correlated to the rainfall amounts measured by a rain gage located on site. The site is further equipped to measure ponded depths and potential overflow. All data are recorded continuously in a data logger.

- Rainfall is measured in 10-minute intervals using a tipping bucket rain gage.
- Pressure transducers that measure the depth in 5 minute intervals are used to measure depths in each rock bed. They are also used in conjunction with a V-notch weir to measure any overflow.

<u>Stormwater Quality</u>: Precipitation event data are collected for surface runoff and sub-surface soil moisture. On average, 12 to 18 storms are sampled yearly.

- Two first-flush samplers catch the first two L of direct runoff from the impervious surfaces upstream of each pervious surface.
- Grab samples of runoff stored in the rock bed are collected following the storm.
- Lysimeters located at 0.15, 0.30, and 0.46 m beneath the surface extract samples from the soil through the use of porous ceramic cups placed under suction during a storm event and pressure after completion using a pressurevacuum soil water sampler.
- The project used Sigma 900 autosamplers capable of taking up to 24 discrete water samples or one composite sample per storm event. To get a consistent sampling routine, the automated samplers are triggered through the data logger through rainfall or depth of water in the BMP. A consistent sampling protocol is established for each site.
- First flush samples were collected using the GKY First Flush Sampler, a passive stormwater sampler that can hold up to 5 L of water (Figure 9). The lid of each sampler is constructed with 5 sampling ports, each of which can be plugged to control the rate at which collected runoff enters the sampler. Plastic flaps on the underside of each port function as closing mechanisms, preventing additional water from entering the sampler once it has reached its capacity. Each sampler is fitted with a 5 L removable plastic container and lid to permit sample transport.

Porous Concrete— Inflow water quality is measured using first flush and lysimeters. Two sets of six soil moisture meters and lysimeters were placed both under and adjacent to the bed at two locations. These were to determine the outflow groundwater quality and quantity. Overflow outflow (large storms only) from each site is measured at weirs in and overflow structure adjacent to the rock bed. Composite water samples for quality measurement of the surface water overflows are taken through a port in the rock bed.

Stormwater Wetland - Both wet weather and baseflow events are included in the monitoring program for this BMP. As the great majority of the inflow is piped to the wetlands through culverts, flow is measured using Sigma Corporation flowmeters. These units measure both velocity and level within the culvert at the inflow and outflow of the BMP (five minute intervals). A rain gage is connected to the flow meter to record the intensity and pattern of the storm. To measure quality, multiple discrete samples are taken during the storm events using automated samplers. Samples are taken at the inflow, the sediment forebay, and the outlet. Probes connected to the flowmeters continuously measure dissolved oxygen, pH, temperature and conductivity. Bimonthly baseflow samples are analyzed for these parameters plus fecal coliform and *E coli*.

Modifications Since Project Start

2005 - "First Flush" samplers were added to the Bioinfiltration Traffic Island and Pervious Concrete and a gutter flow collection device was added to the Pervious Concrete site in 2004.

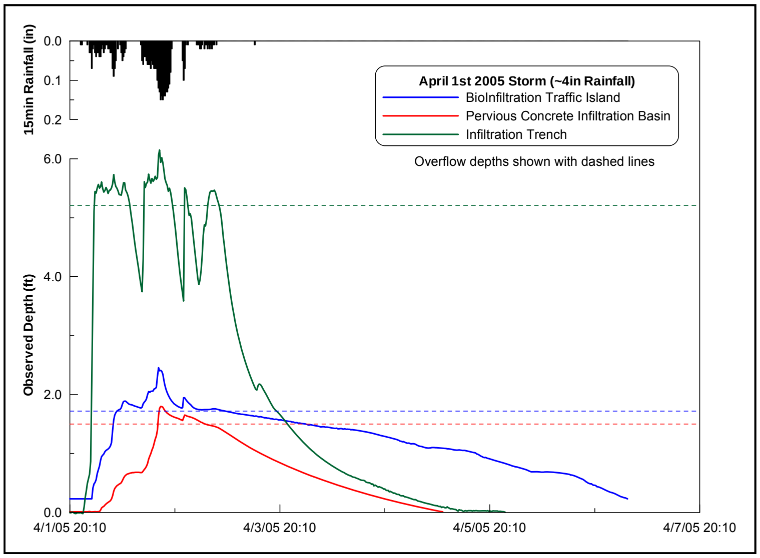
2006 - A groundwater well was added to the Bioinfiltration Site, and an overflow weir and an automated sampler was added to the infiltration Trench.

2007 Additional Groundwater Wells added to the Bioinfiltration Site. Second weir added to the Infiltration Trench inflow.

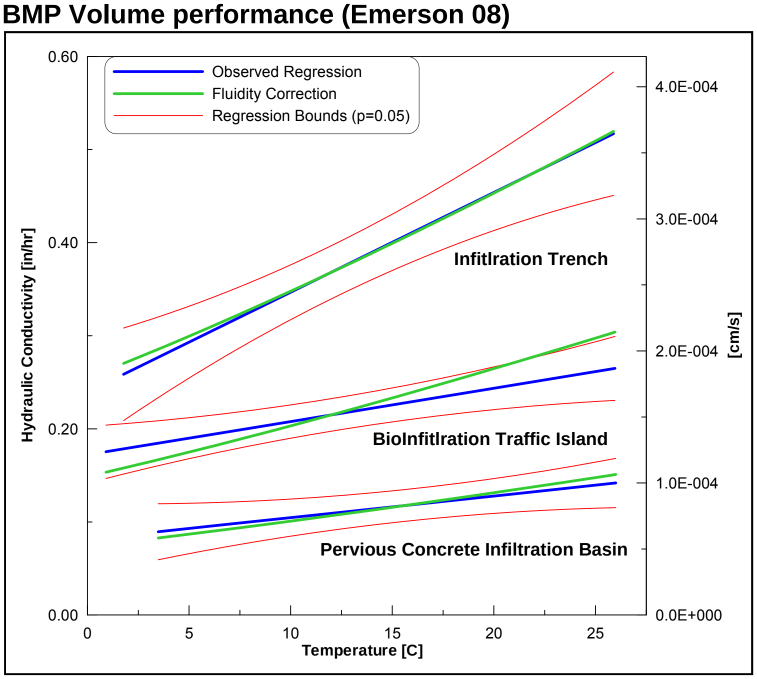
DATA MANAGEMENT AND ANALYSIS

Data has been submitted to the ASCE / EPA Stormwater BMP database and are the focus of numerous student masters theses and dissertation. available through the VUSP website. Multiple Journal articles have been published with more under review.

Flow Example – Infiltration Sites.



BMP Volume performance (Emerson 08)



Overlay of linear regressions for all three infiltration BMPs (Emerson 08)

Water Quality / Quantity Findings To Date

Each of the green infrastructure BMPs is monitored for both quality and flow. Research results are used to further our understanding of how each BMP performs from both a surface and subsurface water perspective. Data from the Bioinfiltration Rain Garden are presented in depth, with selected examples of data from the other sites.

Bioinfiltration Rain Garden (Previously known as the Bioinfiltration Traffic Island). The surface water results of pollutants and flows entering and exiting the BRG from a surface water perspective are presented in Tables 1 and 2. Table 1 is a record of all storm events sampled, while Table 2 presents results from 2008 to allow comparison of the removal percentages for that individual year to that of the complete record.

Note the significant reduction of surface water pollutants achieved through bioinfiltration. It is interesting to observe how much higher the TSS removal is than that of the flow volume. The surface water capture is underrepresented in this report as storms less then 6.3 mm are not included in the statistics, and these storms would be completely captured. The comparison of 2008 to the long term record is used to further our understanding of the volume and pollutant removal of the site as it ages. It appears that the site is increasing in pollutant removal effec tiveness, but that has not as of yet been proven statistically. The exception is TDS / Chlorides / Cadmium, which are skewed due to snow melt operations for 2008. We will learn more as results from 2009 and 2010 are incorporated in the data base, as laboratory detection limits have improved.

Table 1. Bioinfiltration Rain Garden – Surface Flow Performance 2003-2008

Bioinfiltration Rain Garden Surface Water Analysis				
Lifetime Totals				
	# of Storms	Inflow	Outflow	**Removal Efficiency**
Water Quantity (Measured Events)	253	14,548,858 L	7,297,715 L	49.8%
Total Suspended Solids (TSS)	74	410 kg	10 kg	97.5%
Total Dissolved Solids (TDS)	76	408 kg	94 kg	76.9%
Total Nitrogen (TN) as N	41	2848 g	287 g	89.9%
Total Kjeldahl Nitrogen (TKN) as N	1	0 g	0 g	NA
NO2 as N	51	162 g	21 g	87.0%
NO3 as N	55	1226 g	142 g	88.4%
Total Phosphorus (TP) as P	70	2844 g	2073 g	27.1%
Phosphate (PO4) as P	51	254 g	75 g	70.3%
Chloride (CHL)	62	257 kg	4 kg	98.5%
Total Cadmium	25	2243 mg	222 mg	90.1%
Total Chromium	38	42337 mg	14698 mg	65.3%
Total Lead	41	44428 mg	6580 mg	85.2%

Note: Smaller storms less then 6.3 mm are not included.

Table 2. Bioinfiltration Rain Garden – Surface Flow Performance 2008

Bioinfiltration Rain Garden Surface Water Analysis					
2008					
	# of Storms	Inflow	Outflow	Removal Efficiency	Change in Removal Efficiency vs. long-term
Water Quantity (All Recorded Events > 0.25")	38	-	-	-	"+/-
Water Quantity (Measured Events)	29	1,501,589 L	706,432 L	53.0%	3.1%
Total Suspended Solids (TSS)	14	49 kg	3 kg	94.7%	-2.8%
Total Dissolved Solids (TDS)	15	62 kg	23 kg	62.4%	-14.5%
Total Nitrogen as N	12	310 g	17 g	94.5%	4.6%
Total Kjeldahl Nitrogen as N	1	0 g	0 g	-	-
NO2 as N	10	72 g	3 g	95.3%	8.3%
NO3 as N	10	11 g	0 g	99.3%	10.8%
Total Phosphorus (TP) as P	11	127 g	12 g	90.6%	63.5%
Phosphate (PO4) as P	10	50 g	2 g	96.2%	25.8%
Chloride (CHL)	10	7 kg	2 kg	72.2%	-26.3%
Total Cadmium	8	1,244 mg	180 mg	85.5%	-4.6%
Total Chromium	5	30,186 mg	8,248 mg	72.7%	7.4%
Total Lead	8	37,233 mg	3,893 mg	89.5%	4.4%

Note: Smaller storms less then 6.3 mm are not included.

The subsurface results (Table 3) are presented as concentrations (mg/L) of each pollutant as measured at the 0, 1.2, and 2.4 m level. As it is not yet known how much of the captured volumes are infiltrated versus evapotranspired, we are unable to estimate mass loadings.

Note that while TDS, conductivity, TN, and Chloride increase as the stormwater moves through the soil, the pollutants are slightly reduced.

While the pollutant reduction as percent effectiveness is a useful index of BMP performance, an advantage of long-term monitoring is the ability to study the behavior of the BMP based upon a larger data set, especially the more infrequent larger events. Figures 45a1 and 45a2 present analysis from the bioinfiltration rain garden with respect to flow volume and peak flow. In Figure 10, the relationship between inflow and outflow volume is bilinear, with smaller rainfall events being completely infiltrated or evapotranspired. Note that the x intercept of 41.6 m3 represents the average inflow volume that is removed completely with no surface outflows. Based on the regression model, this volume is removed from larger events as well.

Figure 45a2 presents a similar look at the effect of the bioinfiltration BMP on peak flows. While the relationship between inflow and outflow peaks are not as linear as for volume, a clear reduction in peaks is evident.

Extended monitoring allows the researcher to examine the record in new ways to more fully understand the characteristics of the technology under investigation. Figures 45a3 and 45a4present the TSS and TDS results using a probabilistic approach. For each rainfall event, the inflow and outflow TSS or TDS mass values are sorted and assigned probabilities based on the cumulative distribution of observed data in order to understand their significance. For ex ample, it can be stated that a 40% chance exists of the inflow carrying a TSS load of 1 kg, but only an 11% chance of 1 kg of TSS exported in the outflow. Or there is a 15% chance of having less than 10 kg entering, with approximately 0.16 kg leaving at the same probability level.

Table 3. Bioinfiltration Raingarden Vadose Zone Sampling 2008. Concentrations at 0, 25, 50, 75, and 100 percent levels refer to quantiles from cumulative frequency distribution of observed values.

BioInfiltration Traffic Island Groundwater Analysis - Concentrations at Soil Surface							
2008							
Water Quantity	Detection Limit	Num. of Storms	Concentration				
			0% (Min)	25%	50%	75%	100% (Max)
TDS (mg/l)	-	8	53	74	107	385	1445
pH	-	11	4.18	5.96	6.56	6.90	7.33
Conductivity (µS/cm)	-	11	54	68	81	95	135
TN (mg/l) as N	1.7 mg/l	10	0.85	0.85	1.28	2.05	2.40
NO2 (mg/l) as N	0.005 mg/l	9	0.03	0.52	0.74	1.19	4.22
NO3 (mg/l) as N	0.01 mg/l	9	0.00	0.00	0.03	0.21	0.44
TP (mg/l) as P	0.06 mg/l	10	0.14	0.19	0.26	0.48	0.95
PO4 (mg/l) as P	0.01 mg/l	9	0.01	0.02	0.03	0.07	0.94
CHL (mg/l)	0.5 mg/l	9	0.3	9.2	26.7	65.2	407.8
Dissolved Cadmium (µg/l)	0.1 µg/l	4	0.05	0.05	0.14	0.31	0.58
Dissolved Lead (µg/l)	0.5 µg/l	3	0.25	0.33	0.42	1.05	1.68
				*Non-detects are reported as half of the detection limit			

BioInfiltration Traffic Island Groundwater Analysis - Concentrations at 4 feet							
2008							
Water Quantity	Detection Limit	Num. of Storms	Concentration				
			0% (Min)	25%	50%	75%	100% (Max)
TDS (mg/l)	-	10	6	197	237	455	1344
pH	-	11	6.22	6.42	6.70	6.78	7.33
Conductivity (µS/cm)	-	11	330	339	349	397	774
TN (mg/l) as N	1.7 mg/l	12	0.85	0.85	0.85	0.85	1.90
NO2 (mg/l) as N	0.005 mg/l	10	0.03	0.22	0.53	0.83	1.29
NO3 (mg/l) as N	0.01 mg/l	10	0.01	0.01	0.14	0.64	2.12
TP (mg/l) as P	0.06 mg/l	11	0.07	0.17	0.20	0.23	0.34
PO4 (mg/l) as P	0.01 mg/l	10	0.01	0.01	0.03	0.11	0.80
CHL (mg/l)	0.5 mg/l	10	35.6	155.8	292.2	380.5	625.5
Dissolved Cadmium (µg/l)	0.1 µg/l	7	0.05	0.05	0.05	0.05	0.22
Dissolved Lead (µg/l)	0.5 µg/l	7	0.25	0.25	0.25	0.25	0.25
				*Non-detects are reported as half of the detection limit			

BioInfiltration Traffic Island Groundwater Analysis - Concentrations at 8 feet							
2008							
Water Quantity	Detection Limit	Num. of Storms	Concentration				
			0% (Min)	25%	50%	75%	100% (Max)
TDS (mg/l)	-	15	35	209	262	487	8659
pH	-	12	5.97	6.54	6.83	6.99	7.58
Conductivity (µS/cm)	-	12	80	313	383	421	476
TN (mg/l) as N	1.7 mg/l	12	0.85	0.85	0.85	0.85	3.50
NO2 (mg/l) as N	0.005 mg/l	10	0.03	0.24	0.53	0.86	1.19
NO3 (mg/l) as N	0.01 mg/l	10	0.01	0.01	0.02	0.38	1.08
TP (mg/l) as P	0.06 mg/l	11	0.03	0.15	0.19	0.29	0.44
PO4 (mg/l) as P	0.01 mg/l	10	0.00	0.01	0.02	0.04	0.70
CHL (mg/l)	0.5 mg/l	10	34.5	170.5	258.0	354.9	654.8
Dissolved Cadmium (µg/l)	0.1 µg/l	8	0.05	0.05	0.05	0.05	0.05
Dissolved Lead (µg/l)	0.5 µg/l	7	0.25	0.25	0.25	0.25	1.33
				*Non-detects are reported as half of the detection limit			

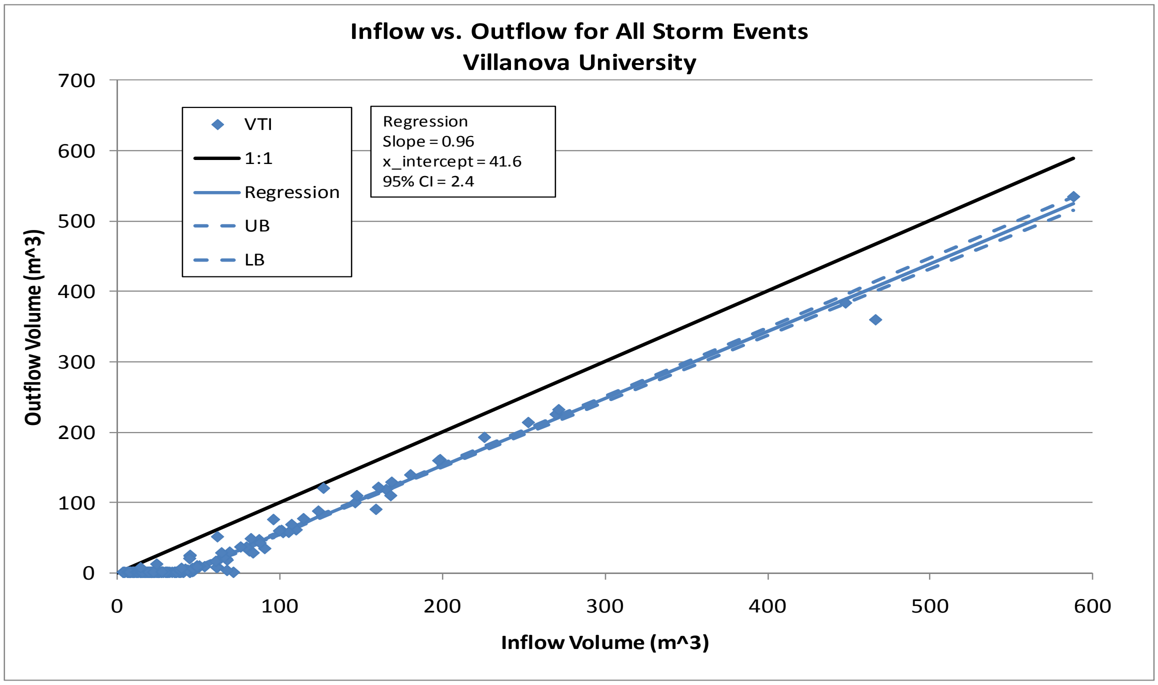


Figure 45a1. Plot of volume inflow / outflow relationship for Bioinfiltration Rain Garden.

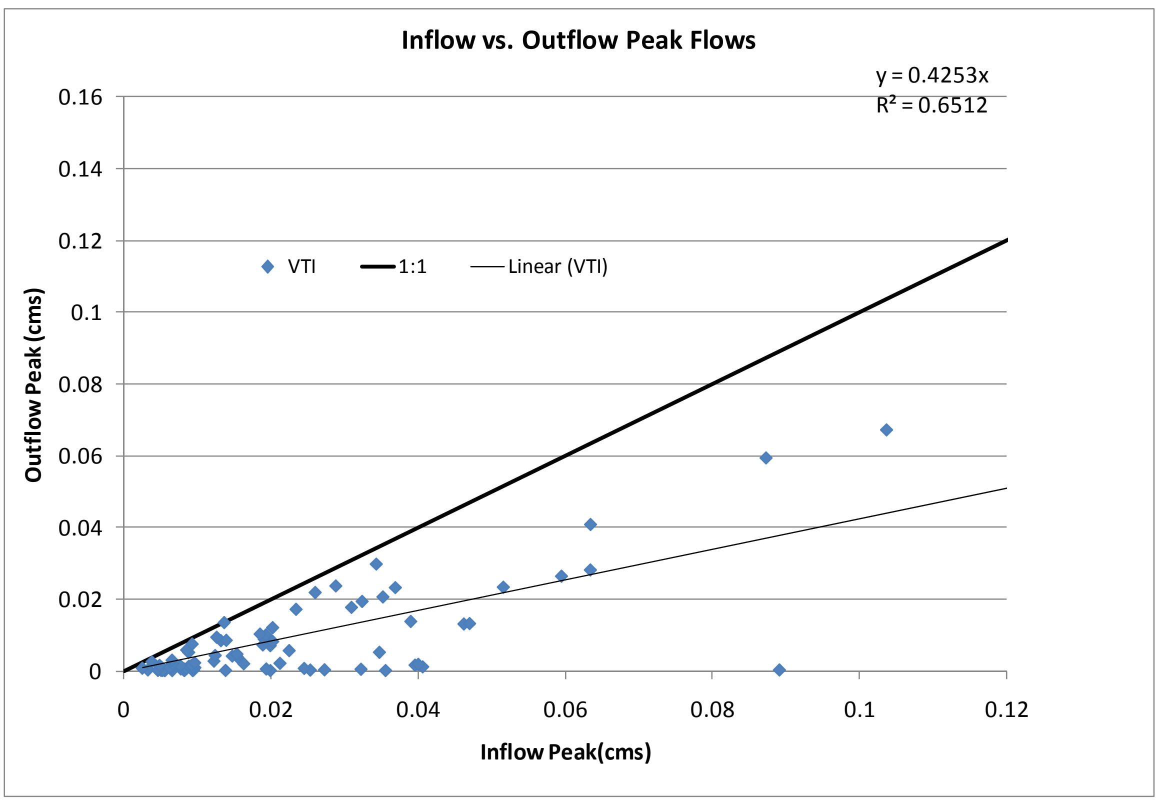


Figure 45a2. Plot of flow inflow / outflow relationship for Bioinfiltration Rain Garden.

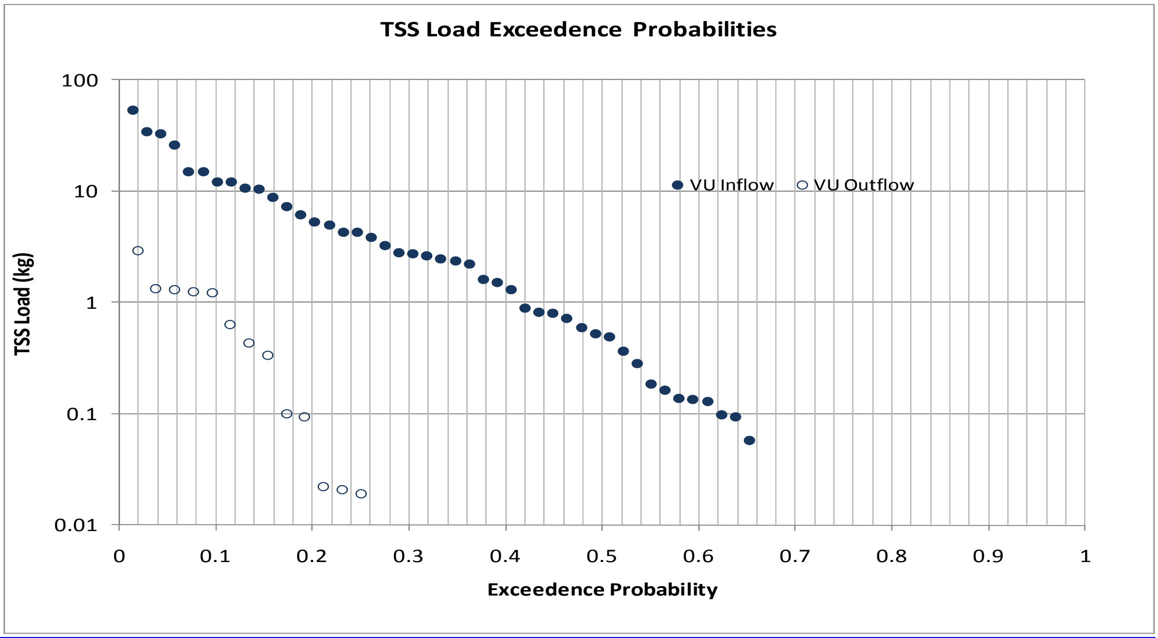


Figure 45a3. TSS exceedence probability plot for the Bioinfiltration Rain Garden.

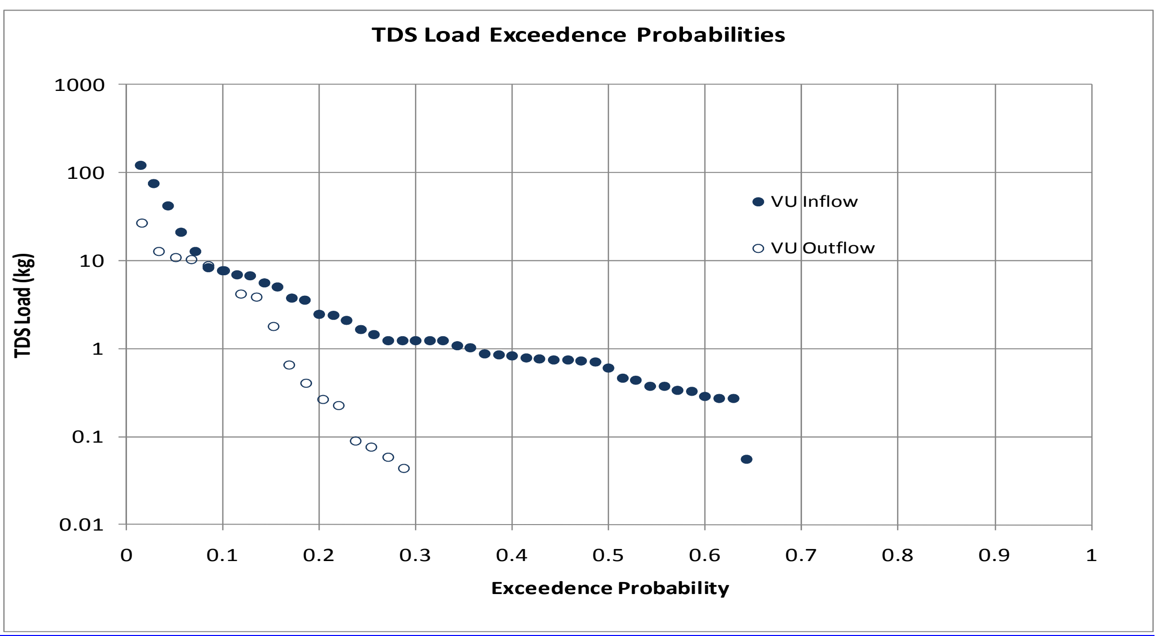


Figure 45a4. TDS exceedence probability plot for the Bioinfiltration Rain Garden.

Infiltration Trench. While no statistical change in performance over seven years was found for the Bioinfiltration Rain Garden (Emerson and Traver 2008) the same is not the case for the infiltration trench. Note in Figure 45b1 the rapid decrease in infiltration rate. We have concluded that the TSS entering the infiltration trench has been compressed at the bottom, and all current infiltration occurs through the side wall accounting for the reduction in volume removal. The influence of temperature is also depicted on this graph. The blue diamonds represent the ground temperature. Note the change in percolation rates with higher ground temperature, likely due to the temperature effect on water viscosity. This seldom reported property is seen on all infiltration sites under study (Heasom et al. 2006, Braga et al. 2007, Emerson and Traver 2008).

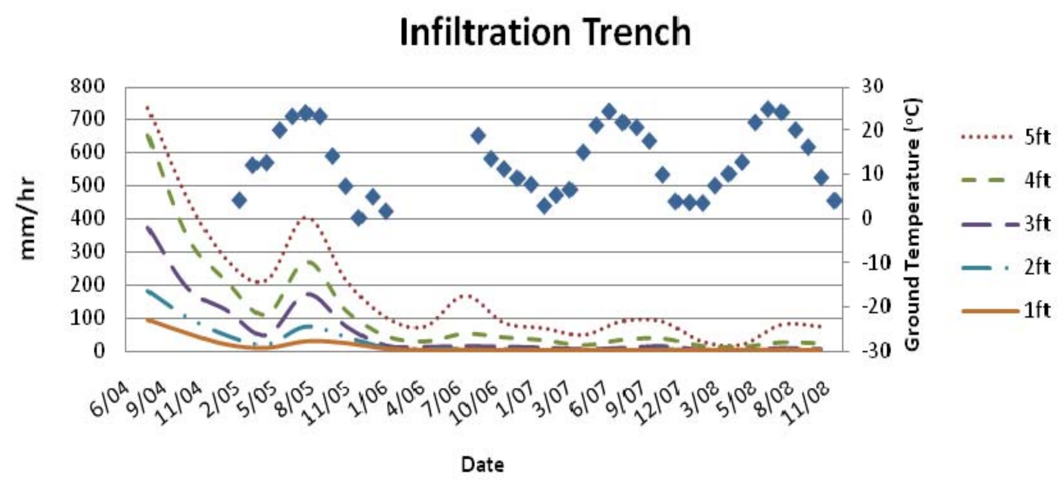


Figure 45b1. Plot of infiltration rates over time for the infiltration trench.

Pervious Concrete – Porous Asphalt. Research on the Pervious Concrete – Porous Asphalt site has shown a significant benefit in the reduction of thermal pollution (Fig. 45c1). The surface temperatures of A (asphalt) and C (concrete) reflect the temperatures of the air. Runoff is clearly heated by the surface (Porous Asphalt (PA) and Pervious Concrete (PC)). However, the runoff entering the bed is quickly cooled as shown by the almost constant bed temperature.

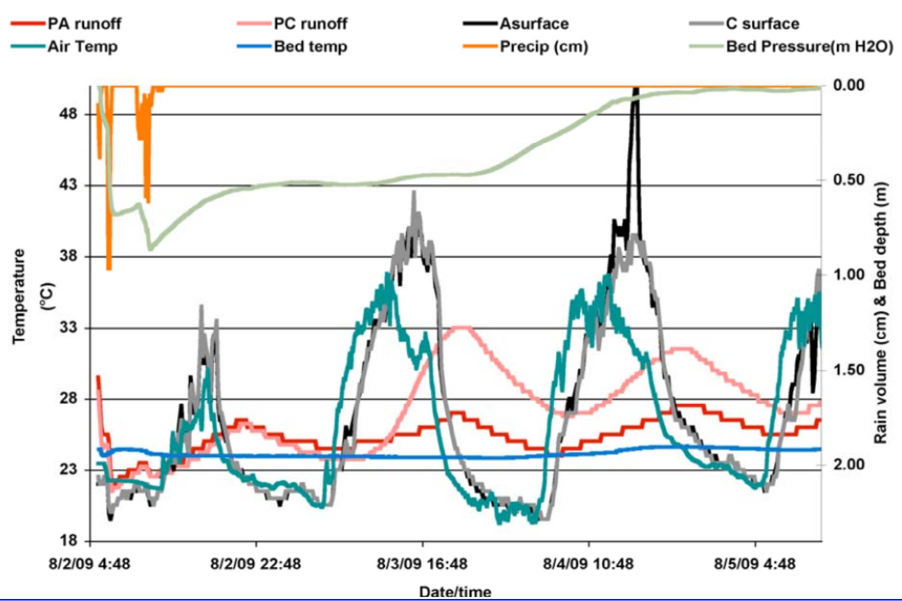


Figure 45c1. Plot of storm event temperature for the Pervious Concrete – Porous Asphalt site.

Green Infrastructure Project Findings Year 1-7 (through 2011)

The advantage of conducting long-term investigation into multiple BMPs has been the ability to track performance changes over time and to contrast performance of different BMP types. Further, additional research grants from CICEET and the Pennsylvania Growing Greener program among others has allowed us to perform expanded analysis beyond that funded by the EPA National Nonpoint Source Monitoring Program. This research work coupled with our day to day experiences have led to the following findings:

Proof of Concept: Results from constructing, operating, and monitoring green infrastructure infiltration BMPs have proven that these devices are effective in removing pollutants and runoff volume from the surface stream.

Effectiveness of Small Storm Capture: The efficiency of designing for small storms has been proven. Results from both the infiltration trench and bioinfiltration raingarden have shown that because the majority of the region's rainfall is produced by smaller storms, BMPs designed for smaller storms are extremely effective in reducing runoff volume and capturing surface pollutants in regions with similar climates.

Variability of Infiltration Rate: Results from all three sites have shown that the rate of infiltration during a specific storm is extremely variable, and dependent on season, temperature, soil moisture, and rainfall pattern. Note that on a yearly basis, this variation has not interfered with performance, but must be considered when conducting municipal inspection / monitoring programs.

Longevity: A study based on the results of this project has shown that there is no statistical reduction in performance for the bioinfiltration rain garden after 7 years, or from the pervious concrete site after 4 years (Emerson and Traver 2008). As long as the site is protected from large sediment loads (i.e., from upstream erosion) there is every expectation that these sites will remain effective for a very long time.

Longevity is achieved through proper design, construction, and siting (characteristics of the drainage area). For the bioinfiltration BMP, freeze - thaw, soil processes and root systems are aiding in maintaining the infiltration capacity. For the pervious concrete site, the lack of suspended sediments in the rooftop runoff, the filtering through the pervious concrete, and the large surface area support its longevity. Conversely, a considerable change in performance has been seen at the infiltration trench due to the theorized clogging of the bottom layer. It should be noted that the ratio of drainage area to the infiltration trench greatly exceeds that of "normal" sites. Using the drainage area sizing recommendations of the Pennsylvania BMP manual, the infiltration trench has experienced a pollutant load equivalent to 80 years during its 5-year lifetime.

Robustness of Green Infrastructure: Continuing performance of the Villanova University stormwater BMPs with minimal maintenance demonstrates the robustness of green infrastructure practices, as long as the systems are sited, designed, and constructed appropriately. After six years, no major maintenance has been required of the bioinfiltration sites, and only street sweeping for the porous concrete/porous asphalt site.

Variation in Pollutant Loading Rate / First Flush: Runoff from different contributing areas has been found to vary considerably in quality. For example, roof runoff from taller buildings has been found to be remarkably free of TSS, which makes it an ideal candidate for infiltration. In contrast, runoff from the parking deck has delivered extremely high pollutant loads to the infiltration trench. Clearly pretreatment devices would extend the life of infiltration BMPs in high loading areas.

Raingarden Volume Removal Repeatability and Predictability: Analysis of data from bioretention / bioinfiltration raingardens at Villanova University, NC State University, and the University of Maryland show repeatability of performance of volume reduction. These results will lead to new design criteria and regulatory approaches

INFORMATION, EDUCATION, AND PUBLICITY

Educational signage has been installed at each BMP site to enhance the learning experience and a website has been created to facilitate technology transfer. The experiences gained through the construction, operation, monitoring, and evaluation of these sites form the basis for the outreach and education component of the Research and Demonstration Park.

Technical Transfer is a prime mission of the VUSP. This task is approached through on-campus symposium's, speaking engagements, publications, tours of the BMP research and demonstration park, and the VUSP website. Every two years the VUSP coordinates the Commonwealth of Pennsylvania Stormwater Management Symposium. This is a two-day event with featured speakers, paper sessions and BMP tours. Additionally, it has been projected live over the internet and the presentations are available through the VUSP website. Prior to the symposium, a workshop for municipal officials is held. Note the symposium is run entirely from attendance fees and no grant monies are used. Faculty and students are also frequent participants at many area seminars. These engagements include everything from national EWRI / AWRA conferences to regional and community organizations. On the off year of the October Symposium, a one-day seminar with invited speakers on stormwater topics is held. Attendance at these events is usually around 150. In 2011, the Villanova project hosted the Annual NPS Monitoring Workshop in conjunction with a national LID Symposium. Attendance exceeded 700.

Many many many visitors have toured the BMP Research and Demonstration Park. Many organizations (AWRA, EWRI, IECA, etc.) have held national conferences in Philadelphia and have included tours of the BMP park. Local watershed groups have also visited the park, as well as many Villanova University classes. Each BMP has an educational sign to help passersby (as well as a website devoted to the BMP).

The VUSP website is a significant tool for outreach (http://www3.villanova.edu/VUSP/). Within the website there are links to every BMP that has been built at the park (and some offsite) with a description, design information, streaming videos, and lessons learned. These sites are updated continuously as results from our studies continue. The website also includes a site for presentations and an interactive database with links to information on all aspects of stormwater BMPs. This structure has been a major emphasis of the VUSP and directly supports all project areas listed previously.

TOTAL PROJECT BUDGET

Note: several of these grants had differing starting dates, this is an estimate.

Financial support for the construction and monitoring of the BMPs has come from a variety of sources. Construction has been funded through the Pennsylvania Section 319 Nonpoint Source program, the Pennsylvania Growing Greener I and II programs, and Villanova University Facilities Department. Monitoring has been supported by EPA Section 319 NMP, along with funds from the William Penn Foundation, Pennsylvania Growing Greener, the VUSP corporate partners, the NOAA Coastal Zone Program, EPA Region III 104B3, and several targeted EPA grants. A project comparing bioretention sites across multiple universities, including Villanova University, is underway, funded by the Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET). Public and private partners are listed at the projects web site: http://www3.villanova.edu/VUSP/.

Year 1: 1 Oct 2003 – 1 Oct 2004
VUSP – PaDep Growing Greener $170,000
NMP – PaDep (319 Funds) $ 53,933
NMP – PaDep (319 Funds) $ 11,733

Year 2: 1 Oct 2004 – 1 Oct 2005
EPA Region III – 104b.3. funds $160,000
NMP – PaDep (319 Funds) $ 56,630

Year 3: Oct 2005 – 1 Oct 2006
TVSSI - William Penn Foundation $70,070
NMP – PaDep (319 Funds) $ 58,561
VUSP - PaDep Growing Greener $175,000

Year 4: Oct 2006 – 1 Oct 2007.
TVSSI - William Penn Foundation $93,507 NMP – PaDep (319 Funds) $ 61,000
VUSP Corporate Donations and Carry Over from previous year.

Year 5: Oct 2007 – 1 Oct 2008.
NMP – PaDep (319 Funds) $ 63,990Note Several other Non PaDEP grants and corporate donations aid this research
Note PC/ PA funds not included

IMPACT OF OTHER FEDERAL AND STATE PROGRAMS

N/A

OTHER PERTINENT INFORMATION

Mission Statement:

The mission of the Villanova Urban Stormwater Partnership (http://www.villanova.edu/VUSP) is: "to advance the evolving field of sustainable stormwater management and to foster the development of public and private partnerships through research on innovative stormwater Best Management Practices, directed studies, technology transfer and education.". The approaches to meet this mission are:

- Research and directed studies to emphasize comprehensive watershed stormwater management planning, implementation, and evaluation.
- Technology transfer to provide tools, guidance and education for the professional.
- Partnerships to promote cooperation amongst the private, public and academic sectors

In 2011, the LID-MARC (Low Impact Development - Mid-Atlantic Research Consortium) was formed between the Villanova Urban Stormwater Partnership in the Civil Engineering Department at Villanova University, Stormwater Engineering Group in the Department of Biological and Agricultural Engineering at NC State University, and Department of Civil and Environmental Engineering at the University of Maryland. LID-MARC's mission is to " Provide research-based recommendations to government and industry on LID stormwater practices, including bioretention and bioinfiltration. Work conducted by the partnership will range from the fundamental to the applied practical and will be able to focus on a variety of land uses and climate conditions found among the Mid-Atlantic States. (http://www.bae.ncsu.edu/stormwater/LID-MARC/, accessed 12/29/11)

PROJECT CONTACTS

Administration

Steve Lathrop
Environmental Planning Supervisor
Bureau of Watershed Management
Pennsylvania Department of Environmental Protection
P.O. Box 8555
Harrisburg, PA 17105-8555
(717)-772-5618
slathrop@state.pa.us

Project Director

Robert G. Traver, Ph.d. PE
Director, Villanova Urban Stormwater Partnership
Professor, Villanova University
Director, Center for the Advancement of Sustainability in Engineering
Department of Civil and Environmental Engineering
800 Lancaster Avenue
Villanova, PA 19085
(610) 519-7899
robert.traver@villanova.edu

REFERENCES

Batroney –Masters Thesis, Villanova University, Villanova, PA - 2008

Braga, A., M. Horst, and R.G. Traver. 2007. Temperature effects on the infiltration rate through an infiltration basin BMP. J. Irr. and Drainage Eng. 133(6):593-601.

Center for Watershed Protection, New Advances in Urban BMPs, Silver Spring, MD 1996

Clausen, J.C., Paired Watershed Study Design, EPA Fact Sheet, Washington D.C., 1993

Emerson, C.H. and R.G. Traver. 2008. Multi-year and seasonal variation of infiltration from stormwater Best Management Practices. J. Irr. and Drainage Eng. 134(5):598-605.

Emerson –Dissertation , Villanova University, Villanova, PA –2008

Ermillio, J., 2005. Characterization study of a bio-infiltration stormwater BMP. Master's Thesis, Villanova University.

Heasom, W., R.G. Traver, and A. Welker. 2006. Hydrologic modeling of a bioinfiltration best management practice. J. Am. Water Res. Assoc. 42(5):1329-1347.

Kwiatkowski, M. 2004. Water Quality Study of a Porous Concrete Infiltration Best Management Practice-Masters Thesis, Villanova University, PA.

National Research Council. 2008. Urban Stormwater Management in the United States. National Academies Press, Washington DC

NCSU, Section 319 Nonpoint Source National Monitoring Program Successes and Recommendations – (EPA Report) - Raleigh, NC, 2000

Pennsylvania Manual of Best Management Practices for Developing Areas. Pennsylvania Association of Conservation Districts, Harrisburg, PA., 1998 (and 2005 update)

Traver, R.G. 2004. Villanova University stormwater best management practice research.

U.S. Environmental Protection Agency (EPA). National Water Quality Inventory-1996 Report to Congress, Office of the Water Program Operations, Water Planning Division, Washington DC, 1998

U.S. Environmental Protection Agency (EPA), Section 319 Success Stories, Vol. III, Office of Water, Washington DC, 2002a

U.S. Environmental Protection Agency (EPA), National Pollutant Discharge Elimination System, Office of Wastewater Management, 2002b, http://cfpub2.epa.gov/npdes