BMP POLLUTANT REMOVAL EFFICIENCY

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ABSTRACT

Stormwater Best Management Practices (BMPs) are receiving national acceptance as a viable means of controlling excess runoff due to rainfall events. BMPs allow for Stormwater to move directly to the localized groundwater table via infiltration and thereby return the post-development outflow hydrograph peak-flow and volume to pre-development conditions. Another advantage to using BMPs instead of a traditional detention basin is thought to be the potential to remove non-point source pollutants accumulated in the surrounding developed areas. Theoretically pollutants are carried into the BMP with the excess runoff and are allowed to infiltrate into the ground, thereby improving the quality of the surface water released by the BMP back into the environment. Additionally, pollutants also have the potential to be caught in the underlying soil layer and removed from the infiltrating water as it makes its way to the groundwater table.

A water quality investigation was completed on three different types of BMPs; a bio-infiltration pond, a Stormwater wetland, and a pervious concrete surface with underlying rock bed, in order to ascertain the pollutant removal efficiency of each of the various BMPs. The investigation involved a statistical analysis of the inflow water quality concentrations versus the outflow and infiltrating concentrations at varying depths beneath the ground surface. Constituents analyzed included: nitrogen, phosphorous, chloride, suspended solids, dissolved solids and Ph. The results of the analysis show mixed results at each site with the Stormwater wetland having the greatest pollutant removal efficiency for surface water flows, and the bio-infiltration pond having the greatest pollutant removal efficiency for infiltrating waters.

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INTRODUCTION

With the increased concern about urban storm water runoff and the pollutants found within, research has focused on best management practices (BMPs) for a solution. A BMP is a practice or a combination of practices that prevent or reduce adverse effects of Stormwater runoff and associated pollutants. Not only are BMPs capable of reducing the peak flows and volume after urbanized development, they are also able to remove many of the pollutants of concern. Research on BMPs is critical due to the lack of historical field data on the performance of such BMPs.

The purpose of this research is to compare the pollutant removal efficiency of three Stormwater best management practices (BMPs) on the campus of Villanova University, Villanova, PA. The study will include a Bio-infiltration BMP, a manmade Stormwater wetland BMP, and a large-scale rock bed Pervious Concrete BMP. Specifically, water quality data collected from both surface water (inflow vs. outflow) and groundwater (inflow vs. infiltration) will be analyzed and compared in order to determine the performance of each of the BMPs and ascertain if there is one optimal design.

BMP DESCRIPTION

Bio-Infiltration Pond

The Bio-infiltration BMP is a retrofit of a pre-existing traffic island. The Bio-infiltration BMP was designed to capture and infiltrate the first inch of runoff, including the first flush of pollutants. Any volume in excess of this amount is diverted to a storm sewer that used to serve the area before the Bio-infiltration BMP was constructed. About half of the 1.2-acre drainage area is impervious cover from parking, with the other half being grass cover. Monitoring instruments were installed to record the pond depth, precipitation data, and outflow. Combining the survey data with the instrument data, a model of the drainage area and BMP was created using HEC-HMS to calculate the amount of runoff infiltrated for a given storm event. The model was calibrated using collected storm data and subsequently verified. For a given storm depth, the model calculates the amount of runoff produced by the watershed, the amount captured by the Bio-infiltration BMP, and the amount of outflow.

The Bio-infiltration BMP is located at the lower portion of the drainage area. Runoff enters the BMP through two curb cuts and a pipe connected from a storm sewer inlet. One curb cut was placed where a storm drain inlet had been located. Placement of the other curb cut was determined by visual inspection of the path of the flow of water across the pavement. The Bio-infiltration BMP is connected to the storm sewer system through a 12 in. corrugated high density polyethylene (HDPE) pipe. This pipe serves as both an inflow and outflow pipe to the BMP. During small storms, water is diverted from the storm sewer through the pipe and into the basin. When the basin fills beyond a maximum volume, the pipe acts as an outflow pipe and takes water back into the sewer system where it is transported downstream. There is a steel plate, v-notch weir located at the intersection between the HDPE pipe and the sewer system which is used to measure the rate of water either entering or leaving the BMP. (Figure 1)

To create the infiltration bed, the original soil was excavated and then sifted with sand to provide a more Pervious surface layer. The soil was mixed to create a 1:1 sand/soil ratio. The made soil then was returned to the basin. Vegetation was planted on the surface of the basin. To prevent erosion until the plants took hold, a layer of mulch was also laid onto the surface. The vegetation chosen needed to be able to withstand significant chloride levels due to salting of the adjacent parking lot during snow storms. Plants chosen for the Bio-infiltration BMP are commonly found in the coastal tidal areas and sand dunes of Southern New Jersey. A partial listing of the types of vegetation used in the bio-infiltration pond include: American Beach Grass, Coastal Panic Grass, Switch Grass, Seaside Goldenrod, Back Chokeberry, Goundsel Tree, Winterberry, Marsh Elder, and Beach Plum.

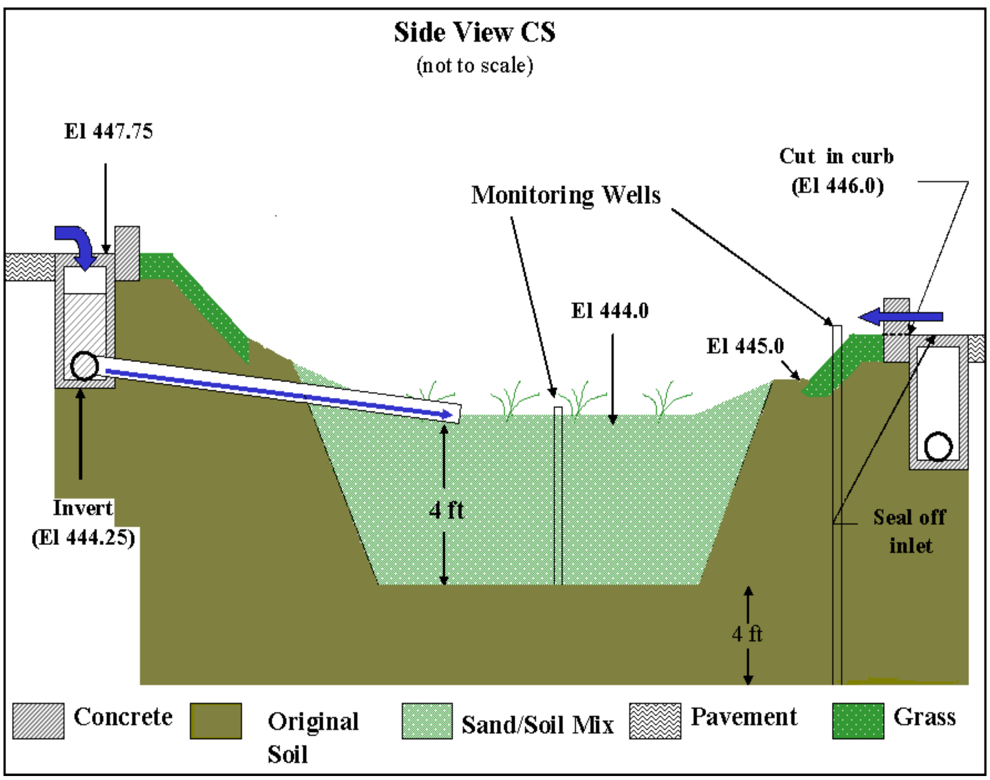

Figure 1 - Cross sectional sketch of Bio-infiltration BMP

Pervious Concrete Rock Bed

The Pervious Concrete site underlies a pedestrian area on Villanova's main campus between two adjacent dormitories. Geologically, the site is situated on a mix of sand

and silty soil, which has a high potential for infiltration. The site was designed to store and infiltrate runoff from the first 2 in. of a storm event. The total drainage area for the Pervious Concrete infiltration area is about 1.3 acres, 62% (0.8 acres) of which is impervious. The impervious areas consist of portions of the dormitory rooftops, concrete walkways, part of an asphalt driveway at the upper end of the watershed, the paving stone border around the Pervious Concrete, and the traditional concrete areas surrounded by the Pervious Concrete. The remaining 0.5 acres of the drainage area, is pervious.

The Pervious Concrete BMP consists of three large rock infiltration beds arranged in a cascading order down the center of the site. In addition to the Pervious concrete, which acts primarily as a transportation medium allowing runoff on the surface to find its way into the infiltration beds underneath, the rooftop gutters of the adjacent dormitories also drain to the infiltration beds. The downspouts from these gutters are connected to 4-inch high density polyethylene (HDPE) pipes which are, in turn, connected directly to the three infiltration beds via perforated piping.

Each of the beds is approximately 3-4 ft deep and filled with course stone aggregate. The aggregate produces a void space of approximately 40% within the infiltration beds and allows quick percolation to the soil layer beneath. The void space also allows for some storage during events when the infiltration rate from the beds is slower than the rate of Stormwater runoff inflow. At the base of the infiltration beds, directly above the undisturbed native soil and below the stone, is a layer of geotextile filter fabric. This layer provides separation between the stones and soil to prevent any upward migration of fines into the infiltration bed. The uppermost, visible layer consists of 6 in of Pervious concrete. (Figure 2)

A 4 in. HDPE pipe located in the berm between the beds connects the bottoms of the lower two infiltration beds. This allows water to travel down from the middle bed to the lower bed, maximizing the infiltration area. Additionally, there are two 6 in. HDPE pipes that run along the top of all three beds. These pipes allow excess water, once bed capacity is reached, to travel down to the bottom of the site and into the existing storm sewer system. This reduces the risk of storm water rising up through the Pervious concrete. The beds are staggered at different depths due to the natural slope of the site. The beds are separated by earthen berms, which prevent continuous flow from bed to bed and allow the water to remain in each bed for infiltration purposes. (Figure 3)

The site is equipped with a rain gage, twelve Campbell Scientific Water Content Reflectometers, Model CS616 (located at various depths below the bed and in the grass areas outside of the bed), an INW PS9505 (0-5psiG, 40ft cable) pressure transducer (used to measure depth in the lower infiltration bed), and an INW PS9800 (0-5psiG, 40ft cable) pressure transducer (used to measure depth behind the outlet weir which is calibrated for flow prediction). In September 2003, a gutter sampler was installed at one of the inlets to collect the first rush of pollutants into the site. In August of 2004, a first flush sampler was added to the same inlet to collect the sheet flow coming into one of the inlets of the BMP.

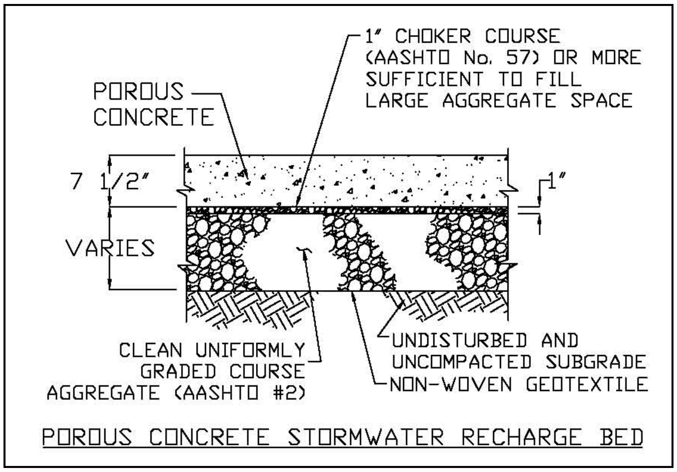

Figure 2 – Cross Section of an Infiltration Bed

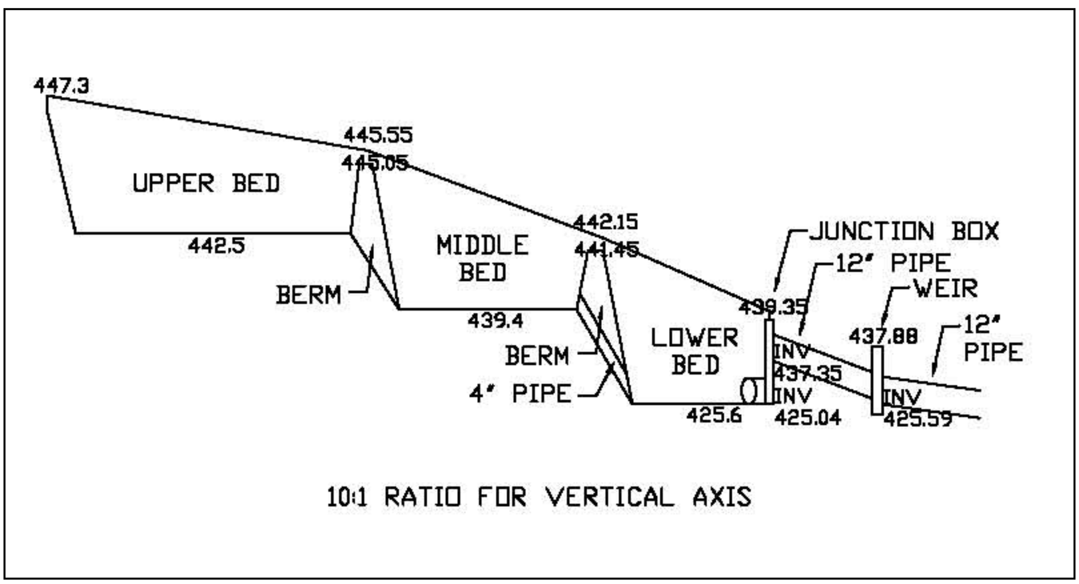

Figure 3 – Profile of Infiltration Beds and Overflow Pipes

Stormwater Wetland

Due to the presence of an active underground spring, an existing dry detention basin , located on the campus of Villanova University, was retrofitted to produce a Stormwater wetland (Figure 4). The retrofitted basin consists of the following structures. Two inlet pipes supply the wetland with Stormwater runoff. One 48 inch pipe serves approximately 25 acres of the contributing watershed, and one 36 inch pipe serves approximately 15 acres of the contributing watershed. A sediment forebay with the purpose of allowing suspended particles from influent waters to settle. Since suspended solids account for the majority of pollutant load in influent Stormwater, this function is vital for water quality control. Traditionally, sediment forebays are located directly downstream from the influent discharge. For this site, the sediment forebay was shifted to a location out of the direct path of influent flow. The reason for this design modification is the high volume of inflow water during large storm events. In the event of a large storm, a sediment forebay in direct line with the influent stream, would be stirred up and sediments would be re-suspended and passed downstream. By placing the forebay to the side, large storm volumes flow directly through the wetlands, bypassing the sediment forebay and leaving it undisturbed. All low flows, however, are routed through the sediment forebay. The sediment forebay is approximately 40 ft x 40 ft in plan view and approximately 4 ft deep. Flow exits through the sediment forebay via a stepped weir created through the use of gabions. The low flow weir passes up to the 2 year storm, and the higher step passes the 10+ year storm.

In order for a wetland to adequately treat Stormwater runoff, the water must be held within the wetland system as long as possible. Maximum exposure to plants allows for maximum absorption or conversion of pollutants. To achieve the maximum retention time of water entering the wetlands system, a series of meanders was developed and constructed. The meanders were formed by moving existing earth around creating earthen berms thereby maximizing flow length. The grading was intentionally left rough to allow for multiple micro-habitats and to strengthen plant hold in the soil. The meandering design was sloped as little as possible to avoid high velocities and channelization. A partial listing of the types of vegetation used in the Stormwater wetland include: Sweet Flag, Swamp Milkweed, New England Aster, Blue Joint Grass, Fringed Sedge, Cardinal Flower and Smooth Alder among others.

The original outlet structure contained a 12 inch orifice. Above this, a t-shaped weir controlled both the 25 and 50 year storms. On the top of the outlet structure was a grate that was designed to handle the 100 year storm. This structure was left unchanged. The site contains a rain gage, flow meter at the inlet pipes, and depth gages at both the sediment forebay and outlet structure.

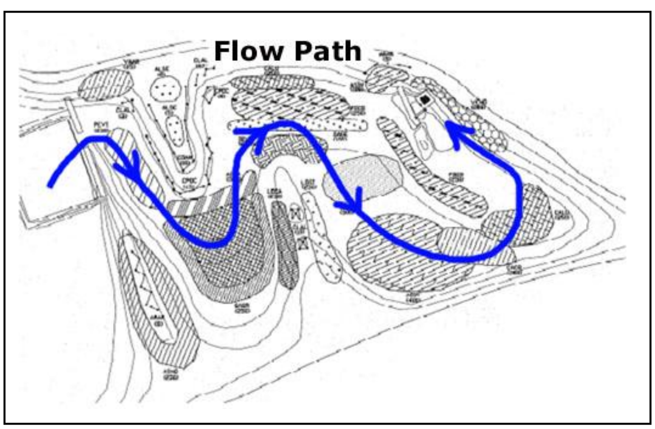

Figure 4 – Plan View of Stormwater Wetland

SAMPLING RESULTS

Stormwater samples were collected at each of the three BMPs between 2003 and 2005. Water quality analysis was conducted on each of the samples and the following constituents were tested for: nitrogen, phosphorous, chloride, suspended solids, dissolved solids and Ph. The total amount of each constituent was determined by measuring the average concentration at both the inlet and outlet of the respective BMP during a given storm and multiplying the concentration by the total volume of either inflow or outflow. The pollutant removal efficiency of each BMP was subsequently determined by determining the ratio of the outflow pollutant mass to the inflow pollutant mass. A statistical analysis was also performed at each of the sites in order to determine the pollutant concentration change. Quartiles were used to group the pollutant concentration data. Maximum and minimum values were also determined. The pollutant removal at each of the sites was determined by comparing the difference in quartile values as well as the maximum and minimum concentrations at the inlet and outlet to each of the sites. Negative values present indicate a decrease in pollutant concentration. Where possible, ground water concentrations were also analyzed. Tables 1-5 below summarize the results of the analysis.

Table 1 – BioInfiltration Pond Surface Water Analysis – Outflow Concentration – Inflow Concentration

BioInfiltration Pond Surface Water Analysis	**Concentration Change (mg/l) ((-) = removal)**					
	Quartiles			**Extremes**		**Removal Efficiency**
	25%	**50%**	**75%**	**Min**	**Max**	**(%)**
Ph	0.183	0.13	0.2	0.88	0.1	
Conductivity (µS/cm)	3.5	-1.8	-0.7	15	1044	
Total Nitrogen (mg/l)	---	---	---	---	-1.2	83.6
Total Phosphorous (mg/l)	-0.01	0.035	0.0175	-0.01	-0.79	38.7
Chloride (mg/l)	0.3	0.7	3.4	0.3	321.1	96.3
Suspended Solids (mg/l)	-1.57	-2.9	-78.3	1	-3061.2	98.3
Dissolved Solids (mg/l)	6.9	1.4	20.6	-0.1	70.5	74.1

Table 2 – BioInfiltration Pond Ground Water Analysis – Infiltrated Concentration – Inflow Concentration

BioInfiltration Pond Ground Water Analysis	Concentration Change (mg/l) ((-) = removal)				
	Quartiles			Extremes	
	25%	50%	75%	Min	Max
Ph	-0.258	-0.485	-0.905	-2.32	-0.77
Conductivity (µS/cm)	238	358.5	378	22.2	-1026
Total Nitrogen (mg/l)	---	---	---	---	1.55
Total Phosphorous (mg/l)	-0.102	-0.07	-0.3325	0.01	0.25
Chloride (mg/l)	4.2	15.5	103.9	0.3	-473.6
Suspended Solids (mg/l)	--	--	--	--	--
Dissolved Solids (mg/l)	211.7	224	316.3	228	-32.9

Table 3 – Pervious Concrete Surface Water Analysis – Outflow Concentration – Inflow Concentration

Pervious Concrete Surface Water Analysis	Concentration Change (mg/l) ((-) = removal)					
	Quartiles			Extremes		Removal Efficiency
	25%	50%	75%	Min	Max	(%)
Ph	0.98	0.26	0.38	1.33	2.48	
Conductivity (µS/cm)	37.65	74.7	143.5	2770.8	6.04	
Copper (mg/l)	-0.3207	-0.86	-1.0325	-1.94	-0.03	98.5
Total Nitrogen (mg/l)	---	---	2.350	3.800	---	95.3
Total Phosphorous (mg/l)	0.05	0.065	-0.0175	-0.1	0.03	94.3
Chloride (mg/l)	1.8	7.5	105.55	765.74	0.3	-806.8
Suspended Solids (mg/l)	2.7	3	-3.75	-1632	1.3	99.4
Dissolved Solids (mg/l)	21.5	44.3	135.3	250.3	12.8	-13.9

Table 4 – Pervious Concrete Ground Water Analysis – Infiltrated Concentration – Inflow Concentration

Pervious Concrete Ground Water Analysis	Concentration Change (mg/l) ((-) = removal)				
	Quartiles			Extremes	
	25%	50%	75%	Min	Max
Ph	-0.2125	-0.2	-0.6375	-2.26	-0.36
Conductivity (µS/cm)	120.5	120	230	283.33	107.4
Copper (mg/l)	-0.1513	-0.266	-0.5125	-1.567	-0.019
Total Nitrogen (mg/l)	---	---	---	---	---
Total Phosphorous (mg/l)	0.055	0.08	0.215	0.3	0.03
Chloride (mg/l)	13.4	14.4	118.8	123.8	2.7

Table 5 – Stormwater Wetland Surface Water Analysis – Outflow Concentration – Inflow Concentration

Stormwater Wetland Surface Water Analysis	Concentration Change (mg/l) ((-) = removal)					
	Quartiles			Extremes		Removal Efficiency
	25%	50%	75%	Min	Max	(%)
Ph	0.1875	0.175	0.1175	0.48	-0.07	
Conductivity (µS/cm)	85	71	160	61	4315	
Total Nitrogen (mg/l)	---	---	---	---	-2.15	74.9
Total Phosphorous (mg/l)	-0.07	-0.12	-0.0575	-0.07	-0.85	51.3
Orthophosphate (mg/l)	-0.033	-0.054	-0.049	-0.018	2.21	52.3
Suspended Solids (mg/l)	-1.107	-1.21	-1.657	-0.01	-24.067	61.9
Dissolved Solids (mg/l)	34.8	73.3	39.5	-0.4	2274.2	-30.1
Lead (ug/L)	-2.65	-2.12	3.56	-0.32	41.47	-13.6
Copper (ug/L)	-4.38	-3.84	-28.21	-1.2	-52.97	58.7
Zinc (ug/L)	-1.7	-6.7	-10	-8.8	165.5	14.6

DISCUSSION

Each of the sites showed a substantial amount of pollutant removal from a mass perspective. The primary reason for this is the percent of water which is infiltrated through the site as opposed to leaving the site as surface water runoff. The infiltrated water carries the pollutants with it as it deposits into the soil, thereby reducing the quantity of pollutants leaving the site through the outlet as surface water runoff. Positive efficiency percentages at each of the sites varied from 38.7-98.3% at the BioInfiltration Pond, 94.3-99.4% at the Pervious Concrete site, and 14.6-74.9% at the Stormwater wetland. Interestingly both the Pervious Concrete site and the Stormwater Wetland actually showed a negative efficiency/increase in Dissolved Solids between the inlet and outlet of each of the sites. The most probable reason for this is the accumulation of chloride particles during the winter months, due to salting of the surrounding areas during snowfall. This is substantiated by the increase in chloride concentration and content measured at the Pervious Concrete site.

With respect to concentration change of each of the pollutants between the inflow and outflow, most constituents show a negative value indicating a decrease in concentration. Once again Dissolved solids and chloride show increases in concentration most likely due to road salting as discussed previously. Interestingly both Ph and Conductivity showed increases between the inflow sample and outflow samples. However, the change in Ph is typically only around 0.5 and is most likely due to the sustained contact of the water with the surrounding vegetation. When comparing the results from each of the three sites it appears that for surface water analysis, the Stormwater wetland generally leads to the greatest concentration change of pollutants, with the BioInfiltration Pond having the 2nd best performance and the Pervious Concrete site last.

For the ground water results, only changes to pollutant concentrations were analyzed. Additionally, no lysimeters were installed at the Stormwater wetland thereby prohibiting the ability to take ground water samples. Therefore, only the BioInfiltration Pond and the Pervious Concrete site were able to be analyzed. Interestingly Ph levels at both sites decreased while the water infiltrated into the ground, as opposed to the increase shown during the surface water analysis. For both sites, with the exception of Copper, there was actually an increase in each of the pollutant concentrations as the water infiltrated through either the rock bed of the Pervious Concrete site, or through the vegetated soil at the BioInfiltration Pond. This result is especially surprising at the BioInfiltration Pond where decreases in pollutants were hypothesized to occur due to plant intake.

CONCLUSION

An analysis of the pollutant removal efficiency and pollutant concentration reduction of three different types of Stormwater Best Management Practices was conducted. The constituents analyzed include: Ph, Conductivity, Total Nitrogen, Total Phosphorous, Chloride, Suspended Solids, and Dissolved Solids. The results of the analysis show the for surface water removal efficiency the Pervious Concrete site performed the best, however, this is most likely due to the pure volume of water infiltrated into ground and kept from exiting the site as surface water runoff. In terms of concentration levels, the Stormwater Wetland showed the greatest reduction in pollutant concentration for surface water flows. For the pollutant concentration of infiltrating water at the Pervious Concrete site and the BioInfiltration pond, Both sites generally showed increases in pollutant concentration which is surprising, especially at the BioInfiltration pond, because of the expected decrease due to plant intake. However, in general, the BioInfiltration pond tended to show better results of pollutant concentration change then the Pervious Concrete site.

In conclusion, the results of the analysis show that for surface water runoff each of the BMPs tended to produce a reduction in both pollutant mass and concentration, and therefore are viable methods for controlling the pollutant levels of Stormwater runoff.