CHARACTERIZATION STUDY OF A BIO-INFILTRATION STORMWATER BMP

A Thesis

Presented to

The Faculty of the Department of Civil and Environmental Engineering

Villanova University

In Partial Fullfillment

Of the Requirements for the Degree of

Master of Civil Engineering

By

Jordan R. Ermilio

October 2005

CHARACTERIZATION STUDY OF A BIO-INFILTRATION STORMWATER BMP

By

Jordan F. Ermilio

October 2005

Ronald A. Chadderton, Ph.D., P.E. Faculty Advisor, Chairman, Department Of Civil and Environmental Engineering	Date
Robert G. Traver, Ph.D., P.E., D.WRE Faculty Reader, Department of Civil and Environmental Engineering	Date
Barry C. Johnson, Ph.D., P.E. Dean, College of Engineering	Date

Acknowledgements

I would like to express my utmost respect and appreciation to the Civil and Environmental Engineering Department at Villanova University for assisting with this work. Dr. Robert Traver designed and implemented this research project by providing his expertise and knowledge on stormwater best management practices. Sincere thanks to Dr. Ronald Chadderton who has provided detailed oversight on this project and who has been incredibly generous with his time. Special thanks to Clay Emerson and Erica Tokarz for their assistance with data collection, modeling, laboratory analysis and for their friendship. I would also like to thank Erica Dean, Andrea Braga, Gregg Woodruff, Bill Heason and Mike Horst for their friendship and assistance with sampling and analysis.

Finally, I would like to thank my wife and family for all of their guidance. To my parents for their moral support and encouragement, to my brother for his perspective on life and to my wife for her love, thank you for everything you are.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

1.1 Site History

The Villanova Urban Stormwater Partnership (VUSP) constructed a Bio-Infiltration Traffic Island Best Management Practice (TI BMP) in August of 2001. This site was retrofit from an existing traffic Island with support from the Pennsylvania Department of Environment Protection's (PADEP) Growing Greener Grant Program. An amount was awarded from PADEP and was matched with funding from Villanova University for the development of this site to demonstrate stormwater management techniques and for research purposes.

The PADEP Growing Greener Grant was awarded in May of 2001. Excavation and construction at the site began in August of 2001 (Figure 1.1). Immediately after site development, there was little opportunity to monitor rainfall events due to a drought which occurred in the summer of 2001. In fact, some of the first events monitored at this site were snowmelt events in January of 2002. During the spring of 2002, monitoring equipment including an ultrasonic sensor, pressure transducers and a tipping bucket rain gauge was installed on site and detailed monitoring of hydraulic parameters began.

In December of 2002 a V-notch weir was installed at the outflow and a computer model was created using Hydraulic Engineering Center's Hydrologic Modeling System (HEC-HMS). This model was developed, calibrated and used to predict long-term effectiveness of this BMP. It was also incorporated into a thesis in May 2003 (Prokop, 2003).

Figure 1.1: Construction Photograph; August 9, 2001 (Prokop, 2003).

Additional monitoring equipment was installed in July of 2003 and included soil moisture meters to investigate saturated conditions in the sub-surface of the infiltration basin. These meters were installed at average depths of 2.0, 4.0 and 8.0 feet below the bottom of the basin surface. At this time, the pressure transducers were removed from the site because the wells in which they were installed were not filling with water and, thus, the readings were inaccurate. In October of 2003, water quality sampling and analysis began when two soil moisture suction lysimeters were installed at depths of 4.0 and 8.0 feet below the bottom of the basin surface. Figure 1.2 details the location of the samplers and monitoring equipment as originally installed in the fall of 2003. This diagram is not

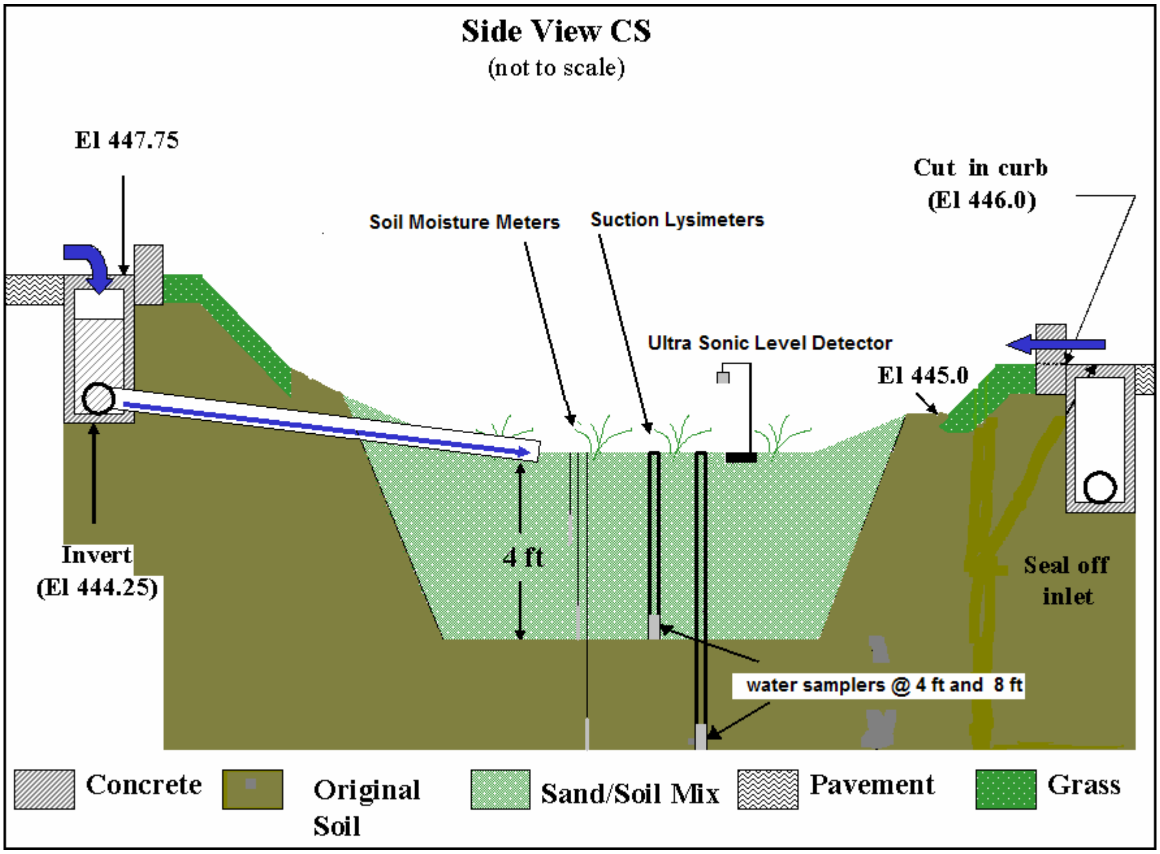


Figure 1.2: Location of Sampling and Monitoring Equipment, October 2003

to scale and does not display the sampling tubes or the electrical lines which were routed off site through PVC conduit. These lines are directed to a locked data collection box which provides easy access.

In December of 2003 a quality assurance and quality control plan was developed to establish sampling protocol. This protocol changed a number of times over the course of the study in order to establish more accurate data collection and analysis. Thus, the available data from this site is dependent on both sampling and laboratory procedures which varied during the study. Chapter 3 of this document details changes made to these procedures.

At the present time, research continues at this site to monitor long-term water quality and quantity parameters. This site continues to operate as a stormwater BMP demonstration site, incorporated into the VUSP stormwater BMP demonstration park along with three other sites; a stormwater wetlands, porous concrete infiltration BMP and an infiltration trench BMP. Additionally, the VUSP Bio-infiltration BMP Traffic Island is a member of the ASCE/EPA National Stormwater BMP Monitoring database and continues to contribute to the research efforts of this organization.

Table A.1 in Appendix A details the site history profile from August of 2001 to April of 2005.

1.2 Site Location

The VUSP Bio-infiltration Traffic Island BMP is located in southeastern Pennsylvania within the Darby Creek sub basin of the Darby – Cobbs Watershed. Located on Villanova University's west campus apartment complex, this 1.21 acre site drains an access road servicing light traffic, a parking facility, and has some recreational land use. Figure 1.3 identifies the project area within the West Campus Complex of Villanova University. This figure shows the drainage area, land use and percent cover for impervious and pervious surfaces.

The study area drains directly into a small unnamed stream which leads to Ithan and then to Darby Creek. This area represents the uppermost headwaters of the Darby – Cobbs Watershed. Figure 1.4 shows the site location within the Darby – Cobbs Watershed.

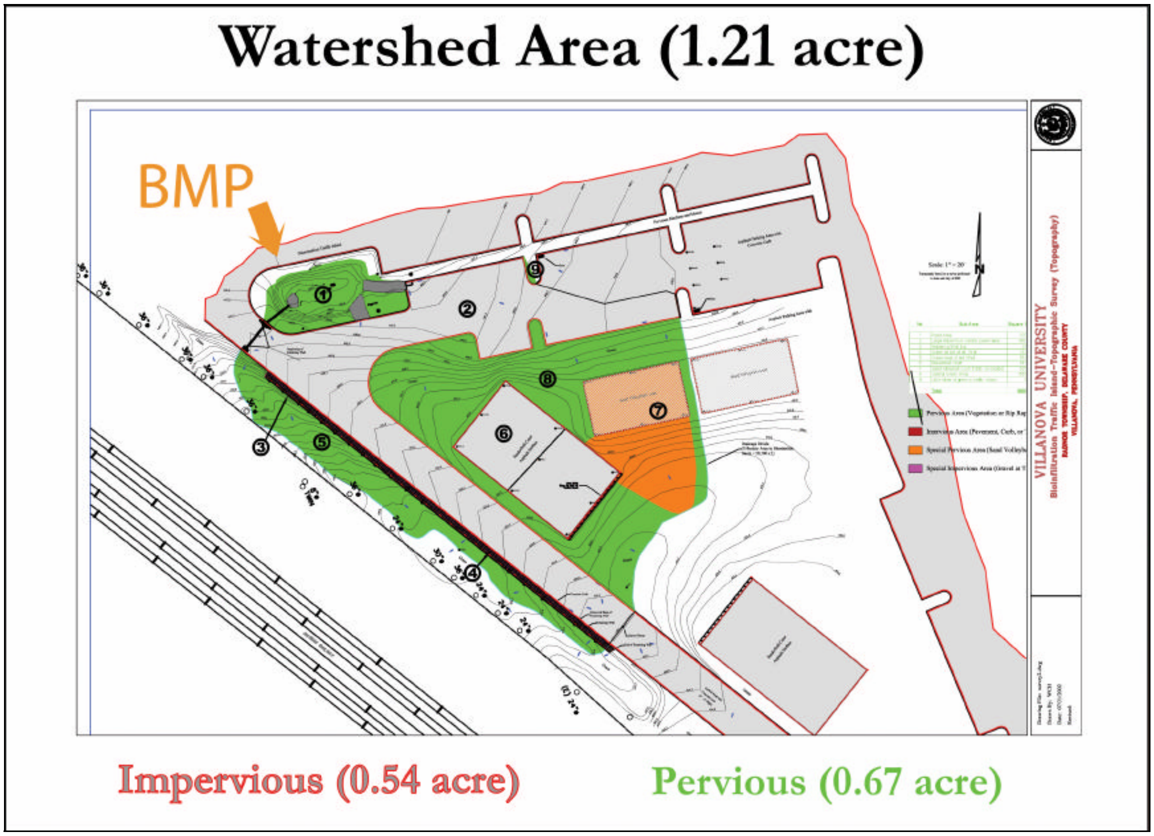


Figure 1.3: BMP Location, Villanova University West Campus Apartment Complex (Heason, 2003).

The Darby – Cobbs watershed is composed of three sub-basins; Cobbs Creek, Darby Creek and Tinicum. The entire watershed is defined as the land area which drains into Darby Creek at the Delaware Estuary and it includes approximately 80 square miles (PWD, 2003). It can be seen in this figure that the VUSP Bio-infiltration BMP is located just along the Delaware – Montgomery County boundary.

The Darby – Cobbs watershed lies within the Coastal Plain and Piedmont physiographic provinces. The geology of this area includes gneiss, schist and serpentine formations. Soils include primarily loams and silty loams.

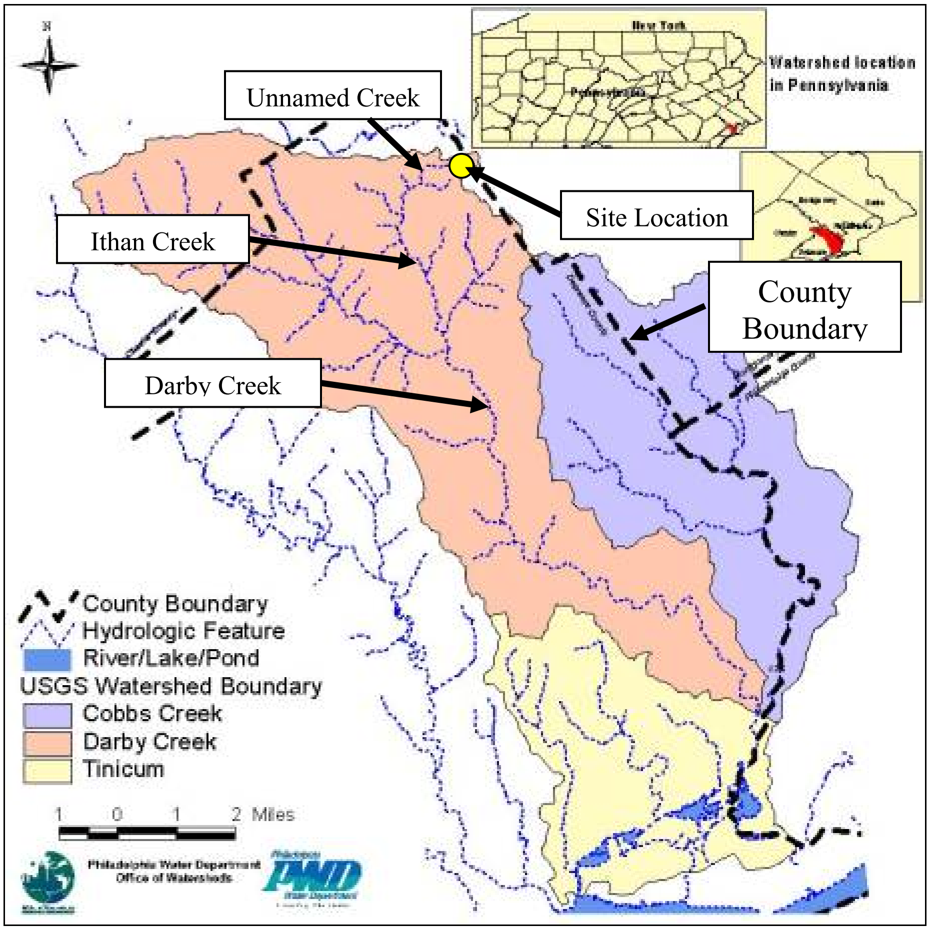


Figure 1.4: Site Location within the Darby-Cobbs Watershed (PWD, 2003).

The demographics of the study area are difficult to define due to the nature of a university setting. The study area is classified as institutional and is a residential area for students who come from middle to high income families. The area surrounding the university is suburban and has a relatively low population density of 3 – 5 people per acre (2000 census). The study area is approximately 50 % impervious cover which compares to 38.7 % impervious cover for the Delaware County portion of the Darby – Cobbs Watershed.

1.3 Design and Construction

The Bio-infiltration Traffic Island BMP was retrofit from an existing Traffic Island on Villanova University's West Campus Apartment Complex in August 2001. This BMP drains stormwater runoff from an impervious access road, parking area and a basketball court. These impervious surfaces include approximately 19,567 square feet (1,817.8 sq. meters) or 0.449 acres (0.182 ha) of land area. An additional 31,087 square feet (2,888.1 sq. meters) or 0.714 acres (0.289 ha) of this drainage area is composed of pervious surfaces such as grass, sand and small foliage (Heasom, survey 2002).

This BMP was designed to retain one inch of precipitation from the drainage area. This means that a total volume of 1.0 inch per acre (2.54 cm/ha) or 3,630 cubic feet per acre (102.8 cubic meters / ha) of runoff is retained within the basin at this site during a rainfall event. Figure 1.5 shows the design parameters used in determining the storage volume for this site. With a total drainage area of 50,654 square feet (4,705.9 sq. meters) and a design target of 1.0 inches (2.54 cm) this BMP is designed to retain a total volume of 4,221 cubic feet (119.5 cu. Meters).

From a site survey conducted in August of 2002, it was determined that the total surface water storage in the basin is 2,250 cubic feet. The additional storage availability within the void space of the backfill material is 2,065 cubic feet and, the total available BMP storage volume is 4,315 cubic feet. Note that this determination of 4,315 cubic feet does not include initial abstractions from within the drainage area nor does it include infiltration outflow from the basin during an event. Another parameter which affects BMP performance includes the soil moisture conditions within the drainage area prior to a precipitation event which may limit the available void space during an event.

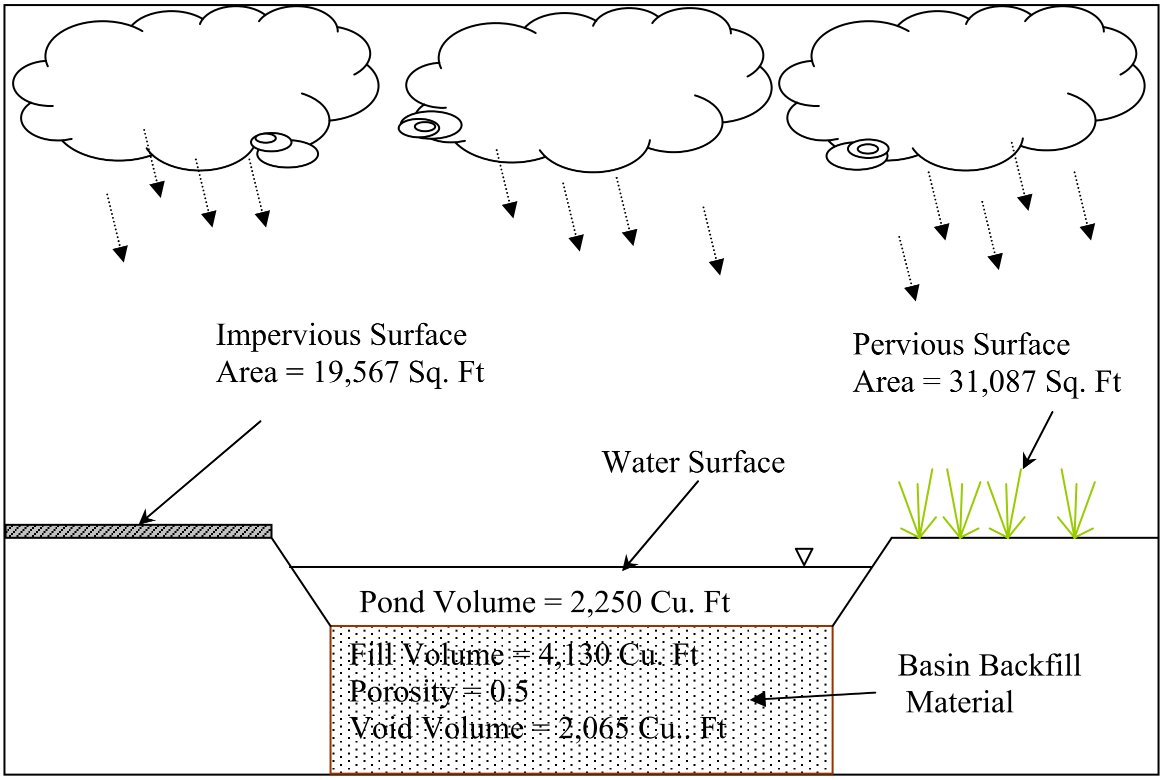
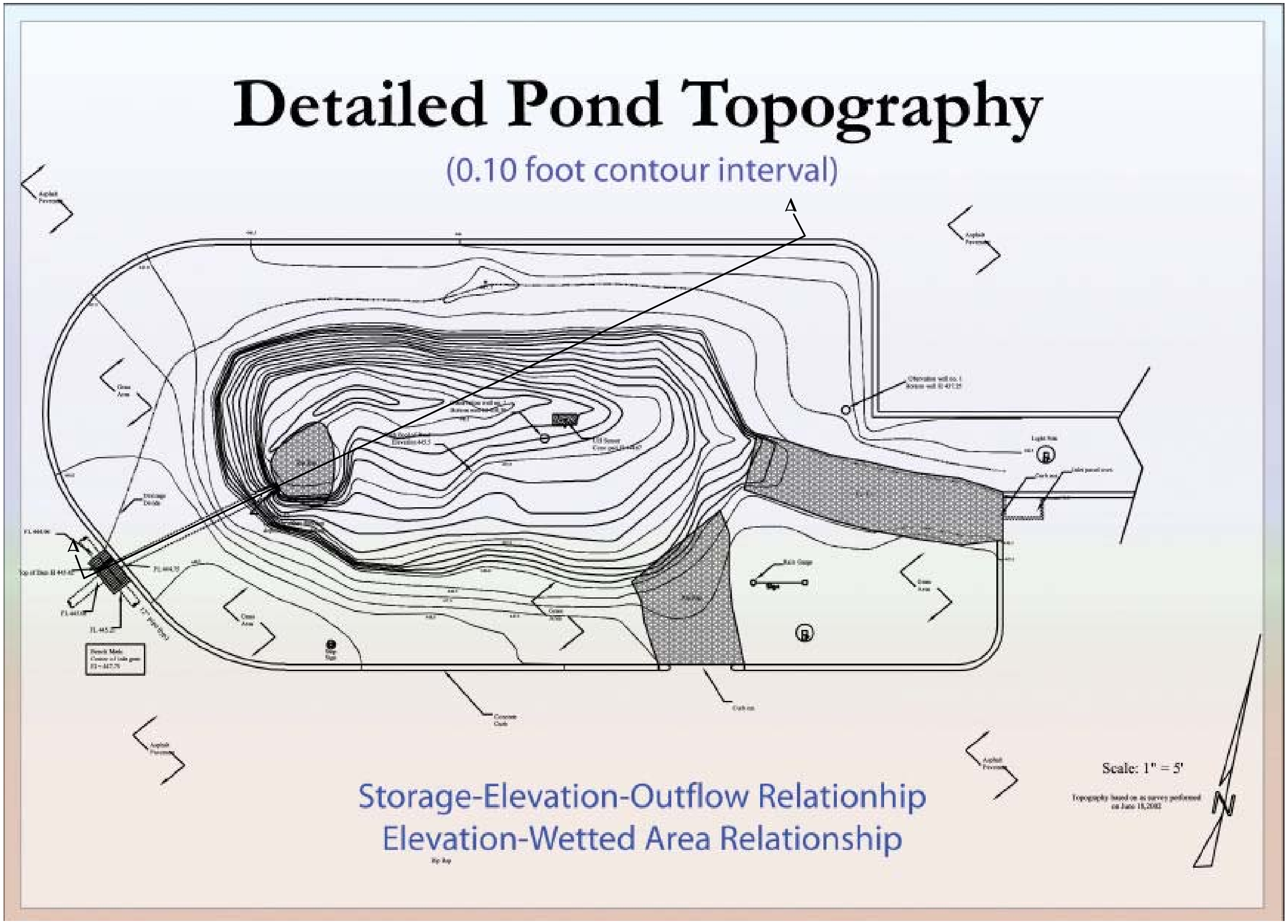


Figure 1.5: Preliminary Design Calculations; Storage Volume

Stormwater runoff enters the TI BMP from three locations (Figure 1.6). Two curb-cuts located in the northern and eastern portion of the BMP collect direct runoff from a parking area and an access road, respectively. The third inlet collects water from a storm drain and culvert system. This inlet was modified from its original design to divert runoff from an existing roadside drainage system and into the Traffic Island BMP. This third inlet located on the southern-most portion of the BMP also serves as an overflow during larger storm events. Using simple principles of gravity flow, once the surface level of the water in the basin reaches an elevation of 445.2 feet ASL, flow in the third inlet changes direction. This elevation of 445.2 feet equates to depth of 1.72 feet of water in the basin. When this water level is reached in the basin, an overflow event has occurred and any additional inflow to the site (minus infiltration) bypasses the BMP and continues down the original stormwater drainage system. Any overflow from the BMP is considered outflow and enters a detention basin which is designed to mitigate larger precipitation events for flood control purposes. Figure 1.6 details the plan view of the TI BMP along with the three inlet structures. Figure 1.2 depicts cross section A-A (from Figure 1.6) and, shows elevation levels of various locations within the BMP. The lowest elevation in the basin is 444.0 feet ASL (135.3 m). Figure 1.2 shows that runoff enters the site from the northern curb cut at an elevation of 446.0 feet (135.9 m) and fills the basin from 444.0 feet (135.3 m). Once water in the basin rises to an elevation of 445.2 feet (135.7 m), runoff water flows up the drain pipe at the south end and, out of the BMP. Since the elevation of the outlet overflow is below that of the curb cut, runoff will never collect in the curb area, but will flow out of the system through the inverted drainpipe.

Appendix A.2 illustrates the construction techniques used in development of this site photographically. The construction techniques for developing this site entailed excavating the existing area to a depth of 6.0 feet (Photo 1). The original soil which was classified as ML using the Unified Classification System was then mixed with a sandy soil classified as SP (Photo 2). Using ASTM D248 classification method, the final backfill material of 1:1 ML to SP mix was determined to be an SP class soil (Prokop, 2003). The combined stormwater inlet and overflow was then installed at a depth of 2 feet below the original ground surface level (Photo 3). Backfill material was then placed into the excavated area to a depth of 4.0 feet (Photo 4). Vegetations were planted and a thin layer of mulch was placed on the surface of the fill material and around the plantings. Finally, equipment was installed at the site for monitoring water quantity parameters (Photo 5).

The plants used in developing this site were chosen based on their ability to survive prolonged wet and dry conditions in sandy soil types. Thus, the plants used are commonly found in coastal areas within the tri-state area (Leeds, 2003). Included in the plantings at this site are grasses such as American Beach Grass, Coastal Panic Grass and Switch Grass. Also included are woody plants, such as Black Chokeberry, Goundset Tree, Winterberry, Marsh Elder and Beach Plum.



Detailed Pond Topography

(0.10 foot contour interval)

Storage-Elevation-Outflow Relationhip

Elevation-Wetted Area Relationship

Scale: 1" = 5'

Topography based on as survey performed on June 18,2002

Figure 1.6: Top view of Traffic Island BMP with inlet structures (Heason, 2003).

1.4 Research Goals and Objectives

The primary goal of this research is to characterize water quality parameters at the VUSP Bio-infiltration Traffic Island Stormwater BMP by analyzing pollutant loads such as nutrients, heavy metals and solids. Single and multivariable linear regression analyses were used to investigate correlations between water quality and quantity parameters. An additional goal is to identify water quality parameters which may present restrictions to using Bio-infiltration in the vicinity of groundwater well fields by comparing allowable limits of pollutant levels in stormwater runoff to national drinking water standards. The final goal of this research is to report long term effectiveness of the BMP in terms of water quantity parameters.

Relationships between water quantity and water quality parameters have been analyzed using r-square correlation coefficients. Water quantity variables monitored in this study include; maximum one hour rainfall intensity, total precipitation, antecedent dry time and date. These variables were analyzed against water quality parameters such as conductivity, total suspended solids, nutrient loads and dissolved metals. Scatter plots were generated and linear regressions were used to identify correlations.

Restrictions to using bio-infiltration have been established by direct comparison of runoff pollutant concentration to national drinking water standards. This study also identifies removal efficiencies of pollutants as a function of depth during infiltration by analyzing influent surface runoff and comparing it to effluent-infiltrated water in the subsurface. In addition to this, long-term effectiveness of this site to retain and infiltrate stormwater runoff is determined by analyzing precipitation events over a two year period and comparing direct measurements of event based average infiltration rates.

Chapter 2: Literature Review

2.1 Stormwater Management Regulations

The protection of water resources has been a national concern since the enactment of the Federal Water Pollution Control Act of 1948. The primary focus of this act was to identify surface water bodies which were polluted and to locate sources of pollution and to eliminate them. This act was amended in 1972 to prohibit any discharges of pollution into a water body without a permit. Furthermore, these amendments focused on effluent standards rather than surface water standards as the driving mechanism for control. In 1977, this act was renamed the Clean Water Act and a number of grants were established for waste water treatment and research.

Regulations were included in the Clean Water Act of 1977 which entailed specific water pollution issues. Section 401 created a permit program entitled the National Pollutant Discharge Elimination System (NPDES) which focuses on point source pollution through effluent limitations, compliance scheduling and monitoring requirements (Dzurik, 2003). In 1987 a two phased program was established to regulate non point source pollution in the form of stormwater runoff. Phase I of this program required permits for stormwater discharge from municipalities having separate storm water sewer systems with populations of 100,000 or more people. In addition to this, this program initiated permitting for stormwater discharge from eleven categories of industrial activities and construction which disturbed five or more acres of land. Phase II of this program was implemented in 1999 and entails permitting for stormwater discharge of smaller municipal separate storm sewer systems as well as construction activities which disturb between one and five acres of land (USEPA, 1999).

In the Commonwealth of Pennsylvania, the Pennsylvania Stormwater Management Act, commonly referred to as Act 167, is the driving legislation for stormwater discharge. This Act establishes a program for managing stormwater using a comprehensive watershed approach. This is accomplished through the use of grants managed by the Pennsylvania Department of Environmental Protection (PA DEP) which provides funding to counties in order to develop stormwater management plans for designated watersheds (PADEP, 2002).

Recently, PA DEP issued a Comprehensive Stormwater Management Policy to update its stormwater management programs. This new policy was created to improve water quality, sustain water quantity including ground water recharge and stream base flow, and to implement federal obligations (PA DEP, September 28, 2002). This policy recommends that to meet regulatory requirements, all persons involved in land development should prepare a comparative pre and post construction stormwater analysis. It also suggests that planners and applicants should utilize Stormwater Best Management Practices (BMPs) which infiltrate stormwater runoff to pre development volumes. Stormwater BMPs are also recommended to ensure the protection of water quality.

In January of 2005, the PA DEP published a guidance manual for the development of stormwater BMPs throughout the state of Pennsylvania. This manual provides technical guidance on methods of reducing the impact of stormwater runoff and is available in draft form through the PA DEP website.

2.2 Stormwater Runoff Quality

Stormwater runoff contains a number of water quality constituents which cause degradation if discharged directly to downstream surface waters. In a 1984 report to the U.S. Congress, the EPA concluded that non-point source pollution in the form of stormwater runoff is the leading cause of remaining water quality problems in the United States (EPA, 1984). In 1992, the EPA ranked urban stormwater runoff as the second largest source of impairment of lakes and estuaries, and the third largest impairment of rivers (Lee et al., 1994).

The Nationwide Urban Runoff Program (NURP) established a list of pollutants which are relevant to stormwater runoff quality. According to NURP, the parameters of primary concern are: suspended solids, biochemical oxygen demand, chemical oxygen demand, copper, lead, zinc, total phosphorous, soluble phosphorous, total kjeldahl nitrogen, and nitrate plus nitrite (EPA, 1983). This list of pollutants can be expanded to include chloride, and metals such as, cadmium, chromium and nickel. Some researchers also believe that polycyclic aromatic hydrocarbons (PAHs) are a primary concern due to their ubiquitous nature (Smith, J. et al., 2000). Additionally, PCBs and pesticides in stormwater runoff are becoming a concern to water resource specialists.

Several factors influence runoff before it reaches a stormwater BMP or a receiving water body. The main factors affecting stormwater runoff quality include hydrologic and hydraulic variables, land use, geologic and geographic considerations and physical parameters of the site drainage area. While these variables are well documented, quantifying their effects on water quality is difficult.

Hydrologic and hydraulic variables include; total rainfall, peak intensity, antecedent dry time, flow rate, and runoff volume. These variables are discussed in more detail in section 2.3. Land use also plays an integral role in stormwater runoff quality (Graves, G. et al., 2004). In urban areas, stormwater runoff travels across roof tops, gutters, walkways and streets before entering a stormwater drainage system. Even stormwater drainage systems can adversely affect stormwater quality if not maintained properly. Stormwater runoff quality in industrial areas is largely a function of the type of industrial activities performed onsite. Land use associated with residential or rural communities will also have a different type and scale of water quality effect resulting from stormwater runoff. Geologic and geographic considerations are also important when analyzing sources of stormwater runoff pollution.

There are a number of physical processes which affect the stormwater runoff quality. These processes include; atmospheric scrubbing, scour and erosion, surface washoff, deposition and transport and transformation (Tsihrintzis et al., 1997). Atmospheric scrubbing is the process by which air born particles in the atmosphere, such as exhaust from vehicles, are absorbed by moisture and released in precipitation. This process can be a significant source of water pollution, commonly referred to as acid rain which results from oxides of nitrogen which are released during the combustion of coal for energy production. Scour and erosion is a result of high intensity rainfall which impacts solid surfaces at high velocities causing deterioration. This process directly affects suspended sediments which typically transport other pollutants in runoff. Surface washing occurs in urbanized areas and is the result of pollutants which build up on impervious surfaces such as roads and buildings and are then removed by runoff during precipitation events. Deposition is not commonly referred to as a pollutant mechanism but can be a significant factor in the fate of certain suspended particles. Many pollutants which are suspended in stormwater runoff can settle out at low velocities and can be deposited on the stream bed. These sediments can suffocate and destroy micro habitats in the aquatic ecosystem where many smaller species of fish and plants reside. Transportation and transformation are processes by which pollutants are re-suspended and altered as a result of physical, chemical and biological mechanisms.

Some common sources of stormwater pollution include pavement wear, atmospheric deposition, road maintenance practices, vehicle wear, animals, fertilizers and other human activities. Of particular interest in this list is the number of pollutants associated with vehicle use and maintenance. The majority of heavy metals pollution in stormwater runoff comes from vehicles. Some of these sources include lead from the exhaust of leaded fuel, zinc from the wear of tires and copper, chromium and nickel from the wear of moving parts (Norman, 1991). In some studies the levels of heavy metals in stormwater runoff have exceeded levels in sanitary sewage. Metals such as copper, cadmium, lead and zinc are soluble in water and can be toxic at certain concentrations. Table 2.1 lists some common sources of stormwater runoff pollution.

Table 2.1: Sources of stormwater runoff pollution (Norman, 1991).

Constituent	**Primary Sources**
Particulates	Pavement wear, vehicles, atmosphere, maintenance, snow/ice abrasives, sediment disturbance
Nitrogen, Phosphorus	Atmosphere, roadside fertilizer use, sediments
Lead	Leaded gasoline, tire wear, lubricating oil and grease, bearing wear, atmospheric fallout
Zinc	Tire wear, motor oil, grease
Iron	Auto rust, steel highway structures, engine parts
Copper	Metal plating, bearing wear, engine parts, brake lining wear, fungicides and insecticides use
Cadmium	Tire wear, insecticide application
Chromium	Metal plating, engine parts, brake lining wear
Nickel	Diesel fuel and gasoline, lubricating oil, metal plating, brake lining wear, asphalt paving
Manganese	Engine parts
Bromide	Exhaust
Cyanide	Compound used to keep deicing salt granular
Sodium, Calcium	De-icing salts, grease
Chloride	De-icing salts
Sulphate	Roadway beds, fuel, de-icing salts
Petroleum	Spills, leaks, blow-by motor lubricants, antifreeze, hydraulic fluids, asphalt surface leachate
PCBs, pesticides	Spraying of highway right of ways, atmospheric deposition, PCB catalyst in synthetic tires
Pathogenic bacteria	Soil litter, bird droppings, trucks hauling livestock/stockyard waste
Rubber	Tire wear

Nutrients listed in this table are common in stormwater runoff pollution and include chloride, nitrate, nitrite and ortho-phosphate. Chlorides are primarily a result of salts which are applied to road surfaces to prevent slipping of vehicles in cold climates. Chlorides are typically washed from road surfaces during snow melt or rain events and enter surface water directly through stormwater drains or as base flow. High levels of chlorides cause stress to the habitat and can result in decreased productivity of plant and aquatic species.

Nitrogen and phosphorous are nutrients which are generally associated with agriculture or landscaping activities such as the application of fertilizers. In fact, these activities can account for 70% of the annual load of these compounds (Chester, Schierow, 1985). The primary concern with nutrient pollution is adverse effects of receiving waters such as streams, rivers and lakes. When high levels of nutrients enter an aquatic ecosystem, excessive plant growth is stimulated in a process known as algal bloom. The decomposition of these plants consumes dissolved oxygen in the water body and alters the natural habitat. Oxygen depletion can destroy fish and other aquatic species.

Other water quality problems associated with nutrients include water treatment issues for water suppliers who use surface water as their primary source of drinking water. Excessive nitrate levels in the water supply can pose serious problems at certain concentrations due to methemoglobinemia, a blood disorder which is linked to birth defects and infant mortality. National Drinking Water Standards regulates Nitrate and Nitrite levels to 10.0 ppm and 1.0 ppm respectively.

2.3 Stormwater Runoff Quantity

Until recently, Pennsylvania's Stormwater Management Act 167 focused entirely on managing peak flows of surface runoff through detention. These practices, however, do not control downstream scouring of surface water channels because volume controls are not considered. Research suggests that peak flow attenuation, only, may cause increases in flow rate when analyzed on a larger watershed scale (Emerson, Welty, Traver 2005). Stormwater detention basins do not consider pre-development volume. When detention basins are implemented on a large scale, adverse effects on regional groundwater recharge can result. An increase in stormwater runoff volume resulting from the development of impervious surfaces, coupled with the ineffectiveness of stormwater detention basins to retain volume or treat pollutants, has forced engineering and planning professionals to reconsider stormwater management practices.

Stormwater quantity parameters of interest to water resource specialists include hydrologic and hydraulic variables (Mays L.W., 2001). Hydrologic variables include precipitation intensity, total precipitation, evaporation, transpiration and infiltration, interception or initial abstractions, seepage or baseflow, recharge and groundwater flow. Hydraulic parameters of interest include; peak flow, peak velocity, total runoff volume, channel slope and time of concentration. Other parameters which are considered in stormwater runoff analysis are antecedent dry time and soil moisture.

The overall goal of any stormwater management program is to return post-development hydrologic and hydraulic characteristics to pre-development levels (Traver, 2002). The primary hydrologic considerations for pre and post development analysis are evapotranspiration and infiltration. Hydraulic design considerations include peak flow, total runoff volume and time of concentration.

The concept of best management practices has been incorporated in stormwater management to eliminate negative effects of land development on water resources. With the increase of impervious surfaces typical of land development comes a number of negative effects including increased runoff volume, increased frequency of near or bankfull water levels in streams and rivers, flooding, erosion, and stream channelization.

Also associated with land development is a depletion of groundwater resources due to directly connected impervious surfaces which do not allow for infiltration or groundwater recharge. Baseflow, the portion of groundwater which flows into a stream channel naturally according to principles of hydrogeology, is also reduced due to the development of impervious surfaces. The result is greater fluctuations of water levels in streams during different seasons which over time can cause some water ways to run dry during portions of the year. Ultimately, without the use of best management practices, land development results in a decrease in groundwater resources and a decrease in surface water quality coupled with an increase in erosion and an increase in frequency of flooding.

2.4 Best Management Practices

Best Management Practices (BMPs) have become a focal point for engineers and planners involved in stormwater management programs. BMPs can be either structural or non structural devices. Non structural methods of stormwater BMPs include public education, street cleaning, fertilizer controls, zoning and disconnected impervious surfaces. Structural BMPs include infiltration/evapotranspiration devices, stormwater wetlands, porous media (pavers, concrete or asphalt) and other commercially available products for retaining and treating stormwater runoff.

A number of technical guidelines have been written with the intent of standardizing the design of structural BMPs. Two manuals which are of relevance to this study are the 2000 Maryland Stormwater Design Manual, because of its broad acceptance in the water resources profession, and the Pennsylvania Stormwater Best Management Practices Manual developed in 2005.

These manuals describe design parameters for a number of structural BMPs which can be used to reduce the negative effects of post development stormwater runoff in terms of quantity and quality. Structural stormwater BMPs can be divided into flood control and volume control BMPs. Water treatment BMPs are also included as structural devices. However, all BMPs claim to have some water quality impact and are incorporated into flood control or volume control devices. Flood control BMPs are designed to retain larger storms (2 – 100 year frequency) and prevent downstream flooding by retaining a large volume of runoff. This volume is slowly released over time in the same manner as in conventional detention basins. Flood control BMPs include detention basins, artificial marshes or man-made wetlands and wet detention basins or man-made ponds.

The primary difference between detention basins and wetland or wet pond BMPs is the ability of a wetland or pond to treat stormwater runoff from smaller storms. Both stormwater wetlands and detention ponds are designed to treat stormwater runoff through processes of sedimentation, dilution, filtration and biological uptake by selected plant species. One study of wetlands pollution removal efficiencies in Southeastern Pennsylvania reports a 60% reduction of suspended solids in runoff during precipitation events. This same study also reported removal efficiencies for total phosphorous of 50% while reducing the first flush effect of dissolved constituents such as reactive phosphorous and chlorides through the process of dilution (Rea, 2004).

Volume control BMPs are used to treat stormwater pollution and recharge groundwater resources through infiltration and evapotranspiration. Infiltration trenches are excavated basins which are backfilled with clean one-to-three inch diameter stones.

Typically, infiltration trenches incorporate some type of pre treatment device such as a grass filter strip or settling zone to prevent direct groundwater contamination and clogging of pore spaces by sediment build up. These BMPs are generally used for sites between 1 and 10 acres in size and are designed to retain and treat between 0.5 and 1.0 inches of stormwater runoff. Another type of volume control infiltration BMP utilizes sedimentation, adsorption, plant uptake and filtration to treat stormwater runoff. Some confusion exists as to the classification of these devices because of the multitude of names used to describe them including infiltration basins, bio-retention BMPs, bio-filters, rain gardens or bio-infiltration BMPs. For the purposes of this study, it is assumed that bio-retention, bio-filtration, rain gardens and bio-infiltration are all similar structures and that infiltration basins are simply detention basins with some capacity to infiltrate runoff without adsorption, or plant uptake. The following section details past research concerning bio-infiltration BMPs.

2.5 Bio-infiltration BMPs

Bio-infiltration BMPs typically consist of small detention basins which are excavated and backfilled with porous media of sand and mixed soil. These basins are convex in shape and contain some storage volume to retain runoff for infiltration. As shown in Figure 2.1, bio-infiltration combines sedimentation, filtration, adsorption and biological processes to treat and infiltrate stormwater runoff. A shallow pond area is used for secondary sedimentation whereas primary sedimentation ideally occurs at the intake channel. Filtration occurs within the porous medium which is usually composed of soil, sand, gravel or a combination of the three. Adsorption is the adhesion of pollutants to soil particles. This occurs naturally during filtration when particulate pollutants attach to soil particles or vegetation surface (EPA, 1999). Biological processes occur as a result of planting materials which consume nutrients and other dissolved pollutants through uptake. The mulch layer induces microbial growth which assists in the decay of organic material and petroleum based hydrocarbons. Some studies have shown, however, that the addition of this mulching layer can introduce nutrient loads to the system, particularly nitrogen in the form of nitrate mixed with mulch to enhance plant growth.

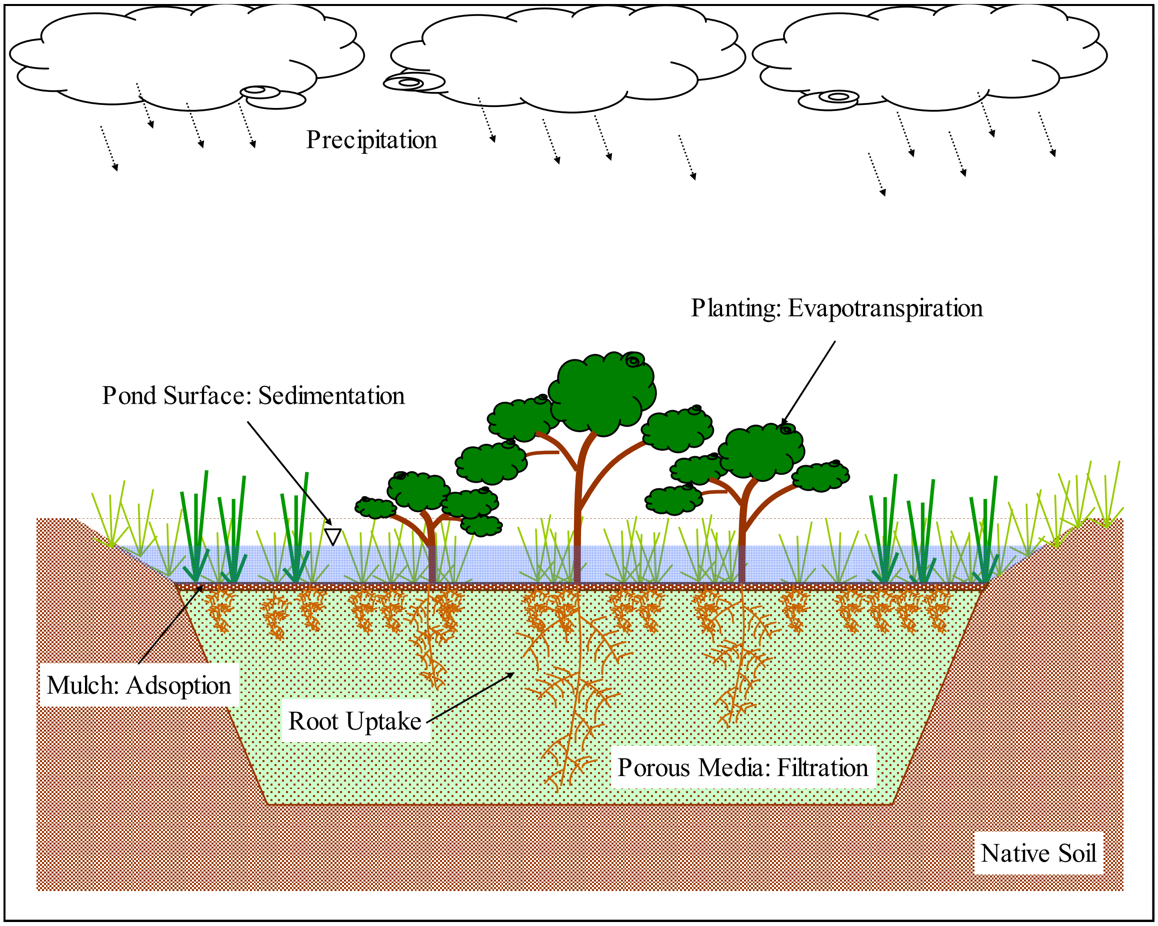


Figure 2.1: Bio-infiltration treatment processes.

Research concerning the effectiveness of bio-infiltration to retain and treat stormwater has typically entailed laboratory studies under controlled environments. Very little field based research exists on long term pollutant removal efficiencies or long term volume control effectiveness. Table 2.2 summarizes removal efficiencies obtained by conventional detention and bio-filtration practices for a number of laboratory studies including research projects by the New Jersey Department of Environmental Protection, the U.S. EPA, and a number of university environmental engineering programs.

The primary benefit of bio-infiltration is the ability to reduce suspended solids from stormwater runoff. It can be seen in Table 2.2 that bio-infiltration is approximately 90% effective in the removal of Total Suspended Solids (TSS). Bio-infiltration is also very effective in removing metals and total petroleum hydrocarbons (Lead, zinc and TPHC), nutrients such as total phosphorous (TP) and total kjeldahl nitrogen (TKN).

Table 2.2: Summary of removal efficiencies for conventional detention and bio-filtration (Davis et al, 2003) (Cosgrove et al, 2003) (Davis et al, 1998).

Parameter	**Dry Detention Basins**	**Biofiltration Basins**
TSS	70% - 90%	90%
TP	10% - 60%	70% - 83%
TKN	20% - 60%	68% - 80%
BOD	30% - 40%	60% - 80%
Lead	20% - 60%	93% - 98%
Zinc	40% - 60%	93% - 98%
TPHC	60% - 77%	90%

Removal efficiencies of pollutants in relation to surface water can be misleading because the potential for groundwater pollution is not considered. When pollutants build up within a bio-filtration system its capacity to retain pollutants will be reached and the system no longer functions effectively. This is particularly important for certain pollutants which are mobile in the soluble form. Some metals such as lead and arsenic can be toxic at certain concentrations and are subject to regulations. These constituents should be more closely monitored in any stormwater management program which includes groundwater recharge through the use of bio-infiltration. Long-term monitoring of bio-infiltration BMPs through field research is recommended to understand how these systems affect environmental water resources.

2.6 Correlation Models

A number of studies have focused on the development of relationships for predicting non point source pollution associated with stormwater runoff. One of the most extensive research efforts in developing correlation parameters was the Minnesota highway stormwater quality database. This study was primarily concerned with the potential effect of highway stormwater runoff on receiving water bodies and groundwater aquifers. Simple regression analysis was employed using linear, log and power models to predict pollutants of interest from known quality parameters of stormwater runoff. The known parameters used for these predictions were Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Total Volatile Solids (TVS) and Total Organic Carbon (TOC). These parameters were then evaluated against known concentrations of constituents of metals (Cr, Cu, Fe, Pb, Zn, Ni, Cd, Al and As) and nutrients such as Chloride, Total Nitrogen, SO_4 and Total Phosphorous to determine dependent correlations. The results of this study show a linear relationship between TDS and chloride ($r^2 = 0.99$), SO_4 ($r^2 = 0.75$) and Arsenic ($r^2 = 0.60$). TDS was a poor predictor of nutrients such as nitrogen for linear, log or power regression analysis. The only model to demonstrate an improvement over the linear regression analysis was aluminum – log TSS. The TSS linear regression showed little correlations for water quality parameters other than Fe ($r^2 = 0.59$) and Zinc ($r^2 = 0.61$).

Additionally, a multiple regression analysis was performed to improve predictions for correlation models using these constituents. Table 2.3 summarizes the best model for each constituent investigated. Highly correlated parameters based on statistical analysis using r-squared correlation included most metal constituents and the sum of total suspended and dissolved solids. Chloride showed the highest correlation with total dissolved solids ($r^2 = 0.996$). Total nitrogen showed very little correlation to TDS ($r^2 = 0.237$). Nitrate plus nitrite showed some correlation with TDS and TOC ($r^2 = 0.498$) and total phosphorous showed good correlation with TVS and TSS ($r^2 = 0.777$).

Table 2.3: Correlation Parameter Relationships: Highway Stormwater Runoff (Thomson et al, 1996).

Parameter	Relationship	Correlation Coefficient (r^2)
Metals		
Chromium (ug/L)	= 0.0879(TSS) + 0.000236(TDS)	0.764
Copper (ug/L)	= 9.49 + 0.248(TSS)	0.634
Iron (ug/L)	= 36.8(TSS) + 0.0638(TDS)	0.846
Lead (ug/L)	= 1.72(TSS) + 0.00286(TDS)	0.832
Zinc (ug/L)	= 1.00(TSS) + 0.00216(TDS) + 2.06(TOC)	0.91
Nickel (ug/L)	= 2.12 + 0.0488(TSS) + 0.0635(TOC)	0.727
Cadmium (ug/L)	= 0.00930(TSS) + 0.000114(TDS)	0.822
Aluminum (ug/L)	= 29.7(TSS) – 0.0620(TDS)	0.79
Arsenic (ug/L)	= 0.00541(TDS)	0.808
Ionic Species		
Chloride (mg/L)	= 0.575(TDS)	0.996
Sulphate (mg/L)	= 0.00837(TDS) + 0.741(TOC)	0.726
Sodium (mg/L)	= 0.652(TDS)	0.501
Nutrients		
Kjeldahl (mg/L)	= 0.00120(TVS) + 0.0556(TOC)	0.836
Total N (mg/L)	= 2.05 + 0.0000870(TDS)	0.237
NO_2 + NO_3 (mg/L)	= -0.0000217(TDS) + 0.0325(TOC)	0.498
Total P (mg/L)	= 0.00292(TVS) + 0.00106(TSS)	0.777
COD (mg/L)	= 0.0479(TDS) – 0.344(TSS) + 4.21(TOC)	0.816

Given the positive correlation between certain water quality parameters Thomson et al. then investigated other environmental variables which may be useful in predicting stormwater runoff pollutant loads. These variables included total traffic count before an event, total rainfall, antecedent dry time, flow duration, average flow intensity and volume. Unfortunately, prediction of TSS, TDS, TVS and TOC using these environmental variables was unsuccessful. These authors suggested that water quality sampling would be necessary rather than using the predictor variables to determine pollutant loads. While TSS, TDS, TVS and TOC proved to be effective forecasting parameters for constituents such as metals and nutrients, hydraulic parameters and traffic flow were not good predictors.

Thomson et al. used event mean concentration data from four different highway sites over a period of seven years. Each site varied in number of traffic lanes, average daily traffic flow, area, percent impervious surfaces, surface type and median type. The multitude of physical site parameters coupled with variable hydraulic and hydrologic factors may have limited this study's ability to derive useful correlation relationships between water quality and water quantity parameters. (Thomson et al, 1997)

Given the relatively small drainage area and the detailed monitoring effort of VUSP's Traffic Island Bio-infiltration BMP, establishing correlation models for environmental parameters may prove to be more effective.

Chapter 3: Research Methods

3.1 Introduction

This section details the procedures for data collection and analysis for the VUSP Traffic Island Bio-infiltration BMP. Both water quantity and water quality data were collected from October of 2003 until April of 2005 at this site. During this time, various procedures were altered for quality assurance and quality control (QAQC) purposes. These changes entailed field sampling and laboratory equipment alterations which improved the accuracy of this study. Collection procedures for water quantity data were generally unchanged throughout the course of this research. This section describes the sampling and analysis methods for this study and any changes made to the QAQC protocol.

3.2 Water Quality

Water quality sampling at the VUSP Bio-infiltration BMP was conducted based on precipitation events. Two types of samples were collected; surface runoff samples and sub-surface soil moisture samples. Analytical results for water quality samples were obtained using High Performance Liquid Chromatography (HPLC), Spectrophotometry, Graphite Furnace Atomic Absorption (GFAA) and standard laboratory procedures for analysis of physical parameters.

3.2.1 Sampling Methods

The target precipitation amount for analyzing stormwater runoff samples was 1.0 inches of rain (2.54 cm) as measured by the VUSP West Campus Rain Gauge. During this study, 28 precipitation events were sampled and analyzed. Of these events, 14 were greater than 0.99 inches and 14 were less than 1.0 inches. The average precipitation amount for sampling runoff was 1.59 inches (4.03 cm).

Any number of circumstances may have led to an event not being sampled. During the months of December, January and February, runoff samples were collected on a limited basis due to icing at the site which affected the accuracy of volume measurements. Also, during colder months sampling equipment was vulnerable to being damaged due to freezing of condensation in the sampling lines. Thus, during these months, runoff sampling was limited to snow melt events or precipitation events which did not involve snow. In some cases when sampling did take place in these months, the data may be limited due to difficulties in sample collection. Care was taken in all situations to protect the integrity of sampling equipment. Sampling was also usually limited to precipitation events which occurred between Monday and Friday due to holding time restrictions on certain parameters which restricted testing to within 24 hours of sample collection.

Two types of samples were collected. A total of four surface runoff samples were collected at three locations; two first-flush samples from the east and south curb-cuts and two surface water samples from the basin pond. Sub-surface samples were collected at three locations at different depths within the basin to represent infiltrated runoff.

3.2.1.1 Surface Water Sampling

Surface water samples were collected from three locations and included first flush samples of direct runoff at two locations and two time weighted grab samples from the pond surface within the bio-infiltration basin during and following an event. Figure 3.1 shows a schematic of the locations for surface water samples. The two first flush samplers were installed within the channel of the BMP's curb cuts in July of 2004. These locations are noted FF1 and FF2, and are also shown as photographs in Figure 3.2. The location for the two basin surface water samples which were collected during and following precipitation events (SA1 & SA2 respectively) are also shown. Sampling at this location began in October of 2003.

Surface samples are defined as follows:

> SA1: Grab sample collected from the surface water within the basin during or just after a precipitation event.
>
> SA2: Grab sample collected from the surface water within the basin approximately one day following a precipitation event.
>
> FF1: Surface runoff sample collected from the first flush sampler at the eastern curb-cut.
>
> FF2: Surface runoff sample collected from the first flush sampler at the southern curb-cut.

First flush samples were collected using the GKY First Flush system. A high density composite plastic casing was installed at the sampling location within the stone lined inlet channel of the two curb cuts. This casing is prefabricated with a removable access cover which allows stormwater runoff to enter the sampler through small ports. A

5.0 liter plastic sampling container is placed into the casing prior to an event. After the sampling container is filled by runoff, a buoyant flap valve closes the inlet port. Following an event, the container is removed by opening the access cover. Rubber inlet port plugs are used to prevent airborne pollutants from entering the sampler during periods without precipitation.

c

Figure 3.1: Surface Water Sampling Locations for Analysis of Water Quality
Top View: VUSP Bio-infiltration Traffic Island BMP

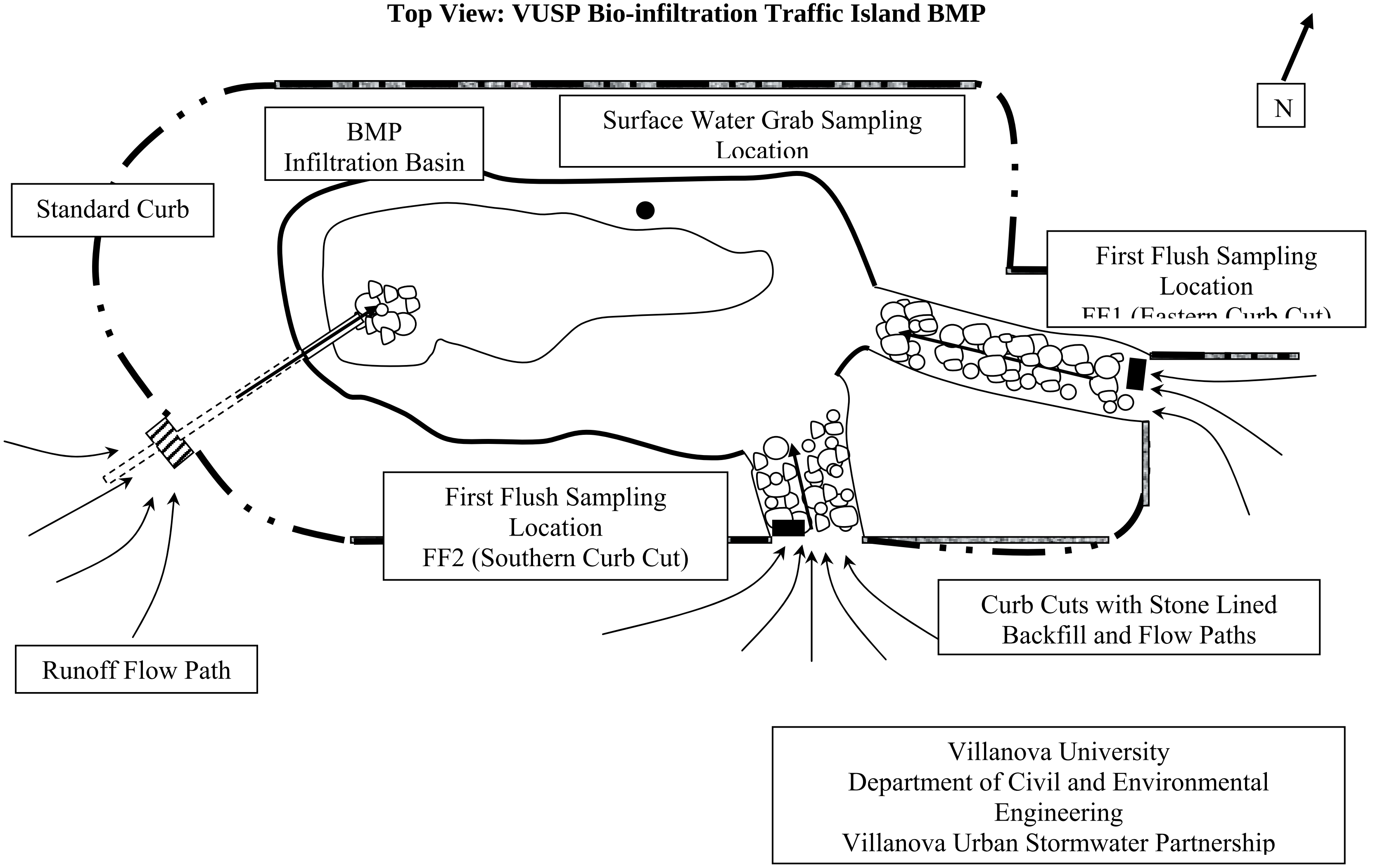


Figure 3.2: Photographs of First Flush Sampling Locations

3.2.1.2 Infiltrated Runoff Sampling

Three infiltrated runoff samples were collected at different depths below the basin. The purpose of this sampling activity was to determine the amount of pollutants introduced to the soil strata, and to track their movement and any reduction in pollutant concentration during infiltration.

Two suction lysimeters (1920F1 Pressure – Vacuum Soil Water Samplers, Soilmoisture Equipment Corp.) were installed at 8.0 and 4.0 feet below the bottom of the basin to sample infiltrated stormwater runoff. An additional lysimeter sampler was installed at the basin surface for comparison purposes. All three lysimeters were installed according to manufacturer's recommendations.

Sub-surface infiltrated runoff samples are defined as follows:

> L0: Lysimeter sample collected at the surface of the basin itself. When the basin is full, this sample is collected at the bottom of the ponded water.
>
> L4: Lysimeter sample collected at a depth of four feet below the basin surface within the mixed backfill region of the basin.
>
> L8: Lysimeter sample collected at a depth of eight feet below the basin surface within the native soil region.

Figure 3.3 shows a side view schematic of the location of these three soil moisture samplers. The lysimeter at the surface collects water from the surface of the basin and the lysimeter at a depth of 4.0 feet collects water from within the backfill soil composed of mixed sand and native soil. Finally, any stormwater runoff which is infiltrated into the original soil is collected from a lysimeter located at a depth of 8.0 feet.

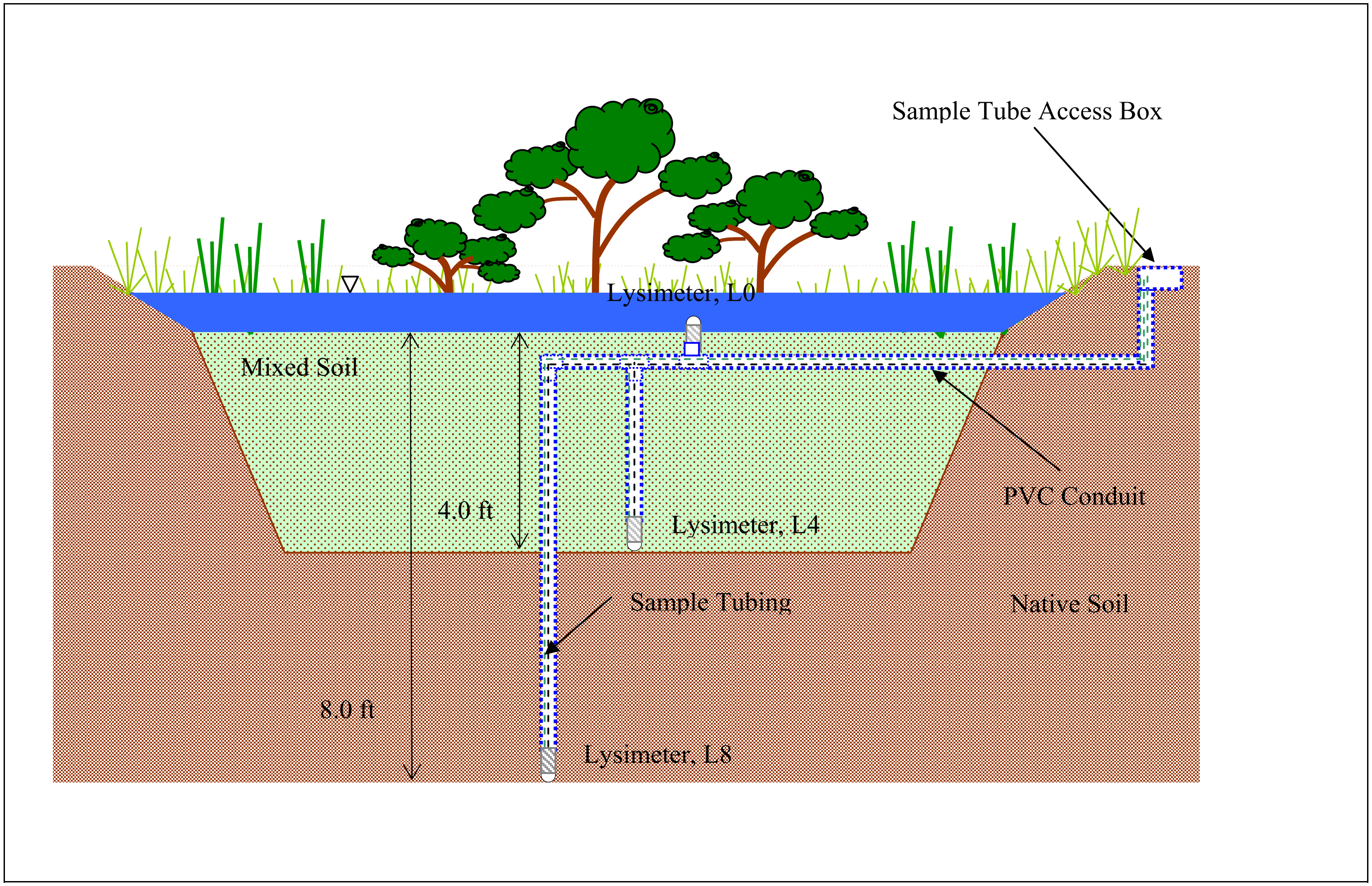


Figure 3.3: Side View Schematic of Sampling Locations for Infiltrated Runoff.

Figure 3.4 is a photograph of the site identifying the conduit, access box and buried lysimeter locations. The actual conduit can not be seen in this photo because it is buried approximately 6 inches below the surface for protection.

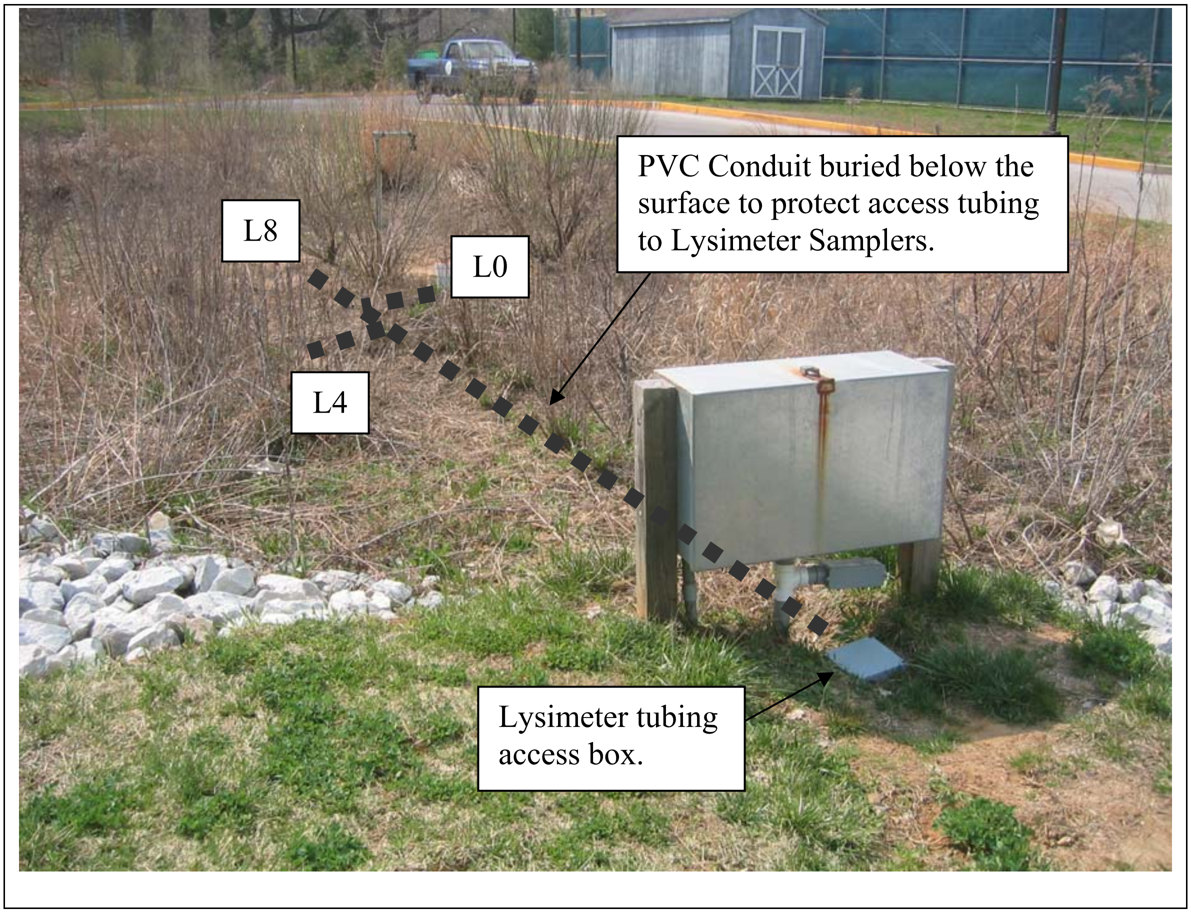


Figure 3.4: Site photograph identifying sampling locations for infiltrated runoff.

Figure 3.5 demonstrates the general process for operating a buried suction lysimeter. By creating a negative pressure inside the sampler which is greater than the tension or capillary forces which are holding the water in the pore spaces of the soil, a hydraulic gradient is created in the direction of the sampler. This negative pressure is created by using a manual pump which applies suction pressure to a 0.25 inch (0.64 cm) polyethylene access tube located at the surface and routed to the sampler through PVC conduit as shown in Figure 3.3. A vacuum pressure of 8 psig (55 cb) was used for all sampling events. Once a hydraulic grade line is created in the direction of the sampler, water retained in the soil through surface tension slowly mobilizes and enters the sampler through the porous cup (see Step 2). After a filling time of approximately 8 to 12 hours, this water sample is extracted through another polyethylene access tube located at the surface for collection. These access tubes are labeled and color coded for identification purposes. The water sample is release from the sampler by applying a positive pressure to the tubing which forces the sample out of the sampling tube as seen in Figure 3.5 (Step 3). The sample is then collected at the surface with a properly prepared and labeled sampling container.

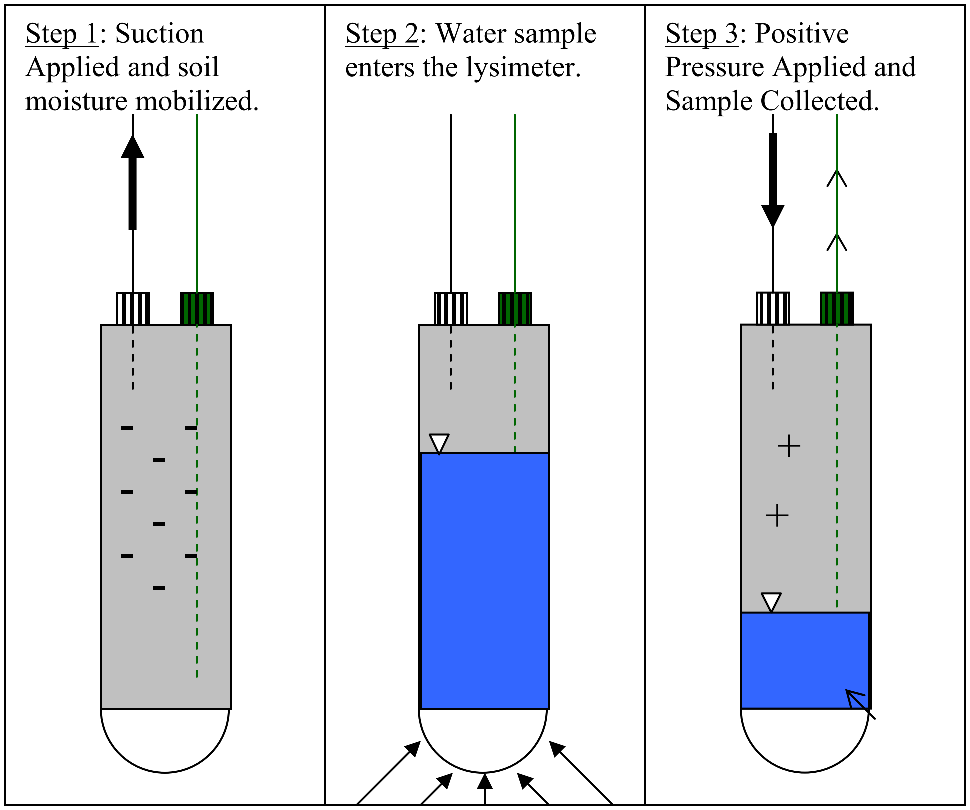


Figure 3.5: Infiltrated runoff suction lysimeter sampler operation

3.2.1.3 Quality Assurance and Quality Control

Samples are collected using designated plastic sampling containers. Sampling bottles are prepared prior to collection by first rinsing the container with tap water and then washing the container with laboratory Alconox detergent. Sample bottles are then soaked in 10% hydrochloric acid solution and then finally rinsed with deionized, distilled laboratory water three times. The containers are then air dried and stored in a laboratory cabinet with the container lid closed. Sample containers for analysis of dissolved metals are prepared in the same manner except that high grade Nitric Acid is used for acid washing.

During an event sampling, laboratory and field preparations began the morning of the event (see the QAQC section in 3.2.2.3 for laboratory procedures). The sampling containers where labeled, noting the time of collection, the sample location and the date. Figure 3.6 shows a typical sample label used at this site. The date notes the month, day and year of the sampling, "T.I." notes the BMP name (in this case Traffic Island), the time notes the actual collection time and the location notes the sampling location within the BMP. Field preparations included a visual inspection of the site to check for any problems with sampling equipment. Finally, in the afternoon of an event or during an event, depending on the timing of the storm, the collection process began. Suction is applied to the lysimeters (L0, L4, L8), the first basin grab sample is collected (SA1) and the two first flush samplers are opened (FF1, FF2). The morning following an event, the lysimeter samples were collected and the sample container was labeled according to time and date (not the time of applied suction). The first flush samples were collected and a second basin grab sample was obtained (SA2). Sample handling or chain of custody procedures were not documented because samples were analyzed in-house and were not sent to an external lab.

Date: 11/12/04 T.I.
Time: 4:00 PM Location: SA1

Figure 3.6: Typical Sampling Label

All samples were transported directly to the VUSP Water Resource Laboratory for analysis the same day as collection (with the exception of SA1 which was collected during an event). In the event that analysis could not take place within the holding time of the testing procedure sampling preservation procedures followed the VUSP QAQC plan. Appendix B.1 shows the sample holding time for each specific parameter studied. Analysis of anions used sulfuric acid preservation to below a pH of 2.0, stored at 4 degrees Celsius when testing could not be performed within 48 hours of sampling. For analysis of soluble metals, sample preservation included filtering the sample through a 0.45-um filter and then acidifying the sample with 2% laboratory grade nitric acid - HNO_3. Sample holding times for the various constituents are detailed in section 3.2.2.3.

The various parameters studied could cause interference with each other if not analyzed properly. For example, the Gel filled pH Electrode could cause low level interference with the analysis of chloride because this probe is maintained in dilute hydrochloric acid for storage. For this reason, the order in which parameters were analyzed is very important to the quality assurance of the study.

Following a sampling event, the samples were first prepared for analysis of nutrients by extracting the sample, filtering 1.0 ml through a 0.2 um syringe and storing it in 1.0 ml HPLC auto sampler vial. This portion of the sample was then stored at 4 degrees Celsius for approximately 6 hours. Following this, all surface water samples were filtered for analysis of suspended solids. Approximately 15 ml was then extracted from the sample bottle for preservation and analysis of dissolved metals. The remaining portion of the sample was then analyzed for Total Nitrogen and Total Phosphorous using a spectrophotometer. This analysis consumes approximately 20 ml of sample. At the same time, analysis of conductivity and pH are performed. When all of the analytes were determined and no additional sample was required, the remaining volume of sample was evaporated for analysis of dissolved solid. Additional information regarding analysis procedures is given in the following sections. Figure 3.7 is a flow chart diagram which details the sampling and laboratory procedures for a typical event.

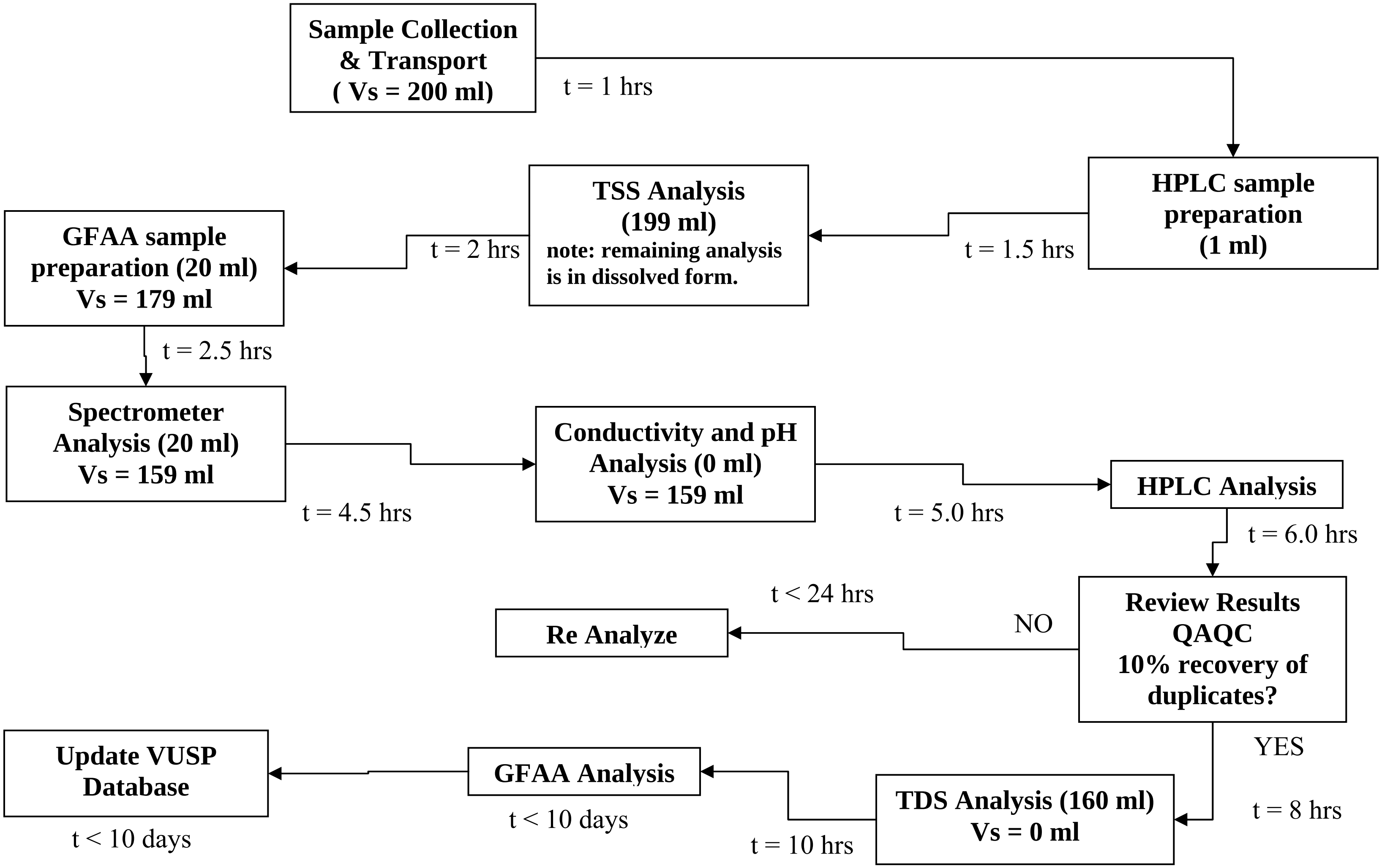


Figure 3.7: Flow Chart Diagram for Water Quality Sampling and Analysis

3.2.2 Analysis

This section describes the general procedures for analysis of water quality parameters of stormwater runoff samples. This study included analysis of ionic species such as Chloride, Nitrate, Nitrite and Phosphate as well as dissolved metals such as copper, lead, chromium, cadmium and zinc. Nutrients such as total phosphorus and total nitrogen were also studied. Additionally, physical parameters were determined such as pH, conductivity, total dissolved solids and total suspended solids.

3.2.2.1 Analysis of Ionic Species

High Performance Liquid Chromatography (HPLC) was used in the analysis of ionic species including; chloride, nitrate, nitrite and phosphate. Ion Chromatography uses ionic exchange to separate anions based on relative affinities for a low capacity, strongly basic anion guard column. A water sample is injected into a stream of eluent, passed through an ionic separator and guard column and then directed through a hollow fiber cation membrane suppressor with a continuous flowing acid regenerate solution. The suppressor converts the anions into their highly conductive acid forms which are passed through a conductivity detector. A plot is created for the analysis of anions such as Chloride (Cl), Nitrite (NO_2), Nitrate (NO_3) and ortho Phosphate (PO_4). These constituents are quantified by comparison of standards on the basis of retention time and an integrated measurement of peak area. (Standard Methods, 2001).

Analysis using HPLC began in October of 2003. Initial samples were sent to Villanova University's Environmental Lab for analysis. The results obtained in October of 2003 were not incorporated into this study for QAQC purposes Additional sampling occurred in November of 2003. These samples were calibrated and analyzed for Chloride.

The anion species of Nitrite, Nitrate and Phosphate were still being calibrated and were not included into the study at this time.

In January of 2004 VUSP began analyzing stormwater runoff samples using HPLC, at the Villanova University's Water Resources laboratory. Samples were still being collected and analyzed for Chloride however; instrument calibration for Nitrite, Nitrate and Phosphate species was still being completed. In February of 2004, calibration was complete and the detection limits of the instrument were determined. In March of 2004, it was concluded that the detection limits of this instrument was approximately 2.0 ppm for all anion species being studied. Since the majority of the anion species studied were below 2.0 ppm, it was determined that conductivity suppression was needed in order to obtain water quality results within the range of stormwater runoff samples. From March until June of 2004, a number of events were analyzed for chloride and were qualified as non-detect for species of nitrite, nitrate and phosphate (ND(2.0 ppm-NO_2), ND(2.0 ppm-NO_3) and ND(1.0 ppm-PO_4) respectively).

In May of 2004, a conductivity suppression unit was installed in the VUSP ion-chromatograph and detection limits were significantly improved. In June, 2004 analysis began for stormwater runoff which were within acceptable detection limits of anionic species typical in stormwater runoff at the VUSP bio-infiltration BMP.

Table 3.1 summarizes the timeframe for various changes made to sampling and HPLC analytical methods. In this table, "X" denotes that the analyte was tested for, "J" denoted interference and "w/o" denotes without suppression or non detect for the analytes of NO2, NO3 and PO4. It can also be seen that for HPLC analysis, anions of chloride in

Table 3.1: HPLC Analytical Summary

	Sampling Method							HPLC			
Date	SA1	SA2	FF1	FF2	L0	L4	L8	Cl	NO2	NO3	PO4
10/27/2003	X	X				X	X	X	X,J	X,J	X,J
11/6/2003	X	X				X	X	X	X,J	X,J	X,J
11/18/2003	X	X				X	X	X	X,J	X,J	X,J
12/10/2003	X	X				X					
2/3/2004	X	X									
2/6/2004	X	X									
3/9/2004	X	X				X		X	X w/o	X w/o	X w/o
3/16/2004	X	X				X		X	X w/o	X w/o	X w/o
3/31/2004	X	X				X		X	X w/o	X w/o	X w/o
4/13/2004	X	X				X	X	X	X w/o	X w/o	X w/o
4/20/2004						X	X	X	X w/o	X w/o	X w/o
4/26/2004	X	X				X	X	X	X w/o	X w/o	X w/o
4/30/2004						X	X	X	X w/o	X w/o	X w/o
5/4/2004	X					X	X	X	X w/o	X w/o	X w/o
5/19/2004	X					X	X	X	X w/o	X w/o	X w/o
6/5/2004	X	X				X	X				
6/11/2004	X	X				X	X	X	X w/o	X w/o	X w/o
6/15/2004	X	X				X		X	X w/o	X w/o	X w/o
7/8/2004						X	X	X	X w/o	X w/o	X w/o
7/12/2004	X	X			X	X	X	X	X w/o	X w/o	X w/o
7/18/2004	X	X			X	X	X	X	X w/o	X w/o	X w/o
7/28/2004	X	X		X	X	X	X	X	X w/o	X w/o	X w/o
9/8/2004			X	X		X	X				
9/27/2004	X	X	X	X	X	X	X				
10/19/2004	X	X	X	X	X	X	X				
11/12/2004	X	X	X	X	X	X	X	X	X	X	X
12/1/2004	X	X	X	X	X	X	X	X	X	X	X
12/7/2004	X	X	X	X	X	X	X	X	X	X	X
2/14/2005	X	X	X	X	X	X	X				
3/23/2005	X	X	X	X	X	X	X	X	X	X	X
3/29/2005	X	X			X	X	X				
Count	27	25	8	9	11	29	24	22	4	4	4
Percent	87.1	80.6	25.8	29.0	35.5	93.5	77.4	71.0	12.9	12.9	12.9

conjunction with surface basin samples and infiltrated samples at 4.0 and 8.0 feet are the most prevalent parameters available for analysis.

The method used for analysis of anionic species using HPLC is EPA Method 300 with some revisions which were specific to our operating conditions. The specifications for each sequence are maintained on file in the VUSP lab. The general specifications for an analysis are shown in Appendix B.2 along with example sequences. The Waters Model 717 plus autosampler with a 96-vial (1.0 ml) carousel was used with an operation isocratic operation mode on the Waters 431 Conductivity Detector. The Water Model 626 pump, in conjunction with the 600s Controller was also used. The Galaxie Chromatography Data System software was used for analysis of specific chromatographs and comparison of sample constituents with known standards. Appendix B.2 also shows example chromatographs for standards used during calibration with retention times noted for specific anion species.

3.2.2.2 Analysis of Nutrients

Nutrient analysis for this study included testing for total phosphorous and total nitrogen. This analysis used the Hach DR/4000 Spectrophotometer method which is not an EPA certified procedure. Analysis of total nitrogen was conducted using Hach Method Number 10071 using persulfate digestion. For the analysis of total phosphorous the Hach test method number 8190 PhosVer3 with acid digestion was used.

All procedures for the analysis of total phosphorous and total nitrogen were followed using the Hach Manual. Pretreated manufacturer supplied digestion vials were used in this method. Since this method utilizes light absorbance for analysis, care must be taken not to smudge the digestion vials during use. Standard issue laboratory rubber gloves along with soft lens wipes were used to prevent fingerprinting and to clean the vial glass during testing. The HACH COD Reactor model 45609 was used for the incubation of runoff samples during this analysis. The COD mode, temperature and digestion time used for each test were specified by manufacturer's recommendation.

The detection limit for the analysis of total phosphorous using this method is 0.06 mg/L – PO_4. The range of concentrations for runoff samples analyzed in this study was from Non Detect (ND) to 2.34 mg/L – PO_4, within the limits of this instrumentation and method. The detection limit for the analysis of total nitrogen using this method is 2.0 mg/L – N. The average stormwater runoff sample fell below this recommended detection limit at 1.06 ppm. Data qualifiers were utilized to identify samples that fell below the detection limit of this method. The results from this study of total nitrogen should consider that the majority of the samples analyzed fell below the detection limits of the instrumentation. The values were however used in the results section of this report and were noted accordingly. Appendix B.3 details the operating conditions as specified by the HACH DR/4000 Operators Manual for these tests.

3.2.2.3 Dissolved Metals

Graphite Furnace Atomic Absorption spectrometry was used for analysis of dissolved metals in this study. Metals analyzed included copper, lead, cadmium, chromium and zinc. GFAA spectrometry uses an electrically heated graphite tube to atomize a discrete sample for analysis. This process occurs in four stages. A sample is dispensed into the furnace and is first heated at a low temperature for drying. Background interferences such as organic matter are then removed by volatizing in the charring stage. Analysis occurs during the third stage when a current heats the tube at high temperatures and atomizes the sample. This atomization process is measured with a photoelectric detector and the intensity is recorded. The Beer-Lambert law relates intensity of transmittance to absorbance logarithmically at low ranges. This relationship is used to determine absorbance levels of known standards to create a calibration curve for a run of samples. In the fourth stage of the analysis, any residual remaining in the graphite tube from the atomization process is cleaned through charring.

Method 3113 of Standard Methods for the Examination of Water and Wastewater, was used for the analysis of all stormwater runoff samples. This method was chosen because sample concentrations of dissolved metals were in the range of the method detection limits for this process. Table 3.2 shows method detection limits (MDLs) for metals analyzed with GFAA (Standard Methods, 1999). MDLs are dependent on a number of variables including the chemical form of the element being analyzed, sample composition and instrument conditions (Standard Methods, 1999). Method Detection Limits are defined as the minimum concentration of an analyte which can be determined within 99% confidence that the concentration is greater than zero. The Minimum Reportable Limit (MRL) is the minimum concentration of an analyte that can be reported and represents the lowest standard concentration during an analysis. MDLs for the GFAA were determined using procedures set forth by the National Exposure Research Laboratory, Office of Research and Development of the United States Environmental Protection Agency. Using de-ionized reagent water blank fortified at a known concentration, seven replicated aliquots were analyzed over a three day period. The detection limit for the method was then determined by calculating three times the standard deviation of the calculated concentrations of the seven analyses.

Although water quality sampling at this site began in October of 2003, the analysis of dissolved metal using GFAA did not begin until September, 2004. This is because initial testing employed conventional flame atomic absorption and did not incorporate graphite furnace technology. As a result, the samples analyzed were below the detection limits of the instrumentation and were not of value for this study. Some analysis of dissolved copper was conducted prior to September, 2004 using a HACH DR/4000 Spectrophotometer. This testing used the bicinchoninate test method number 8506. When over 40% of the samples were detected below 10 ug/L, this testing was stopped until the VUSP water resources lab could establish a procedure for analysis with GFAA.

Table 3.2: Method Detection Limits (Standard Methods, 1999).

Element	MDLs (Method 3113a) ug/L	MDLs (VUSP,manual injection) ug/L	MDLs (VUSP,with auto sampler) ug/L	Optimal Concentration Range (ug/L)
Copper (Cu)	1.0	1.75	1.56	5 – 100
Lead (Pb)	1.0	4.21	1.06	5 – 100
Cadmium (Cd)	0.1	NA	NA	0.5 – 10
Chromium (Cr)	2.0	7.16	5.63	5 – 100
Zinc (Zn)	NA	8.63	4.41	10 – 100

Analysis of a sample using GFAA included pre-treating the sample with 1.5% high grade Nitric Acid. All instrumentation was checked and adjusted for accuracy using the procedures set forth in the Perkin-Elmer's GFAA Operators Manual. The appropriate cathode lamps were installed, the inert gas (argon) was pressurized and the data recorder was turned on for background correction. During the first stage of the analysis, reagent blanks (de-ionized MQ water, 18 ohm with pre-treatment) were analyzed to determine any background interference and to allow for the graphite tube and cathode lamp to stabilize. The Perkin-Elmer Model HGA-300 Programmer along with the AS-1 auto-sampler and the 2380 Spectrophotometer were used for this analysis.

Once duplication of the reagent blank sample was confirmed, the equipment was calibrated using three different concentrations of standard solutions (with pre-treatment) which bracketed the matrix of the samples being tested. A plot was then generated of peak height absorbance versus concentration for each standard solution. Figure 3.8, shows typical calibration curves used for this study for each constituent of dissolved metals determined. In this figure the regression analysis r-squared value along with the regression equation can be seen. These equations were then used to determine concentrations of dissolved metals in a runoff sample during an analysis. Separate calibration curves were used for each storm event analyzed. This figure (Figure 3.8) shows the calibration used for the event analyzed on November 12, 2004 and does not include an example calibration for zinc. This is due to the nature of the calibration for this constituent which requires multiple linear regression curves for its analysis. Figure 3.9 shows the calibration curve and equations used for the analysis of zinc during this analysis. In the event that sample concentrations were above the standard concentrations of the test method, samples were diluted to within acceptable instrumentation range. Standard checks were employed during sample analysis for quality assurance purposes. If standard checks were not within 10% of the initial calibration then, another calibration curve was generated.

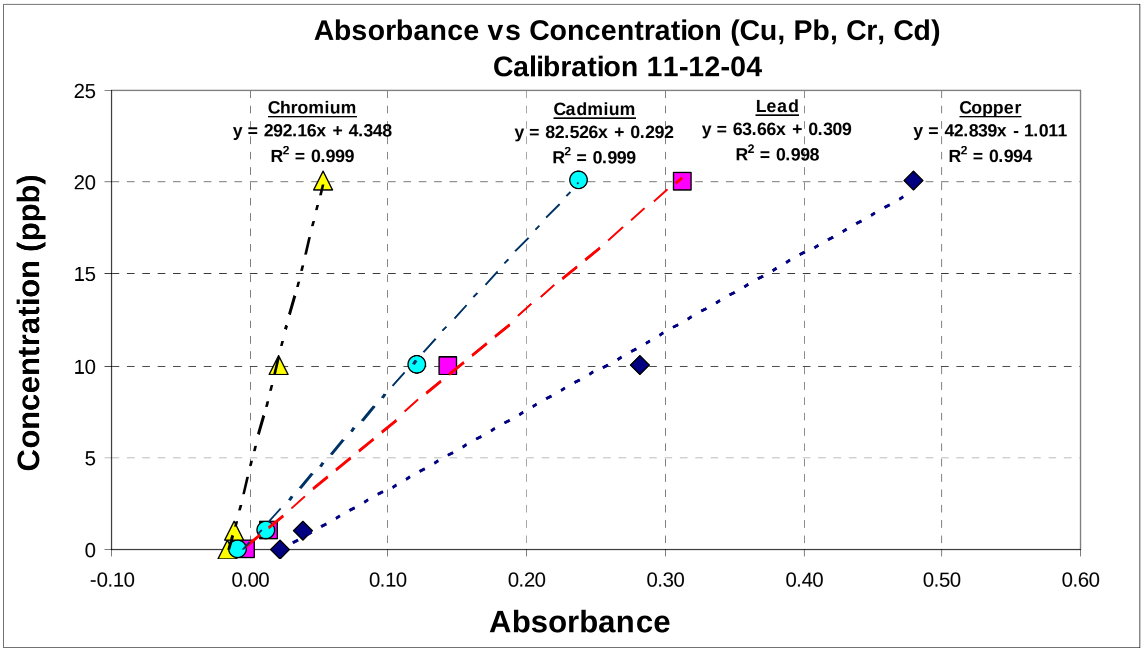


Figure 3.8: Example Calibration Curves for Dissolved Metals (Cu, Pb, Cr, Cd).

Sample duplicates were used to confirm results using a variation of 10% for reproducibility. Due to the nature of GFAA analysis, it was also necessary to check the accuracy of the graphite tube due to deterioration of the inner coating during atomization at high temperatures. At the start of each sample run, the reagent blank is analyzed for sensitivity and reproducibility. When the results of this analysis were not acceptable or stabilization could not be achieved, then the graphite tube was discarded and replaced. Appendix B.4 details the operating conditions for each analyte studied using GFAA.

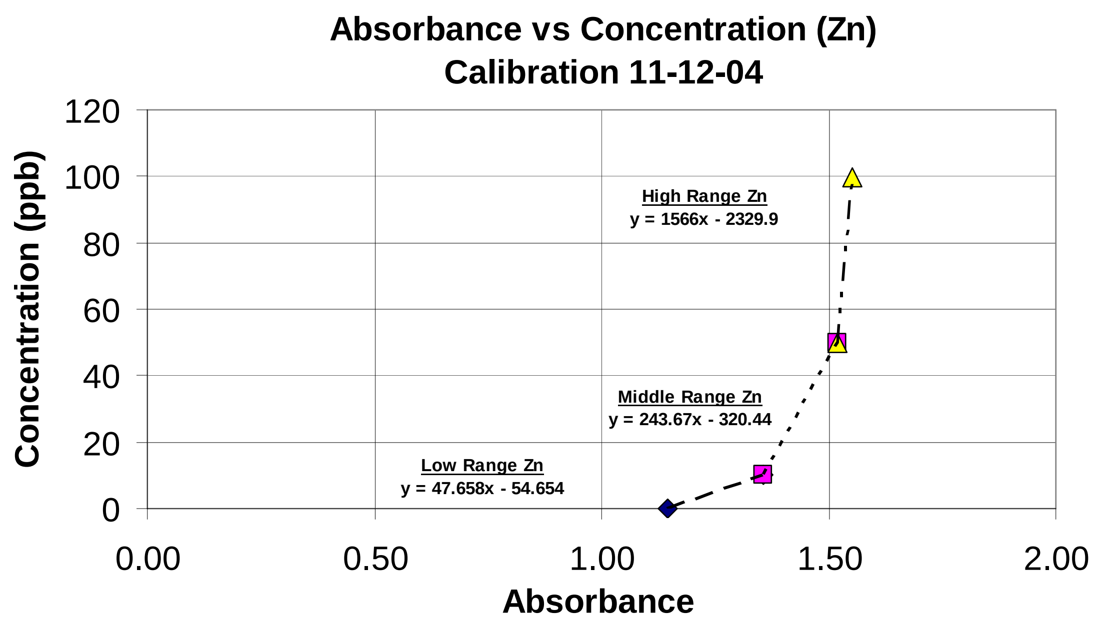


Figure 3.9: Multiple linear regressions used for GFAA analysis of zinc.

3.2.2.4 Physical Parameters

Physical parameters which were analyzed during this study include Total Dissolved and Suspended Solids, Conductivity and pH. Temperature was also recorded for purposes of confirming conductivity results which are temperature dependent. Temperature adjustment was used on the conductivity probe for purposes of quality assurance.

Both pH and conductivity were determined using the Hach Sension 156 Multiparameter meter. To determine pH, the Sension Model 51935-00 Gel-filled pH Electrode was used. The range of this instrument is 0 to 14 pH units. Each sample was analyzed individually directly in the sampling container. The Sension Conductivity Probe Model 51935-00 was used for analysis of conductivity. The range of this instrument is 0.01 uS/cm to 200 mS/cm. The accuracy of this recording is +- 0.5%. The samples analyzed in this study ranged from 11 uS/cm to 5,200 uS/cm. Within the range of 0.01 uS/cm and 19.99 uS/cm, the resolution for measurements of conductivity is 0.01 uS/cm. For a range of 20.0 to 199.9 uS/cm, the resolution for this instrument is 0.1 uS/cm. A range of 200.0 to 1,999 uS/cm, the resolution is 1.0 uS/cm. In between measurements, the pH electrode and the conductivity probe were rinsed in deionized water and blotted dry to prevent cross contamination.

For analysis of Total Dissolved Solids (TDS) Standard Methods 2540C was used. A well mixed sample was filtered through a standard fiber filter with a pore size of 1.5 microns. The filtered sample was then evaporated at 180 degrees Celsius in a pre-weighed, treated ceramic evaporating dish. The volume of the filtered sample was measured prior to evaporation. Evaporation continued until the difference in weight has stabilized (between 8 and 12 hours of drying). The difference between the pre and post evaporation weight of the dish was used along with the measured volume of sample to determine the concentration of dissolved solids in the sample. The concentration of TDS was determined by multiplying the difference in weight by 1000 (to convert grams to milligrams) and was divided by the sample volume in milliliters. It is important to note that for soil moisture samples, filtration did not occur because the sampling method for collection entailed suction lysimeters which have a ceramic intake cup with a pore size of 1.3 microns.

For analysis of Total Suspended Solids (TSS), Standard Method's 2540D was followed. A well mixed sample was filtered through a pre-weighed, prepared standard glass fiber filter with a pore size of 1.5 microns. The residue retained by the filter was then dried at 105 degrees Celsius for between 8 and 12 hours. After drying, the fiber filter was weighed. The difference between the pre and post drying weight of the filter was used along with the measured volume of sample to determine the concentration of suspended solids in the sample. The concentration of TSS was determined by multiplying the difference in weight by 1000 (to convert grams to milligrams) and was divided by the sample volume in milliliters. TSS was not analyzed for soil moisture samples due to sampling procedures which prevent this analysis.

3.2.2.5 Quality Assurance and Quality Control

The VUSP Water Resources Laboratory utilizes a number of techniques to maintain quality assurance and quality control. All instrumentation and laboratory equipment is decontaminated prior to the analysis of an event in order to prevent cross contamination of samples. The use of lab fortified reagent blanks is also employed during a sequence to prevent interferences during an analysis. Lab reagent blanks are made from distilled water which is degassed and de-ionized millique water (MQ 18.2 Ωcm). Standard reagents and blanks are made using the same procedures as those established for sample collection in order to maintain any uncertainty in the collection and analysis of water quality samples throughout the study. Standard calibration curves are established for each analyte tested and calibration checks are used within a sequence in order to check accuracy. If at any point during an analysis, the accuracy of the parameter being studied falls below 10%, a new calibration is used for the remainder of the test. Analytical spikes are also used during testing with 95% recovery in order to check for accuracy during testing.

Instrumentation and operator dependent detection limits (MDL) have been established for each analyte studied. Analytes which fall below the MDL are reported as non-detect (ND). In addition to this, another technique which is employed for data analysis is the use of minimum or maximum reportable limits (MRL). These limits are determined and are specific for each test performed. These limits represent the lowest or the highest concentration of standards within a calibration curve. Sample analysis which falls below or above this limit, are noted using the appropriate qualifier.

Data qualifiers were used to indicate qualitative and quantitative uncertainties in the results. All data is maintained in a master water quality notebook with the appropriate qualifiers. This data was then transferred to the Villanova network and was maintained in a spreadsheet format within the VUSP network folder. Table 3.3 shows the qualifiers used for this study.

Table 3.3: VUSP Qualifier Codes

Qualifier	**Description**
A	Value reported is the mean of two or more determinations
C	Value reported was calculated, in the event that the result was above or below the MRL.
D	Sample was diluted for analysis. Value is the calculated undiluted sample.
G	Value reported is the maximum of tow or more determinations, in the event that a duplicated sample was above the original.
H	Value is based on a field kit determination.
I	Interference. Value reported is not accurate.
J	Estimated. Value reported is not the result of an analytical method.
K	Off-scale low. Actual value not known but is less than the value reported. In the event that the sample was ND and the detection limit was reported.
L	Off-scale high. Actual value is not know but is known to be higher that the value reported. MRL was reported.
M	Presence of the material is verified but not quantified. The sample analysis was above the fortified blank but below the method diction limit.
Q	Sample was analyzed but was held longer than the recommended holding time for the analysis. Data should be used with discretion.
S	Laboratory test.
T	Value reported is less than the criteria of detection.
U	Analyte was not detected and the value reported is at the detection limit.
V	Analyte was detected in the method blank.

3.3 Water Quantity

Accurate water quantity monitoring is an integral part of this study. Water quantity monitoring equipment at this site includes a rain gauge, an ultrasonic level sensor, three soil moisture sensors and a v-notch weir. The first component being monitored is precipitation. For accurate rainfall measurements, an American Sigma (Model 2149) Tipping Bucket Rain Gauge has been installed. In conjunction with the rain gauge, accurate flow measurements are necessary to properly assess the water volume retained within the bio-infiltration basin. The basin water level is recorded using a Sigma 950 Ultra Sonic Level Detector. The volume of water captured by this BMP is calculated using a regression fit relationship between the surface water elevation and a calibrated hydraulic model which was developed during another study entitled; "Determining the Effectiveness of the VUSP Bio-Infiltration Traffic Island BMP" (Prokop, 2003). Water quantity data was continuously collected on 5 minute intervals. All data from the site was recorded on a Sigma 950 Data Logger and is uploaded onto the VUSP database via a Sigma Data Transfer Unit. This data was uploaded twice a month using American Sigma software and then maintained in the database using a spreadsheet format.

Figure 3.10 shows a photograph of the study area identifying various monitoring equipment. Precipitation events larger than 0.5 inches as recorded by the VUSP West Campus Gauge were analyzed for water quantity parameters. A total of 30 months of data was analyzed beginning in October, 2002 and continuing until March of 2005. A total of 6 months of quantity data was not included due to snow and icing conditions at the site which limit the capacity of the monitoring equipment to record accurate data.

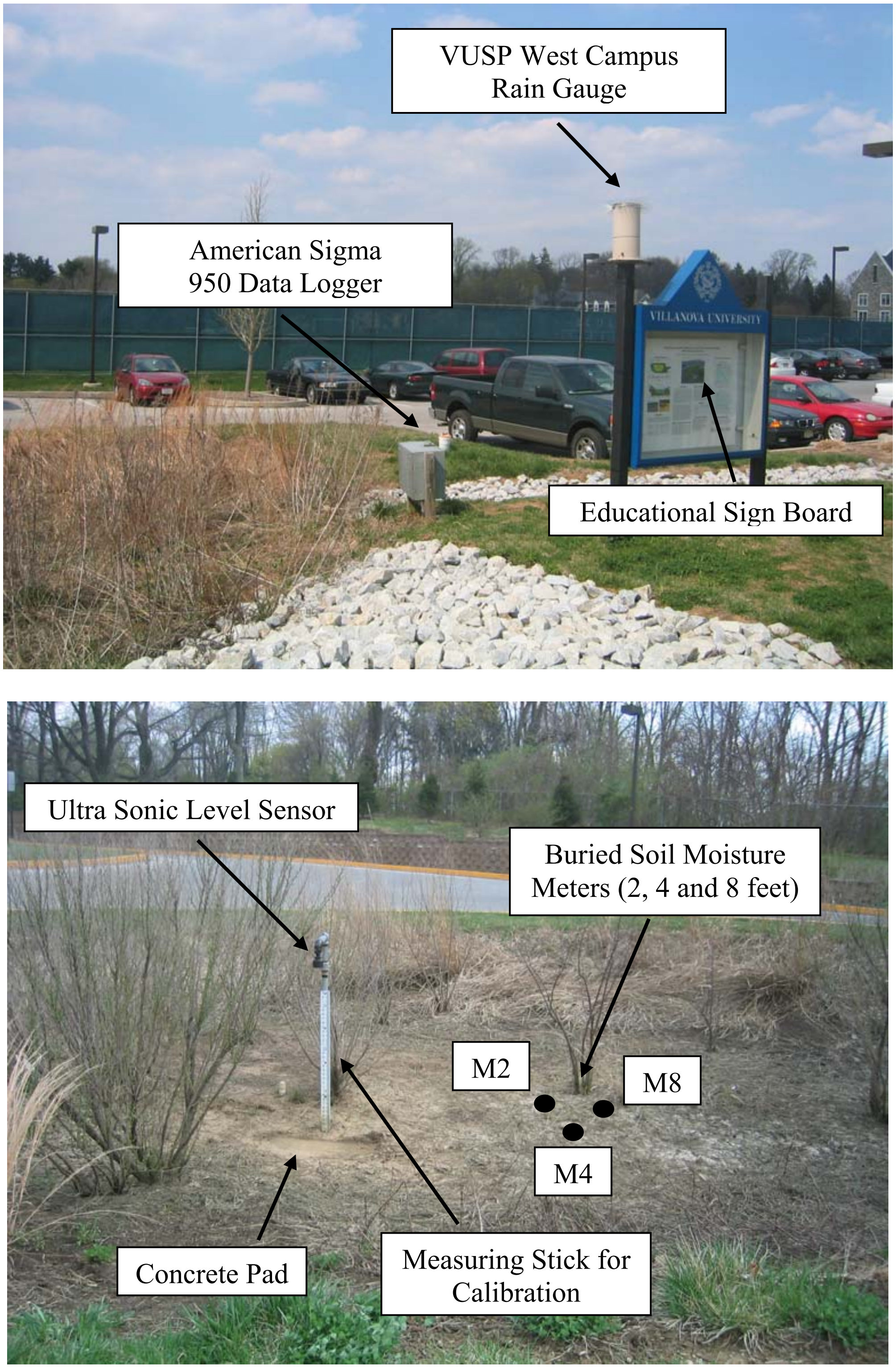


Figure 3.10: Site Hydrologic Monitoring Equipment

During an event, a calibration check was performed visually by comparing the recorded water level from the ultra sonic sensor and the observed level in the basin. A staff gauge which is accurate to 0.02 inches was installed adjacent to the level sensor for visual inspection. Event data is summarized in both graphical and tabular format in the results section of this report.

Water quantity parameters are defined as follows:

TOTAL PRECIPITATION: Precipitation is reported based on data collected by the VUSP West Campus Rain Gauge. This data is recorded on a continuous basis using a five minute interval. An event is defined based on the water level in the bed prior to a single gauge recording. If at any time during an event, the water level in the basin falls below a depth of 1.0 feet, then any additional rainfall at the site is considered a different event.

MAXIMUM ONE-HOUR INTENSITY: A running summation of all precipitation data collected at this site is collected on a one hour timeframe. This data is maintained using spreadsheet software and the maximum 1-hr intensity is reported for each event.

ANTECEDENT DRY TIME: The number of days preceding a single recording of precipitation prior to an event being analyzed as recorded by the VUSP West Campus Rain Gauge.

OVERFLOW: Stormwater runoff bypasses this site when the water level in the basin reaches a depth of 1.72 feet. A 90 degree V-notched weir is located in the outlet outflow. The recorded height of the water level over this weir is used with the weir equation to determine water flowing out of the site. The amount of water overflowing at the site is calculated in cubic feet per second over a time interval of five-minutes and is summed for every event. Overflow from the BMP is reported as inches of water over the watershed.

VOLUME: The amount of runoff into the BMP is reported based on a Hydrologic Model which uses the SCS Curve Number Method for analyzing stormwater runoff. Precipitation data is imported into the HEC-HMS model and total volume of runoff is calculated for each event.

INFILTRATION RATE: Infiltration is defined at this site as the change in water surface elevation with respect to time after a precipitation event. Infiltration is calculated as the slope of the receding limb of the water depth. It is important to note that during any events where overflow is recorded, the slope is calculated below 1.72 feet or the level of the weir. Also, the end-point for calculating the slope of the receding line is defined at a water level of 0.5 feet. This is done to prevent any interference from instrumentation noise.

PERFORMANCE: Two records of performance are maintained for every event at this site. The first is the site performance which compares the total rainfall at the site with the total overflow recorded as inches over the watershed. The BMP performance compares the total volume of runoff into the basin and with the total volume of runoff which overflows out of the site. The primary difference between the two figures is the initial abstractions by the pervious surfaces in the watershed which drains into the BMP.

EVENT-MEAN CONCENTRATION: The concentration of that would result if the entire storm event were collected at a single location (Shelley et al., 1987). This is determined by taking the average of two surface water samples SA1 and SA2 and is noted EMC.

3.4 Hydrologic Modeling and Statistical Methods

The publicly distributed HEC-HMS hydrologic modeling program was used for the analysis of stormwater runoff parameters associated with the drainage area of this site. Water quantity parameters were calculated from individual rainfall events using this program and were maintained in a spreadsheet database. These parameters were then analyzed against water quality parameters using statistical methods. Statistical methods used for this analysis include single and multi variable regression analysis.

3.4.1 Model Development and Calibration

The Thesis entitled, "Determining the Effectiveness of the Villanova Bio-Infiltration Traffic Island in Infiltrating Annual Runoff" is a complimentary study to this research (Prokop, 2003). This study used HEC-HMS to model the VUSP Bio-Infiltration BMP using the NRCS unit hydrograph and soil cover complex methods. This model was calibrated based on precipitation and water surface elevation data. The precipitation event on March 3, 2003 was used for verification of this model. The initial abstraction ratio of the impervious surface was determined, the drainage area was surveyed and a curve number and lag time were estimated. Based on this information, a storage versus outflow relationship was developed based on average infiltration rate and weir flow.

The Traffic Island Model (TI-Model) was used in this study to establish hydrologic variables at this site for certain event specific flow parameters. The TI-Model is divided into two drainage areas, pervious and impervious. A database was established to monitor hydrologic parameters from October of 2003 until May of 2005. Parameters such as Total Precipitation (P_{tot}) and Peak Intensity (I_p) were measured using onsite monitoring equipment. Other parameters such as Runoff Impervious or Pervious (R_i and

R_p), Total Volume (V_T) and Peak Flow (Q_p) were calculated using the TI-Model. Additionally, antecedent dry time (t_{dry}) data, a physically monitored parameter, was collected for each event.

These parameters were then used to evaluate correlations with water quality parameters also monitored. Initial correlations use measured parameters P_{tot}, I_p, and t_{dry} versus physical water quality parameters such as total dissolved (TDS) and suspended solids (TSS) and conductivity (Cond.) in order to establish possible correlation relationships. Additional correlations then incorporate calculated hydrologic parameters which are site specific such as R_i and R_p, V_T and Q_p to investigate this same correlation. In this thesis any measured or calculated value is referred to as a parameter however, when statistical methods are used for evaluation, these values are referred to as variables.

3.4.2 Statistical Methods

Graphical Analysis was incorporated to identify outliers within the data set. A specific variable was plotted and visually inspected for potential outliers. Once a potential outlier was identified, the value was eliminated from the set only if justified by the water qualifier or field notes. Data values were typically eliminated because of interference during testing, the value was below or above the MRL, the value was below the MDL or, an error was made during testing or sampling.

A correlation analysis was performed on variables in order to determine the degree to which certain variables are influenced by another. Correlation between variables indicates how well one can be predicted by the other. This statistical method was also used after a regression equation was developed as a quantitative index. The common variation squared is reported for each variable analyzed and is referred to as the correlation coefficient (R^2).

The purpose of performing a regression analysis is to investigate potential correlation variables and to quantify the extent of these relationships. The criterion variables in this study are water quality pollutants which were sampled and analyzed for during the rainfall events. The predictor or independent variables in this study are the water quantity parameters which were both measured and calculated. Linear bivariate regression was used to predict correlations and establish relation coefficients between two variable systems for comparison purposes. These established relationships were then compared to a linear multivariate regression relationships between the many hydrologic parameters monitored and calculated at this site. Regression coefficients were determined using both methods and are reported in an equation format:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4$$

Standard error of estimation has also been determined for each regression analysis. This value is reported along with standard deviation in order to demonstrate a physical indicator of the error which incorporated degrees of freedom lost due to regression. Also, an analysis of variance (ANOVA) for each regression model was calculated.

Averages are used in the determination of event mean concentration (EMC) which is the primary parameter used in all regression analysis and correlation variable investigation. The EMC is determined by averaging surface water samples within the basin pond. These samples are noted as SA1 and SA2. Averages are also used to report results over the study period. Additionally, statistical values which are reported for the entire study period are mean, maximum, minimum, standard deviation and sample size.

Chapter 4: Results and Discussion

4.1 Introduction

This chapter summarizes the results for water quantity and quality monitoring at the VUSP Traffic Island Bio-infiltration BMP. Three areas of interest are detailed in this section; water quantity results, quality results and correlation models between water quantity and quality variables. This chapter also discusses the implications and importance of any findings from this study.

4.2 Water Quantity Results

Water quantity parameters studied at this site are of two types: monitored and calculated. Monitored data includes hydrologic variables, or physical data which were collected using a number of data-collection and logging instrumentation (Chapter 3, Section 3). Monitored data includes; Total Precipitation (P_{tot}), Depth of Water in the Basin (d_w), Overflow Volume (V_{out}), Peak 1-hour Intensity (I_p), Average Infiltration Rate (Avg.Inf) and Antecedent Dry Time (t_{dry}). Calculated data were determined using HEC-HMS and include site specific runoff values (Chapter 3, Section 4). Calculated data include: Total Runoff Volume (V_{tot}), Peak Flow (Q_p) and Runoff Volume from two types of surfaces at the site, Impervious (R_i) and Pervious (R_p). Appendix C presents monitored data for water quantity parameters, selected event summaries and other data relevant to this section.

During this study a total of 30 precipitation events were monitored, ranging from 0.23 to 7.10 inches with an average precipitation of 1.55 inches. Table 4.1 summarizes the monitored water quantity data. Appendix C.2.1 shows the details of monitored data on an event basis.

Table 4.1: Summary of Monitored Water Quantity Parameters

Summary	Precipitation P_{tot} (in)	1-hr max intensity (in/hr)	Overflow V_{out} (in)	Overflow V_{out} (cu.ft)	Avg Inf (in/hr)	Ant. Dry Time t_{dry} (days)
Average:	1.55	0.34	0.37	1570	0.23	4.06
Maximum:	7.10	1.57	4.81	20304	0.38	11.86
Minimum:	0.23	0.08	0.00	0.00	0.14	0.13
Median	1.04	0.23	0.00	0.00	0.24	3.46
Std Dev:	1.44	0.35	0.97	4106	0.07	2.74
N:	30	30	29	29	26	30

A summary of calculated water quantity values is shown in Table 4.2. Appendix C.2.2 shows the entire data set for the thirty events used to determine these figures.

Table 4.2: Summary of Calculated Water Quantity Data

Summary	Runoff Volume Pervious V_P		Runoff Volume Impervious V_I		Total Runoff Volume $V_{in} = V_P + V_I$			Peak Flow Q_P
	(acre-ft)	(in)	(acre-ft)	(in)	(acre-ft)	(in)	(cu.ft)	(cfs)
Average:	0.03	0.51	0.05	1.34	0.08	0.83	3487.14	0.27
Maximum:	0.29	4.92	0.26	6.98	0.55	5.71	24120.58	1.78
Minimum:	0.00	0.00	0.00	0.08	0.00	0.03	125.98	0.02
Median	0.01	0.09	0.03	0.81	0.04	0.37	1559.35	0.13
Stn Dev:	0.06	1.00	0.05	1.44	0.11	1.16	4913.94	0.42
N:	30	30	30	30	30	30	30	30

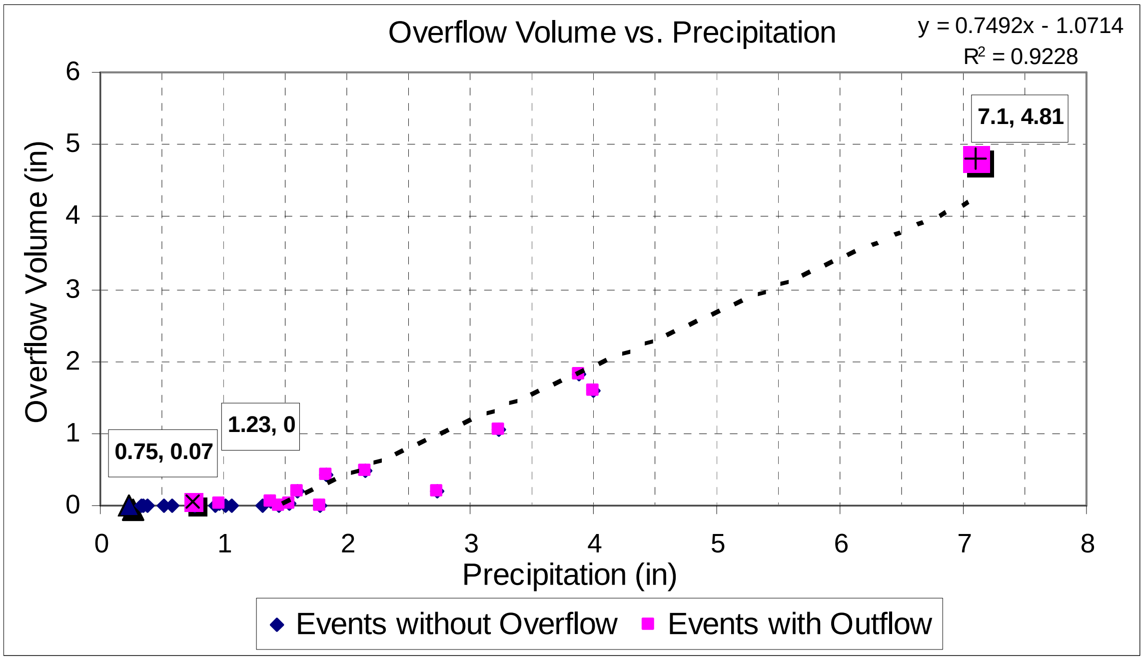
Plots of these data show relationships between various parameters at this site. Figure 4.1 plots Precipitation versus Overflow. In this figure it can be seen that overflow events occur in this BMP at a precipitation amount above the design precipitation of 1.0 inches. The minimum overflow event occurred with a precipitation amount of 0.75 inches on 2/3/04 with an overflow of 0.07 inches. A closer analysis of this event shows that other variables, such as antecedent dry time and peak one-hour intensity, do not explain this low precipitation-overflow event. When this event was analyzed in combination with previous precipitation, it was determined that this overflow resulted from a combined snow melt and precipitation event.

Events of larger precipitation did occur without overflow. The largest event without overflow occurred on 3/16/04 with an amount of 1.32 inches. This event corresponded to an average infiltration rate of 0.27 in/hr and an antecedent dry time of 6.48 days which may account for an event greater than 1.0 inches being retained without overflow. Plots of antecedent dry time and infiltration rate versus overflow do not show any obvious relationship among these parameters. A regression analysis of events that did have overflow does show a linear relationship between Overflow (V_{out}) and Total Precipitation (P_{tot}). Figure 4.1 shows the relationship to be,

$$V_{out} = 0.75 * P_{tot} - 1.07,$$

as previously defined. Note that this relationship applies only to precipitation events where overflow was observed. The r-squared value is 0.92 for this correlation. Setting Overflow (V_{out}) equal to zero and solving for Precipitation (P_{tot}) results in a precipitation value of 1.43 inches.

Figure 4.1: Precipitation versus Overflow



Precipitation versus Inflow Volume is also a very useful relationship because of the importance of determining inflow volume without monitoring flow. This relationship was determined using the calculated inflow-volume using the Traffic Island Model and precipitation data collected onsite. This entire data set can be seen in Appendix C.2.1. Figure 4.2 shows this relationship using Power Regression with an r-squared of 0.997. When used to predict runoff volume this relationship is accurate within acceptable limits of 10% below a precipitation amount of 4.8 inches. This relationship is useful when monitoring long-term effectiveness of this site to store and infiltrate stormwater runoff as well as for determining mass loading from known pollutants.

Figure 4.2: Inflow Volume vs. Precipitation

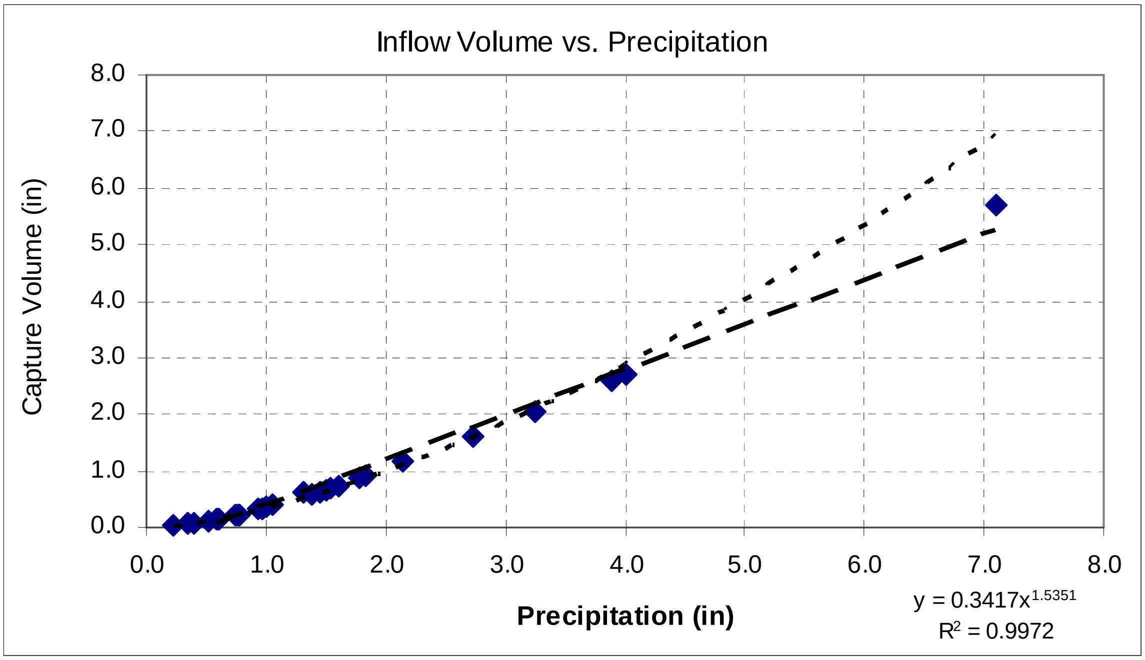


Figure 4.3 shows predicted inflow volumes using this relationship along with associated error for using the power equation to predict runoff volume, identifying the 10% error limit. This figure uses the relationship developed in Figure 4.2;

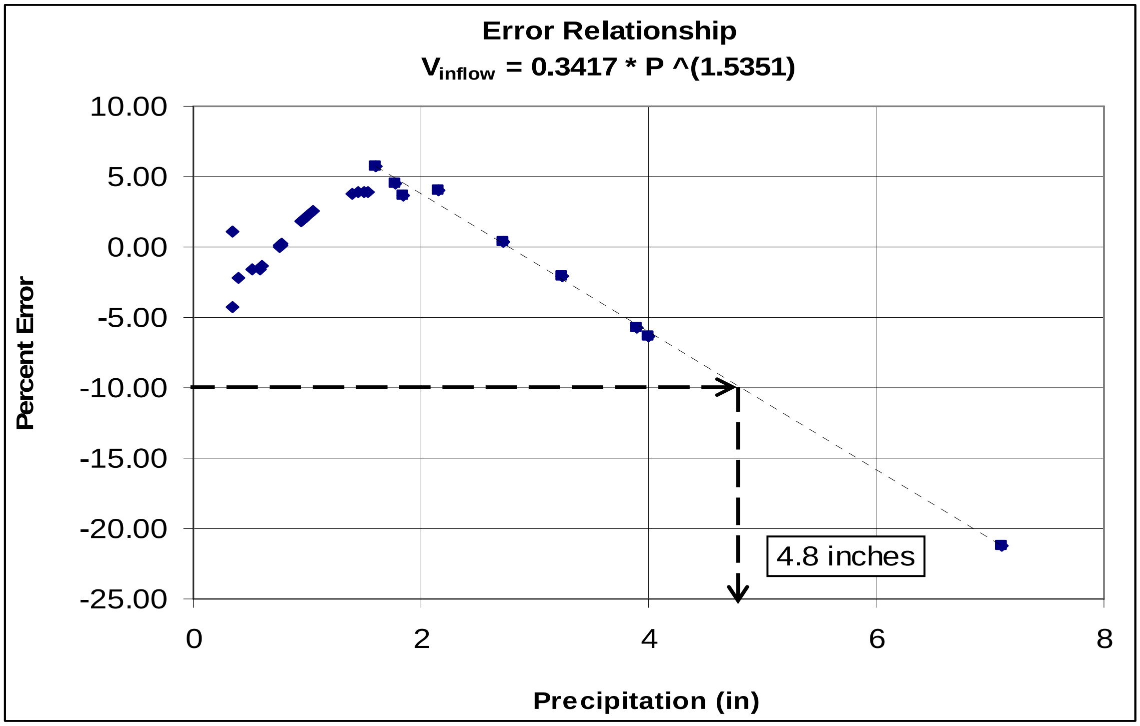
$$V_{in} = 0.342 * P_{tot}\text{\textasciicircum}1.535$$

to predict inflow volume, and then calculates percent error using;

$$\% \text{ Error} = (1 - V_{in.Predicted} / V_{in.TI\text{-}Model})*100.$$

Figure 4.3 is used to identify limits to the use of the power equation for predicting inflow volumes. It can be seen in Figure 4.3 that, using a limit of 10%, this equation can be used to predict inflow volume below a precipitation amount of 4.8 inches.

Figure 4.3: Error Relationship using the Power Equation to predict runoff volume



The largest event monitored at this site occurred on 9/27/04 with an amount of 7.1 inches and an overflow of 4.81 inches. Details from this event can be seen in Figure 4.4. On this figure, Water Depth is shown on the primary vertical axis in feet, precipitation is shown on the secondary vertical axis in reverse order, and time is shown on the horizontal axis in days. During this event, a total of 7.1 inches of rainfall fell over a 26 hour period. A maximum 1-hour intensity of 1.57 in/hr occurred at 5:30PM on 9/28/04. Table 4.3 shows the summary of data collected for this event. It can be seen that the Site Performance and the BMP Performance for this event was very low for this event 32.3% and 15.8% respectively. Site Performance and BMP Performance are determined using;

$$\text{Site Performance} = ((P_{tot} - V_{out}) / P_{tot})*100$$

$$\text{BMP Performance} = ((V_{in} - V_{out}) / V_{in})*100$$

as defined in Chapter 3.

Figure 4.4: Event Summary September 27, 2004

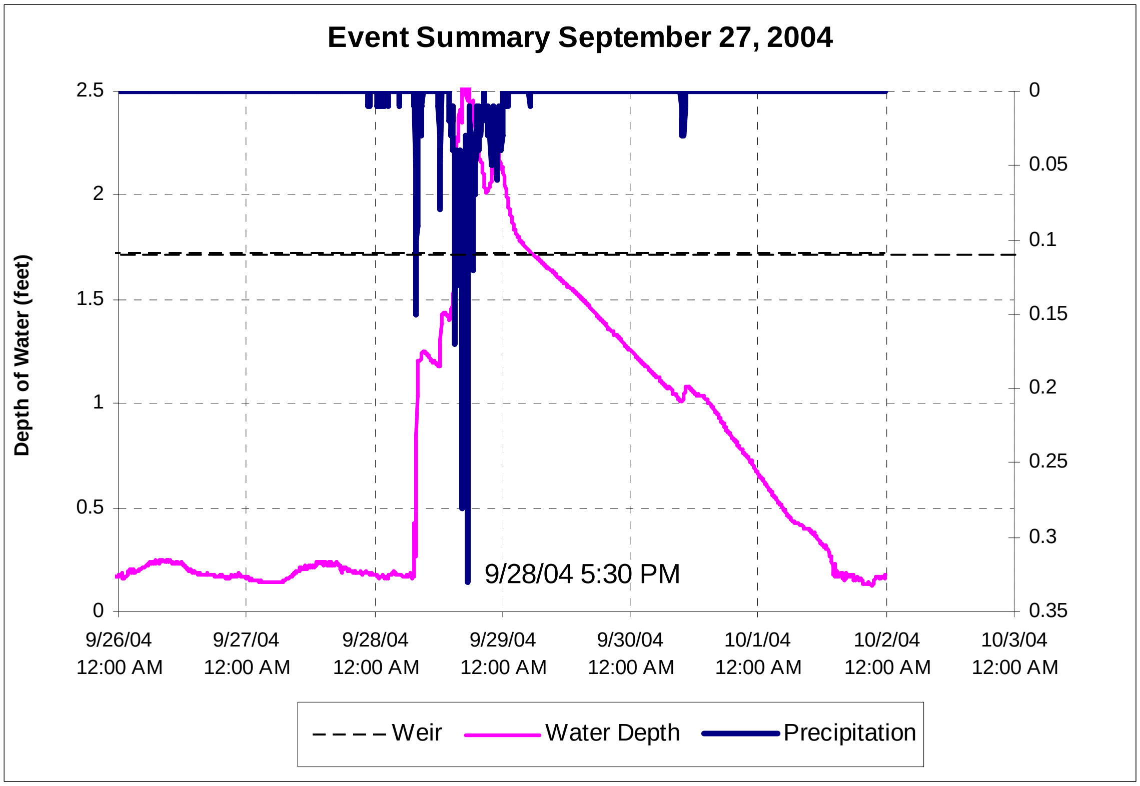


Table 4.3: Event Performance Summary 9/27/04

Event Summary				
	English		SI	
Total Rain (measured):	7.10	inches	18.03	cm
1hr Max Int. (measured):	1.57	in/hr	3.99	cm/hr
Overflow (measured):	4.81	inches	12.21	cm
	20287	cu.ft	574.5	cu.m
Average Infiltration Rate (measured):	0.38	in/hr	0.96	cm/hr
Volume Inflow (calculated):	5.71	inches	14.50	cm
	24103	cu.ft	682.5	cu.m

Performance Summary		
Site Performance (calculated):	32.3	%
BMP Performance (calculated):	15.8	%

Since this BMP was designed to manage smaller precipitation events, these data represent BMP performance under maximum hydrologic conditions. In Table 4.1, it can be seen that the average precipitation amount for this study was 1.55 inches. A more representative summary of BMP performance under average conditions can be seen in Figure 4.5 and Table 4.4. This event occurred on July 18, 2004 with a total precipitation of 0.94 inches, a 1-hr peak intensity of 0.19 in/hr and 0.0 inches of overflow.

Figure 4.5: Event Summary, July 18, 2004.

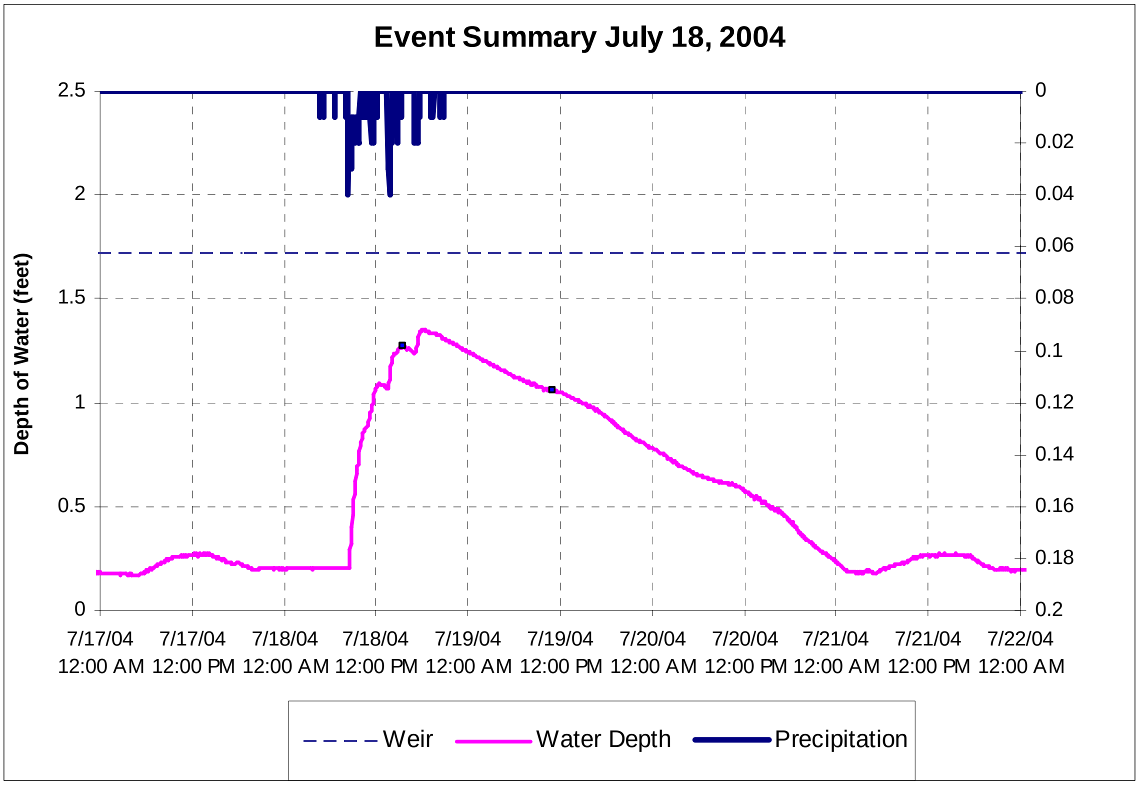


Table 4.4: Event Performance Summary, July 18, 2004

Monthly Summary				
	English		SI	
Total Rain:	0.94	inches	2.39	cm
1hr Max Int.	0.19	in/hr	0.48	cm/hr
Overflow:	0.00	inches	0.00	cm
	0.00	cu.ft	0.00	cu.m
Average Infiltration Rate:	0.24	in/hr	0.61	cm/hr
Volume Inflow:	0.32	inches	0.80	cm
	1333.89	cu.ft	37.8	cu.m

Performance Summary		
Site Performance:	100.0	%
BMP Performance:	100.0	%

Monthly Summary data can be seen in Appendix C.3 for the entire study period. Table 4.5 summarizes this data. This study period can be considered an above average year in terms of precipitation for this region which averages approximately 45 inches per year. During this study, 18 months of data yielded a total of 89.2 inches of rain or 59.5 inches annually. Two months of extreme precipitation were July 2004 and September 2004 with precipitation amounts of 10.48 and 10.36 inches, respectively. The poorest months in terms of BMP performance were September and August of 2004. The poor performance in August is due to an extreme event at the end of July 2004 which carried over into August and, little precipitation thereafter. Therefore, the three months of July, August and September of 2004 need to be considered together. February, 2004 also showed poor performance. However, this is attributed to snow melt from the previous month which was not quantified due to instrumentation limitations. Three months which did not have any overflow at the site were March, May and October of 2004 with precipitation amounts of 3.90, 3.41 and 2.75 inches respectively.

Analysis of performance using event data could be used to determine overall performance efficiency. However this data may misrepresent performance because smaller events would not be included within the data set. It is therefore recommended to use monthly summary data when reporting performance efficiency in order to include every data point for the study period. When analyzed on a monthly basis, the average Site Performance over the 18 month study period was 85.6% and the average BMP Performance was 80.3%.

Table 4.5: Summary of Monthly Water Quantity Data

Date	P_{tot} (in)	I_P (in/hr)	V_{out} (in)	Avg Inf (in/hr)	V_{in} (in)	Site Performance	BMP Performance
October-03	5.3	0.38	1.1	0.36	3.89	79.2	71.7
November-03	4.54	0.77	0.44	0.33	3.19	90.3	86.2
December-03	5.33	0.44	3.87	0.24	3.91	NA	NA
January-04	NA	NA	NA	NA	NA	NA	NA
February-04	**2.94**	0.38	0.56	0.17	1.78	**81.0**	**68.5**
March-04	3.9	0.29	0	0.25	2.61	100.0	100.0
April-04	7.05	0.38	0.24	0.26	5.53	96.6	95.7
May-04	3.41	0.44	0	0.17	2.17	100.0	100.0
June-04	4.04	1.01	0.18	0.28	2.74	95.5	93.4
July-04	**10.48**	1.35	3.39	0.22	8.85	**67.7**	**61.7**
August-04	3.16	0.94	1.06	0.23	1.97	**66.5**	**46.2**
September-04	**10.36**	1.57	5.5	**0.39**	8.73	**46.9**	**37.0**
October-04	2.75	0.46	0	NA	1.62	100.0	100.0
November-04	5.82	0.52	0.91	**0.15**	4.34	84.4	79.0
December-04	3.89	0.59	0.07	0.2	2.6	98.2	97.3
January-05	4.12	0.44	0.46	0.16	2.81	88.8	83.6
February-05	2.06	0.17	0.07	**0.15**	1.05	96.6	93.3
March-05	3.66	0.2	0.25	0.2	2.4	93.2	89.6
April-05	6.34	0.49	1.89	0.21	4.9	70.2	61.5
Average:	4.95	0.60	1.11	0.23	3.62	85.59	80.29
Maximum:	10.48	1.57	5.50	0.39	8.85	100.00	100.00
Minimum:	2.06	0.17	0.00	0.15	1.05	46.91	37.00
Median	4.08	0.45	0.45	0.22	2.78	90.31	86.21
Stn Dev:	2.37	0.38	1.57	0.07	2.22	15.20	19.55
N:	18	18	18	17	18	17	17

NA: Data not available due to interferences or equipment maintenance.

Another important parameter monitored at this site was average infiltration. Based on monthly summary data, the average infiltration rate was 0.23 inches per hour. A maximum of 0.39 in/hr was observed in September of 2004. A Minimum infiltration of 0.15 in/hr occurred twice at this site, once during the month of November, 2004 and again in February, 2005 (Table 4.5). In general, it has been observed that average infiltration at this site increases during the late summer months and decreases between the months of November and March. This is largely due to the definition of infiltration used for this study which includes all forms of storage within the basin; infiltration, evaporation and transpiration. For this research, infiltration is being monitored primarily for the purposes of studying long-term effectiveness of the BMP to retain runoff and thus, this definition is applicable for these purposes.

To quantify infiltration in more detail, a larger set of data is required. Archived data from the VUSP database were used to gain more insight into how infiltration varies during the design life of this BMP. This data, maintained on an event basis, contains a total of 96 data points between September, 2002 and April, 2005. These data can be seen in Appendix C.4.1. This data showed that, over this period, an average infiltration rate of 0.27 in/hr was observed. A maximum of 0.57 in/hr was observed on August 1, 2003 and a minimum of 0.13 in/hr was observed on May 17, 2003. Table 4.6 summarizes this data.

Table 4.6: Summary of Infiltration Data September 2002 to April 2005

	Avg. Inf (in/hr)
Average:	0.27
Maximum:	0.54
Minimum:	0.13
Median	0.25
Std Dev:	0.10
N:	96

Figure 4.6 graphs the entire data set of event-average infiltration rates over this period. A linear regression analysis of these data shows that the slope of the line is negative. The design life of this BMP can be estimated by performing a linear regression on this data and setting the regression equation equal to zero. Then, by solving this relationship for time in days and converting to years, a design life is estimated. When this calculation is performed, it is determined that the infiltration rate at the TI-BMP approaches zero at t = 9.16 years. From this regression analysis, it is also predicted that infiltration rates will decline by approximately 54.5% within 5 years of operation.

Appendix C.4.2 shows additional figures used for this analysis. It is important to note that while the total data set appears to show a declining infiltration rate, the minimum infiltration rate annually, appears to be stable at approximately 0.15 in/hr and is not declining.

Figure 4.6: Event-Averaged Infiltration Rates: Sept. 2002 – April 2005

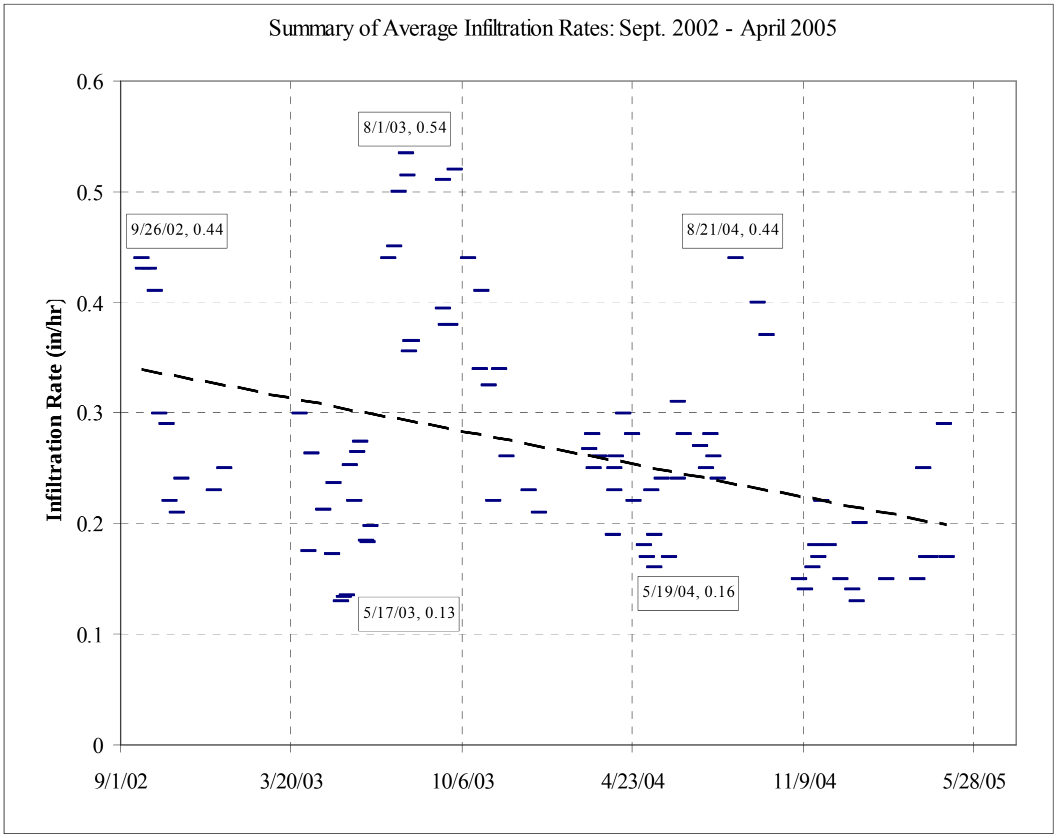
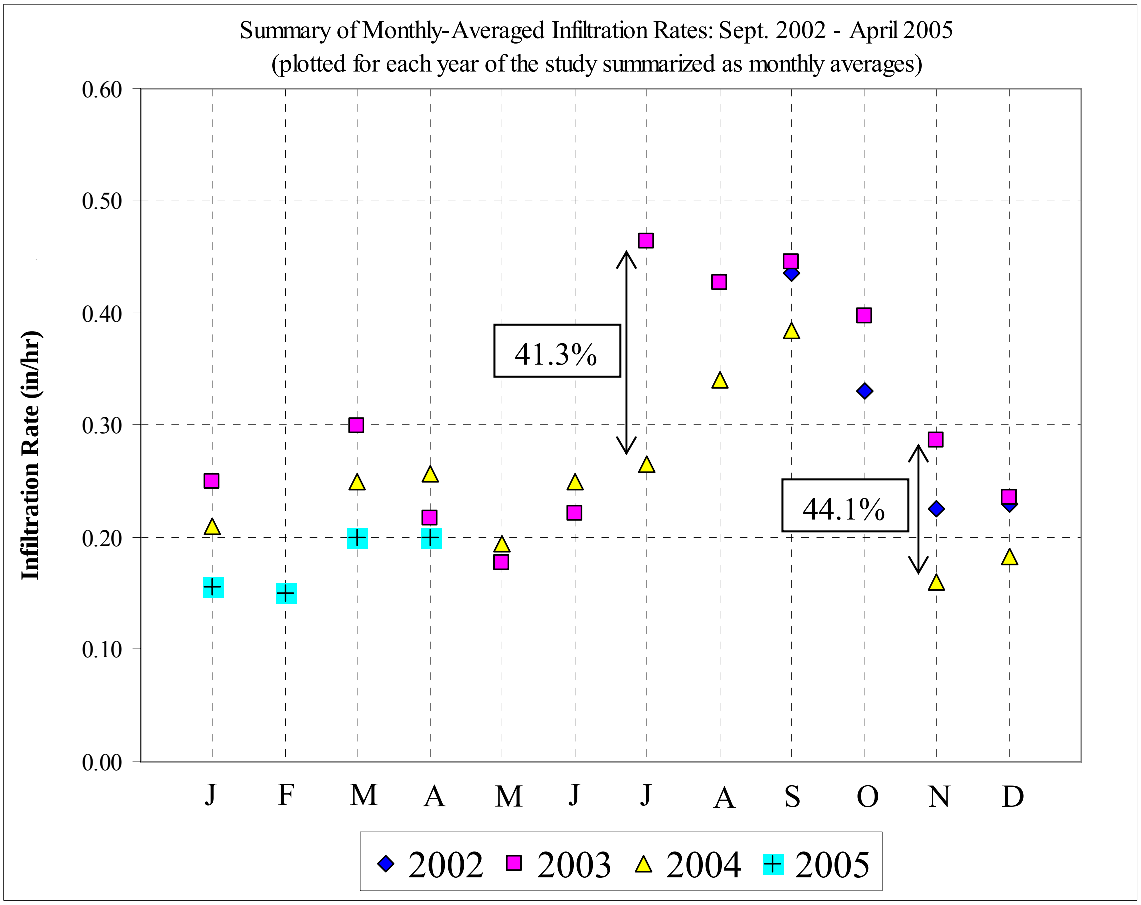


Figure 4.7 shows this same data for monthly-averaged infiltration and plotted separately for each year of the study. Two years of full data are available for 2003 and 2004 and partial data for the years of 2002 and 2005. Figure 4.7 averages event infiltration data for each month of the study and plots these data for comparison of seasonal variation in infiltration over the study period and annual differences in infiltration.

Figure 4.7: Summary of Monthly-Averaged Infiltration Rates



This plot along with Table 4.7 shows that a number of months exhibited a reduction in monthly-averaged infiltration rates when compared to the previous year's data. A maximum reduction occurred from November of 2003 to 2004 of 44.1%. During 2003 an annual average infiltration of 0.31 in/hr was observed while for 2004 an annual average of 0.25 in/hr was observed. This represents a 19.4% reduction in annual-averaged infiltration rate. For the period of available data for 2002 and 2005, an analysis of average infiltration shows that from 2002 to 2003 the average annual infiltration increased by 1.5%. From 2004 to 2005, a 29.2% reduction in average annual infiltration was observed. However, this data set is not complete for the year 2005 and needs additional research for verification. Table 4.7 shows the available data for annual infiltration based on monthly averages. A negative value in this table represents a reduction in infiltration, whereas a positive value represents an increase. This analysis suggests that a reduction in average infiltration has occurred over the period of the study when monthly averages are compared directly. The results presented in Table 4.7 show an average reduction in infiltration of -19.4% between the year 2003 and 2004. The regression analysis from Figure 4.6 shows a reduction of infiltration rate of -21.8% within the first two years of operation. These two analyses verify that infiltration rates are declining within the bio-infiltration basin.

Table 4.7: Average Monthly Infiltration Rates and Annual Percent Differences

Year:	2002	2003	2004	2005	2002-2003	2003-2004	2004-2005
	Monthly	Monthly	Monthly	Monthly	Percent	Percent	Percent
	Avg. Inf	Avg. Inf	Avg. Inf	Avg. Inf	Difference	Difference	Difference
Month	(in/hr)	(in/hr)	(in/hr)	(in/hr)	(%)	(%)	(%)
January	~	0.25	0.21	0.16	~	-16.00	-25.40
February	~	~	~	0.15	~	~	~
March	~	0.30	0.25	0.20	~	-16.87	-19.81
April	~	0.22	0.26	0.20	~	18.46	-22.08
May	~	0.18	0.20	~	~	10.38	~
June	~	0.22	0.25	~	~	13.19	~
July	~	0.46	0.27	~	~	**-41.3**	~
August	~	0.43	0.34	~	~	-20.37	~
September	0.44	0.44	0.39	~	0.41	-11.86	~
October	0.33	0.40	~	~	20.20	~	~
November	0.23	0.29	0.16	~	27.22	**-44.10**	~
December	0.23	0.23	0.18	~	0.00	-20.29	~

	2002	**2003**	**2004**	**2005**
Average:	0.305	0.309	0.249	0.177
% Difference:		1.5	-19.4	-29.2

4.3 Water Quality Results

Water quality components for this study include; analysis of first flush due to mixing, analysis of pollutant removal due to infiltration, and total mass loading of pollutants. In addition to this, water quality data summary tables are presented for analyzed parameters over the 18 month study period.

4.3.1 Analysis of First Flush

First Flush analysis includes water quality data collected from two first flush samplers located directly in the inlet curb-cuts of the BMP Traffic Island (Chapter 3.2.1). First flush samples (FF1, FF2) were compared directly to averaged surface water samples (SA1, SA2) to establish trends in pollutant removal due to the settling and mixing of stormwater runoff. Due to the nature and location of FF1 and FF2, averages were used so that direct comparisons could be made between first flush samples and basin surface samples. Sampling for this analysis began in July, 2004, and ended in March, 2005. A total of nine precipitation events were used to quantify percent removal as a result of capture and induced settling of first flush runoff. From the entire data set of water quality parameters, a number of data points were eliminated for QAQC purposes. In addition to this, other data points were identified as outliers using scatter plots and were reconsidered for use in the data set. Some data points were eliminated from this set because of human or instrumentation error during sampling or analysis.

Table 4.8 summarizes the results and Appendix D.1 shows the entire data set used for this analysis. Table 4.8 shows the percent reduction in each water quality parameter studied due to mixing and settling of precipitation excess entering the BMP. A number of parameters showed an increase in concentration from the curb cut location to the basin surface water. These parameters, therefore, show a negative reduction (an increase in concentration) and are shown as negative values in this table. It should be noted that the overall data for the analysis of first flush reduction in pollutant concentration is small and that these results need to be confirmed with additional sampling.

The values used in Table 4.8 were determined by averaging the concentrations of two first flush samples and then comparing the data with two averaged samples taken from the basin water surface. Percent reduction was then determined using the following relationship;

$$\text{Percent Reduction} = (1-\text{EMC}/\text{AvgFF})*100 \text{ where,}$$

$$\text{EMC} = (\text{SA1} + \text{SA2})/2, \text{ Event Mean Concentration}$$

$$\text{AvgFF} = (\text{FF1} + \text{FF2})/2, \text{ Average First Flush.}$$

In the event that an increase in concentration was observed from the average First Flush to the Event Mean Concentration, then the following relationship was used;

$$\text{Percent Increase} = -(1- \text{AvgFF}/\text{EMC})*100,$$

with a negative denoting the increase in concentration.

From this table, it can be seen that largest reduction in pollutant concentration due to first flush capture is Total Suspended Solids (TSS) with an average of 91.7% reduction. Since the standard deviation of the TSS data set is 4.3, these results are reliable however, the small sample size (n=5) suggests that further testing is needed. Nonetheless, this reduction in concentration is significant because the majority of water quality parameters are correlated with TSS. It is, therefore, not surprising to see reductions in other measured parameters such as metals; Cu (46.5%), Pb (55.2%), Cr (61.9%) and Zn (16.9%). Conductivity, Total Dissolved Solids (TDS) and Total Nitrogen show a consistent reduction in concentration of 43.0%, 38.3% and 47.9% respectively. These reductions in pollutant concentration are attributed to both settling of solids at the inlet location and mixing of first flush runoff with direct precipitation and less polluted runoff. Sedimentation of suspended solids has been observed at the inlet location (Figure 3.2).

Table 4.8: Percent Reduction in First Flush Concentration

Measured Parameter	**N**	**Average Difference (%)**	**Minimum Difference (%)**	**Maximum Difference (%)**	**Standard Deviation**
Conductivity (uS/cm)	7	43.0	27.0	63.3	13.0
Total Suspended Solids (mg/L)	5	91.7	84.6	95.2	4.3
Total Dissolved Solids (mg/L)	6	38.3	9.04	52.3	15.6
Total Nitrogen (mg/L-N)	6	47.9	6.25	100	35.8
Total Phosphorous (mg/L-PO_4)	6	1.07	-48.2	33.9	29.6
Chloride (mg/L-Cl)	4	4.6	-12.0	30.0	20.1
Nitrite (mg/L NO_2-N)	4	-18.7	-55.5	38.2	40.8
Nitrate (mg/L NO_3-N)	4	39.8	27.1	61.7	15.1
Ortho Phosphate (mg/L-PO_4)	4	-11.6	-54.74	41.03	48.9
Dissolved Copper (ug/L – Cu)	6	46.5	-0.88	85.1	32.1
Dissolved Lead (ug/L – Pb)	4	55.2	39.3	100	29.9
Dissolved Chromium (ug/L - Cr)	6	61.9	-23.6	97.7	47.6
Dissolved Zinc (ug/l – Zn)	6	16.9	-35.8	82.9	46.6

Some parameters such as Total Phosphorous, Chloride, Nitrite and Ortho-Phosphate showed a large variation in reduction. For example, the analysis of Total Phosphorous shows a maximum reduction in concentration of 33.9% and a maximum increase in concentration of -48.2%. The average difference in concentration for Total Phosphorous from the inlet to the basin pond is 1.07%. Parameters which showed both an increase and decrease in pollutant concentration over the nine month study period of first flush were Total Phosphorous, Chloride, Nitrite, Ortho Phosphate, Chromium and Zinc.

A graphical interpretation of first flush is seen in Appendix D.2. These figures show each individual water quality parameter for both inlet locations (FF1, FF2) and the basin surface water (SA) and include the entire data set for each parameter. Figure 4.8 details this analysis graphically for Total Suspended Solids. It can be seen from this data set that, TSS was reduced from an overall average concentration of 638.5 mg/L and 251.4 mg/L at the inlet curb cuts to an average of 20.1 mg/L within the basin. This figure uses all data available from July of 2004 to March of 2005 and includes a total of 7 first flush samples at each inlet and 16 basin pond samples during 9 precipitation events. This represents a reduction of approximately 95.5% for the entire data set which corresponds with the average reduction of 91.7% when analyzed on an event basis.

Table 4.9 summarizes the average concentrations for parameters studied which are also identified graphically in Appendix D.2. This table shows reduction in concentrations using average values for the entire data set as compared to Table 4.8 which considers each individual event and determines percent reduction. In Table 4.9 and Appendix D.2 it can be seen that water samples collected from FF1 consistently have higher concentrations than samples collected from FF2. This difference can be attributed to the difference in elevation between these two inlets which results in more sedimentation buildup in the eastern inlet because it is approximately 2 feet below the southern inlet (see Figures 3.1 & 3.2). Sedimentation buildup has been confirmed with field observations at the FF1 location. In fact, during all sampling events, the first flush sampler located at FF1 had to be swept clean of sediment prior to collection due to sediment buildup at this location.

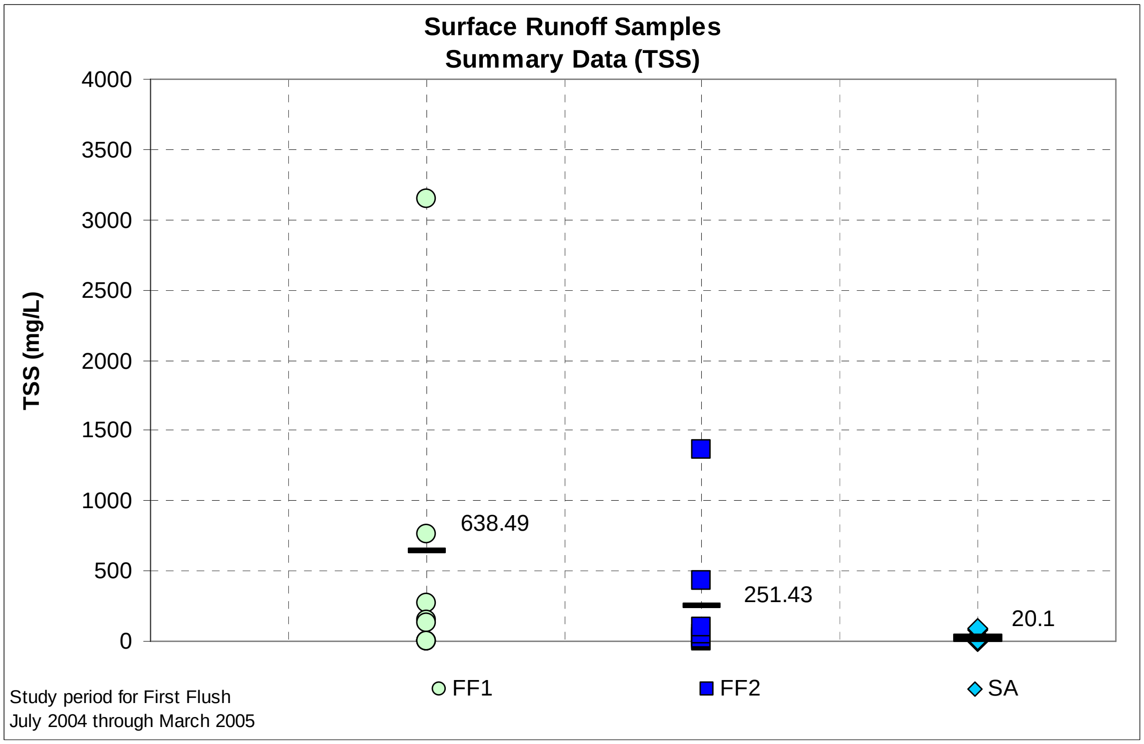
Table 4.9: Average Concentrations for Surface Runoff Samples

(July 2004 through March 2005)

Measured Parameter	FF1	FF2	SA	Percent Difference
pH	7.40	7.36	7.68	**-3.91**
Conductivity (uS/cm)	88.7	61.0	68.5	8.53
Total Suspended Solids (mg/L)	638	251	20.1	95.5
Total Dissolved Solids (mg/L)	81.7	47.9	61.4	5.25
Total Nitrogen (mg/L-N)	1.49	1.39	0.89	38.2
Total Phosphorous (mg/L-PO_4)	0.91	0.77	0.87	-3.45
Chloride (mg/L-Cl)	18.5	5.71	10.1	17.0
Nitrite (mg/L NO_2-N)	0.14	0.09	0.13	-11.5
Nitrate (mg/L NO_3-N)	0.50	0.34	0.34	19.0
Ortho Phosphate (mg/L-PO_4)	0.52	0.34	0.91	-52.7
Dissolved Copper (ug/L - Cu)	7.05	10.1	3.51	59.1
Dissolved Lead (ug/L - Pb)	1.94	1.55	0.75	57.0
Dissolved Chromium (ug/L - Cr)	11.2	11.8	4.11	64.3
Dissolved Zinc (ug/L - Zn)	73.8	49.5	51.8	16.0

Figure 4.8: Surface Runoff Concentration for Total Suspended Solids

(April 2004 through March 2005)



4.3.2 Analysis of Pollutant Removal and Infiltration

Any stormwater management practice which uses infiltration as a mean to control runoff needs to consider the potential for introducing pollutants into subsurface groundwater aquifers through recharge. In this study, water quality parameters were analyzed by collecting subsurface infiltrated stormwater runoff through the use of suction lysimeters located below the infiltration basin's surface (see Chapter 3.2.1.b). Both surface and infiltrated-subsurface runoff samples were compared with National Drinking Water Standards to identify concentration levels which may pose problems in areas where groundwater is the primary source of drinking water. Subsurface samples were also compared to surface water samples within the basin in order to quantify any increase or decrease in concentration as a result of infiltration.

To identify potential water quality issues with infiltrating stormwater runoff, allowable limits were selected using pollutant concentrations from the EPA Surface and Drinking Water Quality Guidelines. Table 4.10 identifies the criteria used for this analysis along with the rationale for using the guidelines. Since no samples analyzed for dissolved metals exceeded the allowable limits for drinking water, it was more useful to apply a guideline which was 100 times more stringent that the EPA criteria. For the analysis of Total Nitrogen and Total Phosphorous, the surface water quality guidelines established for Region IX, South Eastern Temperate Forest Plains and Hills was used as the allowable limit.

Table 4.10: Allowable Limits for Analysis of Runoff Quality

Measured Parameter	Allowable Limit	Rationale
pH	6.5 - 8.5	= National Primary Drinking Water Guideline (EPA)
Total Dissolved Solids (mg/L)	500	= National Secondary Drinking Water Guideline (EPA)
Total Nitrogen (mg/L)	0.69	= Region IX, Surface Water Guideline
Total Phosphorous (mg/L)	0.11	= Region IX, Surface Water Guideline
Chloride (mg/L)	250	= National Secondary Drinking Water Guideline (EPA)
Nitrite (mg/L NO_2-N)	1	= National Primary Drinking Water Guideline (EPA)
Nitrate (mg/L NO_3-N)	10	= National Primary Drinking Water Guideline (EPA)
Ortho Phosphate (mg/L PO_4)	0.5	= VUSP Established Criteria.
Dissolved Copper (ug/L)	13 x 100	= National Primary Drinking Water Guideline (EPA)
Dissolved Lead (ug/L)	0.15 x 100	= National Primary Drinking Water Guideline (EPA)
Dissolved Chromium (ug/L)	1 x 100	= National Primary Drinking Water Guideline (EPA)
Dissolved Zinc (ug/L)	50 x 100	= National Primary Drinking Water Guideline (EPA)

Table 4.11 shows results for each sample location along with the sample size for each constituent analyzed using the criteria in Table 4.10. Table 4.11 was constructed by physically counting each sample which was above the criteria and dividing the total samples above the limit by the total sample size. A total of twenty seven events were sampled. For this analysis Percent Exceedence is defined as the percentage of samples which did not meet the criteria for allowable limits.

Samples collected from L8 were analyzed on an event specific basis, it has been determined that 85.2 % of the events did not pass the allowable criteria. This may be misleading however because this criteria uses a combination of both surface water guidelines and both primary and secondary drinking water guidelines. When these criteria are adjusted for allowable limits using only the primary and secondary drinking water guidelines, allowing for 10 mg/L Total Nitrogen and 2.0 mg/L Total Phosphorous; 29.6% of the samples from L8 did not pass.

Some concern can be identified with introducing chloride into the subsurface due to heavy road salting in the area during winter months. From this analysis, it can be seen that while 20% of the surface water samples exceeded the 250 mg/L criteria, the percent exceedence was reduced in the subsurface to 12% and 11% at 4 and 8 feet below the surface. Assuming a mass balance of chloride in the system, this suggests that chloride is being retained in the basin during the months of January and February and is then released and diluted during periods of heavy rains in the warmer spring and summer months. At the same time, chloride levels this is not a major concern in that the level of 250 mg/L is a secondary drinking water quality guideline. Additional dilution would be expected to occur naturally when this infiltrated water reaches an aquifer, thus reducing chloride concentration to within acceptable levels.

Another interesting result shown in Table 4.11 is the reduction in percentage of samples which have exceeded the allowable limits from the surface to the subsurface. Total Nitrogen concentrations at the surface exceeded the surface water criteria 68.9% of the time. This exceedence is reduced to 54.4% and 33.3% in the subsurface at L4 and L8 respectively. The same result is seen for Total Phosphorous which exceeded the criteria 93.5% of the time at the surface and 87% and 55.6% of the time at L4 and L8 respectively. These results suggest that the use of bio-infiltration BMPs for nutrient removal of non-point source pollutants from surface waters is effective.

From an analysis of dissolved inorganic constituents such as metals, it can be seen that reduction in exceedence from surface runoff to infiltrated runoff is small. The allowable limits for analysis of metals were 100 times less than the national drinking water standards for these constituents. This is because no samples analyzed for metals exceeded the actual guidelines. In Table 4.11, it is seen that all dissolved metal parameters showed a small increase in exceedence from SA to L4 and then a slight decrease in exceedence from L4 to L8. Of 26 samples analyzed for dissolved copper at SA, 23.1% exceeded the allowable criteria (13 ug/L) and, 0% exceeded the drinking water guideline (1.3 mg/L). Of 11 samples analyzed for dissolved copper at L4 and L8, 27.3% exceeded the allowable criteria and, 0% exceeded the drinking water guideline. Similar results are observed for other metals with the exception of one sample at L4 which did not pass the drinking water criteria for dissolved lead. Both criteria for percentage of samples exceeding allowable limits for metals are shown in Table 4.11.

Table 4.11: Percent Exceedence for Surface and Subsurface Stormwater Runoff

Measured Parameter	Allowable Limits	SA		L4		L8	
		n	% Samples exceeding allowable limits	n	% Samples exceeding allowable limits	n	% Samples exceeding allowable limits
pH	6.5 - 8.5	56	17.9	28	17.9	27	3.7
Total Dissolved Solids (mg/L)	500	56	8.9	28	28.6	27	11.1
Total Nitrogen (mg/L)	0.69	45	68.9	22	54.5	27	25.9
Total Phosphorous (mg/L)	0.11	46	93.5	23	87.0	27	55.6
Chloride (mg/L)	250	55	20.0	25	12.0	27	11.1
Nitrite (mg/L NO_2-N)	1	15	0.0	12	25.0	27	11.1
Nitrate (mg/L NO_3-N)	10	18	0.0	13	0.0	27	0.0
Ortho Phosphate (mg/L PO_4)	0.5	15	40.0	11	0.0	27	0.0
Dissolved Copper (ug/L)	13 (1300)	26	23.1 (0.0)	11	27.3 (0.0)	11	27.3 (0.0)
Dissolved Lead (ug/L)	0.15 (15)	14	71.4 (0.0)	8	87.5 (12.5)	11	63.6 (0.0)
Dissolved Chromium (ug/L)	1 (100)	14	64.3 (0.0)	8	87.5 (0.0)	11	63.6 (0.0)
Dissolved Zinc (ug/L)	50 (5000)	14	42.9 (0.0)	8	37.5 (0.0)	11	27.3 (0.0)

To quantify differences between surface runoff samples and infiltrated runoff samples, 25 precipitation events were available. Direct comparisons of pollutant concentrations were made between infiltrated samples at a depth of 8 feet below the basin surface (L8) and event mean concentrations (EMC). Various parameters from the sample set were eliminated for QAQC purposes based on field notes and data outliers. In the event that a set of water quality parameters was eliminated, substitutions were made from infiltrated runoff samples collected at 4 feet below the basin. Appendix D.3 shows the data used for this analysis along with data tables for percent reduction or increase in concentration, as observed. An increase in concentration from the collection point at the surface to the sample collected at the subsurface is considered a negative value and a decrease or reduction in concentration is considered a positive value.

Table 4.12 shows the statistical summary of this analysis for event mean concentrations which are the average of event specific surface water samples collected at SA. Table 4.13 shows the statistical summary of these data for infiltrated-subsurface runoff samples at L8. A comparison of average concentration values for each constituent studied between both locations shows a number of water quality influences as a result of infiltrating stormwater runoff. These influences are made more apparent when seen in conjunction with Table 4.14, which summarizes the percent decrease (positive) and percent increase (negative) in concentration. Table 4.14 has been constructed using data which can be seen in Appendix D.3 and uses the same relationship established for analyzing first flush.

Both conductivity and total dissolved solids show a significant increase in concentrations as a result of infiltration. This is to be expected because of the typically higher concentrations of these parameters in groundwater. Additional parameters which show an increase in average concentration due to infiltration are: Total Nitrogen (0.85 mg/L to 1.24 mg/L), Chloride (49.1 mg/L to 136.3 mg/L), Nitrite (0.10 mg/L to 0.4 mg/L), Lead (1.13 ug/L to 2.92 ug/L) and, Chromium (2.59 ug/L to 16.9 ug/L)

Total Nitrogen which shows an increase in average concentration as runoff passes through the system from the basin surface (EMC) to a depth of 8 feet (L8) is not a conclusive result because the average concentration for both locations is below the recommended detection limit for the instrument of 2.0 mg/L. A more appropriate comparison of Total Nitrogen would compare number of samples collected for each location which did exceed the MDL of the instrument. Of the twenty samples used for this comparison, no surface water samples which were collected from within the basin (EMC) exceeded the threshold of 2.0 mg/L. Of this same sample set however, a total of 4 samples collected at L8 exceeded the 2.0 mg/L detection criteria (see Appendix D.3). Although, Nitrite concentrations increase with depth, from SA to L8; Nitrate levels decrease from SA to L8. Additional research is recommended to quantify this specific effect and to determine whether this observation is a result of anaerobic conversion of different forms of Nitrogen.

Total Phosphorous average concentration decreases as a result of infiltration from 0.63 mg/L to 0.43 mg/L. Additional parameters which show a decrease in average concentration due to infiltration are: Nitrate (0.40 mg/L to 0.10 mg/L), Ortho Phosphate (0.20 mg/L to 0.01 mg/L), Copper (7.28 ug/L to 4.56 ug/L) and, Zinc (53.02 ug/L to 50.31 ug/L).

Table 4.12: EMC (SA) Data Summary for Analysis of Infiltrated Runoff

Measured Parameter	n	Average EMC (SA)	Max EMC (SA)	Min EMC (SA)	Std Dev EMC (SA)
pH	25	7.30	8.68	5.77	0.69
Conductivity (uS/cm)	23	134.3	1729	25.20	351.1
Total Dissolved Solids (mg/L)	22	108.9	864.5	22.70	180.0
Total Nitrogen (mg/L)	20	0.85	1.53	0.00	0.48
Total Phosphorous (mg/L)	18	0.63	1.70	0.05	0.39
Chloride (mg/L)	18	49.08	511.6	0.62	132.2
Nitrite (mg/L NO_2-N)	19	0.10	0.73	0.00	0.20
Nitrate (mg/L NO_3-N)	19	0.40	3.10	0.00	0.80
Ortho Phosphate (mg/L PO_4)	19	0.20	1.26	0.00	0.34
Dissolved Copper (ug/L)	12	7.28	19.00	0.00	6.66
Dissolved Lead (ug/L)	7	1.13	3.38	0.00	1.23
Dissolved Chromium (ug/L)	7	2.59	9.90	0.00	3.65
Dissolved Zinc (ug/L)	7	53.02	110.4	2.06	43.85

Table 4.13: L8 Data Summary for Analysis of Infiltrated Runoff

Measure Parameter	n	Average L8	Max L8	Min L8	Std Dev L8
pH	25	6.78	7.86	4.33	0.79
Conductivity (uS/cm)	23	685.3	4262	52.20	874.8
Total Dissolved Solids (mg/L)	22	469.6	2292	163.4	441.0
Total Nitrogen (mg/L)	20	1.24	4.00	0.00	1.27
Total Phosphorous (mg/L)	18	0.43	0.86	0.05	0.24
Chloride (mg/L)	18	136.3	1306	0.92	304.1
Nitrite (mg/L NO_2-N)	19	0.40	2.66	0.00	0.82
Nitrate (mg/L NO_3-N)	19	0.11	0.59	0.00	0.20
Ortho Phosphate (mg/L PO_4)	19	0.01	0.28	0.00	0.06
Dissolved Copper (ug/L)	12	4.56	17.40	0.00	6.36
Dissolved Lead (ug/L)	7	2.92	4.96	0.00	1.83
Dissolved Chromium (ug/L)	7	16.90	86.74	0.19	31.00
Dissolved Zinc (ug/L)	7	50.31	125.7	1.59	50.85

Table 4.14 was constructed by taking individual event based results for EMC and L8 parameters and identifying a percent increase (-) or decrease (+) in concentration as seen in Appendix D.3. This table confirms the results presented in Tables 4.12 and 4.13 by identifying average percent differences in concentration for the parameters studied. With the exception of Total Nitrogen, this analysis confirms either an increase or a

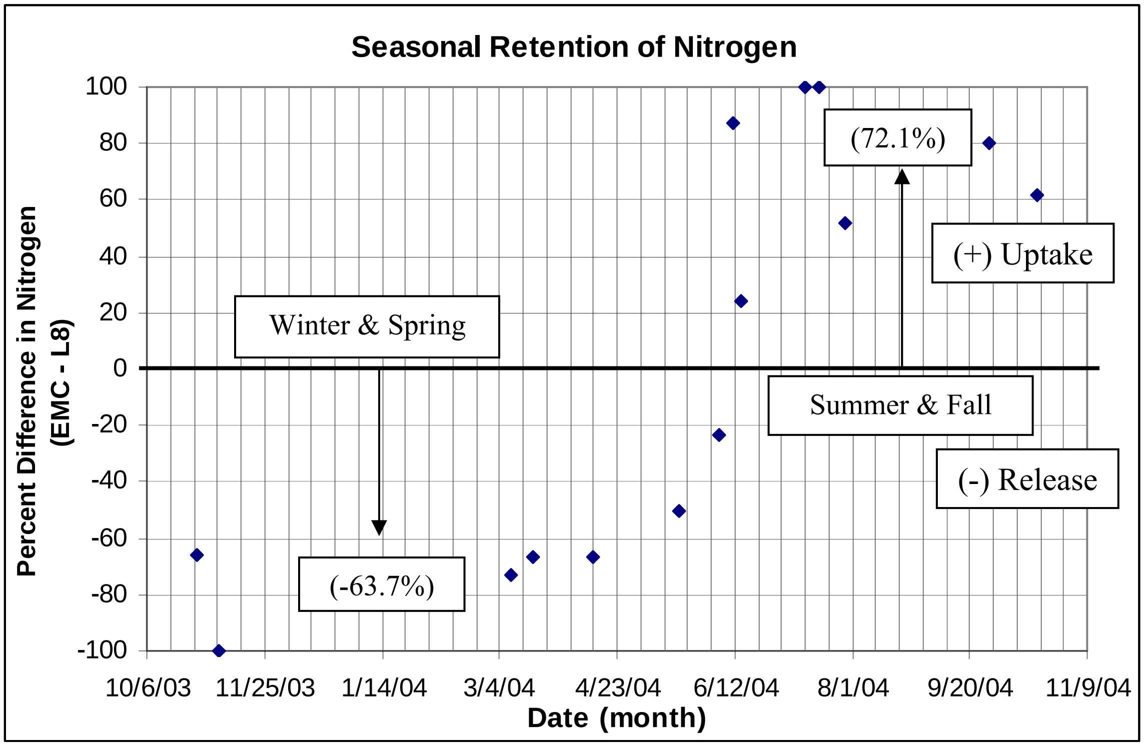
decrease in concentration for all parameters studied. In Table 4.14, Total Nitrogen shows a decrease in concentration of 4.14% from the surface runoff to the infiltrated runoff, where as in Table 4.12 and 4.13, it shows an increase in average concentration.

Table 4.14: Percent Difference in Concentration due to Runoff Infiltration (Event Based)

Measured Parameter	Number	Average Difference (%)	Maximum Difference (%)	Minimum Difference (%)	Standard Deviation
pH	25	6.98	35.98	-26.59	12.19
Conductivity (uS/cm)	23	-82.02	-43.42	-96.45	15.72
Total Dissolved Solids (mg/L)	22	-79.45	-48.77	-95.09	13.08
Total Nitrogen (mg/L)	19	4.14	100.00	-100.00	71.88
Total Phosphorous (mg/L)	18	20.59	81.63	-65.61	47.01
Chloride (mg/L)	18	-55.34	45.41	-98.81	46.63
Nitrite (mg/L NO_2-N)	6	-32.27	100.0	-95.48	78.85
Nitrate (mg/L NO_3-N)	10	40.44	100.0	-75.96	77.10
Ortho Phosphate (mg/L PO_4)	7	83.67	100.0	-14.29	43.20
Dissolved Copper (ug/L)	11	41.92	100.0	-59.71	53.76
Dissolved Lead (ug/L)	6	-52.69	36.97	-100.0	50.43
Dissolved Chromium (ug/L)	7	-78.83	-40.42	-100.0	22.21
Dissolved Zinc (ug/L)	7	11.73	90.67	-47.57	46.03

Average Nitrite and Nitrate concentrations in Tables 4.12 and 4.13 show that Nitrite concentrations increase with depth and, that Nitrate concentration decrease with depth. This suggests that nitrogen is changing forms as it passes through the system. An analysis of seasonal variations in nitrogen constituents reveals that from October 2003 until June 2004; an increase in average nitrogen concentration was observed from EMC to L8 of 0.88 mg/L-N to 2.27 mg/L-N. Furthermore, from June 2004 until October 2005, a decrease in average concentration from EMC to L8 was observed from 0.8 mg/L-N to 0.27 mg/L. This suggests that plant uptake of nitrogen occurs during summer and fall months or, when plant foliage is maximized. This also suggests that nitrogen is released during winter and spring months. These results are consistent with seasonal variations and weather conditions for this region. Figure 4.9 demonstrates this point graphically. With an average percent increase in concentration from EMC to L8 in the winter and spring of negative 63.7%, this system appears to be releasing nitrogen during this period of low plant growth. With an average percent decrease in concentration from EMC to L8 during the summer and fall months of 72.1%, this system appears to be retaining nitrogen. This may be a result of leaves building up within the basin during the fall season and resulting organic decomposition in the winter and early spring season.

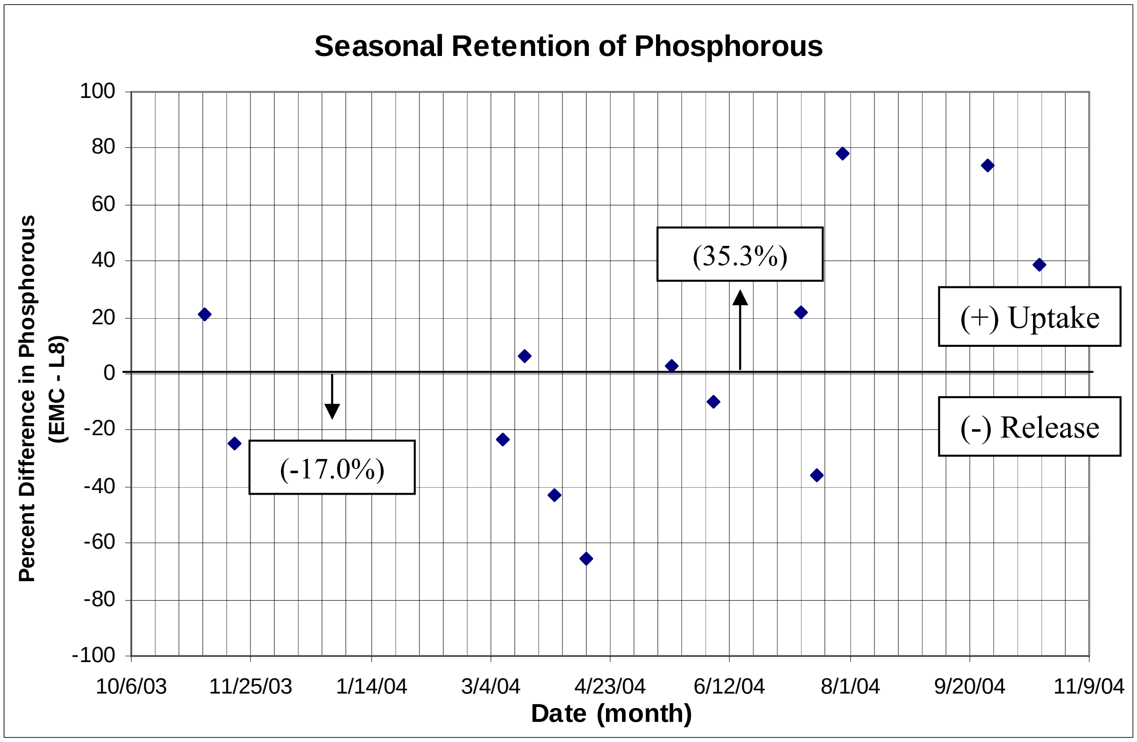
Figure 4.9: Seasonal Differences in Nitrogen for Infiltrated Runoff (EMC to L8)



For the same analysis of Total Phosphorous (as PO_4) data suggests that seasonal effects do not influence this constituent as highly as nitrogen. From October 2003 until June 2004; an increase in average phosphorous concentration was observed from EMC to

L8 of 0.41 mg/L-PO_4 to 0.51 mg/L-PO_4. From June 2004 until October 2005, a decrease in average concentration from EMC to L8 was observed from 0.99 mg/L-PO_4 to 0.51 mg/L-PO_4. This suggests that plant uptake of phosphorous also occurs during summer and fall months and that it is later released during winter and spring months; however, the change in concentrations is much less as compared to Total Nitrogen. Figure 4.10 demonstrates this point graphically. With an average percent increase in total phosphorous from EMC to L8 in the winter and spring of negative 17.0%, this system appears to be releasing TP during this period of low plant growth. With an average percent decrease in concentration from EMC to L8 during the summer and fall months of 35.3%, this system appears to retain phosphorous during the summer and fall months. These trends may also be a result of organic decomposition of leaves within the basin.

Figure 4.10: Seasonal Differences in Phosphorous for Infiltrated Runoff (EMC to L8)



4.3.3 Mass Loading

All stormwater BMPs used for removal of pollutants from runoff need to consider mass loading in order to quantify effectiveness in terms of mass removed from downstream surface water. Due to the hydraulic design of the VUSP Traffic Island BMP, pollutant removal efficiency in terms of mass is directly related to the event specific water quantity efficiency. This is due to the nature of this site's design which captures and infiltrates approximately 1.0 inches of runoff and overflows any additional excess over this amount (see Chapter 1.3).

For the analysis of mass loading, a total of 28 precipitation events were monitored for both water quantity and water quality parameters over a period of 18 months. Over the course of this study, a total of 7,194.5 cubic meters of stormwater runoff entered the BMP and a total of 2,161.7 cubic meters overflowed from the site. It is important to note that these volume calculations were determined using monthly summary data. Thus, this volume represents the total volume into the system over this period which is not necessarily the same as the total volume of runoff represented by events where water quality sampling occurred. The entire data set used for the analysis of mass loading can be seen in Appendix D.5 and the monthly summary data is seen in Appendix C.3.

Table 4.15 shows the results for analysis of mass loading in terms of each parameter studied. The number of samples collected (N) reflects events where analysis yielded a concentration above the detection limit of the instrumentation. Mass inflow represents the total mass based on the number of detected events (N) and is determined by multiplying EMC concentrations by the calculated volume input for each event. The total mass inflow is determined by summing the N values of event specific mass for the entire study period. Total mass outflow is determined by multiplying EMC by the measured volume of overflow from the site, summed over the study period. The total mass retained over the study has been determined by subtracting the mass outflow from the mass inflow and summing the N events. Percent Effectiveness has been determined by dividing the mass retained by the mass inflow and represents the percent mass retained by the system as observed over the study period.

Table 4.15: Results for Analysis of Mass Loading

Measured Parameter	N	Mass Inflow	Mass Outflow	Mass Retained	Effectiveness %
Total Suspended Solids (grams-TSS)	27	28502	9812	18691	65.6
Total Dissolved Solids (grams-TDS)	27	238708	71520	167187	70.0
Total Nitrogen (grams-N)	20	1898	853	1045	55.1
Total Phosphorous (grams-$P0_4$)	20	2215	1438	777	35.1
Chloride (grams-Cl)	25	104950	25498	79452	75.7
Nitrite (grams-N)	7	81.3	19.3	62.0	76.2
Nitrate (grams-N)	11	722.5	362.2	360.3	49.9
Phosphate (grams-PO_4)	10	595.5	306.2	289.4	48.6
Dissolved Copper (grams-Cu)	13	19.8	12.6	7.3	36.7
Dissolved Lead (grams-Pb)	7	2.6	2.0	0.7	24.6
Dissolved Chromium (grams-Cr)	7	4.3	2.9	1.4	32.9
Dissolved Zinc (grams-Zn)	7	94.3	64.8	29.6	31.4

All non-detect events have been assumed to be equal to zero for this analysis. This is important when comparing analysis of Total Nitrogen and its ionic constituents of Nitrite and Nitrate as well as Total Phosphorous and Phosphate. Mass balance is not achieved between these parameters because of differences in instrument detection limits throughout the course of the study which has limited analysis of ionic species of nitrogen and phosphorous at low concentrations. Mass balance for these nutrients may also be influenced by other forms of Nitrogen and Phosphorous which have not been analyzed.

Table 4.15 does not show results for total annual mass into the system because smaller precipitation events have not been accounted for. A more representative analysis of annual mass loading identifies mass load per unit of precipitation to project inflow and outflow mass based on monitored water quality and water quantity data. This ensures that smaller precipitation events are included when determining annual loading for each measured parameter.

Table 4.16 shows the statistical summary of the data used for determining correlations between mass load and precipitation. Table 4.17 shows statistical results for the best fit- regression analysis used for predicting annual mass loading. Appendix D.6 shows the relationships for Mass Load versus Precipitation graphically for each constituent and Appendix D.7 shows the data tables used to establish these relationships. It is not surprising that mass load and precipitation correlate well because mass is a calculated value dependent on volume which is a function of precipitation. Without the use of flow monitoring equipment however, this is the only means available for predicting annual mass loads at the VUSP TI BMP.

Table 4.16: Statistical Data for Mass Loading

Measured Parameter	N	Average Mass	Maximum Mass	Minimum Mass	Stdev Mass
Total Suspended Solids (grams-TSS)	14	309	774.2	12.5	231.2
Total Dissolved Solids (grams-TDS)	15	2179	5862.7	638.7	1647.0
Total Nitrogen (grams-N)	12	43	155.5	6.0	43.8
Total Phosphorous (grams-P)	15	20	48.3	0.8	15.1
Chloride (grams-Cl)	14	102	268.0	15.9	83.1
Nitrite (grams-N)	5	9	13.8	4.1	3.5
Nitrate (grams-N)	7	19	56.2	3.0	17.6
Phosphate (grams-PO_4)	5	29	55.1	13.7	16.8
Dissolved Copper (grams-Cu)	8	0	1.4	0.0	0.5
Dissolved Lead (grams-Pb)	5	0	0.2	0.0	0.1
Dissolved Chromium (grams-Cr)	5	0	0.1	0.0	0.0
Dissolved Zinc (grams-Zn)	4	4	9.9	0.9	4.1

A minimum r-squared of 0.7 was used as a threshold for analysis of annual pollutant loads. Analysis of annual loads for TSS, TDS, TN, TP, Cu and Zn were determined by incorporating 72 precipitation events from March 2004 to March 2005 which ranged from 0.02 inches to 7.24 inches. For lower bound of the regression, where the regression equation yielded a negative value, the predicted value for mass was set at zero. For the upper bound of the regression; where the total precipitation was greater than a known value for mass, two values were used to establish a range of loading. The first method uses the average value of the total data set for mass and the second method uses maximum known value of the total data set for mass. For example, as seen in Appendix D.6, the relationship between TSS and Total Precipitation (cm) yields an r-squared correlation of 0.82. When this relationship is used to predict annual mass of TSS, precipitation amounts below a value of 0.85 cm (0.33 in) result in a negative value for mass. Therefore all events below 0.85 cm are not included in the annual mass calculation for TSS. The upper bound of this relationship is 5.0 cm (1.97 in). Mass contributed to the BMP for any events above this precipitation is calculated using two methods. The first method takes the average mass of the entire data set and sets this value equal to the mass for this upper bound event. The second method uses the maximum known mass and sets this value as the mass input for the upper bound event.

Table 4.17: Precipitation versus Mass Loading Regression Results

Measured Parameter	Precipitation vs. Mass	
	R-Squared	Regression Type
Total Suspended Solids (grams-TSS)	0.82	Linear
Total Dissolved Solids (grams-TDS)	0.78	Linear
Total Nitrogen (grams-N)	0.79	Linear
Total Phosphorous (grams-P)	0.87	Linear
Chloride (grams-Cl)	0.17	Linear
Nitrite (grams-N)	0.01	Linear
Nitrate (grams-N)	0.42	Linear
Phosphate (grams-PO_4)	0.53	Linear
Dissolved Copper (grams-Cu)	0.94	Exponential
Dissolved Lead (grams-Pb)	0.66	Linear
Dissolved Chromium (grams-Cr)	0.69	Linear
Dissolved Zinc (grams-Zn)	0.85	Exponential

Table 4.18 shows the results from this analysis in both kilograms and pounds. From this analysis, it has been determined that an estimated annual load of between 21.2 and 33.2 lbs of suspended solids and an estimated 138.5 to 212.9 lbs of dissolved solids has runoff or has been input into the BMP. In terms of nutrients introduced into the system annually, a range of 3.38 to 5.11 lbs of nitrogen and 1.52 to 2.16 lbs of phosphorous have runoff annually. Metals which correlated well are copper and zinc. From this analysis, an annual load of between 0.012 and 0.034 lbs of copper and 0.079 to 0.226 lbs of zinc were put into this system.

Table 4.18: Calculated Annual Mass Load

Measured Parameter	N	Annual Mass Load (kg)	Annual Mass Load (lbs)
Total Suspended Solids (kg-TSS)	48	9.62 – 15.06	21.2 – 33.2
Total Dissolved Solids (kg-TDS)	48	62.84 – 96.55	138.5 – 212.9
Total Nitrogen (kg-N)	41	1.54 – 2.32	3.38 – 5.11
Total Phosphorous (kg-P)	50	0.69 – 0.98	1.52 – 2.16
Dissolved Copper (kg-Cu)	72	0.005 – 0.015	0.012 – 0.034
Dissolved Zinc (kg-Zn)	72	0.036 – 0.103	0.079 – 0.226

4.4 Correlation Relationships

Stormwater runoff characteristics can be defined in terms of both water quality and water quantity parameters. Water quality constituents are dependent on site characteristics and hydrologic conditions. Hydrologic or water quantity parameters which have been monitored at the VUSP TI BMP include; Total Precipitation, Peak 1-hour Intensity and Antecedent Dry Time. Another important variable monitored at this site is time, which uses the date format converted into month to identify seasonal variations. Water quality parameters which have been monitored at this site include; Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Conductivity (Cond.), Total Nitrogen (Tot N), Total Phosphorous as Phosphate (Tot P), Chloride (Cl), Nitrite (NO_2), Nitrate (NO_3), Ortho Phosphate (PO_4) and dissolved metals such as Copper (Cu), Lead (Pb), Chromium (Cr) and Zinc (Zn).

Having identified variables for both water quality and water quantity in Sections 4.2 and 4.3, it is of interest to investigate relationships amongst these parameters. Relationships analyzed in this study include single and multi variable linear regression correlations between individual water quality parameters as well as single and multi-variable correlations between site hydrologic parameters and water quality constituents. This section describes two types of correlations for relevant parameters at the VUSP TI BMP. The first type of correlation identifies inter-constituent relationships between various water quality parameters. This initial analysis identifies specific water quality parameters which can be useful in predicting other water quality parameters. The second type of correlation analyzes relationships between hydrologic conditions and EMCs using hydrologic data collected onsite and water quality data.

4.4.1 Water Quality Correlations

Event Mean Concentrations as previously defined are used to determine correlations between individual water quality parameters. Statistical analysis was performed using individual scatter plots to identify outliers and r-squared correlations to identify linear relationships. Appendix E shows the data used for this analysis. It is important to note that all water quality analyses which resulted in non-detect (ND) were eliminated from the data-set prior to correlation with the exception of dissolved metals. Correlations investigated for dissolved metals set ND results to zero prior to analysis because the data set had a limited number of observations.

Table 4.19 shows the correlation matrix constructed from the data set seen in Appendix E. R-squared correlations of less than 0.3 have been defined as showing no correlation. R-squared values of between 0.3 and 0.5 have been defined as showing poor correlation. Correlations of greater then 0.5 and less than 0.7 are defined as significant. R-squared values of between 0.7 and 0.9 showed a good correlation and values over 0.9 have been identified as showing an excellent correlation.

From this analysis it can be seen that a number of water quality constituents studied at this site show significant correlation. TDS shows significant correlation with Conductivity (0.629) and dissolved Zinc (0.525). TDS also shows good correlation with Chloride (0.838) and Nitrite (0.738). Figures 4.11 and 4.12 present these correlations graphically for TDS versus Chloride and TDS versus Nitrite respectively.

Table 4.19: Water Quality R-Squared Correlation Matrix

	TDS	**Conductivity**	**Tot N**	**Tot P**	**Cl**	**Nitrite**	**Nitrate**	**PO4**	**Cu**	**Pb**	**Cr**	**Zn**
TSS	0.009	0.003	0.001	0.008	0.001	0.040	0.016	0.028	0.100	0.052	0.079	0.348
TDS	1.000	**0.629**	0.000	0.088	**0.838**	**0.738**	0.045	0.020	0.262	0.015	0.149	**0.525**
Conductivity		1.000	0.035	0.055	0.425	**0.743**	0.002	0.016	0.243	0.001	0.129	0.402
Total N			1.000	0.066	0.000	**0.588**	0.152	0.264	0.011	**0.559**	0.095	0.054
Total P				1.000	0.043	0.011	0.000	**0.733**	0.400	**0.560**	0.407	0.382
Cl					1.000	**0.762**	0.000	0.019	0.237	0.002	0.171	0.362
Nitrite						1.000	0.029	0.001	0.002	0.436	0.024	**0.522**
Nitrate							1.000	0.130	**0.796**	0.387	0.055	0.449
Phosphate								1.000	**0.507**	**0.536**	**0.932**	0.486
Copper									1.000	0.374	0.094	0.421
Lead										1.000	0.076	0.039
Chromium											1.000	0.000
Zinc												1.000

Figure 4.11: TDS versus Chloride; Event Mean Concentration Correlation

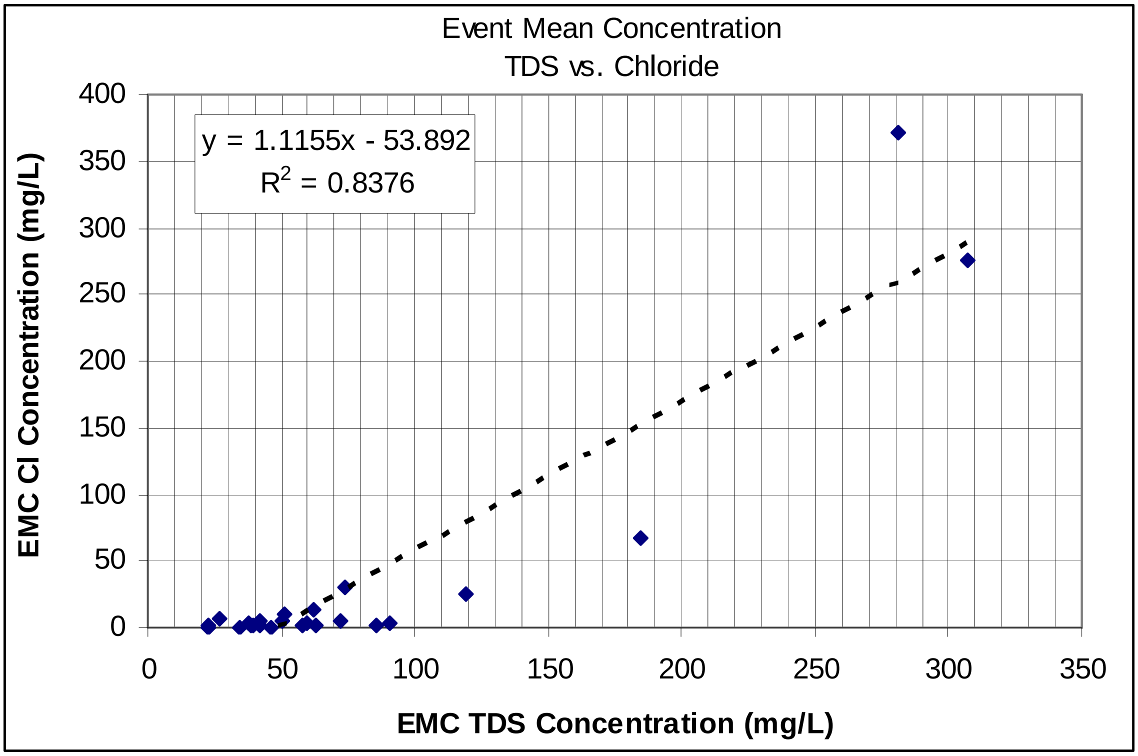
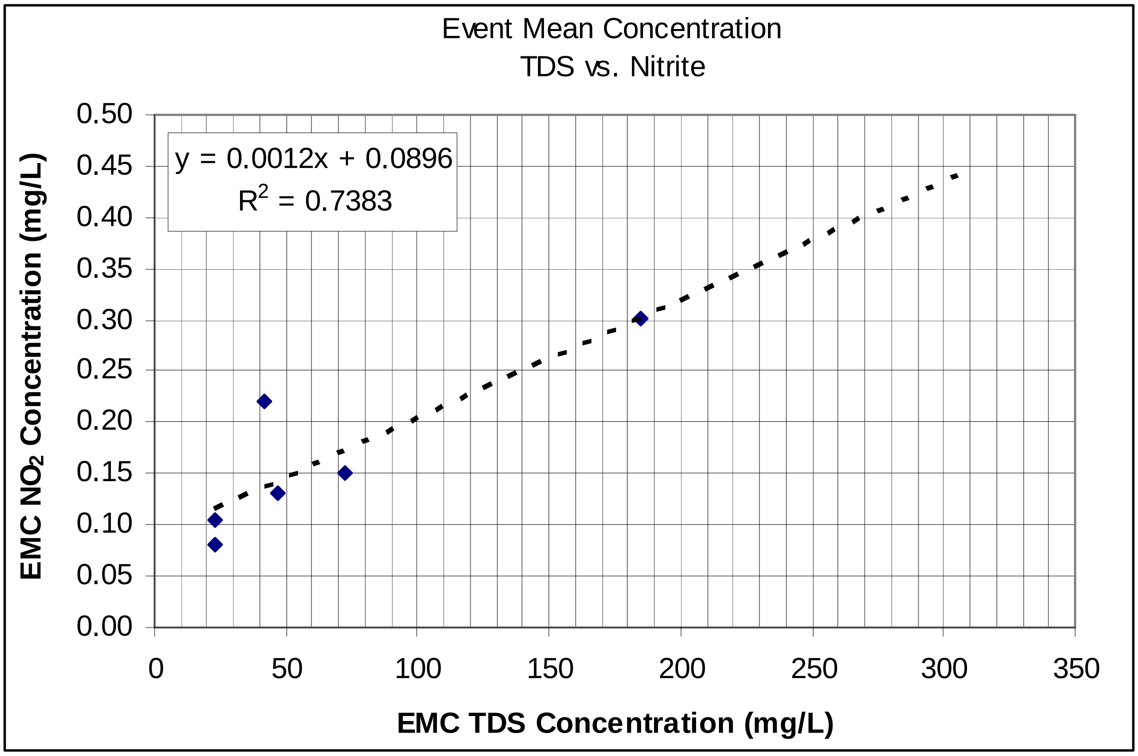


Figure 4.12: TDS versus Nitrite; Event Mean Concentration Correlation



Another parameter which shows good correlation with Nitrite is Conductivity (0.743). This suggests a potentially significant multivariable relationship between TDS, Conductivity and Nitrite. It is, therefore, essential to identify multivariable relationship for predicting NO2 by using data obtained from analysis of TDS and Conductivity. Data from this study using Nitrite as the dependent variable and both TDS and Conductivity as the independent variables shows an improvement in correlation between the three parameters. The R-Squared correlation for this analysis is 0.756 as compared to 0.738 and 0.743 when analyzed using single variable correlation. The multivariable regression relationship from this analysis is given by the following equation;

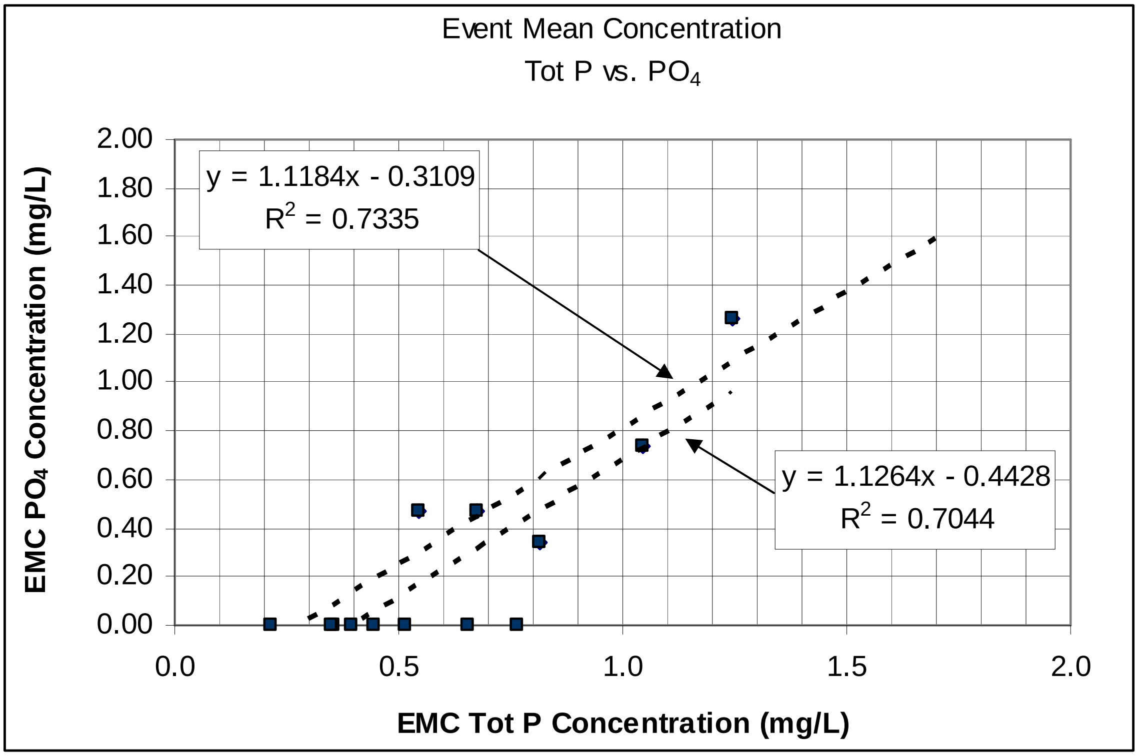
$$[NO2] = 5.23x10^{-4}\ [TDS] + 4.87x10^{-4}\ [Cond] + 0.0974.$$

Other Multivariable correlations among various water quality constituents are discussed briefly at the end of this section.

Total Nitrogen shows a significant correlation with two constituents; Nitrite and Dissolved Lead. R-Squared correlation for Tot N with NO2 is 0.588 and 0.559 with Pb. The correlation between nitrogen and nitrite can be attributed to the chemical composition of nitrite which includes nitrogen. Despite this, both of these correlations need to be further investigated because of the limited sample size ($n_{NO2} = 6$ and $n_{Pb} = 7$).

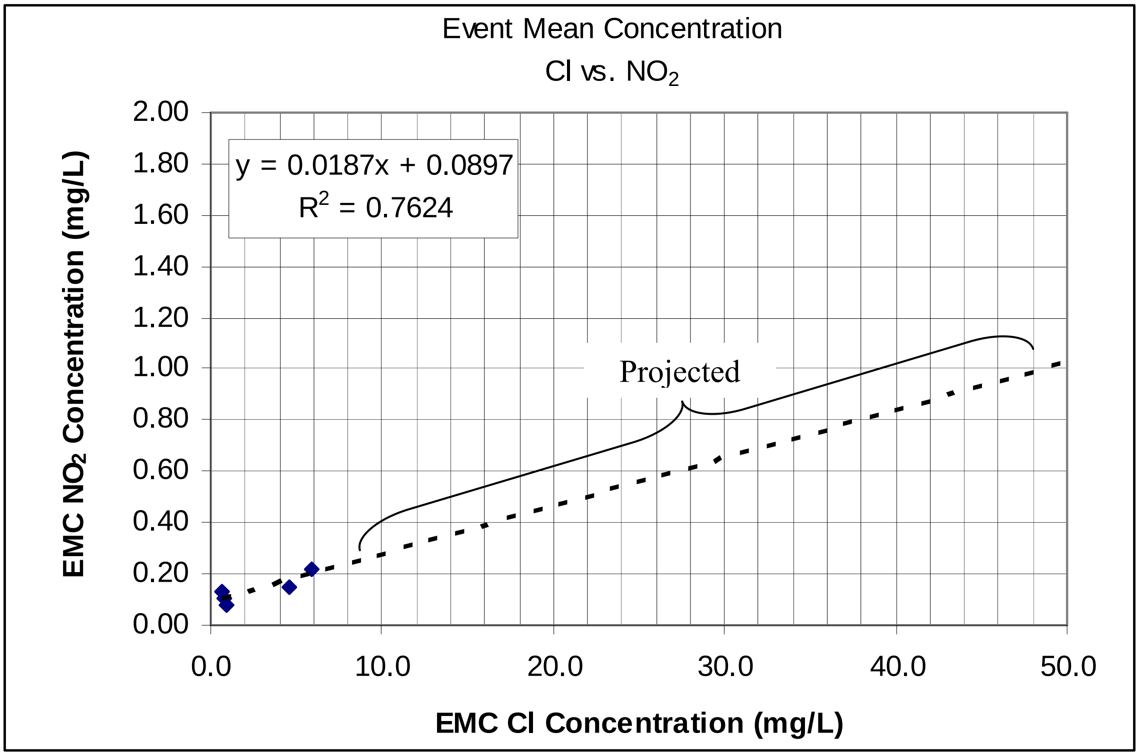
Total Phosphorous (as PO4) shows a good correlation with Ortho Phosphate with an r-squared value of 0.733. Tot P also shows a significant correlation with Lead (0.560). Figure 4.13 shows the relationship between Total Phosphorous and Ortho Phosphate. It is important to note that this analysis has a low number of data points because of the number of ND concentrations associated with Ortho Phosphate. Within the available data set for Tot P, a total of 8 ND values have resulted for analysis of PO4. When non detect samples are included into the data set as zero concentration, this analysis yields an r-squared correlation of 0.704. Both of these analyses are shown in Figure 4.13.

Figure 4.13: Total Phosphorous versus Ortho Phosphate; EMC Correlation



Total Chloride shows good correlations with a number of other water quality parameters. The TDS-Cl correlation of 0.838 was already mentioned. In addition to this, correlation between Cl and Nitrite of 0.762 has been identified. This analysis also has a low number of data points due to minimum detection limits which did not allow for analysis of Nitrite below 2.0 ppm for a number of precipitation events. A total of 13 ND data points were eliminated from the set for this analysis. Figure 4.14 shows the linear correlation for Chloride and Nitrite ($n_{NO2} = 6$). From this figure it can be seen that the entire data set for chloride for this analysis is below 10 ppm. This implies that this correlation is only valid for low concentrations of chloride. Higher concentrations of chloride detected at this site may have interfered with the analysis of other variables including Nitrite (Appendix E.1, see "ND, I"). This is because during events with high concentrations of chloride (during winter months), water samples required dilution prior to analysis using ion-chromatography. This dilution resulted in ND results for other constituents investigated thus causing interference and preventing analysis at low concentrations.

Figure 4.14: Chloride versus Nitrite; EMC Correlation



Nitrite also shows a good correlation with Dissolved Zinc with an r-squared value of 0.522.

Another nitrogen constituent which shows significant correlations with other water quality parameters is Nitrate. Nitrate correlation analysis with Dissolved Copper yields an r-squared value of 0.796. Figure 4.15 shows this correlation.

Ortho Phosphate also has a significant correlation with Dissolved Copper (0.536) and an excellent correlation with Dissolved Chromium (0.932). Figure 4.16 shows this relationship. It should be noted that due to the limited event analysis of dissolved metals, this relationship should be further verified with additional investigation.

Figure 4.15: Nitrate versus Copper; EMC Correlation

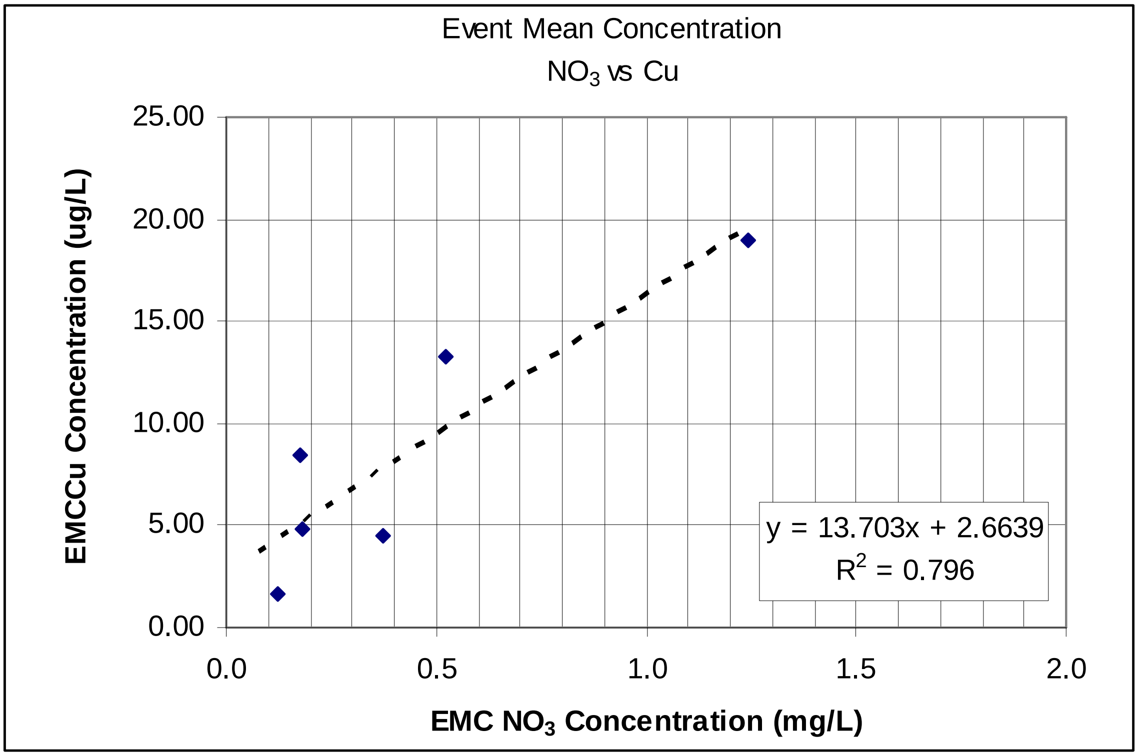
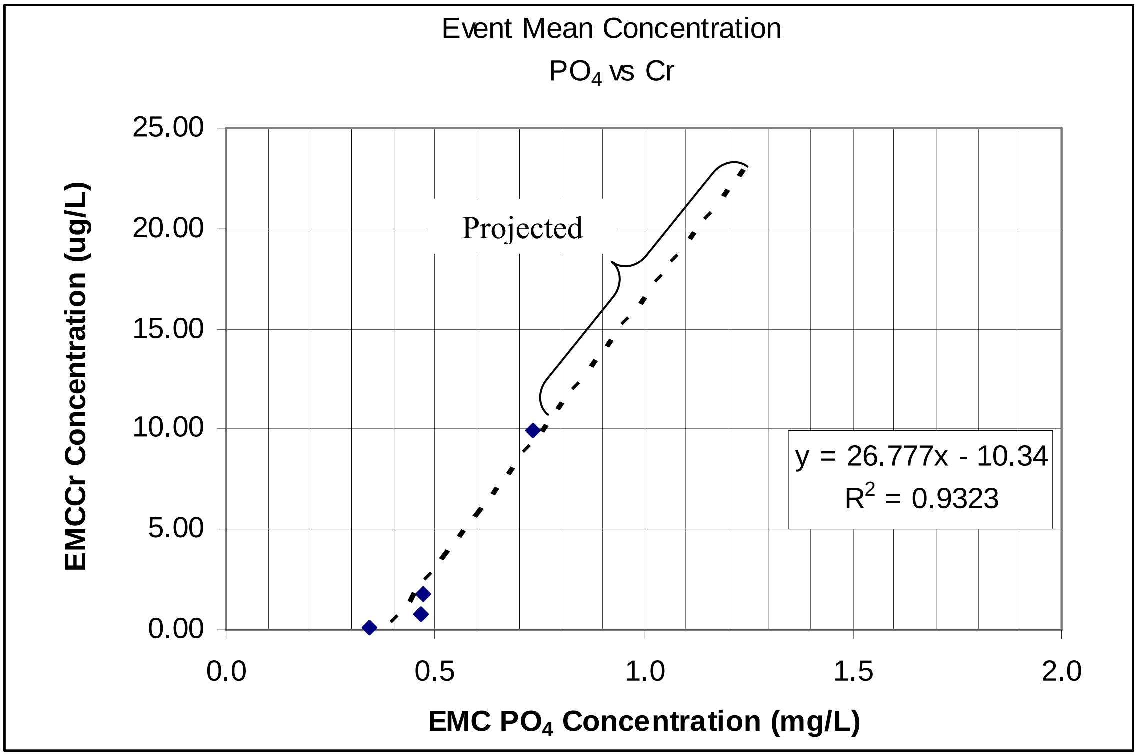


Figure 4.16: Ortho Phosphate versus Dissolved Chromium; EMC Correlation



As mentioned with the previous analysis of TDS, Conductivity and Nitrite; there are a number of relationships which suggest possible improvements in correlation by utilizing multivariable regression analysis. Of particular interest is the ability to use standard laboratory analysis of TSS, TDS and Conductivity to predict other parameters. Available data from this study shows that multivariable correlation using TSS, TDS and COND can be used to predict other water quality parameters. Table 4.20 shows the r-squared correlation results from this investigation. Constituents which have shown a significant correlation with TSS, TDS and COND are NO2 and Cr. Water quality parameters which show a good correlation with TSS, TDS and COND are Cl and Zn. The only relationship which shows an excellent multivariable correlation with TSS, TDS and COND, is NO3.

Table 4.20: R-Squared Multivariable Correlations using TSS, TDS and COND

Parameter	N	R-Squared
Total Nitrogen	17	0.12
Total Phosphorous	18	0.09
Chloride	**22**	**0.88**
NO2	**6**	**0.76**
NO3	**10**	**0.91**
PO4	7	0.07
Cu	12	0.40
Pb	7	0.27
Cr	**7**	**0.61**
Zn	**7**	**0.83**

Table 4.21 shows the multivariable linear regression relationship for the parameters that have a significant correlation with TSS, TDS and COND. It is particularly interesting to note that single variable regression analysis for Nitrate does not show any significant correlation with TSS, TDS or COND; however when analyzed using multivariable correlation, an excellent relationship is identified. Appendix E.2 shows the statistical summary data for the multivariable relationships which showed significant or better correlations.

Table 4.21: Multivariable Correlation for TSS, TDS and COND.

Parameter	R^2	Correlation Equation
Chloride (mg/L)	0.88	[Cl] = - 0.812 [TSS] + 1.378[TDS] - 0.454[COND] - 34.27
NO2 (mg/L)	0.76	$[NO2] = 5.43\text{X}10^{-5}[TSS] + 5.14\text{X}10^{-4}[TDS] + 4.92\text{x}10^{-4}[COND] + 9.69\text{X}10^{-2}$
NO3 (mg/L)	0.91	$[NO3] = -1.20\text{X}10^{-2}[TSS] + 2.48\text{X}10^{-2}[TDS] – 1.74\text{X}10^{-2}[COND] + 0.123$
Cr (ug/L)	0.61	[Cr] = 0.24 [TSS] - 0.18 [TDS] - 0.12 [COND] + 2.7
Zn (ug/L)	0.83	[Zn] = -2.27 [TSS] + 0.78 [TDS] - 0.92 [COND] + 114.6

4.4.2 Event-Water Quantity Correlations

A number of water quality parameters show significant single and multivariable correlations amongst other water quality constituents. It is therefore of particular interest to investigate potential relationships between hydrologic parameters and water quality constituents using event mean concentrations. Event data monitored includes; time (Month), Total Precipitation, 1-hour Peak Intensity and Antecedent Dry Time as previously defined.

The event data used in this analysis can be seen in Appendix E.3 in SI units. Twenty-eight events were sampled and monitored beginning in October of 2003 and ending in March 2005. The number of available data points for water quality constituents studied were often less than twenty-eight for various QAQC reasons including but not limited to low sample volume, poor instrument detection limits and/or instrumentation maintenance. Precipitation events ranged from 0.23 inches to 7.09 inches with an average of 1.63 inches. One-hour Peak Intensity ranged from 0.078 in/hr to 1.57 in/hr and averaged 0.354 in/hr. Antecedent Dry Time ranged from 0.13 days to 11.86 days and averaged 3.75 days.

For this analysis, linear correlations were identified using the square of the Pearson product moment or r-squared correlation. Event Mean Concentrations were used for each water quality constituent studied. These concentrations were compared to hydrologic data collected at the VUSP TI BMP in order to identify linear relationships between various parameters. R-squared correlations of greater than 0.5 have been identified as significant. For these relationships, scatter plots were generated and regression analysis was performed to quantify the relationship mathematically.

Table 4.22 shows the results from the r-squared correlation. Significant relationships have been highlighted. It can be seen in Table 4.22 that a number of water quality parameters showed significant or better correlations with water quantity parameters. Total Nitrite shows a 0.752 correlation with month data which implies seasonal factors for this constituent. Precipitation shows significant correlations with Total Phosphorous (0.550) and Dissolved Lead (0.668). Peak 1-hour intensity also shows a significant correlation with Total Phosphorous (0.554) and Dissolved Lead (0.616). It is particularly interesting to note that TSS and Antecedent Dry Time did not show significant correlations with any event-water quantity data.

Due to the percent removal of TSS from sedimentation removal (91.7%, see Table 4.8), this lack of correlation between TSS and Water Quantity parameters needs to be further investigated (see Chapter 5). The need to investigate the lack of correlation for Antecedent Dry Time is also discussed in Chapter 5.

Table 4.22: R-squared correlations; Event-Water Quantity and Water Quality Parameters

Parameters	N	Month	Precipitation	Peak 1-hr Intensity	Antecedent Dry Time
TSS	28	0.000	0.031	0.051	0.036
TDS	28	0.174	0.040	0.020	0.102
Conductivity	26	0.157	0.012	0.009	0.147
Total Nitrogen	20	0.014	0.019	0.010	0.001
Total Phosphorous	20	0.186	**0.550**	**0.554**	0.318
Chloride	26	0.225	0.034	0.017	0.049
Nitrite	6	**0.752**	0.085	0.000	0.058
Nitrate	11	0.036	0.225	0.054	0.000
PO4	10	0.010	0.080	0.215	0.016
Dissolved Copper	13	0.327	0.389	0.300	0.223
Dissolved Lead	7	0.005	**0.668**	**0.616**	0.382
Dissolved Chromium	7	0.144	0.079	0.068	0.341
Dissolved Zinc	7	0.483	0.336	0.358	0.047

Figure 4.17: Seasonal Nitrite Relationship

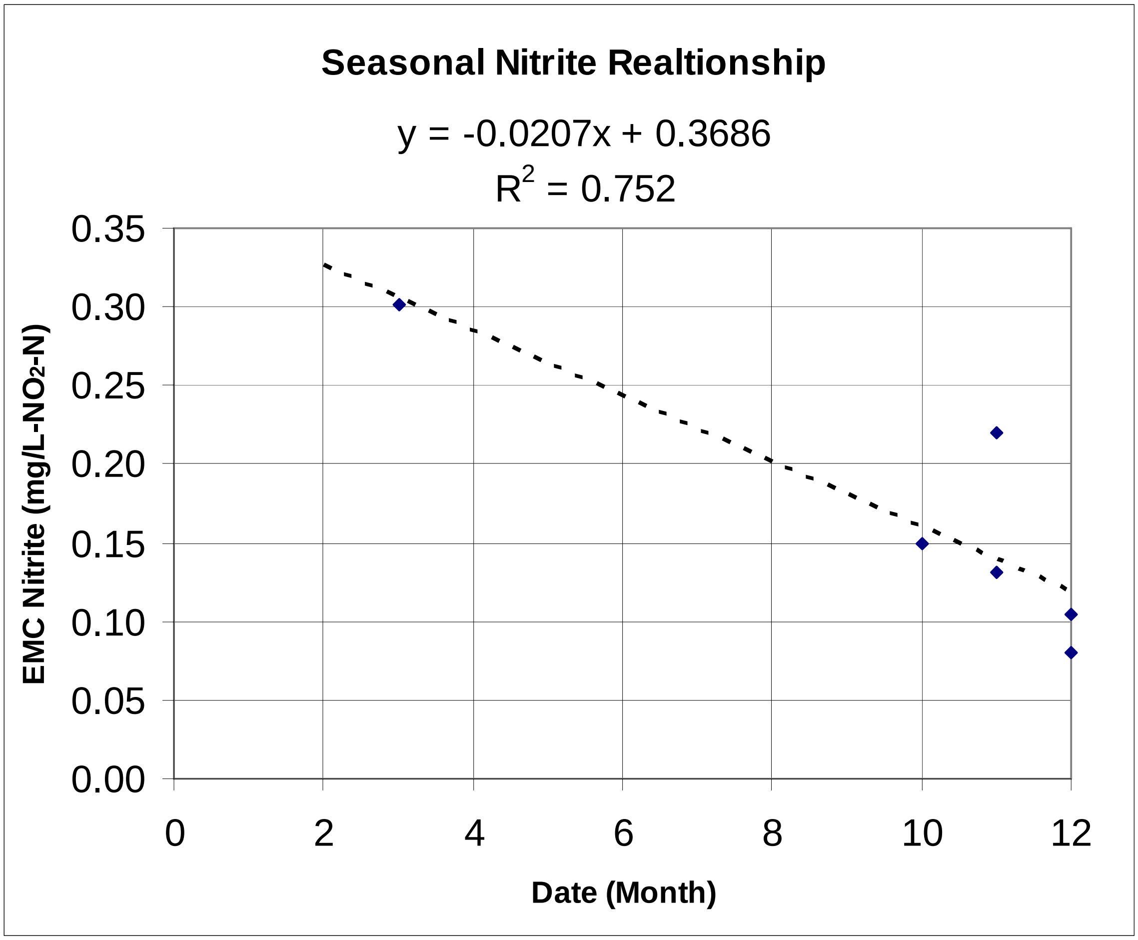


Figure 4.18: Linear Relationship for Total Precipitation and Total Phosphorous

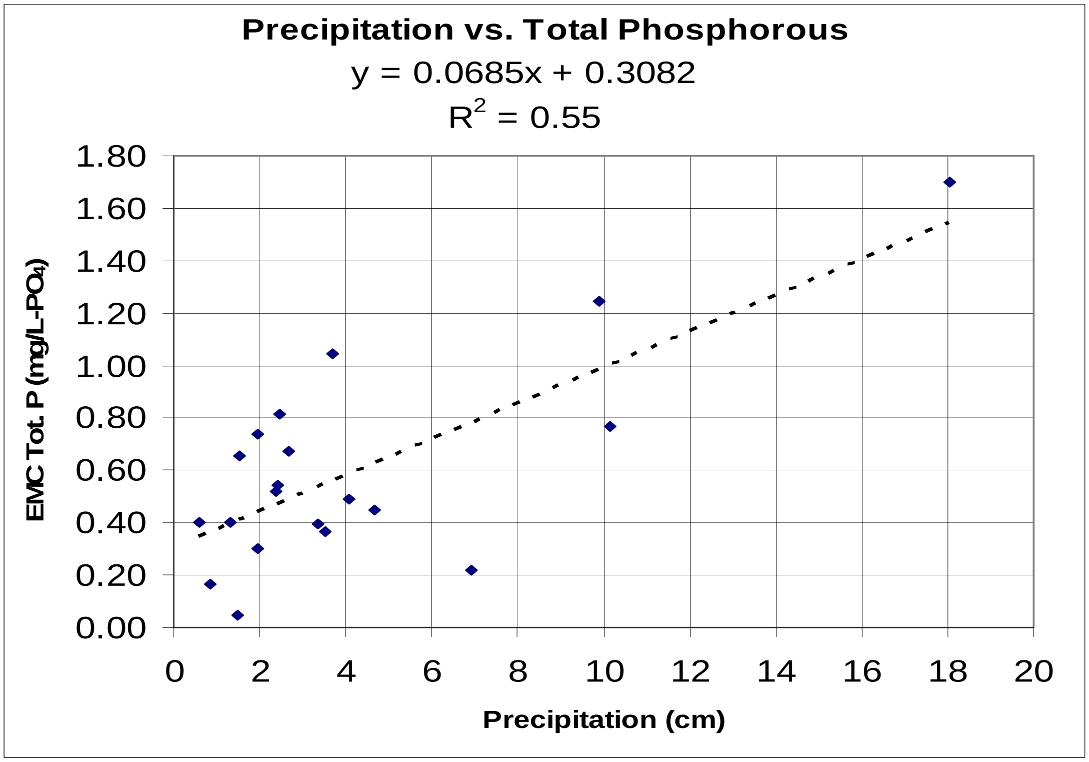


Figure 419: Linear Relationship for Total Precipitation and Dissolved Lead

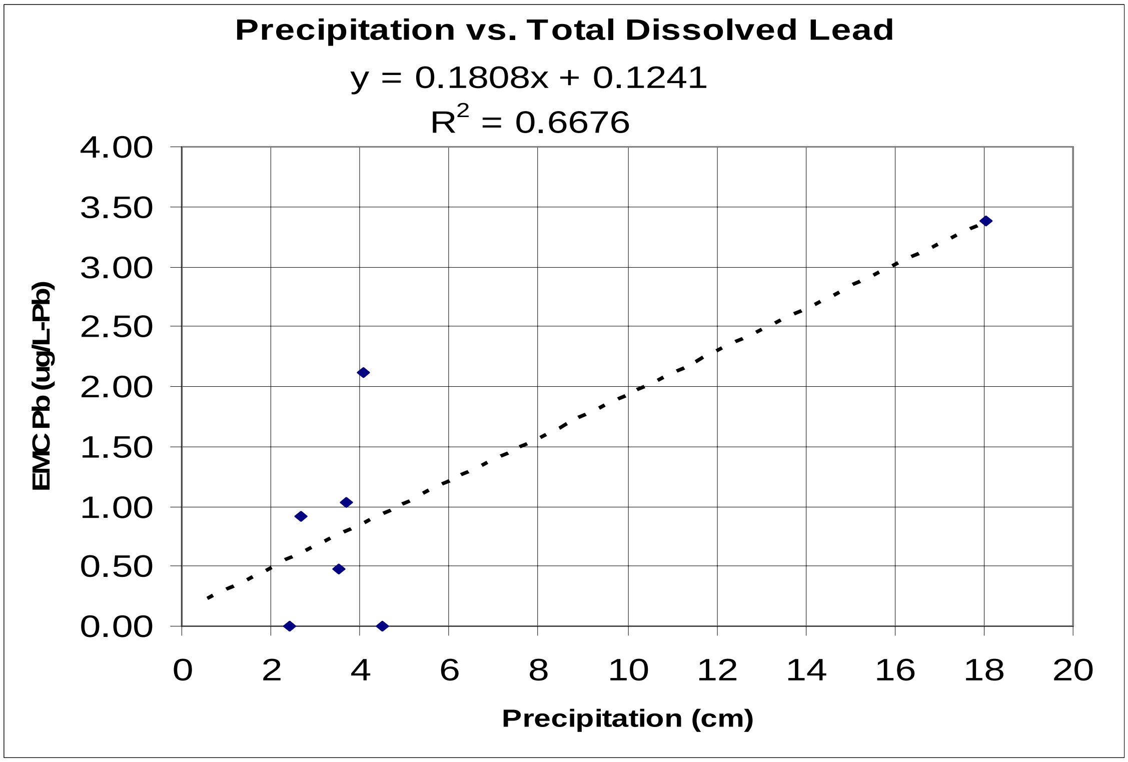


Figure 4.20: Linear Relationship for Peak Intensity and Total Phosphorous

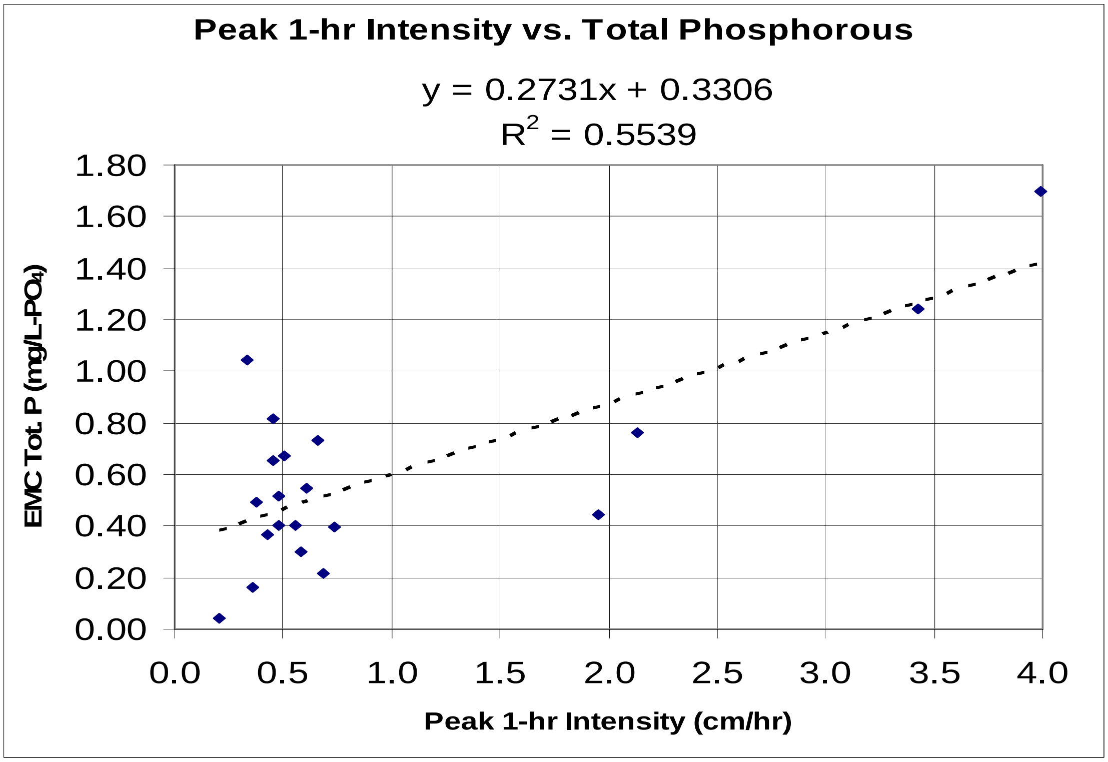
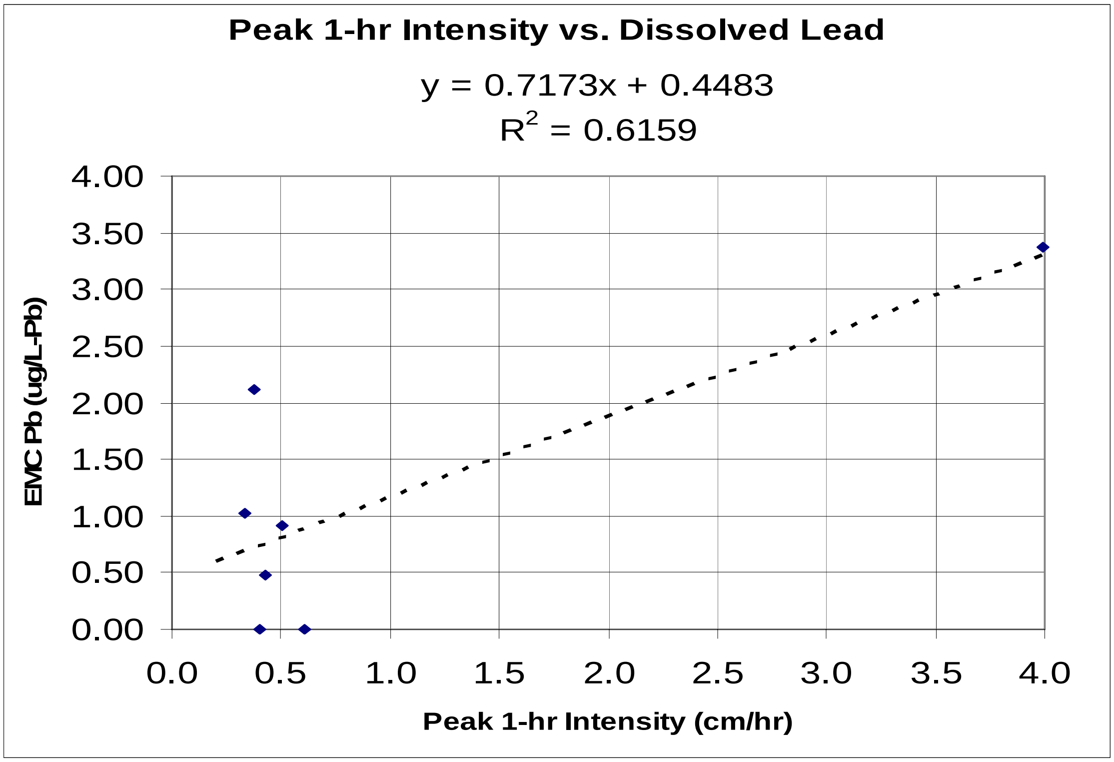


Figure 4.21: Linear Relationship for Peak Intensity and Dissolved Lead



Figures 4.17, 4.18, 4.19, 4.20 and 4.21 show the linear relationships for significant correlations graphically. From these figures a number of problems can be identified which need further investigation. Figure 4.17 shows seasonal correlation for Nitrite as Nitrogen. From this analysis it can be seen that EMC data for the months of March through October are not available. This is due to detection limits which prevented sample analysis during this period of the study. It is therefore recommended to perform additional analysis of Nitrites in stormwater runoff in order to account for this information. Figure 4.18 shows the linear relationship between Precipitation and Total Phosphorous as phosphate. From this figure it can be seen that the majority of samples analyzed for Total Phosphorous were below a Total Precipitation amount of 1.5 inches (3.8 cm). Additional sampling for Total Phosphorous should focus on obtaining data for precipitation events greater than 1.5 inches to confirm these results.

The scatter plot analysis of Total Precipitation and Dissolved Lead also shows a potential problem with the correlation identified. It can be seen in Figure 4.19 that a single event of 7.1 inches (18.0 cm) has ultimately caused this relationships to become linear. When this event which occurred on September 27, 2004 is eliminated from the set, Dissolved Lead shows a correlation of 0.05 with Total Precipitation. This same event caused a peak one-hour intensity of 1.57 in/hr (3.99 cm/hr) and has also influenced results for the correlation of Dissolved Lead and 1-hr Peak Intensity (Figure 4.20). When this event is not included in the analysis, an inverse r-squared correlation for Dissolved Lead and 1-hr Peak Intensity is identified of 0.25.

In addition to single variable linear correlations, multi-variable correlations between event data and water quality parameters have been investigated. In particular, potential improvements in correlations using multi-variable regression analysis have been identified. In all cases, multi-variable regression showed an improvement in correlation between water quantity and water quality parameters. Table 4.23 shows r-squared correlations for these parameters.

Table 4.23: R-squared Multi-variable Correlations using Month, P_{tot}, I_p, t_{dry}.

Parameters	N	Multi-Variable (Month, P_{tot}, I_p, t_{dry})
TSS	28	0.12
TDS	28	0.33
Conductivity	26	0.31
Total Nitrogen	20	0.09
Total Phosphorous	20	**0.685**
Chloride	26	0.301
Nitrite	6	**0.948**
Nitrate	11	0.334
PO4	10	0.378
Dissolved Copper	13	**0.624**
Dissolved Lead	7	**0.794**
Dissolved Chromium	7	**0.819**
Dissolved Zinc	7	**0.968**

From Table 4.22 and Table 4.23 it can be seen that significant single variable linear correlations were improved considerably when using multi-variable analysis. Total Phosphorous shows an r-squared correlation of 0.685 when analyzed with multiple water quantity parameters as compared to 0.550 and 0.554 for P_{tot} and I_p respectively. Nitrite, which correlated well with monthly data (0.752) shows a multi-variable correlation of 0.948. All dissolved inorganic metals showed a significant correlation with hydrologic parameters when using multi-variable regression as compared to single variable. It is important to note that the majority of significant correlations identified in Table 4.23 also have a low sample size. Ultimately a linear relationship between r-squared and inverse sample size ($r^2 \alpha 1/n$) may exist. It is for this reason that additional analysis of metal constituents as well as Nitrite is essential for further confirmation of these results.

Table 4.24 shows the linear relationships having significant correlations identified in Table 4.23. Appendix E.4 shows statistical tables generated for the analysis of water quantity and water quality correlation relationships.

Table 4.24: Prediction Models for Water Quantity and Water Quality Parameters

Parameter	r^2	Correlation Equation
Tot P (mg/L)	0.685	$[TP] = 0.029*Month + 0.017*P_{tot} + 0.149*I_p + 0.044*t_{dry} + 0.04$
NO_2-N (mg/L)	0.948	$[NO2\text{-}N] = -0.02*Month - 0.017*P_{tot} + 0.869*I_p + 0.048*t_{dry} - 0.002$
Copper (mg/L)	0.624	$[Cu] = 0.759*Month + 0.957*P_{tot} - 0.606*I_p - 0.191*t_{dry} - 1.725$
Lead (ug/L)	0.794	$[Pb] = -0.094*Month + 0.256*P_{tot} - 0.297*I_p + 0.02*t_{dry} + 0.598$
Chromium (ug/L)	0.819	$[Cr] = 0.179*Month - 4.128*P_{tot} + 14.153*I_p + 2.284*t_{dry} + 0.051$
Zinc (ug/L)	0.968	$[TP] = 7.21*Month + 33.19*P_{tot} - 94.2*I_p - 17.65*t_{dry} - 12.65$

From the relationships defined in Tables 4.21 and 4.24, substitute variables, or surrogates for water quality parameters are identified. These surrogates can be used to predict water quality variables without the use of expensive and time consuming procedures. It is important however to identify the limits of these relationships. For example, in Table 4.21, TSS, TDS and COND can be used to predict chloride, however the multivariable intersection of this equation (when TSS = TDS = COND = 0) is negative 34.27 mg/L. This means that certain values of TSS, TDS and COND can result in negative values for concentration of chloride. The same is true for TSS, TDS and COND as surrogates for zinc (Zn) which has a multivariable intersection of positive 114.6 mg/L. This means that the use of TSS, TDS and COND to predict zinc is only valid for concentration of zinc about this limit. The limits for using these correlation relationships for predicting water quality constituents by using event-water quantity data also need to be considered. These limits can be identified in Table 4.24 by setting the surrogate variables (P_{tot}, I_p, and t_{dry}) equal to zero and solving for the multivariable intersection. When used properly, the relationships in Table 4.24 can also be used to predict water quality variables. With additional research, these relationships can become essential in predicting pollutant loads on water bodies in similar BMP applications.

Chapter 5: Summary

The Villanova Urban Stormwater Partnership Bio-Infiltration Traffic Island BMP (VUSP-TI) was constructed in August of 2001 to demonstrate innovative techniques of stormwater management and for research purposes. Located in southeastern Pennsylvania within the west campus apartment complex of Villanova University, this BMP retains and infiltrates stormwater runoff from a 1.16 acre area including a parking facility (0.449 acres) and a recreational area (0.714 acres).

Monitoring equipment was installed at the VUSP-TI for the purpose of collecting hydrologic and water quality data. Water quality sampling included grab samples from the ponded runoff within the basin, first flush samples from two inlet curb cuts and infiltrated runoff from below the basin surface. Water quality samples were analyzed for pH, Conductivity, TSS, TDS, Total Nitrogen, Total Phosphorous, Chloride, Nitrite, Nitrate, Phosphate and dissolved metals such as copper, chromium, lead and zinc. Hydrologic or water quantity data was collected using an ultrasonic water level sensor to monitor depth of water within the basin as well as a tipping bucket rain gauge for monitoring precipitation. Monitored variables included Total Precipitation, Basin Water Level, Overflow, Average Infiltration Rate, Peak 1-hour Intensity of Rainfall and Antecedent Dry Time.

This study characterizes hydrologic parameters at this site by monitoring BMP performance in terms of efficiency and analyzing average infiltration rates within the basin. Water quality parameters are characterized by analyzing the effects of capturing first flush of runoff, investigating pollutant concentration as runoff is infiltrated, and estimating annual pollutant loads in terms of mass. This study also identifies single and multivariable correlation relationships amongst water quality variables as well as between water quantity and water quality variables.

Chapter 6: Conclusions and Recommendations

6.1 Conclusions

During this study, a total of 30 precipitation events were monitored, ranging from 0.23 to 7.10 inches, with an average precipitation of 1.55 inches. This study period can be considered an above average year in terms of precipitation for this region which averages approximately 45 inches per year. During this study, 18 months of data yielded a total of 89.2 inches of rain, or 59.5 inches annually. On a monthly basis the Site Performance, this considers total precipitation (inches) over the drainage basin and compares it to volume of runoff which has overflowed from the BMP, was 85.6%. This means that 85.6% of the rainfall at this site has been captured and infiltrated by this BMP. These results are consistent with Regional ITF data which suggests that between 85% and 90% of the total annual rainfall is less than 1.0 inches.

Average infiltration rate includes all forms of uptake within the BMP basin and has been determined by calculating the slope of the declining water level in the basin after a precipitation event. Over the course of this study the average value for infiltration was 0.23 inches per hour. A maximum average infiltration rate of 0.39 inches per hour occurred in September of 2004 and a minimum average infiltration of 0.15 inches per hour occurred twice, once in November of 2004 and again in February of 2005. Comparisons of average infiltration rates between September of 2002 and April of 2005 infers a reduction in event based average infiltration at this site. When individual monthly averages for infiltration are compared between 2003 and 2004, a decline in monthly average infiltration is indicated. This also corresponds with a decline in annual average infiltration which went from 0.31 to 0.25 in/hr in 2003 and 2004 respectively. Despite this notable decline in event, monthly and annually based averaged infiltration over the course of this study, it is important to note that minimum event average infiltration appears to be steady at approximately 0.15 in/hr. Additional monitoring is required to determine if this decline in average infiltration continues for the year 2005, which would be conclusive evidence that average infiltration rates are declining, possibly as a result of sedimentation buildup within the basin. It will also be valuable to investigate the affect of maintenance practices on infiltration rates at this site.

Water quality results show a significant reduction in many pollutants as a result of capturing first flush runoff during precipitation events. TSS samples collected from first flush runoff at the curb cut inlets to the BMP showed a 91.7% reduction when compared to samples from water collected within the basin. Other pollutants which show a reduction in concentration from the BMP inlet location to within the basin are dissolved metals such as Copper (46.5%), Lead (55.2%), Chromium (61.9%), and Zinc (16.9%). Conductivity (43.0%), Total Dissolved Solids (38.3%) and Total Nitrogen (47.9%) also show a consistent reduction in concentration as a result of capturing first flush.

Potential water quality issues with infiltrating stormwater runoff have been identified using allowable limits criteria and direct comparison of surface runoff samples and infiltrated runoff samples. National Primary and Secondary Drinking Water Quality Guidelines used for analysis of infiltrated runoff at a depth of 8 feet below the basin surface have determined that 29.6% of the samples collected exceeded the criteria. When surface water guidelines were used in comparison with grab samples collected from within the basin, 68.9% of the samples for Total Nitrogen and 93.5% of the samples for

Total Phosphorous exceeded the criteria. A reduction in exceedence of these guidelines is shown for Total Nitrogen (33.3%) and Total Phosphorous (55.6%) for samples collected from infiltrated runoff. From 11 events sampled for dissolved metals from infiltrated runoff at a depth of 8 feet below the basin surface, no samples exceeded allowable limits for drinking water quality for copper, chromium, lead or zinc.

Seasonal variations in Nitrogen and Phosphorous have been observed when comparing surface runoff grab samples from within the basin to infiltrated runoff samples from below the basin surface. These observations suggest that nitrogen and phosphorous are retained within the BMP during the summer and fall months and are then released during periods of low plant growth in the winter and spring months.

Annual pollutant loads have been estimated at this site by identifying correlations between mass load and precipitation and then calculating annual loads based on event specific precipitation data. An estimated annual load of between 21.2 and 33.2 lbs of suspended solids and an estimated load of 138.5 to 212.9 lbs of dissolved solids have entered the BMP. An estimated 3.38 to 5.11 lbs of nitrogen and 1.52 to 2.16 lbs of phosphorous have entered the BMP annually. Annual pollutant loads resulting from dissolved metals in stormwater runoff calculated for this site were Copper (0.012 - 0.034 lbs) and Zinc (0.079 - 0.226 lbs).

Two types of correlations have been analyzed in this study. Correlations between individual water quality variables using both single and multivariable linear regression have been identified. Of specific interest is the ability to use standard water quality parameters such as Total Suspended Solids (TSS), Total Dissolved Solids (TDS) and Conductivity (Cond) to predict other water quality constituents. Using r-squared correlation coefficients it has been determined that TSS shows no positive linear correlation with any other parameter measured. TDS shows a correlation with Conductivity (0.629) and Zinc (0.525). TDS also shows a correlation with Chloride (0.838) and Nitrite (0.738). When correlations between Conductivity and other parameters were investigated, only Nitrite (0.743) showed a good r-squared correlation. When multivariable regression correlations were investigated using TSS, TDS and Cond to predict other variables, r-squared correlations improved considerably. Chloride correlations improved to an r-squared correlation of 0.88, Nitrite to 0.76, Nitrate to 0.91 and predictions of metals such as Chromium (0.61) and Zinc (0.83) also improved.

Single and multivariable linear correlations between hydrologic variables and water quality variables have also been investigated. R-squared correlations between water quality constituents and four hydrologic, event-based measurements were investigated; Month, Total Precipitation (Ptot), Peak one-hour Intensity (Ip) and Antecedent Dry Time. Using single variable r-squared correlations, Nitrite and Month showed a good correlation of 0.752. Significant correlations were identified between P_{tot} and Total Phosphorous (0.55), P_{tot} and Dissolved Lead (0.668), Ip and Total Phosphorous (0.554) and Ip and Dissolved Lead (0.616). Antecedent Dry Time did not show significant correlations with any water quality variables. Considerable improvements in r-squared correlations have been achieved using multivariable regression between Month, P_{tot}, Ip and water quality variables. Total Phosphorous (0.685), Nitrite (0.948) and dissolved metals such as Copper (0.624), Lead (0.794), Chromium (0.819) and Zinc (0.968) have all shown improvements in correlation.

6.2 Recommendations

Based on the results and conclusions of this study, a number of recommendations are made. From the investigation of water quantity data, it is demonstrated that some reduction in average infiltration is occurring at the VUSP TI BMP. Additional monitoring of infiltration should be conducted in order to determine if a reduction in average infiltration rates continue. Close monitoring of the annual minimum event based infiltration rate should also be conducted. Careful analysis of infiltration rates within the fifth year of operation will determine if infiltration rates decline by 50% and if these conclusions are accurate. Also, sieve analysis of soil within the BMP basin at various depths directly in front of each runoff inlet will demonstrate the effect of slope and inlet type on sedimentation buildup within the basin. Water quality samples of first-flush at the eastern curb cut location have also verified that sedimentation buildup is occurring at this inlet location and may eventually lead to buildup within the infiltration basin.

Additional recommendations include expanding the water quality investigation to include automobile related pollutants such as Total Petroleum Hydrocarbons (TPHC), Polynuclear Aromatic Hydrocarbons (PAH), Polychlorinated Biphenyls (PCBs) and Volatile Organic Compounds (VOCs) which may present a larger risk to the environment and human health. Since these components are typically used in automobiles for operation and maintenance, the use of traffic flow monitoring equipment is recommended to determine traffic count. Research of this nature would be able to identify direct correlations between volume of traffic and pollutant loads associated with automobile use.

Lastly, a number of correlations which have been identified in this study need further investigation because of the small number of samples collected and analyzed for certain constituents. For any correlation to be conclusive it is recommended that at least 30 samples be included in the regression. It should be noted that although a number of positive correlations have been identified in this study, none of the sample sets for water quality was greater than 30. In particular, Nitrite samples only yielded 6 samples over the instrument detection limits and only 7 samples for dissolved metals in the form of lead, chromium and zinc have been analyzed. Therefore, it is recommended that correlations identified in this study should be verified with additional sampling and analysis of water quantity and water quality variables.

6.3 Lessons Learned

This study identifies a number of lessons which can benefit water resource engineering professionals and the stormwater management industry. A number of water quality concerns related to stormwater runoff have been addressed by this study. The polluting of groundwater resources by infiltrating stormwater runoff does not appear to be a problem in terms of the parameters studied at this site. Stormwater runoff does appear to present a problem in regards to surface water resources thus further verifying the importance of using stormwater BMPs for managing runoff.

A number of water quantity concerns have also been addressed by this study. It has been observed that annual and monthly average infiltration appears to be declining. By designing for a precipitation event of 1.0 inches over the drainage area 85.6% of runoff has been captured at this site over the study period.

References

PWD, (2003). "Report on the Darby-Cobbs Watershed", Philadelphia Water Department, Office of Watersheds.

Leeds, C. (2003), Personal Communication, Villanova University Facilities Management Office, Villanova University, Villanova PA.

U.S. EPA, (1992). "NPDES Storm Water Sampling Guidance Document", U.S. EPA Office of Water, Washington, D.C. 833/B-92-001, (http://cfpub.epa.gov/npdes/).

(Dzurik, 2003)

Barraud, S., A. Gautier, J. P. Bardin, V. Riou. (1999) "The Impact of Intentional Stormwater Infiltration on Soil and Groundwater." Wat. Sci. Tech. 39(2), 185-192

Chester, G. and Schierow, L.J., (1985) "A primer on nonpoint pollution.", Journal of Soil and Water Conservation. 40, pp9-13.

Clesceri, L.S., Greenburg, A.E., Eaton, A.D., Standard Methods for Examination of Water and Wastewater, 20th Edition , 2001.

Cosgrove, J., Bergstrom, J.D., (2003). "Design and Construction of Biofiltration Basins: Lessons Learned", Environmental Water Resources Institute Conference Proceedings.

Davis, A.P., Hsieh, C., (2003). "Multiple Event Study of Bioretention for Treatment of Urban Stormwater Runoff".

Davis, A.P., Shokouhian, M., Sharma, H., and Minani, C., (1998). "Optimization of Bioretention Design for Water Quality and Hydrologic Characteristics".

Department of Environmental Protection, Commonwealth of Pennsylvania, (2002). Title 25, Environmental Protection Department of Environmental Protection- Chapter 250, (www.dep.state.pa.us).

Emerson C., Welty C., Traver R.G., (2005). "Watershed Scale Evaluation of a System of Stormwater Detention Basins", ASCE Journal of Hydrologic Engineering, v10, n3

Graves G, Wan Y, and Fike L., (2004). "Water Quality Characteristics of Stormwater From Major Land Uses in South Florida", Journal of the American Water Resources Association, pp1405–1418

Heason, B., (2003). Personal Communication, Results of Site Survey of the VUSP Bio-Infiltration Traffic Island, Villanova University, Villanova PA.

Lee, F. and Jones-Lee, A., (1994). "Are real water quality problems being addressed by current structural best management practices", Public Works, November, pp. 53-55.

Mays L.W., (2001), Water Resources Engineering, First Edition, John Wiley & Sons, Inc Publishing.

McElmurry, S.P., Aslam, I., Syed, A.U., Voice, T.C., Long, L.D., Phanikumar, M.S., Lusch, D.P., Northcott, W.J., (2003). "Determining the Effects of Various Land Uses within Michigan State University's Watershed on Water Quality in the Red Cedar River", Concerence Proceedings, 8th International Conference of Environmental Science and Technology.

Norman, C.G., (1991). "Urban runoff effects on Ohio river water quality", Water Environ. Technol. 3, 44 – 46.

Pfaff J., Hautman D., Munch D.; USEPA Office of Water, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45368.

Prokop, M.J., (2003), "Determining the Effectiveness of the VUSP Bio-Infiltration Traffic Island BMP", Villanova University, Villanova, PA.

Rea, M.C., (2004), "Pollutant Removal Efficiency of a Stormwater Wetland BMP during Baseflow and Storm Events", Villanova University, Villanova, PA.

Smith, J. Sievers, M., Huang, S., Yu, J., (2000). "Occurrence and phase distribution of polycyclic aromatic hydrocarbons in urban stormwater runoff", Water Science and Technology, Vol 42 No 3-4, pp383-388.

Soil Moisture Equipment Corp. (2002). "1920F1 Pressure-Vacuum Soil Water Sampler Operating Instruction Mannual", Santa Barbara, CA.

Thomson, N.R., McBean, E.A., Snodgrass, W., Monstrenko, I.B.; "Highway Stormwater Runoff Quality: Development of Surrogate Parameter Relationships", Water, Air and Soil Pollution, n94, pp 307 – 347, (1997).

Traver R., (2002). "Urban Hydrology Course Notes", Villanova University, Villanova, PA.

Traver, R., A. Welker, C. Emerson, (2003). "Quality Assurance, Quality Control Project Plan", Villanova Urban Stormwater Partnership, Villanova University, Villanova, PA.

Tsihrintzis, V. A., and Hamid, R. (1997). "Modeling and Management of Urban Stormwater Runoff Quality: A Review." Water Resources Management, 11, 137-164.

U.S. Environmental Protection Agency (1999), "Stormwater Technology – Fact Sheet: Bio-retention.", EPA 832-F-99-012.

U.S. Environmental Protection Agency (1983). "*Results of the Nationwide Urban Runoff Program*", *volume I – Final Report.* U.S. Environmental Protection Agency, Water Planning Division, Washington D.C.

U.S. Environmental Protection Agency (1984). "Report to Congress: Nonpoint source pollution in the U.S.A.", Office of the Water Program Operations, Water Planning Division, Washington D.C., U.S.A.

Appendix A: Historical Summary

A.1: Site History Profile.

Timeframe	Activity
July 2002	Survey to define drainage area.
12/1/2002	Installation of V-Notch weir and development of HMS Model.
3/20/03	Model Verification
9/15/2002	Soil Analysis
10/5/2002	Initial Abstraction Ratio curve number calibrated site surfaces.
5/15/2003	Traffic Island Effectiveness Thesis
6/15/2003	Environmental Water Resource Institute (ASCE) includes the site as a Stormwater BMP demonstration during their national conference in Philadelphia.
8/6/01	Site Excavation
8/9/01	Soil Mixing
8/29/01	Mulch and Planting
3/20/02	Monitoring Equipment Installed.
11/14/02	V-Notched Weir Installed at outflow.
9/11/03	Soil Moisture Meters Installed at average depths of 2.0, 4.0 and 8.0 feet below basin surface.
10/21/03	Installation of Suction Lysimeters at depths of 4.0 and 8.0 feet below basin surface.
10/27/03	Water quality sampling and analysis began for one surface water sample

	and two sub-surface lysimeters samples.
12/7/03	Lysimeter at 8.0 feet malfunctioned due to icing.
12/11/03	Weir Calibration check.
1/12/04	High Pressure Liquid Chromotography (HPLC) Equipment Installed for analysis of nutrients.
1/29/04	Atomic Absorption Spectrophotometer (AA) equipment installed for analysis of metals.
3/15/04	Lysimeter at 8.0 feet reinstalled. Soil samples collected for moisture analysis.
3/16/04	Analysis of metals determines that levels in samples are below detection limits of AA Spec.
3/29/04	National Stormwater BMP Database; data submitted.
4/1/04	Lysimeter at 8.0 feet needs maintenance (low volume of sample).
4/29/04	Moisture meter malfunction at 4.0 feet depth.
6/11/04	Analysis of nutrients determines that samples are below instrument detection limits for Nitrate, Nitrite and Phosphate.
7/9/04	Lysimeter at 8.0 feet was reinstalled. Lysimeter at basin surface installed for direct comparison of loads versus depth.
7/26/04	First Flush water samplers installed for analysis of runoff entering the site through curb cuts. Samples represent direct runoff from access road and parking area.
8/15/04	Conductivity Suppressor installed on HPLC to reduce instrument

	detection limits.
8/20/04	Graphite Furnace installed on AA Spec to reduce instrument detection limits.
9/1/04	Sampling & Testing Procedures Finalized.

A.2: Construction Photos

Photo 1: Excavation


8/3/01

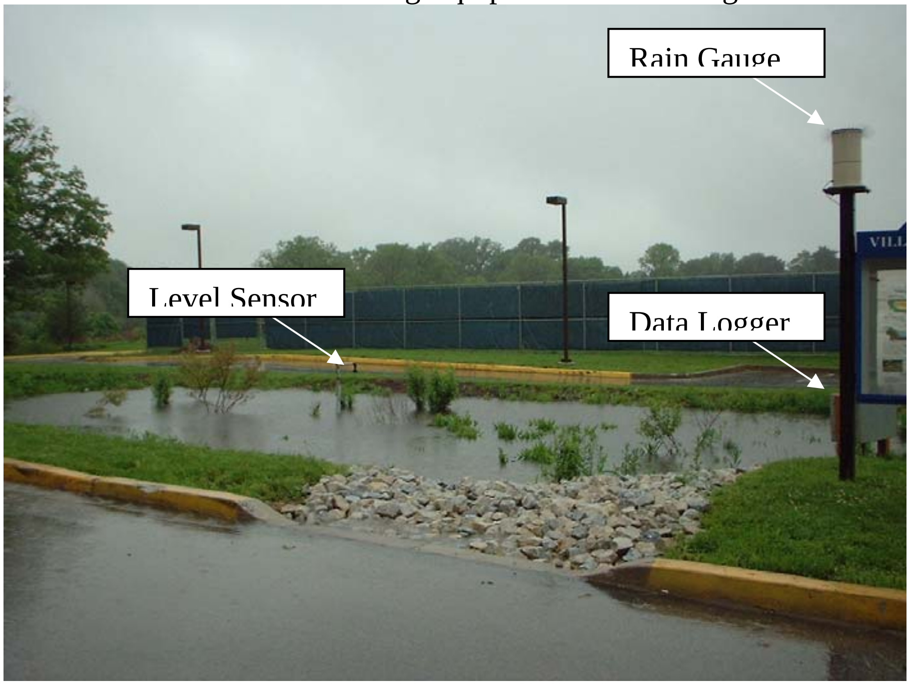
Photo 2: Soil Mixing


8/8/01

Photo 3: Storm drain inlet – overflow installation

Photo 4: Backfilling

Photo 5: Monitoring Equipment and Plantings



Appendix B: Technical Guidelines for Laboratory Procedures

B.1: Sample holding time.

Method	**Parameter**	**Container**	**Holding Time w/o preservation**	**Holding Time w/preservation**
Hach 10071	Total Nitrogen	Polyethylene, Glass	48 hours	28 days
Hach 8190	Total Phosphorus	Polyethylene, Glass	48 hours	28 days
GFAA 3113	Dissolved Metals	Polyethylene	48 hours	6 months
HPLC 300	Anions	Polyethylene, Glass	48 hours	28 days
Method 2540	Solids	Polyethylene, Glass	7 days	NA
---	pH, Conductivity	Polyethylene, Glass	2 hours	NA

B.2: HPLC Operating Conditions

B.3: HACH DR/4000 Operating Conditions

Analysis	Total Phosphorous
Method	8190, PhosVer 3 with Acid Persulfate Digestion
Detection Limit	0.06 mg/L – PO_4
Range:	0.00 – 3.5 mg/L - PO_4
Wavelength:	890 nm
Precision:	3.0 mg/L at 95% confidence
Interferences:	Cu (10 mg/L), Fe (100 mg/L), Zn (8- mg/L)

Analysis:	Total Nitrogen
Method:	10071, Persulfate Digestion
Detection Limit:	2.0 mg/L – N
Range:	(0.00 – 25.0 mg/L – N)
Wavelength:	410 nm
Precision:	15 mg/L with 95 % confidence
Interferences:	Cr (0.5 mg/L), Pb (6.6 mg/L), P (100 mg/L)

B.4: Operating Conditions for GFAA Spectrometer

B.4.1) Instrument Setting

Purge Gas:	Argon
Gas Pressure (kPa)	180
Spectrometer Slit:	0.7
Gain:	75
Tube Type:	Pyrolytic Graphite
Conditioning (^oC)	200
Injection Volume (ul)	20

Analyte	Wavelength (nm)	Pretreatment Temp. (^oC)	Atomization Temp. (^oC)	Lamp Setting (mA)
Copper (Cu)	324.8	1200	2300	15
Lead (Pb)	217.0	850	1800	15
Chromium (Cr)	357.9	1650	2500	12
Zinc (Zn)	213.9	700	1800	15

B.4.2) Program Setting

Analyte: Copper
Injection Volume: 20 uL

Step	1	2	3	4	5
Temp. (^oC)	120	900	2000	2650	0
Ramp time (sec.)	10	5	0	1	0
Hold time (sec)	20	20	5	3	0
Record	--	--	On	On	--
Read	--	--	On	--	--
Baseline	--	--	--	--	--
Power			42		
Stop Flow	--	--	On	--	--

Analyte: Lead
Injection Volume: 20 uL

Step	1	2	3	4	5
Temp. (^oC)	130	850	1800	2000	0
Ramp time (sec.)	1	1	1	1	0
Hold time (sec)	40	30	5	5	0
Record	--	--	On	On	--
Read	--	--	On	--	--
Baseline	--	--	--	--	--
Power			35		
Stop Flow	--	--	On	--	--

Analyte: Chromium
Injection Volume: 20 uL

Step	1	2	3	4	5
Temp. (^oC)	120	1500	2500	2700	20
Ramp time (sec.)	1	1	1	1	1
Hold time (sec)	40	20	4	5	10
Record	--	--	On	On	--
Read	--	--	On	--	--
Baseline	--	--	--	--	--
Power			47		
Stop Flow	--	--	On	--	--

Analyte: Zinc
Injection Volume: 20 uL

Step	1	2	3	4	5
Temp. (^oC)	120	700	1800	2000	20
Ramp time (sec.)	1	1	1	1	1
Hold time (sec)	30	20	5	5	10
Record	--	--	On	On	--
Read	--	--	On	--	--
Baseline	--	--	--	--	--
Power			40		
Stop Flow	--	--	On	--	--

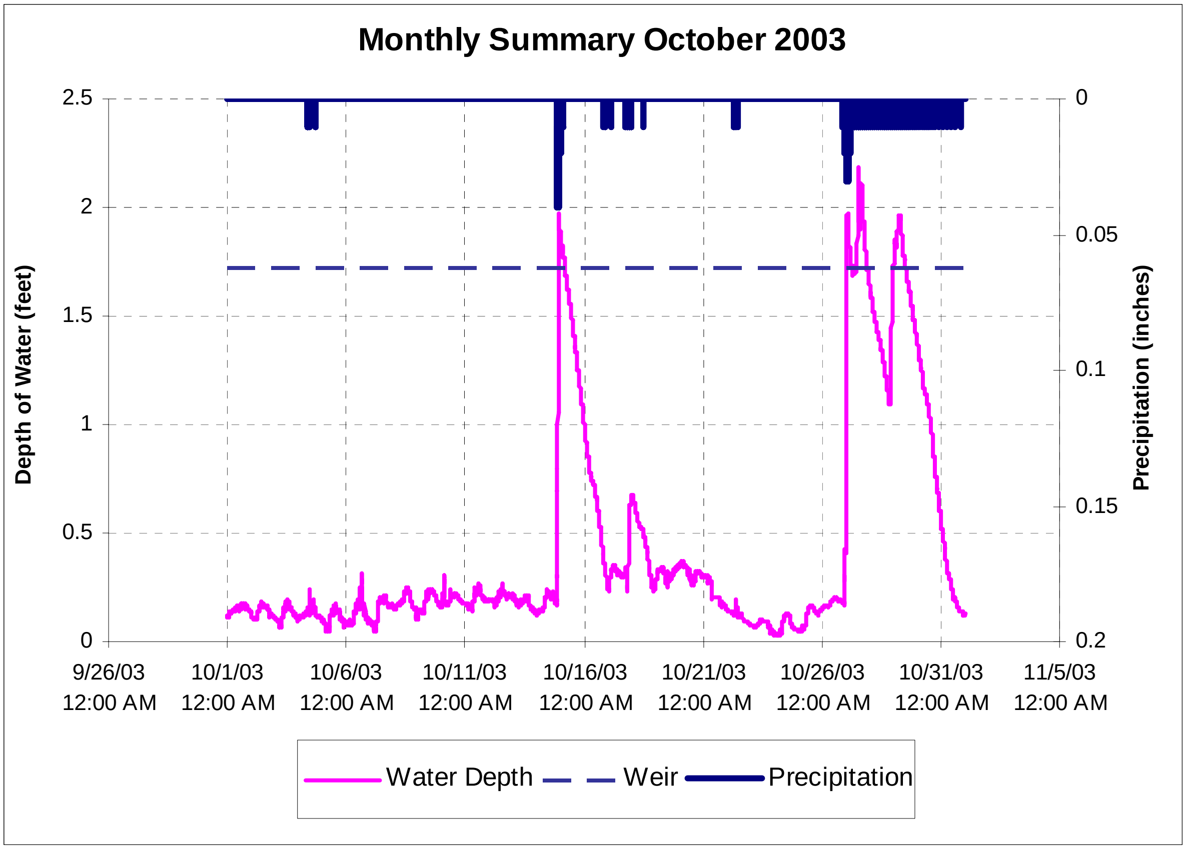
Appendix C: Selected Water Quantity Data

C.1: Monthly Summary Data October 2003 to March 2005

October 2003

Monthly Summary				
	English		SI	
Total Rain:	5.30	inches	13.46	cm
1hr Max Int.	0.38	in/hr	0.97	cm/hr
Overflow:	1.10	inches	2.79	cm
	4640.65	cu.ft	131.4	cu.m
Average Infiltration Rate:	0.36	in/hr	0.91	cm/hr
Volume Inflow:	3.89	inches	9.88	cm
	16420.35	cu.ft	465.0	cu.m

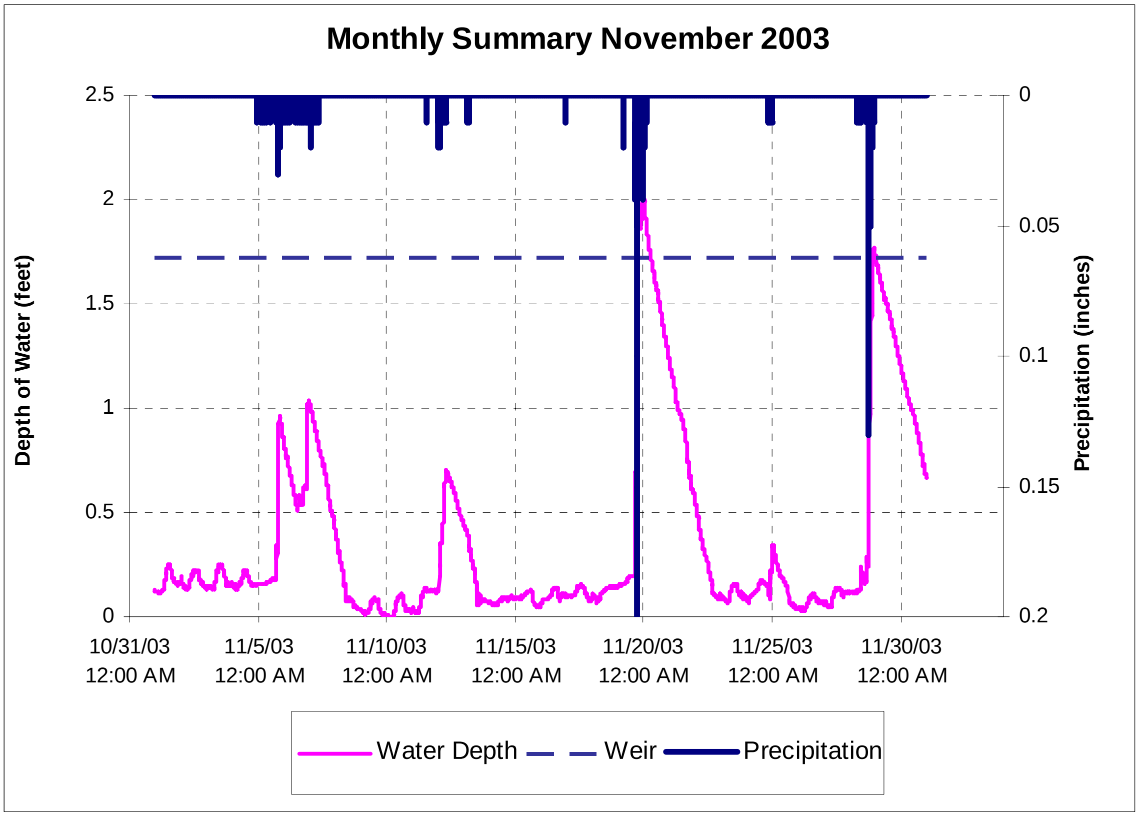
Performance Summary		
Site Performance:	79.3	%
BMP Performance:	71.7	%



November 2003

Monthly Summary				
	English		SI	
Total Rain:	4.54	inches	11.53	cm
1hr Max Int.	0.77	in/hr	1.96	cm/hr
Overflow:	0.44	inches	1.11	cm
	1837.83	cu.ft	52.04	cu.m
Average Infiltration Rate:	0.33	in/hr	0.84	cm/hr
Volume Inflow:	3.19	inches	8.10	cm
	13465.53	cu.ft	381.3	cu.m

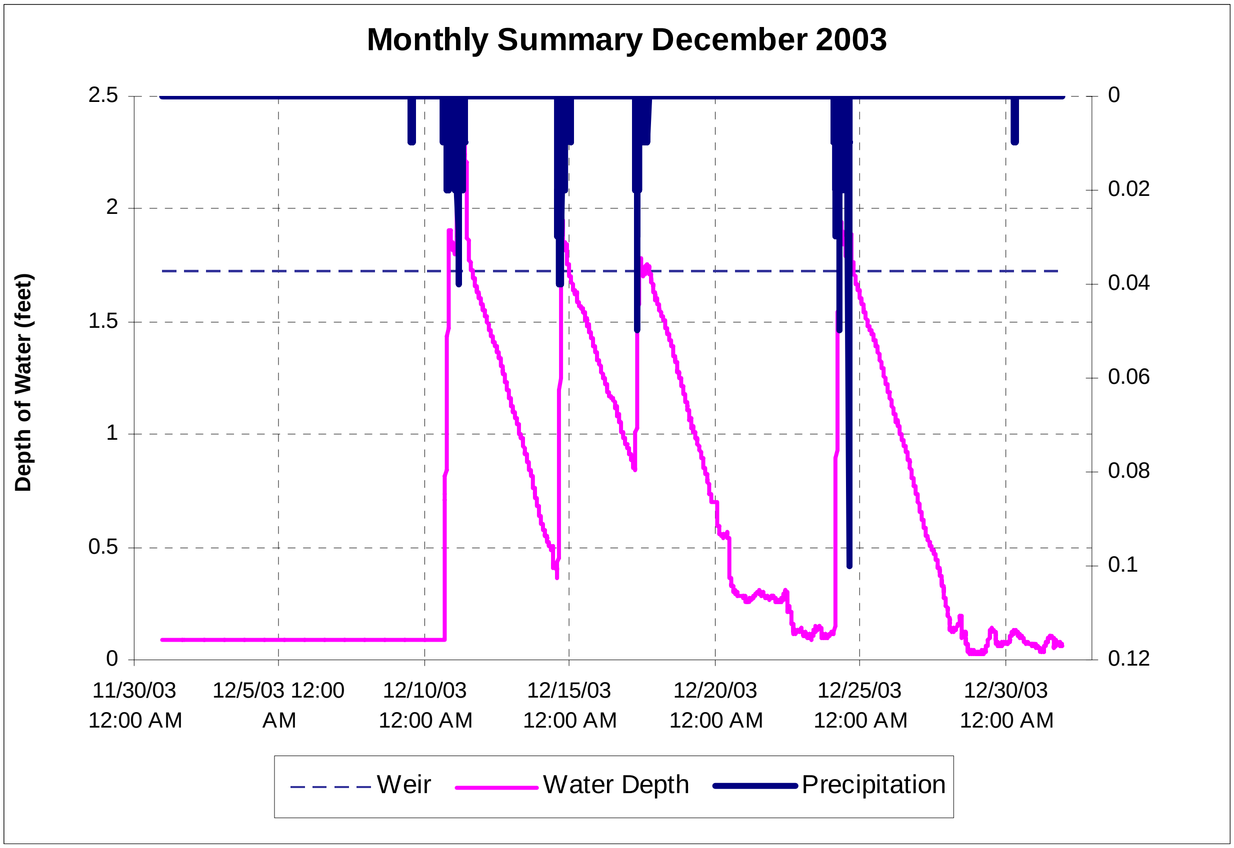
Performance Summary		
Site Performance:	90.4	%
BMP Performance:	86.4	%



December 2003

Monthly Summary				
	English		SI	
Total Rain:	5.33	inches	13.54	cm
1hr Max Int.	0.44	in/hr	1.12	cm/hr
Overflow:	3.87	inches	9.83	cm
	16344.38	cu.ft	462.8	cu.m
Average Infiltration Rate:	0.24	in/hr	0.61	cm/hr
Volume Inflow:	3.91	inches	9.93	cm
	16504.77	cu.ft	467.4	cu.m

Performance Summary		
Site Performance:	27.4	%
BMP Performance:	1.0	%



Monthly Performance Summary data is inaccurate because of interferences due to snow and icing within the basin.

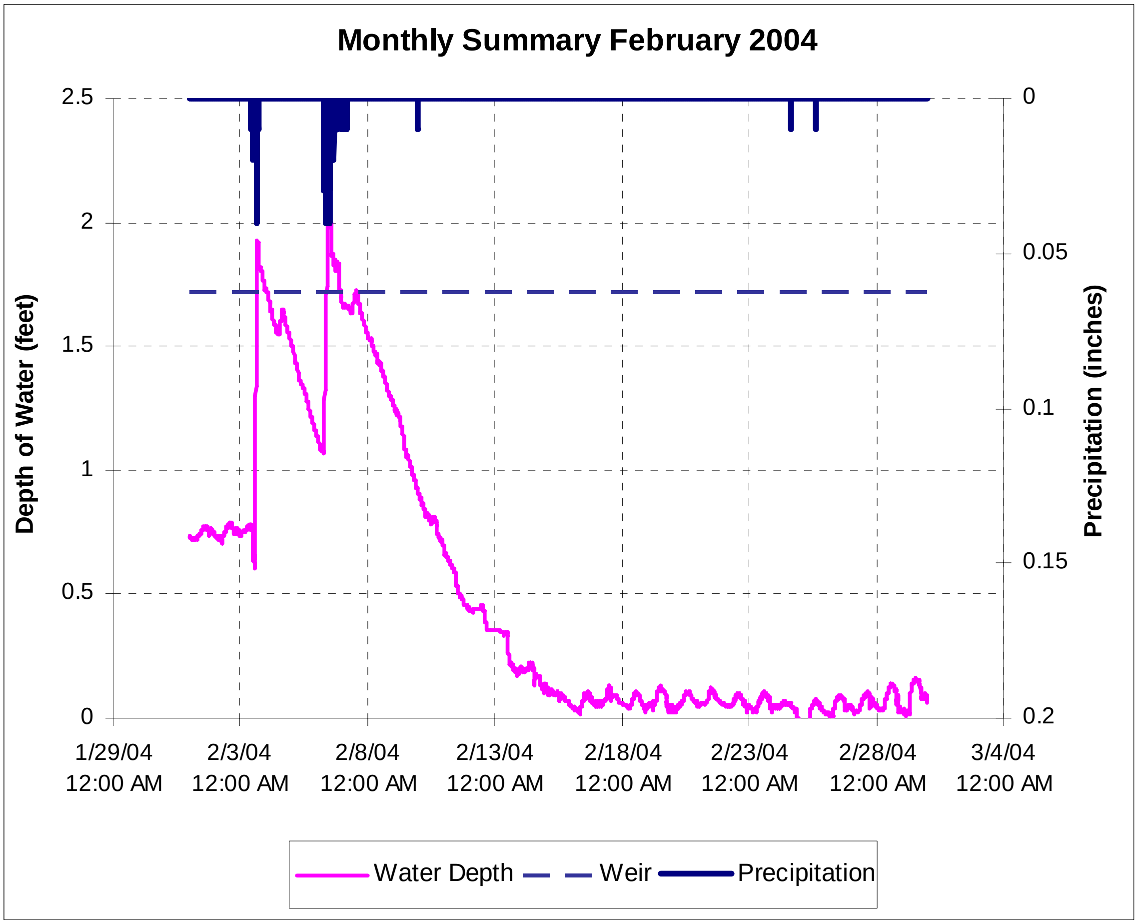
January 2004

Monthly Summary data is unavailable because of interferences due to snow and icing within the basin.

February 2004

Event Summary				
	English		SI	
Total Rain:	2.94	inches	7.47	cm
1hr Max Int.	0.38	in/hr	0.97	cm/hr
Overflow:	0.56	inches	1.42	cm
	2352.42	cu.ft	66.6	cu.m
Average Infiltration Rate:	0.17	in/hr	0.42	cm/hr
Volume Inflow:	1.78	inches	4.52	cm
	7513.68	cu.ft	212.8	cu.m

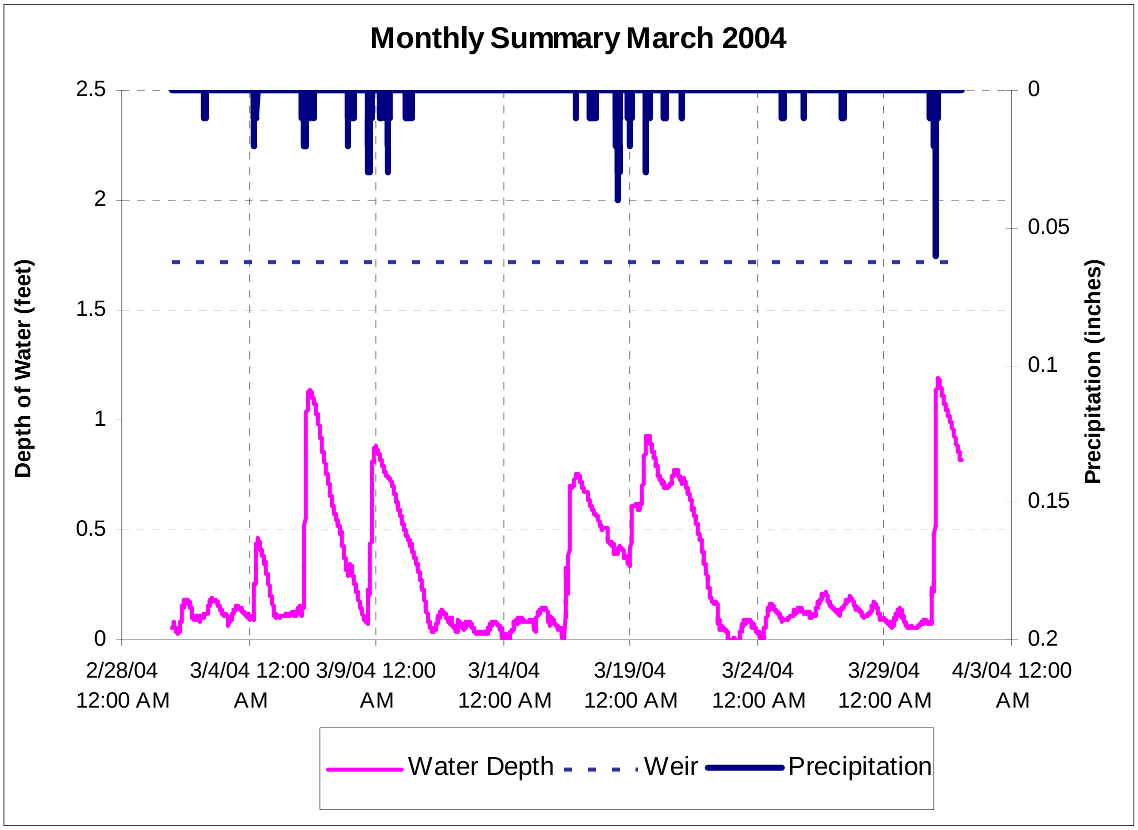
Performance Summary		
Site Performance:	81.0	%
BMP Performance:	68.7	%



March 2004

Monthly Summary				
	English		SI	
Total Rain:	3.90	inches	9.91	cm
1hr Max Int.	0.29	in/hr	0.74	cm/hr
Overflow:	0.00	inches	0.00	cm
	0.00	cu.ft	0.00	cu.m
Infiltration Rate:	0.25	in/hr	0.63	cm/hr
Volume Inflow:	2.61	inches	6.63	cm
	11017.25	cu.ft	312.0	cu.m

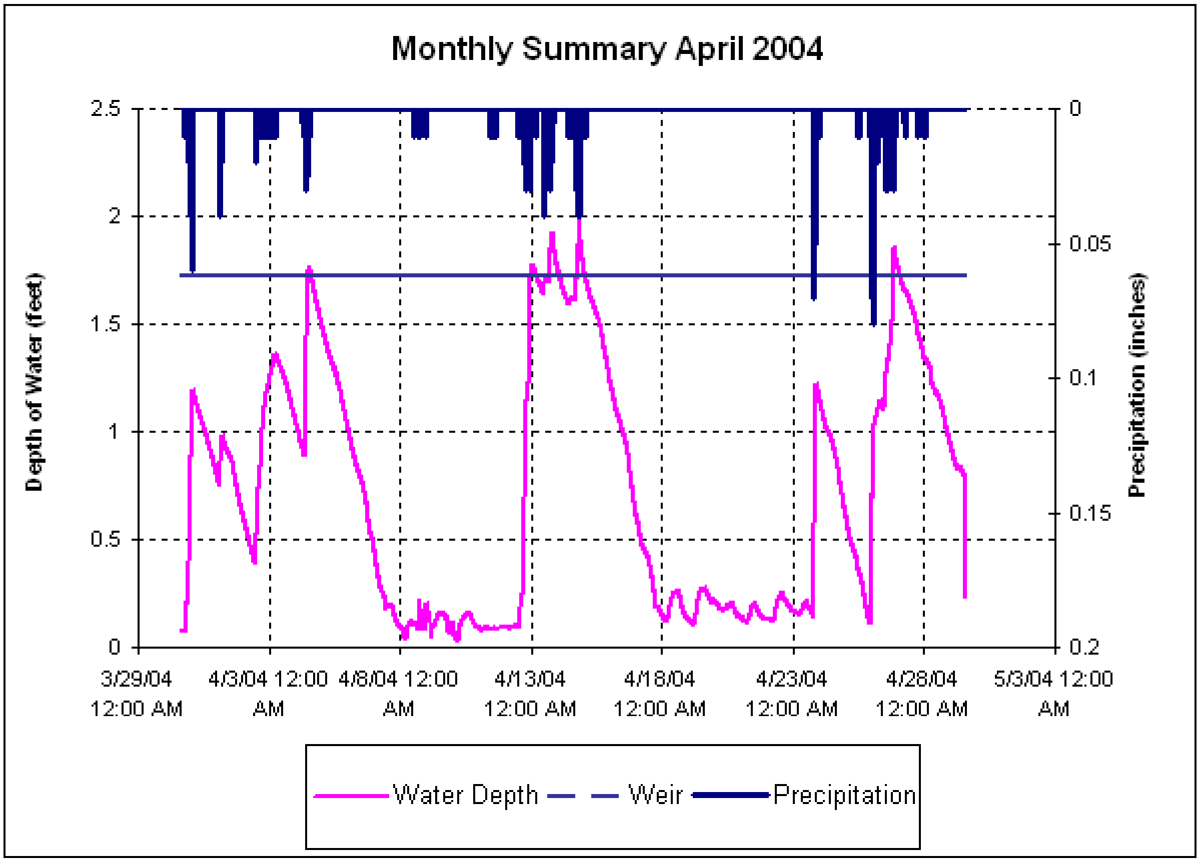
Performance Summary		
Site Performance:	100.0	%
BMP Performance:	100.0	%



April 2004

April 2004 Monthly Summary				
	English		SI	
Total Rain:	7.05	inches	17.91	cm
1hr Max Int.	0.38	in/hr	0.97	cm/hr
Overflow:	0.24	inches	0.61	cm
	1009.65	cu.ft	28.6	cu.m
Average Infiltration Rate:	0.25	in/hr	0.64	cm/hr
Volume Inflow:	5.53	inches	14.05	cm
	23343.06	cu.ft	661.0	cu.m

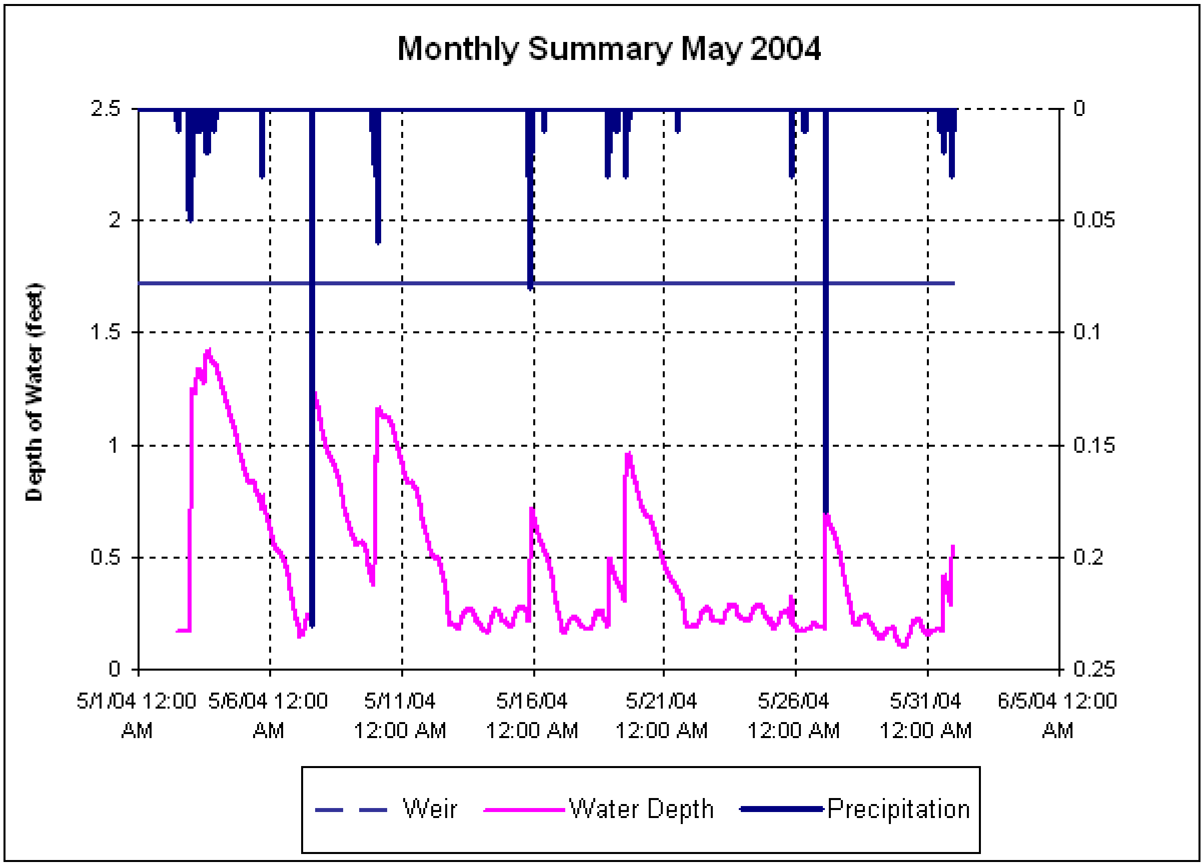
Performance Summary		
Site Performance:	96.6	%
BMP Performance:	95.7	%



May 2004

May 2004 Monthly Summary				
	English		SI	
Total Rain:	3.41	inches	8.66	cm
1hr Max Int.	0.44	in/hr	1.12	cm/hr
Overflow:	0.00	inches	0.00	cm
	0.00	cu.ft	0.00	cu.m
Average Infiltration Rate:	0.17	in/hr	0.43	cm/hr
Volume Inflow:	2.17	inches	5.51	cm
	9159.94	cu.ft	259.4	cu.m

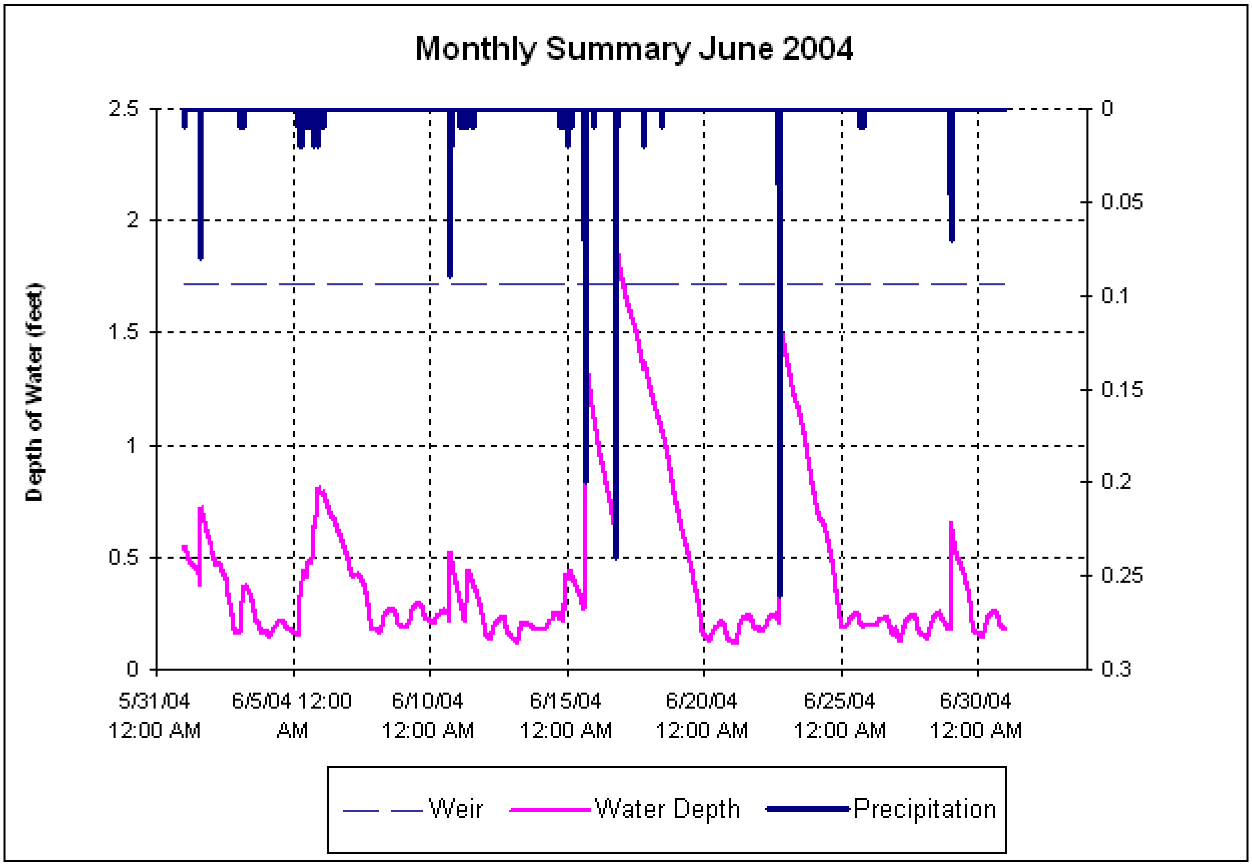
Performance Summary		
Site Performance:	100.0	%
BMP Performance:	100.0	%



June 2004

Monthly Summary				
	English		SI	
Total Rain:	4.04	inches	10.26	cm
1hr Max Int.	1.01	in/hr	2.57	cm/hr
Overflow:	0.18	inches	0.46	cm
	763.34	cu.ft	21.6	cu.m
Average Infiltration Rate:	0.28	in/hr	0.72	cm/hr
Volume Inflow:	2.74	inches	6.96	cm
	11566.00	cu.ft	327.5	cu.m

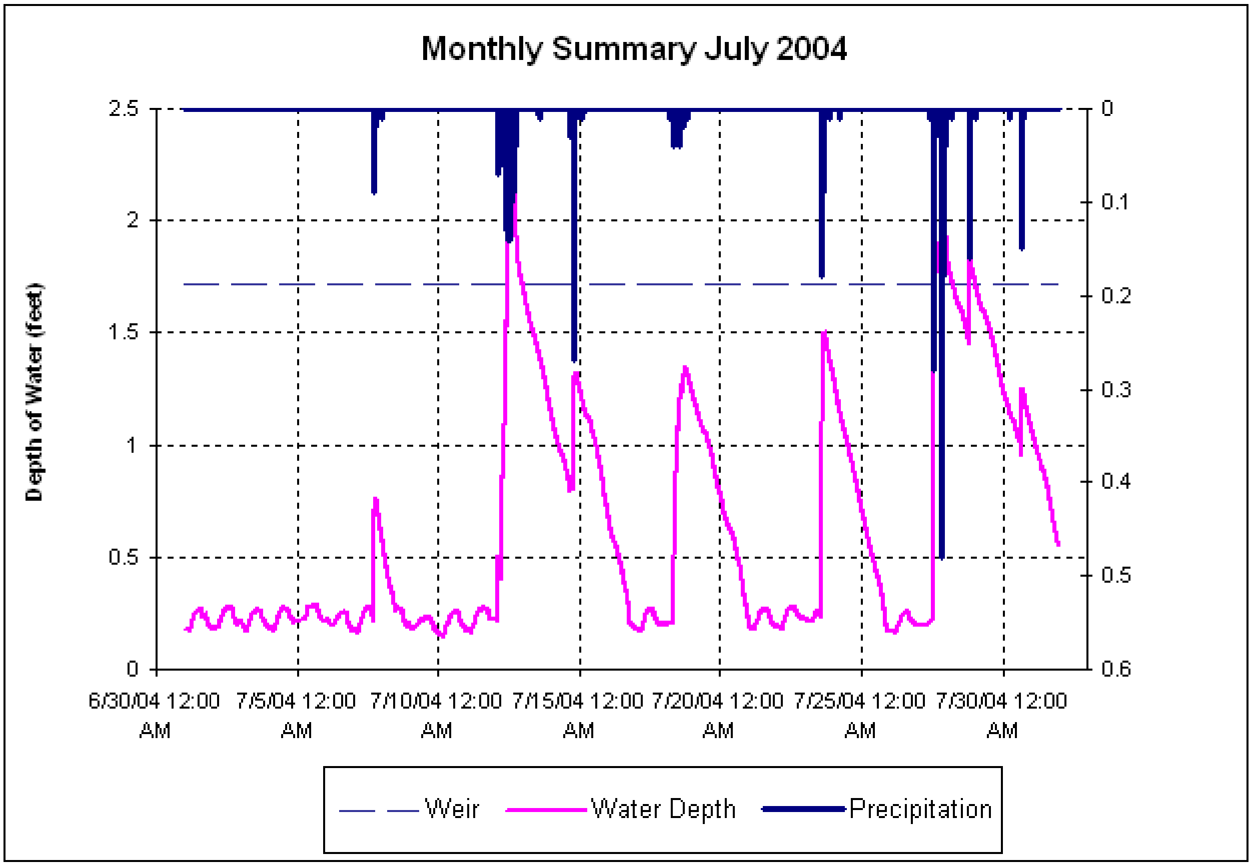
Performance Summary		
Site Performance:	95.5	%
BMP Performance:	93.4	%



July 2004

July 2004 Monthly Summary				
	English		SI	
Total Rain:	10.48	inches	26.62	cm
1hr Max Int.	1.35	in/hr	3.43	cm/hr
Overflow:	3.39	inches	8.61	cm
	14302.81	cu.ft	405.0	cu.m
Average Infiltration Rate:	0.22	in/hr	0.56	cm/hr
Volume Inflow:	8.85	inches	22.48	cm
	37357.34	cu.ft	1057.8	cu.m

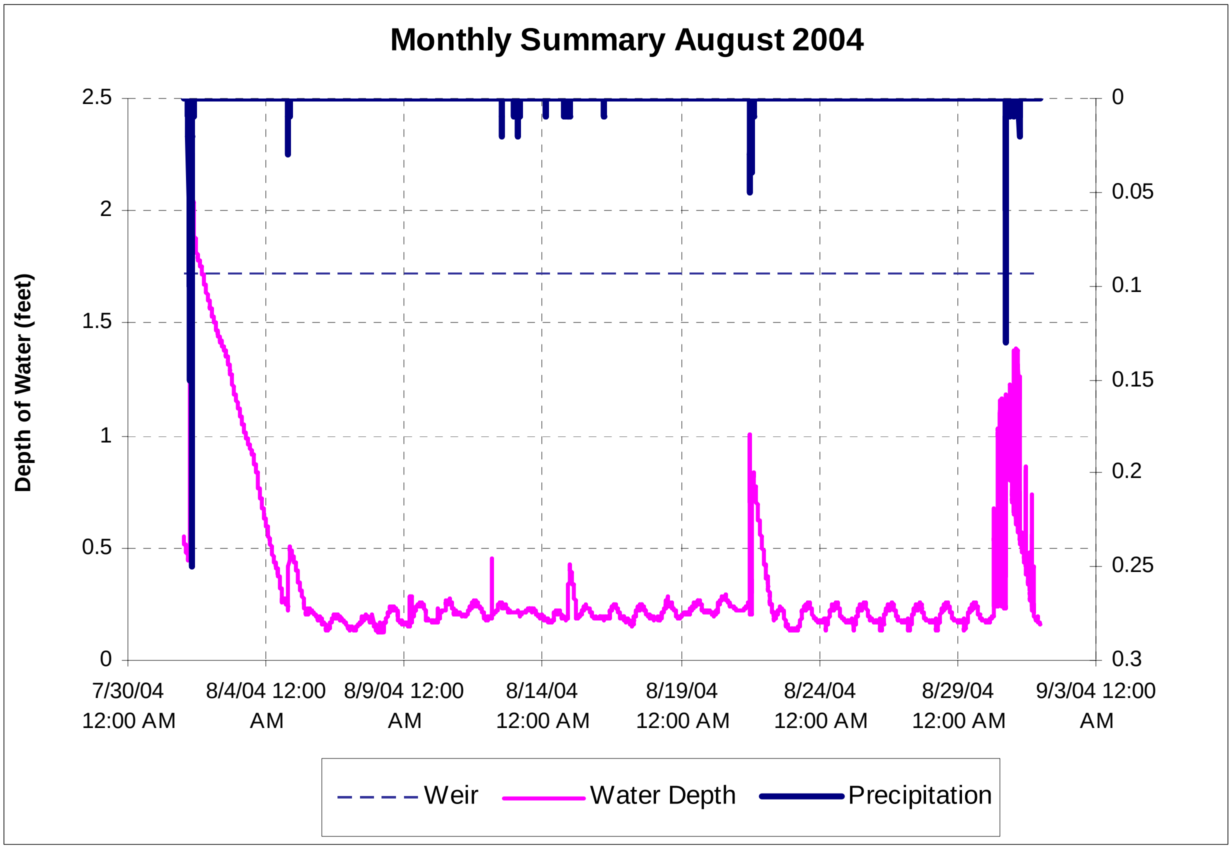
Performance Summary		
Site Performance:	67.7	%
BMP Performance:	61.7	%



August 2004

August 2004 Monthly Summary				
	English		SI	
Total Rain:	3.16	inches	8.03	cm
1hr Max Int.	0.94	in/hr	2.39	cm/hr
Overflow:	1.06	inches	2.68	cm
	4456.35	cu.ft	126.2	cu.m
Average Infiltration Rate:	0.22	in/hr	0.56	cm/hr
Volume Inflow:	1.97	inches	5.00	cm
	8315.70	cu.ft	235.5	cu.m

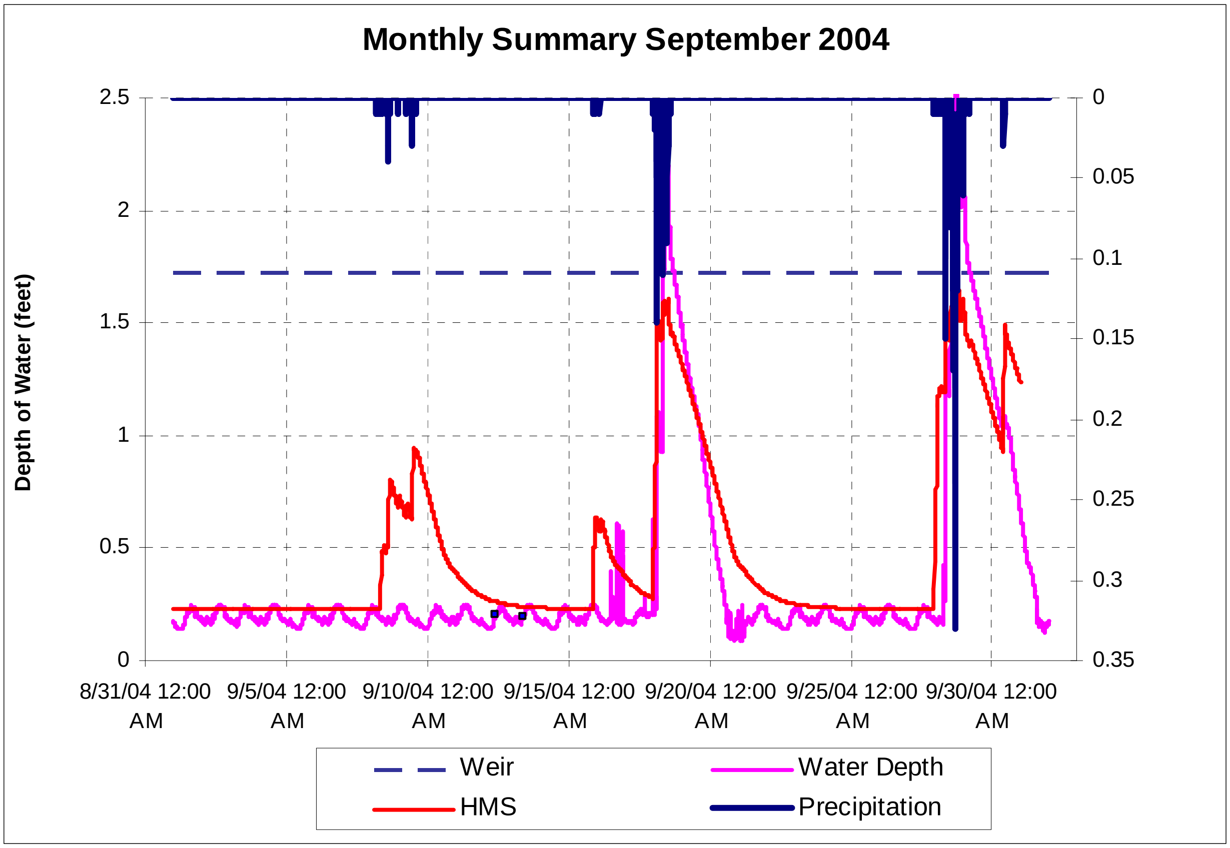
Performance Summary		
Site Performance:	66.6	%
BMP Performance:	46.4	%



September 2004

Monthly Summary				
	English		SI	
Total Rain:	10.36	inches	26.31	cm
1hr Max Int.	1.57	in/hr	3.99	cm/hr
Overflow:	5.50	inches	13.97	cm
	23216.77	cu.ft	657.4	cu.m
Average Infiltration Rate:	0.39	in/hr	0.99	cm/hr
Volume Inflow:	8.73	inches	22.17	cm
	36850.80	cu.ft	1043.5	cu.m

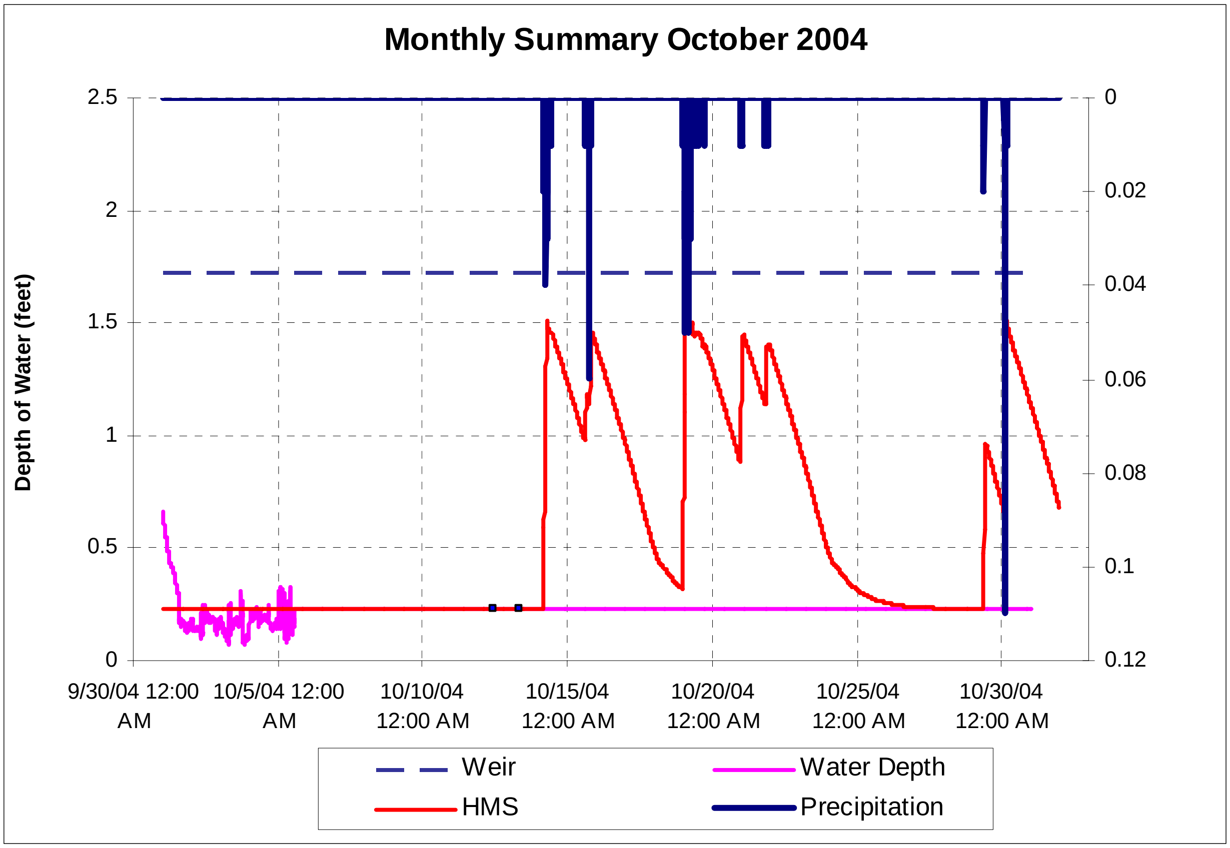
Performance Summary		
Site Performance:	46.9	%
BMP Performance:	37.0	%



October 2004

Monthly Summary				
	English		SI	
Total Rain:	2.75	inches	6.98	cm
1hr Max Int.	0.46	in/hr	1.17	cm/hr
Overflow:	0.00	inches	0.00	cm
	0.00	cu.ft	0.00	cu.m
Average Infiltration Rate:	NA	in/hr	NA	cm/hr
Volume Inflow:	1.62	inches	4.11	cm
	6838.29	cu.ft	193.6	cu.m

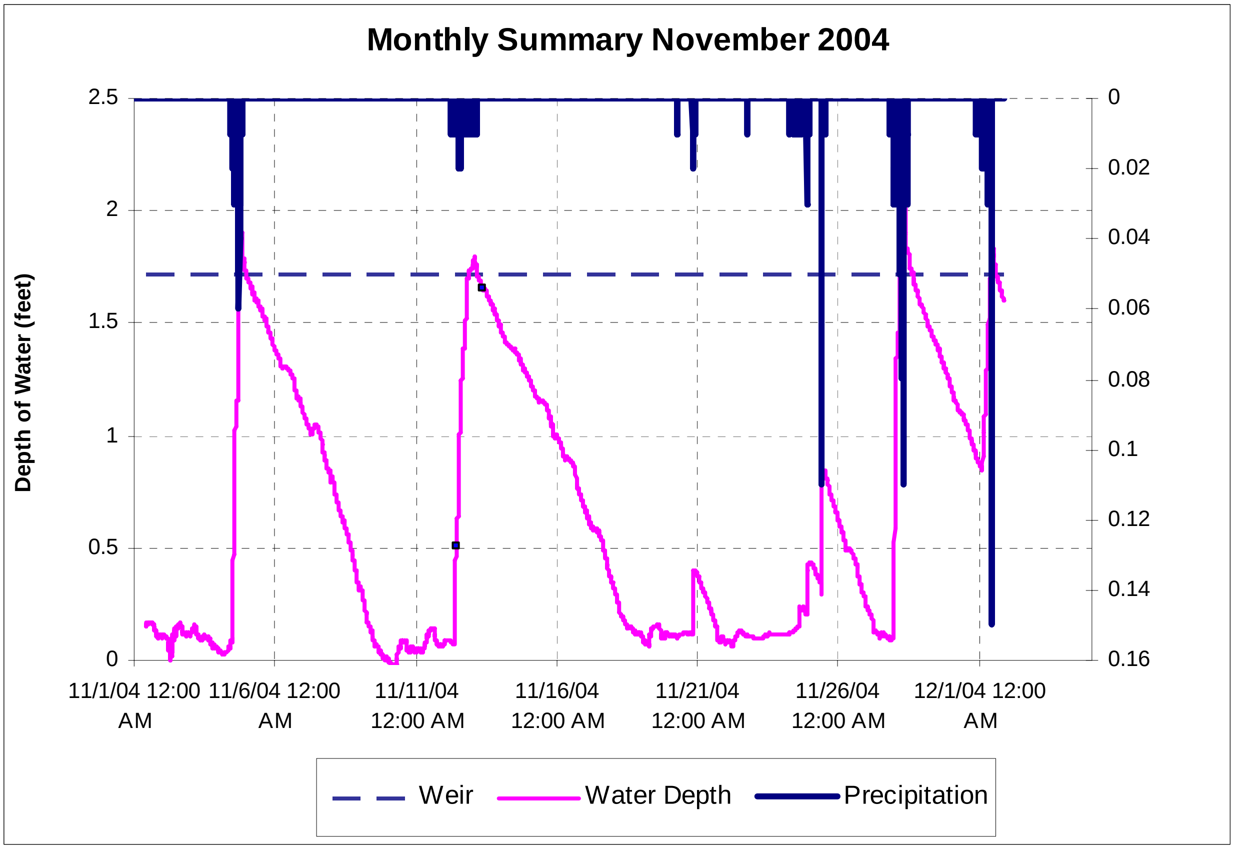
Performance Summary		
Site Performance:	100.0	%
BMP Performance:	100.0	%



November 2004

Monthly Summary				
	English		SI	
Total Rain:	5.82	inches	14.78	cm
1hr Max Int.	0.52	in/hr	1.32	cm/hr
Overflow:	0.91	inches	2.31	cm
	3839.91	cu.ft	108.7	cu.m
Average Infiltration Rate:	0.15	in/hr	0.39	cm/hr
Volume Inflow:	4.34	inches	11.02	cm
	18319.87	cu.ft	518.8	cu.m

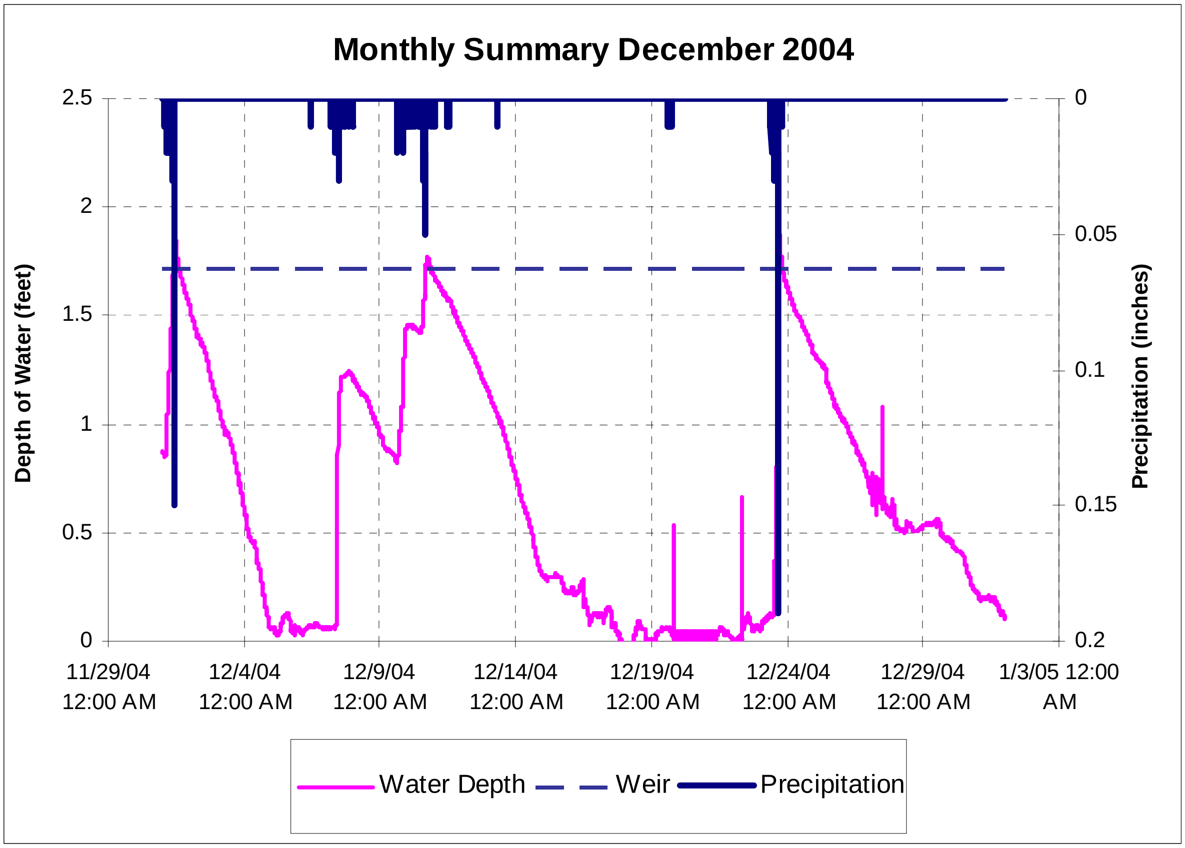
Performance Summary		
Site Performance:	84.4	%
BMP Performance:	79.0	%



December 2004

Monthly Summary				
	English		SI	
Total Rain:	3.89	inches	9.88	cm
1hr Max Int.	0.59	in/hr	1.50	cm/hr
Overflow:	0.07	inches	0.19	cm
	308.30	cu.ft	8.73	cu.m
Average Infiltration Rate:	0.20	in/hr	0.51	cm/hr
Volume Inflow:	2.60	inches	6.60	cm
	10975.04	cu.ft	310.8	cu.m

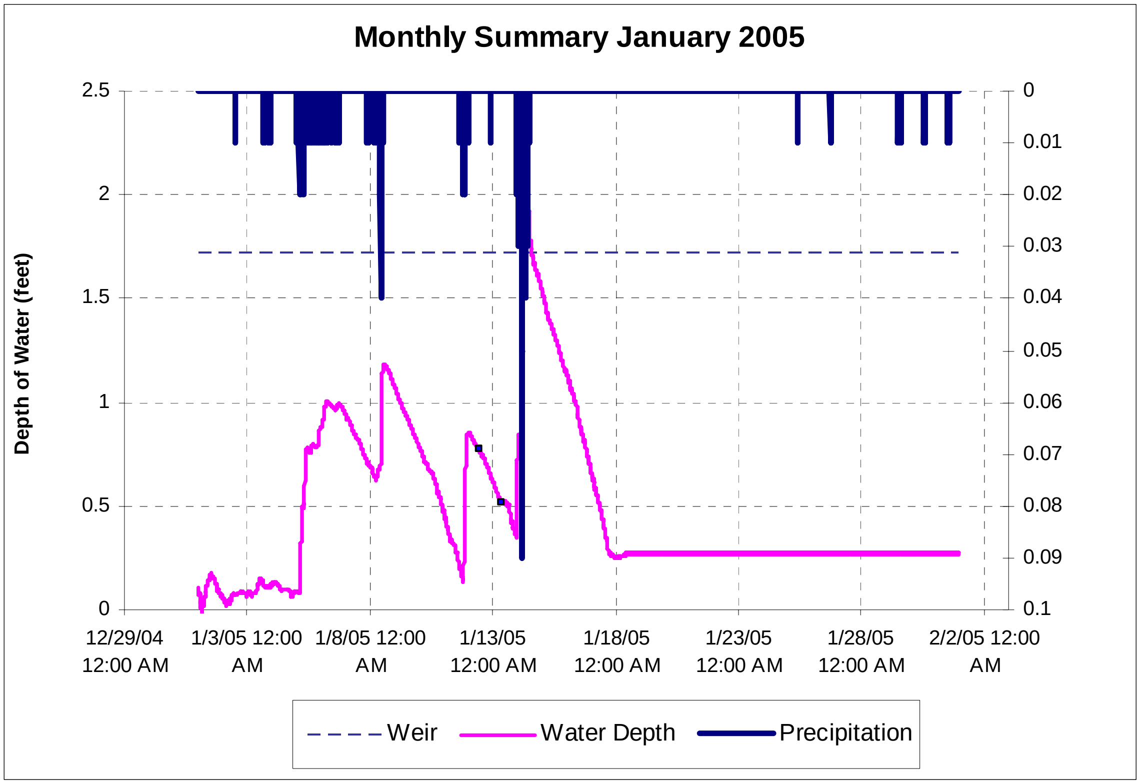
Performance Summary		
Site Performance:	98.1	%
BMP Performance:	97.2	%



January 2005

Monthly Summary				
	English		SI	
Total Rain:	4.12	inches	10.46	cm
1hr Max Int.	0.44	in/hr	1.12	cm/hr
Overflow:	0.46	inches	1.16	cm
	1931.44	cu.ft	54.7	cu.m
Average Infiltration Rate:	0.16	in/hr	0.40	cm/hr
Volume Inflow:	2.81	inches	7.14	cm
	11861.48	cu.ft	335.9	cu.m

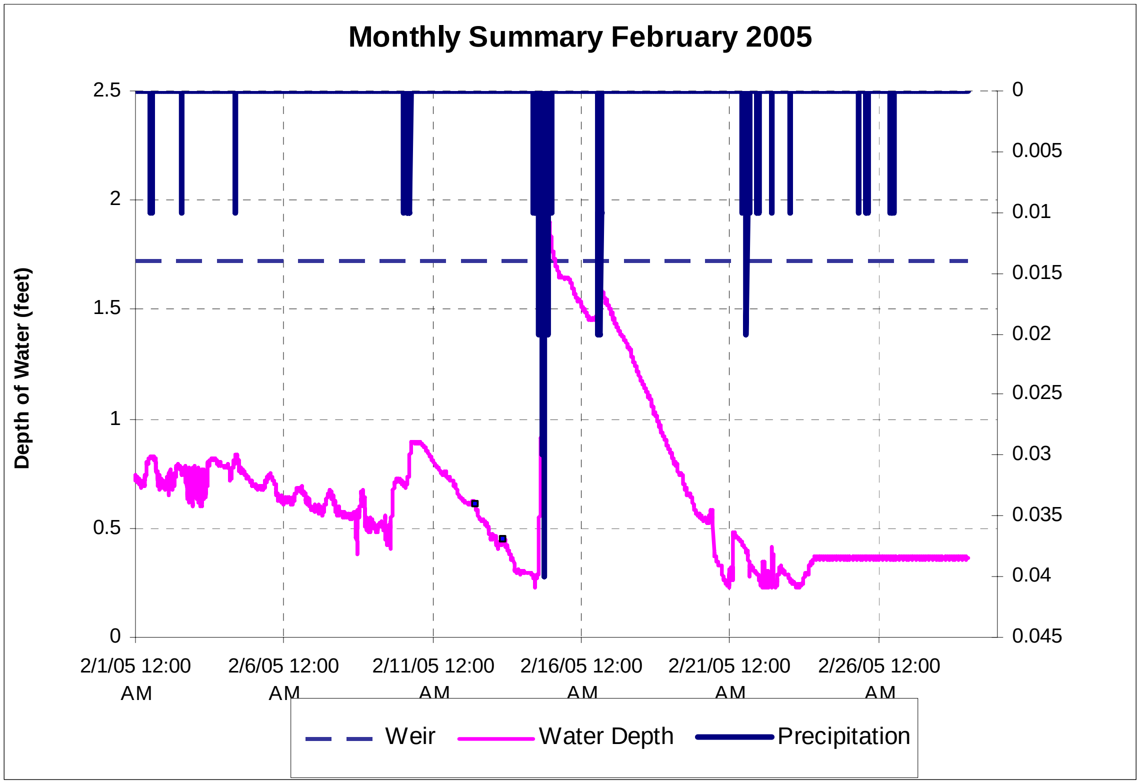
Performance Summary		
Site Performance:	88.9	%
BMP Performance:	83.7	%



February 2005

Monthly Summary				
	English		SI	
Total Rain:	2.06	inches	5.23	cm
1hr Max Int.	0.17	in/hr	0.43	cm/hr
Overflow:	0.07	inches	0.18	cm
	302.76	cu.ft	8.57	cu.m
Average Infiltration Rate:	0.15	in/hr	0.38	cm/hr
Volume Inflow:	1.05	inches	2.67	cm
	4432.23	cu.ft	125.5	cu.m

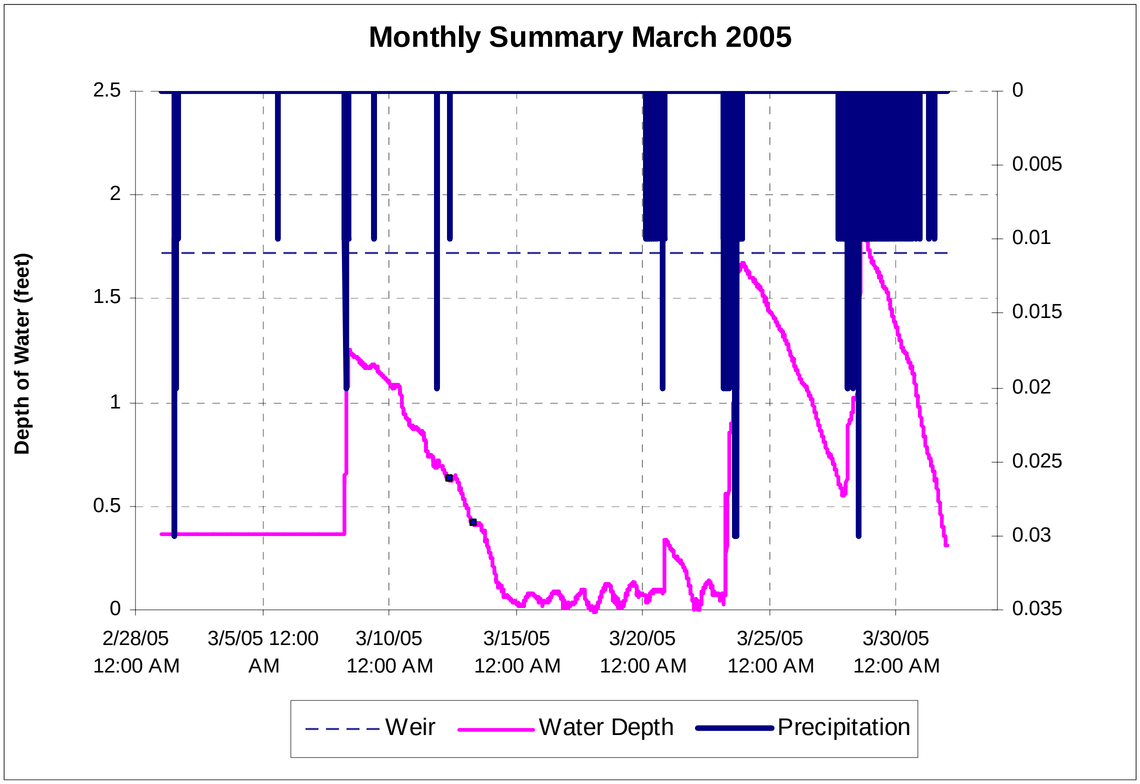
Performance Summary		
Site Performance:	96.5	%
BMP Performance:	93.2	%



March 2005

Monthly Summary				
	English		SI	
Total Rain:	3.66	inches	9.30	cm
1hr Max Int.	0.20	in/hr	0.51	cm/hr
Overflow:	0.25	inches	0.62	cm
	1037.06	cu.ft	29.4	cu.m
Average Infiltration Rate:	0.20	in/hr	0.51	cm/hr
Volume Inflow:	2.40	inches	6.10	cm
	10130.80	cu.ft	286.9	cu.m

Performance Summary		
Site Performance:	93.3	%
BMP Performance:	89.8	%



C.2: Event Summary Data

C.2.1: Summary of Monitored Variables

Event Date	**P_{tot} (in)**	**I_P in/hr**	**V_{out} (in)**	**V_{out} (cu.ft)**	**Avg Inf (in/hr)**	**t_{dry} (days)***
10/27/2003	3.24	0.33	1.04	4390.02	0.36	4.36
11/6/2003	0.97	0.18	0	0.00	0.32	4.09
11/18/2003	1.84	0.77	0.43	1815.10	0.34	2.23
12/10/2003	1.5	0.29	NA	NA	0.24	1.045
2/3/2004	0.75	0.23	0.07	295.48	0.18	11.86
2/6/2004	2.15	0.38	0.49	2068.37	0.15	2.58
3/9/2004	0.61	0.18	0	0.00	0.17	0.74
3/16/2004	1.32	0.29	0	0.00	0.27	6.48
3/31/2004	0.77	0.23	0	0.00	0.23	3.35
4/1/2004	0.23	0.19	0	0.00	0.25	1.06
4/13/2004	2.73	0.27	0.21	886.45	0.31	2.41
4/26/2004	1.54	0.22	0.026	109.75	0.2	1.47
5/4/2004	1.01	0.27	0	0.00	0.17	4.44
5/19/2004	0.51	0.22	0	0.00	0.16	2.48
6/5/2004	0.58	0.08	0	0.00	0.17	1.98
6/11/2004	0.34	0.14	0	0.00	NA	4.61
6/15/2004	0.76	0.42	0	0.00	0.31	3.15
7/8/2004	0.39	0.25	0	0.00	NA	8.66
7/12/2004	4	0.84	1.58	6669.45	0.3	4.06
7/18/2004	0.94	0.19	0	0.00	0.24	3.08
7/28/2004	3.89	1.35	1.81	7640.31	0.26	3.56
9/8/2004	0.35	0.1	0	0.00	NA	7.94
9/27/2004	7.1	1.57	4.81	20303.82	0.38	9.31
10/19/2004	0.77	0.26	0	0	NA	3.14
11/12/2004	1.45	0.13	0.01	42.21	0.14	7.41
12/1/2004	0.96	0.24	0.04	168.85	0.22	0.13
12/7/2004	1.78	0.16	0.002	8.44	0.18	5.73
2/14/2005	1.39	0.17	0.07	295.48	0.15	4.15
3/23/2005	1.06	0.2	0	0.00	0.15	2.35
3/29/2005	1.6	0.15	0.2	844.23	0.25	3.81

Summary	**P_{tot} (in)**	**I_P (in/hr)**	**V_{out} (in)**	**V_{out} (cu.ft)**	**Avg Inf (in/hr)**	**t_{dry} (days)**
Average:	1.55	0.34	0.37	1570.27	0.23	4.06
Maximum:	7.10	1.57	4.81	20303.82	0.38	11.86
Minimum:	0.23	0.08	0.00	0.00	0.14	0.13
Median	1.04	0.23	0.00	0.00	0.24	3.46
Std Dev:	1.44	0.35	0.97	4106.42	0.07	2.74
N:	30	30	29	29	26	30

C.2.2: Summary of Calculated Water Quantity Variables

	Runoff Volume Pervious V_P		Runoff Volume Impervious V_I		Total Runoff Volume $V_{in} = V_P + V_I$			Peak Flow Q_P	
Event Date	**(a-ft)**	**(in)**	**(ac-ft)**	**(in)**	**(ac-ft)**	**(in)**	**(cu.ft)**	**(cfs)**	**(Peak Time)**
10/27/2003	0.0852	1.433	0.1119	2.989	0.1971	2.034	8584.4	0.154	10/27/03 2:15 AM
11/6/2003	0.0044	0.074	0.0278	0.743	0.0322	0.333	1404.7	0.058	11/5/03 8:00 PM
11/18/2003	0.0278	0.468	0.0598	1.597	0.0876	0.904	3815.3	0.476	11/19/03 5:35 PM
12/10/2003	0.0170	0.286	0.0472	1.261	0.0642	0.663	2796.7	0.182	12/11/03 4:20 AM
2/3/2004	0.0014	0.023	0.0199	0.532	0.0213	0.220	927.0	0.121	2/4/04 3:20 PM
2/6/2004	0.0398	0.669	0.0720	1.924	0.1118	1.154	4869.6	0.271	2/6/04 11:55 AM
3/9/2004	0.0003	0.005	0.0150	0.401	0.0153	0.158	666.1	0.070	3/9/04 11:10 AM
3/16/2004	0.0147	0.248	0.0443	1.183	0.0590	0.609	2569.4	0.195	3/19/04 2:50 PM
3/31/2004	0.0016	0.026	0.0206	0.551	0.0222	0.229	967.4	0.137	3/31/04 12:55 AM
4/1/2004	0.0000	0.000	0.0029	0.077	0.0029	0.030	126.0	0.036	4/1/04 4:25 AM
4/13/2004	0.0625	1.051	0.0929	2.480	0.1554	1.603	6768.4	0.315	4/14/04 7:50 PM
4/26/2004	0.0182	0.306	0.0487	1.301	0.0669	0.690	2912.3	0.171	4/26/04 8:15 PM
5/4/2004	0.0051	0.086	0.0293	0.782	0.0344	0.355	1499.0	0.086	5/3/04 12:50 AM
5/19/2004	0.0000	0.000	0.0116	0.310	0.0116	0.120	504.9	0.087	5/19/04 1:10 PM
6/5/2004	0.0001	0.002	0.0140	0.373	0.0141	0.146	615.3	0.041	6/5/04 9:40 PM
6/11/2004	0.0000	0.000	0.0061	0.162	0.0061	0.063	264.1	0.024	6/11/04 8:30 AM
6/15/2004	0.0015	0.024	0.0203	0.542	0.0217	0.224	947.2	0.308	6/15/04 4:50 PM
7/8/2004	0.0000	0.000	0.0076	0.204	0.0076	0.079	332.5	0.064	7/7/04 5:45 PM
7/12/2004	0.1214	2.041	0.1402	3.745	0.2616	2.700	11397.1	0.837	7/12/04 11:35 AM
7/18/2004	0.0039	0.066	0.0267	0.714	0.0307	0.316	1335.4	0.113	7/18/04 2:00 PM
7/28/2004	0.1160	1.951	0.1361	3.636	0.2522	2.602	10983.7	1.653	7/27/04 8:10 PM
9/8/2004	0.0000	0.000	0.0067	0.178	0.0067	0.069	291.1	0.049	9/9/04 11:35 AM
9/27/2004	0.2924	4.917	0.2613	6.980	0.5537	5.714	24120.6	1.779	9/28/04 5:45 PM
10/19/2004	0.0016	0.026	0.0206	0.550	0.0222	0.229	967.5	0.087	10/19/04 1:40 AM
11/12/2004	0.0156	0.262	0.0454	1.212	0.0609	0.629	2654.0	0.072	11/12/04 6:50 PM
12/1/2004	0.0043	0.071	0.0275	0.734	0.0317	0.327	1381.5	0.235	12/1/04 10:15 AM
12/7/2004	0.0266	0.447	0.0579	1.548	0.0840	0.867	3660.7	0.139	12/10/04 4:45 PM
2/14/2005	0.0139	0.234	0.0432	1.153	0.0571	0.589	2485.5	0.123	2/14/05 7:00 PM
3/23/2005	0.0061	0.102	0.0311	0.831	0.0372	0.384	1619.7	0.157	2/23/05 4:30 PM
3/29/2005	0.0206	0.347	0.0516	1.380	0.0722	0.746	3147.1	0.108	3/28/05 1:25 PM
	$V_{in,P}$		**$V_{in,I}$**		**V_{in}**			**Q_P**	
	(a-ft)	**(in)**	**(ac-ft)**	**(in)**	**(ac-ft)**	**(in)**	**(cu.ft)**	**(cfs)**	
Average:	0.03	0.47	0.05	1.28	0.08	0.78	3311.38	0.28	
Maximum:	0.29	4.92	0.26	6.98	0.55	5.71	24120.6	1.78	
Minimum:	0.00	0.00	0.00	0.08	0.00	0.03	125.98	0.02	
Median	0.01	0.09	0.03	0.78	0.03	0.36	1498.99	0.12	
Stn Dev:	0.06	1.00	0.05	1.43	0.11	1.16	4904.01	0.43	
N:	29	29	29	29	29	29	29	29	

Appendix C.3: Monthly Performance Summary

	Month	V in		V out		BMP Performance
		(cu.ft)	(cu.m)	(cu.ft)	(cu.m)	(%)
1	Oct-03	16421.3	465	4640.3	131.4	71.7
2	Nov-03	13458.4	381.1	1836.4	52	86.4
3	Dec-03	16506.1	467.4	16343.6	462.8	--
4	Jan-04	--	--	--	--	--
5	Feb-04	7515.0	212.8	2352.0	66.6	68.7
6	Mar-04	11018.2	312	0.0	0	100.0
7	Apr-04	23343.0	661	1010.0	28.6	95.7
8	May-04	9160.6	259.4	0.0	0	100.0
9	Jun-04	11565.6	327.5	762.8	21.6	93.4
10	Jul-04	37355.9	1057.8	14302.4	405	61.7
11	Aug-04	8316.6	235.5	4456.7	126.2	46.4
12	Sep-04	36850.9	1043.5	23215.9	657.4	37.0
13	Oct-04	6836.9	193.6	0.0	0	100.0
14	Nov-04	18321.3	518.8	3838.7	108.7	79.0
15	Dec-04	10975.8	310.8	308.3	8.73	97.2
16	Jan-05	11862.2	335.9	1931.7	54.7	83.7
17	Feb-05	4432.0	125.5	302.6	8.57	93.2
18	Mar-05	10131.8	286.9	1038.3	29.4	89.8

	V in		V out		BMP Performance
	(cu.ft)	(cu.m)	(cu.ft)	(cu.m)	(%)
Total	254071	7194.5	76340	2161.7	
Average	14945	423.2	4490.6	127.2	81.5
Maximum	37356	1057.8	23216	657.4	100.0
Minimum	4432.0	125.5	0.0	0.0	37.0
Stdev	9536.1	270.0	6798.3	192.5	19.5

Appendix C.4: Infiltration Data; N = 96, September 2002 through April 2005.

C.4.1 Infiltration Data Table

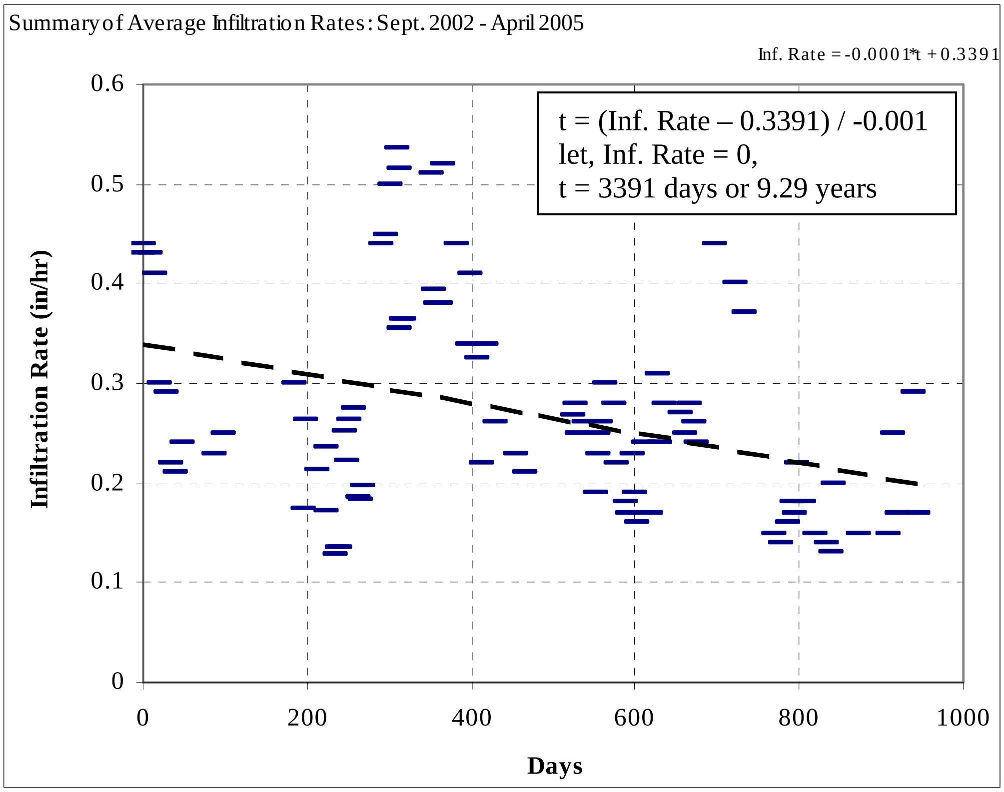
Event Date	Precip (inches)	Total Overflow (inches)	Site Performance (percent)	Average Infiltration (in/hr)
9/26/02	2.36	~	~	0.44
9/27/02	0.64	~	~	0.43
10/4/02	0.33	~	~	0.43
10/10/02	2.86	~	~	0.41
10/16/02	1.38	~	~	0.3
10/25/02	1.17	~	~	0.29
10/29/02	1.52	~	~	0.22
11/5/02	0.54	~	~	0.21
11/11/02	~	~	~	0.24
12/20/02	0.91	~	~	0.23
1/1/03	1.57	~	~	0.25
3/30/03	~	~	~	0.3
4/9/03	0.84	~	~	0.18
4/12/03	0.94	~	~	0.26
4/26/03	0.52	~	~	0.21
5/6/03	0.23	~	~	0.17
5/8/03	0.63	~	~	0.24
5/17/03	0.35	~	~	0.13
5/21/03	0.32	~	~	0.13
5/24/03	0.19	~	~	0.14
5/28/03	1.87	~	~	0.25
6/1/03	1.78	~	~	0.22
6/5/03	1.82	~	~	0.26
6/8/03	0.85	~	~	0.27
6/15/03	0.82	~	~	0.19
6/18/03	1.01	~	~	0.18
6/21/03	2.94	~	~	0.20
7/12/03	0.43	0	100	0.44
7/18/03	0.18	0	100	0.45
7/24/03	0.33	0	100	0.50
8/1/03	0.53	0	100	0.54
8/4/03	0.86	0	100	0.52
8/5/03	1.93	0.75	61.2	0.36
8/7/03	0.58	0	100	0.37
8/9/03	1.61	0.38	76.4	0.37

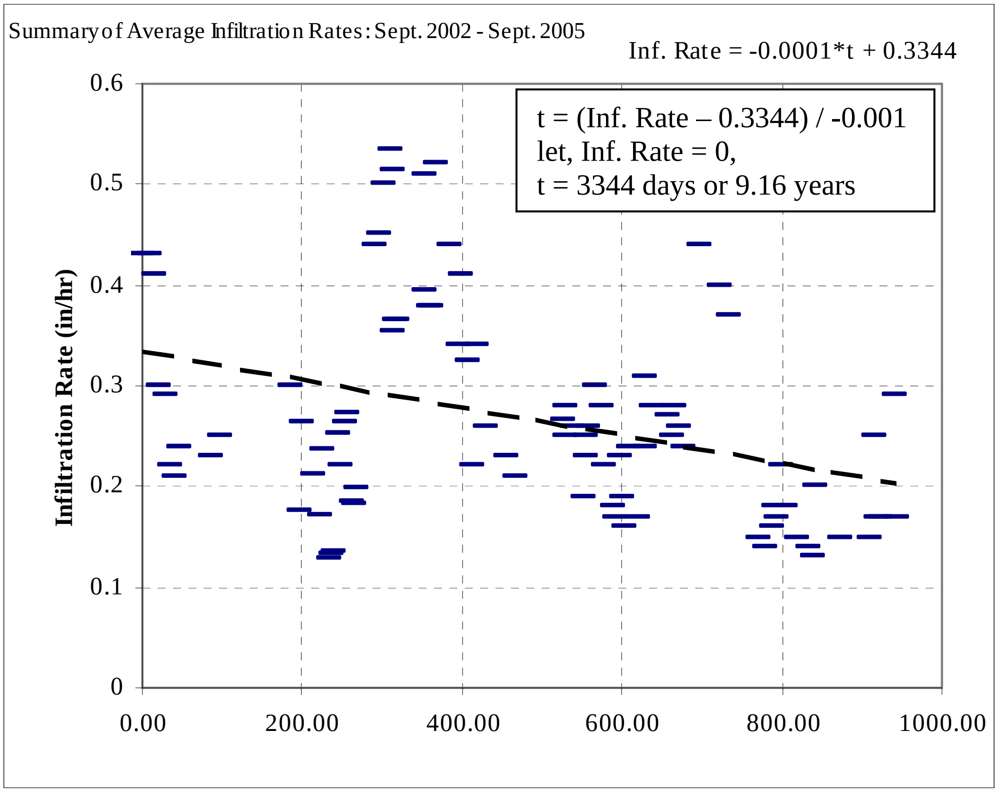
9/13/03	0.81	0	100	0.51
9/14/03	1.57	0.07	95.6	0.39
9/18/03	1.51	0.64	57.3	0.38
9/23/03	1.12	0.001	99.9	0.38
9/27/03	1.02	0	100	0.52
10/14/03	1.45	0.06	96	0.44
10/27/03	2.73	0.8	70.7	0.34
10/28/03	1.36	0.24	82.2	0.41
11/6/03	0.97	0	100	0.33
11/12/03	0.49	0	100	0.22
11/18/03	1.84	0.43	76.4	0.34
11/28/03	0.99	0.001	99.9	0.26
12/24/03	1.8	0.3	82.4	0.23
1/4/04	0.58	0	100	0.21
3/4/04	0.23	0	100	0.27
3/6/04	0.62	0	100	0.28
3/8/04	0.73	0	100	0.25
3/16/04	1.32	0	100.0	0.26
3/31/04	0.77	0	100	0.19
4/1/04	0.23	0	100	0.25
4/2/04	0.89	0	100	0.23
4/4/04	0.77	0.001	99.8	0.26
4/12/04	2.73	0.21	92.2	0.30
4/23/04	0.76	0	100	0.28
4/25/04	1.54	0.03	98.3	0.22
5/7/04	0.44	0	100	0.18
5/9/04	0.49	0	100	0.17
5/15/04	0.31	0	100	0.23
5/18/04	0.15	0	100	0.19
5/19/04	0.36	0	100	0.16
5/27/04	0.22	0	100	0.24
6/5/04	0.58	0	100	0.17
6/15/04	0.76	0	100	0.31
6/16/04	1.14	0.18	84.1	0.24
6/22/04	0.7	0	100	0.28
7/12/04	4	1.58	60.5	0.27
7/18/04	0.94	0	100	0.25
7/23/04	0.79	0	100	0.28
7/27/04	3.89	1.81	53.6	0.26
8/1/04	1.9	1.06	44	0.24
8/21/04	0.35	0	100	0.44

9/17/04	2.72	0.69	74.5	0.40
9/28/04	7.1	4.81	32.3	0.37
11/4/04	1.36	0.09	93.4	0.15
11/12/04	1.45	0.01	99.3	0.14
11/20/04	0.16	0	100.0	0.16
11/24/04	0.46	0	100.0	0.18
11/27/04	2.34	0.81	65.4	0.17
12/1/04	0.96	0.04	95.8	0.22
12/9/04	1.78	0.002	99.9	0.18
12/23/04	0.93	0.03	96.8	0.15
1/5/05	1.37	0	100.0	0.14
1/11/05	0.4	0	100.0	0.13
1/14/05	1.59	0.46	71.1	0.20
2/14/05	1.39	0.07	95.0	0.15
3/7/05	0.28	0	100.0	~
3/23/05	1.06	0	100.0	0.15
3/29/05	1.6	0.25	84.4	0.25
4/2/05	2.95	1.85	37.3	0.17
4/7/05	0.36	0	100.0	0.17
4/23/05	0.69	0	100.0	0.29
4/27/05	0.3	0	100.0	0.17

Average:	1.18	0.25	91.1	0.27
Maximum:	7.10	4.81	100.0	0.54
Minimum:	0.15	0.00	32.3	0.13
Median	0.91	0.00	100.0	0.25
Stn Dev:	1.02	0.69	16.6	0.10
N:	95	70	70	96

C.4.2 Infiltration Figures





Appendix D: Water Quality Data

D.1: Event Summary of Difference Efficiencies for First Flush

	Conductivity (uS/cm)		
Date Collected	Avg FF	EMC	Difference
			(%)
7/29/2004	46.40	28.43	38.74
9/8/2004	80.15	~	~
9/28/2004	87.15	32.00	63.28
10/19/2004	57.20	34.85	39.07
11/12/2004	33.10	24.15	27.04
12/1/2004	46.65	29.95	35.80
12/7/2004	41.00	25.20	38.54
2/14/2005	~	76.60	~
3/23/2005	191.90	79.30	58.68
3/29/2005	~	54.65	~
	Average Difference (%):		43.0

	TSS (mg/L)		
Date Collected	Avg FF	EMC	Difference
			(%)
7/29/2004	~	8.34	~
9/8/2004	1790.70	~	~
9/28/2004	~	5.00	~
10/19/2004	154.25	23.75	84.60
11/12/2004	44.10	3.85	91.27
12/1/2004	85.25	6.00	92.96
12/7/2004	86.50	4.75	94.51
2/14/2005	1367.00	11.00	~
3/23/2005	431.00	20.50	95.24
3/29/2005	~	48.25	~
	Average Difference (%):		91.7

	TDS (mg/L)		
Date Collected	Avg FF	EMC	Difference
			(%)
7/29/2004	~	39.54	~
9/8/2004	92.40	~	~
9/28/2004	87.00	43.50	50.0
10/19/2004	51.67	24.67	52.25
11/12/2004	46.49	28.15	39.45
12/1/2004	40.00	22.70	43.25
12/7/2004	35.65	22.95	35.62
2/14/2005	~	95.95	~
3/23/2005	129.45	117.75	9.04
3/29/2005	0.00	117.50	
	Average Difference (%):		38.3

	Total Nitrogen (mg/L)		
Date Collected	Avg FF	EMC	Difference
			(%)
7/29/2004	~	0.83	~
9/8/2004	1.15	~	~
9/28/2004	2.95	0.50	83.05
10/19/2004	1.85	1.30	29.73
11/12/2004	1.30	0.90	30.77
12/1/2004	1.60	1.00	37.50
12/7/2004	1.60	1.50	6.25
2/14/2005	0.70	~	~
3/23/2005	0.40	0.00	100
3/29/2005		~	~
	Average Difference (%):		47.9

	Total Phosphorous (mg/L-PO_4)		
Date Collected	Avg FF	EMC	Difference
			(%)
7/29/2004	~	1.24	~
9/8/2004	0.50	~	~
9/28/2004	1.84	1.70	7.36
10/19/2004	0.85	0.74	13.02
11/12/2004	0.85	1.05	-18.66
12/1/2004	0.83	0.55	33.94
12/7/2004	~	~	~
2/14/2005	0.45	0.37	18.89
3/23/2005	0.35	0.68	-48.15
3/29/2005	0.00	0.49	~
	Average Difference (%):		1.1

	Total Chloride (mg/L-Cl)		
Date Collected	Avg FF	EMC	Difference
			(%)
7/29/2004	0.32	1.50	~
9/8/2004	NT	NT	~
9/28/2004	NT	3.61	~
10/19/2004	NT	6.69	~
11/12/2004	0.56	0.63	-11.00
12/1/2004	0.87	0.77	11.56
12/7/2004	1.26	0.88	30.03
2/14/2005	NT	NT	~
3/23/2005	48.47	55.10	-12.04
3/29/2005			~
	Average Difference (%):		4.6

	Nitrite (mg/L NO_2-N)		
Date Collected	Avg FF	EMC	Difference
			(%)
7/29/2004	~	ND	~
9/8/2004	~	NT	~
9/28/2004	~	ND	~
10/19/2004	~	ND	~
11/12/2004	0.08	0.13	-38.76
12/1/2004	0.17	0.11	38.24
12/7/2004	0.07	0.08	-18.75
2/14/2005	NT	NT	~
3/23/2005	0.13	0.30	-55.48
3/29/2005	~	ND	~
	Average Difference (%):		-18.7

	Nitrate (mg/L NO_3-N)		
Date Collected	Avg FF	EMC	Difference (%)
7/29/2004	ND	0.33	~
9/8/2004	NT	NT	~
9/28/2004	NT	ND	~
10/19/2004	NT	ND	~
11/12/2004	0.29	0.18	36.24
12/1/2004	0.19	0.13	34.21
12/7/2004	0.24	0.18	27.08
2/14/2005	NT	NT	~
3/23/2005	0.97	0.37	61.68
3/29/2005	~	ND	~
	Average Difference (%):		39.8

	Ortho Phosphate (mg/L PO_4)		
Date Collected	Avg FF	EMC	Difference (%)
7/29/2004	ND	1.26	~
9/8/2004	NT	NT	~
9/28/2004	NT	ND	~
10/19/2004	NT	ND	~
11/12/2004	0.33	0.73	-54.74
12/1/2004	0.58	0.47	18.97
12/7/2004	0.59	0.35	41.03
2/14/2005	NT	NT	~
3/23/2005	0.23	0.47	-51.60
3/29/2005	0.00	0.00	~
	Average Difference (%):		-11.6

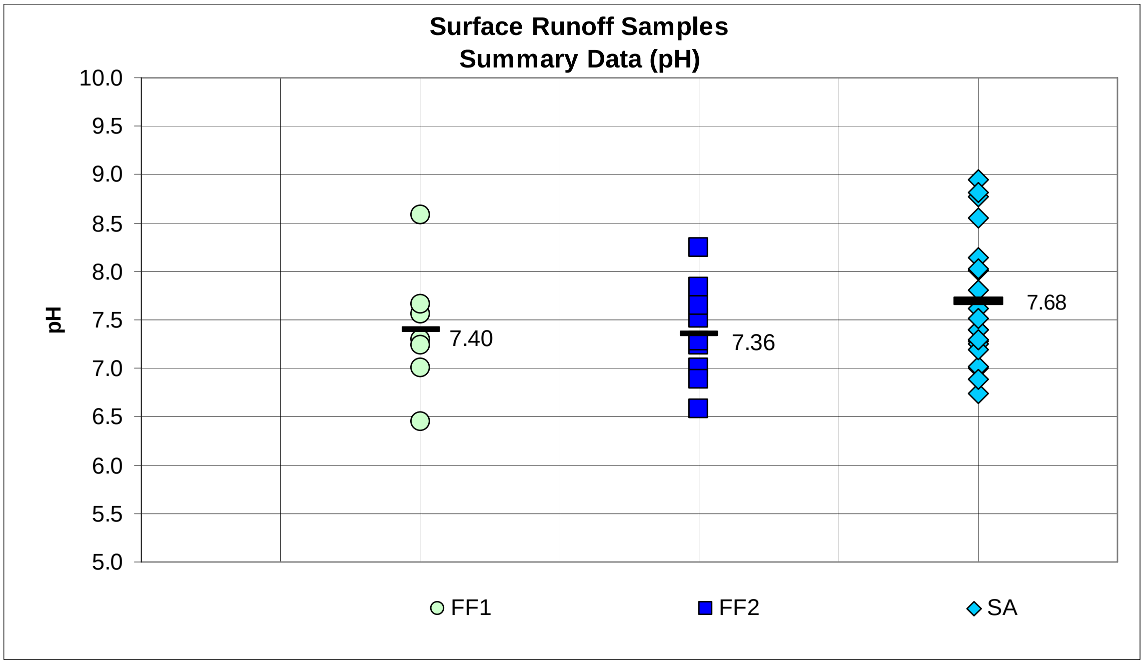
	Dissolved Copper (ug/L-Cu)		
Date Collected	Avg FF	EMC	Difference (%)
7/29/2004	NT	NT	~
9/8/2004	11.24	NT	~
9/28/2004	31.42	16.20	48.43
10/19/2004	NT	NT	~
11/12/2004	4.84	4.88	-0.89
12/1/2004	2.20	1.66	24.55
12/7/2004	15.39	8.49	44.82
2/14/2005	14.96	2.23	85.09
3/23/2005	19.40	4.50	76.80
3/29/2005	NT	1.64	~
	Average Difference (%):		46.5

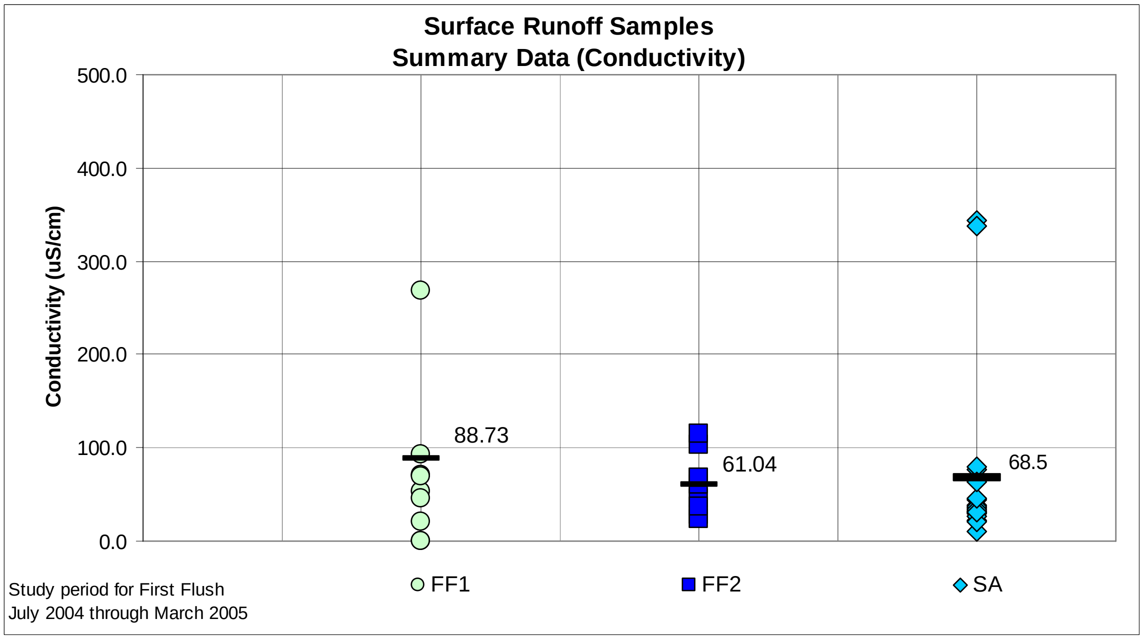
	Dissolved Lead (ug/L-Pb)		
Date Collected	Avg FF	EMC	Difference
			(%)
7/29/2004	NT	NT	
9/8/2004	2.07	NT	
9/28/2004	5.77	3.38	41.46
10/19/2004	NT	NT	~
11/12/2004	1.69	1.03	39.25
12/1/2004	ND	ND	~
12/7/2004	1.86	ND	100.00
2/14/2005	0.80	0.48	40.00
3/23/2005	NT	0.92	
3/29/2005	NT	2.11	~
	Average Difference (%):		55.2

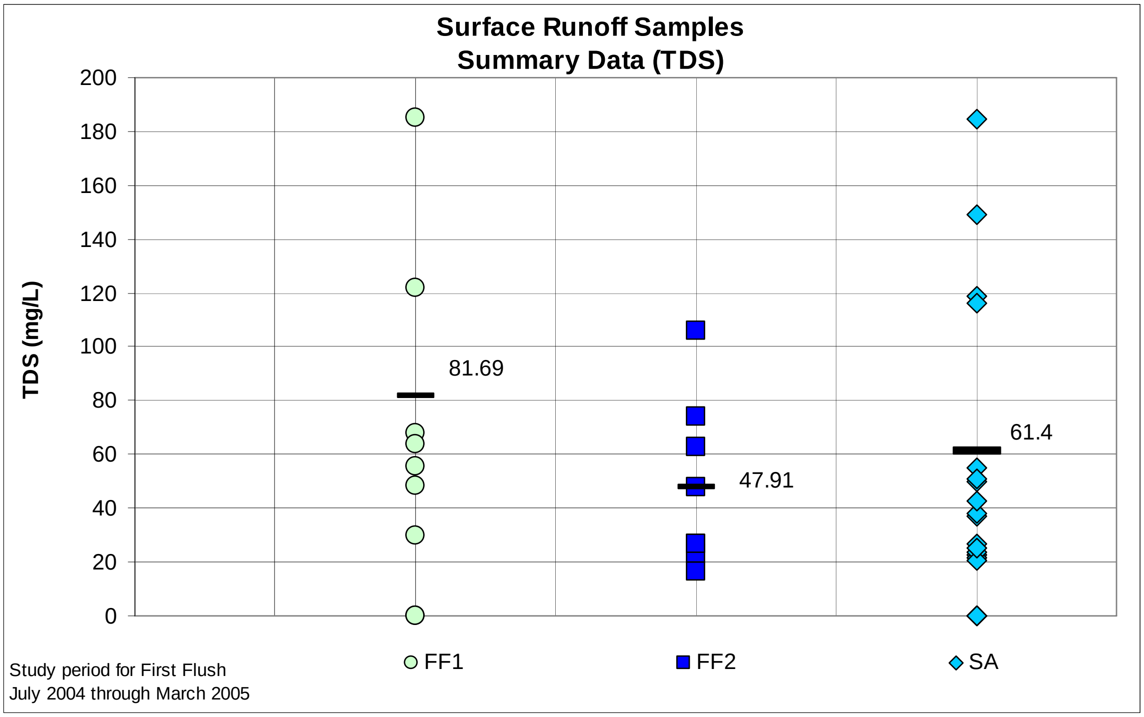
	Dissolved Chromium (ug/L-Cr)		
Date Collected	Avg FF	EMC	Difference
			(%)
7/29/2004	NT	NT	~
9/8/2004	5.68	NT	~
9/28/2004	7.78	4.98	36.05
10/19/2004	NT	NT	~
11/12/2004	7.56	9.90	-23.61
12/1/2004	11.81	1.83	84.50
12/7/2004	4.99	0.16	96.79
2/14/2005	21.96	0.51	97.68
3/23/2005	3.85	0.78	79.74
3/29/2005	NT	ND	~
	Average Difference (%):		61.9

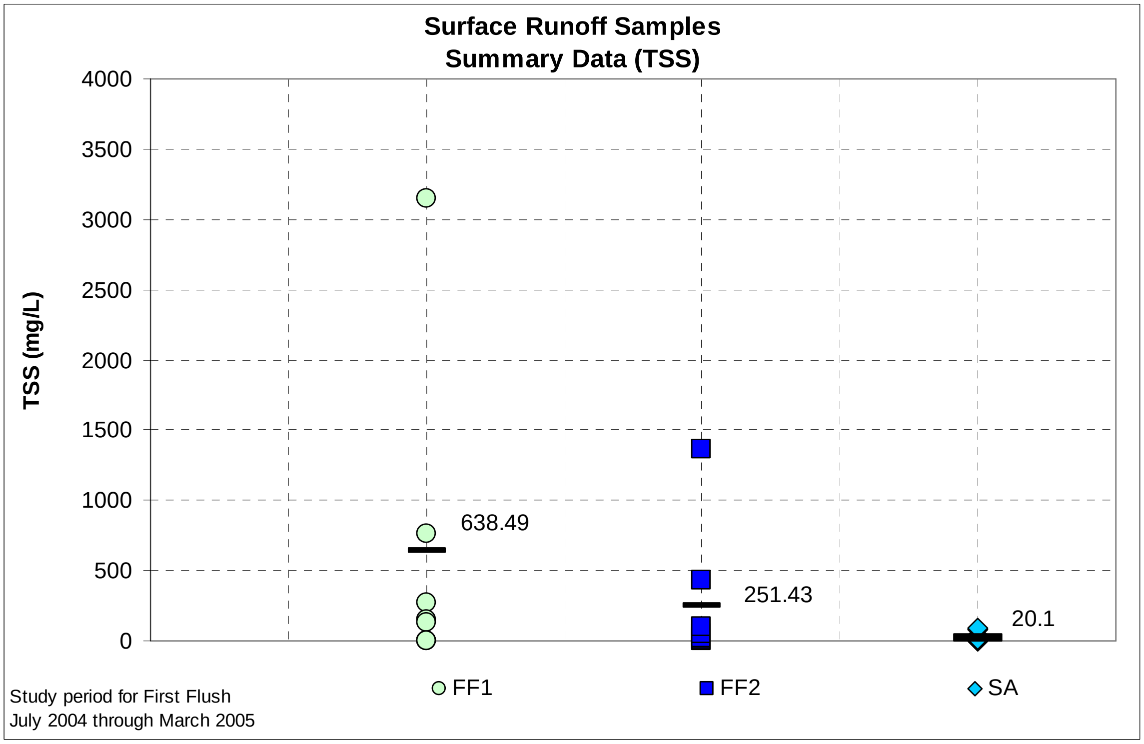
	Dissolved Zinc (ug/L-Zn)		
Date Collected	Avg FF	EMC	Difference
			(%)
7/29/2004	NT	NT	~
9/8/2004	47.46	NT	~
9/28/2004	133.82	110.40	17.50
10/19/2004	NT	NT	~
11/12/2004	38.78	20.44	47.28
12/1/2004	57.52	89.60	-35.80
12/7/2004	126.88	95.16	25.00
2/14/2005	1.33	2.06	-35.28
3/23/2005	117.36	20.11	82.86
3/29/2005	NT	33.35	~
	Average Difference (%):		16.9

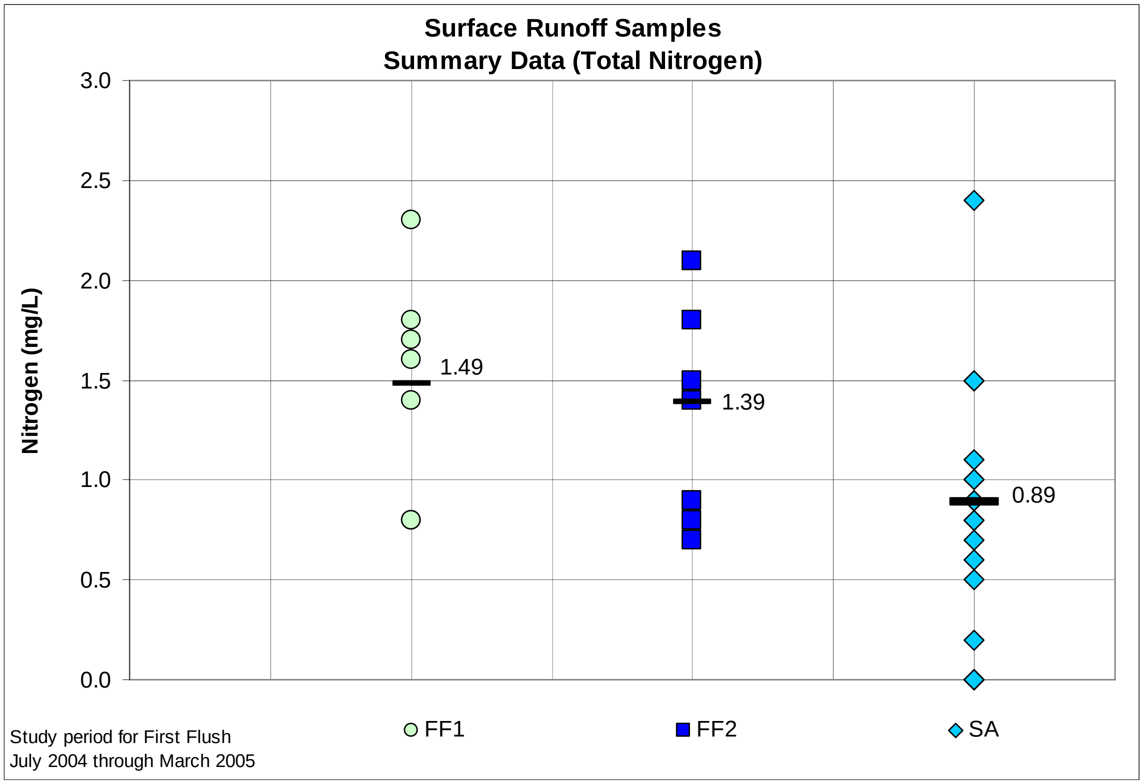
D.2: Graphical Summary of Surface Runoff Samples: FF1, FF2 and SA

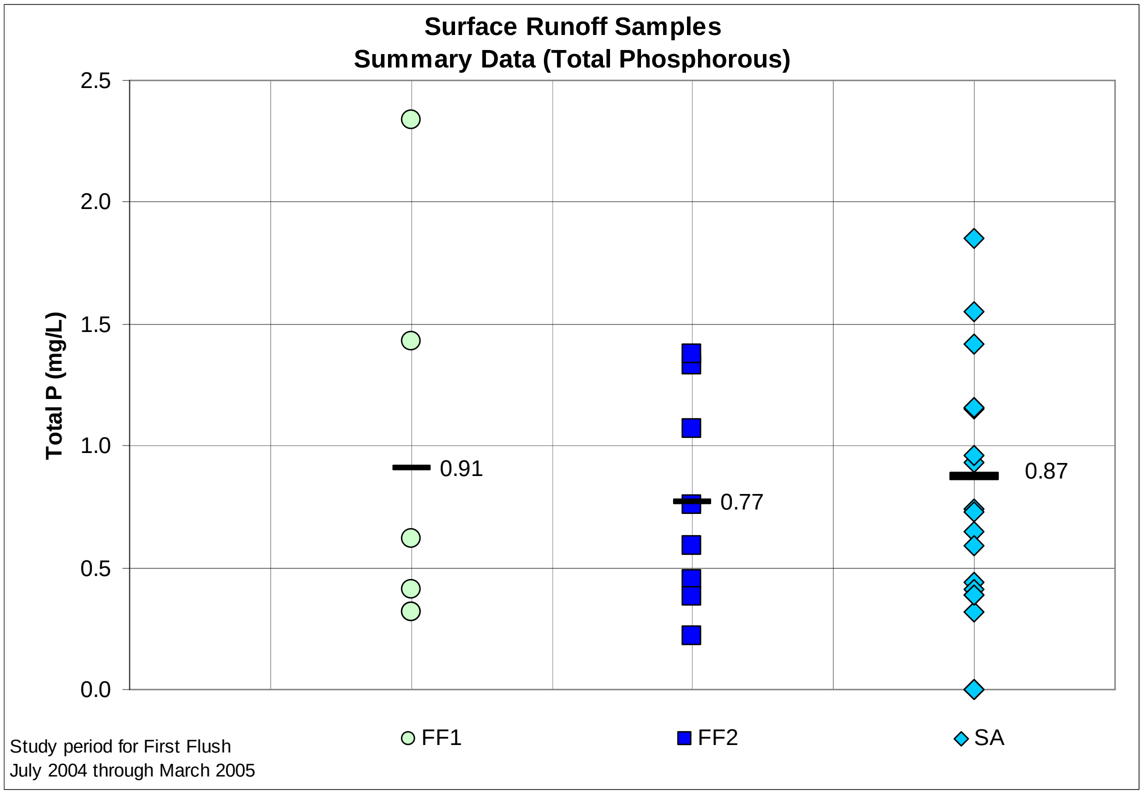


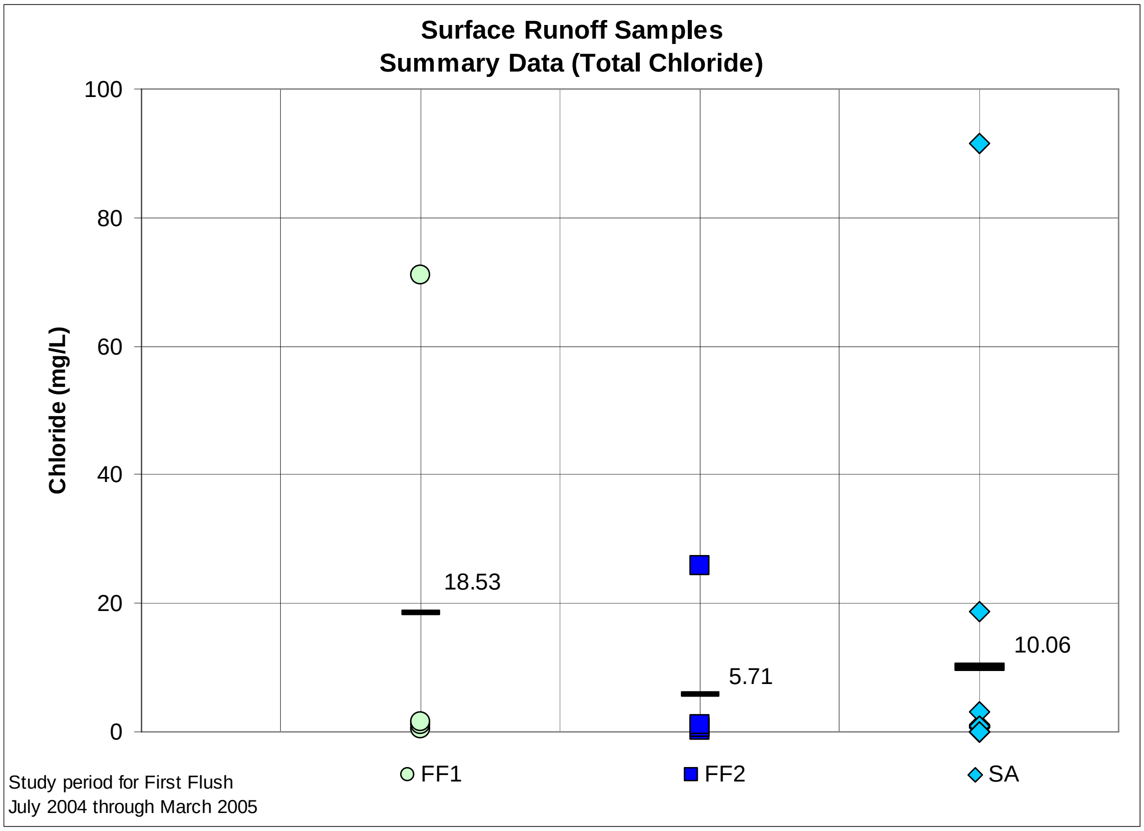



Surface Runoff Samples
Summary Data (TDS)
TDS (mg/L)
200
180
160
140
120
100
80
60
40
20
0
81.69
47.91
61.4
FF1
FF2
SA
Study period for First Flush
July 2004 through March 2005


Surface Runoff Samples
Summary Data (TSS)
TSS (mg/L)
4000
3500
3000
2500
2000
1500
1000
500
0
638.49
251.43
20.1
FF1
FF2
SA
Study period for First Flush
July 2004 through March 2005

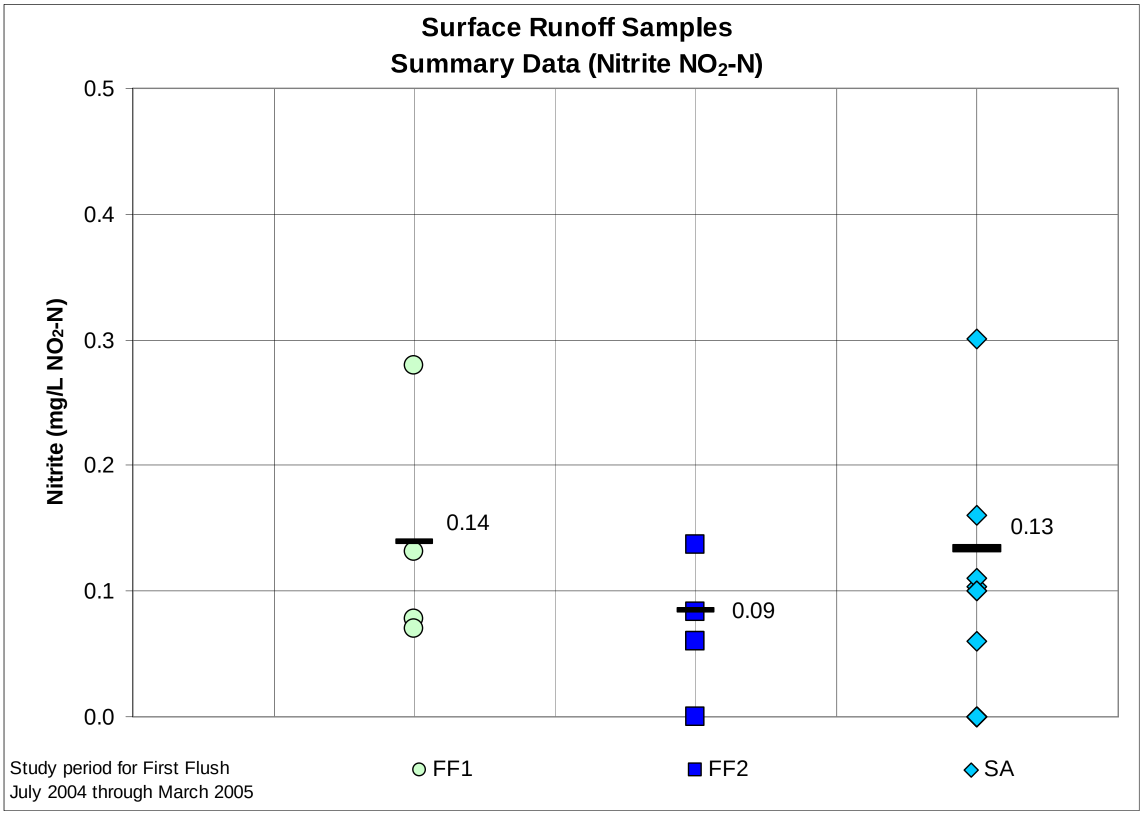

Surface Runoff Samples
Summary Data (Total Nitrogen)
Nitrogen (mg/L)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1.49
1.39
0.89
○ FF1
■ FF2
◆ SA
Study period for First Flush
July 2004 through March 2005


Surface Runoff Samples
Summary Data (Total Phosphorous)
Total P (mg/L)
2.5
2.0
1.5
1.0
0.5
0.0
0.91
0.77
0.87
○ FF1
■ FF2
◆ SA
Study period for First Flush
July 2004 through March 2005



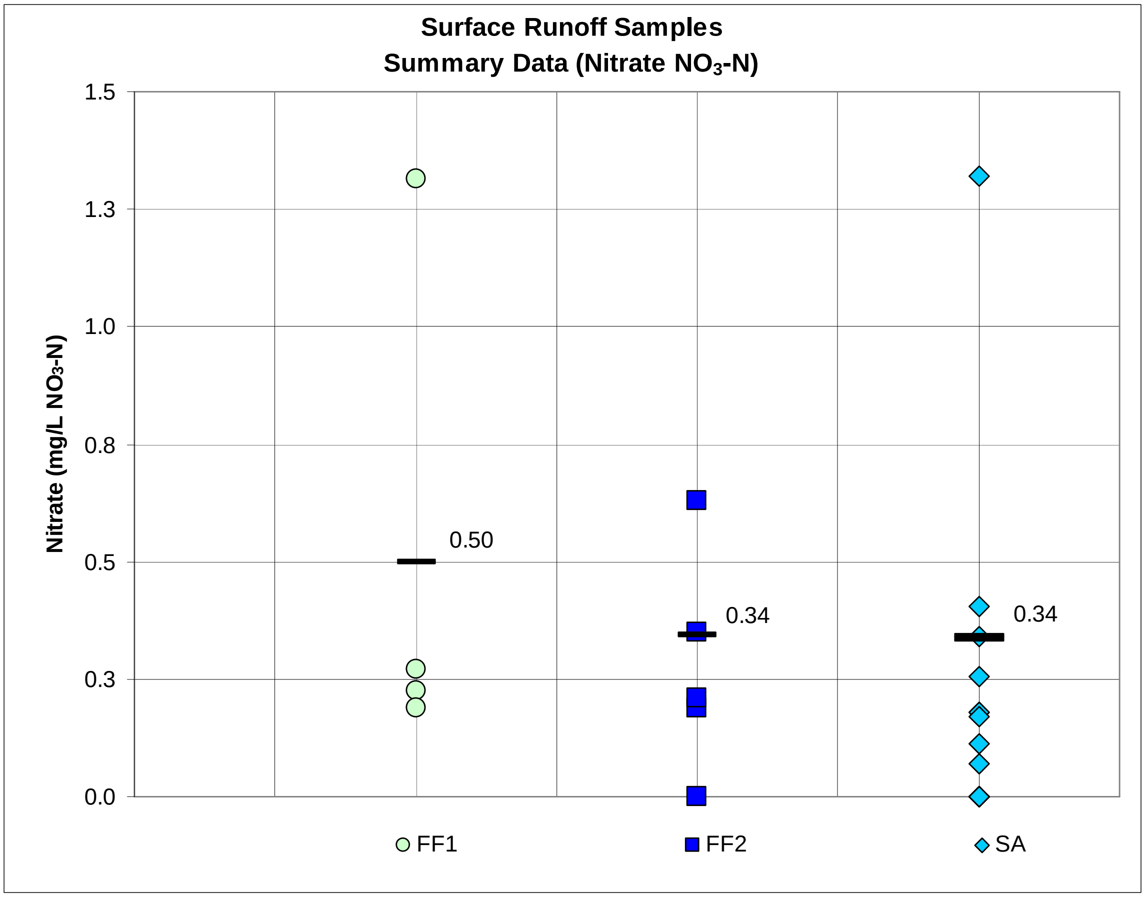
Surface Runoff Samples
Summary Data (Total Chloride)

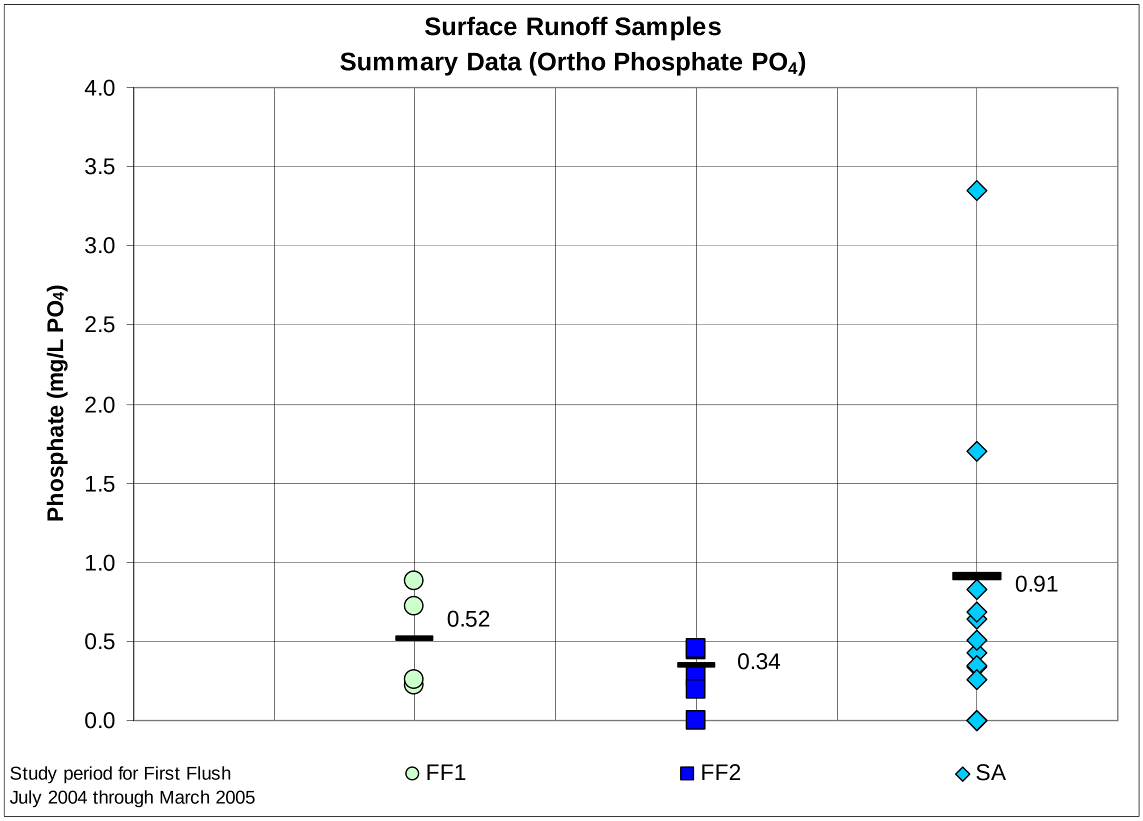
Study period for First Flush
July 2004 through March 2005



Surface Runoff Samples
Summary Data (Nitrite NO_2-N)

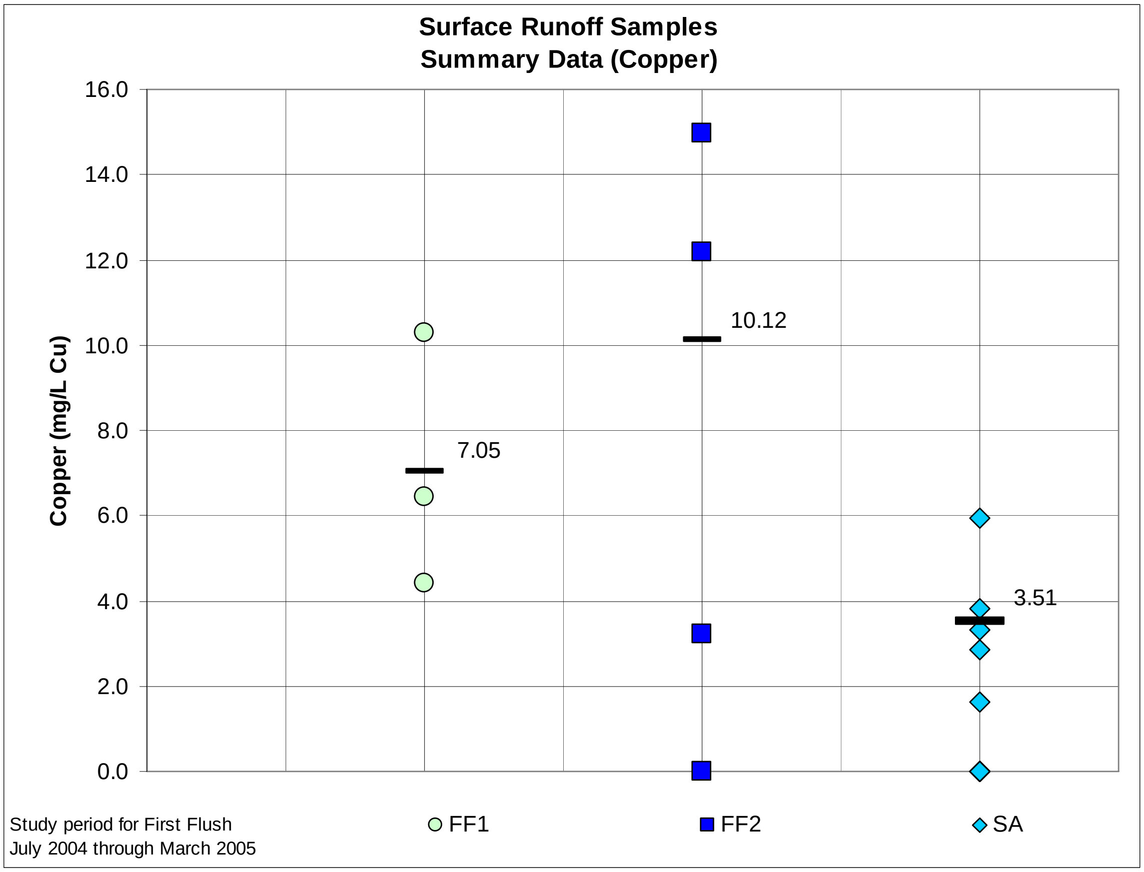
Study period for First Flush
July 2004 through March 2005


Surface Runoff Samples
Summary Data (Nitrate NO3-N)
Nitrate (mg/L NO3-N)
1.5
1.3
1.0
0.8
0.5
0.3
0.0
0.50
0.34
0.34
FF1
FF2
SA



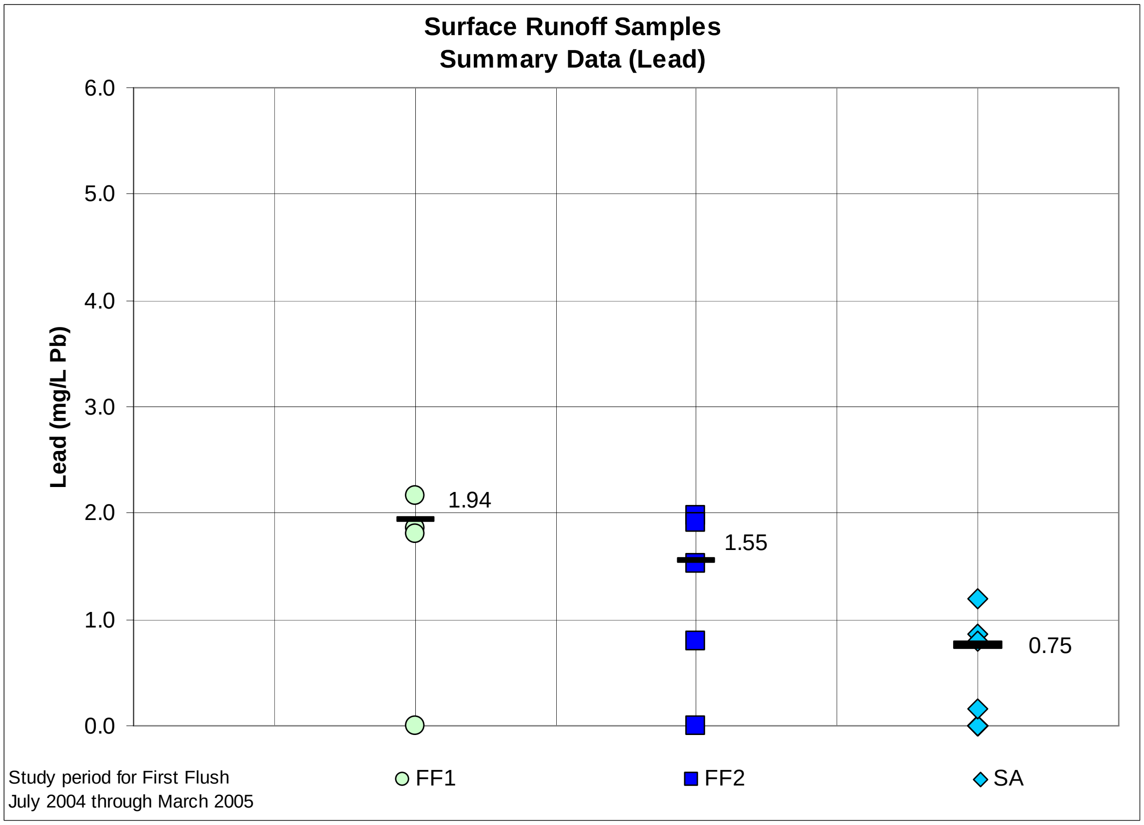
Surface Runoff Samples
Summary Data (Ortho Phosphate PO_4)

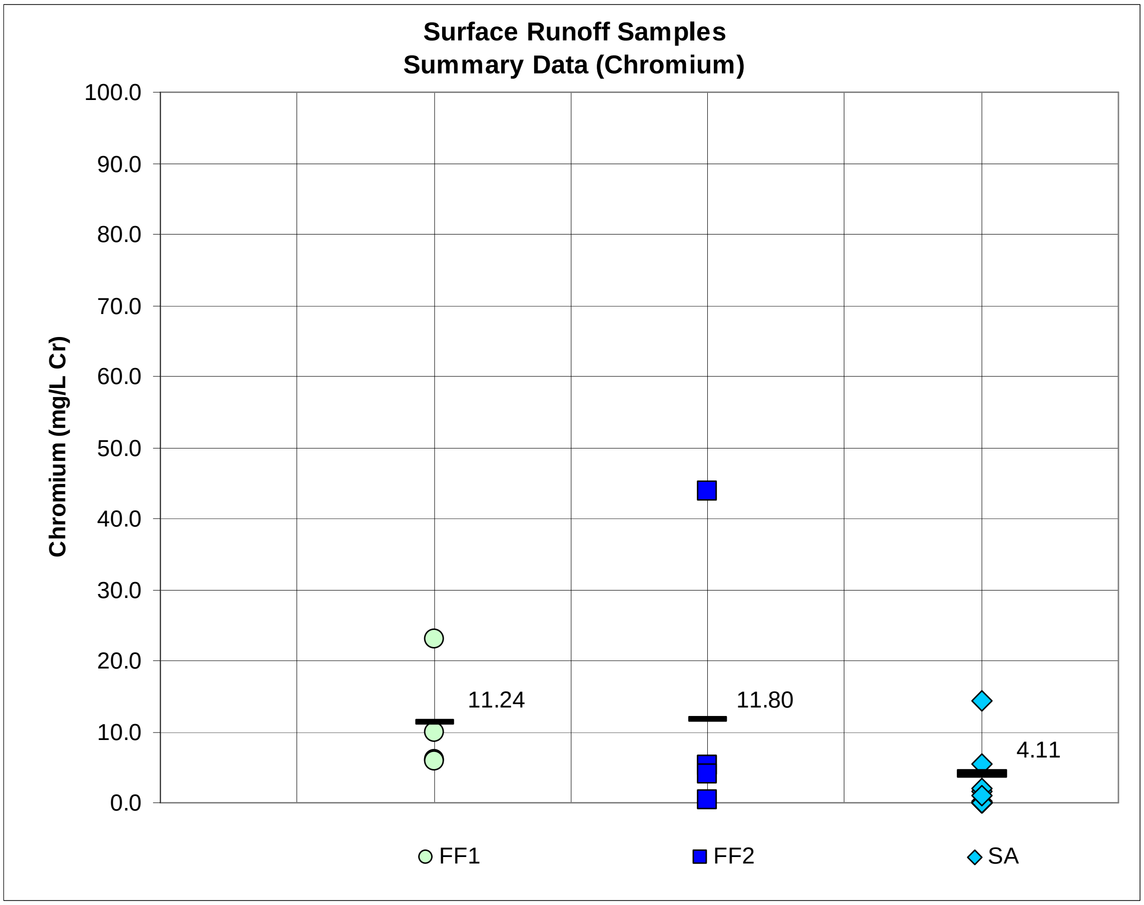
Study period for First Flush
July 2004 through March 2005

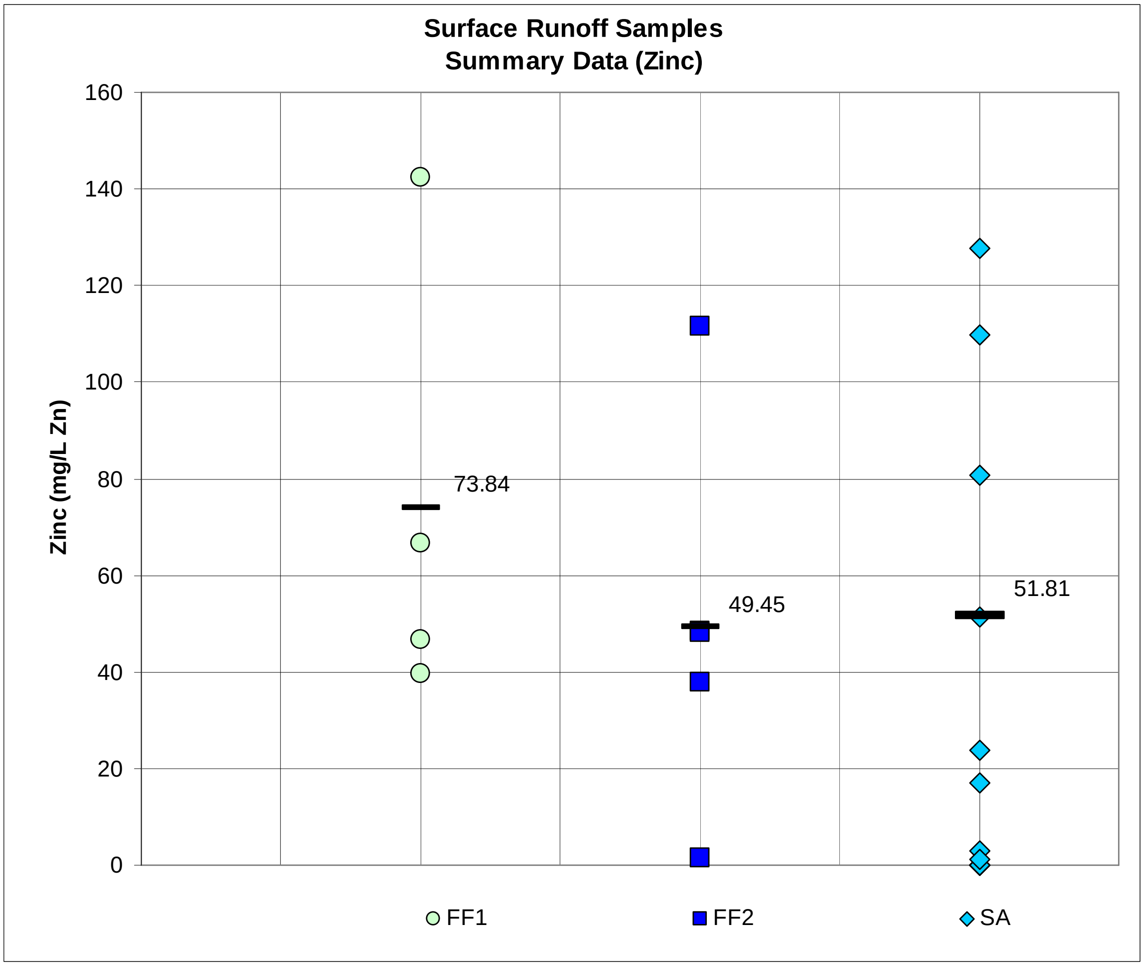


Surface Runoff Samples
Summary Data (Copper)

Study period for First Flush
July 2004 through March 2005


Surface Runoff Samples
Summary Data (Lead)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Lead (mg/L Pb)
1.94
1.55
0.75
○ FF1
■ FF2
◆ SA
Study period for First Flush
July 2004 through March 2005


Surface Runoff Samples
Summary Data (Chromium)
Chromium (mg/L Cr)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
11.24
11.80
4.11
○ FF1
■ FF2
◆ SA


Surface Runoff Samples
Summary Data (Zinc)
Zinc (mg/L Zn)
160
140
120
100
80
60
40
20
0
73.84
49.45
51.81
FF1
FF2
SA

D.3: Water Quality Data for analysis of Pollutant Removal due to Infiltration

Event Mean Concentration Data

Sample Information						
Date Collected	**Location**	**pH**	**Conductivity**	**TDS**	**Total N**	**Total P**
			(uS/cm)	**(mg/L)**	**(mg/L N)**	**(mg/L $P0_4^{3-}$)**
10/27/2003	**EMC**	6.8	29.5	23.1	1.3	NT
10/28/2003	**EMC**	6.5	34.9	146.9	NT	NT
11/6/2003	**EMC**	6.8	49.1	NT	0.0	0.82
11/18/2003	**EMC**	7.4	36.1	51.1	NT	0.45
3/9/2004	**EMC**	7.3	76.4	62.3	0.4	0.66
3/18/2004	**EMC**	6.7	1728.8	864.5	1.3	0.40
3/31/2004	**EMC**	8.1	64.7	307.3	NT	0.36
4/13/2004	**EMC**	7.0	48.9	30.3	0.3	0.22
4/26/2004	**EMC**	7.3	NT	38.0	NT	NT
5/4/2004	**EMC**	7.4	NT	50.0	NT	NT
5/19/2004	**EMC**	5.8	61.1	57.5	1.2	0.35
6/5/2004	**EMC**	7.3	89.4	91.0	1.5	0.05
6/11/2004	**EMC**	6.0	73.7	85.4	0.8	NT
6/15/2004	**EMC**	7.5	60.0	63.3	1.1	NT
7/12/2004	**EMC**	7.5	29.8	34.3	0.8	0.77
7/18/2004	**EMC**	8.4	49.9	NT	0.4	0.52
7/29/2004	**EMC**	8.4	28.4	NT	0.8	1.24
9/28/2004	**EMC**	7.0	32.0	43.5	0.5	1.70
10/19/2004	**EMC**	7.3	34.9	24.7	1.3	0.74
11/12/2004	**EMC**	8.7	33.1	46.5	0.9	1.05
12/1/2004	**EMC**	7.7	30.0	22.7	1.0	0.55
12/7/2004	**EMC**	7.9	25.2	23.0	1.5	NT
2/14/2005	**EMC**	7.0	209.8	96.0	1.3	0.37
3/23/2005	**EMC**	7.1	208.7	117.8	0.6	0.68
3/29/2005	**EMC**	7.4	54.7	117.5	0.0	0.49
Average		7.3	134.3	108.9	0.9	0.63
Maximum		8.7	1728.8	864.5	1.5	1.70
Minimum		5.8	25.2	22.7	0.0	0.05
Stdev		0.7	351.1	180.0	0.5	0.39
N		25	23	22	20	18

Sample Information					
Date Collected	**Location**	**Chloride**	**Nitrite**	**Nitrate**	**Phosphate**
		(mg/L Cl-)	**(mg/L $N0_2^{3-}$)**	**(mg/L $N0_3^{3-}$)**	**(mg/L $P0_4^{3-}$)**
10/27/2003	**EMC**	4.4	0.5	0.5	0.2
10/28/2003	**EMC**	NT	NT	NT	NT
11/6/2003	**EMC**	5.9	0.7	0.0	0.3
11/18/2003	**EMC**	9.4	0.0	2.3	0.0
3/9/2004	**EMC**	1.4	0.0	0.0	0.0
3/18/2004	**EMC**	511.6	0.0	0.0	0.0
3/31/2004	**EMC**	274.9	0.0	0.0	0.0
4/13/2004	**EMC**	1.2	0.0	0.0	0.0
4/26/2004	**EMC**	3.3	0.0	0.0	0.0
5/4/2004	**EMC**	4.6	0.0	0.0	0.0
5/19/2004	**EMC**	2.52	0.0	0.0	0.0
6/5/2004	**EMC**	NT	NT	NT	NT
6/11/2004	**EMC**	2.1	0.0	0.0	0.0
6/15/2004	**EMC**	2.4	0.0	3.1	0.0
7/12/2004	**EMC**	0.6	0.0	0.6	0.0
7/18/2004	**EMC**	1.8	0.0	0.1	0.0
7/29/2004	**EMC**	NT	0.0	0.3	1.3
9/28/2004	**EMC**	NT	NT	NT	NT
10/19/2004	**EMC**	NT	NT	NT	NT
11/12/2004	**EMC**	0.6	0.1	0.2	0.7
12/1/2004	**EMC**	0.8	0.1	0.1	0.5
12/7/2004	**EMC**	0.9	0.1	0.2	0.3
2/14/2005	**EMC**	NT	NT	NT	NT
3/23/2005	**EMC**	55.1	0.3	0.4	0.5
3/29/2005	**EMC**	NT	NT	NT	NT
Average		49.1	0.1	0.4	0.2
Maximum		511.6	0.7	3.1	1.3
Minimum		0.6	0.0	0.0	0.0
Stdev		132.2	0.2	0.8	0.3
N		18	19	19	19

Sample Information					
Date Collected	**Location**	**Cu**	**Pb**	**Cr**	**Zn**
		(ug/L)	**(ug/L)**	**(ug/L)**	**(ug/L)**
10/27/2003	**EMC**	19.0	NT	NT	NT
10/28/2003	**EMC**	NT	NT	NT	NT
11/6/2003	**EMC**	14.0	NT	NT	NT
11/18/2003	**EMC**	13.3	NT	NT	NT
3/9/2004	**EMC**	NT	NT	NT	NT
3/18/2004	**EMC**	NT	NT	NT	NT
3/31/2004	**EMC**	1.5	NT	NT	NT
4/13/2004	**EMC**	NT	NT	NT	NT
4/26/2004	**EMC**	NT	NT	NT	NT
5/4/2004	**EMC**	NT	NT	NT	NT
5/19/2004	**EMC**	0.00	NT	NT	NT
6/5/2004	**EMC**	NT	NT	NT	NT
6/11/2004	**EMC**	NT	NT	NT	NT
6/15/2004	**EMC**	NT	NT	NT	NT
7/12/2004	**EMC**	NT	NT	NT	NT
7/18/2004	**EMC**	NT	NT	NT	NT
7/29/2004	**EMC**	NT	NT	NT	NT
9/28/2004	**EMC**	16.2	3.4	5.0	110.4
10/19/2004	**EMC**	NT	NT	NT	NT
11/12/2004	**EMC**	4.9	1.0	9.9	20.4
12/1/2004	**EMC**	1.7	0.0	1.8	89.6
12/7/2004	**EMC**	8.5	0.0	0.2	95.2
2/14/2005	**EMC**	2.2	0.5	0.5	2.1
3/23/2005	**EMC**	4.5	0.9	0.8	20.1
3/29/2005	**EMC**	1.6	2.1	0.0	33.3
Average		7.3	1.1	2.6	53.0
Maximum		19.0	3.4	9.9	110.4
Minimum		0.0	0.0	0.0	2.1
Stdev		6.7	1.2	3.6	43.8
N		12	7	7	7

Infiltrated Runoff Concentration Data

Sample Information						
Date Collected	**Location**	**pH**	**Conductivity**	**TDS**	**Total N**	**Total P**
			(uS/cm)	**(mg/L)**	**(mg/L N)**	**(mg/L P0$_4^{3-}$)**
10/27/2003	**L8**	4.33	52.2	413	3.95	NT
10/28/2003	**L8**	4.83	200	287	NT	NT
11/6/2003	**L8**	5.7	239	NT	1.05	0.640
11/18/2003	**L8**	6.96	71.3	230	NT	0.595
3/9/2004	**L4**	6.61	779	469	1.50	0.86
3/18/2004	**L4**	6.29	4262	2292	4.00	0.37
3/31/2004	**L4**	7.70	1822	778	NT	0.62
4/13/2004	**L8**	6.72	307	616	1	0.63
4/26/2004	**L8**	7.43	NT	543	NT	NT
5/4/2004	**L8**	7.45	NT	420	NT	NT
5/19/2004	**L8**	7.86	582	163	2.4	0.34
6/5/2004	**L8**	7.25	459	362	2	0.05
6/11/2004	**L8**	7.15	518	425	0.1	NT
6/15/2004	**L4**	7.26	595	410	0.8	NT
7/12/2004	**L8**	6.98	419	277	0	0.6
7/18/2004	**L8**	7.23	381	NT	0	0.81
7/29/2004	**L8**	6.94	379	NT	0.4	0.27
9/28/2004	**L8**	6.83	404	228	0.1	0.44
10/19/2004	**L8**	6.8	411	257	0.5	0.45
11/12/2004	**L8**	7	416	246	1.9	0.385
12/1/2004	**L8**	6.86	411	256	1.8	0.18
12/7/2004	**L8**	6.86	399	249	2.7	NT
2/14/2005	**L8**	6.85	443	238	0.5	0.19
3/23/2005	**L8**	6.7	763	402	0	0.2
3/29/2005	**L8**	6.93	1450	773	0	0.09
Average		6.78	685	470	1.24	0.43
Maximum		7.86	4262	2292	4.00	0.86
Minimum		4.33	52.2	163	0.00	0.05
Stdev		0.79	875	441	1.27	0.24
N		25	23	22	20	18

Sample Information					
Date Collected	**Location**	**Chloride**	**Nitrite**	**Nitrate**	**Phosphate**
		(mg/L Cl-)	**(mg/L $N0_2^{3-}$)**	**(mg/L $N0_3^{3-}$)**	**(mg/L $P0_4^{3-}$)**
10/27/2003	**L8**	34.3	0	0	0.28
10/28/2003	**L8**	NT	NT	NT	NT
11/6/2003	**L8**	7.48	0.7	0	0
11/18/2003	**L8**	8.88	0	0.28	0
3/9/2004	**L4**	20.3	0	0	0
3/18/2004	**L4**	1306	0	0	0
3/31/2004	**L4**	150	0	0	0
4/13/2004	**L8**	38.2	0	0	0
4/26/2004	**L8**	274	0	0	0
5/4/2004	**L8**	232	0	0	0
5/19/2004	**L8**	172	0	0	0
6/5/2004	**L8**		NT	NT	NT
6/11/2004	**L8**	NT	0	0	0
6/15/2004	**L4**	2.29	0	0	0
7/12/2004	**L8**	17.67	0	0	0
7/18/2004	**L8**	14.64	0	0	0
7/29/2004	**L8**		0	0	0
9/28/2004	**L8**	NT	NT	NT	NT
10/19/2004	**L8**	NT	NT	NT	NT
11/12/2004	**L8**	1.08	2.66	0.29	0.00
12/1/2004	**L8**	0.969	2.09	0.52	0
12/7/2004	**L8**	0.918	1.77	0.59	0
2/14/2005	**L8**	NT	NT	NT	NT
3/23/2005	**L8**	112	0.343	0.371	0
3/29/2005	**L8**	NT	NT	NT	NT
Average		136	0.40	0.11	0.01
Maximum		1306	2.66	0.59	0.28
Minimum		0.92	0.00	0.00	0.00
Stdev		304	0.82	0.20	0.06
N		18	19	19	19

Sample Information					
Date Collected	**Location**	**Cu**	**Pb**	**Cr**	**Zn**
		(ug/L)	**(ug/L)**	**(ug/L)**	**(ug/L)**
10/27/2003	**L8**	17.40	NT	NT	NT
10/28/2003	**L8**	NT	NT	NT	NT
11/6/2003	**L8**	2.65	NT	NT	NT
11/18/2003	**L8**	0	NT	NT	NT
3/9/2004	**L4**	NT	NT	NT	NT
3/18/2004	**L4**	NT	NT	NT	NT
3/31/2004	**L4**	0.00	NT	NT	NT
4/13/2004	**L8**	NT	NT	NT	NT
4/26/2004	**L8**	NT	NT	NT	NT
5/4/2004	**L8**	NT	NT	NT	NT
5/19/2004	**L8**	NT	NT	NT	NT
6/5/2004	**L8**	NT	NT	NT	NT
6/11/2004	**L8**	NT	NT	NT	NT
6/15/2004	**L4**	0	NT	NT	NT
7/12/2004	**L8**	NT	NT	NT	NT
7/18/2004	**L8**	NT	NT	NT	NT
7/29/2004	**L8**	NT	NT	NT	NT
9/28/2004	**L8**	17.4	4.54	8.35	126
10/19/2004	**L8**	NT	NT	NT	NT
11/12/2004	**L8**	2.6	3.2	86.7	39.0
12/1/2004	**L8**	0	0	5.86	47.32
12/7/2004	**L8**	7.28	4.24	4.24	115
2/14/2005	**L8**	2.17	2.21	10.9	1.59
3/23/2005	**L8**	1.12	4.96	2.08	20.38
3/29/2005	**L8**	4.07	1.33	0.19	3.11
Average		4.56	2.92	16.9	50.3
Maximum		17.4	4.96	86.7	125.7
Minimum		0.00	0.00	0.19	1.59
Stdev		6.36	1.83	31.0	50.9
N		12	7	7	7

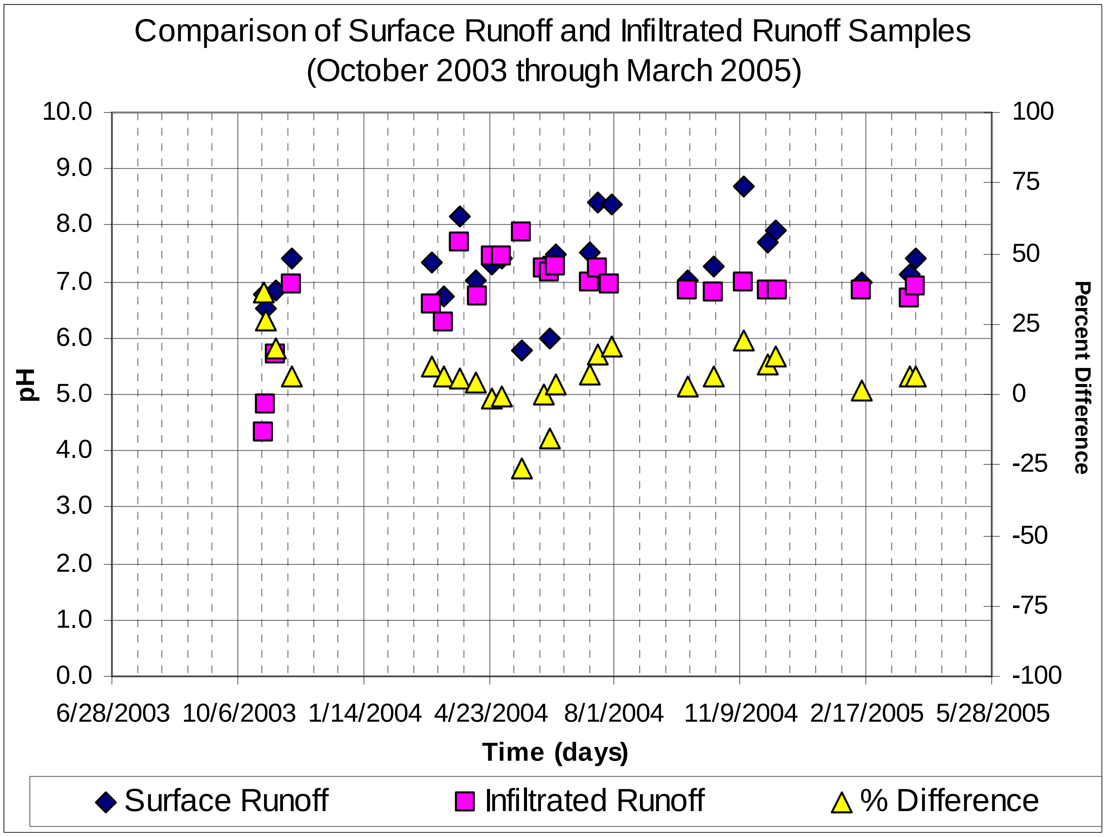
Percent Difference in Concentration (EMC vs L8)

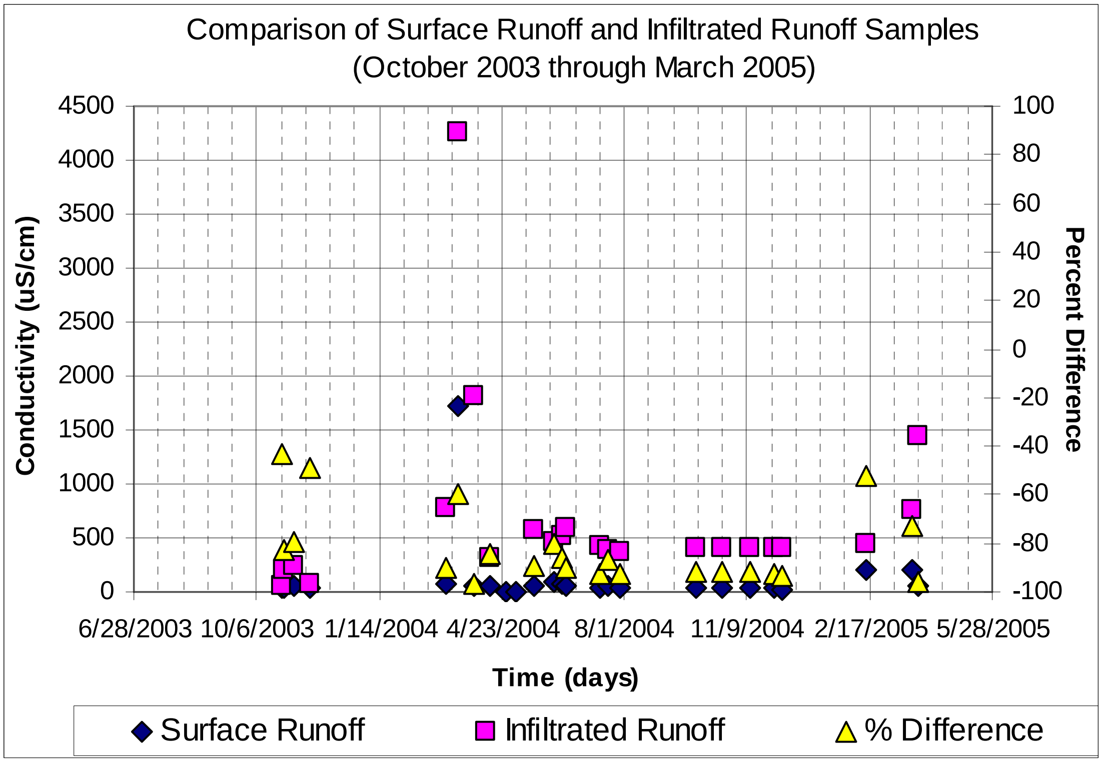
Sample Information		**Percent Difference In Concentration**				
Date Collected	**Location**	**pH**	**Conductivity**	**TDS**	**Total N**	**Total P**
			(uS/cm)	**(mg/L)**	**(mg/L N)**	**(mg/L $P0_4^{3-}$)**
10/27/2003	**EMC-L8**	36.0	-43.4	-94.4	-66.2	
10/28/2003	**EMC-L8**	26.0	-82.6	-48.8		
11/6/2003	**EMC-L8**	16.7	-79.5		-100.0	21.5
11/18/2003	**EMC-L8**	6.1	-49.3	-77.8		-24.9
3/9/2004	**EMC-L8**	9.8	-90.2	-86.7	-73.3	-23.4
3/18/2004	**EMC-L8**	6.7	-59.4	-62.3	-66.7	6.3
3/31/2004	**EMC-L8**	5.4	-96.5	-60.5		-42.7
4/13/2004	**EMC-L8**	4.1	-84.1	-95.1	-66.7	-65.6
4/26/2004	**EMC-L8**	-1.5		-93.0		
5/4/2004	**EMC-L8**	-0.7		-88.1		
5/19/2004	**EMC-L8**	-26.6	-89.5	-64.8	-50.0	2.9
6/5/2004	**EMC-L8**	0.1	-80.5	-74.8	-23.3	-10.0
6/11/2004	**EMC-L8**	-15.9	-85.8	-79.9	87.5	
6/15/2004	**EMC-L8**	3.2	-89.9	-84.6	23.8	
7/12/2004	**EMC-L8**	7.1	-92.9	-87.6	100.0	21.6
7/18/2004	**EMC-L8**	14.0	-86.9		100.0	-36.2
7/29/2004	**EMC-L8**	17.1	-92.5		52.0	78.3
9/28/2004	**EMC-L8**	2.6	-92.1	-80.9	80.0	74.1
10/19/2004	**EMC-L8**	6.4	-91.5	-90.4	61.5	38.8
11/12/2004	**EMC-L8**	19.4	-92.0	-81.1	-52.6	63.2
12/1/2004	**EMC-L8**	11.0	-92.7	-91.1	-44.4	67.0
12/7/2004	**EMC-L8**	13.3	-93.7	-90.8	-44.4	
2/14/2005	**EMC-L8**	1.7	-52.6	-59.7	61.5	47.9
3/23/2005	**EMC-L8**	6.2	-72.7	-70.7	100.0	70.4
3/29/2005	**EMC-L8**	6.4	-96.2	-84.8	NA	81.6
Average		7.0	-82.0	-79.4	4.1	20.59
Maximum		36.0	-43.4	-48.8	100.0	81.63
Minimum		-26.6	-96.5	-95.1	-100.0	-65.61
Stdev		12.2	15.7	13.1	71.9	47.01
N		25	23	22	19	18

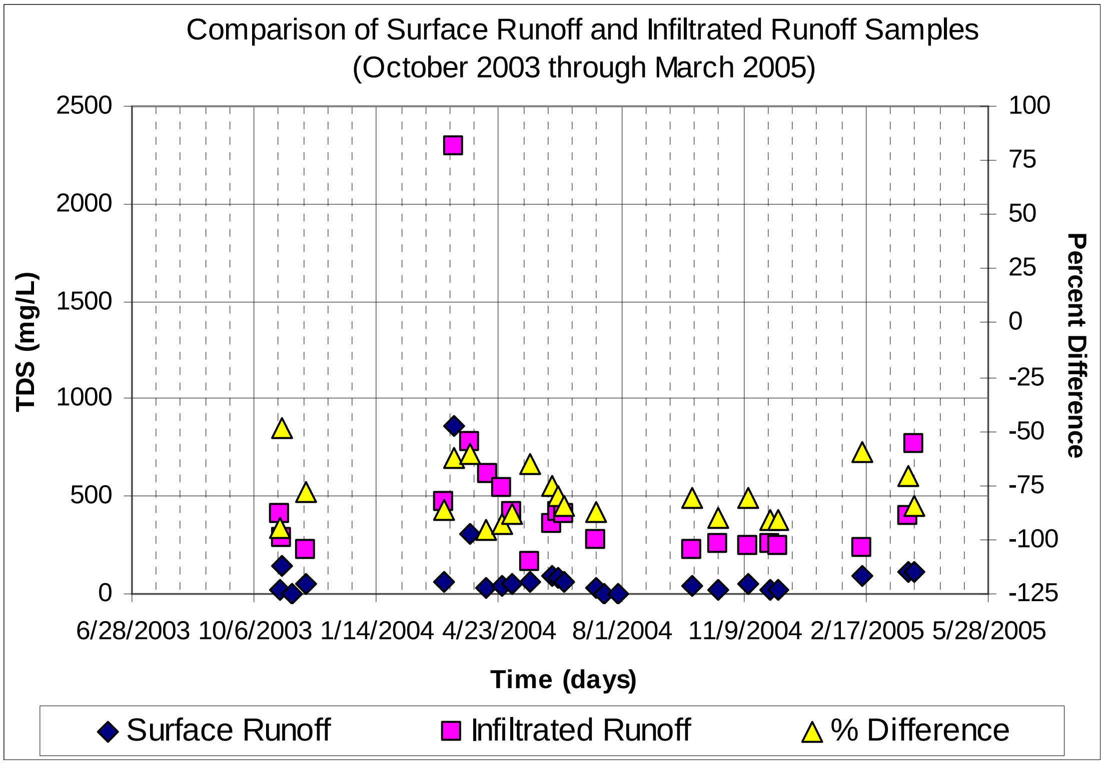
Sample Information		Percent Difference In Concentration			
Date Collected	Location	Chloride	Nitrite	Nitrate	Phosphate
		(mg/L Cl-)	(mg/L $N0_2^{3-}$)	(mg/L $N0_3^{3-}$)	(mg/L $P0_4^{3-}$)
10/27/2003	**EMC-L8**	-87.2	100.0	100.0	-14.3
10/28/2003	**EMC-L8**				
11/6/2003	**EMC-L8**	-21.7	4.1	NA	100.0
11/18/2003	**EMC-L8**	5.6	NA	87.9	NA
3/9/2004	**EMC-L8**	-93.0	NA	NA	NA
3/18/2004	**EMC-L8**	-60.8	NA	NA	NA
3/31/2004	**EMC-L8**	45.4	NA	NA	NA
4/13/2004	**EMC-L8**	-96.9	NA	NA	NA
4/26/2004	**EMC-L8**	-98.8	NA	NA	NA
5/4/2004	**EMC-L8**	-98.0	NA	NA	NA
5/19/2004	**EMC-L8**	-98.5	NA	NA	NA
6/5/2004	**EMC-L8**				
6/11/2004	**EMC-L8**	-96.6	NA	NA	NA
6/15/2004	**EMC-L8**	5.4	NA	100.0	NA
7/12/2004	**EMC-L8**	-96.5	NA	100.0	NA
7/18/2004	**EMC-L8**	-87.5	NA	100.0	NA
7/29/2004	**EMC-L8**		NA	100.0	100.0
9/28/2004	**EMC-L8**				
10/19/2004	**EMC-L8**				MRL(0.20)
11/12/2004	**EMC-L8**	-41.5	-95.0	-37.6	100.0
12/1/2004	**EMC-L8**	-20.6	-95.0	-76.0	100.0
12/7/2004	**EMC-L8**	-3.8	-95.5	-70.3	100.0
2/14/2005	**EMC-L8**				
3/23/2005	**EMC-L8**	-50.8	-12.2	0.4	100.0
3/29/2005	**EMC-L8**				
Average		-55.3	-32.3	40.4	83.7
Maximum		45.4	100.0	100.0	100.0
Minimum		-98.8	-95.5	-76.0	-14.3
Stdev		46.6	78.9	77.1	43.2
N		18	6	10	7

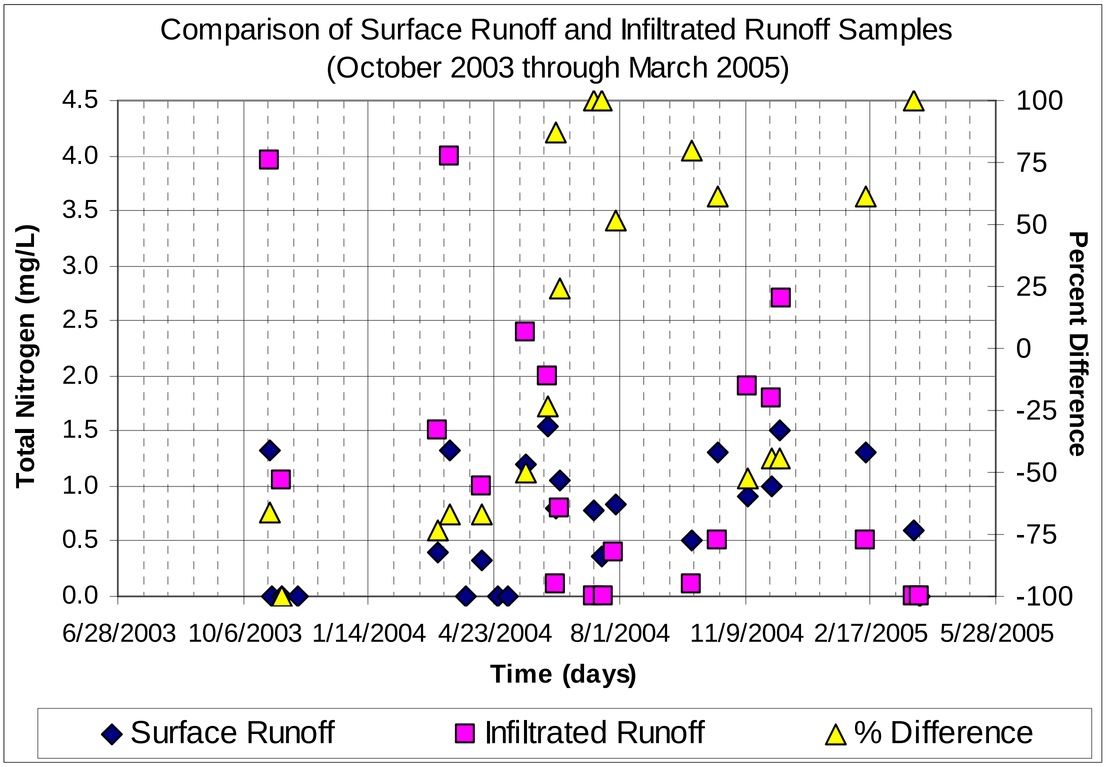
Sample Information		Percent Difference In Concentration			
Date Collected	Location	Cu	Pb	Cr	Zn
		(ug/L)	(ug/L)	(ug/L)	(ug/L)
10/27/2003	**EMC-L8**	8.4			
10/28/2003	**EMC-L8**				
11/6/2003	**EMC-L8**	81.1			
11/18/2003	**EMC-L8**	100.0			
3/9/2004	**EMC-L8**				
3/18/2004	**EMC-L8**				
3/31/2004	**EMC-L8**	100.0			
4/13/2004	**EMC-L8**				
4/26/2004	**EMC-L8**				
5/4/2004	**EMC-L8**				
5/19/2004	**EMC-L8**	NA			
6/5/2004	**EMC-L8**				
6/11/2004	**EMC-L8**				
6/15/2004	**EMC-L8**				
7/12/2004	**EMC-L8**				
7/18/2004	**EMC-L8**				
7/29/2004	**EMC-L8**				
9/28/2004	**EMC-L8**	-6.8	-25.7	-40.4	-12.2
10/19/2004	**EMC-L8**				
11/12/2004	**EMC-L8**	46.1	-67.7	-88.6	-47.6
12/1/2004	**EMC-L8**	100.0	NA	-68.8	47.2
12/7/2004	**EMC-L8**	14.3	-100.0	-96.2	-17.3
2/14/2005	**EMC-L8**	2.7	-78.3	-95.3	22.6
3/23/2005	**EMC-L8**	75.1	-81.5	-62.5	-1.3
3/29/2005	**EMC-L8**	-59.7	37.0	-100.0	90.7
Average		41.9	-52.7	-78.8	11.7
Maximum		100.0	37.0	-40.4	90.7
Minimum		-59.7	-100.0	-100.0	-47.6
Stdev		53.8	50.4	22.2	46.0
N		11	6	7	7

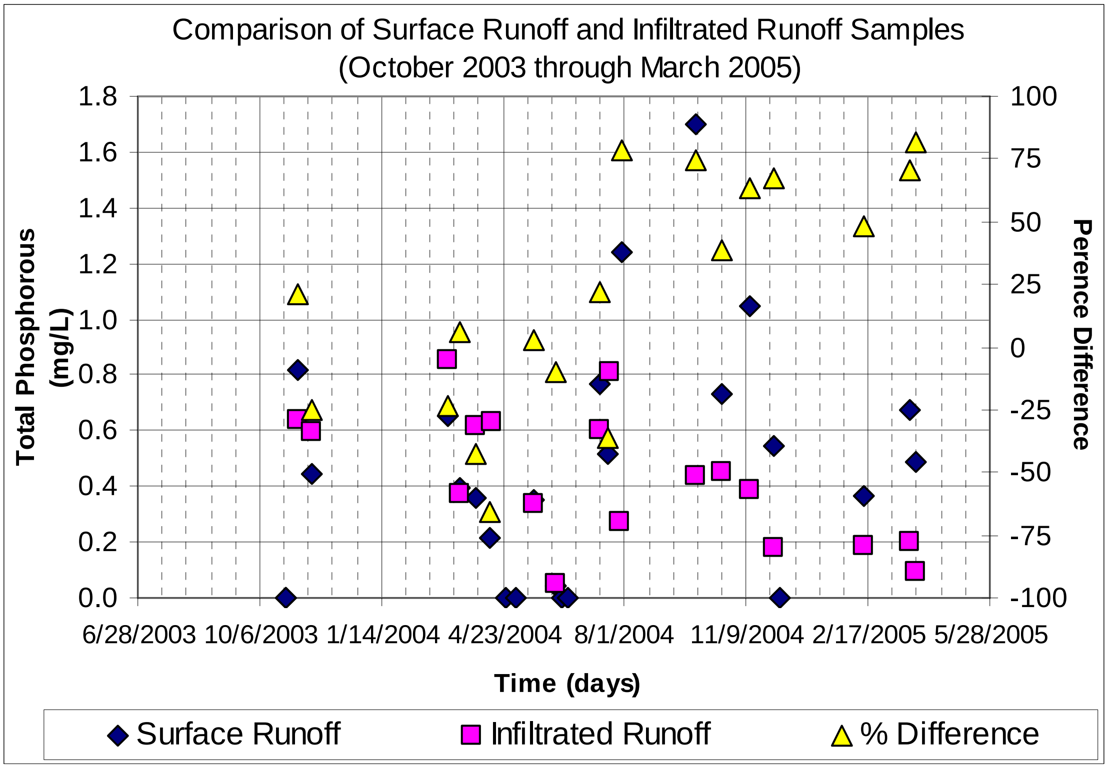
D.4: Water Quality Figures for analysis of Pollutant Removal due to Infiltration

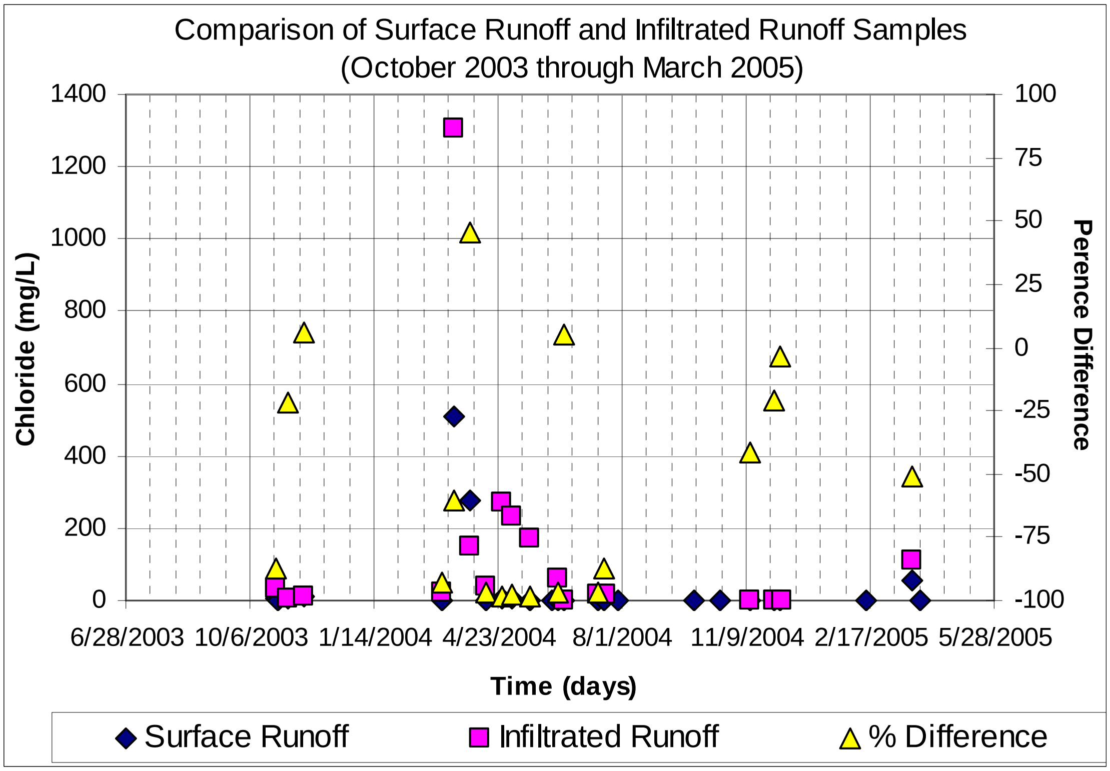


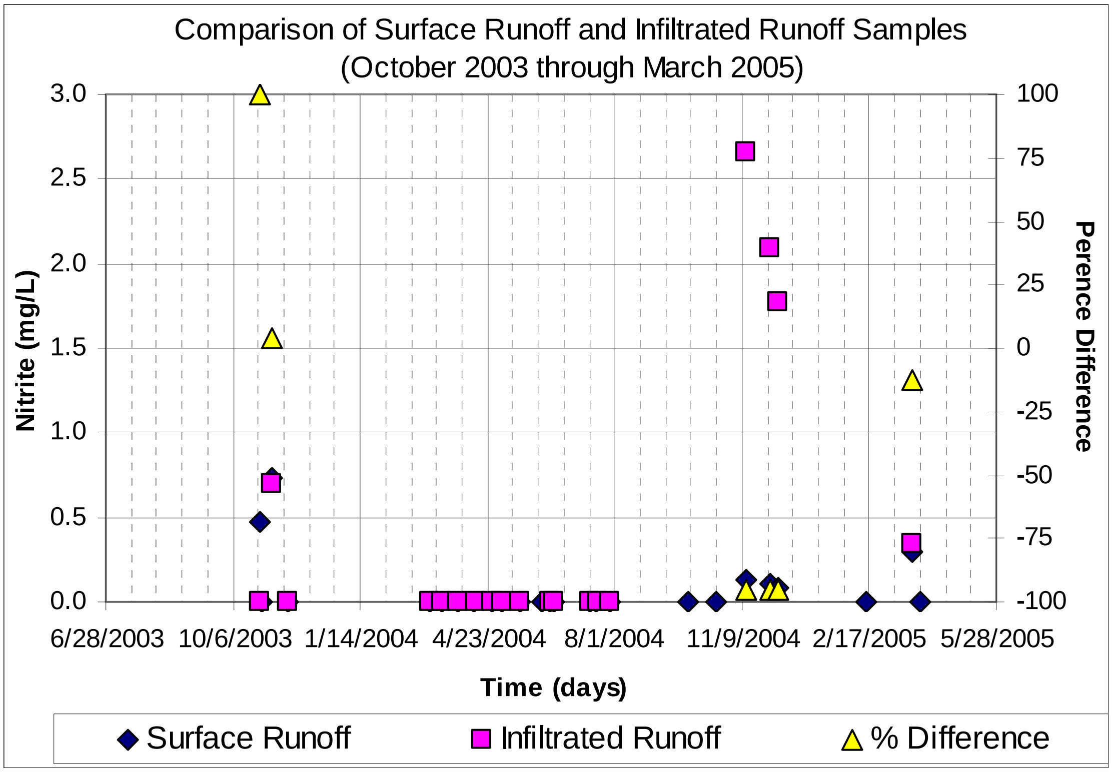


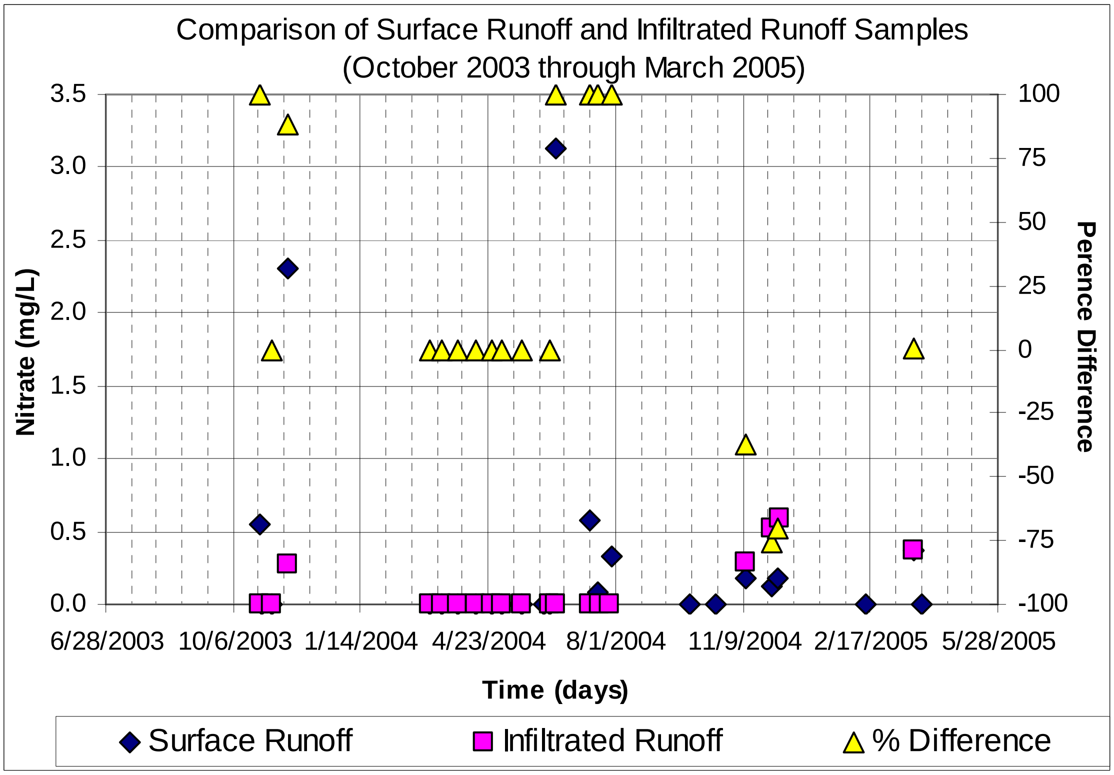

Comparison of Surface Runoff and Infiltrated Runoff Samples
(October 2003 through March 2005)
TDS (mg/L)
2500
2000
1500
1000
500
0
Percent Difference
100
75
50
25
0
-25
-50
-75
-100
-125
6/28/2003
10/6/2003
1/14/2004
4/23/2004
8/1/2004
11/9/2004
2/17/2005
5/28/2005
Time (days)
Surface Runoff
Infiltrated Runoff
% Difference

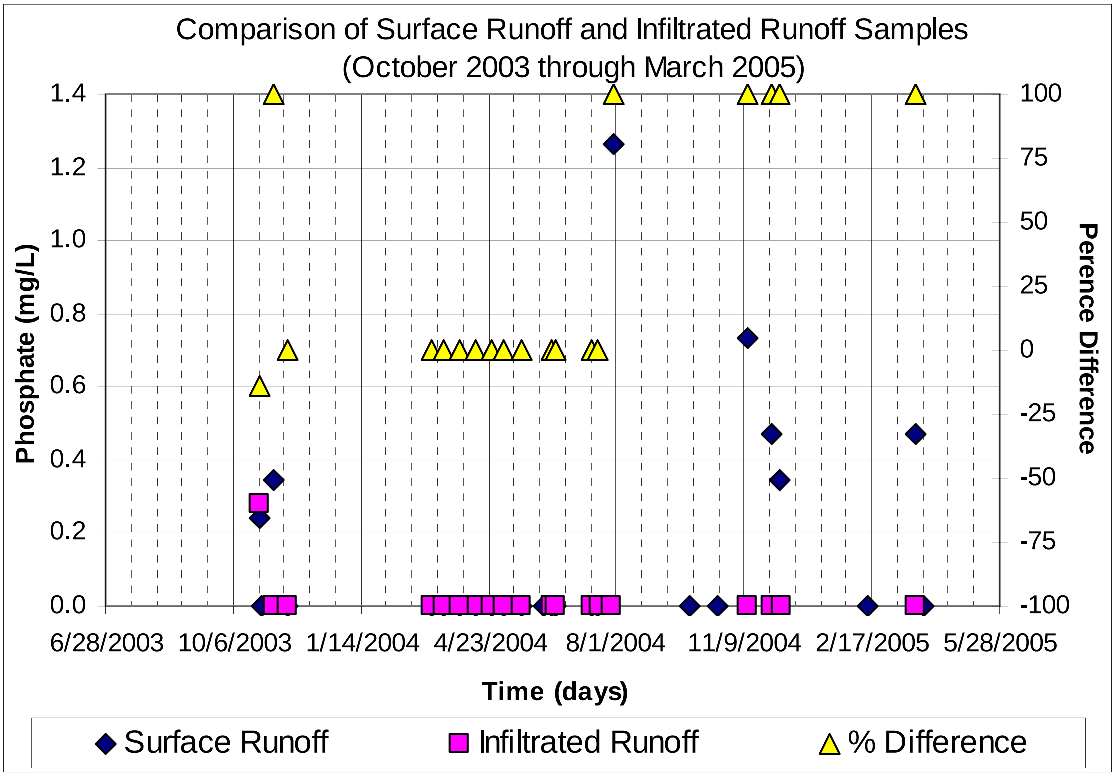

Comparison of Surface Runoff and Infiltrated Runoff Samples
(October 2003 through March 2005)
Total Nitrogen (mg/L)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Percent Difference
100
75
50
25
0
-25
-50
-75
-100
6/28/2003
10/6/2003
1/14/2004
4/23/2004
8/1/2004
11/9/2004
2/17/2005
5/28/2005
Time (days)
Surface Runoff
Infiltrated Runoff
% Difference

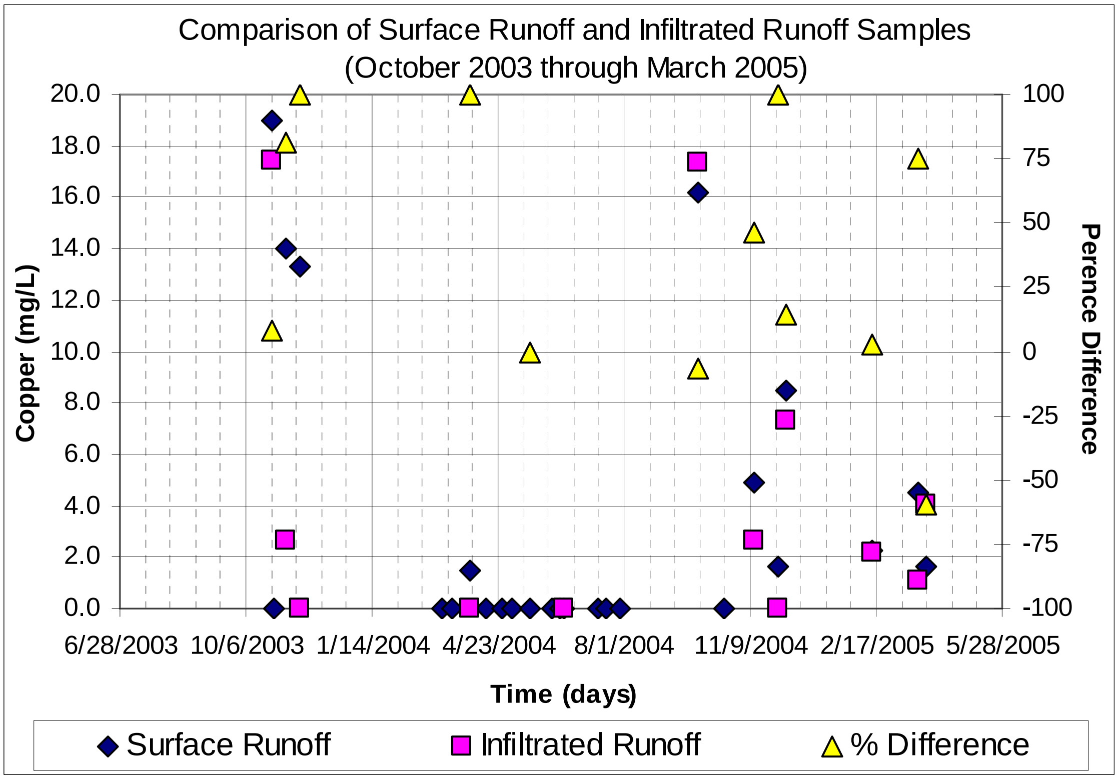

Comparison of Surface Runoff and Infiltrated Runoff Samples
(October 2003 through March 2005)
Total Phosphorous (mg/L)
Perence Difference
Time (days)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
100
75
50
25
0
-25
-50
-75
-100
6/28/2003
10/6/2003
1/14/2004
4/23/2004
8/1/2004
11/9/2004
2/17/2005
5/28/2005
Surface Runoff
Infiltrated Runoff
% Difference

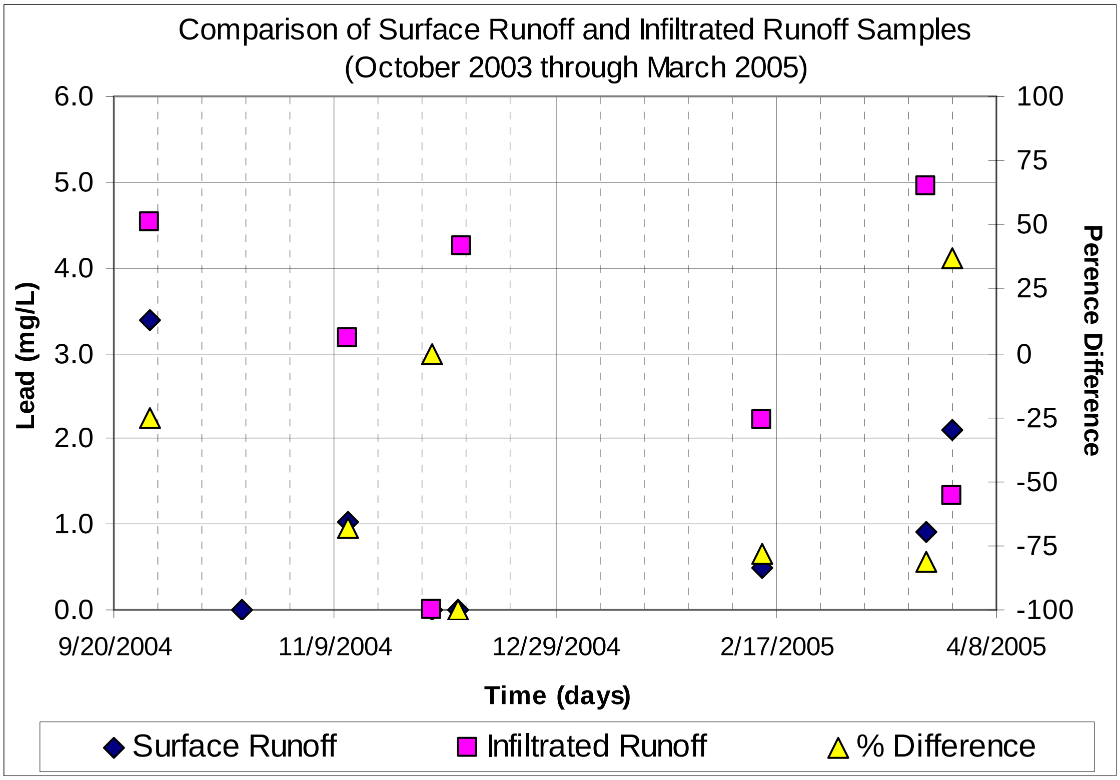

Comparison of Surface Runoff and Infiltrated Runoff Samples
(October 2003 through March 2005)
Chloride (mg/L)
Perence Difference
Time (days)
1400
1200
1000
800
600
400
200
0
100
75
50
25
0
-25
-50
-75
-100
6/28/2003
10/6/2003
1/14/2004
4/23/2004
8/1/2004
11/9/2004
2/17/2005
5/28/2005
Surface Runoff
Infiltrated Runoff
% Difference

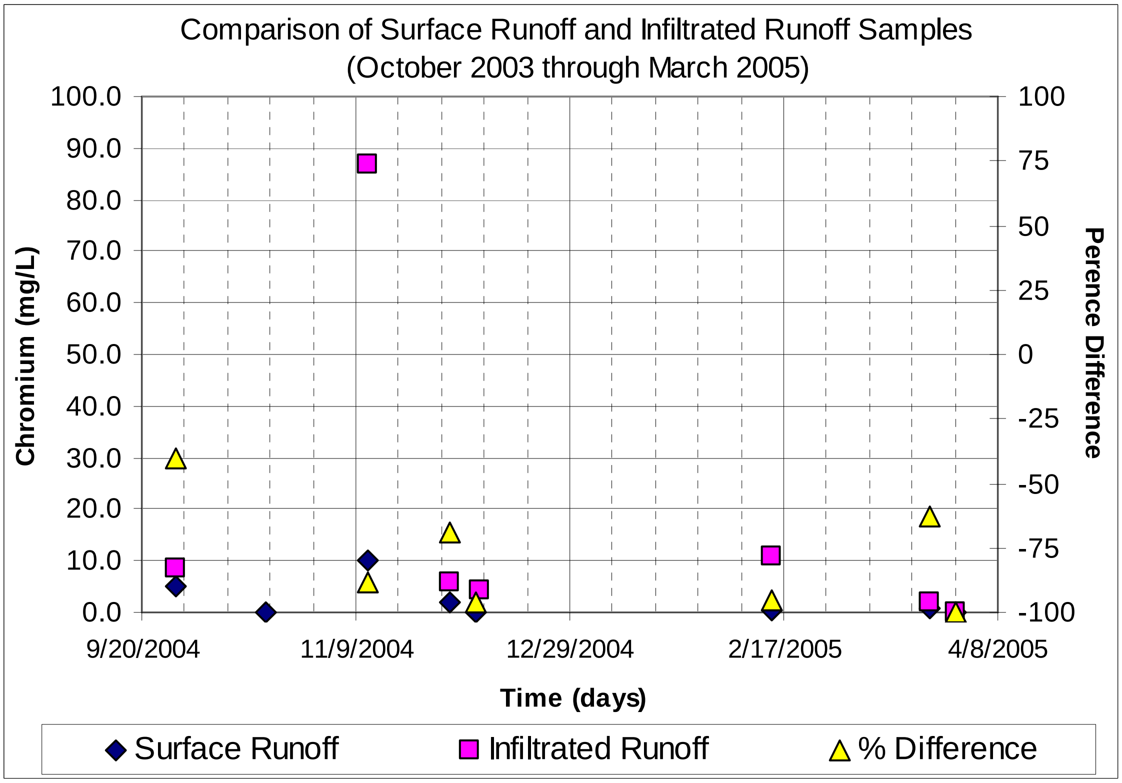

Comparison of Surface Runoff and Infiltrated Runoff Samples
(October 2003 through March 2005)
Nitrite (mg/L)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Perence Difference
100
75
50
25
0
-25
-50
-75
-100
6/28/2003
10/6/2003
1/14/2004
4/23/2004
8/1/2004
11/9/2004
2/17/2005
5/28/2005
Time (days)
Surface Runoff
Infiltrated Runoff
% Difference

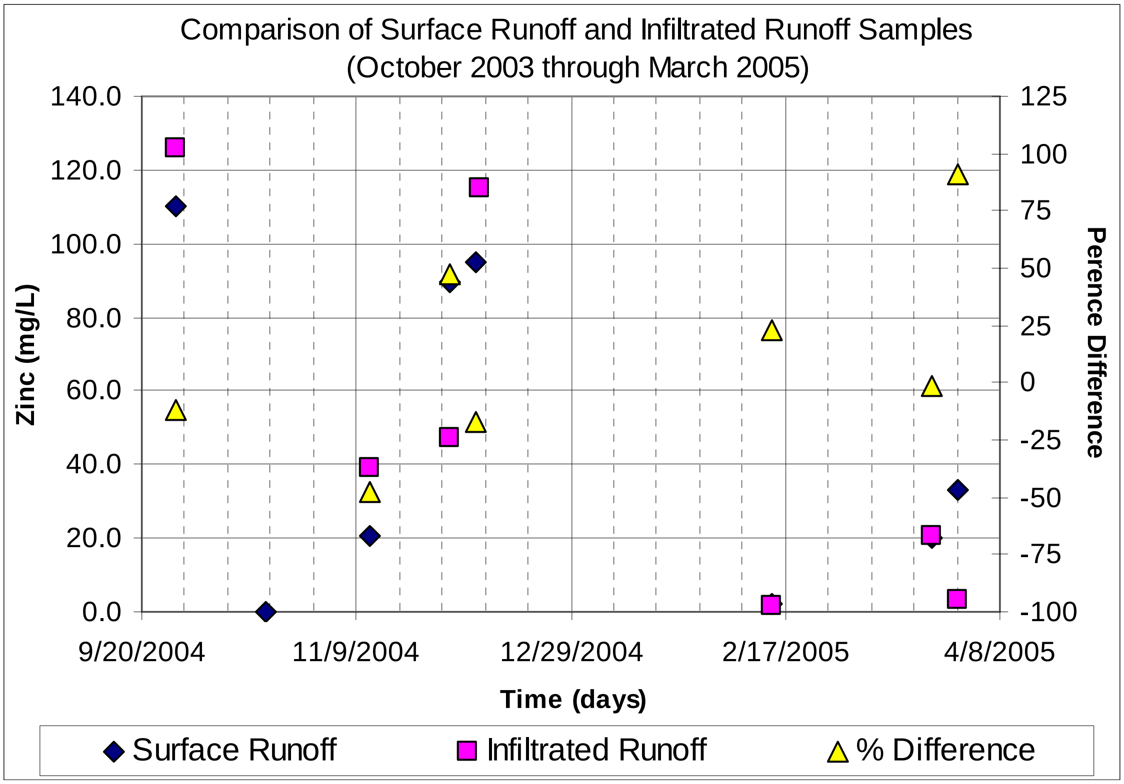

Comparison of Surface Runoff and Infiltrated Runoff Samples
(October 2003 through March 2005)
Nitrate (mg/L)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Perence Difference
100
75
50
25
0
-25
-50
-75
-100
6/28/2003
10/6/2003
1/14/2004
4/23/2004
8/1/2004
11/9/2004
2/17/2005
5/28/2005
Time (days)
Surface Runoff
Infiltrated Runoff
% Difference


Comparison of Surface Runoff and Infiltrated Runoff Samples
(October 2003 through March 2005)
Phosphate (mg/L)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
100
75
50
25
0
-25
-50
-75
-100
Perence Difference
6/28/2003
10/6/2003
1/14/2004
4/23/2004
8/1/2004
11/9/2004
2/17/2005
5/28/2005
Time (days)
◆ Surface Runoff
■ Infiltrated Runoff
△ % Difference


Comparison of Surface Runoff and Infiltrated Runoff Samples
(October 2003 through March 2005)
Copper (mg/L)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
100
75
50
25
0
-25
-50
-75
-100
Perence Difference
6/28/2003
10/6/2003
1/14/2004
4/23/2004
8/1/2004
11/9/2004
2/17/2005
5/28/2005
Time (days)
◆ Surface Runoff
■ Infiltrated Runoff
△ % Difference


Comparison of Surface Runoff and Infiltrated Runoff Samples
(October 2003 through March 2005)
Lead (mg/L)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Perence Difference
100
75
50
25
0
-25
-50
-75
-100
9/20/2004
11/9/2004
12/29/2004
2/17/2005
4/8/2005
Time (days)
◆ Surface Runoff
■ Infiltrated Runoff
△ % Difference


Comparison of Surface Runoff and Infiltrated Runoff Samples
(October 2003 through March 2005)
Chromium (mg/L)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Perence Difference
100
75
50
25
0
-25
-50
-75
-100
9/20/2004
11/9/2004
12/29/2004
2/17/2005
4/8/2005
Time (days)
◆ Surface Runoff
■ Infiltrated Runoff
△ % Difference


Comparison of Surface Runoff and Infiltrated Runoff Samples
(October 2003 through March 2005)
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Zinc (mg/L)
125
100
75
50
25
0
-25
-50
-75
-100
Perence Difference
9/20/2004
11/9/2004
12/29/2004
2/17/2005
4/8/2005
Time (days)
◆ Surface Runoff
■ Infiltrated Runoff
△ % Difference

D.5: Event Mean Concentration Data Tables for Analysis of Mass Loading

Date Collected	Volume Inflow		Volume Outflow		Removal
	(cu.m)	(liters)	(cu.m)	(liters)	Efficiency
10/27/2003	243.08	243080.94	124.31	124310.21	48.86
11/6/2003	39.78	39775.87	0.00	0.00	100.00
11/18/2003	108.04	108035.15	51.40	51397.49	52.43
12/10/2003	79.19	79190.00	NA	NA	NA
2/3/2004	26.25	26250.82	8.37	8367.03	68.13
2/6/2004	137.89	137890.18	58.57	58569.24	57.52
3/9/2004	18.86	18862.30	0.00	0.00	100.00
3/16/2004	72.76	72756.53	0.00	0.00	100.00
3/30/2004	27.39	27394.25	0.00	0.00	100.00
4/1/2004	3.57	3567.21	0.00	0.00	100.00
4/13/2004	191.66	191657.37	25.10	25101.10	86.90
4/26/2004	82.47	82467.68	3.11	3107.76	96.23
5/4/2004	42.45	42446.35	0.00	0.00	100.00
5/19/2004	14.30	14297.21	0.00	0.00	100.00
6/5/2004	17.42	17424.07	0.00	0.00	100.00
6/11/2004	7.48	7478.56	0.00	0.00	100.00
6/15/2004	26.82	26821.92	0.00	0.00	100.00
7/12/2004	322.73	322726.43	188.86	188855.90	41.48
7/18/2004	37.81	37813.41	0.00	0.00	100.00
7/28/2004	311.02	311020.75	216.35	216347.58	30.44
9/27/2004	683.01	683012.18	574.93	574934.74	15.82
10/19/2004	27.40	27395.48	0.00	0.00	100.00
11/12/2004	75.15	75153.17	1.20	1195.29	98.41
12/1/2004	39.12	39118.43	4.78	4781.16	87.78
12/7/2004	103.66	103658.78	0.24	239.06	99.77
2/14/2005	70.38	70380.86	8.37	8367.03	88.11
3/23/2005	45.86	45860.00	0.00	0.00	100.00
3/29/2005	89.21	89210.00	23.91	23905.81	73.20

	Volume Inflow		Volume Outflow		Removal
	(cu.m)	(liters)	(cu.m)	(liters)	Efficiency
Total Volume	2944.7	2944745.9	1289.5	1289479.4	
Average	105.2	105169.5	47.8	47758.5	83.2
Maximum	683.0	683012.2	574.9	574934.7	100.0
Minimum	3.6	3567.2	0.0	0.0	15.8
Median	58.1	58120.4	0.2	239.1	99.8
Stdev	142.0	141965.1	120.0	119990.4	25.3
N	28	28	27	27	27

	Total Suspended Solids			Total Dissolved Solids		
Date Collected	In	Out	Retained	In	Out	Retained
	(grams-TSS)	(grams-TSS)	(grams-TSS)	(grams-TDS)	(grams-TDS)	(grams-TDS)
10/27/2003	2722.5	1392.3	1330.2	20661.9	10566.4	10095.5
11/6/2003	437.5	0.0	437.5	1988.8	0.0	1988.8
11/18/2003	1570.1	747.0	823.1	5521.8	2627.0	2894.8
12/10/2003	528.1	NA	NA	5862.7	NA	NA
2/3/2004	357.0	113.8	243.2	13363.4	4259.4	9104.0
2/6/2004	1720.9	730.9	989.9	21535.7	9147.3	12388.3
3/9/2004	139.6	0.0	139.6	1175.1	0.0	1175.1
3/16/2004	436.5	0.0	436.5	62894.4	0.0	62894.4
3/30/2004	191.8	0.0	191.8	1493.0	0.0	1493.0
4/1/2004	12.5	0.0	12.5	1997.6	0.0	1997.6
4/13/2004	1054.1	138.1	916.1	7474.6	978.9	6495.7
4/26/2004	659.7	24.9	634.9	3133.8	118.1	3015.7
5/4/2004	84.9	0.0	84.9	2122.3	0.0	2122.3
5/19/2004	78.6	0.0	78.6	822.1	0.0	822.1
6/5/2004	63.7	0.0	63.7	1585.6	0.0	1585.6
6/11/2004	403.8	0.0	403.8	638.7	0.0	638.7
6/15/2004	182.4	0.0	182.4	1697.8	0.0	1697.8
7/12/2004	1129.5	661.0	468.5	11069.5	6477.8	4591.8
7/18/2004	223.5	0.0	223.5	1588.2	0.0	1588.2
7/28/2004	2593.9	1804.3	789.6	12297.8	8554.4	3743.4
9/27/2004	3415.1	2874.7	540.4	29711.0	25009.7	4701.4
10/19/2004	650.6	0.0	650.6	675.8	0.0	675.8
11/12/2004	3100.1	49.3	3050.8	3493.9	55.6	3438.3
12/1/2004	234.7	28.7	206.0	888.0	108.5	779.5
12/7/2004	492.4	1.1	491.2	2379.0	5.5	2373.5
2/14/2005	774.2	92.0	682.2	6753.0	802.8	5950.2
3/23/2005	940.1	0.0	940.1	5400.0	0.0	5400.0
3/29/2005	4304.4	1153.5	3150.9	10482.2	2808.9	7673.2

	Total Suspended Solids			Total Dissolved Solids		
	In	Out	Retained	In	Out	Retained
	(grams-TSS)	(grams-TSS)	(grams-TSS)	(grams-TDS)	(grams-TDS)	(grams-TDS)
Total Mass	28502.4	9811.5	18162.7	238707.7	71520.2	161324.7
Average	1017.9	363.4	672.7	8525.3	2648.9	5975.0
Maximum	4304.4	2874.7	3150.9	62894.4	25009.7	62894.4
Minimum	12.5	0.0	12.5	638.7	0.0	638.7
Median	510.3	1.1	468.5	3313.8	5.5	2894.8
Stdev	1162.5	701.5	775.6	12918.3	5480.9	11789.8
N	28	27	27	28	27	27

	Total Nitrogen			Total Phosphorous		
Date Collected	In	Out	Retained	In	Out	Retained
	(grams-N)	(grams-N)	(grams-N)	(grams-P0$_4$)	(grams-P0$_4$)	(grams-P0$_4$)
10/27/2003	324.1	165.7	158.4	NA	NA	NA
11/6/2003	0.0	0.0	0.0	32.4	0.0	32.4
11/18/2003	NA	NA	NA	48.3	23.0	25.3
12/10/2003	NA	NA	NA	NA	NA	NA
2/3/2004	NA	NA	NA	NA	NA	NA
2/6/2004	137.9	58.6	79.3	NA	NA	NA
3/9/2004	7.5	0.0	7.5	12.4	0.0	12.4
3/16/2004	97.0	0.0	97.0	28.7	0.0	28.7
3/30/2004	NA	NA	NA	8.2	0.0	8.2
4/1/2004	NA	NA	NA	1.4	0.0	1.4
4/13/2004	63.9	8.4	55.5	41.5	5.4	36.1
4/26/2004	NA	NA	NA	NA	NA	NA
5/4/2004	NA	NA	NA	NA	NA	NA
5/19/2004	17.2	0.0	17.2	5.7	0.0	5.7
6/5/2004	26.7	0.0	26.7	0.8	0.0	0.8
6/11/2004	6.0	0.0	6.0	1.2	0.0	1.2
6/15/2004	28.2	0.0	28.2	NA	NA	NA
7/12/2004	250.1	146.4	103.7	246.9	144.5	102.4
7/18/2004	13.9	0.0	13.9	19.5	0.0	19.5
7/28/2004	259.2	180.3	78.9	386.7	269.0	117.7
9/27/2004	341.5	287.5	54.0	1161.1	977.4	183.7
10/19/2004	35.6	0.0	35.6	20.1	0.0	20.1
11/12/2004	67.6	1.1	66.6	78.5	1.2	77.3
12/1/2004	39.1	4.8	34.3	21.3	2.6	18.7
12/7/2004	155.5	0.4	155.1	NA	NA	NA
2/14/2005	NA	NA	NA	25.7	3.1	22.6
3/23/2005	27.5	0.0	27.5	31.0	0.0	31.0
3/29/2005	0.0	0.0	0.0	43.7	11.7	32.0

	Total Nitrogen			Total Phosphorous		
	In	Out	Retained	In	Out	Retained
	(grams-N)	(grams-N)	(grams-N)	(grams-P04)	(grams-P04)	(grams-P04)
Total Mass	1898.5	853.0	1045.5	2215.3	1437.9	777.4
Average	94.9	42.7	52.3	110.8	71.9	38.9
Maximum	341.5	287.5	158.4	1161.1	977.4	183.7
Minimum	0.0	0.0	0.0	0.8	0.0	0.8
Median	37.4	0.0	35.0	27.2	0.0	24.0
Stdev	111.9	83.1	47.5	264.6	223.1	46.8
N	20	20	20	20	20	20

	Chloride			Nitrite		
Date Collected	In	Out	Retained	In	Out	Retained
	(grams-Cl)	(grams-Cl)	(grams-Cl)	(grams N0$_2$-N)	(grams N0$_2$-N)	(grams N0$_2$-N)
10/27/2003	1118.2	571.8	546.3	36.5	18.6	17.8
11/6/2003	233.0	0.0	233.0	8.8	0.0	8.8
11/18/2003	1016.3	483.5	532.8	0.0	0.0	0.0
12/10/2003	2376.7	NA	NA	NA	NA	NA
2/3/2004	9763.7	3112.0	6651.6	NA	NA	NA
2/6/2004	44193.8	18771.4	25422.4	NA	NA	NA
3/9/2004	26.8	0.0	26.8	NA	NA	NA
3/16/2004	37222.2	0.0	37222.2	NA	NA	NA
3/30/2004	112.3	0.0	112.3	NA	NA	NA
4/1/2004	1946.3	0.0	1946.3	NA	NA	NA
4/13/2004	223.6	29.3	194.3	NA	NA	NA
4/26/2004	268.0	10.1	257.9	NA	NA	NA
5/4/2004	194.4	0.0	194.4	NA	NA	NA
5/19/2004	35.7	0.0	35.7	NA	NA	NA
6/5/2004	60.3	0.0	60.3	NA	NA	NA
6/11/2004	15.9	0.0	15.9	NA	NA	NA
6/15/2004	64.9	0.0	64.9	NA	NA	NA
7/12/2004	198.5	116.1	82.3	NA	NA	NA
7/18/2004	69.1	0.0	69.1	NA	NA	NA
7/28/2004	465.0	323.4	141.5	NA	NA	NA
9/27/2004	2465.7	2075.5	390.2	NA	NA	NA
10/19/2004	183.3	0.0	183.3	NA	NA	NA
11/12/2004	47.5	0.8	46.8	9.9	0.2	9.7
12/1/2004	30.1	3.7	26.4	4.1	0.5	3.6
12/7/2004	91.5	0.2	91.3	8.3	0.0	8.3
2/14/2005	NA	NA	NA	NA	NA	NA
3/23/2005	2526.9	0.0	2526.9	13.80	0.0	13.8
3/29/2005	NA	NA	NA	NA	NA	NA

	Chloride			Nitrite		
	In	Out	Retained	In	Out	Retained
	(grams-Cl)	(grams-Cl)	(grams-Cl)	(grams N02-N)	(grams N02-N)	(grams N02-N)
Total Mass	104949.6	25497.9	77075.0	81.3	19.3	62.0
Average	4036.5	1019.9	3083.0	11.6	2.8	8.9
Maximum	44193.8	18771.4	37222.2	36.5	18.6	17.8
Minimum	15.9	0.0	15.9	0.0	0.0	0.0
Median	211.0	0.0	183.3	8.8	0.0	8.8
Stdev	11018.2	3769.6	8778.8	11.8	7.0	5.9
N	26	25	25	7	7	7

	Nitrate			Ortho Phosphate		
Date Collected	In	Out	Retained	In	Out	Retained
	(grams NO_3-N)	(grams NO_3-N)	(grams NO_3-N)	(grams-PO_4)	(grams-PO_4)	(grams-PO_4)
10/27/2003	301.4	154.1	147.3	58.3	29.8	28.5
11/6/2003	0.0	0.0	0.0	13.7	0.0	13.7
11/18/2003	56.2	26.7	29.5	NA	NA	NA
12/10/2003	NA	NA	NA	NA	NA	NA
2/3/2004	NA	NA	NA	NA	NA	NA
2/6/2004	NA	NA	NA	NA	NA	NA
3/9/2004	NA	NA	NA	NA	NA	NA
3/16/2004	NA	NA	NA	NA	NA	NA
3/30/2004	NA	NA	NA	NA	NA	NA
4/1/2004	NA	NA	NA	NA	NA	NA
4/13/2004	NA	NA	NA	NA	NA	NA
4/26/2004	NA	NA	NA	NA	NA	NA
5/4/2004	NA	NA	NA	NA	NA	NA
5/19/2004	NA	NA	NA	NA	NA	NA
6/5/2004	NA	NA	NA	NA	NA	NA
6/11/2004	NA	NA	NA	NA	NA	NA
6/15/2004	19.0	0.0	19.0	0.0	0.0	0.0
7/12/2004	186.4	109.1	77.3	0.0	0.0	0.0
7/18/2004	3.0	0.0	3.0	0.0	0.0	0.0
7/28/2004	102.6	71.4	31.2	392.7	273.1	119.5
9/27/2004	NA	NA	NA	NA	NA	NA
10/19/2004	NA	NA	NA	NA	NA	NA
11/12/2004	13.8	0.2	13.6	55.1	0.9	54.3
12/1/2004	4.9	0.6	4.3	18.4	2.2	16.1
12/7/2004	18.1	0.0	18.1	35.8	0.1	35.7
2/14/2005	NA	NA	NA	NA	NA	NA
3/23/2005	17.1	0.0	17.1	21.5	0.0	21.5
3/29/2005	NA	NA	NA	NA	NA	NA

	Nitrate			Ortho Phosphate		
	In	Out	Retained	In	Out	Retained
	(grams NO3-N)	(grams NO3-N)	(grams NO3-N)	(grams-PO4)	(grams-PO4)	(grams-PO4)
Total Mass	722.5	362.2	360.3	595.5	306.2	289.4
Average	65.7	32.9	32.8	59.6	30.6	28.9
Maximum	301.4	154.1	147.3	392.7	273.1	119.5
Minimum	0.0	0.0	0.0	0.0	0.0	0.0
Median	18.1	0.2	18.1	19.9	0.0	18.8
Stdev	96.5	54.4	43.5	119.0	85.7	36.3
N	11	11	11	10	10	10

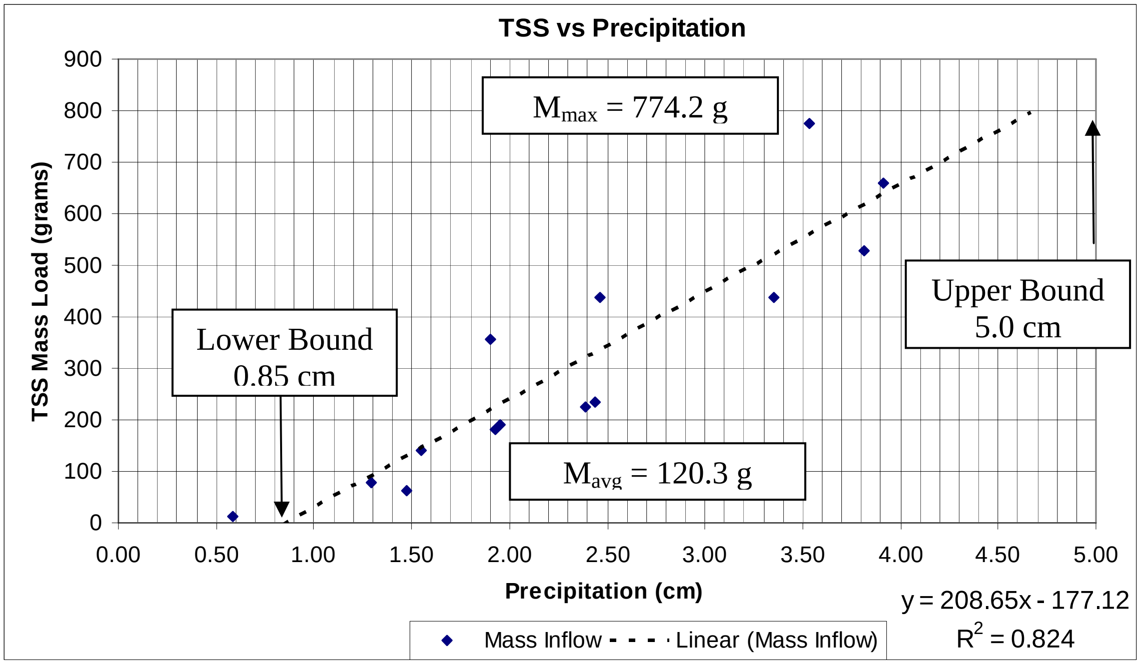
	Copper			Lead		
Date Collected	In	Out	Retained	In	Out	Retained
	(grams-Cu)	(grams-Cu)	(grams-Cu)	(grams-Pb)	(grams-Pb)	(grams-Pb)
10/27/2003	4.6185	2.3619	2.2566	NA	NA	NA
11/6/2003	0.5569	0.0000	0.5569	NA	NA	NA
11/18/2003	1.4369	0.6836	0.7533	NA	NA	NA
12/10/2003	NA	NA	NA	NA	NA	NA
2/3/2004	NA	NA	NA	NA	NA	NA
2/6/2004	0.2758	0.1171	0.1586	NA	NA	NA
3/9/2004	NA	NA	NA	NA	NA	NA
3/16/2004	NA	NA	NA	NA	NA	NA
3/30/2004	0.0548	0.0000	0.0548	NA	NA	NA
4/1/2004	0.0036	0.0000	0.0036	NA	NA	NA
4/13/2004	NA	NA	NA	NA	NA	NA
4/26/2004	NA	NA	NA	NA	NA	NA
5/4/2004	NA	NA	NA	NA	NA	NA
5/19/2004	NA	NA	NA	NA	NA	NA
6/5/2004	NA	NA	NA	NA	NA	NA
6/11/2004	NA	NA	NA	NA	NA	NA
6/15/2004	NA	NA	NA	NA	NA	NA
7/12/2004	NA	NA	NA	NA	NA	NA
7/18/2004	NA	NA	NA	NA	NA	NA
7/28/2004	NA	NA	NA	NA	NA	NA
9/27/2004	11.0648	9.3139	1.7509	2.3052	1.9404	0.3648
10/19/2004	NA	NA	NA	NA	NA	NA
11/12/2004	0.3666	0.0058	0.3608	0.0771	0.0012	0.0759
12/1/2004	0.0649	0.0079	0.0570	0.0000	0.0000	0.0000
12/7/2004	0.8801	0.0020	0.8780	0.0000	0.0000	0.0000
2/14/2005	0.1569	0.0187	0.1383	0.0338	0.0040	0.0298
3/23/2005	0.2064	0.0000	0.2064	0.0422	0.0000	0.0422
3/29/2005	0.1463	0.0392	0.1071	0.1882	0.0504	0.1378

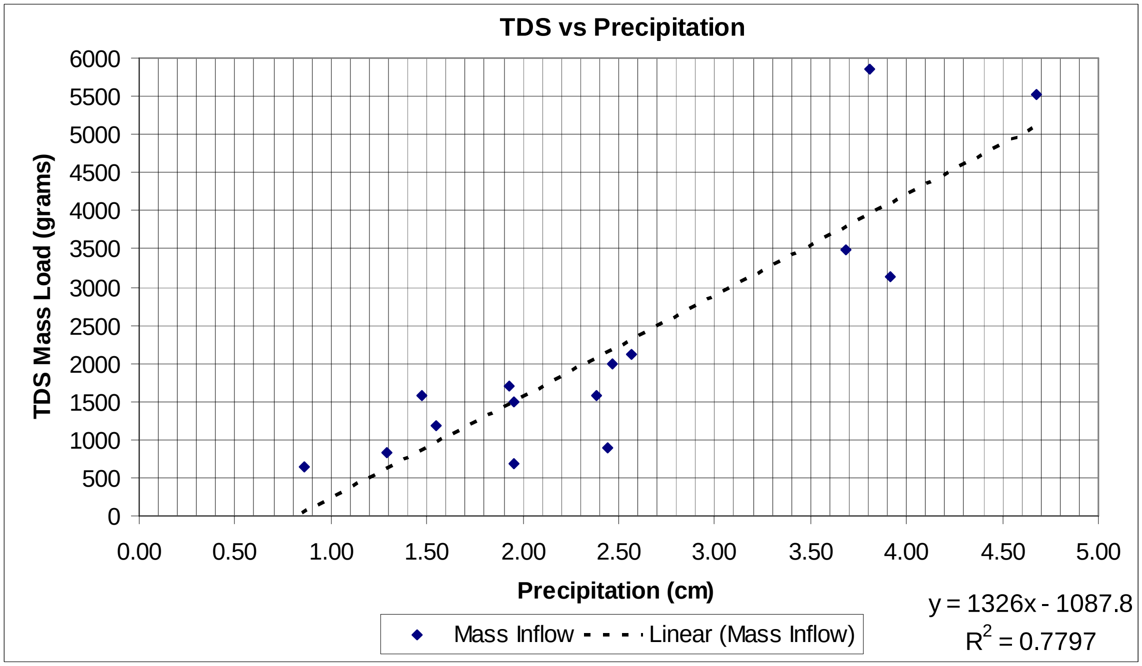
	Copper			Lead		
	In	Out	Retained	In	Out	Retained
	(grams-Cu)	(grams-Cu)	(grams-Cu)	(grams-Pb)	(grams-Pb)	(grams-Pb)
Total Mass	19.8	12.6	7.3	2.6	2.0	0.7
Average	1.5	1.0	0.6	0.4	0.3	0.1
Maximum	11.1	9.3	2.3	2.3	1.9	0.4
Minimum	0.0	0.0	0.0	0.0	0.0	0.0
Median	0.3	0.0	0.2	0.0	0.0	0.0
Stdev	3.1	2.6	0.7	0.9	0.7	0.1
N	13	13	13	7	7	7

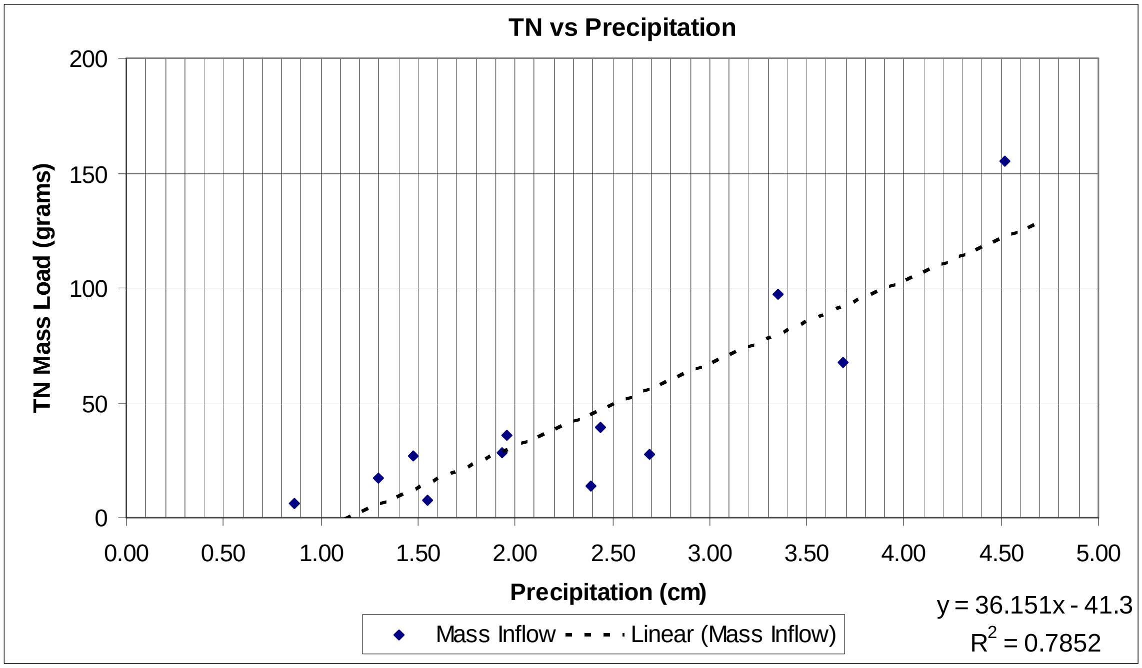
	Chromium			Zinc		
Date Collected	**In**	**Out**	**Retained**	**In**	**Out**	**Retained**
	(grams-Cr)	**(grams-Cr)**	**(grams-Cr)**	**(grams-Zn)**	**(grams-Zn)**	**(grams-Zn)**
10/27/2003	NA	NA	NA	NA	NA	NA
11/6/2003	NA	NA	NA	NA	NA	NA
11/18/2003	NA	NA	NA	NA	NA	NA
12/10/2003	NA	NA	NA	NA	NA	NA
2/3/2004	NA	NA	NA	NA	NA	NA
2/6/2004	NA	NA	NA	NA	NA	NA
3/9/2004	NA	NA	NA	NA	NA	NA
3/16/2004	NA	NA	NA	NA	NA	NA
3/30/2004	NA	NA	NA	NA	NA	NA
4/1/2004	NA	NA	NA	NA	NA	NA
4/13/2004	NA	NA	NA	NA	NA	NA
4/26/2004	NA	NA	NA	NA	NA	NA
5/4/2004	NA	NA	NA	NA	NA	NA
5/19/2004	NA	NA	NA	NA	NA	NA
6/5/2004	NA	NA	NA	NA	NA	NA
6/11/2004	NA	NA	NA	NA	NA	NA
6/15/2004	NA	NA	NA	NA	NA	NA
7/12/2004	NA	NA	NA	NA	NA	NA
7/18/2004	NA	NA	NA	NA	NA	NA
7/28/2004	NA	NA	NA	NA	NA	NA
9/27/2004	3.3980	2.8603	0.5377	75.4011	63.46992019	11.9312
10/19/2004	NA	NA	NA	NA	NA	NA
11/12/2004	0.7440	0.0118	0.7321	1.5365	0.024436878	1.5120
12/1/2004	0.0716	0.0087	0.0628	3.5050	0.428392119	3.0766
12/7/2004	0.0166	0.0000	0.0165	9.8642	0.022748769	9.8414
2/14/2005	0.0359	0.0043	0.0316	0.1446	0.017194254	0.1274
3/23/2005	0.0358	0.0000	0.0358	0.9222	0	0.9222
3/29/2005	0.0000	0.0000	0.0000	2.9747	0.797139242	2.1776

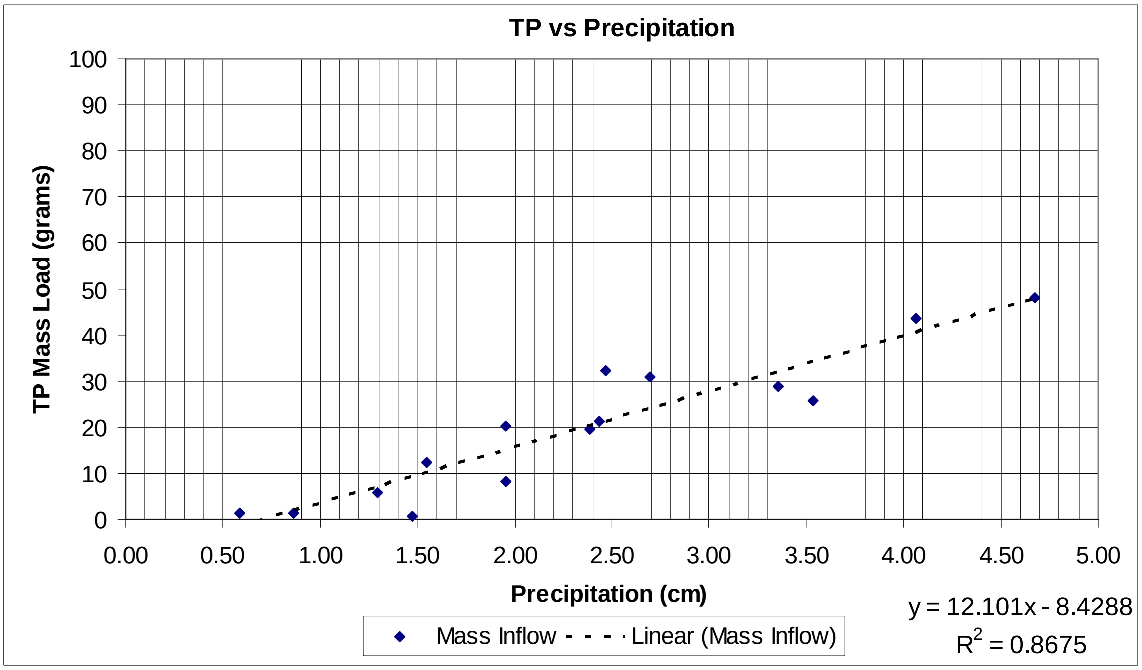
	Chromium			Zinc		
	In	**Out**	**Retained**	**In**	**Out**	**Retained**
	(grams-Cr)	**(grams-Cr)**	**(grams-Cr)**	**(grams-Zn)**	**(grams-Zn)**	**(grams-Zn)**
Total Mass	4.3	2.9	1.4	94.3	64.8	29.6
Average	0.6	0.4	0.2	13.5	9.3	4.2
Maximum	3.4	2.9	0.7	75.4	63.5	11.9
Minimum	0.0	0.0	0.0	0.1	0.0	0.1
Median	0.0	0.0	0.0	3.0	0.0	2.2
Stdev	1.3	1.1	0.3	27.5	23.9	4.7
N	7	7	7	7	7	7

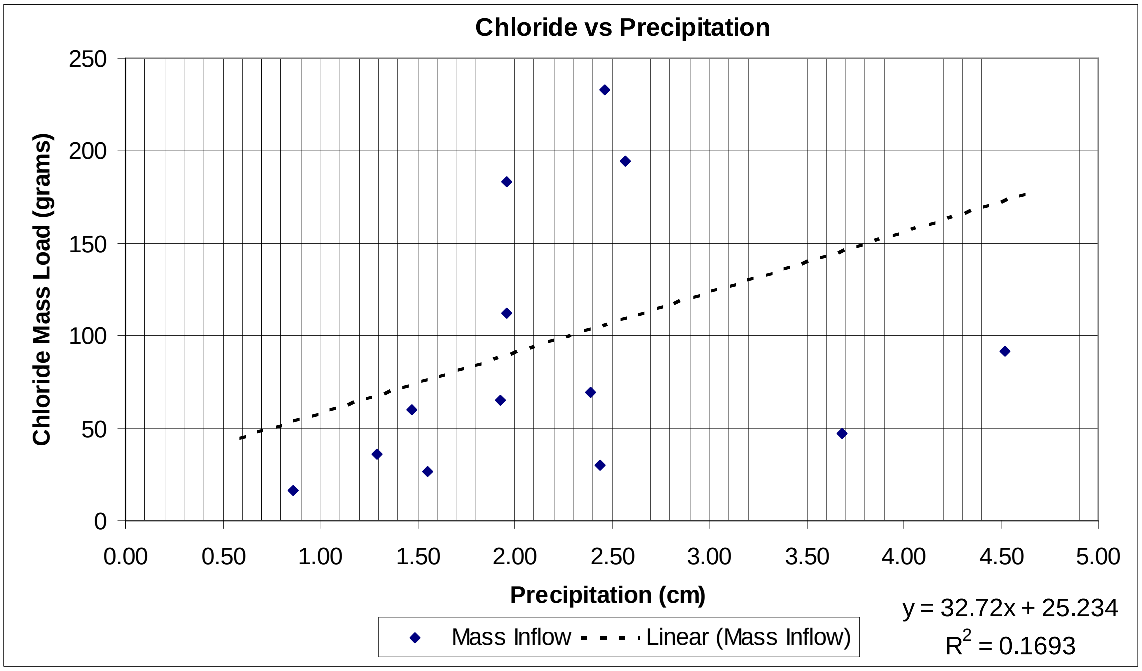
D.6: Precipitation Versus Pollutant Loading in terms of Mass

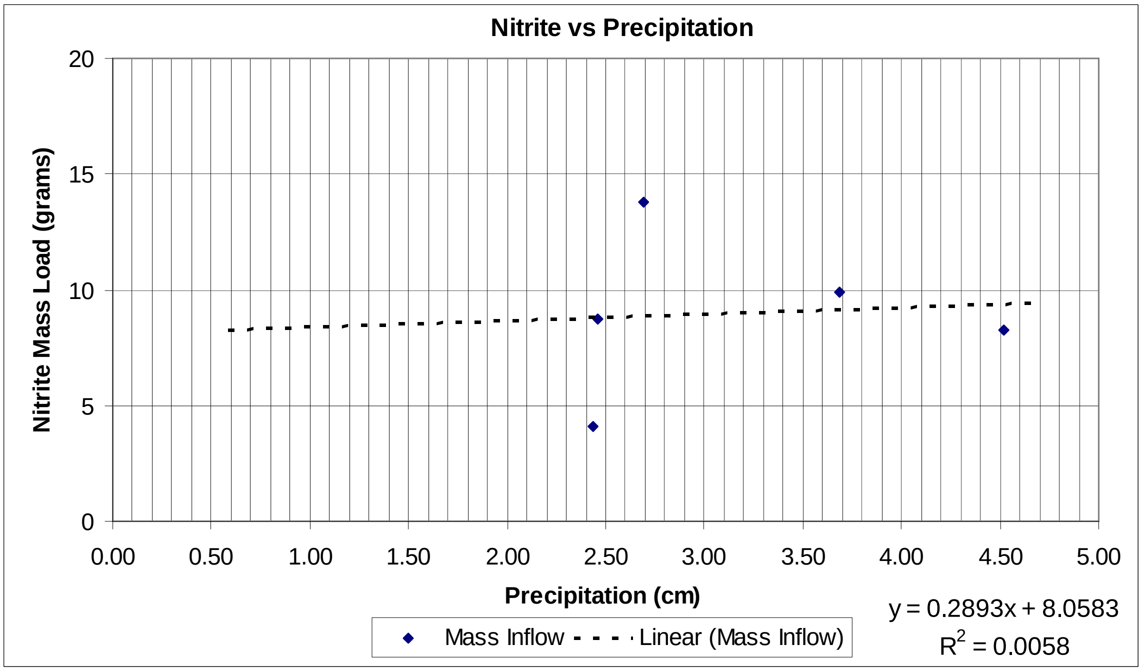


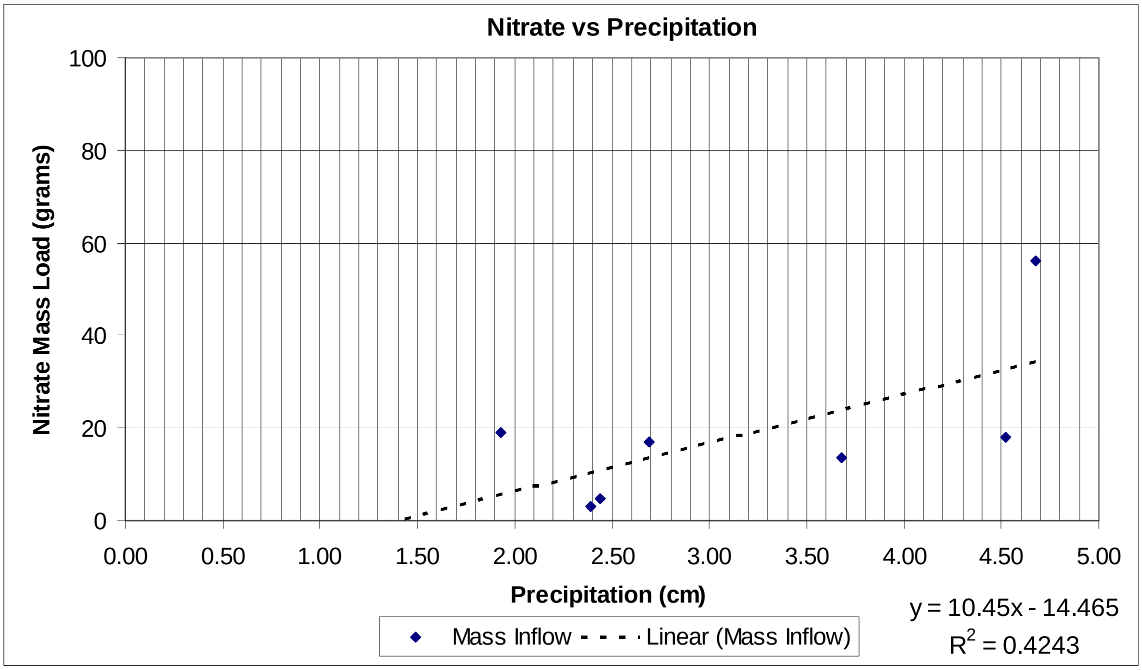


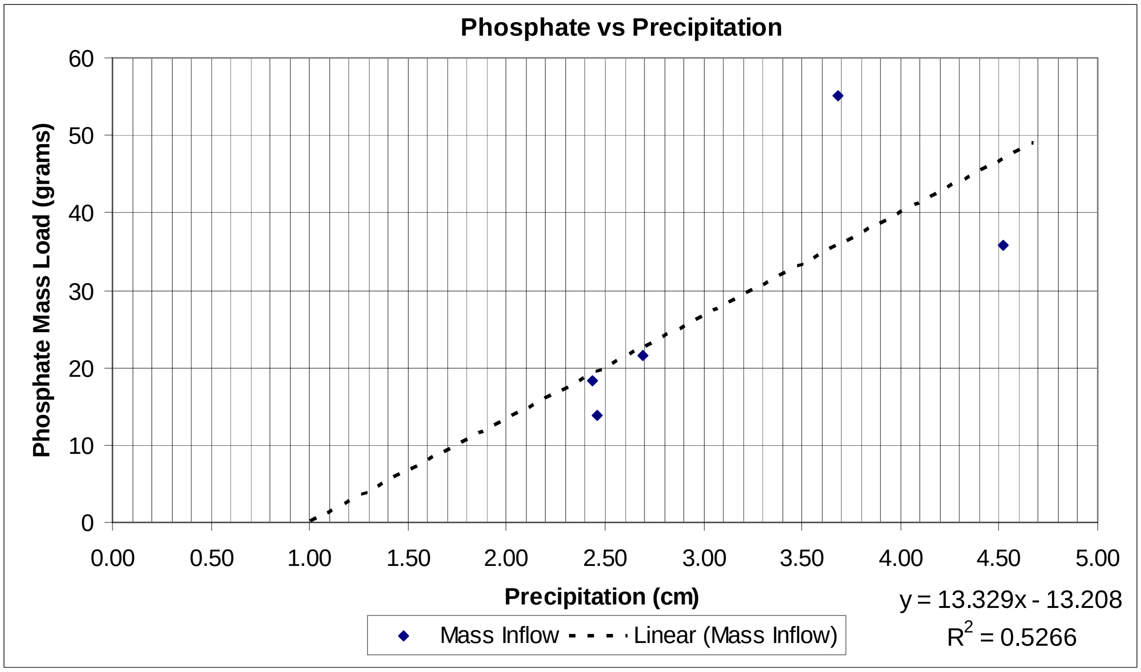

TN vs Precipitation
TN Mass Load (grams)
200
150
100
50
0
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
Precipitation (cm)
◆ Mass Inflow
Linear (Mass Inflow)
y = 36.151x - 41.3
R2 = 0.7852

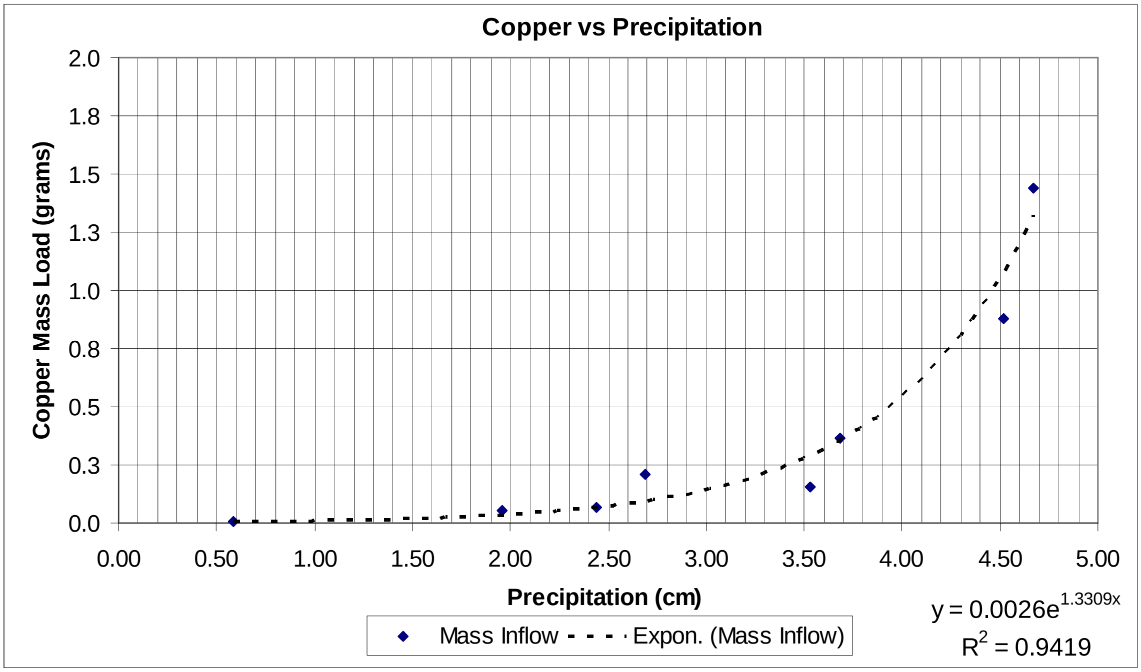

TP vs Precipitation
TP Mass Load (grams)
100
90
80
70
60
50
40
30
20
10
0
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
Precipitation (cm)
◆ Mass Inflow
Linear (Mass Inflow)
y = 12.101x - 8.4288
R2 = 0.8675

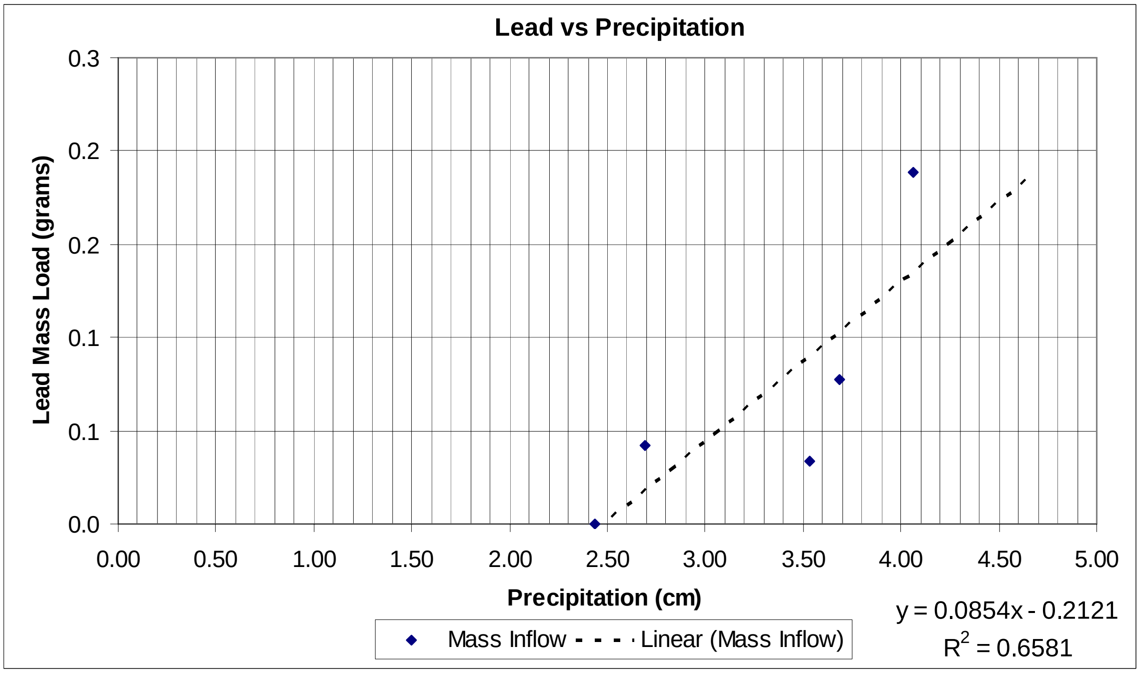

Chloride vs Precipitation
Chloride Mass Load (grams)
250
200
150
100
50
0
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
Precipitation (cm)
Mass Inflow
Linear (Mass Inflow)
y = 32.72x + 25.234
R^2 = 0.1693

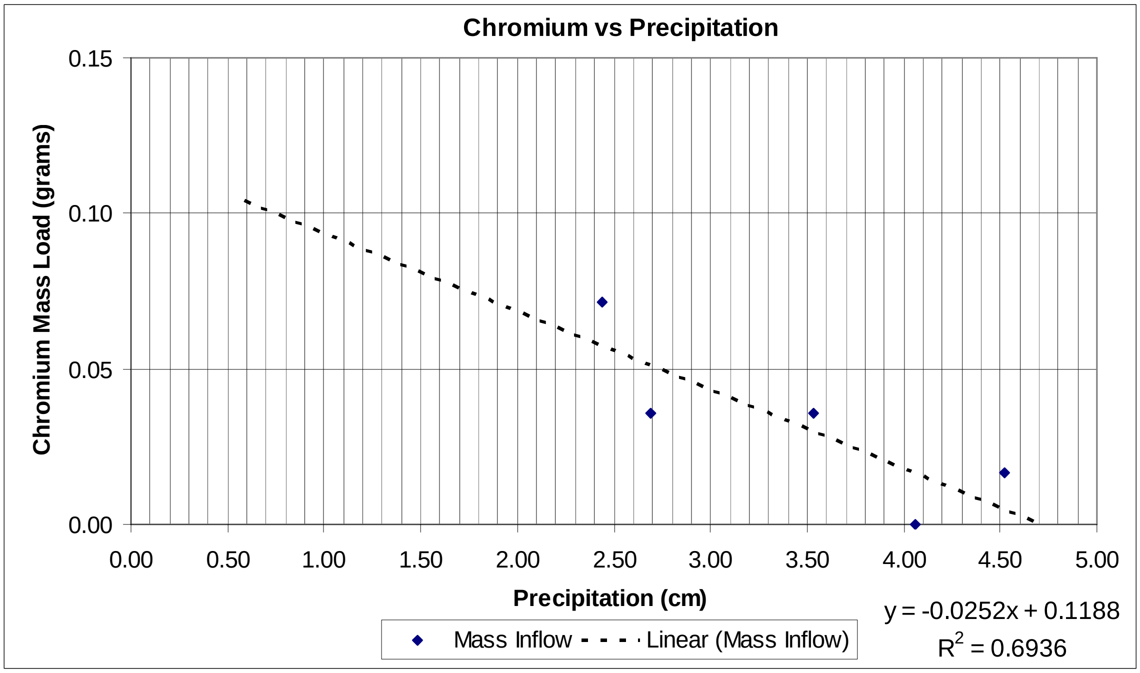

Nitrite vs Precipitation
Nitrite Mass Load (grams)
20
15
10
5
0
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
Precipitation (cm)
Mass Inflow
Linear (Mass Inflow)
y = 0.2893x + 8.0583
R^2 = 0.0058

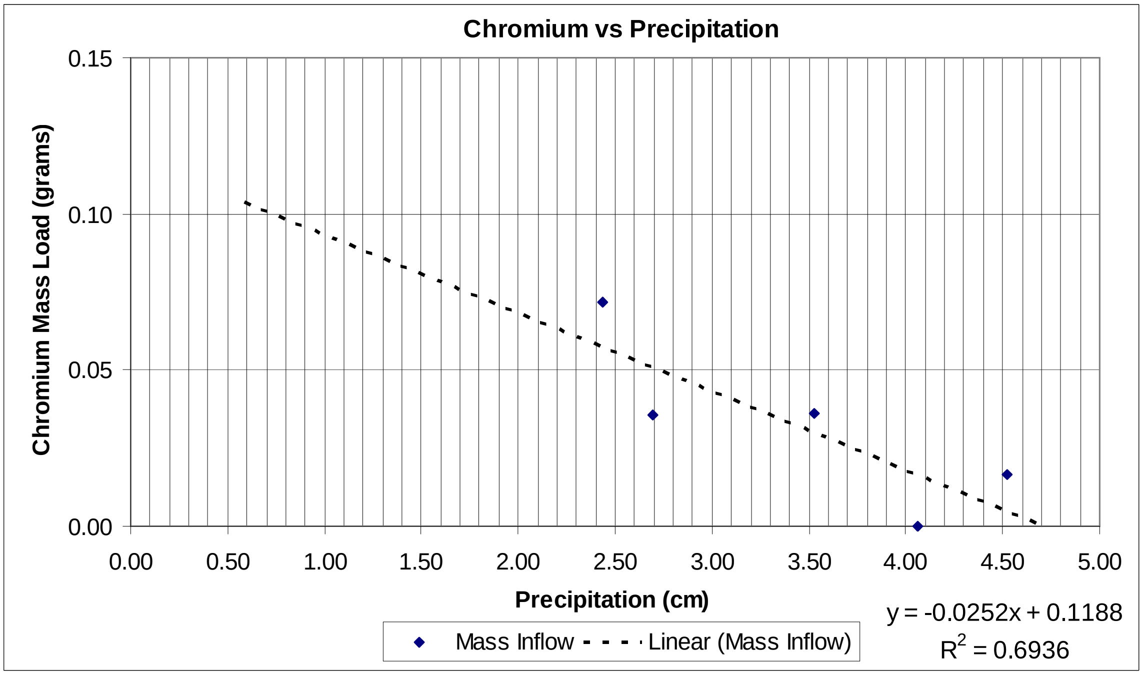

Nitrate vs Precipitation
Nitrate Mass Load (grams)
100
80
60
40
20
0
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
Precipitation (cm)
Mass Inflow
Linear (Mass Inflow)
y = 10.45x - 14.465
R2 = 0.4243

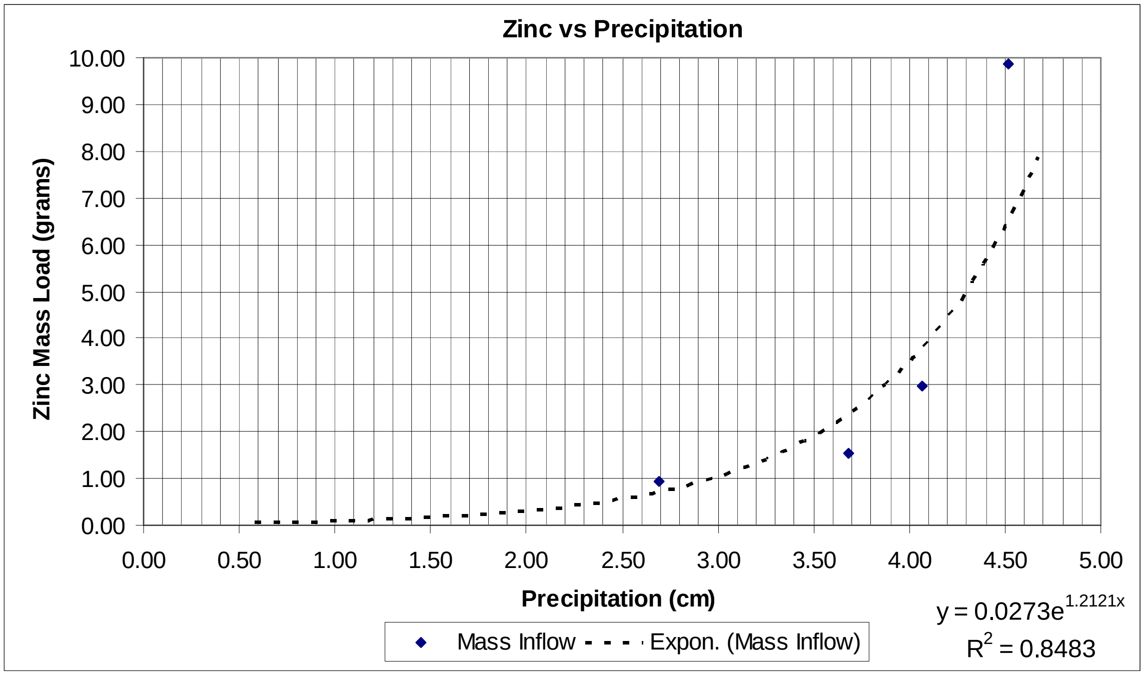

Phosphate vs Precipitation
Phosphate Mass Load (grams)
60
50
40
30
20
10
0
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
Precipitation (cm)
Mass Inflow
Linear (Mass Inflow)
y = 13.329x - 13.208
R2 = 0.5266


Copper vs Precipitation
Copper Mass Load (grams)
2.0
1.8
1.5
1.3
1.0
0.8
0.5
0.3
0.0
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
Precipitation (cm)
◆ Mass Inflow
Expon. (Mass Inflow)
y = 0.0026e^1.3309x
R^2 = 0.9419


Lead vs Precipitation
Lead Mass Load (grams)
0.3
0.2
0.2
0.1
0.1
0.0
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
Precipitation (cm)
◆ Mass Inflow
Linear (Mass Inflow)
y = 0.0854x - 0.2121
R^2 = 0.6581


Chromium vs Precipitation
Chromium Mass Load (grams)
0.15
0.10
0.05
0.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
Precipitation (cm)
Mass Inflow
Linear (Mass Inflow)
y = -0.0252x + 0.1188
R2 = 0.6936


Chromium vs Precipitation
Chromium Mass Load (grams)
0.15
0.10
0.05
0.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
Precipitation (cm)
Mass Inflow
Linear (Mass Inflow)
y = -0.0252x + 0.1188
R2 = 0.6936


Zinc vs Precipitation
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Zinc Mass Load (grams)
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
Precipitation (cm)
y = 0.0273e^1.2121x
R^2 = 0.8483
◆ Mass Inflow
Expon. (Mass Inflow)

D.7: Event Based Mass Loading for Annual Load Predictions

Regression Relationship		y = 208.65x - 177.12	y = 1326x - 1087.8	y = 36.151x - 41.3
		R2 = 0.824	R2 = 0.7797	R2 = 0.7852
Event Date	Precipitation	TSS	TDS	TN
	(cm)	(grams)	(grams)	(grams)
3/2/2004	0.05			
3/4/2004	0.58			
3/6/2004	1.57	151.5	1000.4	15.6
3/8/2004	1.85	209.8	1370.9	25.7
3/17/2004	1.75	188.6	1236.1	22.1
3/19/2004	1.85	209.8	1370.9	25.7
3/25/2004	0.28			
3/31/2004	1.96	231.0	1505.6	29.4
4/1/2004	0.58			
4/5/2004	4.22	702.6	4503.1	111.1
4/8/2004	0.33			
4/15/2004	6.93	1269.7	8106.9	209.4
4/23/2004	1.93	225.7	1471.9	28.5
4/27/2004	3.91	639.0	4099.0	100.1
5/3/2004	0.15			
5/8/2004	1.12	56.1	394.1	0.0
5/10/2004	1.24	82.6	562.5	3.7
5/16/2004	0.79			
5/20/2004	1.30	93.2	629.9	5.5
5/26/2004	0.89	8.4	91.0	0.0
5/31/2004	0.81			
6/2/2004	0.66			
6/6/2004	1.47	130.3	865.7	12.0
6/10/2004	0.86	3.1	57.3	
6/15/2004	1.93	225.7	1471.9	28.5
6/18/2004	2.90	427.0	2751.8	63.4
6/22/2004	1.78	193.9	1269.8	23.0
6/25/2004	0.10			
6/28/2004	0.51			
7/6/2004	0.99	29.6	225.7	0.0
7/12/2004	10.16	1942.8	12384.4	326.0
7/15/2004	1.19	72.0	495.2	1.9
7/19/2004	2.39	321.1	2078.2	45.0
7/24/2004	2.01	241.6	1573.0	31.2
7/27/2004	9.25	1752.0	11171.9	292.9
7/29/2004	0.64			
8/2/2004	4.83	829.8	5311.5	133.2
8/5/2004	0.33			
8/14/2004	0.89	8.4	91.0	
8/22/2004	0.89	8.4	91.0	
8/30/2004	1.09	50.8	360.5	

9/6/2004	0.91	13.7	124.7	
9/14/2004	7.01	1285.6	8208.0	212.1
9/29/2004	18.39	3659.9	23296.8	623.5
10/14/2004	2.31	305.2	1977.1	42.3
10/16/2004	0.53			
10/18/2004	1.96	231.0	1505.6	29.4
10/21/2004	0.61			
10/30/2004	1.57	151.5	1000.4	15.6
11/5/2004	3.45	543.6	3492.7	83.6
11/12/2004	3.68	591.3	3795.9	91.8
11/20/2004	0.61			
11/25/2004	1.09	50.8	360.5	0.0
11/28/2004	5.87	1047.1	6692.4	170.8
11/30/2004	2.51	347.6	2246.6	49.6
12/6/2004	1.80	199.2	1303.5	23.9
12/10/2004	2.74	395.2	2549.7	57.9
12/19/2004	0.18			
12/23/2004	2.72	389.9	2516.0	57.0
1/2/2005	0.25			
1/5/2005	2.67	379.3	2448.6	55.1
1/8/2005	1.22	77.3	528.9	2.8
1/11/2005	1.02	34.9	259.4	
1/15/2005	4.95	856.3	5479.9	137.8
1/26/2005	0.08			
1/30/2005	0.28			
2/2/2005	0.10			
2/9/2005	0.36			
2/14/2005	2.92	432.3	2785.4	64.3
2/16/2005	0.61			
2/22/2005	0.89	8.4	91.0	
2/25/2005	0.36			

	TSS (grams)	TDS (grams)	TN (grams)
Sum	**21,304**	**137,204**	**3,251**
Max	3659.9	23296.8	623.5
Min	3.1	57.3	0.0
Average	443.8	2858.4	79.3
Stdev	649.39	4126.96	116.99
N	48	48	41

Regression Relationship		y = 12.101x - 8.4288	y = 0.0026e1.3309x	y = 0.0273e1.2121x
		R2 = 0.8675	R2 = 0.9419	R2 = 0.8483
Event Date	Precipitation	TP	Cu	Zn
	(cm)	(grams)	(grams)	(grams)
3/2/2004	0.05		0.003	0.029
3/4/2004	0.58		0.006	0.055
3/6/2004	1.57	10.6	0.021	0.184
3/8/2004	1.85	14.0	0.031	0.258
3/17/2004	1.75	12.8	0.027	0.228
3/19/2004	1.85	14.0	0.031	0.258
3/25/2004	0.28		0.004	0.038
3/31/2004	1.96	15.2	0.035	0.292
4/1/2004	0.58		0.006	0.055
4/5/2004	4.22	42.6	0.711	4.526
4/8/2004	0.33		0.004	0.041
4/15/2004	6.93	50.0	1.500	10.000
4/23/2004	1.93	14.9	0.034	0.283
4/27/2004	3.91	38.9	0.474	3.128
5/3/2004	0.15		0.003	0.033
5/8/2004	1.12	5.1	0.012	0.106
5/10/2004	1.24	6.6	0.014	0.123
5/16/2004	0.79	1.1	0.007	0.071
5/20/2004	1.30	7.2	0.015	0.131
5/26/2004	0.89	2.3	0.008	0.080
5/31/2004	0.81	1.4	0.008	0.073
6/2/2004	0.66		0.006	0.061
6/6/2004	1.47	9.4	0.018	0.163
6/10/2004	0.86	2.0	0.008	0.078
6/15/2004	1.93	14.9	0.034	0.283
6/18/2004	2.90	26.6	0.123	0.913
6/22/2004	1.78	13.1	0.028	0.236
6/25/2004	0.10		0.003	0.031
6/28/2004	0.51		0.005	0.051
7/6/2004	0.99	3.6	0.010	0.091
7/12/2004	10.16	50.0	1.500	10.000
7/15/2004	1.19	6.0	0.013	0.116
7/19/2004	2.39	20.5	0.062	0.493
7/24/2004	2.01	15.9	0.038	0.311
7/27/2004	9.25	50.0	1.500	10.000
7/29/2004	0.64		0.006	0.059
8/2/2004	4.83	50.0	1.500	9.476
8/5/2004	0.33		0.004	0.041
8/14/2004	0.89	2.3	0.008	0.080
8/22/2004	0.89	2.3	0.008	0.080
8/30/2004	1.09	4.8	0.011	0.103
9/6/2004	0.91	2.6	0.009	0.083

9/14/2004	7.01	50.0	1.500	10.000
9/29/2004	18.39	50.0	1.500	10.000
10/14/2004	2.31	19.5	0.056	0.450
10/16/2004	0.53		0.005	0.052
10/18/2004	1.96	15.2	0.035	0.292
10/21/2004	0.61		0.006	0.057
10/30/2004	1.57	10.6	0.021	0.184
11/5/2004	3.45	33.4	0.258	1.797
11/12/2004	3.68	36.1	0.350	2.371
11/20/2004	0.61		0.006	0.057
11/25/2004	1.09	4.8	0.011	0.103
11/28/2004	5.87	50.0	1.500	10.000
11/30/2004	2.51	22.0	0.074	0.575
12/6/2004	1.80	13.4	0.029	0.243
12/10/2004	2.74	24.8	0.100	0.759
12/19/2004	0.18		0.003	0.034
12/23/2004	2.72	24.5	0.097	0.736
1/2/2005	0.25		0.004	0.037
1/5/2005	2.67	23.8	0.090	0.692
1/8/2005	1.22	6.3	0.013	0.120
1/11/2005	1.02	3.9	0.010	0.094
1/15/2005	4.95	50.0	1.500	10.000
1/26/2005	0.08		0.003	0.030
1/30/2005	0.28		0.004	0.038
2/2/2005	0.10		0.003	0.031
2/9/2005	0.36		0.004	0.042
2/14/2005	2.92	26.9	0.127	0.941
2/16/2005	0.61		0.006	0.057
2/22/2005	0.89	2.3	0.008	0.080
2/25/2005	0.36		0.004	0.042
		TP	Cu	Zn
		(grams)	(grams)	(grams)
	Sum	**979**	**15.2**	**102.7**
	Max	50.0	1.5	10.0
	Min	1.1	0.0	0.0
	Average	19.6	0.2	1.4
	Stdev	16.77	0.47	3.11
	N	50	72	72

Appendix E: Event Mean Concentration Data used for Regression Analysis

E.1: Event Mean Concentration Data

Date Collected	Location	TSS	TDS	Conductivity	Tot N	Tot P
		(mg/L)	(mg/L)	(uS/cm)	(mg/L N)	(mg/L P0$_4^{3-}$)
10/27/2003	EMC	11.2	72.6	31.7	1.33	
11/6/2003	EMC	11.0	42.0	48.5		0.8
11/18/2003	EMC	14.5	51.1	36.1		0.4
12/10/2003	EMC	6.7	74.0	47.3		
2/6/2004	EMC	12.5	281.0	175.4	1.00	
3/9/2004	EMC	7.4	62.3	76.4	0.40	0.7
3/30/2004	EMC	7.0	307.2	129.3		0.3
4/13/2004	EMC	5.5	39.0	48.9	0.33	0.2
4/26/2004	EMC	8.0	38.0			
5/4/2004	EMC	2.0	50.0			
5/19/2004	EMC	5.5	57.5	61.1	1.20	0.4
6/5/2004	EMC	3.7	91.0	89.4	1.53	0.0
6/11/2004	EMC	54.0	85.4	73.7	0.80	0.2
6/15/2004	EMC	6.8	63.3	60.0	1.05	
7/12/2004	EMC	3.5	34.3	29.8	0.78	0.8
7/18/2004	EMC	5.9	42.0	52.8	0.37	0.5
7/28/2004	EMC	8.3	39.5	28.4	0.83	1.2
9/27/2004	EMC	5.0	59.8	65.0	0.50	1.7
10/19/2004	EMC	23.8	26.7	34.9	1.30	0.7
11/12/2004	EMC	41.3	46.5	36.7	0.90	1.0
12/1/2004	EMC	6.0	22.7	30.0	1.00	0.5
12/7/2004	EMC	4.8	23.0	25.2	1.50	
2/14/2005	EMC	11.0	149.2	186.9		0.4
3/23/2005	EMC	20.5	184.4	233.8	0.60	0.7
3/29/2005	EMC	48.3	119.3	69.9		0.5

		TSS	TDS	Conductivity	Tot N	Tot P
		(mg/L)	(mg/L)	(uS/cm)	(mg/L N)	(mg/L P043-)
Average		13.4	82.5	72.7	0.9	0.6
Maximum		54.0	307.2	233.8	1.5	1.7
Minimum		2.0	22.7	25.2	0.3	0.0
Median		7.4	57.5	52.8	0.9	0.5
Stdev		14.1	74.5	56.1	0.4	0.4
N		25	25	23	17	18

Date Collected	Location	Cl	Nitrite	Nitrate	PO4
		(mg/L Cl-)	(mg/L N0$_2^{3-}$)	(mg/L N0$_3^{3-}$)	(mg/L P0$_4^{3-}$)
10/27/2003	**EMC**	4.6	0.15	1.24	0.2
11/6/2003	**EMC**	5.9	0.22	ND	0.3
11/18/2003	**EMC**	9.4	ND	0.52	ND
12/10/2003	**EMC**	**30.0**	ND, I	ND, I	ND, I
2/6/2004	**EMC**	**371.9**	ND, I	ND, I	ND, I
3/9/2004	**EMC**	14.2	ND, I	ND, I	ND, I
3/30/2004	**EMC**	**274.9**	ND, I	ND, I	ND, I
4/13/2004	**EMC**	1.2	ND	ND	ND
4/26/2004	**EMC**	3.3	ND	ND	ND
5/4/2004	**EMC**	4.6	ND	ND	ND
5/19/2004	**EMC**	2.5	ND	ND	ND
6/5/2004	**EMC**	3.5	ND	ND	ND
6/11/2004	**EMC**	2.1	ND	ND	ND
6/15/2004	**EMC**	2.4	ND	0.71	ND
7/12/2004	**EMC**	0.6	ND	0.58	ND
7/18/2004	**EMC**	2.3	ND	0.08	ND
7/28/2004	**EMC**	1.9	ND	0.33	1.3
9/27/2004	**EMC**	3.6	ND	ND	ND
10/19/2004	**EMC**	6.7	ND	ND	ND
11/12/2004	**EMC**	0.6	0.13	0.18	0.7
12/1/2004	**EMC**	0.8	0.11	0.13	0.5
12/7/2004	**EMC**	0.9	0.08	0.18	0.3
2/14/2005	**EMC**	Conductivity suppression installed, see Appendix A.			
3/23/2005	**EMC**	**66.5**	0.30	0.37	0.5
3/29/2005	**EMC**	25.86	ND	ND	ND

Note: Inference is noted I.

		Cl	Nitrite	Nitrate	PO4
		(mg/L Cl-)	(mg/L N023-)	(mg/L N033-)	(mg/L P043-)
Average		35.0	0.16	0.43	0.55
Maximum		371.9	0.30	1.24	1.26
Minimum		0.6	0.08	0.08	0.24
Median		3.5	0.14	0.35	0.47
Stdev		91.1	0.08	0.35	0.35
N		24	6	10	7

Date Collected	Location	Cu	Pb	Cr	Zn
		(ug/L)	(ug/L)	(ug/L)	(ug/L)
10/27/2003	EMC	19.0			
11/6/2003	EMC	14.0			
11/18/2003	EMC	13.3			
12/10/2003	EMC				
2/6/2004	EMC	2.0			
3/9/2004	EMC				
3/30/2004	EMC	2.0			
4/13/2004	EMC				
4/26/2004	EMC				
5/4/2004	EMC				
5/19/2004	EMC				
6/5/2004	EMC				
6/11/2004	EMC				
6/15/2004	EMC				
7/12/2004	EMC				
7/18/2004	EMC				
7/28/2004	EMC				
9/27/2004	EMC	16.2	3.3750	4.9750	110.3950
10/19/2004	EMC				
11/12/2004	EMC	4.9	1.0266	9.8991	20.4443
12/1/2004	EMC	1.7	ND(0.00)	1.8300	89.6000
12/7/2004	EMC	8.5	ND(0.00)	0.1600	95.1600
2/14/2005	EMC	2.2	0.4800	0.5100	2.0550
3/23/2005	EMC	4.5	0.9200	0.7800	20.1100
3/29/2005	EMC	1.6	2.1100	ND(0.00)	33.3450

		Cu	Pb	Cr	Zn
		(ug/L)	(ug/L)	(ug/L)	(ug/L)
Average		7.5	1.6	3.0	53.0
Maximum		19.0	3.4	9.9	110.4
Minimum		1.6	0.5	0.2	2.1
Median		4.7	1.0	1.3	33.3
Stdev		6.4	1.2	3.8	43.8
N		12	5	6	7

E.2: Multivariable Correlation Analysis; Water Quality Parameters

E.2.1: Total Chloride and TSS, TDS, Conductivity

Multivariable Correlation Statistics

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.94
R Square	0.88
Adjusted R Square	0.85
Standard Error	36.17
Observations	22

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	165256	55085	42.10	0.00
Residual	18	23550	1308		
Total	21	188807			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-34.27	14.57	-2.35	0.03	-64.88	-3.67	-64.88	-3.67
TSS	-0.81	0.54	-1.51	0.15	-1.94	0.32	-1.94	0.32
TDS	1.38	0.17	7.94	0.00	1.01	1.74	1.01	1.74
Cond.	-0.45	0.26	-1.74	0.10	-1.00	0.09	-1.00	0.09

E.2.2: Nitrite and TSS, TDS, Conductivity

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.870
R Square	0.756
Adjusted R Square	0.391
Standard Error	0.064
Observations	6

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	0.025	0.008	2.068	0.342
Residual	2	0.008	0.004		
Total	5	0.033			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	9.69E-02	0.050	1.933	0.193	-0.119	0.312	-0.119	0.312
TSS	5.43E-05	0.002	0.025	0.982	-0.009	0.009	-0.009	0.009
TDS	5.14E-04	0.002	0.312	0.784	-0.007	0.008	-0.007	0.008
Cond	4.92E-04	0.001	0.404	0.725	-0.005	0.006	-0.005	0.006

E.2.3: Nitrate and TSS, TDS, Conductivity

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.956
R Square	0.915
Adjusted R Square	0.872
Standard Error	0.126
Observations	10

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	1.022	0.341	21.422	0.001
Residual	6	0.095	0.016		
Total	9	1.117			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.123	0.080	1.539	0.175	-0.073	0.320	-0.073	0.320
TSS	-0.012	0.004	-3.052	0.022	-0.022	-0.002	-0.022	-0.002
TDS	0.025	0.003	7.943	0.000	0.017	0.032	0.017	0.032
Cond.	-0.017	0.002	-7.623	0.000	-0.023	-0.012	-0.023	-0.012

E.2.4: Chromium and TSS, TDS, Conductivity

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.783
R Square	0.612
Adjusted R Square	0.225
Standard Error	3.213
Observations	7

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	48.934	16.311	1.580	0.358
Residual	3	30.971	10.324		
Total	6	79.905			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	2.701	2.395	1.128	0.341	-4.919	10.322	-4.919	10.322
TSS	0.241	0.127	1.894	0.155	-0.164	0.647	-0.164	0.647
TDS	-0.182	0.102	-1.782	0.173	-0.507	0.143	-0.507	0.143
Cond.	0.118	0.077	1.543	0.221	-0.125	0.361	-0.125	0.361

E.2.4: Zinc and TSS, TDS, Conductivity

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.909
R Square	0.827
Adjusted R Square	0.653
Standard Error	25.810
Observations	7

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	9536	3179	4.77	0.116
Residual	3	1998	666		
Total	6	11535			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	114.65	19.24	5.96	0.009	53.44	175.87	53.44	175.87
TSS	-2.28	1.02	-2.22	0.11	-5.53	0.98	-5.53	0.98
TDS	0.78	0.82	0.95	0.41	-1.83	3.39	-1.83	3.39
Cond.	-0.92	0.61	-1.49	0.23	-2.87	1.04	-2.87	1.04

E.3: Event Data for analysis of Water Quality Correlations

Sample Information	**Precipitation**	**1-hr max intensity**	**Antecedent Dry Time**
Date Collected	**(cm)**	**cm/hr**	**(days)**
10/27/2003	8.23	0.84	4.36
11/6/2003	2.46	0.46	4.09
11/18/2003	4.67	1.96	2.23
12/10/2003	3.81	0.74	1.05
2/3/2004	1.91	0.58	11.86
2/6/2004	5.46	0.97	2.58
3/9/2004	1.55	0.46	0.74
3/16/2004	3.35	0.74	6.48
3/30/2004	1.96	0.58	3.35
4/1/2004	0.58	0.48	1.06
4/13/2004	6.93	0.69	2.41
4/26/2004	3.91	0.56	1.47
5/4/2004	2.57	0.69	4.44
5/19/2004	1.30	0.56	2.48
6/5/2004	1.47	0.20	1.98
6/11/2004	0.86	0.36	4.61
6/15/2004	1.93	1.07	3.15
7/12/2004	10.16	2.13	4.06
7/18/2004	2.39	0.48	3.08
7/28/2004	9.88	3.43	3.56
9/27/2004	18.03	3.99	9.31
10/19/2004	1.96	0.66	3.14
11/12/2004	3.68	0.33	7.41
12/1/2004	2.44	0.61	0.13
12/7/2004	4.52	0.41	5.73
2/14/2005	3.53	0.43	4.15
3/23/2005	2.69	0.51	2.35
3/29/2005	4.06	0.38	3.81
	Precipitation	**1-hr max intensity**	**Antecedent Dry Time**
	(cm)	**cm/hr**	**(days)**
Average	4.15	0.90	3.75
Maximum	18.03	3.99	11.86
Minimum	0.58	0.20	0.13
Median	3.02	0.58	3.25
Stdev	3.69	0.90	2.57
N	28	28	28

E.4: Multivariable Regression Analysis of Water Quality and Water Quantity Data.

E.4.1: Total Phosphorous and Month, Total Precipitation, Peak 1-hour Intensity and Antecedent Dry Time.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.827
R Square	0.685
Adjusted R Square	0.601
Standard Error	0.246
Observations	20

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	1.971	0.493	8.145	0.001
Residual	15	0.908	0.061		
Total	19	2.879			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.040	0.143	0.279	0.784	-0.266	0.346	-0.266	0.346
Month	0.029	0.018	1.619	0.126	-0.009	0.068	-0.009	0.068
Precipitation	0.017	0.036	0.461	0.651	-0.061	0.094	-0.061	0.094
1-hr max intensity	0.149	0.132	1.128	0.277	-0.132	0.430	-0.132	0.430
Antecedent Dry Time	0.044	0.033	1.338	0.201	-0.026	0.114	-0.026	0.114

E.4.2: Nitrite and Month, Total Precipitation, Peak 1-hour Intensity and Antecedent Dry Time

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.974
R Square	0.948
Adjusted R Square	0.740
Standard Error	0.042
Observations	6

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	4	0.032	0.008	4.551	0.336
Residual	1	0.002	0.002		
Total	5	0.034			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.002	0.228	-0.009	0.994	-2.898	2.894	-2.898	2.894
Month	-0.020	0.006	-3.560	0.174	-0.092	0.052	-0.092	0.052
Precipitation	-0.071	0.037	-1.911	0.307	-0.543	0.401	-0.543	0.401
1-hr max intensity	0.869	0.488	1.780	0.326	-5.337	7.076	-5.337	7.076
Antecedent Dry Time	0.048	0.028	1.737	0.333	-0.302	0.398	-0.302	0.398

E.4.3: Dissolved Copper and Month, Total Precipitation, Peak 1-hour Intensity and Antecedent Dry Time

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.790
R Square	0.624
Adjusted R Square	0.436
Standard Error	4.831
Observations	13

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	4	309.622	77.405	3.317	0.070
Residual	8	186.676	23.334		
Total	12	496.297			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-1.725	3.164	-0.545	0.601	-9.021	5.572	-9.021	5.572
Month	0.759	0.341	2.223	0.057	-0.028	1.546	-0.028	1.546
Precipitation	0.957	0.929	1.031	0.333	-1.184	3.099	-1.184	3.099
1-hr max intensity	-0.606	3.263	-0.186	0.857	-8.130	6.918	-8.130	6.918
Antecedent Dry Time	-0.191	0.886	-0.216	0.834	-2.234	1.851	-2.234	1.851

E.4.4: Dissolved Lead and Month, Total Precipitation, Peak 1-hour Intensity and Antecedent Dry Time

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.891
R Square	0.794
Adjusted R Square	0.382
Standard Error	0.965
Observations	7

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	4	7.171	1.793	1.927	0.370
Residual	2	1.861	0.930		
Total	6	9.032			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.598	0.999	0.599	0.610	-3.701	4.898	-3.701	4.898
Month	-0.094	0.090	-1.048	0.405	-0.483	0.294	-0.483	0.294
Precipitation	0.256	0.761	0.336	0.769	-3.020	3.532	-3.020	3.532
1-hr max intensity	-0.297	2.720	-0.109	0.923	-12.001	11.407	-12.001	11.407
Time Factor	0.020	0.331	0.059	0.958	-1.404	1.443	-1.404	1.443

E.4.5: Dissolved Chromium and Month, Total Precipitation, Peak 1-hour Intensity and Antecedent Dry Time

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.905
R Square	0.819
Adjusted R Square	0.456
Standard Error	2.692
Observations	7

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	65.411	16.353	2.257	0.330
Residual	2	14.493	7.247		
Total	6	79.905			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.051	2.789	0.018	0.987	-11.951	12.052	-11.951	12.052
Month	0.179	0.252	0.712	0.551	-0.904	1.262	-0.904	1.262
Precipitation	-4.128	2.125	-1.942	0.192	-13.270	5.015	-13.270	5.015
1-hr max intensity	14.153	7.592	1.864	0.203	-18.513	46.819	-18.513	46.819
Time Factor	2.284	0.924	2.473	0.132	-1.690	6.258	-1.690	6.258

E.4.6: Dissolved Zinc and Month, Total Precipitation, Peak 1-hour Intensity and Antecedent Dry Time

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.98
R Square	0.97
Adjusted R Square	0.90
Standard Error	13.66
Observations	7

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	11161.51	2790.38	14.96	0.06
Residual	2	373.04	186.52		
Total	6	11534.55			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-12.65	14.15	-0.89	0.47	-73.54	48.23	-73.54	48.23
Month	7.21	1.28	5.64	0.03	1.71	12.70	1.71	12.70
Precipitation	33.19	10.78	3.08	0.09	-13.19	79.58	-13.19	79.58
1-hr max intensity	-94.20	38.52	-2.45	0.13	-259.92	71.53	-259.92	71.53
Time Factor	-17.68	4.69	-3.77	0.06	-37.84	2.48	-37.84	2.48