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# An Integrated Monitoring Plan for Best Management Practices

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By

Krista M. Hankins

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Approved: ______________________________
Andrea L. Welker, Ph.D., P.E.
Faculty Advisor, Associate Professor
Department of Civil & Environmental Engineering

Approved: ______________________________
Ronald A. Chadderton, Ph.D., P.E.
Chairman
Department of Civil & Environmental Engineering

Approved: ______________________________
Gary Gabriele, Ph.D.
Dean, College of Engineering

A copy of this thesis is available for research purposes at Falvey Memorial Library.

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# ABSTRACT

Best management practices (BMPs) are currently the application of choice for meeting stormwater regulations. BMPs are structures designed for controlling runoff volumes, controlling peak flow rates, and controlling pollutants. The ability for the BMP to reach these goals is dependent on the nature of its design. BMPs are grouped into four categories based upon these definitions and include infiltration, bio-infiltration, evapotranspiration, and pollutant reduction.

Structural design of the BMPs has been significantly studied and reviewed. Guidelines have been released by state departments of environmental protection explaining design and functions of the BMPs. The problem, however, is that the efficiency of these BMPs is unknown and the effectiveness is assumed to work up to the design specification. Therefore there is a need to determine the effectiveness in the field by observing hydrology, water quality and ecology parameters.

At an education or research level, these parameters are monitored intensively. Most other locales such as commercial, industrial, and residential areas have limited resources to allow for the extensive monitoring. An Integrated Monitoring Plan (IMP) aims to provide guidance on monitoring the effectiveness of the BMPs at a compliance level for rural, suburban and ultra-urban, commercial and industrial level and research and education level.

The need for the IMP is defined by those who will benefit from using BMP technology. It was modeled on the Pennsylvania BMP Manual and is meant to be a supplement. The paper contains the guidance for monitoring post construction and installation of equipment.

The IMP reviews the instrumentation and sampling equipment, monitoring methodology and parameters to be reviewed for each of the four BMPs categorized. Instrumentation and sampling includes the parameters reviewed and the equipment necessary for determination. The monitoring methodology defines the necessary parameters for effectiveness at a compliance level. Structural BMPs are included with a list of the potential equipment that would be found on a stated site.

The information is applied to the Villanova Stormwater Demonstration Park. There are 9 structural BMPs on Villanova's campus each of which has different monitoring method. These BMPs are reviewed with a brief description, a list of site equipment and the intensity of monitoring hydrology, water quality and ecology.

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# INTRODUCTION

## A. Project Statement

Stormwater regulations by state and local government have been on the rise as pervious surfaces are slowly dwindling and past methods of controlling stormwater have been shown to be ineffective. Pervious surfaces have been decreasing due to the increase in land development for residential, commercial and industrial use. Unfortunately with the development of land, comes a detrimental effect to natural waterways. The stormwater runoff produced cannot infiltrate into the ground or evaporate and is forced to travel to the nearest stream producing an increase in volume and peak flow rate. This affects not only the area of new development, but extends to the remainder of the watershed (Heasom 2006).

These effects can be minimized by the incorporation of Best Management Practices (BMPs). There is currently a lot of information circulating about these vegetative/non-vegetative structures, but the field lacks knowledge on how to monitor their effectiveness. In many instances, the BMP is neglected and its effectiveness eventually dwindles. The only BMPs with sufficient knowledge of effectiveness are those on research and educational sites. Many of these BMPs are so extensively monitored that computer models can be created to determine the longevity of performance.

Extensive monitoring, however, is not feasible or appropriate at many sites. Therefore, the Integrated Monitoring Plan (IMP) is designed to provide guidance on how to monitor Structural BMPs at a more appropriate level for residential, commercial and industrial sites.

***Note:*** This *Introduction* and the *Conclusion* are designed to give an overview of the importance of the IMP. They are denoted alphabetically. The *IMP* can, therefore, be removed from this thesis and function as a document on its own. The *IMP chapters* are designated numerically.

## B. Background

### B.1 Stormwater Regulations

The following is a list of stormwater regulations that have been enacted (RRNWWDP 2002).

- 1978: Pennsylvania Act 167 is passed which states that peak flows post construction are limited to preconstruction levels at all points leaving the site. This is to be instituted on the municipal level.

- 1983: Act 167 Revision is passed requiring counties to develop a watershed plan targeting troubled areas. Peak flows are still limited to preconstruction levels, but also to be reviewed for their effect on the watershed.

- 1987: The Water Quality Act amends the Clean Water Act. Stormwater dischargers and municipalities must have separate storm sewer systems (National Pollutant Discharge Elimination System (NPDES) Storm Water Program). The Environmental Protection Agency (EPA) grant program created to expand research and development of non-point storm water discharges.

- 1990: Phase I Storm Water Regulations require permits for storm water discharge from municipal separate storm sewer systems when populations exceeded 100,000 people and eleven categories of industrial activity.

- 1999: Phase II Regulations require permit coverage for storm water discharge from urbanized municipal separate storm sewer systems and construction sites larger than 1 acre.

- 2005: Pennsylvania Department of Protection (PA DEP) develops a stormwater policy and program to improve the way stormwater is managed. The program incorporates Act 167 and NPDES Phase II while stressing the focus on volume and quality as well as peak flows.

- 2006: PA DEP releases their Stormwater BMP Manual.

## B.2 Best Management Practices (BMPs)

Traditionally stormwater regulations focused on reducing peak flow to pre-construction levels. This idea focused solely on detention and control rate of runoff. Therefore, detention basins were the design of choice. Unfortunately, this design neglected to consider increased volumes entering streams and the volume reduced by recharge to the groundwater system.

As regulations have begun to recognize the importance of restoring the whole hydrologic cycle, traditional detention basins are being replaced by alternative structures. Structural BMPs may be natural systems using vegetation and soil for functionality or consist of conventional mortar and brick systems. Many of these systems are similar, but vary off a central theme.

Many structural BMPs are effective in reducing volume and peak flow rates. Volume and peak flow rates can be reduced by infiltration, evaporation, transpiration and a combination of the three mechanisms. Infiltration is said to penetrate the water table where it is considered recharge. Recharge is the infiltrated water that reaches the ground water table.

BMPs aim to increase water quality by pollutant removal. With extended detention time or re-routing flow, a BMP provides time for particulates to fall out of suspension. Vegetation and soil are also mediums that absorb contaminants.

To determine the appropriate BMP for a situation, the PA BMP Manual should be referenced. The manual provides design standards, planning concepts and potential applications for BMPs.

## B.3 Integrated Monitoring Plan (IMP)

The Pennsylvania BMP Manual provides guidance on design, application, construction and maintenance of a BMP. These are all important concepts when trying to obtain a permit during development. They show the intentions of the engineer for meeting stormwater regulations. The problem is what happens after installation of the BMP when the engineer is no longer in the picture. How do we know the BMP is being effective in adhering to the stormwater regulations?

This defines the need for an Integrated Monitoring Plan (IMP). An IMP is a plan designed for local authorities, planners, land developers, engineers, contractors, and others interested in the effectiveness of a BMP. It is for those who want to make sure the BMP is serving its original purpose and protecting the immediate and downstream watersheds.

An IMP will increase the knowledge of local authorities to know what to look for when being presented with a solution to a stormwater problem. It will provide them with a list of potential instrumentation and equipment that should be included in a design.

The IMP will help land developers present their ideas to an engineer. It can help them narrow their search to potential BMPs that will meet the necessary stormwater regulations. The IMP will also provide an overview of what parameters are necessary to measure for a specific land use.

Engineers will be able to use the IMP during the design stages. By knowing the land use and BMP design, the engineer can incorporate the preferred equipment into the design when talking with local authorities or applying for permitting.

Contractor use of the IMP will be at the construction phase. The contractors will need to reference the BMP for proper placement of instrumentation, if not provided by the engineer. The contractor must also make sure the instrumentation and equipment is easily accessible.

An IMP was created as a supplement to the Pennsylvania BMP Manual. It is meant to identify the parameters required for monitoring and how those parameters are monitored for various applications. By monitoring these parameters, the longevity of the site is increased and a general time for maintenance can be determined.

## C. Research Objectives

This research had three main objectives listed below.

- Define the instrumentation and sampling equipment necessary for monitoring BMPs.
- Define a compliance level of monitoring for different methodologies.
- Apply the methodologies to structural BMPs to determine effectiveness.

There are three parameters of monitoring. The three parameters are hydrology, quality and ecology. These parameters help determine the effectiveness of a BMP in reaching the four stormwater functions. The functions reviewed were volume reduction, recharge, peak flow reduction and water quality. For ease of identification, the Structural BMPs were placed into four categories based on their effects on the stormwater functions. These categories are defined as volume/peak rate reduction by infiltration, volume/peak rate reduction by bio-infiltration, volume/peak rate reduction and runoff quality/peak rate reduction.

# AN INTEGRATED MONITORING PLAN

# Chapter 1: Introduction

## 1.1 Purpose of the IMP

Best Management Practices (BMPs) have become increasingly popular over the past decade as stormwater management has evolved from overlooked regulations to mandatory statutes. Laws have evolved due to industrialization and urbanization of rural land and increasing pollution of natural water bodies. As pervious cover diminishes, infiltration is reduced or eliminated and there is an increase in peak flow rates and volumes at nearby waterways. Contaminants created by these processes lie dormant on the impervious surfaces to be swept away by runoff which alters the ecosystem downstream. New and old development alike is, therefore, affected by any alteration to the natural watershed and its neighbors.

Structural BMPs are becoming increasingly popular as fixtures built into the design of residential and commercial developments. These BMPs are designed to protect and restore the natural water cycle by controlling the volume of runoff, and controlling the peak flow of runoff. They also reduce the pollutants which are the product of urban and industrial sprawl. The design is driven by application, purpose and finances. Many of these structures are made of conventional building material like brick and mortar. But many introduce vegetation and soil for stormwater functions (PADEP 2006). Vegetation assists in nutrient removal and evapotranspiration; soil acts as a natural filter and groundwater recharge medium.

The purpose of the Integrated Monitoring Plan (IMP) is to determine the effectiveness of structural BMPs which are representative of the functions stated above. The applications are based upon land uses and are categorized as: (1) residential, suburban, and ultra-urban, (2) commercial and industrial, and (3) research and educational. These applications are reviewed with a focus on practicality and budget (Hankins et. al. 2008).

Dependent on the desired application and purpose, recommendations can be made about the equipment that should be used. The monitoring can be broken into three main components: hydrology, water quality, and ecology.

## 1.2 How to use the IMP

The IMP is meant to be a supplement to the Pennsylvania BMP Manual. The following provides a chapter by chapter summary to help navigate through the plan. If you are looking for a specific structural BMP, use Table 1.0 as a guide.

**Table 1.1: Structural BMPs by Chapter**

| Ch 4: Infiltration BMPs |
|---|
| Pervious Pavement with Infiltration Bed<br>Infiltration Basin<br>Infiltration Trench<br>Dry Well/ Seepage Pit |
| Chapter 5: Bio-Infiltration BMPs |
| Subsurface Infiltration Bed<br>Rain Garden/ Bioretention<br>Constructed Filter<br>Vegetated Swale<br>Vegetated Filter Strip<br>Infiltration Berm & Retentive Grading |
| Chapter 6: Evapotranspiration BMPs |
| Vegetated Roof<br>Runoff Capture & Reuse |
| Chapter 7: Pollutant Reduction BMPs |
| Constructed Wetland<br>Wet Pond/Retention Basin<br>Dry Extended Detention Basin |

***Chapter 1- Introduction***

***Chapter 2- Monitoring Methods***

This chapter describes the three applications used to define the monitoring effort. The applications include (1) residential, suburban, and ultra-urban, (2) commercial and industrial, and (3) research and educational. They are broken down based on land use and budget.

***Chapter 3- Instrumentation & Sampling***

This chapter describes the instrumentation used to monitor hydrologic parameters, collect water quality samples, monitor water quality parameters and complete ecological studies for various structural BMPs.

***Chapter 4-Volume/Peak Rate Reduction by Infiltration BMPs***

Infiltration BMPs try to maximize recharge, to reduce runoff volumes and to reduce peak flow. The effectiveness of Infiltration BMPs is measured through hydrologic and water quality means.

***Chapter 5- Volume/Peak Rate Reduction by Bioinfiltration BMPs***

Bio-Infiltration BMPs reduce peak flows and volumes through the use of vegetation and infiltration. Effectiveness is determined by measuring various aspects of hydrology, water quality and ecology.

***Chapter 6- Volume/Peak Rate Reduction BMPs***

Evapotranspiration BMPs reduce peak flow and volume through evaporation and transpiration. Ecology, water quality, and hydrology are all included in the monitoring process.

***Chapter 7- Runoff Quality/Peak Rate Control BMPs***

Pollution reduction and sedimentation BMPs improve runoff quality and reduce peak flow rates. These BMPs are monitored to meet hydrology, water quality and ecology regulations.

***Chapter 8- Case Study***

This chapter gives an overview of how collected data can show the effectiveness of a BMP. A pervious concrete demonstration park is separated into the three monitoring methodologies and reviewed.

***Chapter 9- Conclusion***

# Chapter 2: Monitoring Methodology

When monitoring a BMP, there is a minimum amount of equipment and manpower needed to prove effectiveness. This level must be increased depending upon land usage. The IMP focuses on monitoring three distinct levels based on economics and land use.

## 2.1 Residential, Suburban and Ultra-Urban Uses

Residential, suburban and ultra-urban sites focus on areas in which society lives and plays. Residential areas tend to be single family homes with open space and minimal street traffic. Suburban homes may be single or double family with less open space and more heavily trafficked roads. Ultra-urban uses are typically found in major metropolitan areas with heavy street traffic and little to no pervious cover.

Designs for this methodology should focus on keeping nature beautiful while protecting the water downstream. Residential and suburban areas require more open space, allowing for installation of a larger variety of BMPs. Urban areas use more compact BMPs. With the advancement of stormwater regulations, new developments, like planned communities, are starting to incorporate BMPs into their design.

Although BMPs can be incorporated elegantly into these uses, overseeing the site is an issue that few homeowners want to do. Consequently, monitoring and maintenance must be completed by municipal or township employees. Therefore, for these BMPs, the monitoring effort must be minimal and efficient.

## 2.2 Commercial and Industrial Uses

BMPs installed at commercial and industrial sites need to be more effective in reducing runoff and pollutant loadings than those installed at residential, suburban, and ultra-urban sites. These sites tend to be locations where the general public works and amasses life's essential needs and wants. As in ultra-urban settings, there is minimal pervious cover caused by the increased need for paved parking lots and buildings.

In a commercial setting, aesthetics are important due to the desire to draw customers. Structural BMPs can be designed to reflect nature or be constructed underground and therefore, be invisible to the naked eye. Aesthetics are not as important in industrial settings, which focus more on the constituents that need to be controlled on site. A BMP at an industrial site must eliminate or remove pollutants to regulated standards.

BMPs in a commercial and industrial setting therefore require more intensive monitoring and maintenance than rural, suburban, and ultra-urban uses. The capital for more intensive monitoring is there, but the desire to use the funds may not be. The task of monitoring the BMPs, in many instances, will be left up to the janitorial or maintenance staff. If the BMP was constructed to control water quality pollutants or contaminants, a scientist or lab technician may be considered.

## 2.3 Research and Educational Uses

BMPs installed at research and educational sites tend to be the most advanced when it comes to monitoring. Sometimes research may even be performed on a commercial or industrial site, with monitoring being performed by a scientist or lab technician.

BMPs used for research or educational purposes are only designed aesthetically when in the public eye. The focus in this setting is on determining the best way to construct BMPs, where BMPs will be most effective, and the longevity of a structural BMP when properly maintained.

Monitoring is completed by those who designed the BMP, with the help of student researchers, to gain further knowledge about all aspects of the BMP. A BMP on a research or educational site therefore will have the greatest amount of equipment and the most intensive monitoring efforts.

# Ch 3: Equipment, Sampling and Parameters

Equipment and sampling needs vary among monitoring levels. At the lowest level, hydrology is usually the only aspect monitored. With an increase in hydrology equipment, quality and ecological monitoring are often added to the plan. The IMP focuses on the parameters that determine the BMPs effectiveness. It describes the proper equipment to be installed and how to use the results.

## 3.1 Hydrologic Sampling

### *Analog Raingage*

An analog raingage is a graduated cylinder with markings delineating values of length. The raingage provides a reasonable estimate of the total amount of precipitation falling on a site during a given storm event.


**Figure 3.1: Analog Raingage**

- *When:* Periodically throughout a storm event.
- *Where:* Placed on site, void of falling debris and other obstacles blocking contact with direct precipitation.
- *How:* Manually read at user defined intervals. Must also be emptied upon full capacity or completion of a storm event.

### *Tipping Bucket Raingage*

A tipping bucket raingage is a cylindrical unit which must be placed level on any surface. The cylinder collects and funnels precipitation towards a lever which tips for every 0.01 inch of rain. The tips are logged through an electric signal that is sent to a data logger/flow meter. Tips are summed to represent the rainfall for a given time interval.

**Figure 3.2: Tipping Bucket Raingage**

- *When:* Digitally recorded at user defined interval.
- *Where:* Placed on site, void of falling debris and other obstacles blocking contact with direct precipitation.
- *How:* Collected from data logger/flow meter at user defined times.

### *Staff Gage*

A staff gage is a long rod with etchings used to denote depths. The staff gage provides reasonable estimates of water elevation at time of reading. The water depths with a time table of recordings can help determine the infiltration rate and storage volume.

**Figure 3.3: Staff Gage**

- *When:* Periodically throughout a storm event and continued until elevation equivalent to zero.
- *Where:* Placed at a location where water is presumed to pond.
- *How:* Manually read at user defined intervals.

### *Ultrasonic Level*

An ultrasonic level is a sensor housed in a water tight aluminum enclosure placed above a location of storage or depression. The sensor uses a sonar technology of bouncing echoes off the lowest point to determine water elevation. Depths are logged by an electronic signal sent to a data logger/flow meter which can later be translated into infiltration rates or volumes.

**Figure 3.4: Ultrasonic Level (Global Water 2008)**

- *When:* Digitally recorded at user defined intervals.
- *Where:* Placed at a location where water is presumed to pond.
- *How:* Collected from data logger/flow meter at user defined intervals.

### *Pressure Transducer*

A pressure transducer is a sensor housed in a water tight aluminum enclosure which measures the change in pressure heads to determine the change it water elevation. Observation of the water elevation drops upon ceasing of the rainfall can help determine infiltration rates and storage volume.

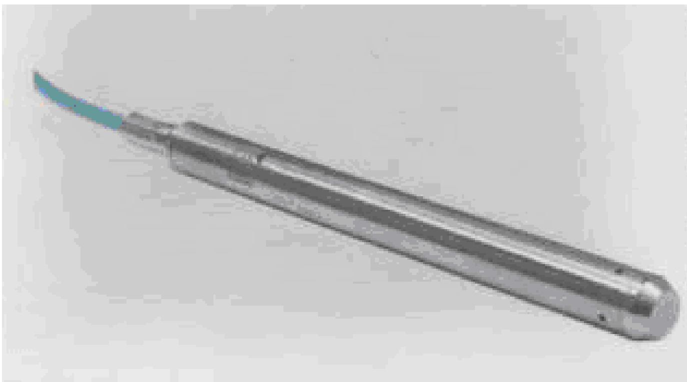


**Figure 3.5: Pressure Transducer (INW 2004)**

- *When:* Digitally recorded at user defined intervals.
- *Where:* Placed at a location where water depth is presumed to pond. Most commonly placed in inlet, outlet or infiltration bed.
- *How:* Collected from data logger/flow meter at user defined intervals.

### *Area/Velocity Bubbler*

Area/velocity probes use air bubble pressure in a pipe to measure the depth of water and Doppler Effect (the shift in frequency as it moves away with the flow) to determine velocity. The velocity and depths help to determine the volume and flow rate.


**Figure 3.6: Area/Velocity Bubbler with Flow meter**

- *When:* Digitally recorded at user defined intervals
- *Where:* Placed at location of continuous flow. Most commonly at an inlet or outlet.
- *How:* Collected from data logger/flow meter at user defined intervals.

### *Weir/Orifice*

A weir/orifice is a structure used to measure the flow of water. Each structure has its own equation and in conjunction with a pressure transducer or area/velocity bubbler, the flow of water can be determined. These values can also help determine the volume of water being retained or leaving a specified area.

**Figure 3.7: Outlet Structure**

- *When:* Used in conjunction with pressure transducer when flow or volume calculations are required.
- *Where:* Commonly located at an inlet or outlet of a BMP.
- *How:* Structure specified equations are used with the information recorded by the pressure transducer or area/velocity bubbler.

***Reflectometers***

Water content Reflectometers measure the passing moisture front as the soil moisture content changes due to infiltrating runoff. The Reflectometers measure volumetric water content which is transmitted via a data logger/ flow meter.


**Figure 3.8: Reflectometers**

- *When:* Digitally recorded at user defined intervals
- *Where:* Placed at various depths beneath infiltrating media.
- *How:* Collected from data logger/flow meter at user defined intervals.

## 3.2 Quality Sampling

### *First Flush*

The "first flush" treatment volume is widely defined as the amount of runoff resulting from 90% of the storm (Sharkey 2006). This volume is crucial in determining the parameters found in the influent, to a BMP.

**Figure 3.9: First Flush Sampler (GKY 2000)**

- *When:* Collected until filled during a storm event.
- *Where:* In a location that leads into the BMP. Typically near an inlet source.
- *How:* Sampler set up prior to storm and collected at end for analysis.

### *Automated Samplers*

An automated sampler is a unit capable of taking several discrete or a single composite sample. Samples are collected by a tube that extends out of the sampler and into the streaming or ponded water. Each sampler is run by a user defined program and is triggered and stopped by a defined variable. The variables include rainfall, flow or volume. Once triggered, the additional samples may be taken over a user defined time table.


**Figure 3.10: Automated Sampler**

- *When:* Collected at user defined intervals throughout the storm.
- *Where:* At a source of continuous flow or ponded water.
- *How:* Sampler set up prior to storm and collected at end for analysis.

### *Grab Samples*

Grab samples are samples collected by hand from an area of ponded depth or continuous flow. The value is representative of a discrete sample because it is taken at a specific time and location.

**Figure 3.11: Grab Sample**

- *When:* Periodically throughout the storm.
- *Where:* At a source of continuous flow or ponded depth.
- *How:* Manually collected as user defined intervals for analysis.

### *Lysimeters*

Lysimeters are used to collect water from the vadose zone through the use of a pressure vacuum system. A vacuum (negative pressure) is created within a ceramic cup that exceeds that of the soil suction within capillary spaces causing water to flow into the sampler (Kwiatkowski 2004).

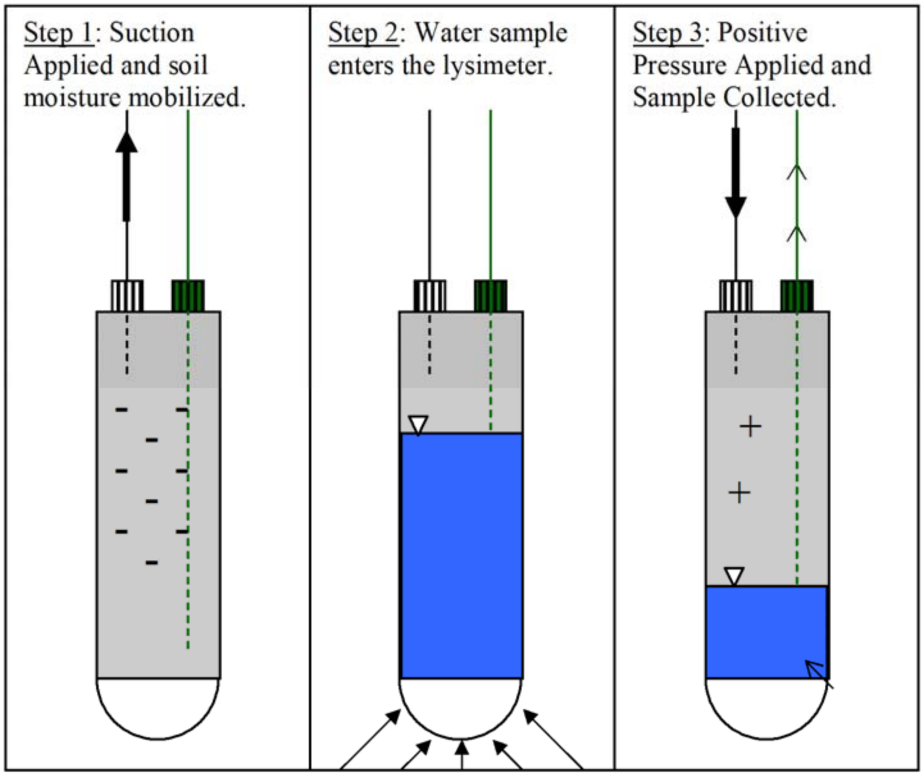



**Figure 3.12: Lysimeters (Ermilio 2005)**

- *When:* Collected during a storm event while the moisture front is moving through the vadose zone.
- *Where:* Various depths beneath the soil strata
- *How:* Vacuum pressure is placed after the storm has initialized. Samples are then extracted via suction 12-24 hours after pressure.

## 3.3 Quality Equipment

### *pH Probe*

A pH probe measures the acidity of water quality samples through the activity of hydrogen ions. The voltage conducted by a glass process electrode is compared to a chemical standard of fixed pH to produce the substance's equivalent pH.

**Figure 3.13: pH Probe**

- *When:* Immediately upon collection of samples.
- *Where:* In the field or laboratory.
- *How:* Manually recorded after probe stabilizes.

### *Conductivity Probe*

A conductivity probe measures the ability of a solution to conduct current through ion transport. Potential difference is measured between two electrodes of known distance resulting in a current proportional to the solution conductivity.

**Figure 3.14: Conductivity Probe**

- *When:* Immediately upon collection of samples.
- *Where:* In the field or laboratory.
- *How:* Manually recorded after probe stabilizes.

### *TSS/TDS Analysis*

Total suspended solid (TSS) is the mass per volume of particles held in suspension for a well mixed sample. Total dissolved solids (TDS) can then be calculated by baking off the sample leaving a residue. The residue is equivalent to the TDS or particles previously dissolved in the sample.

**3.15 Filtration**


**3.16 Weighing**

**Figure 3.15-16: TSS/TDS Set-Up**

- *When:* Immediately upon collection of samples.
- *Where:* In the laboratory
- *How:* Through Standard Methods 2540D

### *Spectrophotometer*

Total nitrogen and total phosphorus can be determined for a sample based on the absorbance of light at a specific wavelength. The absorbance can be related to various chemical parameters through the use of experimental procedures (Traver et. al. 2007).

**Figure 3.17: Spectrophotometer**

- *When:* With in 24 hours of collection unless properly preserved.
- *Where:* In the laboratory.
- *How:* Through Persulfate Digestion.

***HPLC***

High Pressure Liquid Chromatography (HPLC) determines trace levels of ions in solution. The system uses an ion exchange resin to separate the ion mixture with suitable detection of the ions as they exit the ion exchange columns (Traver et. al. 2007). An HPLC unit can determine the level of chloride, phosphate, nitrate and nitrite.

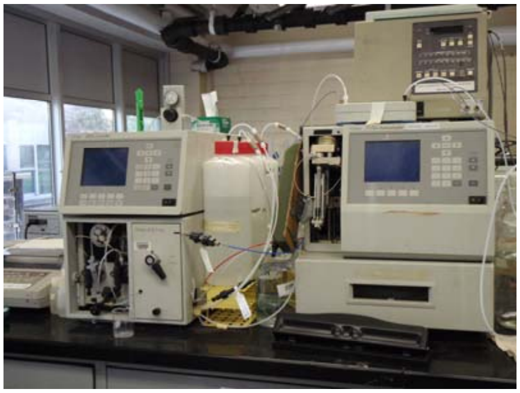


**Figure 3.18: HPLC**

- *When:* Within 24 hours of collection for nutrients. In 28 days of collection for Chloride.
- *Where:* In the laboratory.
- *How:* Through the Modified EPA Method 300.1.

### ***Graphite Furnace***

A graphite furnace helps determine levels of total recoverable metals in solution. A high performance graphite furnace atomic absorption unit utilizes the Zeeman Effect. In essence the sample is heated electrically to create a dissociation of free atoms. A graphite furnace analyzes cadmium, copper, chromium, lead and zinc.

**Figure 3.19: Graphite Furnace**

- *When:* Within 6 months of collection.
- *Where:* In the laboratory.
- *How:* Through the Modified Method 7010.

## 3.4 Ecology Parameters

### *Diversity/Coverage*

Diversity and coverage should review plant migration and plant survivability. The review should include plant growth measured in percent coverage or spread across the soil media (Moran 2004). At this time, invasive species should also be removed (Hankins, et. al. 2008).

**Figure 3.20: Diversity/Coverage (USFWS 2008)**

- *When:* On a seasonal basis.
- *Where:* On site.
- *How:* By visual inspection.

### *Nutrient Up-Take*

All native plant species with proven phyto-remediation capabilities should be sampled for nutrient up-take to determine the amount of nutrients being absorbed (Hankins, et. al 2008).

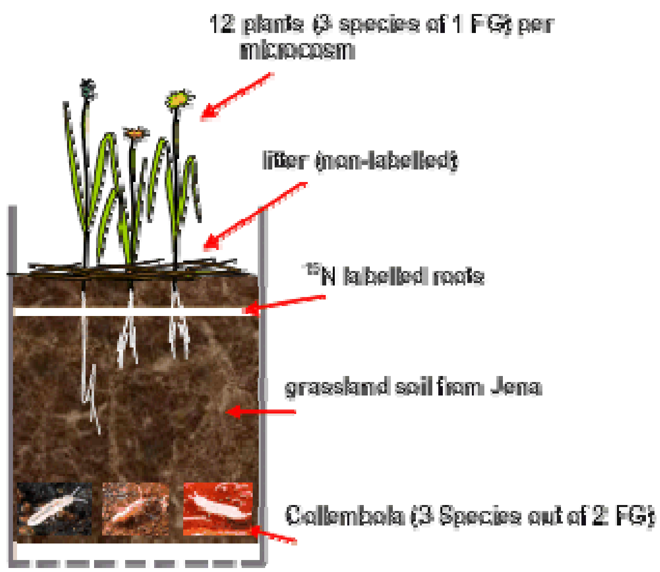



**Figure 3.21: Nutrient Uptake (Scheu, 2008)**

- *When:* Roots and shoots should be collected on a seasonal basis.
- *Where:* Sampled from various locations within the BMP.
- *How:* Through a controlled experimental application.

### *Macro Invertebrates*

An insect identification and count should be completed. Invertebrates should be identified to the lowest taxonomy, abundance, habitat and functional feeding group (Carter 2005).

**Figure 3.22: Macro-Invertebrates (EPA 1997)**

- *When:* On a seasonal basis.
- *Where:* On site.
- *How:* By sweep net and visual inspection.

*Vertebrates*

The possibility for birds and mammals to create nest or habitats is significant. Therefore bio-assessments for the different species including those endangered should occur regularly and include a survey for migrating birds during breeding (Taylor 1999).

**3.23 Birds**

**3.24 Other Mammals**

**Figure 3.23-24: Vertebrates**

- *When:* On a seasonal basis.
- *Where:* On site.
- *How:* By visual inspection.

## Chapter 4: Volume/Peak Rate Reduction by Infiltration

**4.1 Pervious Pavement**


**4.2 Infiltration Basin (PADEP 2006)**

**4.3 Infiltration Trench**

**4.4 Dry Well/Seepage Pit**

**Figure 4.1-4.4: Infiltration BMPs**

Infiltration BMPs are designed to reduce volume and peak flow rates by recharging the groundwater system. These BMPs must be underlain by a highly permeable soil to work effectively.

**Table 4.1: Infiltration BMPs (PADEP 2006)**

| | Volume Reduction | | | Recharge | | | Peak Rate Control | | | Water Quality | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Low | Med | High | Low | Med | High | Low | Med | High | Low | Med | High |
| Pervious Pavement | | X | | | X | | | X | | | X | |
| Infiltration Basin | | | X | | | X | | X | | | | X |
| Infiltration Trench | | X | | | | X | | X | | | | X |
| Dry Well/ Seepage Pit | | X | | | | X | | X | | | X | |

## 4.1 Instrumentation and Sampling

This section lists all the potential parameters and equipment used to measure volume/peak rate reduction from infiltration BMPs. For a description of the equipment, refer to *Chapter 3: Instrumentation and Sampling*.

### 4.1.1 Hydrology Parameters

***Total Precipitation***

Total precipitation is the amount of rain that falls during a storm event. There are various ways for defining a storm event. For our purposes, a storm event is a period of precipitation where there is 24 hours of dry before start of rain and after the last recorded precipitation (Traver et. al. 2007). Precipitation data is helpful in determining the volume of water entering the BMP. Rainfall is monitored by (see CHAPTER 3.1):

- Analog Raingage
- Tipping Bucket Raingage

If equipment is not present, one can download precipitation data for a storm event from a nearby raingage using NOAA-ATLAS 14 (National Weather Service 2007).

***Water Elevation***

Water elevation is the depth of ponded water at a given location whether in a location of storage or stream channel. Water elevation is important to define the volume of water retained by the BMP and for infiltration calculations. Equipment used to monitor water surface elevation is (see CHAPTER 3.1):

- Staff Gage
- Ultra-sonic level
- Pressure transducer
- Area/Velocity bubbler

In conjunction with each other, the staff gage can be used as a calibrator for the level sensor, pressure transducer or area/velocity bubbler.

***Soil Moisture Content***

Moisture content determines the saturated conditions of the soil by measuring the volumetric water content. By measuring the moisture front as it passes, the infiltration rate can be determined. Automated equipment used for monitoring is (see Chapter 3.1):

- Reflectometers

### *Infiltration Rate*

Infiltration rate is the change in stored water elevation with respect to time after a precipitation event. The rate is calculated as the slope of the receding limb of the water depth verse time (Ermilio 2005). Monitoring equipment includes (see Chapter 3.1):

- Staff gage
- Ultra-sonic level
- Pressure transducer
- Area/Velocity Bubbler

Infiltration rates vary on a site by site basis due to soil properties. They are also affected by seasonal/temperature effects peaking in the summer and receding to their lowest values in the winter.

### *Storage Volume*

Storage volume is the amount of water that can be captured and retained by the BMP. Storage volume for a given storm is represented by a contour map of the site or elevation-storage tables (Hankins, et. al. 2008). If the storage space is filled with stone or gravel, the storage volume is represented by the void space. Equipment used to determine volume is (see Chapter 3.1):

- Staff gage
- Ultra-sonic level
- Pressure transducer
- Area/Velocity bubbler

When maximum volume is reached, there is overflow from the site.

### *Overflow*

Overflow is the volume of water that exceeds the BMPs capacity and empties into a downstream water source. During storms, BMPs act to reduce peak flow by retaining the water in volume storage. When storage volume is exceeded, outflow can be measured by (see Chapter 3.1):

- Area/Velocity Bubbler
- Pressure transducer with weir/orifice

Flow is important in determining the volume escaping and the volume being detained within the BMP. The objective of infiltration BMPs is to minimize or eliminate overflow through infiltration (Ermilio 2005 & Sharkey 2006).

### 4.1.2 Quality Sampling

***Surface***

Surface samples are representative of runoff and direct precipitation. They are important in evaluating the contaminants found on nearby impervious surfaces. Surface samples include (see Chapter 3.2)

- First flush samplers

***Subsurface***

Subsurface samples collect infiltrated pore water from the soil strata. The equipment used is (see Chapter 3.2):

- Lysimeters

At varying depths, a record of contaminant removal can be recorded as recharge moves through the vadose zone.

### 4.1.3 Quality Parameters

***Physical Parameters***

Physical parameters are evaluated by test methods that can be completed in the lab or by field test. These parameters include pH, conductivity, TSS and TDS. Conductivity yields the potential level of ionic species. TSS and TDS are the result of erosion and particles carried by the runoff.  Physical parameters are monitored by (see Chapter 3.3):

- pH probe
- Conductivity probe
- TSS/TDS Analysis

The results can be used to predict the levels of other potential contaminants.

***Nutrients/Ionic Species***

Nutrients are important to consider for a heavily vegetated site. Total nitrogen and total phosphorus can enter a water system through industrial emissions or from soil, plant and animal matter. Chloride, nitrate, nitrite and ortho-phosphate are the ionic species of these nutrients (Ermilio, et. al. 2005). Chloride is a result of salt used on pavement during the winter months to prevent icing. Nutrients are tested using the following devices (see Chapter 3.3):

- Spectrophotometer
- HPLC

If the above instrumentation is not available on site, samples should be collected and preserved before being sent to an off-site laboratory for analysis.

***Total Recoverable Metals***

Metals have a tendency to bond to organic material at the surface and the mineral content within the soil (Sharkey 2006). Target metals may include cadmium, copper, chromium, lead and zinc. Cadmium and chromium are a result of industrial emissions such as the burning of coal. The other elements may be used to coat units used to transport runoff such as pipes. Over time the coating wears away and the metals become dissolved in the runoff. Values can be detected through the use of a (see Chapter 3.3):

- Graphite Furnace

If a graphite furnace is not available on site, samples should be collected and sent to an off-site laboratory for analysis.

### 4.1.4 Ecology Parameters

Ecology is not applicable to Volume/Peak Reduction by Infiltration BMPs.

## 4.2 Monitoring Methodology

In this section the parameters necessary for each monitoring method are presented. To determine the proper equipment for use, refer to *Chapter 4.1: Instrumentation and Sampling*.

### 4.2.1 Residential, Suburban, Urban and Ultra-Urban

***Hydrology***

In a residential, suburban, urban and ultra-urban BMP minimal equipment is needed to reach compliance. Storms should be monitored on a seasonal basis to determine the effectiveness of reducing the volume and peak discharge. Data can be compared to precipitation data from a nearby raingage using NOAA-ATLAS 14 (National Weather Service 2007).

**Table 4.2: Residential, Suburban, & Ultra-Urban Hydrology Monitoring for Infiltration BMPs**

| Monitored: Seasonally | |
|---|---|
| Parameter | Compliance |
| Total Precipitation | |
| Water Elevation | X |
| Soil Moisture Content | |
| Infiltration Rate | X |
| Storage Volume | |
| Overflow | |

Water elevation calculations can help in determining the infiltration rate. Infiltration rate is important in helping determine the BMP capacity to reduce the volume downstream and recharge the water table.

If only using one storm a season, it may be necessary to set up a general guideline. For example, only consider storm events with a period of 7 days of dry before the event or storm events with a predicted 1 in (0.025m) of rainfall.

***Quality***

Quality monitoring is not required for Volume/Peak Reduction by Infiltration BMPs at this monitoring level.

***Ecology***

Ecology is not applicable to Volume/Peak Reduction by Infiltration BMPs.

### 4.2.2 Commercial and Industrial

#### *Hydrology*

Hydrologic monitoring is important at a commercial site because of the potential spills that may increase contaminate flow through the BMP. Therefore hydrology should be monitored on a monthly basis.

**Table 4.3: Commercial & Industrial Monitoring for Infiltration BMPs**

| Monitored: Monthly | |
|---|---|
| Parameter | Compliance |
| Total Precipitation | |
| Water Elevation | X |
| Soil Moisture Content | |
| Infiltration Rate | X |
| Storage Volume | |
| Overflow | X |

Water elevation calculations can help in determining the infiltration rate. Infiltration rate is important in helping determine the BMP capacity to reduce the volume downstream and recharge the water table. Infiltration BMPs an attempt to eliminate overflow, but knowing this value shows the ability of the BMP to reduce peak flow when the BMPs capacity is breached.

If only using one storm a month, it may be necessary to set up a general guideline. For example, only consider storm events with a period of 7 days of dry before the event or storm events with a predicted 1 in (0.025m) of rainfall.

#### *Quality*

Quality is important on industrial and commercial sites because of the potential for contaminant spills. Samples should be collected on a seasonal basis and tested for site specific chemical contamination.

**Table 4.4: Commercial & Industrial Quality Parameters for Infiltration BMPs**

| Monitored: Seasonally | |
|---|---|
| Parameter | Compliance |
| Physical Properties | X |
| Nutrients/Ionic Species | |
| Total Recoverable Metals | |

Physical properties are important because they can indicate the potential for other pollutants and whether these pollutants are being eliminated between entry and exit, especially TDS because contaminants stick to solids.

### *Ecology*

Ecology is not applicable to Volume/Peak Reduction by Infiltration BMPs.

## 4.2.3 Research and Education

### *Hydrology*

At research and educational facilities, the manpower and utilities are available to monitor all hydrological aspects. Therefore data should be recorded on a storm by storm basis.

**Table 4.5: Research & Education Hydrology Monitoring for Infiltration BMPs**

| Monitored: Storm by Storm | |
|---|---|
| Parameter | Compliance |
| Total Precipitation | X |
| Water Elevation | X |
| Soil Moisture Content | X |
| Infiltration Rate | X |
| Storage Volume | X |
| Overflow | X |

Water elevation calculations can help in determining the infiltration rate. Infiltration rate is important in helping determine the BMP capacity to reduce the volume downstream and recharge the water table. Infiltration BMPs look to eliminate overflow, but knowing this value shows the ability of the BMP to reduce peak flow when the BMPs capacity is breached. Additional precipitation readings can help determine the amount of water being introduced to the site while soil moisture content helps determine the storage volume. Knowing the storage volume, can give a better understanding of the capacity the BMP to retain water.

### *Quality*

At research and educational facilities, the manpower and utilities are available to monitor all quality parameters. Therefore data should be recorded on a monthly basis.

**Table 4.6: Research & Educational Quality Monitoring for Infiltration BMPs**

| Monitored: Monthly | |
|---|---|
| Parameter | Compliance |
| Physical Properties | X |
| Nutrients/Ionic Species | |
| Total Recoverable Metals | X |

Physical properties are important because they can indicate whether other pollutants potentially contaminate the water source and whether they are being eliminated between entry and exit, especially TDS. Nutrients and ionic species should be reviewed because of their effects on eutrophication. Increased levels of nutrients and metals lead to detrimental effects on aquatic life.

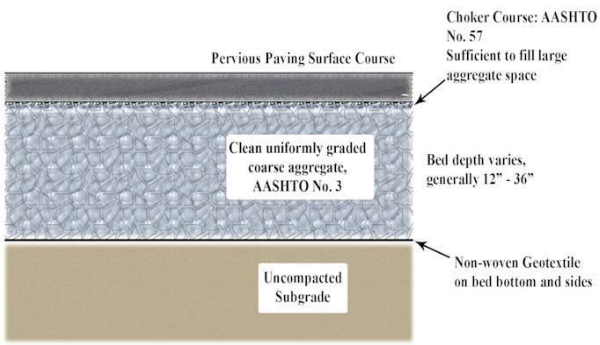
### *Ecology*

Ecology is not applicable to Volume/Peak Reduction by Infiltration BMPs.

### 4.3 BMP Design

In this section specific BMPs are reviewed for the equipment at each monitoring level. For parameters monitored, refer to *Chapter 4.2: Monitoring Methodology*.

#### 4.3.1 Pervious Pavement with Infiltration Bed




Pervious pavement systems are systems that remove fines from conventional asphalt and concrete mixes to create a more pervious top layer. These systems are underlain by infiltration beds which store water and release it into the soil strata.

**Figure 4.5: Pervious Pavement (PADEP 2007)**

Hydrology and quality monitoring are important in showing the difference between pervious pavements and traditional impervious surfaces. Research has shown that pervious pavers have lower pollutants ex-filtrating when compared to traditional runoff (Bean 2005).

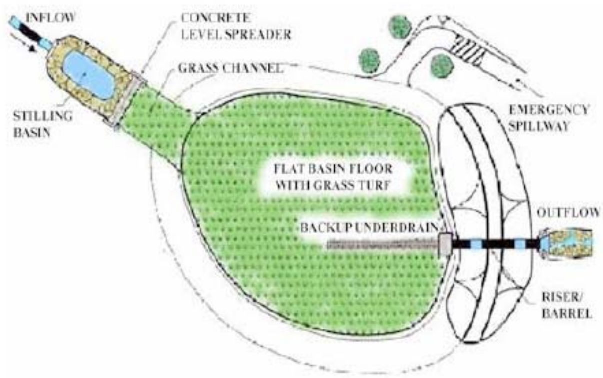
**Table 4.7 Pervious Pavement Sampling Equipment**

| Hydrology Sampling | | | |
|---|---|---|---|
| | R-S-U[1] | C-I[2] | R-E[3] |
| Raingage | | | X |
| Staff Gage | | | |
| Ultra-Sonic Level | | | |
| Pressure Transducer | X | X | X |
| Area/Velocity Bubbler | | | |
| Weir/Orifice | | X | X |
| Reflectometers | | | X |
| Quality Sampling | | | |
| | R-S-U | C-I | R-E |
| First Flush | | X | X |
| Automated Samplers | | | |
| Grab Samples | | | |
| Lysimeters | | | X |

[1] Residential, Suburban & Ultra-urban [2] Commercial & Industrial [3] Research & Educational

Pervious pavement may be used in many applications where the soil below has intrinsically good infiltration properties (Bratteboo 2003). The pavement is best when used in locations such as walkways, driveways or parking lots. It can take general wear and tear, but cannot withstand heavy traffic.

### 4.3.2 Infiltration Basin




An infiltration basin is an undisturbed area of land with permeable soils (PADEP 2007). Typically it consists of a slight depression having very gently sloping sides.

**Figure 4.6: Infiltration Basin (PADEP 2007)**

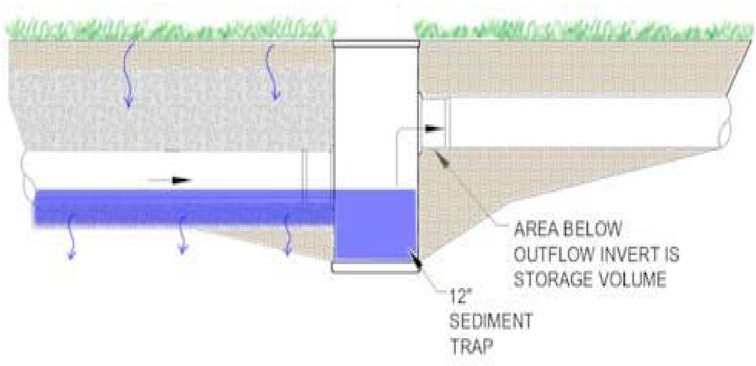
An infiltration basin BMP needs minimal monitoring. Any monitoring conducted should be subsurface.

**Table 4.8: Infiltration Basin Sampling Equipment**

| Hydrology Sampling | | | |
|---|---|---|---|
| | R-S-U | C-I | R-E |
| Raingage | | | |
| Staff Gage | | | |
| Ultra-Sonic Level | | | |
| Pressure Transducer | | | |
| Area/Velocity Bubbler | | | |
| Weir/Orifice | | | |
| Reflectometers | | | X |
| Quality Sampling | | | |
| | R-S-U | C-I | R-E |
| First Flush | | | |
| Automated Samplers | | | |
| Grab Samples | | | |
| Lysimeters | | | X |

Infiltration basins are ideal for open land areas with good soil properties. They may be incorporated in new developments as recreational space (PADEP 2006). They can also be retrofitted into existing lawns or open spaces.

### 4.3.3 Infiltration Trench




An infiltration trench is a drainage pipe that disperses water into a rock bed with maximum pore space which eventually allows water to infiltrate both horizontally and vertically into the soil strata.

**Figure 4.7: Infiltration Trench (PADEP 2007)**

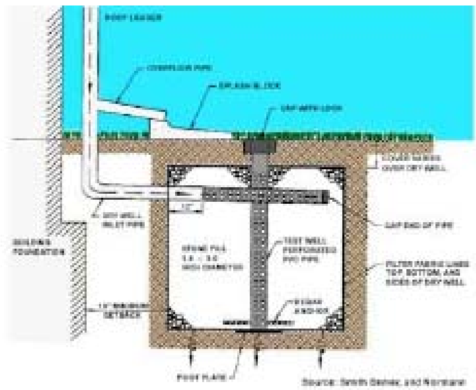
Hydrology is important in determining an infiltration trench's effectiveness in ex-filtrating water into the subsoil from all directions. The influent quality parameters are important in reviewing the potential for fines to fill the rock bed.

**Table 4.9: Infiltration Trench Sampling Equipment**

| Hydrology Sampling | | | |
|---|---|---|---|
| | R-S-U | C-I | R-E |
| Raingage | | | X |
| Staff Gage | | | |
| Ultra-Sonic Level | | | |
| Pressure Transducer | X | X | X |
| Area/Velocity Bubbler | | | |
| Weir/Orifice | | X | X |
| Reflectometers | | | |
| Quality Sampling | | | |
| | R-S-U | C-I | R-E |
| First Flush | | | |
| Automated Samplers | | X | X |
| Grab Samples | | X | X |
| Lysimeters | | | X |

Infiltration trenches are typically found in connection with roof leaders or inlets (PADEP 2006). Runoff from parking lots may be rerouted to infiltration trenches where the soil is found to be most permeable on site. It should be noted that an additional BMP should be used in conjunction with infiltration trenches to control sediment and organic matter input (Goldenfum 2001).

### 4.3.4 Dry Well/Seepage Pits



Dry well/seepage pits are infiltration BMPs that are typically connected to downspouts and directly infiltrate rooftop runoff into the ground. They consist of an open ground cavity with a three foot aggregate fill.

**Figure 4.8: Dry Well/Seepage Pit**

Monitoring dry well/seepage pits is difficult because of subsurface storage. Some hydrology parameters may be monitored.

**Table 4.10: Dry Well/Seepage Pit Sampling Equipment**

| Hydrology Sampling | | | |
|---|---|---|---|
| | R-S-U | C-I | R-E |
| Raingage | | | X |
| Staff Gage | | | |
| Ultra-Sonic Level | | | |
| Pressure Transducer | X | X | X |
| Area/Velocity Bubbler | | | |
| Weir/Orifice | | | |
| Reflectometers | | | |
| Quality Sampling | | | |
| | R-S-U | C-I | R-E |
| First Flush | | | |
| Automated Samplers | | | |
| Grab Samples | | | |
| Lysimeters | | | |

Dry well/seepage pits are best placed in locations where there is a significant depth of soil media with high infiltration capability. They work best in conjunction with roofs or impervious area with a relatively low sediment loading (PADEP 2006).

# Chapter 5: Volume/Peak Rate Reduction by Bio-Infiltration

**5.1 Subsurface Infiltration Bed (PADEP 2006)**

**5.2 Rain Garden/Bio-Retention**


**5.3 Vegetated Swale**

**Figure 5.1-3: Bio-Infiltration BMPs**

Volume/peak rate reduction by bio-infiltration introduces ecological mechanisms to infiltration BMPs. The introduction of these mechanisms improves water quality and reduces volume and peak flow. The amount of recharge is dependent on the type of BMP.

**Table 5.1: Bio-Infiltration BMPs (PADEP 2006)**

| | Volume Reduction | | | Recharge | | | Peak Rate Control | | | Water Quality | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Low | Med | High | Low | Med | High | Low | Med | High | Low | Med | High |
| Subsurface Infiltration Bed | | | X | | | X | | X | | | | X |
| Rain Garden/ Bioretention | | X | | | X | | X | | | | X | |
| Vegetated Swale | X | | | X | | | | X | | | X | |

## 5.1 Instrumentation and Sampling

This section lists all the potential parameters and equipment used to measure volume/peak rate reduction from infiltration BMPs. For a description of the equipment, refer to *Chapter 3: Instrumentation and Sampling*.

### 5.1.1 Hydrology Parameters

***Total Precipitation***

Total precipitation is the amount of rain that falls during a storm event. There are various ways for defining a storm event. For our purposes, a storm event is a period of precipitation where there is 24 hours of dry before start of rain and after the last recorded precipitation (Traver et. al. 2007). Precipitation data is helpful in determining the volume of water entering the BMP. Rainfall is monitored by (see CHAPTER 3.1):

- Analog Raingage
- Tipping Bucket Raingage

If equipment is not present, one can download precipitation data for a storm event from a nearby raingage using NOAA-ATLAS 14 (National Weather Service 2007).

***Water Elevation***

Water elevation is the depth of ponded water at a given location whether in a location of storage or stream channel. Water elevation is important to define the volume of water retained by the BMP and for infiltration calculations. Equipment used to monitor water surface elevation is (see CHAPTER 3.1):

- Staff Gage
- Ultra-sonic level
- Pressure transducer
- Area/Velocity bubbler

In conjunction with each other, the staff gage can be used as a calibrator for the level sensor, pressure transducer or area/velocity bubbler.

***Soil Moisture Content***

Moisture content determines the saturated conditions of the soil by measuring the volumetric water content. By measuring the moisture front as it passes, the infiltration rate can be determined. Automated equipment used for monitoring is (see Chapter 3.1):

- Reflectometers

### *Infiltration Rate*

Infiltration rate is the change in stored water elevation with respect to time after a precipitation event. The rate is calculated as the slope of the receding limb of the water depth verse time (Ermilio 2005). Monitoring equipment includes (see Chapter 3.1):

- Staff gage
- Ultra-sonic level
- Pressure transducer
- Area/Velocity Bubbler

Infiltration rates vary on a site by site basis due to soil properties. They are also affected by seasonal/temperature effects peaking in the summer and receding to their lowest values in the winter.

### *Storage Volume*

Storage volume is the amount of water that can be captured and retained by the BMP. Storage volume for a given storm is represented by a contour map of the site or elevation-storage tables (Hankins, et. al. 2008). If the storage space is filled with stone or gravel, the storage volume is represented by the void space. Equipment used to determine volume is (see Chapter 3.1):

- Staff gage
- Ultra-sonic level
- Pressure transducer
- Area/Velocity bubbler

When maximum volume is reached, there is overflow from the site

### *Overflow*

Overflow is the volume of water that exceeds the BMPs capacity and empties into a downstream water source. During storms, BMPs act to reduce peak flow by retaining the water in volume storage. When storage volume is exceeded, outflow can be measured by using (see Chapter 3.1):

- Area/Velocity Bubbler
- Pressure transducer with weir/orifice

Flow is important in determining the volume escaping and the volume being detained within the BMP. The objective of bio-infiltration BMPs is to minimize or eliminate overflow through infiltration (Ermilio 2005 & Sharkey 2006).

### 5.1.2 Quality Sampling

***Surface***

Surface samples are representative of runoff and direct precipitation. They are important in evaluating the contaminants found on nearby impervious surfaces. Surface samples include (see Chapter 3.2)

- First flush samplers
- Grab Samples
- Automated samplers

Grab samples and automated samplers can be a means of collecting overflow. This can help determine the amount of pollutants being removed by the BMP.

***Subsurface Samples***

Subsurface samples collect infiltrated pore water from the soil strata. The equipment used is (see Chapter 3.2):

- Lysimeters

At varying depths, a record of contaminant removal can be recorded as recharge moves through the vadose zone.

### 5.1.3 Quality Parameters

***Physical Parameters***

Physical parameters are evaluated by test methods that can be completed in the lab or by field test. These parameters include pH, conductivity, TSS and TDS. Conductivity yields the potential level of ionic species. TSS and TDS are the result of erosion and particles carried by the runoff.  Physical parameters are monitored by (see Chapter 3.3):

- pH probe
- Conductivity probe
- TSS/TDS Analysis

The results can be used to predict the levels of other potential contaminants.

***Nutrients/Ionic Species***

Nutrients are important considered for a heavily vegetated site. Total nitrogen and total phosphorus can enter a water system through industrial emissions or from soil, plant and animal matter. Chloride, nitrate, nitrite and ortho-phosphate are the ionic species of these nutrients (Ermilio, et. al. 2005). Chloride is a result of salt used on pavement during the winter months to prevent icing. Nutrients are tested using the following devices (see Chapter 3.3):

- Spectrophotometer
- HPLC

If the above instrumentation is not available on site, samples should be collected and preserved before being sent to an off-site laboratory for analysis.

***Total Recoverable Metals***

Metals have a tendency to bond to organic material at the surface and the mineral content within the soil (Sharkey 2006). Target metals may include cadmium, copper, chromium, lead and zinc. Cadmium and chromium are a result of industrial emissions such as the burning of coal. The other elements may be used to coat units used to transport runoff such as pipes. Over time the coating wears away and the metals become dissolved in the runoff. Values can be detected through the use of a (see Chapter 3.3):

- Graphite Furnace

If a graphite furnace is not available on site, samples should be collected and sent to an off-site laboratory for analysis.

### 5.1.4 Ecology Parameters

Ecology focuses on flora and fauna. Flora reduces peak flows through evaporation and uptakes nutrients. An overview of the fauna can give and idea of water quality issues. Some fauna may be detrimental to the site. For these types of BMPs, studies should be done on (Chapter 3.4):

- Diversity/Coverage
- Nutrient Uptake
- Invertebrates
- Vertebrates

## 5.2 Monitoring Methodology

In this section the parameters necessary for each monitoring method are presented. To determine the proper equipment for use, refer to *Chapter 5.1: Instrumentation and Sampling*.

### 5.2.1 Residential, Suburban, Urban and Ultra-Urban

***Hydrology***

In a residential, suburban, urban and ultra-urban BMP minimal equipment is needed to reach compliance. Storms should be monitored on a seasonal basis to determine the effectiveness of reducing the volume and peak discharge. Data can be compared to precipitation data from a nearby raingage using NOAA-ATLAS 14 (National Weather Service 2007).

**Table 5.2: Residential, Suburban, & Ultra-Urban Hydrology Monitoring for Bio-Infiltration BMPs**

| Monitored: Seasonally | |
|---|---|
| Parameter | Compliance |
| Total Precipitation | |
| Water Elevation | X |
| Soil Moisture Content | |
| Infiltration Rate | X |
| Storage Volume | |
| Overflow | |

Water elevation calculations can help in determining the infiltration rate. Infiltration rate is important in helping determine the BMP capacity to reduce the volume downstream and recharge the water table.

If only using one storm a season, it may be necessary to set up a general guideline. For example, only consider storm events with a predicted 1 in (0.025m) of rainfall.

***Quality***

Quality monitoring is not required for Volume/Peak Reduction by Bio-Infiltration BMPs at this monitoring level.

***Ecology***

Ecology monitoring is not required for Volume/Peak Reduction by Bio-Infiltration BMPs at this monitoring level.

### 5.2.2 Commercial and Industrial

***Hydrology***

Hydrologic monitoring is important at a commercial site because of the potential spills that may increase and contaminate flow through the BMP. Therefore hydrology should be monitored on a monthly basis.

**Table 5.3: Commercial & Industrial Hydrology Monitoring for Bio-Infiltration BMPs**

| Monitored: Monthly | |
|---|---|
| Parameter | Compliance |
| Total Precipitation | |
| Water Elevation | X |
| Soil Moisture Content | |
| Infiltration Rate | X |
| Storage Volume | |
| Overflow | X |

Water elevation calculations can help in determining the infiltration rate. Infiltration rate is important in helping determine the BMP capacity to reduce the volume downstream and recharge the water table. Bio-Infiltration BMPs attempt to eliminate overflow, but knowing this value shows the ability of the BMP to reduce peak flow when the BMPs capacity is breached.

If only using one storm a month, it may be necessary to set up a general guideline. For example, only consider storm events with a predicted 1 in (0.025m) of rainfall.

***Quality***

Quality is important on industrial and commercial sites because of the potential for contaminant spills. Samples should be collected on a seasonal basis and tested for site specific chemical contamination.

**Table 5.4: Commercial & Industrial Quality Monitoring for Bio-Infiltration BMPs**

| Monitored: Seasonally | |
|---|---|
| Parameter | Compliance |
| Physical Properties | X |
| Nutrients/Ionic Species | |
| Total Recoverable Metals | |

Physical properties are important because they can indicate the potential for other pollutants and whether these pollutants are being eliminated between entry and exit, especially TDS because contaminants stick to solids.

#### *Ecology*

Ecology monitoring is not required for Volume/Peak Reduction by Bio-Infiltration BMPs at this monitoring level.

### 5.2.3 Research and Education

#### *Hydrology*

At research and educational facilities, the manpower and utilities are available to monitor all hydrological aspects. Therefore data should be recorded on a storm by storm basis.

**Table 5.5: Research & Education Hydrology Monitoring for Bio-Infiltration BMPs**

| Monitored: Storm by Storm | |
|---|---|
| Parameter | Compliance |
| Total Precipitation | X |
| Water Elevation | X |
| Soil Moisture Content | X |
| Infiltration Rate | X |
| Storage Volume | X |
| Overflow | X |

Water elevation calculations can help in determining the infiltration rate. Infiltration rate is important in helping determine the BMP capacity to reduce the volume downstream and recharge the water table. Bio-Infiltration BMPs look to eliminate overflow, but knowing this value shows the ability of the BMP to reduce peak flow when the BMPs capacity is breached. Additional precipitation readings can help determine the amount of water being introduced to the site while soil moisture content helps determine the storage volume. Knowing the storage volume, can give a better understanding of the capacity the BMP to retain water.

#### *Quality*

At research and educational facilities, the manpower and utilities are available to monitor all quality parameters. Therefore data should be recorded on a monthly basis.

**Table 5.6: Research & Education Quality Monitoring for Bio-Infiltration BMPs**

| Monitored: Monthly | |
|---|---|
| Parameter | Compliance |
| Physical Properties | X |
| Nutrients/Ionic Species | X |
| Total Recoverable Metals | X |

Physical properties are important because they can indicate whether other pollutants potentially contaminate the water source and whether they are being eliminated between entry and exit, especially TDS. Nutrients and ionic species should be reviewed because of their effects on eutrophication. Increased levels of nutrients and metals lead to detrimental effects on aquatic life.

### *Ecology*

At research and educational facilities, the manpower and utilities are available to monitor all ecology parameters. Therefore data should be recorded on a storm by storm basis.

**Table 5.7: Research & Education Ecologic Monitoring for Bio-Infiltration Rate BMPs**

| Monitored: Seasonally | |
|---|---|
| Parameter | Compliance |
| Diversity/Coverage | X |
| Nutrient Uptake | X |
| Invertebrate Studies | X |
| Vertebrate Studies | X |

A review of diversity and coverage can help determine which plants thrive better in the environment. Additional plants can be introduced to increase evapotranspiration. Nutrient uptake will help determine plants ability to absorb excess nutrients and which plants are more conducive to nutrient uptake. Invertebrate studies can determine if the toxin levels are increasing or decreasing based on indicator species results. Vertebrate studies should be completed because of the possible effects of animals of eating the vegetation and the potential for tampering with equipment.

## 5.3 BMP Design

In this section specific BMPs are reviewed for the equipment at each monitoring level. For parameters monitored, refer to *Chapter 5.2: Monitoring Methodology*.

***Note***: There is no specific equipment used for ecological studies; most are conducted by visual inspection and counts.

### 5.3.1 Sub-Surface Infiltration Bed


Sub-surface infiltration beds provide temporary internal storage underneath the ground leading to an increase in infiltration (PADEP 2007). The placement of meadow and dense vegetation over the permeable cover allows for additional volume reduction through evapotranspiration.

**Figure 5.4: Sub-surface Infiltration Bed (PADEP 2007)**

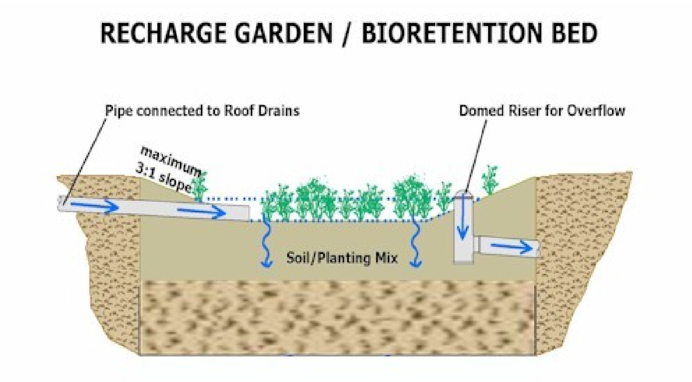
Monitoring hydrology and ecology are important for this BMP because of how well it serves the stormwater functions, if working properly. Ecology should be reviewed for diversity/coverage that may encourage evapotranspiration. The water quality may be difficult to obtain because there is no above ground storage.

**Table 5.8 Sub-Surface Infiltration Bed Sampling Equipment**

| Hydrology Sampling | | | |
|---|---|---|---|
| | R-S-U | C-I | R-E |
| Raingage | | | X |
| Staff Gage | | | |
| Ultra-Sonic Level | | | |
| Pressure Transducer | X | X | X |
| Area/Velocity Bubbler | | | |
| Weir/Orifice | | X | X |
| Reflectometers | | | X |
| Quality Sampling | | | |
| | R-S-U | C-I | R-E |
| First Flush | | | |
| Automated Samplers | | | |
| Grab Samples | | | |
| Lysimeters | | | X |

The purpose of a sub-surface infiltration bed is infiltration and recharge. An ideal application would be under an open field or connected to leaders and/or outlets from other BMPs.

### 5.3.2 Bio-Retention/Bio-Infiltration/Rain Garden




Bio-retention BMPs are becoming popular due to their aesthetic appeal and ability to meet stormwater and landscape permit requirements (Sharkey 2006). A bio-retention basin is a depression with various native plants that captures runoff and treats it in a variety of ways.

**Figure 5.5: Bio-Retention/Infiltration (PADEP 2007)**

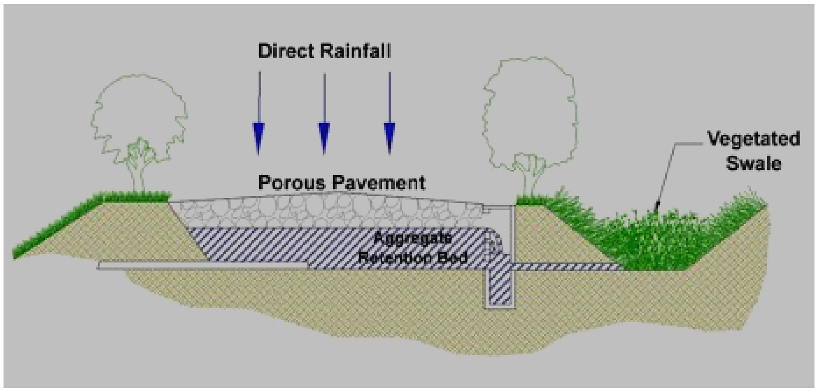
A bio-retention basin forms a natural ecosystem that is able to retain, infiltrate, treat pollutants, and enhance the landscape. It equally incorporates the hydrologic, quality and ecologic aspects of a BMP. Ecology should focus on any of the four aspects defined earlier (diversity/coverage, nutrient uptake, invertebrates, and vertebrates).

**Table 5.9: Bio-Retention/Infiltration Sampling Equipment**

| Hydrology Sampling | | | |
|---|---|---|---|
| | R-S-U | C-I | R-E |
| Raingage | | | X |
| Staff Gage | X | X | X |
| Ultra-Sonic Level | X | X | X |
| Pressure Transducer | | X | X |
| Area/Velocity Bubbler | | | |
| Weir/Orifice | | X | X |
| Reflectometers | | | X |
| Quality Sampling | | | |
| | R-S-U | C-I | R-E |
| First Flush | | X | X |
| Automated Samplers | | X | X |
| Grab Samples | | X | X |
| Lysimeters | | | X |

These BMPs are perfect for parking lots, medians and in connection with roof leaders as long as there is a pervious base soil. They are sometimes problematic because for larger storms they may not be able to reduce the volume or water quality parameters to regulation standards. For this reason, they are often used in connection with other BMPs such as a standard detention basin (Prokop 2003).

### 5.3.3 Vegetated Swale




A vegetated swale is a lengthy shallow depression that typically runs along the sides or roads or highways. It is densely covered with shrubbery and used to attenuate water (PADEP 2007).

**Figure 5.6: Swale (PADEP 2007)**

A vegetated swale works more by evaporation than infiltration. It has the ability to slow runoff and control peak flow providing time for some water quality processes to occur. From an ecological standpoint, a swale should be reviewed for diversity/coverage to prevent erosion and invertebrate studies because of the potential for stagnant water.

**Table 5.10: Swale Sampling Equipment**

| Hydrology Sampling | | | |
|---|---|---|---|
| | R-S-U | C-I | R-E |
| Raingage | | | |
| Staff Gage | | | |
| Ultra-Sonic Level | | | |
| Pressure Transducer | | X | X |
| Area/Velocity Bubbler | X | X | X |
| Weir/Orifice | | X | X |
| Reflectometers | | | X |
| Quality Sampling | | | |
| | R-S-U | C-I | R-E |
| First Flush | | | |
| Automated Samplers | | X | X |
| Grab Samples | | X | X |
| Lysimeters | | | |

# Chapter 6: Volume/Peak Rate Reduction

**6.1 Vegetated Roof**

**6.2 Runoff Capture & Reuse**

**Figure 6.1-2: Volume/Peak Rate BMPs**

Volume/Peak Rate Reduction BMPs provide other means of reduction that do not fit under classification of infiltration or bioinfiltration BMPs. BMPs of this nature do not recharge the groundwater, but provide for evapotranspiration and direct reuse.

**Table 6.1: Volume/Peak Rate (PADEP 2007)**

| | Volume Reduction | | | Recharge | | | Peak Rate Control | | | Water Quality | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Low | Med | High | Low | Med | High | Low | Med | High | Low | Med | High |
| Vegetated Roof | | X | | | | | X | | | | X | |
| Runoff Capture & Reuse | | X | | X | | | X | | | | X | |

## 6.1 Instrumentation and Sampling

This section lists all the potential parameters and equipment used to measure volume/peak rate reduction from infiltration BMPs. For a description of the equipment, refer to *Chapter 3: Instrumentation and Sampling*.

### 6.1.1 Hydrology Parameters

#### *Total Precipitation*

Total precipitation is the amount of rain that falls during a storm event. There are various ways for defining a storm event. For our purposes, a storm event is a period of precipitation where there is 24 hours of dry before start of rain and after the last recorded precipitation (Traver et. al. 2007). Precipitation data is helpful in determining the volume of water entering the BMP. Rainfall is monitored by (see CHAPTER 3.1):

- Analog Raingage
- Tipping Bucket Raingage

If equipment is not present, one can download precipitation data for a storm event from a nearby raingage using NOAA-ATLAS 14 (National Weather Service 2007).

#### *Soil Moisture Content*

Moisture content determines the saturated conditions of the soil by measuring the volumetric water content. By measuring the moisture front as it passes, the infiltration rate can be determined. Automated equipment used for monitoring is (see Chapter 3.1):

- Reflectometers

#### *Storage Volume*

Storage volume is the amount of water that can be captured and retained by the BMP. Storage volume for a given storm is represented by a contour map of the site or elevation-storage tables (Hankins, et. al. 2008). If the storage space is filled with stone or gravel, the storage volume is represented by the void space. Equipment used to determine volume is (see Chapter 3.1):

- Staff gage
- Ultra-sonic level
- Pressure transducer
- Area/Velocity bubbler

When maximum volume is reached, there is overflow from the site.

*Overflow*

Overflow is the volume of water that exceeds the BMPs capacity and empties into a downstream water source. During storms, BMPs act to reduce peak flow by retaining the water in volume storage. When storage volume is exceeded, outflow can be measured by using (see Chapter 3.1):

- Area/Velocity Bubbler
- Pressure transducer with weir/orifice

Flow is important in determining the volume escaping and the volume being detained within the BMP.

### 6.1.2 Quality Sampling

*Surface*

Surface samples are representative of runoff and direct precipitation. They are important in evaluating the contaminants found on nearby impervious surfaces. Surface samples include (see Chapter 3.2)

- Grab Samples
- Automated samplers

Grab samples and automated samplers can be a means of collecting overflow. This can help determine the amount of pollutants being removed by the BMP.

*Subsurface Samples*

Subsurface samples collect infiltrated pore water from the soil strata. The equipment used is (see Chapter 3.2):

- Lysimeters

At varying depths, a record of contaminant removal can be recorded as recharge moves through the vadose zone.

### 6.1.3 Quality Parameters

*Physical Parameters*

Physical parameters are evaluated by test methods that can be completed in the lab or by field test. These parameters include pH, conductivity, TSS and TDS. Conductivity yields the potential level of ionic species. TSS and TDS are the result of erosion and particles carried by the runoff. Physical parameters are monitored by (see Chapter 3.3):

- pH probe
- Conductivity probe
- TSS/TDS Analysis

The results can be used to predict the levels of other potential contaminants.

### *Nutrients/Ionic Species*

Nutrients are important to consider for heavily vegetated site. Total nitrogen and total phosphorus can enter a water system through industrial emissions or from soil, plant and animal matter. Chloride, nitrate, nitrite and ortho-phosphate are the ionic species of these nutrients (Ermilio, et. al. 2005). Chloride is a result of salt used on pavement during the winter months to prevent icing. Nutrients are tested using the following devices (see Chapter 3.3):

- Spectrophotometer
- HPLC

If the above instrumentation is not available on site, samples should be collected and preserved before being sent to an off-site laboratory for analysis.

## 6.1.4 Ecology Parameters

Ecology focuses on flora and fauna. Flora reduces peak flows through evaporation and uptakes nutrients. An overview of the fauna can give and idea of water quality issues. Some fauna may be detrimental to the site. For these types of BMPs, studies should be done on (Chapter 3.4):

- Diversity/Coverage
- Nutrient Uptake

## 6.2 Monitoring Methodology

In this section the parameters necessary for each monitoring method are presented. To determine the proper equipment for use, refer to *Chapter 6.1: Instrumentation and Sampling*.

### 6.2.1 Residential, Suburban, Urban and Ultra-Urban

#### *Hydrology*

In a residential, suburban, urban and ultra-urban BMP minimal equipment is needed to reach compliance. Storms should be monitored on a seasonal basis to determine the effectiveness of reducing the volume and peak discharge. Data can be compared to precipitation data from a nearby raingage using NOAA-ATLAS 14 (National Weather Service 2007).

**Table 6.2: Residential, Suburban, & Ultra-Urban Hydrology Monitoring for Volume/Peak Rate BMPs**

| Monitored: Seasonally | |
|---|---|
| Parameter | Compliance |
| Total Precipitation | |
| Water Elevation | X |
| Soil Moisture Content | |
| Infiltration Rate | |
| Storage Volume | |
| Overflow | X |

Water elevation calculations can help in calculating the overflow. Overflow is important in determining the volume reduction.

If only using one storm a season, it may be necessary to set up a general guideline. For example, only consider storm events with a predicted 1 in (0.025m) of rainfall.

#### *Quality*

Quality monitoring is not required for Volume/Peak Reduction BMPs at this monitoring level.

#### *Ecology*

Ecology provides the appeal of the site. Therefore, it should be reviewed seasonally and evasive species should be removed.

**Table 6.3: Residential, Suburban, & Ultra-Urban Ecologic Monitoring for Volume/Peak Rate BMPs**

| Monitored: Seasonally | |
|---|---|
| Parameter | Compliance |
| Diversity/Coverage | X |
| Nutrient Uptake | |
| Invertebrate Studies | |
| Vertebrate Studies | |

A review of diversity and coverage can help determine which plants thrive better in the environment. Additional plants can be introduced to increase evapotranspiration.

### 6.2.2 Commercial and Industrial

#### *Hydrology*

Hydrologic monitoring is important at a commercial site because of the potential spills that may increase and contaminate flow through the BMP. Therefore hydrology should be reviewed on a monthly basis.

**Table 6.4: Commercial & Industrial Monitoring for Volume/Peak Rate BMPs**

| Monitored: Monthly | |
|---|---|
| Parameter | Compliance |
| Total Precipitation | X |
| Water Elevation | X |
| Soil Moisture Content | |
| Infiltration Rate | |
| Storage Volume | |
| Overflow | X |

Water elevation calculations can help in calculating the overflow. Especially at this type of BMP where the probability of completely eliminating overflow is negligible, there is a better chance of a better reduction in peak flow. Additional precipitation readings can help determine the amount of water being introduced to the site.

If only using one storm a month, it may be necessary to set up a general guideline. For example, only consider storm events with a predicted 1 in (0.025m) of rainfall.

### *Quality*

Quality is important on industrial and commercial sites because of the potential for contaminant spills. Samples should be collected on a seasonal basis and tested for site specific chemical contamination.

**Table 6.5: Commercial & Industrial Quality Monitoring for Volume/Peak Rate BMPs**

| Monitored: Seasonally | |
|---|---|
| Parameter | Compliance |
| Physical Properties | X |
| Nutrients/Ionic Species | |
| Total Recoverable Metals | |

Physical properties are important because they can indicate the potential for other pollutants and whether these pollutants are being eliminated between entry and exit, especially TDS because contaminants stick to solids.

### *Ecology*

Ecology can be important in determining if there are high levels of toxins in runoff. Various toxins can lead to a noticeable decline in plant life or invertebrates. Tests should be completed on a seasonal basis unless funding allows for monthly review.

**Table 6.6: Commercial & Industrial Ecologic Monitoring for Volume/Peak Rate BMPs**

| Monitored: Seasonally | |
|---|---|
| Parameter | Compliance |
| Diversity/Coverage | X |
| Nutrient Uptake | |
| Invertebrate Studies | X |
| Vertebrate Studies | |

A review of diversity and coverage can help determine which plants thrive better in the environment. Additional plants can be introduced to increase evapotranspiration. Invertebrate studies can determine if the toxin levels are increasing or decreasing based on indicator species results.

### 6.2.3 Research and Education

#### *Hydrology*

At research and educational facilities, the manpower and utilities are available to monitor all hydrological aspects. Therefore data should be recorded on a storm by storm basis.

**Table 6.7: Research & Education Hydrology Monitoring for Volume/Peak Rate BMPs**

| Monitored: Storm by Storm | |
|---|---|
| Parameter | Compliance |
| Total Precipitation | X |
| Water Elevation | X |
| Soil Moisture Content | X |
| Infiltration Rate | |
| Storage Volume | X |
| Overflow | X |

Water elevation calculations can help in calculating the overflow. Especially at this type of BMP where the probability of completely eliminating overflow is negligible, there is a better chance of a better reduction in peak flow. Additional precipitation readings can help determine the amount of water being introduced to the site while soil moisture content helps determine the storage volume. Knowing the storage volume, can give a better understanding of the capacity of the BMP to retain water while reducing the peak flow.

#### *Quality*

At research and educational facilities, the manpower and utilities are available to monitor all quality parameters. Therefore data should be recorded on a monthly basis.

**Table 6.8: Research & Education Quality Monitoring for Volume/Peak Rate BMPs**

| Monitored: Monthly | |
|---|---|
| Parameter | Compliance |
| Physical Properties | X |
| Nutrients/Ionic Species | X |
| Total Recoverable Metals | |

Physical properties are important because they can indicate whether other pollutants potentially contaminate the water source and whether they are being eliminated between entry and exit, especially TDS. Nutrients and ionic species should be reviewed because of their effects on eutrophication of downstream waterways.

### *Ecology*

At research and educational facilities, the manpower and utilities are available to monitor all ecology parameters. Therefore data should be recorded on a seasonal basis.

**Table 6.9: Research & Education Ecologic Monitoring for Volume/Peak Rate BMPs**

| Monitored: Seasonally | |
|---|---|
| Parameter | Compliance |
| Diversity/Coverage | X |
| Nutrient Uptake | X |
| Invertebrate Studies | X |
| Vertebrate Studies | |

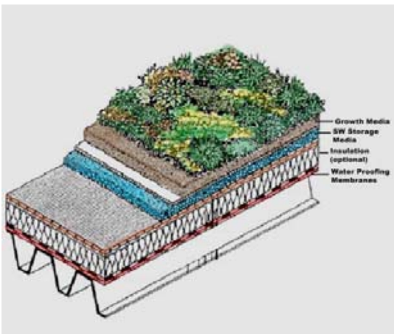
A review of diversity and coverage can help determine which plants thrive better in the environment. Additional plants can be introduced to increase evapotranspiration. Nutrient uptake will help determine plants ability to absorb excess nutrients and which plants are more conducive to nutrient uptake. Invertebrate studies can determine if the toxin levels are increasing or decreasing based on indicator species results.

## 6.3 BMP Design

In this section specific BMPs are reviewed for the equipment at each monitoring level. For parameters monitored, refer to *Chapter 6.2: Monitoring Methodology*.

***Note:*** There is no specific equipment used for ecological studies; most are conducted by visual inspection and counts.

### 6.3.1 Vegetated Roof




Vegetated roofs utilize 1000's of square footage that would otherwise be wasted space (Tokarz 2006). A vegetated roof can be intensive or extensive and consists of various layers of geotextile, a required layer of soil and various plantings. Most common to monitoring are those extensive in design with minimal soil cover and sedum plantings.

**Figure 6.4: Vegetated Roof (PADEP 2007)**

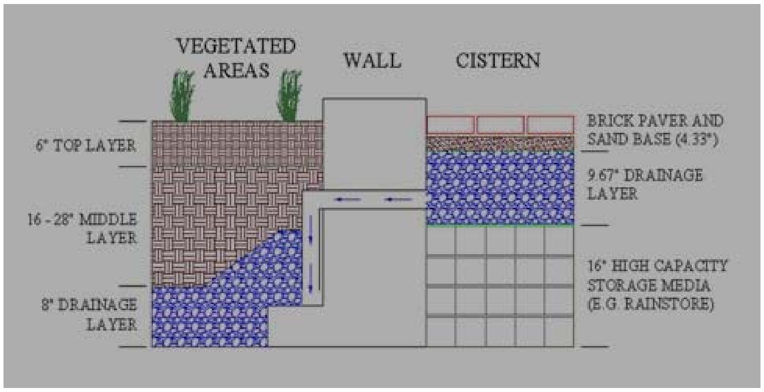
Vegetated roofs are designed for volume reduction. Ecology is important because evapotranspiration increases with the number of plantings. It should be reviewed for diversity/coverage, nutrient uptake and invertebrates. By retaining the water, quality is also improved.

**Table 6.10: Vegetated Roof Sampling Equipment**

| Hydrology Sampling | | | |
|---|---|---|---|
| | R-S-U | C-I | R-E |
| Raingage | | X | X |
| Staff Gage | | | |
| Ultra-Sonic Level | | | |
| Pressure Transducer | | | |
| Area/Velocity Bubbler | X | X | X |
| Weir/Orifice | | | |
| Reflectometers | | | X |
| Quality Sampling | | | |
| | R-S-U | C-I | R-E |
| First Flush | | | |
| Automated Samplers | | X | X |
| Grab Samples | | X | X |
| Lysimeters | | | X |

Vegetated roofs are best used in urban areas where there is no land available for infiltration BMPs. They tend to increase property value, reduce heat and cooling cost and extend the life of the original roof (Tokarz 2006).

### 6.3.2 Capture & Reuse




Runoff capture and reuse includes a wide variety of ways to store precipitation to be reused at a later time. The water may be captured above ground in a barrel or cistern. Other methods include trapping it in a below ground storage unit.

**Figure 6.5: Capture & Reuse (PADEP 2007)**

Runoff capture and reuse are designed with volume/peak reduction and therefore focus on hydrology. Using this method, a water budget must be developed to account for variations of rainfall over the seasons (PADEP 2007). In many cases, quality and ecology can be neglected.

**Table 6.11: Capture & Reuse Sampling Equipment**

| Hydrology Sampling | | | |
|---|---|---|---|
| | R-S-U | C-I | R-E |
| Raingage | | X | X |
| Staff Gage | | | |
| Ultra-Sonic Level | | | |
| Pressure Transducer | | | |
| Area/Velocity Bubbler | X | X | X |
| Weir/Orifice | | | |
| Reflectometers | | | |
| **Quality Sampling** | | | |
| | R-S-U | C-I | R-E |
| First Flush | | | |
| Automated Samplers | | | |
| Grab Samples | | X | X |
| Lysimeters | | | |

This BMP has many practical purposes, where the space to store water is available. The water can be reused for irrigation, firefighting needs and flushing toilets (PADEP 2007).

# Chapter 7: Runoff Quality/Peak Rate Control

**7.1 Constructed Wetlands**

**7.2 Wet Pond/Retention Basin (PADEP 2006)**

**7.3 Dry Extended Detention Basin (PADEP 2006)**

**Figure 7.1-3: Quality Control/Peak Rate BMPs**

Runoff Quality/Peak Rate Control BMPs function by retaining/retarding runoff to reduce the peak flow and improve the water quality. Many of these BMPs allow time for evapotranspiration and infiltration during the process.

**Table 7.1: Quality Control/Peak Rate (PADEP 2007)**

| | Volume Reduction | | | Recharge | | | Peak Rate Control | | | Water Quality | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Low | Med | High | Low | Med | High | Low | Med | High | Low | Med | High |
| Constructed Wetlands | X | | | X | | | | | X | | | X |
| Wet Pond/ Retention | X | | | X | | | | | X | | X | |
| Dry Extended Detention | X | | | | | | | | X | X | | |

## 7.1 Instrumentation and Sampling

This section lists all the potential parameters and equipment used to measure volume/peak rate reduction from infiltration BMPs. For a description of the equipment, refer to *Chapter 3: Instrumentation and Sampling*.

### 7.1.1 Hydrology Parameters

#### *Total Precipitation*

Total precipitation is the amount of rain that falls during a storm event. There are various ways for defining a storm event. For our purposes, a storm event is a period of precipitation where there is 24 hours of dry before start of rain and after the last recorded precipitation (Traver et. al. 2007). Precipitation data is helpful in determining the volume of water entering the BMP. Rainfall is monitored by (see CHAPTER 3.1):

- Analog Raingage
- Tipping Bucket Raingage

If equipment is not present, one can download precipitation data for a storm event from a nearby raingage using NOAA-ATLAS 14 (National Weather Service 2007).

#### *Water Elevation*

Water elevation is the depth of ponded water at a given location whether in a location of storage or stream channel. Water elevation is important to define the volume of water retained by the BMP and for infiltration calculations. Equipment used to monitor water surface elevation is (see CHAPTER 3.1):

- Staff Gage
- Ultra-sonic level
- Pressure transducer
- Area/Velocity bubbler

In conjunction with each other, the staff gage can be used as a calibrator for the level sensor, pressure transducer or area/velocity bubbler.

#### *Soil Moisture Content*

Moisture content determines the saturated conditions of the soil by measuring the volumetric water content. By measuring the moisture front as it passes, the infiltration rate can be determined. Automated equipment used for monitoring is (see Chapter 3.1):

- Reflectometers

### *Infiltration Rate*

Infiltration rate is the change in stored water elevation with respect to time after a precipitation event. The rate is calculated as the slope of the receding limb of the water depth verse time (Ermilio 2005). Monitoring equipment includes (see Chapter 3.1):

- Staff gage
- Ultra-sonic level
- Pressure transducer
- Area/Velocity Bubbler

Infiltration rates vary on a site by site basis due to soil properties. They are also affected by seasonal/temperature effects peaking in the summer and receding to their lowest values in the winter.

### *Storage Volume*

Storage volume is the amount of water that can be captured and retained by the BMP. Storage volume for a given storm is represented by a contour map of the site or elevation-storage tables (Hankins, et. al. 2008). If the storage space is filled with stone or gravel, the storage volume is represented by the void space. Equipment used to determine volume is (see Chapter 3.1):

- Staff gage
- Ultra-sonic level
- Pressure transducer
- Area/Velocity bubbler

When maximum volume is reached, there is overflow from the site.

### *Overflow*

Overflow is the volume of water that exceeds the BMPs capacity and empties into a downstream water source. During storms, BMPs act to reduce peak flow by retaining the water in volume storage. When storage volume is exceeded, outflow can be measured by using (see Chapter 3.1):

- Area/Velocity Bubbler
- Pressure transducer with weir/orifice

Flow is important in determining the volume escaping and the volume being detained within the BMP. It must also be noted that some quality control BMPs have a continuous baseflow, so therefore there is a minimum constant overflow monitored. There must also be an inflowing water source which can be monitored in a similar manner.

### 7.1.2 Quality Sampling

***Surface***

Surface samples are representative of runoff and direct precipitation. They are important in evaluating the contaminants found on nearby impervious surfaces. Surface samples include (see Chapter 3.2)

- Grab Samples
- Automated samplers

Grab samples and automated samplers can be a means of collecting overflow. This can help determine the amount of pollutants being removed by the BMP.

***Subsurface Samples***

Subsurface samples collect infiltrated pore water from the soil strata. The equipment used is (see Chapter 3.2):

- Lysimeters

At varying depths, a record of contaminant removal can be recorded as recharge moves through the vadose zone.

### 7.1.3 Quality Parameters

***Physical Parameters***

Physical parameters are evaluated by test methods that can be completed in the lab or by field test. These parameters include pH and conductivity. PH defines the acidity of the rain. Conductivity yields the potential level of ionic species. TSS and TDS are the result of erosion and particles carried by the runoff. Physical parameters are monitored by (see Chapter 3.3):

- pH probe
- Conductivity probe
- TSS/TDS Analysis

The results can be used to predict the levels of potential other contaminants.

***Nutrients/Ionic Species***

Nutrients are important to consider for a heavily vegetated site. Total nitrogen and total phosphorus can enter a water system through industrial emissions or from soil, plant and animal matter. Chloride, nitrate, nitrite and ortho-phosphate are the ionic species of these nutrients (Ermilio, et. al. 2005). Chloride is a result of salt used on pavement during the winter months to prevent icing. Nutrients are tested using the following devices (see Chapter 3.3):

- Spectrophotometer
- HPLC

If the above instrumentation is not available on site, samples should be collected and preserved before being sent to an off-site laboratory for analysis.

***Total Recoverable Metals***

Metals have a tendency to bond to organic material at the surface and the mineral content within the soil (Sharkey 2006) Target metals may include cadmium, copper, chromium, lead and zinc. Cadmium and chromium are a result of industrial emissions such as the burning of coal. The other elements may be used to coat units used to transport runoff such as pipes. Over time the coating wears away and the metals become dissolved in the runoff. Values can be detected through the use of a (see Chapter 3.3):

- Graphite Furnace

If a graphite furnace is not available on site, samples should be collected and sent to an off-site laboratory for analysis.

### 7.1.4 Ecology Parameters

Ecology focuses on flora and fauna. Flora reduces peak flows through evaporation and uptakes nutrients. An overview of the fauna can give and idea of water quality issues. Some fauna may be detrimental to the site. For these types of BMPs, studies should be done on (Chapter 3.4):

- Diversity/Coverage
- Nutrient Uptake
- Invertebrates
- Vertebrates

## 7.2 Monitoring Methodology

In this section the parameters necessary for each monitoring method are presented. To determine the proper equipment for use, refer to *Chapter 7.1: Instrumentation and Sampling*.

### 7.2.1 Residential, Suburban, Urban and Ultra-Urban

***Hydrology***

In a residential, suburban, urban and ultra-urban BMP minimal equipment is needed to reach compliance. Storms should be monitored on a seasonal basis to determine the effectiveness of reducing the volume and peak discharge. Data can be compared to precipitation data from a nearby raingage using NOAA-ATLAS 14 (National Weather Service 2007).

**Table 7.2: Residential, Suburban, & Ultra-Urban Hydrology Monitoring for Quality Control/Peak Rate BMPs**

| Monitored: Seasonally | |
|---|---|
| Parameter | Compliance |
| Total Precipitation | |
| Water Elevation | X |
| Soil Moisture Content | |
| Infiltration Rate | |
| Storage Volume | |
| Overflow | X |

Water elevation calculations can help in calculating the overflow. Especially at this type of BMP where there is no probability of completely eliminating overflow, there is a better chance of reducing the peak flow.

If only using one storm a season, it may be necessary to set up a general guideline. For example, only consider storm events with a predicted 1 in (0.025m) of rainfall.

***Quality***

Samples should be acquired on a seasonal basis to assure the BMP is functioning as appropriate quality control.

**Table 7.3: Residential, Suburban, & Ultra-Urban Quality Monitoring for Quality Control/Peak Rate BMPs**

| Monitored: Seasonally | |
|---|---|
| Parameter | Compliance |
| Physical Properties | X |
| Nutrients/Ionic Species | |
| Dissolved/Heavy Metals | |

Physical properties are important because they can indicate the potential for other pollutants and whether these pollutants are being eliminated between entry and exit, especially TDS because contaminants stick to solids.

### *Ecology*

Ecology monitoring is not required for Quality Control/Peak Reduction BMPs at this monitoring level.

## 7.2.2 Commercial and Industrial

### *Hydrology*

Hydrologic monitoring is important at a commercial site because of the potential spills that may increase and contaminate flow through the BMP. Therefore at a compliance level, information other than overflow must be reviewed on a monthly basis.

**Table 7.4: Commercial & Industrial Monitoring for Quality Control/Peak Rate BMPs**

| Monitored: Monthly | |
|---|---|
| Parameter | Compliance |
| Total Precipitation | |
| Water Elevation | X |
| Soil Moisture Content | |
| Infiltration Rate | |
| Storage Volume | X |
| Overflow | X |

Water elevation calculations can help in calculating the overflow. Especially at this type of BMP where there is no probability of completely eliminating overflow, there is a better chance of reducing the peak flow.  Knowing the storage volume, can give a better understanding of the capacity of the BMP to retain water while reducing the peak flow. If only using one storm a season, it may be necessary to set up a general guideline. For example, only consider storm events with a predicted 1 in (0.025m) of rainfall.

### *Quality*

Quality is important on industrial and commercial sites because of the potential for contaminant spills. Samples should be collected on a monthly basis and tested for site specific chemical contamination.

**Table 7.5: Commercial & Industrial Quality Monitoring for Quality Control/Peak Rate BMPs**

| Monitored: Monthly | |
|---|---|
| Parameter | Compliance |
| Physical Properties | X |
| Nutrients/Ionic Species | X |
| Total Recoverable Metals | X |

Physical properties are important because they can indicate whether other pollutants potentially contaminate the water source and whether they are being eliminated between entry and exit, especially TDS. Nutrients and ionic species should be reviewed because of their effects on eutrophication. Increased levels of nutrients and metals lead to detrimental effects on aquatic life.

### *Ecology*

Ecology can be important in determining if there are high levels of toxins in runoff. Various toxins can lead to a noticeable decline in plant life or invertebrates. Tests should be completed on a seasonal basis.

**Table 7.6: Commercial & Industrial Ecologic Monitoring for Quality Control/Peak Rate BMPs**

| Monitored: Seasonally | |
|---|---|
| Parameter | Compliance |
| Diversity/Coverage | X |
| Nutrient Uptake | |
| Invertebrate Studies | X |
| Vertebrate Studies | |

A review of diversity and coverage can help determine which plants thrive better in the environment. Additional plants can be introduced to increase evapotranspiration. Invertebrate studies can determine if the toxin levels are increasing or decreasing based on indicator species results.

### 7.2.3 Research and Education

***Hydrology***

At research and educational facilities, the manpower and utilities are available to monitor all hydrological aspects. Therefore data should be recorded on a storm by storm basis with baseflow hydrology being monitored monthly.

**Table 7.7: Research & Education Hydrology Monitoring for Quality Control/Peak Rate BMPs**

| Monitored: Storm by Storm | |
|---|---|
| Parameter | Compliance |
| Total Precipitation | X |
| Water Elevation | X |
| Soil Moisture Content | X |
| Infiltration Rate | |
| Storage Volume | X |
| Overflow | X |

Water elevation calculations can help in calculating the overflow. Especially at this type of BMP where the probability of completely eliminating overflow is negligible, there is a better chance of a better reduction in peak flow. Additional precipitation readings can help determine the amount of water being introduced to the site while soil moisture content helps determine the storage volume. Knowing the storage volume, can give a better understanding of the capacity the BMP to retain water while reducing the peak flow.

***Quality***

At research and educational facilities, the manpower and utilities are available to monitor all quality parameters. Therefore data should be recorded on a monthly basis including sample of baseflow during periods of dry time.

**Table 7.8: Research & Education Quality Monitoring for Quality Control/Peak Rate BMPs**

| Monitored: Monthly | |
|---|---|
| Parameter | Compliance |
| Physical Properties | X |
| Nutrients/Ionic Species | X |
| Total Recoverable Metals | X |

Physical properties are important because they can tell indicate whether other pollutants potentially contaminate the water source and whether they are being eliminated between entry and exit, especially TDS. Nutrients and ionic species should be reviewed because of their effects on eutrophication. Increased levels of nutrients and metals lead to detrimental effects on aquatic life.

### *Ecology*

At research and educational facilities, the manpower and utilities are available to monitor all ecology parameters. Therefore data should be recorded on a seasonal basis.

**Table 7.9: Research & Education Ecologic Monitoring for Quality Control/Peak Rate BMPs**

| Monitored: Seasonally | |
|---|---|
| Parameter | Compliance |
| Diversity/Coverage | X |
| Nutrient Uptake | X |
| Invertebrate Studies | X |
| Vertebrate Studies | X |

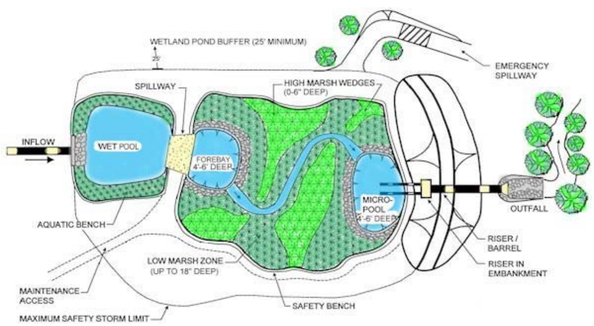
A review of diversity and coverage can help determine which plants thrive better in the environment. Additional plants can be introduced to increase evapotranspiration. Nutrient uptake will help determine plants ability to absorb excess nutrients and which plants are more conducive to nutrient uptake. Invertebrate studies can determine if the toxin levels are increasing or decreasing based on indicator species results. Vertebrate studies should be completed because of the possible effects of animals of eating the vegetation and the potential for tampering with equipment.

## 7.3 BMP Design

In this section specific BMPs are reviewed for the equipment at each monitoring level. For parameters monitored, refer to *Chapter 7.2: Monitoring Methodology*.

***Note:*** There is no specific equipment used for ecological studies; most are conducted by visual inspection and counts.

### 7.3.1 Constructed Wetland




Constructed wetlands are marsh lands developed to treat stormwater runoff (PADEP 2007). There are many different designs that can be incorporated in constructed wetlands such as pocket ponds or stream channels to retain the water. All constructed wetlands incorporate an inlet, sediment forebay and outlet.

**Figure 7.4: Constructed Wetlands (PADEP 2007)**

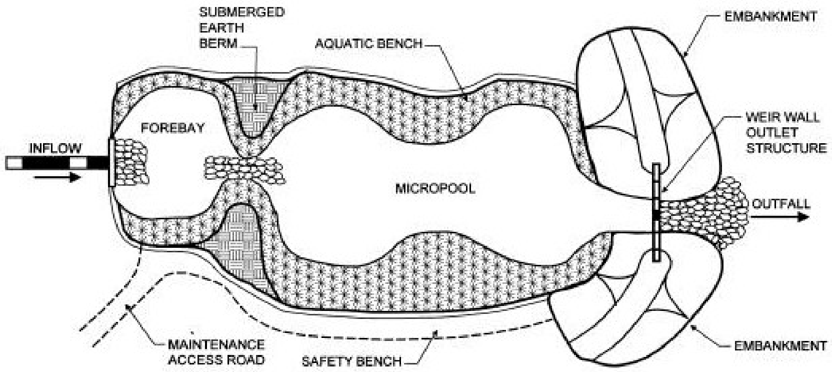
Hydrology and quality are very important to monitor because of continuous baseflow. Ecology should focus on any of the four aspects defined earlier (diversity/coverage, nutrient uptake, invertebrates, and vertebrates.

**Table 7.10: Constructed Wetlands Sampling Equipment**

| Hydrology Sampling | | | |
|---|---|---|---|
| | R-S-U | C-I | R-E |
| Raingage | | | X |
| Staff Gage | | | X |
| Ultra-Sonic Level | | | X |
| Pressure Transducer | | X | X |
| Area/Velocity Bubbler | X | X | X |
| Weir/Orifice | | X | X |
| Reflectometers | | | |
| Quality Sampling | | | |
| | R-S-U | C-I | R-E |
| First Flush | | | |
| Automated Samplers | | X | X |
| Grab Samples | X | X | X |
| Lysimeters | | | |

Because of the amount of land required for constructed wetlands, they are best when placed in planned communities during development. Wetlands tend to develop into a natural ecosystem from all the emergent vegetation.

### 7.3.2 Wet Pond/Retention Basin




Wet ponds are basins with a permanent pool of water fed by urban dry weather flow with the capacity to capture stormwater runoff (Taylor 1999). Components include a sediment forebay and a permanent storage pool.

**Figure 7.5: Wet Pond (PADEP 2007)**

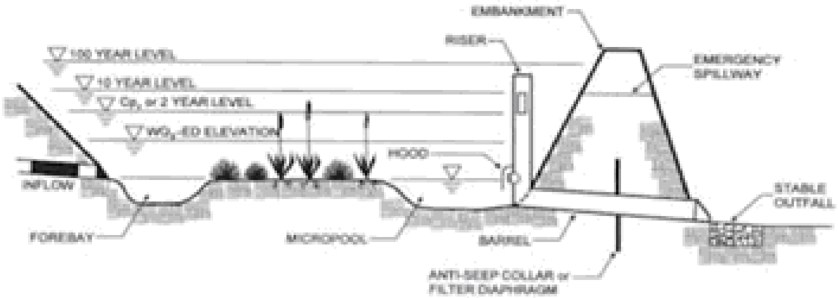
The permanent pool is used for water quality treatment. Ecology is also important because the design usually calls for dense and robust vegetation to surround the wet pond (PADEP 2007). Ecology should focus on any of the four aspects defined earlier (diversity/coverage, nutrient uptake, invertebrates, and vertebrates.

**Table 7.11: Wet Pond Sampling Equipment**

| Hydrology Sampling | | | |
|---|---|---|---|
| | R-S-U | C-I | R-E |
| Raingage | | | X |
| Staff Gage | | | X |
| Ultra-Sonic Level | | | X |
| Pressure Transducer | | X | X |
| Area/Velocity Bubbler | X | X | X |
| Weir/Orifice | | X | X |
| Reflectometers | | | |
| Quality Sampling | | | |
| | R-S-U | C-I | R-E |
| First Flush | | | |
| Automated Samplers | | X | X |
| Grab Samples | X | X | X |
| Lysimeters | | | |

The application of this BMP is dependent on the climate due to the need for a reliable dry weather water supply (Taylor 1999). In some instances it is protected by guardrails or fences because of the permanent pool of water. An ideal application is along highways and freeways with little to no foot traffic.

### 7.3.3 Dry Extended Detention Basin




Dry extended detention basins are depressions of soil used to temporarily store water during a rain event (PADEP 2007). The storage helps reduce flows downstream.

**Figure 7.6: Dry Extended Basin (PADEP 2007)**

The primary function of the detention basin is to retain water. Quality may also be reviewed but is not as significant because containment of water is temporary. Ecology monitoring can be ignored.

**Table 7.12: Dry Extended Basin Sampling Equipment**

| Hydrology Sampling | | | |
|---|---|---|---|
| | R-S-U | C-I | R-E |
| Raingage | | | X |
| Staff Gage | X | X | X |
| Ultra-Sonic Level | | X | X |
| Pressure Transducer | | | X |
| Area/Velocity Bubbler | | | |
| Weir/Orifice | | | X |
| Reflectometers | | | |
| **Quality Sampling** | | | |
| | R-S-U | C-I | R-E |
| First Flush | | | |
| Automated Samplers | | | |
| Grab Samples | X | X | X |
| Lysimeters | | | |

Dry extended detention basins are becoming less popular as other BMPs are being developed. The ideal locations where these basins are still used include commercial and industrial developments.

# Chapter 8: Case Study
## *Pervious Concrete Demonstration Site*

This chapter focuses on a research site completed at Villanova University. This site will be used as an example of how to apply the IMP. At this site, hydrology and water quality were monitored for a volume/peak reduction BMP by infiltration making this a research and educational site.

### 8.1 Overview

The pervious concrete demonstration site was first constructed in the summer of 2002. This BMP replaced a conventional asphalt walkway used for pedestrian traffic. This structure eventually failed due to environmental factors, material inconsistencies, and inadequate finish methods. The site was then reconstructed in the summer of 2003 rectifying many of these issues by changing the design. The redesign featured strips of the pervious media surrounded by traditional concrete crowned to direct runoff towards the strip.

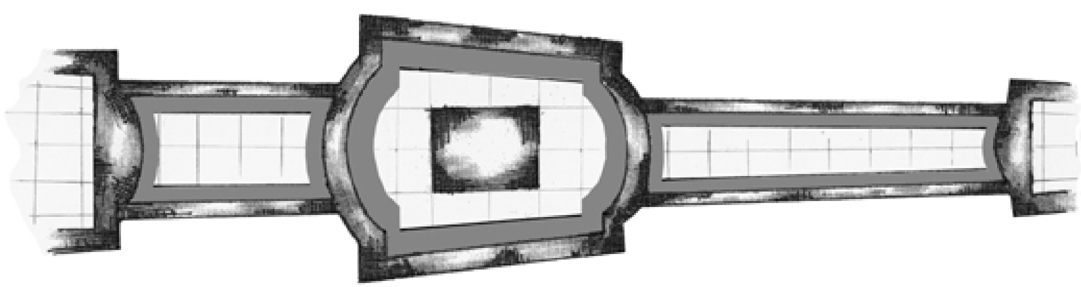


**Figure 8.1: Pervious Concrete Conceptual Design**

Pervious concrete is similar to conventional concrete but lacks fine grain particles, thus creating void space within the finished product. The medium was placed over three rock infiltration beds that are connected to a storm sewer. The basins act as a catch and storage basin for the runoff while allowing for infiltration. As the upper basin reaches maximum capacity, overflow pipes transfer runoff to the next basin. If all basins are filled, excess water would exit the site through an outlet to an adjacent storm sewer.

The site can hold and infiltrate the first two inches of any rain event, before overflow is produced. The purpose of this BMP is to recharge groundwater and maintain baseflow in the first-order streams to which it empties. This is important because the BMPs location is at the extreme headwaters of the watershed.

## 8.2 Instrumentation & Sampling

For the purpose of the case study, a storm on October 24, 2005 which accumulated 1.3 in (0.03 m) of rain was used to define the hydrologic and quality parameters. The storm was selected based on the quality of the hydrology data, the number of quality samples collected and the number of contaminants tested.

### 8.2.1 Hydrology Parameters

The necessary equipment for monitoring a BMP site utilizing pervious concrete is referenced in *Chapter 5.3.2 Table 5.10.* The table is replicated below for ease of review, but does not include quality sampling. For further review of all parameters, please refer back to *Chapter 5.1.1.*

**Table 8.1: Pervious Pavement Hydrology Sampling**

| Hydrology Sampling | | | |
|---|---|---|---|
| | R-S-U | C-I | R-E |
| Raingage | | | X |
| Staff Gage | | | |
| Ultra-Sonic Level | | | |
| Pressure Transducer | X | X | X |
| Area/Velocity Bubbler | | | |
| Weir/Orifice | | X | X |
| Reflectometers | | | X |

***Total Precipitation***

A tipping bucket raingage was installed at the pervious concrete site on the roof of a nearby building. The building is located in close proximity to the site to give a good representation of the amount of precipitation. It was chosen because of its openness to the elements and to avoid any man-made disturbances that may cause inaccurate measures (Braga 2005).

**Figure 8.2: Location of Tipping Bucket Raingage**

The raingage measures precipitation at 5 minute increments on a continuous basis. The data is recorded by a data logger and downloaded weekly. The data is imported into a file for ease of reading. It is converted to total precipitation for a storm event and aids in calculating the runoff entering the BMP.

**Table 8.2: Precipitation Data for Max 1-Hr Intensity from October 24, 2005**

| Time | PC Rainfall (in) |
|---|---|
| 10/24/05 8:25 PM | 0.02 |
| 10/24/05 8:30 PM | 0.01 |
| 10/24/05 8:35 PM | 0.02 |
| 10/24/05 8:40 PM | 0.01 |
| 10/24/05 8:45 PM | 0.02 |
| 10/24/05 8:50 PM | 0.01 |
| 10/24/05 8:55 PM | 0.01 |
| 10/24/05 9:00 PM | 0.01 |
| 10/24/05 9:05 PM | 0.01 |
| 10/24/05 9:10 PM | 0 |
| 10/24/05 9:15 PM | 0.01 |
| 10/24/05 9:20 PM | 0.01 |
| 10/24/05 9:25 PM | 0 |

The data above is an hour of rainfall from October 24, 2005. It is representative of the maximum 1-hr intensity which is the sum of precipitation for an hour with the highest amount of rainfall. “PC rainfall” is the value recorded from the tipping bucket raingage. The max 1-hr intensity for this storm was 0.14 in (0.004 m). For total precipitation, the sum of the entire column of “PC Rainfall” would be calculated from the first recorded data point until there is a span of 24 hours of recorded 0s because of the definition of a storm event. A storm event is a period of precipitation where there is 24 hours of dry before start of rain and after the last recorded precipitation (Traver et. al. 2007).

### *Water Elevation*

Three pressure transducers were installed on the site. The first two were associated with the initial design in 2002. One was mounted upstream of the weir and used to measure the water elevation behind the weir. The weir was placed in the outlet structure housing the overflow drain below the lower infiltration bed. The second was placed in the junction box upstream of the overflow drain at a level equivalent to the lower infiltration bed and measured the water depth within the lower infiltration bed. A third pressure transducer was placed in the upper infiltration bed in 2006 to measure water elevation. The data was used to complete a comparison study of the two beds.

**Figure 8.3 Weir located at the Pervious Concrete Outlet**

Water elevation is measured by pressure heads and recorded every 5 minutes on a continuous basis. The data recorded is sent to a data logger downloaded weekly. The height data was converted into infiltration rates, storage volume and overflow.

**Table 8.3: Water Surface Elevation from October 24, 2005**

| Time | Water Height (in) | Port Depth (in) |
|---|---|---|
| 10/24/05 8:25 PM | 15.46 | 0.240 |
| 10/24/05 8:30 PM | 15.64 | 0.340 |
| 10/24/05 8:35 PM | 15.66 | 0.438 |
| 10/24/05 8:40 PM | 15.65 | 0.534 |
| 10/24/05 8:45 PM | 15.63 | 0.631 |
| 10/24/05 8:50 PM | 15.63 | 0.729 |
| 10/24/05 8:55 PM | 15.61 | 0.824 |
| 10/24/05 9:00 PM | 15.56 | 0.920 |
| 10/24/05 9:05 PM | 15.54 | 0.920 |
| 10/24/05 9:10 PM | 15.52 | 0.967 |
| 10/24/05 9:15 PM | 15.52 | 1.015 |
| 10/24/05 9:20 PM | 15.49 | 1.014 |
| 10/24/05 9:25 PM | 15.48 | 1.062 |

The “water height” measures the water behind the weir with the pressure transducer located upstream of the weir. When the height reaches 18 in (0.46 m), the weir will be overtopped and calculations can be completed for overflow. The “port depth” measures the water depth within the infiltration bed. “Port depth” is recorded from the pressure transducer found in the junction box. Changes in this value can be used to calculate the infiltration rate. The upper bed pressure transducer was not installed at the time of this storm.

### *Soil Moisture Content*

Reflectometers were placed beneath and outside of the lower infiltration bed. The sets were paired off in the north-east and south-west corners. Each set consisted of three Reflectometers which were placed at 1, 2, and 4 ft (0.3, 0.6 and 1.2 m) below the relatively undisturbed soil of the infiltration bed (Kwiatkowski 2004). The Reflectometers were designed to record in situ water content.

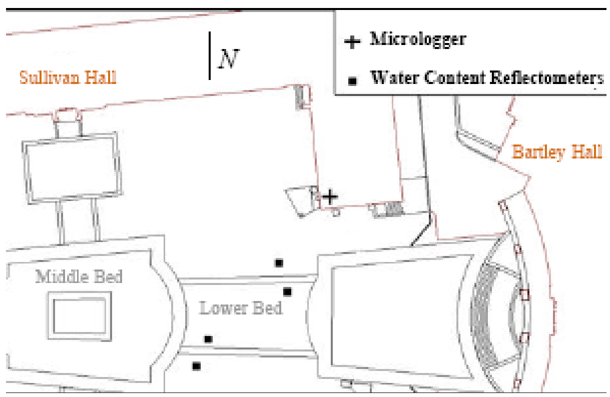



**Figure 8.4: Location of Soil Reflectometers (Kwiatkowski 2004)**

The Reflectometers recorded moisture readings every 15 minutes on a continuous basis. The data recorded is sent to a data logger downloaded weekly. The recorded data was used to monitor the movement of the moisture fronts.

**Table 8.4: Moisture Meter Readings for October 25, 2005**

| Adjusted Time | A11 | A12 | A13 | A21 | A22 | A23 | B11 | B12 | B13 |
|---|---|---|---|---|---|---|---|---|---|
| 10/24/05 8:15 PM | 0.26 | 0.25 | 0.266 | 0.052 | 0.086 | 0.058 | 0.227 | 0.222 | 0.214 |
| 10/24/05 8:30 PM | 0.26 | 0.25 | 0.266 | 0.052 | 0.086 | 0.058 | 0.227 | 0.222 | 0.214 |
| 10/24/05 8:45 PM | 0.26 | 0.25 | 0.266 | 0.052 | 0.086 | 0.058 | 0.227 | 0.222 | 0.214 |
| 10/24/05 9:00 PM | 0.26 | 0.25 | 0.266 | 0.052 | 0.086 | 0.058 | 0.227 | 0.222 | 0.214 |
| 10/24/05 9:15 PM | 0.26 | 0.25 | 0.266 | 0.052 | 0.086 | 0.058 | 0.227 | 0.222 | 0.214 |

The Reflectometers read the volumetric water content. When the values are constant, the soil is 100% saturated and infiltration rate becomes constant. To determine the location of each moisture meter, the moisture meter is assigned a 3 digit combination with the first letter being a letter (A or B) and the second and third as a number (1, 2, or 3). Below is a table to identify what the digits assigned to the moisture meter in question are representing.

**Table 8.5: Defining the Location of Reflectometers**

| | |
|---|---|
| Digit 1 | |
| A | South Set |
| B | North Set |
| Digit 2 | |
| 1 | Inside Bed |
| 2 | Outside Bed |
| Digit 3 | |
| 1 | 1 ft (0.3 m) deep |
| 2 | 2 ft (0.6 m) deep |
| 3 | 4 ft (1.2 m deep) |

### *Infiltration Rate*

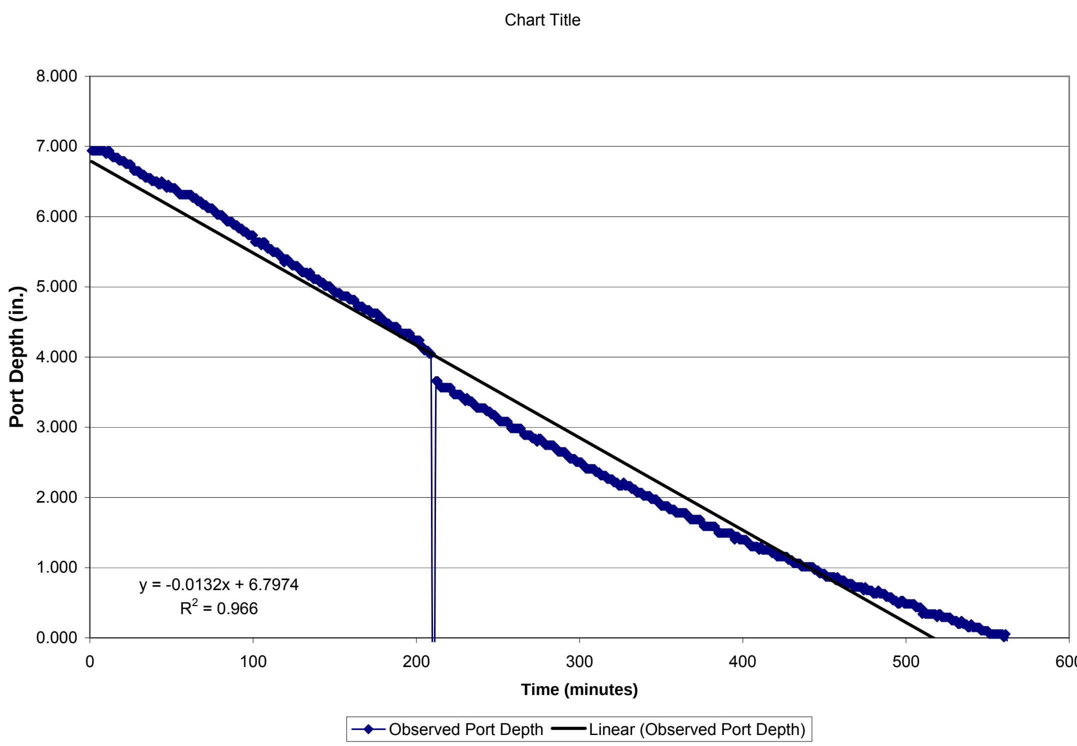



**Figure 8.5 Infiltration Rate for October 25, 2005**

The infiltration rate is the slope of the receding “port depth”. The receding limb was fit with a linear curve. The linear equation was then calculated and the slope recorded. The slope is represented in in/5 min (m/5 min) which is converted to in/hr (m/hr). For this storm, the infiltration rate was 0.07 in/hr (0.002 m/hr).

### *Storage Volume*

**Table 8.6: Lower Infiltration Bed Storage-Volume Calculations**

| Depth (ft) | Area ($ft^2$) | Volume ($ft^3$) | Porosity | Volume ($ft^3$) |
|---|---|---|---|---|
| 0 | 1060.83 | 0 | 0.4 | 0 |
| 0.1 | 1450.97 | 125.59 | 0.4 | 50.24 |
| 0.2 | 1477.68 | 272.02 | 0.4 | 108.81 |
| 0.3 | 1504.65 | 421.14 | 0.4 | 168.46 |
| 0.4 | 1531.83 | 572.96 | 0.4 | 229.18 |
| 0.5 | 1559.27 | 727.52 | 0.4 | 291.01 |
| 0.6 | 1586.94 | 884.83 | 0.4 | 353.93 |

Storage volume within the infiltration bed is predetermined by the area of the bed and the porosity of the stones used. The area of the bed was surveyed before the stone was placed. The porosity of the stone is based on the bed being filled with AASHTO #2 aggregate. With knowledge of the port depth, the storage volume can be calculated. The max depth of the port for this storm was 7.13 in (0.18 m). Therefore from the Storage-Volume Table, the storage volume for this storm was roughly 353.93 cu. ft (10 cu. m).

### *Overflow*

There was no overflow for this storm because the water did not reach a height of 18 in (0.46 m) to overtop the weir.

### 8.2.2 Quality Sampling

The necessary sampling equipment for monitoring a pervious concrete site is referenced in *Chapter 5.3.2 Table 5.10.* The table is replicated below for ease of review, but does not include hydrology sampling. For further review of all parameters, please refer back to *Chapter 5.1.2.*

**Table 8.7: Pervious Pavement Quality Sampling**

| Quality Sampling | | | |
|---|---|---|---|
| | R-S-U | C-I | R-E |
| First Flush | | X | X |
| Automated Samplers | | | |
| Grab Samples | | | |
| Lysimeters | | | X |

### *First Flush*

The pervious concrete housed two first flush samplers. Both were located in the inlet above the upper infiltration bed. The two samplers were labeled “first flush” and “gutter.” The “first flush” sampler collected runoff from the impervious areas above the site. The “gutter” sampler was connected to a downspout which collected runoff from roof top gutters.

**Figure 8.6: Inlet with First Flush and Gutter Sampler**

The samplers were placed prior to a storm when 0.25 in (0.006 m) of precipitation was predicted. They were collected and taken back to the lab, post-storm, to conduct tests for physical parameters, ionic species and total recoverable metals.

### *Lysimeters*

Lysimeters were placed in the northeast and southwest corners of the lower infiltration bed. In the southwest corner, one set was placed beneath the bed and the other at the same depths in an adjacent area. Each of lysimeters within the bed was placed at 1, 2, and 4 ft (0.3, 0.6 and 1.2 m) below the relatively undisturbed soil of the infiltration bed (Kwiatkowski 2004). The lysimeters outside the bed were placed at 8 and 10 ft (2.4 and 3 m) below ground elevation. Currently, only 4 of the 8 lysimeters are in working order. These include the three insides the bed in the northeast corner and one of the comparison samples outside the bed.

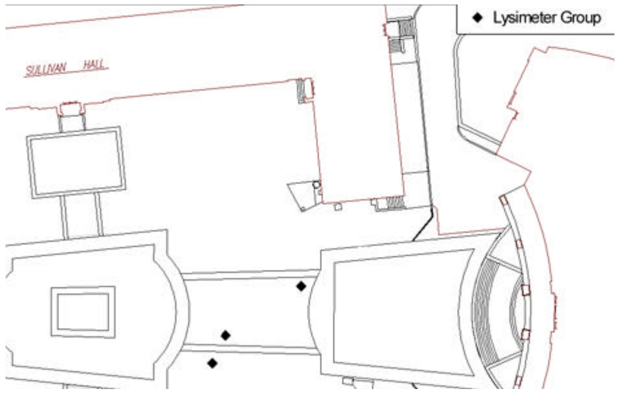



**Figure 8.7: Location of Lysimeters for Pervious Concrete Site**

Vacuum pressure was placed on the lysimeters after 0.1 in (0.003 m) of rain had fallen for a particular event. Suction helped to extract the sample post storm. Samples were sent back to the lab for testing of physical parameters, ionic species and total recoverable metals. To determine the location of each lysimeter, the lysimeter is assigned a 3 digit combination with the first letter being a letter (A or B) and the second and third as a number (1, 2, or 3). Below is a table to identify what the digits assigned to the moisture meter in question are representing.

**Table 8.8: Defining the Location of Lysimeters**

| Digit 1 | |
|---|---|
| A | South Set |
| B | North Set |
| Digit 2 | |
| 1 | Inside Bed |
| 2 | Outside Bed |
| Digit 3 | |
| 1 | 1 ft (0.3 m) deep |
| 2 | 2 ft (0.6 m) deep |
| 3 | 4 ft (1.2 m deep) |

### 8.2.3 Quality Parameters

Quality parameters are based on the primary pollutants found in rain runoff and nearby construction materials. For further review of all parameters, please refer to *Chapter 5.1.3.*

***Physical Parameters***

Physical parameters include pH, conductivity, TSS and TDS. All tests are completed in the water resources laboratory on Villanova University's campus. PH and conductivity are determined with the use of a HACH pH/conductivity probe. TSS/TDS are determined using Standard Methods 2540D.

**Table 8.9: Physical Properties for October 25, 2005**

| Location | pH | Temp. (°C) | Conductivity (μS/cm) | TSS (mg/L) | TDS (mg/L) |
|---|---|---|---|---|---|
| A21 | 7.06 | 14.0 | 591.00 | - | - |
| B11 | 7.25 | 13.8 | 208.00 | - | - |
| B12 | 7.23 | 13.9 | 251.00 | - | - |
| B13 | 7.14 | 13.7 | 150.90 | - | - |
| Gutter FF | 8.04 | 5.6 | 15.20 | 2.3300 | 22.8000 |
| Inlet FF | 7.77 | 3.9 | 37.10 | 261.0000 | 42.4000 |

The location is representative of the samplers referred to in *Chapter 8.2.2.* Conductivity is important in determining if any dilutions need to be completed for other experiments. At the moment, there are no set guidelines for pollutants removal. The PA BMP Manual recommends the removal of 85% of TSS.

### *Nutrients and Ionic Species*

Nutrients and ionic species include total nitrogen, total phosphorus, chloride, nitrite, nitrate, and phosphate. All tests are completed in the water resources laboratory on Villanova University's campus. Total nitrogen and total phosphorus test are completed with a HACH spectrophotometer. Ionic species are determined by a HPLC.

**Table 8.10: Nutrients and Ionic Species for October 25, 2005**

| Location | Total Phosphorous (mg/L $P0_4^{3-}$) | Chloride (mg/L Cl-) | Nitrite (mg/L $NO_2$) | Nitrate (mg/L $NO_3$) | Phosphate (mg/ L $PO_4$) |
|---|---|---|---|---|---|
| A21 | 0.14 | | | | |
| B11 | 0.05 | 10.280 | 0 | 1.2449 | 0 |
| B12 | 0.15 | 8.979 | 0.5833 | 1.5377 | 0 |
| B13 | 0.09 | 8.696 | 0 | 2.3429 | 0 |
| Gutter FF | 0.04 | 1.123 | 0.0804 | 0.3633 | 0.0253 |
| Inlet FF | 0.59 | 2.679 | 0.1302 | 0.2217 | 0.0561 |

The location is representative of the samplers referred to in *Chapter 8.2.2*. Total Nitrogen was not tested because samples from the previous two years were lower than the detection limit of the instrumentation. At the moment, there are no set guidelines for pollutants removal. The PA BMP Manual recommends the removal of 85% of total phosphorus and 30% of nitrate.

### *Total Recoverable Metals*

Total recoverable metals include copper, lead, chromium and zinc. All tests are completed in the water resources laboratory on Villanova University's campus. These tests are performed on a graphite furnace.

**Table 8.11: Total Recoverable Metals for October 25, 2005**

| Location | Copper (μg/L) | Lead (μg/L) | Chromium (μg/L) | Zinc (μg/L) |
|---|---|---|---|---|
| A21 | 1.97 | 0 | 0 | 40.31 |
| B11 | 0 | 0 | 0 | 52.81 |
| B12 | 0 | 0 | 0 | 101.42 |
| B13 | 3.5 | 0 | 0 | 75.03 |
| Gutter FF | | 0 | 0 | 81.97 |
| Inlet FF | 20.2 | 0 | 0 | 95.86 |

The location is representative of the samplers referred to in *Chapter 8.2.2*. Lead and chromium were not detected for this storm. At the moment, there are no set guidelines for pollutants removal. The PA BMP Manual recommends the removal of 85% of total phosphorus and 30% of nitrate.

### 8.2.4 Ecology

Ecology is not applicable to Volume/Peak Reduction by Infiltration BMPs.

## 8.3 Monitoring Methodology

The pervious concrete site was heavily monitored for hydrology and quality. Hydrology monitoring included precipitation, water elevation, moisture content, infiltration rate, storage volume and overflow. Quality was monitored for pH, conductivity, TSS, TDS, chloride, nitrite, nitrate, phosphate, copper, lead, chromium and zinc. A complete database was composed from 2002-2006. In September 2006, data collection was suspended.

### 8.3.1 Residential, Suburban, Urban and Ultra-Urban

#### *Hydrology*

Infiltration rate is needed in determining the effectiveness at a rural, suburban, urban and ultra-urban BMP (review Chapter 5.2.1). Infiltration rate should be reviewed on a seasonal basis and compared yearly. By graphing the points, the seasonal trend and yearly reduction in runoff by infiltration can be determined. If the infiltration starts to decline significantly, the site should undergo maintenance.

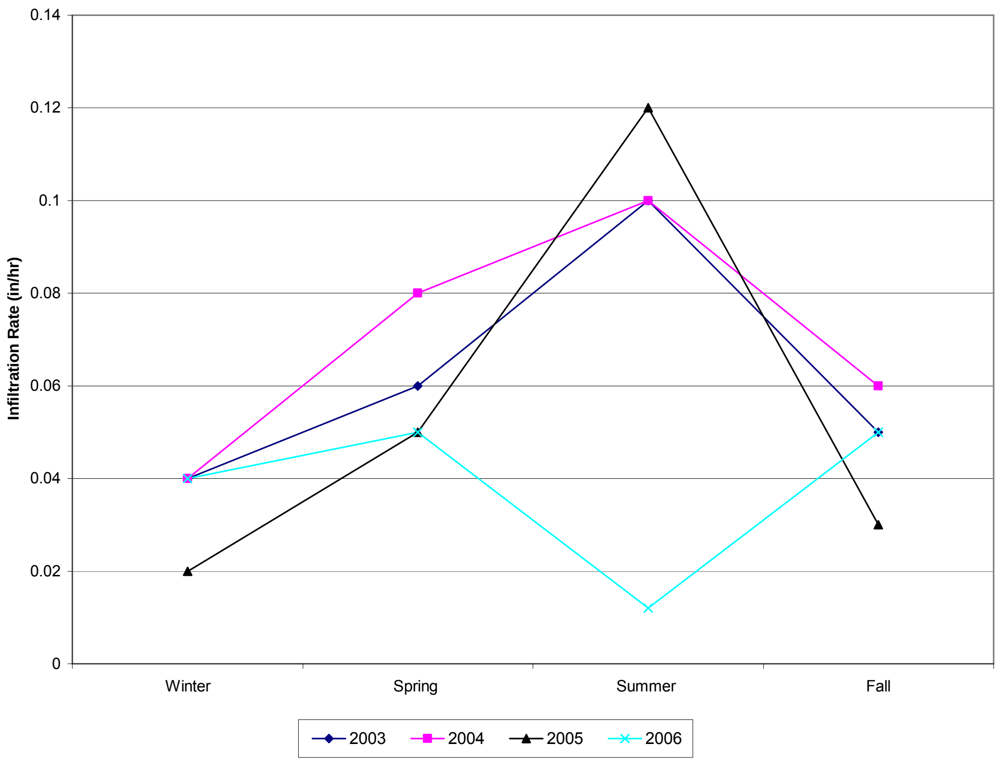



**Figure 8.8: Infiltration Rate for 1 Storm per Season**

A general seasonal trend has been established. There is an increase in infiltration rate during the spring months which peaks during the summer. The rate then begins to decline as fall approaches to its lowest point of about 0.03 in/hr (0.001 m/hr) for winter.

### *Quality*

Quality monitoring is not required for Volume/Peak Reduction by Infiltration BMPs at this monitoring level.

### *Ecology*

Ecology is not applicable to Volume/Peak Reduction by Infiltration BMPs.

## 8.2.2 Commercial and Industrial

### *Hydrology*

Infiltration rates and overflow are important in helping determine if the BMP is effective in reducing volume/peak flow downstream (review Chapter 5.2.1). The data should be collected on a monthly basis and compared yearly. By graphing the points, the monthly trend and yearly reduction in runoff by infiltration can be determined along with the volume of water leaving the site. If the infiltration starts to decline significantly or if overflow volume significantly increases, the site should undergo maintenance

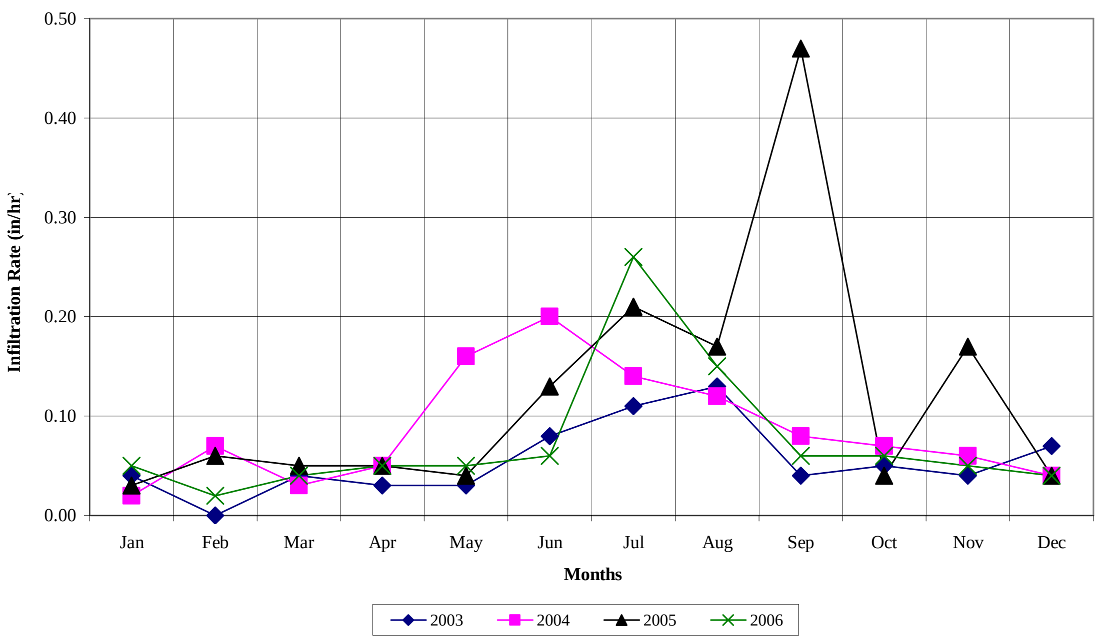



**Figure 8.9: Infiltration Rate for 1 Storm per Month**

Infiltration rate based on a storm a month has a similar trend to a storm a season. The general shape still peaks in the summer and dips in the winter. Therefore it might be necessary to set up a general guideline as to what storm to monitor in a given month. For example, only consider storm events with a period of 7 days of dry before the event.

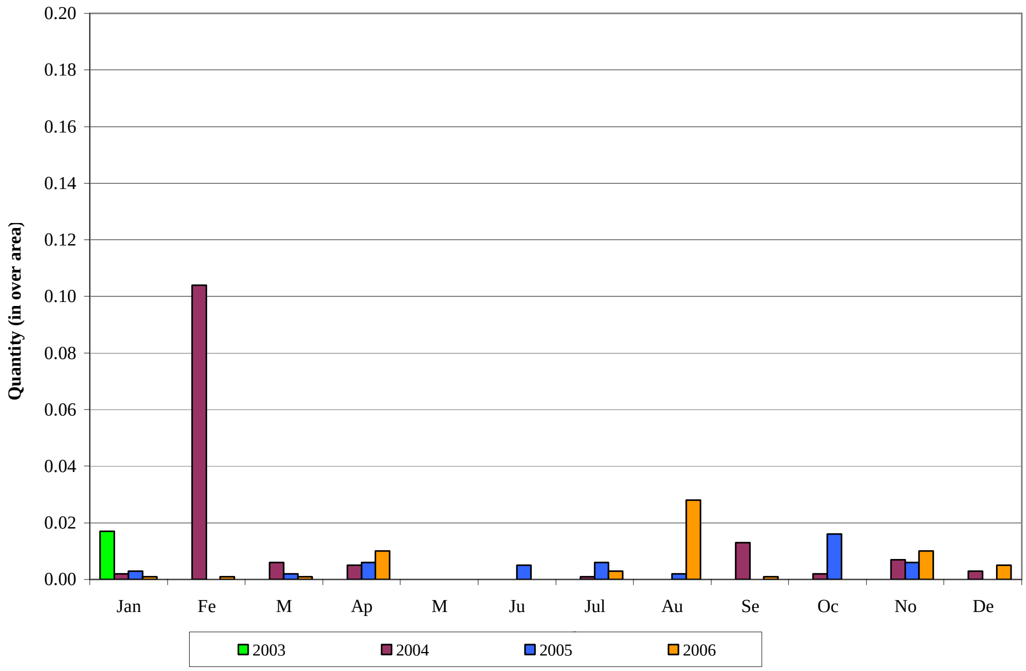



**Figure 8.10: Overflow for 1 Storm per Month**

Overflow is recorded as inches over the drainage area. The drainage area is 1.3 acres (5300 sq. m). Therefore the maximum overflow according to the graph is roughly 470 cu ft. (13.3 cu. m). Overflow is most often associated with short intense storms like summer thunderstorms and long-continuous storms like hurricanes when the infiltration bed does not have time to empty.

These values in the graph represent the median overflow volume per month. The BMP is designed to capture up to 2 in (0.05 m) of runoff. The majority of storms for the region are less than 0.5 in (0.12 m), thus it does not appear to be meeting the design criteria. To determine whether the overflow is representative of the BMP, it may be necessary to set up a general guideline as to what storm to monitor in a given month. For example, only consider storm events with a predicted 1 in (0.025m) of rainfall.

### *Quality*

Physical parameters can provide a firm understanding of the potential for ionic species or total recoverable metals to be circulated in the stormwater (review Chapter 5.2.2). Quality data at this level should be completed on a seasonal basis by first flush sampling and converted to event mean concentrations. The concentrations should be compared to determine if site contamination is increasing.

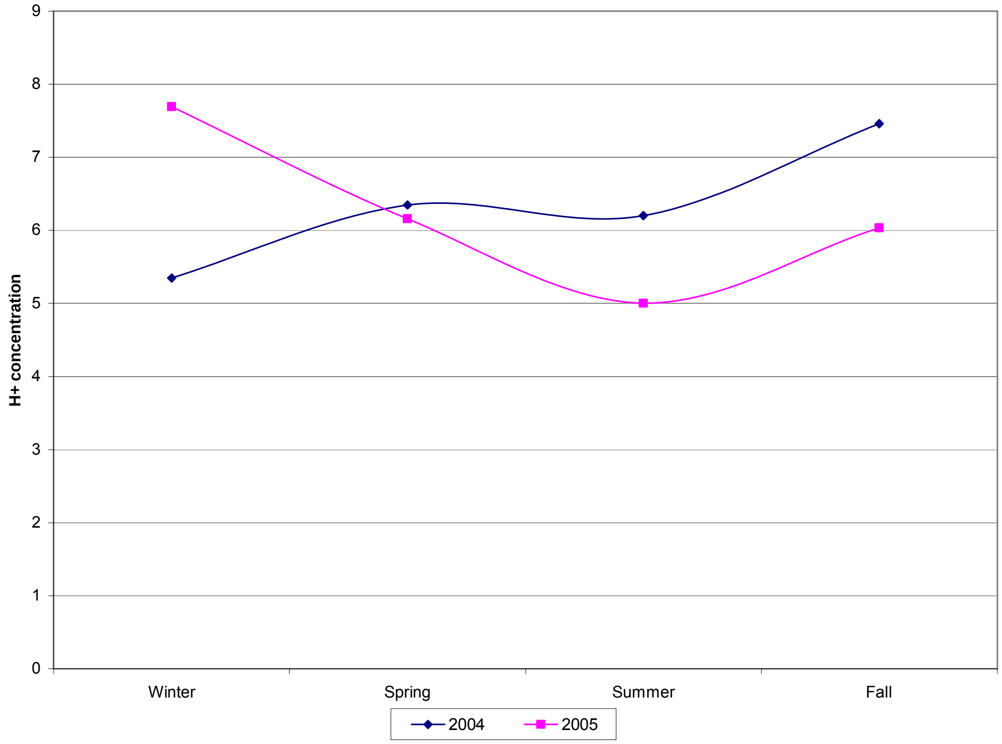



**Figure 8.11: pH concentrations for 1-Storm per Season for 2004-2005**

The pH concentrations were reviewed for a storm per season. The data was only reviewed for 2004 and 2005 because quality data was not complete for the years 2003 or 2006. The value graphed was selected based on the median concentration for each month. PH does not show any discernable patterns. The majority of the data points fall within the standard drinking water range of 6 to 8.5 set out by the EPA.

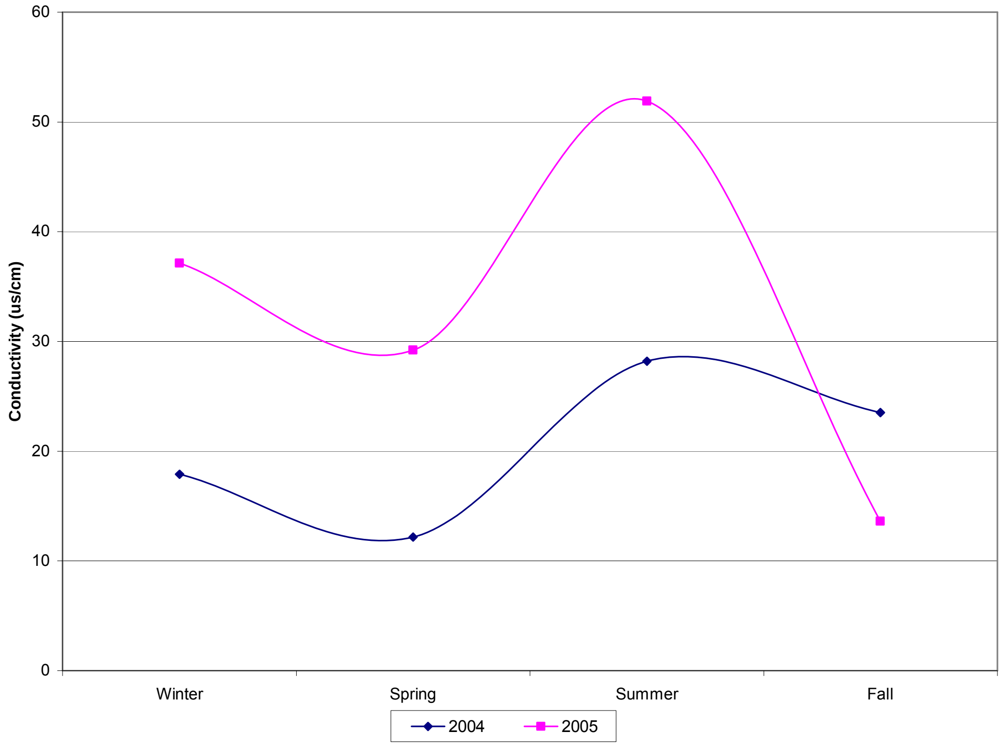



**Figure 8.12: Conductivity for 1-Storm per Season for 2004-2005**

The conductivity was reviewed for a storm per season. The data was only reviewed for 2004 and 2005 because quality data was not complete for the years 2003 or 2006. The value graphed was selected based on the median concentration for each month. Conductivity does not show any discernable patterns.

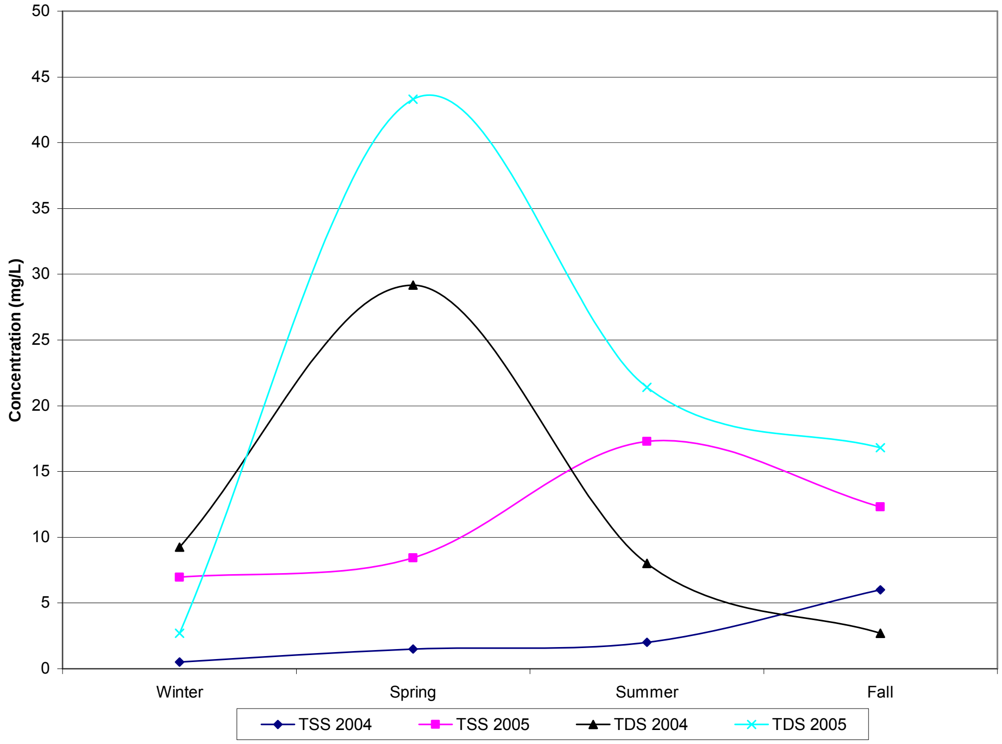



**Figure 8.13: TSS/TDS for 1-Storm per Season for 2004-2005**

TSS and TDS are represented here as event mean concentrations for a storm a season. The data was only reviewed for 2004 and 2005 because quality data was not complete for the years 2003 or 2006. The value graphed was selected based on the median concentration for each month. TSS does not show any discernable patterns. TDS follows a pattern similar to the infiltration rate. The parameter is highest during warmer seasons and significantly lower during the colder climate.

***Ecology***

Ecology is not applicable to Volume/Peak Reduction by Infiltration BMPs.

### 8.2.3 Research and Education

***Hydrology***

Hydrology should be measured for all parameters at a research and educational level of monitoring (review Chapter 5.2.3). The data should be collected for every storm and average should be calculated for monthly and annually comparison. Seasonal and monthly trends should be reviewed for guidance on when maintenance needs to be completed. This data can be used with a computer model to predict peak flows and volumes for various storm events.

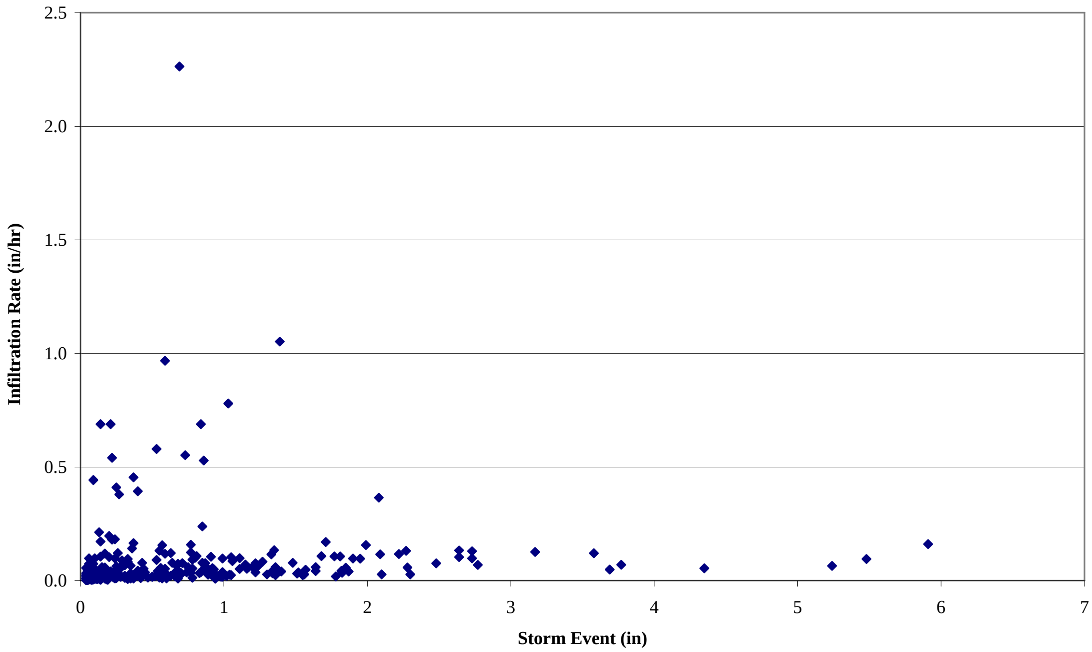



**Figure 8.14: Infiltration Rate for Every Storm from 2003-2006**

The data above is representative for every storm downloaded to the data logger by the pressure transducer located in the junction box. The data collected was converted into infiltration rates which are presented. The infiltration rates for most storms were below 0.1 in/hr (0.003 m/hr). This rate is affected by total precipitation, rainfall intensity, and antecedent dry time which may be determined by a raingage.

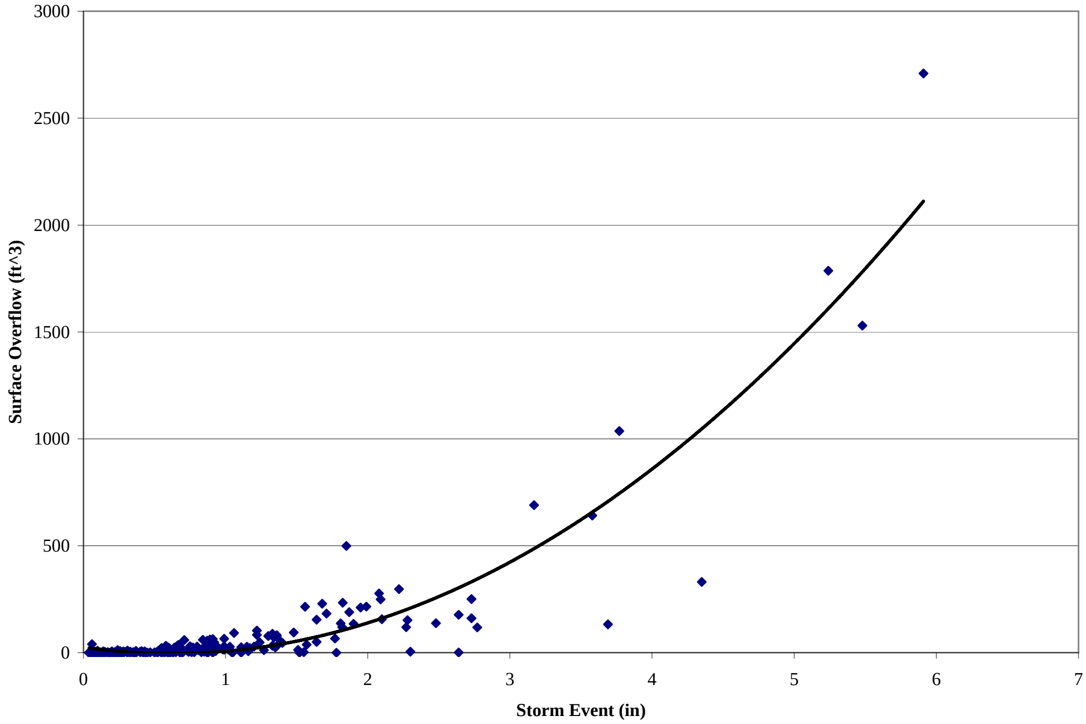



**Figure 8.15: Overflow for Every Storm from 2003-2006**

Overflow is represented for every storm where the water elevation of the pressure transducer behind the weir exceeded 18 in (0.46 m). It is compared to the total precipitation for the event. Overflow volume for the majority of storms was less than 150 cu. ft (4.25 cu. m). The data can be curve fitted to a polynomial function to help predict the amount of runoff for potential storm events.

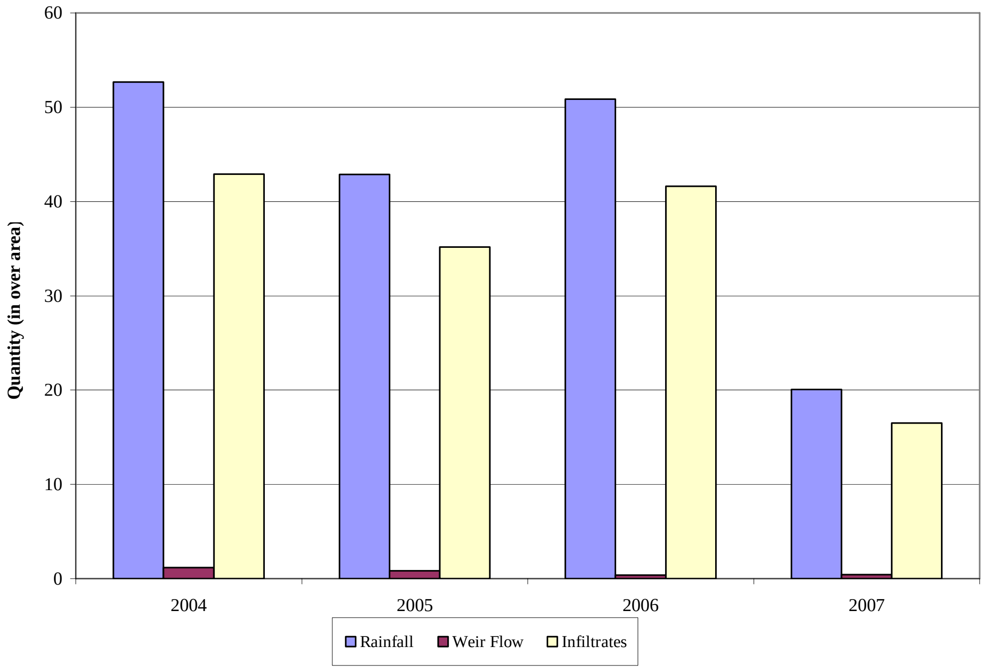



**Figure 8.16: Average Yearly Values of Precipitation, Infiltration, Runoff for 2004-2006**

The volume infiltrating, overflowing (weir flow) and total precipitation can be compared on a bar graph. These values show the overall picture of the BMP to reduce volume and peak flows. The graph above is represented in inches/over the area which can be converted to a volume by multiplying by the drainage area of 1.3 acres (10.2 cu. m).

The values are representative of the overall volume for the years of 2004, 2005 and 2006. The infiltration volume exceeds the overflow by a factor of 100. The BMP is therefore working up to its capability.

### *Quality*

Quality should be measured for all parameters at a research and educational facility. By measuring all parameters, the bigger picture can be reviewed on a site's effectiveness at other locations that may not have the equipment or manpower. Quality should be reviewed for at least one storm a month. This data can be used with a computer model to predict the longevity of the site or when maintenance should be considered.

**Table 8.12: Water Quality Analysis for Lysimeter B11 from 2003-2006**

| Ground Water Analysis (6/03 - 09/06) | | | Concentration (mg/l) | | | | | |
|---|---|---|---|---|---|---|---|---|
| (B11) | | | Quartiles | | | | | |
| Water Quantity | | # Storms | 25% | 50% | 75% | Min | Max | Med |
| Ph | | 52 | 6.705 | 6.91 | 7.103 | 5.93 | 7.68 | 6.91 |
| Conductivity (µS/cm) | | 53 | 206 | 240.67 | 319 | 5.43 | 3876.67 | 240.67 |
| Total Nitrogen (mg/l) | 2.0 mg/l | 29 | 0.8 | 1.1 | 2.0 | 0.1 | 3.6 | 1.11 |
| Nitrite as Total N (mg/l) | 0.1 mg/l | 21 | 0.334 | 0.473 | 1.052 | 0.000 | 46.570 | 4.137 |
| Nitrate as Total N (mg/l) | 0.1 mg/l | 28 | 1.186 | 2.579 | 6.138 | 0.110 | 95.010 | 7.382 |
| Total Phosphorous (mg/l) | 0.015 mg/l | 48 | 0.100 | 0.200 | 0.390 | 0.000 | 0.770 | 0.2 |
| Ortho-Phosphate (mg/l) | 0.1 mg/l | 7 | 0.000 | 0.000 | 0.000 | 0.000 | 0.040 | 0.035 |
| Copper (µg/l) | 1.7 µg/l | 39 | 0.260 | 3.830 | 10.560 | 0.000 | 35.200 | 8.98 |
| Lead (µg/l) | 5.4 µg/l | 17 | 0.045 | 1.270 | 5.363 | 0.000 | 173.570 | 1.27 |
| Chromium (µg/l) | 7.2 µg/l | 13 | 0.000 | 0.970 | 4.620 | 0.000 | 30.490 | 4.2 |
| Zinc (µg/l) | 8.6 µg/l | 15 | 47.303 | 71.745 | 125.155 | 4.500 | 190.450 | 83.821 |
| Chloride (mg/l) | 0.1 mg/l | 33 | 6.130 | 11.200 | 61.230 | 2.220 | 1190.100 | 79.85 |

Lysimeter B11 was a north lysimeter found inside the bed at a depth of 1 ft (0.3 m) below the stone basin. The table represents 55 storms recorded from 2003-2006 for physical parameters, nutrients, ionic species and total recoverable metals.

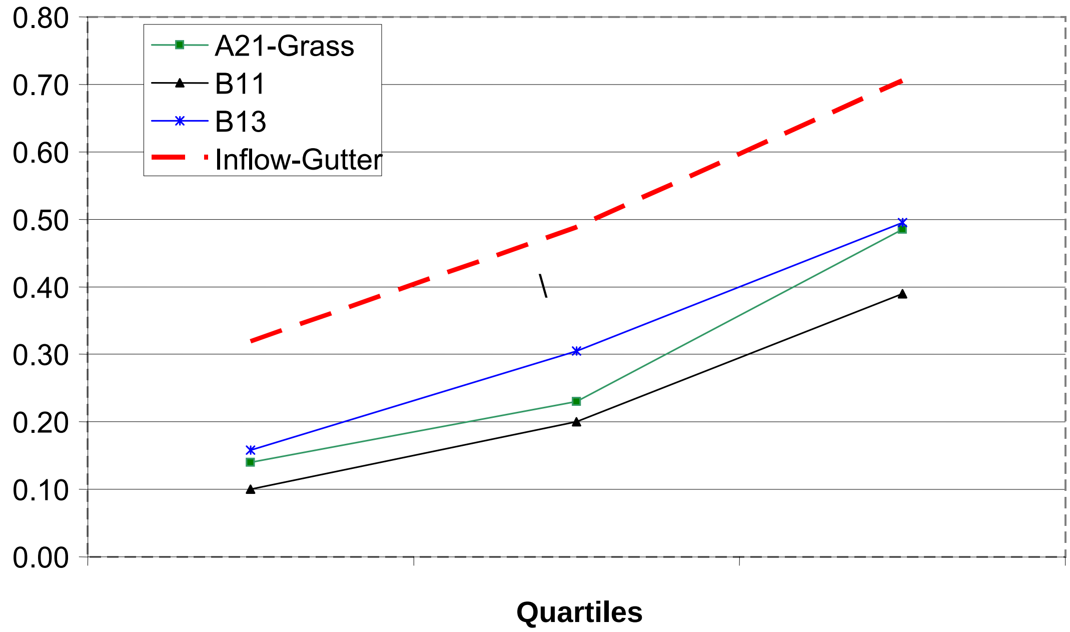



**Figure 8.17: Total Phosphorus Quartiles for 55 Storms during 2003-2006**

The data can be placed in tabular form as above or represented in graphical form. The graphical form helps to visualize the level of contaminants as runoff or after infiltration through various media.

The first flush samplers are directly connected to runoff and have the highest level of total phosphorus. The lysimeters below the infiltration bed (B11 and B13) have lower concentrations than the first flush sampler and therefore are acting to remove nutrients. The lower of the two lysimeters (B13) concentration however increases meaning the soil beneath the bed must consist of some organic matter. The lysimeter A21 was a control used to compare the water infiltrating through natural means. It was located at the same depth as lysimeter B11 and the results fell between the concentrations of the lysimeters beneath the bed.

### *Ecology*

Ecology is not applicable to Volume/Peak Reduction by Infiltration BMPs.

# CONCLUSION

# D. Villanova University's Stormwater Demonstration Park

Villanova University is on the cutting edge for monitoring BMPs. The university currently houses a demonstration park of 8 BMPs. Each BMP has undergone a different level of monitoring with some falling into the Residential, Sub-urban, and Ultra-Urban methodology or the Commercial and Industrial methodology.

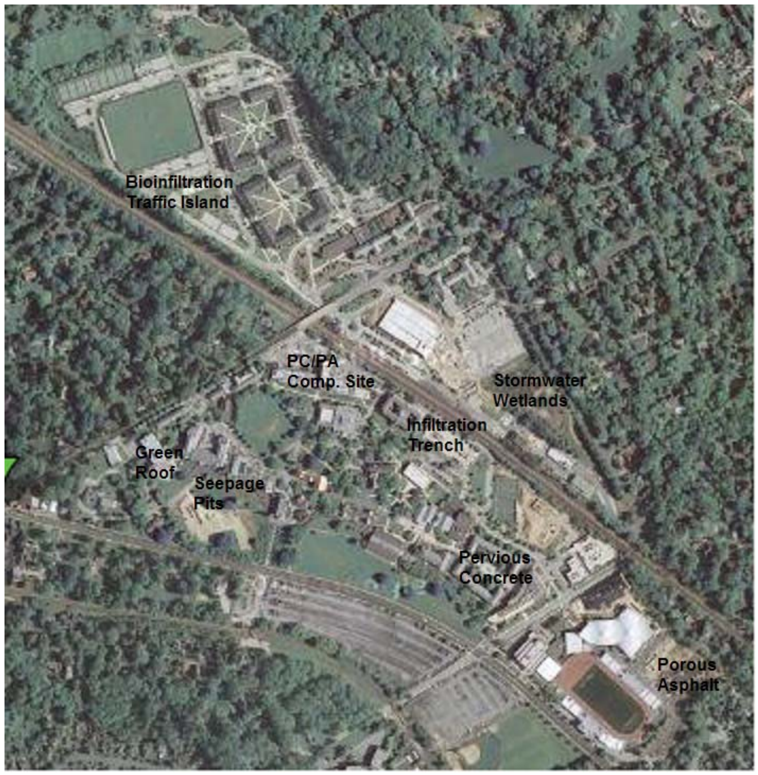



**Figure D.1: Villanova University Stormwater Demonstration Park**

Seven of the eight BMPs are reviewed in this chapter. The pervious concrete demonstration park was ignored because it was used as a Case Study within the IMP. Details on the parameters measured, and the equipment used are provided.

## D.1 Stormwater Wetland

The stormwater wetland is a water runoff quality/peak rate control BMP. It is a retrofit of an existing detention basin constructed in 2000. The construction included meanders and gravel berms to increase travel time. A sediment forebay was also installed to assist in the re-sedimentation process, while wetland plants were added to increase nutrient uptake (Rea 2004).

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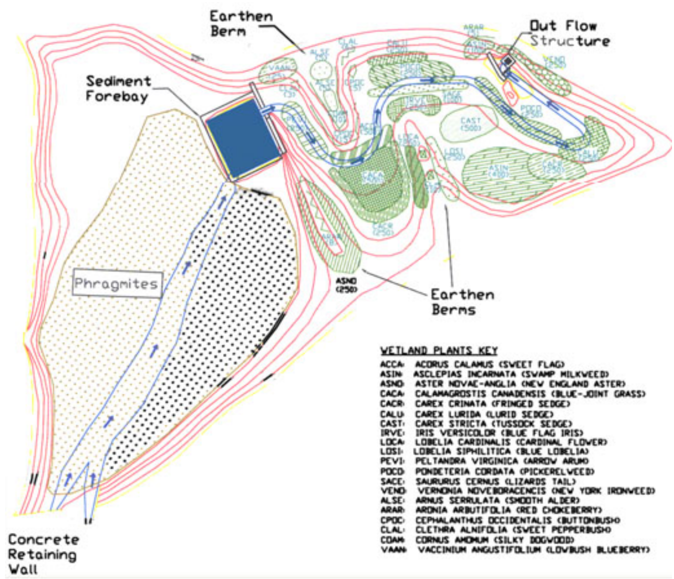


**Figure D.2: Stormwater Wetland Design**

The purpose of the wetlands is to treat runoff in a medium priority degraded watershed whose flows impact a high priority stream. The goal is to modify the flow of water into a two-stage release during low flows via meanders, gravel berms and forebays. The larger storm outflow is not compromised.

### D.1.1 Instrumentation & Sampling

#### *Hydrology*

The stormwater wetland is equipped with three area/velocity bubblers, an ultra-sonic level detector, and a tipping bucket raingage. The area/velocity bubbler monitors continuous velocities at the two inlets (main and west) and outlet pipe. The level detector is in the sediment forebay and is used to accurately measure water depths. The raingage is located at the inlet west.

Data is collected electronically at 5 minute increments. The data collected is downloaded once a week from the three data loggers on site. Data recording has been continuous throughout the life of the stormwater wetlands. Continuous data has been recorded since August of 2006. All other data has been collected periodically from spring 2004 to summer 2006.

***Quality***

Water quality sampling has been reintroduced to the site as of September 2007. Previous sampling was completed via grab samples and only completed during times of baseflow. Presently, there are three automated samplers set up to collect 12 continuous samples at set time intervals. The automated samplers are located at the inlet, sediment forebay and outlet. Each sample is tested for physical parameters, nutrients and ionic species.

Storms are collected based on a standard sampling policy. The sampling policy is to collect when 0.25 inches is predicted with no rain in greater than 0.25 inches in the previous 48 hours. The goal is to collect 3 storms per season and 12 in a 1 year period.

### D.1.2 Monitoring Methodology

The stormwater wetland during the past was monitored at the commercial and industrial level. Recently with an increase in manpower, the hydrology and water quality monitoring programs have increased to a research and educational level. The ecology monitoring is still lacking, but is slated to commence in 2009.

## D.2 Bio-Infiltration Traffic Island

An existing traffic island was converted into a bio-infiltration BMP. A bio-infiltration BMP is similar to a bio-retention basin or rain garden and is categorized as a volume/peak rate reduction by Bio-Infiltration BMP. Constructed in 2001, the BMP is designed to capture runoff and deliver it to a basin where the flow is cleansed or infiltrated (Heasom 2006). Water that exceeds the volume of the basin flows over a weir exiting through a storm sewer.

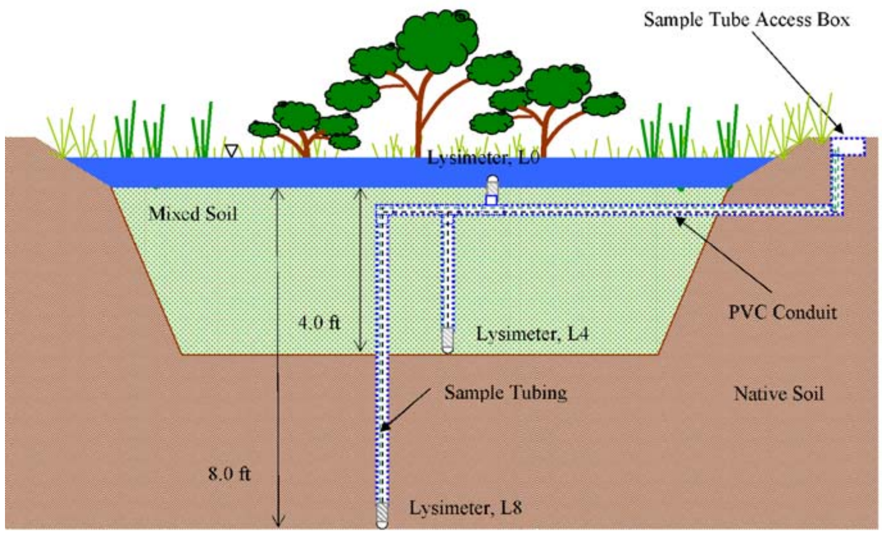


**Figure D.3: Bio-Infiltration Traffic Island Subsurface Monitoring**

The system is designed to capture a significant amount of yearly runoff and recharge the groundwater system. Overflow peaks and volume are reduced. With small storms, discharge may even be eliminated.

### D.2.1 Instrumentation & Sampling

#### *Hydrology*

The bioinfiltration traffic island is equipped with a raingage, V-notch weir, Ultrasonic level sensor, three reflectometers, and pressure transducer. The V-notch weir is located in the inlet box along with a pressure transducer to measure flow. The ultrasonic level sensor is in the basin and used to measure the height of the water. The reflectometers are located at 2, 4, and 8 ft (0.6, 1.2, 2.4 m) beneath the storage basin.

The data is all collected and stored in an equipment box. All data is collected in five minute time intervals. Data collection is done once a week and the records date back to the inception of the site in fall 2002.

### *Quality*

Water quality samples have been collected on site since its inception in fall 2002. Surface and sub-surface samples are collected and analyzed for physical parameters, nutrients, ionic species and total recoverable metals. Surface samples include two first flush samples cut into the curb and two grab samples taken during and after rainfall. Sub-surface samples are collected from three lysimeters at depths of 0, 4, and 8 ft (0, 1.2, 2.4 m) below the basin.

Collection is completed on a storm by storm basis. The same sampling procedure as stated for the Stormwater Wetlands is followed. On average, 20 storms are collected a year.

## D.2.2 Monitoring Methodology

The bio-infiltration traffic island is heavily monitored for hydrology and water quality and therefore falls under the research and educational category. However, ecologic monitoring has not been included in the past. This aspect is set to be added in upcoming months.

## D.3 Infiltration Trench

The infiltration trench is a form of volume/peak reduction by infiltration bmp. Designed and constructed in 2004, it reduces the runoff produced by an impervious parking garage and moves the flow through a series of PVC pipes to a storage unit. Inside the storage unit, debris and sediments have time to settle while flow continues through to a perforated pipe leading to a stone bed. At the stone bed, the water is retained and slowly seeps back into the soil and groundwater system. Water that can not be stored in the bed or storage unit, releases to a stormwater drainage pipe or percolates up through pervious pavers.

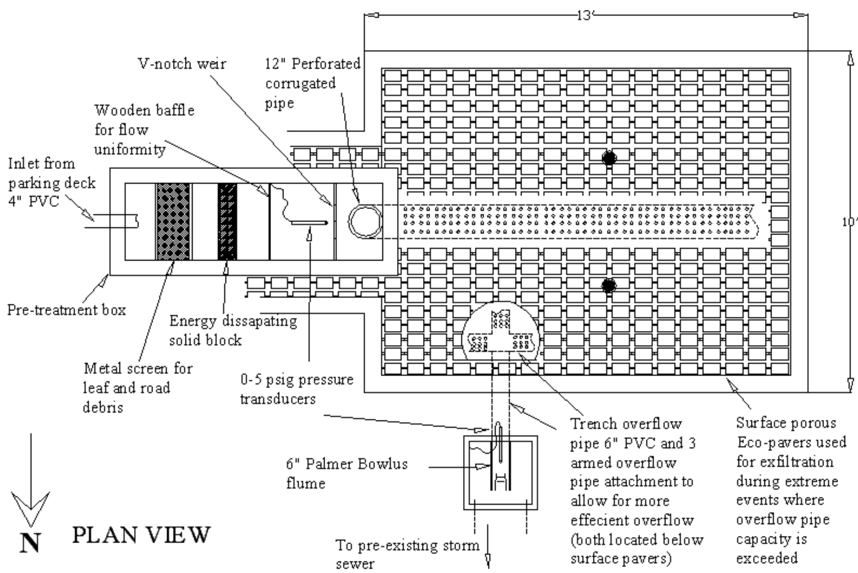


**Figure D.4: Infiltration Trench Technical Drawing**

The purpose of the infiltration trench is to help better manage water resources to slow down stream bank erosion and better maintain baseflow in first order streams. The goal is to see how effectively the BMP can reduce the volume of runoff for the impervious surface.

### D.3.1 Instrumentation & Sampling

#### *Hydrology*

The infiltration trench is equipped with a tipping bucket raingage, three pressure transducers, a V-notch weir, and a Palmer Bowlus flume. The raingage can be found on the roof of the parking garage. A monitoring bench houses the pressure transducer and V-notch weir used to measure inflow. The flume location is in the outlet storm sewer before a second pressure transducer to determine the outflow. A third pressure transducer is located in an observation well measuring the water depth within the rock bed.

A data logger is used to download and store the readings from the raingage, and pressure transducers. The readings are taken every minute from all equipment. The data is downloaded once a week through a dial up modem.

### *Quality*

Water quality samples have been reviewed and modified at this site to produce more accurate results. The samples however, are still tested for the same parameters which are physical properties, nutrients, ionic species and total recoverable metals. Lysimeters at 2 and 4 ft (0.6 and 1.2 m) below the trench are sampled as they were at the inception of the site. Surface samples have changed from a grab sample during the storm to an automated sampler that collects every 0.25 inch of rain from the storms inception. An automated sampler was also setup to collect a composite outflow.

The infiltration trench follows the same procedures as the Stormwater wetlands for collection. The goal at the trench is to collect 20 storms a year.

## D.3.2 Monitoring Methodology

Since the inception of the site, the infiltration trench has been monitored for hydrology and quality. Although the monitoring equipment has changed and/or increased, it has only helped to make the BMP measurements more accurate. Therefore it would be characterized as a research and educational level of monitoring.

## D.4 Pervious Asphalt

The asphalt site is a volume/peak rate reduction BMP. It replaced a gravel parking lot and grass drainage swale in 2006. The addition of the medium over an existing retention basin helps to meet runoff regulations promulgated by the state and localities. The medium allows water to pass through unlike traditional asphalt.

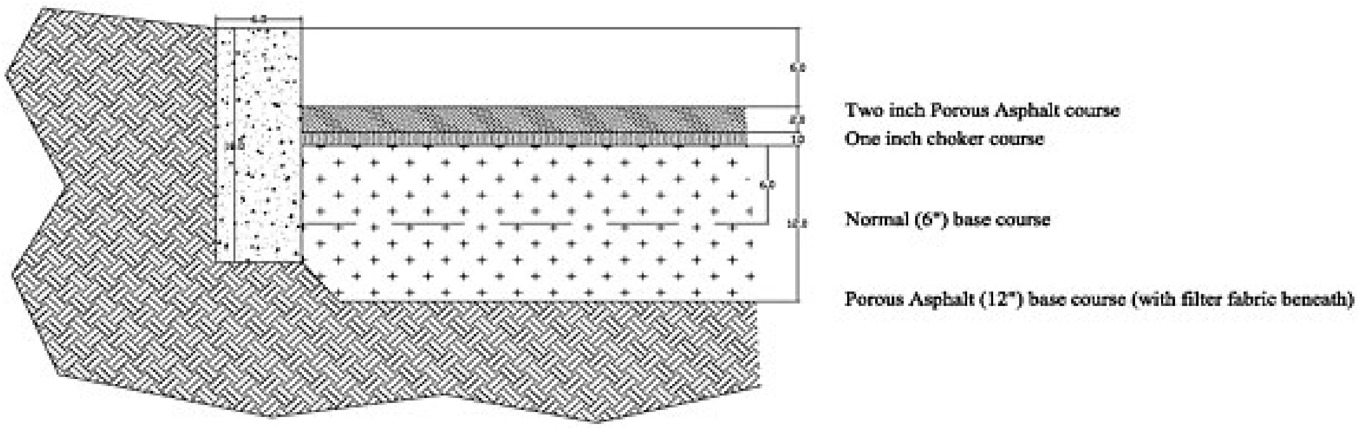


**Figure D.5: Pervious Asphalt Plan View**

The purpose of pervious asphalt is to alleviate stress on a stream by reducing the amount of runoff from impervious surfaces. The asphalt, in conjunction with a crushed gravel infiltration bed helps water infiltrate back into the groundwater system.

### D.4.1 Instrumentation & Sampling

#### *Hydrology*

The site is equipped with a pressure transducer to monitor depth within the infiltration bed. It is located in a storm drain found at the center of the BMP. The water elevation is measured in 5 minute increments and downloaded through a direct laptop connection once a month. The data was reviewed for the 6 months post construction, but monitoring has ceased.

### D.4.2 Monitoring Methodology

The pervious asphalt site was funded by the university and not by a grant. Monitoring on site was instituted at first, but pulled because of the lack of funds. Therefore the site is monitored at a rural, suburban, urban and ultra-urban level.

## D.5 Green Roof

The green roof is a volume/peak rate reduction BMP. It replaced a traditionally finished roof in 2006. Above the traditional layer is a waterproofing layer followed by an insulation layer. The insulation is then covered over by a geosynthetic which serves to provide drainage pathways for stormwater flow, which is then covered over by a filter fabric. The filter fabric allows the passage of water, but traps small particles used as the growth medium to avoid clogging the drainage void space.

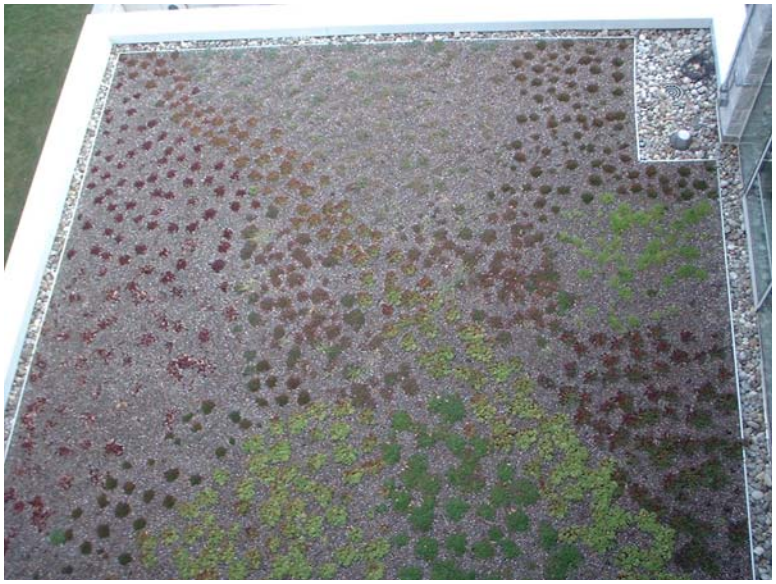

**Figure D.6: Green Roof**

A green roof is a very practical design for most urban settings, if the ultimate goal is to reduce stormwater runoff. There are many environmental advantages to a green roof as well. The roof shields the traditional roof from harmful UV rays and other weather effects thus increasing the lifespan. The design helps to trap heat inside during the cold winter months while keeping radiant roof temperatures from heating a building in the summer.

### D.5.1 Instrumentation & Sampling

#### *Hydrology*

The green roof is outfitted with a flow meter, soil temperature sensors, air temperature sensor and a tipping bucket raingage. The flow meter is located at the outflow pipe and is used to measure the volume of runoff. Temperature sensors are located on the original roof surface and ground surface to measure insulation effects.

All equipment is connected to a data logger. Temperature is recorded at 5 minute intervals. Flow is recorded at minute intervals. The data is collected on a weekly basis. Data records for this site began in fall of 2007.

### D.5.2 Monitoring Methodology

The green roof monitoring is on a residential, sub-urban, urban and ultra-urban platform. This is because it only incorporates hydrology monitoring that is consistent with a research and education level. The site is open for future investigations on quality and ecology that may raise it up to a different monitoring level.

## D.6 Seepage Pits

The Seepage Pits are volume/peak rate reduction by infiltration BMPs. These pits were built some time around the turn of the $20^{th}$ century. Two of the pits have since been converted into culverts while two remain active. The active pits are brick cylinders with sand bottoms over sandy-silt.

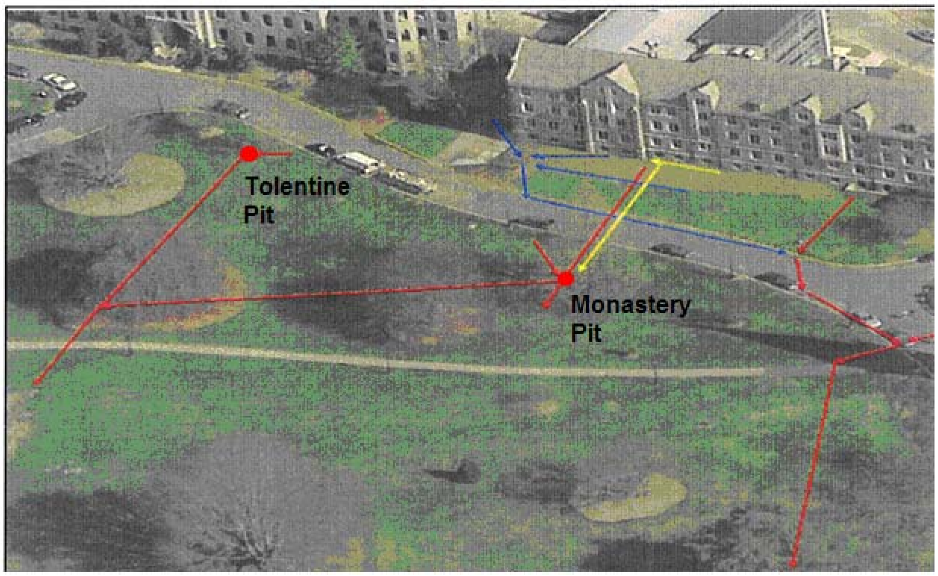


**Figure D.7: Seepage Pits (Gore 2007)**

The purpose of this site is to provide knowledge of the effects of development on infiltration performance BMPs built prior to their design. The site under properly working conditions should continue to recharge groundwater, preserve baseflow in streams and minimize erosion and flooding.

### D.6.1 Instrumentation & Sampling

#### *Hydrology*

The Tolentine Seepage Pit is equipped with a pressure transducer. The sensor reads the drop in water height at the base of the 14 foot pit used to determine the rate of infiltration.

The sensor takes readings every 5 minutes. The data is collected monthly by going out to the field and connecting a laptop to the system. The results are downloaded into a file providing readable water depths and temperatures. Limited data is available because the data was collected for 4 months for a research project in 2007. The site is no longer monitored.

### D.6.2 Monitoring Methodology

The seepage pits are a rare BMP because the rural, suburban, urban and ultra urban, and the commercial and industrial BMP levels of monitoring are the same. The research and educational BMP is not that much different. At present, it is monitored at the rural, suburban, urban and ultra urban level because the data recovered is minimal.

## D.7 Pervious Concrete/Pervious asphalt Comparison Study

The pervious concrete/pervious asphalt comparison is a volume/peak rate reduction by infiltration. The site, constructed in 2007, replaced a traditional asphalt parking lot. The site consists of 2 equally sized and instrumented test sites. Each site is underlain by an infiltration bed before being covered with the permeable pavement. To determine accurate measurements, the two pavements are separated by an impervious barrier.

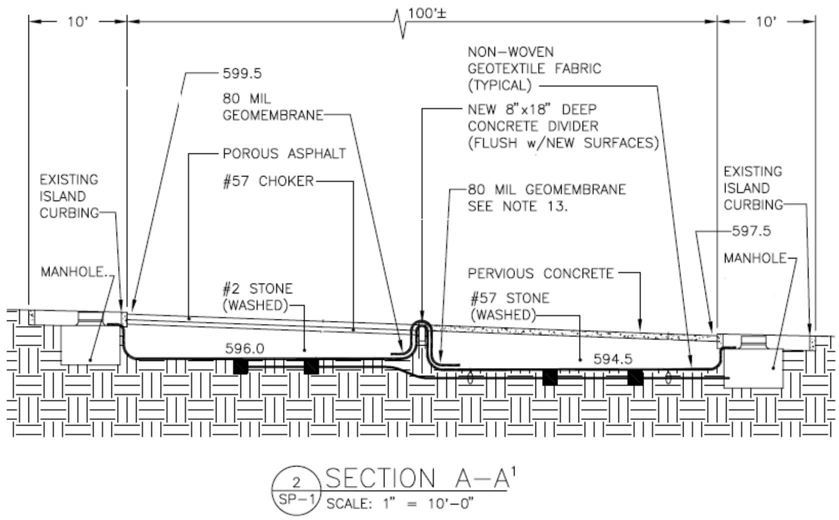


**Figure D.8: Pervious Concrete/Pervious Asphalt Plan View**

The purpose of permeable pavement is to alleviate stress on a stream by reducing the amount of runoff from impervious surfaces. It is designed to recharge groundwater flows and maintain baseflow conditions in the stormwater wetlands.

### D.7.1 Instrumentation & Sampling

#### *Hydrology*

The site is equipped with pressure transducers located at inlets directly connected to the infiltration beds. The water surface elevation is monitored to determine infiltration rates and flow. Precipitation data is collected from a nearby raingage that is part of a weather station maintained by the Villanova Astronomy department.

Water surface elevation is downloaded every 5 minutes. The data is collected weekly by going out to the field and connecting a laptop to the system. The results are downloaded into an excel file providing readable water depths and temperatures. Data collection started in November 2007.

***Quality***

Quality samples are collected through first flush samplers and lysimeters. They are analyzed for physical parameters, nutrients, ionic species and total recoverable metals. There are four first flush samplers with two for each pervious media located at the upper perimeter of the site. Lysimeters are placed beneath the two infiltration beds at 6 inch intervals.

The pervious concrete/pervious asphalt follows the same procedures as the Stormwater wetlands for collection. The goal at this site is to collect 20 storms a year.

### D.7.2 Monitoring Methodology

The pervious concrete/pervious asphalt comparison study is monitored at a research and educational level. It is heavily outfitted with hydrological and water quality equipment. The idea behind it is to show the differences between the two pervious media’s over a period of time.

# E. Conclusions & Recommendations

## E.1 Conclusions

The following is a list of conclusions and observations based on the findings the completed IMP:

- The IMP is meant to be a supplement to the PA BMP Manual or any other structural BMP guidance set out by federal, state or local government. It is not meant to replace these documents; nor does it discuss construction or maintenance of the BMP.

- Water elevation for any BMP with a ponded zone is the most important parameter. By knowing this parameter, recharge, peak flow and volume can be calculated.

- TSS is a good indicator of the amount of nutrients, ionic species and dissolved metals held in suspension. By knowing the percent TSS removal, the effectiveness of quality improvement can be defined.

- Research, suburban, urban and ultra urban BMPs effectiveness can be determined through hydrology monitoring. For these BMPs, the main goal is to combat the increase of runoff caused by impervious areas.

- Commercial and industrial BMPs effectiveness is based on hydrology and quality. Percent removal of pollutants is a goal for monitoring these BMPs.

- Research and educational BMPs are operated to define the variables needed to monitor other classes of BMPs. The sites monitored define, implement and evaluate BMP performance on the most extensive level.

## E.2 Recommendations

The following is a list of recommendations made based on the findings of the completed IMP:

- Instrumentation and sampling equipment should be incorporated in the design of a BMP. It is more economical and time efficient to place these devices during construction.

- Instrumentation and sampling equipment should be placed in easy to access locations. This allows for ease of data collection, maintenance and calibration of equipment.

- If the resources are available, the monitoring method for a particular application should be enhanced. If there is a known contaminant on site; the contaminant should be monitored.

- The decision to use a specific BMP should not be based on the IMP alone. For information regarding potential application and design criteria, refer to the PA BMP Manual.

### E.3 Future of the IMP

The following are suggestions for future development of the IMP:

- A basic procedure was included in the IMP for determining quality parameters. A supplementary document could be produced to better explain and/or introduce other test for the same contaminants.
- Hydrology and quality have been heavily monitored, but ecology monitoring is lacking. Ecological research should be conducted and expanded on.
- With a complete database of hydrology and quality values, a comparison study should be conducted to determine the longevity of BMPs and include any necessary maintenance.

In summary, the IMP reviews the instrumentation and sampling necessary to complete hydrology, quality and ecological monitoring on BMPs. Different applications require different levels of monitoring based on economics and labor. The IMP defines these monitoring methods and the required equipment or parameters necessary to define effectiveness. Effectiveness is important in helping meet the water quality regulations set by the EPA and state mandates.

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