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WATER QUALITY STUDY OF A POROUS CONCRETE INFILTRATION BEST MANAGEMENT PRACTICE

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Abstract

A porous concrete infiltration basin best management practice was installed on the campus of Villanova University, located in Villanova Pennsylvania, in August of 2002. The system consists of porous concrete and three infiltration/storage beds filled with coarse aggregate wrapped in a geotextile filter fabric, underlain by undisturbed sandy silt. The infiltration rate at the site has been observed at an average order of magnitude of 10^{-4} cm/sec. The drainage area (5,210 m^2) primarily consists of grassy surfaces (36%), standard concrete/asphalt (30%), and roof surfaces (30%) that connect directly to the infiltration beds via downspouts and storm sewers.

The chemical performance of the site is the focus of the study. Water samples were collected at various locations using a number of different methods. Composite samples of infiltrated stormwater were collected using soil moisture suction devices. Discrete samples were collected from a port within an infiltration bed and a downspout from a roof surface to gain perspective on cover specific stormwater characteristics. Samples were analyzed for pH, conductivity, and concentrations of suspended solids, dissolved solids, chloride, copper, total phosphorous, total nitrogen, nitrite, and nitrate.

A total of 31 storms were sampled. Acidic runoff was found to be neutralized through contact with the limestone aggregate in the infiltration/storage beds. Copper concentrated stormwater was generated by copper components on the roof, often above drinking water standard levels; however, it was found to be removed from the runoff in the first 0.3 m (1 ft) of soil. Chloride contents increased dramatically as a result of deicing practices and were not reduced by infiltration, but did show signs of some attenuation. Nutrients do not present any concerns in this particular system.

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Chapter 1: Overview

1.1 Introduction

Urbanization and the resulting increase in urban stormwater over the past few decades have led to an increase in runoff and pollution. This increase directly affects the surrounding rivers and streams, with impacts such as increased stream bank erosion, decreased water quality, and decreased base flow as areas become less and less pervious. Studies show this increase in urban stormwater runoff is a leading contributor of non-point source pollution in urban areas (Paul and Meyer, 2001). Such discoveries have led to a demand for innovative practices that will discourage future stream degradation and help deal with, and possibly reverse, some of the damage already done. This demand is becoming more recognized, and as a result, such technologies are emerging.

Many of these technologies are emerging in the form of best management practices (BMPs). BMPs use innovative processes to help minimize adverse effects of urbanization. One of the problems with BMPs is the lack of documented research displaying their effectiveness, especially stormwater infiltration BMPs. The National Stormwater Best Management Practice Database has taken the first steps in dealing with this issue and is pioneering the way in collecting and reviewing numerous documented uses of BMPs (http://www.bmpdatabase.org/). The database is broken into two categories, structural and non-structural. The non-structural BMP database contains a total of 28 BMPs consisting solely of maintenance practice type BMPs. The structural component totals 170 BMPs ranging from biofilters to detention basins to hydrodynamic devices. Of the 170 structural BMPs contained in the database, only five document test sites that utilized porous pavement. Furthermore, within this group of five, only one of these test sites used a concrete-based porous pavement. The need for further documented research using porous concrete BMPs is evident. There is also a need for research concerning the water quality aspect of infiltration BMPs. The assumption has been that infiltration equals treatment; however, there is a deficiency in supporting evidence and, as a result, there is a need for further research.

Villanova University voluntarily retrofitted an existing paved area on campus with an infiltration BMP. The site functions as a demonstration and research project. Now a United States Environmental Protection Agency National Monitoring Site, it will provide important data on both the water quality and water quantity aspects of this type of BMP.

1.2 Site Description

The porous concrete site is located on the campus of Villanova University in South Eastern Pennsylvania. Specifically, the site is situated in a small pedestrian area between two dormitories, Sheehan and Sullivan Hall. Figure 1 depicts the site location.

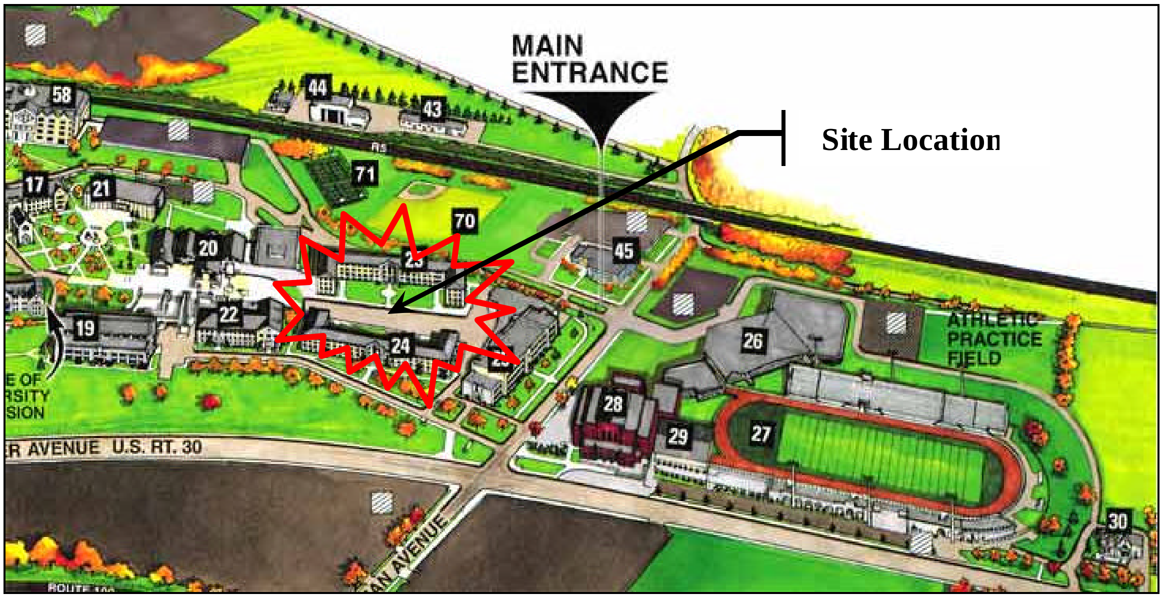


Figure 1. Porous concrete infiltration BMP site location map

The site is located at the headwaters of the Mill Creek watershed. As such, it is important to maintain the health of these waters. Any damage imparted at this point will similarly deteriorate the waters that follow.

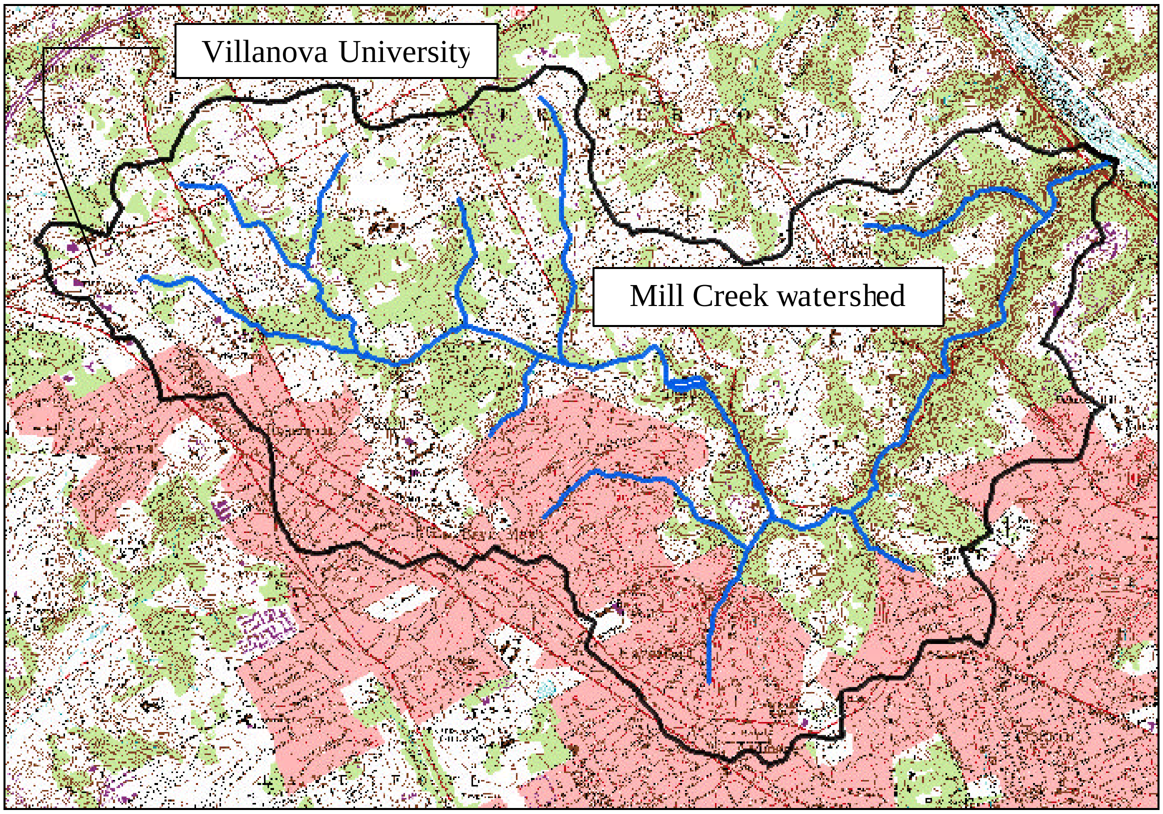


Figure 2. Site location with respect to Mill Creek watershed

Prior to retrofitting the site with the BMP, the area consisted primarily of a very light traffic road/walking path, several concrete walkways, two dormitories, and assorted grass areas. The general layout of the pervious surfaces within the drainage basin remained the same following the retrofit; however, some were altered. The impervious surfaces on the site were crowned to direct runoff toward the porous concrete (concrete walkways) or, in some cases, directly connected to infiltration beds through a system of pipes, as is the case for the roof tops. Figure 3 shows the site prior to, and following, the retrofit.

Figure 3. Pre (left) and post (right) construction photograph of the porous concrete site

Table 1 breaks down the different surface covers into the respective total areas in which they cover with the BMP in place. Based on the totals, the site is 60% impervious. Impervious surfaces alter the characteristics of the surface runoff at the site during rain events. The goal is to return the site to predevelopment hydrologic conditions by retrofitting the site with the BMP.

Table 1. Post-construction surface cover areas

Surface Cover	Porous Concrete	Standard Concrete/ Asphalt	Grass/ Multch Beds	Roof	Total Area	% Impervious
Area (m^2)	217	1529	1887	1576	5208	60

1.3 Porous Concrete Infiltration BMP

The porous concrete site implements a porous concrete infiltration best management practice. The construction of the porous concrete infiltration BMP will ideally mitigate any negative impacts of the initial development of the site. As a best management practice, the goal is to return the developed area back to its predevelopment characteristics from a hydrologic standpoint. Both water quality and water quantity are of interest.

The BMP uses porous concrete in combination with infiltration beds. The porous concrete acts as a means of transmitting stormwater from the surface to the infiltration beds. Porous concrete is comprised of ingredients very similar to that of standard concrete. In porous concrete, the fine-grained aggregate is removed, leaving only coarse aggregate, water, and cement. With no fines in the mix, void space is created resulting in a porous material.

The area composed of porous concrete at the site is highlighted in Figure 4. The tremendous porosity of the material made it necessary to convert only a small fraction of the area to porous concrete to attain the desired infiltration. The typical impervious concrete that made up the remaining walking area is crowned such that the runoff will be directed to the porous material.

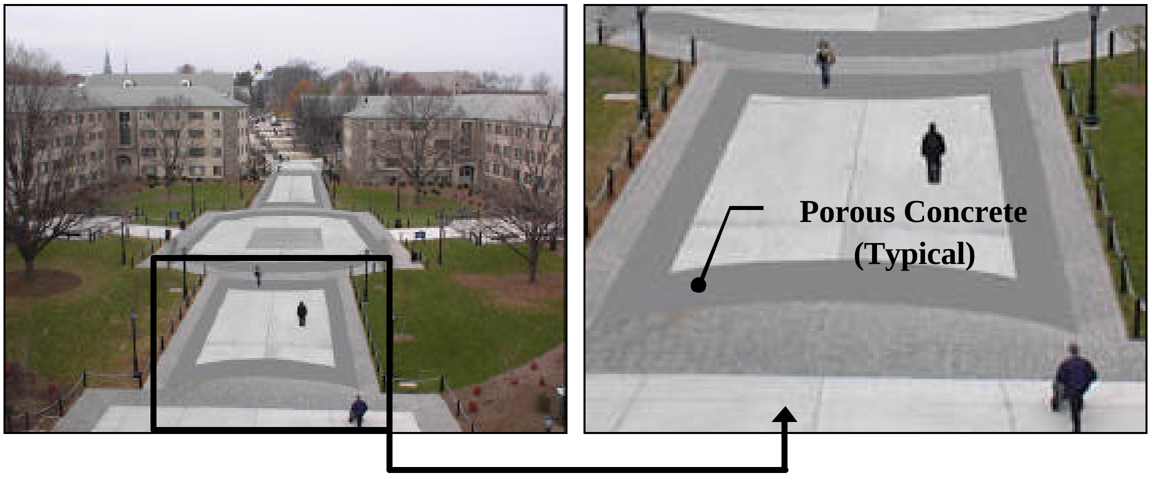


Figure 4. Porous concrete BMP highlighting the porous concrete (dark grey color)

The water passes directly through the porous concrete almost immediately after reaching it. Figure 5 illustrates the ability of the material to convey the water. Once through the porous concrete, the runoff enters one of three infiltration beds, identified in

Figure 6 as the upper, middle and lower bed. The size of each individual bed can be estimated by the dark grey border surrounding the light grey area for the upper, middle, and lower beds, respectively.

Figure 5. Illustration of the ability of porous concrete to convey water

Figure 6. Infiltration bed locations during and after construction

Each of the beds are approximately 1.2 m (4 ft) deep and filled with 5 - 10 cm (2 - 4 in) diameter clean AASHTO #2 storage media. The aggregate produces a void space of ~40% within the infiltration beds allowing for quick percolation to the soil layer beneath. The void space also allows for some storage during events where the infiltration rate is slower than the rate of stormwater runoff inflow. The individual infiltration beds are connected to one another via perforated high density polyethylene (HDPE) pipes to distribute stormwater throughout the system and maximize the infiltration area.

At the base of the infiltration beds, beneath the stone layer, a geotextile is in place. The geotextile serves as a filter prohibiting the upward migration of fines into the infiltration beds. Allowing the fines to migrate upward could eventually lead to a decrease in void space within the beds and alter the effectiveness of the system from a water quantity perspective.

Undisturbed soil, classified as a silty sand (SM) by the Unified Soil Classification System (USCS), lies at the base of the system. During construction, care was taken not to track over the location of the infiltration beds with the excavation equipment to avoid compaction of the soil, which could reduce the infiltration rate of the soil. Figure 7 shows the infiltration beds during construction.

Figure 7. Photographs of infiltration beds during construction

Once runoff enters the infiltration beds, it infiltrates, temporarily resides in the void space of the bed, or exits the beds via perforated HDPE pipes, depending on the amount of runoff present in the infiltration basins. When the infiltration beds are empty, the runoff begins to infiltrate immediately. However, during a storm event, the rate of infiltration may be exceeded by the high rate at which runoff is entering the beds. As a result, the beds will begin to fill. This is the case particularly in larger, more intense events. Perforated HDPE pipes were installed near the top of the lower infiltration bed to prevent runoff from flowing up and out of the porous concrete if the capacity of the infiltration beds was exceeded. Once the beds fill to the elevation of the overflow pipes, the water enters the pipes and flows to an existing storm sewer system.

1.4 Construction

The initial construction of the site occurred during August 2002. The original design consisted of three large porous surfaces bordered with decorative pavers as shown in Figure 8. Unfortunately, the surface of the porous concrete failed shortly after the completion of construction. The failure was caused by a number of elements, the most significant being a lack of understanding of the impact the porous concrete material properties had on construction practice. At the time of construction, this site was the first to use this material in the region. Considerable knowledge was gained in the initial construction, which would be used in the reconstruction of the surface.

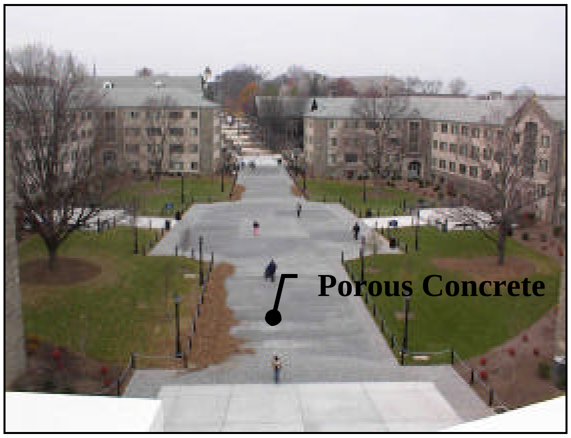


Figure 8. Illustration of completed initial site construction

Due to the surface failure, the porous concrete site was redesigned and resurfaced in the spring of 2003, incorporating the lessons learned from the original construction and information from visits to other sites (Traver et al., 2003). Interestingly, despite the poor cosmetic appearance of the failed porous concrete surface, review of initial data and field observations suggested the original site had more than enough porous concrete surface. As a result, it was determined the porous area could be reduced without affecting the site's performance.

The new design was altered to include narrow strips of porous concrete around the perimeter of each bed with conventional concrete replacing the porous concrete in the middle as illustrated in Figure 9. The pavers would remain along the perimeter. The conventional impervious concrete in the middle was crowned to promote drainage towards the porous strips along the perimeter. The excellent ability of the porous concrete to transmit water suggested it could handle runoff from areas in addition to that occurring on the porous concrete surface itself.

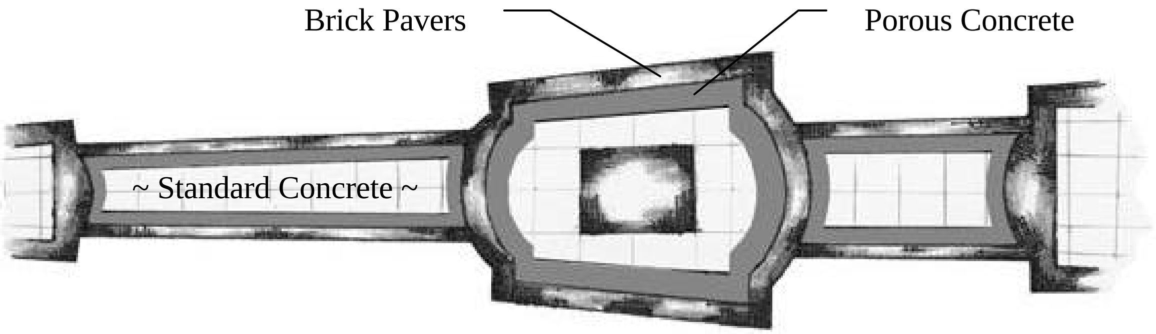


Figure 9. Illustration of new surface design

It appeared as if the second attempt would be successful until the onset of the winter of 2003/2004 and the associated snow/ice events. The events have taken a toll on the porous concrete surface once again. Slowly, small areas began to deteriorate. The surface of the porous concrete is once again flaking, as evidenced by the loose gravel. Current speculation suggests freeze thaw may be responsible for the deterioration; however, no solid conclusions have been drawn. Despite poor esthetic appearance, the porous concrete is still functioning. Plans are in place to resurface the site in the summer of 2004. The details of these plans are in the process of being determined.

1.5 Research Objectives

The objective of this study is to determine the effectiveness of the porous concrete BMP from a water quality perspective. In particular, water samples from various locations will be tested for copper, nutrients, chloride, total and suspended solids, and conventional parameters including pH and conductivity. Composite samples collected from soil water samplers buried beneath an infiltration bed will be compared with samples taken from a soil water sampler outside of the infiltration beds, samples taken from combined runoff collected within the infiltration beds, as well as samples taken directly from rooftop downspouts.

The primary goal is to determine the effect of the infiltration of stormwater for this particular site and possibly gain some knowledge of the quality of runoff originating from the impervious surfaces of a residential and light commercial site. Specifically, the ability of the soil to retain and/or treat contaminants produced from the various impervious surfaces will be examined. Furthermore, information on the quality of the runoff contributed by the various impervious surfaces will be assessed. Finally, it should be noted a companion thesis (Ladd, 2004) investigates and documents the effectiveness of the porous concrete BMP from a water quantity perspective.

Chapter 2: Literature Review

2.1 Introduction

The purpose of the porous concrete infiltration site is to capture and infiltrate the runoff created by the impervious surfaces resulting from the development of the site. Of concern are the potential impacts of infiltrating this runoff. The location of the site and characteristics of traffic do not immediately suggest any reason for alarm when considering infiltrating the runoff; however, there have been relatively few studies proving there should be no concern. In fact, some suggest there is a great reason to be concerned and that contamination of stormwater is highly dependent on the specific site. The sections to follow are a review of select prior studies on stormwater runoff quality as well as the potential impacts of infiltrating stormwater.

2.2 Runoff Quality

It is important to fully understand the elements that combine to make up stormwater runoff. From a water quality perspective, the origin of the runoff helps determine the type and potential for contamination. This becomes increasingly important when considering the runoff is to be infiltrated. Pollution of subsurface elements is no solution to surface pollution.

2.2.1 Roof Runoff Composition and Quality

Zorbist et al. (1999) challenged the assumption that roof runoff can be considered non-polluted stormwater using a field study in Switzerland. Prior to recent changes, a unitary drainage concept was in place in Switzerland that required all waters arising from human activities be conveyed to a wastewater treatment plant via this unitary drainage system. This included sewage, street and roof runoff, and seepage water. Infiltration of these waters was prohibited. A number of reasons, such as high costs and system overload, led to a revision of the water protection law, which now prohibits discharge of non-polluted wastewater into the public sewers. This led to debate over what was to be considered an admissible level of pollutants to be considered non-polluted wastewater.

Runoff from roofs became a center of attention. "With respect to its pollutants, roof runoff is generally considered as non-polluted, or at least not significantly polluted, compared to waste waters and highway runoff, since it consists of rainwater flowing over various, in general less abrasive materials, such as tiles, bitumen, less corrosive metals and concrete" (Zobrist et al., 1999). Their study attempts to prove or disprove this widely held assumption with a field study.

Three different roof types, in combination with selected drainage materials, were used in the study representing the majority of the buildings in Switzerland. Each roof was equipped with devices that enabled the capture of the first liter of runoff with further capture at varying pre-set volumes of discharged water. The testing program included the following parameters: alkalinity (Alk); chloride (Cl), nitrate (NO_3) and sulphate (SO_4); ammonium (NH_4); total nitrogen (N) and total phosphorus (P); suspended particular matter (SS); total and dissolved organic carbon; total calcium (Ca), magnesium (Mg) and sodium (Na); total and dissolved copper (Cu), zinc (Zn), lead (Pb), chromium (Cr), cadmium (Cd), manganese (Mn) and iron (Fe); pH; triazines, acetamides and phenoxy acids.

Table 2. Characteristics of roof studied (Zobrist et al., 1999)

Type of roof (cover material)	Area (m^2)	Inclination (^{o})	Material drainage system
Tile (clay)	115.9	28	Copper (~15 years old)
Plyester	109.2	5.6	Copper (new)
Gravel	134	0	PVC

The results showed that the majority of the constituents such as major ions, nutrients, heavy metals and pesticides appeared in high concentrations in the first few minutes of runoff and exponentially decreased with increasing time or runoff depth until it had leveled off. This supports the first-flush effect which is common when matter deposited on the roof during the preceding dry period is washed off by falling rain; weathering and corrosion products of the roof cover and drainage system are washed off; and concentrations in falling rain itself are decreasing with increasing rainfall depth due to scavenging of particles, aerosols and gases by rain droplets (Zinder et al., 1988). Values of 5.3 to 6.2 for pH were recorded for roof runoff during rain events. Lead and iron on the iron and polyester roof runoff appeared predominantly in particulate form, whereas Cu, Zn, Cd, Mn, and Cr occurred mostly in dissolved form. For the polyester roof, the particulate/dissolved ratio remained the same throughout the event whereas this ratio decreased for the tile roof. The gravel roof runoff exhibited the highest percentage of the dissolved fraction of heavy metals.

The tile and polyester roofs, and respective drains, in particular were found to be sources of a number of the elements for which they were testing. Most notably was that of copper. The metal parts that were exposed to the atmosphere were weathered and the products were washed off by the rainwater. The roof also acted as a source of other parameters including Alk, SS, Mn_{tot}, Pb_{tot}, and Fe_{tot}. The gravel roof performed differently. The weathered gravel produced significant amounts of Ca and Alk. The gravel roof also retained most heavy metals and phosphorus, but not copper. Interestingly, the roof supported nitrification, as observed from the transformation of NH_4 to NO_3. For pesticides, significant retention was noted for the gravel roof, minor retention by the tile roof, and none for the polyester roof.

The quality of runoff may decrease depending on the materials used for roof cover and drainage systems. Roofs releasing large quantities of pollutants run the risk of impairing the water quality of receiving waters. A local quality problem in receiving waters could emerge as a result of those constituents for which the roof system acts like a conveyor.

2.2.2 Patterns of Roof Runoff

Environmental issues when assessing an urban hydrologic setting should not be ignored when considering roof runoff. Approximately half of the total runoff volume from impermeable surfaces in an urban setting can be attributed to roof surfaces in industrialized countries. Control of pollution from these surfaces consequently is as important as the need to control the runoff volumes. Uncertainty is abound as literature in the past have deemed roof runoff as unpolluted to severely polluted (Forseter, 1996).

Forester (1996) described a study where the runoff was analyzed from several different roof types, ranging from copper and zinc metal to a fibrous cement roof to concrete tiling. Samples were taken at close intervals at the beginning of the storm and steadily increasing intervals were used as the rainfall depth increased. Each was tested for organic micropollutants, heavy metals, and sum parameters.

The organic trace pollutants and sum parameters that were analyzed included 2,4-dinitrophenol, 2,4-dinitro-6-methylphenol, 3-methyl-4-nitrophenol, suspended solids, electric conductivity, DOC, 4-NP, and γ-HCH. The results of the testing indicated that the roofs all contributed to the pollution of the runoff. The results were highly variable both from one storm to the next for the same parameter and for varying roof types for the same parameter. Those that were deemed to be contributing to the pollution were shown to have concentrations of a particular parameter in the resulting runoff higher than that of the concentration of that parameter in the associated rain event. The pollutants were added to the runoff by wash off of substances dry deposited to the roof surface before the precipitation event or by dissolution of the roof material itself due to weathering. Pollutographs, or runoff profiles, clearly revealed the first flush concept, where concentrations of the pollutants were several orders of magnitude higher in the first part of the storm and decreased in a negative exponential curve and leveled out as the runoff depth increased.

The pH of the rainwater was lower, or more acidic, than the runoff from all of the varying roof types. Some roofs produce slightly more alkaline runoff due to the influence of dissolution of the roof material itself, such as for the concrete tiles. The results for electrical conductivity were similar in that the rainwater had a lower conductivity than that of the various roofs.

The analysis of metals, in particular zinc and copper, revealed that the more of this metal present on the roof, the greater the opportunity there is for heavy metal contamination. The concentrations of heavy metals on the metal roofs were many orders of magnitude higher than the concrete tile roof. Of interest was a comparison of three pantile roofs of varying ages. Two had been in use for some time, and one had just recently been constructed. A comparison of copper concentrations for the roofs showed the new roof had much higher dissolved and particulate copper concentrations revealing the early effects of the weathering of the copper sheets.

2.2.3 First Flush Effect

The first flush phenomenon is best described by a significantly higher concentration of a particular contaminant occurring at the start of a storm event as compared to the concentration later in the event and at the end. Although not as prevalent in larger drainage basins, smaller drainage basins appear to show this trend. The following sections are studies that investigate first flush with respect to various parameters and settings.

2.2.3.1 Urban

Deletic (1998) discusses the treatment of urban surface runoff and conducts an investigation on the concept and nature of the first flush load of pollution into drainage systems. A controversial subject, the first flush concept has had numerous studies supporting and refuting its existence. There are several different aspects that need to be considered for the first flush concept as there can be various contributing components of urban storm runoff. These include rainwater, roof runoff, surface runoff, discharge into separate or combined systems, and flow of receiving waters. The first flush phenomenon has been observed in roof runoff (e.g. Forster, 1996 and Zorbist et al., 2000).

Two urban asphalt catchments, one in Yugoslavia and one in Sweden, were monitored for suspended solids, conductivity, pH, and temperature. Both catchments were of similar area, slope and traffic patterns. The catchments were approximately

250m^2 in size and received medium traffic. Equipment was placed within the inlet that served the area that was capable of making and recording measurements over the course of the storm events. Recording was triggered by one tip of the rain gauge followed by ten second interval measurement and recording.

First flush was defined as “the percentage of total event pollution load transported by the first 20% of storm runoff volume” (Deletic, 1998). A first flush value significantly exceeding 20% justified a first flush concept being present in the event. A distinctive first flush effect for suspended solids was not observed at either of the two sites. During a couple of the larger events at the catchment in Yugoslavia, the first flush effect was noticeable, but inconsistent enough to be discredited. No such tendency was observed at the catchment in Sweden, possibly due to an additional small inflow from a nearby grass area not previously noticed. The first flush of conductivity was not present at either of the catchments; however, the larger events again began to show signs of first flush. First flush was not discovered at any level for either pH or temperature (Deletic, 1998).

Finally, Deletic (1998) concluded that if, at the end of a drainage system, a strong first flush effect is observed, it is unlikely the cause is first flush input into the system. Rather Deletic (1998) suggests the cause may be some sort of pollutant transformation in the actual drainage system. It was clear from the study that typically there is sufficient pollution on the surface to continually wash off during a rain event, thus first flush is more likely to occur in large, intense events. These events tend to quickly rinse off and flush out the pollution that may be present, rather than steadily removing the pollution as would a smaller less intense storm.

2.2.3.2 Industrial

Industrial sites have not been the focus of very many studies concerning the quality of the runoff leaving these sites. It is important to characterize discharge from all sites so that pollution control plans may be developed. “In the National Water Quality Inventory, 1990 Report to Congress, states estimated that approximately 30% of identified cases of water quality impairment are attributable to stormwater discharge” (Line, 1997; U.S. EPA, 1992).

A sampling program described by Line (1997) involved assessing the quality of first flush water runoff from ten industrial groups located in North Carolina. The industrial groups included chemical repackaging, furniture manufacturer, junkyard, landfill, metal fabricator, paint manufacturer, scrap and recycler, textile manufacturer, vehicle maintenance, and wood preserver. A number of constituents were measured in the runoff. Metals included arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc. Conventional parameters were also measured including biological oxygen demand, chemical oxygen demand, and various forms of nitrogen, phosphorus, and solids (Line, 1997).

Zinc was found to have the highest metal concentration at all of the industrial sites. Copper and lead were also found to be prevalent. In general, higher levels of metals were found at sites storing exposed metal or wood containing metal based compounds. Runoff from wood preservers had high concentrations of arsenic, chromium, and copper, likely due to the use of these metals in the preserving process. Interestingly, the junkyards, which had the highest level of exposed metal, did not contain the highest level of metals. This proves that there are more factors that go into determining metal concentration in runoff than the amount of metal exposed. Factors such as rust, cut metal surfaces, and hydrologic transport efficiency all have an effect. Finally, industrial sites where consumer products were actually stored on site or processed on site tended to have higher levels of biological oxygen demand, chemical oxygen demand, and nitrogen concentrations.

2.3 Impacts of Runoff Infiltration

The runoff from urban and industrialized areas resulting from impervious surfaces such as paved streets and parking areas or roof tops has been shown to be contaminated at varying levels (e.g. Zobrist et al., 1999; Forster, 1996; Deletic, 1998; and Line, 1997). The question remains, however, what should be done with this contaminated runoff. Sewer systems are not capable, in most cases, of dealing with the frequent high quantities produced (Zorbist et al., 1999). The water quality of receiving waters is diminished where this contaminated runoff is deposited. Infiltration has consequently become a consideration where natural processes may have a chance to cleanse the runoff. The impacts of such a practice are not well documented to date. This section is a summary of a selection of the available articles and the conclusions drawn from the studies.

2.3.1 Roof Runoff

The goal of a study described by Mason et al. (1999) was to evaluate the behavior of roof runoff constituents during infiltration through soil. An infiltration pit was designed and equipped with the monitoring equipment. “Heavy metals were of particular interest because of their potential toxic effects on groundwater used for drinking water, while infiltration of nutrients could increase bacterial growth and development of anoxic conditions” (Mason et al., 1999).

Transport of metals in soils is governed by a number of factors. Physical and chemical soil properties, pH, and redox conditions all play a role. Metals may be retained in soils by adsorption reactions on the surfaces of soil minerals and organic matter and by precipitation reactions. Microbial processes can change redox potential, soil pH, and CO_2 concentrations which can result in the mobilization or immobilization of heavy metals (Mason et al., 1999).

The site specific soil conditions are important to note when attempting to understand the behavior of the metals when infiltrated. The top soil layer at the site consisted of a 5 - 15 cm layer of organic rich material mixed with medium sized stones. A 2.9 m layer followed consisting of clay, sandy gravel with some small stones and gravel-silt soil material. From 2.9 m to 15 m, there was a layer of quaternary glacial-fluvial washout. The groundwater level was at approximately 12 m deep with the potential to rise to 6.5 m in flood events. Carbonate was contained within the unsaturated zone with a small clay content, but high specific surface area. The soils at the site were under oxic conditions and drinking water from the site was drawn from the aquifer in a nearby well (Mason et al., 1999).

The behavior of the metals was monitored at three locations within the soil profile; the top soil layer, 1 m, and 1.6 m deep. Metal concentrations in the top soil layer were much lower than the concentrations in the lower layers. This indicates the metals were able to migrate downward into the unsaturated zone. The lower concentrations are believed to be a result of dilution of percolating runoff by direct rainfall as well as uneven distribution of the infiltration pit with existing preferential flow paths. Two types of behavior were identified in the unsaturated zone for the metals. The first dealt with copper, cadmium and chromium. Concentrations increased and decreased with the increase and decrease of inflow concentrations. In other words, these metals were only partially retained by the soil and significant amounts were transported through the unsaturated zone remaining mobile. The second type of behavior was observed for zinc and lead. Concentrations of infiltrated water decreased rapidly despite steady high concentrations of inflow. This indicates at least short term immobilization and retention of the metals (Mason et al., 1999).

A long term study of the site revealed heavy metal accumulation in the soil. During the first four months of operation at the site, all concentrations of metals except chromium increased in the top layer. In a period of sixteen months, the concentration of zinc, lead, and copper were found to have increased two-fold at a depth of 1 m with chromium decreasing in concentration over the same time period and cadmium not changing much. Soil profiles revealed the concentrations to be unevenly distributed throughout the soil layer with higher concentrations in the deeper layers; however, sixteen months later, the metals were found to be evenly distributed throughout the soil layers. The results showed that chromium was the most mobile of the metals and copper, zinc, and lead were slower.

The concentration of chloride, sulfate, nitrate, and SRP in the lysimeters at all depths followed the concentration fluctuations of those components in the roof top runoff. This indicates a lack of an efficient retention time or mechanism. Chloride and sulfide in particular were observed with this behavior and thus were considered by Mason et al. (1999) as internal tracers. Dissolved organic carbon exhibited similar behavior. Ammonium concentrations were found to decrease with depth. The highest concentrations were found in the shallow soils and the lowest concentrations were found in the deepest lysimeter. The decrease can be attributed to nitrification taking place in the soil with possibly some adsorption of ammonium on to negatively charged material by ionic interaction (Mason et al., 1999).

Mason et al. (1999) conclude that the artificial infiltration of roof runoff for this site was inadequately designed. Specifically, there was insufficient retention of heavy metals and nutrients. Too little contact time between the infiltrating roof runoff water and the top soil layer resulted from strong preferential flow paths and immediate percolation. Artificial infiltration is seen by Mason et al. (1999) to have its advantages from a groundwater recharge respect; however, it is felt that the probability of increased groundwater contamination needs to be considered.

A study described by Barraud et al. (1999) attempts to assess the potential impacts of the infiltration of stormwater that is likely to contain high levels of contaminants using two catchments located in France. Specifically, the experiment involved measuring quantitative and qualitative inflow over a ten-month period and evaluating the effectiveness of the catchments in capturing pollutants. Both infiltration facilities were located on the same street serving identical catchment areas consisting of classical urban type habitat with one road receiving heavy traffic of approximately 7,000 vehicles per day. One of the catchments had just recently been constructed and the other had been in operation for approximately thirty years, offering a great point for comparison and analysis of long-term potential impacts.

Little information was provided on the soil characteristics of the soakaways. Both, however, were three meters deep. The aquifer was found to have a low hydraulic gradient with constant flow. The hydraulic conductivity (K) of the alluvia within the aquifer was 10^{-2} m/s (Barraud et al., 1999).

Two approaches were used for the experiment. The first approach involved measuring pollutant transfer during each event by monitoring the inflow and groundwater concentrations. The second approach sought out long-term impacts. This was achieved by measuring pollutant accumulation at the bottom of the facilities at the beginning and end of the test phase. The flow rates entering the infiltration pits as well as the rates of infiltration within the pits were measured. The local groundwater level was also continuously monitored using a series of piezometers (Barraud et al., 1999).

The following parameters were measured for the runoff water quality aspect of the study: conductivity, pH, nitrates, total nitrogen, zinc, lead, cadmium, chemical oxygen demand (COD), total organic carbon (TOC), suspended solids, and mineral oil. All pollutants were found to be in the typical ranges for runoff from similar areas. Great variation was noted in the concentrations of suspended solids, lead, and zinc from one storm to the next. Table 3 lists the results.

Table 3. Runoff-water quality at soakaway entry (Barroaud et al., 1999)

Parameter	Min	Max	Mean	Standard Deviation
Conductivity (μS/cm)	54	110	74.4	17.4
pH	6.7	7.7	7.1	0.3
Nitrates (NO3 (mg/l)	2	4	2.75	0.66
N total (mg/l)	1.2	3.6	2.23	0.86
Zn (μg/l)	64	5700	802.4	1851
Pb (μg/l)	<	692	97.75	225
Cd (μg/l)	<5	<5	<5	<5
COD (mg/l)	15	123	77.13	29.83
TOC (mg/l)	0.7	45	20.46	15.2
SS (mg/l)	4	130	44.62	36.73
Mineral oil (μg/l)	<	270	110.12	72

The effect of the newer soakaway on the runoff for one particular storm can be seen in Table 4. The organic pollution, specifically COD, TOC, and TKN, were all found at high levels similar to entry concentration levels. This suggests a lack of retention, which is not uncharacteristic, as most soluble organic matter cannot be purified out except via a non-saturated area, which was not present for the most part in these installations (Barraud et al., 1999). Metals acted slightly differently. Lead and zinc concentrations increased during rain events. This suggests that some fraction of the metals were transported past the soakaway floor barrier and some retention did occur.

Table 4. Groundwater analyses during the rainfall (Barraud et al., 1999)

Parameter	Runoff water at soakaway entry (01/10/96)	Groundwater under dry weather conditions (mean value)	Groundwater druing the rainfall downstream from newer soakaway	
			1:15 PM	3:20 PM
Conductivity (µS/cm)	54	675	179	123
pH	7	7.4	7.4	8.2
Nitrates (NO_3 (mg/l)	3	59	13	4
TKN (mg/l)	1.2	<1	1.2	1.4
Zn (µg/l)	5700		90	50
Pb (µg/l)	45	0 to 8	8	13
Cd (µg/l)	<5	<5	<5	<5
COD (mg/l)	63	0	42	27
TOC (mg/l)	8.7	0.9	21.2	3.5

Metal and hydrocarbon concentrations were found to be very high in the first few centimeters from the surface, but dropping significantly with increasing depth to a low level. This was more the case for the newer soakaway than for the older. Barraud et al. (1999) believe in the long term, thirty years or more, “heavy metals and mineral oils can contaminate the soil over a radius of at least one meter around installations, with concentrations significantly higher than for control soil” (Barraud et al., 1999). Consequently, pollution can be spread over time.

In conclusion, the groundwater impact was determined to be low. Heavy metal concentrations did increase indicating retention is less than total when the depth of non-saturated soil is around 40 cm. Finer soil combined with a deeper water table was suggested as a possibility for providing more favorable conditions for purification (Barraud et al., 1999).

2.3.2 Risk of Pollution

Mikkelsen et al. (1997) addressed the concern for soil and groundwater pollution in light of increased use of infiltration as an alternative to conventional sewer systems for treating contaminated stormwater. Typically, infiltration systems are not designed with pollution control in mind. Consequently, there is a risk of polluting subsurface soils and groundwater. Mikkelsen et al. (1997) aim to determine whether this practice will lead to unacceptable levels of contamination.

Two study sites were used in Switzerland, site A and B. Calcareous gravel deposits characterize both sites soils. The groundwater was extremely deep and used extensively for drinking water production. Site A had a mixture of residential and light industrial areas with some agriculture. At the time of the study, traffic densities of 37,000 vehicles per day were counted on the stretch of road from which runoff flows through pipes onto a grassy area along the roadside. Infiltration took place in the available depressions and, in extreme events, a nearby farmland. Site B is dominated by city environment and by a waste incineration plant 1200 m away. Traffic density was recorded at 2,300 vehicles per day. All runoff from this site traveled to three meter deep infiltration shafts. No pretreatment took place on either site (Mikkelsen et al., 1997).

Heavy metals that were measured in the study include chromium, cobalt, nickel, copper, zinc, cadmium, and lead. Polyaromatic hydrocarbons (PAH) and the content of adsorbed organically bound halogen (AOX) were also measured. Both areas influenced by the runoff and areas not influenced by the runoff were analyzed for comparison purposes (Mikkelsen et al., 1997).

Figure 10 shows a summary of the findings at both site A and B. Site A is a surface infiltration system. The various total concentrations and exchangeable concentration correlate well with the soil characteristics. It is necessary to better define the soil profile to fully understand the phenomenon occurring in the soils with respect to the various concentrations. At the top of the profile is a black silty sand layer resulting from sediment washed off the road surface and deposited on top of the sub-base gravel layer that extends laterally several meters away from the roadside. The soil characteristics and resulting concentrations appear to peak at this layer. An old plough layer, identified as a compressed and humic layer, resides approximately 2 m under the sub-base gravel. Similar to the layer created by runoff deposits, the soil characteristics and concentration peak at this point. Both of these layers have high levels of fine content and organic matter. The other layers are composed of mainly particles larger than 2 mm (Mikkelsen et al., 1997).

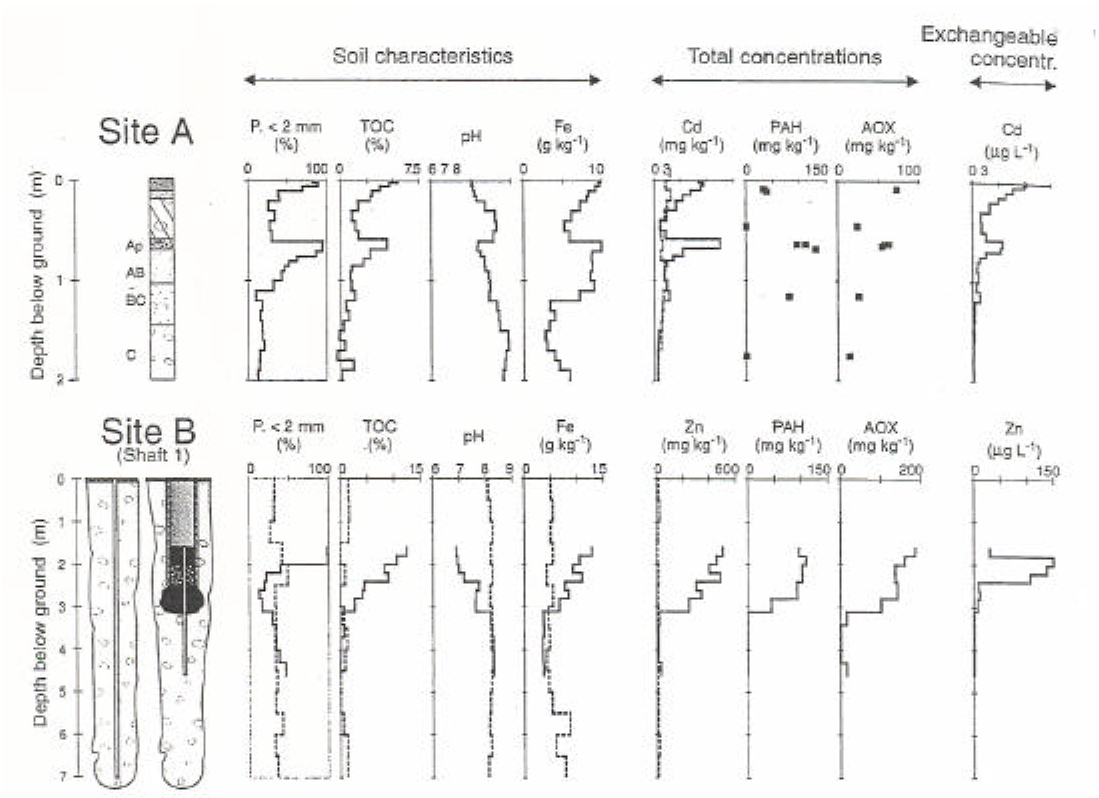


Figure 10. Verticlal profiles showing the depth distribution of selected soil characteristics and pollutant parameters inside the infiltration systems (solid line) and background levels (dashed line). (Mikkelsen et al., 1997)

The uppermost layer and the old plough layer contain high values of both total and exchangeable metal concentrations, and those concentrations decrease rapidly with depth thereafter for site A. This was the case for Cd, PAH and AOX.. For Cu, Zn, Cd, and Pb, the concentrations were two to three times the concentrations expected for typical roadside runoff sludge. For Cr, Co, and Ni, similar patterns were not found (Mikkelsen et al., 1997).

At site B, similar trends can be observed in Figure 10. Again, the soil profile merits a more detailed description. The infiltration shafts primarily consisted of coarse stone gravel. At the base of the shafts, a layer of pebbles was present which had, over the course of the many years of operation, accumulated a silty black sludge, likely the result of runoff deposits. Some shafts appeared to have a natural humic layer at the base of the shafts intertwined with the pebbles. The total concentrations in Figure 10 are closely connected with this sludge layer, with low concentrations in the layers to follow. Chromium, cobalt and nickel were generally low (Mikkelsen et al., 1997).

Significant build-up of Cu, Zn, Cd, Pb, PAH and AOX in the sludge layers, which play a role as a pollutant source and sorbent, results from infiltration of contaminated runoff from a large area in a concentrated area. There was not a significant build up of Cr and Co. Consequently, Mikkelsen et al. (1997) do not believe they pose environmental problems. Indications are that the leaching of metals is limited and it is believed that groundwater contamination is of little practical concern. Similar conclusions were drawn for PAH's and the constituents in the AOX analysis. "Infiltration systems evidently act as effective pollutant traps for these types of contaminants" (Mikkelsen et al., 1997).

Blaszczyk (1997) summarizes the key points of a process taken in Poland to change the law to allow infiltration of stormwater runoff into soils. It was necessary to determine whether stormwater from various types of urban surfaces such as roof top, streets and parking lots could be infiltrated without adverse impacts on the soils and groundwater.

Runoff from tar-paper, sheet-metal, and clay tile roofs as well as downtown streets and municipal parking lots were used for the study. The effects of infiltration were analyzed for a sandy soil with good permeability, thick sandy clay with limited permeability, and grass turf planted on topsoil. The characterization of the stormwater quality was based on a comparison to water quality indicators for Class II rivers and sewage effluents discharged to surface waters or disposed on soils. The indicators included suspended solids, nitrates, phosphates, biochemical oxygen demand, chemical oxygen demand, and lead (Blaszczyk, 1997).

The results of the study indicated that quality of roof runoff for all roof materials studied met the set requirements. Consequently, it was determined that infiltration of this sort of runoff should be permitted. With respect to heavily contaminated streets and parking lots, the study found that this runoff was clean enough to be infiltrated only if pretreated to remove suspended solids prior to infiltration. Where pretreatment is not possible, Blaszczyk (1997) suggests that runoff be directed into conventional sewer systems to be treated at a treatment plant.

2.3.3 Advantages and Disadvantages

Mikkelsen et al. (1996) discuss the advantages and disadvantages of infiltration as an alternative to discharging stormwater to conventional pipe sewers. The focus of the paper is to review the recent developments and highlight problems that still remain. A significant part of the study presented in the paper addresses the risk of contaminating soil and groundwater by infiltration of stormwater. Comparisons are made with respect to the reduction and abatement of pollution discharge to detention basins.

Priority pollutants in relation to urban stormwater infiltration are addressed in the paper. “Direct comparison of typical concentration levels in stormwater runoff with drinking water quality criteria readily reveals that nitrogen (N) and phosporus (P) is of little concern” (Mikkelsen et al., 1996). Mikkelsen et al. (1996) claim metals also appear not to be a great threat if a large degree of attachment to particles is considered.

However, river water quality standards and targets for groundwater quality must be considered beyond just using drinking water standards. Surprisingly, highly soluble compounds, which happen to be of greatest risk to groundwater pollution, have been researched the least. Road salts are provided as an example (Mikkelsen et al., 1996).

Experimental evidence from field studies assessing the groundwater quality below and downstream from an infiltration system may hold answers to some of the doubts associated with these types of systems. In several studies that have been conducted, “no significant increased levels of priority pollutants, including selected heavy metals and trace organics, were found in the groundwater” (Mikkelsen et al., 1996). It is noted that this conclusion may be premature in that the absence of visible effects may be attributed to limited time of operation as well as the possibility of significant dilution with groundwater prior to sampling.

Soil sampling has also permitted the drawing of some conclusions. In particular, these systems have been found to act as effective pollutant traps with respect to heavy metals. Again, the short term nature of these studies appears to be the downfall as uncertainty creeps in when predicting long term potential for leaching of highly contaminated soils (Mikkelsen et al., 1996).

Infiltration basins need to first be seen as a means of sustainable control of stormwater contaminants before there will be general acceptance of this practice. Contamination of surface soils needs to be addressed as well. For example, Mikkelsen et al. (1996) points out an estimate made showing up to 75% of the total mass load of copper in a Swiss city would end up in farmland from sludge application, river sediments, or urban soils. If it is determined that infiltration is an effective means of capturing this pollutant, acceptance will be gained. Once several such assessments are made for other contaminants, the use of infiltration basins will be well on the way.

2.3.4 Porous Pavement Infiltration Basin BMP

In a study very similar to this particular study, Swisher (2002) evaluated a porous pavement parking lot. The hydraulic performance and chemical characteristics of the infiltrating water were of interest. In particular, the potential to contaminate the groundwater and the tendency of the infiltrating water to dissolve underlying limestone were of concern (Swisher, 2002).

A control lot was used for comparison purposes. Results of the study showed that the quality of stormwater from the control lot was very similar to that of the porous pavement lot. This was anticipated due similarities with respect to the impervious surfaces at each of the sites; roof drains and parking lot surfaces.

Stormwater runoff samples were collected and tested for a number of different parameters from the various impervious surfaces and inside the infiltration beds. One of the key points of interest in the study dealt with the aggressiveness of the stormwater with respect to the dilution of calcium carbonate. Located in a karst topography area, infiltration of stormwater is generally unacceptable due to the potential sinkhole formation. Analysis of the results showed that the stormwater from the infiltration beds was only slightly aggressive. The larger the amount of time the stormwater remained in the infiltration beds, the greater this aggressiveness was reduced. The reduction was attributed to contact with the limestone aggregate in the infiltration beds (Swisher, 2002).

Toxic metals were also monitored in the study. Concentrations were found to be relatively low. Mass loading rates were determined and found to be significantly lower than rates permitted in associated regulations. Additionally, literature showing the ability of soil to remove metals such as lead, zinc, and copper were provided. Swisher (2002) concluded the risk of contaminating the groundwater with these particular heavy metals was extremely low compared to traditional forms of stormwater management, where contaminated stormwater is discharged directly into surface water.

It was determined that there were only small amounts of organic material in the stormwater in the infiltration bed based on low chemical oxygen demand values. Swisher (2002) believes "there is little potential for petroleum hydrocarbon contamination of groundwater from the normal use of the porous parking lots". Literature was also cited that indicates petroleum products would be biologically degraded in the infiltration bed. Finally, it was noted that micro-organisms were observed in the infiltration bed indicating the existence of an ecosystem.

Chapter 3: Methods

3.1 Introduction

The purpose of this section is to familiarize the reader with the test methods and setup involved in the collection of data. The water quality portion of the study will be described at depth with respect to the instrumentation and test procedures. The chapter will conclude with a brief description of the soil tests and a section describing the test method and setup for soil moisture reflectometer devices.

3.2 Water Quality

Water quality is a crucial component of any infiltration BMP. The contributing watershed for the porous concrete site does not present any apparent significant concerns for water quality; however, data supporting this assumption is necessary. The site was outfitted with a number of different instruments to enable the quality of the water to be monitored. The devices allow for the collection of samples, which are transported to a laboratory and analyzed for pH, conductivity, total suspended solids (TSS), total dissolved solids (TDS), chloride, total phosphorous, total nitrogen, nitrate, nitrite, and copper.

3.2.1 Sampling Methods

The water quality sampling was a storm-event based program. The sampling procedure was initiated for all storms forecasted with rainfall totals of 2.54 cm (1 in) or greater, and for selected smaller events based on availability. In winter, when deicing practices were required, the water quality procedure was initiated on all events possible. Table 5 is a summary of the storms that were sampled.

Table 5. Summary of storms sampled

Date	Precipitation (mm)	Precipitation (in.)	# of Lysimeter Samples	Port Sample	Downspout Sample	pH, Conductivity	SS, DS	Cl	Cu	Total N	NO_2, NO_3	Total P
03/20/03	46.2	1.82	4			X		X				
03/26/03	8.4	0.33	4			X		X				
03/31/03	15.2	0.60		X		X		X				
04/07/03	Trace		3			X		X	X			
04/09/03	Trace		4			X		X				
05/06/03	5.8	0.23	4			X		X		X		
05/08/03	16.8	0.66	4			X		X				X
06/03/03	47.5	1.87	4	X		X		X	X	X		X
06/18/03	25.1	0.99	4	X		X		X	X	X		X
06/21/03	80.5	3.17	4	X		X		X	X	X		X
09/02/03	45.2	1.78	5	X		X	X	X	X	X	X	X
09/05/03	┴	┴	5	X		X	X	X	X		X	
09/13/03	58.4	2.30	5	X		X	X	X	X	X	X	X
09/15/03	┴	┴	5	X		X	X		X	X		X
09/18/03	32.3	1.27	5	X	X	X	X		X	X		X
09/23/03	23.6	0.93	5	X	X	X	X	X	X	X	X	X
10/04/03	2.8	0.11	5		X	X	X	X	X	X	X	X
10/23/03	2.5	0.10	4		X	X	X	X	X	X	X	X
10/27/03	69.3	2.73	4	X	X	X	X	X	X	X	X	
10/29/03	34.5	1.36	4	X	X	X	X	X	X	X	X	X
11/06/03	19.8	0.78	4	X	X	X	X	X	X	X	X	X
11/19/03	41.7	1.64	4	X	X	X	X	X	X	X	X	X
12/08/03	39.6	1.56 (MIX)	4			X		X				
12/09/04	│	│	3			X		X				
12/11/04	┴	┴	4			X		X				
02/02/04	SNOW	SNOW	2			X		X	X	X	X	X
02/03/04	│	│	4			X		X	X	X	X	X
02/06/04	┴	┴	4	X	X	X	X	X	X	X	X	X
03/17/04	1.5	0.06	4		X	X	X	X	X	X		X
03/31/04	17.0	0.67	4	X		X	X	X	X	X		X
04/13/04	53.3	2.10	4	X	X	X	X	X	X	X		X

Three different sampling methods were utilized. They include (1) sampling of soil water from the vadose zone, (2) sampling of runoff from a rooftop downspout, and (3) sampling of runoff directly from an infiltration bed. A comparison of the results from these three areas will be used to evaluate the impact of infiltrating stormwater for this particular site. Furthermore, knowledge will be gained concerning the general quality of stormwater runoff from a small residential and light industrial watershed. This section will go into depth on each of the three different sampling methods used with respect to the instrumentation and collection procedures in the order previously listed.

3.2.1.1 Soil Water Sampling

According to the EPA (2002) Urban Stormwater BMP Performance Monitoring manual, "Proper sampling methods are essential in conducting a BMP monitoring program in order to ensure resulting data are meaningful and representative of the water and other media being processed by the BMP" (USEPA, 2002). For this application, eight Soilmoisture Equipment Corp. 1920F1 Pressure-Vacuum Soil Water Samplers, commonly referred to as lysimeters, have been installed at three different locations within the study area for the purpose of collecting samples of infiltrated stormwater runoff.

The installation process first involved coring holes for the devices using an AMS Signature Series 8.3 cm (3.25 in) auger. Each hole was cored to a predetermined depth. The soil from the hole was set aside for later use. The critical phase of installation involved the backfilling process. The holes were properly backfilled using silica slurry in combination with compacted on-site fill. The silica slurry ensured intimate contact with the porous ceramic cup on the lysimeters, which ensured water could move readily from the pores of the soil into the sampler. The slurry was made with U.S. Silica Company Sil-Co-Sil, mixed to a consistency similar to that of cement. Enough slurry was poured into the holes to cover the bottom of the hole at which point the lysimeters were inserted. The remaining mixture was poured into the hole to completely cover the ceramic cup. The slurry was given time to solidify at which point the hole was backfilled with soil that had been sifted using a #4 sieve (4.75 mm diameter) to remove pebbles and rocks. The soil was tamped during the backfill process to prevent any preferential flow paths. In some cases, the shallower bore holes were simply filled with the silica slurry. Figure 11 shows the lysimeters being installed.

Figure 11. Installation of soil water samplers

Two of the sampling locations are within the lower infiltration bed and one is outside the lower bed for base comparison purposes. The lysimeters within the lower infiltration bed are staggered at 0.3 m (1 ft), 0.6 m (2 ft) and 1.2 m (4 ft) depths beneath the base of the storage beds in the vadose zone. The location outside the bed has two lysimeters at depths of 2.4 m (8 ft) and 3 m (10 ft) beneath the surface. These depths correspond to the lysimeters located 0.3 and 0.6 meters below the storage beds. The locations in plan view can be seen in Figure 12. The lysimeters were used to collect samples of infiltrated stormwater runoff for water quality testing purposes.

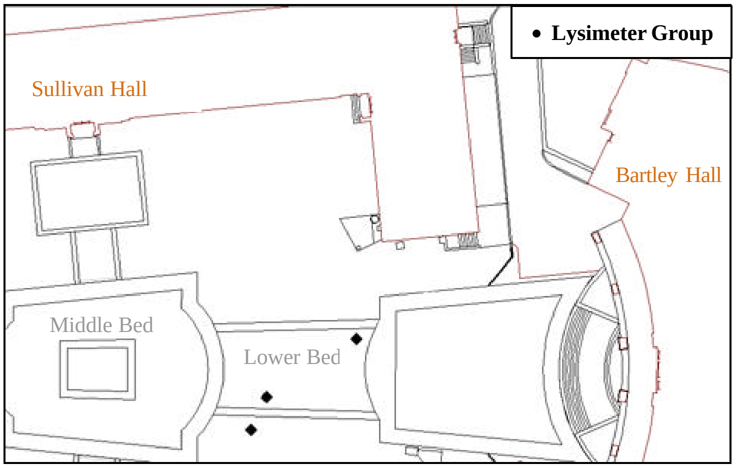


Figure 12. Soil water sampler (lysimeter) locations

The manual describes the Pressure-Vacuum Soil Water Samplers as follows. “The Pressure-Vacuum Soil Water Sampler is constructed of a 4.8 cm (1.9 in) O.D. PVC tube (made of FDA approved material) with a 2 bar porous ceramic cup bonded to one end…Two, 0.64 cm (0.25 in) O.D. polyethylene access tubes are used for pressurizing and recovering samples which are terminated in neoprene tubing. Clamping rings are used to clamp the neoprene to keep the Sampler under negative pressure” (Soil Moisture Equipment Corp., 2002).

The soil water sampler tubes are accessible via utility access boxes adjacent to the lower infiltration bed on either side. The tubes are labeled and mounted to a block of wood, which is affixed to the inside of the utility box. The wood is also labeled to denote the exact location and depth of each lysimeter. The tubing is color coded to indicate which tube is for pressurizing and which tube is for collecting samples. The access box is only opened during pressurization or extraction of samples. It is kept bolted shut at all other times to avoid possible tampering or damage from machinery or animals. Figure 13 illustrates the arrangement of the sampling tubes within the access box.

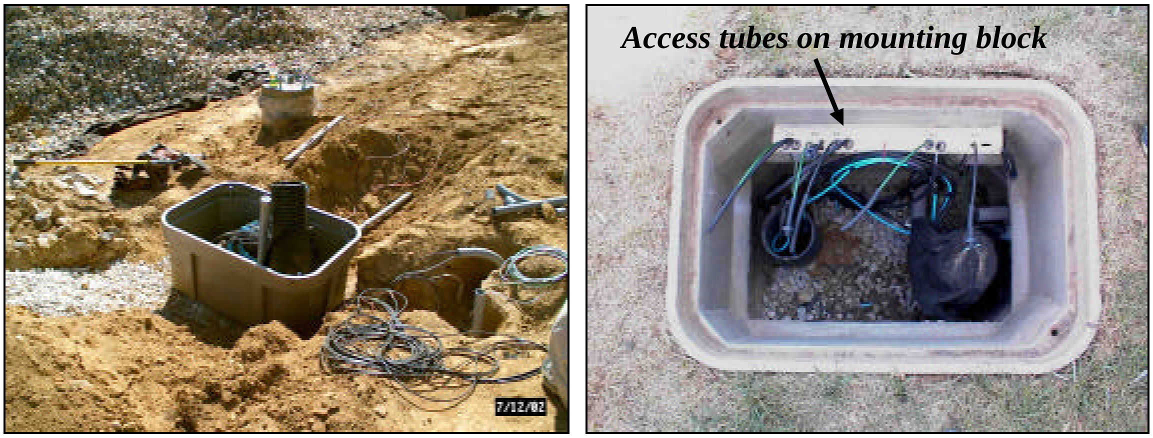


Figure 13. Access box during (left) and after construction (right)

Lysimeters work by overcoming soil water tension or negative pressure, which is created by capillary forces. These forces are the sum of the adhesive and cohesive forces. By creating a vacuum or negative pressure greater than the soil suction holding the water within the capillary spaces, a hydraulic gradient is established for the water to flow through the porous ceramic cup into the sampler. "The practical limit for water flow in soils is about 65 cb (9.4 psi), although in some soils, the value can approach 85 cb (12 psi)" (Soil Moisture Equipment Corp., 2002). A vacuum of 55 cb (8 psi) was used for this project based upon the soil type present, a silty sand (ML).

The water quality sampling was a storm-event based program. Suction was applied to the lysimeters and kept for a minimum period of 12 hours and a maximum of 24 hours. It was important that the resulting moisture front from the storm pass during this sampling window. This ensured that the sample was representative of the storm event. A simple procedure was developed for approximating the time to apply suction. Analysis of the soil moisture reflectometer data, discussed in depth in Chapter 4, revealed a lag time of approximately one hour from when the rainfall began to when the moisture front began to pass the lysimeters. It was determined the vacuum should be applied approximately one hour following the start of the storm event. This time was delayed in some cases to ensure the capture of the moisture front.

The sampling process involved applying a vacuum of approximately 55 cb (8 psi). The devices require approximately 12 to 24 hours to obtain the maximum volume of sample, 150 ml. The samples are composite samples in that they are more representative of an average concentration of the parameters over the course of the storm rather than discrete samples that could potentially change concentration over the course of the event from one sample to the next. To collect the sample, a positive pressure was applied to the lysimeter. This forced the sample out through the sample tube and into a properly prepared and clearly labeled sample container. The sample containers were labeled with the date, time, and lysimeter identification.

3.2.1.2 Downspout Sampling

Samples were also gathered using two other methods over the course of the storm. One of the methods involved sampling of runoff created by a portion of the rooftop. A roof downspout, which tied into an inlet and eventually led to the infiltration beds, was accessible for sample collection. At this location, stormwater runoff created by a portion of the impervious roof surface drained into a catch basin. Figure 14 shows the sampling location. Note the blue/green discoloration beneath the pipe in the inlet resulting from the copper concentrated roof runoff.

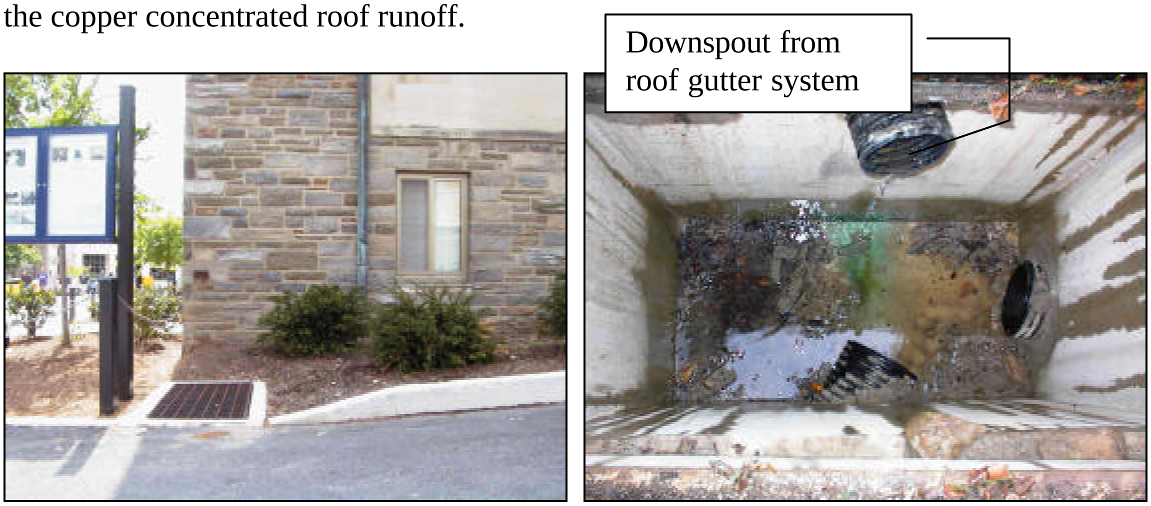


Figure 14. Photograph of downspout sampling location

Samples were collected manually at this location simply by holding a prepared and clearly labeled sample container beneath the downspout. This was possible as the downspout was elevated inside the catch basin significantly, allowing the stormwater to fall freely during a storm event. Samples were taken randomly throughout the storm;

however, an effort was made to catch the initial runoff resulting from the event. Multiple samples were taken during larger events.

3.2.1.3 Port Sampling

The final sampling method involved collecting samples from a port within the lower infiltration bed. Figure 15 shows the port prior to and following pouring the porous concrete. Prior to the retrofit, the port was a functioning inlet responsible for capturing runoff created by the impervious pedestrian traffic area.

Figure 15. Port prior to (left) and following (right) the installation of porous concrete

A special tool for gathering the samples from within the port was designed to allow more efficient sampling. The device is illustrated in Figure 16. It is used in combination with a Soil Moisture Equipment Corp. 2006G2 Pressure-Vacuum Hand Pump with Gauge (formerly 1920k1).

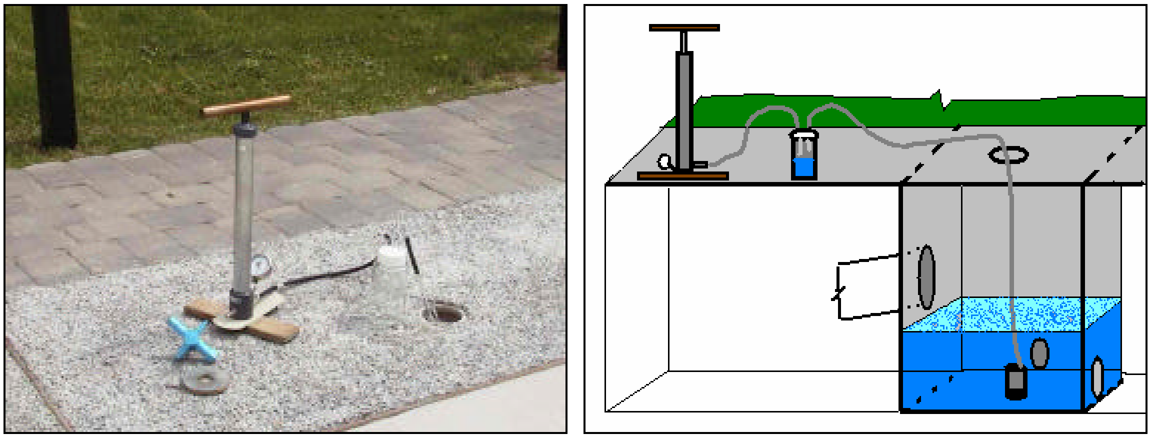


Figure 16. Port sampling device setup (left) and artistic rendering (right)

Applying a vacuum to the device draws a sample from the port through 0.64 cm (0.25 in) tubing and deposits it in a prepared bottle. The sampling end of the tube is enclosed in a hollowed metal weight, which holds the end of the tube at the bottom of the port and also filters out larger suspended material. Once the bottle was filled, the sample was poured out into a prepared and properly labeled sample container for transport back to the laboratory. Samples were collected in a random fashion throughout the duration of the storm event. Larger events tended to permit a larger number of samples to be collected.

3.2.1.4 Quality Control

All glassware and plastic ware used for collection, transportation, and laboratory analysis of the samples were acid-washed using the following procedure specified by the Hach DR/4000 Spectrophotometer Handbook. The glassware and plastic ware was first cleaned with a laboratory detergent and rinsed with tap water. Next, the container was rinsed in 1:1 hydrochloric acid solution. The container was then rinsed with deionized water three times and allowed to air dry.

The samples were analyzed immediately upon collection for most cases. However, in the event that the samples could not be analyzed promptly, a preservation plan was in place. Each of the tests had a specific method required to properly preserve the sample. Preservation methods included pH control, chemical addition, and refrigeration. Sample preservation was performed according to the Hach testing procedures. Table 6 is a summary of the specific preservation instructions as well as the maximum holding times until sample analysis. A quality assurance and quality control (QA/QC) document was developed for this project and complied with (Traver et al., 2003).

Table 6. Sample preservation summary

Parameter	Container Type	Preservation	Holding Time
pH	Plastic	store at 4^oC	24 hours
Conductivity	Plastic	store at 4^oC	24 hours
Chloride	Plastic	store at room temp.	28 days
Total Dissolved Solids	Plastic	store at 4^oC	24 hours
Total Suspended Solids	Plastic	store at 4^oC	24 hours
Nutrients			
Total Phosphorus	Plastic	H_2SO_4 to pH <2, store at 4^oC	28 days
Total Nitrogen	Plastic	H_2SO_4 to pH <2, store at 4^oC	28 days
Nitrate	Plastic	store at 4^oC	2 days
Nitrite	Plastic	store at 4^oC	2 days
Metals - Dissolved			
Copper	Plastic	HNO_3 to pH < 2, store at room temp.	6 months

3.2.2 Sample Handling and Custody

Similar sample handling and custody methods were in place for the three sampling methods previously discussed. With respect to the soil moisture sampling devices, samples were removed approximately 24 hours following the documented time of negative pressure application for a storm event. The samples were extracted into properly prepared and labeled sample containers. Figure 17 is an example of the labels used for the transport of sample containers. These containers were hand transported back to the laboratory for immediate analysis. Because the samples were not being sent to alternate sites for laboratory analysis, no packaging or shipment procedures were required. Concerning sampling of the downspouts and port, the same transportation, sample labeling, and custody specifications apply as described for the soil moisture samples.

Location: A12
Date: 03/01/03 **Time:** 9:00AM

Figure 17. Sample container label

Sample location nomenclature for all samples collected is translated as follows:

1st Digit –
A - South set of lysimeters
B – North set of lysimeters
I – Bed sampling port
O – Sample at outflow
G – Gutter downspout sample

2nd Digit – (A&B Only)
1 – Inside bed
2 – Outside bed

3rd Digit – (A&B Only)
1 – Shallow lysimeter (0.3m (1ft) below infiltration bed)
2 – Middle lysimeter (0.6m (2ft) below infiltration bed)
3 – Deep lysimeter (1.2m (4ft) below infiltration bed)

(Date / Time group will be used instead of 2nd and 3rd digit for I, O, and G samples)

3.2.3 Analytical Methods

This section will discuss the analytical methods for the various parameters of interest in the water quality study of the porous concrete infiltration site. Included in each subsection is a description of the test apparatus and overview, or reference to an overview, of the specific test procedures. The capabilities and limitations of the instruments and procedures are also discussed when merited.

3.2.3.1 pH and Conductivity

The Hach Company Sension156 Multiparameter meter was used to measure pH and conductivity. The Sension156 has a variety of modes to test for different parameters. For this study, the pH and conductivity modes were used. Both the pH and conductivity probes also measure temperature; however temperature was not being recorded for this project.

The Sension Model 51935-00 Gel-filled pH Electrode is a combined pH and temperature probe. The range of the electrode is 0 to 14 pH units. To prevent contamination of samples and ensure accurate readings the electrode was rinsed with deionized water and blotted dry between sample measurements.

The Hach Conductivity Probe Model 51935-00 is a combined conductivity and temperature probe. The range of the conductivity probe is 0.01 μS to 200 μS. The resolution of the multiparameter meter varies depending on the range of the sample being tested. Between 0.00 and 19.99 μS/cm, the resolution is 0.01 μS/cm. For conductivities between 20.0 and 199.9 μS/cm, the resolution is 0.1 μS/cm and 1 μS/cm between 200 and 1,999 μS/cm. For a range of 2.00 to 19.99 μS/cm, the resolution is 0.01 μS/cm and for the range 20.0 to 199.9 μS/cm, the resolution is 0.1 μS/cm. The accuracy while in conductivity mode is ± 0.5% of the range. Typically the samples for this project range from 300 μS/cm to 1,500 μS/cm. Again, between sample testing, the probe was rinsed with deionized water and blotted dry to ensure accurate readings.

3.2.3.2 Total Phosphorus, Total Nitrogen, Copper

The total phosphorus, total nitrogen, and copper tests were all conducted using the Hach DR/4000 Spectrophotometer. The parameters are listed in Table 7 with their respective test methods and associated Hach method number. The EPA approval verification is also listed.

Table 7. Spectrophotometer test table

Parameter	Test Method	Hach Method Number	EPA Approved
Nutrients			
Phosphorous - Total	PhosVer3 with acid persulfate digestion	8190	No
Nitrogen - Total	Persulfate digestion	10071	No
Metals - Dissolved			
Copper	Bicinchoninate	8506	Yes

Spectrophotometry is the measurement of the light absorbance of a sample. This absorbance can be related to various chemical parameters through the use of experimental procedures. The spectrophotometer's light source can be set to a wide range of wavelengths from the visible to the ultraviolet scale.

TenSette Pipets were used to make accurate measurements when performing tests using this apparatus. Both models 19700-01 (1 ml max) and 19700-10 (10 ml max) pipets were used depending on the volume of sample needed. For quality assurance purposes, the tip was replaced between uses to prevent cross-contamination between samples.

The dissolved copper spectrophotometric analysis was performed in square, glass, 2.54 cm (1 in) sample cells. The recommended cleaning and handling procedures were strictly followed to prevent interference from the glassware. Contact was avoided with the clear sides of the cells with fingers to avoid the possible creation of imperfections or smudges in the samples cells which could potentially cause unanticipated absorbance and inaccurate readings. The cells were wiped with a soft cloth to remove any smudges or inadvertent fingerprints. To avoid degradation or staining of the sample cells, they were emptied immediately following the analysis and were cleaned in between each use, as per Hach's instructions, to avoid degradation or staining. When not in use, the sample cells were stored in their boxes to protect them from damage.

The Total Nitrogen and Total Phosphorus spectrophotometric analyses were performed in manufacturer prepared digestion vials. Care was again taken not to touch the glass vials, which were handled by the plastic caps. The glass vials were also wiped with a soft cloth prior to analysis in the spectrophotometer as a precaution against inadvertent smudges or smears. The vials were not reusable and were disposed of as per the product's Material Safety Data Sheet (MSDS).

The Total Nitrogen and Total Phosphrous tests required the samples to undergo a digestion period at specific temperatures. The Hach COD Reactor Model 45600 was used to incubate the samples for the required times. The COD Reactor holds up to 25, 16 mm x 100 mm vials and is capable of sustaining temperatures up to 150 degrees Celsius with an accuracy of ± 2 degrees Celsius. A thermometer was used to verify the temperature.

3.2.3.3 Chloride, Nitrate, Nitrite, and Phosphate

Chloride, nitrate, nitrite, and phosphate were tested using a High Pressure Liquid Chromatograph (HPLC) / Ion Chromatograph (IC). In general, the machine works by injecting small amounts of sample into an anion exchange column where the various anions present are separated out. Once through the anion exchange column, they enter and are read by a conductivity detector. The determined conductivities are plotted and software is used to integrate the area underneath the peaks for the each individual anion. These areas are related back to calibration standards to determine the concentrations of the various parameters within each sample. Figure 18 is an example of a resulting chromatogram for a sample.

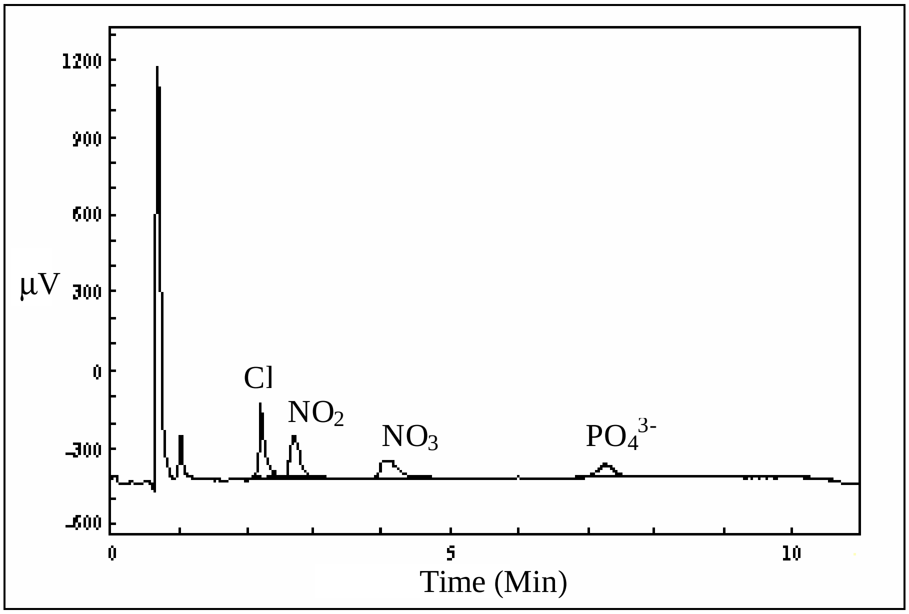


Figure 18. Sample chromatogram

The resulting peaks for chloride (Cl), nitrite (NO_2), nitrate (NO_3), and phosphate (PO_4^{3-}) are denoted on the plot. The areas beneath these peaks are integrated and related to the calibration standards, as described previously, to determine the concentrations. The chromatogram is specific to the column utilized. All tests were conducted with a Hamilton PRP-X110 column, using 2mM p-hydroxybenzoic acid with 2.5% MeOH eluent at a pH of 9.3.

3.2.3.4 Total Dissolved Solids (TDS) and Total Suspended Solids (TSS)

The Standard Methods procedure 2540C was followed for TDS analysis. A filter paper with a 1.5 micron pore size was utilized to filter out the suspended solids in the sample. The filtrate was then evaporated accordingly in pre-weighed and properly prepared evaporating dishes.

It was decided to test for TDS on only the samples collected from the downspout and port, not the lysimeter samples. According to Standards Methods, the filter paper pore size required to remove suspended solids is 1.5 microns. The pore size of the ceramic cup on the lysimeters is 1.3 microns. It is therefore unlikely that any suspended solids are present in these samples. Furthermore, the lysimeters are limited in the volume of sample they are capable of collecting. The volume collected from each lysimeter is typically around 150 ml. The TDS analysis would require the majority of that sample. With the volume of sample exhausted, the remaining tests could not be conducted due to lack of sample. The downspout and port locations produced ample volumes of sample; therefore, testing for the remaining parameters was feasible.

The Standard Methods procedure 2540D was followed for TSS analysis. Predetermined volumes of sample were filtered. Once again, TSS could not be performed on samples produced by the lysimeters due to a lack of sample. Relatively large amounts of sample were required for the test due to the good quality, or lack of suspended particles, in the samples produced by the downspout and port sampling locations. Once again, there were no real constraints on the volume of sample that could be collected at a given time for these to locations. As a result, using a larger volume of sample for this particular test did not inhibit the use of sample for alternate parameter testing.

3.3 Soil

Identifying some of the basic site specific soil properties is essential for proper monitoring of a BMP. Consequently, a number of tests were performed to gather some necessary information on various soil properties. A soil sample was collected from the lower infiltration bed during the excavation stage of the construction process. A sieve analysis and hydrometer test were performed to properly classify the soil. The Atterberg limits were also determined. A flexible wall hydraulic conductivity test was performed. To monitor the moisture content at the site at all times, soil moisture reflectometers were installed in the lower infiltration bed. Finally, a percolation test was performed at the site to determine an expected rate of infiltration. The procedures for test and setup of each of the soil tests mentioned above will be discussed briefly in the sections to follow.

3.3.1 Soil Classification

A soil sample was taken from the base of the lower infiltration bed during the excavation process and brought back to the lab for testing. The soil was classified according to the Unified Soil Classification System (USCS) (ASTM D-2487) by implementing grain-size analysis (ASTM D-422) and Atterberg limits (ASTM D-4318). All tests were conducted in accordance with American Society for Testing and Materials (ASTM) standards.

3.3.2 Flexible Wall Hydraulic Conductivity

To determine the hydraulic conductivity of the soil beneath the infiltration beds, a flexible wall hydraulic conductivity test (ASTM D-5084) was performed. An undisturbed sample was used for the test. The sample was collected using a hollow tube sampler at the end of an extended auger shaft. Because the sample was collected after the infiltration beds had been constructed, there was no way to get an undisturbed sample from directly beneath the beds. Consequently, it was decided to auger down to the same approximate depth parallel to the lower infiltration bed and take a sample there. Once the hollowed tube was forced into the undisturbed soil, the apparatus was removed and disassembled such that the tube containing the sample could be capped and brought back to the lab to be extruded and tested.

The inside diameter of the sample tube measured 4.5 cm (1.8 in). The pedestals being used for the flexible wall hydraulic conductivity test required the sample to be a slightly smaller diameter. As a result, the sample, once extruded, needed to be shaved down. Once this was complete, the sample was set up in the apparatus and tested following the procedure outlined in ASTM D-5084. Figure 19 is a photograph of the sample just prior to the test commencing.

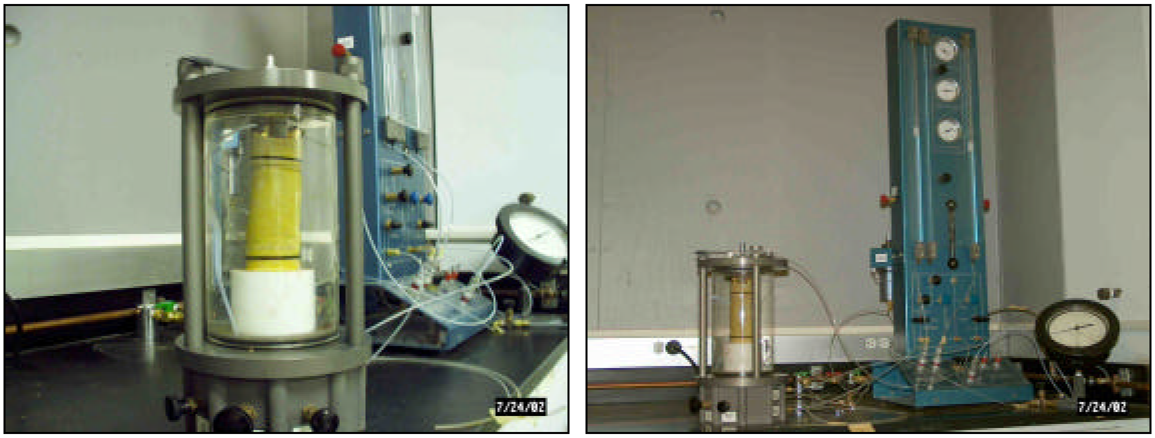


Figure 19. Flexible wall hydraulic conductivity test apparatus

3.3.3 Percolation Test

Prior to the start of construction, percolation tests were conducted at select locations within and outside the confines of what would soon become the infiltration beds to determine whether or not the soils on site were conducive for an infiltration BMP. The two locations, test pits one and two, are shown in Figure 20. Soil descriptions were also noted as the test pits were excavated to the desired depth. Test pit #1 was excavated to a depth of 0.9 m (3 ft) and test pit #2 was excavated to 1.2 m (4 ft).

Figure 20. Illustration of percolation test pit (left) and test pit locations (right)

The percolation tests were conducted by Cahill Associates. The test involved filling a small hole with water to a known elevation and recording the drop in elevation, over a period of time for several time increments, as the water infiltrated. Figure 20 shows a percolation test in progress (left) and the locations of the two percolation test pits with relation to Bartley Hall (right). Results of the percolation tests are discussed in Chapter 4.

3.3.4 Soil Suction Test

The soil suction, or soil potential of the soil beneath the infiltration beds, was determined following the guidelines provided by ASTM D 5298-94 for the test setup and procedure for the filter paper method. The test was conducted to gather information that may be useful in future studies analyzing unsaturated flow characteristics at the site. Unsaturated flow dominates the conditions at the site due to the extreme depth of the water table.

Due to the limitation of the means to collect undisturbed samples at the site, attempting to gather the number of undisturbed samples required for the test would have proven extremely difficult and time consuming. As a result, it was decided that molding samples to match site conditions would be an accurate and more efficient means to run the test.

The samples were molded at a range of moisture contents. Specifically, the goal was to have the samples at 5, 10, 13, 16, 20 and 25% gravimetric moisture content. To get the samples at these moisture contents, specific amounts of water had to be added to each of the soil samples. The large batch of soil being used in for the test was assumed to have an approximate water content of 2%. Calculations were performed to determine the necessary volume of water to be added to a predetermined mass of soil using the formula $W = W_w/W_s$, where W is gravimetric water content, W_W is the weight of the water, and W_S is the weight of the soil. The water was added to the soil and mixed manually.

To mold the samples, the soil was compacted to match the in-situ dry density of the soil beneath the infiltration beds, 1.60 g/cm^3 (100 pcf). The samples were compacted in a 3.2 cm (1.25 in) mold using two layers with scarification in between layers to insure continuity of the sample. The proper density was achieved by compacting a specific mass of soil at known water content into a known volume. Once all of the samples were prepared at the various moisture contents, the testing commenced following ASTM D 5298-94. The results of the test are presented and discussed in Chapter 4.

3.4.5 In-situ Density

The in-situ density of the soil beneath the infiltration beds was determined for future reference in the event a test was being conducted that required samples to be as close as possible to in-situ soil conditions. Ideally, the density would have been determined immediately following the excavation of the infiltration beds during the construction process. This did not occur. Consequently, the test was performed on the soil just outside the infiltration beds at the location shown in Figure 21.

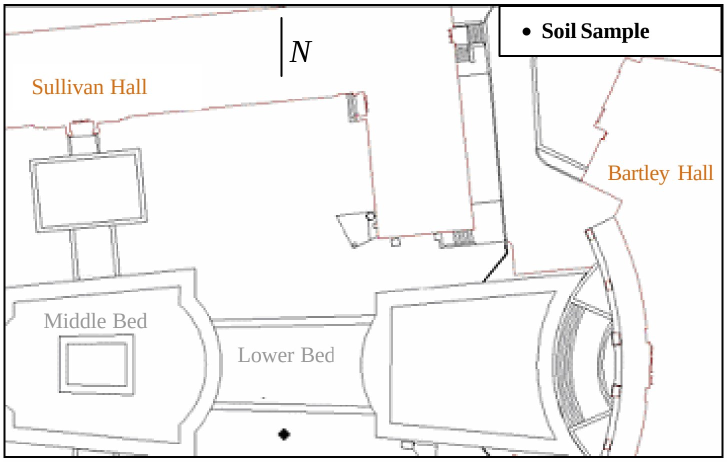


Figure 21. Sampling location for in-situ density determination

The soil sampling process involved using a hand auger initially, to bore down to an elevation just outside the lower infiltration bed that would coincide with the elevation of interest within the lower infiltration bed. It was determined that this sample location would most closely represent the conditions of interest beneath the infiltration bed. Once the proper depth was reached, all loose soil was carefully removed from the bore hole such that the bottom of the bore hole remained undisturbed. A thin-walled sampling tube of known volume 246 cm^3 (15 in^3) was then pressed firmly into the base of the bore hole until refusal and removed with an undisturbed sample within the sampling tube. The sampling tube was capped and brought back to the lab for immediate analysis. Once at the lab, the weight of the undisturbed sample and moisture content were determined. The density was then calculated based on the information collected.

3.4.6 In-situ Water Content

In-situ monitoring of the infiltration process is an important component of the soil study. Twelve Campbell Scientific CS616 Water Content Reflectometers were used to monitor the passing moisture fronts as the infiltrating runoff changed the soil moisture content. The reflectometers measure the volumetric water content of the surrounding soil. A CS CR23X Micrologger was used to power the instruments, and collect and store data. A CS NL100 Network Link Interface connects the Logger to the Villanova network. The instrument locations are summarized in Figure 22.

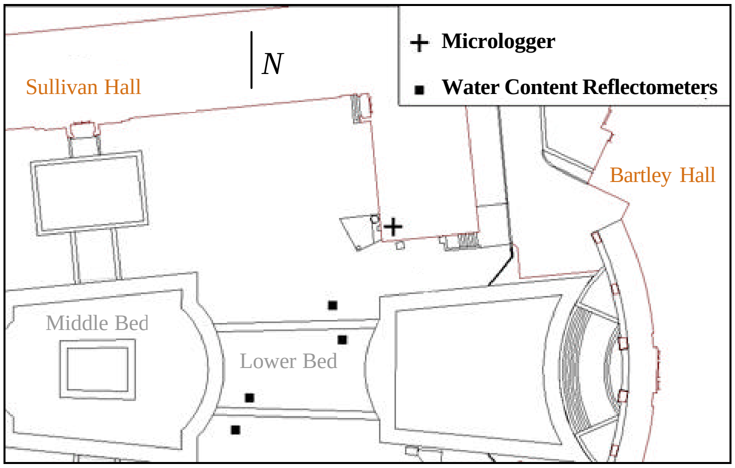


Figure 22. Layout of water content reflectometer groups

3.4.6.1 Equipment Installation

The Campbell Scientific CS616 Water Content Reflectometers were installed in groups of three, at four locations as shown in Figure 22. Two groups were placed outside of the lower infiltration bed on opposing sides to serve as control values. The two remaining groups were placed underneath the lower infiltration bed at the southwest and northeast corners. The CS616s were placed at depths of 0.3 m (1 ft), 0.6 m (2 ft), and 1.2 m (4 ft) relative to the undisturbed soil at the bottom of the lower infiltration bed. The

Campbell Scientific Model 14383 Installation Tool and Model 14384 Pilot Tool were used to properly install the probes. The 14383 Installation Tool was used as a guide to keep the probe rods parallel and aligned as they entered the soil wall. The 14384 Pilot Tool was used in conjunction with the installation guide before the CS616's were inserted to create holes in the soil wall that were of the proper depth and diameter. The Pilot Tool was then removed and the CS616's were inserted into the holes ensuring proper installation. Figure 23 shows the probes during the installation process, prior to backfilling.

Figure 23. Installation of CS616's

3.4.6.2 Instrument Description

The CS616 Water Content Reflectometer is comprised of two, 30 cm (11.8 in.) long, stainless steel rods attached to a printed circuit board. The circuit board is encased in epoxy and connected to a shielded four-conductor cable. The cable is run through a 3.8 cm (1.5 in) diameter electrical conduit into the basement of Sullivan Hall. The cable is connected to the Micrologger using the wiring scheme in Table 8.

Table 8. CS616 wiring scheme

Color	Function	Micrologger Connection
Red	Power (+12 V)	12 V
Green	Output	Single ended analog channel
Black	Output ground	Ground
Orange	Enable	Control port
Clear	Shield/Power ground	Ground

The printed circuit board is designed to function as a bi-stable multi-vibrator. The output signal created by the vibrator is directed down the probe rods which act as a guide. The time it takes the signal to travel down the rods depends on the dielectric permittivity of the material surrounding them. Water is the only soil constituent that has both a high value for dielectric permittivity and is the only component other than air that changes in concentration. Therefore the CS616's sensitivity to the dielectric permittivity can be used to measure soil volumetric water content. The Campbell Scientific CS616 Water Content Reflectometer Instruction Manual details the specifics of the CS616 operation as follows.

> Electromagnetic pulses will propagate along a transmission line (the probe rod) at a velocity dependent on the dielectric constant of the material surrounding the line. As dielectric constant increases the propagation velocity decreases. The travel time of the applied signal determines the output period of the CS616. The CS616 circuit generates a high-speed pulse that is applied to the probe rods. This electromagnetic pulse travels the length of the rods and is reflected back to the source. A part of the circuit detects the reflection and triggers the next pulse. Subsequently, this pulse travels the rod length and returns to trigger another pulse. The frequency of the applied pulse is monitored by a scaling circuit which reduces the frequency to the response range of a datalogger. The final output of the probe is a square wave with amplitude ± 0.7 volts and frequency dependent on dielectric constant, or water content (Campbell Scientific, 2002).

"Instruction 138" is a special Micrologger instruction that was developed specifically for the CS616. Instruction 138 measures the output period of the CS616 in microseconds. The output period is then converted into volumetric water content. The Edlog program enables the probes every 5 minutes and the Micrologger takes a reading. Every 15 minutes the Micrologger is programmed to average the last three readings and record the averaged value. The Micrologger then stores the values.

3.4.6.3 Calibration

The CS616 Water Content Reflectometer period was converted to a volumetric water content measurement by “Instruction 55”. The instruction uses a quadratic equation to relate the CS616 period to the volumetric water content. The resolution of the CS616 is 0.10% of the volumetric water content. This is the minimum change that can reliably be detected.

Campbell Scientific supplies three sets of coefficients for different soil characteristics. The standard set of coefficients apply to soils with a bulk electrical conductivity of less than 0.5 dS/m, a bulk density of less than 1.55 g/cm^3, and a clay content less than 30%. The other two sets of coefficients are for sandy clay loams with bulk densities of 1.6 g/cm^3 and the specified bulk electrical conductivities. These coefficients are summarized in Table 9. Figure 24 illustrates the difference between the three sets of coefficients.

Table 9. Quadratic fit coefficients

Condition	C_0	C_1	C_2
Standard	-0.0663	-0.0063	0.0007
0.4 dS/m	0.095	-0.0211	0.001
0.75 dS/m	-0.018	-0.007	0.0006

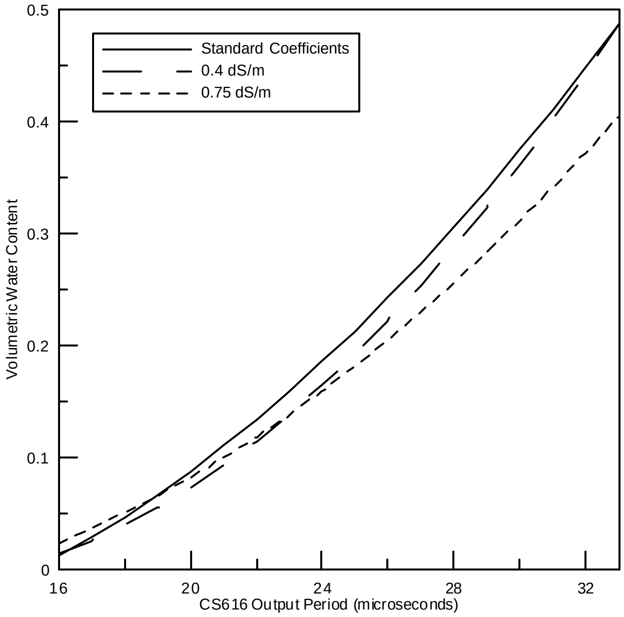


Figure 24. CS616 quadratic fit coefficients

Alternatively, the coefficients for the equation can be determined through a calibration procedure using soil samples collected from the site. This was the chosen means to calibrate the probes. Calibrating the probes in the identical soil in which they were installed is extremely important and difficult. The soil sample was collected from the lower infiltration bed for calibration, as this was the location in which the probes were installed.

Calibration of the probes involved determining the period associated with various predetermined volumetric water contents. The soils were compacted to a target dry density of 1.60 g/cm^3 (100 pcf) for each of the tests. The resulting period for each of the volumetric water contents was plotted. This plot was fit with a quadratic equation to describe volumetric water content as a function of CS616 period. The calibration coefficients were taken from this equation. The resulting calibration coefficients were

-0.358, 0.0173 and 0.000156 for C_0, C_1, and C_2, respectively. The calibration curve is presented in Figure 25. Finally, Figure 26 shows segments from the calibration process.

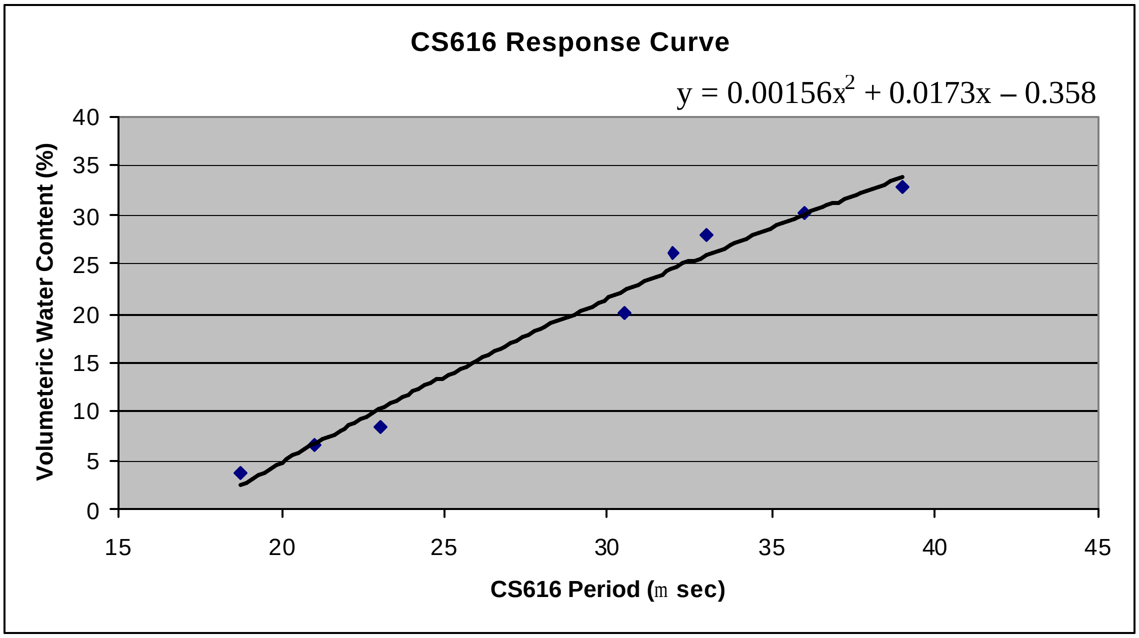


Figure 25. C616 Water Content Reflectometer calibration curve

Figure 26. Soil compaction (left) and frequency response monitoring (right)

Chapter 4: Experimental Results and Discussion

4.1 Introduction

The purpose of this chapter is to summarize the results of the tests conducted and expand upon their significance. The chapter is separated into two main areas, specifically, water quality test results and soil test results. The results for each individual parameter monitored are further separated into individual sections. The importance and any implications that may be determined from the results are discussed.

4.2 Water Quality Test Results

This section will focus on the water quality results of the study. A variety of comparisons of the individual parameters are analyzed. Of interest are the variations in concentration of the parameters from one storm to another, variations during one storm event at the different sampling locations, and finally, the comparison of the resulting concentrations to rainwater and water quality standards. The raw data for all of the parameters are located in Appendix B.

4.2.1 pH

The pH of every sample for each of the storms used in this study was determined. Figure 27 is a plot of those results over the course of the study period. Also plotted in Figure 27 is the average pH of rainfall for each week between December 2002 and October 2003, the most current data available, for two locations, station PA47 and NJ99. The data for these two stations were obtained through the National Atmospheric Deposition Program (NADP). The two stations were selected for comparison purposes due to their close proximity to the test site at Villanova University. Their locations are illustrated in Figure 28.

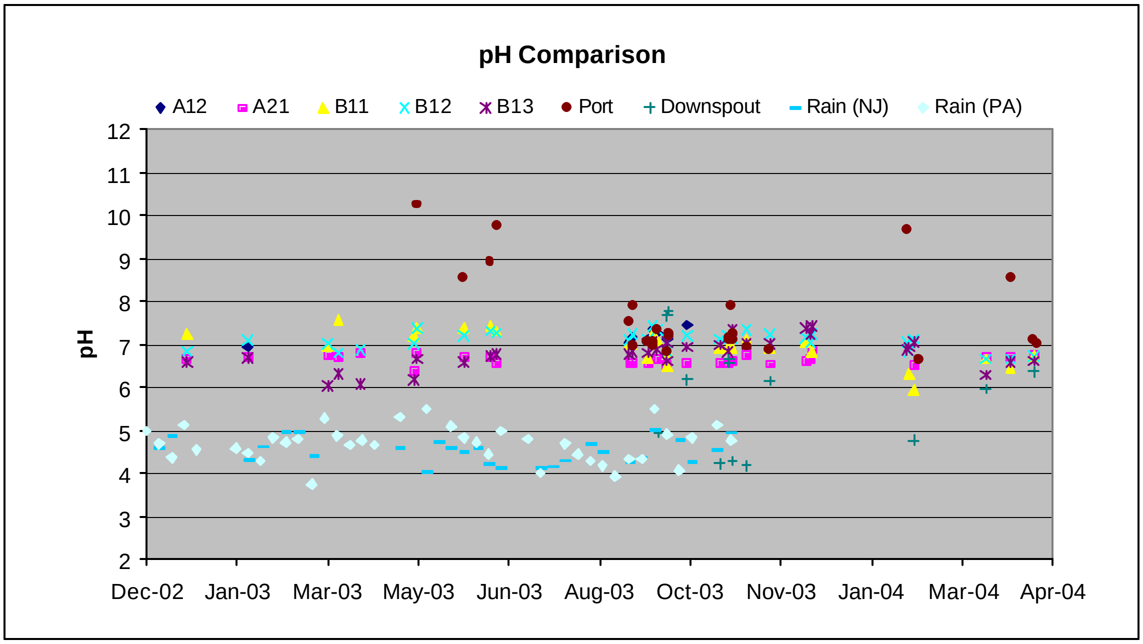


Figure 27. Comparison of pH levels

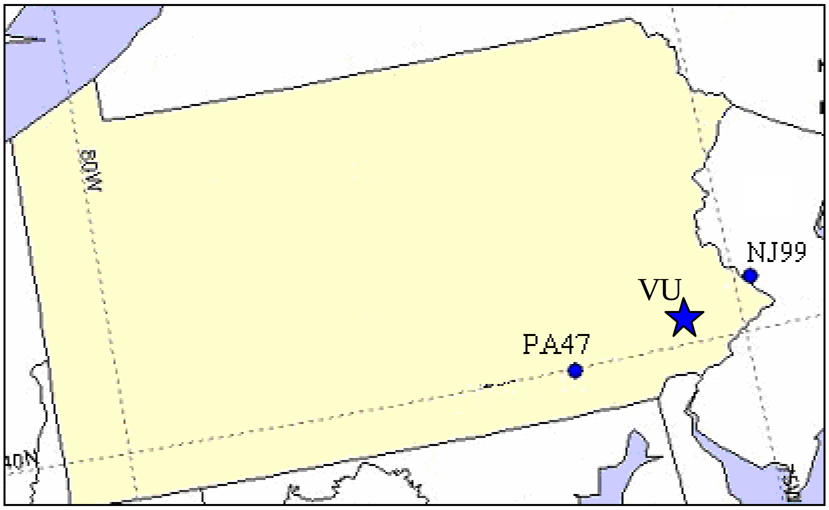


Figure 28. Map of PA47 and NJ99 locations with respect to Villanova University (VU)

One of the most important findings with respect to the pH results was acidic rainwater is neutralized prior to infiltration, as shown in Figure 27. In general, the pH of the samples collected from the port and lysimeters were 2 to 3 units higher in pH than the acidic rainwater. The levels from port samples and soil water samples consistently approached a pH of 7. The increase in pH may be attributed to the stormwater runoff coming in contact with the limestone aggregate once it entered the infiltration beds. Once inside the beds, calcium carbonate ($CaCO_3$) begins to dissolve, which effectively raises the pH of the collected stormwater runoff.

It is unknown whether the soil had any impact on the acidic stormwater runoff because the pH is altered significantly prior to infiltration into the soil strata. Only subtle variations were noted in the results from the soil water samples collected in the lysimeters beneath the infiltration beds when compared to the port samples. Generally, these soil water samples were slightly lower in pH than the port samples. This may be attributed to the naturally occurring acidity of the soil strata. The soil water samples collected outside the infiltration bed, A21, remained relatively constant ranging from a slightly acidic 6.5 to 7.0 throughout the duration of the study.

Figure 29 shows a comparison of the pH results from two storms, September 18, 2003 and October 28, 2003. Again, it is clear that the rainwater and stormwater runoff generated from the roof tops were much more acidic than the port and soil water samples. In general, this was the case for all storms sampled. No clear trends in pH were present with respect to the lysimeters at the various depths when comparing all storms sampled.

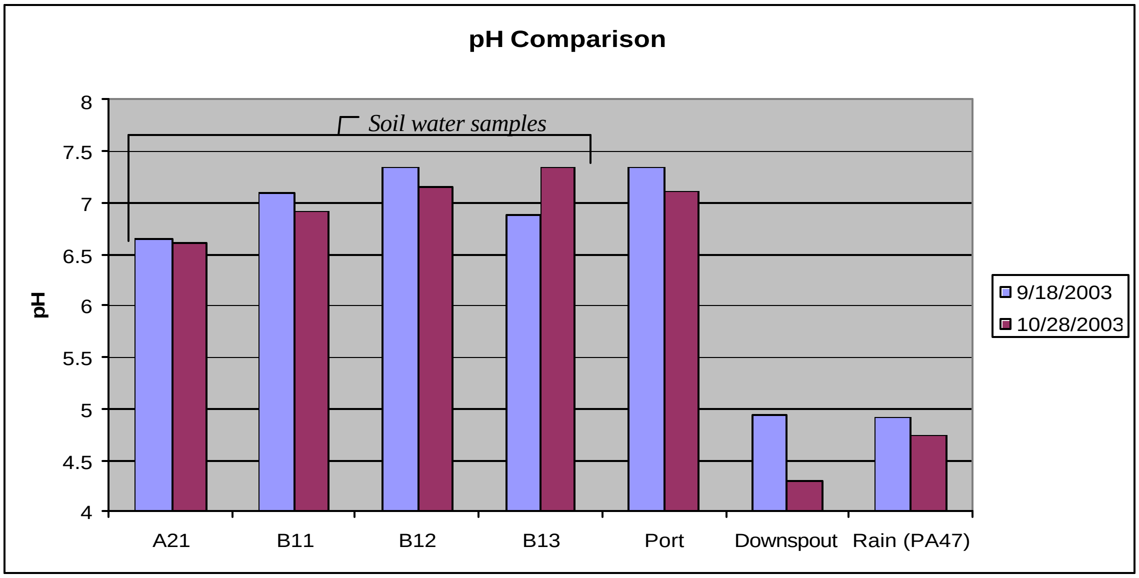


Figure 29. Comparison of pH results from two storm events

Villanova University is located near a karst topography region. Some engineers are concerned that infiltration of acidic stormwater runoff could lead to sinkhole formation as a result of dissolution of limestone bedrock. The acidity of the stormwater, as well as infiltrating large amounts of stormwater runoff into small areas, contributes to potential sinkhole formation. It is speculated that the acidity of the water is more critical in this particular application because the stormwater is being infiltrated over a large area, rather than a concentrated area.

Future studies at the site should be conducted to determine the saturation levels of the infiltrating water with respect to $CaCO_3$, or saturation indexes. It is believed that the contact with the limestone aggregate within the infiltration beds will sufficiently reduce the aggressiveness of the stormwater towards $CaCO_3$, reducing the potential for sinkhole formation; however, tests supporting this theory are necessary. Swisher (2002) showed in a similar study at Penn State University, also a karst topography region, that contact with the limestone aggregate within the beds was sufficient in reducing the acidity and overall aggressiveness of the stormwater. The study showed that the infiltrating stormwater was no more aggressive towards $CaCO_3$ than the local well water, as discussed previously in Chapter 2.

4.2.2 Conductivity

Electrical conductivity estimates the amount of total dissolved salts or the total amount of dissolved ions in water. Conductivity was determined for each sample, on every storm. This data is plotted in Figure 30.

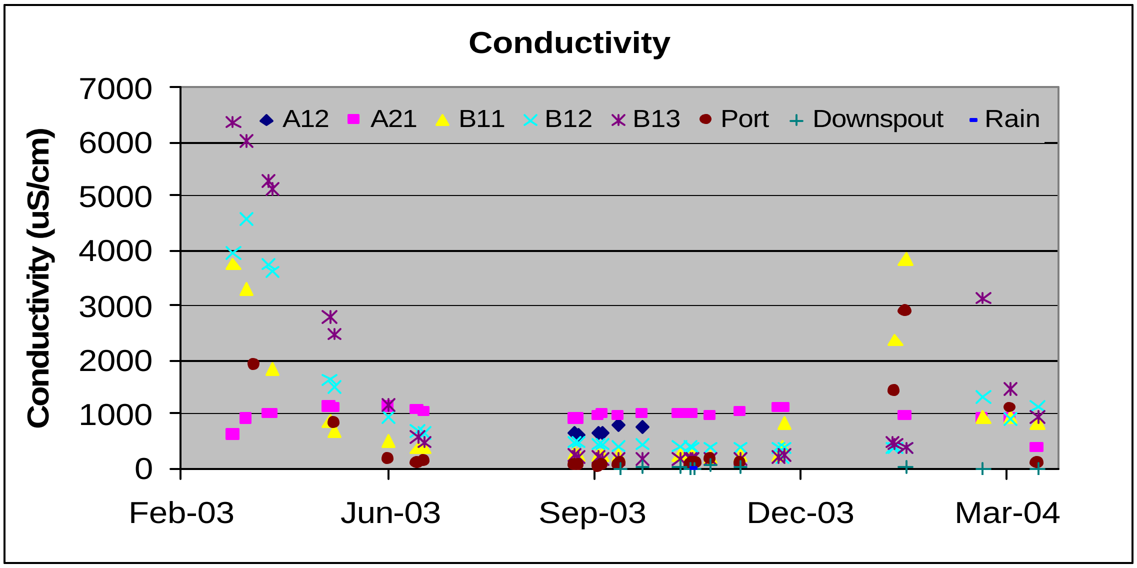


Figure 30. Conductivity results

Rainwater, when not significantly polluted, tends to have a fairly low conductivity. Although there is not a tremendous amount of data, the tests that were conducted on the rainwater revealed a low conductivity, never exceeding 14 µS/cm. Similarly, the stormwater runoff resulting from the impervious roofs, or downspout samples, had low conductivities. The highest recorded conductivity from the downspout samples was 57 µS/cm. This is sensible because there is not a high potential for the rainwater to pick up dissolved ions based on the roof type; slate, underlain by copper sheathing with copper downspouts. Other roof surfaces, such as gravel roofs, have a higher potential to increase the conductivity of the runoff.

The soil water samples taken outside of the infiltration bed at sample location A21 remained very steady throughout the study at approximately 1000 μS/cm. The resulting conductivity is a function of the naturally occurring dissolved ions in the soil water at that location. The moisture content at this location does not fluctuate much, which means the likelihood of fluids, with the ability to alter the conductivity of the soil water, flushing through this region are minimal. The result is a constant conductivity at this particular sampling location, which is useful for comparison purposes with the other soil water samples.

The soil water samples from beneath the infiltration beds, B11, B12, and B13, as well as the samples from the port within the infiltration bed, showed some interesting results. The conductivities of these samples ranged from a minimum conductivity of 162.1 μS/cm to a maximum conductivity of 3880 μS/cm. During the winter months, when snow and ice storm events occurred, deicers, calcium chloride in particular, were used to melt snow and ice. The resulting runoff flowed through the porous concrete, into the infiltration beds, and eventually into the soil. The stormwater runoff was highly concentrated with dissolved ions, the result of which was a spike in conductivity for the soil water. Correlations with the total dissolved solids tests are discussed in Section 4.2.3.

The soil does not appear to have an effect on the conductivity of the runoff, based on the conductivities of the soil water samples beneath the infiltration beds and the similar peak conductivities of the samples from the port within the lower infiltration bed.

The highly conductive runoff is unchanged during the process of infiltration. During the spring, and months leading up to winter, low conductivity rainwater runoff is infiltrated, and the soil water samples from beneath the bed are reduced until they approach the conductivity of the rainwater runoff. This process is illustrated in Figure 30.

4.2.3 Total Suspended and Total Dissolved Solids

The port and the downspout sampling locations were the only locations to have the samples tested for Total Suspended Solids (TSS) and Total Dissolved Solids (TDS). These locations were selected because sample volumes exceeding what was necessary to perform these tests, as well as the tests for the other various parameters, were available. The TSS and TDS results for the port and downspout sampling locations are plotted in Figure 31 and Figure 32, respectively. The raw data is available in Appendix B.

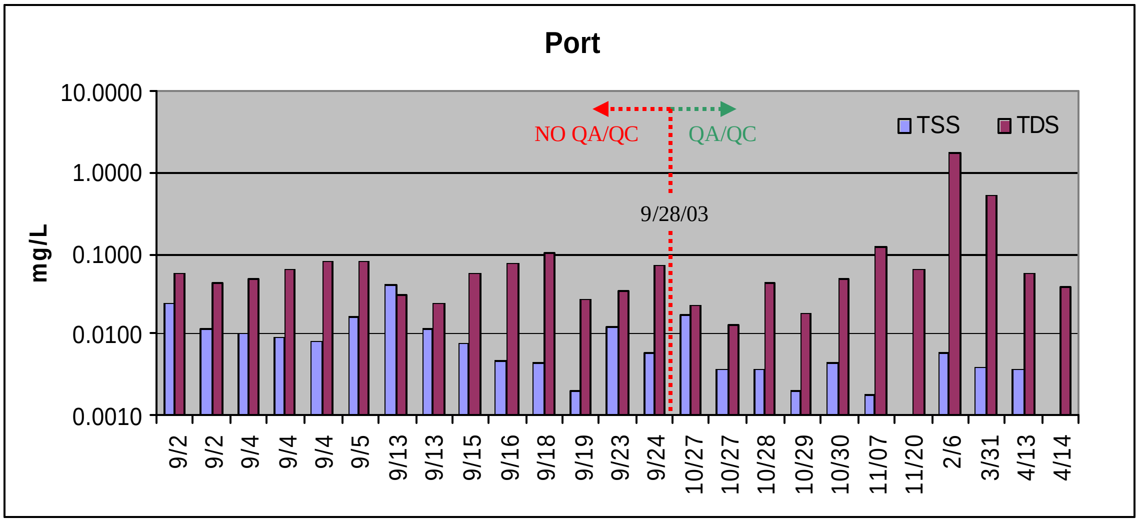


Figure 31. Total Suspended Solids (TSS) & Total Dissolved Solids (TDS) for the port sampling location. Note: y-axis is log scale and x-axis is not to scale.

The dividing line in Figure 31 located at September 28, 2003 marks the date when the method used to gather samples at the port location was changed. Prior to this date, samples were gathered by forcing a prepared sample container beneath the water surface.

This method tended to disturb the water in the port and suspend additional solids in the water that were not suspended prior to the attempted sampling. It was determined that a less disruptive sampling method, the process described in Section 3.2.1.3 in particular, would provide more representative sample. The data following the September 28, 2003 dividing line is representative of the improved sampling method.

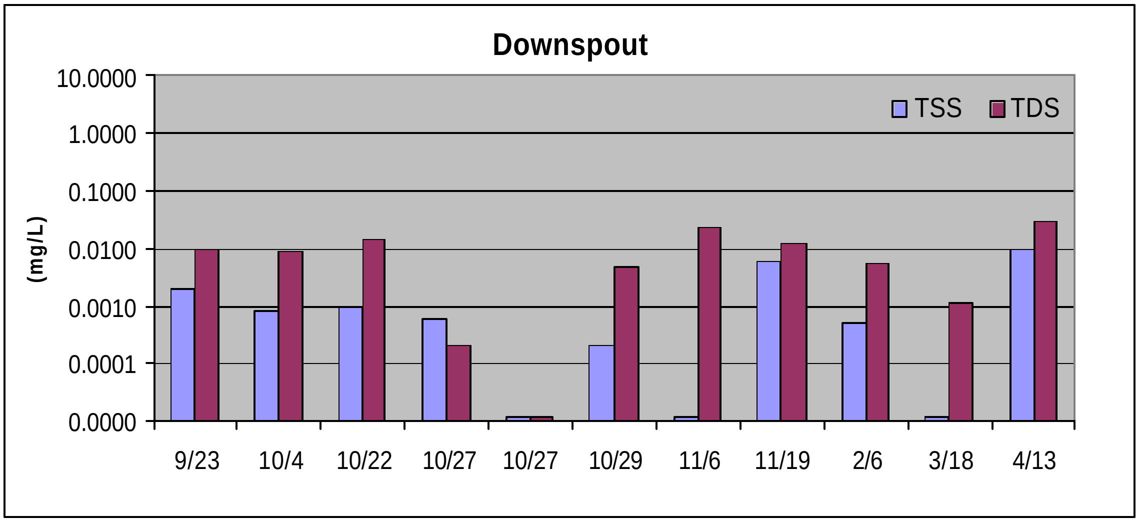


Figure 32. Total Suspended Solids (TSS) and Total Dissolved Solids (TDS) for the downspout sample location. Note: y-axis is log scale and x-axis is not to scale.

Analysis of the data showed that both the port and downspout samples had relatively low concentrations of suspended and dissolved solids. In general, the port samples contained slightly higher concentrations of suspended and dissolved solids than the downspout samples. The difference was anticipated due to the origin of the downspout samples, a roof surface with a low potential to pick up fines, compared to the port samples, which were sampled directly from the lower infiltration bed. These samples consist of a combination of roof runoff from the downspouts, and runoff from the other various impervious surfaces including standard concrete walkways and grass surfaces that enter the infiltration beds via the porous concrete. The runoff from the walkways and grass surfaces has a higher potential to pick up fines; therefore, an increase in total suspended and dissolved solids could be expected.

The runoff entering the infiltration beds via the porous concrete is, in theory, filtered as the runoff passes through the tight matrix of voids within the porous concrete. Consequently, the runoff from these surfaces entering the beds through the porous concrete may not be the only reason for the increase in TSS.

The presence of fines that migrated into the infiltration beds during construction is an alternate factor contributing to the increase in total solids in the port samples compared to the downspout samples. The aggregate used in the infiltration beds was specified as washed aggregate, such that fines that could result in a decrease in infiltration capacity were removed. However, it was not possible to prevent some inadvertent migration of fines into the infiltration beds. These fines were likely suspended by the runoff entering the bed, thus increasing the port samples TSS concentration, and potentially the TDS concentration, depending on the solubility of the solids.

From the first to last storm sampled, it appears as if the concentration of TSS is decreasing in the port samples. This may be a result of the small particles present in the infiltration beds, immediately following the completion of construction, being washed out. If this trend continues, the TSS concentration will approach and stabilize close to the respective concentrations of the downspout samples.

The TDS concentration for the port samples followed a different trend. They appeared to remain relatively constant until the winter months, at which point a spike in concentration of dissolved solids emerged. The TDS concentration was quickly reduced as rainwater from non-snow events flushed the system. This trend was consistent with both the conductivity results and the chloride results where, during the winter months following snow events, both conductivity and chloride concentrations increased dramatically. The relationship between chloride and TDS is discussed in more depth in Section 4.2.4. Figure 33 illustrates the relation between conductivity and TDS. The data for the samples taken from the port and downspout are shown. Clearly there is a linear trend with a positive slope, verifying that as the conductivity increases, the TDS is also increasing.

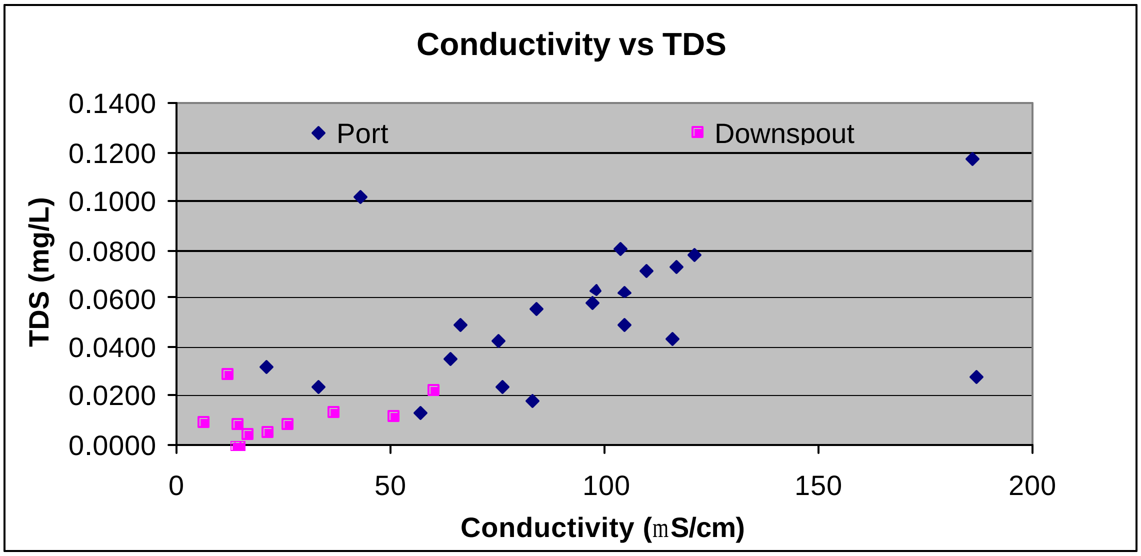


Figure 33. Conductivity vs. TDS

4.2.4 Chloride

The chloride content of the samples was of high interest in this study. The effects of the infiltration basin on chloride concentrated stormwater runoff were recommended as future study topics in a number of investigations. A study performed by Masson et al. (1999) included an investigation on chloride concentrations that suggested chloride acts as an internal tracer. Analysis of the results from this particular study supports this theory.

The chloride concentrations recorded over the course of the sampling period are plotted in Figure 34. The soil water chloride concentrations at sampling location A21, outside the lower infiltration bed, remained relatively constant over the testing period, hovering in the area of 100 mg/l. The rain and downspout samples were extremely low in chloride concentration, never exceeding 15 mg/l. The port and soil water samples beneath the infiltration beds, however, varied considerably and revealed a trend. The chloride contents of the soil water sampled at locations B11, B12, and B13, as well as the port samples, were found to rise considerably during the winter months. The trend is similar to that discovered for both the conductivity and TDS, as would be expected. The concentrations dropped fairly quickly during the spring and eventually leveled out during the summer and fall months. These trends were analyzed and the findings are discussed.

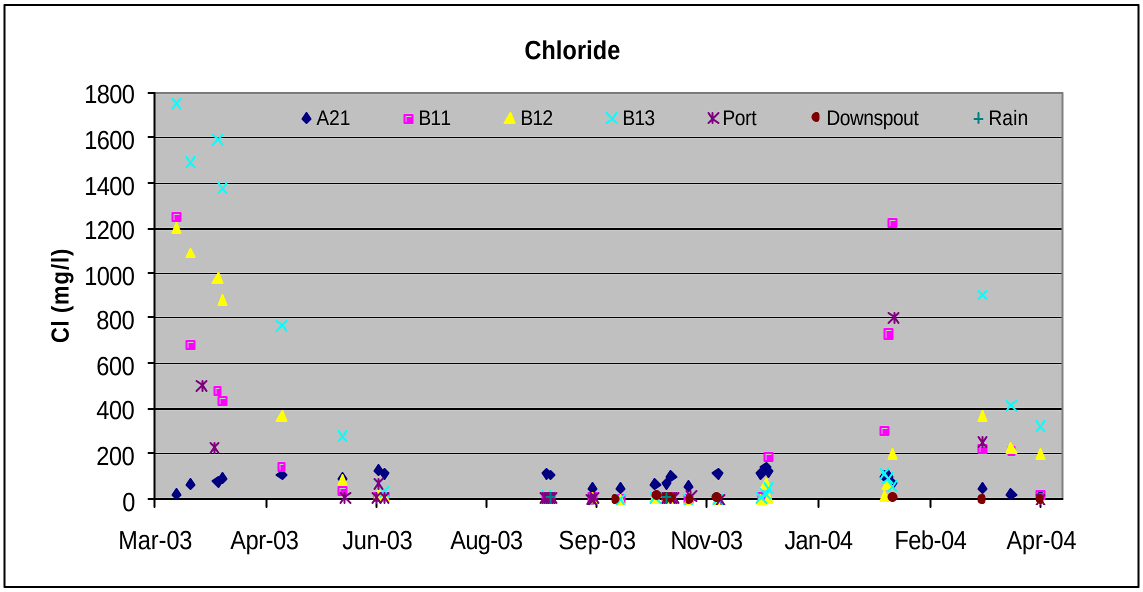


Figure 34. Chloride results

The spikes in chloride concentration can be attributed to the deicing practices used at the university. The porous concrete infiltration basin is located in a highly traveled pedestrian area near the center of the campus. Any slippery surfaces resulting from frozen precipitation, snow or ice, are quickly treated to avoid accidents. The grounds crew for the campus use calcium chloride pellets, called Peladow, exclusively in this area. Manufactured by the Dow Chemical Company, the pellets consist of 90 – 97% calcium chloride, 1 – 2% sodium chloride, and 2 – 3% potassium chloride. Any runoff resulting from the treated surfaces is therefore highly concentrated with chloride.

Elevated chloride concentrations were found in port samples following the deicing events. This highly concentrated runoff enters the infiltration beds via the porous concrete and is retained awaiting infiltration into the soil. It should be noted that the chloride concentration of the port samples are representative of a mixed batch of runoff produced from various surfaces. Consequently, the runoff that entered the infiltration bed from the calcium chloride treated surfaces is diluted to a degree while in the infiltration beds by stormwater runoff produced by the roof surfaces, which have little to no chloride content.

The chloride was not removed from the runoff while in the infiltration beds or as it was infiltrated. As a soluble ion, there are no reactions that take place in the soil capable of reducing the chloride content. The circumstances are governed by conservation of mass. Following the first deicing event of the winter, the chloride content of soil water sampler B11, the shallowest soil water sampler located at 0.3 m (1 ft) beneath the lower infiltration bed, is the first to show a spike in concentration. Soil water samplers B12 and B13, located at 0.6 m (2 ft) and 1.2 m (4 ft), respectively, beneath the infiltration beds, follow in order as the highly concentrated runoff is infiltrated. Larger snow events typically require larger quantities of the calcium chloride, which result in more concentrated runoff. With the return of warmer weather and non-snow events, fresh rainwater and runoff, with little to no chloride content, is infiltrated and the chloride contents in the soil water are reduced. The chloride contents are not immediately returned to mid summer levels. The highly concentrated runoff infiltrated in the winter takes time to work through the soil strata. Concentrations are reduced in reverse order to which they increased with respect to depth beneath the infiltration beds. These trends are illustrated in Figure 34.

The groundwater is clearly being affected as the high chloride concentration stormwater is being infiltrated. However, the degree to which the groundwater is being affected is unknown. As illustrated and discussed previously, the chloride content in the soil water just beneath the infiltration beds takes some time and a series of non-deicing events to bring the chloride concentrations back to a low level, suggesting some form of attenuation. This is positive only if the soil sufficiently attenuates enough of the highly concentrated runoff to minimize the effect on the groundwater. The maximum contaminant level (MCL) for chloride in drinking water is 250 mg/L (Department of Environmental Protection, 1997). If the chloride concentration in the groundwater does increase above allowable limits, then clearly insufficient attenuation is taking place. Further complicating matters, if the chloride is being trapped during the deicing events and slowly released over a series of non-deicing events, the infiltration beds could be acting as a source of chloride, capable of increasing chloride concentrations in the groundwater above allowable limits. This has the potential to occur over prolonged periods as the chloride is flushed out of the infiltration beds. Only testing of the groundwater at multiple points downstream of the infiltration basin could begin to identify the extent to which the groundwater is effected. It is believed that as the runoff is infiltrated and enters the actual groundwater table, the concentration would be reduced significantly to levels below the MCL of Cl for drinking water standards.

The increase and decrease of chloride is mirrored by the measured conductivity level of the samples as previously discussed in Section 4.2.2. Figure 35 is a plot of the conductivity versus the associated chloride concentration data for all samples available. There is a linear relationship with a positive slope, verifying that conductivity increases as the chloride concentration increases. Because conductivity also increases with increasing TDS, it can be deduced that the TDS concentration increases with increasing chloride concentration.

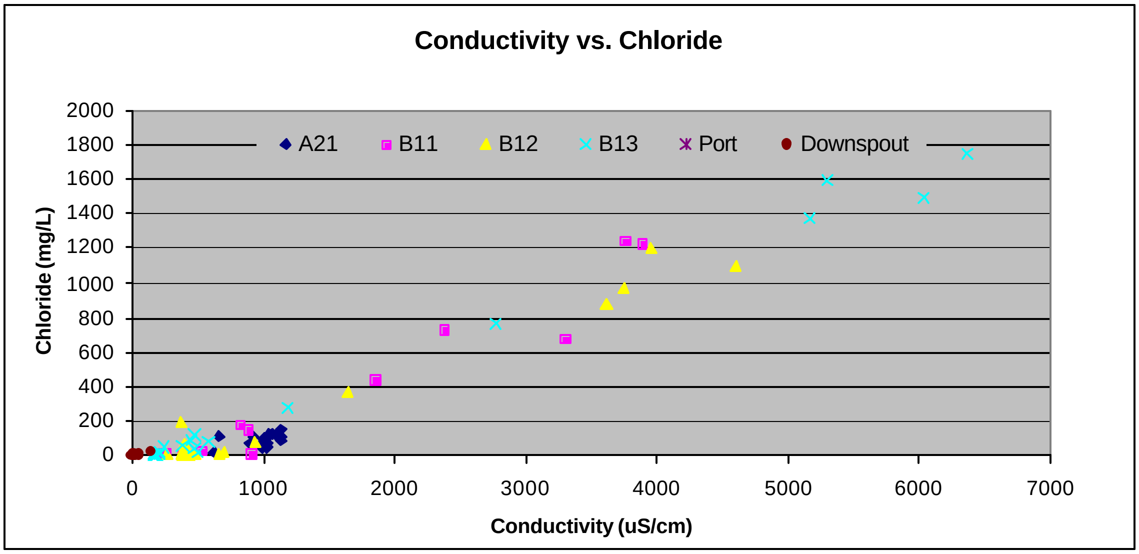


Figure 35. Conductivity vs. Chloride

4.2.5 Nutrients

Nutrients are a potential form of groundwater pollution. Common forms of nutrients are fertilizers, livestock waste, and septic systems. Nutrients, in the form of dissolved nitrogen and phosphorus, move readily through soil systems. Although these nutrients are necessary to aquatic life, excess amounts are harmful. Excess levels of nutrients in the form of nitrogen and phosphorus may result in adverse health affects and can contribute to algae growths in streams.

The only potential sources of nitrogen at the site are fertilizers and atmospheric deposition. According to the head of grounds at the university, fertilizers are not used in this area now that there is an infiltration system in place. As a result, the only realistic source of nitrogen is atmospheric deposition.

Nitrogen not utilized by plants, volatilized, or carried away by surface runoff leaches into the ground. The most common form of this leachate is nitrate. Nitrite, a more dangerous from of nitrogen, can be formed by the process of reduction of nitrate. Nitrate typically does not cause health problems unless it is reduced to nitrite.

The federal standard for nitrate in drinking water is 10 mg/l nitrate-N, or 45 mg/l nitrate-NO_3, when taking into consideration oxygen levels (Department of Environmental Protection, 1997). Short-term exposure to levels in excess of 10 mg/l nitrate-N is primarily a potential risk to infants. Immature digestive systems are more likely than adult digestive tracks to allow the reduction of nitrate to nitrite. Nitrite in the digestive track of newborns can lead to methemoglobinemia, or what is commonly referred to as blue baby syndrome, where the body tissue is deprived of oxygen. The MCL for nitrite is 1.0 mg/l nitrite-NO_2 (Department of Environmental Protection, 1997).

Phosphorus occurs naturally in rocks and other mineral deposits and also results from decaying animal waste. Phosphorus is not toxic to humans unless at very high concentrations. Digestive problems are the most common result of extremely high levels. High levels of phosphate do impact the environment as it is known to stimulate the growth of aquatic plants much like nitrate. Phosphate, however, tends to govern the process.

Total nitrogen, nitrate, nitrite, and total phosphorus were measured for a number of storms and the data was analyzed. As anticipated, nutrients do not appear to present any problems at this site. The only source of nutrients is what is naturally occurring in the soil and what may result from dry or wet deposition on the various impervious surfaces.

The results of the nitrogen based nutrients showed that there are higher concentrations of the various parameters already present in the soil water than compared to what is entering the system. The soil water samples collected from outside of the infiltration bed, A21, had concentrations higher than any of the soil water samples collected from beneath the infiltration bed, the port samples, and the downspout samples. In other words, there are no sources within the watershed that are capable of raising the concentrations to alarming levels.

4.2.6 Copper

Metals are an important facet to consider when determining the effectiveness of an infiltration BMP from a water quality standpoint. Rooftop runoff can be a large contributor of metals depending on the type and age of the materials, as discussed in Chapter 2. Based on the many copper components of the roof structure at the porous concrete site, this parameter was of high interest. The surrounding rooftops in the drainage basin area contribute a large percentage, 30%, of the total volume of runoff to the infiltration basins; consequently, there is an increased potential for contamination of the groundwater and subsurface soils.

A sample of the results from storms on November 19, 2003 and February 6, 2003 are presented in Figure 36. The exact sampling locations are described in detail in Chapter 3. The port sample is a mixed batch of runoff from the various surfaces that are stored in the infiltration beds. The downspout is runoff coming off of a section of the roof. The A21 samples are soil water samples taken from along side of the infiltration beds. Finally, the remaining samples, B11, B12, and B13, are the soil moisture samplers beneath the lower infiltration bed staggered at 0.3 m (1 ft), 0.6 m (2 ft), and 1.2 m (4 ft), respectively.

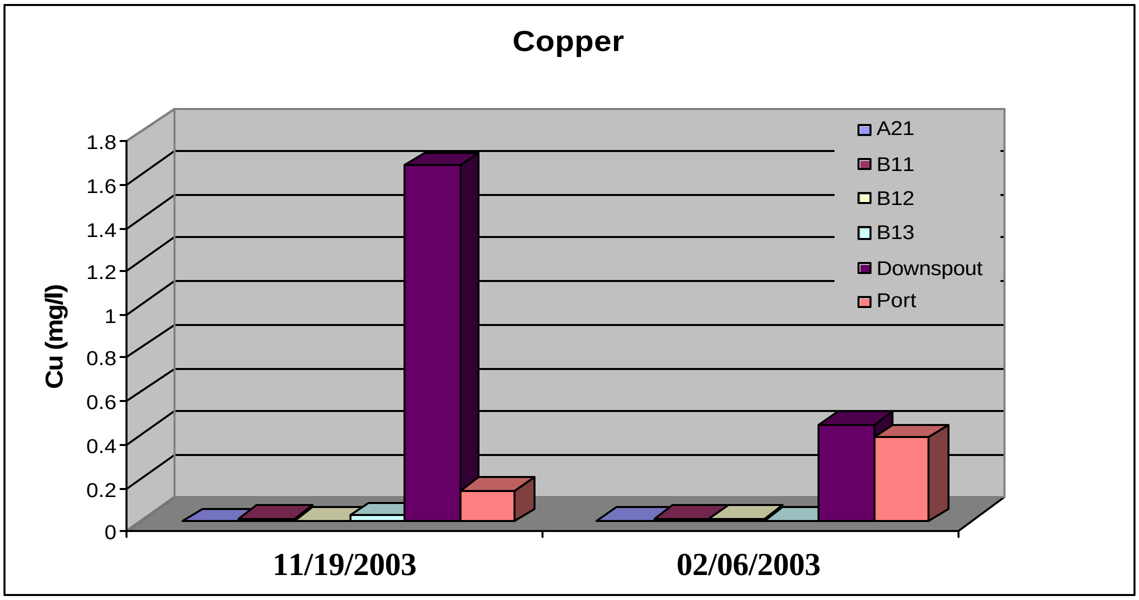


Figure 36. Copper results

The results displayed in Figure 36 are typical of the copper concentrations observed for all of the storms sampled. In general, there is high copper concentration runoff coming off of the roof, lower concentration runoff in the port, and essentially no copper present in the soil water samples. The runoff resulting from the impervious roof structure has a significantly higher concentration of copper when compared to the other sampling locations. Some samples actually exceeded the MCL for copper, 1.0 mg/L Cu (Department of Environmental Protection, 1997). The elevated concentrations do not come as a surprise. There are a number of copper components on the roof such as copper sheathing beneath the slate tiles and copper downspouts. The runoff comes into contact with these weathered surfaces, reacts, and dissolves copper, as shown in Figure 36.

The copper concentrations of the roof samples were found to be variable. This was the case when comparing one storm to another and when comparing multiple samples taken at different times during one event. A number of studies have shown a first flush effect for copper concentrations from roof surfaces similar in composition to the one in the current study. This may account for the variations noted. Samples were taken at random times with respect to the start of the event due to constraints in the sample method. In particular, samples were taken by hand; therefore, storms occurring extremely late at night or early in the morning made manual sampling at the very beginning extremely difficult. Samples were therefore taken at completely random times. If the concentrations coming off the roofs vary as a function of time, as suggested in other studies, chances are the variations in the concentrations recorded are largely a result of this phenomenon. In addition, antecedent rainfall may play a roll in the variations in concentrations coming off the roof surface. Setting aside these variations, the important finding is that there are high concentrations of copper in the runoff produced by the roof surfaces and downspouts.

The runoff from the roof is directed into the infiltration beds by means of downspouts and lateral drains. Once in the infiltration beds, the roof runoff mixes with other runoff from various impervious surfaces that enter the bed via the porous concrete. The samples taken at the port are comprised of this combination of that runoff. The runoff from these surfaces has little to no copper concentration because there are no sources for copper. The copper concentration in the infiltration beds is, therefore, highly dependent on the ratio of the volume of runoff from the roof surfaces to the various other impervious surfaces that enter the bed via the porous concrete. The runoff entering the infiltration beds via the porous concrete is essentially void of copper; therefore, depending on the ratio of contributing runoff, the concentration in the bed will be either close to or lower than the concentration of the roof runoff.

Comparing the two storms presented in Figure 36, it becomes evident the concentration can vary, depending on this ratio. In larger, more intense storms, runoff may overload, and potentially bypass the porous concrete at times and never reach the infiltration beds. In this case, the port sample would be mostly comprised of roof runoff. This was the case in the February 6, 2003 storm, where the port sample was similar in concentration to the downspout sample. Conversely, if the runoff collecting inside the infiltration bed had a larger percent of runoff from the roof surfaces, as is the case in the November 19, 2003 storm, the roof runoff from the downspouts inside the bed will be less diluted, and the port sample will have a concentration closer to that of the roof runoff. When no runoff bypasses the BMP, 30% of the runoff is contributed by the copper laden roof surfaces, and 70% is contributed by other copper-free impervious surfaces.

Previous studies have suggested the copper present in the roof runoff would be removed through the process of adsorption once infiltrated (Mason et al., 1999; Blaszczyk, 1997; and Mikkelsen et al., 1996). Analysis of the soil water samples supported these findings. No significant copper concentrations were found in any of the soil water samples collected during this phase of testing. This includes the shallowest soil water samplers located 0.3 m beneath the lower infiltration bed, which never produced copper concentrations above 0.021 mg/L Cu, the minimum detection limit (MDL) for the test procedure. This is well below the maximum contaminant level goal (MCLG) for copper, 1.0 mg/L Cu. From this data, it can be deduced that the copper is being removed immediately, or at least within the first 0.3 m (1 ft) of soil. The copper likely is adsorbing to the soil particles in the first few inches of soil beneath the infiltration bed.

It is not known whether the rocks within the infiltration beds have any effect on the copper concentration of the runoff collected there. It is possible that some of the copper sorbs to the aggregate; however, the data does not clearly support or refute this process. In all cases, the copper concentrations in the port were less than the concentrations of copper in the runoff coming directly from the roof downspouts. It is not possible to determine what fraction of this change is a result of dilution, as described previously, or a result of copper adsorbing to the aggregate.

Long term monitoring of the site is essential. The current data suggests that copper is being removed from the stormwater runoff, but it is unknown whether or not the system will function the same 20 or 30 years from now. The potential is there for the system to become overloaded with copper and begin to act as a source, rather than a means of remediation. Only the continual monitoring of the conditions at the site will answer these questions.

4.3 Soil Test Results

This section will focus on the results of the various soil tests performed on the soils sampled from the test site. Although the focus of this thesis concerns the water quality at the site, some basic soil characteristics are of interest as many of the water quality results may be dependent upon the soil conditions. Finally, the soil characteristics determined in this study may aid in future studies in determining various other characteristics at the site such as hydrologic flow.

4.3.1 Soil Classification

The results of the grain-size analysis utilizing sieve data, soil wash, and hydrometer data are shown in Figure 37. The Atterberg limits were utilized to identify the soil’s liquid limit (LL) and plastic limit (PL), which were determined to be 42.9%, and its 33.0%, respectively. The resulting plasticity index (PI) was 9.9%. The USCS was used to classify the soil as a sandy silt (ML) of low plasticity.

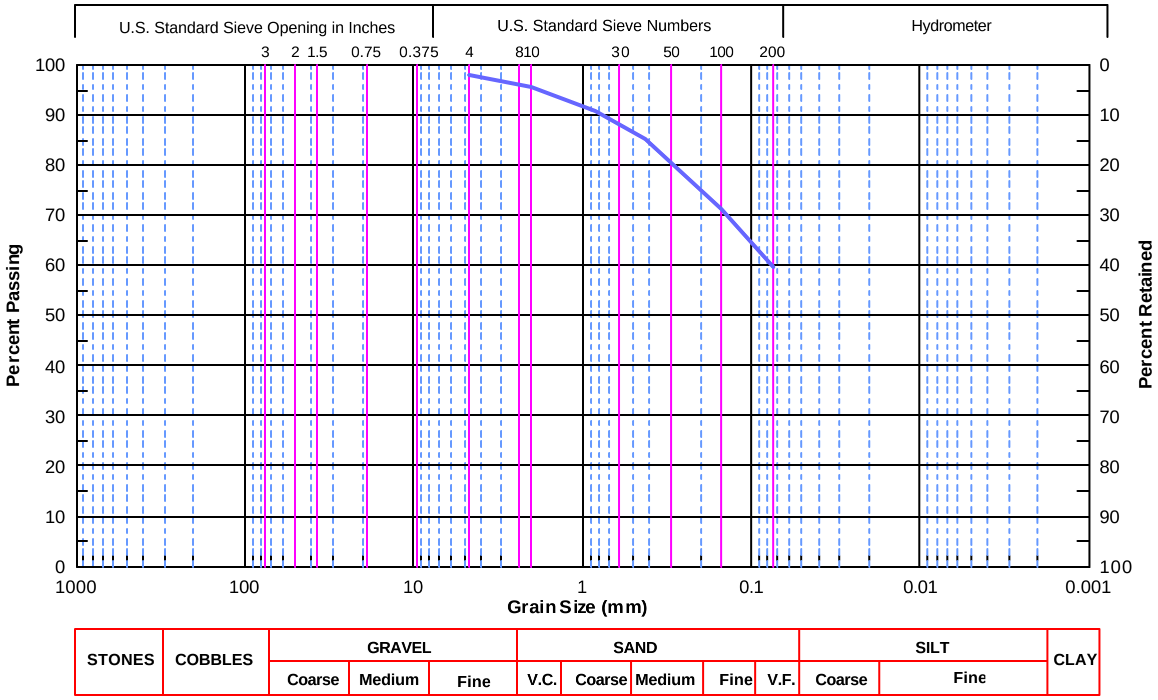


Figure 37. Grain-size distribution

4.3.2 Flexible Wall Hydraulic Conductivity

A flexible wall hydraulic conductivity test was performed on an undisturbed sample collected from beneath the lower infiltration bed. The resulting hydraulic conductivity was K = 1.67 x 10^{-4} cm/sec (0.24 in/hr). This value is based on the average of four measurements following the completion of the back saturation of the sample. The raw data can be found in Appendix C.

For comparison purposes, a port within the lower infiltration bed was outfitted with a pressure transducer to allow the water depth to be monitored constantly. The data from this instrument enables the rate at which the water is infiltrating within the beds to be monitored. Figure 38 is a plot of the receding limb of the water surface elevation in the lower infiltration bed for some select storms. The slope of this line represents the infiltration rate.

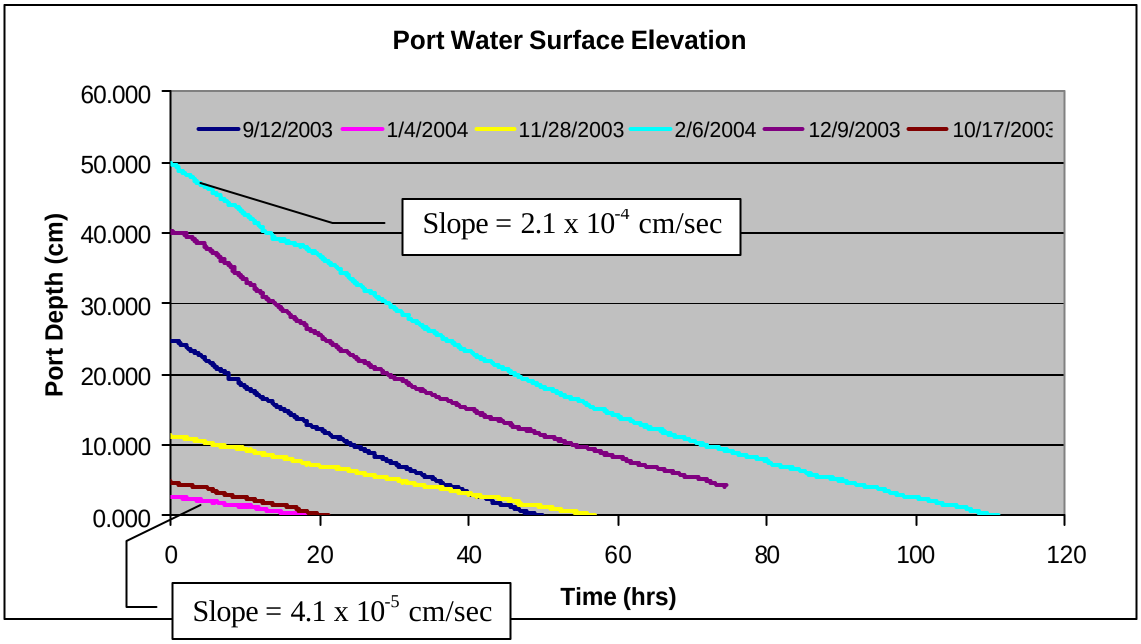


Figure 38. Infiltration bed water surface elevations for select storms

The water surface elevation was plotted, and the rate at which the water infiltrated was determined, for each storm. The raw data and calculations are presented in Ladd (2004), a companion thesis investigating the water quantity aspects of the porous concrete infiltration BMP at Villanova. The maximum and minimum infiltration rates in Figure 38 are 2.1×10^{-4} cm/sec (0.30 in/hr) and 4.1×10^{-5} cm/sec (0.06 in/hr), respectively. The infiltration rate varies depending on the depth of water, or head, in the infiltration bed. Larger heads increases the infiltration rate, whereas smaller heads result in slower infiltration rates. The average infiltration rates determined are in close correlation with the rate determined in the flexible wall hydraulic conductivity test.

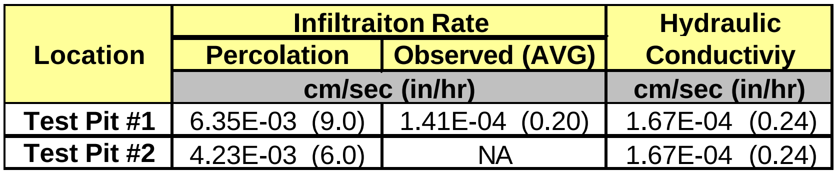
The hydraulic conductivity of the soil beneath the infiltration bed is an important piece of information. Generally, this value is more closely associated with the water quantity aspect of infiltration BMPs; however, it also impacts the water quality. For many different pollutants, nutrients in particular, retention time plays an important role in determining the extent to which the pollutants are removed. Metals are known to adsorb to soil particles. Strong preferential flow paths reduce the opportunity for this to occur, thus slower infiltration may allow greater opportunity for the necessary processes to occur.

Mason et al. (1999) concluded in one study that the artificial infiltration of roof runoff at a particular site was inadequately designed in that there was too little contact time between the infiltrating roof runoff water and the top soil layer. The strong preferential flow paths resulted in immediate percolation, which helped from a water quantity aspect; however, Mason et al. (1999) suggests groundwater contamination must be considered with insufficient retention time.

4.3.3 Percolation Test

Prior to construction, percolation tests were conducted by Cahill Associates. Test pit #1 and #2 coincide with the lower and middle infiltration bed, respectively. Table 10 shows a comparison of the infiltration rates determined for the two test pits using the percolation tests to the hydraulic conductivity test and the infiltration rates measured directly from observed data.

Table 10. Infiltration rate and hydraulic conductivity results comparison



Location	Infiltraiton Rate		Hydraulic Conductiviy
	Percolation	Observed (AVG)	
	cm/sec (in/hr)		cm/sec (in/hr)
Test Pit #1	6.35E-03 (9.0)	1.41E-04 (0.20)	1.67E-04 (0.24)
Test Pit #2	4.23E-03 (6.0)	NA	1.67E-04 (0.24)

Recently, there has been disputes over the reliability of infiltration rates determined using the percolation test. Currently, there is no ASTM method for performing this test; however, percolation tests have always been the industry standard.

When comparing the actual observed infiltration rate to the rate determined using the percolation test, the numbers are in disagreement. There is even significant variability between the two percolation test results, despite their close proximity to one another with respect to the location in which the tests were performed. The disagreement in the numbers supports the argument that the percolation test is an inaccurate means of measuring infiltration rates. An order of magnitude variance is a rather significant variance and should not be considered acceptable.

The hydraulic conductivity determined using the undisturbed sample supports the observed infiltration rate. It should be recognized that the observed infiltration rate is slightly variable. The rate at which the water infiltrates is dependent on both the antecedent rainfall as well as the depth of the water in the bed. The rate tends to increase when a prolonged dry period precedes the event. The rate also fluctuates as the depth of the water in the bed increase or decreases. These phenomena are more closely examined in Ladd (2004).

4.3.4 Soil Suction Test

The soil suction curve was determined by measuring the matric suction over a range of soil water contents, 5 to 25%. Matric suction is “the negative pressure (expressed as a positive value), relative to ambient atmospheric pressure on the soil water, to which a solution identical in composition with the soil water must be subjected in order to be in equilibrium through a porous permeable wall with the soil water” (ASTM D 5298–94). The test was performed using the contact method in ASTM D 5298-94 with Whatman No. 42 filter papers.

The resulting matric suction values for the six different water contents analyzed are presented in Table 11. The raw data used to determine the matric suction is located in Appendix D. Target soil water contents ranged from 5 to 25%. Equation 1 is the general form of calibration curve used to calculate the suction, h.

$$h = mw_f + b \tag{1}$$

where,

h = suction (total or matric)

m = slope of the filter paper calibration curve, $\log_{10}$ kPa / % water content

b = intercept of the filter paper calibration, $\log_{10}$ kPa, and

w_f = gravimetric water content of the filter paper

Equation 2 was used where the gravimetric moisture content was less than 45% and Equation 3 was used when the gravimetric moisture content was greater than 45%. These formulas are based on the calibration curves presented in ASTM D-5298 for Whatman No. 42 filter papers.

$$h = 5.327 - 0.0779 w_f \text{ —— Filter paper gravimetric water content} < 45\% \tag{2}$$

$$h = 2.412 - 0.01359 w_f \text{ —— Filter paper gravimetric water content} > 45\% \tag{3}$$

Table 11. Soil suction results

Parameter	Target Soil Moisture Content (%)					
	5	10	13	16	20	25
Matric Suction (log kPa)	4.45	4.06	3.41	3.08	2.19	1.51

The soil suction curve resulting from the soil suction test is shown in Figure 39. "Soil suction is a measure of the free energy of the pore-water in a soil. Soil suction in practical terms is a measure of the affinity of soil to retain water and can provide information on soil parameters that are influenced by the soil water; for example, volume change, deformation, and strength characteristics of the soil" (ASTM D 5298-94).

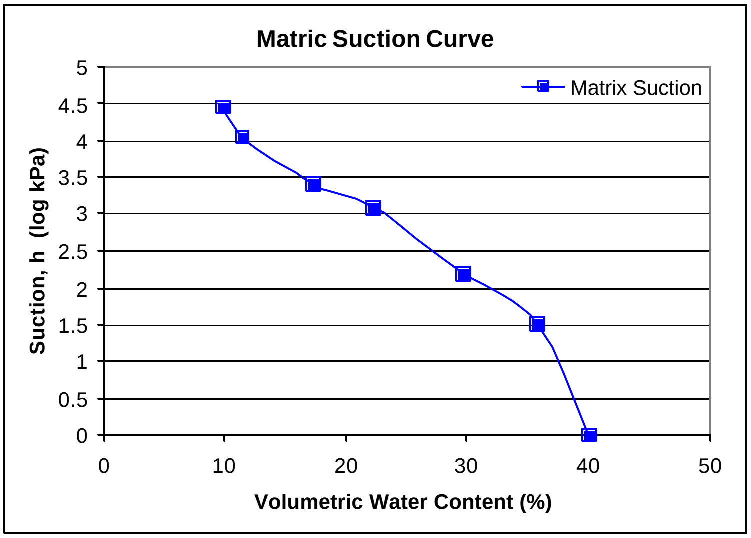


Figure 39. Matric suction curve

The matric suction curve may be used in future studies with other soil and environmental parameters to continue to evaluate hydrologic processes. Furthermore, the information gathered can aid in determining the potential for heave or shrinkage, shear strength, modulus, insitu stress and the unsaturated hydraulic conductivity of the soil.

4.3.5 In-situ Density

The in-situ density of the soil at the base of the lower infiltration bed was determined by collecting a sample at an equivalent elevation parallel to the bed. The soil was sampled using a thin walled sampling tube. The sample tube was sealed at either end once removed from the soil and brought back to the lab for immediate analysis.

The in-situ density of the sample was determined to be 18.4 kN/m^3 (116.8 pcf) at a moisture content of 16.6%. The resulting dry density was 15.8 kN/m^3 (100.3 pcf). The raw data and raw calculations for the density are located in Appendix E.

The density of the subgrade was utilized for the soil tests performed that require the test be performed at site specific conditions. It was not always possible to obtain an undisturbed sample. Consequently, samples had to be molded to match the conditions present at the site. The density may also be useful for comparison purposes with other infiltration BMPs.

4.3.6 In-situ Water Content

A total of twelve CS616 Water Content Reflectometers were installed beneath, and immediately outside, the lower infiltration bed to monitor the constant fluctuations in the moisture content of the soil. The probes were set up such that measurements were taken every 5 minutes and recorded in 15 minute increments. To ensure the accuracy of the readings, the probes were calibrated at the site specific dry density.

Figure 40 is a plot of the data collected from October 10, 2002 to October 28, 2002 for the group of water content reflectometers located beneath the lower infiltration bed, in the southwest corner. The specific location can be seen in Figure 22. Three probes were placed at this location, staggered at 0.3 m (1 ft), 0.6 m (2 ft), and 1.2 m (4 ft). Two rainfall events are presented in this data subset.

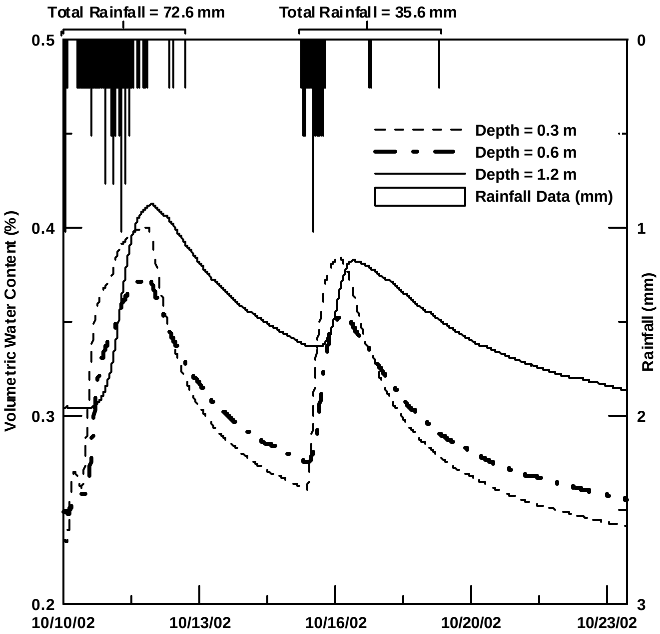


Figure 40. Water content reflectometer data for two storms

The moisture fronts result from the infiltration of the stormwater runoff in the infiltration bed. As the moisture front passes through the soil, the water content changes. Knowing the time it takes for the moisture front to travel from one water content reflectometer to another helps create a rough estimate of the infiltration rate of the soil. On average, the leading edge of the moisture front passed at an average rate of approximately 4.0 x 10^{-3} cm/sec (5.7 in/hr).

A sample storm is shown in more detail in Figure 41 to illustrate the means by which the rate was determined. Prior to the start of the rain event, the soil moisture level was approaching normal conditions. The shallowest probe, 0.3 m (1 ft) beneath the infiltration bed, was the first to detect the moisture front after the start of the event. Approximately 1.5 hours later, the 0.6 m (2 ft) deep probe detected the front. Finally, 7.5 hours after the 0.6 m (2 ft) probe detected the moisture front, the 1.2 m (4 ft) deep probe detected the front, as illustrated in Figure 41. Knowing the necessary time for the front to travel a specific distance enables the rate at which the lead edge of the moisture front passes between 0.3 – 0.6 m, 0.6 – 1.2 m, and 0.3 – 1.2 m to be determined. Table 12 lists the associated rates of travel from one probe to another for the storm shown in Figure 41.

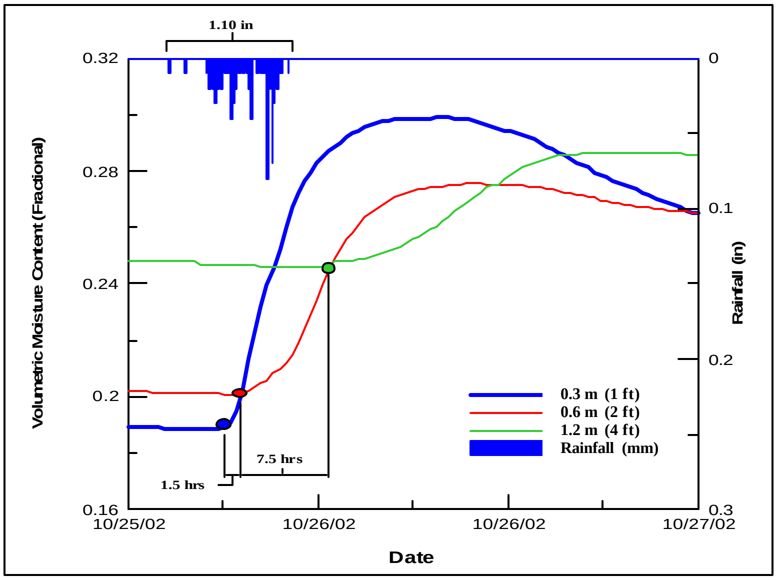


Figure 41. Moisture front rate of travel

Table 12. Moisture front rate of travel

Probe Location	D Time	D Dist.	Rate
	hr	m (ft)	cm/sec (in/hr)
0.3m - 0.6m	1.5	0.3 (1.0)	5.64E-03 (8.0)
0.6m - 1.2m	7.5	0.6 (2.0)	2.26E-03 (3.2)
0.3m - 1.2m	9.0	0.9 (3.0)	2.82E-03 (4.0)

Interestingly, the average rate at which the moisture front passes closely resembles the infiltration rate determined by the percolation test. Figure 15 compares this rate to the rates previously determined using the percolation test, the flexible wall hydraulic conductivity test, and observed data. Test pit #1 and #2 refer to the lower and upper infiltration beds, respectively.

Table 13. Comparison of rates

Location	Infiltration Rate		Hydraulic Conductiviy	Moisture Front
	Percolation	Observed (AVG)		
	cm/sec (in/hr)		cm/sec (in/hr)	cm/sec (in/hr)
Test Pit #1	6.35E-03 (9.0)	1.41E-04 (0.20)	1.67E-04 (0.24)	4.0E-03 (5.7)
Test Pit #2	4.23E-03 (6.0)	NA	1.67E-04 (0.24)	NA

Data collected from the water content reflectometers is also used to aid in determining when to begin collecting samples. It is important to collect samples representative of the runoff created by the current event. If samples are collected too far in advance or after the moisture front has passed, the sample may not be representative of the event of interest.

Chapter 5: Conclusions

5.1 Water Quality Study

The drainage area of the porous concrete infiltration basin is an exceptional quality sub-watershed with respect to the various parameters investigated in this study. The area, composed of pedestrian walkways, grassy surfaces and impervious roofing, lacks a potential source of contamination for the most part. Only chloride and copper were found to be reasons for any concern.

Based on the data collected throughout the testing period, the concern for infiltrating acidic rainwater has been reduced. Samples collected from within the infiltration beds compared to samples of rainwater and downspout samples revealed that the acidic water is being sufficiently neutralized as a result of contact with the limestone aggregate within the infiltration beds. The reduced acidity of the stormwater coupled with spreading the infiltration over a large area reduces the potential for sinkhole formation. This supports the theory that it is acceptable to infiltrate stormwater in karst topography regions.

Similarly, pollution of the local groundwater system via nutrient loading has been dismissed as a concern. Nutrients were found at higher levels in the soil water outside the infiltration bed compared to the downspout samples, port samples, or soil water samples from beneath the infiltration beds. In short, the nutrients that are naturally occurring in the soil water have a higher concentration than what is entering the ground via the infiltration beds, which rules out the facility as a potential source of nutrient contamination.

One concern at the porous concrete infiltration basin is the infiltration of high chloride concentration stormwater. The chloride concentrations were found to become an issue in the winter following deicing events, where port and soil water samples revealed the dramatic increase in concentration. The spikes in TDS and conductivity following deicing events similarly reflect the spikes in chloride concentration. These elevated concentrations were found to remain this way for short durations in general. Concentrations were quickly reduced to pre-winter levels after several non-deicing events. Again, the TDS and conductivity reflected this trend.

The elevated chloride concentrations are a concern. The soil water samples from beneath the infiltration beds revealed that the process of infiltration has no effect on the stormwater with respect to this parameter. Chloride is a conservative solute; chloride that enters the infiltration beds passes through the soil uninhibited. The result of infiltrating this highly concentrated stormwater on the groundwater is unknown. The concern is that the concentration of chloride locally in the groundwater may be elevated above acceptable limits during and following these events, as the concentrated runoff is rinsed out of the infiltration beds.

Analysis of the resulting concentrations of copper in the various sampling locations revealed copper is effectively removed from the stormwater by the process of infiltration. The primary source of copper in the system is the various copper roofing components, such as the sheathing and downspouts on the roof structure of the two neighboring dormitories, Sheehan and Sullivan Hall. Copper concentrations of downspout and soil water samples beneath the infiltration beds reveal that the copper is effectively removed from the stormwater in the first 0.3 m (1 ft) of soil.

5.2 Geotechnical Study

Although not the focus of this study, the specific geologic and hydrogeologic conditions at the site are extremely important from both the water quantity and water quality perspective. A number of soil tests were performed to help identify these characteristics. The data collected will be useful for comparison purposes with previous similar studies and, furthermore, will provide information that may be useful in future studies focusing on this particular aspect.

The soil at the site was identified as sandy silt (ML) of low plasticity. This is a desirable soil type for this particular application in that favorable drainage characteristics are generally associated. The in-situ dry density was determined such that tests requiring site specific conditions could be conducted.

The soil can be characterized as a well draining soil based on the results of the observed infiltration rates, various percolation tests, and modified rates determined by observing the moisture front traveling through the soil strata. There was variability observed in the assortment of rates determined. The observed infiltration rate agreed with the rate determined with the flexible wall hydraulic conductivity tests, both having rates of an order of magnitude of 10^{-4} cm/sec. However, rates on an order 10^{-3} cm/sec were determined by the percolation tests and by observing the passing of the moisture front. These differences reflect existing concerns with respect to the standard utilized in practice to measure this parameter. Based on the observed rate of infiltration and results from Ladd (2004), the main conclusion is the site is effective in infiltrating the stormwater from a water quantity perspective.

Similarly the soil type and hydrogeologic conditions are sufficient for this particular site from the water quality perspective. Copper and chloride are the only concerns at the site, as discussed previously. A change in the soil type, however, would not resolve any issues. Copper is removed from the stormwater by the soil in the first few inches of infiltration. Chloride can not be removed from the stormwater via infiltration regardless of the soil type. Nutrients, which require time to be broken down, are not entering this system. Consequently, soil that decreases the infiltration rate to prolong holding times of the stormwater in the soil strata to allow the nutrients to break down is not required.

5.3 Future Recommendations

Expanding the scope of the water quality investigation to include a broader band of parameters would be beneficial in future studies. Budget restrictions, sample volume constraints, and limitations on time lead to limitations on what and how many tests could be conducted on a regular basis. An apparatus capable of identifying a larger variety of parameters simultaneously on a small volume of sample will greatly improve the efficiency of the process and help to attain these goals.

When possible, sampling of the soil beneath the infiltration basin to test for various forms of contamination would unquestionably provide valuable information. An investigation focusing on determining the extent of contamination of the soil by metals, copper in particular, should be conducted. It has already been shown that copper is removed from the stormwater runoff generated from the roof structure. The extent to which these soils underlying the infiltration basin are being loaded and the extent to which the metals may be migrating through the soil are critical in determining the capacity and practicality of future systems.

Saturation indices should be generated to more closely determine the aggressiveness of the stormwater toward dissolution of the limestone bedrock. The analysis of the pH results suggests the aggressiveness will be minor.

Varying retentions times and the effect on the efficiency of the system from a water quality standpoint should be investigated. Correlations may exist between the time it takes for the stormwater to work through the entire system and the resulting quality of the infiltrated stormwater. Discovery of such a relationship may help to shape the method used to determine ideal rates of infiltration and recommended soil types.

Finally, long term monitoring of the site is crucial. The current performance of the site, from both the water quality and water quantity perspectives, cannot be assumed to represent the performance of the site 10, 20, or more years in the future. Arguments can be made both supporting and refuting the notion that what is currently being remediated by the system will continue to do so in the distant future. The water quantity data should be combined with the water quality data to determine loading rates, and these rates should be compared and contrasted with existing standards and regulations.

The possibility exists that the system could become a source of contamination. If copper, for example, continues to be removed by the system over the next several years until the system becomes overloaded, the copper could begin to leach back out of the soil in which it was once retained. Only continued monitoring of the site will begin to answer these questions.

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Appendix A – Water Quality Data Qualifier Codes

A data qualifier is a code that is applied to an experimental result to indicate any uncertainties, whether qualitative or quantitative, in the result. After reviewing the results and checking all calculations the appropriate qualifier is noted directly to the right of the documented result, if required.

Qualifier	Description
A	Value reported is the mean of two or more determinations.
C	Calculated. Value stored was not measured directly, but was calculated from other data available.
D	Sample diluted for analysis. Value stored is representative of the undiluted sample.
G	Value reported is the maximum of two or more determinations.
H	Value based on field kit determination; results may not be accurate.
I	Interference. Value reported is not accurate due to interfering substances.
J	Estimated. Value shown is not a result of analytical measurement.
K	Off-scale low. Actual value not known, but known to be less than value shown.
L	Off-scale high. Actual value not known, but known to be greater than the value shown.
M	Presence of material verified, but not quantified. Indicates a positive detection, at a level too low to permit accurate quantification.
N	Presumptive evidence of presence of material.
Q	Sample held beyond normal holding time.
S	Laboratory test.
T	Value reported is less than the criteria of detection.
U	Material was analyzed for, but not detected. Value stored is the limit of the detection for the process in use.
V	Indicates the analyte was detected in both the sample and associated method blank.
Y	Laboratory analysis from unpreserved sample. Data may not be accurate.

Appendix B – Water Quality Data

The results displayed are separated by their respective storm events in chronological order. The parameters are grouped based on the analytical method or test instrument utilized to perform the analysis. Suspended solids and dissolved solids are listed separately. The date and time in which the sampling period for the given storm event began and the date and time in which the samples were collected are listed. Rainfall totals for each event sampled are also listed. Finally, data listed in *italics* denote the sample that was used to generate the spiked sample for the respective parameter.

Date Applied	3/20/2003	Total Rainfall (mm)
Date Collected	3/21/2003	46.2

Spectrophotometer		Temp. (°C)	Conductivity (µS/cm)			Temp. (°C)	Copper (mg/L Cu)		Total Nitrogen (mg/L N)		Total Phosphorous (mg/L PO_4^{3-})	
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)	(2)	(1)	(2)	(1)	(2)
A21	6.77	12.9	619			12.9						
B11	6.94	18	3760			18						
B12	7.01	18.8	3960			18.8						
B13	6.04	21.3	6370			21.3						
Standard												
Spike												

Ion Chromatograph	Cl- (mg/L Cl)		NO_2 (mg/L NO_2)		NO_3 (mg/ L NO_3)		
Sample Location	(1)	(2)	(1)	(2)	(1)	(2)	I.C. LABEL

Suspended Solids	Volume		Pre-weight	Post-weight	Suspended Solids
Sample Location	(ml)	Tray	(mg)	(mg)	(mg/L)

Dissolved Solids	Volume		Pre-weight	Post-weight	Disolved Solids
Sample Location	(ml)	Tray	(mg)	(mg)	(mg/L)

Date Applied	3/26/2003	Total Rainfall (mm)	
Date Collected	3/28/2003	8.4	

Spectrophotometer		Temp. (°C)	Conductivity (µS/cm)			Temp. (°C)	Copper (mg/L Cu)		Total Nitrogen (mg/L N)		Total Phosphorous (mg/L P0$_4^{3-}$)	
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)	(2)	(1)	(2)	(1)	(2)
A21	6.69	12.3	890			12.3						
B11	7.58	19.1	3300			19.1						
B12	6.81	20.3	4600			20.3						
B13	6.34	22.7	6040			22.7						
Standard												
Spike												

Ion Chromatograph	Cl- (mg/L Cl)		NO_2 (mg/L NO_2)		NO_3 (mg/ L NO_3)		
Sample Location	(1)	(2)	(1)	(2)	(1)	(2)	I.C. LABEL

Suspended Solids	Volume		Pre-weight	Post-weight	Suspended Solids
Sample Location	(ml)	Tray	(mg)	(mg)	(mg/L)

Dissolved Solids	Volume		Pre-weight	Post-weight	Disolved Solids
Sample Location	(ml)	Tray	(mg)	(mg)	(mg/L)

Date Applied		Total Rainfall (mm)	
Date Collected	3/31/2003	15.2	

Spectrophotometer		Temp. (°C)	Conductivity (µS/cm)			Temp. (°C)	Copper (mg/L Cu)		Total Nitrogen (mg/L N)		Total Phosphorous (mg/L PO_4^{3-})	
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)	(2)	(1)	(2)	(1)	(2)
Port			1900			17.8						
Standard												
Spike												

Ion Chromatograph	Cl- (mg/L Cl)		NO_2 (mg/L NO_2)		NO_3 (mg/ L NO_3)		
Sample Location	(1)	(2)	(1)	(2)	(1)	(2)	I.C. LABEL
Port	477.5	480.6					

Suspended Solids	Volume		Pre-weight	Post-weight	Suspended Solids
Sample Location	(ml)	Tray	(mg)	(mg)	(mg/L)

Dissolved Solids	Volume		Pre-weight	Post-weight	Disolved Solids
Sample Location	(ml)	Tray	(mg)	(mg)	(mg/L)

Date Applied	4/7/2003	Total Rainfall (mm)
Date Collected	4/8/2003	Trace

Spectrophotometer		Temp. (°C)	Conductivity (µS/cm)			Temp. (°C)	Copper (mg/L Cu)			Total Nitrogen (mg/L N)		Total Phosphorous (mg/L PO_4^{3-})	
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)		(2)	(1)	(2)	(1)	(2)
A21	6.81		1012				< 0.021	K					
B11							< 0.021	K					
B12	6.89		3750				< 0.021	K					
B13	6.09		5300				< 0.021	K					
Standard							1.973 (2.0)						
Spike							0.98 (.99)						

Ion Chromatograph	Cl- (mg/L Cl)				NO_2 (mg/L NO_2)		NO_3 (mg/ L NO_3)		
Sample Location	(1)		(2)		(1)	(2)	(1)	(2)	I.C. LABEL
A21	98.5		98.3						
B11	549.3	D	548.7	D					
B12	582.2	D	584.6	D					
B13	1824.3	D	1824.1	D					
Port	276.1	D	277.2	D					

Suspended Solids	Volume		Pre-weight	Post-weight	Suspended Solids
Sample Location	(ml)	Tray	(mg)	(mg)	(mg/L)

Dissolved Solids	Volume		Pre-weight	Post-weight	Disolved Solids
Sample Location	(ml)	Tray	(mg)	(mg)	(mg/L)

Date Applied	4/9/2003	Total Rainfall (in.)
Date Collected	4/10/2003	Trace

Spectrophotometer		Temp. (°C)	Conductivity (µS/cm)			Temp. (°C)	Copper (mg/L Cu)		Total Nitrogen (mg/L N)		Total Phosphorous (mg/L $P0_4^{3-}$)	
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)	(2)	(1)	(2)	(1)	(2)
A21	6.82		1015									
B11	7.47		1860									
B12	7.02		3620									
B13	6.55		5170									
Standard												
Spike												

Ion Chromatograph	Cl- (mg/L Cl)				NO_2 (mg/L NO_2)		NO_3 (mg/ L NO_3)		
Sample Location	(1)		(2)		(1)	(2)	(1)	(2)	I.C. LABEL
A21									
B11	471.2	D	471.2	D					
B12	1129.9	D	1155.1	D					
B13	1801.3	D	1818.9	D					

Suspended Solids	Volume		Pre-weight	Post-weight	Suspended Solids
Sample Location	(ml)	Tray	(mg)	(mg)	(mg/L)

Dissolved Solids	Volume		Pre-weight	Post-weight	Disolved Solids
Sample Location	(ml)	Tray	(mg)	(mg)	(mg/L)

Date Applied	5/6/2003	9:00am	Total Rainfall (mm)
Date Collected	5/7/2003	9:30am	5.8

Spectrophotometer		Temp. (°C)	Conductivity (µS/cm)			Temp. (°C)	Copper (mg/L Cu)		Total Nitrogen (mg/L N)			Total Phosphorous (mg/L PO_4^{3-})	
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)	(2)	(1)		(2)	(1)	(2)
A21	6.38		1132						> 25.0	L			
B11	7.2		880						< 2	K			
B12	7.03		1641						< 2	K			
B13	6.2		2780						< 2	K			
Standard									14.9 (15.0)				
Spike													

Ion Chromatograph	Cl- (mg/L Cl)				NO_2 (mg/L NO_2)		NO_3 (mg/ L NO_3)		
Sample Location	(1)		(2)		(1)	(2)	(1)	(2)	I.C. LABEL
A21	115.2		115.7						
B11	132.8		131.7						
B12	418.2	D	414.8	D					
B13	929.0	D	930.8	D					

Suspended Solids	Volume		Pre-weight	Post-weight	Suspended Solids
Sample Location	(ml)	Tray	(mg)	(mg)	(mg/L)

Dissolved Solids	Volume		Pre-weight	Post-weight	Disolved Solids
Sample Location	(ml)	Tray	(mg)	(mg)	(mg/L)

Date Applied	5/8/2003	9:45am	Total Rainfall (mm)
Date Collected	5/9/2003	8:30am	16.8

Spectrophotometer		Temp. (°C)	Conductivity (µS/cm)			Temp. (°C)	Copper (mg/L Cu)		Total Nitrogen (mg/L N)		Total Phosphorous (mg/L $P0_4^{3}$)	
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)	(2)	(1)	(2)	(1)	(2)
A21	6.8	16.8	1113			16.8					0.34	
B11	7.39	24.5	704			24.5					0.15	
B12	7.39	24	1484			24.0					0.18	
B13	6.67	25.3	2480			25.3					0.18	
Port	10.27	22	833			22.0					0.60	
Standard												
Spike												

Ion Chromatograph	Cl- (mg/L Cl)				NO_2 (mg/L NO_2)		NO_3 (mg/ L NO_3)		
Sample Location	(1)		(2)		(1)	(2)	(1)	(2)	I.C. LABEL
A21	111.1		110.9						
B11	113.2		114.6						
B12	341.6	D	346.9	D					
B13	819.7	D	822.0	D					
Port	77.0		75.6						

Suspended Solids	Volume		Pre-weight	Post-weight	Suspended Solids
Sample Location	(ml)	Tray	(mg)	(mg)	(mg/L)

Dissolved Solids	Volume		Pre-weight	Post-weight	Disolved Solids
Sample Location	(ml)	Tray	(mg)	(mg)	(mg/L)

Date Applied	6/3/2003	3:30pm	Total Rainfall (in.)
Date Collected	6/4/2003	9:45am	47.5

Spectrophotometer		Temp. (°C)	Conductivity (µS/cm)			Temp. (°C)	Copper (mg/L Cu)		Total Nitrogen (mg/L N)		Total Phosphorous (mg/L P0$_4^{3-}$)	
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)	(2)	(1)	(2)	(1)	(2)
A21	6.68		1137			15.5	0.831 I		> 25.0 L		0.12	
B11	7.37		531			19.6	< 0.021 K		< 2 K		0.21	
B12	7.2		930			20.2	0.034		2.70		0.34	
B13	6.6		1184			22.0	0.033		3.10		0.18	
Port	8.53		178			17.6	0.165		2.10		0.49	
Rain									4.90			
Standard							4.033 (4.0)		20.1 (20.0)		0.98 (1.00)	
Spike												

Ion Chromatograph	Cl- (mg/L Cl)		NO$_2$ (mg/L NO$_2$)		NO$_3$ (mg/ L NO$_3$)		
Sample Location	(1)	(2)	(1)	(2)	(1)	(2)	I.C. LABEL
A21	118.1	118.0					
B11	36.3	36.2					
B12	94.8	94.1					
B13	355.9 D	358.0 D					
Port	3.7	3.7					

Suspended Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Suspended Solids (mg/L)

Dissolved Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Disolved Solids (mg/L)

Date Applied			Total Rainfall (mm)	
Date Collected	6/18/2003	9:00am	25.2	

Spectrophotometer		Temp. (°C)	Conductivity (µS/cm)			Temp. (°C)	Copper (mg/L Cu)		Total Nitrogen (mg/L N)		Total Phosphorous (mg/L P0$_4^{3}$)	
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)	(2)	(1)	(2)	(1)	(2)
Port	8.47	22.8	108			22.8	0.22		< 2 K		0.24	
Standard												
Spike												

Ion Chromatograph	Cl- (mg/L Cl)		NO$_2$ (mg/L NO$_2$)		NO$_3$ (mg/ L NO$_3$)		
Sample Location	(1)	(2)	(1)	(2)	(1)	(2)	I.C. LABEL
Port	4.5	4.6					

Suspended Solids	Volume		Pre-weight	Post-weight	Suspended Solids
Sample Location	(ml)	Tray	(mg)	(mg)	(mg/L)

Dissolved Solids	Volume		Pre-weight	Post-weight	Disolved Solids
Sample Location	(ml)	Tray	(mg)	(mg)	(mg/L)

Date Applied	6/18/2003	9:00am	Total Rainfall (mm)
Date Collected	6/19/2003	9:00am	25.2

Spectrophotometer		Temp. (°C)	Conductivity (µS/cm)			Temp. (°C)	Copper (mg/L Cu)		Total Nitrogen (mg/L N)		Total Phosphorous (mg/L P0$_4^{3-}$)	
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)	(2)	(1)	(2)	(1)	(2)
A21	6.7		1070				0.635	I	> 25	L	0.2	
B11	7.42		394				< 0.021	K	< 2	K	0.23	
B12	7.32		701				0.03		< 2	K	0.32	
B13	6.72		575				< 0.021	K	< 2	K	0.4	
Port	8.95		361				0.202		< 2	K	0.36	
Standard							4.048 (4.0)		19.4 (20.0)		0.97 (1.00)	
Spike												

Ion Chromatograph	Cl- (mg/L Cl)		NO_2 (mg/L NO_2)		NO_3 (mg/ L NO_3)		
Sample Location	(1)	(2)	(1)	(2)	(1)	(2)	I.C. LABEL
A21	122.1	121.5					
B11	14.1	14.1					
B12	19.0	19.0					
B13	75.4	75.4					
Port	73.9	73.6					

Suspended Solids	Volume		Pre-weight	Post-weight	Suspended Solids
Sample Location	(ml)	Tray	(mg)	(mg)	(mg/L)

Dissolved Solids	Volume		Pre-weight	Post-weight	Disolved Solids
Sample Location	(ml)	Tray	(mg)	(mg)	(mg/L)

Date Applied	6/21/2003	8:30am	Total Rainfall (mm
Date Collected	6/22/2003	8:30am	80.5

Spectrophotometer		Temp. (°C)	Conductivity (µS/cm)			Temp. (°C)	Copper (mg/L Cu)		Total Nitrogen (mg/L N)		Total Phosphorous (mg/L PO_4^{3})	
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)	(2)	(1)	(2)	(1)	(2)
A21	6.57	20.2	1038			20.2	0.461 I		> 25 L		0.12	
B11	7.3	22.2	386			22.2	< 0.021 K		< 2 K		0.18	
B12	7.26	22.7	654			22.7	0.044		< 2 K		0.2	
B13	6.77	23.2	480			23.2	< 0.021 K		< 2 K		0.28	
Port	9.75	19	155.2			19	0.406		2.50		0.28	
Standard							2.927 (3.00)		20.4 (20.0)		0.99 (1.00)	
Spike												

Ion Chromatograph	Cl- (mg/L Cl)		NO_2 (mg/L NO_2)		NO_3 (mg/ L NO_3)		
Sample Location	(1)	(2)	(1)	(2)	(1)	(2)	I.C. LABEL
A21	117.6	117.5					
B11	9.0	8.9					
B12	10.0	10.0					
B13	38.0	38.0					
Port	5.3	5.4					

Suspended Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Suspended Solids (mg/L)

Dissolved Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Disolved Solids (mg/L)

Date Applied	9/2/2003	8:30am	Total Rainfall (mm)
Date Collected	9/3/2003	9:00am	45.2

Spectrophotometer		Temp. (°C)	Conductivity (µS/cm)			Temp. (°C)	Copper (mg/L Cu)				Total Nitrogen (mg/L N)				Total Phosphorous (mg/L P0$_4^{3}$)	
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)		(2)		(1)		(2)		(1)	(2)
A12	7.05	23.2	657	661	662	23.3	< 0.021	K	< 0.021	K	< 2	K	< 2	K	0.12	0.13
A21	6.58	22.4	904	904	904	21.4	0.436	I	0.438	I					0.14	0.15
B11	7.01	25.4	266	265	264	27.3	0.015		< 0.021		< 2	K	< 2	K	0.14	1.50
B12	7.1	26.3	495	498	497	28.1	0.025		0.024		< 2	K	< 2	K	0.31	0.30
B13	6.76	26	249	250	249	29.0	< 0.021	K	< 0.021	K	< 2	K	< 2	K	0.21	0.21
Port 9/2 5:40pm Unf	7.39	17.7	73.2	72.7	73	9.8	1.102		1.103		2.5		2.4		0.20	0.19
Port 9/2 5:40pm Filt	7.57	19.4	75	75.2	75.2	19.6	0.556		0.556		2.3		2.4		0.08	0.09
Port 9/2 8:30am Unf	7.69	18.2	92.4	95.2	95.8	9.8	0.176		0.178		2.3		2.2		0.30	0.29
Port 9/2 8:30am Filt	7.61	19.3	97	97.7	97.7	19.7	0.103		0.107		2.1		2.2		0.21	0.20
Port 9/3 9:00am Unf	7.34	23.1	82.6	83	82.9	24.2	0.805		0.809		2.5		2.5		0.29	0.30
Standard							2.998 (3.00)				20.1(20.0)				1.01 (1.0)	
Spike																

Ion Chromatograph	Cl- (mg/L Cl)			NO$_2$ (mg/L NO$_2$)			NO$_3$ (mg/ L NO$_3$)			
Sample Location	(1)		(2)	(1)		(2)	(1)		(2)	I.C. LABEL
A12	27.9			1.396			< 10.8	K		1
A21	112.3			0.937			< 10.8	K		2
B11	< 9.5	K		0.816			< 10.8	K		3
B12	< 9.5	K		1.510			7.76			4
B13	14.77			0.362			8.83			5
Port 9/2 8:30am Unf	< 9.5	K		< 0.33	K		6.77			6
Port 9/2 5:40pm Unf	< 9.5	K		0.770			9.68			7
Port 9/3 9:00am Unf	< 9.5	K		0.145			< 10.8	K		8

Suspended Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Suspended Solids (mg/L)
Port 9/2 8:30am	575	503	1.0888	1.1028	0.0243
Port 9/2 5:40pm	600	411	1.0824	1.0895	0.0118

Dissolved Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Disolved Solids (mg/L)
Port 9/2 8:30am	450	I4	79.3783	79.4042	0.0576
Port 9/2 5:40pm	500	I6	79.1074	79.1287	0.0426

Date Applied	9/4/2003	10:45am	Total Rainfall (mm)
Date Collected	9/5/2003	10:00am	45.2

Spectrophotometer		Temp. (°C)	Conductivity (µS/cm)			Temp. (°C)	Copper (mg/L Cu)		Total Nitrogen (mg/L N)		Total Phosphorous (mg/L P0$_4^{3}$)	
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)	(2)	(1)	(2)	(1)	(2)
A12	7.15	23.0	622	627	626	23.6	< 0.021 K	< 0.021 K				
A21	6.60	21.1	922	921	921	20.7	0.327 I	0.330 I				
B11	7.00	25.5	253	252	252	27.9	0.032	0.033				
B12	7.23	26.0	475	477	476	28.5	< 0.021 K	< 0.021 K				
B13	6.85	25.4	216	216	216	29.1	< 0.021 K	< 0.021 K				
Port 9/4 10:45am Unf	6.99	15.3	65.1	65.9	66	19.2	0.482	0.486				
Port 9/4 10:45am Filt							0.332	0.333				
Port 9/4 12:15pm Unf	6.95	15.0	103.4	104.6	104.7	21.3	0.351	0.351				
Port 9/4 12:15pm Filt							0.194	0.198				
Port 9/4 2:00pm Unf	7.20	16.5	121.0	121.4	121.7	21.4	0.301	0.300				
Port 9/4 2:00pm Filt							0.195	0.191				
Port 9/5 10:00am Unf	7.88	21.5	103.8	104.0	104.3	19.0	0.153	0.155				
Port 9/5 10:00am Filt							0.091	0.088				
Rain	7.38	20.9	22.3	22.2	22.0	20.9	0.060	0.059				
Standard							3.002 (3.00)					
Spike												

Ion Chromatograph	Cl- (mg/L Cl)		NO$_2$ (mg/L NO$_2$)		NO$_3$ (mg/ L NO$_3$)		
Sample Location	(1)	(2)	(1)	(2)	(1)	(2)	I.C. LABEL
A12	18.49		1.071		> 10.8 L		2A
A21	> 80.0 L		0.980		> 10.8 L		1A
B11	5.72		0.836		10.74		3A
B12	5.86		1.509		7.95		4A
B13	9.56				7.77		5A
Port 9/4 10:45am Unf	5.06		< 0.34 K		9.14		6A
Port 9/4 10:45am Filt	6.59	6.61	< 0.34 K	< 0.34 L	9.21	9.25	7A
Port 9/4 12:15pm Unf	9.37		< 0.34 K		> 10.8 L		8A
Port 9/4 12:15pm Filt	10.36		< 0.34 K		> 10.8 L		9A
Port 9/4 2:00pm Unf	5.86				> 10.8 L		10A
Port 9/4 2:00pm Filt	5.81		< 0.34 K		> 10.8 L		11A
Port 9/5 10:00am Unf	5.77				8.81		12A
Port 9/5 10:00am Filt	6.23				8.97		13A
Rain	8.64		< 0.34 K		3.21		14A

Suspended Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Suspended Solids (mg/L)
Port 9/4 10:45am	500	640	1.0637	1.0689	0.0104
Port 9/4 12:15pm	500	A55	1.0856	1.09009	0.0090
Port 9/4 2:00pm	500	M24	1.0819	1.086	0.0082
Port 9/5 10:00am	500	N3	1.0727	1.081	0.0166

Dissolved Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Disolved Solids (mg/L)
Port 9/4 10:45am	500	"big one"	93.5257	93.55	0.0486
Port 9/4 12:15pm	500	3	79.3327	79.3641	0.0628
Port 9/4 2:00pm	500	"blank"	73.1886	73.2278	0.0784
Port 9/5 10:00am	500	I5	78.4353	78.4755	0.0804

Date Applied	9/13/2003	10:00am	Total Rainfall (mm)
Date Collected	9/15/2003	9:00am	58.4

Spectrophotometer		Temp. (°C)	Conductivity (µS/cm)			Temp. (°C)	Copper (mg/L Cu)				Total Nitrogen (mg/L N)				Total Phosphorous (mg/L $P0_4^{3-}$)		
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)		(2)		(1)		(2)		(1)		(2)
A12	7.11	23	662	663	663	22.0	< 0.021	K	< 0.021	K	4.5		5.1		0.26		0.26
A21	6.57	22.6	969	973	974	23.2	0.628	I	0.630	I	7.2		7.2		0.08		0.1
B11	6.69	25.0	242	240	240	27.5	0.029		0.027		< 2	K	< 2	K	0.12		0.14
B12	7.14	26.1	470	466	467	28.5	< 0.021	K	< 0.021	K	< 2	K	< 2	K	0.27		0.27
B13	6.79	25.9	195	195	195	29.7	< 0.021	K	< 0.021	K	< 2	K	< 2	K	0.31		0.29
Port 9/13 12:30pm Unf	7.04	21.1	22.7	23.9	22.9	17.9	0.412		0.416		< 2	K	< 2	K	0.32		0.32
Port 9/13 12:30pm Filt	7.04	21.5	21.2	21.2	21.2	18.9	0.088		0.089		< 2	K	< 2	K	< 0.06	K	0.07
Port 9/13 5:30pm Unf	7.05	20.8	33.1	33.5	33.5	17.6	0.289		0.289		< 2	K	< 2	K	0.28		0.27
Port 9/13 5:30pm Filt	7.04	21.5	34.3	34.4	34.5	19.2	0.096		0.096		6.7		6.7		0.19		0.2
Standard							2.989 (3.00)				9.3 (10.0)				0.95 (1.00)		
Spike																	

Ion Chromatograph	Cl- (mg/L Cl)				NO_2 (mg/L NO_2)				NO_3 (mg/ L NO_3)				
Sample Location	(1)		(2)		(1)		(2)		(1)		(2)		I.C. LABEL
A12	7.64		7.65		0.529		0.648		< 10.8	L	< 10.8	L	2
A21	64.51		65.12						< 10.8	L	< 10.8	L	1
B11	< 9.5	K	< 9.5	K	1.017		1.125		5.92		5.94		3
B12	< 9.5	K	< 9.5	K	1.664		1.690		6.73		6.73		4
B13	< 9.5	K	< 9.5	K	0.413		0.456		5.22		5.22		5
Port 9/13 12:30pm Unf	< 9.5	K	< 9.5	K			< 0.34	K	1.40		1.40		6
Port 9/13 5:30pm Unf	< 9.5	K	< 9.5	K	< 0.34	K	< 0.34	K	2.26		2.26		7

Suspended Solids	Volume		Pre-weight	Post-weight	Suspended Solids
Sample Location	(ml)	Tray	(mg)	(mg)	(mg/L)
Port 9/13 12:30pm	500	N12	1.087	1.1076	0.0412
Port 9/13 5:30pm	500	520	1.0894	1.0953	0.0118

Dissolved Solids	Volume		Pre-weight	Post-weight	Disolved Solids
Sample Location	(ml)	Tray	(mg)	(mg)	(mg/L)
Port 9/13 12:30pm	500	5	73.83	73.8458	0.0316
Port 9/13 5:30pm	500	I6	79.0801	79.0918	0.0234

Date Applied	9/15/2003	12:00PM	Total Rainfall (mm)
Date Collected	9/16/2003	3:15PM	58.4

Spectrophotometer		Temp. (°C)	Conductivity (µS/cm)			Temp. (°C)	Copper (mg/L Cu)				Total Nitrogen (mg/L N)				Total Phosphorous (mg/L $P0_4^{3-}$)	
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)		(2)		(1)		(2)		(1)	(2)
A12	7.34	11.5	670	675	681	5.2	< 0.021	K	< 0.021	K	6.2		6.1		0.18	0.16
A21	7.03	12.0	962	998	1004	5.8	0.602	I	0.604	I	8.1		8		0.27	0.25
B11	7.24	12.5	242	245	244	5.5	0.031		0.029		< 2	K	< 2	K	0.14	0.13
B12	7.42	13.4	444	447	450	6.9	0.037		0.037		< 2	K	< 2	K	0.27	0.25
B13	7.04	14.8	185	185	187	7.9	< 0.021	K	0.022		< 2	K	< 2	K	0.25	0.24
Port 9/15 5:45pm Unf	6.97	15.9	82.3	84.0	84.3	8.4	0.189		0.190		< 2	K	< 2	K	0.17	0.18
Port 9/15 5:45pm Filt	6.95	17.2	84.7	84.4	84.4	9.0	0.159		0.161		< 2	K	< 2	K	0.18	0.18
Port 9/16 3:15pm Unf	7.00	17.1	115.8	116.6	116.8	9.1	0.085		0.083		< 2	K	< 2	K	0.16	0.18
Port 9/16 3:15pm Filt	7.03	18.7	118.3	118.1	118.1	10.4	0.061		0.06		< 2	K	< 2	K	0.17	0.18
Standard							3.010 (3.00)				9.7 (10.0)				.98 (1.00)	
Spike																

Ion Chromatograph	Cl- (mg/L Cl)		NO_2 (mg/L NO_2)		NO_3 (mg/ L NO_3)		
Sample Location	(1)	(2)	(1)	(2)	(1)	(2)	I.C. LABEL
A12							
A21							
B11							
B12							
B13							
Port 9/15 5:45pm Unf							
Port 9/16 3:15pm Unf							

Suspended Solids	Volume		Pre-weight	Post-weight	Suspended Solids
Sample Location	(ml)	Tray	(mg)	(mg)	(mg/L)
Port 9/15 5:45pm	500	11	1.1025	1.1063	0.0076
Port 9/16 3:15pm	500	621	1.0849	1.0873	0.0048

Dissolved Solids	Volume		Pre-weight	Post-weight	Disolved Solids
Sample Location	(ml)	Tray	(mg)	(mg)	(mg/L)
Port 9/15 5:45pm	500	11	78.43	78.4577	0.0554
Port 9/16 3:15pm	500	621	75.4774	75.5142	0.0736

Date Applied	9/18/2003	5:15PM	Total Rainfall (mm)
Date Collected	9/19/2003	9:15AM	32.3

Spectrophotometer		Temp. (°C)	Conductivity (µS/cm)			Temp. (°C)	Copper (mg/L Cu)				Total Nitrogen (mg/L N)			Total Phosphorous (mg/L $P0_4^{3}$)	
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)		(2)		(1)		(2)	(1)	(2)
A12	7.28	25.3	983	987	988	25.1	< 0.021	K	< 0.021	K	8.9			0.27	
A21	6.65	25.4	714	715	715	25.1	0.659	I	0.659	I	> 25	L		0.13	
B11	7.1	25.3	244	244	244	25	0.036		0.034					0.15	
B12	7.35	25.4	450	450	450	25	< 0.021	K	< 0.021	K	1.3				
B13	6.88	25.4	184	184.2	184.2	25	< 0.021	K	< 0.021	K	1.6			0.33	
Port 9/19 9:15am Unf	7.35	25.5	153.2	153.4	153.4	25.2	0.159		0.160		1.6			0.22	
Port 9/19 9:15am Filt	6.03	25.6	187.1	187.2	187.2	25.3	0.137		0.140		1.5			0.23	
Dwnspt 9/18 5:15pm Unf	4.91	25.5	40.1	40.1	40.1	24.9	1.17		1.171		1.4			0.08	
Dwnspt 9/18 5:15pm Filt	4.97	25.5	42.9	43.1	43.1	25.2	1.172		1.171		1.5			0.08	
Standard							3.01 (3.00)				9.9 (10.0)			0.98 (1.00)	
Spike															

Ion Chromatograph	Cl- (mg/L Cl)		NO_2 (mg/L NO_2)		NO_3 (mg/ L NO_3)		
Sample Location	(1)	(2)	(1)	(2)	(1)	(2)	I.C. LABEL
A12							
A21							
B11							
B12							
B13							
Port 9/19 9:15am Unf							
Dwnspt 9/18 5:15pm Unf							

Suspended Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Suspended Solids (mg/L)
Port 9/18 5:15pm	500	N15	1.0587	1.061	0.0046
Port 9/19 9:15am	500	A40	1.0867	1.0877	0.0020

Dissolved Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Disolved Solids (mg/L)
Port 9/18 5:15pm	500	10	115.0971	115.148	0.1018
Port 9/19 9:15am	500	11	116.44	116.4537	0.0274

Date Applied	9/23/2003	9:45AM	Total Rainfall (mm)
Date Collected	9/24/2003	9:00AM	23.6

Spectrophotometer		Temp. (°C)	Conductivity (µS/cm)			Temp. (°C)	Copper (mg/L Cu)				Total Nitrogen (mg/L N)		Total Phosphorous (mg/L $P0_4^{3-}$)	
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)		(2)		(1)	(2)	(1)	(2)
A12	7.14	19.5	810	809	809	20.8	0.033		0.032		10.3	10.7	0.06	0.07
A21	6.51	21.9	982	988	989	20	0.659	I	0.659	I	7.5	7.3	0.19	0.18
B11	6.83	24.6	232	233	233	22	0.032		0.033		< 2	< 2	0.07	0.06
B12	7.05	25.4	436	434	435	22.9	< 0.021	K	< 0.021	K	< 2	< 2	0.18	0.16
B13	6.63	25.3	171.1	171.7	171.8	22.8	< 0.021	K	< 0.021	K	< 2	< 2	0.22	0.21
Port 9/23 9:45am Unf	6.84	8.5	63	63.6	63.7	15.9	0.267		0.266		< 2	< 2	0.18	0.16
Port 9/23 9:45am Filt	6.86	12.2	64	63.8	63.9	16.5	0.215		0.217		< 2	< 2	0.18	0.17
Port 9/24 9:00am Unf	7.2	21	112.9	112.4	112.5	20.4	0.091		0.094		< 2	< 2	0.17	0.16
Port 9/24 9:00am Filt	7.27	20.3	109.8	109.9	110	20.1	0.053		0.052		< 2	< 2	0.15	0.15
Dwnspt 9/23 9:45pm Unf	7.78	12.3	5.85	5.88	5.92	15.3	0.365		0.369		< 2	< 2	0.06	0.06
Dwnspt 9/23 9:45pm Filt	7.6	14.8	6.65	6.65	6.62	16.6	0.272		0.265		< 2	< 2	0.07	0.06
Standard							3.080 (3.000)				10.6 (10.0)		1.01 (1.0)	
Spike														

Ion Chromatograph	Cl- (mg/L Cl)				NO_2 (mg/L NO_2)				NO_3 (mg/ L NO_3)				
Sample Location	(1)		(2)		(1)		(2)		(1)		(2)		I.C. LABEL
A12	10.67		10.7						< 9.7	L	< 9.7	L	2D
A21	49.39		49.83		1.297		1.268		< 9.7	L	< 9.7	L	1D
B11	10.67		10.7		1.646		1.663		3.69		3.69		3D
B12	< 9.7	K	< 9.7	K	2.676		2.723		4.7		4.72		4D
B13	< 9.7	K	< 9.7	K	1.265		1.278		6.55		6.66		5D
Port 9/23 9:45am Unf	< 9.7	K	< 9.7	K		M		M	2.53		2.55		6D
Port 9/24 9:00am Unf	< 9.7	K	< 9.7	K	0.943		0.947		3.64		3.64		7D
Dwnspt 9/23 9:45pm Unf	< 9.7	K	< 9.7	K		M		M	0.84		0.84		8D

Suspended Solids	Volume		Pre-weight	Post-weight	Suspended Solids
Sample Location	(ml)	Tray	(mg)	(mg)	(mg/L)
Port 9/23 9:45am	500	E46	1.0611	1.0673	0.0124
Port 9/24 9:00am	500	E43	1.0656	1.0685	0.0058
Dwnspt 9/23 9:45pm	500	826	1.0808	1.0818	0.0020

Dissolved Solids	Volume		Pre-weight	Post-weight	Disolved Solids
Sample Location	(ml)	Tray	(mg)	(mg)	(mg/L)
Port 9/23 9:45am	500	4	73.1853	73.2029	0.0352
Port 9/24 9:00am	500	"big one"	93.5235	93.5593	0.0716
Dwnspt 9/23 9:45pm	500	1	73.7749	73.7796	0.0094

Date Applied	10/4/2003	11:00AM	Total Rainfall (mm)
Date Collected	10/6/2003	9:15AM	2.8

Spectrophotometer		Temp. (°C)	Conductivity (µS/cm)			Temp. (°C)	Copper (mg/L Cu)				Total Nitrogen (mg/L N)				Total Phosphorous (mg/L PO_4^{3-})	
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)		(2)		(1)		(2)		(1)	(2)
A12	7.47	21.6	757	758	759	21.5					7.1		7.3		0.09	0.08
A21	6.58	21.8	1023	1026	1021	21.6	0.669	I	0.659	I	7.2		7.1		0.14	0.13
B11							< 0.021	K	< 0.021	K	< 2	K	< 2	K	0.17	0.18
B12	7.21	21.6	437	437	437	21.5	< 0.021	K	< 0.021	K	< 2	K	< 2	K	0.18	0.18
B13	6.96	21.5	164	164.3	164.3	21.5	< 0.021	K	< 0.021	K	< 2	K	< 2	K	0.26	0.27
Dwnspt 10/4 11:00am Unf	6.2	21.2	24.6	24.6	24.6	21.3	1.296		1.295		< 2	K	< 2	K	0.11	0.12
Dwnspt 10/4 11:00am Filt	6.1	21.2	25.9	25.9	25.9	21.4	1.292		1.296		< 2	K	< 2	K	0.11	0.11
Standard							3.010 (3.000)				10.0 (10.0)				0.99 (1.00)	
Spike																

Ion Chromatograph	Cl- (mg/L Cl)				NO_2 (mg/L NO_2)				NO_3 (mg/ L NO_3)				
Sample Location	(1)		(2)		(1)		(2)		(1)		(2)		I.C. LABEL
A12	< 9.7	K	< 9.7	K					> 9.7	L	> 9.7	L	2E
A21	51.87		51.86		0.646		0.625		> 9.7	L	> 9.7	L	1E
B11	< 9.7	K	< 9.7	K	1.063		1.035		1.23		1.23		3E
B12	< 9.7	K	< 9.7	K	1.642		1.64		3.4		3.39		4E
B13	< 9.7	K	< 9.7	K	0.685		0.661		3.8		3.79		5E
Dwnspt 10/4 11:00am Unf	< 9.7	K	< 9.7	K	< 0.33	K	< 0.33	K	3.26		3.22		6E

Suspended Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Suspended Solids (mg/L)
Dwnspt 10/4 11:00am	500	m8	1.0761	1.0765	0.0008

Dissolved Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Disolved Solids (mg/L)
Dwnspt 10/4 11:00am	500	12	110.3056	110.3101	0.0090

			Total Rainfall (mm)
Date Applied	10/22/2003	9:30AM	
Date Collected	10/23/2003	9:30AM	2.5

Spectrophotometer		Temp. (°C)	Conductivity (µS/cm)			Temp. (°C)	Copper (mg/L Cu)				Total Nitrogen (mg/L N)				Total Phosphorous (mg/L P0$_4^{3-}$)	
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)		(2)		(1)		(2)		(1)	(2)
A21	6.58	19.2	1029	1025	1025	19.4	0.406	I	0.403	I	7.2				0.11	0.12
B11	6.92	19.8	248	248	248	19.6	< 0.021	K	< 0.021	K	< 2	K	< 2	K	0.25	0.24
B12	7.14	19.8	413	414	415	19.6	0.025		0.029		< 2	K	< 2	K	0.31	0.33
B13	6.99	19.8	161.9	162.1	162.2	19.5	< 0.021		< 0.021		< 2	K	< 2	K	0.3	0.35
Dwnspt 10/22 9:30am Unf	4.22	19.8	36.2	37	37.2	18.9	0.943		0.947		< 2	K	< 2	K	0.16	0.14
Dwnspt 10/22 9:30am Filt	3.48	19	139.5	143.2	143.1	19.1	0.951		0.949		< 2	K	< 2	K	0.17	0.15
Standard							3.041 (3.000)				9.9 (1.0)				0.98 (1.00)	
Spike																

Ion Chromatograph	Cl- (mg/L Cl)				NO$_2$ (mg/L NO$_2$)		NO$_3$ (mg/ L NO$_3$)		
Sample Location	(1)		(2)		(1)	(2)	(1)	(2)	I.C. LABEL
A21	65.95		66.12						1G
B11	< 9.7	K	< 9.7	K	0.535	0.531			2G
B12	< 9.7	K	< 9.7	K	0.785	0.78			3G
B13	< 9.7	K	< 9.7	K	0.432	0.451			4G
Dwnspt 10/22 9:30am Unf	15.26		15.31		0.384	0.379			5G

Suspended Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Suspended Solids (mg/L)
Dwnspt 10/22 9:30am	500	n12	1.0861	1.0866	0.0010

Dissolved Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Disolved Solids (mg/L)
Dwnspt 10/22 9:30am	500	13	109.8513	109.8584	0.0142

Date Applied	10/27/2003	9:45AM	Total Rainfall (mm)
Date Collected	10/28/2003	9:45AM	69.3

Spectrophotometer		Temp. (°C)	Conductivity (µS/cm)			Temp. (°C)	Total Copper (mg/L Cu)			Total Nitrogen (mg/L N)				Total Phosphorous (mg/L PO_4^{3-})	
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)		(2)	(1)		(2)		(1)	(2)
A21	6.56	17.6	1025	1025	1024	21	0.572	I		8.9		9		0.67	
B11	6.91	19	236	236	237	20.8	0.055			< 2	K	< 2	K	0.64	
B12	7.2	20.7	408	408	409	21.2	0.055			< 2	K	< 2	K	0.26	0.25
B13	6.85	21	169.7	170.1	170.2	20.8	< 0.021	K		< 2	K	< 2	K	0.44	
Port 10/27 9:45am Unf	7.08	12.7	75.3	75.4	75.4	20.2	0.293			< 2	K	< 2	K	0.3	
Port 10/27 9:45am Filt	7.12	13.9	75.7	76	75.9	20									
Port 10/27 11:45am Unf	7.18	12.7	56.4	56.5	56.5	19.8	0.31			2		< 2	K		
Port 10/27 11:45am Filt	7.15	13.9	56.5	56.5	56.6	19.9									
Port 10/28 9:45am Unf	7.89	18.2	108	108.3	108.3	20.2				< 2	K	2.1			
Port 10/28 9:45am Filt	7.2	18.7	115.3	115.7	115.8	20.2									
Dwnspt 10/27 9:45am Unf	6.64	17	13.34	13.32	13.35	20.2	0.671		0.672	< 2	K	< 2	K	0.16	
Dwnspt 10/27 9:45am Filt	6.43	18.4	14.78	14.76	14.7	20.3									
Dwnspt 10/27 11:45am Unf	6.57	18.6	7.5	7.51	7.5	20.3	0.467		0.463	< 2	K	< 2	K		
Dwnspt 10/28 11:45am Filt	6.46	19	8.9	8.95	8.96	20.4									
Rainwater	6.5	5.9	15.38	13.53	13.3	20.2	0.046			< 2	K	< 2	K		
Standard							3.003 (3.000)			10.3 (1.0)				1.01 (1.00)	
Spike															

Ion Chromatograph	Cl-				NO_2		NO_3				
Sample Location	(1)		(2)		(1)	(2)	(1)		(2)		I.C. LABEL
A12											
A21	70.3		70.49		0.999	0.867					
B11	< 9.7	K	< 9.7	K	1.758	1.693					
B12	< 9.7	K	< 9.7	K	2.621	2.669					
B13	< 9.7	K	< 9.7	K	0.842	0.848					
Port 10/27 9:45am Unf	< 9.7	K	< 9.7	K	0.616	0.63	> 9.4	L	> 9.4	L	
Dwnspt 10/27 9:45am Unf	< 9.7	K	< 9.7	K	0.391	0.391	> 9.4	L	> 9.4	L	
Port 10/27 11:45am Unf	< 9.7	K	< 9.7	K	0.536	0.528	> 9.4	L	> 9.4	L	
Dwnspt 10/27 11:45am Unf	< 9.7	K	< 9.7	K	0.389	0.394	> 9.4	L	> 9.4	L	
Port 10/28 9:45am Unf	< 9.7	K	< 9.7	K	0.716	0.675	> 9.4	L			
Rainwater	< 9.7	K	< 9.7	K	0.413	0.408	> 9.4	L	> 9.4	L	

Suspended Solids					Suspended Solids
Sample Location	Vol. (ml)	Tray	Pre-weight	Post-weight	(mg/L)
Port 10/27 9:45am	500	640	1.0597	1.0686	0.0178
Dwnspt 10/27 9:45am	500	m87	1.0546	1.0549	0.0006
Port 10/27 11:45am	500	504	1.0896	1.0914	0.0036
Dwnspt 10/27 11:45am	500	619	1.078	1.078	0.0000
Port 10/28 9:45am	500	153	1.0942	1.096	0.0036

Disolved Solids					Disolved Solids	
Sample Location	Vol. (ml)	Tray	Pre-weight	Post-weight	(mg/L)	
Port 10/27 9:45am	500	B21	110.9045	110.9161	0.0232	
Dwnspt 10/27 9:45am	500	M27	117.6697	117.6698	0.0002	
Port 10/27 11:45am	500	SB	116.3735	116.3801	0.0132	
Dwnspt 10/27 11:45am	500	L8	116.3637	116.3635	-0.0004	I
Port 10/28 9:45am	500	L4	115.3448	115.3663	0.0430	

Date Applied	10/29/2003	10:45AM	Total Rainfall (mm)
Date Collected	10/30/2003	9:45AM	34.5

Spectrophotometer		Temp. (°C)	Conductivity (µS/cm)			Temp. (°C)	Copper (mg/L Cu)				Total Nitrogen (mg/L N)				Total Phosphorous (mg/L PO_4^{3-})	
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)		(2)		(1)		(2)		(1)	(2)
A21	6.61	19.6	1002	999	1001	15.1	0.129	I	0.133	I	8.2		8.1		0.25	0.24
B11	6.92	19.7	229	230	230	15.2	< 0.021	K	< 0.021	K	< 2	K	< 2	K	0.16	0.17
B12	7.16	19.7	398	401	400	15.8	< 0.021	K	< 0.021	K	< 2	K	< 2	K	0.25	0.26
B13	7.34	19.8	167.3	168.1	168.3	15.9	< 0.021	K	< 0.021	K	< 2	K	< 2	K	0.51	0.53
Port 10/29 10:45am Unf	7.12	19.8	87.6	87.7	87.7	15.6	0.118		0.12		< 2	K	< 2	K	0.33	0.35
Port 10/29 10:45am Filt	7.06	20.3	82.8	82.8	82.8	16.3	0.12		0.119		< 2	K	< 2	K	0.32	0.29
Port 10/30 9:45am Unf	7.24	19.5	105.6	106.1	106	16.9	0.073		0.074		< 2	K	< 2	K	0.27	0.25
Port 10/30 9:45am Filt	7.19	20.3	105.1	105.4	105.4	17	*0.067*		0.064		< 2	K	< 2	K	0.21	0.24
Dwnspt 10/29 10:45am Unf	4.3	18.5	16.5	16.6	16.58	17	0.495		0.497		< 2	K	< 2	K	0.14	0.17
Dwnspt 10/29 10:45am Filt	4.22	18.5	43	43	43.1	17.3	0.5		0.501		< 2	K	< 2	K	0.13	0.12
Standard							3.009 (3.000)				9.7 (1.0)				1.01 (1.00)	
Spike							2.975 (2.908)				2.2 (2.1)				.63 (.64)	

Ion Chromatograph	Cl- (mg/L Cl)				NO_2 (mg/L NO_2)				NO_3 (mg/ L NO_3)		
Sample Location	(1)		(2)		(1)		(2)		(1)	(2)	I.C. LABEL
A21	99.6		101.28			N		N			1J
B11	< 9.7	K	< 9.7	K		N		N			2J
B12	< 9.7	K	< 9.7	K		N		N			3J
B13	< 9.7	K	< 9.7	K		N		N			4J
Port 10/29 10:45am Unf	< 9.7	K	< 9.7	K		N		N			5J
Dwnspt 10/29 10:45am Unf	< 9.7	K	< 9.7	K		N		N			6J
Port 10/30 9:45am Unf	< 9.7	K	< 9.7	K		N		N			7J

Suspended Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Suspended Solids (mg/L)
Port 10/29 10:45am	500	361	1.0799	1.0809	0.0020
Dwnspt 10/29 10:45am	500	A77	1.0884	1.0885	0.0002
Port 10/30 9:45am	500	120	1.0768	1.079	0.0044

Dissolved Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Disolved Solids (mg/L)
Port 10/29 10:45am	500	274	94.6383	94.6474	0.0182
Dwnspt 10/29 10:45am	500	69	108.2814	108.2837	0.0046
Port 10/30 9:45am	500	SC	101.8972	101.9216	0.0488

Date Applied:	11/6/2003	1:00PM	Total Rainfall (mm)
Date Collected:	11/7/2003	9:00AM	19.8

Spectrophotometer		Temp. (°C)	Conductivity (µS/cm)			Temp. (°C)	Copper (mg/L Cu)				Total Nitrogen (mg/L N)				Total Phosphorous (mg/L P0$_4^{3-}$)	
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)		(2)		(1)		(2)		(1)	(2)
A21	6.78	21.3	969	976	974	21.1	0.25	I	0.249	I	7.1		7.2		0.39	0.43
B11	7.14	21.3	223	223	223	21.4	< 0.021	K	0.021		< 2	K	< 2	K	0.26	0.29
B12	7.34	21.4	396	395	395	21.5	< 0.021	K	< 0.021	K	< 2	K	< 2	K	0.33	0.34
B13	7.02	21.2	168.9	169.7	169.7	21.3	< 0.021	K	< 0.021	K	< 2	K	< 2	K	0.55	0.54
Dwnspt 11/6 1:00pm Unf	4.17	21	56	57	57.2	21	2.092		2.081		< 2	K	< 2	K	0.45	0.51
Dwnspt 11/6 1:00pm Filt	4.18	21	59	59.6	59.5	21.1	2.08		2.079		< 2	K	< 2	K	0.16	0.19
Port 11/07 9:00am Unf	6.84	21.2	186.4	186.3	186.3	21.2	< 0.021	K	0.021		< 2	K	< 2	K	0.3	0.31
Port 11/07 9:00am Filt	7.09	21.2	185	185.9	185.9	21.4	< 0.021	K	< 0.021	K	< 2	K	< 2	K	0.29	0.3
Standard							3.003 (3.000)				9.7 (10.0)				1.01 (1.00)	
Spike							2.975 (2.908)				2.2 (2.08)				0.63 (0.64)	

Ion Chromatograph	Cl- (mg/L Cl)				NO$_2$ (mg/L NO$_2$)				NO$_3$ (mg/ L NO$_3$)				
Sample Location	(1)		(2)		(1)		(2)		(1)		(2)		I.C. LABEL
A21	60.63		62.86			N		N		N		N	A21
B11	< 5.6	K	< 5.6	K		N		N		N		N	B11
B12	< 5.6	K	< 5.6	K		N		N		N		N	B12
B13	< 5.6	K	< 5.6	K		N		N		N		N	B13
Dwnspt 11/6 1:00pm Unf	< 5.6	K	< 5.6	K		N		N		N		N	GU
Port 11/07 9:00am Unf	14.17		14.2			N		N		N		N	PU

Suspended Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Suspended Solids (mg/L)
Dwnspt 11/6 1:00pm	500	A77	1.0888	1.0887	-0.0002
Port 11/07 9:00am	500	M42	1.0918	1.0927	0.0018

Dissolved Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Disolved Solids (mg/L)
Dwnspt 11/6 1:00pm	500	SA	93.5169	93.5281	0.0224
Port 11/07 9:00am	500	13	109.8468	109.9056	0.1176

Date Applied	11/19/2003	4:00PM	Total Rainfall (mm)
Date Collected	11/20/2003	8:30AM	41.7

Spectrophotometer		Temp. (°C)	Conductivity (µS/cm)			Temp. (°C)	Copper (mg/L Cu)				Total Nitrogen (mg/L N)				Total Phosphorous (mg/L P0$_4^{3-}$)	
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)		(2)		(1)		(2)		(1)	(2)
A21	6.54	17.1	1045	1046	1045	20.7	0.001		0.002		8.9		9.1		0.08	0.07
B11	6.91	19.4	250	250	250	21.1	< 0.021	K	< 0.021	K	< 2	K	< 2	K	0.11	0.12
B12	7.25	20.6	390	391	390	21.6	< 0.021	K	< 0.021	K	< 2	K	< 2	K	0.26	0.24
B13	7.01	21.5	180.6	180.7	180.7	21.5	0.022		0.025		< 2	K	< 2	K	0.34	0.34
Dwnspt 11/19 4:00pm Unf	6.3	15.3	46.3	46.3	46.3	18.2	1.59		1.62		< 2	K	2		0.05	0.05
Dwnspt 11/19 4:00pm Filt	6.02	17	50.4	50.7	50.7	19.1	1.642		1.624		< 2	K	2		0.02	0.01
Port 11/20 8:30am Unf	6.89	19.3	94.4	94.5	94.5	20.1	0.14		0.143		< 2	K	< 2	K	0.13	0.13
Port 11/20 8:30am Filt	6.87	19.8	97.7	98.1	98.1	20.3	0.14		0.135		< 2	K	< 2	K	0.1	0.12
Standard							4.011 (4.000)				9.1 (10.0)				0.99 (1.00)	
Spike							3.75 (3.76)				2.7 (2.8)				0.24 (0.28)	

Ion Chromatograph	Cl- (mg/L Cl)				NO$_2$ (mg/L NO$_2$)				NO$_3$ (mg/ L NO$_3$)				
Sample Location	(1)		(2)		(1)		(2)		(1)		(2)		I.C. LABEL
A21	114.29		116.26		< 0.460	K	< 0.460	K	> 12.76	L	> 12.76	L	A21
B11	< 4.7	K	< 4.7	K	2.459		2.391		10.58		10.76		B11
B12	< 4.7	K	< 4.7	K	3.888		3.901		4.04		4.04		B12
B13	< 4.7	K	< 4.7	K	1.584		1.875		5.28		5.35		B13
Dwnspt 11/19 4:00pm Unf	8.31		8.29		< 0.460	K			7.16		7.17		GU
Port 11/20 8:30am Unf	< 4.7	K	< 4.7	K	< 0.460	K	< 0.460	K	2.91		2.78		PU

Suspended Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Suspended Solids (mg/L)
Dwnspt 11/19 4:00pm	500	M3	1.113	1.1161	0.0062
Port 11/20 8:30am	500	857	1.1167	1.1123	-0.0088

Dissolved Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Disolved Solids (mg/L)
Dwnspt 11/19 4:00pm	200	L4	115.3286	115.3310	0.0120
Port 11/20 8:30am	200	M27	117.6593	117.6720	0.0635

Date Applied	12/8/2003	12/9/2003	12/11/2003	**SNOW STORM
Date Collected	12/9/2003	12/11/2003	12/12/2003	

Spectrophotometer		Temp. (°C)	Conductivity (µS/cm)			Temp. (°C)	Copper (mg/L Cu)		Total Nitrogen (mg/L N)		Total Phosphorous (mg/L $P0_4^{3-}$)	
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)	(2)	(1)	(2)	(1)	(2)
12/9/03 A21	6.63	15.2	1099	1100	1100	15.2						
12/9/03 B11	7.05	13.4	243	245	245	13.4						
12/9/03 B12	7.17	12.9	376	376	376	12.9						
12/9/03 B13	7.38	12.7	202	203	203	12.7						
12/11/03 A21	6.67	12.9	1126	1127	1126	12.9						
12/11/03 B12	7.05	12.7	411	411	412	12.7						
12/11/03 B13	7.25	13.3	213	213	213	13.3						
12/12/03 A21	6.89	13.7	1106	1107	1107	13.7						
12/12/03 B11	6.84	14.2	834	835	834	14.2						
12/12/03 B12	7.25	15	371	370	371	15						
12/12/03 B13	7.41	15.9	232	232	233	15.9						
Standard												
Spike												

Ion Chromatograph	Cl- (mg/L Cl)		NO_2 (mg/L NO_2)		NO_3 (mg/ L NO_3)		
Sample Location	(1)	(2)	(1)	(2)	(1)	(2)	I.C. LABEL
12/9/03 A21	116.3						
12/9/03 B11	10.8						
12/9/03 B12	2.9						
12/9/03 B13	4.98						
12/11/03 A21	145						
12/11/03 B12	62.5						
12/11/03 B13	19.4						
12/12/03 A21	122.5						
12/12/03 B11	184						
12/12/03 B12	8.9						
12/12/03 B13	47						

Suspended Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Suspended Solids (mg/L)

Dissolved Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Disolved Solids (mg/L)

Date Applied 2/2/2004 2/3/2004 **SNOW STORM
Date Collected 2/3/2004 2/4/2004

Spectrophotometer		Temp. (°C)	Conductivity (µS/cm)			Temp. (°C)	Copper (mg/L Cu)		Total Nitrogen (mg/L N)		Total Phosphorous (mg/L P0$_4^{3-}$)	
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)	(2)	(1)	(2)	(1)	(2)
2/3/2004 B12	7.06	20.8	397	396	396		< 0.021 K		< 2 K		0.1	0.11
2/3/2004 B13	6.89	19.7	475	476	476		< 0.021 K		< 2 K	< 2 K	0.3	
2/4/2004 A21											< 0.06 K	
2/4/2004 B11	6.31	19.1	2370	2380	2380		< 0.021 K		< 2 K		0.09	
2/4/2004 B12	6.85	19.7	404	399	399		< 0.021 K	< 0.021 K	2 K		0.27	
2/4/2004 B13	6.93	19.4	447	448	448		< 0.021 K		< 2 K	< 2 K		
Port 2/3 1:30pm Unf	9.67	16.1	1394	1412	1414							
Standard							3.996 (4.000)		10.2 (10.0)		0.99 (1.00)	
Spike							3.593 (3.601)		2.78 (2.72)		0.28 (0.28)	

Ion Chromatograph	Cl- (mg/L Cl)		NO$_2$ (mg/L NO$_2$)		NO$_3$ (mg/ L NO$_3$)		
Sample Location	(1)	(2)	(1)	(2)	(1)	(2)	I.C. LABEL
2/3/2004 B12	19.4		< 1.0 K		< 1.0 K		
2/3/2004 B13	116.6		< 1.0 K		< 1.0 K		
2/4/2004 A21							
2/4/2004 B11	733.6		< 1.0 K		< 1.0 K		
2/4/2004 B12	41		< 1.0 K		< 1.0 K		
2/4/2004 B13	91.1		< 1.0 K		< 1.0 K		
Port 2/3 1:30pm Unf	402.9		< 1.0 K		< 1.0 K		

Suspended Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Suspended Solids (mg/L)

Dissolved Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Disolved Solids (mg/L)

Date Applied	2/6/2004	4:00PM	**SNOW STORM
Date Collected	2/9/2004	8:30AM	

Spectrophotometer		Temp. (°C)	Conductivity (µS/cm)			Temp. (°C)	Copper (mg/L Cu)				Total Nitrogen (mg/L N)			Total Phosphorous (mg/L P0$_4^{3-}$)		
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)		(2)		(1)		(2)	(1)		(2)
A21	6.5	12.6	978	982	981	12.6	< 0.021	K			4.4			*0.1*		0.1
B11	5.93	13.7	3860	3880	3890	13.7	< *0.021*	K			< *2*	K		0.06		
B12	7.11	14.8	366	364	372	14.8	< 0.021	K	< 0.021	K	< 2	K		0.08		
B13	7.05	16.2	384	384	383	16.2	< 0.021	K			< 2	K	0.8	0.21		
Dwnspt 2/6 1:30pm Unf	4.75	8.8	21.4	21.3	21.2	8.8	0.447				< 2	K		< 0.06	K	
Dwnspt 2/6 1:30pm Filt							0.448				< 2	K		< 0.06	K	
Port 2/6 1:30pm Unf	6.65	10.6	2820	2880	2880	10.6	0.387				< 2	K		0.15		
Port 2/6 1:30pm Filt							0.384				< 2	K		0.16		
Standard							3.996 (4.000)				10.2 (10.0)			0.99 (1.00)		
Spike							3.593 (3.601)				2.78 (2.72)			0.28 (0.28)		

Ion Chromatograph	Cl- (mg/L Cl)				NO$_2$ (mg/L NO$_2$)			NO$_3$ (mg/ L NO$_3$)			
Sample Location	(1)		(2)		(1)		(2)	(1)		(2)	I.C. LABEL
A21	83.8				< 1.0	K		< 1.0	K		
B11	1190.1	D			< 1.0	K		< 1.0	K		
B12	11.5				< 1.0	K		< 1.0	K		
B13	69.8				< 1.0	K		< 1.0	K		
Dwnspt 2/6 1:30pm	3.7				< 1.0	K		< 1.0	K		
Port 2/6 1:30pm	781	D	764.5	D	< 1.0	K		< 1.0	K		

Suspended Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Suspended Solids (mg/L)
Dwnspt 2/6 1:30pm	200	A29	1.1188	1.1189	0.0005
Port 2/6 1:30pm	200	A78	1.117	1.1182	0.0060

Dissolved Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Disolved Solids (mg/L)
Dwnspt 2/6 1:30pm	200	69	108.8125	108.8136	0.0055
Port 2/6 1:30pm	200	87	116.3499	116.7164	1.8325

Date Applied	3/17/2004	9:00AM	Total Rainfall (mm)
Date Collected	3/18/2004	8:30AM	1.5

Spectrophotometer		Temp. (°C)	Conductivity (µS/cm)			Temp. (°C)	Copper (mg/L Cu)			Total Nitrogen (mg/L N)				Total Phosphorous (mg/L P0$_4^{3-}$)	
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)		(2)	(1)		(2)		(1)	(2)
A21	6.68		922	920	921		< 0.021	K		*5*				0.29	
B11	6.67		942	942	942		< 0.021	K		< 2	K			0.39	
B12	6.65		1320	1321	1321		< 0.021	K		< 2	K			0.32	0.38
B13	6.29		3140	3150	3140		< 0.021	K		< 2	K			0.56	
Dwnspt 3/18 8:30am Unf	5.95		14.5	14.5	14.5		*1.125*		1.126	< 2	K	< 2	K	0.15	
Dwnspt 3/18 8:30am Filt							0.448								
Standard							3.996 (4.000)			10 (10.0)				1.02 (1.00)	
Spike							3.423 (3.425)			6 (6)					

Ion Chromatograph	Cl- (mg/L Cl)			NO$_2$ (mg/L NO$_2$)			NO$_3$ (mg/ L NO$_3$)			
Sample Location	(1)		(2)	(1)		(2)	(1)		(2)	I.C. LABEL
A21	52.1			< 1.0	K		< 1.0	K		
B11	222.2			< 1.0	K		< 1.0	K		
B12	362.7			< 1.0	K		< 1.0	K		
B13	904.8	D		< 1.0	D		< 1.0	D		
Dwnspt 3/18 8:30am	1.3			< 1.0	K		< 1.0	K		

Suspended Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Suspended Solids (mg/L)
Dwnspt 3/18 8:30am	400	22	1.1229	1.1229	0.0000

Dissolved Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Disolved Solids (mg/L)
Dwnspt 3/18 8:30am	400	613	112.2056	112.2093	0.0092

Date Applied	3/31/2004	2:00PM	Total Rainfall (mm)
Date Collected	4/1/2004	8:30AM	17.0

Spectrophotometer		Temp. (°C)	Conductivity (µS/cm)			Temp. (°C)	Copper (mg/L Cu)		Total Nitrogen (mg/L N)		Total Phosphorous (mg/L P0₄ $^{3-}$)	
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)	(2)	(1)	(2)	(1)	(2)
A21	6.7		902	902	901		< 0.021 K		*3*	3	0.11	
B11	6.43		929	932	931		< 0.021 K		< 2 K		0.07	
B12	6.66		923	921	922		< 0.021 K		< 2 K		*0.07*	0.07
B13	6.58		1468	1469	1471		< 0.021 K		< 2 K		0.12	
Port 3/31 2:00pm Unf	8.55		1109	1123	1123		*0.301*	0.303	< 2 K		0.22	
Standard							3.998 (4.000)		10 (10.0)		1.02 (1.00)	
Spike							3.262 (3.260)		4 (4.4)		0.81 (0.81)	

Ion Chromatograph	Cl- (mg/L Cl)		NO_2 (mg/L NO_2)		NO_3 (mg/ L NO_3)		
Sample Location	(1)	(2)	(1)	(2)	(1)	(2)	I.C. LABEL
A21	18		< 1.0 K		< 1.0 K		
B11	213.2		< 1.0 K		< 1.0 K		
B12	231.1		< 1.0 K		< 1.0 K		
B13	416.9		< 1.0 K		< 1.0 K		
Port 3/31 2:00pm	250.8		< 1.0 K		< 1.0 K		

Suspended Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Suspended Solids (mg/L)
Port 3/31 2:00pm	400	292	1.1114	1.1129	0.0038

Dissolved Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Disolved Solids (mg/L)
Port 3/31 2:00pm	400	999	108.2583	108.4702	0.5298

Date Applied	4/13/2004	10:30AM	Total Rainfall (mm)
Date Collected	4/14/2004	8:30AM	53.3

Spectrophotometer		Temp. (°C)	Conductivity (μS/cm)			Temp. (°C)	Copper (mg/L Cu)		Total Nitrogen (mg/L N)		Total Phosphorous (mg/L $P0_4^{3-}$)	
Sample Location	pH	*pH*	(1)	(2)	(3)	*Cond.*	(1)	(2)	(1)	(2)	(1)	(2)
A21	6.77	23.6	395	397	397		< 0.021 K		*5.6*		*0.07*	0.06
B11	6.72	23.7	840	844	840		< 0.021 K		< 2 K		< 0.06 K	
B12	6.73	23.4	1140	1142	1142		< 0.021 K		< 2 K		0.08	
B13	6.63	23.5	929	930	929		< 0.021 K		2		0.1	
Port 4/13 10:30am Unf	7.14	19.4	99	98.6	98.5		0.151		< 2 K		0.1	
Dwnspt 4/13 10:30am Unf	6.35	21.1	12.14	12.19	12.15		*1.204*	1.205	< 2 K		< 0.06 K	
Port 4/14 8:30am Unf	7.03	18.5	137.2	137.1	137.21		0.14		< 2 K		< 0.06 K	
Standard							3.997 (4.000)		10 (10)		0.95 (1.00)	
Spike							3.440 (3.441)		6 (6)		0.24 (0.24)	

Ion Chromatograph	Cl- (mg/L Cl)		NO_2 (mg/L NO_2)		NO_3 (mg/ L NO_3)		
Sample Location	(1)	(2)	(1)	(2)	(1)	(2)	I.C. LABEL
A21	16.7		< 1.0 K		< 1.0 K		
B11	23.0		< 1.0 K		< 1.0 K		
B12	202.3		< 1.0 K		< 1.0 K		
B13	319.9		< 1.0 K		< 1.0 K		
Port 4/13 10:30am	3.0		< 1.0 K		< 1.0 K		
Dwnspt 4/13 10:30am	< 1.0 K		< 1.0 K		< 1.0 K		
Port 4/14 8:30am	7.7		< 1.0 K		< 1.0 K		

Suspended Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Suspended Solids (mg/L)
Port 4/13 10:30am	400	259	1.104	1.1055	0.0037
Dwnspt 4/13 10:30am	400	14	1.0881	1.0887	0.0015
Port 4/14 8:30am	425	M110	1.1188	1.1189	0.0002

Dissolved Solids Sample Location	Volume (ml)	Tray	Pre-weight (mg)	Post-weight (mg)	Disolved Solids (mg/L)
Port 4/13 10:30am	400	D9	116.3625	116.3848	0.0558
Dwnspt 4/13 10:30am	425	69	108.8141	108.8265	0.0292
Port 4/14 8:30am	400	D4	115.3291	115.345	0.0398

Appendix C – Flexible Wall Hydraulic Conductivity Test Data

$$k = \frac{a_{in} a_{out} L}{At(a_{in} + a_{out})} \ln(h_1 / h_2)$$

The following data represent the four runs, or time increments, used to determine the saturated hydraulic conductivity of the soil sample. The start time and finish time for each of the runs are represented by T_1 and T_2 respectively. The readings on the burettes are represented by bottom and top for the head water and tail water levels, respectively.

Time: 11:19 AM - 11:26 AM

T_1:		T_2:	
Bottom:	18.1	Bottom:	29.2
Top:	17.9	Top:	7.1

Where:

a_{in} =	1	0.0001	Cross-sectional area of the reservoir containing the influent liquid, cm^2...m^2
a_{out} =	1	0.0001	Cross-sectional area of the reservoir containing the effluent liquid, cm2...m^2
L =	8.2	0.082	Length of the specimen, cm...m
A =	1.54	0.000994	Cross-sectional area of the specimen, in^2...m^2
t =	0.116667	420	Elapsed time between determination of h_1 and h_2, hr...s
h_1 =	1.408		Head loss across the specimen at time t_1, m
h_2 =	1.189		Head loss across the specimen at time t_2, m

k = 1.66E-04 cm/s

Time: 1:22 PM - 1:33 PM

T_1:		T_2:	
Bottom:	1.8	Bottom:	23.75
Top:	34.7	Top:	13.5

Where:

a_{in} =	1	0.0001	Cross-sectional area of the reservoir containing the influent liquid, cm^2...m^2
a_{out} =	1	0.0001	Cross-sectional area of the reservoir containing the effluent liquid, cm2...m^2
L =	8.2	0.082	Length of the specimen, cm...m
A =	1.54	0.000994	Cross-sectional area of the specimen, in^2...m^2
t =	0.183333	660	Elapsed time between determination of h_1 and h_2, hr...s
h_1 =	1.739		Head loss across the specimen at time t_1, m
h_2 =	1.3075		Head loss across the specimen at time t_2, m

k = 1.78E-04 cm/s

Time: 1:41 PM - 1:47 PM

T_1:		T_2:	
Bottom:	23.75	Bottom:	33.2
Top:	13.5	Top:	4

Where:

a_{in} =	1	0.0001	Cross-sectional area of the reservoir containing the influent liquid, cm^2...m^2
a_{out} =	1	0.0001	Cross-sectional area of the reservoir containing the effluent liquid, cm2...m^2
L =	8.2	0.082	Length of the specimen, cm...m
A =	1.54	0.000994	Cross-sectional area of the specimen, in^2...m^2
t =	0.1	360	Elapsed time between determination of h_1 and h_2, hr...s
h_1 =	1.3075		Head loss across the specimen at time t_1, m
h_2 =	1.118		Head loss across the specimen at time t_2, m

k = 1.79E-04 cm/s

Time: 1:47 PM - 1:55 PM

T_1:		T_2:	
Bottom:	6.2	Bottom:	19.65
Top:	35.7	Top:	23.1

Where:

a_{in} =	1	0.0001	Cross-sectional area of the reservoir containing the influent liquid, cm^2...m^2
a_{out} =	1	0.0001	Cross-sectional area of the reservoir containing the effluent liquid, cm2...m^2
L =	8.2	0.082	Length of the specimen, cm...m
A =	1.54	0.000994	Cross-sectional area of the specimen, in^2...m^2
t =	0.133	480	Elapsed time between determination of h_1 and h_2, hr...s
h_1 =	1.705		Head loss across the specimen at time t_1, m
h_2 =	1.4445		Head loss across the specimen at time t_2, m

k = 1.43E-04 cm/s

AVERAGE K = 1.67E-04

Appendix D – Soil Suction Test Data

To determine the soil suction, h, the following formula was utilized:

$$h = 5.327 - 0.0779 w_f \qquad \text{Filter paper water content} < 45\%$$

$$h = 2.412 - 0.01359 w_f \qquad \text{Filter paper water content} > 45\%$$

where,

h = Soil suction (log kPa)

w_f = Moisture content of the filter paper

Table 14. Filter paper water contents

Target Soil Moist. Content	Cold Tare	Cold Tare and Wet Paper	Hot Tare and Dry Paper	Hot Tare	Paper Wet	Paper Dry	w_f (%)	**Soil Suction log kPa**
5	37.7413	37.9922	37.9595	37.734	0.2509	0.2255	11.26	4.45
10	33.7392	34.0019	33.9583	33.7323	0.2627	0.226	16.24	4.06
13	33.7646	34.0545	33.9958	33.7631	0.2899	0.2327	24.58	3.41
16	37.6481	37.9297	37.8582	37.6397	0.2816	0.2185	28.88	3.08
20	37.7577	38.0722	37.9726	37.7484	0.3145	0.2242	40.28	2.19
25	33.8151	34.1854	34.0315	33.81	0.3703	0.2215	67.18	1.51

The soil moisture contents were calculated using the data in Table 15.

Table 15. Soil moisture contents

Tin #	Tin Weight (g)	Tin & Soil Wet (g)	Tin & Soil Dry (g)	Weight of Water (g)	Weight Soil Dry (g)	Gravametric Moisture Cont.
5	31.92	83.99	80.78	3.21	48.86	6.57
10	24.8	70.88	67.68	3.20	42.88	7.46
13	31.41	85.59	80.24	5.35	48.83	10.96
16	24.92	114.34	103.88	10.46	78.96	13.25
20	24.63	76.08	68.32	7.76	43.69	17.76
25	31.69	73.13	65.69	7.44	34.00	21.88

The gravimetric water content was then converted to volumetric water content (Table 16). The resulting soil suction and respective volumetric water contents were then plotted to form the soil's matric suction curve (Figure 42).

Table 16. Volumetric water content - Matric suction

Volumetric Water Content		Matric Suction	
%	Fractional	(Log kPa)	(kPa)
9.7915	0.098	4.45	28154.35
11.4811	0.115	4.06	11534.18
17.3827	0.174	3.41	2583.09
22.2910	0.223	3.08	1194.94
29.6025	0.296	2.19	154.69
35.7692	0.358	1.51	32.00
40.0000	0.400	0.00	0.00

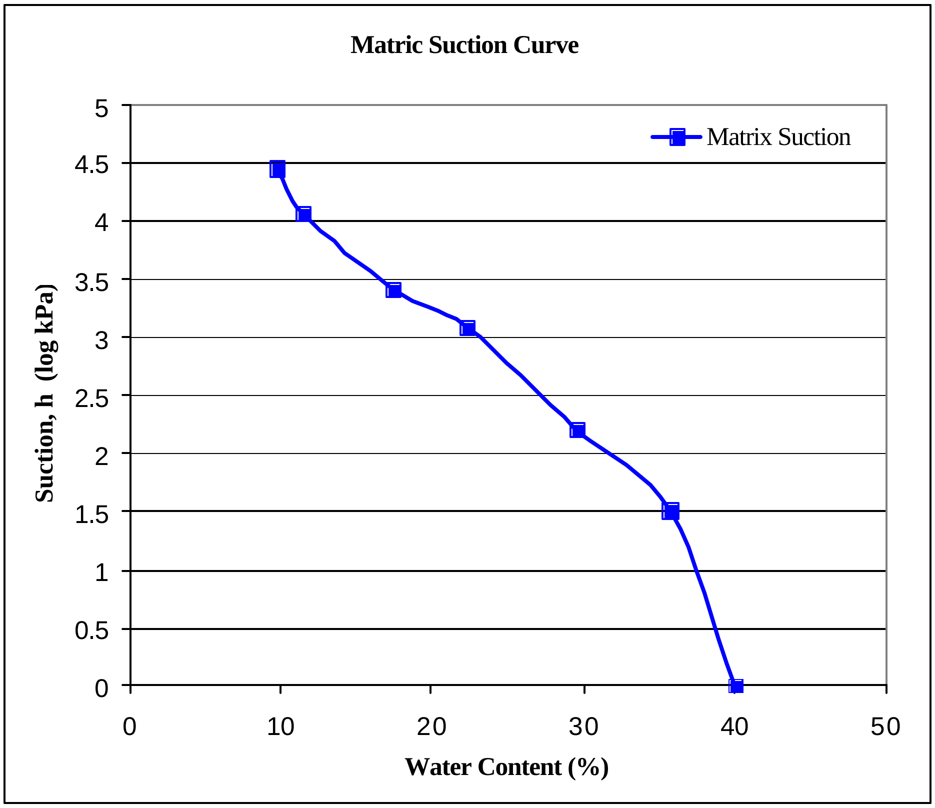

Figure 42. Matric suction curve from raw data

Appendix E – In-situ Density Data

$$g = \frac{Mass\ of\ Dry\ Soil}{Volume\ of\ Sample}$$

Length of Sampler (cm) = 15.2
Radius of Sampler (cm) = 2.27
Volume of Sample (cm^3) = 246

Mass of Sampler (g) = 92.34
Mass of Sampler and Soil (g) = 553.45
Mass of Soil (g) = 461.11
Gravametric Moisture Content (%) = 16.57
Dry Mass of Soil (g) = 395.56

In-Situ Density of Soil (kN/m^3) = 18.36 (116.8 pcf)
In-Situ Dry Density of Soil (kN/m^3) = 15.75 (100.3 pcf)