Multi Year Performance of a Pervious Concrete Infiltration Basin BMP

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Abstract: The use of infiltration stormwater best management practices (BMPs) has become a more commonly used approach as a means of reducing post-development runoff volumes in many areas throughout the US. While studies regarding the performance of infiltration BMPs are emerging, much remains to be learned about their design, construction, and operation. The increase in knowledge will improve the performance and longevity of these BMPs. The performance of one such infiltration basin over a two-year cycle is presented in this paper. The study site is a pervious concrete infiltration basin BMP built in 2002 in a courtyard common area at Villanova University. The system consists of three linked infiltration beds lined with geotextile filter fabric, filled with coarse aggregate, and overlain with pervious concrete. The natural soil beneath the infiltration BMP is a silty sand. The BMP is extensively instrumented to facilitate water quantity and quality research.

Both water quantity and quality results are presented. The water quantity analysis showed the performance of the basin was directly related to its infiltration characteristics. The infiltration rate of the silty sand is cyclic, with higher rates during warmer periods and lower rates during colder periods. The water quality analysis investigated the pollutant reduction for chloride, copper, nitrogen and phosphorus from

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the inlet to the surface water outlet of the structure, as well as differences in pollutant concentration levels between the basin, surrounding ground, and varying soil layer elevations beneath the basin. In general, the pollutant reduction to the surface waters was greater than 90% from inlet to outlet, primarily influenced by the infiltration of the stormwater into the natural soils below the BMP**.** The pollutant concentration of the infiltrating runoff was found to be higher than expected in the area adjacent to the bed when compared to concentration levels found at a similar depth beneath the infiltration bed. Comparison of pollutant concentration levels, as the water moved from within the storage bed to the soil beneath the bed, were shown to vary, with statistical differences found for mean concentration levels of both pH and copper levels and no statistical differences found for conductivity, total phosphorous, and chloride at each elevation.

CE Database Subject Headings: Infiltration, Temperature effects, Best Management Practice, Stormwater Management, Pervious Pavements, Stormwater Control Measures

INTRODUCTION

Urbanization has a significant negative effect on the quality and quantity of both ground and surface waters. With increasing urbanization, there is a quantifiable loss of area available to stormwater for infiltration. Instead of returning to the soil through infiltration, stormwater bypasses this critical step and alters the hydrologic cycle by flowing over impervious areas, such as parking lots, rooftops, and roadways. This results in an increase in direct runoff to nearby surface waters, and a corresponding loss to the subsurface systems. These elevated volumes of runoff carry sediments, suspended and dissolved solids, metals, and other pollutants to the surface waters. Not only does this adversely affect the ecology and health of the local rivers and streams, but it also has a regional effect, with the potential to cause flooding and erosion near the source, and sedimentation downstream from the source.

Best Management Practices (BMPs) are gaining popularity throughout the United States for their beneficial water quantity and quality characteristics. Infiltration BMPs alleviate both the increased post-development runoff as well as the non-point source pollutants from entering downstream surface waters. Typical stormwater pollutants are total suspended solids (TSS), metals, hydrocarbons, and nutrients. Source control BMPs establish a passive system that intercepts pollutants and removes them close to the point of the rainfall (Barbosa et al. 2001). Infiltrating stormwater locally is increasingly considered a means of controlling urban stormwater runoff, thereby reducing runoff peaks and volumes, and returning the urban hydrologic cycle toward a more natural state (Mikkelsen et al. 1996). These systems are an innovative way to minimize the adverse effects of urbanization by reducing or eliminating runoff from the site.

Unlike detention basins, infiltration basins do not have widely accepted design standards and procedures (Akan 2002). The reason for the lack of an accepted design standard is that each basin has the potential to be affected by numerous factors including: infiltration, groundwater levels, subsurface contamination, engineering issues, and in some areas liquefaction and slope stability, among others. The variables that presented the most concern in the design process at this particular location were the infiltration properties of the soils on site. Many times, designers size infiltration basins with sufficient volume to hold and store a specific amount of runoff volume from over the site's impervious area (typically, this volume is called the water quality volume). This method of sizing BMPs does not account for the infiltration that is occurring in the BMP during the storm event; which could result in substantially oversized BMPs. Not only is the BMP oversized and overdesigned, but the cost of the BMP is increased because of the increased excavation, soil removal, and aggregate costs.

The goals and objectives of this research project were threefold. First, the water quantity characteristics (inflow vs outflow) of the site were determined so that conclusions could be drawn regarding the infiltration capacity of this particular basin. Second, a water quality investigation was completed to determine if a low impact development (LID) rock storage bed infiltration BMP could improve water quality by reducing non-point source pollution to downstream receiving bodies. Third, a water quality investigation was completed to determine the variation of pollutant concentration levels of various constituents within the stormwater as it infiltrates through the ground.

SITE DESCRIPTION

The infiltration basin BMP is located on the campus of Villanova University in southeastern Pennsylvania, approximately 30 kilometers west of Philadelphia, PA. Geologically, the site is situated on silty sand, which has a specific yield of approximately 20%. The total drainage area for the BMP is 5,360 square meters, 62% of which (3,330 sq. m.) is impervious due to surrounding rooftops and walkways. There are no vehicular roadways present within the drainage area; however the area is used briefly by cars when the students move in and out of the surrounding dormitories.

The BMP consists of three large rock infiltration beds arranged in a cascading manner down the center of the site. This cascading was necessary to account for the slope of the site while providing a flat bottom to each bed (Figure 1). The infiltration data presented in this report are specific to the lower infiltration bed, which was instrumented with the following: an outlet weir, depth sensors, and pore water samplers. A rain gauge was also present on the rooftop of a building located immediately downstream of the BMP. The beds were separated by earthen berms, which prevented flow from traveling from bed to bed and allowed the water to remain in each bed while infiltrating. Each of the beds was approximately 0.9-1.2 m deep and filled with 7.6-10 cm diameter American Association of State Highway and Transportation Officials (AASHTO) No. 2 clean-washed coarse stone aggregate. The aggregate produced a void space of approximately 40% within the infiltration beds which provided storage for stormwater during events when the infiltration rate of the underlying soils was slower than the rate of stormwater runoff inflow (Kwiatkowski, et al. 2007). At the base of the infiltration beds, directly above the undisturbed native soil and below the stone, was a layer of geotextile filter fabric that extended over the bed bottom and up the side slopes of the BMP. This layer provided separation between the stones and soil and prevented any upward migration of fines into the infiltration bed. The geotextile filter fabric used for the BMP had a flow through capacity several orders of magnitude higher than that of the soil, therefore providing uninhibited flow through the fabric. Located above the coarse aggregate was a 2.5 cm layer of AASHTO No. 57 clean-washed stone, which served as a choker layer. Above the No. 57 stone was a layer of pervious concrete approximately 19 cm thick. Stormwater entered the infiltration bed in two ways. First, overland runoff directly entered the infiltration basin by flowing through the pervious concrete. Second, the infiltration beds received inflow from a series of roof drains connected to PVC pipes and tied directly to the beds from adjacent buildings. Figure 2 shows a typical cross section sketch of an infiltration bed. A 10 cm HDPE pipe located in the berm between the beds connected the bottoms of the lower two infiltration beds. This allowed water to travel from the middle bed to the lower bed, maximizing the infiltration area (Figure 1). Because of a construction error, there was no connecting pipe between the upper bed and the middle bed. Should the upper bed had become completely filled with water, any additional surface water trying to enter the upper basin would have bypassed it and continued along the natural gradient of the site and enter into either the middle or lower bed.

The BMP was designed to store and infiltrate runoff from the first 5 cm of a storm event falling over the entire watershed. Storms of this size represent approximately 90% of the annual storm events for this region according to the Philadelphia Intensity Duration Frequency curve (NOAA http://hdsc.nws.noaa.gov/hdsc/pfds/). When the design capture volume was exceeded, the excess stormwater left the site through the existing storm sewer system by means of an overflow pipe. This pipe was located in a junction box that was directly adjacent to the bottom corner of the lower infiltration bed.

The soil immediately beneath the lower infiltration bed was classified according to the Unified Soil Classification System (USCS) (ASTM D-2487) by implementing grain-size analysis (ASTM D-422) and determing the Atterberg limits (ASTM D-4318). The Atterberg limits were used to identify the soil’s liquid limit (LL) and plastic limit (PL), which were determined to be 42.9%, and 33.0%, respectively. The resulting plasticity index (PI) was 9.9%. According to the USCS the soil was classified as inorganic silty sand (SM) of low plasticity. According to the Natural Resource Conservation Service (NRCS) it is a Silt Loam under Soil Class - B Type Soil (Rawls et al. 1983). Additionally, a soil sample was taken and a flexible wall hydraulic conductivity test (ASTM D-5084) was performed yielding a saturated hydraulic conductivity (K_s) of 1.6×10^{-4} cm/s.

The site was instrumented with two Instrumentation Northwest (INW) PS-9805 Pressure/Temperature Transducers manufactured in Kirkland, WA. This instrumentation measured the elevation and temperature of the water in the lower infiltration bed. The depth of water as measured by the pressure transducer is directly related to the hydrostatic pressure exerted by the water. One probe was located in a perforated PVC pipe in the lower infiltration bed, and was situated on the infiltration bed bottom such that no impediment of water would occur around it. The probe was programmed so that measurements were taken and recorded in 5-minute increments. By observing the drop in bed water surface elevation after the rainfall ceases, infiltration rates were determined for each storm event.

A second pressure transducer, in conjunction with the V-Notch weir, was located in the junction box at the downstream end of the lower infiltration bed's overflow pipe. This probe measured the height of water in the junction box and, from that value, calculated the flow and volume of water passing over the weir and exiting the system.

WATER QUANTITY DATA COLLECTION

Because of the multiple inflow pipes from the surrounding rooftop gutters and the infiltration into the storage beds through the pervious concrete, no direct measurement of total inflow into the system was possible. Therefore, to estimate the inflow, the US Army Corps of Engineers Hydrologic Modeling Software (HEC-HMS) was used to create a hydrologic simulation of the site. Rainfall data was collected from the rain gauge located onsite and entered into the model. The basin was divided into four separate components: the pervious area of the contributing watershed which flowed into the upper basin, the impervious area flowing into the upper basin, the contributing area (100% impervious) flowing into the middle basin, and the contributing area (100% impervious) flowing to the lower basin. Hydrologic losses were simulated using the NRCS curve number method. A curve number sensitivity analysis was performed by Ladd (2004) which resulted in the following curve numbers used for each of the four components: 75 (upper pervious area), 98 (upper impervious area), 98 (middle basin), 98 (lower basin). Continuous simulation was completed and the corresponding inflow is presented on a monthly basis between September 2003 and June 2005 (Table 1). Surface water outflow from the BMP was measured directly from the weir located upstream of the overflow pipe which leads from the BMP to the municipal sewer system. Infiltration rates through the bottom of the basin (into the ground) were determined by evaluating the data from the pressure transducer located in the lower basin. The total depth of water in the basin was determined from the pressure transducer readings. The rate of the change in depth is equivalent to the infiltration rate.

WATER QUANTITY RESULTS AND DISCUSSION

The monthly inflow and surface water outflow (normalized over the basin area), as well as the percent of inflow captured through the infiltration basin are summarized in

Table 1. The data show an extremely high efficiency, with an average inflow retention of over 91%. There is one peculiar month of data (April 2005) which shows a negative efficiency. Closer inspection of the results for this month shows a relatively small amount of both total inflow and outflow (0.5 cm / 0.6 cm). The most likely explanation for the negative efficiency is the presence of additional water flowing over the outlet weir due to snowmelt occurring during the month via ground warming and not significant rainfall.

The performance of the BMP over time was also analyzed by studying the infiltration rates in the lower basin for select storms. The infiltration rate was determined by calculating the slope of the recession limb of the stage hydrograph (depth vs flow) for each storm (Emerson and Traver 2008). A total of 15 storms were used for the analysis. These storms were all single peaking with a uniform declining recession limb of the stage hydrograph. Figure 3 shows the infiltration rate as a function of time over the period of recorded data for the 15 storms. The corresponding mean temperature of the water in the infiltration basin is also shown on the secondary y-axis.

In general, the infiltration rate varied in a cyclical fashion according to time of year. Colder months were shown to have lower infiltration rates, and warmer months were shown to have higher infiltration rates. An analysis completed by Emerson and Traver (2008) showed the primary reason for the cyclical nature of the infiltration rates based on season is that the viscosity of water increases as the temperature decreases. Furthermore, Emerson and Traver (2008) also showed that there has not been a statistically significant change in the infiltration capacity of this basin over time.

SURFACE WATER QUALITY RESULTS AND DISCUSSION

Inflow and outflow stormwater samples were collected at the site between September 2003 and June 2005. Inflow samples were collected at a junction box located immediately upstream of the upper storage bed. Runoff from one of the adjacent rooftops was piped directly into the junction box. Additionally, an obstruction was placed on the ground immediately adjacent to the junction box which directed a portion of the surface water runoff from the surrounding watershed area into the box. The inflow runoff, from both the rooftops and overland flow, pooled in the junction box before being piped directly into the upper storage bed. During the initial stages of the rain event, when runoff was considered to be most polluted with constituents such as nutrients and metals, grab samples were collected from the junction box. Because of the mixing of both the rooftop and ground runoff that took place in the junction box, the samples were considered composite inflow samples representing the entire watershed. It should be noted that because grab samples were collected during the initial stages of runoff that there is a potential bias for the results to show higher pollutant concentration levels for both nutrients and metals than if a series of samples were collected at discreet time intervals over the entire duration of the storm.

Over the two year period of the study a total of 10 outflow samples were collected and analyzed. These 10 events which allowed samples to be collected constituted all storms in which the inflow volume exceeded the capacity of the lower basin and the excess water was conveyed over the downstream weir and into the existing municipal sewer system. The samples were collected at the end of the storm at a point immediately downstream of the outflow weir. Due to the detention time of the water in the lower basin as it accumulated before being conveyed over the outflow weir, the samples from this location are composite. Additionally, because of the amount of time it took the basin to fill and the ensuing mixing of the water that took place in the lower basin while it was filling, the authors feel that there is no bias in the pollutant concentration levels for the various constituents at the outlet of the basin. Surface water quality analysis was conducted on each of the samples and the following constituents were determined: pH, conductivity, copper, total nitrogen, total phosphorous, chloride, suspended solids, and dissolved solids. The total amount (mass) of each constituent was determined by measuring its concentration at either the inlet or outlet during a given storm and multiplying the concentration by the total volume of either inflow or outflow. The pollutant removal efficiency of each constituent was subsequently ascertained by determining the ratio of the outflow pollutant mass to the inflow pollutant mass. Table 2 shows the gross pollutant mass level and removal efficiency of the infiltration basin.

The infiltration basin showed a substantial amount of pollutant removal for most of the constituents tested, from a mass perspective. There are two potential reasons for the substantial pollutant removal. The primary reason is that most of the water entering the basin was infiltrated into the soils below it. The infiltrated water carried the pollutants with it, thereby reducing the quantity of pollutants which left the site through the outlet as surface water runoff. It should be noted that this is a direct result of the hydraulic design of the BMP and if the BMP were designed to have a reduced amount of storage, then the pollutant removal efficiency potentially would not have been as high. The second reason is that there may have been a potential bias for the inflow pollutant concentration levels, which was explained previously. If the inflow pollutant concentration levels were overestimated then the removal efficiency would also have been overestimated. Positive efficiencies were found for four of the six constituents and ranged from 94.3% to 99.4%. It is interesting to note that these removal efficiencies are higher than the water quantity removal efficiency (92.9%). The most likely reason for the increase in efficiency is that the “first flush”, which is typically considered to have the highest pollutant concentration for constituents such as nutrients and metals, was immediately captured and infiltrated through the basin. Another study on a nearby BMP confirmed the presence of a first flush from small impervious surfaces (Batroney et al, 2010). The overall high infiltration capacity of the basin and the increased pollutant removal efficiency implies the basin is functioning properly. Additionally, because the pollutant levels were decreasing between inflow and outflow within the basin, the various pollutants were settling out, thereby reducing non-point source pollution to downstream receiving bodies.

Two related constituents showed a negative efficiency (increase) between the inlet and outlet masses: chloride and dissolved solids. The most probable reason for this is the accumulation of chloride particles during the winter months, caused by salting of the surrounding areas during times of snowfall. The salt particles were sprayed over the entire surface area of the pervious concrete allowing easy penetration into the three beds. There is also the possibility that the salt particles were sprayed directly into the junction box housing the outlet weir which would have therefore recorded as chloride and dissolved solids leaving the site without entering the infiltration basin. The high chloride concentration explains why it was the primary constituent in the total dissolved solids.

INFILTRATED WATER QUALITY RESULTS

A small well with a removable cap was installed at the lower basin which allowed for samples to be collected from within the basin. A foot pump was used to apply suction to a hose which was used to draw water from the basin to a sampling jar. Additionally, three Soilmoisture Equipment Corporation 1920F1 Pressure-Vacuum Soil Water Samplers were installed beneath the bed of the lower Infiltration basin which allowed for infiltrated water samples to be collected and analyzed from the vadose zone. The pore water samplers are located at depths of approximately 0.3, 0.6, and 1.2 meters beneath the lower bed. Sampling from the pore water samplers was accomplished by applying a suction of approximately 55 KiloPascals one hour after the storm commenced, as recommended by the manufacturer, and then waiting 12-24 hours before drawing the water from the pore water samplers into the sampling jar. Because of the required waiting period (12-24 hours) for the pore water samplers to collect enough of a sample necessary for analysis (150ml), the samples taken from the pore water samplers were composite, representing an average concentration over the course of the entire storm. An additional pore water sampler was installed at a depth of 0.3 meters under a grass lawn immediately adjacent to the BMP. A total of 37 samples between September 2003 and June 2005 were collected and analyzed. Analysis was completed by determining the statistical quartiles of each pollutant over the lifespan of the study. Additionally, a statistical t-test (alpha = 0.05) was performed on each constituent to determine if there was a significant difference between the constituent means at each location. The parameters analyzed include: pH, conductivity, copper, total nitrogen, total phosphorous, and chloride.

Infiltrated Water Quality Comparison to Adjacent Location

The results of the stormwater samples collected at a depth of 0.3 meters below the infiltration bed were compared to samples collected from the pore water sampler located at a depth of 0.3 meters below the ground surface at a location directly adjacent to the bed. The samples collected from the pore water samplers at the adjacent location (not below the bed surface) provide an estimate of what is naturally occurring in the ground from the contributing watershed. The results of the comparison are presented in Table 3. The values in the table show the concentration of each constituent at both locations at the 25th, 50th, and 75th% quartile. Minimum detection limits of the measuring equipment are shown in parenthesis next to the constituent.

A statistical t-test (alpha = 0.05) was conducted for each constituent to determine if there was a significant difference between the means of the concentrations of the constituents at the two locations. The following statistical hypothesis was tested:

H_o: $\mu_1 = \mu_2$

H_1: $\mu_1 \neq \mu_2$

Where μ_i = mean constituent concentration. The results of the t-test are shown in Table 4.

The statistical analysis shows there is a difference in mean concentrations of pH, conductivity, copper, and total nitrogen, between the two locations. Additionally, analysis of the quartile values (Table 3) show the concentrations for conductivity, copper, and total nitrogen to be higher in the ground located adjacent to the bed for these constituents. This result is surprising as stormwater infiltration BMPs are thought to collect pollutants and prohibit them from transporting to downstream receiving bodies. This assumption leads to the expectation that the pollutant concentrations would have been higher in the soil beneath the bed as opposed to the soil beneath the ground adjacent to the bed, due to the continual accumulation of each pollutant. No statistical difference in mean concentrations were found for both total phosphorous and chloride levels.

Infiltrated Water Quality Analysis

Samples were collected from the lower bed and the three pore water samplers located at elevations of 0.3 m, 0.6 m, and 1.2 m beneath the lower bed, for the purpose of determining if there is a significant change in pollutant concentration level as the water infiltrated through the ground. ANOVA (alpha = 0.05) was conducted on each constituent to test for differences in means between all of the samples at each location. The following statistical hypothesis was tested:

$H_o: \mu_1 = \mu_2 = \mu_3 = \mu_4$

$H_1: \mu_1 \neq \mu_2 \neq \mu_3 \neq \mu_4$

Where μ_i = mean constituent concentration. The constituent levels and the results of ANOVA are shown below in Tables 5-10. Total nitrogen levels were not analyzed using ANOVA because an overwhelming majority of the samples had results below the detection limit of the measuring equipment.

The results of ANOVA show that there is no statistical difference in mean concentrations at each location for conductivity, total phosphorous, and chloride, respectively. A conclusion therefore is drawn that each of these constituents pass directly from the rock storage bed through the soil without accumulating at any given location. This is potentially problematic should these constituents continue to pass through the soil and ultimately enter to the groundwater. This could have adverse effects on the groundwater quality. pH and copper levels, respectively, were shown to have statistically different means at each location. A review of the quartiles show pH levels tended to decrease as the infiltrating water passed through the soil. The decrease in pH is most likely explained by the majority of the stormwater tested having a pH level less than 7 and therefore causing the soil to become more acidic over time. Copper levels decreased to amounts below the minimum detection limit of the instrumentation, as the infiltrating water passed through the soil. The decrease in copper levels with depth is expected as previous research has shown that metals have a tendency to bind to the soil and accumulate in the first couple of centimeters below the ground surface (Welker et al 2006 and Mason 1999).

CONCLUSIONS

A two year study was completed on a rock storage infiltration basin BMP. The basin was designed to store runoff produced from 5 cm of rainfall uniformly distributed over the entire watershed area. The results of the study showed the basin was highly efficient at controlling inflow and allowing it to infiltrate into the ground beneath the basin, thereby reducing the deleterious effects of runoff from a developed site. The overall efficiency of the basin for capturing and storing excess runoff through the duration of the study was over 91%. Infiltration rates of the water inside the basin were shown to vary cyclically with temperature and no decrease in infiltration capacity was noted during the study. The basin also served to reduce non-point source pollution from entering downstream receiving bodies. Removal efficiencies of various surface water pollutants on a load basis ranged from 94.3% to 99.4%. Only chloride and dissolved solids, 2 related constituents, were shown to increase in mass between inlet and outlet. This is a result of salting the area during times of snowfall. An analysis of pollutant levels beneath the basin to those in the soil beneath the ground adjacent to the basin showed that pollutant concentration levels of conductivity, copper, and total nitrogen were higher in the adjacent soil. This result is surprising as there was an expectation that all constituent levels would have been higher in the basin due to the abundance of stormwater entering and being detained in the BMP for each storm event. An analysis of pollutant concentration levels between the lower bed and depths up to 1.2 meters below the bed showed there was no statistical difference in the constituent concentration means for conductivity, total phosphorous, and chloride, respectively. This results implies that these constituents move through the soil without accumulating at any one given location or depth. This is potentially problematic and can lead to adverse effects to groundwater quality. Alternatively, pH and copper levels, respectively, were shown to vary between each sampling location. Since most pH levels fell below 7, the soil is assumed to be becoming more acidic over time which is causing the variation in levels at each depth. The change in copper levels supports research conducted by Welker et al (2006) and Mason (1999) which showed metals have a tendency to bind to the soil and accumulate within the first couple of centimeters below the ground surface. Considering one of the main functions of an infiltration BMP is to help improve water quality of downstream receiving water bodies, this particular BMP is performing with positive results.

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List of Figure Headings

Table 1 - Monthly Performance of Infiltration Basin

Date	Inflow (cm)	Outflow (cm)	Capture (%)
Sep-03	4.8	0.014	99.7
Oct-03	6.0	0.142	97.6
Nov-03	3.3	0.040	98.8
Dec-03	5.0	0.251	95.0
Jan-04	0.4	0.006	98.6
Feb-04	1.9	0.264	86.4
Mar-04	1.5	0.084	94.3
Apr-04	5.6	0.200	96.4
May-04	1.4	0.015	98.9
Jun-04	1.7	0.005	99.7
Jul-04	7.9	0.478	93.9
Aug-04	2.2	0.147	93.4
Sep-04	9.9	1.494	84.9
Oct-04	2.2	0.046	97.9
Nov-04	6.2	0.221	96.4
Dec-04	2.4	0.025	98.9
Jan-05	3.3	0.132	96.0
Feb-05	1.4	0.015	98.9
Mar-05	2.1	0.091	95.5
Apr-05	0.5	0.584	-12.2
May-05	0.6	0.009	98.7
Jun-05	1.9	0.038	98.0

Table 2 – Surface Water Quality Data

Constituent	Inflow	Outflow	Removal Efficiency
Water Quantity (cm)	45.06	3.20	92.9
pH	4.17 < pH < 8.42	6.65 < pH < 9.75	
Conductivity (μS/cm)	2.96 < Cond < 89.2	9.0 < Cond < 2860	
Copper (kg)	1.58	0.02	98.5
Total Nitrogen (kg)	2.21	0.10	95.3
Total Phosphorous (kg)	0.44	0.03	94.3
Chloride (kg)	1.28	11.59	-806.8
Suspended Solids (kg)	30.29	0.17	99.4
Dissolved Solids (kg)	24.24	27.61	-13.9

Table 3 – Water quality concentration values from lysimeter located 0.3m beneath lower bed and lysimeter located 0.3m beneath the ground adjacent to lower bed

Constituent	Quartiles					
	25%		50%		75%	
	Bed	Adjacent	Bed	Adjacent	Bed	Adjacent
Ph	6.75	6.58	6.92	6.68	7.14	7.33
Conductivity (0.01 μS/cm)	223	814	250	973	394	1032
Copper (0.02 mg/l)	< .02	0.23	< .02	0.46	0.03	0.66
Total Nitrogen (2.0 mg/l)	< 2.0	2.9	< 2.0	4.6	2	7.2
Total Phosphorous (0.015 mg/l)	0.1	0.12	0.15	0.2	0.26	0.38
Chloride (1.01 mg/l)	10.6	41.7	14.1	66	130.2	116.2

Table 4 - t-test results comparing water quality concentrations, of each constituent, at 0.3m below the lower bed and 0.3 m below the ground adjacent to the lower bed (alpha = 0.05)

Constituent	p-value	Results
Ph	0.013	$\mu_1 \neq \mu_2$
Conductivity	0.001	$\mu_1 \neq \mu_2$
Copper	0	$\mu_1 \neq \mu_2$
Total Nitrogen	0	$\mu_1 \neq \mu_2$
Total Phosphorous	0.193	$\mu_1 = \mu_2$
Chloride	0.48	$\mu_1 = \mu_3$

Table 5 - Comparison of pH levels from samples collected within the lower bed and the three pore water samplers located beneath the lower bed

Ph	Quartiles			ANOVA	
	25%	50%	75%	p-value	Result
Bed	6.98	7.21	7.87	0	H_1: $\mu_1 \neq \mu_2 \neq \mu_3 \neq \mu_4$
0.3 m below bed	6.75	6.92	7.14		
0.6 m below bed	7.05	7.17	7.29		
1.2 m below bed	6.77	7.01	7.23		

Table 6 - Comparison of Conductivity levels from samples collected within the lower bed and the three pore water samplers located beneath the lower bed (minimum detection limits are shown in parenthesis)

Conductivity (0.01µS/cm)	Quartiles			ANOVA	
	25%	**50%**	**75%**	**p-value**	**Result**
Bed	51	96	186	0.507	$H_o: \mu_1 = \mu_2 = \mu_3 = \mu_4$
0.3 m below bed	223	250	394		
0.6 m below bed	302	399	543		
1.2 m below bed	171	216	416		

Table 7 - Comparison of Copper levels from samples collected within the lower bed and the three pore water samplers located beneath the lower bed (minimum detection limits are shown in parenthesis)

Copper (0.02 mg/l)	Quartiles			ANOVA	
	25%	50%	75%	p-value	Result
Bed	0.15	0.27	0.52	0	$H_1: \mu_1 \neq \mu_2 \neq \mu_3 \neq \mu_4$
0.3 m below bed	< 0.02	< 0.02	0.03		
0.6 m below bed	< 0.02	0.025	0.034		
1.2 m below bed	< 0.02	< 0.02	< 0.02		

Table 8 - Comparison of Total Phosphorous levels from samples collected within the lower bed and the three pore water samplers located beneath the lower bed (minimum detection limits are shown in parenthesis)

Total Phosphorous (0.015mg/l)	Quartiles			ANOVA	
	25%	50%	75%	p-value	Result
Bed	0.15	0.23	0.3	0.051	$H_o: \mu_1 = \mu_2 = \mu_3 = \mu_4$
0.3 m below bed	0.1	0.16	0.26		
0.6 m below bed	0.18	0.27	0.38		
1.2 m below bed	0.2	0.31	0.52		

Table 9 - Comparison of Chloride levels from samples collected within the lower bed and the three pore water samplers located beneath the lower bed (minimum detection limits are shown in parenthesis)

Chloride (1.01 mg/l)	Quartiles			ANOVA	
	25%	**50%**	**75%**	**p-value**	**Result**
Bed	2.6	8.8	118.1	0.822	$H_o: \mu_1 = \mu_2 = \mu_3 = \mu_4$
0.3 m below bed	10.6	14.1	130.2		
0.6 m below bed	11.6	14.2	134.3		
1.2 m below bed	16	23.2	236.9		

Table 10 - Comparison of total nitrogen levels from samples collected within the lower bed and the three pore water samplers located beneath the lower bed (minimum detection limits are shown in parenthesis)

Total Nitrogen (2.0 mg/l)	Quartiles			ANOVA	
	25%	50%	75%	p-value	Result
Bed	< 2.0	< 2.0	< 2.0	ANOVA not performed	
0.3 m below bed	< 2.0	< 2.0	< 2.0		
0.6 m below bed	< 2.0	< 2.0	< 2.0		
1.2 m below bed	< 2.0	< 2.0	< 2.0		